DESIGN COMPUTATIONS

Traffic Signal & Intersection Improvements
In the City of
Meriden, Connecticut

State Project No. 0079-0241

January, 2021

RIFAT HASSAN SALEH
No. 18455
LICENSED PROFESSIONAL ENGINEER

Rifat Saleh
2021.01.13
17:55:27-05'00'

Submitted by:

RHS Consulting Design, LLC
Engineering | Surveying | Construction Inspection

345 HIGHLAND AVENUE
CHESHIRE, CT 06410
(203) 439-9340

State Project No. 079-241
Traffic Signal & Intersection Improvements
For the City of
Meriden, Connecticut

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DESIGN ASSUMPTIONS

The mast-arm and span pole structures are designed based on the project special provisions and CDM traffic control plan sheets. RHS design was performed in accordance with the 2013 AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals, 6th edition with 2015 interims and as supplemented by ConnDOT Traffic Signal Design Manual, Chapter 10 requirements.

Design Criteria

- Reference: CDM Semifinal Traffic Signal Layout of mast-arm and span pole structures used for the analysis
- Reference: Freeman Geotechnical Report and boring logs for the design of drilled shaft foundations
- Florida DOT Mathcad Program was used for the design of the drilled shaft foundations. Every mast-arm foundation was analyzed separately based on its soil condition and loadings. The foundations were grouped into three embedment lengths; 12 ft., 14 ft., and 20 ft. to reduce the cost for fabrication and construction.
- Brass Pole Software version 4.7 (September 2019) was used for this analysis
- ConnDOT Guide Sheets were used for calculating the surface areas and weights of the signal heads, cameras, etc.
- Design Wind Speed: 120 mph per ConnDOT guidelines
- Fatigue category 1
- Fatigue Stress range 7 ksi for Category D, Base plate to round pole and arm pole to base plate
- Importance Factor: 1.0
- Guest Effect Factor: 1.14
- Wind Drag: 1.1
- Reoccurrence intervals: 50 years
- Base plate min. thickness: 2” per ConnDOT guidelines
- 24 inch bolt circle with min. bolt diameter of 2” per ConnDOT Guidelines
- Min. pole diameter of 12” used for the analysis
- Min. wall thickness of 3/8” thick used for the analysis
- Twin mast-arms have same arm diameter
- All mast-arm structures are assumed to have round section
- 30” dia. dilled shaft foundation assumed

State Project No. 079-241
Traffic Signal & Intersection Improvements
For the City of
Meriden, Connecticut

Mast-Arm Design

BRASS-POLE™ 4.7.0

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**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
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**                              Copyright (c) 1999 - 2019 WYDOT                               **
**                                                                                            **
**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
**                               Release Date: August 15, 2019                                **
**                                                                                            **
**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
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**                    For user assistance and system information contact:                     **
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**      all responsibility and liability arising from such use or reliance.                  **
**                                                                                            **
**   AASHTO Standard Specifications (LFD):                                                    **
**                                                                                            **
**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural     **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,      **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1       13 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

            BASE    AVERAGE     WALL        MODULUS
          DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       18.00     13.00     0.44       29000000.

           YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
          STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)               (FEET)
    1      65000.      50.0           18.5                 21.1

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                  SIDE                    ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  SIGN PANEL    17.0   7.5    N/A     19.4    30.0     7.5   36.0    30.0
   2  TRAFFIC SIG.  24.0   9.0    N/A     19.6    65.0    28.0   N/A     N/A
   3  SIGN PANEL    27.0   7.5    N/A     19.9    30.0     7.5   36.0    30.0
   4  TRAFFIC SIG.  29.0   9.0    N/A     20.0    65.0    28.0   N/A     N/A
   5  TRAFFIC SIG.  32.0   9.0    N/A     20.2    65.0    28.0   N/A     N/A
   6  TRAFFIC SIG.  35.0   9.0    N/A     20.2    65.0    28.0   N/A     N/A
   7  ROUNDED LUM.  40.0   1.0    N/A     20.6     2.0     1.0   N/A     N/A
   8  ROUNDED LUM.  43.0   1.0    N/A     20.8     2.0     1.0   N/A     N/A
   9  TRAFFIC SIG.  46.0  12.0    N/A     20.9    65.0    28.0   N/A     N/A
  10  TRAFFIC SIG.  50.0   9.0    N/A     21.1    65.0    28.0   N/A     N/A
  11  TRAFFIC SIG.   0.0   9.0    N/A     16.0    65.0    28.0   N/A     N/A
  12  TRAFFIC SIG.   0.0   8.2    N/A      8.0    44.0     8.2   N/A     N/A
  13  ROUNDED LUM.   0.0  11.8    N/A     16.0   450.0    11.8   N/A     N/A
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am

_______________________WIND LOADING ON ARM # 1_________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

                HEIGHT      AREA                PRESSURE     FORCE
  COMPONENT      (FT)       (FT^2)      CD       (PSF)       (LBS)
 SEGMENT # 1     19.6      54.24      1.10       41.53     2252.8
   UNIT # 1      19.9        7.50      1.13       42.93      322.0
   UNIT # 2      20.1        9.00      1.20       45.53      409.8
   UNIT # 3      20.4        7.50      1.13       43.16      323.7
   UNIT # 4      20.5        9.00      1.20       45.73      411.6
   UNIT # 5      20.7        9.00      1.20       45.80      412.2
   UNIT # 6      20.7        9.00      1.20       45.80      412.2
   UNIT # 7      21.1        1.00      0.50       19.17       19.2
   UNIT # 8      21.2        1.00      0.50       19.19       19.2
   UNIT # 9      21.4       12.00      1.20       46.14      553.7
   UNIT #10      21.6        9.00      1.20       46.21      415.9
   UNIT #11      16.5        9.00      1.20       43.68      393.1
   UNIT #12       8.5        8.20      1.20       43.87      359.8
   UNIT #13      16.5       11.80      0.50       18.20      214.7

________________________LOADS APPLIED TO ARM # 1_______________________

  WEIGHT OF ARM                                =   3046.1 LBS
  WEIGHT OF ATTACHMENTS                        =   1013.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS         =   6519.9 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS           =   1211.0 LBS
  DEAD LOAD MOMENT                             =  81915.7 FT-LBS
  WIND MOMENT                                  = 160559.5 FT-LBS
  ICE MOMENT                                   =  30550.7 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1________________

                     MOMENT       SHEAR        TORSION
                   (FT-LBS)       (LBS)        (FT-LBS)
  GROUP I           81915.7      3500.1          N/A
  GROUP II         180248.5      6563.4          150.1
  GROUP III        138319.7      5347.6           75.0

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1____________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       9270.       290.          42900.      21450.
  GROUP II     20397.       552.          57057.      28528.
  GROUP III    15652.       447.          57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1____________

                         GROUP I   = 0.2163
                         GROUP II  = 0.3579
                         GROUP III = 0.2746
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                  =  29000.0 KSI
      Fy                                 =  55000.0 PSI
      LENGTH OF POLE                     =     20.0 FEET
      WALL THICKNESS                     =   0.4380 IN
      BOTTOM OD                          =   18.000 IN
      TOP OD                             =   18.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND        =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =    1644.6 LBS.
                      AXIAL LOAD  =    5703.7 LBS.
                      MOMENT      =  161730.8 FT-LBS
                      SHEAR       =    7701.7 LBS.
                      TORQUE      =  159540.4 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        236.          18292.            9664.
  ALLOWABLE    43890.          48279.           24140.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0054 +  0.3789 +  0.1603 =  0.5445
                        (AXIAL)   (BENDING) (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   94 DEGREES

_________________________BASEPLATE DESIGN LOADS_________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE = 163650. FT-LBS
  WITH WIND APPLIED AT  103 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       = 129306. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     = 100307. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           = 160559. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   7731. LBS
  WITH WIND APPLIED AT   90 DEGREES
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                        =      8.00
  BOLT CIRCLE DIAMETER                   =     24.00 INCHES
  ANCHOR BOLT DIAMETER                   =      2.00 INCHES
  THREADS PER INCH                       =      4.00
  TENSILE STRESS AREA                    =      2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT          =   105000. PSI

  DIMENSION OF BASE PLATE                =     30.00 INCHES
  BASE PLATE THICKNESS                   =      2.00 INCHES
  YIELD STRENGTH OF BASE PLATE           =    50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP        =   1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =    116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =   162164. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =     7685. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =   158970. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =       95. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)            =    16732. PSI
  ALLOWABLE TENSILE STRESS (Ft)          =    69825. PSI
  ft/Ft                                  =      0.24

  SHEAR STRESS ON BOLT (fv)              =     8598. PSI
  ALLOWABLE SHEAR STRESS (Fv)            =    41895. PSI
  fv/Fv                                  =      0.21

  (ft/Ft)^2 + (fv/Fv)^2                  =      0.10

_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                     =     18.00 INCHES
  BOLT LOAD                              =    40913. LBS
  MOMENT ON BASE PLATE                   =   122738. IN-LBS
  PLATE EFFECTIVE WIDTH                  =     18.00 INCHES
  PLATE SECTION MODULUS                  =     12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)      =    10228. PSI
  ALLOWABLE BENDING STRESS (Fb)          =    43890. PSI
  fb/Fb                                  =      0.23

________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                    =     5406. PSI
  ALLOWABLE FATIGUE STRESS               =     7000. PSI
  FATIGUE STRESS RATIO                   =      0.77
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am

______________________________GALLOPING_____________________________

  IMPORTANCE FACTOR =       1.00

                    ----Arm  1, Segment  1----
              AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)      (PSF)       (LBS)    (FT-LBS)
    1       7.50       21.00      157.50     2677.50

    2       9.00       21.00      189.00     4536.00

    3       7.50       21.00      157.50     4252.50

    4       9.00       21.00      189.00     5481.00

    5       9.00       21.00      189.00     6048.00

    6       9.00       21.00      189.00     6615.00

    7       1.00       21.00       21.00      840.00

    8       1.00       21.00       21.00      903.00

    9      12.00       21.00      252.00    11592.00

   10       9.00       21.00      189.00     9450.00

   11       9.00       21.00      189.00        0.00

   12       8.20       21.00      172.20        0.00

   13      11.80       21.00      247.80        0.00


                     FATIGUE    STRESS     FATIGUE
      BASE            MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION         (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM  1 SEG  1     52395.00    5929.       7000.       0.85
      POLE           52395.00    5926.       7000.       0.85
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am

___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA              PRESSURE     FORCE
  COMPONENT       (FT^2)     CD       (PSF)       (LBS)
  ARM 1 SEG 1      54.24    1.10       5.72      310.26
  ARM 1 UNIT 1      7.50    1.13       5.90       44.23
  ARM 1 UNIT 2      9.00    1.20       6.24       56.16
  ARM 1 UNIT 3      7.50    1.13       5.90       44.23
  ARM 1 UNIT 4      9.00    1.20       6.24       56.16
  ARM 1 UNIT 5      9.00    1.20       6.24       56.16
  ARM 1 UNIT 6      9.00    1.20       6.24       56.16
  ARM 1 UNIT 7      1.00    0.50       2.60        2.60
  ARM 1 UNIT 8      1.00    0.50       2.60        2.60
  ARM 1 UNIT 9     12.00    1.20       6.24       74.88
  ARM 1 UNIT10      9.00    1.20       6.24       56.16
  ARM 1 UNIT11      9.00    1.20       6.24       56.16
  ARM 1 UNIT12      8.20    1.20       6.24       51.17
  ARM 1 UNIT13     11.80    0.50       2.60       30.68
  POLE             30.00    1.10       5.72      171.60

                 FATIGUE   STRESS     FATIGUE              WIND
    BASE          MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
   LOCATION      (FT-LBS)   (PSI)      (PSI)      RATIO    (DEG)
   ARM 1 SEG 1   21915.5    2480.      7000.      0.35
       POLE      18695.3    2114.      7000.      0.30       90
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am


_______________________________TRUCK GUST_____________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA              PRESSURE     FORCE
  COMPONENT       (FT^2)     CD       (PSF)       (LBS)
  ARM 1 SEG 1       9.20    0.51       8.41       77.40
  ARM 1 UNIT 1      0.20    1.13      21.32        4.26
  ARM 1 UNIT 2      1.20    1.20      22.39       26.86
  ARM 1 UNIT 3      0.20    1.13      20.65        4.13
  ARM 1 UNIT 4      1.20    1.20      21.66       25.99
  ARM 1 UNIT 5      1.20    1.20      21.38       25.66
  ARM 1 UNIT 6      1.20    1.20      21.38       25.66
  ARM 1 UNIT 7      0.20    0.50       8.60        1.72
  ARM 1 UNIT 8      0.20    0.50       8.50        1.70
  ARM 1 UNIT 9      1.20    1.20      20.11       24.14
  ARM 1 UNIT10      1.20    1.20      19.84       23.80
  ARM 1 UNIT11      8.62    1.20      22.56      194.47
  ARM 1 UNIT12      2.03    1.20      22.56       45.80
  ARM 1 UNIT13      5.20    0.50       9.40       48.88

                 FATIGUE    STRESS     FATIGUE
                  MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION     (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1    9149.22    1035.      7000.       0.15
      POLE        9149.22    1035.      7000.       0.15
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
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**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
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**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
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**   AASHTO Standard Specifications (LFD):                                                    **
**                                                                                            **
**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural      **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,       **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE         ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1       13 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

            BASE    AVERAGE     WALL        MODULUS
          DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       18.00     13.00     0.44       29000000.

           YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
          STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)               (FEET)
    1      65000.      50.0           18.5                 21.1

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                  SIDE                    ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  SIGN PANEL    17.0   7.5    N/A     19.4    30.0     7.5   36.0    30.0
   2  TRAFFIC SIG.  24.0   9.0    N/A     19.6    65.0    28.0   N/A     N/A
   3  SIGN PANEL    27.0   7.5    N/A     19.9    30.0     7.5   36.0    30.0
   4  TRAFFIC SIG.  29.0   9.0    N/A     20.0    65.0    28.0   N/A     N/A
   5  TRAFFIC SIG.  32.0   9.0    N/A     20.2    65.0    28.0   N/A     N/A
   6  TRAFFIC SIG.  35.0   9.0    N/A     20.2    65.0    28.0   N/A     N/A
   7  ROUNDED LUM.  40.0   1.0    N/A     20.6     2.0     1.0   N/A     N/A
   8  ROUNDED LUM.  43.0   1.0    N/A     20.8     2.0     1.0   N/A     N/A
   9  TRAFFIC SIG.  46.0  12.0    N/A     20.9    65.0    28.0   N/A     N/A
  10  TRAFFIC SIG.  50.0   9.0    N/A     21.1    65.0    28.0   N/A     N/A
  11  TRAFFIC SIG.   0.0   9.0    N/A     16.0    65.0    28.0   N/A     N/A
  12  TRAFFIC SIG.   0.0   8.2    N/A      8.0    44.0     8.2   N/A     N/A
  13  ROUNDED LUM.   0.0  11.8    N/A     16.0   450.0    11.8   N/A     N/A
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

                HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT       (FT)       (FT^2)      CD          (PSF)       (LBS)
 SEGMENT # 1     19.6       54.24      1.10        41.53     2252.8
   UNIT # 1      19.9        7.50      1.13        42.93      322.0
   UNIT # 2      20.1        9.00      1.20        45.53      409.8
   UNIT # 3      20.4        7.50      1.13        43.16      323.7
   UNIT # 4      20.5        9.00      1.20        45.73      411.6
   UNIT # 5      20.7        9.00      1.20        45.80      412.2
   UNIT # 6      20.7        9.00      1.20        45.80      412.2
   UNIT # 7      21.1        1.00      0.50        19.17       19.2
   UNIT # 8      21.2        1.00      0.50        19.19       19.2
   UNIT # 9      21.4       12.00      1.20        46.14      553.7
   UNIT #10      21.6        9.00      1.20        46.21      415.9
   UNIT #11      16.5        9.00      1.20        43.68      393.1
   UNIT #12       8.5        8.20      1.20        43.87      359.8
   UNIT #13      16.5       11.80      0.50        18.20      214.7

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                              =   3046.1 LBS
  WEIGHT OF ATTACHMENTS                      =   1013.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS       =   6519.9 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS         =   1211.0 LBS
  DEAD LOAD MOMENT                           =  81915.7 FT-LBS
  WIND MOMENT                                = 160559.5 FT-LBS
  ICE MOMENT                                 =  30550.7 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                     MOMENT       SHEAR        TORSION
                   (FT-LBS)       (LBS)        (FT-LBS)
  GROUP I           81915.7      3500.1          N/A
  GROUP II         180248.5      6563.4          150.1
  GROUP III        138319.7      5347.6           75.0

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       9270.       290.         42900.      21450.
  GROUP II     20397.       552.         57057.      28528.
  GROUP III    15652.       447.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                         GROUP I   = 0.2163
                         GROUP II  = 0.3579
                         GROUP III = 0.2746
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                 =  29000.0 KSI
      Fy                                =  55000.0 PSI
      LENGTH OF POLE                    =     20.0 FEET
      WALL THICKNESS                    =   0.4380 IN
      BOTTOM OD                         =   18.000 IN
      TOP OD                            =   18.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND       =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =    1644.6 LBS.
                      AXIAL LOAD  =    5703.7 LBS.
                      MOMENT      =  161730.8 FT-LBS
                      SHEAR       =    7701.7 LBS.
                      TORQUE      =  159540.4 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        236.          18292.            9664.
  ALLOWABLE    43890.          48279.           24140.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0054 +  0.3789 +  0.1603 =  0.5445
                        (AXIAL)   (BENDING) (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   94 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE = 163650. FT-LBS
  WITH WIND APPLIED AT  103 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       = 129306. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     = 100307. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           = 160559. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   7731. LBS
  WITH WIND APPLIED AT   90 DEGREES
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                          =       8.00
  BOLT CIRCLE DIAMETER                     =      24.00 INCHES
  ANCHOR BOLT DIAMETER                     =       2.00 INCHES
  THREADS PER INCH                         =       4.00
  TENSILE STRESS AREA                      =       2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT            =    105000. PSI

  DIMENSION OF BASE PLATE                  =      30.00 INCHES
  BASE PLATE THICKNESS                     =       2.00 INCHES
  YIELD STRENGTH OF BASE PLATE             =     50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP          =    1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =     116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =    162164. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =      7685. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =    158970. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =        95. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)              =     16732. PSI
  ALLOWABLE TENSILE STRESS (Ft)            =     69825. PSI
  ft/Ft                                    =       0.24

  SHEAR STRESS ON BOLT (fv)                =      8598. PSI
  ALLOWABLE SHEAR STRESS (Fv)              =     41895. PSI
  fv/Fv                                    =       0.21

  (ft/Ft)^2 + (fv/Fv)^2                    =       0.10

_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                       =      18.00 INCHES
  BOLT LOAD                                =     40913. LBS
  MOMENT ON BASE PLATE                     =    122738. IN-LBS
  PLATE EFFECTIVE WIDTH                    =      18.00 INCHES
  PLATE SECTION MODULUS                    =      12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)        =     10228. PSI
  ALLOWABLE BENDING STRESS (Fb)            =     43890. PSI
  fb/Fb                                    =       0.23

________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                      =      5406. PSI
  ALLOWABLE FATIGUE STRESS                 =      7000. PSI
  FATIGUE STRESS RATIO                     =       0.77
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am

_______________________________GALLOPING______________________________

  IMPORTANCE FACTOR =       1.00

                    ----Arm  1, Segment  1----
          AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)     (PSF)       (LBS)    (FT-LBS)
    1      7.50      21.00      157.50     2677.50

    2      9.00      21.00      189.00     4536.00

    3      7.50      21.00      157.50     4252.50

    4      9.00      21.00      189.00     5481.00

    5      9.00      21.00      189.00     6048.00

    6      9.00      21.00      189.00     6615.00

    7      1.00      21.00       21.00      840.00

    8      1.00      21.00       21.00      903.00

    9     12.00      21.00      252.00    11592.00

   10      9.00      21.00      189.00     9450.00

   11      9.00      21.00      189.00        0.00

   12      8.20      21.00      172.20        0.00

   13     11.80      21.00      247.80        0.00


                     FATIGUE    STRESS     FATIGUE
      BASE            MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION         (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM  1 SEG  1     52395.00    5929.       7000.       0.85
      POLE           52395.00    5926.       7000.       0.85
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA              PRESSURE     FORCE
  COMPONENT       (FT^2)     CD       (PSF)       (LBS)
  ARM 1 SEG 1      54.24    1.10       5.72      310.26
  ARM 1 UNIT 1      7.50    1.13       5.90       44.23
  ARM 1 UNIT 2      9.00    1.20       6.24       56.16
  ARM 1 UNIT 3      7.50    1.13       5.90       44.23
  ARM 1 UNIT 4      9.00    1.20       6.24       56.16
  ARM 1 UNIT 5      9.00    1.20       6.24       56.16
  ARM 1 UNIT 6      9.00    1.20       6.24       56.16
  ARM 1 UNIT 7      1.00    0.50       2.60        2.60
  ARM 1 UNIT 8      1.00    0.50       2.60        2.60
  ARM 1 UNIT 9     12.00    1.20       6.24       74.88
  ARM 1 UNIT10      9.00    1.20       6.24       56.16
  ARM 1 UNIT11      9.00    1.20       6.24       56.16
  ARM 1 UNIT12      8.20    1.20       6.24       51.17
  ARM 1 UNIT13     11.80    0.50       2.60       30.68
  POLE             30.00    1.10       5.72      171.60

                 FATIGUE   STRESS     FATIGUE              WIND
      BASE        MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
    LOCATION     (FT-LBS)   (PSI)      (PSI)      RATIO    (DEG)
   ARM 1 SEG 1   21915.5    2480.      7000.      0.35
       POLE      18695.3    2114.      7000.      0.30       90
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am


_______________________________TRUCK GUST_____________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA              PRESSURE     FORCE
  COMPONENT       (FT^2)      CD       (PSF)       (LBS)
  ARM 1 SEG 1       9.20    0.51       8.41       77.40
  ARM 1 UNIT 1      0.20    1.13      21.32        4.26
  ARM 1 UNIT 2      1.20    1.20      22.39       26.86
  ARM 1 UNIT 3      0.20    1.13      20.65        4.13
  ARM 1 UNIT 4      1.20    1.20      21.66       25.99
  ARM 1 UNIT 5      1.20    1.20      21.38       25.66
  ARM 1 UNIT 6      1.20    1.20      21.38       25.66
  ARM 1 UNIT 7      0.20    0.50       8.60        1.72
  ARM 1 UNIT 8      0.20    0.50       8.50        1.70
  ARM 1 UNIT 9      1.20    1.20      20.11       24.14
  ARM 1 UNIT10      1.20    1.20      19.84       23.80
  ARM 1 UNIT11      8.62    1.20      22.56      194.47
  ARM 1 UNIT12      2.03    1.20      22.56       45.80
  ARM 1 UNIT13      5.20    0.50       9.40       48.88

                 FATIGUE    STRESS     FATIGUE
                  MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION     (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1    9149.22    1035.      7000.       0.15
      POLE        9149.22    1035.      7000.       0.15
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 City of Meriden_West Main Street at Route 71(Cook Ave)_Mast Arm 079-241-A_TCS-1

  01/11/2021  11:35 am


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
**                                                                                            **
**                                                                                            **
**                   PPPPPPPPPPP    OOOOOOOOOO   LL            EEEEEEEEEEEE                   **
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**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PPPPPPPPPPPP  OO        OO  LL            EEEEEEEEE                      **
**                   PPPPPPPPPPP   OO        OO  LL            EEEEEEEEE                      **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OOOOOOOOOOOO  LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                   PP             OOOOOOOOOO   LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                                                                                            **
**                                                                                            **
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**                                                                                            **
**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
**                               Release Date: August 15, 2019                                **
**                                                                                            **
**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
**                                                                                            **
**                    For user assistance and system information contact:                     **
**                                   Phone: (307) 777-4489                                    **
**                              E-mail: BRASSTechSupport@wyo.gov                              **
**                                                                                            **
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**                                                                                            **
**   AASHTO Standard Specifications (LFD):                                                    **
**                                                                                            **
**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural     **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,      **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
**                                                                                            **
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-B_TCS-2

  01/11/2021  11:39 am

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS        SHAPE          (DEGREES)    (DEGREES)
      1        8 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

           BASE    AVERAGE     WALL        MODULUS
         DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT   (IN)      (IN)      (IN)         (PSI)
    1      15.00     11.50     0.38       29000000.

          YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
         STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)     (FEET)         (FEET)              (FEET)
    1     65000.      40.0          17.5                 19.6

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                 SIDE                        ICE    SIGN    SIGN
                     DIST  AREA    AREA    HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)    (FT)    (LBS)   (FT^2)  (IN)    (IN)
   1  SIGN PANEL    16.0   9.0    N/A      18.4    36.0     9.0   36.0    36.0
   2  TRAFFIC SIG.  24.0   9.0    N/A      18.8    65.0    28.0   N/A     N/A
   3  TRAFFIC SIG.  27.0   9.0    N/A      18.9    65.0    28.0   N/A     N/A
   4  ROUNDED LUM.  29.0   1.0    N/A      19.0     2.0     1.0   N/A     N/A
   5  SIGN PANEL    31.0   4.0    N/A      19.1    16.0     4.0   24.0    24.0
   6  ROUNDED LUM.  33.0   1.0    N/A      19.2     2.0     1.0   N/A     N/A
   7  TRAFFIC SIG.  35.0   9.0    N/A      19.3    65.0    28.0   N/A     N/A
   8  TRAFFIC SIG.  38.0   9.0    N/A      19.5    65.0    28.0   N/A     N/A
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-B_TCS-2

  01/11/2021  11:39 am

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

                HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT      (FT)      (FT^2)      CD        (PSF)      (LBS)
 SEGMENT # 1     18.4      38.39      1.10       40.99     1573.3
   UNIT # 1      18.9       9.00      1.12       41.97      377.7
   UNIT # 2      19.3       9.00      1.20       45.12      406.1
   UNIT # 3      19.4       9.00      1.20       45.20      406.8
   UNIT # 4      19.5       1.00      0.50       18.85       18.9
   UNIT # 5      19.6       4.00      1.12       42.28      169.1
   UNIT # 6      19.7       1.00      0.50       18.90       18.9
   UNIT # 7      19.8       9.00      1.20       45.40      408.6
   UNIT # 8      20.0       9.00      1.20       45.48      409.3

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                               =   1845.6 LBS
  WEIGHT OF ATTACHMENTS                       =    316.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS        =   3788.6 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS          =    743.3 LBS
  DEAD LOAD MOMENT                            =  42424.1 FT-LBS
  WIND MOMENT                                 =  91313.0 FT-LBS
  ICE MOMENT                                  =  17922.4 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                     MOMENT       SHEAR        TORSION
                    (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I           42424.1      2161.6          N/A
  GROUP II         100687.0      4361.9            34.0
  GROUP III         75786.5      3471.3            17.0

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       8085.       251.         42900.      21450.
  GROUP II     19189.       510.         57057.      28528.
  GROUP III    14444.       405.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                         GROUP I   = 0.1886
                         GROUP II  = 0.3366
                         GROUP III = 0.2533
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-B_TCS-2

  01/11/2021  11:39 am

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                  =  29000.0 KSI
      Fy                                 =  65000.0 PSI
      LENGTH OF POLE                     =     19.0 FEET
      WALL THICKNESS                     =   0.3750 IN
      BOTTOM OD                          =   15.000 IN
      TOP OD                             =   15.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND        =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =    1113.9 LBS.
                      AXIAL LOAD  =    3275.6 LBS.
                      MOMENT      =   92233.6 FT-LBS
                      SHEAR       =    4724.7 LBS.
                      TORQUE      =   90731.8 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        190.          17569.            9195.
  ALLOWABLE    51870.          57057.           28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0037 +  0.3079 +  0.1039 =  0.4155
                        (AXIAL)   (BENDING)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   94 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE =  92584. FT-LBS
  WITH WIND APPLIED AT   98 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       =  78887. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =  48463. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           =  91313. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   4745. LBS
  WITH WIND APPLIED AT   90 DEGREES
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-B_TCS-2

  01/11/2021  11:39 am


______________POLE DESCRIPTION AT APPROXIMATE MAXIMUM CSR______________

  LENGTH OF SEGMENT = 19.00 FEET
  WALL THICKNESS          = 0.3750 IN.
  BOTTOM or EQUIVALENT OD = 15.000 IN.
  TOP or EQUIVALENT OD    = 15.000 IN.
  HEIGHT OF SEGMENT
  BASE ABOVE GROUND         =  0.5 FEET

___________________DESIGN LOADS AT POLE SEGMENT BASE___________________

    MOMENT      = 92234. FT-LBS
    SHEAR       =  4725. LBS.
    TORQUE      = 90732. FT-LBS

  MAXIMUM COMBINED STRESS RATIO =  0.0037 +  0.3079 +  0.1039 =  0.4155
                                  (AXIAL)    (MOMENT)   (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   94 DEGREES
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-B_TCS-2

  01/11/2021  11:39 am

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                        =       8.00
  BOLT CIRCLE DIAMETER                   =      24.00 INCHES
  ANCHOR BOLT DIAMETER                   =       2.00 INCHES
  THREADS PER INCH                       =       4.00
  TENSILE STRESS AREA                    =       2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT          =    105000. PSI

  DIMENSION OF BASE PLATE                =      30.00 INCHES
  BASE PLATE THICKNESS                   =       2.00 INCHES
  YIELD STRENGTH OF BASE PLATE           =     50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP        =    1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =     116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =     92046. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =      4734. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =     90986. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =        93. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)            =      9497. PSI
  ALLOWABLE TENSILE STRESS (Ft)          =     69825. PSI
  ft/Ft                                  =       0.14

  SHEAR STRESS ON BOLT (fv)              =      4938. PSI
  ALLOWABLE SHEAR STRESS (Fv)            =     41895. PSI
  fv/Fv                                  =       0.12

  (ft/Ft)^2 + (fv/Fv)^2                  =       0.03
_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                     =      15.00 INCHES
  BOLT LOAD                              =     23146. LBS
  MOMENT ON BASE PLATE                   =    104157. IN-LBS
  PLATE EFFECTIVE WIDTH                  =      18.00 INCHES
  PLATE SECTION MODULUS                  =      12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)      =      8680. PSI
  ALLOWABLE BENDING STRESS (Fb)          =     43890. PSI
  fb/Fb                                  =       0.20
________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                    =      3133. PSI
  ALLOWABLE FATIGUE STRESS               =      7000. PSI
  FATIGUE STRESS RATIO                   =       0.45
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-B_TCS-2

  01/11/2021  11:39 am

_______________________________GALLOPING______________________________

  IMPORTANCE FACTOR =       1.00

                    ----Arm  1, Segment  1----
            AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)     (PSF)       (LBS)     (FT-LBS)
    1       9.00      21.00      189.00     3024.00

    2       9.00      21.00      189.00     4536.00

    3       9.00      21.00      189.00     5103.00

    4       1.00      21.00       21.00      609.00

    5       4.00      21.00       84.00     2604.00

    6       1.00      21.00       21.00      693.00

    7       9.00      21.00      189.00     6615.00

    8       9.00      21.00      189.00     7182.00


                     FATIGUE    STRESS     FATIGUE
       BASE          MOMENT      RANGE    THRESHOLD    STRESS
     LOCATION        (FT-LBS)    (PSI)       (PSI)        RATIO
   ARM  1 SEG  1     30366.00    5787.        7000.        0.83
       POLE          30366.00    5784.        7000.        0.83
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-B_TCS-2

  01/11/2021  11:39 am


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)      (LBS)
  ARM 1 SEG 1      38.39    1.10      5.72      219.57
  ARM 1 UNIT 1      9.00    1.12      5.82       52.42
  ARM 1 UNIT 2      9.00    1.20      6.24       56.16
  ARM 1 UNIT 3      9.00    1.20      6.24       56.16
  ARM 1 UNIT 4      1.00    0.50      2.60        2.60
  ARM 1 UNIT 5      4.00    1.12      5.82       23.30
  ARM 1 UNIT 6      1.00    0.50      2.60        2.60
  ARM 1 UNIT 7      9.00    1.20      6.24       56.16
  ARM 1 UNIT 8      9.00    1.20      6.24       56.16
  POLE             23.75    1.10      5.72      135.85

                 FATIGUE   STRESS     FATIGUE              WIND
      BASE        MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
    LOCATION     (FT-LBS)   (PSI)      (PSI)      RATIO    (DEG)
   ARM 1 SEG 1   12631.7    2407.      7000.      0.34
       POLE      11146.9    2123.      7000.      0.30       90
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-B_TCS-2

  01/11/2021  11:39 am


_______________________________TRUCK GUST_____________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)       (LBS)
  ARM 1 SEG 1       9.05    0.60     11.19      101.25
  ARM 1 UNIT 1      0.20    1.12     21.06        4.21
  ARM 1 UNIT 2      1.20    1.20     22.56       27.07
  ARM 1 UNIT 3      1.20    1.20     22.56       27.07
  ARM 1 UNIT 4      0.20    0.50      9.40        1.88
  ARM 1 UNIT 5      1.00    1.12     21.06       21.06
  ARM 1 UNIT 6      0.20    0.50      9.40        1.88
  ARM 1 UNIT 7      1.20    1.20     22.56       27.07
  ARM 1 UNIT 8      1.20    1.20     22.56       27.07

                 FATIGUE    STRESS     FATIGUE
                  MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION     (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1    7636.20    1455.      7000.       0.21
      POLE        7636.20    1455.      7000.       0.21
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-B_TCS-2

  01/11/2021  11:39 am


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                                                                                            **
**                                                                                            **
**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
**                                                                                            **
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**                   PPPPPPPPPPP    OOOOOOOOOO   LL            EEEEEEEEEEEE                   **
**                   PPPPPPPPPPPP  OOOOOOOOOOOO  LL            EEEEEEEEEEEE                   **
**                   PP        PP  OO        OO  LL            EE                             **
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**                   PP        PP  OO        OO  LL            EE                             **
**                   PPPPPPPPPPPP  OO        OO  LL            EEEEEEEEE                      **
**                   PPPPPPPPPPP   OO        OO  LL            EEEEEEEEE                      **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OOOOOOOOOOOO  LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                   PP             OOOOOOOOOO   LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                                                                                            **
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**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
**                               Release Date: August 15, 2019                                **
**                                                                                            **
**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
**                                                                                            **
**                    For user assistance and system information contact:                     **
**                                   Phone: (307) 777-4489                                    **
**                              E-mail: BRASSTechSupport@wyo.gov                              **
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**                                                                                            **
**   AASHTO Standard Specifications (LFD):                                                    **
**                                                                                            **
**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural     **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,      **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
**                                                                                            **
**                                                                                            **
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-C_TCS-2

  04/01/2020  8:44 am

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE         ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1        9 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

            BASE    AVERAGE     WALL        MODULUS
          DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       15.00     11.50     0.38       29000000.

           YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
          STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)               (FEET)
    1      65000.      35.0           17.5                 19.3

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                  SIDE                    ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.  12.0   9.0    N/A     18.1    65.0    28.0   N/A     N/A
   2  ROUNDED LUM.  17.0   1.0    N/A     18.4     2.0     1.0   N/A     N/A
   3  TRAFFIC SIG.  22.0   9.0    N/A     18.6    65.0    28.0   N/A     N/A
   4  TRAFFIC SIG.  26.0  14.0    N/A     18.9   105.0    41.0   N/A     N/A
   5  SIGN PANEL    29.0   9.0    N/A     19.0    36.0     9.0   36.0    36.0
   6  ROUNDED LUM.  31.0   1.0    N/A     19.1     2.0     1.0   N/A     N/A
   7  TRAFFIC SIG.  34.0   9.0    N/A     19.3    72.0    28.0   N/A     N/A
   8  ROUNDED LUM.   0.0   8.2    N/A      8.0    22.0     8.2   N/A     N/A
   9  ROUNDED LUM.   0.0  11.8    N/A     10.0   450.0    11.8   N/A     N/A
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-C_TCS-2

  04/01/2020  8:44 am

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

                HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT      (FT)      (FT^2)     CD        (PSF)       (LBS)
 SEGMENT # 1     18.3      33.59      1.10       40.93     1374.8
   UNIT # 1      18.6       9.00      1.20       44.81      403.3
   UNIT # 2      18.9       1.00      0.50       18.72       18.7
   UNIT # 3      19.1       9.00      1.20       45.07      405.6
   UNIT # 4      19.4      14.00      1.20       45.17      632.4
   UNIT # 5      19.5       9.00      1.12       42.23      380.1
   UNIT # 6      19.6       1.00      0.50       18.87       18.9
   UNIT # 7      19.8       9.00      1.20       45.38      408.4
   UNIT # 8       8.5       8.20      0.50       18.28      149.9
   UNIT # 9      10.5      11.80      0.50       18.28      215.7

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                              =   1614.9 LBS
  WEIGHT OF ATTACHMENTS                      =    819.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS       =   4007.8 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS         =    785.0 LBS
  DEAD LOAD MOMENT                           =  33922.3 FT-LBS
  WIND MOMENT                                =  77634.4 FT-LBS
  ICE MOMENT                                 =  14826.0 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                     MOMENT       SHEAR        TORSION
                    (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I           33922.3      1961.9           N/A
  GROUP II          84722.0      4137.0             3.2
  GROUP III         62407.6      3249.4             1.6

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I         6465.       228.          42900.      21450.
  GROUP II       16147.       481.          57057.      28528.
  GROUP III      11894.       377.          57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                         GROUP I   = 0.1508
                         GROUP II  = 0.2833
                         GROUP III = 0.2086
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-C_TCS-2

  04/01/2020  8:44 am

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                     =  29000.0 KSI
      Fy                                    =  65000.0 PSI
      LENGTH OF POLE                        =     19.0 FEET
      WALL THICKNESS                        =   0.3750 IN
      BOTTOM OD                             =   15.000 IN
      TOP OD                                =   15.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND           =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =    1113.9 LBS.
                      AXIAL LOAD  =    3547.9 LBS.
                      MOMENT      =   88621.5 FT-LBS
                      SHEAR       =    4946.7 LBS.
                      TORQUE      =   77152.0 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        206.          16881.            7926.
  ALLOWABLE    51870.          57057.           28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0040 +  0.2959 +  0.0772 =  0.3770
                        (AXIAL)   (BENDING)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   94 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE =  89053. FT-LBS
  WITH WIND APPLIED AT   99 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       =  78679. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =  41713. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           =  77634. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   4965. LBS
  WITH WIND APPLIED AT   90 DEGREES
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-C_TCS-2

  04/01/2020  8:44 am


______________POLE DESCRIPTION AT APPROXIMATE MAXIMUM CSR______________

  LENGTH OF SEGMENT = 19.00 FEET
  WALL THICKNESS          = 0.3750 IN.
  BOTTOM or EQUIVALENT OD = 15.000 IN.
  TOP or EQUIVALENT OD    = 15.000 IN.
  HEIGHT OF SEGMENT
  BASE ABOVE GROUND         =  0.5 FEET

___________________DESIGN LOADS AT POLE SEGMENT BASE___________________

    MOMENT      = 88622. FT-LBS
    SHEAR       =  4947. LBS.
    TORQUE      = 77152. FT-LBS

  MAXIMUM COMBINED STRESS RATIO =  0.0040 +  0.2959 +  0.0772 =  0.3770
                                  (AXIAL)   (MOMENT)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   94 DEGREES
```

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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-C_TCS-2

  04/01/2020  8:44 am

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                        =       8.00
  BOLT CIRCLE DIAMETER                   =      24.00 INCHES
  ANCHOR BOLT DIAMETER                   =       2.00 INCHES
  THREADS PER INCH                       =       4.00
  TENSILE STRESS AREA                    =       2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT          =    105000. PSI

  DIMENSION OF BASE PLATE                =      30.00 INCHES
  BASE PLATE THICKNESS                   =       2.00 INCHES
  YIELD STRENGTH OF BASE PLATE           =     50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP        =    1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =     116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =     88622. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =      4947. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =     77152. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =        94. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)            =      9144. PSI
  ALLOWABLE TENSILE STRESS (Ft)          =     69825. PSI
  ft/Ft                                  =       0.13

  SHEAR STRESS ON BOLT (fv)              =      4235. PSI
  ALLOWABLE SHEAR STRESS (Fv)            =     41895. PSI
  fv/Fv                                  =       0.10

  (ft/Ft)^2 + (fv/Fv)^2                  =       0.03

_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                     =      15.00 INCHES
  BOLT LOAD                              =     22263. LBS
  MOMENT ON BASE PLATE                   =    100185. IN-LBS
  PLATE EFFECTIVE WIDTH                  =      18.00 INCHES
  PLATE SECTION MODULUS                  =      12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)      =      8349. PSI
  ALLOWABLE BENDING STRESS (Fb)          =     43890. PSI
  fb/Fb                                  =       0.19

________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                    =      2784. PSI
  ALLOWABLE FATIGUE STRESS               =      7000. PSI
  FATIGUE STRESS RATIO                   =       0.40
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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-C_TCS-2

  04/01/2020  8:44 am

_______________________________GALLOPING______________________________

  IMPORTANCE FACTOR =       1.00

                     ----Arm  1, Segment  1----
          AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)    (PSF)       (LBS)    (FT-LBS)
    1       9.00     21.00      189.00     2268.00

    2       1.00     21.00       21.00      357.00

    3       9.00     21.00      189.00     4158.00

    4      14.00     21.00      294.00     7644.00

    5       9.00     21.00      189.00     5481.00

    6       1.00     21.00       21.00      651.00

    7       9.00     21.00      189.00     6426.00

    8       8.20     21.00      172.20        0.00

    9      11.80     21.00      247.80        0.00


                      FATIGUE    STRESS     FATIGUE
      BASE             MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION          (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM  1 SEG  1     26985.00    5143.       7000.       0.73
      POLE           26985.00    5140.       7000.       0.73
```

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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-C_TCS-2

  04/01/2020  8:44 am


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA              PRESSURE     FORCE
  COMPONENT       (FT^2)      CD      (PSF)       (LBS)
  ARM 1 SEG 1      33.59    1.10       5.72      192.12
  ARM 1 UNIT 1      9.00    1.20       6.24       56.16
  ARM 1 UNIT 2      1.00    0.50       2.60        2.60
  ARM 1 UNIT 3      9.00    1.20       6.24       56.16
  ARM 1 UNIT 4     14.00    1.20       6.24       87.36
  ARM 1 UNIT 5      9.00    1.12       5.82       52.42
  ARM 1 UNIT 6      1.00    0.50       2.60        2.60
  ARM 1 UNIT 7      9.00    1.20       6.24       56.16
  ARM 1 UNIT 8      8.20    0.50       2.60       21.32
  ARM 1 UNIT 9     11.80    0.50       2.60       30.68
  POLE             23.75    1.10       5.72      135.85

                 FATIGUE   STRESS     FATIGUE              WIND
      BASE        MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
    LOCATION     (FT-LBS)   (PSI)      (PSI)      RATIO    (DEG)
   ARM 1 SEG 1   10756.1    2050.      7000.      0.29
       POLE      11178.8    2129.      7000.      0.30       90
```

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 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-C_TCS-2

  04/01/2020  8:44 am


_______________________________TRUCK GUST_____________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA               PRESSURE     FORCE
  COMPONENT       (FT^2)     CD        (PSF)       (LBS)
  ARM 1 SEG 1       9.20    0.60      11.27      103.70
  ARM 1 UNIT 1      1.20    1.20      22.56       27.07
  ARM 1 UNIT 2      0.20    0.50       9.40        1.88
  ARM 1 UNIT 3      1.20    1.20      22.56       27.07
  ARM 1 UNIT 4      2.58    1.20      22.56       58.20
  ARM 1 UNIT 5      1.00    1.12      21.06       21.06
  ARM 1 UNIT 6      0.20    0.50       9.40        1.88
  ARM 1 UNIT 7      1.20    1.20      22.56       27.07
  ARM 1 UNIT 8      1.03    0.50       9.40        9.68
  ARM 1 UNIT 9      1.00    0.50       9.40        9.40

                 FATIGUE    STRESS     FATIGUE
                  MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION     (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1    7062.37    1346.      7000.       0.19
      POLE        7062.37    1345.      7000.       0.19
```

```
 City of Meriden_Hanover Street at Route 71(Cook Ave)_Mast Arm 079-241-C_TCS-2

  04/01/2020  8:44 am

________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                                                                                            **
**                                                                                            **
**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
**                                                                                            **
**                                                                                            **
**                   PPPPPPPPPPP    OOOOOOOOOO   LL            EEEEEEEEEEEE                   **
**                   PPPPPPPPPPPP  OOOOOOOOOOOO  LL            EEEEEEEEEEEE                   **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PPPPPPPPPPPP  OO        OO  LL            EEEEEEEEE                      **
**                   PPPPPPPPPPP   OO        OO  LL            EEEEEEEEE                      **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OOOOOOOOOOOO  LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                   PP             OOOOOOOOOO   LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                                                                                            **
**                                                                                            **
**                              Copyright (c) 1999 - 2019 WYDOT                               **
**                                                                                            **
**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
**                               Release Date: August 15, 2019                                **
**                                                                                            **
**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
**                                                                                            **
**                    For user assistance and system information contact:                     **
**                                   Phone: (307) 777-4489                                    **
**                              E-mail: BRASSTechSupport@wyo.gov                              **
**                                                                                            **
**            The source version is maintained by BridgeTech, Inc.                            **
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**                                                                                            **
**   AASHTO Standard Specifications (LFD):                                                    **
**                                                                                            **
**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural     **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,      **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
**                                                                                            **
**                                                                                            **
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-D_TCS-3
  01/06/2021  3:39 pm

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE         ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1        4 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

            BASE    AVERAGE     WALL        MODULUS
          DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       12.00      9.00     0.38       29000000.

           YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
          STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)                (FEET)
    1      65000.      40.0           16.5                  18.6

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                  SIDE                    ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.  22.0   9.0    N/A     17.6    65.0    28.0   N/A     N/A
   2  ROUNDED LUM.  30.0   1.0    N/A     18.1     2.0     1.0   N/A     N/A
   3  TRAFFIC SIG.  35.0   9.0    N/A     18.3    72.0    28.0   N/A     N/A
   4  ROUNDED LUM.   0.0  11.8    N/A     16.0   450.0    11.8   N/A     N/A
__________________ARM  2 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE         ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1        2 ROUND OR EQUIV ROUND    90.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 2___________________

            BASE    AVERAGE     WALL        MODULUS
          DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       12.00      9.00     0.38       29000000.

           YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
          STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)                (FEET)
    1      65000.      45.0           16.5                  18.9

___________________DESCRIPTION OF UNITS ON ARM # 2____________________

                                  SIDE                    ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.  34.0   9.0    N/A     18.3    65.0    28.0   N/A     N/A
   2  TRAFFIC SIG.  42.0   9.0    N/A     18.7    65.0    28.0   N/A     N/A
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-D_TCS-3
  01/06/2021  3:39 pm

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

                HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT      (FT)      (FT^2)      CD        (PSF)      (LBS)
 SEGMENT # 1     17.4      30.04      1.10       40.50     1216.8
   UNIT # 1      18.1       9.00      1.20       44.56      401.1
   UNIT # 2      18.6       1.00      0.50       18.66       18.7
   UNIT # 3      18.8       9.00      1.20       44.91      404.2
   UNIT # 4      16.5      11.80      0.50       18.20      214.7

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                               =   1444.4 LBS
  WEIGHT OF ATTACHMENTS                       =    589.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS        =   2255.4 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS          =    489.8 LBS
  DEAD LOAD MOMENT                            =  29688.5 FT-LBS
  WIND MOMENT                                 =  45160.3 FT-LBS
  ICE MOMENT                                  =   9918.3 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                     MOMENT       SHEAR        TORSION
                    (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I           29688.5      1583.4          N/A
  GROUP II          54045.0      2582.9            3.0
  GROUP III         45638.5      2280.4            1.5

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       8955.       231.         42900.      21450.
  GROUP II     16302.       378.         57057.      28528.
  GROUP III    13767.       333.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                         GROUP I   = 0.2089
                         GROUP II  = 0.2859
                         GROUP III = 0.2414
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-D_TCS-3
  01/06/2021  3:39 pm

_______________________WIND LOADING ON ARM # 2________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

                HEIGHT      AREA              PRESSURE     FORCE
  COMPONENT      (FT)      (FT^2)      CD       (PSF)      (LBS)
 SEGMENT # 1     17.5       33.80      1.10      40.56     1370.8
   UNIT # 1      18.8        9.00      1.20      44.88      404.0
   UNIT # 2      19.2        9.00      1.20      45.09      405.8

________________________LOADS APPLIED TO ARM # 2______________________

  WEIGHT OF ARM                               =   1625.0 LBS
  WEIGHT OF ATTACHMENTS                       =    130.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS        =   2180.6 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS          =    486.8 LBS
  DEAD LOAD MOMENT                            =  37439.4 FT-LBS
  WIND MOMENT                                 =  58194.7 FT-LBS
  ICE MOMENT                                  =  12763.6 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 2 SEG # 1_______________

                     MOMENT       SHEAR        TORSION
                    (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I           37439.4      1755.0          N/A
  GROUP II          69197.8      2799.1            1.2
  GROUP III         58025.8      2492.8            0.6

______________GROUP LOAD STRESSES FOR ARM # 2, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I      11293.       256.         42900.      21450.
  GROUP II     20873.       409.         57057.      28528.
  GROUP III    17503.       364.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 2, SEG # 1___________

                         GROUP I   = 0.2634
                         GROUP II  = 0.3660
                         GROUP III = 0.3069
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-D_TCS-3
  01/06/2021  3:39 pm

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

     E                                 =  29000.0 KSI
     Fy                                =  65000.0 PSI
     LENGTH OF POLE                    =     18.0 FEET
     WALL THICKNESS                    =   0.3750 IN
     BOTTOM OD                         =   12.000 IN
     TOP OD                            =   12.000 IN
     ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
     HEIGHT OF BASE ABOVE GROUND       =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

            STANDARD WIND METHOD, ARTICLE 3.8, USED:
            DESIGN WIND VELOCITY = 120.0 MPH
            RECURRENCE INTERVAL  =    50 YEARS
            GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                     POLE WEIGHT =     838.8 LBS.
                     AXIAL LOAD  =    4627.2 LBS.
                     MOMENT      =  103164.0 FT-LBS
                     SHEAR       =    3928.3 LBS.
                     TORQUE      =   57778.8 FT-LBS

___________________________GROUP II STRESSES__________________________

              AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED       338.          31103.           9288.
  ALLOWABLE    51870.         57057.          28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0065 +  0.5451 +  0.1060 =  0.6576
                        (AXIAL)   (BENDING) (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =  184 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE = 105156. FT-LBS
  WITH WIND APPLIED AT  263 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       =  99082. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =  35222. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           =  58195. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   3944. LBS
  WITH WIND APPLIED AT  180 DEGREES
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```
 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-D_TCS-3
  01/06/2021  3:39 pm

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                         =      8.00
  BOLT CIRCLE DIAMETER                    =     24.00 INCHES
  ANCHOR BOLT DIAMETER                    =      2.00 INCHES
  THREADS PER INCH                        =      4.00
  TENSILE STRESS AREA                     =      2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT           =   105000. PSI

  DIMENSION OF BASE PLATE                 =     30.00 INCHES
  BASE PLATE THICKNESS                    =      2.00 INCHES
  YIELD STRENGTH OF BASE PLATE            =    50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP         =   1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =    116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =   103274. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =     3920. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =    57546. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =      185. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)             =    10656. PSI
  ALLOWABLE TENSILE STRESS (Ft)           =    69825. PSI
  ft/Ft                                   =      0.15

  SHEAR STRESS ON BOLT (fv)               =     3171. PSI
  ALLOWABLE SHEAR STRESS (Fv)             =    41895. PSI
  fv/Fv                                   =      0.08

  (ft/Ft)^2 + (fv/Fv)^2                   =      0.03

_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                      =     12.00 INCHES
  BOLT LOAD                               =    26289. LBS
  MOMENT ON BASE PLATE                    =   157734. IN-LBS
  PLATE EFFECTIVE WIDTH                   =     18.00 INCHES
  PLATE SECTION MODULUS                   =     12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)       =    13145. PSI
  ALLOWABLE BENDING STRESS (Fb)           =    43890. PSI
  fb/Fb                                   =      0.30

________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                     =     1482. PSI
  ALLOWABLE FATIGUE STRESS                =     7000. PSI
  FATIGUE STRESS RATIO                    =      0.21
```

```
 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-D_TCS-3
  01/06/2021  3:39 pm

_______________________________GALLOPING______________________________

  IMPORTANCE FACTOR =       1.00

                    ----Arm  1, Segment  1----
          AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)    (PSF)       (LBS)    (FT-LBS)
    1       9.00     21.00      189.00     4158.00

    2       1.00     21.00       21.00      630.00

    3       9.00     21.00      189.00     6615.00

    4      11.80     21.00      247.80        0.00

                    ----Arm  2, Segment  1----
          AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)    (PSF)       (LBS)    (FT-LBS)
    1       9.00     21.00      189.00     6426.00

    2       9.00     21.00      189.00     7938.00


                     FATIGUE    STRESS     FATIGUE
      BASE            MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION         (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM  1 SEG  1     11403.00    3440.       7000.       0.49
   ARM  2 SEG  1     14364.00    4333.       7000.       0.62
       POLE          14364.00    4331.       7000.       0.62
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-D_TCS-3
  01/06/2021  3:39 pm


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA            PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)       (LBS)
  ARM 1 SEG 1      30.04    1.10      5.72      171.84
  ARM 1 UNIT 1      9.00    1.20      6.24       56.16
  ARM 1 UNIT 2      1.00    0.50      2.60        2.60
  ARM 1 UNIT 3      9.00    1.20      6.24       56.16
  ARM 1 UNIT 4     11.80    0.50      2.60       30.68
  ARM 2 SEG 1      33.80    1.10      5.72      193.31
  ARM 2 UNIT 1      9.00    1.20      6.24       56.16
  ARM 2 UNIT 2      9.00    1.20      6.24       56.16
  POLE             18.00    1.10      5.72      102.96

                 FATIGUE   STRESS     FATIGUE              WIND
      BASE        MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
    LOCATION     (FT-LBS)   (PSI)      (PSI)       RATIO    (DEG)
   ARM 1 SEG 1    6334.0    1911.      7000.       0.27
   ARM 2 SEG 1    8134.5    2454.      7000.       0.35
       POLE       8954.3    2700.      7000.       0.39      180
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-D_TCS-3
  01/06/2021  3:39 pm


_______________________________TRUCK GUST_____________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)       (LBS)
  ARM 1 SEG 1       6.90    0.82     15.50      106.96
  ARM 1 UNIT 1      1.20    1.20     22.56       27.07
  ARM 1 UNIT 2      0.20    0.50      9.40        1.88
  ARM 1 UNIT 3      1.20    1.20     22.56       27.07
  ARM 1 UNIT 4      5.20    0.50      9.40       48.88
  ARM 2 SEG 1       6.80    0.82     15.50      105.41
  ARM 2 UNIT 1      1.20    1.20     22.56       27.07
  ARM 2 UNIT 2      1.20    1.20     22.56       27.07

                 FATIGUE    STRESS     FATIGUE
                  MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION     (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1    5236.21    1579.      7000.       0.23
   ARM 2 SEG 1    6168.54    1861.      7000.       0.27
      POLE        6168.54    1860.      7000.       0.27
```

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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-D_TCS-3
  01/06/2021  3:39 pm


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
**                                                                                            **
**                                                                                            **
**                   PPPPPPPPPPP    OOOOOOOOOO   LL            EEEEEEEEEEEE                   **
**                   PPPPPPPPPPPP  OOOOOOOOOOOO  LL            EEEEEEEEEEEE                   **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PPPPPPPPPPPP  OO        OO  LL            EEEEEEEEE                      **
**                   PPPPPPPPPPP   OO        OO  LL            EEEEEEEEE                      **
**                   PP            OO        OO  LL            EE                             **
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**                   PP            OO        OO  LL            EE                             **
**                   PP            OOOOOOOOOOOO  LLLLLLLLLLL   EEEEEEEEEEEE                   **
**                   PP             OOOOOOOOOO   LLLLLLLLLLL   EEEEEEEEEEEE                   **
**                                                                                            **
**                                                                                            **
**                              Copyright (c) 1999 - 2019 WYDOT                               **
**                                                                                            **
**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
**                               Release Date: August 15, 2019                                **
**                                                                                            **
**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
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**      with 2015, 2019, and 2020 Interim Revisions.                                          **
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-E_TCS-4
  04/01/2020  9:00 am

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1       5 ROUND OR EQUIV ROUND      0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

          BASE    AVERAGE     WALL        MODULUS
        DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT   (IN)      (IN)      (IN)         (PSI)
    1      12.00     10.00     0.38       29000000.

         YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
        STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)        (FEET)              (FEET)
    1     65000.      25.0          17.5                18.8

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                  SIDE                         ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #   ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.  17.0   9.0    N/A     18.4    65.0    28.0   N/A     N/A
   2  ROUNDED LUM.  21.0   1.0    N/A     18.6     2.0     1.0   N/A     N/A
   3  TRAFFIC SIG.  25.0   9.0    N/A     18.8    65.0    28.0   N/A     N/A
   4  TRAFFIC SIG.   0.0   8.2    N/A      8.0    22.0     8.2   N/A     N/A
   5  ROUNDED LUM.   0.0  11.8    N/A     16.0   450.0    11.8   N/A     N/A
```

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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-E_TCS-4
  04/01/2020  9:00 am

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

               HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT     (FT)      (FT^2)      CD        (PSF)      (LBS)
 SEGMENT # 1     18.1      20.86      1.10       40.83      851.8
   UNIT # 1      18.9       9.00      1.20       44.94      404.4
   UNIT # 2      19.1       1.00      0.50       18.77       18.8
   UNIT # 3      19.3       9.00      1.20       45.15      406.3
   UNIT # 4       8.5       8.20      1.20       43.87      359.8
   UNIT # 5      16.5      11.80      0.50       18.20      214.7

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                             =   1003.1 LBS
  WEIGHT OF ATTACHMENTS                     =    604.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS      =   2255.8 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS        =    427.9 LBS
  DEAD LOAD MOMENT                          =  14474.5 FT-LBS
  WIND MOMENT                               =  27365.5 FT-LBS
  ICE MOMENT                                =   5889.9 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                     MOMENT       SHEAR        TORSION
                    (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I           14474.5      1135.1          N/A
  GROUP II          30957.7      2028.6            0.5
  GROUP III         24570.7      1723.6            0.2

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       4366.       166.         42900.      21450.
  GROUP II      9338.       296.         57057.      28528.
  GROUP III     7412.       252.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                         GROUP I   = 0.1018
                         GROUP II  = 0.1638
                         GROUP III = 0.1300
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-E_TCS-4
  04/01/2020  9:00 am

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                   =  29000.0 KSI
      Fy                                  =  65000.0 PSI
      LENGTH OF POLE                      =     19.0 FEET
      WALL THICKNESS                      =   0.3750 IN
      BOTTOM OD                           =   12.000 IN
      TOP OD                              =   12.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND         =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =     885.4 LBS.
                      AXIAL LOAD  =    2492.5 LBS.
                      MOMENT      =   47654.1 FT-LBS
                      SHEAR       =    2999.5 LBS.
                      TORQUE      =   26959.1 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        182.          14367.            4504.
  ALLOWABLE    51870.          57057.           28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0035 +  0.2518 +  0.0249 =  0.2802
                        (AXIAL)   (BENDING)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   96 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE =  47687. FT-LBS
  WITH WIND APPLIED AT   98 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       =  43869. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =  18696. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           =  27365. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   3021. LBS
  WITH WIND APPLIED AT   90 DEGREES
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-E_TCS-4
  04/01/2020  9:00 am


______________POLE DESCRIPTION AT APPROXIMATE MAXIMUM CSR______________

  LENGTH OF SEGMENT = 19.00 FEET
  WALL THICKNESS          = 0.3750 IN.
  BOTTOM or EQUIVALENT OD = 12.000 IN.
  TOP or EQUIVALENT OD    = 12.000 IN.
  HEIGHT OF SEGMENT
  BASE ABOVE GROUND         =  0.5 FEET

___________________DESIGN LOADS AT POLE SEGMENT BASE___________________

    MOMENT      = 47654. FT-LBS
    SHEAR       =  3000. LBS.
    TORQUE      = 26959. FT-LBS

  MAXIMUM COMBINED STRESS RATIO =  0.0035 +  0.2518 +  0.0249 =  0.2802
                                 (AXIAL)   (MOMENT)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   96 DEGREES
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-E_TCS-4
  04/01/2020  9:00 am

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                        =      8.00
  BOLT CIRCLE DIAMETER                   =     24.00 INCHES
  ANCHOR BOLT DIAMETER                   =      2.00 INCHES
  THREADS PER INCH                       =      4.00
  TENSILE STRESS AREA                    =      2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT          =   105000. PSI

  DIMENSION OF BASE PLATE                =     30.00 INCHES
  BASE PLATE THICKNESS                   =      2.00 INCHES
  YIELD STRENGTH OF BASE PLATE           =    50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP        =   1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =    116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =    47609. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =     3006. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =    27083. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =       95. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)            =     4912. PSI
  ALLOWABLE TENSILE STRESS (Ft)          =    69825. PSI
  ft/Ft                                  =      0.07

  SHEAR STRESS ON BOLT (fv)              =     1552. PSI
  ALLOWABLE SHEAR STRESS (Fv)            =    41895. PSI
  fv/Fv                                  =      0.04

  (ft/Ft)^2 + (fv/Fv)^2                  =      0.01

_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                     =     12.00 INCHES
  BOLT LOAD                              =    11922. LBS
  MOMENT ON BASE PLATE                   =    71530. IN-LBS
  PLATE EFFECTIVE WIDTH                  =     18.00 INCHES
  PLATE SECTION MODULUS                  =     12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)      =     5961. PSI
  ALLOWABLE BENDING STRESS (Fb)          =    43890. PSI
  fb/Fb                                  =      0.14

________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                    =      865. PSI
  ALLOWABLE FATIGUE STRESS               =     7000. PSI
  FATIGUE STRESS RATIO                   =      0.12
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-E_TCS-4
  04/01/2020  9:00 am

_______________________________GALLOPING______________________________

  IMPORTANCE FACTOR =       1.00

                    ----Arm  1, Segment  1----
            AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)     (PSF)       (LBS)    (FT-LBS)
    1       9.00      21.00      189.00     3213.00

    2       1.00      21.00       21.00      441.00

    3       9.00      21.00      189.00     4725.00

    4       8.20      21.00      172.20        0.00

    5      11.80      21.00      247.80        0.00


                     FATIGUE    STRESS     FATIGUE
       BASE           MOMENT     RANGE    THRESHOLD    STRESS
     LOCATION        (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM  1 SEG  1      8379.00    2527.       7000.       0.36
       POLE           8379.00    2526.       7000.       0.36
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-E_TCS-4
  04/01/2020  9:00 am


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)        (LBS)
  ARM 1 SEG 1      20.86    1.10      5.72      119.33
  ARM 1 UNIT 1      9.00    1.20      6.24       56.16
  ARM 1 UNIT 2      1.00    0.50      2.60        2.60
  ARM 1 UNIT 3      9.00    1.20      6.24       56.16
  ARM 1 UNIT 4      8.20    1.20      6.24       51.17
  ARM 1 UNIT 5     11.80    0.50      2.60       30.68
  POLE             19.00    1.10      5.72      108.68

                 FATIGUE   STRESS     FATIGUE              WIND
      BASE        MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
    LOCATION     (FT-LBS)   (PSI)      (PSI)      RATIO    (DEG)
   ARM 1 SEG 1    3805.5    1148.      7000.      0.16
       POLE       6231.4    1879.      7000.      0.27       90
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-E_TCS-4
  04/01/2020  9:00 am


_______________________________TRUCK GUST_____________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                 AREA              PRESSURE     FORCE
  COMPONENT      (FT^2)     CD      (PSF)       (LBS)
  ARM 1 SEG 1      8.96    0.72     13.52      121.12
  ARM 1 UNIT 1     1.20    1.20     22.56       27.07
  ARM 1 UNIT 2     0.20    0.50      9.40        1.88
  ARM 1 UNIT 3     1.20    1.20     22.56       27.07
  ARM 1 UNIT 4     1.03    1.20     22.56       23.24
  ARM 1 UNIT 5     5.00    0.50      9.40       47.00

               FATIGUE    STRESS     FATIGUE
                MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION   (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1   3477.72    1049.      7000.       0.15
      POLE       3477.72    1049.      7000.       0.15
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-E_TCS-4
  04/01/2020  9:00 am


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
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**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
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**                   PPPPPPPPPPP    OOOOOOOOOO   LL            EEEEEEEEEEEE                   **
**                   PPPPPPPPPPPP  OOOOOOOOOOOO  LL            EEEEEEEEEEEE                   **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PPPPPPPPPPPP  OO        OO  LL            EEEEEEEEE                      **
**                   PPPPPPPPPPP   OO        OO  LL            EEEEEEEEE                      **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OOOOOOOOOOOO  LLLLLLLLLLL   EEEEEEEEEEEE                   **
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**                                                                                            **
**                               Release Date: August 15, 2019                                **
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**                              E-mail: BRASSTechSupport@wyo.gov                              **
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**                                                                                            **
**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural      **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,       **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-F_TCS-4
  04/01/2020  9:21 am

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1        2 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

            BASE    AVERAGE     WALL        MODULUS
          DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       12.00     10.00     0.38       29000000.

           YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
          STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)              (FEET)
    1      65000.      35.0           17.5                19.3

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                  SIDE                    ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.  25.0   9.0    N/A     18.8    65.0    28.0   N/A     N/A
   2  TRAFFIC SIG.  33.0   9.0    N/A     19.2    65.0    28.0   N/A     N/A
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-F_TCS-4
  04/01/2020  9:21 am

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

              HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT     (FT)      (FT^2)      CD        (PSF)      (LBS)
 SEGMENT # 1    18.4      29.21      1.10       40.95     1195.9
   UNIT # 1     19.3       9.00      1.20       45.15      406.3
   UNIT # 2     19.7       9.00      1.20       45.35      408.2

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                             =   1404.3 LBS
  WEIGHT OF ATTACHMENTS                     =    130.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS      =   2010.4 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS        =    443.5 LBS
  DEAD LOAD MOMENT                          =  26706.8 FT-LBS
  WIND MOMENT                               =  43160.5 FT-LBS
  ICE MOMENT                                =   9375.0 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                    MOMENT       SHEAR        TORSION
                   (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I          26706.8      1534.3          N/A
  GROUP II         50755.1      2529.0            0.1
  GROUP III        42042.9      2218.6            0.1

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       8056.       224.         42900.      21450.
  GROUP II     15310.       369.         57057.      28528.
  GROUP III    12682.       324.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                         GROUP I   = 0.1879
                         GROUP II  = 0.2685
                         GROUP III = 0.2224
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-F_TCS-4
  04/01/2020  9:21 am

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                    =  29000.0 KSI
      Fy                                   =  65000.0 PSI
      LENGTH OF POLE                       =     19.0 FEET
      WALL THICKNESS                       =   0.3750 IN
      BOTTOM OD                            =   12.000 IN
      TOP OD                               =   12.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND          =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =     885.4 LBS.
                      AXIAL LOAD  =    2419.7 LBS.
                      MOMENT      =   53194.7 FT-LBS
                      SHEAR       =    2755.2 LBS.
                      TORQUE      =   42685.4 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        177.          16038.            6840.
  ALLOWABLE    51870.          57057.           28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0034 +  0.2811 +  0.0575 =  0.3420
                        (AXIAL)   (BENDING) (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   95 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE =  53317. FT-LBS
  WITH WIND APPLIED AT   98 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       =  43958. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =  30174. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           =  43161. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   2776. LBS
  WITH WIND APPLIED AT   90 DEGREES
```

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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-F_TCS-4
  04/01/2020  9:21 am


______________POLE DESCRIPTION AT APPROXIMATE MAXIMUM CSR______________

  LENGTH OF SEGMENT = 19.00 FEET
  WALL THICKNESS          = 0.3750 IN.
  BOTTOM or EQUIVALENT OD = 12.000 IN.
  TOP or EQUIVALENT OD    = 12.000 IN.
  HEIGHT OF SEGMENT
  BASE ABOVE GROUND         =  0.5 FEET

___________________DESIGN LOADS AT POLE SEGMENT BASE___________________

    MOMENT      = 53195. FT-LBS
    SHEAR       =  2755. LBS.
    TORQUE      = 42685. FT-LBS

  MAXIMUM COMBINED STRESS RATIO =  0.0034 +  0.2811 +  0.0575 =  0.3420
                                  (AXIAL)   (MOMENT)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   95 DEGREES
```

```
 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-F_TCS-4
  04/01/2020  9:21 am

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                         =      8.00
  BOLT CIRCLE DIAMETER                    =     24.00 INCHES
  ANCHOR BOLT DIAMETER                    =      2.00 INCHES
  THREADS PER INCH                        =      4.00
  TENSILE STRESS AREA                     =      2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT           =   105000. PSI

  DIMENSION OF BASE PLATE                 =     30.00 INCHES
  BASE PLATE THICKNESS                    =      2.00 INCHES
  YIELD STRENGTH OF BASE PLATE            =    50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP         =   1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =    116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =    53106. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =     2763. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =    42856. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =       94. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)             =     5479. PSI
  ALLOWABLE TENSILE STRESS (Ft)           =    69825. PSI
  ft/Ft                                   =      0.08

  SHEAR STRESS ON BOLT (fv)               =     2353. PSI
  ALLOWABLE SHEAR STRESS (Fv)             =    41895. PSI
  fv/Fv                                   =      0.06

  (ft/Ft)^2 + (fv/Fv)^2                   =      0.01

_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                      =     12.00 INCHES
  BOLT LOAD                               =    13329. LBS
  MOMENT ON BASE PLATE                    =    79976. IN-LBS
  PLATE EFFECTIVE WIDTH                   =     18.00 INCHES
  PLATE SECTION MODULUS                   =     12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)       =     6665. PSI
  ALLOWABLE BENDING STRESS (Fb)           =    43890. PSI
  fb/Fb                                   =      0.15

________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                     =     1131. PSI
  ALLOWABLE FATIGUE STRESS                =     7000. PSI
  FATIGUE STRESS RATIO                    =      0.16
```

```
 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-F_TCS-4
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______________________________GALLOPING______________________________

  IMPORTANCE FACTOR =       1.00

                   ----Arm  1, Segment  1----
          AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)     (PSF)       (LBS)    (FT-LBS)
    1       9.00      21.00      189.00     4725.00

    2       9.00      21.00      189.00     6237.00


                    FATIGUE    STRESS     FATIGUE
      BASE           MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION        (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM  1 SEG  1    10962.00    3307.       7000.       0.47
       POLE         10962.00    3305.       7000.       0.47
```

```
 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-F_TCS-4
  04/01/2020  9:21 am


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)       (LBS)
  ARM 1 SEG 1      29.21    1.10      5.72      167.06
  ARM 1 UNIT 1      9.00    1.20      6.24       56.16
  ARM 1 UNIT 2      9.00    1.20      6.24       56.16
  POLE             19.00    1.10      5.72      108.68

                 FATIGUE   STRESS     FATIGUE             WIND
      BASE        MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
    LOCATION     (FT-LBS)   (PSI)      (PSI)      RATIO    (DEG)
   ARM 1 SEG 1    5986.0    1806.      7000.      0.26
       POLE       6235.4    1880.      7000.      0.27       90
```

```
 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-F_TCS-4
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_______________________________TRUCK GUST_____________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                  AREA              PRESSURE    FORCE
  COMPONENT       (FT^2)     CD      (PSF)      (LBS)
  ARM 1 SEG 1       8.69    0.72     13.52     117.41
  ARM 1 UNIT 1      1.20    1.20     22.56      27.07
  ARM 1 UNIT 2      1.20    1.20     22.56      27.07

                FATIGUE    STRESS     FATIGUE
                 MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION    (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1   4975.04    1501.      7000.       0.21
      POLE       4975.04    1500.      7000.       0.21
```

```
 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-F_TCS-4
  04/01/2020  9:21 am


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                                                                                            **
**                                                                                            **
**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
**                                                                                            **
**                                                                                            **
**                   PPPPPPPPPPP    OOOOOOOOOO   LL            EEEEEEEEEEEE                   **
**                   PPPPPPPPPPPP  OOOOOOOOOOOO  LL            EEEEEEEEEEEE                   **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PPPPPPPPPPPP  OO        OO  LL            EEEEEEEEE                      **
**                   PPPPPPPPPPP   OO        OO  LL            EEEEEEEEE                      **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OOOOOOOOOOOO  LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                   PP             OOOOOOOOOO   LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                                                                                            **
**                                                                                            **
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**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
**                               Release Date: August 15, 2019                                **
**                                                                                            **
**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
**                                                                                            **
**                    For user assistance and system information contact:                     **
**                                   Phone: (307) 777-4489                                    **
**                              E-mail: BRASSTechSupport@wyo.gov                              **
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**            The source version is maintained by BridgeTech, Inc.                            **
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**                                                                                            **
**   AASHTO Standard Specifications (LFD):                                                    **
**                                                                                            **
**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural      **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,      **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
**                                                                                            **
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-G_TCS-4
  04/01/2020  9:25 am

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1        4 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

            BASE    AVERAGE     WALL        MODULUS
          DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       12.00     10.00     0.38       29000000.

           YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
          STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)              (FEET)
    1      65000.      20.0          17.5                18.5

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                  SIDE                    ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.  10.0   9.0    N/A     18.0    65.0    28.0   N/A     N/A
   2  TRAFFIC SIG.  18.0   9.0    N/A     18.4    65.0    28.0   N/A     N/A
   3  ROUNDED LUM.   7.0   1.0    N/A     17.9     6.6     1.0   N/A     N/A
   4  ROUNDED LUM.  14.0   1.0    N/A     18.2     1.0     1.0   N/A     N/A
```

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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-G_TCS-4
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_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

               HEIGHT      AREA              PRESSURE     FORCE
  COMPONENT     (FT)      (FT^2)      CD       (PSF)      (LBS)
 SEGMENT # 1    18.0      16.69      1.10       40.77      680.5
   UNIT # 1     18.5       9.00      1.20       44.75      402.8
   UNIT # 2     18.9       9.00      1.20       44.96      404.7
   UNIT # 3     18.4       1.00      0.50       18.61       18.6
   UNIT # 4     18.7       1.00      0.50       18.69       18.7

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                                =    802.5 LBS
  WEIGHT OF ATTACHMENTS                        =    137.6 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS         =   1525.2 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS           =    331.5 LBS
  DEAD LOAD MOMENT                             =   9369.8 FT-LBS
  WIND MOMENT                                  =  18054.8 FT-LBS
  ICE MOMENT                                   =   3886.4 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                    MOMENT       SHEAR        TORSION
                   (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I           9369.8       940.1          N/A
  GROUP II         20341.3      1791.6            3.2
  GROUP III        16075.6      1486.0            1.6

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       2826.       137.         42900.      21450.
  GROUP II      6136.       262.         57057.      28528.
  GROUP III     4849.       217.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                         GROUP I   = 0.0659
                         GROUP II  = 0.1076
                         GROUP III = 0.0850
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-G_TCS-4
  04/01/2020  9:25 am

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                    =  29000.0 KSI
      Fy                                   =  65000.0 PSI
      LENGTH OF POLE                       =     19.0 FEET
      WALL THICKNESS                       =   0.3750 IN
      BOTTOM OD                            =   12.000 IN
      TOP OD                               =   12.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND          =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =     885.4 LBS.
                      AXIAL LOAD  =    1825.5 LBS.
                      MOMENT      =   36627.7 FT-LBS
                      SHEAR       =    2278.6 LBS.
                      TORQUE      =   17869.7 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        133.          11043.            3028.
  ALLOWABLE    51870.          57057.           28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0026 +  0.1935 +  0.0113 =  0.2074
                        (AXIAL)   (BENDING) (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   95 DEGREES
_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE =  36640. FT-LBS
  WITH WIND APPLIED AT   96 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       =  34683. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =  11816. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           =  18055. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   2291. LBS
  WITH WIND APPLIED AT   90 DEGREES
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-G_TCS-4
  04/01/2020  9:25 am


______________POLE DESCRIPTION AT APPROXIMATE MAXIMUM CSR______________

  LENGTH OF SEGMENT = 19.00 FEET
  WALL THICKNESS          = 0.3750 IN.
  BOTTOM or EQUIVALENT OD = 12.000 IN.
  TOP or EQUIVALENT OD    = 12.000 IN.
  HEIGHT OF SEGMENT
  BASE ABOVE GROUND         =  0.5 FEET

___________________DESIGN LOADS AT POLE SEGMENT BASE___________________

    MOMENT      = 36628. FT-LBS
    SHEAR       =  2279. LBS.
    TORQUE      = 17870. FT-LBS

  MAXIMUM COMBINED STRESS RATIO =  0.0026 +  0.1935 +  0.0113 =  0.2074
                                  (AXIAL)   (MOMENT)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   95 DEGREES
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-G_TCS-4
  04/01/2020  9:25 am

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                        =       8.00
  BOLT CIRCLE DIAMETER                   =      24.00 INCHES
  ANCHOR BOLT DIAMETER                   =       2.00 INCHES
  THREADS PER INCH                       =       4.00
  TENSILE STRESS AREA                    =       2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT          =    105000. PSI

  DIMENSION OF BASE PLATE                =      30.00 INCHES
  BASE PLATE THICKNESS                   =       2.00 INCHES
  YIELD STRENGTH OF BASE PLATE           =     50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP        =    1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =     116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =     36628. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =      2279. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =     17870. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =        95. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)            =      3779. PSI
  ALLOWABLE TENSILE STRESS (Ft)          =     69825. PSI
  ft/Ft                                  =       0.05

  SHEAR STRESS ON BOLT (fv)              =      1039. PSI
  ALLOWABLE SHEAR STRESS (Fv)            =     41895. PSI
  fv/Fv                                  =       0.02

  (ft/Ft)^2 + (fv/Fv)^2                  =       0.00

_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                     =      12.00 INCHES
  BOLT LOAD                              =      9160. LBS
  MOMENT ON BASE PLATE                   =     54960. IN-LBS
  PLATE EFFECTIVE WIDTH                  =      18.00 INCHES
  PLATE SECTION MODULUS                  =      12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)      =      4580. PSI
  ALLOWABLE BENDING STRESS (Fb)          =     43890. PSI
  fb/Fb                                  =       0.10

________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                    =       592. PSI
  ALLOWABLE FATIGUE STRESS               =      7000. PSI
  FATIGUE STRESS RATIO                   =       0.08
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-G_TCS-4
  04/01/2020  9:25 am

________________________________GALLOPING_______________________________

  IMPORTANCE FACTOR =       1.00

                    ----Arm  1, Segment  1----
           AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)    (PSF)       (LBS)    (FT-LBS)
    1       9.00     21.00      189.00     1890.00

    2       9.00     21.00      189.00     3402.00

    3       1.00     21.00       21.00      147.00

    4       1.00     21.00       21.00      294.00


                     FATIGUE    STRESS     FATIGUE
       BASE          MOMENT     RANGE     THRESHOLD    STRESS
     LOCATION       (FT-LBS)    (PSI)       (PSI)       RATIO
   ARM  1 SEG  1     5733.00    1729.       7000.        0.25
       POLE          5733.00    1728.       7000.        0.25
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-G_TCS-4
  04/01/2020  9:25 am


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA              PRESSURE     FORCE
  COMPONENT       (FT^2)     CD       (PSF)       (LBS)
  ARM 1 SEG 1      16.69    1.10      5.72        95.46
  ARM 1 UNIT 1      9.00    1.20      6.24        56.16
  ARM 1 UNIT 2      9.00    1.20      6.24        56.16
  ARM 1 UNIT 3      1.00    0.50      2.60         2.60
  ARM 1 UNIT 4      1.00    0.50      2.60         2.60
  POLE             19.00    1.10      5.72       108.68

                 FATIGUE   STRESS      FATIGUE              WIND
      BASE        MOMENT    RANGE     THRESHOLD   STRESS    ANGLE
    LOCATION     (FT-LBS)    (PSI)      (PSI)      RATIO    (DEG)
   ARM 1 SEG 1    2518.1     760.       7000.      0.11
       POLE       4891.2    1475.       7000.      0.21       90
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-G_TCS-4
  04/01/2020  9:25 am


_______________________________TRUCK GUST_____________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA              PRESSURE     FORCE
  COMPONENT       (FT^2)      CD      (PSF)       (LBS)
  ARM 1 SEG 1       9.20    0.72     13.52      124.36
  ARM 1 UNIT 1      1.20    1.20     22.56       27.07
  ARM 1 UNIT 2      1.20    1.20     22.56       27.07
  ARM 1 UNIT 3      0.70    0.50      9.40        6.58
  ARM 1 UNIT 4      0.70    0.50      9.40        6.58

                 FATIGUE    STRESS     FATIGUE
                  MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION     (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1    2637.25     796.      7000.        0.11
      POLE        2637.25     795.      7000.        0.11
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 City of Meriden_West Main Stree at Butler Street_Mast Arm 079-241-G_TCS-4
  04/01/2020  9:25 am


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                            WYOMING DEPARTMENT OF TRANSPORTATION                             **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
**                                                                                            **
**                                                                                            **
**                   PPPPPPPPPPP    OOOOOOOOOO   LL            EEEEEEEEEEEE                   **
**                   PPPPPPPPPPPP  OOOOOOOOOOOO  LL            EEEEEEEEEEEE                   **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PPPPPPPPPPPP  OO        OO  LL            EEEEEEEEE                      **
**                   PPPPPPPPPPP   OO        OO  LL            EEEEEEEEE                      **
**                   PP            OO        OO  LL            EE                             **
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**                   PP            OOOOOOOOOOOO  LLLLLLLLLLLL  EEEEEEEEEEEE                   **
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**                                                                                            **
**                                                                                            **
**                              Copyright (c) 1999 - 2019 WYDOT                               **
**                                                                                            **
**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
**                               Release Date: August 15, 2019                                **
**                                                                                            **
**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
**                                                                                            **
**                    For user assistance and system information contact:                     **
**                                   Phone: (307) 777-4489                                    **
**                              E-mail: BRASSTechSupport@wyo.gov                              **
**                                                                                            **
**            The source version is maintained by BridgeTech, Inc.                            **
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**                                                                                            **
**   AASHTO Standard Specifications (LFD):                                                    **
**                                                                                            **
**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural     **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,      **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
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 City of Meriden_West Main Stree at Grove, S. Grove Street_Mast Arm 079-241-H_TC
 S-5
  01/11/2021  11:45 am

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS         SHAPE        (DEGREES)    (DEGREES)
      1        7 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

           BASE    AVERAGE     WALL        MODULUS
         DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       12.00     10.00     0.38       29000000.

          YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
         STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)     (FEET)         (FEET)              (FEET)
    1      65000.     30.0           17.5                19.1

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                SIDE                          ICE    SIGN    SIGN
                   DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____ (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  SIGN PANEL     5.0   9.0    N/A     17.7    36.0     9.0  36.0    36.0
   2  TRAFFIC SIG.  11.0   9.0    N/A     18.0    65.0    28.0  N/A     N/A
   3  TRAFFIC SIG.  19.0   9.0    N/A     18.4    65.0    28.0  N/A     N/A
   4  TRAFFIC SIG.  22.0   9.0    N/A     18.6    65.0    28.0  N/A     N/A
   5  TRAFFIC SIG.  30.0   9.0    N/A     19.0    65.0    28.0  N/A     N/A
   6  TRAFFIC SIG.   0.0   8.2    N/A      8.0    22.0     8.2  N/A     N/A
   7  ROUNDED LUM.   0.0  11.8    N/A     16.0   450.0    11.8  N/A     N/A
__________________ARM  2 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS         SHAPE        (DEGREES)    (DEGREES)
      1        5 ROUND OR EQUIV ROUND    76.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 2___________________

           BASE    AVERAGE     WALL        MODULUS
         DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       12.00     10.00     0.38       29000000.

          YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
         STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)     (FEET)         (FEET)              (FEET)
    1      65000.     35.0           17.5                19.3

___________________DESCRIPTION OF UNITS ON ARM # 2____________________

                                SIDE                          ICE    SIGN    SIGN
                   DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____ (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  ROUNDED LUM.  18.0   1.0    N/A     18.6     1.0     1.0  N/A     N/A
   2  TRAFFIC SIG.  25.0   9.0    N/A     18.8    65.0    28.0  N/A     N/A
   3  SIGN PANEL    30.0  12.0    N/A     19.1    48.0    12.0  48.0    36.0
   4  TRAFFIC SIG.  35.0   9.0    N/A     19.3    72.0    28.0  N/A     N/A
   5  SIGN PANEL    21.0  12.0    N/A     18.8    48.0    12.0  48.0    36.0
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 City of Meriden_West Main Stree at Grove, S. Grove Street_Mast Arm 079-241-H_TC
 S-5
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_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

              HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT    (FT)      (FT^2)      CD        (PSF)      (LBS)
 SEGMENT # 1   18.2      25.03      1.10       40.89     1023.6
   UNIT # 1    18.2       9.00      1.12       41.62      374.6
   UNIT # 2    18.5       9.00      1.20       44.75      402.8
   UNIT # 3    18.9       9.00      1.20       44.96      404.7
   UNIT # 4    19.1       9.00      1.20       45.04      405.4
   UNIT # 5    19.5       9.00      1.20       45.25      407.3
   UNIT # 6     8.5       8.20      1.20       43.87      359.8
   UNIT # 7    16.5      11.80      0.50       18.20      214.7

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                                =   1203.7 LBS
  WEIGHT OF ATTACHMENTS                        =    768.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS         =   3592.8 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS           =    659.4 LBS
  DEAD LOAD MOMENT                             =  22361.5 FT-LBS
  WIND MOMENT                                  =  49458.7 FT-LBS
  ICE MOMENT                                   =  10336.0 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                     MOMENT       SHEAR        TORSION
                    (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I           22361.5      1499.7          N/A
  GROUP II          54278.9      3370.3          107.4
  GROUP III         40996.0      2585.3           53.7

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       6745.       219.          42900.      21450.
  GROUP II     16373.       508.          57057.      28528.
  GROUP III    12366.       386.          57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                         GROUP I   = 0.1573
                         GROUP II  = 0.2873
                         GROUP III = 0.2169
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_______________________WIND LOADING ON ARM # 2________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

              HEIGHT      AREA                PRESSURE     FORCE
  COMPONENT    (FT)       (FT^2)      CD        (PSF)      (LBS)
 SEGMENT # 1   18.4       29.21      1.10       40.95     1195.9
   UNIT # 1    19.1        1.00      0.50       18.77       18.8
   UNIT # 2    19.3        9.00      1.20       45.12      406.1
   UNIT # 3    19.6       12.00      1.14       43.14      517.6
   UNIT # 4    19.8        9.00      1.20       45.38      408.4
   UNIT # 5    19.3       12.00      1.14       43.01      516.1

________________________LOADS APPLIED TO ARM # 2______________________

  WEIGHT OF ARM                                 =   1404.3 LBS
  WEIGHT OF ATTACHMENTS                         =    234.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS          =   3062.9 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS            =    518.5 LBS
  DEAD LOAD MOMENT                              =  29547.8 FT-LBS
  WIND MOMENT                                   =  70684.5 FT-LBS
  ICE MOMENT                                    =  11433.2 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 2 SEG # 1_______________

                       MOMENT       SHEAR        TORSION
                      (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I             29547.8      1638.3          N/A
  GROUP II            76611.8      3473.5           62.1
  GROUP III           54152.4      2647.0           31.5

______________GROUP LOAD STRESSES FOR ARM # 2, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       8913.       239.          42900.      21450.
  GROUP II     23109.       517.          57057.      28528.
  GROUP III    16335.       391.          57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 2, SEG # 1___________

                            GROUP I   = 0.2079
                            GROUP II  = 0.4054
                            GROUP III = 0.2865
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_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                    =  29000.0 KSI
      Fy                                   =  65000.0 PSI
      LENGTH OF POLE                       =     19.0 FEET
      WALL THICKNESS                       =   0.3750 IN
      BOTTOM OD                            =   12.000 IN
      TOP OD                               =   12.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND          =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =     885.4 LBS.
                      AXIAL LOAD  =    4495.4 LBS.
                      MOMENT      =  129606.8 FT-LBS
                      SHEAR       =    6029.2 LBS.
                      TORQUE      =   72789.5 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        328.          39075.           11859.
  ALLOWABLE    51870.          57057.           28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0063 +  0.6848 +  0.1728 =  0.8640
                        (AXIAL)   (BENDING) (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =  166 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE = 130510. FT-LBS
  WITH WIND APPLIED AT  172 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       =  10757. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     = 130066. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           =  74186. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   5932. LBS
  WITH WIND APPLIED AT  336 DEGREES
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______________POLE DESCRIPTION AT APPROXIMATE MAXIMUM CSR______________

  LENGTH OF SEGMENT = 19.00 FEET
  WALL THICKNESS          = 0.3750 IN.
  BOTTOM or EQUIVALENT OD = 12.000 IN.
  TOP or EQUIVALENT OD    = 12.000 IN.
  HEIGHT OF SEGMENT
  BASE ABOVE GROUND         =  0.5 FEET

___________________DESIGN LOADS AT POLE SEGMENT BASE___________________

    MOMENT      = ****** FT-LBS
    SHEAR       =  6029. LBS.
    TORQUE      = 72790. FT-LBS

  MAXIMUM COMBINED STRESS RATIO =  0.0063 +  0.6848 +  0.1728 =  0.8640
                                  (AXIAL)   (MOMENT)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =  166 DEGREES
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__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                        =       8.00
  BOLT CIRCLE DIAMETER                   =      24.00 INCHES
  ANCHOR BOLT DIAMETER                   =       2.00 INCHES
  THREADS PER INCH                       =       4.00
  TENSILE STRESS AREA                    =       2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT          =    105000. PSI

  DIMENSION OF BASE PLATE                =      30.00 INCHES
  BASE PLATE THICKNESS                   =       2.00 INCHES
  YIELD STRENGTH OF BASE PLATE           =     50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP        =    1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =     116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =    130264. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =      6015. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =     71735. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =       169. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)            =     13441. PSI
  ALLOWABLE TENSILE STRESS (Ft)          =     69825. PSI
  ft/Ft                                  =       0.19

  SHEAR STRESS ON BOLT (fv)              =      4011. PSI
  ALLOWABLE SHEAR STRESS (Fv)            =     41895. PSI
  fv/Fv                                  =       0.10

  (ft/Ft)^2 + (fv/Fv)^2                  =       0.05

_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                     =      12.00 INCHES
  BOLT LOAD                              =     32628. LBS
  MOMENT ON BASE PLATE                   =    195765. IN-LBS
  PLATE EFFECTIVE WIDTH                  =      18.00 INCHES
  PLATE SECTION MODULUS                  =      12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)      =     16314. PSI
  ALLOWABLE BENDING STRESS (Fb)          =     43890. PSI
  fb/Fb                                  =       0.37

________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                    =      2535. PSI
  ALLOWABLE FATIGUE STRESS               =      7000. PSI
  FATIGUE STRESS RATIO                   =       0.36
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______________________________GALLOPING______________________________

  IMPORTANCE FACTOR =       1.00

                   ----Arm  1, Segment  1----
            AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)      (PSF)       (LBS)    (FT-LBS)
    1       9.00      21.00      189.00      945.00

    2       9.00      21.00      189.00     2079.00

    3       9.00      21.00      189.00     3591.00

    4       9.00      21.00      189.00     4158.00

    5       9.00      21.00      189.00     5670.00

    6       8.20      21.00      172.20        0.00

    7      11.80      21.00      247.80        0.00

                   ----Arm  2, Segment  1----
            AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)      (PSF)       (LBS)    (FT-LBS)
    1       1.00      21.00       21.00      378.00

    2       9.00      21.00      189.00     4725.00

    3      12.00      21.00      252.00     7560.00

    4       9.00      21.00      189.00     6615.00

    5      12.00      21.00      252.00     5292.00


                    FATIGUE    STRESS     FATIGUE
      BASE           MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION        (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM  1 SEG  1    16443.00    4960.       7000.       0.71
   ARM  2 SEG  1    24570.00    7411.       7000.       1.06
       POLE         24570.00    7408.       7000.       1.06
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___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)       (LBS)
  ARM 1 SEG 1      25.03    1.10      5.72      143.20
  ARM 1 UNIT 1      9.00    1.12      5.82       52.42
  ARM 1 UNIT 2      9.00    1.20      6.24       56.16
  ARM 1 UNIT 3      9.00    1.20      6.24       56.16
  ARM 1 UNIT 4      9.00    1.20      6.24       56.16
  ARM 1 UNIT 5      9.00    1.20      6.24       56.16
  ARM 1 UNIT 6      8.20    1.20      6.24       51.17
  ARM 1 UNIT 7     11.80    0.50      2.60       30.68
  ARM 2 SEG 1      29.21    1.10      5.72      167.06
  ARM 2 UNIT 1      1.00    0.50      2.60        2.60
  ARM 2 UNIT 2      9.00    1.20      6.24       56.16
  ARM 2 UNIT 3     12.00    1.14      5.95       71.34
  ARM 2 UNIT 4      9.00    1.20      6.24       56.16
  ARM 2 UNIT 5     12.00    1.14      5.95       71.34
  POLE             19.00    1.10      5.72      108.68

                 FATIGUE   STRESS     FATIGUE              WIND
      BASE        MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
    LOCATION     (FT-LBS)   (PSI)       (PSI)      RATIO    (DEG)
   ARM 1 SEG 1    6871.9    2073.      7000.      0.30
   ARM 2 SEG 1    9783.6    2951.      7000.      0.42
       POLE      14061.7    4239.      7000.      0.61      165
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 City of Meriden_West Main Stree at Grove, S. Grove Street_Mast Arm 079-241-H_TC
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_______________________________TRUCK GUST_____________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                  AREA              PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)       (LBS)
  ARM 1 SEG 1       8.80    0.72     13.52      118.95
  ARM 1 UNIT 1      0.70    1.12     21.06       14.74
  ARM 1 UNIT 2      1.20    1.20     22.56       27.07
  ARM 1 UNIT 3      1.20    1.20     22.56       27.07
  ARM 1 UNIT 4      1.20    1.20     22.56       27.07
  ARM 1 UNIT 5      1.20    1.20     22.56       27.07
  ARM 1 UNIT 6      0.50    1.20     22.56       11.28
  ARM 1 UNIT 7      0.50    0.50      9.40        4.70
  ARM 2 SEG 1       8.69    0.72     13.52      117.41
  ARM 2 UNIT 1      0.50    0.50      9.40        4.70
  ARM 2 UNIT 2      1.20    1.20     22.56       27.07
  ARM 2 UNIT 3      1.00    1.14     21.49       21.49
  ARM 2 UNIT 4      1.20    1.20     22.56       27.07
  ARM 2 UNIT 5      1.00    1.14     21.49       21.49

                FATIGUE    STRESS     FATIGUE
                 MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION    (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1    5148.49    1553.      7000.       0.22
   ARM 2 SEG 1    6210.01    1873.      7000.       0.27
      POLE        6210.01    1872.      7000.       0.27
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________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                                                                                            **
**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
**                                                                                            **
**                                                                                            **
**                   PPPPPPPPPPP    OOOOOOOOOO   LL            EEEEEEEEEEEE                   **
**                   PPPPPPPPPPPP  OOOOOOOOOOOO  LL            EEEEEEEEEEEE                   **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PPPPPPPPPPPP  OO        OO  LL            EEEEEEEEE                      **
**                   PPPPPPPPPPP   OO        OO  LL            EEEEEEEEE                      **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OOOOOOOOOOOO  LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                   PP             OOOOOOOOOO   LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                                                                                            **
**                                                                                            **
**                              Copyright (c) 1999 - 2019 WYDOT                               **
**                                                                                            **
**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
**                               Release Date: August 15, 2019                                **
**                                                                                            **
**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
**                                                                                            **
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**                                   Phone: (307) 777-4489                                    **
**                              E-mail: BRASSTechSupport@wyo.gov                              **
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**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,       **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
**                                                                                            **
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 City of Meriden_Hanover Stree atSouth Grove Street_Mast Arm 079-241-I_TCS-6
  01/11/2021  11:49 am

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS         SHAPE         (DEGREES)    (DEGREES)
      1       6 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

            BASE    AVERAGE     WALL        MODULUS
          DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       15.00     11.50     0.38       29000000.

           YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
          STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)               (FEET)
    1      65000.      45.0           17.5                 19.9

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                  SIDE                          ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)   (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.  11.0   9.0    N/A     18.3    65.0    28.0   N/A     N/A
   2  ROUNDED LUM.  15.0   1.0    N/A     18.5     2.0     1.0   N/A     N/A
   3  TRAFFIC SIG.  20.0   9.0    N/A     18.8    65.0    28.0   N/A     N/A
   4  TRAFFIC SIG.  23.0   9.0    N/A     18.9    65.0    28.0   N/A     N/A
   5  TRAFFIC SIG.  41.0   9.0    N/A     19.9    65.0    28.0   N/A     N/A
   6  ROUNDED LUM.  21.0   1.0    N/A     24.0     7.0     1.0   N/A     N/A
```

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 City of Meriden_Hanover Stree atSouth Grove Street_Mast Arm 079-241-I_TCS-6
  01/11/2021  11:49 am

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

              HEIGHT      AREA              PRESSURE     FORCE
  COMPONENT    (FT)      (FT^2)      CD       (PSF)       (LBS)
 SEGMENT # 1   18.6      43.18      1.10      41.04     1772.3
   UNIT # 1    18.8       9.00      1.20      44.89      404.0
   UNIT # 2    19.0       1.00      0.50      18.75       18.7
   UNIT # 3    19.3       9.00      1.20      45.12      406.1
   UNIT # 4    19.4       9.00      1.20      45.20      406.8
   UNIT # 5    20.4       9.00      1.20      45.65      410.9
   UNIT # 6    24.5       1.00      0.50      19.78       19.8

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                                 =   2076.3 LBS
  WEIGHT OF ATTACHMENTS                         =    269.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS          =   3438.6 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS            =    749.5 LBS
  DEAD LOAD MOMENT                              =  48330.4 FT-LBS
  WIND MOMENT                                   =  75295.8 FT-LBS
  ICE MOMENT                                    =  16327.9 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                   MOMENT       SHEAR        TORSION
                  (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I         48330.4      2345.3          N/A
  GROUP II        89472.3      4162.3          452.5
  GROUP III       74871.4      3543.1          241.0

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       9211.       272.          42900.      21450.
  GROUP II     17052.       526.          57057.      28528.
  GROUP III    14269.       434.          57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                         GROUP I   = 0.2149
                         GROUP II  = 0.2992
                         GROUP III = 0.2503
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 City of Meriden_Hanover Stree atSouth Grove Street_Mast Arm 079-241-I_TCS-6
  01/11/2021  11:49 am

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                    =  29000.0 KSI
      Fy                                   =  65000.0 PSI
      LENGTH OF POLE                       =     19.0 FEET
      WALL THICKNESS                       =   0.3750 IN
      BOTTOM OD                            =   15.000 IN
      TOP OD                               =   15.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND          =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =    1113.9 LBS.
                      AXIAL LOAD  =    3459.3 LBS.
                      MOMENT      =   90108.5 FT-LBS
                      SHEAR       =    4364.6 LBS.
                      TORQUE      =   74453.8 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        201.          17165.           7602.
  ALLOWABLE    51870.          57057.          28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0039 +  0.3008 +  0.0710 =  0.3757
                        (AXIAL)   (BENDING) (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   95 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE =  90701. FT-LBS
  WITH WIND APPLIED AT  101 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       =  70935. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =  56523. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           =  75296. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   4395. LBS
  WITH WIND APPLIED AT   90 DEGREES
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 City of Meriden_Hanover Stree atSouth Grove Street_Mast Arm 079-241-I_TCS-6
  01/11/2021  11:49 am


______________POLE DESCRIPTION AT APPROXIMATE MAXIMUM CSR______________

  LENGTH OF SEGMENT = 19.00 FEET
  WALL THICKNESS          = 0.3750 IN.
  BOTTOM or EQUIVALENT OD = 15.000 IN.
  TOP or EQUIVALENT OD    = 15.000 IN.
  HEIGHT OF SEGMENT
  BASE ABOVE GROUND         =  0.5 FEET

___________________DESIGN LOADS AT POLE SEGMENT BASE___________________

    MOMENT      = 90108. FT-LBS
    SHEAR       =  4365. LBS.
    TORQUE      = 74454. FT-LBS

  MAXIMUM COMBINED STRESS RATIO =  0.0039 +  0.3008 +  0.0710 =  0.3757
                                  (AXIAL)    (MOMENT)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   95 DEGREES
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 City of Meriden_Hanover Stree atSouth Grove Street_Mast Arm 079-241-I_TCS-6
  01/11/2021  11:49 am

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                         =       8.00
  BOLT CIRCLE DIAMETER                    =      24.00 INCHES
  ANCHOR BOLT DIAMETER                    =       2.00 INCHES
  THREADS PER INCH                        =       4.00
  TENSILE STRESS AREA                     =       2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT           =    105000. PSI

  DIMENSION OF BASE PLATE                 =      30.00 INCHES
  BASE PLATE THICKNESS                    =       2.00 INCHES
  YIELD STRENGTH OF BASE PLATE            =     50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP         =    1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP  =     116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO   =     90108. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO    =      4365. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO   =     74454. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO    =        95. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)             =      9297. PSI
  ALLOWABLE TENSILE STRESS (Ft)           =     69825. PSI
  ft/Ft                                   =       0.13

  SHEAR STRESS ON BOLT (fv)               =      4066. PSI
  ALLOWABLE SHEAR STRESS (Fv)             =     41895. PSI
  fv/Fv                                   =       0.10

  (ft/Ft)^2 + (fv/Fv)^2                   =       0.03

_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                      =      15.00 INCHES
  BOLT LOAD                               =     22675. LBS
  MOMENT ON BASE PLATE                    =    102039. IN-LBS
  PLATE EFFECTIVE WIDTH                   =      18.00 INCHES
  PLATE SECTION MODULUS                   =      12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)       =      8503. PSI
  ALLOWABLE BENDING STRESS (Fb)           =     43890. PSI
  fb/Fb                                   =       0.19

________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                     =      1931. PSI
  ALLOWABLE FATIGUE STRESS                =      7000. PSI
  FATIGUE STRESS RATIO                    =       0.28
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 City of Meriden_Hanover Stree atSouth Grove Street_Mast Arm 079-241-I_TCS-6
  01/11/2021  11:49 am

_______________________________GALLOPING______________________________

  IMPORTANCE FACTOR =       1.00

                   ----Arm  1, Segment  1----
          AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)     (PSF)       (LBS)    (FT-LBS)
    1       9.00      21.00      189.00     2079.00

    2       1.00      21.00       21.00      315.00

    3       9.00      21.00      189.00     3780.00

    4       9.00      21.00      189.00     4347.00

    5       9.00      21.00      189.00     7749.00

    6       1.00      21.00       21.00      441.00


                    FATIGUE    STRESS     FATIGUE
      BASE           MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION        (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM  1 SEG  1     18711.00    3566.       7000.       0.51
      POLE           18711.00    3564.       7000.       0.51
```

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 City of Meriden_Hanover Stree atSouth Grove Street_Mast Arm 079-241-I_TCS-6
  01/11/2021  11:49 am


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)        (LBS)
  ARM 1 SEG 1      43.18    1.10      5.72      247.01
  ARM 1 UNIT 1      9.00    1.20      6.24       56.16
  ARM 1 UNIT 2      1.00    0.50      2.60        2.60
  ARM 1 UNIT 3      9.00    1.20      6.24       56.16
  ARM 1 UNIT 4      9.00    1.20      6.24       56.16
  ARM 1 UNIT 5      9.00    1.20      6.24       56.16
  ARM 1 UNIT 6      1.00    0.50      2.60        2.60
  POLE             23.75    1.10      5.72      135.85

                 FATIGUE   STRESS     FATIGUE               WIND
      BASE        MOMENT    RANGE    THRESHOLD    STRESS    ANGLE
    LOCATION     (FT-LBS)   (PSI)      (PSI)       RATIO    (DEG)
   ARM 1 SEG 1   10422.8    1986.      7000.       0.28
       POLE      10243.6    1951.      7000.       0.28       90
```

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______________________________TRUCK GUST____________________________

 TRUCK SPEED       =      65.00 MPH
 IMPORTANCE FACTOR =       1.00

                  AREA             PRESSURE     FORCE
 COMPONENT       (FT^2)     CD      (PSF)       (LBS)
 ARM 1 SEG 1       8.93    0.60     10.96       97.92
 ARM 1 UNIT 1      1.20    1.20     22.56       27.07
 ARM 1 UNIT 2      0.50    0.50      9.40        4.70
 ARM 1 UNIT 3      1.20    1.20     22.56       27.07
 ARM 1 UNIT 4      1.20    1.20     22.56       27.07
 ARM 1 UNIT 5      1.20    1.20     21.94       26.32
 ARM 1 UNIT 6      0.50    0.50      6.15        3.07

                FATIGUE    STRESS    FATIGUE
                 MOMENT     RANGE   THRESHOLD    STRESS
   LOCATION     (FT-LBS)    (PSI)     (PSI)       RATIO
  ARM 1 SEG 1    6494.94    1238.      7000.       0.18
     POLE        6494.94    1237.      7000.       0.18
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 City of Meriden_Hanover Stree atSouth Grove Street_Mast Arm 079-241-I_TCS-6
  01/11/2021  11:49 am


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                                                                                            **
**                                                                                            **
**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
**                                                                                            **
**                                                                                            **
**                   PPPPPPPPPPP    OOOOOOOOOO   LL            EEEEEEEEEEEE                   **
**                   PPPPPPPPPPPP  OOOOOOOOOOOO  LL            EEEEEEEEEEEE                   **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PPPPPPPPPPPP  OO        OO  LL            EEEEEEEEE                      **
**                   PPPPPPPPPPP   OO        OO  LL            EEEEEEEEE                      **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OOOOOOOOOOOO  LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                   PP             OOOOOOOOOO   LLLLLLLLLLLL  EEEEEEEEEEEE                   **
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**                                                                                            **
**                               Release Date: August 15, 2019                                **
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**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
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**                                                                                            **
**   AASHTO Standard Specifications (LFD):                                                    **
**                                                                                            **
**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural      **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,       **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-J_TCS-7
  01/04/2021  3:36 pm

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1       11 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

            BASE    AVERAGE     WALL        MODULUS
          DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       18.00     13.00     0.38       29000000.

           YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
          STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)              (FEET)
    1      65000.      50.0           17.5                20.1

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                  SIDE                       ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT    AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.   9.0   9.0    N/A     18.0    65.0    28.0   N/A     N/A
   2  SIGN PANEL    21.0   4.0    N/A     18.6    16.0     4.0   24.0    24.0
   3  TRAFFIC SIG.  25.0   9.0    N/A     18.8    65.0    28.0   N/A     N/A
   4  ROUNDED LUM.  28.0   1.0    N/A     19.0     1.0     1.0   N/A     N/A
   5  TRAFFIC SIG.  32.0   9.0    N/A     19.2    65.0    28.0   N/A     N/A
   6  TRAFFIC SIG.  36.0   9.0    N/A     19.4    65.0    28.0   N/A     N/A
   7  ROUNDED LUM.  38.0   1.0    N/A     19.4     1.0     1.0   N/A     N/A
   8  TRAFFIC SIG.  39.0   9.0    N/A     19.5    65.0    28.0   N/A     N/A
   9  ROUNDED LUM.  42.0   1.0    N/A     19.7     7.0     2.0   N/A     N/A
  10  SIGN PANEL    46.0   4.0    N/A     19.9    16.0     4.0   24.0    24.0
  11  TRAFFIC SIG.  49.0   9.0    N/A     20.1    65.0    28.0   N/A     N/A
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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-J_TCS-7
  01/04/2021  3:36 pm

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

              HEIGHT      AREA                PRESSURE     FORCE
  COMPONENT    (FT)      (FT^2)      CD        (PSF)       (LBS)
 SEGMENT # 1   18.6      54.24      1.10       41.08      2228.2
   UNIT # 1    18.5       9.00      1.20       44.73       402.5
   UNIT # 2    19.1       4.00      1.12       42.04       168.2
   UNIT # 3    19.3       9.00      1.20       45.15       406.3
   UNIT # 4    19.5       1.00      0.50       18.84        18.8
   UNIT # 5    19.7       9.00      1.20       45.33       408.0
   UNIT # 6    19.9       9.00      1.20       45.43       408.9
   UNIT # 7    19.9       1.00      0.50       18.94        18.9
   UNIT # 8    20.0       9.00      1.20       45.50       409.5
   UNIT # 9    20.2       1.00      0.50       18.99        19.0
   UNIT #10    20.4       4.00      1.12       42.63       170.5
   UNIT #11    20.6       9.00      1.20       45.75       411.8

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                                =   2608.0 LBS
  WEIGHT OF ATTACHMENTS                        =    431.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS         =   5070.6 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS           =   1051.9 LBS
  DEAD LOAD MOMENT                             =  70622.5 FT-LBS
  WIND MOMENT                                  = 139685.4 FT-LBS
  ICE MOMENT                                   =  28378.5 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                   MOMENT       SHEAR        TORSION
                  (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I          70622.5     3039.0          N/A
  GROUP II        156523.3     5911.5            0.1
  GROUP III       121346.9     4817.6            0.2

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       9268.       293.         42900.      21450.
  GROUP II     20540.       569.         57057.      28528.
  GROUP III    15924.       464.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                         GROUP I   = 0.2162
                         GROUP II  = 0.3604
                         GROUP III = 0.2794
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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-J_TCS-7
  01/04/2021  3:36 pm

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                    =  29000.0 KSI
      Fy                                   =  65000.0 PSI
      LENGTH OF POLE                       =     19.0 FEET
      WALL THICKNESS                       =   0.3750 IN
      BOTTOM OD                            =   18.000 IN
      TOP OD                               =   18.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND          =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =    1342.4 LBS.
                      AXIAL LOAD  =    4381.4 LBS.
                      MOMENT      =  130587.7 FT-LBS
                      SHEAR       =    6191.9 LBS.
                      TORQUE      =  138770.6 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        211.          17128.            9702.
  ALLOWABLE    51870.          57057.           28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0041 +  0.3002 +  0.1157 =  0.4199
                        (AXIAL)   (BENDING)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   94 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE = 131918. FT-LBS
  WITH WIND APPLIED AT  102 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       = 102279. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =  83316. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           = 139685. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   6219. LBS
  WITH WIND APPLIED AT   90 DEGREES
```

```
 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-J_TCS-7
  01/04/2021  3:36 pm


______________POLE DESCRIPTION AT APPROXIMATE MAXIMUM CSR______________

  LENGTH OF SEGMENT = 19.00 FEET
  WALL THICKNESS          = 0.3750 IN.
  BOTTOM or EQUIVALENT OD = 18.000 IN.
  TOP or EQUIVALENT OD    = 18.000 IN.
  HEIGHT OF SEGMENT
  BASE ABOVE GROUND         =  0.5 FEET

___________________DESIGN LOADS AT POLE SEGMENT BASE___________________

    MOMENT      = ****** FT-LBS
    SHEAR       =  6192. LBS.
    TORQUE      =138771. FT-LBS

  MAXIMUM COMBINED STRESS RATIO =  0.0041 +  0.3002 +  0.1157 =  0.4199
                                  (AXIAL)   (MOMENT)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   94 DEGREES
```

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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-J_TCS-7
  01/04/2021  3:36 pm

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                        =       8.00
  BOLT CIRCLE DIAMETER                   =      24.00 INCHES
  ANCHOR BOLT DIAMETER                   =       2.00 INCHES
  THREADS PER INCH                       =       4.00
  TENSILE STRESS AREA                    =       2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT          =    105000. PSI

  DIMENSION OF BASE PLATE                =      30.00 INCHES
  BASE PLATE THICKNESS                   =       2.00 INCHES
  YIELD STRENGTH OF BASE PLATE           =     50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP        =    1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =     116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =    130588. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =      6192. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =    138771. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =        94. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)            =     13474. PSI
  ALLOWABLE TENSILE STRESS (Ft)          =     69825. PSI
  ft/Ft                                  =       0.19

  SHEAR STRESS ON BOLT (fv)              =      7479. PSI
  ALLOWABLE SHEAR STRESS (Fv)            =     41895. PSI
  fv/Fv                                  =       0.18

  (ft/Ft)^2 + (fv/Fv)^2                  =       0.07

_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                     =      18.00 INCHES
  BOLT LOAD                              =     32980. LBS
  MOMENT ON BASE PLATE                   =     98939. IN-LBS
  PLATE EFFECTIVE WIDTH                  =      18.00 INCHES
  PLATE SECTION MODULUS                  =      12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)      =      8245. PSI
  ALLOWABLE BENDING STRESS (Fb)          =     43890. PSI
  fb/Fb                                  =       0.19

________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                    =      4520. PSI
  ALLOWABLE FATIGUE STRESS               =      7000. PSI
  FATIGUE STRESS RATIO                   =       0.65
```

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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-J_TCS-7
  01/04/2021  3:36 pm

_______________________________GALLOPING______________________________

  IMPORTANCE FACTOR =       1.00

                  ----Arm  1, Segment  1----
          AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)    (PSF)       (LBS)    (FT-LBS)
    1      9.00      21.00      189.00     1701.00

    2      4.00      21.00       84.00     1764.00

    3      9.00      21.00      189.00     4725.00

    4      1.00      21.00       21.00      588.00

    5      9.00      21.00      189.00     6048.00

    6      9.00      21.00      189.00     6804.00

    7      1.00      21.00       21.00      798.00

    8      9.00      21.00      189.00     7371.00

    9      1.00      21.00       21.00      882.00

   10      4.00      21.00       84.00     3864.00

   11      9.00      21.00      189.00     9261.00


                   FATIGUE    STRESS     FATIGUE
      BASE          MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION       (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM  1 SEG  1   43806.00    5749.       7000.        0.82
      POLE         43806.00    5746.       7000.        0.82
```

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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-J_TCS-7
  01/04/2021  3:36 pm


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                  AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)      (LBS)
  ARM 1 SEG 1      54.24    1.10      5.72      310.26
  ARM 1 UNIT 1      9.00    1.20      6.24       56.16
  ARM 1 UNIT 2      4.00    1.12      5.82       23.30
  ARM 1 UNIT 3      9.00    1.20      6.24       56.16
  ARM 1 UNIT 4      1.00    0.50      2.60        2.60
  ARM 1 UNIT 5      9.00    1.20      6.24       56.16
  ARM 1 UNIT 6      9.00    1.20      6.24       56.16
  ARM 1 UNIT 7      1.00    0.50      2.60        2.60
  ARM 1 UNIT 8      9.00    1.20      6.24       56.16
  ARM 1 UNIT 9      1.00    0.50      2.60        2.60
  ARM 1 UNIT10      4.00    1.12      5.82       23.30
  ARM 1 UNIT11      9.00    1.20      6.24       56.16
  POLE             28.50    1.10      5.72      163.02

                FATIGUE   STRESS     FATIGUE              WIND
      BASE       MOMENT    RANGE    THRESHOLD    STRESS    ANGLE
    LOCATION    (FT-LBS)   (PSI)      (PSI)       RATIO    (DEG)
   ARM 1 SEG 1   19274.1    2529.      7000.       0.36
       POLE      14837.0    1946.      7000.       0.28       90
```

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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-J_TCS-7
  01/04/2021  3:36 pm


_______________________________TRUCK GUST_____________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                  AREA              PRESSURE     FORCE
  COMPONENT      (FT^2)     CD       (PSF)       (LBS)
  ARM 1 SEG 1      9.20    0.51       9.15       84.20
  ARM 1 UNIT 1     1.20    1.20      22.56       27.07
  ARM 1 UNIT 2     1.00    1.12      21.06       21.06
  ARM 1 UNIT 3     1.20    1.20      22.56       27.07
  ARM 1 UNIT 4     0.50    0.50       9.40        4.70
  ARM 1 UNIT 5     1.20    1.20      22.56       27.07
  ARM 1 UNIT 6     1.20    1.20      22.56       27.07
  ARM 1 UNIT 7     0.50    0.50       9.40        4.70
  ARM 1 UNIT 8     1.20    1.20      22.49       26.99
  ARM 1 UNIT 9     1.00    0.50       9.26        9.26
  ARM 1 UNIT10     1.00    1.12      20.39       20.39
  ARM 1 UNIT11     1.20    1.20      21.57       25.88

                FATIGUE    STRESS     FATIGUE
                 MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION    (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1  10866.27    1426.      7000.       0.20
      POLE      10866.27    1425.      7000.       0.20
```

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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-J_TCS-7
  01/04/2021  3:36 pm


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                                                                                            **
**                                                                                            **
**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
**                                                                                            **
**                                                                                            **
**                   PPPPPPPPPPP    OOOOOOOOOO   LL            EEEEEEEEEEEE                   **
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**                   PP        PP  OO        OO  LL            EE                             **
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**                   PP        PP  OO        OO  LL            EE                             **
**                   PPPPPPPPPPPP  OO        OO  LL            EEEEEEEEE                      **
**                   PPPPPPPPPPP   OO        OO  LL            EEEEEEEEE                      **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OOOOOOOOOOOO  LLLLLLLLLLL   EEEEEEEEEEEE                   **
**                   PP             OOOOOOOOOO   LLLLLLLLLLL   EEEEEEEEEEEE                   **
**                                                                                            **
**                                                                                            **
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**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
**                               Release Date: August 15, 2019                                **
**                                                                                            **
**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
**                                                                                            **
**                    For user assistance and system information contact:                     **
**                                   Phone: (307) 777-4489                                    **
**                              E-mail: BRASSTechSupport@wyo.gov                              **
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**                                                                                            **
**   AASHTO Standard Specifications (LFD):                                                    **
**                                                                                            **
**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural      **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,       **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
**                                                                                            **
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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-K_TCS-7
  04/01/2020  9:45 am

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1        5 ROUND OR EQUIV ROUND     0.0         3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

            BASE    AVERAGE     WALL        MODULUS
          DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       12.00     10.00     0.38       29000000.

           YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
          STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)              (FEET)
    1      65000.      30.0          17.5                19.1

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                  SIDE                      ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.  16.0   9.0    N/A     18.3    65.0    28.0   N/A     N/A
   2  TRAFFIC SIG.  25.0   9.0    N/A     18.8    65.0    28.0   N/A     N/A
   3  TRAFFIC SIG.  29.0   9.0    N/A     19.0    65.0    28.0   N/A     N/A
   4  TRAFFIC SIG.   0.0   8.2    N/A      0.0    22.0     8.2   N/A     N/A
   5  ROUNDED LUM.   0.0  12.0    N/A     16.0   450.0    12.0   N/A     N/A
```

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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-K_TCS-7
  04/01/2020  9:45 am

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

              HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT    (FT)      (FT^2)      CD        (PSF)      (LBS)
 SEGMENT # 1    18.2      25.03      1.10       40.89     1023.6
   UNIT # 1     18.8       9.00      1.20       44.91      404.2
   UNIT # 2     19.3       9.00      1.20       45.15      406.3
   UNIT # 3     19.5       9.00      1.20       45.25      407.3
   UNIT # 4      0.5       8.20      1.20       43.87      359.8
   UNIT # 5     16.5      12.00      0.50       18.20      218.4

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                               =   1203.7 LBS
  WEIGHT OF ATTACHMENTS                       =    667.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS        =   2819.6 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS          =    548.9 LBS
  DEAD LOAD MOMENT                            =  21401.5 FT-LBS
  WIND MOMENT                                 =  42766.4 FT-LBS
  ICE MOMENT                                  =   9191.6 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                   MOMENT       SHEAR        TORSION
                  (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I          21401.5     1398.7          N/A
  GROUP II         47822.5     2642.0            0.6
  GROUP III        37325.3     2194.7            0.3

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       6456.       204.         42900.      21450.
  GROUP II     14425.       386.         57057.      28528.
  GROUP III    11259.       321.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                        GROUP I   = 0.1506
                        GROUP II  = 0.2530
                        GROUP III = 0.1975
```

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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-K_TCS-7
  04/01/2020  9:45 am

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

     E                                  =  29000.0 KSI
     Fy                                 =  65000.0 PSI
     LENGTH OF POLE                     =     19.0 FEET
     WALL THICKNESS                     =   0.3750 IN
     BOTTOM OD                          =   12.000 IN
     TOP OD                             =   12.000 IN
     ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
     HEIGHT OF BASE ABOVE GROUND        =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

            STANDARD WIND METHOD, ARTICLE 3.8, USED:
            DESIGN WIND VELOCITY = 120.0 MPH
            RECURRENCE INTERVAL  =    50 YEARS
            GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                     POLE WEIGHT =     885.4 LBS.
                     AXIAL LOAD  =    2756.1 LBS.
                     MOMENT      =   57728.7 FT-LBS
                     SHEAR       =    3566.8 LBS.
                     TORQUE      =   42333.5 FT-LBS

___________________________GROUP II STRESSES__________________________

              AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED       201.          17405.           6906.
  ALLOWABLE    51870.         57057.          28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0039 +  0.3050 +  0.0586 =  0.3675
                        (AXIAL)   (BENDING) (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   95 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE =  57960. FT-LBS
  WITH WIND APPLIED AT  100 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       =  51002. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =  27536. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           =  42766. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   3585. LBS
  WITH WIND APPLIED AT   90 DEGREES
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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-K_TCS-7
  04/01/2020  9:45 am


______________POLE DESCRIPTION AT APPROXIMATE MAXIMUM CSR______________

  LENGTH OF SEGMENT = 19.00 FEET
  WALL THICKNESS          = 0.3750 IN.
  BOTTOM or EQUIVALENT OD = 12.000 IN.
  TOP or EQUIVALENT OD    = 12.000 IN.
  HEIGHT OF SEGMENT
  BASE ABOVE GROUND         =  0.5 FEET

___________________DESIGN LOADS AT POLE SEGMENT BASE___________________

    MOMENT      = 57729. FT-LBS
    SHEAR       =  3567. LBS.
    TORQUE      = 42334. FT-LBS

  MAXIMUM COMBINED STRESS RATIO =  0.0039 +  0.3050 +  0.0586 =  0.3675
                                  (AXIAL)   (MOMENT)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   95 DEGREES
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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-K_TCS-7
  04/01/2020  9:45 am

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                        =       8.00
  BOLT CIRCLE DIAMETER                   =      24.00 INCHES
  ANCHOR BOLT DIAMETER                   =       2.00 INCHES
  THREADS PER INCH                       =       4.00
  TENSILE STRESS AREA                    =       2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT          =    105000. PSI

  DIMENSION OF BASE PLATE                =      30.00 INCHES
  BASE PLATE THICKNESS                   =       2.00 INCHES
  YIELD STRENGTH OF BASE PLATE           =     50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP        =    1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =     116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =     57729. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =      3567. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =     42334. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =        95. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)            =      5956. PSI
  ALLOWABLE TENSILE STRESS (Ft)          =     69825. PSI
  ft/Ft                                  =       0.09

  SHEAR STRESS ON BOLT (fv)              =      2368. PSI
  ALLOWABLE SHEAR STRESS (Fv)            =     41895. PSI
  fv/Fv                                  =       0.06

  (ft/Ft)^2 + (fv/Fv)^2                  =       0.01

_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                     =      12.00 INCHES
  BOLT LOAD                              =     14490. LBS
  MOMENT ON BASE PLATE                   =     86941. IN-LBS
  PLATE EFFECTIVE WIDTH                  =      18.00 INCHES
  PLATE SECTION MODULUS                  =      12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)      =      7245. PSI
  ALLOWABLE BENDING STRESS (Fb)          =     43890. PSI
  fb/Fb                                  =       0.17

________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                    =      1365. PSI
  ALLOWABLE FATIGUE STRESS               =      7000. PSI
  FATIGUE STRESS RATIO                   =       0.20
```

```
 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-K_TCS-7
  04/01/2020  9:45 am

_______________________________GALLOPING______________________________

  IMPORTANCE FACTOR =       1.00

                    ----Arm  1, Segment  1----
            AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)     (PSF)       (LBS)    (FT-LBS)
    1       9.00      21.00      189.00     3024.00

    2       9.00      21.00      189.00     4725.00

    3       9.00      21.00      189.00     5481.00

    4       8.20      21.00      172.20        0.00

    5      12.00      21.00      252.00        0.00


                     FATIGUE    STRESS     FATIGUE
       BASE           MOMENT     RANGE    THRESHOLD    STRESS
     LOCATION       (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM  1 SEG  1     13230.00    3991.       7000.       0.57
       POLE          13230.00    3989.       7000.       0.57
```

```
 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-K_TCS-7
  04/01/2020  9:45 am


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                  AREA              PRESSURE     FORCE
  COMPONENT      (FT^2)     CD       (PSF)       (LBS)
  ARM 1 SEG 1     25.03    1.10       5.72      143.20
  ARM 1 UNIT 1     9.00    1.20       6.24       56.16
  ARM 1 UNIT 2     9.00    1.20       6.24       56.16
  ARM 1 UNIT 3     9.00    1.20       6.24       56.16
  ARM 1 UNIT 4     8.20    1.20       6.24       51.17
  ARM 1 UNIT 5    12.00    0.50       2.60       31.20
  POLE            19.00    1.10       5.72      108.68

                FATIGUE   STRESS     FATIGUE              WIND
      BASE       MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
    LOCATION    (FT-LBS)   (PSI)      (PSI)      RATIO    (DEG)
   ARM 1 SEG 1    5935.9    1791.      7000.      0.26
       POLE       7297.2    2200.      7000.      0.31       90
```

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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-K_TCS-7
  04/01/2020  9:45 am


_______________________________TRUCK GUST_____________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                  AREA              PRESSURE     FORCE
  COMPONENT      (FT^2)     CD       (PSF)       (LBS)
  ARM 1 SEG 1      8.80    0.72      13.52      118.95
  ARM 1 UNIT 1     1.20    1.20      22.56       27.07
  ARM 1 UNIT 2     1.20    1.20      22.56       27.07
  ARM 1 UNIT 3     1.20    1.20      22.56       27.07
  ARM 1 UNIT 4     1.00    1.20      22.56       22.56
  ARM 1 UNIT 5     1.00    0.50       9.40        9.40

                FATIGUE    STRESS     FATIGUE
                 MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION    (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1   4749.93    1433.      7000.        0.20
      POLE       4749.93    1432.      7000.        0.20
```

```
 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-K_TCS-7
  04/01/2020  9:45 am


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                                                                                            **
**                                                                                            **
**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
**                                                                                            **
**                                                                                            **
**                   PPPPPPPPPPP    OOOOOOOOOO   LL            EEEEEEEEEEEE                   **
**                   PPPPPPPPPPPP  OOOOOOOOOOOO  LL            EEEEEEEEEEEE                   **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PPPPPPPPPPPP  OO        OO  LL            EEEEEEEEE                      **
**                   PPPPPPPPPPP   OO        OO  LL            EEEEEEEEE                      **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OOOOOOOOOOOO  LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                   PP             OOOOOOOOOO   LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                                                                                            **
**                                                                                            **
**                              Copyright (c) 1999 - 2019 WYDOT                               **
**                                                                                            **
**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
**                               Release Date: August 15, 2019                                **
**                                                                                            **
**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
**                                                                                            **
**                    For user assistance and system information contact:                     **
**                                   Phone: (307) 777-4489                                    **
**                              E-mail: BRASSTechSupport@wyo.gov                              **
**                                                                                            **
**            The source version is maintained by BridgeTech, Inc.                            **
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**      all responsibility and liability arising from such use or reliance.                   **
**                                                                                            **
**   AASHTO Standard Specifications (LFD):                                                    **
**                                                                                            **
**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural      **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,       **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
**                                                                                            **
**                                                                                            **
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 City of Meriden_Hanover Stree at Colony Street and Perkins Street_Mast Arm 079-
 241-L_TCS-8
  01/04/2021  3:38 pm

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1        3 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

           BASE    AVERAGE     WALL        MODULUS
         DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1      12.00     10.00     0.38       29000000.

          YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
         STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)        (FEET)               (FEET)
    1     65000.      40.0          16.5                 18.6

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                SIDE                         ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #   ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)   (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.  25.0   9.0    N/A     17.8    65.0    28.0   N/A     N/A
   2  TRAFFIC SIG.  35.0   9.0    N/A     18.3    65.0    28.0   N/A     N/A
   3  TRAFFIC SIG.   0.0   9.0    N/A     12.0    65.0    28.0   N/A     N/A
__________________ARM  2 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1        3 ROUND OR EQUIV ROUND    66.4          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 2___________________

           BASE    AVERAGE     WALL        MODULUS
         DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1      12.00     10.00     0.38       29000000.

          YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
         STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)        (FEET)               (FEET)
    1     65000.      25.0          16.5                 17.8

___________________DESCRIPTION OF UNITS ON ARM # 2____________________

                                SIDE                         ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #   ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)   (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.   8.0   9.0    N/A     16.9    65.0    28.0   N/A     N/A
   2  TRAFFIC SIG.  18.0   9.0    N/A     17.4    65.0    28.0   N/A     N/A
   3  ROUNDED LUM.  10.0   1.0    N/A     17.0     7.0     1.0   N/A     N/A
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 City of Meriden_Hanover Stree at Colony Street and Perkins Street_Mast Arm 079-
 241-L_TCS-8
  01/04/2021  3:38 pm

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

                HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT      (FT)      (FT^2)      CD        (PSF)      (LBS)
 SEGMENT # 1     17.5      33.38      1.10       40.53     1352.7
   UNIT # 1      18.3       9.00      1.20       44.64      401.8
   UNIT # 2      18.8       9.00      1.20       44.91      404.2
   UNIT # 3      12.5       9.00      1.20       43.87      394.9

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                                 =   1604.9 LBS
  WEIGHT OF ATTACHMENTS                         =    195.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS          =   2553.5 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS            =    567.0 LBS
  DEAD LOAD MOMENT                              =  33858.3 FT-LBS
  WIND MOMENT                                   =  49441.7 FT-LBS
  ICE MOMENT                                    =  10919.6 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                     MOMENT       SHEAR        TORSION
                    (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I           33858.3      1734.9          N/A
  GROUP II          59923.8      2769.4            1.8
  GROUP III         51148.6      2466.4            0.9

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I      10213.       253.          42900.      21450.
  GROUP II     18076.       405.          57057.      28528.
  GROUP III    15429.       360.          57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                           GROUP I   = 0.2382
                           GROUP II  = 0.3170
                           GROUP III = 0.2706
```

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 City of Meriden_Hanover Stree at Colony Street and Perkins Street_Mast Arm 079-
 241-L_TCS-8
  01/04/2021  3:38 pm

_______________________WIND LOADING ON ARM # 2________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

                HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT      (FT)      (FT^2)      CD        (PSF)      (LBS)
 SEGMENT # 1     17.1      20.86      1.10       40.34      841.7
   UNIT # 1      17.4       9.00      1.20       44.18      397.6
   UNIT # 2      17.9       9.00      1.20       44.45      400.1
   UNIT # 3      17.5       1.00      0.50       18.43       18.4

________________________LOADS APPLIED TO ARM # 2______________________

  WEIGHT OF ARM                                 =   1003.1 LBS
  WEIGHT OF ATTACHMENTS                         =    137.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS          =   1657.8 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS            =    367.9 LBS
  DEAD LOAD MOMENT                              =  13462.5 FT-LBS
  WIND MOMENT                                   =  20386.1 FT-LBS
  ICE MOMENT                                    =   4511.0 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 2 SEG # 1_______________

                     MOMENT       SHEAR        TORSION
                    (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I           13462.5      1140.1          N/A
  GROUP II          24430.1      2012.0            1.1
  GROUP III         20678.8      1722.3            0.6

______________GROUP LOAD STRESSES FOR ARM # 2, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       4061.       166.         42900.      21450.
  GROUP II      7369.       294.         57057.      28528.
  GROUP III     6238.       252.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 2, SEG # 1___________

                         GROUP I   = 0.0947
                         GROUP II  = 0.1293
                         GROUP III = 0.1094
```

```
 City of Meriden_Hanover Stree at Colony Street and Perkins Street_Mast Arm 079-
 241-L_TCS-8
  01/04/2021  3:38 pm

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                    =  29000.0 KSI
      Fy                                   =  65000.0 PSI
      LENGTH OF POLE                       =     18.0 FEET
      WALL THICKNESS                       =   0.3750 IN
      BOTTOM OD                            =   12.000 IN
      TOP OD                               =   12.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND          =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =     838.8 LBS.
                      AXIAL LOAD  =    3778.8 LBS.
                      MOMENT      =   87475.9 FT-LBS
                      SHEAR       =    4082.7 LBS.
                      TORQUE      =   50392.2 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        276.          26373.            8197.
  ALLOWABLE    51870.          57057.           28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0053 +  0.4622 +  0.0826 =  0.5501
                        (AXIAL)   (BENDING)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =  266 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE =  91607. FT-LBS
  WITH WIND APPLIED AT  166 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       =   2894. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =  91561. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           =  51813. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   4091. LBS
  WITH WIND APPLIED AT   95 DEGREES
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 City of Meriden_Hanover Stree at Colony Street and Perkins Street_Mast Arm 079-
 241-L_TCS-8
  01/04/2021  3:38 pm

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                       =      8.00
  BOLT CIRCLE DIAMETER                  =     24.00 INCHES
  ANCHOR BOLT DIAMETER                  =      2.00 INCHES
  THREADS PER INCH                      =      4.00
  TENSILE STRESS AREA                   =      2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT         =   105000. PSI

  DIMENSION OF BASE PLATE               =     30.00 INCHES
  BASE PLATE THICKNESS                  =      2.00 INCHES
  YIELD STRENGTH OF BASE PLATE          =    50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP       =   1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =    116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =    87661. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =     4073. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =    50052. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =      265. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)           =     9045. PSI
  ALLOWABLE TENSILE STRESS (Ft)         =    69825. PSI
  ft/Ft                                 =      0.13

  SHEAR STRESS ON BOLT (fv)             =     2792. PSI
  ALLOWABLE SHEAR STRESS (Fv)           =    41895. PSI
  fv/Fv                                 =      0.07

  (ft/Ft)^2 + (fv/Fv)^2                 =      0.02

_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                    =     12.00 INCHES
  BOLT LOAD                             =    22902. LBS
  MOMENT ON BASE PLATE                  =   137410. IN-LBS
  PLATE EFFECTIVE WIDTH                 =     18.00 INCHES
  PLATE SECTION MODULUS                 =     12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)     =    11451. PSI
  ALLOWABLE BENDING STRESS (Fb)         =    43890. PSI
  fb/Fb                                 =      0.26

________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                   =     1170. PSI
  ALLOWABLE FATIGUE STRESS              =     7000. PSI
  FATIGUE STRESS RATIO                  =      0.17
```

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City of Meriden_Hanover Stree at Colony Street and Perkins Street_Mast Arm 079-
241-L_TCS-8
 01/04/2021  3:38 pm

_______________________________GALLOPING______________________________

 IMPORTANCE FACTOR =       1.00

                  ----Arm  1, Segment  1----
          AREA     PRESSURE     FORCE     MOMENT
 UNIT #   (FT^2)     (PSF)       (LBS)    (FT-LBS)
   1       9.00      21.00      189.00     4725.00

   2       9.00      21.00      189.00     6615.00

   3       9.00      21.00      189.00        0.00

                  ----Arm  2, Segment  1----
          AREA     PRESSURE     FORCE     MOMENT
 UNIT #   (FT^2)     (PSF)       (LBS)    (FT-LBS)
   1       9.00      21.00      189.00     1512.00

   2       9.00      21.00      189.00     3402.00

   3       1.00      21.00       21.00      210.00


                    FATIGUE    STRESS     FATIGUE
     BASE            MOMENT     RANGE    THRESHOLD    STRESS
   LOCATION        (FT-LBS)    (PSI)       (PSI)       RATIO
  ARM  1 SEG  1    11340.00    3421.        7000.       0.49
  ARM  2 SEG  1     5124.00    1546.        7000.       0.22
     POLE          11340.00    3419.        7000.       0.49
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City of Meriden_Hanover Stree at Colony Street and Perkins Street_Mast Arm 079-
241-L_TCS-8
 01/04/2021  3:38 pm


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA              PRESSURE     FORCE
  COMPONENT       (FT^2)     CD       (PSF)       (LBS)
  ARM 1 SEG 1      33.38    1.10       5.72      190.93
  ARM 1 UNIT 1      9.00    1.20       6.24       56.16
  ARM 1 UNIT 2      9.00    1.20       6.24       56.16
  ARM 1 UNIT 3      9.00    1.20       6.24       56.16
  ARM 2 SEG 1      20.86    1.10       5.72      119.33
  ARM 2 UNIT 1      9.00    1.20       6.24       56.16
  ARM 2 UNIT 2      9.00    1.20       6.24       56.16
  ARM 2 UNIT 3      1.00    0.50       2.60        2.60
  POLE             18.00    1.10       5.72      102.96

                 FATIGUE   STRESS    FATIGUE               WIND
      BASE        MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
    LOCATION     (FT-LBS)   (PSI)      (PSI)      RATIO    (DEG)
   ARM 1 SEG 1    6933.6    2091.      7000.      0.30
   ARM 2 SEG 1    2878.3     868.      7000.      0.12
       POLE       8964.2    2703.      7000.      0.39       91
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City of Meriden_Hanover Stree at Colony Street and Perkins Street_Mast Arm 079-
241-L_TCS-8
 01/04/2021  3:38 pm


_____________________________TRUCK GUST___________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                 AREA              PRESSURE     FORCE
  COMPONENT     (FT^2)     CD       (PSF)       (LBS)
  ARM 1 SEG 1     8.60    0.72      13.52      116.25
  ARM 1 UNIT 1    1.20    1.20      22.56       27.07
  ARM 1 UNIT 2    1.20    1.20      22.56       27.07
  ARM 1 UNIT 3    1.20    1.20      22.56       27.07
  ARM 2 SEG 1     8.96    0.72      13.52      121.12
  ARM 2 UNIT 1    1.20    1.20      22.56       27.07
  ARM 2 UNIT 2    1.20    1.20      22.56       27.07
  ARM 2 UNIT 3    0.70    0.50       9.40        6.58

               FATIGUE    STRESS     FATIGUE
                MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION   (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1   5576.83    1682.      7000.       0.24
   ARM 2 SEG 1   3070.89     926.      7000.       0.13
      POLE       5576.83    1681.      7000.       0.24
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 City of Meriden_Hanover Stree at Colony Street and Perkins Street_Mast Arm 079-
 241-L_TCS-8
  01/04/2021  3:38 pm


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
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**                                                                                            **
**                                                                                            **
**                              Copyright (c) 1999 - 2019 WYDOT                               **
**                                                                                            **
**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
**                               Release Date: August 15, 2019                                **
**                                                                                            **
**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
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**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural     **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,      **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-O_TCS-10
  01/04/2021  4:06 pm

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1       4 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

            BASE    AVERAGE     WALL        MODULUS
          DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       12.00     10.00     0.38       29000000.

           YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
          STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)              (FEET)
    1      65000.      30.0           17.5                19.1

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                SIDE                        ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #   ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.  21.0  11.0    N/A     18.4    80.0    35.5   N/A     N/A
   2  TRAFFIC SIG.  29.0  11.0    N/A     18.8    80.0    35.5   N/A     N/A
   3  TRAFFIC SIG.   0.0   9.0    N/A     13.5    65.0    28.0   N/A     N/A
   4  TRAFFIC SIG.   0.0   8.2    N/A      8.0    22.0     8.2   N/A     N/A
```

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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-O_TCS-10
  01/04/2021  4:06 pm

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

                HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT      (FT)      (FT^2)       CD       (PSF)      (LBS)
 SEGMENT # 1     18.2      25.03      1.10       40.89     1023.6
   UNIT # 1      18.9      11.00      1.20       44.94      494.3
   UNIT # 2      19.3      11.00      1.20       45.15      496.6
   UNIT # 3      14.0       9.00      1.20       43.87      394.9
   UNIT # 4       8.5       8.20      1.20       43.87      359.8

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                               =   1203.7 LBS
  WEIGHT OF ATTACHMENTS                       =    247.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS        =   2769.2 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS          =    557.7 LBS
  DEAD LOAD MOMENT                            =  20851.5 FT-LBS
  WIND MOMENT                                 =  39113.2 FT-LBS
  ICE MOMENT                                  =   8628.2 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                   MOMENT       SHEAR        TORSION
                  (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I         20851.5      1363.7          N/A
  GROUP II        44324.2      2432.7          208.0
  GROUP III       35376.8      2073.7          104.0

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       6290.       199.         42900.      21450.
  GROUP II     13370.       387.         57057.      28528.
  GROUP III    10671.       319.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                         GROUP I   = 0.1467
                         GROUP II  = 0.2345
                         GROUP III = 0.1872
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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-O_TCS-10
  01/04/2021  4:06 pm

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                    =  29000.0 KSI
      Fy                                   =  65000.0 PSI
      LENGTH OF POLE                       =     19.0 FEET
      WALL THICKNESS                       =   0.3750 IN
      BOTTOM OD                            =   12.000 IN
      TOP OD                               =   12.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND          =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =     885.4 LBS.
                      AXIAL LOAD  =    2336.1 LBS.
                      MOMENT      =   57819.6 FT-LBS
                      SHEAR       =    3508.5 LBS.
                      TORQUE      =   38531.0 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        171.          17432.            6324.
  ALLOWABLE    51870.          57057.           28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0033 +  0.3055 +  0.0491 =  0.3579
                        (AXIAL)   (BENDING) (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   96 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE =  57942. FT-LBS
  WITH WIND APPLIED AT   99 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       =  51581. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =  26395. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           =  39113. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   3535. LBS
  WITH WIND APPLIED AT   90 DEGREES
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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-O_TCS-10
  01/04/2021  4:06 pm


______________POLE DESCRIPTION AT APPROXIMATE MAXIMUM CSR______________

  LENGTH OF SEGMENT = 19.00 FEET
  WALL THICKNESS          = 0.3750 IN.
  BOTTOM or EQUIVALENT OD = 12.000 IN.
  TOP or EQUIVALENT OD    = 12.000 IN.
  HEIGHT OF SEGMENT
  BASE ABOVE GROUND         =  0.5 FEET

___________________DESIGN LOADS AT POLE SEGMENT BASE___________________

    MOMENT      = 57820. FT-LBS
    SHEAR       =  3509. LBS.
    TORQUE      = 38531. FT-LBS

  MAXIMUM COMBINED STRESS RATIO =  0.0033 +  0.3055 +  0.0491 =  0.3579
                                  (AXIAL)   (MOMENT)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   96 DEGREES
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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-O_TCS-10
  01/04/2021  4:06 pm

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                        =       8.00
  BOLT CIRCLE DIAMETER                   =      24.00 INCHES
  ANCHOR BOLT DIAMETER                   =       2.00 INCHES
  THREADS PER INCH                       =       4.00
  TENSILE STRESS AREA                    =       2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT          =    105000. PSI

  DIMENSION OF BASE PLATE                =      30.00 INCHES
  BASE PLATE THICKNESS                   =       2.00 INCHES
  YIELD STRENGTH OF BASE PLATE           =     50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP        =    1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =     116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =     57734. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =      3516. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =     38708. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =        95. DEGREES
_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)            =      5957. PSI
  ALLOWABLE TENSILE STRESS (Ft)          =     69825. PSI
  ft/Ft                                  =       0.09

  SHEAR STRESS ON BOLT (fv)              =      2178. PSI
  ALLOWABLE SHEAR STRESS (Fv)            =     41895. PSI
  fv/Fv                                  =       0.05

  (ft/Ft)^2 + (fv/Fv)^2                  =       0.01
_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                     =      12.00 INCHES
  BOLT LOAD                              =     14486. LBS
  MOMENT ON BASE PLATE                   =     86913. IN-LBS
  PLATE EFFECTIVE WIDTH                  =      18.00 INCHES
  PLATE SECTION MODULUS                  =      12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)      =      7243. PSI
  ALLOWABLE BENDING STRESS (Fb)          =     43890. PSI
  fb/Fb                                  =       0.17
________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                    =      1192. PSI
  ALLOWABLE FATIGUE STRESS               =      7000. PSI
  FATIGUE STRESS RATIO                   =       0.17
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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-O_TCS-10
  01/04/2021  4:06 pm

______________________________GALLOPING______________________________

  IMPORTANCE FACTOR =       1.00

                  ----Arm  1, Segment  1----
          AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)     (PSF)       (LBS)    (FT-LBS)
    1      11.00      21.00      231.00     4851.00

    2      11.00      21.00      231.00     6699.00

    3       9.00      21.00      189.00        0.00

    4       8.20      21.00      172.20        0.00


                   FATIGUE    STRESS     FATIGUE
      BASE          MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION       (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM  1 SEG  1     11550.00    3484.       7000.        0.50
      POLE         11550.00    3482.       7000.        0.50
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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-O_TCS-10
  01/04/2021  4:06 pm


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)       (LBS)
  ARM 1 SEG 1      25.03    1.10      5.72      143.20
  ARM 1 UNIT 1     11.00    1.20      6.24       68.64
  ARM 1 UNIT 2     11.00    1.20      6.24       68.64
  ARM 1 UNIT 3      9.00    1.20      6.24       56.16
  ARM 1 UNIT 4      8.20    1.20      6.24       51.17
  POLE             19.00    1.10      5.72      108.68

                 FATIGUE   STRESS     FATIGUE              WIND
      BASE        MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
    LOCATION     (FT-LBS)   (PSI)      (PSI)      RATIO    (DEG)
   ARM 1 SEG 1    5436.7    1640.      7000.      0.23
       POLE       7364.4    2220.      7000.      0.32       90
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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-O_TCS-10
  01/04/2021  4:06 pm


________________________________TRUCK GUST______________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                  AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)       (LBS)
  ARM 1 SEG 1       8.80    0.72     13.52      118.95
  ARM 1 UNIT 1      1.20    1.20     22.56       27.07
  ARM 1 UNIT 2      1.20    1.20     22.56       27.07
  ARM 1 UNIT 3      1.20    1.20     22.56       27.07
  ARM 1 UNIT 4      1.00    1.20     22.56       22.56

                FATIGUE    STRESS     FATIGUE
                 MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION    (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1   4208.49    1269.      7000.       0.18
      POLE       4208.49    1269.      7000.       0.18
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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-O_TCS-10
  01/04/2021  4:06 pm


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
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**                               Release Date: August 15, 2019                                **
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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-P_TCS-10
  01/11/2021  11:50 am

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS         SHAPE         (DEGREES)    (DEGREES)
      1        6 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

          BASE    AVERAGE     WALL        MODULUS
        DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT   (IN)     (IN)      (IN)         (PSI)
    1      12.00    10.00     0.38       29000000.

         YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
        STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT  (PSI)     (FEET)         (FEET)              (FEET)
    1     65000.     35.0          16.5                 18.3

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                              SIDE                        ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #   ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.  15.0   9.0    N/A     17.3    65.0    28.0   N/A     N/A
   2  ROUNDED LUM.  21.0   2.0    N/A     17.6     7.0    28.0   N/A     N/A
   3  TRAFFIC SIG.  26.0   9.0    N/A     17.9    65.0    28.0   N/A     N/A
   4  ROUNDED LUM.  30.0   1.0    N/A     18.1     1.0     1.0   N/A     N/A
   5  TRAFFIC SIG.  35.0   9.0    N/A     18.3    65.0    28.0   N/A     N/A
   6  TRAFFIC SIG.   0.0   8.2    N/A      8.0    22.0     8.2   N/A     N/A
__________________ARM  2 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS         SHAPE         (DEGREES)    (DEGREES)
      1        2 ROUND OR EQUIV ROUND   108.6          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 2___________________

          BASE    AVERAGE     WALL        MODULUS
        DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT   (IN)     (IN)      (IN)         (PSI)
    1      12.00    10.00     0.38       29000000.

         YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
        STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT  (PSI)     (FEET)         (FEET)              (FEET)
    1     65000.     20.0          16.5                 17.5

___________________DESCRIPTION OF UNITS ON ARM # 2____________________

                              SIDE                        ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #   ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.  10.0   9.0    N/A     17.0    65.0    28.0   N/A     N/A
   2  TRAFFIC SIG.  18.0   9.0    N/A     17.5    65.0    28.0   N/A     N/A
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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-P_TCS-10
  01/11/2021  11:50 am

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

                HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT      (FT)      (FT^2)      CD        (PSF)       (LBS)
 SEGMENT # 1     17.4      29.21      1.10        40.47     1181.9
   UNIT # 1      17.8       9.00      1.20        44.37      399.3
   UNIT # 2      18.1       2.00      0.50        18.56       37.1
   UNIT # 3      18.4       9.00      1.20        44.67      402.0
   UNIT # 4      18.6       1.00      0.50        18.66       18.7
   UNIT # 5      18.8       9.00      1.20        44.91      404.2
   UNIT # 6       8.5       8.20      1.20        43.87      359.8

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                              =   1404.3 LBS
  WEIGHT OF ATTACHMENTS                      =    225.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS       =   2802.9 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS         =    639.4 LBS
  DEAD LOAD MOMENT                           =  28053.8 FT-LBS
  WIND MOMENT                                =  51231.8 FT-LBS
  ICE MOMENT                                 =  12745.8 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                     MOMENT       SHEAR        TORSION
                    (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I           28053.8      1607.3          N/A
  GROUP II          58409.9      2924.5            5.3
  GROUP III         48297.4      2540.3            2.6

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       8462.       235.          42900.      21450.
  GROUP II     17619.       428.          57057.      28528.
  GROUP III    14569.       371.          57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                         GROUP I   = 0.1974
                         GROUP II  = 0.3090
                         GROUP III = 0.2555
```

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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-P_TCS-10
  01/11/2021  11:50 am

_______________________WIND LOADING ON ARM # 2________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

                HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT      (FT)      (FT^2)      CD        (PSF)      (LBS)
 SEGMENT # 1     17.0      16.69      1.10       40.28      672.3
   UNIT # 1      17.5       9.00      1.20       44.23      398.1
   UNIT # 2      18.0       9.00      1.20       44.48      400.4

________________________LOADS APPLIED TO ARM # 2______________________

  WEIGHT OF ARM                              =    802.5 LBS
  WEIGHT OF ATTACHMENTS                      =    130.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS       =   1470.8 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS         =    325.5 LBS
  DEAD LOAD MOMENT                           =   9309.6 FT-LBS
  WIND MOMENT                                =  17462.3 FT-LBS
  ICE MOMENT                                 =   3823.4 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 2 SEG # 1_______________

                     MOMENT       SHEAR        TORSION
                    (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I            9309.6       932.5          N/A
  GROUP II          19788.9      1741.4           21.0
  GROUP III         15770.5      1457.2           10.5

______________GROUP LOAD STRESSES FOR ARM # 2, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       2808.       136.         42900.      21450.
  GROUP II      5969.       257.         57057.      28528.
  GROUP III     4757.       214.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 2, SEG # 1___________

                         GROUP I   = 0.0655
                         GROUP II  = 0.1047
                         GROUP III = 0.0834
```

```
 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-P_TCS-10
  01/11/2021  11:50 am

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                    =  29000.0 KSI
      Fy                                   =  65000.0 PSI
      LENGTH OF POLE                       =     18.0 FEET
      WALL THICKNESS                       =   0.3750 IN
      BOTTOM OD                            =   12.000 IN
      TOP OD                               =   12.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND          =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =     838.8 LBS.
                      AXIAL LOAD  =    3400.6 LBS.
                      MOMENT      =   81001.4 FT-LBS
                      SHEAR       =    4311.4 LBS.
                      TORQUE      =   50697.1 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        248.          24421.            8276.
  ALLOWABLE    51870.          57057.           28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0048 +  0.4280 +  0.0842 =  0.5170
                        (AXIAL)   (BENDING) (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =  265 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE =  84661. FT-LBS
  WITH WIND APPLIED AT  200 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       =  28667. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =  79660. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           =  51232. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   4328. LBS
  WITH WIND APPLIED AT   90 DEGREES
```

```
 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-P_TCS-10
  01/11/2021  11:50 am

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                        =       8.00
  BOLT CIRCLE DIAMETER                   =      24.00 INCHES
  ANCHOR BOLT DIAMETER                   =       2.00 INCHES
  THREADS PER INCH                       =       4.00
  TENSILE STRESS AREA                    =       2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT          =    105000. PSI

  DIMENSION OF BASE PLATE                =      30.00 INCHES
  BASE PLATE THICKNESS                   =       2.00 INCHES
  YIELD STRENGTH OF BASE PLATE           =     50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP        =    1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =     116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =     81133. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =      4304. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =     50463. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =       264. DEGREES

_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)            =      8371. PSI
  ALLOWABLE TENSILE STRESS (Ft)          =     69825. PSI
  ft/Ft                                  =       0.12

  SHEAR STRESS ON BOLT (fv)              =      2825. PSI
  ALLOWABLE SHEAR STRESS (Fv)            =     41895. PSI
  fv/Fv                                  =       0.07

  (ft/Ft)^2 + (fv/Fv)^2                  =       0.02

_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                     =      12.00 INCHES
  BOLT LOAD                              =     21165. LBS
  MOMENT ON BASE PLATE                   =    126992. IN-LBS
  PLATE EFFECTIVE WIDTH                  =      18.00 INCHES
  PLATE SECTION MODULUS                  =      12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)      =     10583. PSI
  ALLOWABLE BENDING STRESS (Fb)          =     43890. PSI
  fb/Fb                                  =       0.24

________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                    =      1638. PSI
  ALLOWABLE FATIGUE STRESS               =      7000. PSI
  FATIGUE STRESS RATIO                   =       0.23
```

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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-P_TCS-10
  01/11/2021  11:50 am

_______________________________GALLOPING______________________________

  IMPORTANCE FACTOR =       1.00

                     ----Arm  1, Segment  1----
            AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)     (PSF)       (LBS)    (FT-LBS)
    1       9.00      21.00      189.00     2835.00

    2       2.00      21.00       42.00      882.00

    3       9.00      21.00      189.00     4914.00

    4       1.00      21.00       21.00      630.00

    5       9.00      21.00      189.00     6615.00

    6       8.20      21.00      172.20        0.00

                     ----Arm  2, Segment  1----
            AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)     (PSF)       (LBS)    (FT-LBS)
    1       9.00      21.00      189.00     1890.00

    2       9.00      21.00      189.00     3402.00


                      FATIGUE    STRESS     FATIGUE
       BASE            MOMENT     RANGE    THRESHOLD    STRESS
     LOCATION         (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM  1 SEG  1      15876.00    4789.       7000.       0.68
   ARM  2 SEG  1       5292.00    1596.       7000.       0.23
       POLE           15876.00    4786.       7000.       0.68
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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-P_TCS-10
  01/11/2021  11:50 am


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)      CD      (PSF)       (LBS)
  ARM 1 SEG 1      29.21    1.10      5.72      167.06
  ARM 1 UNIT 1      9.00    1.20      6.24       56.16
  ARM 1 UNIT 2      2.00    0.50      2.60        5.20
  ARM 1 UNIT 3      9.00    1.20      6.24       56.16
  ARM 1 UNIT 4      1.00    0.50      2.60        2.60
  ARM 1 UNIT 5      9.00    1.20      6.24       56.16
  ARM 1 UNIT 6      8.20    1.20      6.24       51.17
  ARM 2 SEG 1      16.69    1.10      5.72       95.46
  ARM 2 UNIT 1      9.00    1.20      6.24       56.16
  ARM 2 UNIT 2      9.00    1.20      6.24       56.16
  POLE             18.00    1.10      5.72      102.96

                 FATIGUE   STRESS     FATIGUE             WIND
      BASE        MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
    LOCATION     (FT-LBS)   (PSI)      (PSI)      RATIO    (DEG)
   ARM 1 SEG 1    7184.0    2167.       7000.      0.31
   ARM 2 SEG 1    2463.5     743.       7000.      0.11
       POLE       9320.9    2810.       7000.      0.40       90
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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-P_TCS-10
  01/11/2021  11:50 am


_______________________________TRUCK GUST_____________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)       (LBS)
  ARM 1 SEG 1       8.69    0.72     13.52      117.41
  ARM 1 UNIT 1      1.20    1.20     22.56       27.07
  ARM 1 UNIT 2      0.70    0.50      9.40        6.58
  ARM 1 UNIT 3      1.20    1.20     22.56       27.07
  ARM 1 UNIT 4      0.50    0.50      9.40        4.70
  ARM 1 UNIT 5      1.20    1.20     22.56       27.07
  ARM 1 UNIT 6      1.00    1.20     22.56       22.56
  ARM 2 SEG 1       9.20    0.72     13.52      124.36
  ARM 2 UNIT 1      1.20    1.20     22.56       27.07
  ARM 2 UNIT 2      1.20    1.20     22.56       27.07

                 FATIGUE    STRESS     FATIGUE
                  MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION     (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1    5741.51    1732.      7000.       0.25
   ARM 2 SEG 1    2499.07     754.      7000.       0.11
      POLE        5741.51    1731.      7000.       0.25
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 City of Meriden_Perkins Street at Crown Street_Mast Arm 079-241-P_TCS-10
  01/11/2021  11:50 am


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                                                                                            **
**                                                                                            **
**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
**                                                                                            **
**                                                                                            **
**                   PPPPPPPPPPP    OOOOOOOOOO   LL            EEEEEEEEEEEE                   **
**                   PPPPPPPPPPPP  OOOOOOOOOOOO  LL            EEEEEEEEEEEE                   **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PPPPPPPPPPPP  OO        OO  LL            EEEEEEEEE                      **
**                   PPPPPPPPPPP   OO        OO  LL            EEEEEEEEE                      **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OOOOOOOOOOOO  LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                   PP             OOOOOOOOOO   LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                                                                                            **
**                                                                                            **
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**                                                                                            **
**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
**                               Release Date: August 15, 2019                                **
**                                                                                            **
**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
**                                                                                            **
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**                              E-mail: BRASSTechSupport@wyo.gov                              **
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**   AASHTO Standard Specifications (LFD):                                                    **
**                                                                                            **
**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural      **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,      **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
**                                                                                            **
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 City of Meriden_Colony Street at Church Street _Mast Arm 079-241-Q_TCS-11
  01/04/2021  3:59 pm

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS        SHAPE         (DEGREES)    (DEGREES)
      1       12 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

            BASE    AVERAGE     WALL        MODULUS
          DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       18.00     13.00     0.44       29000000.

           YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
          STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)               (FEET)
    1      65000.      50.0           16.5                 19.1

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                  SIDE                    ICE    SIGN    SIGN
                    DIST  AREA    AREA   HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)   (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  TRAFFIC SIG.  23.0   9.0    N/A     17.8    65.0    28.0   N/A     N/A
   2  SIGN PANEL    16.0   7.5    N/A     17.9    30.0     7.5   36.0    30.0
   3  TRAFFIC SIG.  27.0   9.0    N/A     18.0    65.0    28.0   N/A     N/A
   4  SIGN PANEL    32.0   7.5    N/A     18.2    30.0     7.5   36.0    30.0
   5  TRAFFIC SIG.  36.0   9.0    N/A     18.4    65.0    28.0   N/A     N/A
   6  TRAFFIC SIG.  40.0   9.0    N/A     18.6    65.0    28.0   N/A     N/A
   7  TRAFFIC SIG.  43.0   9.0    N/A     18.8    65.0    28.0   N/A     N/A
   8  SIGN PANEL    45.0   4.0    N/A     18.9    16.0     4.0   24.0    24.0
   9  ROUNDED LUM.  46.0   2.0    N/A     19.0     7.0     2.0   N/A     N/A
  10  TRAFFIC SIG.  49.0   9.0    N/A     19.1    65.0    28.0   N/A     N/A
  11  TRAFFIC SIG.   0.0   8.2    N/A      8.0    22.0     8.2   N/A     N/A
  12  ROUNDED LUM.   0.0  12.0    N/A     15.0   450.0    12.0   N/A     N/A
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 City of Meriden_Colony Street at Church Street _Mast Arm 079-241-Q_TCS-11
  01/04/2021  3:59 pm

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

                HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT      (FT)      (FT^2)      CD          (PSF)      (LBS)
 SEGMENT # 1     17.6      54.24      1.10       40.61     2202.5
   UNIT # 1      18.3       9.00      1.20       44.62      401.6
   UNIT # 2      18.4       7.50      1.13       42.21      316.6
   UNIT # 3      18.5       9.00      1.20       44.73      402.5
   UNIT # 4      18.7       7.50      1.13       42.39      317.9
   UNIT # 5      18.9       9.00      1.20       44.96      404.7
   UNIT # 6      19.1       9.00      1.20       45.07      405.6
   UNIT # 7      19.3       9.00      1.20       45.15      406.3
   UNIT # 8      19.4       4.00      1.12       42.18      168.7
   UNIT # 9      19.5       2.00      0.50       18.84       37.7
   UNIT #10      19.6       9.00      1.20       45.30      407.7
   UNIT #11       8.5       8.20      1.20       43.87      359.8
   UNIT #12      15.5      12.00      0.50       18.28      219.4

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                               =   3046.1 LBS
  WEIGHT OF ATTACHMENTS                       =    945.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS        =   6051.0 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS          =   1139.5 LBS
  DEAD LOAD MOMENT                            =  83041.7 FT-LBS
  WIND MOMENT                                 = 160914.4 FT-LBS
  ICE MOMENT                                  =  31375.9 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                     MOMENT       SHEAR        TORSION
                    (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I           83041.7      3519.1          N/A
  GROUP II         181078.3      6505.8          323.6
  GROUP III        140037.2      5353.6          162.1

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       9397.       291.         42900.      21450.
  GROUP II     20491.       557.         57057.      28528.
  GROUP III    15846.       452.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                         GROUP I   = 0.2192
                         GROUP II  = 0.3595
                         GROUP III = 0.2780
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 City of Meriden_Colony Street at Church Street _Mast Arm 079-241-Q_TCS-11
  01/04/2021  3:59 pm

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                    =  29000.0 KSI
      Fy                                   =  65000.0 PSI
      LENGTH OF POLE                       =     18.0 FEET
      WALL THICKNESS                       =   0.4380 IN
      BOTTOM OD                            =   18.000 IN
      TOP OD                               =   18.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND          =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =    1480.1 LBS.
                      AXIAL LOAD  =    5471.3 LBS.
                      MOMENT      =  144553.6 FT-LBS
                      SHEAR       =    7108.3 LBS.
                      TORQUE      =  159898.9 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        227.          16349.            9636.
  ALLOWABLE    51870.          57057.           28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0044 +  0.2865 +  0.1141 =  0.4050
                        (AXIAL)   (BENDING)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =   94 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE = 146360. FT-LBS
  WITH WIND APPLIED AT  103 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       = 109250. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =  97394. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           = 160914. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   7138. LBS
  WITH WIND APPLIED AT   90 DEGREES
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 City of Meriden_Colony Street at Church Street _Mast Arm 079-241-Q_TCS-11
  01/04/2021  3:59 pm

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                        =       8.00
  BOLT CIRCLE DIAMETER                   =      24.00 INCHES
  ANCHOR BOLT DIAMETER                   =       2.00 INCHES
  THREADS PER INCH                       =       4.00
  TENSILE STRESS AREA                    =       2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT          =    105000. PSI

  DIMENSION OF BASE PLATE                =      30.00 INCHES
  BASE PLATE THICKNESS                   =       2.00 INCHES
  YIELD STRENGTH OF BASE PLATE           =     50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP        =    1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =     116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =    144554. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =      7108. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =    159899. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =        94. DEGREES
_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)            =     14915. PSI
  ALLOWABLE TENSILE STRESS (Ft)          =     69825. PSI
  ft/Ft                                  =       0.21

  SHEAR STRESS ON BOLT (fv)              =      8616. PSI
  ALLOWABLE SHEAR STRESS (Fv)            =     41895. PSI
  fv/Fv                                  =       0.21

  (ft/Ft)^2 + (fv/Fv)^2                  =       0.09
_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                     =      18.00 INCHES
  BOLT LOAD                              =     36590. LBS
  MOMENT ON BASE PLATE                   =    109770. IN-LBS
  PLATE EFFECTIVE WIDTH                  =      18.00 INCHES
  PLATE SECTION MODULUS                  =      12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)      =      9147. PSI
  ALLOWABLE BENDING STRESS (Fb)          =     43890. PSI
  fb/Fb                                  =       0.21
________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                    =      5621. PSI
  ALLOWABLE FATIGUE STRESS               =      7000. PSI
  FATIGUE STRESS RATIO                   =       0.80
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 City of Meriden_Colony Street at Church Street _Mast Arm 079-241-Q_TCS-11
  01/04/2021  3:59 pm

________________________________GALLOPING_______________________________

  IMPORTANCE FACTOR =       1.00

                     ----Arm  1, Segment  1----
          AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)     (PSF)       (LBS)    (FT-LBS)
    1       9.00      21.00      189.00     4347.00

    2       7.50      21.00      157.50     2520.00

    3       9.00      21.00      189.00     5103.00

    4       7.50      21.00      157.50     5040.00

    5       9.00      21.00      189.00     6804.00

    6       9.00      21.00      189.00     7560.00

    7       9.00      21.00      189.00     8127.00

    8       4.00      21.00       84.00     3780.00

    9       2.00      21.00       42.00     1932.00

   10       9.00      21.00      189.00     9261.00

   11       8.20      21.00      172.20        0.00

   12      12.00      21.00      252.00        0.00


                      FATIGUE    STRESS     FATIGUE
      BASE             MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION          (FT-LBS)    (PSI)       (PSI)      RATIO
   ARM  1 SEG  1      54474.00    6164.        7000.       0.88
      POLE            54474.00    6161.        7000.       0.88
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 City of Meriden_Colony Street at Church Street _Mast Arm 079-241-Q_TCS-11
  01/04/2021  3:59 pm


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)       (LBS)
  ARM 1 SEG 1      54.24    1.10      5.72      310.26
  ARM 1 UNIT 1      9.00    1.20      6.24       56.16
  ARM 1 UNIT 2      7.50    1.13      5.90       44.23
  ARM 1 UNIT 3      9.00    1.20      6.24       56.16
  ARM 1 UNIT 4      7.50    1.13      5.90       44.23
  ARM 1 UNIT 5      9.00    1.20      6.24       56.16
  ARM 1 UNIT 6      9.00    1.20      6.24       56.16
  ARM 1 UNIT 7      9.00    1.20      6.24       56.16
  ARM 1 UNIT 8      4.00    1.12      5.82       23.30
  ARM 1 UNIT 9      2.00    0.50      2.60        5.20
  ARM 1 UNIT10      9.00    1.20      6.24       56.16
  ARM 1 UNIT11      8.20    1.20      6.24       51.17
  ARM 1 UNIT12     12.00    0.50      2.60       31.20
  POLE             27.00    1.10      5.72      154.44

                 FATIGUE   STRESS     FATIGUE              WIND
      BASE        MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
    LOCATION     (FT-LBS)   (PSI)      (PSI)      RATIO    (DEG)
   ARM 1 SEG 1   22415.3    2536.      7000.      0.36
       POLE      16095.9    1820.      7000.      0.26       90
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 City of Meriden_Colony Street at Church Street _Mast Arm 079-241-Q_TCS-11
  01/04/2021  3:59 pm


_______________________________TRUCK GUST_____________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)      CD      (PSF)       (LBS)
  ARM 1 SEG 1       9.20    0.51      9.61       88.42
  ARM 1 UNIT 1      1.20    1.20     22.56       27.07
  ARM 1 UNIT 2      1.00    1.13     21.32       21.32
  ARM 1 UNIT 3      1.20    1.20     22.56       27.07
  ARM 1 UNIT 4      1.00    1.13     21.32       21.32
  ARM 1 UNIT 5      1.20    1.20     22.56       27.07
  ARM 1 UNIT 6      1.20    1.20     22.56       27.07
  ARM 1 UNIT 7      1.20    1.20     22.56       27.07
  ARM 1 UNIT 8      1.00    1.12     21.06       21.06
  ARM 1 UNIT 9      0.70    0.50      9.40        6.58
  ARM 1 UNIT10      1.20    1.20     22.56       27.07
  ARM 1 UNIT11      1.00    1.20     22.56       22.56
  ARM 1 UNIT12      1.00    0.50      9.40        9.40

                 FATIGUE    STRESS     FATIGUE
                  MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION     (FT-LBS)    (PSI)       (PSI)       RATIO
   ARM 1 SEG 1   12065.76    1365.       7000.       0.20
      POLE       12065.76    1365.       7000.       0.19
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 City of Meriden_Colony Street at Church Street _Mast Arm 079-241-Q_TCS-11
  01/04/2021  3:59 pm


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
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BRASS-POLE™ 4.7.0

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**                                                                                            **
**                                                                                            **
**                            WYOMING DEPARTMENT OF TRANSPORTATION                            **
**                     BRIDGE RATING AND ANALYSIS OF STRUCTURAL SYSTEMS                       **
**                                                                                            **
**                                                                                            **
**            BBBBBBBBBBB   RRRRRRRRRRR    AAAAAAAAAA    SSSSSSSSSS    SSSSSSSSSS             **
**            BBBBBBBBBBBB  RRRRRRRRRRRR  AAAAAAAAAAAA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BB        BB  RR        RR  AA        AA  SS        SS  SS        SS            **
**            BB        BB  RR        RR  AA        AA  SS            SS                      **
**            BB       BB   RR        RR  AA        AA  SSS           SSS                     **
**            BBBBBBBBBB    RRRRRRRRRRRR  AAAAAAAAAAAA   SSSSSSSSS     SSSSSSSSS              **
**            BBBBBBBBBB    RRRRRRRRRRR   AAAAAAAAAAAA    SSSSSSSSS     SSSSSSSSS             **
**            BB       BB   RR    RR      AA        AA           SSS           SSS            **
**            BB        BB  RR     RR     AA        AA            SS            SS            **
**            BB        BB  RR      RR    AA        AA  SS        SS  SS        SS            **
**            BBBBBBBBBBBB  RR       RR   AA        AA  SSSSSSSSSSSS  SSSSSSSSSSSS            **
**            BBBBBBBBBBB   RR        RR  AA        AA   SSSSSSSSSS    SSSSSSSSSS             **
**                                                                                            **
**                                                                                            **
**                   PPPPPPPPPPP    OOOOOOOOOO   LL            EEEEEEEEEEEE                   **
**                   PPPPPPPPPPPP  OOOOOOOOOOOO  LL            EEEEEEEEEEEE                   **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PP        PP  OO        OO  LL            EE                             **
**                   PPPPPPPPPPPP  OO        OO  LL            EEEEEEEEE                      **
**                   PPPPPPPPPPP   OO        OO  LL            EEEEEEEEE                      **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OO        OO  LL            EE                             **
**                   PP            OOOOOOOOOOOO  LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                   PP             OOOOOOOOOO   LLLLLLLLLLLL  EEEEEEEEEEEE                   **
**                                                                                            **
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**                                                                                            **
**                          Version  4   Release  7   Service Pack  0                         **
**                                                                                            **
**                               Release Date: August 15, 2019                                **
**                                                                                            **
**                      HIGHMAST AND MASTARM ANALYSIS - ENGLISH VERSION                       **
**                                                                                            **
**                    For user assistance and system information contact:                    **
**                                   Phone: (307) 777-4489                                    **
**                              E-mail: BRASSTechSupport@wyo.gov                              **
**                                                                                            **
**            The source version is maintained by BridgeTech, Inc.                            **
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**                                                                                            **
**   AASHTO Standard Specifications (LFD):                                                    **
**                                                                                            **
**      BRASS-POLE(TM) is current with the AASHTO Standard Specifications for Structural      **
**      Supports for Highway Signs, Luminaires, and Traffic Signals, 6th Edition, 2013,       **
**      with 2015, 2019, and 2020 Interim Revisions.                                          **
**                                                                                            **
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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-R_TCS-7
  01/04/2021  4:00 pm

Engineer: RHS CONSULTING DESIGN
Comments: Design analysis of the mast arm for the design of the drilled shaft foundation

__________________ARM  1 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS         SHAPE        (DEGREES)    (DEGREES)
      1       1 ROUND OR EQUIV ROUND     0.0          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 1___________________

          BASE    AVERAGE     WALL        MODULUS
        DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       12.00     10.00     0.38       29000000.

         YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
        STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)              (FEET)
    1      65000.      15.0          17.5                18.3

___________________DESCRIPTION OF UNITS ON ARM # 1____________________

                                SIDE                         ICE    SIGN    SIGN
                    DIST  AREA    AREA    HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)    (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  SIGN PANEL    14.0   2.2    N/A     18.2     9.0     2.2   18.0    18.0
__________________ARM  2 DESCRIPTIONS AND PROPERTIES___________________

                                       HORIZONTAL    VERTICAL
    # OF    # OF                         ANGLE        ANGLE
  SEGMENTS  UNITS         SHAPE        (DEGREES)    (DEGREES)
      1       2 ROUND OR EQUIV ROUND   176.5          3.0

_________________DESCRIPTION OF SEGMENTS ON ARM # 2___________________

          BASE    AVERAGE     WALL        MODULUS
        DIAMETER  DIAMETER  THICKNESS  OF ELASTICITY
 SEGMENT    (IN)      (IN)      (IN)         (PSI)
    1       12.00     10.00     0.38       29000000.

         YIELD    HORIZONTAL  HEIGHT OF SEG BASE  HEIGHT OF SEG TIP
        STRENGTH    LENGTH     ABOVE POLE BASE     ABOVE POLE BASE
 SEGMENT   (PSI)      (FEET)         (FEET)              (FEET)
    1      65000.      25.0          17.5                18.8

___________________DESCRIPTION OF UNITS ON ARM # 2____________________

                                SIDE                         ICE    SIGN    SIGN
                    DIST  AREA    AREA    HEIGHT  WEIGHT   AREA  HEIGHT  LENGTH
   #  ____TYPE____  (FT) (FT^2)  (FT^2)    (FT)    (LBS)  (FT^2)  (IN)    (IN)
   1  SIGN PANEL    14.0   2.2    N/A     18.2     9.0     2.2   18.0    18.0
   2  SIGN PANEL    24.0   2.2    N/A     18.8     9.0     2.2   18.0    18.0
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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-R_TCS-7
  01/04/2021  4:00 pm

_______________________WIND LOADING ON ARM # 1________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

                HEIGHT      AREA              PRESSURE     FORCE
  COMPONENT      (FT)      (FT^2)      CD       (PSF)      (LBS)
 SEGMENT # 1     17.9      12.52      1.10      40.71      509.6
   UNIT # 1      18.7       2.25      1.12      41.87       94.2

________________________LOADS APPLIED TO ARM # 1______________________

  WEIGHT OF ARM                               =    601.8 LBS
  WEIGHT OF ATTACHMENTS                       =      9.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS        =    603.8 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS          =    124.7 LBS
  DEAD LOAD MOMENT                            =   4338.9 FT-LBS
  WIND MOMENT                                 =   4886.2 FT-LBS
  ICE MOMENT                                  =    920.3 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 1 SEG # 1_______________

                    MOMENT       SHEAR        TORSION
                   (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I           4338.9       610.8          N/A
  GROUP II          6534.6       858.9            0.3
  GROUP III         5798.9       795.1            0.2

______________GROUP LOAD STRESSES FOR ARM # 1, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       1309.        89.          42900.      21450.
  GROUP II      1971.       125.          57057.      28528.
  GROUP III     1749.       116.          57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 1, SEG # 1___________

                       GROUP I   = 0.0305
                       GROUP II  = 0.0346
                       GROUP III = 0.0307
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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-R_TCS-7
  01/04/2021  4:00 pm

_______________________WIND LOADING ON ARM # 2________________________

  STANDARD WIND METHOD, ARTICLE 3.8, USED:
  DESIGN WIND VELOCITY = 120.0 MPH
  RECURRENCE INTERVAL  =    50 YEARS
  GUST EFFECT FACTOR   =  1.14

              HEIGHT      AREA               PRESSURE     FORCE
  COMPONENT     (FT)      (FT^2)      CD        (PSF)      (LBS)
 SEGMENT # 1     18.1       20.86      1.10       40.83      851.8
   UNIT # 1      18.7        2.25      1.12       41.87       94.2
   UNIT # 2      19.3        2.25      1.12       42.11       94.8

________________________LOADS APPLIED TO ARM # 2______________________

  WEIGHT OF ARM                              =   1003.1 LBS
  WEIGHT OF ATTACHMENTS                      =     18.0 LBS
  WIND FORCE ON ARM AND ATTACHED UNITS       =   1040.8 LBS
  ICE LOAD ON ARM AND ATTACHED UNITS         =    210.1 LBS
  DEAD LOAD MOMENT                           =  12044.5 FT-LBS
  WIND MOMENT                                =  13530.6 FT-LBS
  ICE MOMENT                                 =   2550.4 FT-LBS

_____________GROUP LOAD COMBINATIONS FOR ARM # 2 SEG # 1_______________

                   MOMENT       SHEAR        TORSION
                  (FT-LBS)      (LBS)        (FT-LBS)
  GROUP I         12044.5      1021.1          N/A
  GROUP II        18114.8      1458.0            0.1
  GROUP III       16086.6      1336.6            0.1

______________GROUP LOAD STRESSES FOR ARM # 2, SEG # 1___________

              __APPLIED_(PSI)__          _ALLOWABLE_(PSI)_
              BENDING     SHEAR          BENDING     SHEAR
  GROUP I       3633.       149.         42900.      21450.
  GROUP II      5464.       213.         57057.      28528.
  GROUP III     4852.       195.         57057.      28528.

_____________COMBINED STRESS RATIOS FOR ARM # 2, SEG # 1___________

                         GROUP I   = 0.0847
                         GROUP II  = 0.0958
                         GROUP III = 0.0851
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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-R_TCS-7
  01/04/2021  4:00 pm

_____________POLE DESCRIPTION AND PROPERTIES AT POLE BASE_____________

      E                                 =  29000.0 KSI
      Fy                                =  65000.0 PSI
      LENGTH OF POLE                    =     19.0 FEET
      WALL THICKNESS                    =   0.3750 IN
      BOTTOM OD                         =   12.000 IN
      TOP OD                            =   12.000 IN
      ACTUAL or POLYGONAL EQUIVALENT SHAPE =    ROUND
      HEIGHT OF BASE ABOVE GROUND       =      0.5 FEET

________________________WIND LOADING ON POLE__________________________

             STANDARD WIND METHOD, ARTICLE 3.8, USED:
             DESIGN WIND VELOCITY = 120.0 MPH
             RECURRENCE INTERVAL  =    50 YEARS
             GUST EFFECT FACTOR   =  1.14


______________GROUP II LOADS AT POLE BASE FOR MAXIMUM CSR_____________

                      POLE WEIGHT =     885.4 LBS.
                      AXIAL LOAD  =    2517.4 LBS.
                      MOMENT      =   38468.5 FT-LBS
                      SHEAR       =    2406.7 LBS.
                      TORQUE      =   13514.6 FT-LBS

___________________________GROUP II STRESSES__________________________

               AXIAL (PSI)     BENDING (PSI)    SHEAR (PSI)
  APPLIED        184.          11598.           2390.
  ALLOWABLE    51870.          57057.          28529.

  MAXIMUM COMBINED STRESS
  RATIO AT POLE BASE  =  0.0035 +  0.2033 +  0.0070 =  0.2138
                        (AXIAL)   (BENDING) (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =  268 DEGREES

_________________________BASEPLATE DESIGN LOADS________________________

  MAXIMUM RESULTANT MOMENT AT POLE BASE =  38470. FT-LBS
  WITH WIND APPLIED AT  269 DEGREES
  X-AXIS COMPONENT (AT 0 DEGREES)       =  37921. FT-LBS
  Y-AXIS COMPONENT (AT 180 DEGREES)     =   6479. FT-LBS

  MAXIMUM TORQUE AT POLE BASE           =  13529. FT-LBS
  MAXIMUM SHEAR AT POLE BASE            =   2404. LBS
  WITH WIND APPLIED AT  266 DEGREES
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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-R_TCS-7
  01/04/2021  4:00 pm


______________POLE DESCRIPTION AT APPROXIMATE MAXIMUM CSR______________

  LENGTH OF SEGMENT = 19.00 FEET
  WALL THICKNESS          = 0.3750 IN.
  BOTTOM or EQUIVALENT OD = 12.000 IN.
  TOP or EQUIVALENT OD    = 12.000 IN.
  HEIGHT OF SEGMENT
  BASE ABOVE GROUND         =  0.5 FEET

___________________DESIGN LOADS AT POLE SEGMENT BASE___________________

    MOMENT      = 38468. FT-LBS
    SHEAR       =  2407. LBS.
    TORQUE      = 13515. FT-LBS

  MAXIMUM COMBINED STRESS RATIO =  0.0035 +  0.2033 +  0.0070 =  0.2138
                                  (AXIAL)   (MOMENT)  (SHEAR)

  ANGLE OF WIND WHEN CSR IS MAXIMUM =  268 DEGREES
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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-R_TCS-7
  01/04/2021  4:00 pm

__________________ANCHOR BOLT AND BASE PLATE ANALYSIS_________________

  NUMBER OF BOLTS                        =      8.00
  BOLT CIRCLE DIAMETER                   =     24.00 INCHES
  ANCHOR BOLT DIAMETER                   =      2.00 INCHES
  THREADS PER INCH                       =      4.00
  TENSILE STRESS AREA                    =      2.42 IN^2
  YIELD STRENGTH OF ANCHOR BOLT          =   105000. PSI

  DIMENSION OF BASE PLATE                =     30.00 INCHES
  BASE PLATE THICKNESS                   =      2.00 INCHES
  YIELD STRENGTH OF BASE PLATE           =    50000. PSI

  MOMENT OF INERTIA OF BOLT GROUP        =   1395.63 IN^4
  CRITICAL SECTION MODULUS OF BOLT GROUP =    116.30 IN^3

  BASE MOMENT FOR MAX BOLT STRESS RATIO  =    38468. FT-LBS
  BASE SHEAR FOR MAX BOLT STRESS RATIO   =     2407. LBS
  BASE TORQUE FOR MAX BOLT STRESS RATIO  =    13515. FT-LBS
  WIND ANGLE FOR MAX BOLT STRESS RATIO   =      268. DEGREES
_________________________ANCHOR BOLT STRESSES_________________________

  TENSILE STRESS ON BOLT (ft)            =     3969. PSI
  ALLOWABLE TENSILE STRESS (Ft)          =    69825. PSI
  ft/Ft                                  =      0.06

  SHEAR STRESS ON BOLT (fv)              =      821. PSI
  ALLOWABLE SHEAR STRESS (Fv)            =    41895. PSI
  fv/Fv                                  =      0.02

  (ft/Ft)^2 + (fv/Fv)^2                  =      0.00
_________________________BASE PLATE STRESSES__________________________

  POLE BASE DIAMETER                     =     12.00 INCHES
  BOLT LOAD                              =     9618. LBS
  MOMENT ON BASE PLATE                   =    57705. IN-LBS
  PLATE EFFECTIVE WIDTH                  =     18.00 INCHES
  PLATE SECTION MODULUS                  =     12.00 IN^3

  BENDING STRESS IN BASE PLATE (fb)      =     4809. PSI
  ALLOWABLE BENDING STRESS (Fb)          =    43890. PSI
  fb/Fb                                  =      0.11
________________________BOLT FATIGUE ANALYSIS_________________________

  BOLT FATIGUE STRESS                    =      535. PSI
  ALLOWABLE FATIGUE STRESS               =     7000. PSI
  FATIGUE STRESS RATIO                   =      0.08
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 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-R_TCS-7
  01/04/2021  4:00 pm

_______________________________GALLOPING______________________________

  IMPORTANCE FACTOR =       1.00

                  ----Arm  1, Segment  1----
          AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)     (PSF)       (LBS)    (FT-LBS)
    1       2.25      21.00       47.25      661.50

                  ----Arm  2, Segment  1----
          AREA     PRESSURE     FORCE     MOMENT
  UNIT #   (FT^2)     (PSF)       (LBS)    (FT-LBS)
    1       2.25      21.00       47.25      661.50

    2       2.25      21.00       47.25     1134.00


                   FATIGUE    STRESS     FATIGUE
      BASE          MOMENT     RANGE     THRESHOLD    STRESS
    LOCATION       (FT-LBS)    (PSI)       (PSI)       RATIO
   ARM  1 SEG  1      661.50     200.        7000.       0.03
   ARM  2 SEG  1     1795.50     542.        7000.       0.08
       POLE          1795.50     541.        7000.       0.08
```

```
 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-R_TCS-7
  01/04/2021  4:00 pm


___________________________NATURAL WIND GUST__________________________

  MEAN WIND SPEED   =      11.20 MPH
  IMPORTANCE FACTOR =       1.00

                  AREA             PRESSURE     FORCE
  COMPONENT      (FT^2)     CD      (PSF)       (LBS)
  ARM 1 SEG 1     12.52    1.10      5.72       71.60
  ARM 1 UNIT 1     2.25    1.12      5.82       13.10
  ARM 2 SEG 1     20.86    1.10      5.72      119.33
  ARM 2 UNIT 1     2.25    1.12      5.82       13.10
  ARM 2 UNIT 2     2.25    1.12      5.82       13.10
  POLE            19.00    1.10      5.72      108.68

                FATIGUE   STRESS     FATIGUE              WIND
      BASE       MOMENT    RANGE    THRESHOLD   STRESS    ANGLE
    LOCATION    (FT-LBS)   (PSI)      (PSI)      RATIO    (DEG)
   ARM 1 SEG 1    684.6     207.      7000.      0.03
   ARM 2 SEG 1   1890.1     570.      7000.      0.08
       POLE      5188.0    1564.      7000.      0.22       88
```

```
 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-R_TCS-7
  01/04/2021  4:00 pm


________________________________TRUCK GUST______________________________

  TRUCK SPEED       =      65.00 MPH
  IMPORTANCE FACTOR =       1.00

                   AREA             PRESSURE     FORCE
  COMPONENT       (FT^2)     CD      (PSF)       (LBS)
  ARM 1 SEG 1       9.60    0.72     13.52      129.77
  ARM 1 UNIT 1      1.00    1.12     21.06       21.06
  ARM 2 SEG 1       8.96    0.72     13.52      121.12
  ARM 2 UNIT 1      1.00    1.12     21.06       21.06
  ARM 2 UNIT 2      1.00    1.12     21.06       21.06

                 FATIGUE    STRESS     FATIGUE
                  MOMENT     RANGE    THRESHOLD    STRESS
    LOCATION     (FT-LBS)    (PSI)      (PSI)       RATIO
   ARM 1 SEG 1    1462.69     441.      7000.       0.06
   ARM 2 SEG 1    3101.34     936.      7000.       0.13
      POLE        3101.34     935.      7000.       0.13
```

```
 City of Meriden_West Main Stree at Colony Street_Mast Arm 079-241-R_TCS-7
  01/04/2021  4:00 pm


________________________________NOTES_________________________________

- Per AASHTO Specification, Article 5.6, the allowable stress and wind pressure
  computations for polygonal sections use the flat-to-flat dimension as an equivalent
  round section.

- For polygonal sections, the flat-to-flat dimension is used for the section
  outer diameter.

- The pole section is analyzed for Group II loads only.
```

State Project No. 079-241
Traffic Signal & Intersection Improvements
For the City of
Meriden, Connecticut

Span Pole Design

```
Project Name:      East Main Street at Pratt and Perkins street
County Name:       Suffolk
Intersection Name: East Main Street at Pratt and Perkins street
Signal Number:     079-241-M & N
Cable Type:        Tethered
Wind Zone:         B
Units:             US Cust

Designed By: AA                                        Date: 2/27/2020

Height of Pole #1: 32.00 ft.
Height of Pole #2: 32.00 ft.

Point  Mat.  Lens  8 in  12 in  No.  Disc        BkPl  Sign   Sign Area Dist. Load
Load   Type  Mat.  Sect  Sect   Ways  Hang  BkPl   Matl  Hang   Area(ft.^2) to
Load(ft.)
 1     Poly   LED   0     3      1     Y     5-in  Alum    --    0.00       5.00
 2     Poly   LED   0     3      1     Y     5-in  Alum    --    0.00      18.00
 3      --    --    0     0      0     --    --    --    Sing    2.00       5.00
 4      --    --    0     0      0     --    --    --    Sing    1.00       8.00
 5     Poly   LED   0     3      1     Y     5-in  Alum    --    0.00       6.00
 6     Poly   LED   0     3      1     Y     5-in  Alum    --    0.00      19.00
 7     Poly   LED   0     3      1     Y     5-in  Alum    --    0.00      18.00
 8     Poly   LED   0     3      1     Y     5-in  Alum    --    0.00       4.00
 9      --    --    0     0      0     --    --    --    Sing    1.00      11.00
10     Poly   LED   0     3      1     Y     5-in  Alum    --    0.00       5.00
                                                                          50.00

End of Input Data


 ************************* Analysis Results As Following  *************************

Point          8 in   12 in   Sign         Dist. between     Dead          Ice Dead
Load    Way    Sect   Sect    Area(ft.^2)  Pt. Loads(ft.)    Load(lbs.)
Load(lbs.)
 1       1      0      3       0.00           5.00          81.80        76.90
 2       1      0      3       0.00          18.00          81.80        76.90
 3       0      0      0       2.00           5.00          18.00         9.90
 4       0      0      0       1.00           8.00          16.50         7.20
 5       1      0      3       0.00           6.00          82.80        77.50
 6       1      0      3       0.00          19.00          88.80        81.10
```

```
 7       1      0      3      0.00         18.00          81.30        76.60
 8       1      0      3      0.00          4.00          77.80        74.50
 9       0      0      0      1.00         11.00          17.50         7.80
10       1      0      3      0.00          5.00          97.80        86.50
                                                    5% Span Length
Span Length:            149.00 ft.                 Sag: Max                7.45 ft.
Left Reaction:          399.19 lbs. use 400        Right Reaction:        244.89 lbs.
Zero Shear:              79.00 ft.  lbs.           Resultant HD:         1961.45 lbs.
Left Reaction Ice:      357.29 lbs.                Right Reaction Ice:    217.61 lbs.
Zero Ice Shear:          79.00 ft.                 Resultant HI:         1756.70 lbs.

Pole Height No. 1:       32.00 ft.                 Pole Height No. 2:      32.00 ft.
Group Loading 1:       1961.45 lbs.  DL            Group Loading 1:      1961.45 lbs.
Group Loading 2:      5312.24 lbs. DL + WL         Group Loading 2:     5312.24 lbs.
Group Loading 3:      5393.54 lbs. DL + Ice + 1/2 WLGroup Loading 3:    5393.54 lbs.
Design Loading:       6000.00 lbsString Tensioning Design Loading:       6000.00 lbs.
Wind Load:            3350.79 lbs.                 Wind Load:           3350.79 lbs.
Ftg. Moment:            183.00 ft-k                Ftg. Moment:           183.00 ft-k

 ********************************* End of Analysis *********************************
```

RHS Consulting Design, LLC
Engineering | Surveying | Construction Inspection

Designed By AA
Checked By DS
Date 12/4/2020

tt and Perkins St.

YSIS

RHS JOB NO. R097 **PROJECT NO. 232-593**

Wire Loading Reaction Only:

LOAD CASE I: **POLE #1$_{REACTION}$** 400 lbs
POLE #2$_{REACTION}$ 250 lbs
Use 400 lbs.

LOAD CASE I CALCULATED STRINGING TENSION (#) = ST= 1960 lbs DL only
LOAD CASE I CALCULATED BASE SHEAR(#) = BS= 1960 lbs
LOAD CASE I CALCULATED AXIAL LOAD(#) = AL= 2200 lbs
LOAD CASE II CALCULATED STRINGING TENSION (#) = ST= 5312 lbs
LOAD CASE II CALCULATED BASE SHEAR(#) = BS= 5312 lbs DL + WL
LOAD CASE II CALCULATED AXIAL LOAD(#) = AL= 2200 lbs
LOAD CASE III CALCULATED STRINGING TENSION (#) = ST= 5393 lbs Governing Case
LOAD CASE III CALCULATED BASE SHEAR(#) = BS= 5393 lbs DL + ICE + 1/2 WL
LOAD CASE III CALCULATED AXIAL LOAD(#) = AL= 2200 lbs Includes weight of pole
USE STRINGING TENSION = **6000**

ALLOWABLE STRESS FACTOR FOR CASE I: 100% (DL) ONLY **ALLOWABLE STRESS FACTOR FOR CASE II & III: 133%**

ALLOWABLE INCREASED BY 33%
POLE TYPE (FT.) = H = 30 feet **STEEL** Grade 65 65000 psi 86450 psi
SPAN WIRE HT = SWH = 28.5 **feet** BENDING STRESS=0.66Fy F_{B} = 42900 psi 57057 psi
ALLOWABLE STRESSES: SHEAR STRESS=0.33Fy F_V = 21450 psi 28529 psi
AXIAL STRESS=0.60Fy F_A = 39000 psi 51870 psi

CTDOT SPECIFIED BOLT CIRCLE= 24.00 in
PROPOSED OUTSIDE DIAMETER (IN.) OF POLE @ BASE= ODB = 15 in
PROPOSED WALL (IN.) THICKNESS = t = 0.3750 in
MID WALL RADIUS (IN.) @ POLE BASE = R = (ODB-t)/2 = **7.313** in
SECTION MODULUS = 3.14(R^2)t= SM = **62.996** in^3
POLE CROSS SECTIONAL AREA AT BASE =A=(3.14*ODB^2)/4 **8.721**

MAXIMUM MOMENT (IN.-#) @ POLE BASE = SWH*12*ST+ 12*M$_{attachements.DL}$= Mmax **44057** lb.in
MAXIMUM BENDING STRESS(PSI) @ BASE = Mmax/SM = LOAD CASE I **699** psi
MAXIMUM SHEAR STRESS(PSI) @ BASE = BS/A = **225** psi
MAXIMUM AXIAL LOAD STRESS(PSI) @ BASE = AL/A = **252** psi

MAXIMUM MOMENT (IN.-#) @ POLE BASE = SWH*12*DT+ 12*M$_{attachments.WL}$= Mmax **2192204** lb.in
MAXIMUM BENDING STRESS(PSI) @ BASE = Mmax/SM = LOAD CASE II & III **34799** psi Based on 6,000 Stringining Tension
MAXIMUM SHEAR STRESS(PSI) @ BASE = BS/A = **618** psi
MAXIMUM AXIAL LOAD STRESS(PSI) @ BASE = AL/A = **0** psi

MID WALL RADIUS (IN.) @ POLE TOP = R = (ODT-t)/2 = **5.213** in
POLE TOP DIAMETER (IN.) = ODT = ODB-(0.14*H) = **10.80** in
Ib (IN^4) = 3.1416*(R^3)*t = **460.66** in^4
Im (IN.^4) = ((((ODB + ODT)/2)-t)^3)*3.1416*t = **289.35** in^4
COMBINED STRESS RATIO (CSR) LOAD CASE I = fa/Fa+fv/Fv+fb/Fb **OK** **0.03**
COMBINED STRESS RATIO (CSR) LOAD CASE II =fa/Fa+fv/Fv+fb/F Allowable increased by 33% **OK** **0.63**

CHECK DEFLECTION

ALLOWABLE CTDOT DEFLECTION @ POLE TOP (IN.) = 9.60 in
APPLIED DEFLECTION (IN.)TO PROP t" POLE@ ST=(288)*(ST)*(H)^3/E)*(1/Ib+1/Im)= **7.761** in
OK

CHECK A/BOLTS ASSUMED: F1554 A.BOLTS, FY: 105,000

A/BOLT DIA.(IN.)= 2 in
BOLT CIRCLE(IN.)=BC 24 in
STRESS AREA OF ANCHOR BOLT(SQ. IN.) = SA = 3.14 in^2

MAX. BOLT TENSION (LBS.) = Mmax/.707*BC*2=MBT 1298 lbf
MAX. BOLT STRESS (PSI) = MBT/S/A = Ft = MBT/SA LOAD CASE I 413 psi
ALLOWABLE STRESS IN BOLT= 0.5 FY 52500 PSI **GR. 105** **OK**

MAX. BOLT TENSION (LBS.) = Mmax/.707*BC*2=MBT 64598 lbf
MAX. BOLT STRESS (PSI) = MBT/S/A = Ft = MBT/SA LOAD CASE II & III 20573 psi Based on 6,000 Stringining Tension

ALLOWABLE STRESS IN BOLT=	**69825**	PSI	**OK**	
CHECK BASE PLATE				
SQUARE OF BASE PLATE(IN.)=SQBP			30	in
THICKNESS OF BASE PLATE(IN.)=T=			2	in
BENDING WIDTH OF BASE PLATE(IN)=BWP=(SQBP*1.414)-ODB=			27.42	in
SECTION MODULUS OF BASE PLATE(IN.^3)=(BWP*T^2)/6=SMP			**18.28**	in^3
MAXIMUM MOMENT ON BASE PLATE(IN.-LBS.)=MBP=MBT*(BC-ODB)=			5842	lb.in
BENDING STRESS IN BASE PLATE(PSI)=fb=MBP/SMP=	LOAD CASE I		320	psi
ALLOWABLE BENDING STRESS IN BASE PLATE=	42900	PSI	**OK**	
MAXIMUM MOMENT ON BASE PLATE(IN.-LBS.)=MBP=MBT*(BC-ODB)=			290692	lb.in
BENDING STRESS IN BASE PLATE(PSI)=fb=MBP/SMP=	LOAD CASE III		15902	psi
ALLOWABLE BENDING STRESS IN BASE PLATE=	57185.7	PSI	**OK**	

Total Axial Loads:
Case I: Equipments and signs Dl + Self weight of the Pole:)400 + 1800) = 2200 lbs.
Case I = Case I = Case III = 2200 lbs.

Span Wire: (Refer to Form 817, M.16.15)

Stringing Tension: 6,000 lbs. *2 (F.S.) = 12,000 lbs.

3/8" (7) Strand wire has a breaking strength of 11,200 lbs.

Use 7/16" (7) Strand Wire Double Galvanized, with a breaking Force: 20,800 lbs.

State Project No. 079-241
Traffic Signal & Intersection Improvements
For the City of
Meriden, Connecticut

Foundation Design

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

State Structures Design Office

SUBJECT 079-241-A MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

SoilType :=
Sand
Clay

$\phi_{soil} := \mathbf{32} \cdot deg$ *soil friction angle (sand)*

$c_{soil} := \mathbf{0.0} \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

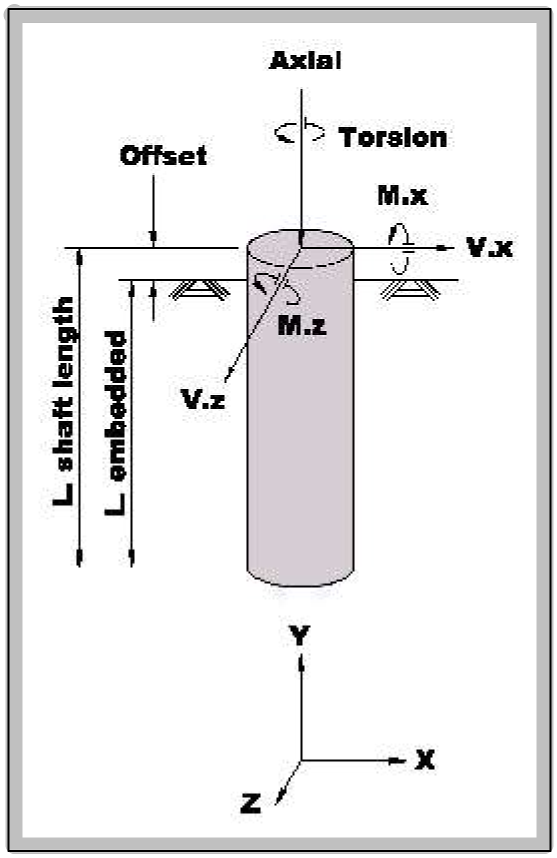
$N_{blows} := 29$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := \mathbf{125} \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*

Geometry

$b := \mathbf{3.0} \cdot ft$ *shaft diameter*

$Offset := \mathbf{0.50} \cdot ft$ *groundline to top of foundation*



Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := \mathbf{142.20} \cdot kip \cdot ft$ $V_x := \mathbf{0.05} \cdot kip$ $Torsion := \mathbf{173.80} \cdot kip \cdot ft$

$M_z := \mathbf{109.80} \cdot kip \cdot ft$ $V_z := \mathbf{8.50} \cdot kip$ $Axial := \mathbf{23.10} \cdot kip$

StructureType :=
Cantilever Overhead Sign Structure
Mast Arm Signal Structure
Concrete/Steel Strain Poles
Ground Sign

$StructureType = 1$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

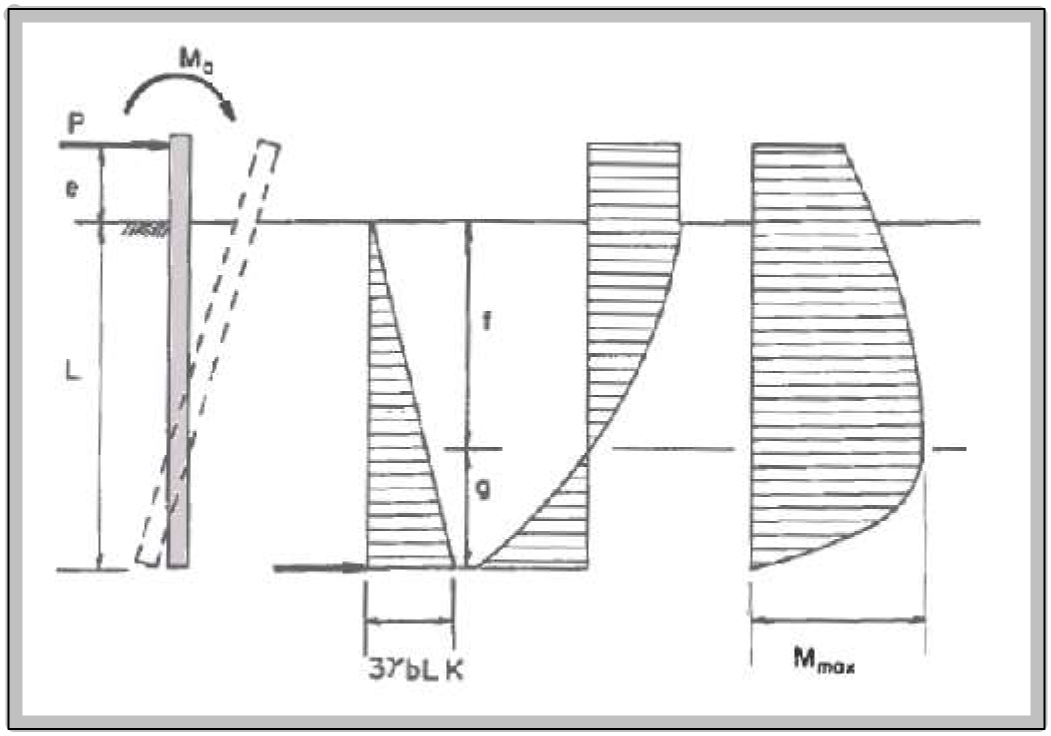
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x{}^2 + M_z{}^2} = 179.7 \cdot \text{kip} \cdot \text{ft}$

$P_u := \sqrt{V_x{}^2 + V_z{}^2} = 8.5 \cdot \text{kip}$

$T_u := \text{Torsion} = 173.8 \cdot \text{kip} \cdot \text{ft}$

*short free-head pile in **cohesionless soil** using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(45 \cdot \text{deg} + \frac{\phi_{soil}}{2}\right)^2 = 3.3$ $\qquad$ $e_{sand} := \text{Offset} = 0.5\,\text{ft}$

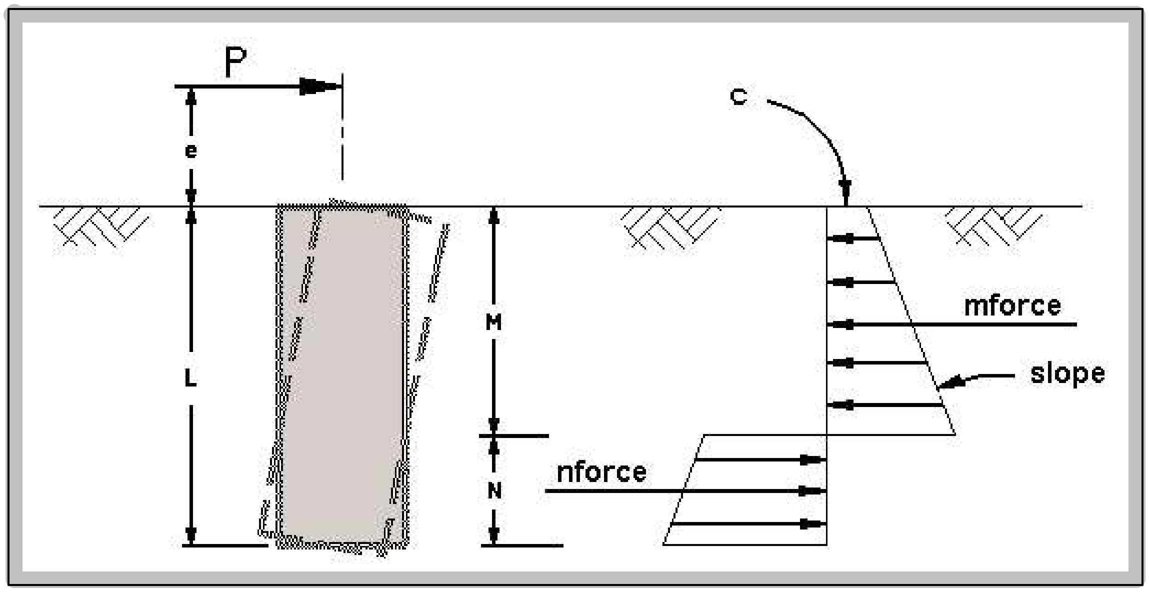
Guess value $\qquad L_{otSand} := 8 \cdot \text{ft}$

Given $\qquad P_u \cdot (e_{sand} + L_{otSand}) + M_u = \phi_{ot} \cdot \left[(3 \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p) \cdot \left(\frac{1}{2} \cdot L_{otSand}\right) \cdot \left(\frac{1}{3} \cdot L_{otSand}\right) \right]$

$L_{otSand} := \text{Find}(L_{otSand}) = 12.4\,\text{ft}$

$L_{otSand} := \text{ceil}\left(\frac{L_{otSand}}{\text{ft}}\right) \cdot \text{ft} = 13\,\text{ft}$ $\qquad$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}\left(c_{soil} = 0\cdot\text{ksf}, 0.1\cdot\text{ksf}, c_{soil}\right) = 0.1\cdot\text{ksf}$

$\text{Slope} := 8\cdot\frac{c_{soil}}{3\cdot b} = 0.1\cdot\frac{\text{kip}}{\text{ft}^3}$ $\qquad$ $e_{clay} := \frac{M_u}{P_u} + \text{Offset} = 21.6\,\text{ft}$

$\text{nforce}(M,N) := \left[\text{Slope}\cdot(2\cdot M + N) + 2\cdot c_{soil}\right]\cdot N\cdot\frac{b}{2}$ $\qquad$ $\text{mforce}(M) := \left(2\cdot c_{soil} + M\cdot\text{Slope}\right)\cdot M\cdot\frac{b}{2}$

$$\text{m\_arm}(M) := e_{clay} + \frac{M}{3}\cdot\frac{2\cdot\left(M\cdot\text{Slope} + c_{soil}\right) + c_{soil}}{M\cdot\text{Slope} + 2\cdot c_{soil}}$$

$$\text{n\_arm}(M,N) := e_{clay} + M + \frac{N}{3}\cdot\frac{2\cdot\left(N\cdot\text{Slope} + M\cdot\text{Slope} + c_{soil}\right) + \left(M\cdot\text{Slope} + c_{soil}\right)}{\text{Slope}\cdot(2\cdot M + N) + 2\cdot c_{soil}}$$

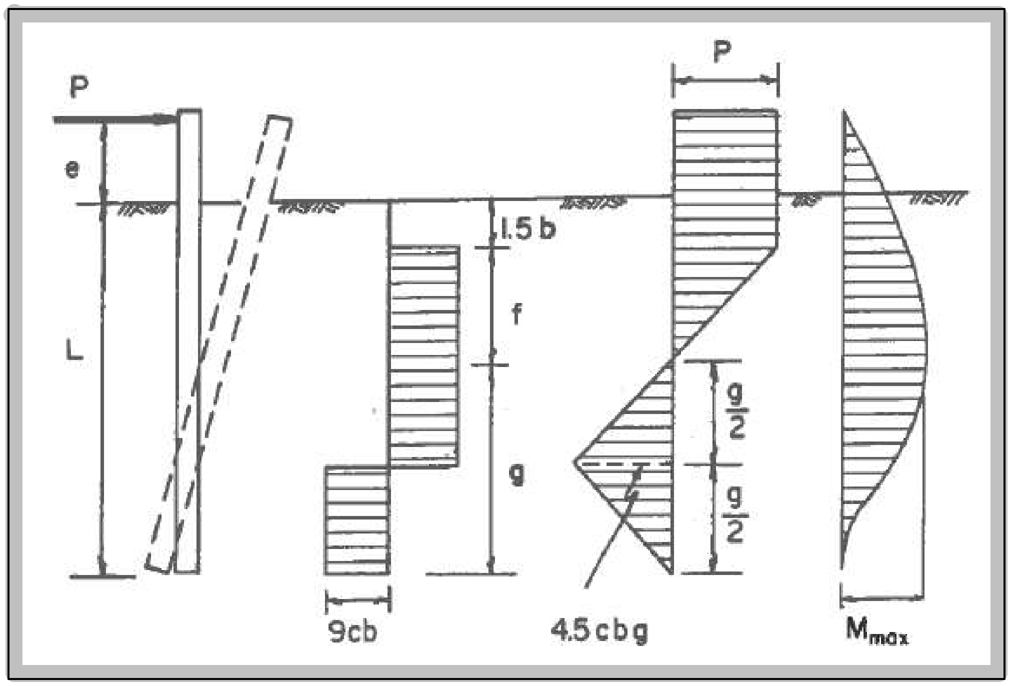
Guess value $\quad M := 4.0\cdot\text{ft} \qquad N := 4.0\cdot\text{ft}$

Given $\quad P_u + \phi_{ot}\cdot\text{nforce}(M,N) = \phi_{ot}\cdot\text{mforce}(M) \qquad \text{mforce}(M)\cdot\text{m\_arm}(M) = \text{nforce}(M,N)\cdot\text{n\_arm}(M,N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M,N) \qquad L_{ot1Clay} := M + N = 11.3\,\text{ft}$

$L_{ot1Clay} := \text{ceil}\left(\frac{L_{ot1Clay}}{\text{ft}}\right)\cdot\text{ft} = 12\,\text{ft}$ $\qquad$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot 9 \cdot c_{soil} \cdot b} = 12.6\,ft$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + 1.5 \cdot b + 0.5 \cdot f\right) = 275.7 \cdot kip \cdot ft$$

$$g := \sqrt{\frac{M_{max.clay}}{2.25 \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = 40.4\,ft$$

$$L_{ot2Clay} := (1.5 \cdot b + f + g) = 57.5\,ft$$

$$L_{ot2Clay} := ceil\left(\frac{L_{ot2Clay}}{ft}\right) \cdot ft = 58\,ft$$ *(round up to next foot)*

$$L_{otClay} := if\left(L_{ot1Clay} < 3 \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = 58\,ft$$ *(If L_{ot} < 3b, use Modified Broms method)*

$$L_{reqdOT} := if\left(SoilType = \text{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$L_{reqdOT} = 13\,ft$ *required shaft embedment depth to resist overturning*

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = 29$

$$\omega_{fdot} := \text{if}\left(N_{blows} < 5, 0, \text{if}\left(N_{blows} \geq 15, 1.5, 1.5 \cdot \frac{N_{blows}}{15}\right)\right) = 1.5$$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\frac{N_{blows}}{15}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = 13\,\text{ft}$

Given $T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot (L_{torSand}) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right]$

$L_{torSand} := \text{Find}(L_{torSand}) = 11.5\,\text{ft}$

$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{\text{ft}}\right) \cdot \text{ft} = 12\,\text{ft}$ *(round up to next foot)*

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := 0.55$

$f_{se} := \text{CohesionFactor} \cdot c_{soil} = 0.1 \cdot \text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

Given $T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot (L_{torClay} - 1.5 \cdot \text{ft}) \cdot \frac{b}{2}\right]$

$L_{torClay} := \text{Find}(L_{torClay}) = 225\,\text{ft}$

$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{\text{ft}}\right) \cdot \text{ft} = 226\,\text{ft}$ *(round up to next foot)*

$L_{reqdTor} := \text{if}(\text{SoilType} = \text{"Sand"}, L_{torSand}, L_{torClay})$

$L_{reqdTor} = 12\,\text{ft}$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}) = 13\,\text{ft}$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = 13.5\,\text{ft}$ *shaft length*

Min Shaft embedment depth=14 ft

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2 \cdot P_u}{3 \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = 4.3\ \text{ft}$$

$$M_{maxSand} := P_u \cdot \left(e_{sand} + f_{sand}\right) - \frac{P_u \cdot f_{sand}}{3} + M_u = 208.3 \cdot \text{kip} \cdot \text{ft}$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0 \cdot \text{ft}$

Given $P_u = \frac{f_{mod} \cdot b}{2} \cdot \left(2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot \text{Slope}\right)$

$$f_{mod} := \text{Find}\left(f_{mod}\right) = 14.9\ \text{ft}$$

$$M_{modBroms} := P_u \cdot \left(e_{clay} + f_{mod}\right) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^{\ 2}}{2} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^{\ 3} \cdot \text{Slope}}{6} = 265.5 \cdot \text{kip} \cdot \text{ft}$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot \left(e_{clay} + 1.5 \cdot b + 0.5 \cdot f\right) = 275.7 \cdot \text{kip} \cdot \text{ft}$$

$M_{maxClay} := \text{if}\left(L_{ot1Clay} < 3 \cdot b, M_{modBroms}, M_{Broms}\right) = 275.7 \cdot \text{kip} \cdot \text{ft}$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$$M_{max} := \text{if}\left(\text{SoilType} = \text{"Sand"}, M_{maxSand}, M_{maxClay}\right) = 208.3 \cdot \text{kip} \cdot \text{ft}$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := \mathbf{60} \cdot ksi$ *reinforcing yield strength*

$f_c := \mathbf{4.0} \cdot ksi$ *concrete strength* *Spec 346-3*

$Cover := 3 \cdot in$ *cover* *SDG Table 1.4.2-1*

$Num_{bar} := \mathbf{11}$ *number of longitudinal bars*

$A_{long.bar} := \mathbf{1.0} \cdot in^2$ *longitudinal bar area*

$d_{long.bar} := \mathbf{1.125} \cdot in$ *longitudinal bar diameter*

$A_{v.bar} := \mathbf{0.20} \cdot in^2$ *stirrup area* *SM Vol-3 13.6.2*

$d_{v.bar} := \mathbf{0.5} \cdot in$ *stirrup diameter*

$s_{v1} := \mathbf{3} \cdot in$ *stirrup spacing, depth = 0 ft-2 ft* *SM Vol-3 13.6.2*

$s_{v2} := \mathbf{3} \cdot in$ *stirrup spacing, depth = 2 ft-depth.stir*

$s_{v3} := \mathbf{6} \cdot in$ *stirrup spacing, depth > depth.stir*

$depth_{stir} := \mathbf{11.0} \cdot ft$ *stirrup depth, see s.v2 and s.v3 above*

$b = 3\ ft$ *shaft diameter*

$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$ *required 1% steel* *SM Vol-3 13.6.2*

$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$ *LRFD 5.7.4.2*

$A_{req} := \max\left(A_{req1}, A_{req2}\right) = 10.2 \cdot in^2$

$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$ *total area of longitudinal steel*

$CheckLongitudinalReinf := if\left(A_{long} \ge A_{req}, \text{"OK"}, \text{"No Good"}\right)$ $CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if\left(Clearance_{vert.reinf} \ge 6in, \text{"OK"}, \text{"No Good"}\right)$ $CheckReinfClearSpacing = \text{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$V_u := \sqrt{V_x^{\,2} + V_z^{\,2}} = 8.5 \cdot kip$

$T_u = 173.8 \cdot kip \cdot ft$

Effective shear depth

$D_r := b - 2 \cdot \left(Cover + d_{v.bar} + \frac{d_{long.bar}}{2} \right) = 2.3\,ft$ $d_e := \frac{b}{2} + \frac{D_r}{\pi} = 2.2\,ft$ *LRFD C5.8.2.9-2*

$d_v := \max(0.9 \cdot d_e, 0.72 \cdot b) = 2.2\,ft$

Check Shear Strength

$V_c := 0.0316 \cdot (2.0) \cdot \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{b}{in}\right) \cdot \left(\frac{d_v}{in}\right) \cdot kip = 117.9 \cdot kip$ *LRFD Eqn 5.8.3.3-3* *LRFD 5.8.3.4.1* *ACI 11.3.3*

$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max(s_{v1}, s_{v2}, s_{v3})} = 51.8 \cdot kip$ *LRFD Eqn 5.8.3.3-4*

$ShearRatio := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -2.1$

$ShearRatio := \text{if}(ShearRatio \le 0, 0, ShearRatio) = 0$

Check Torsion Strength

$A_{cp} := \pi \cdot \left(\frac{b}{2}\right)^2 = 1017.9 \cdot in^2$ $p_{cp} := 2 \cdot \pi \cdot \left(\frac{b}{2}\right) = 113.1 \cdot in$ *Area and perimeter of concrete cross-section*

$d_{oh} := b - 2 \cdot \left(Cover + \frac{d_{v.bar}}{2} \right) = 29.5 \cdot in$ $p_h := \pi \cdot d_{oh} = 92.7 \cdot in$ *Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement*

$A_{oh} := \pi \left(\frac{d_{oh}}{2}\right)^2 = 683.5 \cdot in^2$ $A_o := 0.85 \cdot A_{oh} = 581 \cdot in^2$

$T_{n1} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = 387.3 \cdot kip \cdot ft$ *LRFD Eqn 5.8.3.6.2-1*

$T_{n2} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = 387.3 \cdot kip \cdot ft$ *LRFD 5.8.3.4.1*

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = 193.7 \cdot kip \cdot ft$$

$\phi_v = 0.9$ $T_u = 173.8 \cdot kip \cdot ft$ $L_{reqdTor} = 12\,ft$

$$Tor2_{sand} := T_u - if\left[2ft > Offset, \left[\pi \cdot b \cdot (2 \cdot ft - Offset) \cdot \gamma_{soil} \cdot \left(\frac{2 \cdot ft - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 170.8 \cdot kip \cdot ft$$

$$Tor3_{sand} := T_u - if\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot (depth_{stir} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 27.7 \cdot kip \cdot ft$$

$$Tor2_{clay} := T_u - if\left[2ft - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (2.0 \cdot ft - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 173.8 \cdot kip \cdot ft$$

$$Tor3_{clay} := T_u - if\left[depth_{stir} - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (depth_{stir} - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 166.8 \cdot kip \cdot ft$$

$$Tor2 := if(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}) = 170.8 \cdot kip \cdot ft$$

$$Tor3 := if(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}) = 27.7 \cdot kip \cdot ft$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = 0.45$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = 0.44$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = 0.14$$

$$TorsionRatio := max(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}) = 0.45$$

$$T_{cr} := 0.125 \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{A_{cp}^{\,2}}{p_{cp} \cdot in^3}\right) \cdot kip \cdot in = 190.9 \cdot kip \cdot ft$$

LRFD Eqn 5.8.2.1-4

$$TorsionRatio := if(T_u \le 0.25 \cdot \phi_{tor} \cdot T_{cr}, 0, TorsionRatio) = 0.4$$

LRFD Eqn 5.8.2.1-3

$ShearRatio = 0$

CheckShearTorsion := if(ShearRatio + TorsionRatio ≤ 1, "OK", "No Good")

CheckShearTorsion = "OK"

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = 0.010122 \cdot ksi$$

$0.125 \cdot f_c = 0.5 \cdot ksi$

LRFD Eqn 5.8.2.9-1

$s_{max1} := \text{if}\left(0.8 \cdot d_v < 24 \cdot in, 0.8d_v, 24 \cdot in\right) = 20.7 \cdot in$ LRFD Eqn 5.8.2.7-1

$s_{max2} := \text{if}\left(0.4 \cdot d_v < 12 \cdot in, 0.4d_v, 12 \cdot in\right) = 10.4 \cdot in$ LRFD Eqn 5.8.2.7-2

$s_{max} := \text{if}\left(v_u < 0.125 \cdot f_c, s_{max1}, s_{max2}\right) = 20.7 \cdot in$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = 6 \cdot in$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \text{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion LRFD Eqn 5.8.3.6.3-1

LRFD 5.8.3.4.1

$M_u = 179.7 \cdot kip \cdot ft$

$$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5 \cdot V_s > 0 \cdot kip, \frac{V_u}{\phi_v} - 0.5 \cdot V_s, 0 \cdot kip\right) = 0 \cdot kip$$

$$\text{LongReinf}_{shr.tor} := \frac{\dfrac{M_u}{\phi_v \cdot d_v} + \sqrt{\left(V_{temp}\right)^2 + \left(\dfrac{0.45 \cdot p_h \cdot T_u}{2 \cdot A_o \cdot \phi_v}\right)^2}}{F_{y.rebar}} = 2.9 \cdot in^2$$

$\text{Num}_{bar} \cdot A_{long.bar} = 11 \cdot in^2$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(\text{Num}_{bar} \cdot A_{long.bar} \ge \text{LongReinf}_{shr.tor}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \text{"OK"}$

Anchor Bolt Strength Check

$Num_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot in$ *anchor bolt nominal diameter*

$Dia_{anchor.circle} := 24 \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{Dia_{anchor.circle}^{\,2}}{8} \cdot Num_{anchor} = 576 \cdot in^{2}$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{Dia_{anchor.circle}}{2}} = 48 \cdot in$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 44.9 \cdot kip$$ *anchor tension force*

$$V_{anchor} := \frac{V_u}{Num_{anchor}} + \frac{T_u}{0.5Dia_{anchor.circle} \cdot Num_{anchor}} = 22.8 \cdot kip$$ *anchor shear force*

$$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}^{\,2} = 3.1 \cdot in^{2}$$ *anchor bolt nominal area*

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 14.3 \cdot ksi$$ *anchor tensile stress*

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 7.3 \cdot ksi$$ *anchor shear stress*

$\phi_{anchor} := 0.75$ *resistance factor* AISC J3-1

$F_{nt} := 0.75F_{u.anchor} = 78.8 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := 0.45F_{u.anchor} = 47.2 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot kip$ *design sghear strength*

$CheckAnchorT := if\left(\phi R_{nt} \geq T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$CheckAnchorT = \text{"OK"}$

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check shear rupture*

$\text{CheckAnchorV} = \text{"OK"}$

$$F_{ntv} := \min\left(\left(\begin{array}{c} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{array}\right)\right) = 78.8 \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = 185.6 \cdot \text{kip}$

design tension strength modified to include the effects of shearing stress

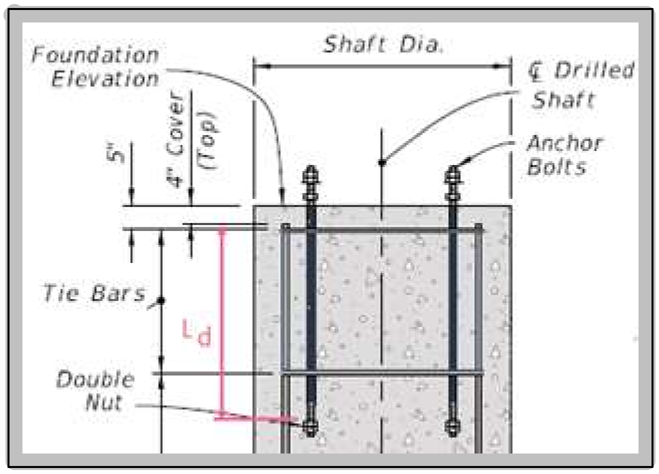
$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq 20\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq 20\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \text{"OK"}, \text{"No Good"}\right]$

$\text{CheckAnchorTV} = \text{"OK"}$ *check combined tension and shear rupture*

$\text{CheckAnchorStrength} := \text{if}[(\text{CheckAnchorT} = \text{"OK"}) \cdot (\text{CheckAnchorV} = \text{"OK"}) \cdot (\text{CheckAnchorTV} = \text{"OK"}), \text{"OK"}, \text{"No Good"}]$

$\text{CheckAnchorStrength} = \text{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = 44.9 \cdot \text{kip}$ *tension force in anchor*

$\text{Dia}_{bar.circle} = 27.9 \cdot \text{in}$ $\text{Dia}_{anchor.circle} = 24 \cdot \text{in}$

center-to-center distance

$$\text{Dist}_{bar.to.bolt} := \frac{\text{Dia}_{bar.circle} - \text{Dia}_{anchor.circle}}{2} = 1.9 \cdot \text{in}$$

$$\text{Num}_{bars.per.anchor} := \min\left(\frac{\text{Num}_{bar}}{\text{Num}_{anchor}}, 3\right) = 1.4$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := 0.9$

$$\text{Num}_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{\text{Dia}_{anchor.circle}}{\text{Dia}_{bar.circle}} = 0.72$$

$$\text{AreaRatio} := \min\left(\frac{\text{Num}_{bars.reqd.per.anchor}}{\text{Num}_{bars.per.anchor}}, 1\right) = 0.52$$

2015 AASHTO Development Length of Deformed Bars in Tension ***5.11.2.1***

$\text{Cover} = 3 \cdot \text{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half the center-to-center spacing of the bars or wires being developed*

$$c_b := \min\left(\left(\begin{matrix} Cover + d_{v.bar} + \dfrac{d_{long.bar}}{2} \\ \dfrac{Spacing_{vert.reinf}}{2} \end{matrix}\right)\right) = 4 \cdot in$$

$k_{tr} := 0 \cdot in$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\left[\begin{matrix} 1.0 \\ \max\left(\left(\begin{matrix} 0.4 \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{matrix}\right)\right) \end{matrix}\right]\right] = 0.4$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\left(\begin{matrix} 12 \cdot in \\ \lambda_{rc} \cdot 2.4 \cdot d_{long.bar} \cdot \dfrac{F_{y.rebar}}{\sqrt{f_c \cdot ksi}} \end{matrix}\right)\right) = 32.4 \cdot in$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$SpacingFactor := \max\left[\left(\begin{matrix} 0.5 \\ Num_{bars.per.anchor} \cdot 0.5 - 0.5 \end{matrix}\right)\right] = 0.5$$

$$L_{embedment.added} := \sqrt{\left(Clearance_{vert.reinf} \cdot SpacingFactor\right)^2 + Dist_{bar.to.bolt}^{\;2}} = 3.9 \cdot in$$

$$L_{embedment.anchor} := \max\left[\left[\begin{matrix} L_{d.bar} \cdot (AreaRatio) + 12 \cdot in + L_{embedment.added} \\ 20 \cdot d_{anchor} \end{matrix}\right]\right] = 40 \cdot in$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := Ceil\left(L_{embedment.anchor}, in\right)$

$L_{embedment.anchor} = 40 \cdot in$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^{\,2} + 3.25 \cdot \left(r^2 - r_b^{\,2}\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\begin{pmatrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{pmatrix}\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2\,\mathrm{asin}\left[\frac{(1.5 \cdot c_{a1})}{r}\right] = 45.2 \cdot deg$$

OverlapTest := if$\left(A_{bolt.sector} \le \alpha\right.$, "Overlap of Failure Cones" , "No Overlap of Failure Cones" $\left.\right)$ = "Overlap of Failure Cones"

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{\,2} = 95.9 \cdot in^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \mathrm{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$$

$\psi_{ecV} := \mathbf{1.0}$ *eccentric load modifier* *ACI D.6.2.5*

$\psi_{edV} := \mathbf{1.0}$ *edge effect modifier* *ACI D.6.2.6*

$\psi_{cV} := \mathbf{1.4}$ *cracked section modifier* *ACI D.6.2.7* *(stirrup spacing <= 4")*

$\psi_{hV} := \mathbf{1.0}$ *member thickness modifier* *ACI D.6.2.8*

$\phi_{breakout} := \mathbf{0.75}$ *strength reduction factor* *ACI D.4.4.c.i* *(shear breakout, condition A)*

$$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = 194.7 \cdot kip$$

concrete breakout strength - shear

ACI Eqn D-22 *Shear force ⊥ to edge*

$V_{cbg\_parallel} := 2 \cdot V_{cbg} = 389.5 \cdot kip$ *ACI D.6.2.1.c* *Shear force ∥ to edge*

$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = 389.5 \cdot kip \cdot ft$ *concrete breakout strength - torsion*

$\phi_{breakout} \cdot T_{n.breakout} = 292.1 \cdot kip \cdot ft$

$T_u = 173.8 \cdot kip \cdot ft$

BreakoutTest := if$\left(\phi_{breakout} \cdot T_{n.breakout} \geq T_u\right.$, "OK" , "No Good")

BreakoutTest = "OK"

OverlapDesign := if$\left(A_{bolt.sector} \leq \alpha\right.$, "Based on Overlap of Failure Cones" , "Based on No Overlap of Failure Cones")

OverlapDesign = "Based on Overlap of Failure Cones"

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = 1.9 \cdot in$ *center-to-center distance*

$d_{anchor.nut} := 1.85 \cdot d_{anchor} = 3.7 \cdot in$ *use* $1.85 \cdot d_{anchor}$ *.to account for anchor nut*

$$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{2}\right) = -0.5 \cdot in$$

CheckAnchorageClearance := if$\left[\left(Clearance_{bar.to.nut} \geq 2 \cdot in\right)\right.$, "OK" , "No Good, increase ped. diameter"]

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0..48 \qquad r_{ds} := \frac{b}{2}$

$x_{ds_{pt}} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{ds_{pt}} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$x_{stir.od_{pt}} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.od_{pt}} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$x_{stir.id_{pt}} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.id_{pt}} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$x_{bar_{pt}} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max(x_{stir.id}) - d_{v.bar} \qquad y_{bar_{pt}} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$x_{boltcircle_{pt}} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{boltcircle_{pt}} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$$r_{boltr} := \frac{d_{anchor}}{2} = 1\cdot in$$

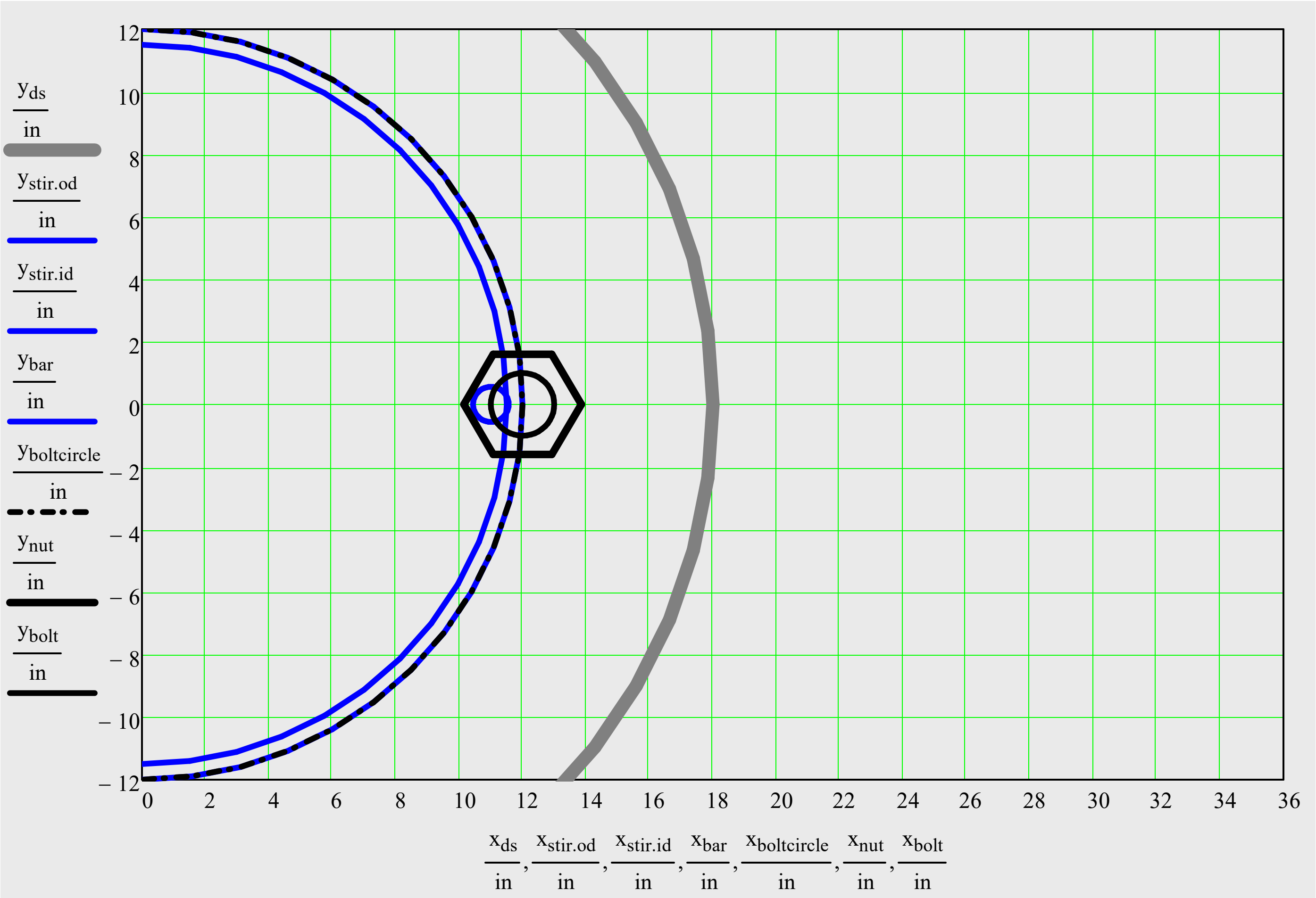
$x_{bolt_{pt}} := r_{boltr}\cdot\cos\left[(2\cdot\pi)\cdot\frac{pt}{48} + \frac{2\cdot\pi}{48}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $y_{bolt_{pt}} := r_{boltr}\cdot\sin\left[\left(2\cdot\pi\cdot\frac{pt}{48}\right) + \frac{2\cdot\pi}{48}\right]$

$pt := 0\,..\,6$ $r_{nut} := \frac{d_{anchor}\cdot 1.85}{2} = 1.9\cdot in$

$x_{nut_{pt}} := r_{nut}\cdot\cos\left[(2\cdot\pi)\cdot\frac{pt}{6} + \frac{2\cdot\pi}{6}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $y_{nut_{pt}} := r_{nut}\cdot\sin\left[\left(2\cdot\pi\cdot\frac{pt}{6}\right) + \frac{2\cdot\pi}{6}\right]$

$x_{nut_{pt}} := r_{nut}\cdot\cos\left[(2\cdot\pi)\cdot\frac{pt}{6} + \frac{1\cdot\pi}{6}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ *enable to rotate nut* $y_{nut_{pt}} := r_{nut}\cdot\sin\left[\left(2\cdot\pi\cdot\frac{pt}{6}\right) + \frac{1\cdot\pi}{6}\right]$

$$\min\left(x_{bar}\right) - \max\left(x_{nut}\right) = -3.4\cdot in$$



$$\text{Bolts} := \begin{pmatrix} 1 & 1.125 & 1.25 & 1.375 & 1.5 & 1.625 & 1.75 & 1.875 & 2 & 2.25 & 2.5 & 2.75 & 3 \\ 1.5 & 1.688 & 1.875 & 2.063 & 2.25 & 2.438 & 2.625 & 2.938 & 3 & 3.375 & 3.75 & 4.125 & 4.25 \end{pmatrix} \cdot \text{in}$$

$$\left(\left(\text{Bolts}^{T}\right)^{\langle 0 \rangle}\right)^{T} \cdot 1.6 - \left(\left(\text{Bolts}^{T}\right)^{\langle 1 \rangle}\right)^{T} = \begin{pmatrix} 0.1 & 0.112 & 0.125 & 0.137 & 0.15 & 0.162 & 0.175 & 0.062 & 0.2 & 0.225 & 0.25 & 0.275 & 0.55 \end{pmatrix} \cdot \text{in}$$

$$\left(\left(\text{Bolts}^{T}\right)^{\langle 0 \rangle}\right)^{T} - \left(\left(\text{Bolts}^{T}\right)^{\langle 1 \rangle}\right)^{T} = \begin{pmatrix} -0.5 & -0.563 & -0.625 & -0.688 & -0.75 & -0.813 & -0.875 & -1.063 & -1 & -1.125 & -1.25 & -1.375 & -1.25 \end{pmatrix} \cdot \text{i}$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

FDOT
State Structures Design Office

SUBJECT 079-241-B MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

SoilType :=
Sand
Clay

$\phi_{soil} := \mathbf{32} \cdot deg$ *soil friction angle (sand)*

$c_{soil} := \mathbf{0.0} \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

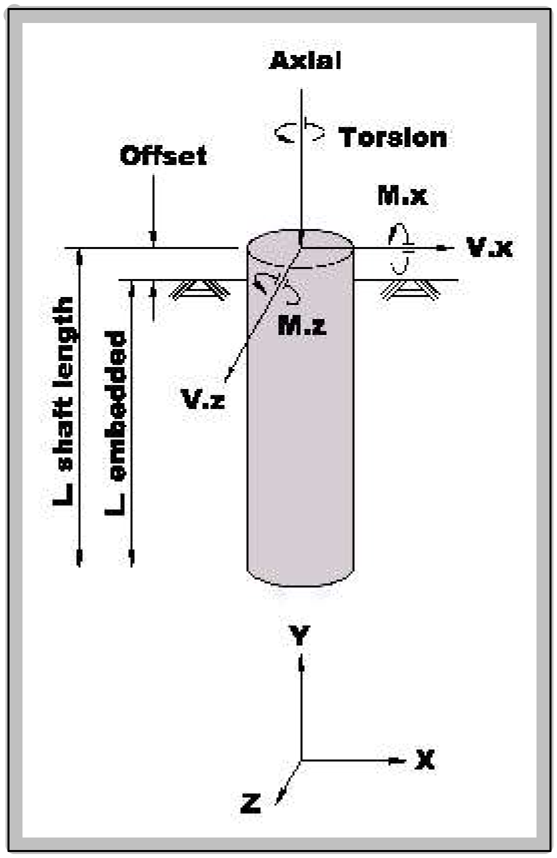
$N_{blows} := 14$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := 71 \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*

Geometry

$b := \mathbf{3.0} \cdot ft$ *shaft diameter*

$Offset := \mathbf{0.50} \cdot ft$ *groundline to top of foundation*



Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := \mathbf{86.80} \cdot kip \cdot ft$ $V_x := \mathbf{0.05} \cdot kip$ $Torsion := \mathbf{101.30} \cdot kip \cdot ft$

$M_z := \mathbf{53.40} \cdot kip \cdot ft$ $V_z := \mathbf{5.20} \cdot kip$ $Axial := \mathbf{20.40} \cdot kip$

StructureType :=
Cantilever Overhead Sign Structure
Mast Arm Signal Structure
Concrete/Steel Strain Poles
Ground Sign

$StructureType = 1$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

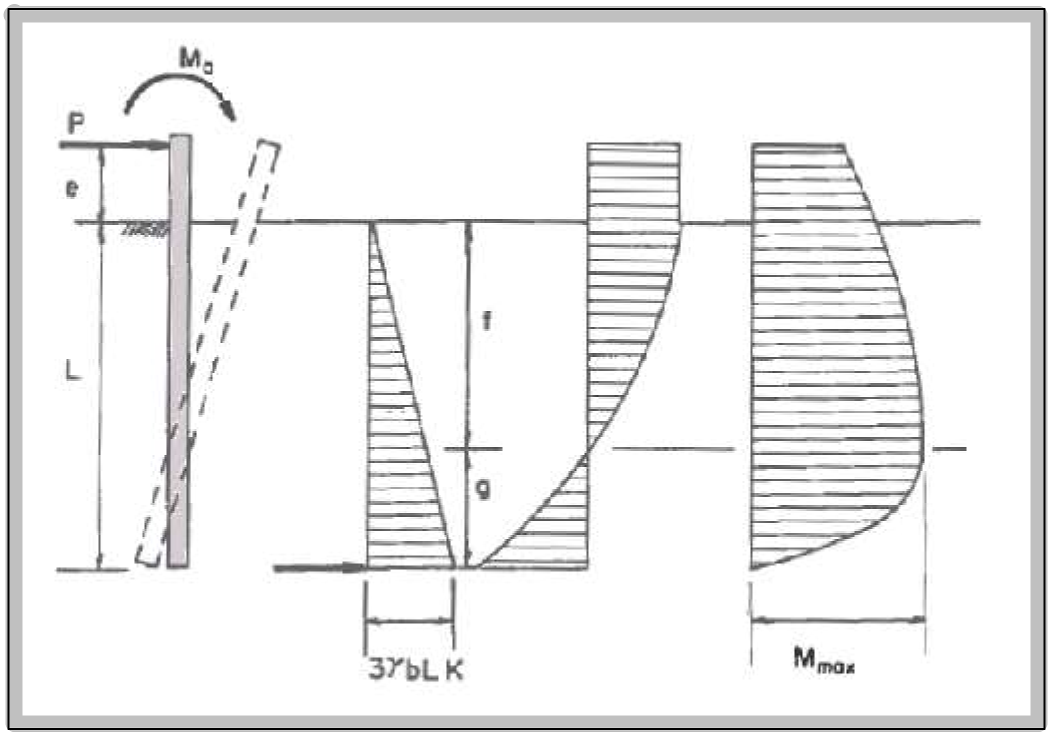
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{{M_x}^2 + {M_z}^2} = 101.9 \cdot kip \cdot ft$

$P_u := \sqrt{{V_x}^2 + {V_z}^2} = 5.2 \cdot kip$

$T_u :=$ Torsion $= 101.3 \cdot kip \cdot ft$

*short free-head pile in **cohesionless soil** using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(45 \cdot deg + \frac{\phi_{soil}}{2}\right)^2 = 3.3$ $\qquad e_{sand} :=$ Offset $= 0.5\,ft$

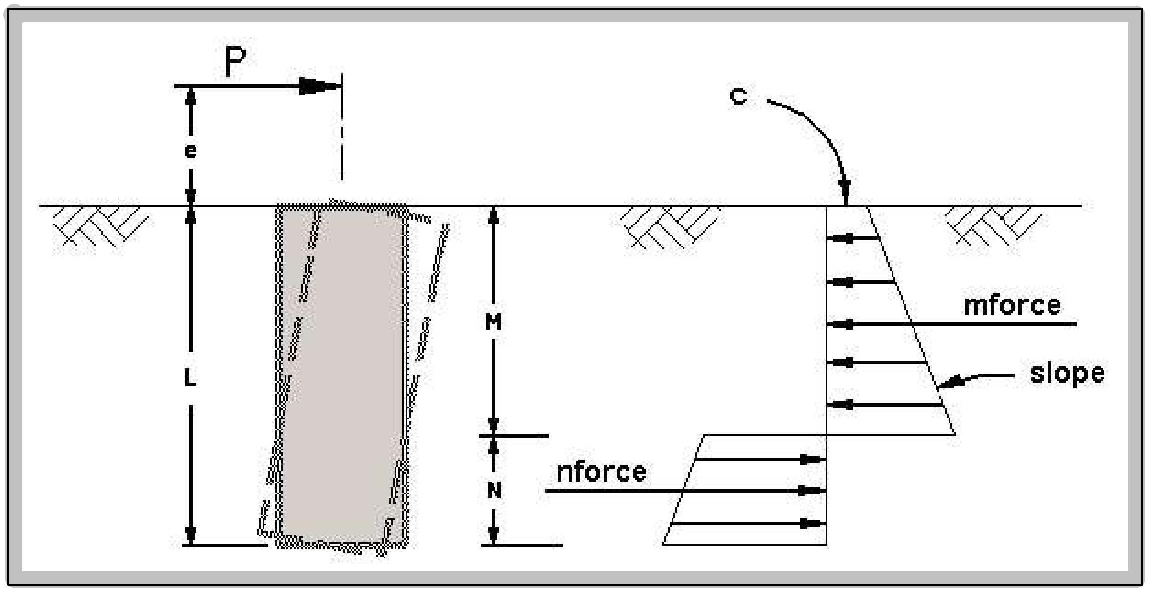
Guess value $\qquad L_{otSand} := 8 \cdot ft$

Given $\qquad P_u \cdot \left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot} \cdot \left[\left(3 \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{1}{2} \cdot L_{otSand}\right) \cdot \left(\frac{1}{3} \cdot L_{otSand}\right)\right]$

$L_{otSand} := \text{Find}\left(L_{otSand}\right) = 12.5\,ft$

$L_{otSand} := \text{ceil}\left(\frac{L_{otSand}}{ft}\right) \cdot ft = 13\,ft$ $\qquad$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$$c_{soil} := \text{if}\left(c_{soil} = 0\cdot ksf, 0.1\cdot ksf, c_{soil}\right) = 0.1\cdot ksf$$

$$\text{Slope} := 8\cdot\frac{c_{soil}}{3\cdot b} = 0.1\cdot\frac{kip}{ft^3} \qquad e_{clay} := \frac{M_u}{P_u} + \text{Offset} = 20.1\,ft$$

$$\text{nforce}(M,N) := \left[\text{Slope}\cdot(2\cdot M + N) + 2\cdot c_{soil}\right]\cdot N\cdot\frac{b}{2} \qquad \text{mforce}(M) := \left(2\cdot c_{soil} + M\cdot\text{Slope}\right)\cdot M\cdot\frac{b}{2}$$

$$\text{m\_arm}(M) := e_{clay} + \frac{M}{3}\cdot\frac{2\cdot\left(M\cdot\text{Slope} + c_{soil}\right) + c_{soil}}{M\cdot\text{Slope} + 2\cdot c_{soil}}$$

$$\text{n\_arm}(M,N) := e_{clay} + M + \frac{N}{3}\cdot\frac{2\cdot\left(N\cdot\text{Slope} + M\cdot\text{Slope} + c_{soil}\right) + \left(M\cdot\text{Slope} + c_{soil}\right)}{\text{Slope}\cdot(2\cdot M + N) + 2\cdot c_{soil}}$$

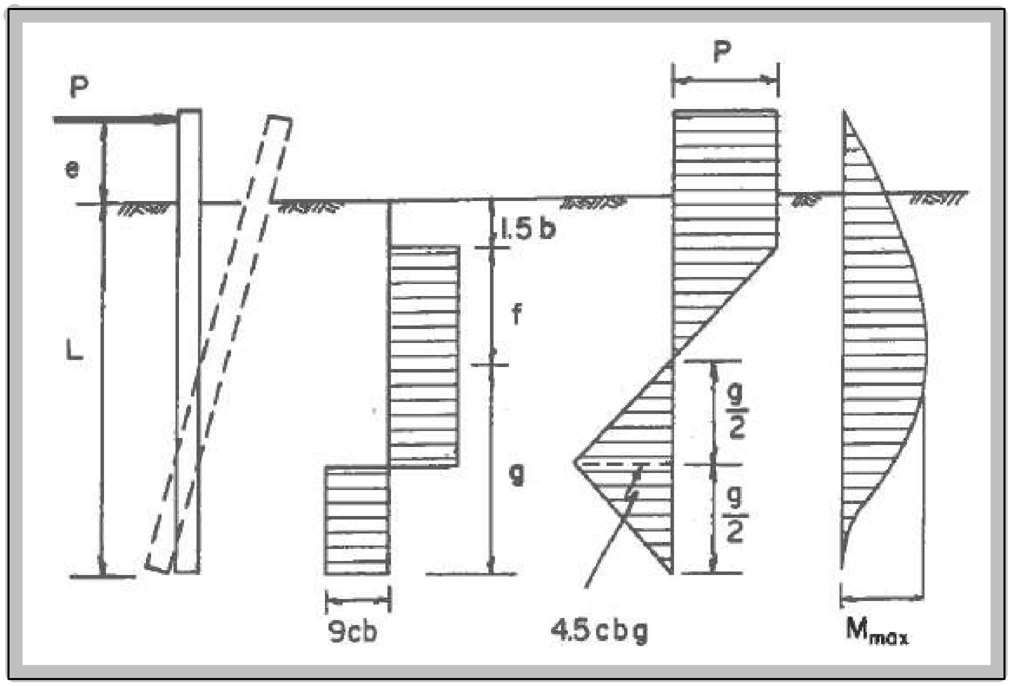
Guess value $M := 4.0\cdot ft$ $N := 4.0\cdot ft$

Given $P_u + \phi_{ot}\cdot\text{nforce}(M,N) = \phi_{ot}\cdot\text{mforce}(M)$ $\text{mforce}(M)\cdot\text{m\_arm}(M) = \text{nforce}(M,N)\cdot\text{n\_arm}(M,N)$

$$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M,N) \qquad L_{ot1Clay} := M + N = 9.6\,ft$$

$$L_{ot1Clay} := \text{ceil}\left(\frac{L_{ot1Clay}}{ft}\right)\cdot ft = 10\,ft$$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot 9 \cdot c_{soil} \cdot b} = 7.7\,\text{ft}$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + 1.5 \cdot b + 0.5 \cdot f\right) = 147.9 \cdot \text{kip} \cdot \text{ft}$$

$$g := \sqrt{\frac{M_{max.clay}}{2.25 \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = 29.6\,\text{ft}$$

$$L_{ot2Clay} := (1.5 \cdot b + f + g) = 41.8\,\text{ft}$$

$$L_{ot2Clay} := \text{ceil}\left(\frac{L_{ot2Clay}}{\text{ft}}\right) \cdot \text{ft} = 42\,\text{ft}$$ *(round up to next foot)*

$$L_{otClay} := \text{if}\left(L_{ot1Clay} < 3 \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = 42\,\text{ft}$$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$$L_{reqdOT} := \text{if}\left(\text{SoilType} = \text{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$L_{reqdOT} = 13\,\text{ft}$ *required shaft embedment depth to resist overturning*

Shaft Depth Required to Resist Torsion

short free-head pile in ***cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = 14$

$$\omega_{fdot} := \text{if}\left(N_{blows} < 5, 0, \text{if}\left(N_{blows} \geq 15, 1.5, 1.5 \cdot \frac{N_{blows}}{15}\right)\right) = 1.4$$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\frac{N_{blows}}{15}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = 13\ \text{ft}$

Given $T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot (L_{torSand}) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right]$

$L_{torSand} := \text{Find}(L_{torSand}) = 12\ \text{ft}$

$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{\text{ft}}\right) \cdot \text{ft} = 13\ \text{ft}$ *(round up to next foot)*

short free-head pile in ***cohesive soil***

$\text{CohesionFactor} := 0.55$

$f_{se} := \text{CohesionFactor} \cdot c_{soil} = 0.1 \cdot \text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

Given $T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot (L_{torClay} - 1.5 \cdot \text{ft}) \cdot \frac{b}{2}\right]$

$L_{torClay} := \text{Find}(L_{torClay}) = 131.8\ \text{ft}$

$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{\text{ft}}\right) \cdot \text{ft} = 132\ \text{ft}$ *(round up to next foot)*

$L_{reqdTor} := \text{if}(\text{SoilType} = \text{"Sand"}, L_{torSand}, L_{torClay})$

$L_{reqdTor} = 13\ \text{ft}$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}) = 13\ \text{ft}$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = 13.5\ \text{ft}$ *shaft length*

Min Shaft embedment depth=16 ft

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2 \cdot P_u}{3 \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = 4.5\,ft$$

$$M_{maxSand} := P_u \cdot (e_{sand} + f_{sand}) - \frac{P_u \cdot f_{sand}}{3} + M_u = 120 \cdot kip \cdot ft$$

short free-head pile in ***cohesive soil*** *using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0 \cdot ft$

Given $P_u = \frac{f_{mod} \cdot b}{2} \cdot (2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot Slope)$

$f_{mod} := Find(f_{mod}) = 11.4\,ft$

$$M_{modBroms} := P_u \cdot (e_{clay} + f_{mod}) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^{2}}{2} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^{3} \cdot Slope}{6} = 142.5 \cdot kip \cdot ft$$

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot (e_{clay} + 1.5 \cdot b + 0.5 \cdot f) = 147.9 \cdot kip \cdot ft$$

$M_{maxClay} := if(L_{ot1Clay} < 3 \cdot b, M_{modBroms}, M_{Broms}) = 147.9 \cdot kip \cdot ft$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$M_{max} := if(SoilType = "Sand", M_{maxSand}, M_{maxClay}) = 120 \cdot kip \cdot ft$

Minimum Reinforcing and Spacing

$F_{y.rebar} := \mathbf{60} \cdot ksi$ *reinforcing yield strength*

$f_c := \mathbf{4.0} \cdot ksi$ *concrete strength* *Spec 346-3*

$Cover := \mathbf{3} \cdot in$ *cover* *SDG Table 1.4.2-1*

$Num_{bar} := \mathbf{11}$ *number of longitudinal bars*

$A_{long.bar} := \mathbf{1.0} \cdot in^2$ *longitudinal bar area*

$d_{long.bar} := \mathbf{1.125} \cdot in$ *longitudinal bar diameter*

$A_{v.bar} := \mathbf{0.20} \cdot in^2$ *stirrup area* *SM Vol-3 13.6.2*

$d_{v.bar} := \mathbf{0.5} \cdot in$ *stirrup diameter*

$s_{v1} := \mathbf{3} \cdot in$ *stirrup spacing, depth = 0 ft-2 ft* *SM Vol-3 13.6.2*

$s_{v2} := \mathbf{3} \cdot in$ *stirrup spacing, depth = 2 ft-depth.stir*

$s_{v3} := \mathbf{6} \cdot in$ *stirrup spacing, depth > depth.stir*

$depth_{stir} := \mathbf{15.0} \cdot ft$ *stirrup depth, see s.v2 and s.v3 above*

$b = 3\ ft$ *shaft diameter*

$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$ *required 1% steel* *SM Vol-3 13.6.2*

$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$ *LRFD 5.7.4.2*

$A_{req} := \max\left(A_{req1}, A_{req2}\right) = 10.2 \cdot in^2$

$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$ *total area of longitudinal steel*

$CheckLongitudinalReinf := if\left(A_{long} \ge A_{req}, \text{"OK"}, \text{"No Good"}\right)$ $CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if\left(Clearance_{vert.reinf} \ge 6in, \text{"OK"}, \text{"No Good"}\right)$ $CheckReinfClearSpacing = \text{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$$V_u := \sqrt{V_x^2 + V_z^2} = 5.2 \cdot kip$$

$$T_u = 101.3 \cdot kip \cdot ft$$

Effective shear depth

$$D_r := b - 2 \cdot \left(Cover + d_{v.bar} + \frac{d_{long.bar}}{2} \right) = 2.3\,ft \qquad d_e := \frac{b}{2} + \frac{D_r}{\pi} = 2.2\,ft$$

LRFD C5.8.2.9-2

$$d_v := \max(0.9 \cdot d_e, 0.72 \cdot b) = 2.2\,ft$$

Check Shear Strength

$$V_c := 0.0316 \cdot (2.0) \cdot \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{b}{in}\right) \cdot \left(\frac{d_v}{in}\right) \cdot kip = 117.9 \cdot kip$$

LRFD Eqn 5.8.3.3-3 *LRFD 5.8.3.4.1* *ACI 11.3.3*

$$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max(s_{v1}, s_{v2}, s_{v3})} = 51.8 \cdot kip$$

LRFD Eqn 5.8.3.3-4

$$ShearRatio := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -2.2$$

$$ShearRatio := if(ShearRatio \le 0, 0, ShearRatio) = 0$$

Check Torsion Strength

$$A_{cp} := \pi \cdot \left(\frac{b}{2}\right)^2 = 1017.9 \cdot in^2 \qquad p_{cp} := 2 \cdot \pi \cdot \left(\frac{b}{2}\right) = 113.1 \cdot in$$

Area and perimeter of concrete cross-section

$$d_{oh} := b - 2 \cdot \left(Cover + \frac{d_{v.bar}}{2} \right) = 29.5 \cdot in \qquad p_h := \pi \cdot d_{oh} = 92.7 \cdot in$$

Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement

$$A_{oh} := \pi \left(\frac{d_{oh}}{2}\right)^2 = 683.5 \cdot in^2 \qquad A_o := 0.85 \cdot A_{oh} = 581 \cdot in^2$$

$$T_{n1} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = 387.3 \cdot kip \cdot ft$$

LRFD Eqn 5.8.3.6.2-1

$$T_{n2} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = 387.3 \cdot kip \cdot ft$$

LRFD 5.8.3.4.1

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = 193.7 \cdot kip \cdot ft$$

$\phi_v = 0.9$ $\quad T_u = 101.3 \cdot kip \cdot ft$ $\quad L_{reqdTor} = 13\,ft$

$$Tor2_{sand} := T_u - if\left[2ft > Offset, \left[\pi \cdot b \cdot (2 \cdot ft - Offset) \cdot \gamma_{soil} \cdot \left(\frac{2 \cdot ft - Offset}{2}\right) \cdot \left(\omega_{fdot}\right) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 99.7 \cdot kip \cdot ft$$

$$Tor3_{sand} := T_u - if\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot \left(depth_{stir} - Offset\right) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{2}\right) \cdot \left(\omega_{fdot}\right) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -46.4 \cdot kip \cdot ft$$

$$Tor2_{clay} := T_u - if\left[2ft - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (2.0 \cdot ft - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 101.3 \cdot kip \cdot ft$$

$$Tor3_{clay} := T_u - if\left[depth_{stir} - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot \left(depth_{stir} - Offset - 1.5 \cdot ft\right) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 91.2 \cdot kip \cdot ft$$

$$Tor2 := if\left(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}\right) = 99.7 \cdot kip \cdot ft$$

$$Tor3 := if\left(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}\right) = -46.4 \cdot kip \cdot ft$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = 0.26$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = 0.26$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = -0.24$$

$$TorsionRatio := max\left(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}\right) = 0.26$$

$$T_{cr} := 0.125 \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{A_{cp}^{\ 2}}{p_{cp} \cdot in^3}\right) \cdot kip \cdot in = 190.9 \cdot kip \cdot ft$$ *LRFD Eqn 5.8.2.1-4*

$$TorsionRatio := if\left(T_u \le 0.25 \cdot \phi_{tor} \cdot T_{cr}, 0, TorsionRatio\right) = 0.3$$ *LRFD Eqn 5.8.2.1-3*

$ShearRatio = 0$

$CheckShearTorsion := if(ShearRatio + TorsionRatio \le 1, \text{"OK"}, \text{"No Good"})$

$CheckShearTorsion = \text{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = 0.006192 \cdot ksi$$ $\quad 0.125 \cdot f_c = 0.5 \cdot ksi$ *LRFD Eqn 5.8.2.9-1*

$s_{max1} := \text{if}\left(0.8 \cdot d_v < 24 \cdot in, 0.8d_v, 24 \cdot in\right) = 20.7 \cdot in$ LRFD Eqn 5.8.2.7-1

$s_{max2} := \text{if}\left(0.4 \cdot d_v < 12 \cdot in, 0.4d_v, 12 \cdot in\right) = 10.4 \cdot in$ LRFD Eqn 5.8.2.7-2

$s_{max} := \text{if}\left(v_u < 0.125 \cdot f_c, s_{max1}, s_{max2}\right) = 20.7 \cdot in$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = 6 \cdot in$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \leq s_{max}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \text{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion LRFD Eqn 5.8.3.6.3-1

LRFD 5.8.3.4.1

$M_u = 101.9 \cdot kip \cdot ft$

$$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5 \cdot V_s > 0 \cdot kip, \frac{V_u}{\phi_v} - 0.5 \cdot V_s, 0 \cdot kip\right) = 0 \cdot kip$$

$$\text{LongReinf}_{shr.tor} := \frac{\dfrac{M_u}{\phi_v \cdot d_v} + \sqrt{\left(V_{temp}\right)^2 + \left(\dfrac{0.45 \cdot p_h \cdot T_u}{2 \cdot A_o \cdot \phi_v}\right)^2}}{F_{y.rebar}} = 1.7 \cdot in^2$$

$Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(Num_{bar} \cdot A_{long.bar} \geq \text{LongReinf}_{shr.tor}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \text{"OK"}$

Anchor Bolt Strength Check

$\mathrm{Num}_{anchor} := \mathbf{8}$ *number of anchor bolts*

$d_{anchor} := \mathbf{2} \cdot in$ *anchor bolt nominal diameter*

$\mathrm{Dia}_{anchor.circle} := 24 \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := \mathbf{105} \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{\mathrm{Dia}_{anchor.circle}^{\ 2}}{8} \cdot \mathrm{Num}_{anchor} = 576 \cdot in^2$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{\mathrm{Dia}_{anchor.circle}}{2}} = 48 \cdot in$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 25.5 \cdot kip$$

anchor tension force

$$V_{anchor} := \frac{V_u}{\mathrm{Num}_{anchor}} + \frac{T_u}{0.5\mathrm{Dia}_{anchor.circle} \cdot \mathrm{Num}_{anchor}} = 13.3 \cdot kip$$

anchor shear force

$$A_{b.anchor} := \frac{1}{4}\pi \cdot d_{anchor}^{\ 2} = 3.1 \cdot in^2$$

anchor bolt nominal area

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 8.1 \cdot ksi$$

anchor tensile stress

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 4.2 \cdot ksi$$

anchor shear stress

$\phi_{anchor} := 0.75$ *resistance factor* AISC J3-1

$F_{nt} := 0.75 F_{u.anchor} = 78.8 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := 0.45 F_{u.anchor} = 47.2 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot kip$ *design sghear strength*

$\mathrm{CheckAnchorT} := \mathrm{if}\left(\phi R_{nt} \geq T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$\mathrm{CheckAnchorT} = \text{"OK"}$

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check shear rupture*

$\text{CheckAnchorV} = \text{"OK"}$

$$F_{ntv} := \min\left(\left(\begin{matrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{matrix}\right)\right) = 78.8 \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = 185.6 \cdot \text{kip}$

design tension strength modified to include the effects of shearing stress

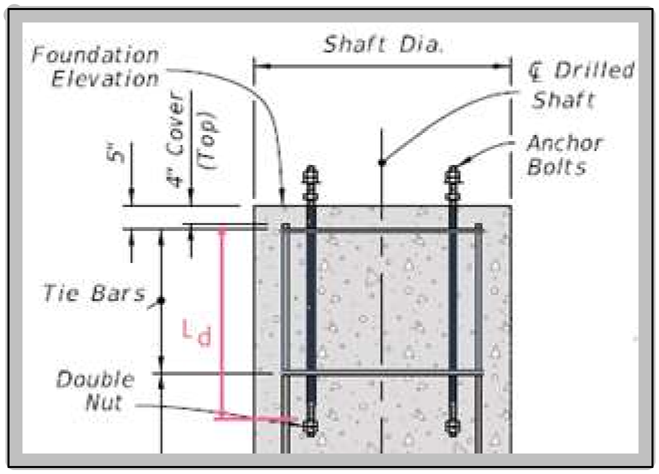
$$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq 20\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq 20\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \text{"OK"}, \text{"No Good"}\right]$$

$\text{CheckAnchorTV} = \text{"OK"}$ *check combined tension and shear rupture*

$$\text{CheckAnchorStrength} := \text{if}\left[(\text{CheckAnchorT} = \text{"OK"}) \cdot (\text{CheckAnchorV} = \text{"OK"}) \cdot (\text{CheckAnchorTV} = \text{"OK"}), \text{"OK"}, \text{"No Good"}\right]$$

$\text{CheckAnchorStrength} = \text{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = 25.5 \cdot \text{kip}$ *tension force in anchor*

$\text{Dia}_{bar.circle} = 27.9 \cdot \text{in}$ $\text{Dia}_{anchor.circle} = 24 \cdot \text{in}$

center-to-center distance

$$\text{Dist}_{bar.to.bolt} := \frac{\text{Dia}_{bar.circle} - \text{Dia}_{anchor.circle}}{2} = 1.9 \cdot \text{in}$$

$$\text{Num}_{bars.per.anchor} := \min\left(\frac{\text{Num}_{bar}}{\text{Num}_{anchor}}, 3\right) = 1.4$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := 0.9$

$$\text{Num}_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{\text{Dia}_{anchor.circle}}{\text{Dia}_{bar.circle}} = 0.41$$

$$\text{AreaRatio} := \min\left(\frac{\text{Num}_{bars.reqd.per.anchor}}{\text{Num}_{bars.per.anchor}}, 1\right) = 0.3$$

2015 AASHTO Development Length of Deformed Bars in Tension ***5.11.2.1***

$\text{Cover} = 3 \cdot \text{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half the center-to-center spacing of the bars or wires being developed*

$$c_b := \min\left(\left(\begin{array}{c} Cover + d_{v.bar} + \dfrac{d_{long.bar}}{2} \\ \dfrac{Spacing_{vert.reinf}}{2} \end{array}\right)\right) = 4 \cdot in$$

$k_{tr} := 0 \cdot in$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\left[\begin{array}{c} 1.0 \\ \max\left(\left(\begin{array}{c} 0.4 \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{array}\right)\right) \end{array}\right]\right] = 0.4$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\left(\begin{array}{c} 12 \cdot in \\ \lambda_{rc} \cdot 2.4 \cdot d_{long.bar} \cdot \dfrac{F_{y.rebar}}{\sqrt{f_c \cdot ksi}} \end{array}\right)\right) = 32.4 \cdot in$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$SpacingFactor := \max\left[\left(\begin{array}{c} 0.5 \\ Num_{bars.per.anchor} \cdot 0.5 - 0.5 \end{array}\right)\right] = 0.5$$

$$L_{embedment.added} := \sqrt{\left(Clearance_{vert.reinf} \cdot SpacingFactor\right)^2 + Dist_{bar.to.bolt}^{\ 2}} = 3.9 \cdot in$$

$$L_{embedment.anchor} := \max\left[\left[\begin{array}{c} L_{d.bar} \cdot (AreaRatio) + 12 \cdot in + L_{embedment.added} \\ 20 \cdot d_{anchor} \end{array}\right]\right] = 40 \cdot in$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := Ceil\left(L_{embedment.anchor}, in\right)$ $L_{embedment.anchor} = 40 \cdot in$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^{\,2} + 3.25 \cdot \left(r^2 - r_b^{\,2}\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\begin{pmatrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{pmatrix}\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2\,\mathrm{asin}\left[\frac{\left(1.5 \cdot c_{a1}\right)}{r}\right] = 45.2 \cdot deg$$

$$OverlapTest := \mathrm{if}\left(A_{bolt.sector} \le \alpha, \text{"Overlap of Failure Cones"}, \text{"No Overlap of Failure Cones"}\right) = \text{"Overlap of Failure Cones"}$$

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{\,2} = 95.9 \cdot in^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \mathrm{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$$

$\psi_{ecV} := \mathbf{1.0}$ *eccentric load modifier* *ACI D.6.2.5*

$\psi_{edV} := \mathbf{1.0}$ *edge effect modifier* *ACI D.6.2.6*

$\psi_{cV} := \mathbf{1.4}$ *cracked section modifier* *ACI D.6.2.7* *(stirrup spacing <= 4")*

$\psi_{hV} := \mathbf{1.0}$ *member thickness modifier* *ACI D.6.2.8*

$\phi_{breakout} := \mathbf{0.75}$ *strength reduction factor* *ACI D.4.4.c.i* *(shear breakout, condition A)*

$$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = 194.7 \cdot kip$$

concrete breakout strength - shear

ACI Eqn D-22 *Shear force ⊥ to edge*

$$V_{cbg\_parallel} := 2 \cdot V_{cbg} = 389.5 \cdot kip$$

ACI D.6.2.1.c *Shear force ∥ to edge*

$$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = 389.5 \cdot kip \cdot ft$$

concrete breakout strength - torsion

$$\phi_{breakout} \cdot T_{n.breakout} = 292.1 \cdot kip \cdot ft$$

$$T_u = 101.3 \cdot kip \cdot ft$$

$$BreakoutTest := if\left(\phi_{breakout} \cdot T_{n.breakout} \geq T_u, \text{"OK"}, \text{"No Good"}\right)$$

$BreakoutTest = \text{"OK"}$

$$OverlapDesign := if\left(A_{bolt.sector} \leq \alpha, \text{"Based on Overlap of Failure Cones"}, \text{"Based on No Overlap of Failure Cones"}\right)$$

$OverlapDesign = \text{"Based on Overlap of Failure Cones"}$

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = 1.9 \cdot in$ *center-to-center distance*

$d_{anchor.nut} := 1.85 \cdot d_{anchor} = 3.7 \cdot in$ *use* $1.85 \cdot d_{anchor}$ *.to account for anchor nut*

$$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{2}\right) = -0.5 \cdot in$$

$$CheckAnchorageClearance := if\left[\left(Clearance_{bar.to.nut} \geq 2 \cdot in\right), \text{"OK"}, \text{"No Good, increase ped. diameter"}\right]$$

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0..48 \qquad r_{ds} := \frac{b}{2}$

$x_{ds_{pt}} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{ds_{pt}} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$x_{stir.od_{pt}} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.od_{pt}} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$x_{stir.id_{pt}} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.id_{pt}} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$x_{bar_{pt}} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max\left(x_{stir.id}\right) - d_{v.bar} \qquad y_{bar_{pt}} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$x_{boltcircle_{pt}} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{boltcircle_{pt}} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$$r_{boltr} := \frac{d_{anchor}}{2} = 1 \cdot in$$

$$x_{bolt_{pt}} := r_{boltr} \cdot \cos\left[(2\cdot\pi)\cdot\frac{pt}{48} + \frac{2\cdot\pi}{48}\right] + \left(\max\left(x_{boltcircle}\right)\right) \qquad y_{bolt_{pt}} := r_{boltr}\cdot \sin\left[\left(2\cdot\pi\cdot\frac{pt}{48}\right) + \frac{2\cdot\pi}{48}\right]$$

$$pt := 0 .. 6 \qquad r_{nut} := \frac{d_{anchor}\cdot 1.85}{2} = 1.9\cdot in$$

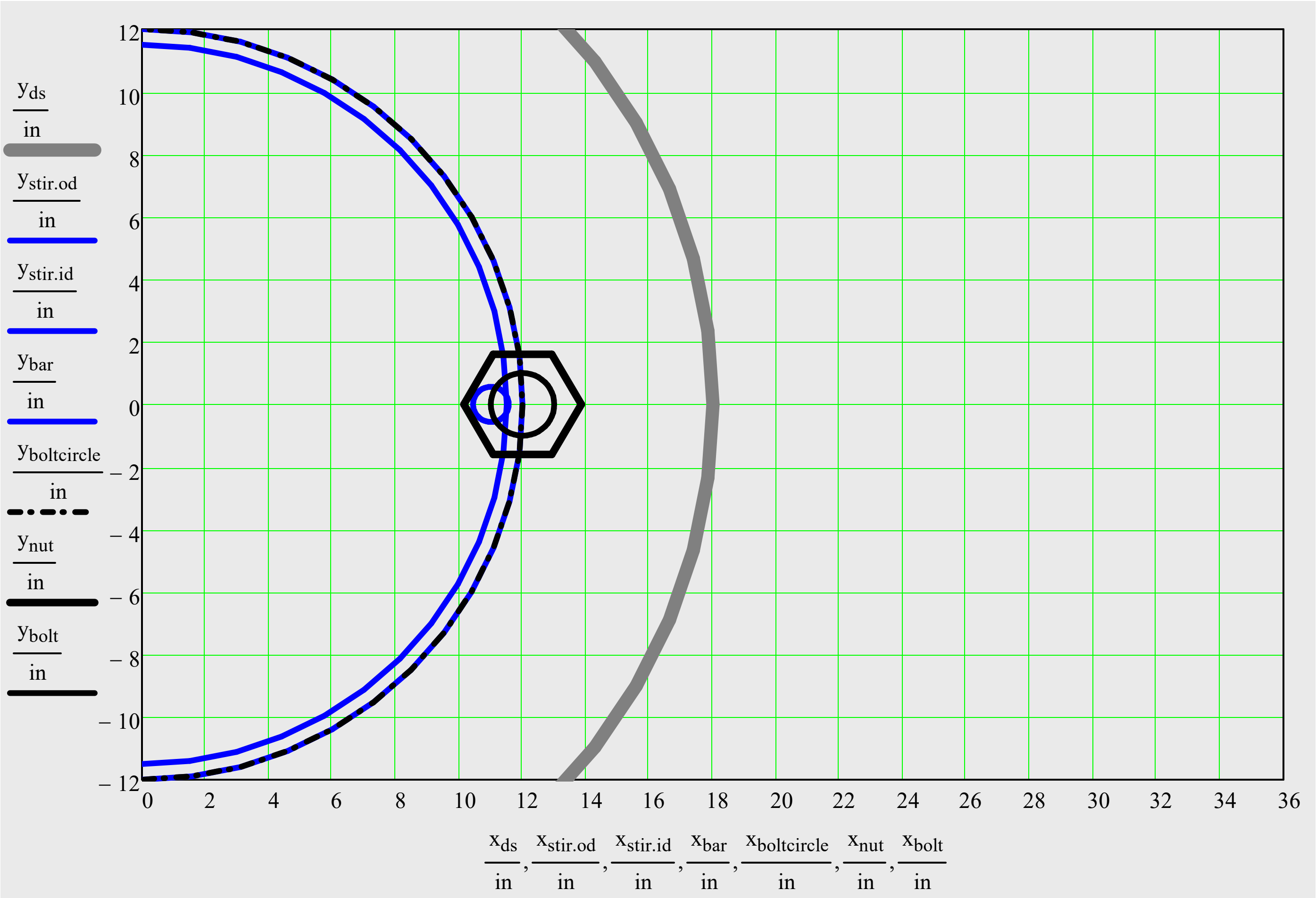
$$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(2\cdot\pi)\cdot\frac{pt}{6} + \frac{2\cdot\pi}{6}\right] + \left(\max\left(x_{boltcircle}\right)\right) \qquad y_{nut_{pt}} := r_{nut}\cdot \sin\left[\left(2\cdot\pi\cdot\frac{pt}{6}\right) + \frac{2\cdot\pi}{6}\right]$$

$$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(2\cdot\pi)\cdot\frac{pt}{6} + \frac{1\cdot\pi}{6}\right] + \left(\max\left(x_{boltcircle}\right)\right)$$

enable to rotate nut

$$y_{nut_{pt}} := r_{nut}\cdot \sin\left[\left(2\cdot\pi\cdot\frac{pt}{6}\right) + \frac{1\cdot\pi}{6}\right]$$

$$\min\left(x_{bar}\right) - \max\left(x_{nut}\right) = -3.4\cdot in$$



$$\text{Bolts} := \begin{pmatrix} 1 & 1.125 & 1.25 & 1.375 & 1.5 & 1.625 & 1.75 & 1.875 & 2 & 2.25 & 2.5 & 2.75 & 3 \\ 1.5 & 1.688 & 1.875 & 2.063 & 2.25 & 2.438 & 2.625 & 2.938 & 3 & 3.375 & 3.75 & 4.125 & 4.25 \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{T}\right)^{\langle 0 \rangle^{T}} \cdot 1.6 - \left(\text{Bolts}^{T}\right)^{\langle 1 \rangle^{T}} = \begin{pmatrix} 0.1 & 0.112 & 0.125 & 0.137 & 0.15 & 0.162 & 0.175 & 0.062 & 0.2 & 0.225 & 0.25 & 0.275 & 0.55 \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{T}\right)^{\langle 0 \rangle^{T}} - \left(\text{Bolts}^{T}\right)^{\langle 1 \rangle^{T}} = \begin{pmatrix} -0.5 & -0.563 & -0.625 & -0.688 & -0.75 & -0.813 & -0.875 & -1.063 & -1 & -1.125 & -1.25 & -1.375 & -1.25 \end{pmatrix} \cdot \text{i}$$

Drilled Shaft Foundation for Sign, Signal, and Lighting Support Structures v1.1

FDOT
State Structures Design Office

SUBJECT 079-241-**C** MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

SoilType :=
- **Sand**
- Clay

$\phi_{soil} := \mathbf{32} \cdot deg$ *soil friction angle (sand)*

$c_{soil} := \mathbf{0.0} \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

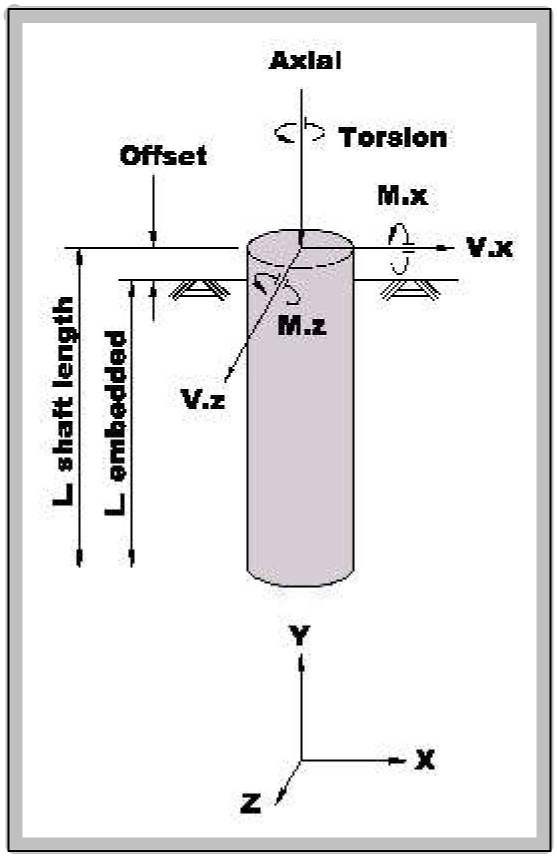
$N_{blows} := 14$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := 71 \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*

Geometry

$b := \mathbf{3.0} \cdot ft$ *shaft diameter*

$Offset := \mathbf{0.50} \cdot ft$ *groundline to top of foundation*



Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := \mathbf{86.50} \cdot kip \cdot ft$ $V_x := \mathbf{0.05} \cdot kip$ $Torsion := \mathbf{85.40} \cdot kip \cdot ft$

$M_z := \mathbf{45.90} \cdot kip \cdot ft$ $V_z := \mathbf{5.50} \cdot kip$ $Axial := \mathbf{20.90} \cdot kip$

StructureType :=
- Cantilever Overhead Sign Structure
- **Mast Arm Signal Structure**
- Concrete/Steel Strain Poles
- Ground Sign

$StructureType = 1$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

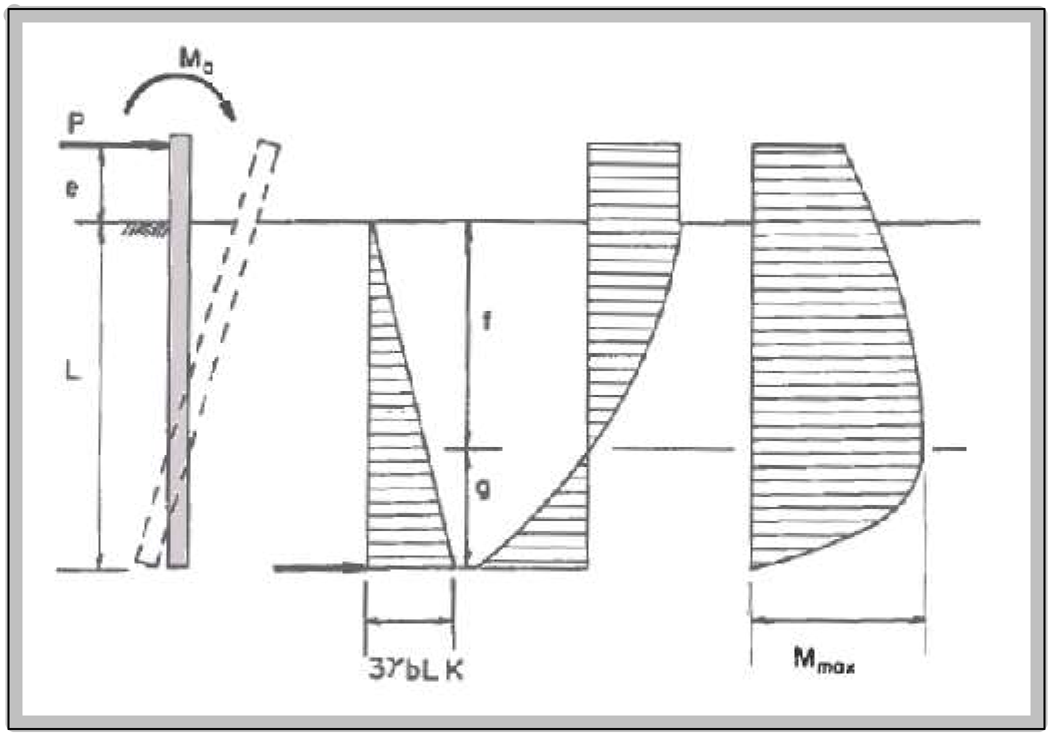
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{{M_x}^2 + {M_z}^2} = 97.9\cdot kip\cdot ft$

$P_u := \sqrt{{V_x}^2 + {V_z}^2} = 5.5\cdot kip$

$T_u :=$ Torsion $= 85.4\cdot kip\cdot ft$

*short free-head pile in **cohesionless soil** using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(45\cdot deg + \frac{\phi_{soil}}{2}\right)^2 = 3.3$ $\qquad e_{sand} :=$ Offset $= 0.5\,ft$

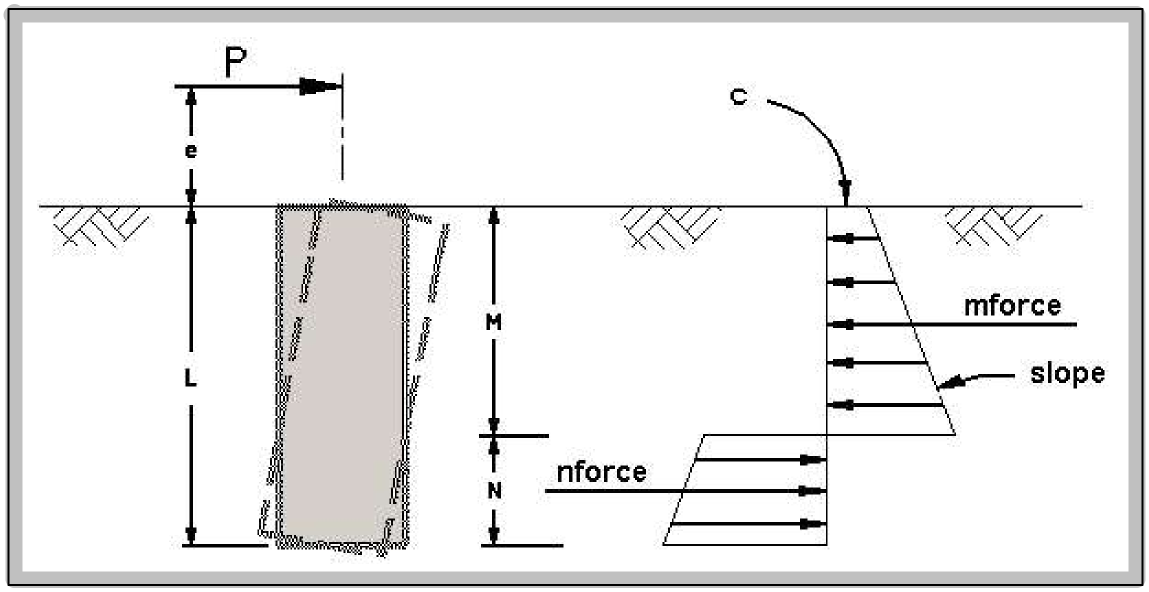
Guess value $\qquad L_{otSand} := 8\cdot ft$

Given $\qquad P_u\cdot\left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot}\cdot\left[\left(3\cdot\gamma_{soil}\cdot b\cdot L_{otSand}\cdot K_p\right)\cdot\left(\frac{1}{2}\cdot L_{otSand}\right)\cdot\left(\frac{1}{3}\cdot L_{otSand}\right)\right]$

$L_{otSand} :=$ Find$\left(L_{otSand}\right) = 12.5\,ft$

$L_{otSand} :=$ ceil$\left(\frac{L_{otSand}}{ft}\right)\cdot ft = 13\,ft$ $\qquad$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}\left(c_{soil} = 0\cdot ksf, 0.1\cdot ksf, c_{soil}\right) = 0.1\cdot ksf$

$\text{Slope} := 8\cdot\frac{c_{soil}}{3\cdot b} = 0.1\cdot\frac{kip}{ft^3}$ $\qquad$ $e_{clay} := \frac{M_u}{P_u} + \text{Offset} = 18.3\,ft$

$\text{nforce}(M,N) := \left[\text{Slope}\cdot(2\cdot M + N) + 2\cdot c_{soil}\right]\cdot N\cdot\frac{b}{2}$ $\qquad$ $\text{mforce}(M) := \left(2\cdot c_{soil} + M\cdot\text{Slope}\right)\cdot M\cdot\frac{b}{2}$

$$\text{m\_arm}(M) := e_{clay} + \frac{M}{3}\cdot\frac{2\cdot\left(M\cdot\text{Slope} + c_{soil}\right) + c_{soil}}{M\cdot\text{Slope} + 2\cdot c_{soil}}$$

$$\text{n\_arm}(M,N) := e_{clay} + M + \frac{N}{3}\cdot\frac{2\cdot\left(N\cdot\text{Slope} + M\cdot\text{Slope} + c_{soil}\right) + \left(M\cdot\text{Slope} + c_{soil}\right)}{\text{Slope}\cdot(2\cdot M + N) + 2\cdot c_{soil}}$$

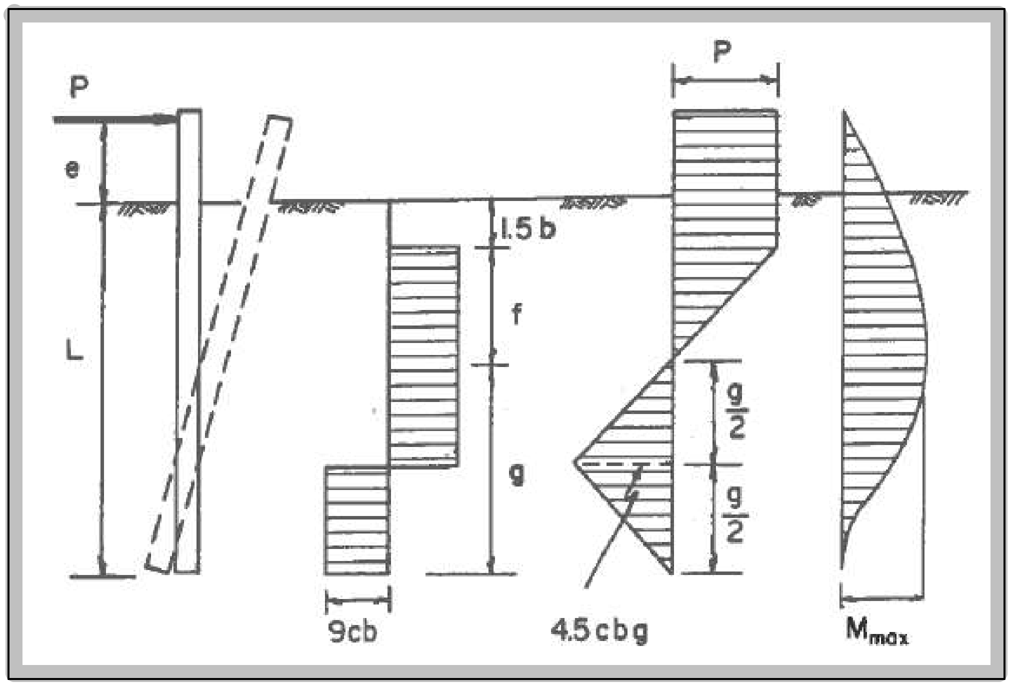
Guess value $\qquad M := 4.0\cdot ft \qquad N := 4.0\cdot ft$

Given $\qquad P_u + \phi_{ot}\cdot\text{nforce}(M,N) = \phi_{ot}\cdot\text{mforce}(M) \qquad \text{mforce}(M)\cdot\text{m\_arm}(M) = \text{nforce}(M,N)\cdot\text{n\_arm}(M,N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M,N) \qquad L_{ot1Clay} := M + N = 9.1\,ft$

$L_{ot1Clay} := \text{ceil}\left(\frac{L_{ot1Clay}}{ft}\right)\cdot ft = 10\,ft$ $\qquad$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot 9 \cdot c_{soil} \cdot b} = 8.1\ ft$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + 1.5 \cdot b + 0.5 \cdot f\right) = 147.8 \cdot kip \cdot ft$$

$$g := \sqrt{\frac{M_{max.clay}}{2.25 \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = 29.6\ ft$$

$$L_{ot2Clay} := (1.5 \cdot b + f + g) = 42.2\ ft$$

$$L_{ot2Clay} := ceil\left(\frac{L_{ot2Clay}}{ft}\right) \cdot ft = 43\ ft$$ *(round up to next foot)*

$$L_{otClay} := if\left(L_{ot1Clay} < 3 \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = 43\ ft$$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$$L_{reqdOT} := if\left(SoilType = \text{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$L_{reqdOT} = 13\ ft$ *required shaft embedment depth to resist overturning*

Shaft Depth Required to Resist Torsion

short free-head pile in ***cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = 14$

$$\omega_{fdot} := \text{if}\left(N_{blows} < 5, 0, \text{if}\left(N_{blows} \geq 15, 1.5, 1.5\cdot\frac{N_{blows}}{15}\right)\right) = 1.4$$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\dfrac{N_{blows}}{15}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = 13\ \text{ft}$

Given $$T_u = \phi_{tor}\cdot\left[\pi\cdot b\cdot\left(L_{torSand}\right)\cdot\gamma_{soil}\cdot\left(\frac{L_{torSand}}{2}\right)\cdot\left(\omega_{fdot}\right)\cdot\frac{b}{2}\right]$$

$L_{torSand} := \text{Find}\left(L_{torSand}\right) = 11\ \text{ft}$

$L_{torSand} := \text{ceil}\left(\dfrac{L_{torSand}}{\text{ft}}\right)\cdot\text{ft} = 12\ \text{ft}$ *(round up to next foot)*

short free-head pile in ***cohesive soil***

$\text{CohesionFactor} := 0.55$

$f_{se} := \text{CohesionFactor}\cdot c_{soil} = 0.1\cdot\text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

Given $$T_u = \phi_{tor}\cdot\left[f_{se}\cdot(\pi\cdot b)\cdot\left(L_{torClay} - 1.5\cdot\text{ft}\right)\cdot\frac{b}{2}\right]$$

$L_{torClay} := \text{Find}\left(L_{torClay}\right) = 111.3\ \text{ft}$

$L_{torClay} := \text{ceil}\left(\dfrac{L_{torClay}}{\text{ft}}\right)\cdot\text{ft} = 112\ \text{ft}$ *(round up to next foot)*

$L_{reqdTor} := \text{if}\left(\text{SoilType} = \text{"Sand"}, L_{torSand}, L_{torClay}\right)$

$L_{reqdTor} = 12\ \text{ft}$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}\left(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}\right) = 13\ \text{ft}$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = 13.5\ \text{ft}$ *shaft length*

Min Shaft embedment depth=16 ft

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2\cdot P_u}{3\cdot\gamma_{soil}\cdot b\cdot K_p\cdot\phi_{ot}}} = 4.6\,ft$$

$$M_{maxSand} := P_u\cdot\left(e_{sand} + f_{sand}\right) - \frac{P_u\cdot f_{sand}}{3} + M_u = 117.5\cdot kip\cdot ft$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0\cdot ft$

Given $P_u = \frac{f_{mod}\cdot b}{2}\cdot\left(2\phi_{ot}\cdot c_{soil} + \phi_{ot}\cdot f_{mod}\cdot Slope\right)$

$f_{mod} := Find\left(f_{mod}\right) = 11.8\,ft$

$$M_{modBroms} := P_u\cdot\left(e_{clay} + f_{mod}\right) - \frac{\phi_{ot}\cdot c_{soil}\cdot b\cdot f_{mod}^{\ 2}}{2} - \frac{\phi_{ot}\cdot b\cdot f_{mod}^{\ 3}\cdot Slope}{6} = 142.1\cdot kip\cdot ft$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u\cdot\left(e_{clay} + 1.5\cdot b + 0.5\cdot f\right) = 147.8\cdot kip\cdot ft$$

$M_{maxClay} := if\left(L_{ot1Clay} < 3\cdot b, M_{modBroms}, M_{Broms}\right) = 147.8\cdot kip\cdot ft$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$M_{max} := if\left(SoilType = \text{"Sand"}, M_{maxSand}, M_{maxClay}\right) = 117.5\cdot kip\cdot ft$

Minimum Reinforcing and Spacing

$F_{y.rebar} := \mathbf{60} \cdot \text{ksi}$ *reinforcing yield strength*

$f_c := \mathbf{4.0} \cdot \text{ksi}$ *concrete strength* *Spec 346-3*

$\text{Cover} := \mathbf{3} \cdot \text{in}$ *cover* *SDG Table 1.4.2-1*

$\text{Num}_{bar} := \mathbf{11}$ *number of longitudinal bars*

$A_{long.bar} := \mathbf{1.0} \cdot \text{in}^2$ *longitudinal bar area*

$d_{long.bar} := \mathbf{1.125} \cdot \text{in}$ *longitudinal bar diameter*

$A_{v.bar} := \mathbf{0.20} \cdot \text{in}^2$ *stirrup area* *SM Vol-3 13.6.2*

$d_{v.bar} := \mathbf{0.5} \cdot \text{in}$ *stirrup diameter*

$s_{v1} := \mathbf{3} \cdot \text{in}$ *stirrup spacing, depth = 0 ft-2 ft* *SM Vol-3 13.6.2*

$s_{v2} := \mathbf{3} \cdot \text{in}$ *stirrup spacing, depth = 2 ft-depth.stir*

$s_{v3} := \mathbf{6} \cdot \text{in}$ *stirrup spacing, depth > depth.stir*

$\text{depth}_{stir} := \mathbf{14.0} \cdot \text{ft}$ *stirrup depth, see s.v2 and s.v3 above*

$b = 3\ \text{ft}$ *shaft diameter*

$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot \text{in}^2$ *required 1% steel* *SM Vol-3 13.6.2*

$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot \text{in}^2$ *LRFD 5.7.4.2*

$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot \text{in}^2$

$A_{long} := \text{Num}_{bar} \cdot A_{long.bar} = 11 \cdot \text{in}^2$ *total area of longitudinal steel*

$\text{CheckLongitudinalReinf} := \text{if}(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"})$ $\text{CheckLongitudinalReinf} = \text{"OK"}$

$\text{Dia}_{bar.circle} := b - 2 \cdot \text{Cover} - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot \text{in}$

$\text{Spacing}_{vert.reinf} := \text{Dia}_{bar.circle} \cdot \frac{\pi}{\text{Num}_{bar}} = 8 \cdot \text{in}$ $\text{Clearance}_{vert.reinf} := \text{Spacing}_{vert.reinf} - d_{long.bar} = 6.84 \cdot \text{in}$

$\text{CheckReinfClearSpacing} := \text{if}(\text{Clearance}_{vert.reinf} \geq 6\text{in}, \text{"OK"}, \text{"No Good"})$ $\text{CheckReinfClearSpacing} = \text{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$$V_u := \sqrt{V_x^2 + V_z^2} = 5.5 \cdot \text{kip}$$

$$T_u = 85.4 \cdot \text{kip} \cdot \text{ft}$$

Effective shear depth

$$D_r := b - 2 \cdot \left(\text{Cover} + d_{v.bar} + \frac{d_{long.bar}}{2} \right) = 2.3\,\text{ft} \qquad d_e := \frac{b}{2} + \frac{D_r}{\pi} = 2.2\,\text{ft}$$

LRFD C5.8.2.9-2

$$d_v := \max\left(0.9 \cdot d_e, 0.72 \cdot b\right) = 2.2\,\text{ft}$$

Check Shear Strength

$$V_c := 0.0316 \cdot (2.0) \cdot \sqrt{\frac{f_c}{\text{ksi}}} \cdot \left(\frac{b}{\text{in}}\right) \cdot \left(\frac{d_v}{\text{in}}\right) \cdot \text{kip} = 117.9 \cdot \text{kip}$$

LRFD Eqn 5.8.3.3-3 *LRFD 5.8.3.4.1* *ACI 11.3.3*

$$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max\left(s_{v1}, s_{v2}, s_{v3}\right)} = 51.8 \cdot \text{kip}$$

LRFD Eqn 5.8.3.3-4

$$\text{ShearRatio} := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -2.2$$

$$\text{ShearRatio} := \text{if}\left(\text{ShearRatio} \le 0, 0, \text{ShearRatio}\right) = 0$$

Check Torsion Strength

$$A_{cp} := \pi \cdot \left(\frac{b}{2}\right)^2 = 1017.9 \cdot \text{in}^2 \qquad p_{cp} := 2 \cdot \pi \cdot \left(\frac{b}{2}\right) = 113.1 \cdot \text{in}$$

Area and perimeter of concrete cross-section

$$d_{oh} := b - 2 \cdot \left(\text{Cover} + \frac{d_{v.bar}}{2} \right) = 29.5 \cdot \text{in} \qquad p_h := \pi \cdot d_{oh} = 92.7 \cdot \text{in}$$

Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement

$$A_{oh} := \pi \left(\frac{d_{oh}}{2}\right)^2 = 683.5 \cdot \text{in}^2 \qquad A_o := 0.85 \cdot A_{oh} = 581 \cdot \text{in}^2$$

$$T_{n1} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = 387.3 \cdot \text{kip} \cdot \text{ft}$$

LRFD Eqn 5.8.3.6.2-1

$$T_{n2} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = 387.3 \cdot \text{kip} \cdot \text{ft}$$

LRFD 5.8.3.4.1

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = 193.7 \cdot kip \cdot ft$$

$\phi_v = 0.9$ $\quad T_u = 85.4 \cdot kip \cdot ft$ $\quad L_{reqdTor} = 12\,ft$

$$Tor2_{sand} := T_u - if\left[2ft > Offset, \left[\pi \cdot b \cdot (2 \cdot ft - Offset) \cdot \gamma_{soil} \cdot \left(\frac{2 \cdot ft - Offset}{2}\right) \cdot \left(\omega_{fdot}\right) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 83.8 \cdot kip \cdot ft$$

$$Tor3_{sand} := T_u - if\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot \left(depth_{stir} - Offset\right) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{2}\right) \cdot \left(\omega_{fdot}\right) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -42.7 \cdot kip \cdot ft$$

$$Tor2_{clay} := T_u - if\left[2ft - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (2.0 \cdot ft - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 85.4 \cdot kip \cdot ft$$

$$Tor3_{clay} := T_u - if\left[depth_{stir} - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot \left(depth_{stir} - Offset - 1.5 \cdot ft\right) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 76.1 \cdot kip \cdot ft$$

$$Tor2 := if\left(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}\right) = 83.8 \cdot kip \cdot ft$$

$$Tor3 := if\left(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}\right) = -42.7 \cdot kip \cdot ft$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = 0.22$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = 0.22$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = -0.22$$

$$TorsionRatio := max\left(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}\right) = 0.22$$

$$T_{cr} := 0.125 \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{A_{cp}^{\ 2}}{p_{cp} \cdot in^3}\right) \cdot kip \cdot in = 190.9 \cdot kip \cdot ft$$ *LRFD Eqn 5.8.2.1-4*

$$TorsionRatio := if\left(T_u \le 0.25 \cdot \phi_{tor} \cdot T_{cr}, 0, TorsionRatio\right) = 0.2$$ *LRFD Eqn 5.8.2.1-3*

$ShearRatio = 0$

$$CheckShearTorsion := if(ShearRatio + TorsionRatio \le 1, \text{"OK"}, \text{"No Good"})$$

$CheckShearTorsion = \text{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = 0.006549 \cdot ksi \qquad 0.125 \cdot f_c = 0.5 \cdot ksi$$ *LRFD Eqn 5.8.2.9-1*

$s_{max1} := \text{if}\left(0.8\cdot d_v < 24\cdot in, 0.8d_v, 24\cdot in\right) = 20.7\cdot in$ *LRFD Eqn 5.8.2.7-1*

$s_{max2} := \text{if}\left(0.4\cdot d_v < 12\cdot in, 0.4d_v, 12\cdot in\right) = 10.4\cdot in$ *LRFD Eqn 5.8.2.7-2*

$s_{max} := \text{if}\left(v_u < 0.125\cdot f_c, s_{max1}, s_{max2}\right) = 20.7\cdot in$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = 6\cdot in$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \text{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion *LRFD Eqn 5.8.3.6.3-1*

LRFD 5.8.3.4.1

$M_u = 97.9\cdot kip\cdot ft$

$$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5\cdot V_s > 0\cdot kip, \frac{V_u}{\phi_v} - 0.5\cdot V_s, 0\cdot kip\right) = 0\cdot kip$$

$$\text{LongReinf}_{shr.tor} := \frac{\frac{M_u}{\phi_v\cdot d_v} + \sqrt{\left(V_{temp}\right)^2 + \left(\frac{0.45\cdot p_h\cdot T_u}{2\cdot A_o\cdot \phi_v}\right)^2}}{F_{y.rebar}} = 1.5\cdot in^2$$

$\text{Num}_{bar}\cdot A_{long.bar} = 11\cdot in^2$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(\text{Num}_{bar}\cdot A_{long.bar} \ge \text{LongReinf}_{shr.tor}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \text{"OK"}$

Anchor Bolt Strength Check

$\text{Num}_{\text{anchor}} := \mathbf{8}$ *number of anchor bolts*

$d_{\text{anchor}} := \mathbf{2} \cdot \text{in}$ *anchor bolt nominal diameter*

$\text{Dia}_{\text{anchor.circle}} := 24 \cdot \text{in}$ *anchor bolt circle diameter*

$F_{\text{u.anchor}} := \mathbf{105} \cdot \text{ksi}$ *anchor bolt specified minimum tensile strength*

$$I_{\text{anchor}} := \frac{\text{Dia}_{\text{anchor.circle}}^{\;2}}{8} \cdot \text{Num}_{\text{anchor}} = 576 \cdot \text{in}^2$$

$$S_{\text{anchor}} := \frac{I_{\text{anchor}}}{\frac{\text{Dia}_{\text{anchor.circle}}}{2}} = 48 \cdot \text{in}$$

$$T_{\text{anchor}} := \frac{M_u}{S_{\text{anchor}}} = 24.5 \cdot \text{kip}$$ *anchor tension force*

$$V_{\text{anchor}} := \frac{V_u}{\text{Num}_{\text{anchor}}} + \frac{T_u}{0.5\text{Dia}_{\text{anchor.circle}} \cdot \text{Num}_{\text{anchor}}} = 11.4 \cdot \text{kip}$$ *anchor shear force*

$$A_{\text{b.anchor}} := \frac{1}{4} \pi \cdot d_{\text{anchor}}^{\;2} = 3.1 \cdot \text{in}^2$$ *anchor bolt nominal area*

$$f_{\text{t.anchor}} := \frac{T_{\text{anchor}}}{A_{\text{b.anchor}}} = 7.8 \cdot \text{ksi}$$ *anchor tensile stress*

$$f_{\text{v.anchor}} := \frac{V_{\text{anchor}}}{A_{\text{b.anchor}}} = 3.6 \cdot \text{ksi}$$ *anchor shear stress*

$\phi_{\text{anchor}} := 0.75$ *resistance factor* AISC J3-1

$F_{nt} := 0.75F_{\text{u.anchor}} = 78.8 \cdot \text{ksi}$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := 0.45F_{\text{u.anchor}} = 47.2 \cdot \text{ksi}$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{\text{anchor}} \cdot F_{nt} \cdot A_{\text{b.anchor}} = 185.6 \cdot \text{kip}$ *design tension strength*

$\phi R_{nv} := \phi_{\text{anchor}} \cdot F_{nv} \cdot A_{\text{b.anchor}} = 111.3 \cdot \text{kip}$ *design sghear strength*

$\text{CheckAnchorT} := \text{if}\left(\phi R_{nt} \geq T_{\text{anchor}}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

CheckAnchorT = "OK"

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check shear rupture*

$\text{CheckAnchorV} = \text{"OK"}$

$$F_{ntv} := \min\left(\left(\begin{array}{c} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{array}\right)\right) = 78.8 \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = 185.6 \cdot \text{kip}$ *design tension strength modified to include the effects of shearing stress*

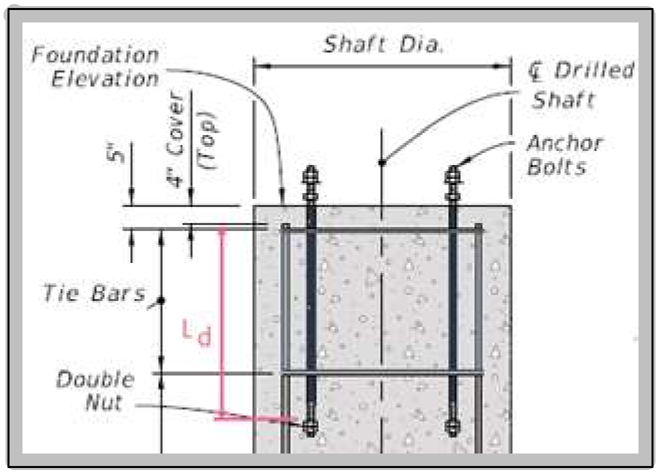
$$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq 20\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq 20\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \text{"OK"}, \text{"No Good"}\right]$$

$\text{CheckAnchorTV} = \text{"OK"}$ *check combined tension and shear rupture*

$$\text{CheckAnchorStrength} := \text{if}\left[(\text{CheckAnchorT} = \text{"OK"}) \cdot (\text{CheckAnchorV} = \text{"OK"}) \cdot (\text{CheckAnchorTV} = \text{"OK"}), \text{"OK"}, \text{"No Good"}\right]$$

$\text{CheckAnchorStrength} = \text{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = 24.5 \cdot \text{kip}$ *tension force in anchor*

$Dia_{bar.circle} = 27.9 \cdot \text{in}$ $Dia_{anchor.circle} = 24 \cdot \text{in}$

center-to-center distance

$$Dist_{bar.to.bolt} := \frac{Dia_{bar.circle} - Dia_{anchor.circle}}{2} = 1.9 \cdot \text{in}$$

$$Num_{bars.per.anchor} := \min\left(\frac{Num_{bar}}{Num_{anchor}}, 3\right) = 1.4$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := 0.9$

$$Num_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{Dia_{anchor.circle}}{Dia_{bar.circle}} = 0.39$$

$$\text{AreaRatio} := \min\left(\frac{Num_{bars.reqd.per.anchor}}{Num_{bars.per.anchor}}, 1\right) = 0.28$$

2015 AASHTO Development Length of Deformed Bars in Tension ***5.11.2.1***

$\text{Cover} = 3 \cdot \text{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half the center-to-center spacing of the bars or wires being developed*

$$c_b := \min\left(\left(\begin{matrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{2} \\ \dfrac{\text{Spacing}_{vert.reinf}}{2} \end{matrix}\right)\right) = 4 \cdot in$$

$k_{tr} := 0 \cdot in$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\left[\begin{matrix} 1.0 \\ \max\left(\left(\begin{matrix} 0.4 \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{matrix}\right)\right) \end{matrix}\right]\right] = 0.4$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\left(\begin{matrix} 12 \cdot in \\ \lambda_{rc} \cdot 2.4 \cdot d_{long.bar} \cdot \dfrac{F_{y.rebar}}{\sqrt{f_c \cdot ksi}} \end{matrix}\right)\right) = 32.4 \cdot in$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$\text{SpacingFactor} := \max\left[\left(\begin{matrix} 0.5 \\ \text{Num}_{bars.per.anchor} \cdot 0.5 - 0.5 \end{matrix}\right)\right] = 0.5$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf} \cdot \text{SpacingFactor}\right)^2 + \text{Dist}_{bar.to.bolt}^{\;2}} = 3.9 \cdot in$$

$$L_{embedment.anchor} := \max\left[\left[\begin{matrix} L_{d.bar} \cdot (\text{AreaRatio}) + 12 \cdot in + L_{embedment.added} \\ 20 \cdot d_{anchor} \end{matrix}\right]\right] = 40 \cdot in$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, in\right)$ $L_{embedment.anchor} = 40 \cdot in$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^2 + 3.25 \cdot \left(r^2 - r_b^2\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\begin{pmatrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{pmatrix}\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2\,\mathrm{asin}\left[\frac{(1.5 \cdot c_{a1})}{r}\right] = 45.2 \cdot deg$$

$$OverlapTest := \mathrm{if}\left(A_{bolt.sector} \le \alpha, \text{"Overlap of Failure Cones"}, \text{"No Overlap of Failure Cones"}\right) = \text{"Overlap of Failure Cones"}$$

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{\;2} = 95.9 \cdot in^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \mathrm{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$$

$\psi_{ecV} := \mathbf{1.0}$ *eccentric load modifier* ACI D.6.2.5

$\psi_{edV} := \mathbf{1.0}$ *edge effect modifier* ACI D.6.2.6

$\psi_{cV} := \mathbf{1.4}$ *cracked section modifier* ACI D.6.2.7 *(stirrup spacing <= 4")*

$\psi_{hV} := \mathbf{1.0}$ *member thickness modifier* ACI D.6.2.8

$\phi_{breakout} := \mathbf{0.75}$ *strength reduction factor* ACI D.4.4.c.i *(shear breakout, condition A)*

$$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}} \right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV} \right) \cdot V_b = 194.7 \cdot kip$$

concrete breakout strength - shear

ACI Eqn D-22 *Shear force ⊥ to edge*

$V_{cbg\_parallel} := 2 \cdot V_{cbg} = 389.5 \cdot kip$ ACI D.6.2.1.c *Shear force ∥ to edge*

$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = 389.5 \cdot kip \cdot ft$ *concrete breakout strength - torsion*

$\phi_{breakout} \cdot T_{n.breakout} = 292.1 \cdot kip \cdot ft$

$T_u = 85.4 \cdot kip \cdot ft$

$BreakoutTest := if\left(\phi_{breakout} \cdot T_{n.breakout} \geq T_u, \text{"OK"}, \text{"No Good"} \right)$

$BreakoutTest = \text{"OK"}$

$OverlapDesign := if\left(A_{bolt.sector} \leq \alpha, \text{"Based on Overlap of Failure Cones"}, \text{"Based on No Overlap of Failure Cones"} \right)$

$OverlapDesign = \text{"Based on Overlap of Failure Cones"}$

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = 1.9 \cdot in$ *center-to-center distance*

$d_{anchor.nut} := 1.85 \cdot d_{anchor} = 3.7 \cdot in$ *use* $1.85 \cdot d_{anchor}$ *.to account for anchor nut*

$$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{2} \right) = -0.5 \cdot in$$

$CheckAnchorageClearance := if\left[\left(Clearance_{bar.to.nut} \geq 2 \cdot in \right), \text{"OK"}, \text{"No Good, increase ped. diameter"} \right]$

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0 .. 48 \qquad r_{ds} := \frac{b}{2}$

$x_{ds_{pt}} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{ds_{pt}} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$x_{stir.od_{pt}} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.od_{pt}} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$x_{stir.id_{pt}} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.id_{pt}} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$x_{bar_{pt}} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max\left(x_{stir.id}\right) - d_{v.bar} \qquad y_{bar_{pt}} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$x_{boltcircle_{pt}} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{boltcircle_{pt}} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltr} := \frac{d_{anchor}}{2} = 1 \cdot in$

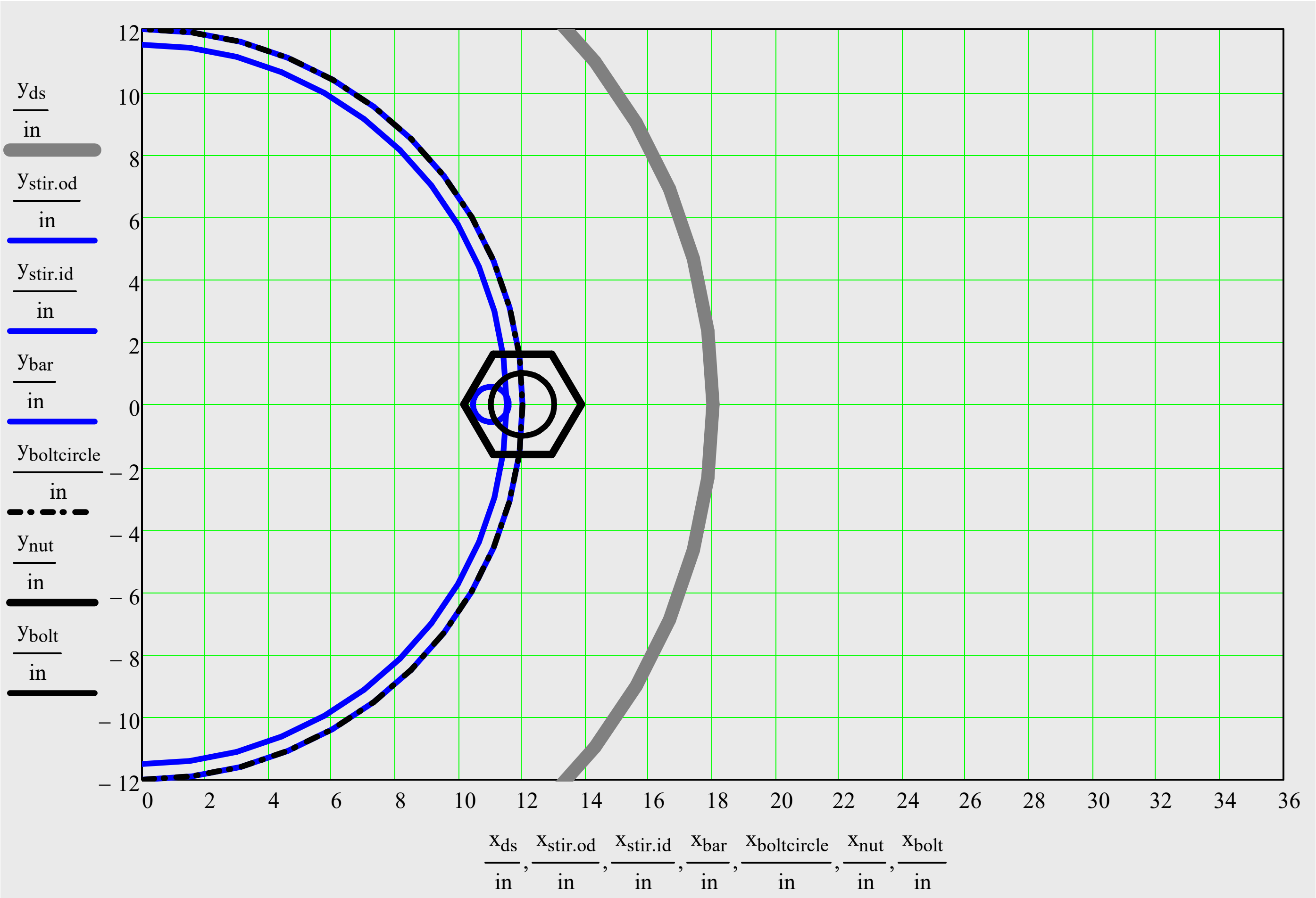
$x_{bolt_{pt}} := r_{boltr} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $y_{bolt_{pt}} := r_{boltr} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$pt := 0 .. 6$ $r_{nut} := \frac{d_{anchor} \cdot 1.85}{2} = 1.9 \cdot in$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{6} + \frac{2 \cdot \pi}{6}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{6}\right) + \frac{2 \cdot \pi}{6}\right]$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{6} + \frac{1 \cdot \pi}{6}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ *enable to rotate nut* $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{6}\right) + \frac{1 \cdot \pi}{6}\right]$

$\min\left(x_{bar}\right) - \max\left(x_{nut}\right) = -3.4 \cdot in$



$$\text{Bolts} := \begin{pmatrix} 1 & 1.125 & 1.25 & 1.375 & 1.5 & 1.625 & 1.75 & 1.875 & 2 & 2.25 & 2.5 & 2.75 & 3 \\ 1.5 & 1.688 & 1.875 & 2.063 & 2.25 & 2.438 & 2.625 & 2.938 & 3 & 3.375 & 3.75 & 4.125 & 4.25 \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{T}\right)^{\langle 0\rangle^{T}} \cdot 1.6 - \left(\text{Bolts}^{T}\right)^{\langle 1\rangle^{T}} = \begin{pmatrix} 0.1 & 0.112 & 0.125 & 0.137 & 0.15 & 0.162 & 0.175 & 0.062 & 0.2 & 0.225 & 0.25 & 0.275 & 0.55 \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{T}\right)^{\langle 0\rangle^{T}} - \left(\text{Bolts}^{T}\right)^{\langle 1\rangle^{T}} = \begin{pmatrix} -0.5 & -0.563 & -0.625 & -0.688 & -0.75 & -0.813 & -0.875 & -1.063 & -1 & -1.125 & -1.25 & -1.375 & -1.25 \end{pmatrix} \cdot \text{i}$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

State Structures Design Office

SUBJECT 079-241-D MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

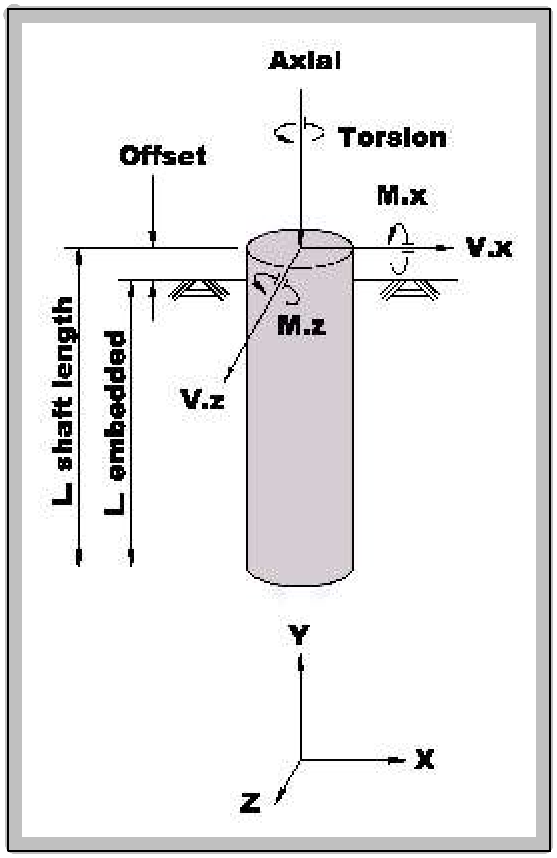
SoilType :=
- **Sand**
- Clay

$\phi_{soil} := \mathbf{32} \cdot deg$ *soil friction angle (sand)*

$c_{soil} := \mathbf{0.0} \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

$N_{blows} := \mathbf{20}$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := \mathbf{74} \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*



Geometry

$b := \mathbf{3.0} \cdot ft$ *shaft diameter*

$Offset := \mathbf{0.50} \cdot ft$ *groundline to top of foundation*

Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := \mathbf{109.0} \cdot kip \cdot ft$ $V_x := \mathbf{0.05} \cdot kip$ $Torsion := \mathbf{64.0} \cdot kip \cdot ft$

$M_z := \mathbf{38.75} \cdot kip \cdot ft$ $V_z := \mathbf{4.40} \cdot kip$ $Axial := \mathbf{19.80} \cdot kip$

StructureType :=
- Cantilever Overhead Sign Structure
- **Mast Arm Signal Structure**
- Concrete/Steel Strain Poles
- Ground Sign

$StructureType = \mathbf{1}$

$\phi_{ot} := if(StructureType = \mathbf{2}, \mathbf{0.8}, \mathbf{0.25})$ $\phi_{ot} = \mathbf{0.3}$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = \mathbf{0}, \mathbf{0.9}, \mathbf{1.0})$ $\phi_{tor} = \mathbf{1}$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

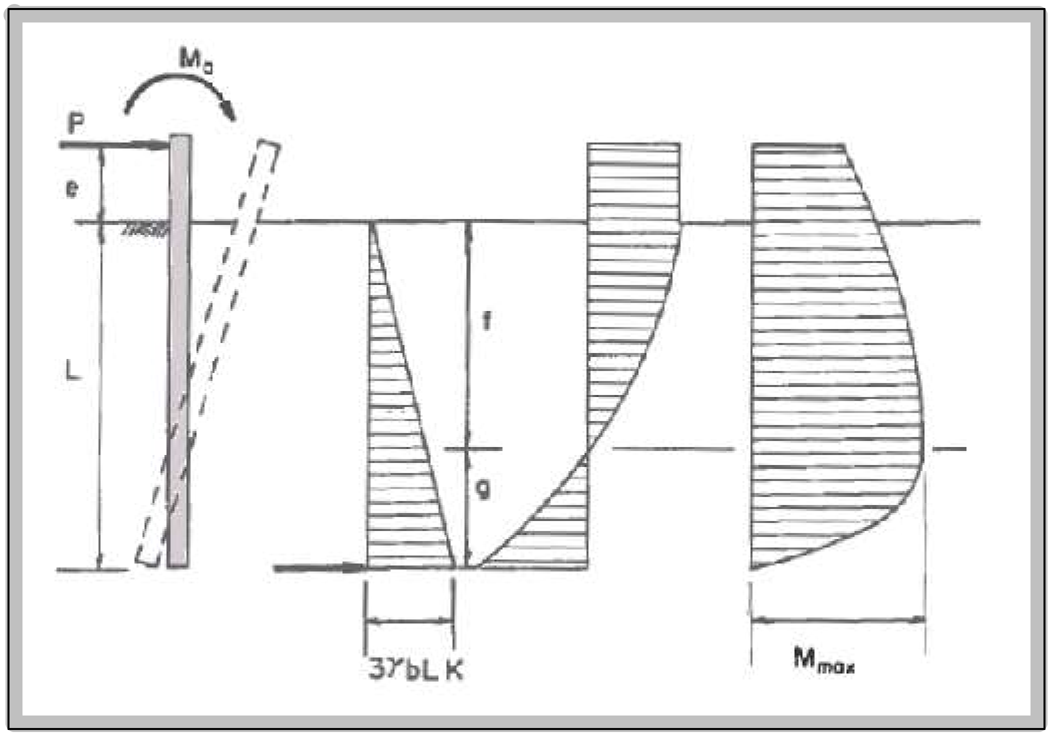
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x^{2} + M_z^{2}} = \mathbf{115.7} \cdot kip \cdot ft$

$P_u := \sqrt{V_x^{2} + V_z^{2}} = \mathbf{4.4} \cdot kip$

$T_u := Torsion = \mathbf{64} \cdot kip \cdot ft$

short free-head pile in ***cohesionless soil*** *using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(\mathbf{45} \cdot deg + \frac{\phi_{soil}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{3.3}$ $\qquad e_{sand} := Offset = \mathbf{0.5}\, ft$

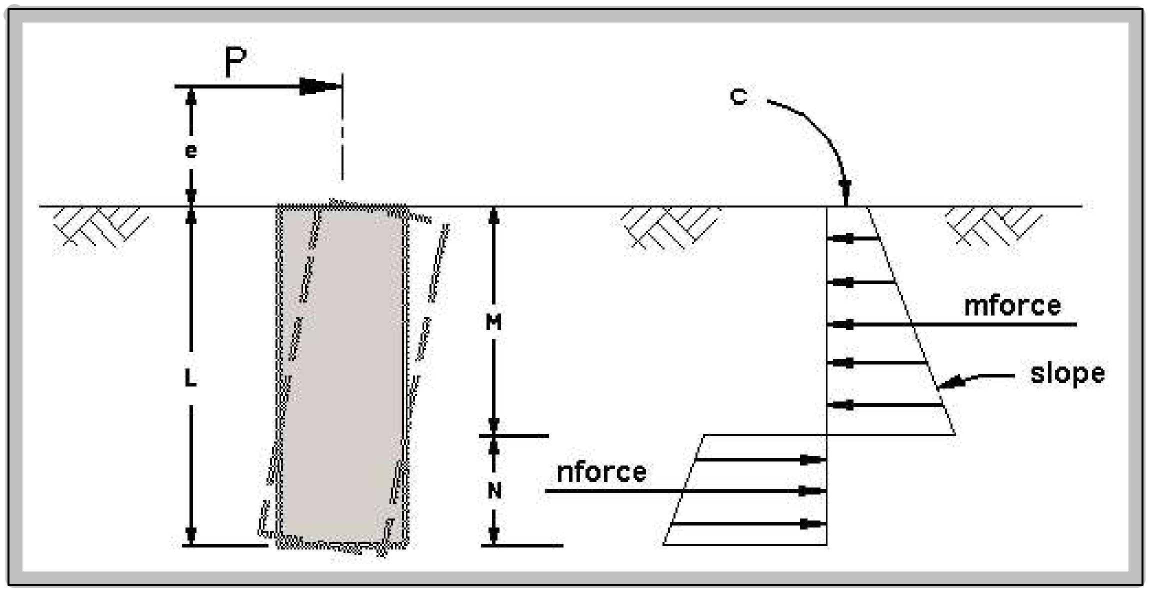
Guess value $\qquad L_{otSand} := \mathbf{8} \cdot ft$

Given $\qquad P_u \cdot (e_{sand} + L_{otSand}) + M_u = \phi_{ot} \cdot \left[\left(\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{2}} \cdot L_{otSand}\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{3}} \cdot L_{otSand}\right) \right]$

$L_{otSand} := Find(L_{otSand}) = \mathbf{12.4}\, ft$

$L_{otSand} := ceil\left(\frac{L_{otSand}}{ft}\right) \cdot ft = \mathbf{13}\, ft$ $\qquad$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$$c_{soil} := \text{if}\left(c_{soil} = \mathbf{0}\cdot \text{ksf}, \mathbf{0.1}\cdot \text{ksf}, c_{soil}\right) = \mathbf{0.1}\cdot \text{ksf}$$

$$\text{Slope} := \mathbf{8}\cdot\frac{c_{soil}}{\mathbf{3}\cdot b} = \mathbf{0.1}\cdot\frac{\text{kip}}{\text{ft}^{\mathbf{3}}} \qquad e_{clay} := \frac{M_u}{P_u} + \text{Offset} = \mathbf{26.8}\ \text{ft}$$

$$\text{nforce}(M,N) := \left[\text{Slope}\cdot(\mathbf{2}\cdot M + N) + \mathbf{2}\cdot c_{soil}\right]\cdot N\cdot\frac{b}{\mathbf{2}} \qquad \text{mforce}(M) := \left(\mathbf{2}\cdot c_{soil} + M\cdot \text{Slope}\right)\cdot M\cdot\frac{b}{\mathbf{2}}$$

$$\text{m\_arm}(M) := e_{clay} + \frac{M}{\mathbf{3}}\cdot\frac{\mathbf{2}\cdot\left(M\cdot \text{Slope} + c_{soil}\right) + c_{soil}}{M\cdot \text{Slope} + \mathbf{2}\cdot c_{soil}}$$

$$\text{n\_arm}(M,N) := e_{clay} + M + \frac{N}{\mathbf{3}}\cdot\frac{\mathbf{2}\cdot\left(N\cdot \text{Slope} + M\cdot \text{Slope} + c_{soil}\right) + \left(M\cdot \text{Slope} + c_{soil}\right)}{\text{Slope}\cdot(\mathbf{2}\cdot M + N) + \mathbf{2}\cdot c_{soil}}$$

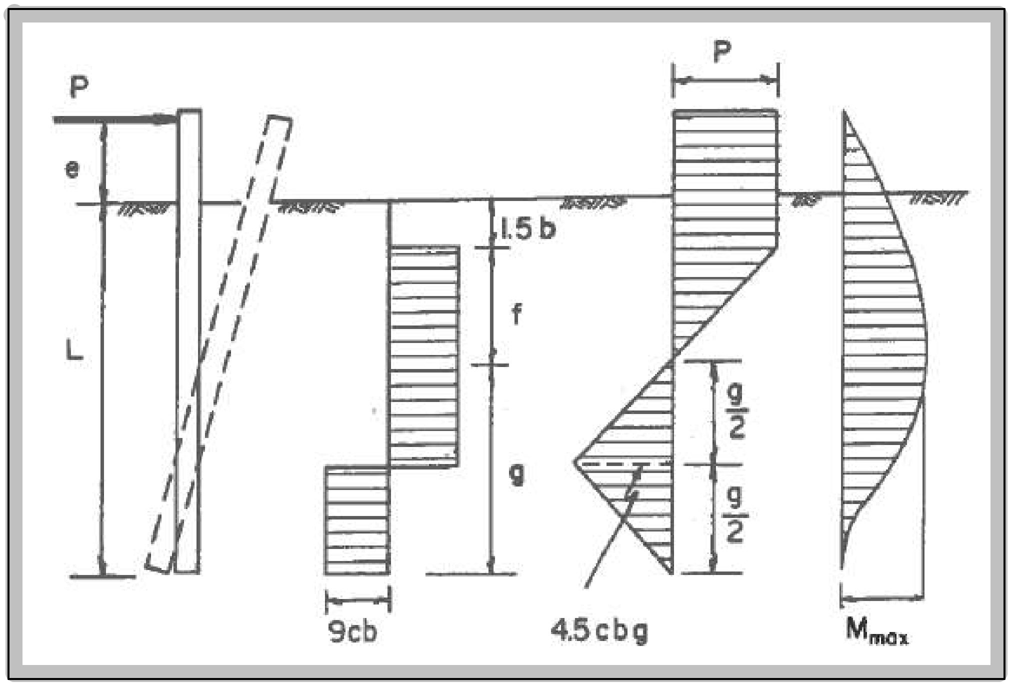
Guess value $M := \mathbf{4.0}\cdot \text{ft}$ $\quad N := \mathbf{4.0}\cdot \text{ft}$

Given $P_u + \phi_{ot}\cdot \text{nforce}(M,N) = \phi_{ot}\cdot \text{mforce}(M)$ $\quad \text{mforce}(M)\cdot \text{m\_arm}(M) = \text{nforce}(M,N)\cdot \text{n\_arm}(M,N)$

$$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M,N) \qquad L_{ot1Clay} := M + N = \mathbf{11.0}\ \text{ft}$$

$$L_{ot1Clay} := \text{ceil}\left(\frac{L_{ot1Clay}}{\text{ft}}\right)\cdot \text{ft} = \mathbf{11}\ \text{ft}$$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot \mathbf{9} \cdot c_{soil} \cdot b} = \mathbf{6.5}\,\text{ft}$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + \mathbf{1.5} \cdot b + \mathbf{0.5} \cdot f\right) = \mathbf{152} \cdot \text{kip} \cdot \text{ft}$$

$$g := \sqrt{\frac{M_{max.clay}}{\mathbf{2.25} \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = \mathbf{30}\,\text{ft}$$

$$L_{ot2Clay} := (\mathbf{1.5} \cdot b + f + g) = \mathbf{41}\,\text{ft}$$

$$L_{ot2Clay} := \text{ceil}\left(\frac{L_{ot2Clay}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{42}\,\text{ft}$$ *(round up to next foot)*

$$L_{otClay} := \text{if}\left(L_{ot1Clay} < \mathbf{3} \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = \mathbf{42}\,\text{ft}$$ *(If* $L_{ot} < 3b$*, use Modified Broms method)*

$$L_{reqdOT} := \text{if}\left(\text{SoilType} = \textbf{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$$L_{reqdOT} = \mathbf{13}\,\text{ft}$$ *required shaft embedment depth to resist overturning*

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = 20$

$$\omega_{fdot} := \text{if}\left(N_{blows} < 5, 0, \text{if}\left(N_{blows} \geq 15, 1.5, 1.5 \cdot \frac{N_{blows}}{15}\right)\right) = 1.5$$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\frac{N_{blows}}{15}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = 13\ \text{ft}$

$$\text{Given} \quad T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot (L_{torSand}) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right]$$

$$L_{torSand} := \text{Find}(L_{torSand}) = 9\ \text{ft}$$

$$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{\text{ft}}\right) \cdot \text{ft} = 10\ \text{ft}$$

(round up to next foot)

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := 0.55$

$f_{se} := \text{CohesionFactor} \cdot c_{soil} = 0.1 \cdot \text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

$$\text{Given} \quad T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot (L_{torClay} - 1.5 \cdot \text{ft}) \cdot \frac{b}{2}\right]$$

$$L_{torClay} := \text{Find}(L_{torClay}) = 83.8\ \text{ft}$$

$$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{\text{ft}}\right) \cdot \text{ft} = 84\ \text{ft}$$

(round up to next foot)

$$L_{reqdTor} := \text{if}(\text{SoilType} = \text{"Sand"}, L_{torSand}, L_{torClay})$$

$L_{reqdTor} = 10\ \text{ft}$

required shaft embedment depth to resist torsion

$$L_{embedded} := \text{if}(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}) = 13\ \text{ft}$$

$$L_{shaft.length} := L_{embedded} + \text{Offset}$$

$L_{shaft.length} = 13.5\ \text{ft}$

shaft length

Min Shaft embedment depth=14 ft

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2 \cdot P_u}{3 \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = 4\ \text{ft}$$

$$M_{maxSand} := P_u \cdot \left(e_{sand} + f_{sand}\right) - \frac{P_u \cdot f_{sand}}{3} + M_u = 129.7 \cdot \text{kip} \cdot \text{ft}$$

short free-head pile in ***cohesive soil*** *using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0 \cdot \text{ft}$

Given $P_u = \frac{f_{mod} \cdot b}{2} \cdot \left(2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot Slope\right)$

$$f_{mod} := \text{Find}\left(f_{mod}\right) = 10.4\ \text{ft}$$

$$M_{modBroms} := P_u \cdot \left(e_{clay} + f_{mod}\right) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^{2}}{2} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^{3} \cdot Slope}{6} = 147.1 \cdot \text{kip} \cdot \text{ft}$$

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot \left(e_{clay} + 1.5 \cdot b + 0.5 \cdot f\right) = 152 \cdot \text{kip} \cdot \text{ft}$$

$M_{maxClay} := \text{if}\left(L_{ot1Clay} < 3 \cdot b, M_{modBroms}, M_{Broms}\right) = 152 \cdot \text{kip} \cdot \text{ft}$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$$M_{max} := \text{if}\left(SoilType = \text{"Sand"}, M_{maxSand}, M_{maxClay}\right) = 129.7 \cdot \text{kip} \cdot \text{ft}$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$	*reinforcing yield strength*	
$f_c := 4.0 \cdot ksi$	*concrete strength* *Spec 346-3*	
$Cover := 3 \cdot in$	*cover* *SDG Table 1.4.2-1*	
$Num_{bar} := 11$	*number of longitudinal bars*	
$A_{long.bar} := 1.0 \cdot in^2$	*longitudinal bar area*	
$d_{long.bar} := 1.125 \cdot in$	*longitudinal bar diameter*	
$A_{v.bar} := 0.20 \cdot in^2$	*stirrup area*	*SM Vol-3 13.6.2*
$d_{v.bar} := 0.5 \cdot in$	*stirrup diameter*	
$s_{v1} := 3 \cdot in$	*stirrup spacing, depth = 0 ft-2 ft*	*SM Vol-3 13.6.2*
$s_{v2} := 3 \cdot in$	*stirrup spacing, depth = 2 ft-depth.stir*	
$s_{v3} := 6 \cdot in$	*stirrup spacing, depth > depth.stir*	
$depth_{stir} := 10.0 \cdot ft$	*stirrup depth, see s.v2 and s.v3 above*	
$b = 3\ ft$	*shaft diameter*	
$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$	*required 1% steel*	*SM Vol-3 13.6.2*
$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$		*LRFD 5.7.4.2*

$$A_{req} := \max\left(A_{req1}, A_{req2}\right) = 10.2 \cdot in^2$$

$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$ *total area of longitudinal steel*

$CheckLongitudinalReinf := if\left(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"}\right)$ $CheckLongitudinalReinf = \text{"OK"}$

$$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if\left(Clearance_{vert.reinf} \geq 6in, \text{"OK"}, \text{"No Good"}\right)$ $CheckReinfClearSpacing = \text{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$V_u := \sqrt{V_x^{2} + V_z^{2}} = \mathbf{4.4} \cdot \text{kip}$

$T_u = \mathbf{64} \cdot \text{kip} \cdot \text{ft}$

Effective shear depth

$D_r := b - \mathbf{2} \cdot \left(\text{Cover} + d_{v.bar} + \frac{d_{long.bar}}{\mathbf{2}} \right) = \mathbf{2.3}\,\text{ft}$ $\quad d_e := \frac{b}{\mathbf{2}} + \frac{D_r}{\pi} = \mathbf{2.2}\,\text{ft}$

LRFD C5.8.2.9-2

$d_v := \max\left(\mathbf{0.9} \cdot d_e, \mathbf{0.72} \cdot b\right) = \mathbf{2.2}\,\text{ft}$

Check Shear Strength

$V_c := \mathbf{0.0316} \cdot (\mathbf{2.0}) \cdot \sqrt{\frac{f_c}{\text{ksi}}} \cdot \left(\frac{b}{\text{in}}\right) \cdot \left(\frac{d_v}{\text{in}}\right) \cdot \text{kip} = \mathbf{117.9} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-3* *LRFD 5.8.3.4.1* *ACI 11.3.3*

$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max\left(s_{v1}, s_{v2}, s_{v3}\right)} = \mathbf{51.8} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-4*

$\text{ShearRatio} := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = \mathbf{-2.2}$

$\text{ShearRatio} := \text{if}\left(\text{ShearRatio} \le \mathbf{0}, \mathbf{0}, \text{ShearRatio}\right) = \mathbf{0}$

Check Torsion Strength

$A_{cp} := \pi \cdot \left(\frac{b}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1017.9} \cdot \text{in}^{\mathbf{2}}$ $\quad p_{cp} := \mathbf{2} \cdot \pi \cdot \left(\frac{b}{\mathbf{2}}\right) = \mathbf{113.1} \cdot \text{in}$ *Area and perimeter of concrete cross-section*

$d_{oh} := b - \mathbf{2} \cdot \left(\text{Cover} + \frac{d_{v.bar}}{\mathbf{2}}\right) = \mathbf{29.5} \cdot \text{in}$ $\quad p_h := \pi \cdot d_{oh} = \mathbf{92.7} \cdot \text{in}$ *Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement*

$A_{oh} := \pi \left(\frac{d_{oh}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{683.5} \cdot \text{in}^{\mathbf{2}}$ $\quad A_o := \mathbf{0.85} \cdot A_{oh} = \mathbf{581} \cdot \text{in}^{\mathbf{2}}$

$T_{n1} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD Eqn 5.8.3.6.2-1*

$T_{n2} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD 5.8.3.4.1*

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = \mathbf{193.7} \cdot kip \cdot ft$$

$\phi_v = \mathbf{0.9}$ $T_u = \mathbf{64} \cdot kip \cdot ft$ $L_{reqdTor} = \mathbf{10}\,ft$

$$Tor2_{sand} := T_u - if\left[2ft > Offset, \left[\pi \cdot b \cdot (2 \cdot ft - Offset) \cdot \gamma_{soil} \cdot \left(\frac{2 \cdot ft - Offset}{2}\right) \cdot \left(\omega_{fdot}\right) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = \mathbf{62.2} \cdot kip \cdot ft$$

$$Tor3_{sand} := T_u - if\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot \left(depth_{stir} - Offset\right) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{2}\right) \cdot \left(\omega_{fdot}\right) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = \mathbf{-6.8} \cdot kip \cdot ft$$

$$Tor2_{clay} := T_u - if\left[2ft - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (2.0 \cdot ft - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = \mathbf{64} \cdot kip \cdot ft$$

$$Tor3_{clay} := T_u - if\left[depth_{stir} - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot \left(depth_{stir} - Offset - 1.5 \cdot ft\right) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = \mathbf{57.8} \cdot kip \cdot ft$$

$$Tor2 := if\left(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}\right) = \mathbf{62.2} \cdot kip \cdot ft$$

$$Tor3 := if\left(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}\right) = \mathbf{-6.8} \cdot kip \cdot ft$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = \mathbf{0.17}$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = \mathbf{0.16}$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = \mathbf{-0.04}$$

$$TorsionRatio := max\left(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}\right) = \mathbf{0.17}$$

$$T_{cr} := 0.125 \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{A_{cp}^{\ 2}}{p_{cp} \cdot in^3}\right) \cdot kip \cdot in = \mathbf{190.9} \cdot kip \cdot ft$$

LRFD Eqn 5.8.2.1-4

$$TorsionRatio := if\left(T_u \le 0.25 \cdot \phi_{tor} \cdot T_{cr}, 0, TorsionRatio\right) = \mathbf{0.2}$$

LRFD Eqn 5.8.2.1-3

$ShearRatio = \mathbf{0}$

$$CheckShearTorsion := if\left(ShearRatio + TorsionRatio \le 1, \text{"OK"}, \text{"No Good"}\right)$$

$CheckShearTorsion = \text{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = \mathbf{0.00524} \cdot ksi$ $0.125 \cdot f_c = \mathbf{0.5} \cdot ksi$

LRFD Eqn 5.8.2.9-1

$s_{max1} := \text{if}\left(\mathbf{0.8}\cdot d_v < \mathbf{24}\cdot \text{in}, \mathbf{0.8}d_v, \mathbf{24}\cdot \text{in}\right) = \mathbf{20.7}\cdot \text{in}$ *LRFD Eqn 5.8.2.7-1*

$s_{max2} := \text{if}\left(\mathbf{0.4}\cdot d_v < \mathbf{12}\cdot \text{in}, \mathbf{0.4}d_v, \mathbf{12}\cdot \text{in}\right) = \mathbf{10.4}\cdot \text{in}$ *LRFD Eqn 5.8.2.7-2*

$s_{max} := \text{if}\left(v_u < \mathbf{0.125}\cdot f_c, s_{max1}, s_{max2}\right) = \mathbf{20.7}\cdot \text{in}$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = \mathbf{6}\cdot \text{in}$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \textbf{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion *LRFD Eqn 5.8.3.6.3-1*

LRFD 5.8.3.4.1

$M_u = \mathbf{115.7}\cdot \text{kip}\cdot \text{ft}$

$$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5\cdot V_s > \mathbf{0}\cdot \text{kip}, \frac{V_u}{\phi_v} - 0.5\cdot V_s, \mathbf{0}\cdot \text{kip}\right) = \mathbf{0}\cdot \text{kip}$$

$$\text{LongReinf}_{shr.tor} := \frac{\dfrac{M_u}{\phi_v\cdot d_v} + \sqrt{\left(V_{temp}\right)^{\mathbf{2}} + \left(\dfrac{\mathbf{0.45}\cdot p_h\cdot T_u}{\mathbf{2}\cdot A_o\cdot \phi_v}\right)^{\mathbf{2}}}}{F_{y.rebar}} = \mathbf{1.5}\cdot \text{in}^{\mathbf{2}}$$

$\text{Num}_{bar}\cdot A_{long.bar} = \mathbf{11}\cdot \text{in}^{\mathbf{2}}$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(\text{Num}_{bar}\cdot A_{long.bar} \ge \text{LongReinf}_{shr.tor}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \textbf{"OK"}$

Anchor Bolt Strength Check

$\mathrm{Num}_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot \mathrm{in}$ *anchor bolt nominal diameter*

$\mathrm{Dia}_{anchor.circle} := 24 \cdot \mathrm{in}$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot \mathrm{ksi}$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{\mathrm{Dia}_{anchor.circle}^{2}}{8} \cdot \mathrm{Num}_{anchor} = 576 \cdot \mathrm{in}^{2}$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{\mathrm{Dia}_{anchor.circle}}{2}} = 48 \cdot \mathrm{in}$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 28.9 \cdot \mathrm{kip}$$ *anchor tension force*

$$V_{anchor} := \frac{V_u}{\mathrm{Num}_{anchor}} + \frac{T_u}{0.5\mathrm{Dia}_{anchor.circle} \cdot \mathrm{Num}_{anchor}} = 8.6 \cdot \mathrm{kip}$$ *anchor shear force*

$$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}^{2} = 3.1 \cdot \mathrm{in}^{2}$$ *anchor bolt nominal area*

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 9.2 \cdot \mathrm{ksi}$$ *anchor tensile stress*

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 2.7 \cdot \mathrm{ksi}$$ *anchor shear stress*

$\phi_{anchor} := 0.75$ *resistance factor* AISC J3-1

$F_{nt} := 0.75 F_{u.anchor} = 78.8 \cdot \mathrm{ksi}$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := 0.45 F_{u.anchor} = 47.2 \cdot \mathrm{ksi}$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot \mathrm{kip}$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot \mathrm{kip}$ *design sghear strength*

$\mathrm{CheckAnchorT} := \mathrm{if}\left(\phi R_{nt} \ge T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$\mathrm{CheckAnchorT} = \text{"OK"}$

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \textbf{"OK"}, \textbf{"No Good"}\right)$ *check shear rupture*

$\text{CheckAnchorV} = \textbf{"OK"}$

$$F_{ntv} := \textbf{min}\left(\left(\begin{matrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{matrix}\right)\right) = \mathbf{78.8} \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = \mathbf{185.6} \cdot \text{kip}$

design tension strength modified to include the effects of shearing stress

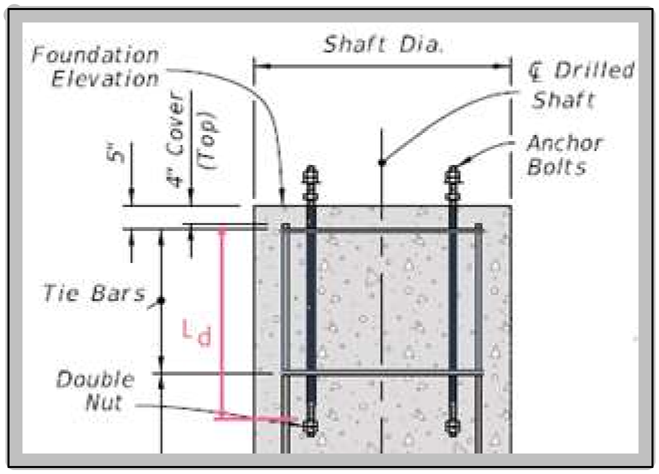
$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq \mathbf{20}\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq \mathbf{20}\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \textbf{"OK"}, \textbf{"No Good"}\right]$

$\text{CheckAnchorTV} = \textbf{"OK"}$ *check combined tension and shear rupture*

$\text{CheckAnchorStrength} := \text{if}[(\text{CheckAnchorT} = \textbf{"OK"}) \cdot (\text{CheckAnchorV} = \textbf{"OK"}) \cdot (\text{CheckAnchorTV} = \textbf{"OK"}), \textbf{"OK"}, \textbf{"No Good"}$

$\text{CheckAnchorStrength} = \textbf{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = \mathbf{28.9} \cdot \text{kip}$ *tension force in anchor*

$\text{Dia}_{bar.circle} = \mathbf{27.9} \cdot \text{in}$ $\text{Dia}_{anchor.circle} = \mathbf{24} \cdot \text{in}$

center-to-center distance

$$\text{Dist}_{bar.to.bolt} := \frac{\text{Dia}_{bar.circle} - \text{Dia}_{anchor.circle}}{\mathbf{2}} = \mathbf{1.9} \cdot \text{in}$$

$$\text{Num}_{bars.per.anchor} := \text{min}\left(\frac{\text{Num}_{bar}}{\text{Num}_{anchor}}, \mathbf{3}\right) = \mathbf{1.4}$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := \mathbf{0.9}$

$$\text{Num}_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{\text{Dia}_{anchor.circle}}{\text{Dia}_{bar.circle}} = \mathbf{0.46}$$

$$\text{AreaRatio} := \text{min}\left(\frac{\text{Num}_{bars.reqd.per.anchor}}{\text{Num}_{bars.per.anchor}}, \mathbf{1}\right) = \mathbf{0.34}$$

2015 AASHTO Development Length of Deformed Bars in Tension 5.11.2.1

$\text{Cover} = \mathbf{3} \cdot \text{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half the center-to-center spacing of the bars or wires being developed*

$$c_b := \min\left(\left(\begin{matrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{\mathbf{2}} \\ \dfrac{\text{Spacing}_{vert.reinf}}{\mathbf{2}} \end{matrix}\right)\right) = \mathbf{4}\cdot \text{in}$$

$k_{tr} := \mathbf{0}\cdot \text{in}$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\left[\begin{matrix} \mathbf{1.0} \\ \max\left(\left(\begin{matrix} \mathbf{0.4} \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{matrix}\right)\right) \end{matrix}\right]\right] = \mathbf{0.4}$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\left(\begin{matrix} \mathbf{12}\cdot \text{in} \\ \lambda_{rc}\cdot \mathbf{2.4}\cdot d_{long.bar}\cdot \dfrac{F_{y.rebar}}{\sqrt{f_c\cdot \text{ksi}}} \end{matrix}\right)\right) = \mathbf{32.4}\cdot \text{in}$$

tension development length *LRFD Eqn 5.11.2.1.1-2*

$$\text{SpacingFactor} := \max\left[\left(\begin{matrix} \mathbf{0.5} \\ \text{Num}_{bars.per.anchor}\cdot \mathbf{0.5} - \mathbf{0.5} \end{matrix}\right)\right] = \mathbf{0.5}$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf}\cdot \text{SpacingFactor}\right)^{\mathbf{2}} + \text{Dist}_{bar.to.bolt}^{\ \mathbf{2}}} = \mathbf{3.9}\cdot \text{in}$$

$$L_{embedment.anchor} := \max\left[\left[\begin{matrix} L_{d.bar}\cdot (\text{AreaRatio}) + \mathbf{12}\cdot \text{in} + L_{embedment.added} \\ \mathbf{20}\cdot d_{anchor} \end{matrix}\right]\right] = \mathbf{40}\cdot \text{in}$$

Note: $20 d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, \text{in}\right)$

$L_{embedment.anchor} = \mathbf{40}\cdot \text{in}$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^2 + 3.25 \cdot \left(r^2 - r_b^2\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\begin{pmatrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{pmatrix}\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2 \operatorname{asin}\left[\frac{(1.5 \cdot c_{a1})}{r}\right] = 45.2 \cdot deg$$

$$OverlapTest := if\left(A_{bolt.sector} \le \alpha, \text{"Overlap of Failure Cones"}, \text{"No Overlap of Failure Cones"}\right) = \text{"Overlap of Failure Cones"}$$

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^2 = 95.9 \cdot in^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := if\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$$

$\psi_{ecV} := \mathbf{1.0}$ *eccentric load modifier* *ACI D.6.2.5*

$\psi_{edV} := \mathbf{1.0}$ *edge effect modifier* *ACI D.6.2.6*

$\psi_{cV} := \mathbf{1.4}$ *cracked section modifier* *ACI D.6.2.7* *(stirrup spacing <= 4")*

$\psi_{hV} := \mathbf{1.0}$ *member thickness modifier* *ACI D.6.2.8*

$\phi_{breakout} := \mathbf{0.75}$ *strength reduction factor* *ACI D.4.4.c.i* *(shear breakout, condition A)*

$$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = \mathbf{194.7} \cdot kip$$

concrete breakout strength - shear

ACI Eqn D-22 *Shear force ⊥ to edge*

$V_{cbg\_parallel} := 2 \cdot V_{cbg} = \mathbf{389.5} \cdot kip$ *ACI D.6.2.1.c* *Shear force ∥ to edge*

$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = \mathbf{389.5} \cdot kip \cdot ft$ *concrete breakout strength - torsion*

$\phi_{breakout} \cdot T_{n.breakout} = \mathbf{292.1} \cdot kip \cdot ft$

$T_u = \mathbf{64} \cdot kip \cdot ft$

BreakoutTest := if$(\phi_{breakout} \cdot T_{n.breakout} \geq T_u$, **"OK"** , **"No Good"**)

BreakoutTest = **"OK"**

OverlapDesign := if$(A_{bolt.sector} \leq \alpha$, **"Based on Overlap of Failure Cones"** , **"Based on No Overlap of Failure Cones"**)

OverlapDesign = **"Based on Overlap of Failure Cones"**

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = \mathbf{1.9} \cdot in$ *center-to-center distance*

$d_{anchor.nut} := \mathbf{1.85} \cdot d_{anchor} = \mathbf{3.7} \cdot in$ *use* $\mathbf{1.85} \cdot d_{anchor}$ *.to account for anchor nut*

$$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{\mathbf{2}}\right) = \mathbf{-0.5} \cdot in$$

CheckAnchorageClearance := if$\left[\left(Clearance_{bar.to.nut} \geq \mathbf{2} \cdot in\right)\right.$, **"OK"** , **"No Good, increase ped. diameter"**]

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := \mathbf{2} \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = \mathbf{-1.3} \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := \mathbf{0} .. \mathbf{48} \qquad r_{ds} := \frac{b}{\mathbf{2}}$

$x_{ds_{pt}} := r_{ds} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] \qquad y_{ds_{pt}} := r_{ds} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$r_{v.od} := \frac{b}{\mathbf{2}} - \mathbf{6} \cdot in \qquad r_{v.id} := \frac{b}{\mathbf{2}} - \mathbf{6} \cdot in - d_{v.bar}$

$x_{stir.od_{pt}} := r_{v.od} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] \qquad y_{stir.od_{pt}} := r_{v.od} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$x_{stir.id_{pt}} := r_{v.id} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] \qquad y_{stir.id_{pt}} := r_{v.id} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$r_{bar} := \frac{d_{long.bar}}{\mathbf{2}} = \mathbf{0.6} \cdot in$

$x_{bar_{pt}} := r_{bar} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] + \max\left(x_{stir.id}\right) - d_{v.bar} \qquad y_{bar_{pt}} := r_{bar} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{\mathbf{2}} = \mathbf{12} \cdot in$

$x_{boltcircle_{pt}} := r_{boltcircle} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] \qquad y_{boltcircle_{pt}} := r_{boltcircle} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$r_{boltr} := \frac{d_{anchor}}{2} = \mathbf{1}\cdot in$

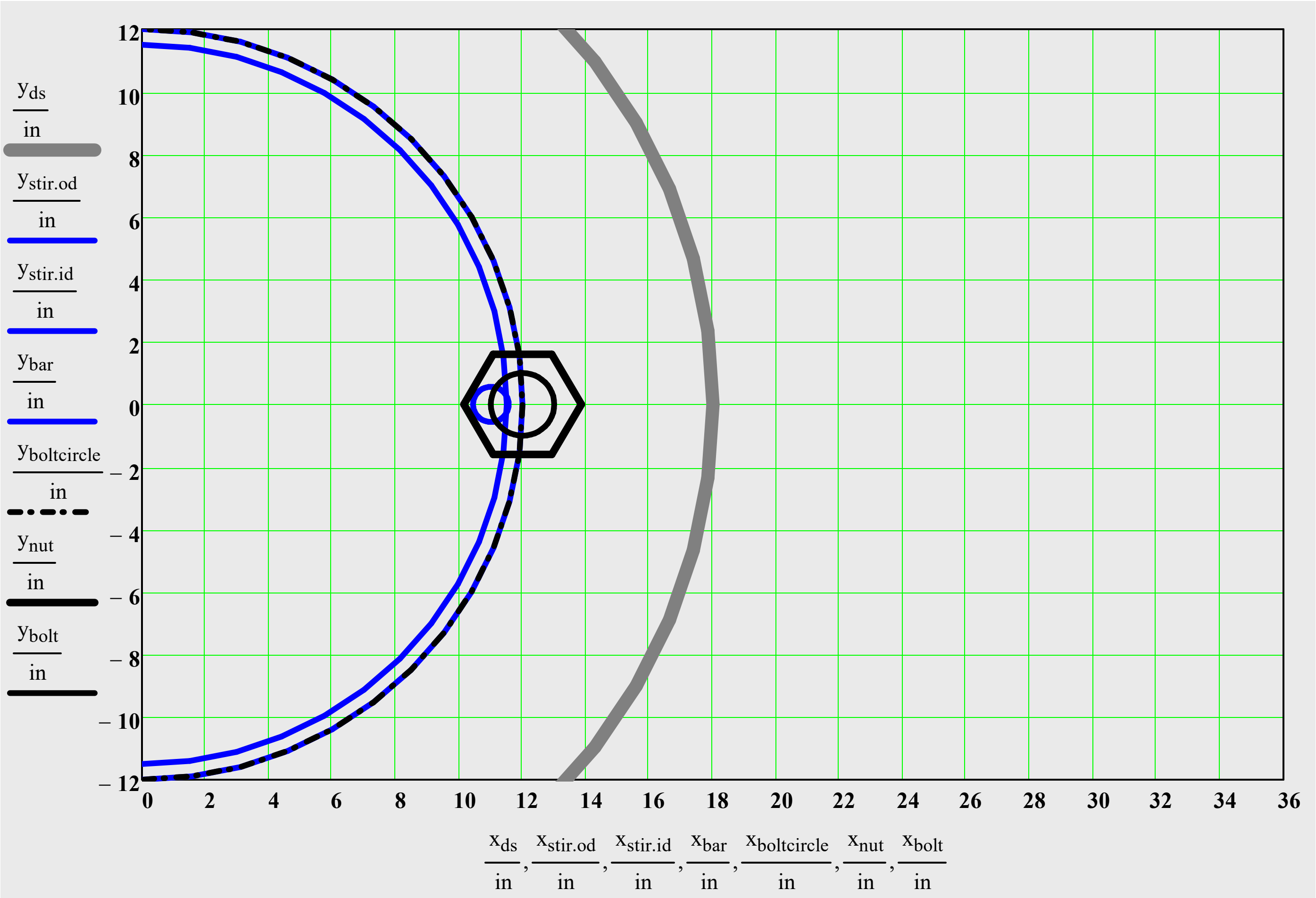
$x_{bolt_{pt}} := r_{boltr}\cdot\cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{48}} + \frac{\mathbf{2}\cdot\pi}{\mathbf{48}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $\qquad$ $y_{bolt_{pt}} := r_{boltr}\cdot\sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2}\cdot\pi}{\mathbf{48}}\right]$

$pt := \mathbf{0}\,..\,\mathbf{6}$ $\qquad$ $r_{nut} := \frac{d_{anchor}\cdot 1.85}{\mathbf{2}} = \mathbf{1.9}\cdot in$

$x_{nut_{pt}} := r_{nut}\cdot\cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{6}} + \frac{\mathbf{2}\cdot\pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $\qquad$ $y_{nut_{pt}} := r_{nut}\cdot\sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{2}\cdot\pi}{\mathbf{6}}\right]$

$x_{nut_{pt}} := r_{nut}\cdot\cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{6}} + \frac{\mathbf{1}\cdot\pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ *enable to rotate nut* $y_{nut_{pt}} := r_{nut}\cdot\sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{1}\cdot\pi}{\mathbf{6}}\right]$

$\min\left(x_{bar}\right) - \max\left(x_{nut}\right) = \mathbf{-3.4}\cdot in$



$$\text{Bolts} := \begin{pmatrix} \mathbf{1} & \mathbf{1.125} & \mathbf{1.25} & \mathbf{1.375} & \mathbf{1.5} & \mathbf{1.625} & \mathbf{1.75} & \mathbf{1.875} & \mathbf{2} & \mathbf{2.25} & \mathbf{2.5} & \mathbf{2.75} & \mathbf{3} \\ \mathbf{1.5} & \mathbf{1.688} & \mathbf{1.875} & \mathbf{2.063} & \mathbf{2.25} & \mathbf{2.438} & \mathbf{2.625} & \mathbf{2.938} & \mathbf{3} & \mathbf{3.375} & \mathbf{3.75} & \mathbf{4.125} & \mathbf{4.25} \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{\text{T}}\right)^{\langle \mathbf{0} \rangle^{\text{T}}} \cdot \mathbf{1.6} - \left(\text{Bolts}^{\text{T}}\right)^{\langle \mathbf{1} \rangle^{\text{T}}} = \begin{pmatrix} \mathbf{0.1} & \mathbf{0.112} & \mathbf{0.125} & \mathbf{0.137} & \mathbf{0.15} & \mathbf{0.162} & \mathbf{0.175} & \mathbf{0.062} & \mathbf{0.2} & \mathbf{0.225} & \mathbf{0.25} & \mathbf{0.275} & \mathbf{0.55} \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{\text{T}}\right)^{\langle \mathbf{0} \rangle^{\text{T}}} - \left(\text{Bolts}^{\text{T}}\right)^{\langle \mathbf{1} \rangle^{\text{T}}} = \begin{pmatrix} \mathbf{-0.5} & \mathbf{-0.563} & \mathbf{-0.625} & \mathbf{-0.688} & \mathbf{-0.75} & \mathbf{-0.813} & \mathbf{-0.875} & \mathbf{-1.063} & \mathbf{-1} & \mathbf{-1.125} & \mathbf{-1.25} & \mathbf{-1.375} & \mathbf{-1.25} \end{pmatrix} \cdot \text{i}$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

FDOT
State Structures Design Office

SUBJECT 079-241-E MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

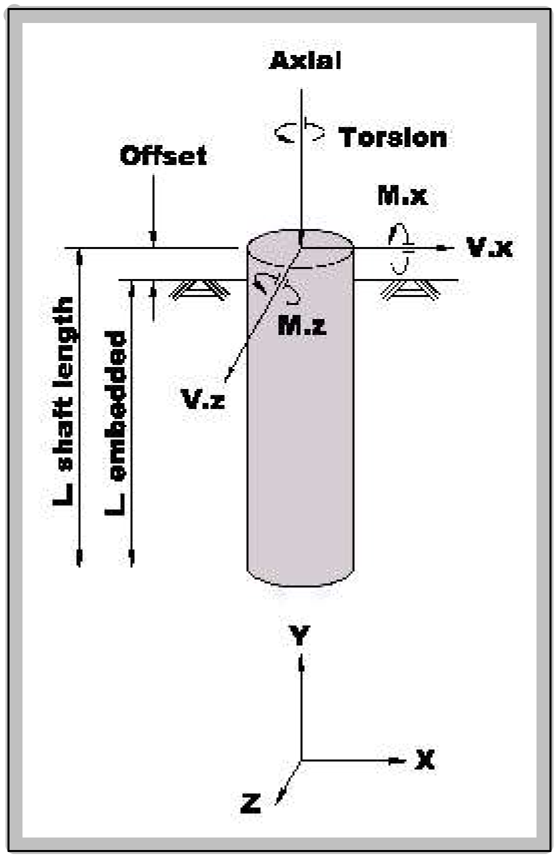
SoilType :=
- **Sand**
- Clay

$\phi_{soil} := \mathbf{32} \cdot deg$ *soil friction angle (sand)*

$c_{soil} := \mathbf{0.0} \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

$N_{blows} := \mathbf{14}$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := \mathbf{63} \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*



Geometry

$b := \mathbf{3.0} \cdot ft$ *shaft diameter*

$Offset := \mathbf{0.50} \cdot ft$ *groundline to top of foundation*

Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := \mathbf{48.25} \cdot kip \cdot ft$ $V_x := \mathbf{0.05} \cdot kip$ $Torsion := \mathbf{30.1} \cdot kip \cdot ft$

$M_z := \mathbf{20.60} \cdot kip \cdot ft$ $V_z := \mathbf{3.30} \cdot kip$ $Axial := \mathbf{17.60} \cdot kip$

StructureType :=
- Cantilever Overhead Sign Structure
- **Mast Arm Signal Structure**
- Concrete/Steel Strain Poles
- Ground Sign

$StructureType = \mathbf{1}$

$\phi_{ot} := if(StructureType = \mathbf{2}, \mathbf{0.8}, \mathbf{0.25})$ $\phi_{ot} = \mathbf{0.3}$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = \mathbf{0}, \mathbf{0.9}, \mathbf{1.0})$ $\phi_{tor} = \mathbf{1}$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

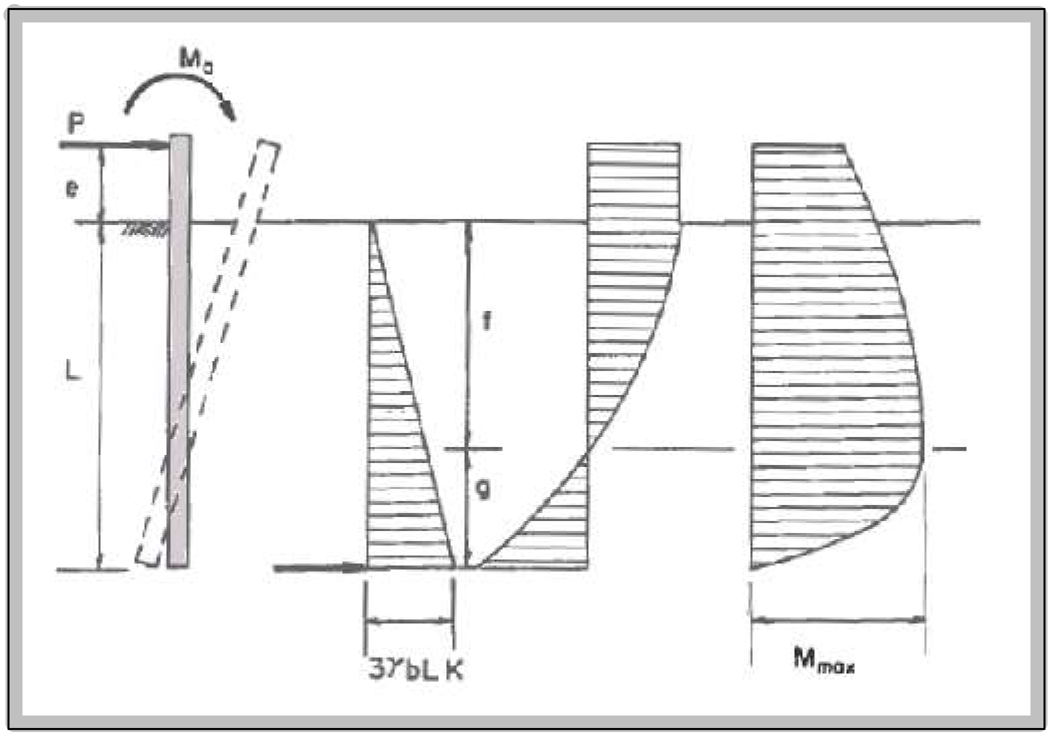
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x{}^2 + M_z{}^2} = \mathbf{52.5} \cdot kip \cdot ft$

$P_u := \sqrt{V_x{}^2 + V_z{}^2} = \mathbf{3.3} \cdot kip$

$T_u := Torsion = \mathbf{30.1} \cdot kip \cdot ft$

short free-head pile in ***cohesionless soil*** *using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(\mathbf{45} \cdot deg + \frac{\phi_{soil}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{3.3}$ $\qquad e_{sand} := Offset = \mathbf{0.5}\,ft$

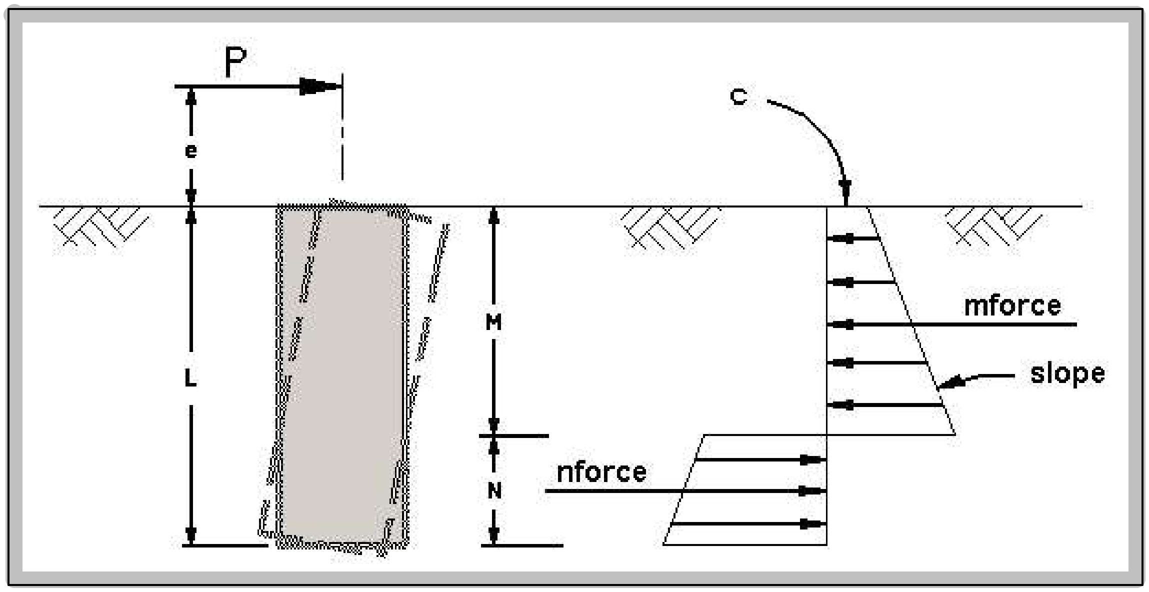
Guess value $\qquad L_{otSand} := \mathbf{8} \cdot ft$

Given $\quad P_u \cdot \left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot} \cdot \left[\left(\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{2}} \cdot L_{otSand}\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{3}} \cdot L_{otSand}\right)\right]$

$L_{otSand} := Find\left(L_{otSand}\right) = \mathbf{10.5}\,ft$

$L_{otSand} := ceil\left(\frac{L_{otSand}}{ft}\right) \cdot ft = \mathbf{11}\,ft$ $\qquad$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}(c_{soil} = 0\cdot ksf, 0.1\cdot ksf, c_{soil}) = 0.1\cdot ksf$

$Slope := 8\cdot\frac{c_{soil}}{3\cdot b} = 0.1\cdot\frac{kip}{ft^3}$

$e_{clay} := \frac{M_u}{P_u} + Offset = 16.4\,ft$

$nforce(M,N) := [Slope\cdot(2\cdot M + N) + 2\cdot c_{soil}]\cdot N\cdot\frac{b}{2}$

$mforce(M) := (2\cdot c_{soil} + M\cdot Slope)\cdot M\cdot\frac{b}{2}$

$$m\_arm(M) := e_{clay} + \frac{M}{3}\cdot\frac{2\cdot(M\cdot Slope + c_{soil}) + c_{soil}}{M\cdot Slope + 2\cdot c_{soil}}$$

$$n\_arm(M,N) := e_{clay} + M + \frac{N}{3}\cdot\frac{2\cdot(N\cdot Slope + M\cdot Slope + c_{soil}) + (M\cdot Slope + c_{soil})}{Slope\cdot(2\cdot M + N) + 2\cdot c_{soil}}$$

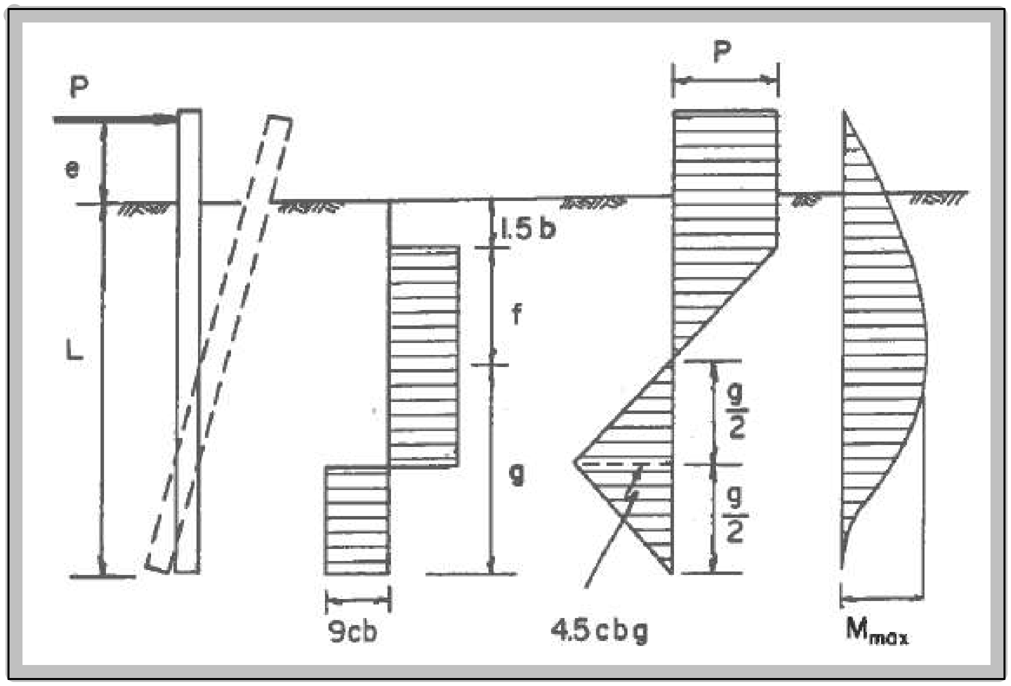
Guess value $M := 4.0\cdot ft$ $N := 4.0\cdot ft$

Given $P_u + \phi_{ot}\cdot nforce(M,N) = \phi_{ot}\cdot mforce(M)$ $mforce(M)\cdot m\_arm(M) = nforce(M,N)\cdot n\_arm(M,N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M,N)$ $L_{ot1Clay} := M + N = 7.5\,ft$

$L_{ot1Clay} := \text{ceil}\left(\frac{L_{ot1Clay}}{ft}\right)\cdot ft = 8\,ft$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot \mathbf{9} \cdot c_{soil} \cdot b} = \mathbf{4.9}\ ft$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + \mathbf{1.5} \cdot b + \mathbf{0.5} \cdot f\right) = \mathbf{77} \cdot kip \cdot ft$$

$$g := \sqrt{\frac{M_{max.clay}}{\mathbf{2.25} \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = \mathbf{21.4}\ ft$$

$$L_{ot2Clay} := (\mathbf{1.5} \cdot b + f + g) = \mathbf{30.8}\ ft$$

$$L_{ot2Clay} := ceil\left(\frac{L_{ot2Clay}}{ft}\right) \cdot ft = \mathbf{31}\ ft$$

(round up to next foot)

$$L_{otClay} := if\left(L_{ot1Clay} < \mathbf{3} \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = \mathbf{8}\ ft$$

(If $L_{ot} < 3b$*, use Modified Broms method)*

$$L_{reqdOT} := if\left(SoilType = \textbf{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$$L_{reqdOT} = \mathbf{11}\ ft$$

required shaft embedment depth to resist overturning

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = \mathbf{14}$

$$\omega_{fdot} := \text{if}\left(N_{blows} < 5, 0, \text{if}\left(N_{blows} \geq 15, 1.5, 1.5 \cdot \frac{N_{blows}}{15}\right)\right) = 1.4$$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\frac{N_{blows}}{15}$ *SM Vol-3 13.6*

Guess value $L_{torSand} := L_{reqdOT} = 11\ \text{ft}$

Given $$T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot (L_{torSand}) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right]$$

$L_{torSand} := \text{Find}(L_{torSand}) = 6.9\ \text{ft}$

$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{\text{ft}}\right) \cdot \text{ft} = 7\ \text{ft}$ *(round up to next foot)*

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := \mathbf{0.55}$

$f_{se} := \text{CohesionFactor} \cdot c_{soil} = 0.1 \cdot \text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

Given $$T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot (L_{torClay} - 1.5 \cdot \text{ft}) \cdot \frac{b}{2}\right]$$

$L_{torClay} := \text{Find}(L_{torClay}) = 40.2\ \text{ft}$

$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{\text{ft}}\right) \cdot \text{ft} = 41\ \text{ft}$ *(round up to next foot)*

$L_{reqdTor} := \text{if}(\text{SoilType} = \text{"Sand"}, L_{torSand}, L_{torClay})$

$L_{reqdTor} = 7\ \text{ft}$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}) = 11\ \text{ft}$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = 11.5\ \text{ft}$ **Min Shaft embedment depth=12 ft** *shaft length*

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{\mathbf{2}\cdot P_u}{\mathbf{3}\cdot\gamma_{soil}\cdot b\cdot K_p\cdot\phi_{ot}}} = \mathbf{3.8}\,\text{ft}$$

$$M_{maxSand} := P_u\cdot\left(e_{sand} + f_{sand}\right) - \frac{P_u\cdot f_{sand}}{\mathbf{3}} + M_u = \mathbf{62.4}\cdot\text{kip}\cdot\text{ft}$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := \mathbf{4.0}\cdot\text{ft}$

Given $P_u = \frac{f_{mod}\cdot b}{\mathbf{2}}\cdot\left(2\phi_{ot}\cdot c_{soil} + \phi_{ot}\cdot f_{mod}\cdot\text{Slope}\right)$

$$f_{mod} := \text{Find}\left(f_{mod}\right) = \mathbf{8.9}\,\text{ft}$$

$$M_{modBroms} := P_u\cdot\left(e_{clay} + f_{mod}\right) - \frac{\phi_{ot}\cdot c_{soil}\cdot b\cdot f_{mod}^{\mathbf{2}}}{\mathbf{2}} - \frac{\phi_{ot}\cdot b\cdot f_{mod}^{\mathbf{3}}\cdot\text{Slope}}{\mathbf{6}} = \mathbf{72.7}\cdot\text{kip}\cdot\text{ft}$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u\cdot\left(e_{clay} + \mathbf{1.5}\cdot b + \mathbf{0.5}\cdot f\right) = \mathbf{77}\cdot\text{kip}\cdot\text{ft}$$

$$M_{maxClay} := \text{if}\left(L_{ot1Clay} < \mathbf{3}\cdot b, M_{modBroms}, M_{Broms}\right) = \mathbf{72.7}\cdot\text{kip}\cdot\text{ft}$$

(If $L_{ot} < 3b$, use Modified Broms method)

$$M_{max} := \text{if}\left(\text{SoilType} = \textbf{"Sand"}, M_{maxSand}, M_{maxClay}\right) = \mathbf{62.4}\cdot\text{kip}\cdot\text{ft}$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := \mathbf{60} \cdot ksi$ *reinforcing yield strength*

$f_c := \mathbf{4.0} \cdot ksi$ *concrete strength* *Spec 346-3*

$Cover := \mathbf{3} \cdot in$ *cover* *SDG Table 1.4.2-1*

$Num_{bar} := \mathbf{11}$ *number of longitudinal bars*

$A_{long.bar} := \mathbf{1.0} \cdot in^2$ *longitudinal bar area*

$d_{long.bar} := \mathbf{1.125} \cdot in$ *longitudinal bar diameter*

$A_{v.bar} := \mathbf{0.20} \cdot in^2$ *stirrup area* *SM Vol-3 13.6.2*

$d_{v.bar} := \mathbf{0.5} \cdot in$ *stirrup diameter*

$s_{v1} := \mathbf{3} \cdot in$ *stirrup spacing, depth = 0 ft-2 ft* *SM Vol-3 13.6.2*

$s_{v2} := \mathbf{3} \cdot in$ *stirrup spacing, depth = 2 ft-depth.stir*

$s_{v3} := \mathbf{6} \cdot in$ *stirrup spacing, depth > depth.stir*

$depth_{stir} := \mathbf{9.0} \cdot ft$ *stirrup depth, see s.v2 and s.v3 above*

$b = \mathbf{3}\ ft$ *shaft diameter*

$A_{req1} := \mathbf{0.01} \cdot \frac{\pi \cdot b^2}{4} = \mathbf{10.2} \cdot in^2$ *required 1% steel* *SM Vol-3 13.6.2*

$A_{req2} := \min\left(\mathbf{0.135} \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, \mathbf{0.015} \cdot \frac{\pi \cdot b^2}{4}\right) = \mathbf{9.2} \cdot in^2$ *LRFD 5.7.4.2*

$A_{req} := \max\left(A_{req1}, A_{req2}\right) = \mathbf{10.2} \cdot in^2$

$A_{long} := Num_{bar} \cdot A_{long.bar} = \mathbf{11} \cdot in^2$ *total area of longitudinal steel*

$CheckLongitudinalReinf := if\left(A_{long} \geq A_{req}, \textbf{"OK"}, \textbf{"No Good"}\right)$ $CheckLongitudinalReinf = \textbf{"OK"}$

$Dia_{bar.circle} := b - \mathbf{2} \cdot Cover - \mathbf{2} \cdot d_{v.bar} - d_{long.bar} = \mathbf{27.9} \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = \mathbf{8} \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = \mathbf{6.84} \cdot in$

$CheckReinfClearSpacing := if\left(Clearance_{vert.reinf} \geq 6in, \textbf{"OK"}, \textbf{"No Good"}\right)$ $CheckReinfClearSpacing = \textbf{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$$V_u := \sqrt{V_x^{2} + V_z^{2}} = \mathbf{3.3} \cdot \text{kip}$$

$$T_u = \mathbf{30.1} \cdot \text{kip} \cdot \text{ft}$$

Effective shear depth

$$D_r := b - \mathbf{2} \cdot \left(\text{Cover} + d_{v.bar} + \frac{d_{long.bar}}{\mathbf{2}} \right) = \mathbf{2.3}\,\text{ft} \qquad d_e := \frac{b}{\mathbf{2}} + \frac{D_r}{\pi} = \mathbf{2.2}\,\text{ft}$$

LRFD C5.8.2.9-2

$$d_v := \max\left(\mathbf{0.9} \cdot d_e, \mathbf{0.72} \cdot b\right) = \mathbf{2.2}\,\text{ft}$$

Check Shear Strength

$$V_c := \mathbf{0.0316} \cdot (\mathbf{2.0}) \cdot \sqrt{\frac{f_c}{\text{ksi}}} \cdot \left(\frac{b}{\text{in}}\right) \cdot \left(\frac{d_v}{\text{in}}\right) \cdot \text{kip} = \mathbf{117.9} \cdot \text{kip}$$

LRFD Eqn 5.8.3.3-3 *LRFD 5.8.3.4.1* *ACI 11.3.3*

$$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max\left(s_{v1}, s_{v2}, s_{v3}\right)} = \mathbf{51.8} \cdot \text{kip}$$

LRFD Eqn 5.8.3.3-4

$$\text{ShearRatio} := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = \mathbf{-2.2}$$

$$\text{ShearRatio} := \text{if}\left(\text{ShearRatio} \le \mathbf{0}, \mathbf{0}, \text{ShearRatio}\right) = \mathbf{0}$$

Check Torsion Strength

$$A_{cp} := \pi \cdot \left(\frac{b}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1017.9} \cdot \text{in}^{\mathbf{2}} \qquad p_{cp} := \mathbf{2} \cdot \pi \cdot \left(\frac{b}{\mathbf{2}}\right) = \mathbf{113.1} \cdot \text{in}$$

Area and perimeter of concrete cross-section

$$d_{oh} := b - \mathbf{2} \cdot \left(\text{Cover} + \frac{d_{v.bar}}{\mathbf{2}} \right) = \mathbf{29.5} \cdot \text{in} \qquad p_h := \pi \cdot d_{oh} = \mathbf{92.7} \cdot \text{in}$$

Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement

$$A_{oh} := \pi \left(\frac{d_{oh}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{683.5} \cdot \text{in}^{\mathbf{2}} \qquad A_o := \mathbf{0.85} \cdot A_{oh} = \mathbf{581} \cdot \text{in}^{\mathbf{2}}$$

$$T_{n1} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$$

LRFD Eqn 5.8.3.6.2-1

$$T_{n2} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$$

LRFD 5.8.3.4.1

$$T_{n3} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = \mathbf{193.7} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$\phi_v = \mathbf{0.9}$ $\quad T_u = \mathbf{30.1} \cdot \mathrm{kip} \cdot \mathrm{ft}$ $\quad L_{reqdTor} = \mathbf{7}\ \mathrm{ft}$

$$Tor2_{sand} := T_u - \mathrm{if}\left[\mathbf{2}\mathrm{ft} > Offset, \left[\pi \cdot b \cdot (\mathbf{2} \cdot \mathrm{ft} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{\mathbf{2} \cdot \mathrm{ft} - Offset}{\mathbf{2}}\right) \cdot \left(\omega_{fdot}\right) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot \mathrm{kip} \cdot \mathrm{ft}\right] = \mathbf{28.7} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor3_{sand} := T_u - \mathrm{if}\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot \left(depth_{stir} - Offset\right) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{\mathbf{2}}\right) \cdot \left(\omega_{fdot}\right) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot \mathrm{kip} \cdot \mathrm{ft}\right] = \mathbf{-14.9} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor2_{clay} := T_u - \mathrm{if}\left[\mathbf{2}\mathrm{ft} - \mathbf{1.5}\mathrm{ft} > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (\mathbf{2.0} \cdot \mathrm{ft} - Offset - \mathbf{1.5} \cdot \mathrm{ft}) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot \mathrm{kip} \cdot \mathrm{ft}\right] = \mathbf{30.1} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor3_{clay} := T_u - \mathrm{if}\left[depth_{stir} - \mathbf{1.5}\mathrm{ft} > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot \left(depth_{stir} - Offset - \mathbf{1.5} \cdot \mathrm{ft}\right) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot \mathrm{kip} \cdot \mathrm{ft}\right] = \mathbf{24.7} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor2 := \mathrm{if}\left(SoilType = \textbf{"Sand"}, Tor2_{sand}, Tor2_{clay}\right) = \mathbf{28.7} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor3 := \mathrm{if}\left(SoilType = \textbf{"Sand"}, Tor3_{sand}, Tor3_{clay}\right) = \mathbf{-14.9} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = \mathbf{0.08}$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = \mathbf{0.07}$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = \mathbf{-0.08}$$

$$TorsionRatio := \max\left(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}\right) = \mathbf{0.08}$$

$$T_{cr} := \mathbf{0.125} \sqrt{\frac{f_c}{\mathrm{ksi}}} \cdot \left(\frac{{A_{cp}}^{\mathbf{2}}}{p_{cp} \cdot \mathrm{in}^{\mathbf{3}}}\right) \cdot \mathrm{kip} \cdot \mathrm{in} = \mathbf{190.9} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

LRFD Eqn 5.8.2.1-4

$$TorsionRatio := \mathrm{if}\left(T_u \le \mathbf{0.25} \cdot \phi_{tor} \cdot T_{cr}, \mathbf{0}, TorsionRatio\right) = \mathbf{0}$$

LRFD Eqn 5.8.2.1-3

$ShearRatio = \mathbf{0}$

$$CheckShearTorsion := \mathrm{if}\left(ShearRatio + TorsionRatio \le \mathbf{1}, \textbf{"OK"}, \textbf{"No Good"}\right)$$

$CheckShearTorsion = \textbf{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = \mathbf{0.00393} \cdot \mathrm{ksi} \qquad \mathbf{0.125} \cdot f_c = \mathbf{0.5} \cdot \mathrm{ksi}$$

LRFD Eqn 5.8.2.9-1

$s_{max1} := \text{if}\left(\mathbf{0.8}\cdot d_v < \mathbf{24}\cdot in, \mathbf{0.8}d_v, \mathbf{24}\cdot in\right) = \mathbf{20.7}\cdot in$ *LRFD Eqn 5.8.2.7-1*

$s_{max2} := \text{if}\left(\mathbf{0.4}\cdot d_v < \mathbf{12}\cdot in, \mathbf{0.4}d_v, \mathbf{12}\cdot in\right) = \mathbf{10.4}\cdot in$ *LRFD Eqn 5.8.2.7-2*

$s_{max} := \text{if}\left(v_u < \mathbf{0.125}\cdot f_c, s_{max1}, s_{max2}\right) = \mathbf{20.7}\cdot in$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = \mathbf{6}\cdot in$

$CheckMaxSpacingTransvReinf := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$CheckMaxSpacingTransvReinf = \textbf{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion *LRFD Eqn 5.8.3.6.3-1*

LRFD 5.8.3.4.1

$M_u = \mathbf{52.5}\cdot kip\cdot ft$

$$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5\cdot V_s > \mathbf{0}\cdot kip, \frac{V_u}{\phi_v} - 0.5\cdot V_s, \mathbf{0}\cdot kip\right) = \mathbf{0}\cdot kip$$

$$LongReinf_{shr.tor} := \frac{\dfrac{M_u}{\phi_v\cdot d_v} + \sqrt{\left(V_{temp}\right)^{\mathbf{2}} + \left(\dfrac{\mathbf{0.45}\cdot p_h\cdot T_u}{\mathbf{2}\cdot A_o\cdot \phi_v}\right)^{\mathbf{2}}}}{F_{y.rebar}} = \mathbf{0.7}\cdot in^{\mathbf{2}}$$

$Num_{bar}\cdot A_{long.bar} = \mathbf{11}\cdot in^{\mathbf{2}}$

$CheckLongReinf_{shr.tor} := \text{if}\left(Num_{bar}\cdot A_{long.bar} \ge LongReinf_{shr.tor}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$CheckLongReinf_{shr.tor} = \textbf{"OK"}$

Anchor Bolt Strength Check

$Num_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot in$ *anchor bolt nominal diameter*

$Dia_{anchor.circle} := 24 \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{Dia_{anchor.circle}^{2}}{8} \cdot Num_{anchor} = 576 \cdot in^{2}$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{Dia_{anchor.circle}}{2}} = 48 \cdot in$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 13.1 \cdot kip$$

anchor tension force

$$V_{anchor} := \frac{V_u}{Num_{anchor}} + \frac{T_u}{0.5Dia_{anchor.circle} \cdot Num_{anchor}} = 4.2 \cdot kip$$

anchor shear force

$$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}^{2} = 3.1 \cdot in^{2}$$

anchor bolt nominal area

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 4.2 \cdot ksi$$

anchor tensile stress

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 1.3 \cdot ksi$$

anchor shear stress

$\phi_{anchor} := 0.75$ *resistance factor* AISC J3-1

$F_{nt} := 0.75F_{u.anchor} = 78.8 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := 0.45F_{u.anchor} = 47.2 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot kip$ *design sghear strength*

$CheckAnchorT := if\left(\phi R_{nt} \geq T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$CheckAnchorT = \text{"OK"}$

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \textbf{"OK"}, \textbf{"No Good"}\right)$ *check shear rupture*

$\text{CheckAnchorV} = \textbf{"OK"}$

$$F_{ntv} := \min\left(\begin{pmatrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{pmatrix}\right) = \mathbf{78.8} \cdot ksi$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = \mathbf{185.6} \cdot kip$

design tension strength modified to include the effects of shearing stress

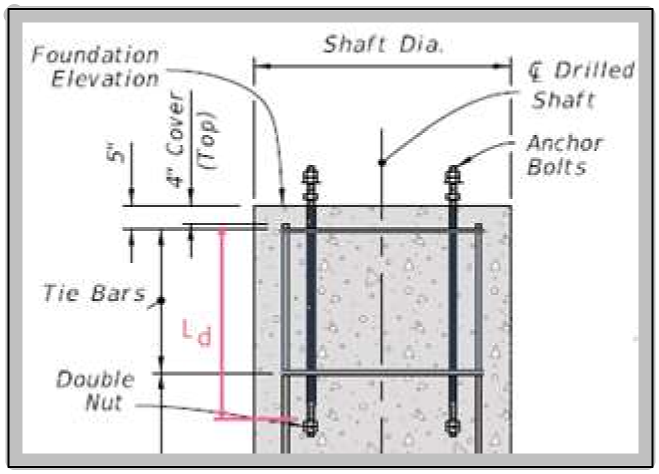
$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq \mathbf{20}\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq \mathbf{20}\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \textbf{"OK"}, \textbf{"No Good"}\right]$

$\text{CheckAnchorTV} = \textbf{"OK"}$ *check combined tension and shear rupture*

$\text{CheckAnchorStrength} := \text{if}[(\text{CheckAnchorT} \mathbf{=} \textbf{"OK"}) \cdot (\text{CheckAnchorV} \mathbf{=} \textbf{"OK"}) \cdot (\text{CheckAnchorTV} \mathbf{=} \textbf{"OK"}), \textbf{"OK"}, \textbf{"No Good"}$

$\text{CheckAnchorStrength} = \textbf{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = \mathbf{13.1} \cdot kip$ *tension force in anchor*

$Dia_{bar.circle} = \mathbf{27.9} \cdot in$ $Dia_{anchor.circle} = \mathbf{24} \cdot in$

center-to-center distance

$$Dist_{bar.to.bolt} := \frac{Dia_{bar.circle} - Dia_{anchor.circle}}{\mathbf{2}} = \mathbf{1.9} \cdot in$$

$$Num_{bars.per.anchor} := \min\left(\frac{Num_{bar}}{Num_{anchor}}, \mathbf{3}\right) = \mathbf{1.4}$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := \mathbf{0.9}$

$$Num_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{Dia_{anchor.circle}}{Dia_{bar.circle}} = \mathbf{0.21}$$

$$AreaRatio := \min\left(\frac{Num_{bars.reqd.per.anchor}}{Num_{bars.per.anchor}}, \mathbf{1}\right) = \mathbf{0.15}$$

2015 AASHTO Development Length of Deformed Bars in Tension ***5.11.2.1***

$Cover = \mathbf{3} \cdot in$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half the center-to-center spacing of the bars or wires being developed*

$$c_b := \min\left(\begin{pmatrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{2} \\ \dfrac{\text{Spacing}_{vert.reinf}}{2} \end{pmatrix}\right) = 4 \cdot \text{in}$$

$k_{tr} := 0 \cdot \text{in}$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\begin{bmatrix} 1.0 \\ \max\left(\begin{pmatrix} 0.4 \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{pmatrix}\right) \end{bmatrix}\right] = 0.4$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\begin{pmatrix} 12 \cdot \text{in} \\ \lambda_{rc} \cdot 2.4 \cdot d_{long.bar} \cdot \dfrac{F_{y.rebar}}{\sqrt{f_c \cdot \text{ksi}}} \end{pmatrix}\right) = 32.4 \cdot \text{in}$$

tension development length *LRFD Eqn 5.11.2.1.1-2*

$$\text{SpacingFactor} := \max\left[\begin{pmatrix} 0.5 \\ \text{Num}_{bars.per.anchor} \cdot 0.5 - 0.5 \end{pmatrix}\right] = 0.5$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf} \cdot \text{SpacingFactor}\right)^2 + \text{Dist}_{bar.to.bolt}^{\;2}} = 3.9 \cdot \text{in}$$

$$L_{embedment.anchor} := \max\left[\begin{bmatrix} L_{d.bar} \cdot (\text{AreaRatio}) + 12 \cdot \text{in} + L_{embedment.added} \\ 20 \cdot d_{anchor} \end{bmatrix}\right] = 40 \cdot \text{in}$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, \text{in}\right)$

$L_{embedment.anchor} = 40 \cdot \text{in}$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^2 + 3.25 \cdot \left(r^2 - r_b^2\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\begin{pmatrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{pmatrix}\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2\,\mathrm{asin}\left[\frac{(1.5 \cdot c_{a1})}{r}\right] = 45.2 \cdot deg$$

$$OverlapTest := if\left(A_{bolt.sector} \le \alpha, \text{"Overlap of Failure Cones"}, \text{"No Overlap of Failure Cones"}\right) = \text{"Overlap of Failure Cones"}$$

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{\;2} = 95.9 \cdot in^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := if\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$$

$\psi_{ecV} := \mathbf{1.0}$ *eccentric load modifier* *ACI D.6.2.5*

$\psi_{edV} := \mathbf{1.0}$ *edge effect modifier* *ACI D.6.2.6*

$\psi_{cV} := \mathbf{1.4}$ *cracked section modifier* *ACI D.6.2.7* *(stirrup spacing <= 4")*

$\psi_{hV} := \mathbf{1.0}$ *member thickness modifier* *ACI D.6.2.8*

$\phi_{breakout} := \mathbf{0.75}$ *strength reduction factor* *ACI D.4.4.c.i* *(shear breakout, condition A)*

$$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = \mathbf{194.7} \cdot kip$$

concrete breakout strength - shear

ACI Eqn D-22 *Shear force ⊥ to edge*

$$V_{cbg\_parallel} := \mathbf{2} \cdot V_{cbg} = \mathbf{389.5} \cdot kip$$

ACI D.6.2.1.c *Shear force ∥ to edge*

$$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = \mathbf{389.5} \cdot kip \cdot ft$$

concrete breakout strength - torsion

$$\phi_{breakout} \cdot T_{n.breakout} = \mathbf{292.1} \cdot kip \cdot ft$$

$$T_u = \mathbf{30.1} \cdot kip \cdot ft$$

BreakoutTest := if$\left(\phi_{breakout} \cdot T_{n.breakout} \ge T_u,\right.$ **"OK"** , **"No Good"**)

BreakoutTest = **"OK"**

OverlapDesign := if($A_{bolt.sector} \le \alpha$, **"Based on Overlap of Failure Cones"** , **"Based on No Overlap of Failure Cones"**)

OverlapDesign = **"Based on Overlap of Failure Cones"**

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = \mathbf{1.9} \cdot in$ *center-to-center distance*

$d_{anchor.nut} := \mathbf{1.85} \cdot d_{anchor} = \mathbf{3.7} \cdot in$ *use* $\mathbf{1.85} \cdot d_{anchor}$ *.to account for anchor nut*

$$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{\mathbf{2}}\right) = -\mathbf{0.5} \cdot in$$

CheckAnchorageClearance := if[($Clearance_{bar.to.nut} \ge \mathbf{2} \cdot in$), **"OK"** , **"No Good, increase ped. diameter"**]

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0 .. 48 \qquad r_{ds} := \frac{b}{2}$

$x_{ds_{pt}} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{ds_{pt}} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$x_{stir.od_{pt}} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.od_{pt}} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$x_{stir.id_{pt}} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.id_{pt}} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$x_{bar_{pt}} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max\left(x_{stir.id}\right) - d_{v.bar} \qquad y_{bar_{pt}} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$x_{boltcircle_{pt}} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{boltcircle_{pt}} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltr} := \frac{d_{anchor}}{2} = \mathbf{1} \cdot in$

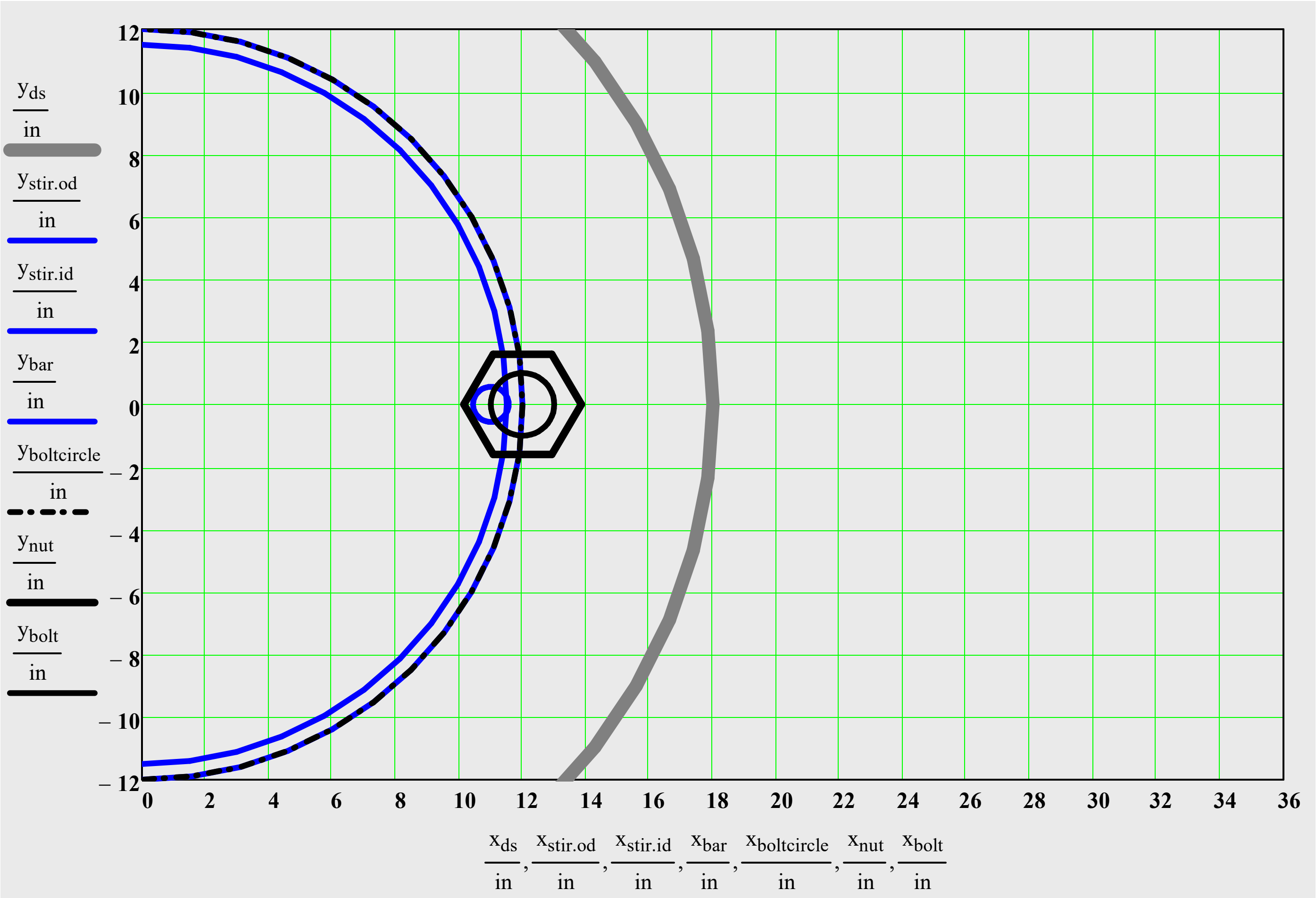
$x_{bolt_{pt}} := r_{boltr} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $y_{bolt_{pt}} := r_{boltr} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$pt := \mathbf{0} .. \mathbf{6}$ $r_{nut} := \frac{d_{anchor} \cdot 1.85}{2} = \mathbf{1.9} \cdot in$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right]$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ *enable to rotate nut* $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right]$

$\min\left(x_{bar}\right) - \max\left(x_{nut}\right) = -\mathbf{3.4} \cdot in$



$$\text{Bolts} := \begin{pmatrix} \mathbf{1} & \mathbf{1.125} & \mathbf{1.25} & \mathbf{1.375} & \mathbf{1.5} & \mathbf{1.625} & \mathbf{1.75} & \mathbf{1.875} & \mathbf{2} & \mathbf{2.25} & \mathbf{2.5} & \mathbf{2.75} & \mathbf{3} \\ \mathbf{1.5} & \mathbf{1.688} & \mathbf{1.875} & \mathbf{2.063} & \mathbf{2.25} & \mathbf{2.438} & \mathbf{2.625} & \mathbf{2.938} & \mathbf{3} & \mathbf{3.375} & \mathbf{3.75} & \mathbf{4.125} & \mathbf{4.25} \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{\text{T}}\right)^{\langle \mathbf{0} \rangle^{\text{T}}} \cdot \mathbf{1.6} - \left(\text{Bolts}^{\text{T}}\right)^{\langle \mathbf{1} \rangle^{\text{T}}} = \begin{pmatrix} \mathbf{0.1} & \mathbf{0.112} & \mathbf{0.125} & \mathbf{0.137} & \mathbf{0.15} & \mathbf{0.162} & \mathbf{0.175} & \mathbf{0.062} & \mathbf{0.2} & \mathbf{0.225} & \mathbf{0.25} & \mathbf{0.275} & \mathbf{0.55} \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{\text{T}}\right)^{\langle \mathbf{0} \rangle^{\text{T}}} - \left(\text{Bolts}^{\text{T}}\right)^{\langle \mathbf{1} \rangle^{\text{T}}} = \begin{pmatrix} \mathbf{-0.5} & \mathbf{-0.563} & \mathbf{-0.625} & \mathbf{-0.688} & \mathbf{-0.75} & \mathbf{-0.813} & \mathbf{-0.875} & \mathbf{-1.063} & \mathbf{-1} & \mathbf{-1.125} & \mathbf{-1.25} & \mathbf{-1.375} & \mathbf{-1.25} \end{pmatrix} \cdot \text{i}$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

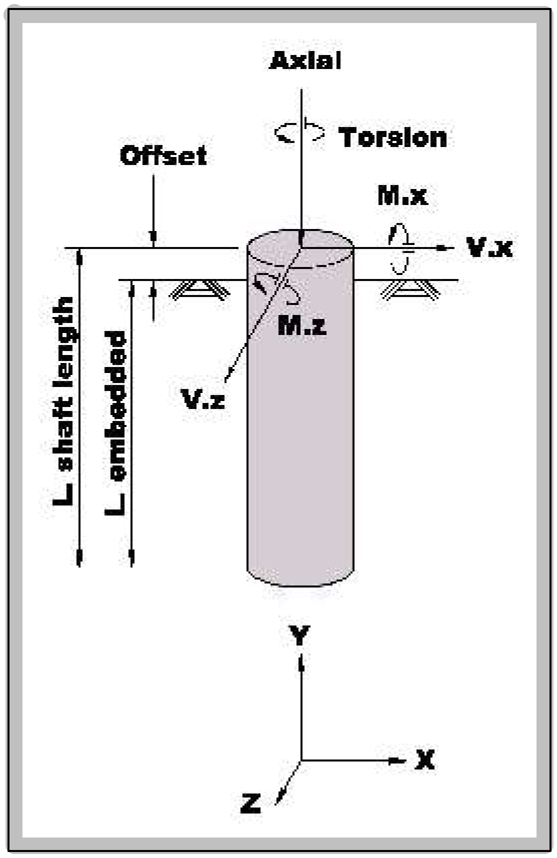
State Structures Design Office

SUBJECT 079-241-F MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

SoilType :=
- Sand
- Clay



$\phi_{soil} := 32 \cdot deg$ *soil friction angle (sand)*

$c_{soil} := 0.0 \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

$N_{blows} := 14$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := 63 \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*

Geometry

$b := 3.0 \cdot ft$ *shaft diameter*

$Offset := 0.50 \cdot ft$ *groundline to top of foundation*

Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := 48.4 \cdot kip \cdot ft$ $V_x := 0.05 \cdot kip$ $Torsion := 47.50 \cdot kip \cdot ft$

$M_z := 33.20 \cdot kip \cdot ft$ $V_z := 3.05 \cdot kip$ $Axial := 16.50 \cdot kip$

StructureType :=
- Cantilever Overhead Sign Structure
- Mast Arm Signal Structure
- Concrete/Steel Strain Poles
- Ground Sign

$StructureType = 1$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

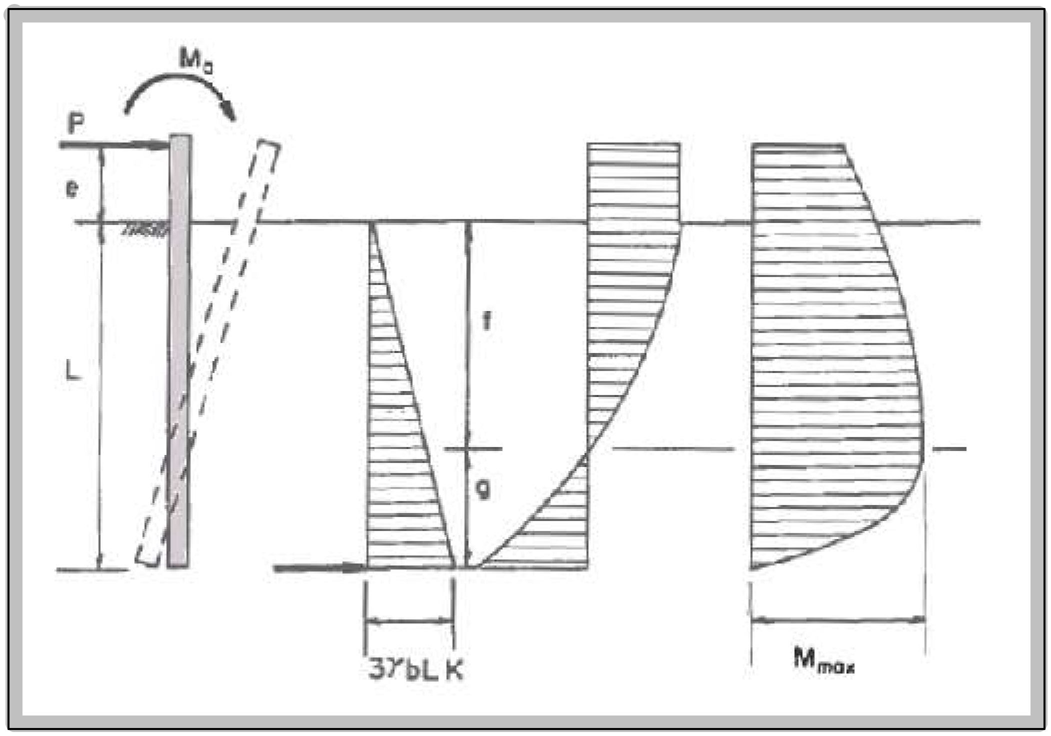
Shaft Depth Required to Resist Overturning

$$M_u := \sqrt{M_x^{\mathbf{2}} + M_z^{\mathbf{2}}} = \mathbf{58.7} \cdot kip \cdot ft$$

$$P_u := \sqrt{V_x^{\mathbf{2}} + V_z^{\mathbf{2}}} = \mathbf{3.1} \cdot kip$$

$$T_u := Torsion = \mathbf{47.5} \cdot kip \cdot ft$$

short free-head pile in ***cohesionless soil*** *using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$$K_p := \tan\left(\mathbf{45} \cdot deg + \frac{\phi_{soil}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{3.3} \qquad e_{sand} := Offset = \mathbf{0.5}\,ft$$

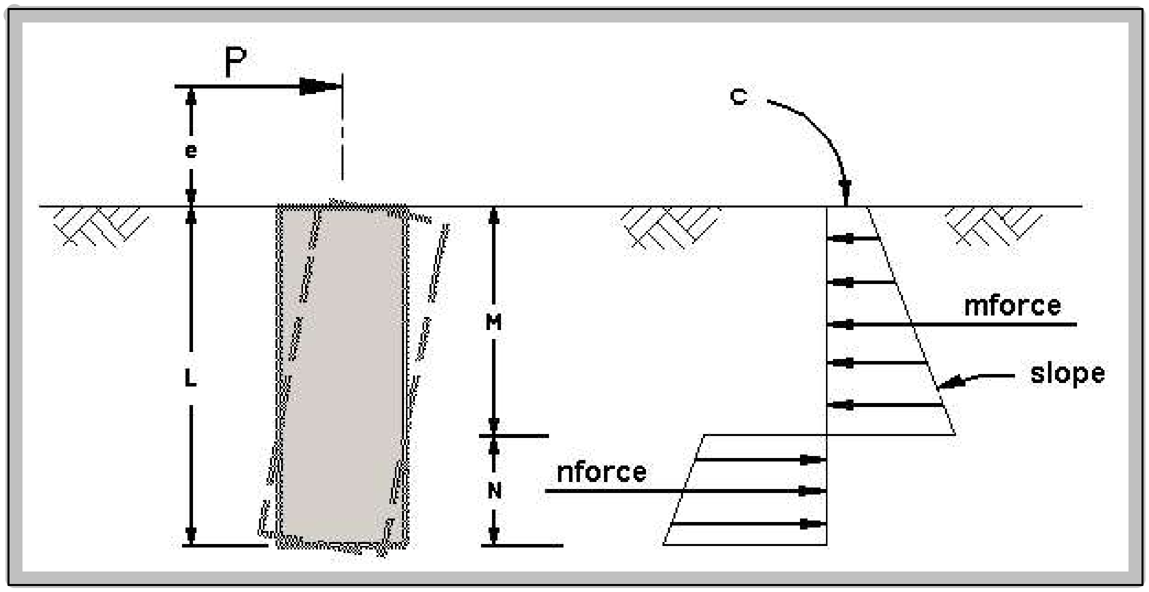
Guess value $L_{otSand} := \mathbf{8} \cdot ft$

Given $P_u \cdot \left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot} \cdot \left[\left(\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{2}} \cdot L_{otSand}\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{3}} \cdot L_{otSand}\right)\right]$

$$L_{otSand} := Find\left(L_{otSand}\right) = \mathbf{10.6}\,ft$$

$$L_{otSand} := ceil\left(\frac{L_{otSand}}{ft}\right) \cdot ft = \mathbf{11}\,ft$$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}\left(c_{soil} = 0 \cdot \text{ksf}, 0.1 \cdot \text{ksf}, c_{soil}\right) = 0.1 \cdot \text{ksf}$

$\text{Slope} := 8 \cdot \frac{c_{soil}}{3 \cdot b} = 0.1 \cdot \frac{\text{kip}}{\text{ft}^3}$

$e_{clay} := \frac{M_u}{P_u} + \text{Offset} = 19.7 \text{ ft}$

$\text{nforce}(M, N) := \left[\text{Slope} \cdot (2 \cdot M + N) + 2 \cdot c_{soil}\right] \cdot N \cdot \frac{b}{2}$

$\text{mforce}(M) := \left(2 \cdot c_{soil} + M \cdot \text{Slope}\right) \cdot M \cdot \frac{b}{2}$

$\text{m\_arm}(M) := e_{clay} + \frac{M}{3} \cdot \frac{2 \cdot \left(M \cdot \text{Slope} + c_{soil}\right) + c_{soil}}{M \cdot \text{Slope} + 2 \cdot c_{soil}}$

$\text{n\_arm}(M, N) := e_{clay} + M + \frac{N}{3} \cdot \frac{2 \cdot \left(N \cdot \text{Slope} + M \cdot \text{Slope} + c_{soil}\right) + \left(M \cdot \text{Slope} + c_{soil}\right)}{\text{Slope} \cdot (2 \cdot M + N) + 2 \cdot c_{soil}}$

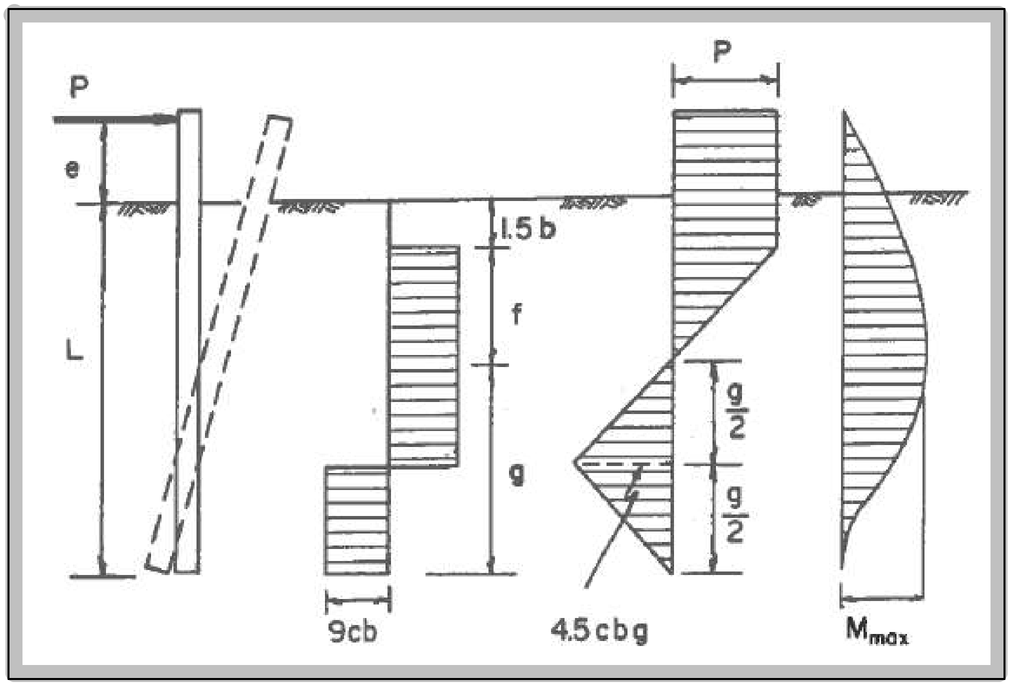
Guess value $M := 4.0 \cdot \text{ft}$ $N := 4.0 \cdot \text{ft}$

Given $P_u + \phi_{ot} \cdot \text{nforce}(M, N) = \phi_{ot} \cdot \text{mforce}(M)$ $\text{mforce}(M) \cdot \text{m\_arm}(M) = \text{nforce}(M, N) \cdot \text{n\_arm}(M, N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M, N)$ $L_{ot1Clay} := M + N = 8.3 \text{ ft}$

$L_{ot1Clay} := \text{ceil}\left(\frac{L_{ot1Clay}}{\text{ft}}\right) \cdot \text{ft} = 9 \text{ ft}$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot \mathbf{9} \cdot c_{soil} \cdot b} = \mathbf{4.5}\ \text{ft}$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + \mathbf{1.5} \cdot b + \mathbf{0.5} \cdot f\right) = \mathbf{80.8} \cdot \text{kip} \cdot \text{ft}$$

$$g := \sqrt{\frac{M_{max.clay}}{\mathbf{2.25} \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = \mathbf{21.9}\ \text{ft}$$

$$L_{ot2Clay} := (\mathbf{1.5} \cdot b + f + g) = \mathbf{30.9}\ \text{ft}$$

$$L_{ot2Clay} := \text{ceil}\left(\frac{L_{ot2Clay}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{31}\ \text{ft}$$ *(round up to next foot)*

$$L_{otClay} := \text{if}\left(L_{ot1Clay} < \mathbf{3} \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = \mathbf{31}\ \text{ft}$$ *(If* $L_{ot} < 3b$*, use Modified Broms method)*

$$L_{reqdOT} := \text{if}\left(\text{SoilType} = \textbf{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$L_{reqdOT} = \mathbf{11}\ \text{ft}$ *required shaft embedment depth to resist overturning*

Shaft Depth Required to Resist Torsion

short free-head pile in ***cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = 14$

$$\omega_{fdot} := \text{if}\left(N_{blows} < 5, 0, \text{if}\left(N_{blows} \ge 15, 1.5, 1.5\cdot\frac{N_{blows}}{15}\right)\right) = 1.4$$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\frac{N_{blows}}{15}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = 11\ \text{ft}$

$$\text{Given} \quad T_u = \phi_{tor}\cdot\left[\pi\cdot b\cdot\left(L_{torSand}\right)\cdot\gamma_{soil}\cdot\left(\frac{L_{torSand}}{2}\right)\cdot\left(\omega_{fdot}\right)\cdot\frac{b}{2}\right]$$

$$L_{torSand} := \text{Find}\left(L_{torSand}\right) = 8.7\ \text{ft}$$

$$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{\text{ft}}\right)\cdot\text{ft} = 9\ \text{ft}$$

(round up to next foot)

short free-head pile in ***cohesive soil***

$\text{CohesionFactor} := 0.55$

$f_{se} := \text{CohesionFactor}\cdot c_{soil} = 0.1\cdot\text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

$$\text{Given} \quad T_u = \phi_{tor}\cdot\left[f_{se}\cdot(\pi\cdot b)\cdot\left(L_{torClay} - 1.5\cdot\text{ft}\right)\cdot\frac{b}{2}\right]$$

$$L_{torClay} := \text{Find}\left(L_{torClay}\right) = 62.6\ \text{ft}$$

$$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{\text{ft}}\right)\cdot\text{ft} = 63\ \text{ft}$$

(round up to next foot)

$L_{reqdTor} := \text{if}\left(\text{SoilType} = \text{"Sand"}, L_{torSand}, L_{torClay}\right)$

$L_{reqdTor} = 9\ \text{ft}$

required shaft embedment depth to resist torsion

$L_{embedded} := \text{if}\left(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}\right) = 11\ \text{ft}$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = 11.5\ \text{ft}$

shaft length

Min Shaft embedment depth=12 ft

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2 \cdot P_u}{3 \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = 3.6\,ft$$

$$M_{maxSand} := P_u \cdot (e_{sand} + f_{sand}) - \frac{P_u \cdot f_{sand}}{3} + M_u = 67.6 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0 \cdot ft$

Given $P_u = \frac{f_{mod} \cdot b}{2} \cdot (2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot Slope)$

$f_{mod} := Find(f_{mod}) = 8.5\,ft$

$$M_{modBroms} := P_u \cdot (e_{clay} + f_{mod}) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^{2}}{2} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^{3} \cdot Slope}{6} = 76.6 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot (e_{clay} + 1.5 \cdot b + 0.5 \cdot f) = 80.8 \cdot kip \cdot ft$$

$M_{maxClay} := if(L_{ot1Clay} < 3 \cdot b, M_{modBroms}, M_{Broms}) = 80.8 \cdot kip \cdot ft$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$$M_{max} := if(SoilType = "Sand", M_{maxSand}, M_{maxClay}) = 67.6 \cdot kip \cdot ft$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$ *reinforcing yield strength*

$f_c := 4.0 \cdot ksi$ *concrete strength* *Spec 346-3*

$Cover := 3 \cdot in$ *cover* *SDG Table 1.4.2-1*

$Num_{bar} := 11$ *number of longitudinal bars*

$A_{long.bar} := 1.0 \cdot in^2$ *longitudinal bar area*

$d_{long.bar} := 1.125 \cdot in$ *longitudinal bar diameter*

$A_{v.bar} := 0.20 \cdot in^2$ *stirrup area* *SM Vol-3 13.6.2*

$d_{v.bar} := 0.5 \cdot in$ *stirrup diameter*

$s_{v1} := 3 \cdot in$ *stirrup spacing, depth = 0 ft-2 ft* *SM Vol-3 13.6.2*

$s_{v2} := 3 \cdot in$ *stirrup spacing, depth = 2 ft-depth.stir*

$s_{v3} := 6 \cdot in$ *stirrup spacing, depth > depth.stir*

$depth_{stir} := 10.0 \cdot ft$ *stirrup depth, see s.v2 and s.v3 above*

$b = 3\ ft$ *shaft diameter*

$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$ *required 1% steel* *SM Vol-3 13.6.2*

$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$ *LRFD 5.7.4.2*

$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot in^2$

$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$ *total area of longitudinal steel*

$CheckLongitudinalReinf := if(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"})$ $CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if(Clearance_{vert.reinf} \geq 6in, \text{"OK"}, \text{"No Good"})$ $CheckReinfClearSpacing = \text{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$$V_u := \sqrt{V_x^2 + V_z^2} = \mathbf{3.1} \cdot \text{kip}$$

$$T_u = \mathbf{47.5} \cdot \text{kip} \cdot \text{ft}$$

Effective shear depth

$$D_r := b - \mathbf{2} \cdot \left(\text{Cover} + d_{v.bar} + \frac{d_{long.bar}}{\mathbf{2}}\right) = \mathbf{2.3}\,\text{ft} \qquad d_e := \frac{b}{\mathbf{2}} + \frac{D_r}{\pi} = \mathbf{2.2}\,\text{ft}$$

LRFD C5.8.2.9-2

$$d_v := \max(\mathbf{0.9} \cdot d_e, \mathbf{0.72} \cdot b) = \mathbf{2.2}\,\text{ft}$$

Check Shear Strength

$$V_c := \mathbf{0.0316} \cdot (\mathbf{2.0}) \cdot \sqrt{\frac{f_c}{\text{ksi}}} \cdot \left(\frac{b}{\text{in}}\right) \cdot \left(\frac{d_v}{\text{in}}\right) \cdot \text{kip} = \mathbf{117.9} \cdot \text{kip}$$

LRFD Eqn 5.8.3.3-3 *LRFD 5.8.3.4.1* *ACI 11.3.3*

$$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max(s_{v1}, s_{v2}, s_{v3})} = \mathbf{51.8} \cdot \text{kip}$$

LRFD Eqn 5.8.3.3-4

$$\text{ShearRatio} := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = \mathbf{-2.2}$$

$$\text{ShearRatio} := \text{if}(\text{ShearRatio} \le \mathbf{0}, \mathbf{0}, \text{ShearRatio}) = \mathbf{0}$$

Check Torsion Strength

$$A_{cp} := \pi \cdot \left(\frac{b}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1017.9} \cdot \text{in}^{\mathbf{2}} \qquad p_{cp} := \mathbf{2} \cdot \pi \cdot \left(\frac{b}{\mathbf{2}}\right) = \mathbf{113.1} \cdot \text{in}$$

Area and perimeter of concrete cross-section

$$d_{oh} := b - \mathbf{2} \cdot \left(\text{Cover} + \frac{d_{v.bar}}{\mathbf{2}}\right) = \mathbf{29.5} \cdot \text{in} \qquad p_h := \pi \cdot d_{oh} = \mathbf{92.7} \cdot \text{in}$$

Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement

$$A_{oh} := \pi \left(\frac{d_{oh}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{683.5} \cdot \text{in}^{\mathbf{2}} \qquad A_o := \mathbf{0.85} \cdot A_{oh} = \mathbf{581} \cdot \text{in}^{\mathbf{2}}$$

$$T_{n1} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$$

LRFD Eqn 5.8.3.6.2-1

$$T_{n2} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$$

LRFD 5.8.3.4.1

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = \mathbf{193.7} \cdot kip \cdot ft$$

$\phi_v = \mathbf{0.9}$ $T_u = \mathbf{47.5} \cdot kip \cdot ft$ $L_{reqdTor} = \mathbf{9}\ ft$

$$Tor2_{sand} := T_u - if\left[\mathbf{2}ft > Offset, \left[\pi \cdot b \cdot (\mathbf{2} \cdot ft - Offset) \cdot \gamma_{soil} \cdot \left(\frac{\mathbf{2} \cdot ft - Offset}{\mathbf{2}}\right) \cdot \left(\omega_{fdot}\right) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot kip \cdot ft\right] = \mathbf{46.1} \cdot kip \cdot ft$$

$$Tor3_{sand} := T_u - if\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot \left(depth_{stir} - Offset\right) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{\mathbf{2}}\right) \cdot \left(\omega_{fdot}\right) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot kip \cdot ft\right] = -\mathbf{8.8} \cdot kip \cdot ft$$

$$Tor2_{clay} := T_u - if\left[\mathbf{2}ft - \mathbf{1.5}ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (\mathbf{2.0} \cdot ft - Offset - \mathbf{1.5} \cdot ft) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot kip \cdot ft\right] = \mathbf{47.5} \cdot kip \cdot ft$$

$$Tor3_{clay} := T_u - if\left[depth_{stir} - \mathbf{1.5}ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot \left(depth_{stir} - Offset - \mathbf{1.5} \cdot ft\right) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot kip \cdot ft\right] = \mathbf{41.3} \cdot kip \cdot ft$$

$$Tor2 := if\left(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}\right) = \mathbf{46.1} \cdot kip \cdot ft$$

$$Tor3 := if\left(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}\right) = -\mathbf{8.8} \cdot kip \cdot ft$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = \mathbf{0.12}$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = \mathbf{0.12}$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = -\mathbf{0.05}$$

$$TorsionRatio := max\left(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}\right) = \mathbf{0.12}$$

$$T_{cr} := \mathbf{0.125} \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{A_{cp}{}^{\mathbf{2}}}{p_{cp} \cdot in^{\mathbf{3}}}\right) \cdot kip \cdot in = \mathbf{190.9} \cdot kip \cdot ft$$

LRFD Eqn 5.8.2.1-4

$$TorsionRatio := if\left(T_u \le \mathbf{0.25} \cdot \phi_{tor} \cdot T_{cr}, \mathbf{0}, TorsionRatio\right) = \mathbf{0}$$

LRFD Eqn 5.8.2.1-3

$ShearRatio = \mathbf{0}$

CheckShearTorsion := if(ShearRatio + TorsionRatio ≤ **1**, **"OK"**, **"No Good"**)

CheckShearTorsion = **"OK"**

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = \mathbf{0.003632} \cdot ksi$$

$\mathbf{0.125} \cdot f_c = \mathbf{0.5} \cdot ksi$

LRFD Eqn 5.8.2.9-1

$s_{max1} := \text{if}\left(\mathbf{0.8}\cdot d_v < \mathbf{24}\cdot\text{in}, \mathbf{0.8}d_v, \mathbf{24}\cdot\text{in}\right) = \mathbf{20.7}\cdot\text{in}$ *LRFD Eqn 5.8.2.7-1*

$s_{max2} := \text{if}\left(\mathbf{0.4}\cdot d_v < \mathbf{12}\cdot\text{in}, \mathbf{0.4}d_v, \mathbf{12}\cdot\text{in}\right) = \mathbf{10.4}\cdot\text{in}$ *LRFD Eqn 5.8.2.7-2*

$s_{max} := \text{if}\left(v_u < \mathbf{0.125}\cdot f_c, s_{max1}, s_{max2}\right) = \mathbf{20.7}\cdot\text{in}$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = \mathbf{6}\cdot\text{in}$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \textbf{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion *LRFD Eqn 5.8.3.6.3-1*

LRFD 5.8.3.4.1

$M_u = \mathbf{58.7}\cdot\text{kip}\cdot\text{ft}$

$$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5\cdot V_s > \mathbf{0}\cdot\text{kip}, \frac{V_u}{\phi_v} - 0.5\cdot V_s, \mathbf{0}\cdot\text{kip}\right) = \mathbf{0}\cdot\text{kip}$$

$$\text{LongReinf}_{shr.tor} := \frac{\dfrac{M_u}{\phi_v\cdot d_v} + \sqrt{\left(V_{temp}\right)^{\mathbf{2}} + \left(\dfrac{\mathbf{0.45}\cdot p_h\cdot T_u}{\mathbf{2}\cdot A_o\cdot\phi_v}\right)^{\mathbf{2}}}}{F_{y.rebar}} = \mathbf{0.9}\cdot\text{in}^{\mathbf{2}}$$

$\text{Num}_{bar}\cdot A_{long.bar} = \mathbf{11}\cdot\text{in}^{\mathbf{2}}$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(\text{Num}_{bar}\cdot A_{long.bar} \ge \text{LongReinf}_{shr.tor}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \textbf{"OK"}$

Anchor Bolt Strength Check

$\text{Num}_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot \text{in}$ *anchor bolt nominal diameter*

$\text{Dia}_{anchor.circle} := 24 \cdot \text{in}$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot \text{ksi}$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{\text{Dia}_{anchor.circle}{}^{2}}{8} \cdot \text{Num}_{anchor} = 576 \cdot \text{in}^{2}$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{\text{Dia}_{anchor.circle}}{2}} = 48 \cdot \text{in}$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 14.7 \cdot \text{kip}$$ *anchor tension force*

$$V_{anchor} := \frac{V_u}{\text{Num}_{anchor}} + \frac{T_u}{0.5\text{Dia}_{anchor.circle} \cdot \text{Num}_{anchor}} = 6.3 \cdot \text{kip}$$ *anchor shear force*

$$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}{}^{2} = 3.1 \cdot \text{in}^{2}$$ *anchor bolt nominal area*

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 4.7 \cdot \text{ksi}$$ *anchor tensile stress*

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 2 \cdot \text{ksi}$$ *anchor shear stress*

$\phi_{anchor} := 0.75$ *resistance factor* AISC J3-1

$F_{nt} := 0.75 F_{u.anchor} = 78.8 \cdot \text{ksi}$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := 0.45 F_{u.anchor} = 47.2 \cdot \text{ksi}$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot \text{kip}$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot \text{kip}$ *design sghear strength*

$\text{CheckAnchorT} := \text{if}\left(\phi R_{nt} \geq T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$\text{CheckAnchorT} = \text{"OK"}$

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \textbf{"OK"}, \textbf{"No Good"}\right)$ *check shear rupture*

$\text{CheckAnchorV} = \textbf{"OK"}$

$$F_{ntv} := \textbf{min}\left(\begin{pmatrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{pmatrix}\right) = \textbf{78.8} \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = \textbf{185.6} \cdot \text{kip}$

design tension strength modified to include the effects of shearing stress

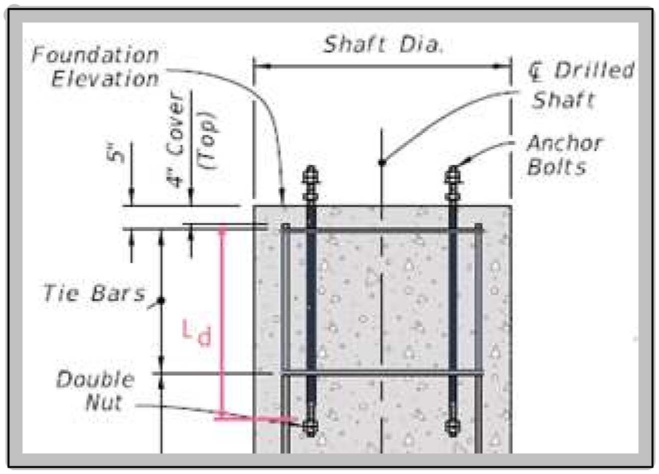
$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq \textbf{20}\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq \textbf{20}\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \textbf{"OK"}, \textbf{"No Good"}\right]$

$\text{CheckAnchorTV} = \textbf{"OK"}$ *check combined tension and shear rupture*

$\text{CheckAnchorStrength} := \text{if}[(\text{CheckAnchorT} \textbf{ = "OK"}) \cdot (\text{CheckAnchorV} \textbf{ = "OK"}) \cdot (\text{CheckAnchorTV} \textbf{ = "OK"}), \textbf{"OK"}, \textbf{"No Good"}$

$\text{CheckAnchorStrength} = \textbf{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = \textbf{14.7} \cdot \text{kip}$ *tension force in anchor*

$\text{Dia}_{bar.circle} = \textbf{27.9} \cdot \text{in}$ $\text{Dia}_{anchor.circle} = \textbf{24} \cdot \text{in}$

center-to-center distance

$$\text{Dist}_{bar.to.bolt} := \frac{\text{Dia}_{bar.circle} - \text{Dia}_{anchor.circle}}{\textbf{2}} = \textbf{1.9} \cdot \text{in}$$

$$\text{Num}_{bars.per.anchor} := \min\left(\frac{\text{Num}_{bar}}{\text{Num}_{anchor}}, \textbf{3}\right) = \textbf{1.4}$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := \textbf{0.9}$

$$\text{Num}_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{\text{Dia}_{anchor.circle}}{\text{Dia}_{bar.circle}} = \textbf{0.23}$$

$$\text{AreaRatio} := \min\left(\frac{\text{Num}_{bars.reqd.per.anchor}}{\text{Num}_{bars.per.anchor}}, \textbf{1}\right) = \textbf{0.17}$$

2015 AASHTO Development Length of Deformed Bars in Tension 5.11.2.1

$\text{Cover} = \textbf{3} \cdot \text{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half the center-to-center spacing of the bars or wires being developed*

$$c_b := \min\left(\left(\begin{array}{c} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{\mathbf{2}} \\ \dfrac{\text{Spacing}_{vert.reinf}}{\mathbf{2}} \end{array}\right)\right) = \mathbf{4}\cdot\text{in}$$

$k_{tr} := \mathbf{0}\cdot\text{in}$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\left[\begin{array}{c} \mathbf{1.0} \\ \max\left(\left(\begin{array}{c} \mathbf{0.4} \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{array}\right)\right) \end{array}\right]\right] = \mathbf{0.4}$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\left(\begin{array}{c} \mathbf{12}\cdot\text{in} \\ \lambda_{rc}\cdot\mathbf{2.4}\cdot d_{long.bar}\cdot\dfrac{F_{y.rebar}}{\sqrt{f_c\cdot\text{ksi}}} \end{array}\right)\right) = \mathbf{32.4}\cdot\text{in}$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$\text{SpacingFactor} := \max\left[\left(\begin{array}{c} \mathbf{0.5} \\ \text{Num}_{bars.per.anchor}\cdot\mathbf{0.5} - \mathbf{0.5} \end{array}\right)\right] = \mathbf{0.5}$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf}\cdot\text{SpacingFactor}\right)^{\mathbf{2}} + \text{Dist}_{bar.to.bolt}{}^{\mathbf{2}}} = \mathbf{3.9}\cdot\text{in}$$

$$L_{embedment.anchor} := \max\left[\left[\begin{array}{c} L_{d.bar}\cdot(\text{AreaRatio}) + \mathbf{12}\cdot\text{in} + L_{embedment.added} \\ \mathbf{20}\cdot d_{anchor} \end{array}\right]\right] = \mathbf{40}\cdot\text{in}$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, \text{in}\right)$

$L_{embedment.anchor} = \mathbf{40}\cdot\text{in}$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^2 + 3.25 \cdot \left(r^2 - r_b^2\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\begin{pmatrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{pmatrix}\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2\, \text{asin}\left[\frac{(1.5 \cdot c_{a1})}{r}\right] = 45.2 \cdot deg$$

$$OverlapTest := \text{if}\left(A_{bolt.sector} \le \alpha, \textbf{"Overlap of Failure Cones"}, \textbf{"No Overlap of Failure Cones"}\right) = \textbf{"Overlap of Failure Cones"}$$

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{\ 2} = 95.9 \cdot in^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \text{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$$

$\psi_{ecV} := 1.0$ *eccentric load modifier* ACI D.6.2.5

$\psi_{edV} := 1.0$ *edge effect modifier* ACI D.6.2.6

$\psi_{cV} := 1.4$ *cracked section modifier* ACI D.6.2.7 *(stirrup spacing <= 4")*

$\psi_{hV} := 1.0$ *member thickness modifier* ACI D.6.2.8

$\phi_{breakout} := 0.75$ *strength reduction factor* ACI D.4.4.c.i *(shear breakout, condition A)*

$$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = \mathbf{194.7} \cdot kip$$

concrete breakout strength - shear

ACI Eqn D-22 *Shear force ⊥ to edge*

$$V_{cbg\_parallel} := \mathbf{2} \cdot V_{cbg} = \mathbf{389.5} \cdot kip$$

ACI D.6.2.1.c *Shear force ∥ to edge*

$$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = \mathbf{389.5} \cdot kip \cdot ft$$

concrete breakout strength - torsion

$$\phi_{breakout} \cdot T_{n.breakout} = \mathbf{292.1} \cdot kip \cdot ft$$

$$T_u = \mathbf{47.5} \cdot kip \cdot ft$$

BreakoutTest := if$\left(\phi_{breakout} \cdot T_{n.breakout} \geq T_u\right.$, **"OK"** , **"No Good"**)

BreakoutTest = **"OK"**

OverlapDesign := if$\left(A_{bolt.sector} \leq \alpha\right.$, **"Based on Overlap of Failure Cones"** , **"Based on No Overlap of Failure Cones"**)

OverlapDesign = **"Based on Overlap of Failure Cones"**

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = \mathbf{1.9} \cdot in$ *center-to-center distance*

$d_{anchor.nut} := \mathbf{1.85} \cdot d_{anchor} = \mathbf{3.7} \cdot in$ *use* $\mathbf{1.85} \cdot d_{anchor}$ *.to account for anchor nut*

$$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{\mathbf{2}}\right) = -\mathbf{0.5} \cdot in$$

CheckAnchorageClearance := if[$\left(Clearance_{bar.to.nut} \geq \mathbf{2} \cdot in\right)$, **"OK"** , **"No Good, increase ped. diameter"**]

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0..48 \qquad r_{ds} := \frac{b}{2}$

$x_{ds_{pt}} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{ds_{pt}} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$x_{stir.od_{pt}} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.od_{pt}} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$x_{stir.id_{pt}} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.id_{pt}} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$x_{bar_{pt}} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max(x_{stir.id}) - d_{v.bar} \qquad y_{bar_{pt}} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$x_{boltcircle_{pt}} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{boltcircle_{pt}} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltr} := \frac{d_{anchor}}{2} = 1 \cdot in$

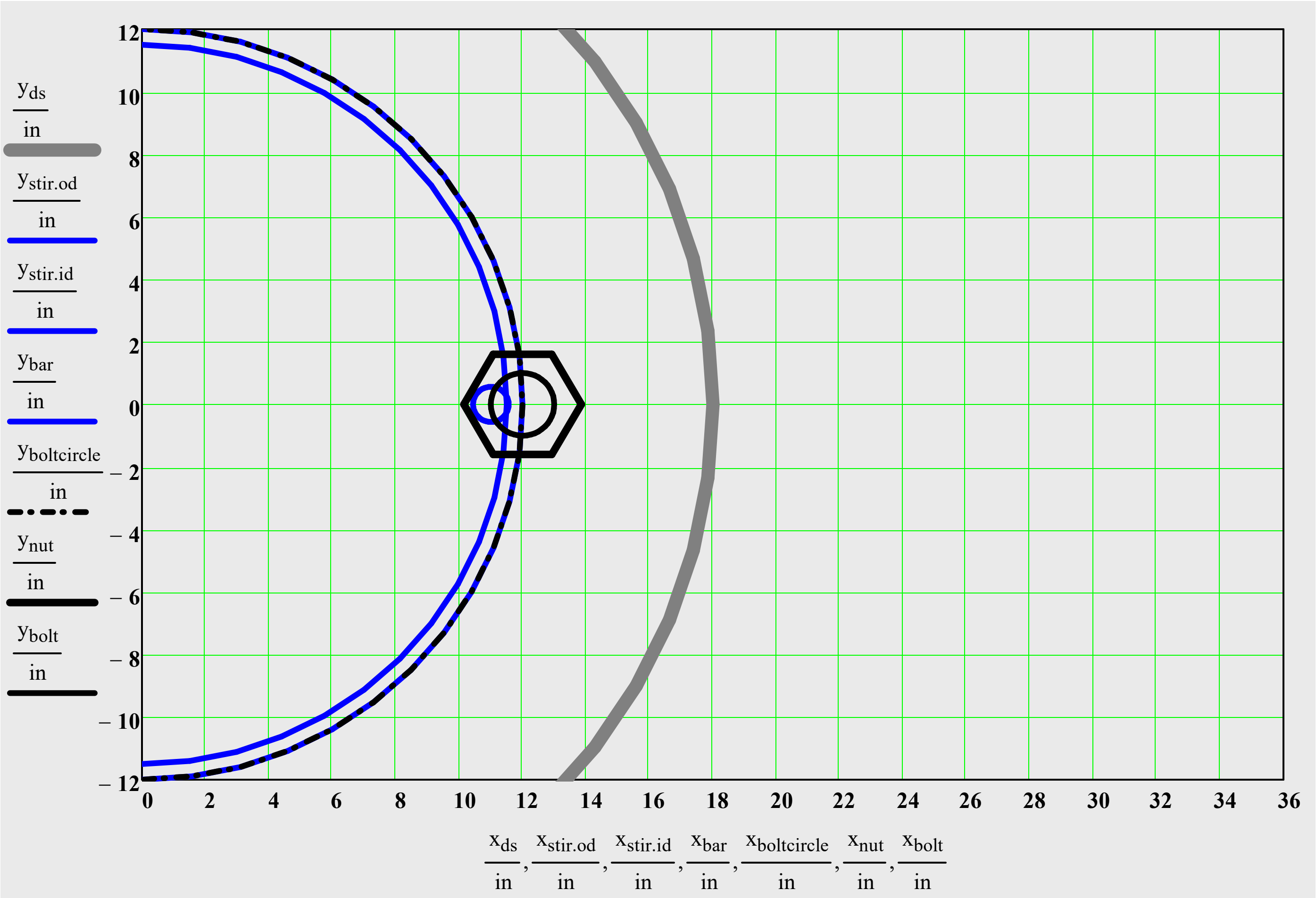
$x_{bolt_{pt}} := r_{boltr} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $\qquad$ $y_{bolt_{pt}} := r_{boltr} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$pt := 0 .. 6$ $\qquad$ $r_{nut} := \frac{d_{anchor} \cdot 1.85}{2} = 1.9 \cdot in$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{6} + \frac{2 \cdot \pi}{6}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $\qquad$ $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{6}\right) + \frac{2 \cdot \pi}{6}\right]$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{6} + \frac{1 \cdot \pi}{6}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $\qquad$ *enable to rotate nut* $\qquad$ $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{6}\right) + \frac{1 \cdot \pi}{6}\right]$

$\min\left(x_{bar}\right) - \max\left(x_{nut}\right) = -3.4 \cdot in$



$$\text{Bolts} := \begin{pmatrix} \mathbf{1} & \mathbf{1.125} & \mathbf{1.25} & \mathbf{1.375} & \mathbf{1.5} & \mathbf{1.625} & \mathbf{1.75} & \mathbf{1.875} & \mathbf{2} & \mathbf{2.25} & \mathbf{2.5} & \mathbf{2.75} & \mathbf{3} \\ \mathbf{1.5} & \mathbf{1.688} & \mathbf{1.875} & \mathbf{2.063} & \mathbf{2.25} & \mathbf{2.438} & \mathbf{2.625} & \mathbf{2.938} & \mathbf{3} & \mathbf{3.375} & \mathbf{3.75} & \mathbf{4.125} & \mathbf{4.25} \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{T}\right)^{\langle \mathbf{0} \rangle^{T}} \cdot \mathbf{1.6} - \left(\text{Bolts}^{T}\right)^{\langle \mathbf{1} \rangle^{T}} = \begin{pmatrix} \mathbf{0.1} & \mathbf{0.112} & \mathbf{0.125} & \mathbf{0.137} & \mathbf{0.15} & \mathbf{0.162} & \mathbf{0.175} & \mathbf{0.062} & \mathbf{0.2} & \mathbf{0.225} & \mathbf{0.25} & \mathbf{0.275} & \mathbf{0.55} \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{T}\right)^{\langle \mathbf{0} \rangle^{T}} - \left(\text{Bolts}^{T}\right)^{\langle \mathbf{1} \rangle^{T}} = \begin{pmatrix} \mathbf{-0.5} & \mathbf{-0.563} & \mathbf{-0.625} & \mathbf{-0.688} & \mathbf{-0.75} & \mathbf{-0.813} & \mathbf{-0.875} & \mathbf{-1.063} & \mathbf{-1} & \mathbf{-1.125} & \mathbf{-1.25} & \mathbf{-1.375} & \mathbf{-1.25} \end{pmatrix} \cdot \text{i}$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

FDOT
State Structures Design Office

SUBJECT 079-241-G MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

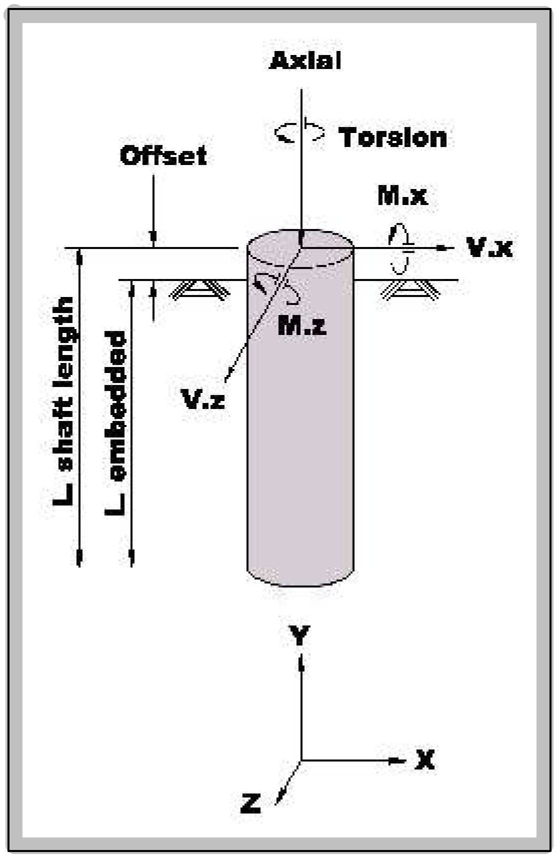
SoilType :=
- Sand
- Clay

$\phi_{soil} := \mathbf{32} \cdot deg$ *soil friction angle (sand)*

$c_{soil} := \mathbf{0.0} \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

$N_{blows} := \mathbf{14}$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := \mathbf{63} \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*



Geometry

$b := \mathbf{3.0} \cdot ft$ *shaft diameter*

$Offset := \mathbf{0.50} \cdot ft$ *groundline to top of foundation*

Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := \mathbf{38.2} \cdot kip \cdot ft$ $V_x := \mathbf{0.05} \cdot kip$ $Torsion := \mathbf{19.90} \cdot kip \cdot ft$

$M_z := \mathbf{13.0} \cdot kip \cdot ft$ $V_z := \mathbf{2.5} \cdot kip$ $Axial := \mathbf{16.50} \cdot kip$

StructureType :=
- Cantilever Overhead Sign Structure
- Mast Arm Signal Structure
- Concrete/Steel Strain Poles
- Ground Sign

$StructureType = 1$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

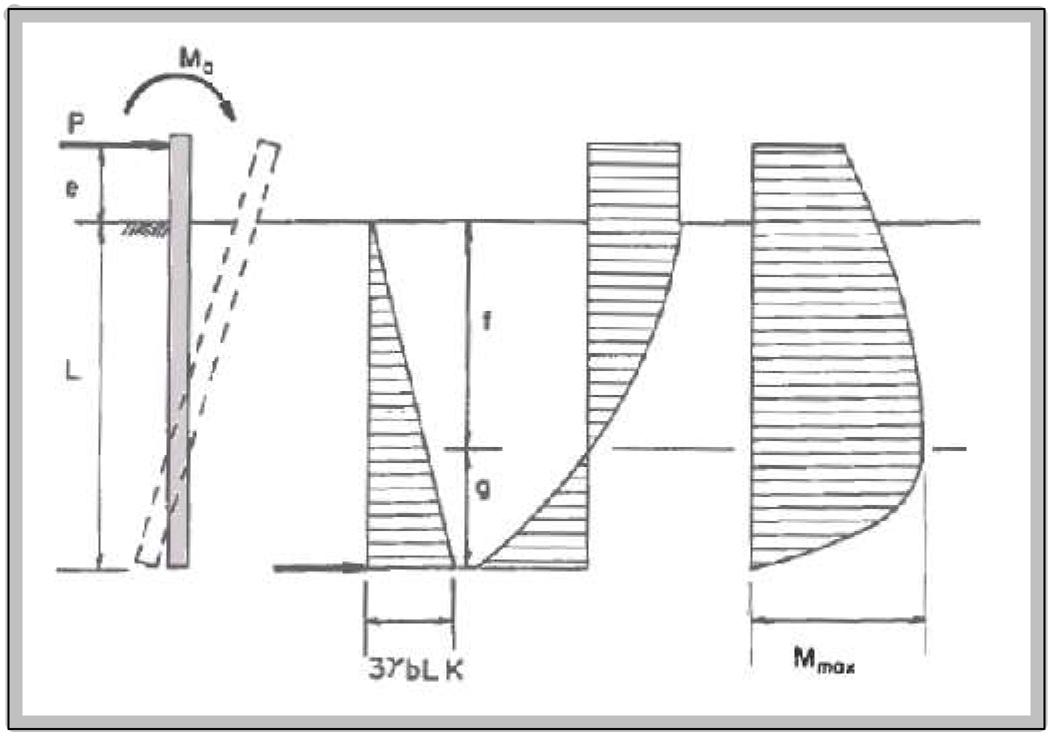
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x^{2} + M_z^{2}} = \mathbf{40.4} \cdot \text{kip} \cdot \text{ft}$

$P_u := \sqrt{V_x^{2} + V_z^{2}} = \mathbf{2.5} \cdot \text{kip}$

$T_u := \text{Torsion} = \mathbf{19.9} \cdot \text{kip} \cdot \text{ft}$

short free-head pile in ***cohesionless soil*** *using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(\mathbf{45} \cdot \text{deg} + \frac{\phi_{soil}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{3.3}$ $\qquad e_{sand} := \text{Offset} = \mathbf{0.5} \text{ft}$

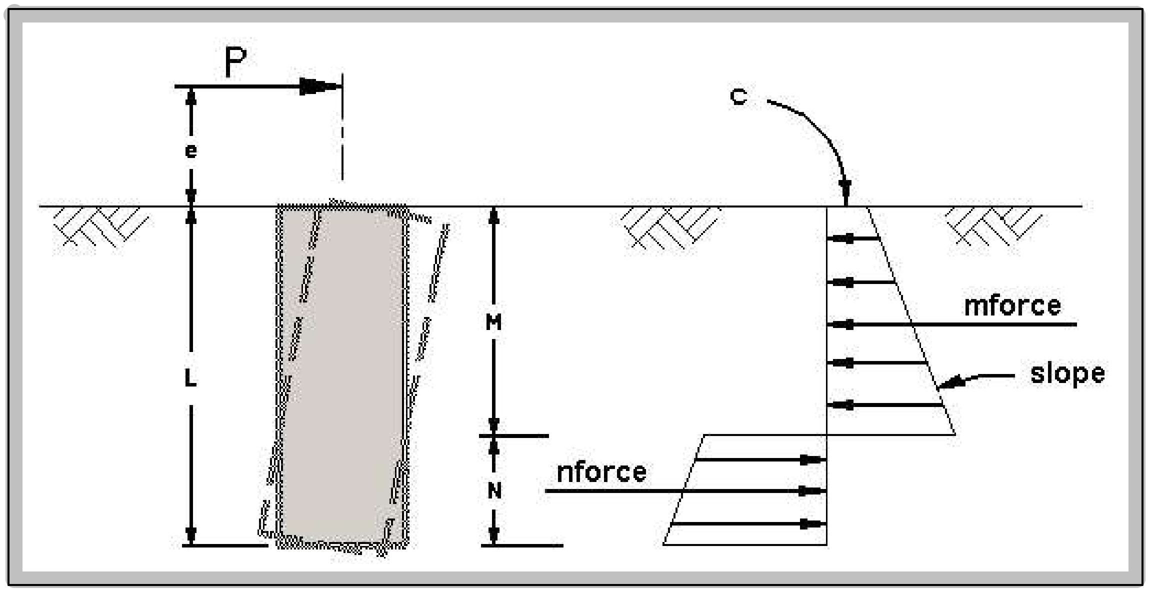
Guess value $\qquad L_{otSand} := \mathbf{8} \cdot \text{ft}$

Given $\qquad P_u \cdot \left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot} \cdot \left[\left(\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{2}} \cdot L_{otSand}\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{3}} \cdot L_{otSand}\right)\right]$

$L_{otSand} := \text{Find}\left(L_{otSand}\right) = \mathbf{9.5} \text{ft}$

$L_{otSand} := \text{ceil}\left(\frac{L_{otSand}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{10} \text{ft}$ $\qquad$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$$c_{soil} := \text{if}\left(c_{soil} = 0 \cdot ksf, 0.1 \cdot ksf, c_{soil}\right) = 0.1 \cdot ksf$$

$$Slope := 8 \cdot \frac{c_{soil}}{3 \cdot b} = 0.1 \cdot \frac{kip}{ft^3}$$

$$e_{clay} := \frac{M_u}{P_u} + Offset = 16.6\,ft$$

$$nforce(M,N) := \left[Slope \cdot (2 \cdot M + N) + 2 \cdot c_{soil}\right] \cdot N \cdot \frac{b}{2}$$

$$mforce(M) := \left(2 \cdot c_{soil} + M \cdot Slope\right) \cdot M \cdot \frac{b}{2}$$

$$m\_arm(M) := e_{clay} + \frac{M}{3} \cdot \frac{2 \cdot (M \cdot Slope + c_{soil}) + c_{soil}}{M \cdot Slope + 2 \cdot c_{soil}}$$

$$n\_arm(M,N) := e_{clay} + M + \frac{N}{3} \cdot \frac{2 \cdot (N \cdot Slope + M \cdot Slope + c_{soil}) + (M \cdot Slope + c_{soil})}{Slope \cdot (2 \cdot M + N) + 2 \cdot c_{soil}}$$

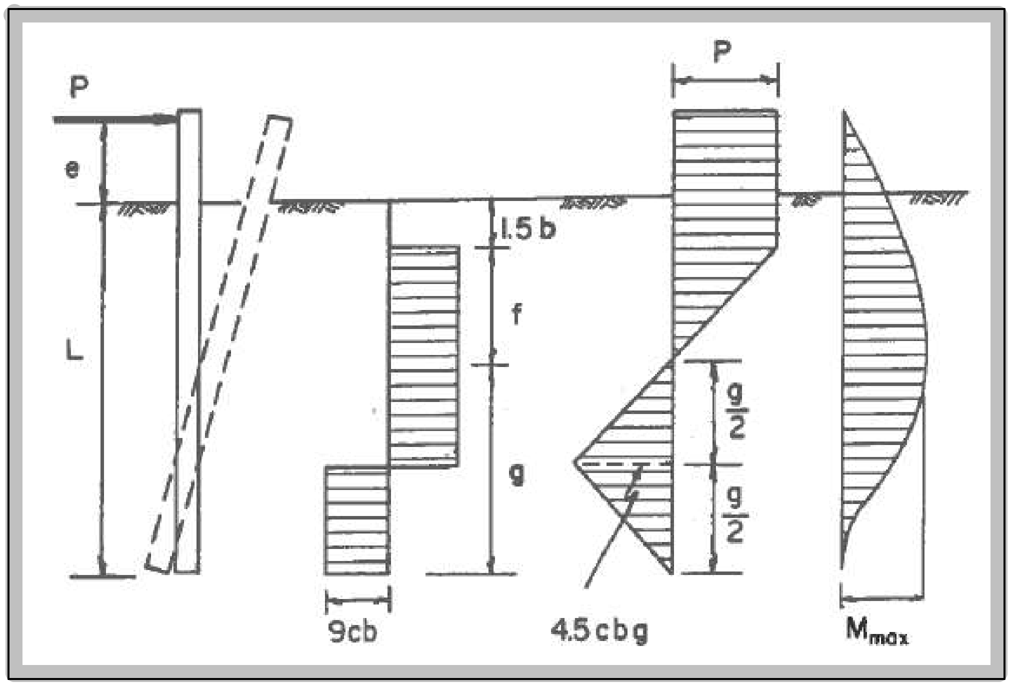
Guess value $M := 4.0 \cdot ft$ $N := 4.0 \cdot ft$

Given $P_u + \phi_{ot} \cdot nforce(M,N) = \phi_{ot} \cdot mforce(M)$ $mforce(M) \cdot m\_arm(M) = nforce(M,N) \cdot n\_arm(M,N)$

$$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M,N) \qquad L_{ot1Clay} := M + N = 7.0\,ft$$

$$L_{ot1Clay} := \text{ceil}\left(\frac{L_{ot1Clay}}{ft}\right) \cdot ft = 8\,ft$$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot 9 \cdot c_{soil} \cdot b} = 3.7 \, ft$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + 1.5 \cdot b + 0.5 \cdot f\right) = 57.5 \cdot kip \cdot ft$$

$$g := \sqrt{\frac{M_{max.clay}}{2.25 \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = 18.5 \, ft$$

$$L_{ot2Clay} := \left(1.5 \cdot b + f + g\right) = 26.7 \, ft$$

$$L_{ot2Clay} := ceil\left(\frac{L_{ot2Clay}}{ft}\right) \cdot ft = 27 \, ft$$ *(round up to next foot)*

$$L_{otClay} := if\left(L_{ot1Clay} < 3 \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = 8 \, ft$$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$$L_{reqdOT} := if\left(SoilType = \text{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$$L_{reqdOT} = 10 \, ft$$ *required shaft embedment depth to resist overturning*

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = 14$

$\omega_{fdot} := \text{if}\left(N_{blows} < 5, 0, \text{if}\left(N_{blows} \geq 15, 1.5, 1.5 \cdot \frac{N_{blows}}{15}\right)\right) = 1.4$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\frac{N_{blows}}{15}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = 10\,\text{ft}$

Given $T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot (L_{torSand}) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right]$

$L_{torSand} := \text{Find}(L_{torSand}) = 5.6\,\text{ft}$

$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{\text{ft}}\right) \cdot \text{ft} = 6\,\text{ft}$ *(round up to next foot)*

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := 0.55$

$f_{se} := \text{CohesionFactor} \cdot c_{soil} = 0.1 \cdot \text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

Given $T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot (L_{torClay} - 1.5 \cdot \text{ft}) \cdot \frac{b}{2}\right]$

$L_{torClay} := \text{Find}(L_{torClay}) = 27.1\,\text{ft}$

$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{\text{ft}}\right) \cdot \text{ft} = 28\,\text{ft}$ *(round up to next foot)*

$L_{reqdTor} := \text{if}(\text{SoilType} = \text{"Sand"}, L_{torSand}, L_{torClay})$

$L_{reqdTor} = 6\,\text{ft}$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}) = 10\,\text{ft}$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = 10.5\,\text{ft}$ **Min Shaft embedment depth=12 ft** *shaft length*

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{\mathbf{2} \cdot P_u}{\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = \mathbf{3.3}\,ft$$

$$M_{maxSand} := P_u \cdot (e_{sand} + f_{sand}) - \frac{P_u \cdot f_{sand}}{\mathbf{3}} + M_u = \mathbf{47.1} \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := \mathbf{4.0} \cdot ft$

Given $P_u = \frac{f_{mod} \cdot b}{\mathbf{2}} \cdot (2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot Slope)$

$f_{mod} := Find(f_{mod}) = \mathbf{7.6}\,ft$

$$M_{modBroms} := P_u \cdot (e_{clay} + f_{mod}) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^{\mathbf{2}}}{\mathbf{2}} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^{\mathbf{3}} \cdot Slope}{\mathbf{6}} = \mathbf{53.6} \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot (e_{clay} + \mathbf{1.5} \cdot b + \mathbf{0.5} \cdot f) = \mathbf{57.5} \cdot kip \cdot ft$$

$$M_{maxClay} := if(L_{ot1Clay} < \mathbf{3} \cdot b, M_{modBroms}, M_{Broms}) = \mathbf{53.6} \cdot kip \cdot ft$$

(If $L_{ot} < 3b$, use Modified Broms method)

$$M_{max} := if(SoilType = \mathbf{"Sand"}, M_{maxSand}, M_{maxClay}) = \mathbf{47.1} \cdot kip \cdot ft$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$ *reinforcing yield strength*

$f_c := 4.0 \cdot ksi$ *concrete strength* *Spec 346-3*

$Cover := 3 \cdot in$ *cover* *SDG Table 1.4.2-1*

$Num_{bar} := 11$ *number of longitudinal bars*

$A_{long.bar} := 1.0 \cdot in^2$ *longitudinal bar area*

$d_{long.bar} := 1.125 \cdot in$ *longitudinal bar diameter*

$A_{v.bar} := 0.20 \cdot in^2$ *stirrup area* *SM Vol-3 13.6.2*

$d_{v.bar} := 0.5 \cdot in$ *stirrup diameter*

$s_{v1} := 3 \cdot in$ *stirrup spacing, depth = 0 ft-2 ft* *SM Vol-3 13.6.2*

$s_{v2} := 3 \cdot in$ *stirrup spacing, depth = 2 ft-depth.stir*

$s_{v3} := 6 \cdot in$ *stirrup spacing, depth > depth.stir*

$depth_{stir} := 10.0 \cdot ft$ *stirrup depth, see s.v2 and s.v3 above*

$b = 3 \, ft$ *shaft diameter*

$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$ *required 1% steel* *SM Vol-3 13.6.2*

$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$ *LRFD 5.7.4.2*

$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot in^2$

$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$ *total area of longitudinal steel*

$CheckLongitudinalReinf := if(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"})$ $CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if(Clearance_{vert.reinf} \geq 6in, \text{"OK"}, \text{"No Good"})$ $CheckReinfClearSpacing = \text{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$V_u := \sqrt{V_x^{2} + V_z^{2}} = 2.5 \cdot \text{kip}$

$T_u = 19.9 \cdot \text{kip} \cdot \text{ft}$

Effective shear depth

$D_r := b - 2 \cdot \left(\text{Cover} + d_{v.bar} + \frac{d_{long.bar}}{2} \right) = 2.3 \,\text{ft}$ $d_e := \frac{b}{2} + \frac{D_r}{\pi} = 2.2 \,\text{ft}$ *LRFD C5.8.2.9-2*

$d_v := \max(0.9 \cdot d_e, 0.72 \cdot b) = 2.2 \,\text{ft}$

Check Shear Strength

$V_c := 0.0316 \cdot (2.0) \cdot \sqrt{\frac{f_c}{\text{ksi}}} \cdot \left(\frac{b}{\text{in}}\right) \cdot \left(\frac{d_v}{\text{in}}\right) \cdot \text{kip} = 117.9 \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-3* *LRFD 5.8.3.4.1* *ACI 11.3.3*

$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max(s_{v1}, s_{v2}, s_{v3})} = 51.8 \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-4*

$\text{ShearRatio} := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -2.2$

$\text{ShearRatio} := \text{if}(\text{ShearRatio} \le 0, 0, \text{ShearRatio}) = 0$

Check Torsion Strength

$A_{cp} := \pi \cdot \left(\frac{b}{2}\right)^{2} = 1017.9 \cdot \text{in}^{2}$ $p_{cp} := 2 \cdot \pi \cdot \left(\frac{b}{2}\right) = 113.1 \cdot \text{in}$ *Area and perimeter of concrete cross-section*

$d_{oh} := b - 2 \cdot \left(\text{Cover} + \frac{d_{v.bar}}{2} \right) = 29.5 \cdot \text{in}$ $p_h := \pi \cdot d_{oh} = 92.7 \cdot \text{in}$ *Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement*

$A_{oh} := \pi \left(\frac{d_{oh}}{2}\right)^{2} = 683.5 \cdot \text{in}^{2}$ $A_o := 0.85 \cdot A_{oh} = 581 \cdot \text{in}^{2}$

$T_{n1} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = 387.3 \cdot \text{kip} \cdot \text{ft}$ *LRFD Eqn 5.8.3.6.2-1*

$T_{n2} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = 387.3 \cdot \text{kip} \cdot \text{ft}$ *LRFD 5.8.3.4.1*

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = 193.7 \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$\phi_v = 0.9$ $T_u = 19.9 \cdot \mathrm{kip} \cdot \mathrm{ft}$ $L_{reqdTor} = 6\,\mathrm{ft}$

$$Tor2_{sand} := T_u - \mathrm{if}\left[2\mathrm{ft} > Offset, \left[\pi \cdot b \cdot (2 \cdot \mathrm{ft} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{2 \cdot \mathrm{ft} - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot \mathrm{kip} \cdot \mathrm{ft}\right] = 18.5 \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor3_{sand} := T_u - \mathrm{if}\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot (depth_{stir} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot \mathrm{kip} \cdot \mathrm{ft}\right] = -36.4 \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor2_{clay} := T_u - \mathrm{if}\left[2\mathrm{ft} - 1.5\mathrm{ft} > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (2.0 \cdot \mathrm{ft} - Offset - 1.5 \cdot \mathrm{ft}) \cdot \frac{b}{2}\right], 0 \cdot \mathrm{kip} \cdot \mathrm{ft}\right] = 19.9 \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor3_{clay} := T_u - \mathrm{if}\left[depth_{stir} - 1.5\mathrm{ft} > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (depth_{stir} - Offset - 1.5 \cdot \mathrm{ft}) \cdot \frac{b}{2}\right], 0 \cdot \mathrm{kip} \cdot \mathrm{ft}\right] = 13.7 \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor2 := \mathrm{if}(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}) = 18.5 \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor3 := \mathrm{if}(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}) = -36.4 \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = 0.05$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = 0.05$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = -0.19$$

$$TorsionRatio := \max(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}) = 0.05$$

$$T_{cr} := 0.125 \sqrt{\frac{f_c}{\mathrm{ksi}}} \cdot \left(\frac{A_{cp}{}^2}{p_{cp} \cdot \mathrm{in}^3}\right) \cdot \mathrm{kip} \cdot \mathrm{in} = 190.9 \cdot \mathrm{kip} \cdot \mathrm{ft}$$

LRFD Eqn 5.8.2.1-4

$$TorsionRatio := \mathrm{if}(T_u \le 0.25 \cdot \phi_{tor} \cdot T_{cr}, 0, TorsionRatio) = 0$$

LRFD Eqn 5.8.2.1-3

$ShearRatio = 0$

$$CheckShearTorsion := \mathrm{if}(ShearRatio + TorsionRatio \le 1, \text{"OK"}, \text{"No Good"})$$

$CheckShearTorsion = \text{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = 0.002977 \cdot \mathrm{ksi}$$

$0.125 \cdot f_c = 0.5 \cdot \mathrm{ksi}$

LRFD Eqn 5.8.2.9-1

$$s_{max1} := \mathrm{if}(0.8 \cdot d_v < 24 \cdot \mathrm{in}, 0.8 d_v, 24 \cdot \mathrm{in}) = 20.7 \cdot \mathrm{in}$$

LRFD Eqn 5.8.2.7-1

$s_{max2} := \text{if}\left(0.4 \cdot d_v < 12 \cdot \text{in}, 0.4 d_v, 12 \cdot \text{in}\right) = 10.4 \cdot \text{in}$

LRFD Eqn 5.8.2.7-2

$s_{max} := \text{if}\left(v_u < 0.125 \cdot f_c, s_{max1}, s_{max2}\right) = 20.7 \cdot \text{in}$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = 6 \cdot \text{in}$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \leq s_{max}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \text{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion

LRFD Eqn 5.8.3.6.3-1

LRFD 5.8.3.4.1

$M_u = 40.4 \cdot \text{kip} \cdot \text{ft}$

$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5 \cdot V_s > 0 \cdot \text{kip}, \frac{V_u}{\phi_v} - 0.5 \cdot V_s, 0 \cdot \text{kip}\right) = 0 \cdot \text{kip}$

$$\text{LongReinf}_{shr.tor} := \frac{\frac{M_u}{\phi_v \cdot d_v} + \sqrt{\left(V_{temp}\right)^2 + \left(\frac{0.45 \cdot p_h \cdot T_u}{2 \cdot A_o \cdot \phi_v}\right)^2}}{F_{y.rebar}} = 0.5 \cdot \text{in}^2$$

$\text{Num}_{bar} \cdot A_{long.bar} = 11 \cdot \text{in}^2$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(\text{Num}_{bar} \cdot A_{long.bar} \geq \text{LongReinf}_{shr.tor}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \text{"OK"}$

Anchor Bolt Strength Check

$Num_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot in$ *anchor bolt nominal diameter*

$Dia_{anchor.circle} := 24 \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{Dia_{anchor.circle}^{2}}{8} \cdot Num_{anchor} = 576 \cdot in^{2}$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{Dia_{anchor.circle}}{2}} = 48 \cdot in$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 10.1 \cdot kip$$ *anchor tension force*

$$V_{anchor} := \frac{V_u}{Num_{anchor}} + \frac{T_u}{0.5Dia_{anchor.circle} \cdot Num_{anchor}} = 2.8 \cdot kip$$ *anchor shear force*

$$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}^{2} = 3.1 \cdot in^{2}$$ *anchor bolt nominal area*

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 3.2 \cdot ksi$$ *anchor tensile stress*

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 0.9 \cdot ksi$$ *anchor shear stress*

$\phi_{anchor} := 0.75$ *resistance factor* AISC J3-1

$F_{nt} := 0.75 F_{u.anchor} = 78.8 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := 0.45 F_{u.anchor} = 47.2 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot kip$ *design sghear strength*

$CheckAnchorT := if\left(\phi R_{nt} \geq T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$CheckAnchorT = \text{"OK"}$

$$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \text{"OK"}, \text{"No Good"}\right)$$

check shear rupture

$$\text{CheckAnchorV} = \text{"OK"}$$

$$F_{ntv} := \min\left(\left(\begin{matrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{matrix}\right)\right) = 78.8 \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = 185.6 \cdot \text{kip}$$

design tension strength modified to include the effects of shearing stress

$$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq 20\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq 20\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \text{"OK"}, \text{"No Good"}\right]$$

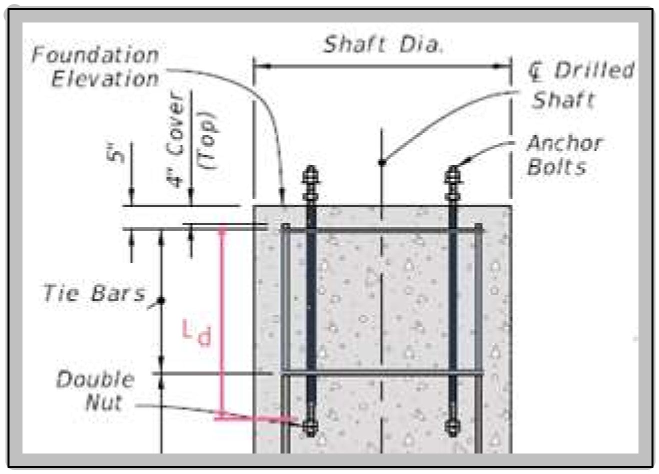
$$\text{CheckAnchorTV} = \text{"OK"}$$

check combined tension and shear rupture

$$\text{CheckAnchorStrength} := \text{if}\left[\left(\text{CheckAnchorT} = \text{"OK"}\right) \cdot \left(\text{CheckAnchorV} = \text{"OK"}\right) \cdot \left(\text{CheckAnchorTV} = \text{"OK"}\right), \text{"OK"}, \text{"No Good"}\right]$$

$$\text{CheckAnchorStrength} = \text{"OK"}$$

Anchor Bolt Embedment



$T_{anchor} = 10.1 \cdot \text{kip}$ *tension force in anchor*

$Dia_{bar.circle} = 27.9 \cdot \text{in}$ $Dia_{anchor.circle} = 24 \cdot \text{in}$

center-to-center distance

$$Dist_{bar.to.bolt} := \frac{Dia_{bar.circle} - Dia_{anchor.circle}}{2} = 1.9 \cdot \text{in}$$

$$Num_{bars.per.anchor} := \min\left(\frac{Num_{bar}}{Num_{anchor}}, 3\right) = 1.4$$

Use a maximum of three rebar per anchor bolt (conservative)

$$\phi := 0.9$$

$$Num_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{Dia_{anchor.circle}}{Dia_{bar.circle}} = 0.16$$

$$\text{AreaRatio} := \min\left(\frac{Num_{bars.reqd.per.anchor}}{Num_{bars.per.anchor}}, 1\right) = 0.12$$

2015 AASHTO Development Length of Deformed Bars in Tension ***5.11.2.1***

$\text{Cover} = 3 \cdot \text{in}$

c_b = *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half*

the center-to-center spacing of the bars or wires being developed

$$c_b := \min\left(\begin{pmatrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{\mathbf{2}} \\ \dfrac{\text{Spacing}_{vert.reinf}}{\mathbf{2}} \end{pmatrix}\right) = \mathbf{4} \cdot \text{in}$$

$k_{tr} := \mathbf{0} \cdot \text{in}$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\begin{bmatrix} \mathbf{1.0} \\ \max\left(\begin{pmatrix} \mathbf{0.4} \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{pmatrix}\right) \end{bmatrix}\right] = \mathbf{0.4}$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\begin{pmatrix} \mathbf{12} \cdot \text{in} \\ \lambda_{rc} \cdot \mathbf{2.4} \cdot d_{long.bar} \cdot \dfrac{F_{y.rebar}}{\sqrt{f_c \cdot \text{ksi}}} \end{pmatrix}\right) = \mathbf{32.4} \cdot \text{in}$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$\text{SpacingFactor} := \max\left[\begin{pmatrix} \mathbf{0.5} \\ \text{Num}_{bars.per.anchor} \cdot \mathbf{0.5} - \mathbf{0.5} \end{pmatrix}\right] = \mathbf{0.5}$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf} \cdot \text{SpacingFactor}\right)^{\mathbf{2}} + \text{Dist}_{bar.to.bolt}^{\ \mathbf{2}}} = \mathbf{3.9} \cdot \text{in}$$

$$L_{embedment.anchor} := \max\left[\begin{bmatrix} L_{d.bar} \cdot (\text{AreaRatio}) + \mathbf{12} \cdot \text{in} + L_{embedment.added} \\ \mathbf{20} \cdot d_{anchor} \end{bmatrix}\right] = \mathbf{40} \cdot \text{in}$$

Note: $20 d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, \text{in}\right)$

$L_{embedment.anchor} = \mathbf{40} \cdot \text{in}$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^{\,2} + 3.25 \cdot \left(r^2 - r_b^{\,2}\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\begin{pmatrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{pmatrix}\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2 \operatorname{asin}\left[\frac{(1.5 \cdot c_{a1})}{r}\right] = 45.2 \cdot deg$$

OverlapTest := if$\left(A_{bolt.sector} \le \alpha\right.$, **"Overlap of Failure Cones"** , **"No Overlap of Failure Cones"**$)$ = **"Overlap of Failur**

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{\,2} = 95.9 \cdot in^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \text{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$$

$\psi_{ecV} := \mathbf{1.0}$ *eccentric load modifier* *ACI D.6.2.5*

$\psi_{edV} := \mathbf{1.0}$ *edge effect modifier* *ACI D.6.2.6*

$\psi_{cV} := \mathbf{1.4}$ *cracked section modifier* *ACI D.6.2.7* *(stirrup spacing <= 4")*

$\psi_{hV} := \mathbf{1.0}$ *member thickness modifier* *ACI D.6.2.8*

$\phi_{breakout} := \mathbf{0.75}$ *strength reduction factor* *ACI D.4.4.c.i* *(shear breakout, condition A)*

$V_{cbg} := Num_{anchor} \cdot \left(\frac{AV_c}{AV_{co}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = \mathbf{194.7} \cdot kip$ *concrete breakout strength - shear*

ACI Eqn D-22 *Shear force ⊥ to edge*

$V_{cbg\_parallel} := \mathbf{2} \cdot V_{cbg} = \mathbf{389.5} \cdot kip$ *ACI D.6.2.1.c* *Shear force ∥ to edge*

$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = \mathbf{389.5} \cdot kip \cdot ft$ *concrete breakout strength - torsion*

$\phi_{breakout} \cdot T_{n.breakout} = \mathbf{292.1} \cdot kip \cdot ft$

$T_u = \mathbf{19.9} \cdot kip \cdot ft$

$BreakoutTest := if\left(\phi_{breakout} \cdot T_{n.breakout} \geq T_u, \text{"OK"}, \text{"No Good"}\right)$

$BreakoutTest = \text{"OK"}$

$OverlapDesign := if\left(A_{bolt.sector} \leq \alpha, \text{"Based on Overlap of Failure Cones"}, \text{"Based on No Overlap of Failure Cones"}\right)$

$OverlapDesign = \text{"Based on Overlap of Failure Cones"}$

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = \mathbf{1.9} \cdot in$ *center-to-center distance*

$d_{anchor.nut} := \mathbf{1.85} \cdot d_{anchor} = \mathbf{3.7} \cdot in$ *use* $\mathbf{1.85} \cdot d_{anchor}$ *.to account for anchor nut*

$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{\mathbf{2}}\right) = -\mathbf{0.5} \cdot in$

$CheckAnchorageClearance := if\left[\left(Clearance_{bar.to.nut} \geq \mathbf{2} \cdot in\right), \text{"OK"}, \text{"No Good, increase ped. diameter"}\right]$

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := \mathbf{2} \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -\mathbf{1.3} \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := \mathbf{0} .. \mathbf{48} \qquad r_{ds} := \frac{b}{\mathbf{2}}$

$xds_{pt} := r_{ds} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] \qquad yds_{pt} := r_{ds} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$r_{v.od} := \frac{b}{\mathbf{2}} - \mathbf{6} \cdot in \qquad r_{v.id} := \frac{b}{\mathbf{2}} - \mathbf{6} \cdot in - d_{v.bar}$

$xstir.od_{pt} := r_{v.od} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] \qquad ystir.od_{pt} := r_{v.od} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$xstir.id_{pt} := r_{v.id} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] \qquad ystir.id_{pt} := r_{v.id} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$r_{bar} := \frac{d_{long.bar}}{\mathbf{2}} = \mathbf{0.6} \cdot in$

$xbar_{pt} := r_{bar} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] + \max(xstir.id) - d_{v.bar} \qquad ybar_{pt} := r_{bar} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{\mathbf{2}} = \mathbf{12} \cdot in$

$xboltcircle_{pt} := r_{boltcircle} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] \qquad yboltcircle_{pt} := r_{boltcircle} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$r_{boltr} := \frac{d_{anchor}}{2} = \mathbf{1} \cdot in$

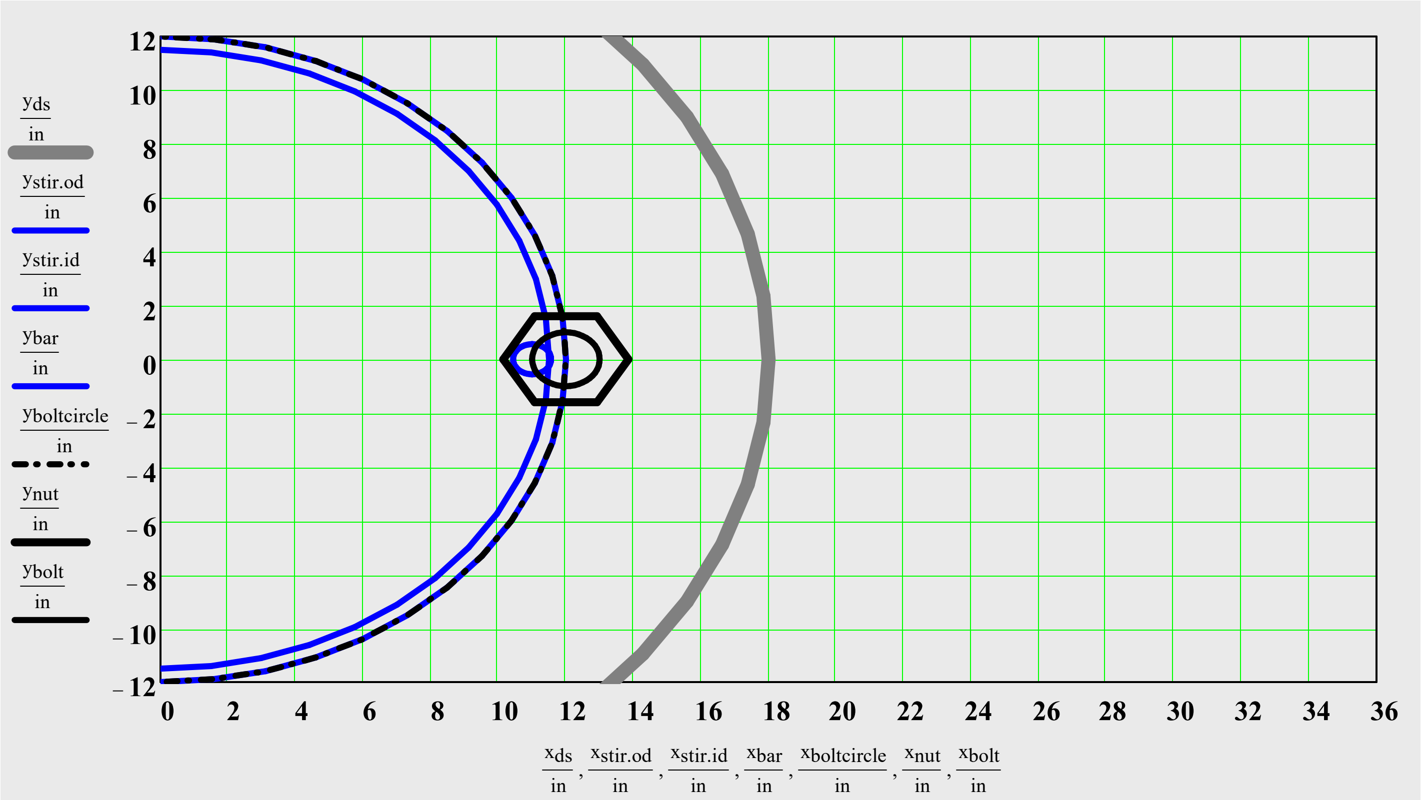
$x_{bolt_{pt}} := r_{boltr} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] + (\max(x_{boltcircle}))$ $y_{bolt_{pt}} := r_{boltr} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$pt := \mathbf{0} .. \mathbf{6}$ $r_{nut} := \frac{d_{anchor} \cdot 1.85}{\mathbf{2}} = \mathbf{1.9} \cdot in$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right] + (\max(x_{boltcircle}))$ $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right]$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right] + (\max(x_{boltcircle}))$ *enable to rotate nut* $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right]$

$\min(x_{bar}) - \max(x_{nut}) = -\mathbf{3.4} \cdot in$



$$\mathrm{Bolts} := \begin{pmatrix} \mathbf{1} & \mathbf{1.125} & \mathbf{1.25} & \mathbf{1.375} & \mathbf{1.5} & \mathbf{1.625} & \mathbf{1.75} & \mathbf{1.875} & \mathbf{2} & \mathbf{2.25} & \mathbf{2.5} & \mathbf{2.75} & \mathbf{3} \\ \mathbf{1.5} & \mathbf{1.688} & \mathbf{1.875} & \mathbf{2.063} & \mathbf{2.25} & \mathbf{2.438} & \mathbf{2.625} & \mathbf{2.938} & \mathbf{3} & \mathbf{3.375} & \mathbf{3.75} & \mathbf{4.125} & \mathbf{4.25} \end{pmatrix} \cdot \mathrm{in}$$

$$\left(\left(\mathrm{Bolts}^{\mathrm{T}}\right)^{\langle \mathbf{0} \rangle}\right)^{\mathrm{T}} \cdot \mathbf{1.6} - \left(\left(\mathrm{Bolts}^{\mathrm{T}}\right)^{\langle \mathbf{1} \rangle}\right)^{\mathrm{T}} = \begin{pmatrix} \mathbf{0.1} & \mathbf{0.112} & \mathbf{0.125} & \mathbf{0.137} & \mathbf{0.15} & \mathbf{0.162} & \mathbf{0.175} & \mathbf{0.062} & \mathbf{0.2} & \mathbf{0.225} & \mathbf{0.25} & \mathbf{0.275} & \mathbf{0.55} \end{pmatrix} \cdot \mathrm{in}$$

$$\left(\left(\mathrm{Bolts}^{\mathrm{T}}\right)^{\langle \mathbf{0} \rangle}\right)^{\mathrm{T}} - \left(\left(\mathrm{Bolts}^{\mathrm{T}}\right)^{\langle \mathbf{1} \rangle}\right)^{\mathrm{T}} = \begin{pmatrix} -\mathbf{0.5} & -\mathbf{0.563} & -\mathbf{0.625} & -\mathbf{0.688} & -\mathbf{0.75} & -\mathbf{0.813} & -\mathbf{0.875} & -\mathbf{1.063} & -\mathbf{1} & -\mathbf{1.125} & -\mathbf{1.25} & -\mathbf{1.375} & -\mathbf{1.25} \end{pmatrix} \cdot$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

FDOT
State Structures Design Office

SUBJECT 079-241-H MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

SoilType :=
Sand
Clay

$\phi_{soil} := 30 \cdot deg$ *soil friction angle (sand)*

$c_{soil} := 0.0 \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

$N_{blows} := 8$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := 71 \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*

Geometry

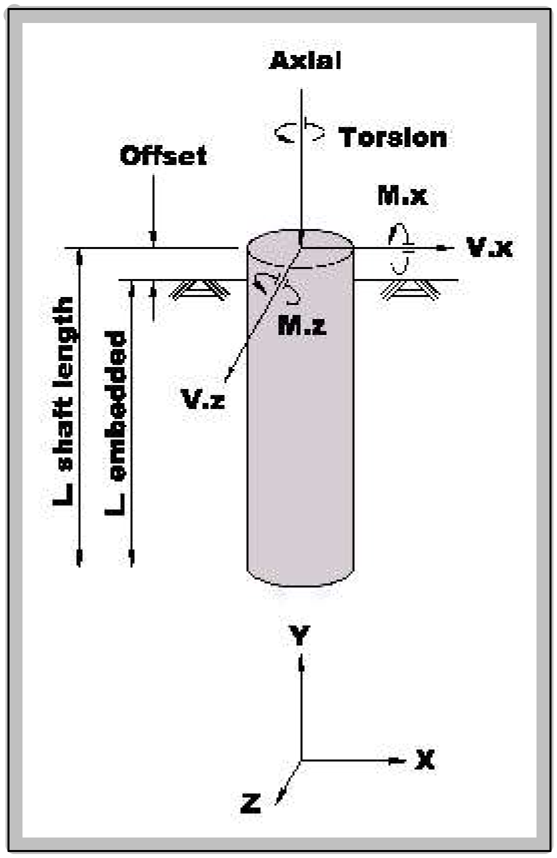
$b := 3.0 \cdot ft$ *shaft diameter*

$Offset := 0.50 \cdot ft$ *groundline to top of foundation*

Applied Loads (Extreme I)

$M_x := 11.83 \cdot kip \cdot ft$ $V_x := 0.05 \cdot kip$ $Torsion := 81.60 \cdot kip \cdot ft$

$M_z := 143.0 \cdot kip \cdot ft$ $V_z := 6.50 \cdot kip$ $Axial := 20.9 \cdot kip$



StructureType :=
Cantilever Overhead Sign Structure
Mast Arm Signal Structure
Concrete/Steel Strain Poles
Ground Sign

$StructureType = 1$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

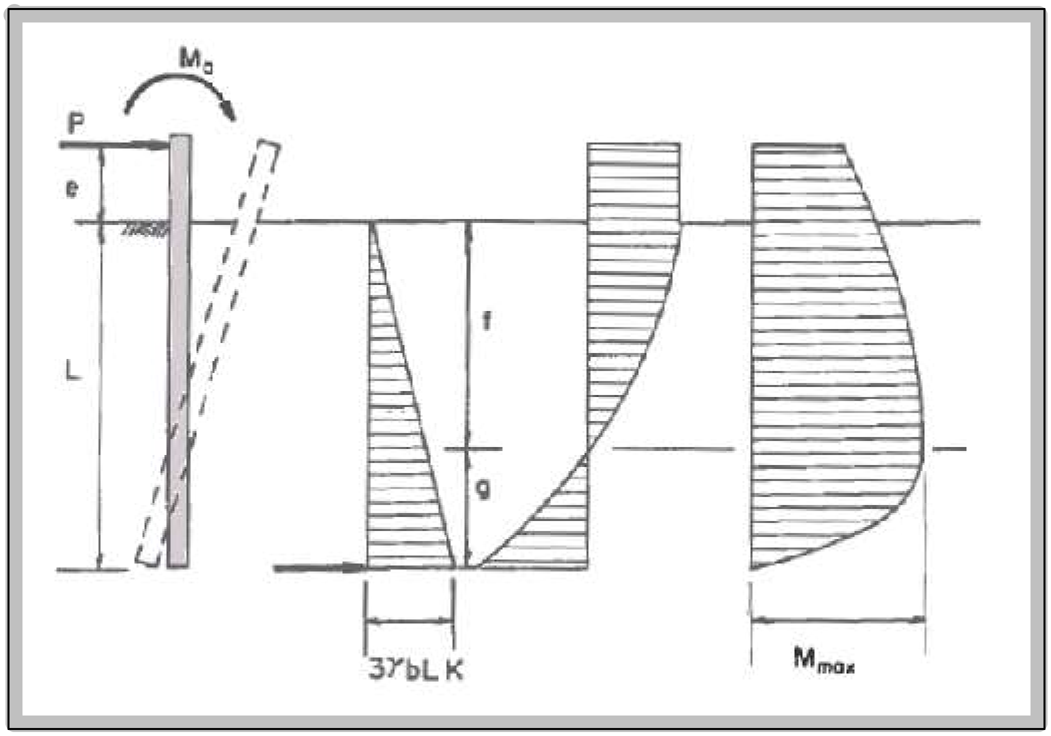
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{{M_x}^2 + {M_z}^2} = 143.5 \cdot kip \cdot ft$

$P_u := \sqrt{{V_x}^2 + {V_z}^2} = 6.5 \cdot kip$

$T_u :=$ Torsion $= 81.6 \cdot kip \cdot ft$

short free-head pile in ***cohesionless soil*** *using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(45 \cdot deg + \frac{\phi_{soil}}{2}\right)^2 = 3$

$e_{sand} :=$ Offset $= 0.5 \, ft$

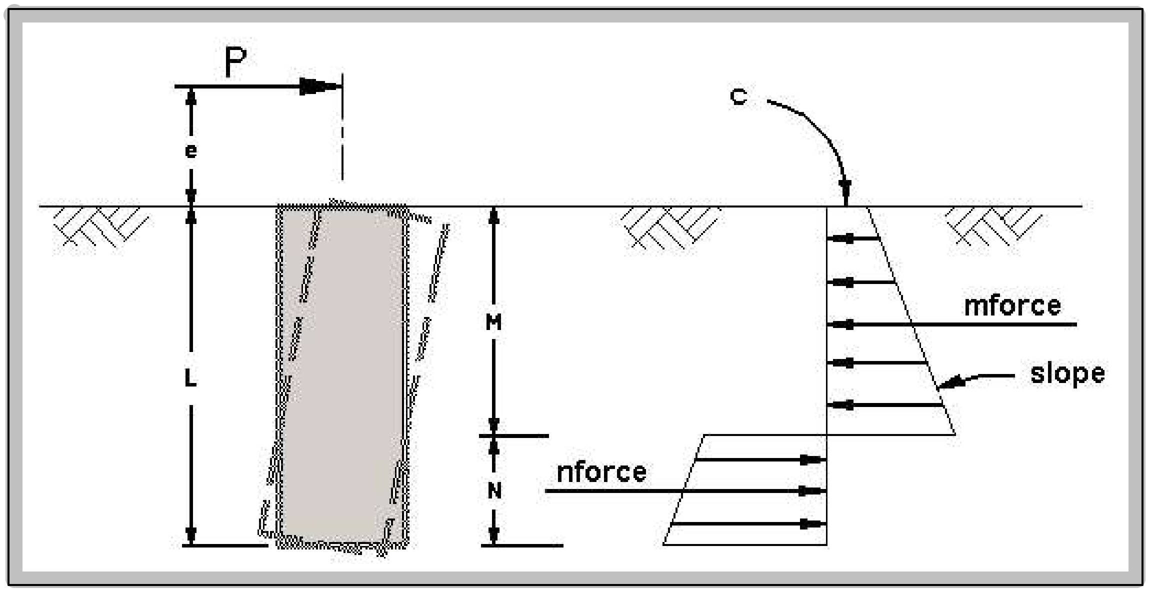
Guess value $L_{otSand} := 8 \cdot ft$

Given $P_u \cdot \left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot} \cdot \left[\left(3 \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{1}{2} \cdot L_{otSand}\right) \cdot \left(\frac{1}{3} \cdot L_{otSand}\right)\right]$

$L_{otSand} := \text{Find}\left(L_{otSand}\right) = 14.4 \, ft$

$L_{otSand} := \text{ceil}\left(\frac{L_{otSand}}{ft}\right) \cdot ft = 15 \, ft$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$$c_{soil} := \text{if}\left(c_{soil} = 0\cdot ksf, 0.1\cdot ksf, c_{soil}\right) = 0.1\cdot ksf$$

$$Slope := 8\cdot\frac{c_{soil}}{3\cdot b} = 0.1\cdot\frac{kip}{ft^3}$$

$$e_{clay} := \frac{M_u}{P_u} + Offset = 22.6\,ft$$

$$nforce(M,N) := \left[Slope\cdot\left(2\cdot M + N\right) + 2\cdot c_{soil}\right]\cdot N\cdot\frac{b}{2}$$

$$mforce(M) := \left(2\cdot c_{soil} + M\cdot Slope\right)\cdot M\cdot\frac{b}{2}$$

$$m\_arm(M) := e_{clay} + \frac{M}{3}\cdot\frac{2\cdot\left(M\cdot Slope + c_{soil}\right) + c_{soil}}{M\cdot Slope + 2\cdot c_{soil}}$$

$$n\_arm(M,N) := e_{clay} + M + \frac{N}{3}\cdot\frac{2\cdot\left(N\cdot Slope + M\cdot Slope + c_{soil}\right) + \left(M\cdot Slope + c_{soil}\right)}{Slope\cdot\left(2\cdot M + N\right) + 2\cdot c_{soil}}$$

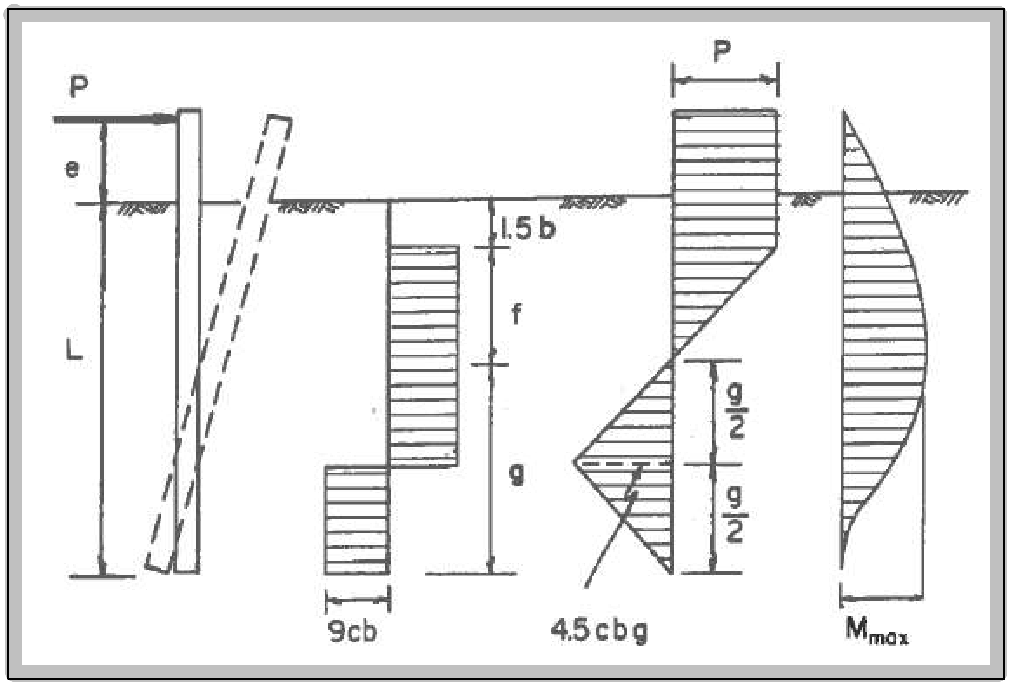
Guess value $M := 4.0\cdot ft$ $N := 4.0\cdot ft$

Given $P_u + \phi_{ot}\cdot nforce(M,N) = \phi_{ot}\cdot mforce(M)$ $mforce(M)\cdot m\_arm(M) = nforce(M,N)\cdot n\_arm(M,N)$

$$\begin{pmatrix} M \\ N \end{pmatrix} := Find(M,N) \qquad L_{ot1Clay} := M + N = 11.0\,ft$$

$$L_{ot1Clay} := ceil\left(\frac{L_{ot1Clay}}{ft}\right)\cdot ft = 11\,ft$$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot 9 \cdot c_{soil} \cdot b} = 9.6\,ft$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + 1.5 \cdot b + 0.5 \cdot f\right) = 207.3 \cdot kip \cdot ft$$

$$g := \sqrt{\frac{M_{max.clay}}{2.25 \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = 35\,ft$$

$$L_{ot2Clay} := \left(1.5 \cdot b + f + g\right) = 49.2\,ft$$

$$L_{ot2Clay} := ceil\left(\frac{L_{ot2Clay}}{ft}\right) \cdot ft = 50\,ft$$

(round up to next foot)

$$L_{otClay} := if\left(L_{ot1Clay} < 3 \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = 50\,ft$$

(If $L_{ot} < 3b$*, use Modified Broms method)*

$$L_{reqdOT} := if\left(SoilType = \text{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$$L_{reqdOT} = 15\,ft$$

required shaft embedment depth to resist overturning

Shaft Depth Required to Resist Torsion

short free-head pile in ***cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = \mathbf{8}$

$\omega_{fdot} := \mathrm{if}\left(N_{blows} < \mathbf{5}, \mathbf{0}, \mathrm{if}\left(N_{blows} \geq \mathbf{15}, \mathbf{1.5}, \mathbf{1.5} \cdot \frac{N_{blows}}{\mathbf{15}}\right)\right) = \mathbf{0.8}$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\frac{N_{blows}}{\mathbf{15}}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = \mathbf{15}\,\mathrm{ft}$

Given $T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot \left(L_{torSand}\right) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{\mathbf{2}}\right) \cdot \left(\omega_{fdot}\right) \cdot \frac{b}{\mathbf{2}}\right]$

$L_{torSand} := \mathrm{Find}\left(L_{torSand}\right) = \mathbf{14.3}\,\mathrm{ft}$

$L_{torSand} := \mathrm{ceil}\left(\frac{L_{torSand}}{\mathrm{ft}}\right) \cdot \mathrm{ft} = \mathbf{15}\,\mathrm{ft}$ *(round up to next foot)*

short free-head pile in ***cohesive soil***

$\mathrm{CohesionFactor} := \mathbf{0.55}$

$f_{se} := \mathrm{CohesionFactor} \cdot c_{soil} = \mathbf{0.1} \cdot \mathrm{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

Given $T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot \left(L_{torClay} - \mathbf{1.5} \cdot \mathrm{ft}\right) \cdot \frac{b}{\mathbf{2}}\right]$

$L_{torClay} := \mathrm{Find}\left(L_{torClay}\right) = \mathbf{106.4}\,\mathrm{ft}$

$L_{torClay} := \mathrm{ceil}\left(\frac{L_{torClay}}{\mathrm{ft}}\right) \cdot \mathrm{ft} = \mathbf{107}\,\mathrm{ft}$ *(round up to next foot)*

$L_{reqdTor} := \mathrm{if}\left(\mathrm{SoilType} = \mathbf{\text{"Sand"}}, L_{torSand}, L_{torClay}\right)$

$L_{reqdTor} = \mathbf{15}\,\mathrm{ft}$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \mathrm{if}\left(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}\right) = \mathbf{15}\,\mathrm{ft}$

$L_{shaft.length} := L_{embedded} + \mathrm{Offset}$

$L_{shaft.length} = \mathbf{15.5}\,\mathrm{ft}$ *shaft length*

Minimum Shaft Embedment length is 16 ft

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2 \cdot P_u}{3 \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = 5.2 \, ft$$

$$M_{maxSand} := P_u \cdot (e_{sand} + f_{sand}) - \frac{P_u \cdot f_{sand}}{3} + M_u = 169.3 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0 \cdot ft$

Given $P_u = \frac{f_{mod} \cdot b}{2} \cdot (2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot Slope)$

$$f_{mod} := Find(f_{mod}) = 12.9 \, ft$$

$$M_{modBroms} := P_u \cdot (e_{clay} + f_{mod}) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^{2}}{2} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^{3} \cdot Slope}{6} = 200.5 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot (e_{clay} + 1.5 \cdot b + 0.5 \cdot f) = 207.3 \cdot kip \cdot ft$$

$$M_{maxClay} := if(L_{ot1Clay} < 3 \cdot b, M_{modBroms}, M_{Broms}) = 207.3 \cdot kip \cdot ft$$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$$M_{max} := if(SoilType = \text{"Sand"}, M_{maxSand}, M_{maxClay}) = 169.3 \cdot kip \cdot ft$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$	*reinforcing yield strength*	
$f_c := 4.0 \cdot ksi$	*concrete strength*	Spec 346-3
$Cover := 3 \cdot in$	*cover*	SDG Table 1.4.2-1
$Num_{bar} := 11$	*number of longitudinal bars*	
$A_{long.bar} := 1.0 \cdot in^2$	*longitudinal bar area*	
$d_{long.bar} := 1.125 \cdot in$	*longitudinal bar diameter*	
$A_{v.bar} := 0.20 \cdot in^2$	*stirrup area*	SM Vol-3 13.6.2
$d_{v.bar} := 0.5 \cdot in$	*stirrup diameter*	
$s_{v1} := 3 \cdot in$	*stirrup spacing, depth = 0 ft-2 ft*	SM Vol-3 13.6.2
$s_{v2} := 3 \cdot in$	*stirrup spacing, depth = 2 ft-depth.stir*	
$s_{v3} := 6 \cdot in$	*stirrup spacing, depth > depth.stir*	
$depth_{stir} := 15.0 \cdot ft$	*stirrup depth, see s.v2 and s.v3 above*	
$b = 3\,ft$	*shaft diameter*	
$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$	*required 1% steel*	SM Vol-3 13.6.2
$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$		LRFD 5.7.4.2
$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot in^2$		
$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$	*total area of longitudinal steel*	

$CheckLongitudinalReinf := if\left(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"}\right)$ $CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if\left(Clearance_{vert.reinf} \geq 6in, \text{"OK"}, \text{"No Good"}\right)$ $CheckReinfClearSpacing = \text{"OK"}$ SDG 3.6.10

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$V_u := \sqrt{V_x^{2} + V_z^{2}} = \mathbf{6.5} \cdot kip$

$T_u = \mathbf{81.6} \cdot kip \cdot ft$

Effective shear depth

$D_r := b - 2 \cdot \left(Cover + d_{v.bar} + \frac{d_{long.bar}}{2} \right) = \mathbf{2.3}\, ft$ $d_e := \frac{b}{2} + \frac{D_r}{\pi} = \mathbf{2.2}\, ft$ *LRFD C5.8.2.9-2*

$d_v := \max(0.9 \cdot d_e, 0.72 \cdot b) = \mathbf{2.2}\, ft$

Check Shear Strength

$V_c := 0.0316 \cdot (2.0) \cdot \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{b}{in}\right) \cdot \left(\frac{d_v}{in}\right) \cdot kip = \mathbf{117.9} \cdot kip$ *LRFD Eqn 5.8.3.3-3* *LRFD 5.8.3.4.1* *ACI 11.3.3*

$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max(s_{v1}, s_{v2}, s_{v3})} = \mathbf{51.8} \cdot kip$ *LRFD Eqn 5.8.3.3-4*

$ShearRatio := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = \mathbf{-2.1}$

$ShearRatio := if(ShearRatio \le 0, 0, ShearRatio) = \mathbf{0}$

Check Torsion Strength

$A_{cp} := \pi \cdot \left(\frac{b}{2}\right)^{2} = \mathbf{1017.9} \cdot in^{2}$ $p_{cp} := 2 \cdot \pi \cdot \left(\frac{b}{2}\right) = \mathbf{113.1} \cdot in$ *Area and perimeter of concrete cross-section*

$d_{oh} := b - 2 \cdot \left(Cover + \frac{d_{v.bar}}{2} \right) = \mathbf{29.5} \cdot in$ $p_h := \pi \cdot d_{oh} = \mathbf{92.7} \cdot in$ *Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement*

$A_{oh} := \pi \left(\frac{d_{oh}}{2}\right)^{2} = \mathbf{683.5} \cdot in^{2}$ $A_o := 0.85 \cdot A_{oh} = \mathbf{581} \cdot in^{2}$

$T_{n1} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = \mathbf{387.3} \cdot kip \cdot ft$ *LRFD Eqn 5.8.3.6.2-1*

$T_{n2} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = \mathbf{387.3} \cdot kip \cdot ft$ *LRFD 5.8.3.4.1*

$$T_{n3} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = \mathbf{193.7} \cdot \text{kip} \cdot \text{ft}$$

$\phi_v = \mathbf{0.9}$ $\qquad$ $T_u = \mathbf{81.6} \cdot \text{kip} \cdot \text{ft}$ $\qquad$ $L_{reqdTor} = \mathbf{15}\,\text{ft}$

$$Tor2_{sand} := T_u - \text{if}\left[\mathbf{2}\,\text{ft} > \text{Offset}, \left[\pi \cdot b \cdot (\mathbf{2} \cdot \text{ft} - \text{Offset}) \cdot \gamma_{soil} \cdot \left(\frac{\mathbf{2} \cdot \text{ft} - \text{Offset}}{\mathbf{2}}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot \text{kip} \cdot \text{ft}\right] = \mathbf{80.7} \cdot \text{kip} \cdot \text{ft}$$

$$Tor3_{sand} := T_u - \text{if}\left[\text{depth}_{stir} > \text{Offset}, \left[\pi \cdot b \cdot (\text{depth}_{stir} - \text{Offset}) \cdot \gamma_{soil} \cdot \left(\frac{\text{depth}_{stir} - \text{Offset}}{\mathbf{2}}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot \text{kip} \cdot \text{ft}\right] = -\mathbf{2.8} \cdot \text{kip} \cdot \text{ft}$$

$$Tor2_{clay} := T_u - \text{if}\left[\mathbf{2}\,\text{ft} - \mathbf{1.5}\,\text{ft} > \text{Offset}, \left[f_{se} \cdot (\pi \cdot b) \cdot (\mathbf{2.0} \cdot \text{ft} - \text{Offset} - \mathbf{1.5} \cdot \text{ft}) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot \text{kip} \cdot \text{ft}\right] = \mathbf{81.6} \cdot \text{kip} \cdot \text{ft}$$

$$Tor3_{clay} := T_u - \text{if}\left[\text{depth}_{stir} - \mathbf{1.5}\,\text{ft} > \text{Offset}, \left[f_{se} \cdot (\pi \cdot b) \cdot (\text{depth}_{stir} - \text{Offset} - \mathbf{1.5} \cdot \text{ft}) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot \text{kip} \cdot \text{ft}\right] = \mathbf{71.5} \cdot \text{kip} \cdot \text{ft}$$

$$Tor2 := \text{if}(\text{SoilType} = \textbf{"Sand"}, Tor2_{sand}, Tor2_{clay}) = \mathbf{80.7} \cdot \text{kip} \cdot \text{ft}$$

$$Tor3 := \text{if}(\text{SoilType} = \textbf{"Sand"}, Tor3_{sand}, Tor3_{clay}) = -\mathbf{2.8} \cdot \text{kip} \cdot \text{ft}$$

$$\text{TorsionRatio}_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = \mathbf{0.21}$$

$$\text{TorsionRatio}_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = \mathbf{0.21}$$

$$\text{TorsionRatio}_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = -\mathbf{0.01}$$

$$\text{TorsionRatio} := \max(\text{TorsionRatio}_{n1}, \text{TorsionRatio}_{n2}, \text{TorsionRatio}_{n3}) = \mathbf{0.21}$$

$$T_{cr} := \mathbf{0.125}\sqrt{\frac{f_c}{\text{ksi}}} \cdot \left(\frac{A_{cp}^{\mathbf{2}}}{p_{cp} \cdot \text{in}^{\mathbf{3}}}\right) \cdot \text{kip} \cdot \text{in} = \mathbf{190.9} \cdot \text{kip} \cdot \text{ft}$$ LRFD Eqn 5.8.2.1-4

$$\text{TorsionRatio} := \text{if}(T_u \le \mathbf{0.25} \cdot \phi_{tor} \cdot T_{cr}, \mathbf{0}, \text{TorsionRatio}) = \mathbf{0.2}$$ LRFD Eqn 5.8.2.1-3

$\text{ShearRatio} = \mathbf{0}$

$$\text{CheckShearTorsion} := \text{if}(\text{ShearRatio} + \text{TorsionRatio} \le \mathbf{1}, \textbf{"OK"}, \textbf{"No Good"})$$

$\text{CheckShearTorsion} = \textbf{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = \mathbf{0.00774} \cdot \text{ksi} \qquad \mathbf{0.125} \cdot f_c = \mathbf{0.5} \cdot \text{ksi}$$ LRFD Eqn 5.8.2.9-1

$$s_{max1} := \text{if}(\mathbf{0.8} \cdot d_v < \mathbf{24} \cdot \text{in}, \mathbf{0.8} d_v, \mathbf{24} \cdot \text{in}) = \mathbf{20.7} \cdot \text{in}$$ LRFD Eqn 5.8.2.7-1

$s_{max2} := \text{if}\left(0.4 \cdot d_v < 12 \cdot in, 0.4 d_v, 12 \cdot in\right) = 10.4 \cdot in$ *LRFD Eqn 5.8.2.7-2*

$s_{max} := \text{if}\left(v_u < 0.125 \cdot f_c, s_{max1}, s_{max2}\right) = 20.7 \cdot in$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = 6 \cdot in$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \text{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion

LRFD Eqn 5.8.3.6.3-1

LRFD 5.8.3.4.1

$M_u = 143.5 \cdot kip \cdot ft$

$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5 \cdot V_s > 0 \cdot kip, \frac{V_u}{\phi_v} - 0.5 \cdot V_s, 0 \cdot kip\right) = 0 \cdot kip$

$$\text{LongReinf}_{shr.tor} := \frac{\frac{M_u}{\phi_v \cdot d_v} + \sqrt{\left(V_{temp}\right)^2 + \left(\frac{0.45 \cdot p_h \cdot T_u}{2 \cdot A_o \cdot \phi_v}\right)^2}}{F_{y.rebar}} = 1.9 \cdot in^2$$

$\text{Num}_{bar} \cdot A_{long.bar} = 11 \cdot in^2$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(\text{Num}_{bar} \cdot A_{long.bar} \ge \text{LongReinf}_{shr.tor}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \text{"OK"}$

Anchor Bolt Strength Check

$\mathrm{Num}_{anchor} := \mathbf{8}$ *number of anchor bolts*

$d_{anchor} := \mathbf{2} \cdot in$ *anchor bolt nominal diameter*

$\mathrm{Dia}_{anchor.circle} := \mathbf{24} \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := \mathbf{105} \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{\mathrm{Dia}_{anchor.circle}^{\mathbf{2}}}{\mathbf{8}} \cdot \mathrm{Num}_{anchor} = \mathbf{576} \cdot in^{\mathbf{2}}$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{\mathrm{Dia}_{anchor.circle}}{\mathbf{2}}} = \mathbf{48} \cdot in$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = \mathbf{35.9} \cdot kip$$ *anchor tension force*

$$V_{anchor} := \frac{V_u}{\mathrm{Num}_{anchor}} + \frac{T_u}{0.5\mathrm{Dia}_{anchor.circle} \cdot \mathrm{Num}_{anchor}} = \mathbf{11} \cdot kip$$ *anchor shear force*

$$A_{b.anchor} := \frac{1}{\mathbf{4}} \pi \cdot d_{anchor}^{\mathbf{2}} = \mathbf{3.1} \cdot in^{\mathbf{2}}$$ *anchor bolt nominal area*

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = \mathbf{11.4} \cdot ksi$$ *anchor tensile stress*

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = \mathbf{3.5} \cdot ksi$$ *anchor shear stress*

$\phi_{anchor} := \mathbf{0.75}$ *resistance factor* AISC J3-1

$F_{nt} := \mathbf{0.75} F_{u.anchor} = \mathbf{78.8} \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := \mathbf{0.45} F_{u.anchor} = \mathbf{47.2} \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = \mathbf{185.6} \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = \mathbf{111.3} \cdot kip$ *design sghear strength*

$\mathrm{CheckAnchorT} := \mathrm{if}\left(\phi R_{nt} \geq T_{anchor}, \mathbf{"OK"}, \mathbf{"No\ Good"}\right)$ *check tensile rupture*

$\mathrm{CheckAnchorT} = \mathbf{"OK"}$

$\mathrm{CheckAnchorV} := \mathrm{if}\left(\phi R_{nv} \geq V_{anchor}, \textbf{"OK"}, \textbf{"No Good"}\right)$ *check shear rupture*

$\mathrm{CheckAnchorV} = \textbf{"OK"}$

$$F_{ntv} := \mathbf{min}\left(\left(\begin{matrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{matrix}\right)\right) = \mathbf{78.8} \cdot \mathrm{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = \mathbf{185.6} \cdot \mathrm{kip}$

design tension strength modified to include the effects of shearing stress

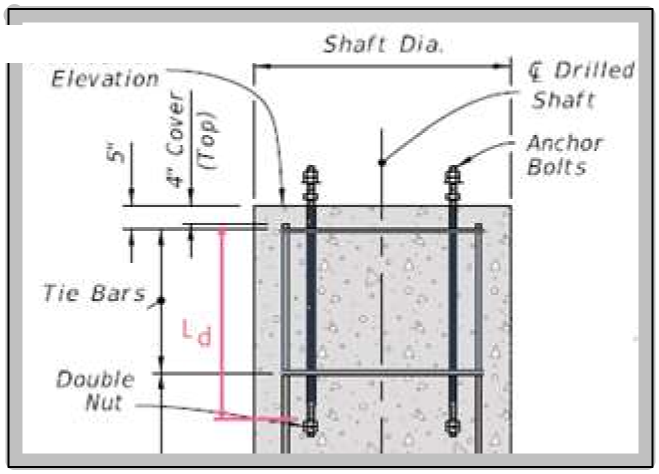
$\mathrm{CheckAnchorTV} := \mathrm{if}\left[\left(f_{t.anchor} \leq \mathbf{20}\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq \mathbf{20}\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \textbf{"OK"}, \textbf{"No Good"}\right]$

$\mathrm{CheckAnchorTV} = \textbf{"OK"}$ *check combined tension and shear rupture*

$\mathrm{CheckAnchorStrength} := \mathrm{if}\left[\left(\mathrm{CheckAnchorT} = \textbf{"OK"}\right) \cdot \left(\mathrm{CheckAnchorV} = \textbf{"OK"}\right) \cdot \left(\mathrm{CheckAnchorTV} = \textbf{"OK"}\right), \textbf{"OK"}, \textbf{"No Good"}\right]$

$\mathrm{CheckAnchorStrength} = \textbf{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = \mathbf{35.9} \cdot \mathrm{kip}$ *tension force in anchor*

$\mathrm{Dia}_{bar.circle} = \mathbf{27.9} \cdot \mathrm{in}$ $\mathrm{Dia}_{anchor.circle} = \mathbf{24} \cdot \mathrm{in}$

center-to-center distance

$$\mathrm{Dist}_{bar.to.bolt} := \frac{\mathrm{Dia}_{bar.circle} - \mathrm{Dia}_{anchor.circle}}{\mathbf{2}} = \mathbf{1.9} \cdot \mathrm{in}$$

$$\mathrm{Num}_{bars.per.anchor} := \min\left(\frac{\mathrm{Num}_{bar}}{\mathrm{Num}_{anchor}}, \mathbf{3}\right) = \mathbf{1.4}$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := \mathbf{0.9}$

$$\mathrm{Num}_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{\mathrm{Dia}_{anchor.circle}}{\mathrm{Dia}_{bar.circle}} = \mathbf{0.57}$$

$$\mathrm{AreaRatio} := \min\left(\frac{\mathrm{Num}_{bars.reqd.per.anchor}}{\mathrm{Num}_{bars.per.anchor}}, \mathbf{1}\right) = \mathbf{0.42}$$

*2015 AASHTO Development Length of Deformed Bars in Tension **5.11.2.1***

$\mathrm{Cover} = \mathbf{3} \cdot \mathrm{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half*

the center-to-center spacing of the bars or wires being developed

$$c_b := \min\left(\left(\begin{matrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{\mathbf{2}} \\ \dfrac{\text{Spacing}_{vert.reinf}}{\mathbf{2}} \end{matrix}\right)\right) = \mathbf{4}\cdot \text{in}$$

$k_{tr} := \mathbf{0}\cdot \text{in}$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\left[\begin{matrix} \mathbf{1.0} \\ \max\left(\left(\begin{matrix} \mathbf{0.4} \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{matrix}\right)\right) \end{matrix}\right]\right] = \mathbf{0.4}$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\left(\begin{matrix} \mathbf{12}\cdot \text{in} \\ \lambda_{rc}\cdot \mathbf{2.4}\cdot d_{long.bar}\cdot \dfrac{F_{y.rebar}}{\sqrt{f_c\cdot \text{ksi}}} \end{matrix}\right)\right) = \mathbf{32.4}\cdot \text{in}$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$\text{SpacingFactor} := \max\left[\left(\begin{matrix} \mathbf{0.5} \\ \text{Num}_{bars.per.anchor}\cdot \mathbf{0.5} - \mathbf{0.5} \end{matrix}\right)\right] = \mathbf{0.5}$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf}\cdot \text{SpacingFactor}\right)^{\mathbf{2}} + \text{Dist}_{bar.to.bolt}{}^{\mathbf{2}}} = \mathbf{3.9}\cdot \text{in}$$

$$L_{embedment.anchor} := \max\left[\left[\begin{matrix} L_{d.bar}\cdot(\text{AreaRatio}) + \mathbf{12}\cdot \text{in} + L_{embedment.added} \\ \mathbf{20}\cdot d_{anchor} \end{matrix}\right]\right] = \mathbf{40}\cdot \text{in}$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, \text{in}\right)$

$L_{embedment.anchor} = \mathbf{40}\cdot \text{in}$

Minimum Anchor Bolts Embedment length is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^{\,2} + 3.25 \cdot \left(r^2 - r_b^{\,2}\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\begin{pmatrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{pmatrix}\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2 \operatorname{asin}\left[\frac{(1.5 \cdot c_{a1})}{r}\right] = 45.2 \cdot deg$$

OverlapTest := if$\left(A_{bolt.sector} \le \alpha\right.$, **"Overlap of Failure Cones"** , **"No Overlap of Failure Cones"**$\left.\right)$ = **"Overlap of Failur**

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{\,2} = 95.9 \cdot in^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \text{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$$

$\psi_{ecV} := \mathbf{1.0}$ *eccentric load modifier* *ACI D.6.2.5*

$\psi_{edV} := \mathbf{1.0}$ *edge effect modifier* *ACI D.6.2.6*

$\psi_{cV} := \mathbf{1.4}$ *cracked section modifier* *ACI D.6.2.7* *(stirrup spacing <= 4")*

$\psi_{hV} := \mathbf{1.0}$ *member thickness modifier* *ACI D.6.2.8*

$\phi_{breakout} := \mathbf{0.75}$ *strength reduction factor* *ACI D.4.4.c.i* *(shear breakout, condition A)*

$V_{cbg} := Num_{anchor} \cdot \left(\frac{AV_c}{AV_{co}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = \mathbf{194.7} \cdot kip$ *concrete breakout strength - shear*

ACI Eqn D-22 *Shear force ⊥ to edge*

$V_{cbg\_parallel} := \mathbf{2} \cdot V_{cbg} = \mathbf{389.5} \cdot kip$ *ACI D.6.2.1.c* *Shear force ‖ to edge*

$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = \mathbf{389.5} \cdot kip \cdot ft$ *concrete breakout strength - torsion*

$\phi_{breakout} \cdot T_{n.breakout} = \mathbf{292.1} \cdot kip \cdot ft$

$T_u = \mathbf{81.6} \cdot kip \cdot ft$

BreakoutTest := if($\phi_{breakout} \cdot T_{n.breakout} \geq T_u$, **"OK"** , **"No Good"**)

BreakoutTest = **"OK"**

OverlapDesign := if($A_{bolt.sector} \leq \alpha$, **"Based on Overlap of Failure Cones"** , **"Based on No Overlap of Failure Cones"**)

OverlapDesign = **"Based on Overlap of Failure Cones"**

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = \mathbf{1.9} \cdot in$ *center-to-center distance*

$d_{anchor.nut} := \mathbf{1.85} \cdot d_{anchor} = \mathbf{3.7} \cdot in$ *use* $\mathbf{1.85} \cdot d_{anchor}$ *.to account for anchor nut*

$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{\mathbf{2}}\right) = -\mathbf{0.5} \cdot in$

CheckAnchorageClearance := if[($Clearance_{bar.to.nut} \geq \mathbf{2} \cdot in$), **"OK"** , **"No Good, increase ped. diameter"**]

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0 .. 48 \qquad r_{ds} := \frac{b}{2}$

$xds_{pt} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yds_{pt} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$xstir.od_{pt} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.od_{pt} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$xstir.id_{pt} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.id_{pt} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$xbar_{pt} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max(xstir.id) - d_{v.bar} \qquad ybar_{pt} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$xboltcircle_{pt} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yboltcircle_{pt} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltr} := \frac{d_{anchor}}{2} = \mathbf{1}\cdot in$

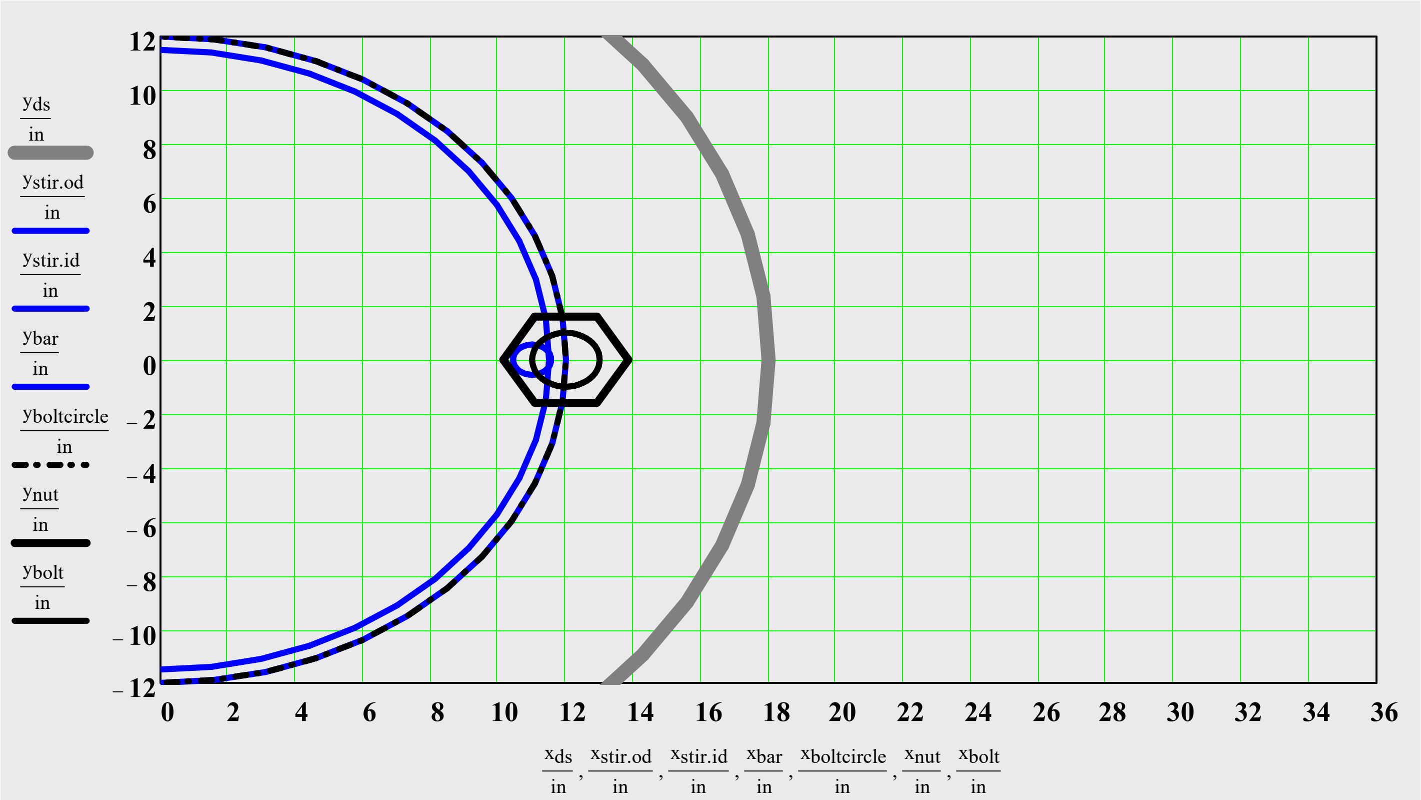
$x_{bolt_{pt}} := r_{boltr}\cdot \cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{48}} + \frac{\mathbf{2}\cdot\pi}{\mathbf{48}}\right] + (\max(x_{boltcircle}))$ $\qquad$ $y_{bolt_{pt}} := r_{boltr}\cdot \sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2}\cdot\pi}{\mathbf{48}}\right]$

$pt := \mathbf{0}..\mathbf{6}$ $\qquad$ $r_{nut} := \frac{d_{anchor}\cdot 1.85}{\mathbf{2}} = \mathbf{1.9}\cdot in$

$x_{nut_{pt}} := r_{nut}\cdot \cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{6}} + \frac{\mathbf{2}\cdot\pi}{\mathbf{6}}\right] + (\max(x_{boltcircle}))$ $\qquad$ $y_{nut_{pt}} := r_{nut}\cdot \sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{2}\cdot\pi}{\mathbf{6}}\right]$

$x_{nut_{pt}} := r_{nut}\cdot \cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{6}} + \frac{\mathbf{1}\cdot\pi}{\mathbf{6}}\right] + (\max(x_{boltcircle}))$ $\qquad$ *enable to rotate nut* $\qquad$ $y_{nut_{pt}} := r_{nut}\cdot \sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{1}\cdot\pi}{\mathbf{6}}\right]$

$\min(x_{bar}) - \max(x_{nut}) = -\mathbf{3.4}\cdot in$



$$Bolts := \begin{pmatrix} \mathbf{1} & \mathbf{1.125} & \mathbf{1.25} & \mathbf{1.375} & \mathbf{1.5} & \mathbf{1.625} & \mathbf{1.75} & \mathbf{1.875} & \mathbf{2} & \mathbf{2.25} & \mathbf{2.5} & \mathbf{2.75} & \mathbf{3} \\ \mathbf{1.5} & \mathbf{1.688} & \mathbf{1.875} & \mathbf{2.063} & \mathbf{2.25} & \mathbf{2.438} & \mathbf{2.625} & \mathbf{2.938} & \mathbf{3} & \mathbf{3.375} & \mathbf{3.75} & \mathbf{4.125} & \mathbf{4.25} \end{pmatrix}\cdot in$$

$$\left(Bolts^{T}\right)^{\langle\mathbf{0}\rangle^{T}}\cdot\mathbf{1.6} - \left(Bolts^{T}\right)^{\langle\mathbf{1}\rangle^{T}} = \begin{pmatrix}\mathbf{0.1} & \mathbf{0.112} & \mathbf{0.125} & \mathbf{0.137} & \mathbf{0.15} & \mathbf{0.162} & \mathbf{0.175} & \mathbf{0.062} & \mathbf{0.2} & \mathbf{0.225} & \mathbf{0.25} & \mathbf{0.275} & \mathbf{0.55}\end{pmatrix}\cdot in$$

$$\left(Bolts^{T}\right)^{\langle\mathbf{0}\rangle^{T}} - \left(Bolts^{T}\right)^{\langle\mathbf{1}\rangle^{T}} = \begin{pmatrix}-\mathbf{0.5} & -\mathbf{0.563} & -\mathbf{0.625} & -\mathbf{0.688} & -\mathbf{0.75} & -\mathbf{0.813} & -\mathbf{0.875} & -\mathbf{1.063} & -\mathbf{1} & -\mathbf{1.125} & -\mathbf{1.25} & -\mathbf{1.375} & -\mathbf{1.25}\end{pmatrix}\cdot$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

State Structures Design Office

SUBJECT 079-241-I MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

SoilType :=
- Sand
- **Clay**

$\phi_{soil} := 0.0 \cdot deg$ soil friction angle (sand)

$c_{soil} := 1.50 \cdot \frac{kip}{ft^2}$ soil shear strength (clay)

$N_{blows} := 14$ number of blows per foot. If N< 5, contact the district geotech Engineer

$\gamma_{soil} := 64 \cdot pcf$ effective soil weight (typical design value = 45 ~ 50 pcf)

Geometry

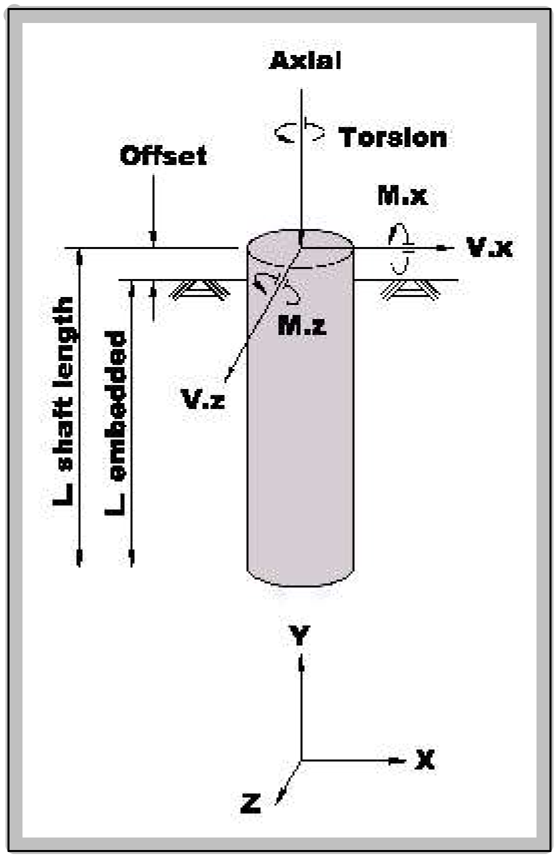
$b := 3.0 \cdot ft$ shaft diameter

$Offset := 0.50 \cdot ft$ groundline to top of foundation

Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := 78.03 \cdot kip \cdot ft$ $V_x := 0.05 \cdot kip$ $Torsion := 90.20 \cdot kip \cdot ft$

$M_z := 63.40 \cdot kip \cdot ft$ $V_z := 4.83 \cdot kip$ $Axial := 17.60 \cdot kip$



StructureType :=
- Cantilever Overhead Sign Structure
- **Mast Arm Signal Structure**
- Concrete/Steel Strain Poles
- Ground Sign

$StructureType = 1$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

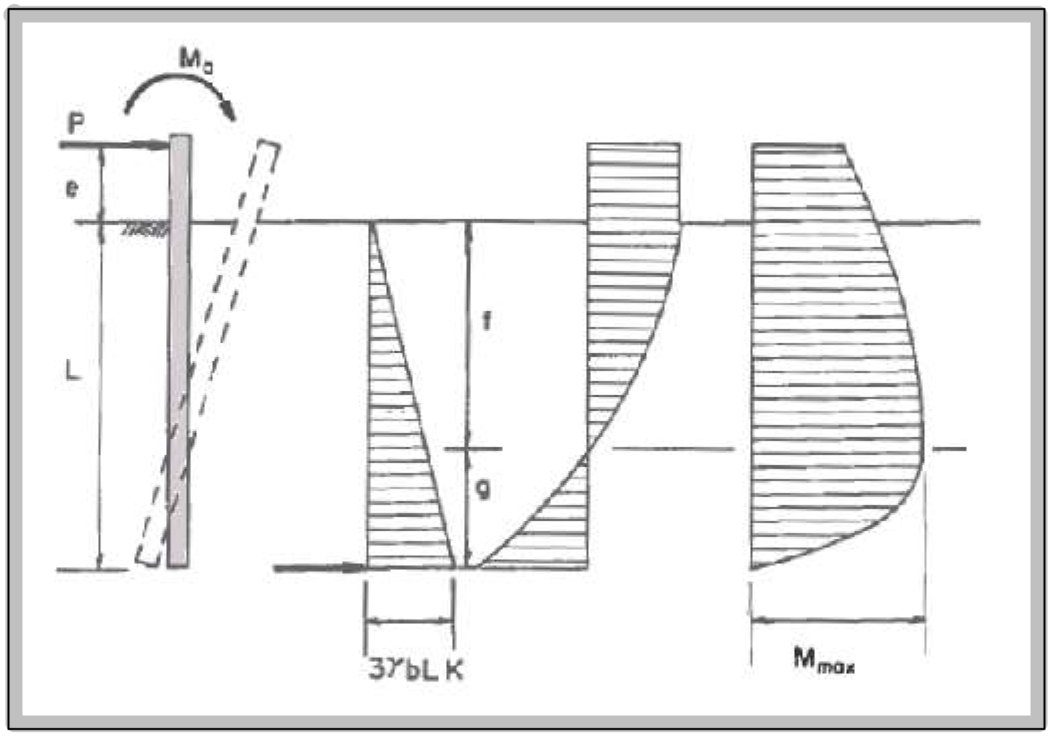
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x^{\,2} + M_z^{\,2}} = \mathbf{100.5} \cdot \text{kip} \cdot \text{ft}$

$P_u := \sqrt{V_x^{\,2} + V_z^{\,2}} = \mathbf{4.8} \cdot \text{kip}$

$T_u := \text{Torsion} = \mathbf{90.2} \cdot \text{kip} \cdot \text{ft}$

*short free-head pile in **cohesionless soil** using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(\mathbf{45} \cdot \text{deg} + \frac{\phi_{soil}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1}$ $\qquad e_{sand} := \text{Offset} = \mathbf{0.5}\,\text{ft}$

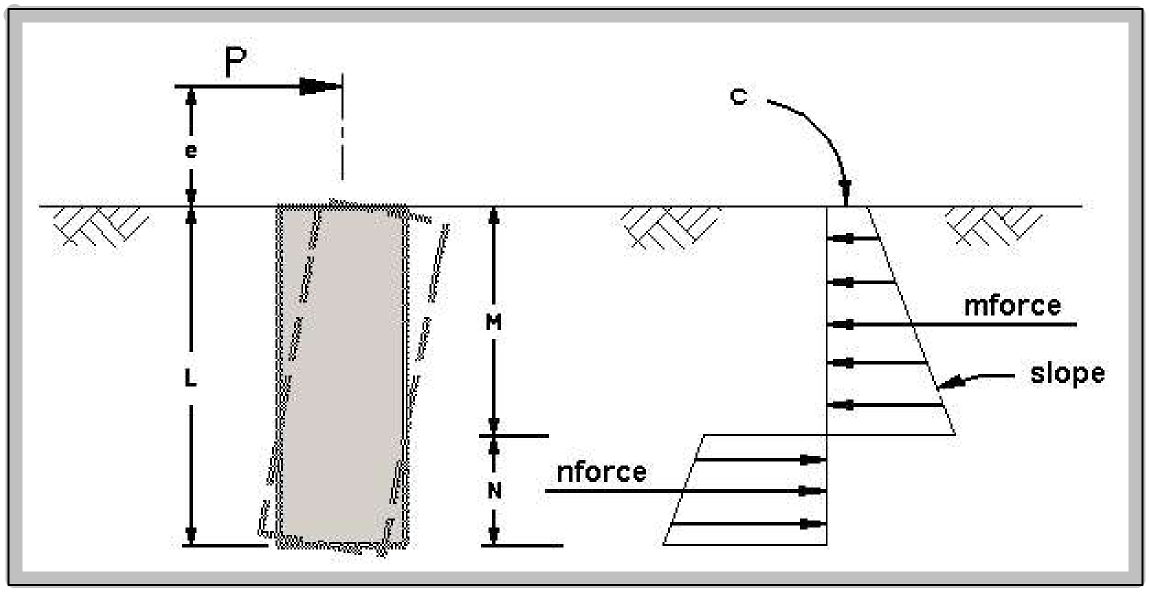
Guess value $\qquad L_{otSand} := \mathbf{10} \cdot \text{ft}$

Given $\qquad P_u \cdot \left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot} \cdot \left[\left(\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{2}} \cdot L_{otSand}\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{3}} \cdot L_{otSand}\right)\right]$

$L_{otSand} := \text{Find}\left(L_{otSand}\right) = \mathbf{20.3}\,\text{ft}$

$L_{otSand} := \text{ceil}\left(\frac{L_{otSand}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{21}\,\text{ft}$ $\qquad$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}\left(c_{soil} = \mathbf{0} \cdot \text{ksf}, \mathbf{0.1} \cdot \text{ksf}, c_{soil}\right) = \mathbf{1.5} \cdot \text{ksf}$

$\text{Slope} := \mathbf{8} \cdot \dfrac{c_{soil}}{\mathbf{3} \cdot b} = \mathbf{1.3} \cdot \dfrac{\text{kip}}{\text{ft}^{\mathbf{3}}}$

$e_{clay} := \dfrac{M_u}{P_u} + \text{Offset} = \mathbf{21.3} \, \text{ft}$

$\text{nforce}(M, N) := \left[\text{Slope} \cdot (\mathbf{2} \cdot M + N) + \mathbf{2} \cdot c_{soil}\right] \cdot N \cdot \dfrac{b}{\mathbf{2}}$

$\text{mforce}(M) := \left(\mathbf{2} \cdot c_{soil} + M \cdot \text{Slope}\right) \cdot M \cdot \dfrac{b}{\mathbf{2}}$

$\text{m\_arm}(M) := e_{clay} + \dfrac{M}{\mathbf{3}} \cdot \dfrac{\mathbf{2} \cdot (M \cdot \text{Slope} + c_{soil}) + c_{soil}}{M \cdot \text{Slope} + \mathbf{2} \cdot c_{soil}}$

$\text{n\_arm}(M, N) := e_{clay} + M + \dfrac{N}{\mathbf{3}} \cdot \dfrac{\mathbf{2} \cdot (N \cdot \text{Slope} + M \cdot \text{Slope} + c_{soil}) + (M \cdot \text{Slope} + c_{soil})}{\text{Slope} \cdot (\mathbf{2} \cdot M + N) + \mathbf{2} \cdot c_{soil}}$

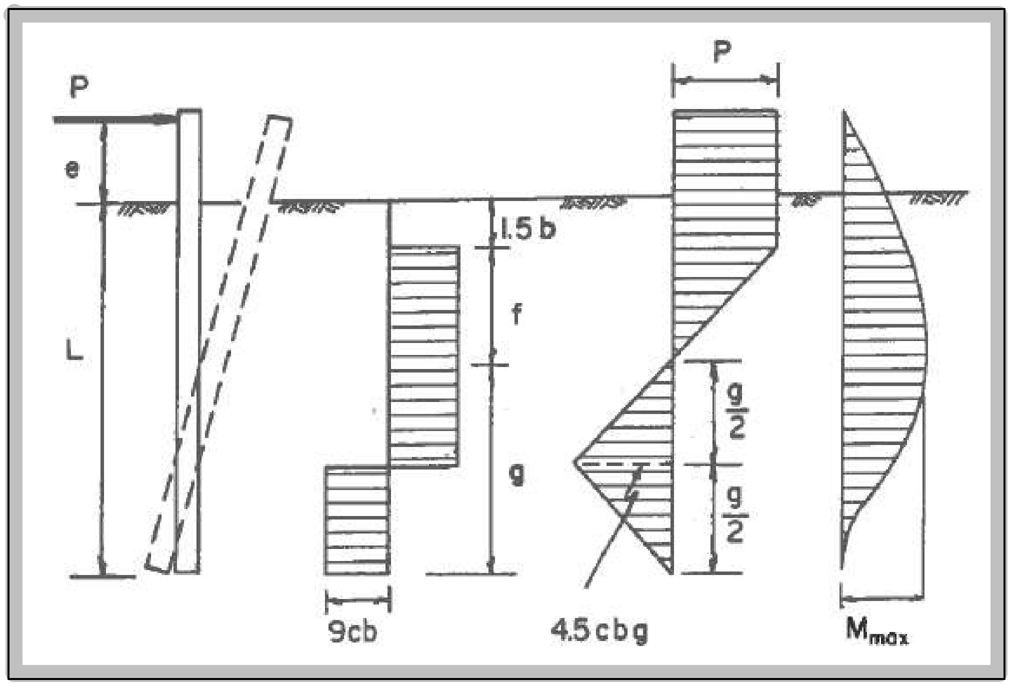
Guess value $M := \mathbf{4.0} \cdot \text{ft}$ $N := \mathbf{4.0} \cdot \text{ft}$

Given $P_u + \phi_{ot} \cdot \text{nforce}(M, N) = \phi_{ot} \cdot \text{mforce}(M)$ $\text{mforce}(M) \cdot \text{m\_arm}(M) = \text{nforce}(M, N) \cdot \text{n\_arm}(M, N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M, N)$ $L_{ot1Clay} := M + N = \mathbf{10.2} \, \text{ft}$

$L_{ot1Clay} := \text{ceil}\left(\dfrac{L_{ot1Clay}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{11} \, \text{ft}$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot \mathbf{9} \cdot c_{soil} \cdot b} = \mathbf{0.5}\,\text{ft}$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + \mathbf{1.5} \cdot b + \mathbf{0.5} \cdot f\right) = \mathbf{125.8} \cdot \text{kip} \cdot \text{ft}$$

$$g := \sqrt{\frac{M_{max.clay}}{\mathbf{2.25} \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = \mathbf{7.1}\,\text{ft}$$

$$L_{ot2Clay} := \left(\mathbf{1.5} \cdot b + f + g\right) = \mathbf{12}\,\text{ft}$$

$$L_{ot2Clay} := \text{ceil}\left(\frac{L_{ot2Clay}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{13}\,\text{ft}$$

(round up to next foot)

$$L_{otClay} := \text{if}\left(L_{ot1Clay} < \mathbf{3} \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = \mathbf{13}\,\text{ft}$$

(If $L_{ot} < 3b$*, use Modified Broms method)*

$$L_{reqdOT} := \text{if}\left(\text{SoilType} = \textbf{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$$L_{reqdOT} = \mathbf{13}\,\text{ft}$$

required shaft embedment depth to resist overturning

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = 14$

$\omega_{fdot} := \text{if}\left(N_{blows} < 5, 0, \text{if}\left(N_{blows} \ge 15, 1.5, 1.5\cdot\frac{N_{blows}}{15}\right)\right) = 1.4$

load transfer ratio, If 5<N<15, ω_{fdot} *is reduced by a factor of* $\frac{N_{blows}}{15}$ *SM Vol-3 13.6*

Guess value $L_{torSand} := L_{reqdOT} = 13\,ft$

Given $T_u = \phi_{tor}\cdot\left[\pi\cdot b\cdot\left(L_{torSand}\right)\cdot\gamma_{soil}\cdot\left(\frac{L_{torSand}}{2}\right)\cdot\left(\omega_{fdot}\right)\cdot\frac{b}{2}\right]$

$L_{torSand} := \text{Find}\left(L_{torSand}\right) = 11.9\,ft$

$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{ft}\right)\cdot ft = 12\,ft$ *(round up to next foot)*

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := 0.55$

$f_{se} := \text{CohesionFactor}\cdot c_{soil} = 0.8\cdot ksf$

Guess value $L_{torClay} := L_{reqdOT}$

Given $T_u = \phi_{tor}\cdot\left[f_{se}\cdot(\pi\cdot b)\cdot\left(L_{torClay} - 1.5\cdot ft\right)\cdot\frac{b}{2}\right]$

$L_{torClay} := \text{Find}\left(L_{torClay}\right) = 9.2\,ft$

$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{ft}\right)\cdot ft = 10\,ft$ *(round up to next foot)*

$L_{reqdTor} := \text{if}\left(\text{SoilType} = \text{"Sand"}, L_{torSand}, L_{torClay}\right)$

$L_{reqdTor} = 10\,ft$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}\left(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}\right) = 13\,ft$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = 13.5\,ft$ *shaft length*

Min Shaft embedment depth=14 ft

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2 \cdot P_u}{3 \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = 8.2 \text{ ft}$$

$$M_{maxSand} := P_u \cdot (e_{sand} + f_{sand}) - \frac{P_u \cdot f_{sand}}{3} + M_u = 129.3 \cdot \text{kip} \cdot \text{ft}$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0 \cdot \text{ft}$

Given $$P_u = \frac{f_{mod} \cdot b}{2} \cdot (2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot Slope)$$

$$f_{mod} := Find(f_{mod}) = 2.2 \text{ ft}$$

$$M_{modBroms} := P_u \cdot (e_{clay} + f_{mod}) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^{2}}{2} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^{3} \cdot Slope}{6} = 109.1 \cdot \text{kip} \cdot \text{ft}$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot (e_{clay} + 1.5 \cdot b + 0.5 \cdot f) = 125.8 \cdot \text{kip} \cdot \text{ft}$$

$$M_{maxClay} := if(L_{ot1Clay} < 3 \cdot b, M_{modBroms}, M_{Broms}) = 125.8 \cdot \text{kip} \cdot \text{ft}$$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$$M_{max} := if(SoilType = \text{"Sand"}, M_{maxSand}, M_{maxClay}) = 125.8 \cdot \text{kip} \cdot \text{ft}$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$ *reinforcing yield strength*

$f_c := 4.0 \cdot ksi$ *concrete strength* *Spec 346-3*

$Cover := 3 \cdot in$ *cover* *SDG Table 1.4.2-1*

$Num_{bar} := 11$ *number of longitudinal bars*

$A_{long.bar} := 1.0 \cdot in^2$ *longitudinal bar area*

$d_{long.bar} := 1.125 \cdot in$ *longitudinal bar diameter*

$A_{v.bar} := 0.20 \cdot in^2$ *stirrup area* *SM Vol-3 13.6.2*

$d_{v.bar} := 0.5 \cdot in$ *stirrup diameter*

$s_{v1} := 3 \cdot in$ *stirrup spacing, depth = 0 ft-2 ft* *SM Vol-3 13.6.2*

$s_{v2} := 3 \cdot in$ *stirrup spacing, depth = 2 ft-depth.stir*

$s_{v3} := 6 \cdot in$ *stirrup spacing, depth > depth.stir*

$depth_{stir} := 15.0 \cdot ft$ *stirrup depth, see s.v2 and s.v3 above*

$b = 3 \, ft$ *shaft diameter*

$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$ *required 1% steel* *SM Vol-3 13.6.2*

$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$ *LRFD 5.7.4.2*

$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot in^2$

$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$ *total area of longitudinal steel*

$CheckLongitudinalReinf := if(A_{long} \ge A_{req}, \text{"OK"}, \text{"No Good"})$ $CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if(Clearance_{vert.reinf} \ge 6 in, \text{"OK"}, \text{"No Good"})$ $CheckReinfClearSpacing = \text{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$V_u := \sqrt{V_x^{\mathbf{2}} + V_z^{\mathbf{2}}} = \mathbf{4.8} \cdot kip$

$T_u = \mathbf{90.2} \cdot kip \cdot ft$

Effective shear depth

$D_r := b - \mathbf{2} \cdot \left(Cover + d_{v.bar} + \frac{d_{long.bar}}{\mathbf{2}}\right) = \mathbf{2.3}\, ft$ $d_e := \frac{b}{\mathbf{2}} + \frac{D_r}{\pi} = \mathbf{2.2}\, ft$ *LRFD C5.8.2.9-2*

$d_v := \max(\mathbf{0.9} \cdot d_e, \mathbf{0.72} \cdot b) = \mathbf{2.2}\, ft$

Check Shear Strength

$V_c := \mathbf{0.0316} \cdot (\mathbf{2.0}) \cdot \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{b}{in}\right) \cdot \left(\frac{d_v}{in}\right) \cdot kip = \mathbf{117.9} \cdot kip$ *LRFD Eqn 5.8.3.3-3* *LRFD 5.8.3.4.1* *ACI 11.3.3*

$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max(s_{v1}, s_{v2}, s_{v3})} = \mathbf{51.8} \cdot kip$ *LRFD Eqn 5.8.3.3-4*

$ShearRatio := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -\mathbf{2.2}$

$ShearRatio := if(ShearRatio \le \mathbf{0}, \mathbf{0}, ShearRatio) = \mathbf{0}$

Check Torsion Strength

$A_{cp} := \pi \cdot \left(\frac{b}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1017.9} \cdot in^{\mathbf{2}}$ $p_{cp} := \mathbf{2} \cdot \pi \cdot \left(\frac{b}{\mathbf{2}}\right) = \mathbf{113.1} \cdot in$ *Area and perimeter of concrete cross-section*

$d_{oh} := b - \mathbf{2} \cdot \left(Cover + \frac{d_{v.bar}}{\mathbf{2}}\right) = \mathbf{29.5} \cdot in$ $p_h := \pi \cdot d_{oh} = \mathbf{92.7} \cdot in$ *Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement*

$A_{oh} := \pi \left(\frac{d_{oh}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{683.5} \cdot in^{\mathbf{2}}$ $A_o := \mathbf{0.85} \cdot A_{oh} = \mathbf{581} \cdot in^{\mathbf{2}}$

$T_{n1} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = \mathbf{387.3} \cdot kip \cdot ft$ *LRFD Eqn 5.8.3.6.2-1*

$T_{n2} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = \mathbf{387.3} \cdot kip \cdot ft$ *LRFD 5.8.3.4.1*

$$T_{n3} := \frac{\mathbf{2}\cdot A_o\cdot A_{v.bar}\cdot F_{y.rebar}}{s_{v3}} = \mathbf{193.7}\cdot\text{kip}\cdot\text{ft}$$

$\phi_v = \mathbf{0.9}$ $T_u = \mathbf{90.2}\cdot\text{kip}\cdot\text{ft}$ $L_{reqdTor} = \mathbf{10}\,\text{ft}$

$$Tor2_{sand} := T_u - \text{if}\left[\mathbf{2}\text{ft} > \text{Offset}, \left[\pi\cdot b\cdot(\mathbf{2}\cdot\text{ft} - \text{Offset})\cdot\gamma_{soil}\cdot\left(\frac{\mathbf{2}\cdot\text{ft} - \text{Offset}}{\mathbf{2}}\right)\cdot(\omega_{fdot})\cdot\frac{b}{\mathbf{2}}\right], \mathbf{0}\cdot\text{kip}\cdot\text{ft}\right] = \mathbf{88.8}\cdot\text{kip}\cdot\text{ft}$$

$$Tor3_{sand} := T_u - \text{if}\left[\text{depth}_{stir} > \text{Offset}, \left[\pi\cdot b\cdot(\text{depth}_{stir} - \text{Offset})\cdot\gamma_{soil}\cdot\left(\frac{\text{depth}_{stir} - \text{Offset}}{\mathbf{2}}\right)\cdot(\omega_{fdot})\cdot\frac{b}{\mathbf{2}}\right], \mathbf{0}\cdot\text{kip}\cdot\text{ft}\right] = -\mathbf{43}\cdot\text{kip}\cdot\text{ft}$$

$$Tor2_{clay} := T_u - \text{if}\left[\mathbf{2}\text{ft} - \mathbf{1.5}\text{ft} > \text{Offset}, \left[f_{se}\cdot(\pi\cdot b)\cdot(\mathbf{2.0}\cdot\text{ft} - \text{Offset} - \mathbf{1.5}\cdot\text{ft})\cdot\frac{b}{\mathbf{2}}\right], \mathbf{0}\cdot\text{kip}\cdot\text{ft}\right] = \mathbf{90.2}\cdot\text{kip}\cdot\text{ft}$$

$$Tor3_{clay} := T_u - \text{if}\left[\text{depth}_{stir} - \mathbf{1.5}\text{ft} > \text{Offset}, \left[f_{se}\cdot(\pi\cdot b)\cdot(\text{depth}_{stir} - \text{Offset} - \mathbf{1.5}\cdot\text{ft})\cdot\frac{b}{\mathbf{2}}\right], \mathbf{0}\cdot\text{kip}\cdot\text{ft}\right] = -\mathbf{61.4}\cdot\text{kip}\cdot\text{ft}$$

$$Tor2 := \text{if}(\text{SoilType} = \mathbf{"Sand"}, Tor2_{sand}, Tor2_{clay}) = \mathbf{90.2}\cdot\text{kip}\cdot\text{ft}$$

$$Tor3 := \text{if}(\text{SoilType} = \mathbf{"Sand"}, Tor3_{sand}, Tor3_{clay}) = -\mathbf{61.4}\cdot\text{kip}\cdot\text{ft}$$

$$\text{TorsionRatio}_{n1} := \frac{T_u}{\phi_{tor}\cdot T_{n1}} = \mathbf{0.23}$$

$$\text{TorsionRatio}_{n2} := \frac{Tor2}{\phi_{tor}\cdot T_{n2}} = \mathbf{0.23}$$

$$\text{TorsionRatio}_{n3} := \frac{Tor3}{\phi_{tor}\cdot T_{n3}} = -\mathbf{0.32}$$

$$\text{TorsionRatio} := \max(\text{TorsionRatio}_{n1}, \text{TorsionRatio}_{n2}, \text{TorsionRatio}_{n3}) = \mathbf{0.23}$$

$$T_{cr} := \mathbf{0.125}\sqrt{\frac{f_c}{\text{ksi}}}\cdot\left(\frac{A_{cp}^{\ \mathbf{2}}}{p_{cp}\cdot\text{in}^{\mathbf{3}}}\right)\cdot\text{kip}\cdot\text{in} = \mathbf{190.9}\cdot\text{kip}\cdot\text{ft}$$

LRFD Eqn 5.8.2.1-4

$$\text{TorsionRatio} := \text{if}(T_u \le \mathbf{0.25}\cdot\phi_{tor}\cdot T_{cr}, \mathbf{0}, \text{TorsionRatio}) = \mathbf{0.2}$$

LRFD Eqn 5.8.2.1-3

$\text{ShearRatio} = \mathbf{0}$

$$\text{CheckShearTorsion} := \text{if}(\text{ShearRatio} + \text{TorsionRatio} \le \mathbf{1}, \mathbf{"OK"}, \mathbf{"No\ Good"})$$

$\text{CheckShearTorsion} = \mathbf{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v\cdot b\cdot d_v} = \mathbf{0.005752}\cdot\text{ksi}$$ $$\mathbf{0.125}\cdot f_c = \mathbf{0.5}\cdot\text{ksi}$$

LRFD Eqn 5.8.2.9-1

$$s_{max1} := \text{if}(\mathbf{0.8}\cdot d_v < \mathbf{24}\cdot\text{in}, \mathbf{0.8}d_v, \mathbf{24}\cdot\text{in}) = \mathbf{20.7}\cdot\text{in}$$

LRFD Eqn 5.8.2.7-1

$s_{max2} := \text{if}\left(\mathbf{0.4} \cdot d_v < \mathbf{12} \cdot in, \mathbf{0.4} d_v, \mathbf{12} \cdot in\right) = \mathbf{10.4} \cdot in$ LRFD Eqn 5.8.2.7-2

$s_{max} := \text{if}\left(v_u < \mathbf{0.125} \cdot f_c, s_{max1}, s_{max2}\right) = \mathbf{20.7} \cdot in$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = \mathbf{6} \cdot in$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \textbf{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion

LRFD Eqn 5.8.3.6.3-1

LRFD 5.8.3.4.1

$M_u = \mathbf{100.5} \cdot kip \cdot ft$

$$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5 \cdot V_s > \mathbf{0} \cdot kip, \frac{V_u}{\phi_v} - 0.5 \cdot V_s, \mathbf{0} \cdot kip\right) = \mathbf{0} \cdot kip$$

$$\text{LongReinf}_{shr.tor} := \frac{\dfrac{M_u}{\phi_v \cdot d_v} + \sqrt{\left(V_{temp}\right)^{\mathbf{2}} + \left(\dfrac{\mathbf{0.45} \cdot p_h \cdot T_u}{\mathbf{2} \cdot A_o \cdot \phi_v}\right)^{\mathbf{2}}}}{F_{y.rebar}} = \mathbf{1.6} \cdot in^{\mathbf{2}}$$

$\text{Num}_{bar} \cdot A_{long.bar} = \mathbf{11} \cdot in^{\mathbf{2}}$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(\text{Num}_{bar} \cdot A_{long.bar} \ge \text{LongReinf}_{shr.tor}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \textbf{"OK"}$

Anchor Bolt Strength Check

$Num_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot in$ *anchor bolt nominal diameter*

$Dia_{anchor.circle} := 24 \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{Dia_{anchor.circle}^{\,2}}{8} \cdot Num_{anchor} = 576 \cdot in^2$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{Dia_{anchor.circle}}{2}} = 48 \cdot in$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 25.1 \cdot kip$$ *anchor tension force*

$$V_{anchor} := \frac{V_u}{Num_{anchor}} + \frac{T_u}{0.5 Dia_{anchor.circle} \cdot Num_{anchor}} = 11.9 \cdot kip$$ *anchor shear force*

$$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}^{\,2} = 3.1 \cdot in^2$$ *anchor bolt nominal area*

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 8 \cdot ksi$$ *anchor tensile stress*

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 3.8 \cdot ksi$$ *anchor shear stress*

$\phi_{anchor} := 0.75$ *resistance factor* AISC J3-1

$F_{nt} := 0.75 F_{u.anchor} = 78.8 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := 0.45 F_{u.anchor} = 47.2 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot kip$ *design sghear strength*

$CheckAnchorT := if\left(\phi R_{nt} \geq T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$CheckAnchorT = \text{"OK"}$

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check shear rupture*

$\text{CheckAnchorV} = \text{"OK"}$

$$F_{ntv} := \min\left(\begin{pmatrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{pmatrix}\right) = 78.8 \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = 185.6 \cdot \text{kip}$

design tension strength modified to include the effects of shearing stress

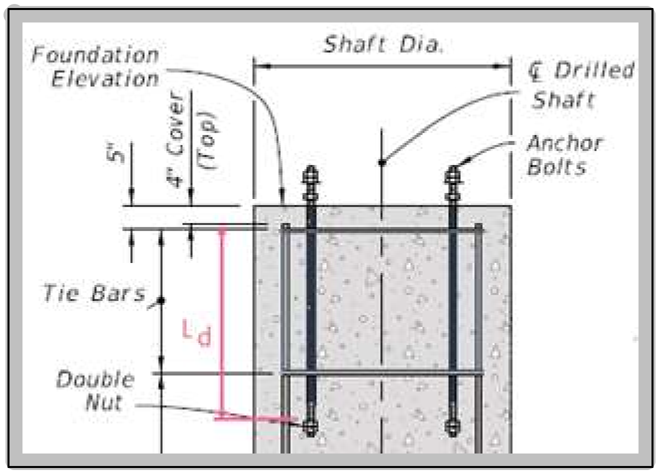
$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq 20\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq 20\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \text{"OK"}, \text{"No Good"}\right]$

$\text{CheckAnchorTV} = \text{"OK"}$ *check combined tension and shear rupture*

$\text{CheckAnchorStrength} := \text{if}\left[(\text{CheckAnchorT} = \text{"OK"}) \cdot (\text{CheckAnchorV} = \text{"OK"}) \cdot (\text{CheckAnchorTV} = \text{"OK"}), \text{"OK"}, \text{"No Good"}\right]$

$\text{CheckAnchorStrength} = \text{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = 25.1 \cdot \text{kip}$ *tension force in anchor*

$\text{Dia}_{bar.circle} = 27.9 \cdot \text{in}$ $\text{Dia}_{anchor.circle} = 24 \cdot \text{in}$

center-to-center distance

$$\text{Dist}_{bar.to.bolt} := \frac{\text{Dia}_{bar.circle} - \text{Dia}_{anchor.circle}}{2} = 1.9 \cdot \text{in}$$

$$\text{Num}_{bars.per.anchor} := \min\left(\frac{\text{Num}_{bar}}{\text{Num}_{anchor}}, 3\right) = 1.4$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := 0.9$

$$\text{Num}_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot (\phi \cdot F_{y.rebar})} \cdot \frac{\text{Dia}_{anchor.circle}}{\text{Dia}_{bar.circle}} = 0.4$$

$$\text{AreaRatio} := \min\left(\frac{\text{Num}_{bars.reqd.per.anchor}}{\text{Num}_{bars.per.anchor}}, 1\right) = 0.29$$

2015 AASHTO Development Length of Deformed Bars in Tension ***5.11.2.1***

$\text{Cover} = 3 \cdot \text{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half*

the center-to-center spacing of the bars or wires being developed

$$c_b := \min\left(\begin{pmatrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{2} \\ \dfrac{\text{Spacing}_{vert.reinf}}{2} \end{pmatrix}\right) = 4 \cdot in$$

$k_{tr} := 0 \cdot in$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\begin{bmatrix} 1.0 \\ \max\left(\begin{pmatrix} 0.4 \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{pmatrix}\right) \end{bmatrix}\right] = 0.4$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\begin{pmatrix} 12 \cdot in \\ \lambda_{rc} \cdot 2.4 \cdot d_{long.bar} \cdot \dfrac{F_{y.rebar}}{\sqrt{f_c \cdot ksi}} \end{pmatrix}\right) = 32.4 \cdot in$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$\text{SpacingFactor} := \max\left[\begin{pmatrix} 0.5 \\ \text{Num}_{bars.per.anchor} \cdot 0.5 - 0.5 \end{pmatrix}\right] = 0.5$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf} \cdot \text{SpacingFactor}\right)^2 + \text{Dist}_{bar.to.bolt}^{\,2}} = 3.9 \cdot in$$

$$L_{embedment.anchor} := \max\left[\begin{bmatrix} L_{d.bar} \cdot (\text{AreaRatio}) + 12 \cdot in + L_{embedment.added} \\ 20 \cdot d_{anchor} \end{bmatrix}\right] = 40 \cdot in$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, in\right)$ $L_{embedment.anchor} = 40 \cdot in$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{\mathrm{Dia}_{\mathrm{anchor.circle}}}{\mathbf{2}} = \mathbf{12}\cdot\mathrm{in}$$

$$r := \frac{b}{\mathbf{2}} = \mathbf{18}\cdot\mathrm{in}$$

$$c_{a1} := \frac{\sqrt{r_b^{\mathbf{2}} + \mathbf{3.25}\cdot\left(r^{\mathbf{2}} - r_b^{\mathbf{2}}\right)} - r_b}{\mathbf{3.25}} = \mathbf{4.6}\cdot\mathrm{in}$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\begin{pmatrix} \mathbf{8}\cdot d_{\mathrm{anchor}} \\ L_{\mathrm{embedment.anchor}} \end{pmatrix}\right) = \mathbf{16}\cdot\mathrm{in}$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := \mathbf{13}\cdot\left(\frac{L_e}{d_{\mathrm{anchor}}}\right)^{\mathbf{0.2}}\cdot\sqrt{\frac{d_{\mathrm{anchor}}}{\mathrm{in}}}\cdot\sqrt{\frac{f_c}{\mathrm{psi}}}\left(\frac{c_{a1}}{\mathrm{in}}\right)^{\mathbf{1.5}}\cdot\mathrm{lbf} = \mathbf{17.5}\cdot\mathrm{kip}$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{\mathrm{bolt.sector}} := \frac{(\mathbf{360}\cdot\mathrm{deg})}{\mathrm{Num}_{\mathrm{anchor}}} = \mathbf{45}\cdot\mathrm{deg}$$

UF Report Fig 3-7

$$\alpha := 2\,\mathrm{asin}\left[\frac{(\mathbf{1.5}\cdot c_{a1})}{r}\right] = \mathbf{45.2}\cdot\mathrm{deg}$$

$$\mathrm{OverlapTest} := \mathrm{if}\left(A_{\mathrm{bolt.sector}} \le \alpha, \textbf{"Overlap of Failure Cones"}, \textbf{"No Overlap of Failure Cones"}\right) = \textbf{"Overlap of Failur}$$

$$\mathrm{chord} := \mathbf{2}\cdot r\cdot\sin\left(\frac{A_{\mathrm{bolt.sector}}}{\mathbf{2}}\right) = \mathbf{13.8}\cdot\mathrm{in}$$

UF Report Fig 3-7

$$A_{Vco} := \mathbf{4.5}\cdot c_{a1}^{\mathbf{2}} = \mathbf{95.9}\cdot\mathrm{in}^{\mathbf{2}}$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := \mathrm{chord}\cdot\mathbf{1.5}\cdot c_{a1} = \mathbf{95.4}\cdot\mathrm{in}^{\mathbf{2}}$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \mathrm{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = \mathbf{95.4}\cdot\mathrm{in}^{\mathbf{2}}$$

$\psi_{ecV} := 1.0$	*eccentric load modifier*	ACI D.6.2.5	
$\psi_{edV} := 1.0$	*edge effect modifier*	ACI D.6.2.6	
$\psi_{cV} := 1.4$	*cracked section modifier*	ACI D.6.2.7	*(stirrup spacing <= 4")*
$\psi_{hV} := 1.0$	*member thickness modifier*	ACI D.6.2.8	
$\phi_{breakout} := 0.75$	*strength reduction factor*	ACI D.4.4.c.i	*(shear breakout, condition A)*

$V_{cbg} := Num_{anchor} \cdot \left(\frac{AV_c}{AV_{co}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = 194.7 \cdot kip$ *concrete breakout strength - shear*

ACI Eqn D-22 *Shear force $\perp$ to edge*

$V_{cbg\_parallel} := 2 \cdot V_{cbg} = 389.5 \cdot kip$ ACI D.6.2.1.c *Shear force $\parallel$ to edge*

$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = 389.5 \cdot kip \cdot ft$ *concrete breakout strength - torsion*

$\phi_{breakout} \cdot T_{n.breakout} = 292.1 \cdot kip \cdot ft$

$T_u = 90.2 \cdot kip \cdot ft$

$BreakoutTest := if\left(\phi_{breakout} \cdot T_{n.breakout} \ge T_u, \text{"OK"}, \text{"No Good"}\right)$

$BreakoutTest = \text{"OK"}$

$OverlapDesign := if\left(A_{bolt.sector} \le \alpha, \text{"Based on Overlap of Failure Cones"}, \text{"Based on No Overlap of Failure Cones"}\right)$

$OverlapDesign = \text{"Based on Overlap of Failure Cones"}$

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = 1.9 \cdot in$ *center-to-center distance*

$d_{anchor.nut} := 1.85 \cdot d_{anchor} = 3.7 \cdot in$ *use* $1.85 \cdot d_{anchor}$ *.to account for anchor nut*

$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{2}\right) = -0.5 \cdot in$

$CheckAnchorageClearance := if\left[\left(Clearance_{bar.to.nut} \ge 2 \cdot in\right), \text{"OK"}, \text{"No Good, increase ped. diameter"}\right]$

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0 .. 48 \qquad r_{ds} := \frac{b}{2}$

$$x_{ds_{pt}} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{ds_{pt}} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$$x_{stir.od_{pt}} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.od_{pt}} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$$

$$x_{stir.id_{pt}} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.id_{pt}} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$$x_{bar_{pt}} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max(x_{stir.id}) - d_{v.bar} \qquad y_{bar_{pt}} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$$x_{boltcircle_{pt}} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{boltcircle_{pt}} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$$

$r_{boltr} := \frac{d_{anchor}}{2} = \mathbf{1}\cdot in$

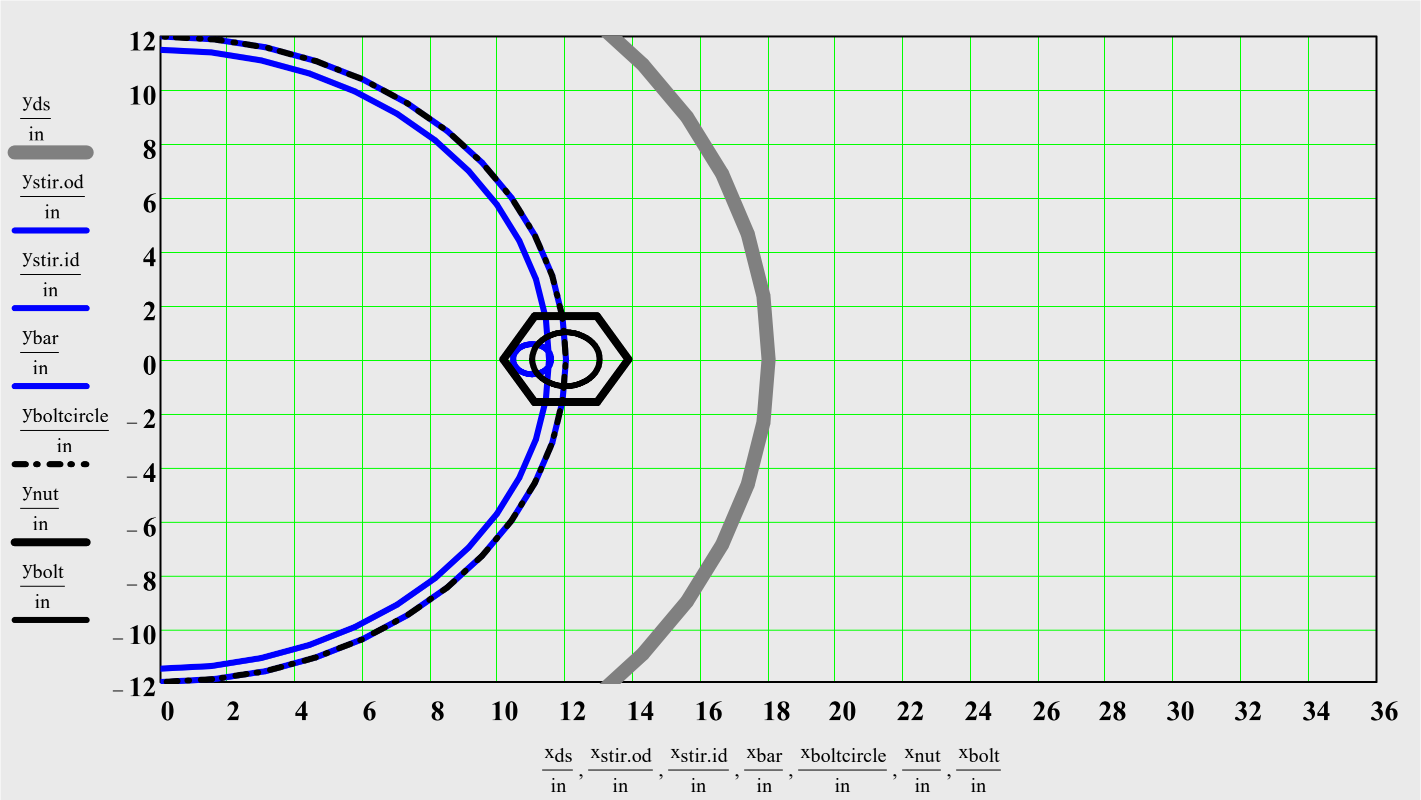
$x_{bolt_{pt}} := r_{boltr}\cdot\cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{48}} + \frac{\mathbf{2}\cdot\pi}{\mathbf{48}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $y_{bolt_{pt}} := r_{boltr}\cdot\sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2}\cdot\pi}{\mathbf{48}}\right]$

$pt := \mathbf{0}..\mathbf{6}$ $r_{nut} := \frac{d_{anchor}\cdot 1.85}{\mathbf{2}} = \mathbf{1.9}\cdot in$

$x_{nut_{pt}} := r_{nut}\cdot\cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{6}} + \frac{\mathbf{2}\cdot\pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $y_{nut_{pt}} := r_{nut}\cdot\sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{2}\cdot\pi}{\mathbf{6}}\right]$

$x_{nut_{pt}} := r_{nut}\cdot\cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{6}} + \frac{\mathbf{1}\cdot\pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ *enable to rotate nut* $y_{nut_{pt}} := r_{nut}\cdot\sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{1}\cdot\pi}{\mathbf{6}}\right]$

$\min\left(x_{bar}\right) - \max\left(x_{nut}\right) = -\mathbf{3.4}\cdot in$



$$\text{Bolts} := \begin{pmatrix} 1 & 1.125 & 1.25 & 1.375 & 1.5 & 1.625 & 1.75 & 1.875 & 2 & 2.25 & 2.5 & 2.75 & 3 \\ 1.5 & 1.688 & 1.875 & 2.063 & 2.25 & 2.438 & 2.625 & 2.938 & 3 & 3.375 & 3.75 & 4.125 & 4.25 \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{T}\right)^{\langle 0 \rangle T} \cdot 1.6 - \left(\text{Bolts}^{T}\right)^{\langle 1 \rangle T} = \begin{pmatrix} 0.1 & 0.112 & 0.125 & 0.137 & 0.15 & 0.162 & 0.175 & 0.062 & 0.2 & 0.225 & 0.25 & 0.275 & 0.55 \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{T}\right)^{\langle 0 \rangle T} - \left(\text{Bolts}^{T}\right)^{\langle 1 \rangle T} = \begin{pmatrix} -0.5 & -0.563 & -0.625 & -0.688 & -0.75 & -0.813 & -0.875 & -1.063 & -1 & -1.125 & -1.25 & -1.375 & -1.25 \end{pmatrix} \cdot$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

State Structures Design Office

SUBJECT 079-241-J MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

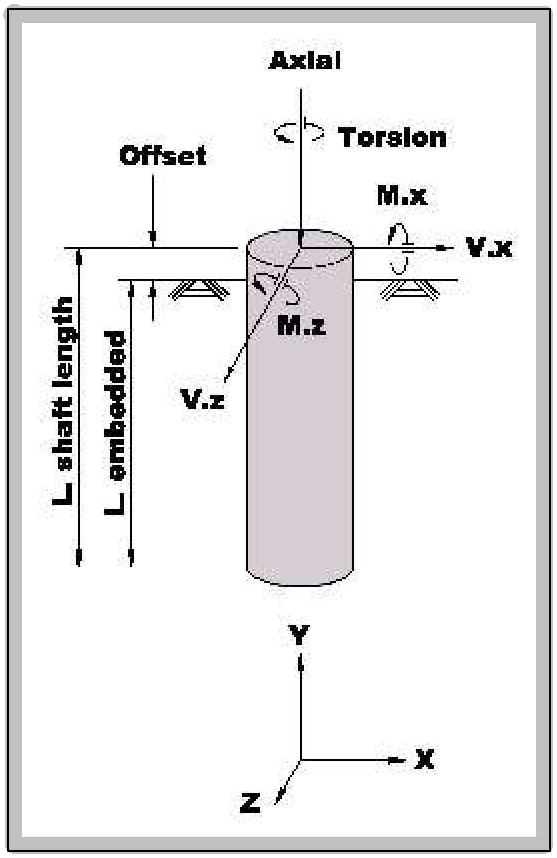
SoilType :=
- Sand
- Clay

$\phi_{soil} := 32.0 \cdot deg$ *soil friction angle (sand)*

$c_{soil} := 0.0 \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

$N_{blows} := 10$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := 69 \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*



Geometry

$b := 3.0 \cdot ft$ *shaft diameter*

$Offset := 0.50 \cdot ft$ *groundline to top of foundation*

Applied Loads (Extreme I) **Actual Loads Increased by 10%**

$M_x := 112.50 \cdot kip \cdot ft$ $V_x := 0.05 \cdot kip$ $Torsion := 153.7 \cdot kip \cdot ft$

$M_z := 91.7 \cdot kip \cdot ft$ $V_z := 6.84 \cdot kip$ $Axial := 28.60 \cdot kip$

StructureType :=
- Cantilever Overhead Sign Structure
- Mast Arm Signal Structure
- Concrete/Steel Strain Poles
- Ground Sign

$StructureType = 1$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

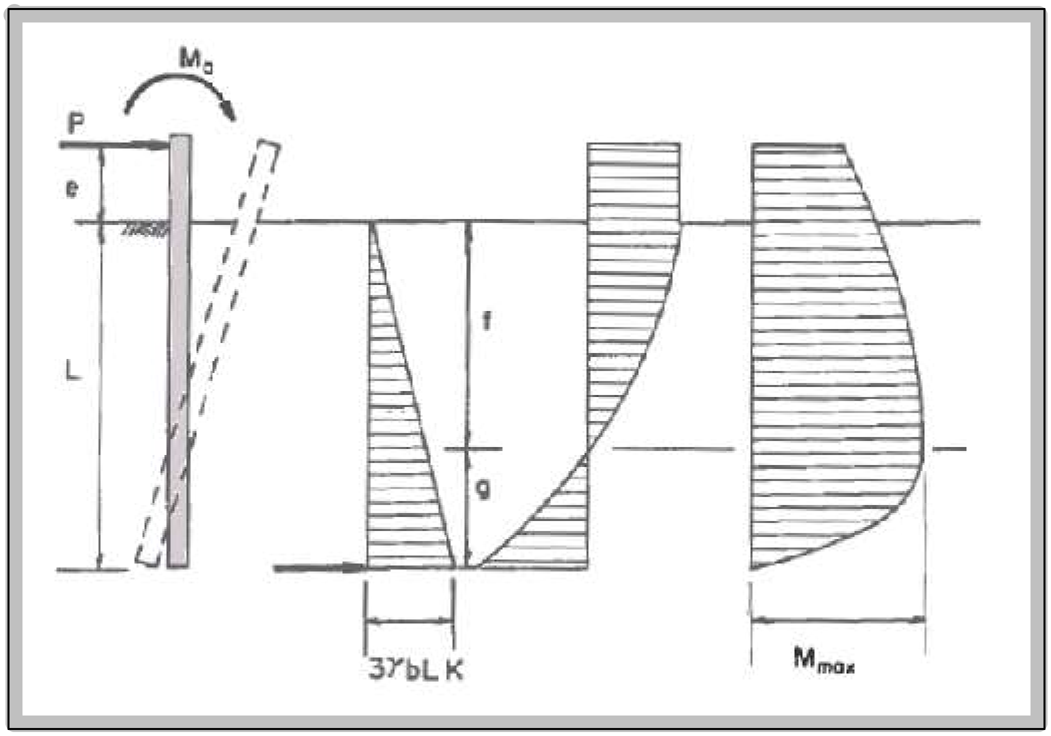
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x^2 + M_z^2} = \mathbf{145.1} \cdot kip \cdot ft$

$P_u := \sqrt{V_x^2 + V_z^2} = \mathbf{6.8} \cdot kip$

$T_u := Torsion = \mathbf{153.7} \cdot kip \cdot ft$

*short free-head pile in **cohesionless soil** using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(\mathbf{45} \cdot deg + \frac{\phi_{soil}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{3.3}$ $\qquad e_{sand} := Offset = \mathbf{0.5} ft$

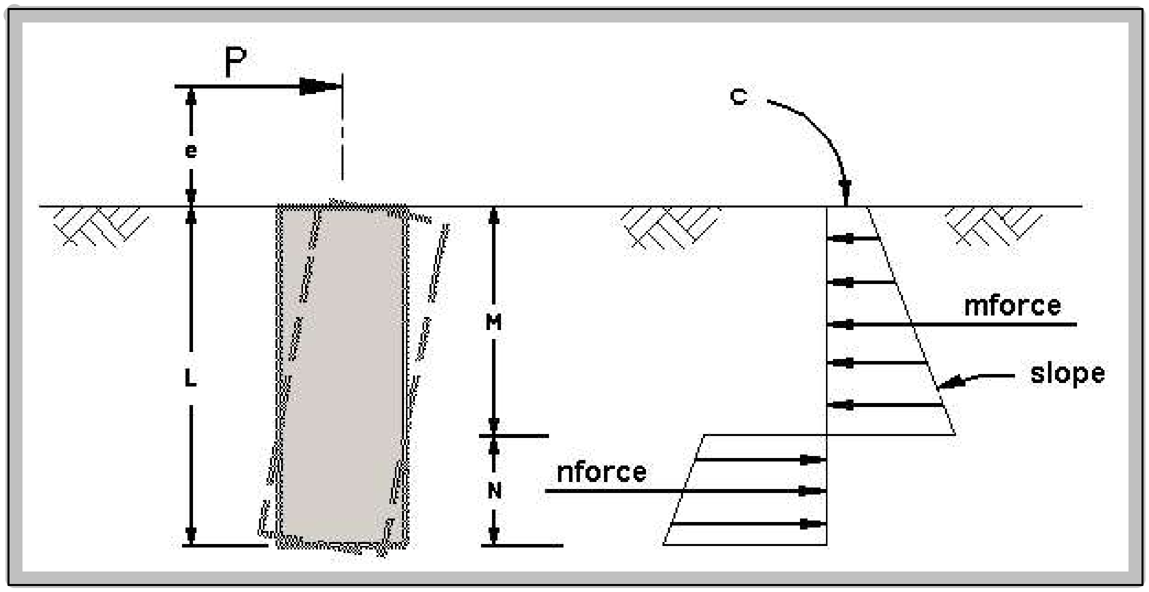
Guess value $\qquad L_{otSand} := \mathbf{10} \cdot ft$

Given $\quad P_u \cdot (e_{sand} + L_{otSand}) + M_u = \phi_{ot} \cdot \left[(\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p) \cdot \left(\frac{\mathbf{1}}{\mathbf{2}} \cdot L_{otSand} \right) \cdot \left(\frac{\mathbf{1}}{\mathbf{3}} \cdot L_{otSand} \right) \right]$

$L_{otSand} := Find(L_{otSand}) = \mathbf{14.3} ft$

$L_{otSand} := ceil\left(\frac{L_{otSand}}{ft}\right) \cdot ft = \mathbf{15} ft$ $\qquad$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}\left(c_{soil} = 0 \cdot ksf, 0.1 \cdot ksf, c_{soil}\right) = 0.1 \cdot ksf$

$\text{Slope} := 8 \cdot \frac{c_{soil}}{3 \cdot b} = 0.1 \cdot \frac{kip}{ft^3}$

$e_{clay} := \frac{M_u}{P_u} + \text{Offset} = 21.7 \, ft$

$\text{nforce}(M, N) := \left[\text{Slope} \cdot (2 \cdot M + N) + 2 \cdot c_{soil}\right] \cdot N \cdot \frac{b}{2}$

$\text{mforce}(M) := \left(2 \cdot c_{soil} + M \cdot \text{Slope}\right) \cdot M \cdot \frac{b}{2}$

$\text{m\_arm}(M) := e_{clay} + \frac{M}{3} \cdot \frac{2 \cdot (M \cdot \text{Slope} + c_{soil}) + c_{soil}}{M \cdot \text{Slope} + 2 \cdot c_{soil}}$

$\text{n\_arm}(M, N) := e_{clay} + M + \frac{N}{3} \cdot \frac{2 \cdot (N \cdot \text{Slope} + M \cdot \text{Slope} + c_{soil}) + (M \cdot \text{Slope} + c_{soil})}{\text{Slope} \cdot (2 \cdot M + N) + 2 \cdot c_{soil}}$

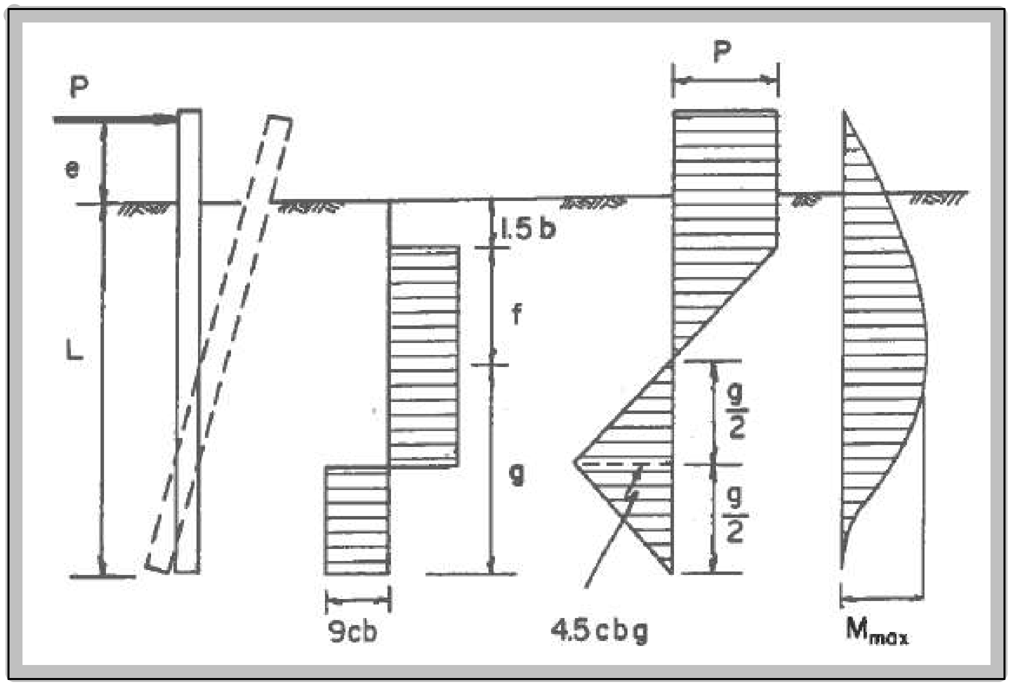
Guess value $M := 4.0 \cdot ft$ $N := 4.0 \cdot ft$

Given $P_u + \phi_{ot} \cdot \text{nforce}(M, N) = \phi_{ot} \cdot \text{mforce}(M)$ $\text{mforce}(M) \cdot \text{m\_arm}(M) = \text{nforce}(M, N) \cdot \text{n\_arm}(M, N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M, N)$ $L_{ot1Clay} := M + N = 10.8 \, ft$

$L_{ot1Clay} := \text{ceil}\left(\frac{L_{ot1Clay}}{ft}\right) \cdot ft = 11 \, ft$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot}\cdot \mathbf{9}\cdot c_{soil}\cdot b} = \mathbf{10.1}\,ft$$

$$M_{max.clay} := P_u\cdot\left(e_{clay} + \mathbf{1.5}\cdot b + \mathbf{0.5}\cdot f\right) = \mathbf{214}\cdot kip\cdot ft$$

$$g := \sqrt{\frac{M_{max.clay}}{\mathbf{2.25}\cdot\phi_{ot}\cdot c_{soil}\cdot b}} = \mathbf{35.6}\,ft$$

$$L_{ot2Clay} := \left(\mathbf{1.5}\cdot b + f + g\right) = \mathbf{50.2}\,ft$$

$$L_{ot2Clay} := ceil\left(\frac{L_{ot2Clay}}{ft}\right)\cdot ft = \mathbf{51}\,ft$$

(round up to next foot)

$$L_{otClay} := if\left(L_{ot1Clay} < \mathbf{3}\cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = \mathbf{51}\,ft$$

(If $L_{ot} < 3b$*, use Modified Broms method)*

$$L_{reqdOT} := if\left(SoilType = \text{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$$L_{reqdOT} = \mathbf{15}\,ft$$

required shaft embedment depth to resist overturning

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = \mathbf{10}$

$$\omega_{fdot} := \text{if}\left(N_{blows} < \mathbf{5}, \mathbf{0}, \text{if}\left(N_{blows} \ge \mathbf{15}, \mathbf{1.5}, \mathbf{1.5}\cdot\frac{N_{blows}}{\mathbf{15}}\right)\right) = \mathbf{1}$$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\frac{N_{blows}}{\mathbf{15}}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = \mathbf{15}\,ft$

Given $T_u = \phi_{tor}\cdot\left[\pi\cdot b\cdot\left(L_{torSand}\right)\cdot\gamma_{soil}\cdot\left(\frac{L_{torSand}}{\mathbf{2}}\right)\cdot\left(\omega_{fdot}\right)\cdot\frac{b}{\mathbf{2}}\right]$

$L_{torSand} := \text{Find}\left(L_{torSand}\right) = \mathbf{17.8}\,ft$

$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{ft}\right)\cdot ft = \mathbf{18}\,ft$ *(round up to next foot)*

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := \mathbf{0.55}$

$f_{se} := \text{CohesionFactor}\cdot c_{soil} = \mathbf{0.1}\cdot ksf$

Guess value $L_{torClay} := L_{reqdOT}$

Given $T_u = \phi_{tor}\cdot\left[f_{se}\cdot(\pi\cdot b)\cdot\left(L_{torClay} - \mathbf{1.5}\cdot ft\right)\cdot\frac{b}{\mathbf{2}}\right]$

$L_{torClay} := \text{Find}\left(L_{torClay}\right) = \mathbf{199.2}\,ft$

$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{ft}\right)\cdot ft = \mathbf{200}\,ft$ *(round up to next foot)*

$L_{reqdTor} := \text{if}\left(\text{SoilType} = \mathbf{\text{"Sand"}}, L_{torSand}, L_{torClay}\right)$

$L_{reqdTor} = \mathbf{18}\,ft$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}\left(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}\right) = \mathbf{18}\,ft$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = \mathbf{18.5}\,ft$ *shaft length*

Min Shaft embedment depth=20 ft

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2 \cdot P_u}{3 \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = 5.2 \, ft$$

$$M_{maxSand} := P_u \cdot \left(e_{sand} + f_{sand}\right) - \frac{P_u \cdot f_{sand}}{3} + M_u = 172.3 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0 \cdot ft$

Given $P_u = \frac{f_{mod} \cdot b}{2} \cdot \left(2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot Slope\right)$

$$f_{mod} := Find\left(f_{mod}\right) = 13.2 \, ft$$

$$M_{modBroms} := P_u \cdot \left(e_{clay} + f_{mod}\right) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^{2}}{2} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^{3} \cdot Slope}{6} = 206.8 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot \left(e_{clay} + 1.5 \cdot b + 0.5 \cdot f\right) = 214 \cdot kip \cdot ft$$

$$M_{maxClay} := if\left(L_{ot1Clay} < 3 \cdot b, M_{modBroms}, M_{Broms}\right) = 214 \cdot kip \cdot ft$$

(If L_{ot} < 3b, use Modified Broms method)

$$M_{max} := if\left(SoilType = \text{"Sand"}, M_{maxSand}, M_{maxClay}\right) = 172.3 \cdot kip \cdot ft$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$ *reinforcing yield strength*

$f_c := 4.0 \cdot ksi$ *concrete strength* *Spec 346-3*

$Cover := 3 \cdot in$ *cover* *SDG Table 1.4.2-1*

$Num_{bar} := 11$ *number of longitudinal bars*

$A_{long.bar} := 1.0 \cdot in^2$ *longitudinal bar area*

$d_{long.bar} := 1.125 \cdot in$ *longitudinal bar diameter*

$A_{v.bar} := 0.20 \cdot in^2$ *stirrup area* *SM Vol-3 13.6.2*

$d_{v.bar} := 0.5 \cdot in$ *stirrup diameter*

$s_{v1} := 3 \cdot in$ *stirrup spacing, depth = 0 ft-2 ft* *SM Vol-3 13.6.2*

$s_{v2} := 3 \cdot in$ *stirrup spacing, depth = 2 ft-depth.stir*

$s_{v3} := 6 \cdot in$ *stirrup spacing, depth > depth.stir*

$depth_{stir} := 15.0 \cdot ft$ *stirrup depth, see s.v2 and s.v3 above*

$b = 3\,ft$ *shaft diameter*

$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$ *required 1% steel* *SM Vol-3 13.6.2*

$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$ *LRFD 5.7.4.2*

$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot in^2$

$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$ *total area of longitudinal steel*

$CheckLongitudinalReinf := if(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"})$ $CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if(Clearance_{vert.reinf} \geq 6in, \text{"OK"}, \text{"No Good"})$ $CheckReinfClearSpacing = \text{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$V_u := \sqrt{V_x^{2} + V_z^{2}} = \mathbf{6.8} \cdot \text{kip}$

$T_u = \mathbf{153.7} \cdot \text{kip} \cdot \text{ft}$

Effective shear depth

$D_r := b - 2 \cdot \left(\text{Cover} + d_{v.bar} + \frac{d_{long.bar}}{2} \right) = \mathbf{2.3}\,\text{ft}$ $d_e := \frac{b}{2} + \frac{D_r}{\pi} = \mathbf{2.2}\,\text{ft}$ *LRFD C5.8.2.9-2*

$d_v := \max\left(0.9 \cdot d_e , 0.72 \cdot b \right) = \mathbf{2.2}\,\text{ft}$

Check Shear Strength

$V_c := 0.0316 \cdot (2.0) \cdot \sqrt{\frac{f_c}{\text{ksi}}} \cdot \left(\frac{b}{\text{in}} \right) \cdot \left(\frac{d_v}{\text{in}} \right) \cdot \text{kip} = \mathbf{117.9} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-3* *LRFD 5.8.3.4.1* *ACI 11.3.3*

$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max\left(s_{v1}, s_{v2}, s_{v3} \right)} = \mathbf{51.8} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-4*

$\text{ShearRatio} := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -\mathbf{2.1}$

$\text{ShearRatio} := \text{if}\left(\text{ShearRatio} \le 0 , 0 , \text{ShearRatio} \right) = \mathbf{0}$

Check Torsion Strength

$A_{cp} := \pi \cdot \left(\frac{b}{2} \right)^{2} = \mathbf{1017.9} \cdot \text{in}^{2}$ $p_{cp} := 2 \cdot \pi \cdot \left(\frac{b}{2} \right) = \mathbf{113.1} \cdot \text{in}$ *Area and perimeter of concrete cross-section*

$d_{oh} := b - 2 \cdot \left(\text{Cover} + \frac{d_{v.bar}}{2} \right) = \mathbf{29.5} \cdot \text{in}$ $p_h := \pi \cdot d_{oh} = \mathbf{92.7} \cdot \text{in}$ *Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement*

$A_{oh} := \pi \left(\frac{d_{oh}}{2} \right)^{2} = \mathbf{683.5} \cdot \text{in}^{2}$ $A_o := 0.85 \cdot A_{oh} = \mathbf{581} \cdot \text{in}^{2}$

$T_{n1} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD Eqn 5.8.3.6.2-1*

$T_{n2} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD 5.8.3.4.1*

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = 193.7 \cdot kip \cdot ft$$

$\phi_v = 0.9$ $T_u = 153.7 \cdot kip \cdot ft$ $L_{reqdTor} = 18\,ft$

$$Tor2_{sand} := T_u - if\left[2ft > Offset, \left[\pi \cdot b \cdot (2 \cdot ft - Offset) \cdot \gamma_{soil} \cdot \left(\frac{2 \cdot ft - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 152.6 \cdot kip \cdot ft$$

$$Tor3_{sand} := T_u - if\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot (depth_{stir} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 51.2 \cdot kip \cdot ft$$

$$Tor2_{clay} := T_u - if\left[2ft - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (2.0 \cdot ft - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 153.7 \cdot kip \cdot ft$$

$$Tor3_{clay} := T_u - if\left[depth_{stir} - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (depth_{stir} - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 143.6 \cdot kip \cdot ft$$

$$Tor2 := if(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}) = 152.6 \cdot kip \cdot ft$$

$$Tor3 := if(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}) = 51.2 \cdot kip \cdot ft$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = 0.4$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = 0.39$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = 0.26$$

$$TorsionRatio := max(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}) = 0.4$$

$$T_{cr} := 0.125\sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{A_{cp}^{\;2}}{\frac{3}{p_{cp} \cdot in}}\right) \cdot kip \cdot in = 190.9 \cdot kip \cdot ft$$

LRFD Eqn 5.8.2.1-4

$$TorsionRatio := if(T_u \le 0.25 \cdot \phi_{tor} \cdot T_{cr}, 0, TorsionRatio) = 0.4$$

LRFD Eqn 5.8.2.1-3

$ShearRatio = 0$

$$CheckShearTorsion := if(ShearRatio + TorsionRatio \le 1, \text{"OK"}, \text{"No Good"})$$

$CheckShearTorsion = \text{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = 0.008145 \cdot ksi$$ $$0.125 \cdot f_c = 0.5 \cdot ksi$$

LRFD Eqn 5.8.2.9-1

$$s_{max1} := if(0.8 \cdot d_v < 24 \cdot in, 0.8 d_v, 24 \cdot in) = 20.7 \cdot in$$

LRFD Eqn 5.8.2.7-1

$s_{max2} := \text{if}\left(\mathbf{0.4} \cdot d_v < \mathbf{12} \cdot \text{in}, \mathbf{0.4} d_v, \mathbf{12} \cdot \text{in}\right) = \mathbf{10.4} \cdot \text{in}$ *LRFD Eqn 5.8.2.7-2*

$s_{max} := \text{if}\left(v_u < \mathbf{0.125} \cdot f_c, s_{max1}, s_{max2}\right) = \mathbf{20.7} \cdot \text{in}$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = \mathbf{6} \cdot \text{in}$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \textbf{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion *LRFD Eqn 5.8.3.6.3-1*

LRFD 5.8.3.4.1

$M_u = \mathbf{145.1} \cdot \text{kip} \cdot \text{ft}$

$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5 \cdot V_s > \mathbf{0} \cdot \text{kip}, \frac{V_u}{\phi_v} - 0.5 \cdot V_s, \mathbf{0} \cdot \text{kip}\right) = \blacksquare \cdot \text{kip}$

$$\text{LongReinf}_{shr.tor} := \frac{\frac{M_u}{\phi_v \cdot d_v} + \sqrt{\left(V_{temp}\right)^{\mathbf{2}} + \left(\frac{\mathbf{0.45} \cdot p_h \cdot T_u}{\mathbf{2} \cdot A_o \cdot \phi_v}\right)^{\mathbf{2}}}}{F_{y.rebar}} = \mathbf{2.5} \cdot \text{in}^{\mathbf{2}}$$

$\text{Num}_{bar} \cdot A_{long.bar} = \mathbf{11} \cdot \text{in}^{\mathbf{2}}$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(\text{Num}_{bar} \cdot A_{long.bar} \ge \text{LongReinf}_{shr.tor}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \textbf{"OK"}$

Anchor Bolt Strength Check

$\mathrm{Num}_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot in$ *anchor bolt nominal diameter*

$\mathrm{Dia}_{anchor.circle} := 24 \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{\mathrm{Dia}_{anchor.circle}^{2}}{8} \cdot \mathrm{Num}_{anchor} = 576 \cdot in^{2}$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{\mathrm{Dia}_{anchor.circle}}{2}} = 48 \cdot in$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 36.3 \cdot kip$$ *anchor tension force*

$$V_{anchor} := \frac{V_u}{\mathrm{Num}_{anchor}} + \frac{T_u}{0.5\mathrm{Dia}_{anchor.circle} \cdot \mathrm{Num}_{anchor}} = 20.1 \cdot kip$$ *anchor shear force*

$$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}^{2} = 3.1 \cdot in^{2}$$ *anchor bolt nominal area*

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 11.5 \cdot ksi$$ *anchor tensile stress*

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 6.4 \cdot ksi$$ *anchor shear stress*

$\phi_{anchor} := 0.75$ *resistance factor* *AISC J3-1*

$F_{nt} := 0.75 F_{u.anchor} = 78.8 \cdot ksi$ *nominal tensile stress* *AISC Table J3.2*

$F_{nv} := 0.45 F_{u.anchor} = 47.2 \cdot ksi$ *nominal tensile stress* *AISC Table J3.2*

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot kip$ *design sghear strength*

$\mathrm{CheckAnchorT} := \mathrm{if}\left(\phi R_{nt} \geq T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$\mathrm{CheckAnchorT} = \text{"OK"}$

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check shear rupture*

$\text{CheckAnchorV} = \text{"OK"}$

$$F_{ntv} := \min\left(\left(\begin{array}{c} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{array}\right)\right) = 78.8 \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = 185.6 \cdot \text{kip}$

design tension strength modified to include the effects of shearing stress

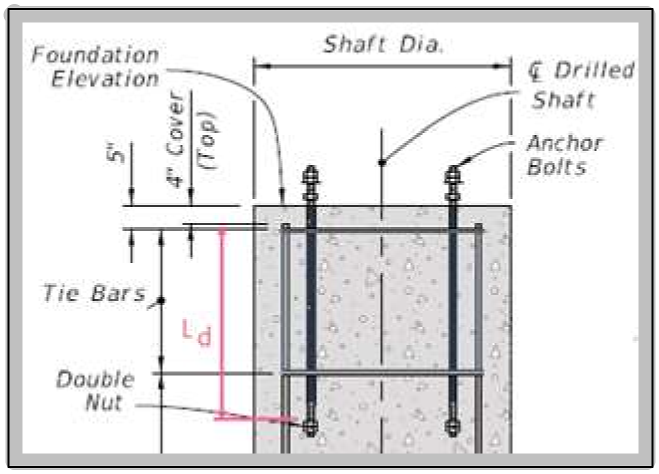
$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq 20\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq 20\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \text{"OK"}, \text{"No Good"}\right]$

$\text{CheckAnchorTV} = \text{"OK"}$ *check combined tension and shear rupture*

$\text{CheckAnchorStrength} := \text{if}\left[\left(\text{CheckAnchorT} = \text{"OK"}\right) \cdot \left(\text{CheckAnchorV} = \text{"OK"}\right) \cdot \left(\text{CheckAnchorTV} = \text{"OK"}\right), \text{"OK"}, \text{"No Good"}\right]$

$\text{CheckAnchorStrength} = \text{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = 36.3 \cdot \text{kip}$ *tension force in anchor*

$Dia_{bar.circle} = 27.9 \cdot \text{in}$ $Dia_{anchor.circle} = 24 \cdot \text{in}$

center-to-center distance

$$Dist_{bar.to.bolt} := \frac{Dia_{bar.circle} - Dia_{anchor.circle}}{2} = 1.9 \cdot \text{in}$$

$$Num_{bars.per.anchor} := \min\left(\frac{Num_{bar}}{Num_{anchor}}, 3\right) = 1.4$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := 0.9$

$$Num_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{Dia_{anchor.circle}}{Dia_{bar.circle}} = 0.58$$

$$AreaRatio := \min\left(\frac{Num_{bars.reqd.per.anchor}}{Num_{bars.per.anchor}}, 1\right) = 0.42$$

2015 AASHTO Development Length of Deformed Bars in Tension ***5.11.2.1***

$Cover = 3 \cdot \text{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half*

the center-to-center spacing of the bars or wires being developed

$$c_b := \min\left(\begin{pmatrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{\mathbf{2}} \\ \dfrac{\text{Spacing}_{vert.reinf}}{\mathbf{2}} \end{pmatrix}\right) = \mathbf{4} \cdot \text{in}$$

$k_{tr} := \mathbf{0} \cdot \text{in}$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\begin{bmatrix} \mathbf{1.0} \\ \max\left(\begin{pmatrix} \mathbf{0.4} \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{pmatrix}\right) \end{bmatrix}\right] = \mathbf{0.4}$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\begin{pmatrix} \mathbf{12} \cdot \text{in} \\ \lambda_{rc} \cdot \mathbf{2.4} \cdot d_{long.bar} \cdot \dfrac{F_{y.rebar}}{\sqrt{f_c \cdot \text{ksi}}} \end{pmatrix}\right) = \mathbf{32.4} \cdot \text{in}$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$\text{SpacingFactor} := \max\left[\begin{pmatrix} \mathbf{0.5} \\ \text{Num}_{bars.per.anchor} \cdot \mathbf{0.5} - \mathbf{0.5} \end{pmatrix}\right] = \mathbf{0.5}$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf} \cdot \text{SpacingFactor}\right)^{\mathbf{2}} + \text{Dist}_{bar.to.bolt}^{\;\mathbf{2}}} = \mathbf{3.9} \cdot \text{in}$$

$$L_{embedment.anchor} := \max\left[\begin{bmatrix} L_{d.bar} \cdot (\text{AreaRatio}) + \mathbf{12} \cdot \text{in} + L_{embedment.added} \\ \mathbf{20} \cdot d_{anchor} \end{bmatrix}\right] = \mathbf{40} \cdot \text{in}$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, \text{in}\right)$

$L_{embedment.anchor} = \mathbf{40} \cdot \text{in}$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^{\,2} + 3.25 \cdot \left(r^2 - r_b^{\,2}\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\left(\begin{matrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{matrix}\right)\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2 \operatorname{asin}\left[\frac{\left(1.5 \cdot c_{a1}\right)}{r}\right] = 45.2 \cdot deg$$

$$OverlapTest := \mathrm{if}\left(A_{bolt.sector} \le \alpha, \text{"Overlap of Failure Cones"}, \text{"No Overlap of Failure Cones"}\right) = \text{"Overlap of Failur}$$

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{\,2} = 95.9 \cdot in^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \mathrm{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$$

$\psi_{ecV} := \mathbf{1.0}$ *eccentric load modifier* *ACI D.6.2.5*

$\psi_{edV} := \mathbf{1.0}$ *edge effect modifier* *ACI D.6.2.6*

$\psi_{cV} := \mathbf{1.4}$ *cracked section modifier* *ACI D.6.2.7* *(stirrup spacing <= 4")*

$\psi_{hV} := \mathbf{1.0}$ *member thickness modifier* *ACI D.6.2.8*

$\phi_{breakout} := \mathbf{0.75}$ *strength reduction factor* *ACI D.4.4.c.i* *(shear breakout, condition A)*

$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = \mathbf{194.7} \cdot kip$ *concrete breakout strength - shear*

ACI Eqn D-22 *Shear force ⊥ to edge*

$V_{cbg\_parallel} := \mathbf{2} \cdot V_{cbg} = \mathbf{389.5} \cdot kip$ *ACI D.6.2.1.c* *Shear force ∥ to edge*

$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = \mathbf{389.5} \cdot kip \cdot ft$ *concrete breakout strength - torsion*

$\phi_{breakout} \cdot T_{n.breakout} = \mathbf{292.1} \cdot kip \cdot ft$

$T_u = \mathbf{153.7} \cdot kip \cdot ft$

$BreakoutTest := if\left(\phi_{breakout} \cdot T_{n.breakout} \geq T_u, \text{"OK"}, \text{"No Good"}\right)$

$BreakoutTest = \text{"OK"}$

$OverlapDesign := if\left(A_{bolt.sector} \leq \alpha, \text{"Based on Overlap of Failure Cones"}, \text{"Based on No Overlap of Failure Cones"}\right)$

$OverlapDesign = \text{"Based on Overlap of Failure Cones"}$

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = \mathbf{1.9} \cdot in$ *center-to-center distance*

$d_{anchor.nut} := \mathbf{1.85} \cdot d_{anchor} = \mathbf{3.7} \cdot in$ *use* $\mathbf{1.85} \cdot d_{anchor}$ *.to account for anchor nut*

$$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{\mathbf{2}}\right) = -\mathbf{0.5} \cdot in$$

$CheckAnchorageClearance := if\left[\left(Clearance_{bar.to.nut} \geq \mathbf{2} \cdot in\right), \text{"OK"}, \text{"No Good, increase ped. diameter"}\right]$

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0 .. 48 \qquad r_{ds} := \frac{b}{2}$

$xds_{pt} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yds_{pt} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$xstir.od_{pt} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.od_{pt} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$xstir.id_{pt} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.id_{pt} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$xbar_{pt} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max(xstir.id) - d_{v.bar} \qquad ybar_{pt} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$xboltcircle_{pt} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yboltcircle_{pt} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltr} := \frac{d_{anchor}}{2} = 1 \cdot in$

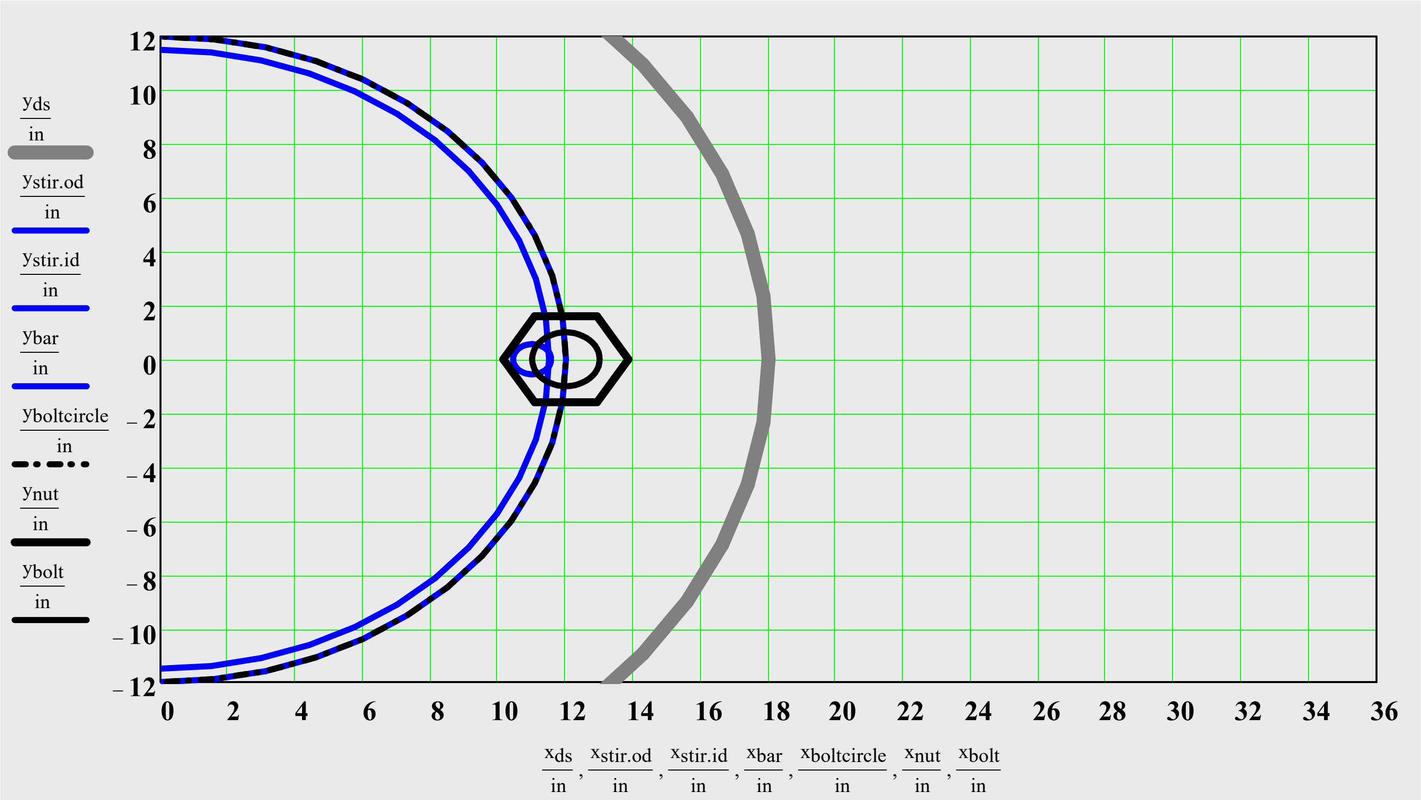
$x_{bolt_{pt}} := r_{boltr} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $y_{bolt_{pt}} := r_{boltr} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$pt := 0 .. 6$ $r_{nut} := \frac{d_{anchor} \cdot 1.85}{2} = 1.9 \cdot in$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{6} + \frac{2 \cdot \pi}{6}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{6}\right) + \frac{2 \cdot \pi}{6}\right]$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{6} + \frac{1 \cdot \pi}{6}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ *enable to rotate nut* $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{6}\right) + \frac{1 \cdot \pi}{6}\right]$

$\min\left(x_{bar}\right) - \max\left(x_{nut}\right) = -3.4 \cdot in$



$$\text{Bolts} := \begin{pmatrix} \mathbf{1} & \mathbf{1.125} & \mathbf{1.25} & \mathbf{1.375} & \mathbf{1.5} & \mathbf{1.625} & \mathbf{1.75} & \mathbf{1.875} & \mathbf{2} & \mathbf{2.25} & \mathbf{2.5} & \mathbf{2.75} & \mathbf{3} \\ \mathbf{1.5} & \mathbf{1.688} & \mathbf{1.875} & \mathbf{2.063} & \mathbf{2.25} & \mathbf{2.438} & \mathbf{2.625} & \mathbf{2.938} & \mathbf{3} & \mathbf{3.375} & \mathbf{3.75} & \mathbf{4.125} & \mathbf{4.25} \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{T}\right)^{\langle \mathbf{0} \rangle^{T}} \cdot \mathbf{1.6} - \left(\text{Bolts}^{T}\right)^{\langle \mathbf{1} \rangle^{T}} = \begin{pmatrix} \mathbf{0.1} & \mathbf{0.112} & \mathbf{0.125} & \mathbf{0.137} & \mathbf{0.15} & \mathbf{0.162} & \mathbf{0.175} & \mathbf{0.062} & \mathbf{0.2} & \mathbf{0.225} & \mathbf{0.25} & \mathbf{0.275} & \mathbf{0.55} \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{T}\right)^{\langle \mathbf{0} \rangle^{T}} - \left(\text{Bolts}^{T}\right)^{\langle \mathbf{1} \rangle^{T}} = \begin{pmatrix} -\mathbf{0.5} & -\mathbf{0.563} & -\mathbf{0.625} & -\mathbf{0.688} & -\mathbf{0.75} & -\mathbf{0.813} & -\mathbf{0.875} & -\mathbf{1.063} & -\mathbf{1} & -\mathbf{1.125} & -\mathbf{1.25} & -\mathbf{1.375} & -\mathbf{1.25} \end{pmatrix} \cdot$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

State Structures Design Office

SUBJECT 079-241-K MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

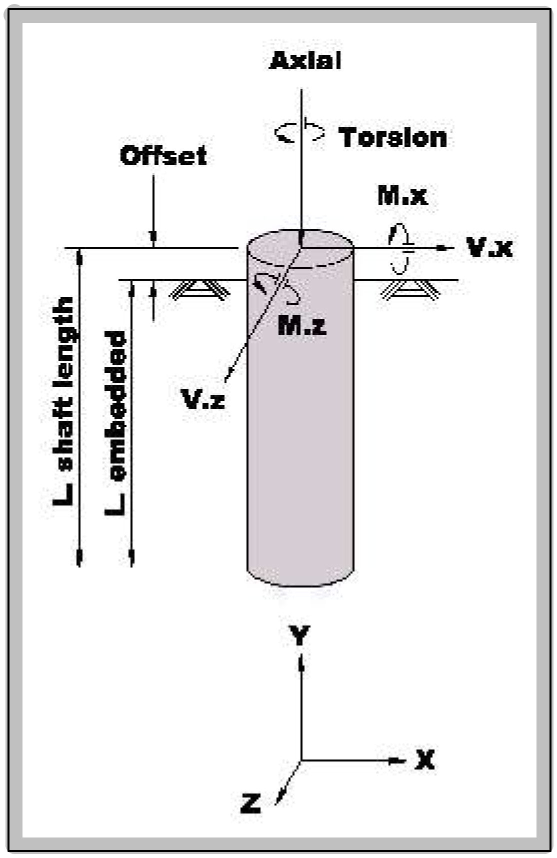
SoilType :=
- Sand
- Clay

$\phi_{soil} := 32.0 \cdot deg$ *soil friction angle (sand)*

$c_{soil} := 0.0 \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

$N_{blows} := 10$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := 69 \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*



Geometry

$b := 3.0 \cdot ft$ *shaft diameter*

$Offset := 0.50 \cdot ft$ *groundline to top of foundation*

Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := 56.10 \cdot kip \cdot ft$ $V_x := 0.05 \cdot kip$ $Torsion := 47.0 \cdot kip \cdot ft$

$M_z := 30.3 \cdot kip \cdot ft$ $V_z := 3.94 \cdot kip$ $Axial := 17.60 \cdot kip$

StructureType :=
- Cantilever Overhead Sign Structure
- Mast Arm Signal Structure
- Concrete/Steel Strain Poles
- Ground Sign

$StructureType = 1$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

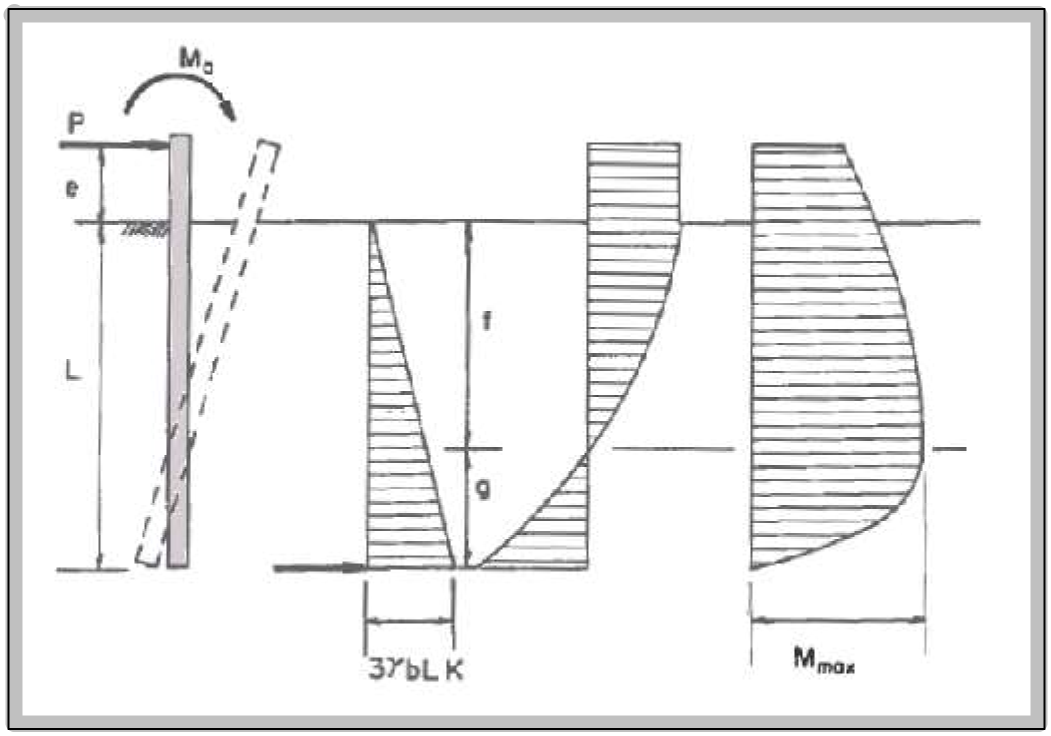
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x^2 + M_z^2} = \mathbf{63.8} \cdot kip \cdot ft$

$P_u := \sqrt{V_x^2 + V_z^2} = \mathbf{3.9} \cdot kip$

$T_u := Torsion = \mathbf{47} \cdot kip \cdot ft$

short free-head pile in ***cohesionless soil*** *using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(\mathbf{45} \cdot deg + \frac{\phi_{soil}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{3.3}$

$e_{sand} := Offset = \mathbf{0.5} ft$

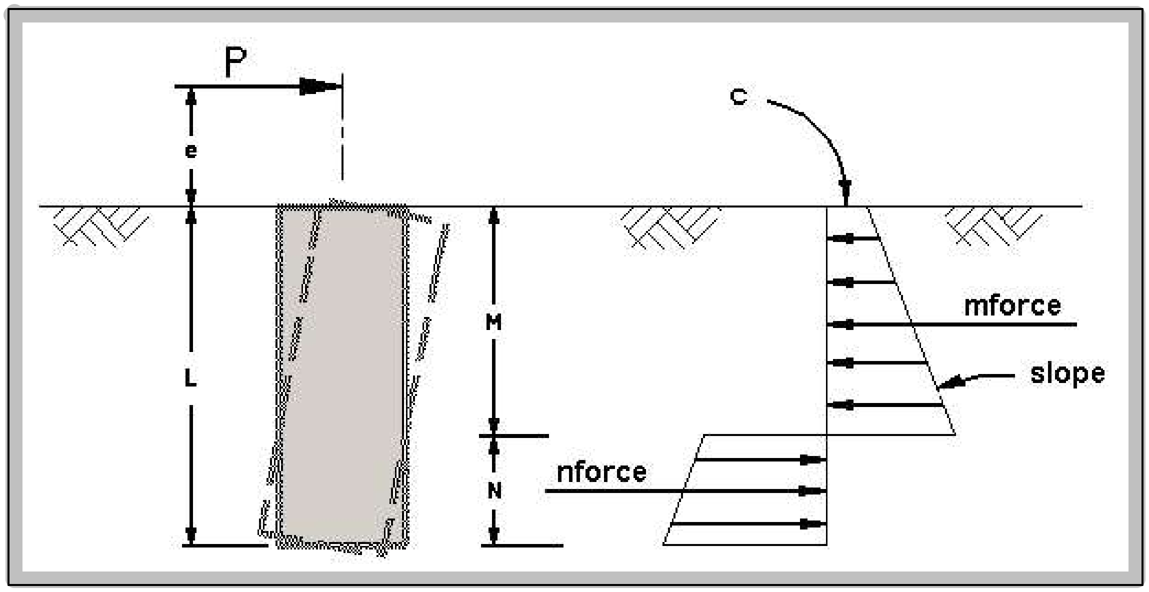
Guess value $L_{otSand} := \mathbf{10} \cdot ft$

Given $P_u \cdot \left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot} \cdot \left[\left(\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{2}} \cdot L_{otSand}\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{3}} \cdot L_{otSand}\right)\right]$

$L_{otSand} := Find\left(L_{otSand}\right) = \mathbf{10.9} ft$

$L_{otSand} := ceil\left(\frac{L_{otSand}}{ft}\right) \cdot ft = \mathbf{11} ft$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}(c_{soil} = 0 \cdot ksf, 0.1 \cdot ksf, c_{soil}) = 0.1 \cdot ksf$

$\text{Slope} := 8 \cdot \frac{c_{soil}}{3 \cdot b} = 0.1 \cdot \frac{kip}{ft^3}$

$e_{clay} := \frac{M_u}{P_u} + \text{Offset} = 16.7\,ft$

$\text{nforce}(M,N) := \left[\text{Slope} \cdot (2 \cdot M + N) + 2 \cdot c_{soil}\right] \cdot N \cdot \frac{b}{2}$

$\text{mforce}(M) := (2 \cdot c_{soil} + M \cdot \text{Slope}) \cdot M \cdot \frac{b}{2}$

$\text{m\_arm}(M) := e_{clay} + \frac{M}{3} \cdot \frac{2 \cdot (M \cdot \text{Slope} + c_{soil}) + c_{soil}}{M \cdot \text{Slope} + 2 \cdot c_{soil}}$

$\text{n\_arm}(M,N) := e_{clay} + M + \frac{N}{3} \cdot \frac{2 \cdot (N \cdot \text{Slope} + M \cdot \text{Slope} + c_{soil}) + (M \cdot \text{Slope} + c_{soil})}{\text{Slope} \cdot (2 \cdot M + N) + 2 \cdot c_{soil}}$

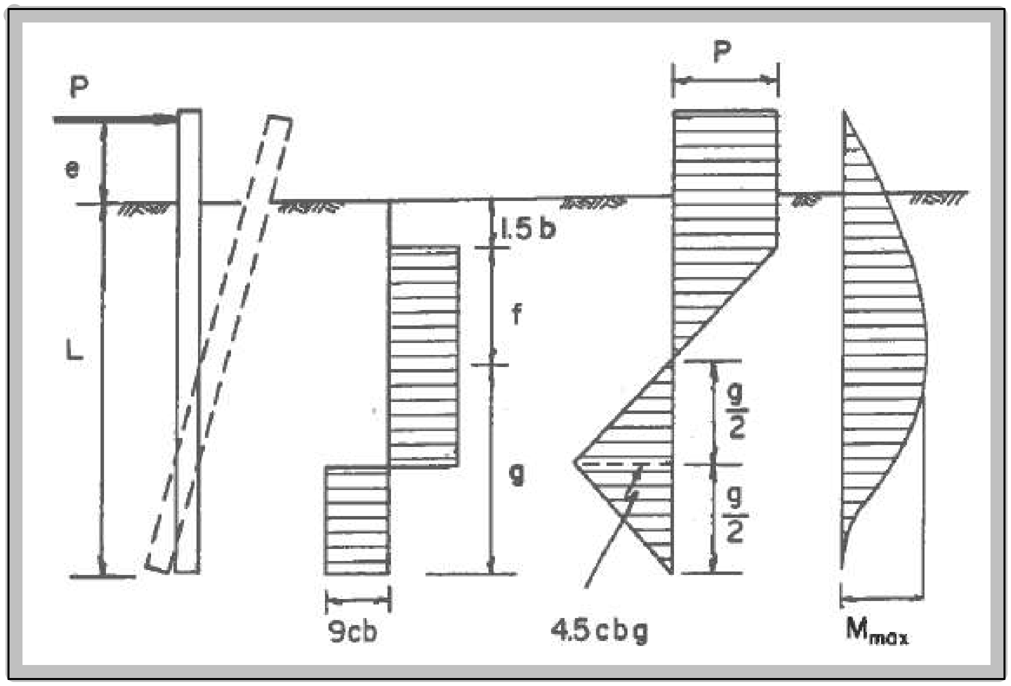
Guess value $M := 4.0 \cdot ft$ $N := 4.0 \cdot ft$

Given $P_u + \phi_{ot} \cdot \text{nforce}(M,N) = \phi_{ot} \cdot \text{mforce}(M)$ $\text{mforce}(M) \cdot \text{m\_arm}(M) = \text{nforce}(M,N) \cdot \text{n\_arm}(M,N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M,N)$ $L_{ot1Clay} := M + N = 7.9\,ft$

$L_{ot1Clay} := \text{ceil}\left(\frac{L_{ot1Clay}}{ft}\right) \cdot ft = 8\,ft$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot \mathbf{9} \cdot c_{soil} \cdot b} = \mathbf{5.8}\,ft$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + \mathbf{1.5} \cdot b + \mathbf{0.5} \cdot f\right) = \mathbf{95} \cdot kip \cdot ft$$

$$g := \sqrt{\frac{M_{max.clay}}{\mathbf{2.25} \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = \mathbf{23.7}\,ft$$

$$L_{ot2Clay} := \left(\mathbf{1.5} \cdot b + f + g\right) = \mathbf{34.1}\,ft$$

$$L_{ot2Clay} := ceil\left(\frac{L_{ot2Clay}}{ft}\right) \cdot ft = \mathbf{35}\,ft$$

(round up to next foot)

$$L_{otClay} := if\left(L_{ot1Clay} < \mathbf{3} \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = \mathbf{8}\,ft$$

(If L_{ot} < 3b, use Modified Broms method)

$$L_{reqdOT} := if\left(SoilType = \mathbf{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$$L_{reqdOT} = \mathbf{11}\,ft$$

required shaft embedment depth to resist overturning

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = \mathbf{10}$

$$\omega_{fdot} := \text{if}\left(N_{blows} < \mathbf{5}, \mathbf{0}, \text{if}\left(N_{blows} \geq \mathbf{15}, \mathbf{1.5}, \mathbf{1.5} \cdot \frac{N_{blows}}{\mathbf{15}}\right)\right) = \mathbf{1}$$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\frac{N_{blows}}{\mathbf{15}}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = \mathbf{11}\,\text{ft}$

Given $T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot (L_{torSand}) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{\mathbf{2}}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{\mathbf{2}}\right]$

$L_{torSand} := \text{Find}(L_{torSand}) = \mathbf{9.8}\,\text{ft}$

$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{10}\,\text{ft}$ *(round up to next foot)*

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := \mathbf{0.55}$

$f_{se} := \text{CohesionFactor} \cdot c_{soil} = \mathbf{0.1} \cdot \text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

Given $T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot (L_{torClay} - \mathbf{1.5} \cdot \text{ft}) \cdot \frac{b}{\mathbf{2}}\right]$

$L_{torClay} := \text{Find}(L_{torClay}) = \mathbf{61.9}\,\text{ft}$

$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{62}\,\text{ft}$ *(round up to next foot)*

$L_{reqdTor} := \text{if}(\text{SoilType} = \mathbf{"Sand"}, L_{torSand}, L_{torClay})$

$L_{reqdTor} = \mathbf{10}\,\text{ft}$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}) = \mathbf{11}\,\text{ft}$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = \mathbf{11.5}\,\text{ft}$ **Min Shaft embedment depth=12 ft** *shaft length*

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2 \cdot P_u}{3 \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = 3.9 \text{ ft}$$

$$M_{maxSand} := P_u \cdot (e_{sand} + f_{sand}) - \frac{P_u \cdot f_{sand}}{3} + M_u = 76.1 \cdot \text{kip} \cdot \text{ft}$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0 \cdot \text{ft}$

Given $P_u = \frac{f_{mod} \cdot b}{2} \cdot (2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot \text{Slope})$

$f_{mod} := \text{Find}(f_{mod}) = 9.8 \text{ ft}$

$$M_{modBroms} := P_u \cdot (e_{clay} + f_{mod}) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^2}{2} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^3 \cdot \text{Slope}}{6} = 90.3 \cdot \text{kip} \cdot \text{ft}$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot (e_{clay} + 1.5 \cdot b + 0.5 \cdot f) = 95 \cdot \text{kip} \cdot \text{ft}$$

$M_{maxClay} := \text{if}(L_{ot1Clay} < 3 \cdot b, M_{modBroms}, M_{Broms}) = 90.3 \cdot \text{kip} \cdot \text{ft}$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$$M_{max} := \text{if}(\text{SoilType} = \text{"Sand"}, M_{maxSand}, M_{maxClay}) = 76.1 \cdot \text{kip} \cdot \text{ft}$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$ *reinforcing yield strength*

$f_c := 4.0 \cdot ksi$ *concrete strength* *Spec 346-3*

$Cover := 3 \cdot in$ *cover* *SDG Table 1.4.2-1*

$Num_{bar} := 11$ *number of longitudinal bars*

$A_{long.bar} := 1.0 \cdot in^2$ *longitudinal bar area*

$d_{long.bar} := 1.125 \cdot in$ *longitudinal bar diameter*

$A_{v.bar} := 0.20 \cdot in^2$ *stirrup area* *SM Vol-3 13.6.2*

$d_{v.bar} := 0.5 \cdot in$ *stirrup diameter*

$s_{v1} := 3 \cdot in$ *stirrup spacing, depth = 0 ft-2 ft* *SM Vol-3 13.6.2*

$s_{v2} := 3 \cdot in$ *stirrup spacing, depth = 2 ft-depth.stir*

$s_{v3} := 6 \cdot in$ *stirrup spacing, depth > depth.stir*

$depth_{stir} := 12.0 \cdot ft$ *stirrup depth, see s.v2 and s.v3 above*

$b = 3\,ft$ *shaft diameter*

$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$ *required 1% steel* *SM Vol-3 13.6.2*

$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$ *LRFD 5.7.4.2*

$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot in^2$

$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$ *total area of longitudinal steel*

$CheckLongitudinalReinf := if(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"})$ $CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if(Clearance_{vert.reinf} \geq 6in, \text{"OK"}, \text{"No Good"})$ $CheckReinfClearSpacing = \text{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$V_u := \sqrt{V_x^{2} + V_z^{2}} = \mathbf{3.9} \cdot \text{kip}$

$T_u = \mathbf{47} \cdot \text{kip} \cdot \text{ft}$

Effective shear depth

$D_r := b - \mathbf{2} \cdot \left(\text{Cover} + d_{v.bar} + \frac{d_{long.bar}}{\mathbf{2}} \right) = \mathbf{2.3}\,\text{ft}$ $d_e := \frac{b}{\mathbf{2}} + \frac{D_r}{\pi} = \mathbf{2.2}\,\text{ft}$ *LRFD C5.8.2.9-2*

$d_v := \max\left(\mathbf{0.9} \cdot d_e , \mathbf{0.72} \cdot b\right) = \mathbf{2.2}\,\text{ft}$

Check Shear Strength

$V_c := \mathbf{0.0316} \cdot (\mathbf{2.0}) \cdot \sqrt{\frac{f_c}{\text{ksi}}} \cdot \left(\frac{b}{\text{in}}\right) \cdot \left(\frac{d_v}{\text{in}}\right) \cdot \text{kip} = \mathbf{117.9} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-3* *LRFD 5.8.3.4.1* *ACI 11.3.3*

$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max\left(s_{v1}, s_{v2}, s_{v3}\right)} = \mathbf{51.8} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-4*

$\text{ShearRatio} := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -\mathbf{2.2}$

$\text{ShearRatio} := \text{if}\left(\text{ShearRatio} \le \mathbf{0}, \mathbf{0}, \text{ShearRatio}\right) = \mathbf{0}$

Check Torsion Strength

$A_{cp} := \pi \cdot \left(\frac{b}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1017.9} \cdot \text{in}^{\mathbf{2}}$ $p_{cp} := \mathbf{2} \cdot \pi \cdot \left(\frac{b}{\mathbf{2}}\right) = \mathbf{113.1} \cdot \text{in}$ *Area and perimeter of concrete cross-section*

$d_{oh} := b - \mathbf{2} \cdot \left(\text{Cover} + \frac{d_{v.bar}}{\mathbf{2}} \right) = \mathbf{29.5} \cdot \text{in}$ $p_h := \pi \cdot d_{oh} = \mathbf{92.7} \cdot \text{in}$ *Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement*

$A_{oh} := \pi \left(\frac{d_{oh}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{683.5} \cdot \text{in}^{\mathbf{2}}$ $A_o := \mathbf{0.85} \cdot A_{oh} = \mathbf{581} \cdot \text{in}^{\mathbf{2}}$

$T_{n1} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD Eqn 5.8.3.6.2-1*

$T_{n2} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD 5.8.3.4.1*

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = 193.7 \cdot kip \cdot ft$$

$\phi_v = 0.9$ $\quad T_u = 47 \cdot kip \cdot ft$ $\quad L_{reqdTor} = 10\,ft$

$$Tor2_{sand} := T_u - if\left[2ft > Offset, \left[\pi \cdot b \cdot (2 \cdot ft - Offset) \cdot \gamma_{soil} \cdot \left(\frac{2 \cdot ft - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 45.9 \cdot kip \cdot ft$$

$$Tor3_{sand} := T_u - if\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot (depth_{stir} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -17.5 \cdot kip \cdot ft$$

$$Tor2_{clay} := T_u - if\left[2ft - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (2.0 \cdot ft - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 47 \cdot kip \cdot ft$$

$$Tor3_{clay} := T_u - if\left[depth_{stir} - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (depth_{stir} - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 39.2 \cdot kip \cdot ft$$

$$Tor2 := if(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}) = 45.9 \cdot kip \cdot ft$$

$$Tor3 := if(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}) = -17.5 \cdot kip \cdot ft$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = 0.12$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = 0.12$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = -0.09$$

$$TorsionRatio := \max(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}) = 0.12$$

$$T_{cr} := 0.125 \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{A_{cp}{}^2}{p_{cp} \cdot in^3}\right) \cdot kip \cdot in = 190.9 \cdot kip \cdot ft$$ LRFD Eqn 5.8.2.1-4

$$TorsionRatio := if(T_u \le 0.25 \cdot \phi_{tor} \cdot T_{cr}, 0, TorsionRatio) = 0$$ LRFD Eqn 5.8.2.1-3

$ShearRatio = 0$

$$CheckShearTorsion := if(ShearRatio + TorsionRatio \le 1, \text{"OK"}, \text{"No Good"})$$

CheckShearTorsion = "OK"

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = 0.004692 \cdot ksi$$ $\quad 0.125 \cdot f_c = 0.5 \cdot ksi$ LRFD Eqn 5.8.2.9-1

$$s_{max1} := if(0.8 \cdot d_v < 24 \cdot in, 0.8 d_v, 24 \cdot in) = 20.7 \cdot in$$ LRFD Eqn 5.8.2.7-1

$s_{max2} := \text{if}\left(\mathbf{0.4}\cdot d_v < \mathbf{12}\cdot \text{in}, \mathbf{0.4} d_v, \mathbf{12}\cdot \text{in}\right) = \mathbf{10.4}\cdot \text{in}$ *LRFD Eqn 5.8.2.7-2*

$s_{max} := \text{if}\left(v_u < \mathbf{0.125}\cdot f_c, s_{max1}, s_{max2}\right) = \mathbf{20.7}\cdot \text{in}$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = \mathbf{6}\cdot \text{in}$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \textbf{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion *LRFD Eqn 5.8.3.6.3-1*

LRFD 5.8.3.4.1

$M_u = \mathbf{63.8}\cdot \text{kip}\cdot \text{ft}$

$$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5\cdot V_s > \mathbf{0}\cdot \text{kip}, \frac{V_u}{\phi_v} - 0.5\cdot V_s, \mathbf{0}\cdot \text{kip}\right) = \mathbf{0}\cdot \text{kip}$$

$$\text{LongReinf}_{shr.tor} := \frac{\dfrac{M_u}{\phi_v\cdot d_v} + \sqrt{\left(V_{temp}\right)^{\mathbf{2}} + \left(\dfrac{\mathbf{0.45}\cdot p_h\cdot T_u}{\mathbf{2}\cdot A_o\cdot \phi_v}\right)^{\mathbf{2}}}}{F_{y.rebar}} = \mathbf{0.9}\cdot \text{in}^{\mathbf{2}}$$

$\text{Num}_{bar}\cdot A_{long.bar} = \mathbf{11}\cdot \text{in}^{\mathbf{2}}$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(\text{Num}_{bar}\cdot A_{long.bar} \ge \text{LongReinf}_{shr.tor}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \textbf{"OK"}$

Anchor Bolt Strength Check

$Num_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot in$ *anchor bolt nominal diameter*

$Dia_{anchor.circle} := 24 \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{Dia_{anchor.circle}^{2}}{8} \cdot Num_{anchor} = 576 \cdot in^{2}$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{Dia_{anchor.circle}}{2}} = 48 \cdot in$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 15.9 \cdot kip$$ *anchor tension force*

$$V_{anchor} := \frac{V_u}{Num_{anchor}} + \frac{T_u}{0.5 Dia_{anchor.circle} \cdot Num_{anchor}} = 6.4 \cdot kip$$ *anchor shear force*

$$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}^{2} = 3.1 \cdot in^{2}$$ *anchor bolt nominal area*

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 5.1 \cdot ksi$$ *anchor tensile stress*

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 2 \cdot ksi$$ *anchor shear stress*

$\phi_{anchor} := 0.75$ *resistance factor* *AISC J3-1*

$F_{nt} := 0.75 F_{u.anchor} = 78.8 \cdot ksi$ *nominal tensile stress* *AISC Table J3.2*

$F_{nv} := 0.45 F_{u.anchor} = 47.2 \cdot ksi$ *nominal tensile stress* *AISC Table J3.2*

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot kip$ *design sghear strength*

$CheckAnchorT := if(\phi R_{nt} \geq T_{anchor}, \text{"OK"}, \text{"No Good"})$ *check tensile rupture*

$CheckAnchorT = \text{"OK"}$

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \textbf{"OK"}, \textbf{"No Good"}\right)$ *check shear rupture*

$\text{CheckAnchorV} = \textbf{"OK"}$

$$F_{ntv} := \min\left(\begin{pmatrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{pmatrix}\right) = \mathbf{78.8} \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = \mathbf{185.6} \cdot \text{kip}$

design tension strength modified to include the effects of shearing stress

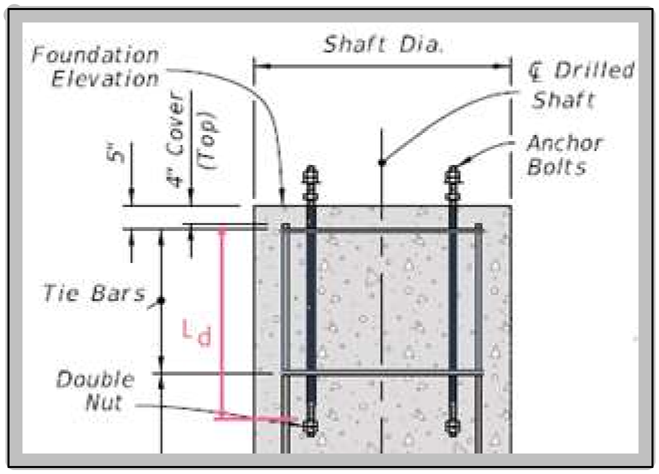
$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq \mathbf{20}\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq \mathbf{20}\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \textbf{"OK"}, \textbf{"No Good"}\right]$

$\text{CheckAnchorTV} = \textbf{"OK"}$ *check combined tension and shear rupture*

$\text{CheckAnchorStrength} := \text{if}\left[\left(\text{CheckAnchorT} = \textbf{"OK"}\right) \cdot \left(\text{CheckAnchorV} = \textbf{"OK"}\right) \cdot \left(\text{CheckAnchorTV} = \textbf{"OK"}\right), \textbf{"OK"}, \textbf{"No Good"}\right]$

$\text{CheckAnchorStrength} = \textbf{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = \mathbf{15.9} \cdot \text{kip}$ *tension force in anchor*

$\text{Dia}_{bar.circle} = \mathbf{27.9} \cdot \text{in}$ $\text{Dia}_{anchor.circle} = \mathbf{24} \cdot \text{in}$

center-to-center distance

$$\text{Dist}_{bar.to.bolt} := \frac{\text{Dia}_{bar.circle} - \text{Dia}_{anchor.circle}}{\mathbf{2}} = \mathbf{1.9} \cdot \text{in}$$

$$\text{Num}_{bars.per.anchor} := \min\left(\frac{\text{Num}_{bar}}{\text{Num}_{anchor}}, \mathbf{3}\right) = \mathbf{1.4}$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := \mathbf{0.9}$

$$\text{Num}_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{\text{Dia}_{anchor.circle}}{\text{Dia}_{bar.circle}} = \mathbf{0.25}$$

$$\text{AreaRatio} := \min\left(\frac{\text{Num}_{bars.reqd.per.anchor}}{\text{Num}_{bars.per.anchor}}, \mathbf{1}\right) = \mathbf{0.18}$$

2015 AASHTO Development Length of Deformed Bars in Tension ***5.11.2.1***

$\text{Cover} = \mathbf{3} \cdot \text{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half*

the center-to-center spacing of the bars or wires being developed

$$c_b := \min\left(\left(\begin{array}{c} Cover + d_{v.bar} + \dfrac{d_{long.bar}}{\mathbf{2}} \\ \dfrac{Spacing_{vert.reinf}}{\mathbf{2}} \end{array}\right)\right) = \mathbf{4} \cdot in$$

$k_{tr} := \mathbf{0} \cdot in$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\left[\begin{array}{c} \mathbf{1.0} \\ \max\left(\left(\begin{array}{c} \mathbf{0.4} \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{array}\right)\right) \end{array}\right]\right] = \mathbf{0.4}$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\left(\begin{array}{c} \mathbf{12} \cdot in \\ \lambda_{rc} \cdot \mathbf{2.4} \cdot d_{long.bar} \cdot \dfrac{F_{y.rebar}}{\sqrt{f_c \cdot ksi}} \end{array}\right)\right) = \mathbf{32.4} \cdot in$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$SpacingFactor := \max\left[\left(\begin{array}{c} \mathbf{0.5} \\ Num_{bars.per.anchor} \cdot \mathbf{0.5} - \mathbf{0.5} \end{array}\right)\right] = \mathbf{0.5}$$

$$L_{embedment.added} := \sqrt{\left(Clearance_{vert.reinf} \cdot SpacingFactor\right)^{\mathbf{2}} + Dist_{bar.to.bolt}^{\ \mathbf{2}}} = \mathbf{3.9} \cdot in$$

$$L_{embedment.anchor} := \max\left[\left[\begin{array}{c} L_{d.bar} \cdot (AreaRatio) + \mathbf{12} \cdot in + L_{embedment.added} \\ \mathbf{20} \cdot d_{anchor} \end{array}\right]\right] = \mathbf{40} \cdot in$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := Ceil\left(L_{embedment.anchor}, in\right)$

$L_{embedment.anchor} = \mathbf{40} \cdot in$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^{\,2} + 3.25 \cdot \left(r^2 - r_b^{\,2}\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\left(\begin{matrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{matrix}\right)\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2\,\mathrm{asin}\left[\frac{(1.5 \cdot c_{a1})}{r}\right] = 45.2 \cdot deg$$

OverlapTest := if$\left(A_{bolt.sector} \le \alpha\right.$, **"Overlap of Failure Cones"** , **"No Overlap of Failure Cones"**$\left.\right)$ = **"Overlap of Failur**

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{\;2} = 95.9 \cdot in^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \mathrm{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$$

$\psi_{ecV} := \mathbf{1.0}$	*eccentric load modifier*	*ACI D.6.2.5*	
$\psi_{edV} := \mathbf{1.0}$	*edge effect modifier*	*ACI D.6.2.6*	
$\psi_{cV} := \mathbf{1.4}$	*cracked section modifier*	*ACI D.6.2.7*	*(stirrup spacing <= 4")*
$\psi_{hV} := \mathbf{1.0}$	*member thickness modifier*	*ACI D.6.2.8*	
$\phi_{breakout} := \mathbf{0.75}$	*strength reduction factor*	*ACI D.4.4.c.i*	*(shear breakout, condition A)*

$V_{cbg} := Num_{anchor} \cdot \left(\frac{AV_c}{AV_{co}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = \mathbf{194.7} \cdot kip$ *concrete breakout strength - shear*

ACI Eqn D-22 *Shear force ⊥ to edge*

$V_{cbg\_parallel} := \mathbf{2} \cdot V_{cbg} = \mathbf{389.5} \cdot kip$ *ACI D.6.2.1.c* *Shear force ∥ to edge*

$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = \mathbf{389.5} \cdot kip \cdot ft$ *concrete breakout strength - torsion*

$\phi_{breakout} \cdot T_{n.breakout} = \mathbf{292.1} \cdot kip \cdot ft$

$T_u = \mathbf{47} \cdot kip \cdot ft$

$BreakoutTest := if\left(\phi_{breakout} \cdot T_{n.breakout} \ge T_u, \text{"OK"}, \text{"No Good"}\right)$

$BreakoutTest = \text{"OK"}$

$OverlapDesign := if\left(A_{bolt.sector} \le \alpha, \text{"Based on Overlap of Failure Cones"}, \text{"Based on No Overlap of Failure Cones"}\right)$

$OverlapDesign = \text{"Based on Overlap of Failure Cones"}$

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = \mathbf{1.9} \cdot in$ *center-to-center distance*

$d_{anchor.nut} := \mathbf{1.85} \cdot d_{anchor} = \mathbf{3.7} \cdot in$ *use* $\mathbf{1.85} \cdot d_{anchor}$ *.to account for anchor nut*

$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{\mathbf{2}}\right) = -\mathbf{0.5} \cdot in$

$CheckAnchorageClearance := if\left[\left(Clearance_{bar.to.nut} \ge \mathbf{2} \cdot in\right), \text{"OK"}, \text{"No Good, increase ped. diameter"}\right]$

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0 .. 48 \qquad r_{ds} := \frac{b}{2}$

$xds_{pt} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yds_{pt} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$xstir.od_{pt} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.od_{pt} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$xstir.id_{pt} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.id_{pt} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$xbar_{pt} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max(xstir.id) - d_{v.bar} \qquad ybar_{pt} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$xboltcircle_{pt} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yboltcircle_{pt} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltr} := \frac{d_{anchor}}{2} = \mathbf{1} \cdot in$

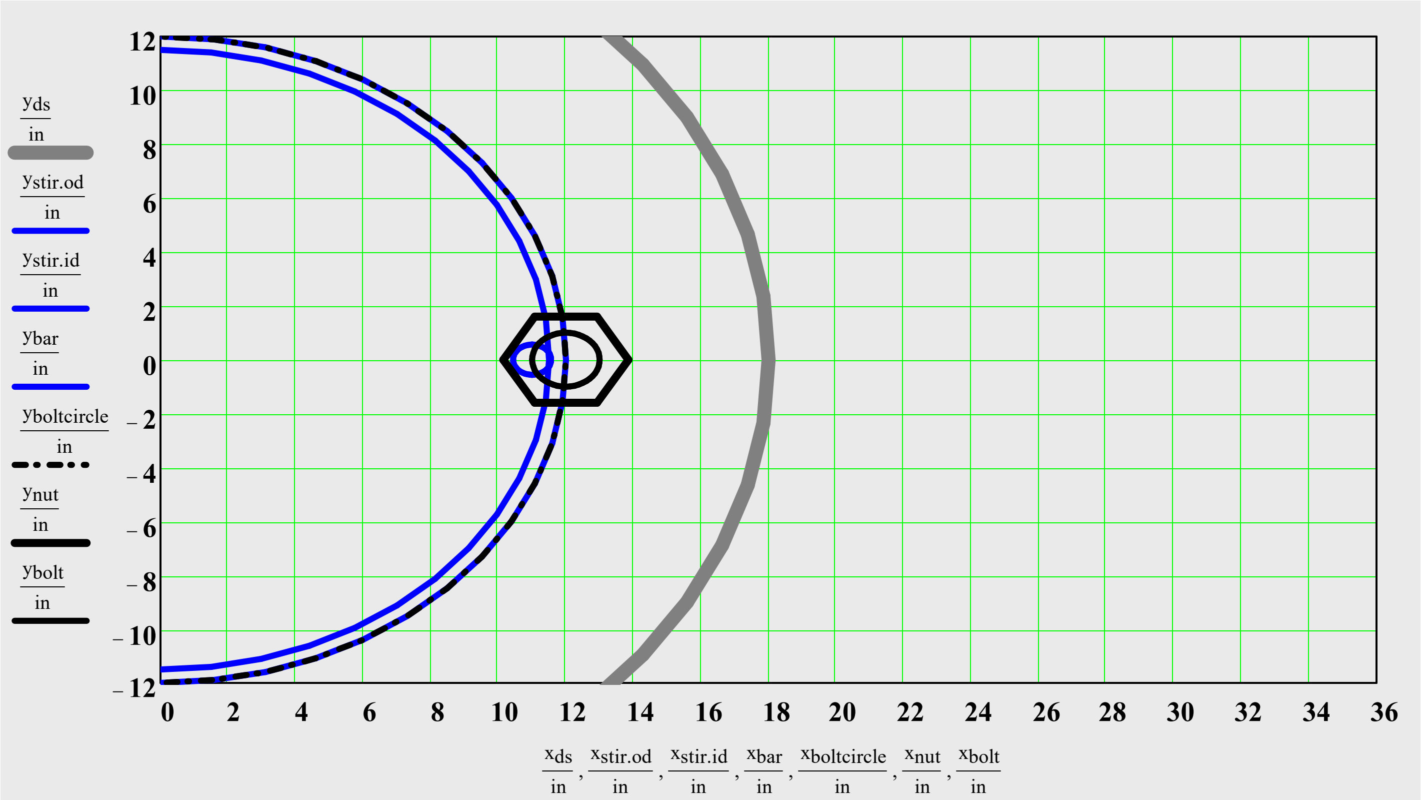
$x_{bolt_{pt}} := r_{boltr} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] + (\max(x_{boltcircle}))$ $\qquad y_{bolt_{pt}} := r_{boltr} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$pt := \mathbf{0} .. \mathbf{6}$ $\qquad r_{nut} := \frac{d_{anchor} \cdot 1.85}{\mathbf{2}} = \mathbf{1.9} \cdot in$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right] + (\max(x_{boltcircle}))$ $\qquad y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right]$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right] + (\max(x_{boltcircle}))$ $\qquad$ *enable to rotate nut* $\qquad y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right]$

$\min(x_{bar}) - \max(x_{nut}) = -\mathbf{3.4} \cdot in$



$$\mathrm{Bolts} := \begin{pmatrix} \mathbf{1} & \mathbf{1.125} & \mathbf{1.25} & \mathbf{1.375} & \mathbf{1.5} & \mathbf{1.625} & \mathbf{1.75} & \mathbf{1.875} & \mathbf{2} & \mathbf{2.25} & \mathbf{2.5} & \mathbf{2.75} & \mathbf{3} \\ \mathbf{1.5} & \mathbf{1.688} & \mathbf{1.875} & \mathbf{2.063} & \mathbf{2.25} & \mathbf{2.438} & \mathbf{2.625} & \mathbf{2.938} & \mathbf{3} & \mathbf{3.375} & \mathbf{3.75} & \mathbf{4.125} & \mathbf{4.25} \end{pmatrix} \cdot \mathrm{in}$$

$$\left(\mathrm{Bolts}^{\mathrm{T}}\right)^{\langle \mathbf{0} \rangle^{\mathrm{T}}} \cdot \mathbf{1.6} - \left(\mathrm{Bolts}^{\mathrm{T}}\right)^{\langle \mathbf{1} \rangle^{\mathrm{T}}} = \begin{pmatrix} \mathbf{0.1} & \mathbf{0.112} & \mathbf{0.125} & \mathbf{0.137} & \mathbf{0.15} & \mathbf{0.162} & \mathbf{0.175} & \mathbf{0.062} & \mathbf{0.2} & \mathbf{0.225} & \mathbf{0.25} & \mathbf{0.275} & \mathbf{0.55} \end{pmatrix} \cdot \mathrm{in}$$

$$\left(\mathrm{Bolts}^{\mathrm{T}}\right)^{\langle \mathbf{0} \rangle^{\mathrm{T}}} - \left(\mathrm{Bolts}^{\mathrm{T}}\right)^{\langle \mathbf{1} \rangle^{\mathrm{T}}} = \begin{pmatrix} -\mathbf{0.5} & -\mathbf{0.563} & -\mathbf{0.625} & -\mathbf{0.688} & -\mathbf{0.75} & -\mathbf{0.813} & -\mathbf{0.875} & -\mathbf{1.063} & -\mathbf{1} & -\mathbf{1.125} & -\mathbf{1.25} & -\mathbf{1.375} & -\mathbf{1.25} \end{pmatrix} \cdot$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

State Structures Design Office

SUBJECT 079-241-L MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

SoilType :=
- Sand
- [✓ Clay]

$\phi_{soil} := \mathbf{0.0} \cdot deg$ *soil friction angle (sand)*

$c_{soil} := \mathbf{1.50} \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

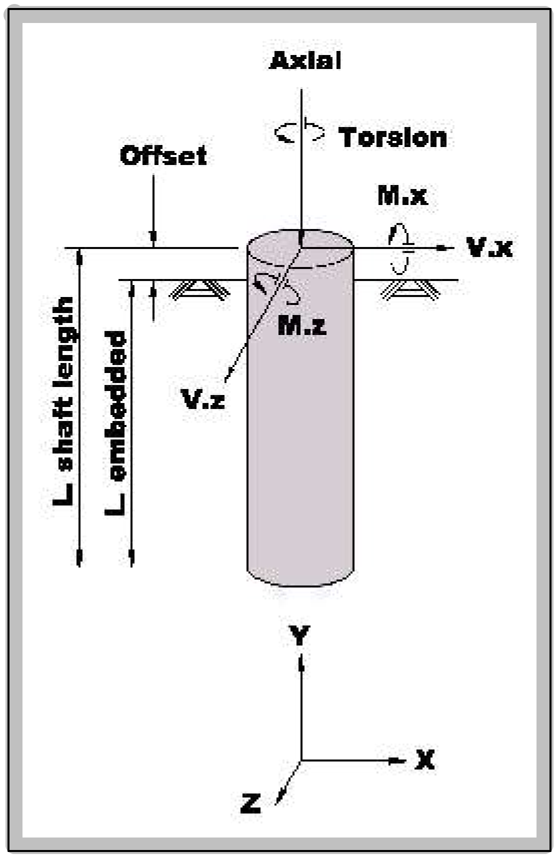
$N_{blows} := \mathbf{16}$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := \mathbf{74} \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*

Geometry

$b := \mathbf{3.0} \cdot ft$ *shaft diameter*

$Offset := \mathbf{0.50} \cdot ft$ *groundline to top of foundation*



Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := \mathbf{3.20} \cdot kip \cdot ft$ $V_x := \mathbf{0.05} \cdot kip$ $Torsion := \mathbf{57.0} \cdot kip \cdot ft$

$M_z := \mathbf{100.7} \cdot kip \cdot ft$ $V_z := \mathbf{4.50} \cdot kip$ $Axial := \mathbf{18.70} \cdot kip$

StructureType :=
- Cantilever Overhead Sign Structure
- [✓ Mast Arm Signal Structure]
- Concrete/Steel Strain Poles
- Ground Sign

$StructureType = \mathbf{1}$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = \mathbf{0.3}$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = \mathbf{1}$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

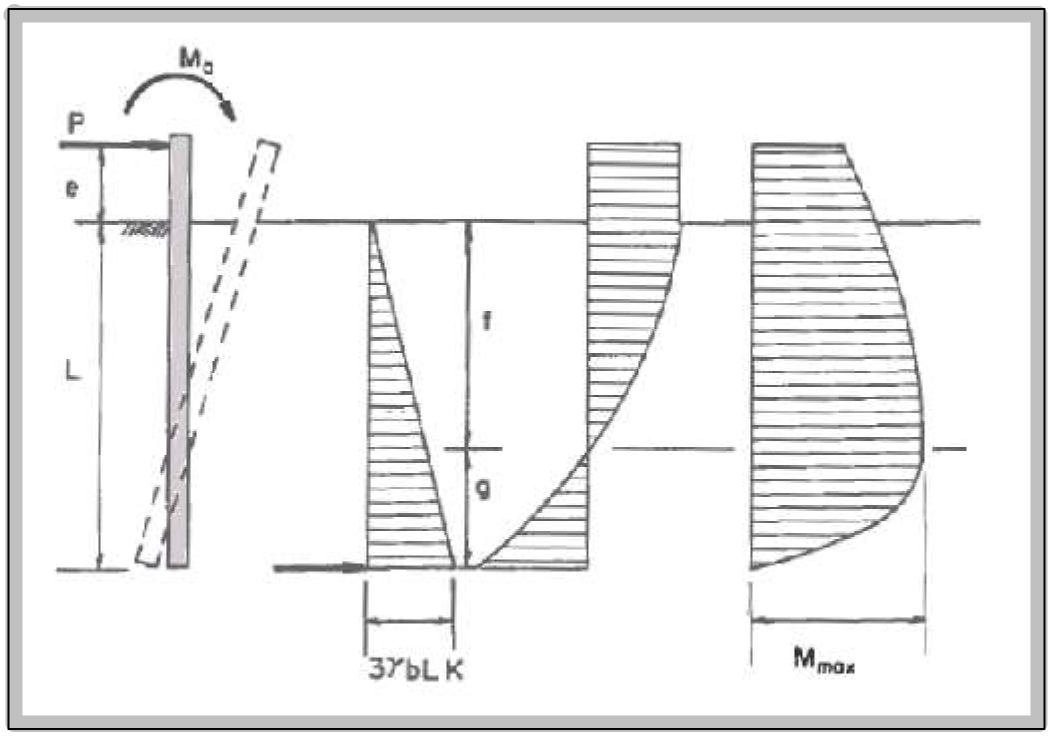
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x^{2} + M_z^{2}} = \mathbf{100.8} \cdot kip \cdot ft$

$P_u := \sqrt{V_x^{2} + V_z^{2}} = \mathbf{4.5} \cdot kip$

$T_u := Torsion = \mathbf{57} \cdot kip \cdot ft$

short free-head pile in ***cohesionless soil*** *using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(\mathbf{45} \cdot deg + \frac{\phi_{soil}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1}$ $\qquad$ $e_{sand} := Offset = \mathbf{0.5} ft$

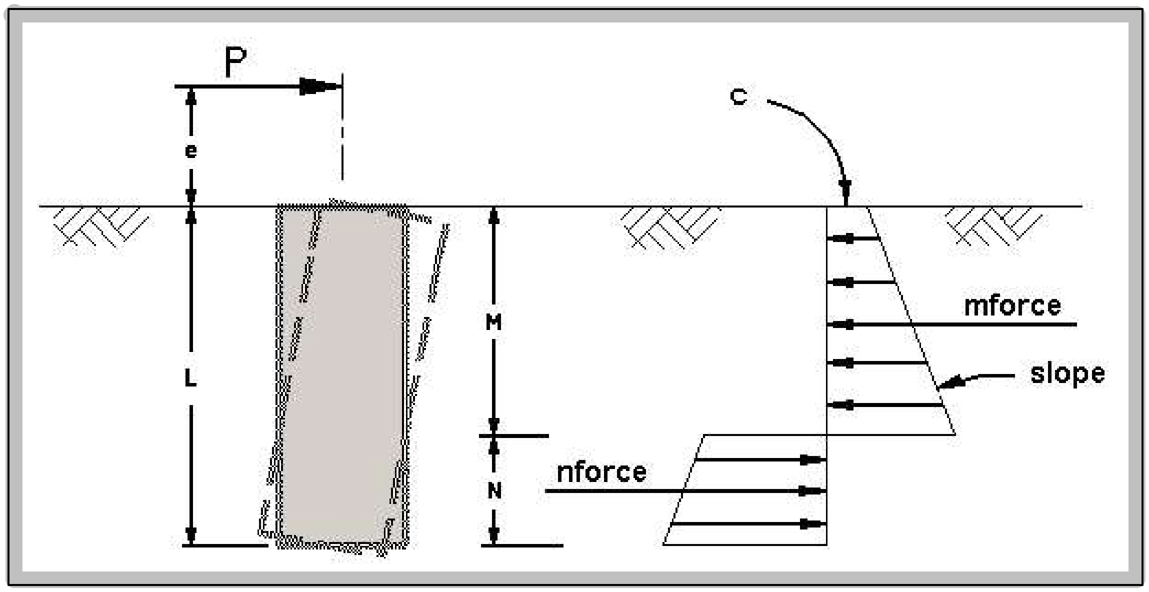
Guess value $\qquad L_{otSand} := \mathbf{10} \cdot ft$

Given $\qquad P_u \cdot \left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot} \cdot \left[\left(\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{2}} \cdot L_{otSand}\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{3}} \cdot L_{otSand}\right)\right]$

$L_{otSand} := Find\left(L_{otSand}\right) = \mathbf{18.9} ft$

$L_{otSand} := ceil\left(\frac{L_{otSand}}{ft}\right) \cdot ft = \mathbf{19} ft$ $\qquad$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}\left(c_{soil} = 0\cdot\text{ksf}, 0.1\cdot\text{ksf}, c_{soil}\right) = 1.5\cdot\text{ksf}$

$\text{Slope} := 8\cdot\dfrac{c_{soil}}{3\cdot b} = 1.3\cdot\dfrac{\text{kip}}{\text{ft}^3}$

$e_{clay} := \dfrac{M_u}{P_u} + \text{Offset} = 22.9\,\text{ft}$

$\text{nforce}(M,N) := \left[\text{Slope}\cdot(2\cdot M + N) + 2\cdot c_{soil}\right]\cdot N\cdot\dfrac{b}{2}$

$\text{mforce}(M) := \left(2\cdot c_{soil} + M\cdot\text{Slope}\right)\cdot M\cdot\dfrac{b}{2}$

$\text{m\_arm}(M) := e_{clay} + \dfrac{M}{3}\cdot\dfrac{2\cdot(M\cdot\text{Slope} + c_{soil}) + c_{soil}}{M\cdot\text{Slope} + 2\cdot c_{soil}}$

$\text{n\_arm}(M,N) := e_{clay} + M + \dfrac{N}{3}\cdot\dfrac{2\cdot(N\cdot\text{Slope} + M\cdot\text{Slope} + c_{soil}) + (M\cdot\text{Slope} + c_{soil})}{\text{Slope}\cdot(2\cdot M + N) + 2\cdot c_{soil}}$

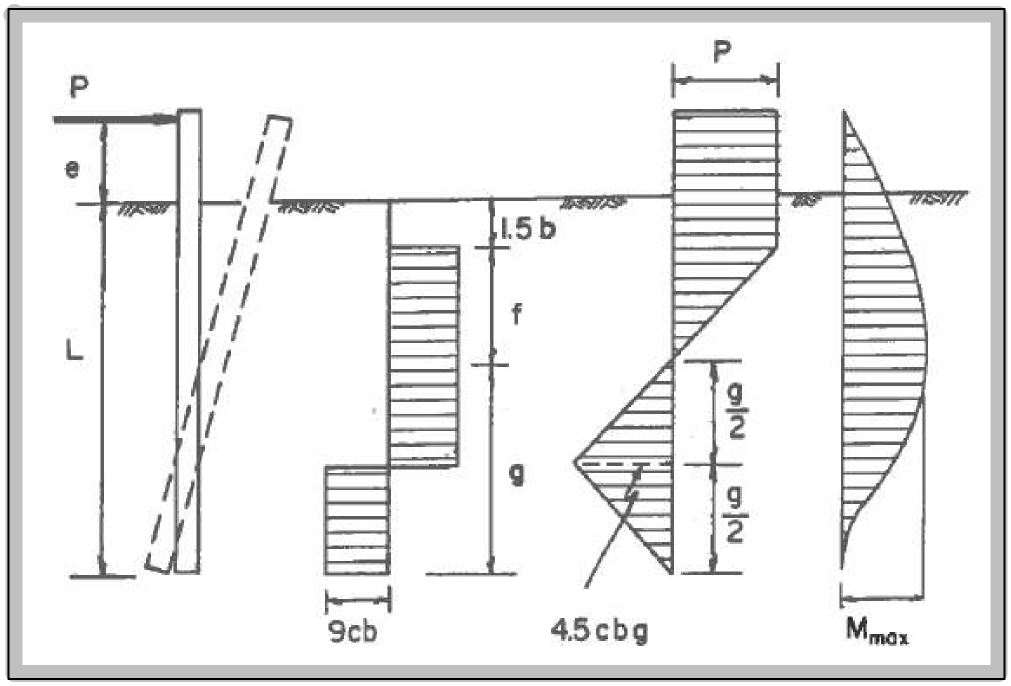
Guess value $M := 4.0\cdot\text{ft}$ $N := 4.0\cdot\text{ft}$

Given $P_u + \phi_{ot}\cdot\text{nforce}(M,N) = \phi_{ot}\cdot\text{mforce}(M)$ $\text{mforce}(M)\cdot\text{m\_arm}(M) = \text{nforce}(M,N)\cdot\text{n\_arm}(M,N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M,N)$ $L_{ot1Clay} := M + N = 10.1\,\text{ft}$

$L_{ot1Clay} := \text{ceil}\left(\dfrac{L_{ot1Clay}}{\text{ft}}\right)\cdot\text{ft} = 11\,\text{ft}$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot \mathbf{9} \cdot c_{soil} \cdot b} = \mathbf{0.4}\,\text{ft}$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + \mathbf{1.5} \cdot b + \mathbf{0.5} \cdot f\right) = \mathbf{124.3} \cdot \text{kip} \cdot \text{ft}$$

$$g := \sqrt{\frac{M_{max.clay}}{\mathbf{2.25} \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = \mathbf{7}\,\text{ft}$$

$$L_{ot2Clay} := \left(\mathbf{1.5} \cdot b + f + g\right) = \mathbf{12}\,\text{ft}$$

$$L_{ot2Clay} := \text{ceil}\left(\frac{L_{ot2Clay}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{12}\,\text{ft}$$

(round up to next foot)

$$L_{otClay} := \text{if}\left(L_{ot1Clay} < \mathbf{3} \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = \mathbf{12}\,\text{ft}$$

(If $L_{ot} < 3b$*, use Modified Broms method)*

$$L_{reqdOT} := \text{if}\left(\text{SoilType} = \textbf{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$L_{reqdOT} = \mathbf{12}\,\text{ft}$

required shaft embedment depth to resist overturning

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = \mathbf{16}$

$$\omega_{fdot} := \text{if}\left(N_{blows} < \mathbf{5}, \mathbf{0}, \text{if}\left(N_{blows} \ge \mathbf{15}, \mathbf{1.5}, \mathbf{1.5} \cdot \frac{N_{blows}}{\mathbf{15}}\right)\right) = \mathbf{1.5}$$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\frac{N_{blows}}{\mathbf{15}}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = \mathbf{12}\,\text{ft}$

Given $$T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot (L_{torSand}) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{\mathbf{2}}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{\mathbf{2}}\right]$$

$L_{torSand} := \text{Find}(L_{torSand}) = \mathbf{8.5}\,\text{ft}$

$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{9}\,\text{ft}$ *(round up to next foot)*

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := \mathbf{0.55}$

$f_{se} := \text{CohesionFactor} \cdot c_{soil} = \mathbf{0.8} \cdot \text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

Given $$T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot \left(L_{torClay} - \mathbf{1.5} \cdot \text{ft}\right) \cdot \frac{b}{\mathbf{2}}\right]$$

$L_{torClay} := \text{Find}(L_{torClay}) = \mathbf{6.4}\,\text{ft}$

$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{7}\,\text{ft}$ *(round up to next foot)*

$L_{reqdTor} := \text{if}\left(\text{SoilType} = \mathbf{\text{"Sand"}}, L_{torSand}, L_{torClay}\right)$

$L_{reqdTor} = \mathbf{7}\,\text{ft}$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}\left(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}\right) = \mathbf{12}\,\text{ft}$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = \mathbf{12.5}\,\text{ft}$ *shaft length*

Min Shaft embedment depth=14 ft

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2 \cdot P_u}{3 \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = 7.4 \, ft$$

$$M_{maxSand} := P_u \cdot (e_{sand} + f_{sand}) - \frac{P_u \cdot f_{sand}}{3} + M_u = 125.1 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0 \cdot ft$

Given $P_u = \frac{f_{mod} \cdot b}{2} \cdot (2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot Slope)$

$f_{mod} := Find(f_{mod}) = 2.1 \, ft$

$$M_{modBroms} := P_u \cdot (e_{clay} + f_{mod}) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^{\,2}}{2} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^{\,3} \cdot Slope}{6} = 108.4 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot (e_{clay} + 1.5 \cdot b + 0.5 \cdot f) = 124.3 \cdot kip \cdot ft$$

$M_{maxClay} := if(L_{ot1Clay} < 3 \cdot b, M_{modBroms}, M_{Broms}) = 124.3 \cdot kip \cdot ft$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$$M_{max} := if(SoilType = \text{"Sand"}, M_{maxSand}, M_{maxClay}) = 124.3 \cdot kip \cdot ft$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$ *reinforcing yield strength*

$f_c := 4.0 \cdot ksi$ *concrete strength* *Spec 346-3*

$Cover := 3 \cdot in$ *cover* *SDG Table 1.4.2-1*

$Num_{bar} := 11$ *number of longitudinal bars*

$A_{long.bar} := 1.0 \cdot in^2$ *longitudinal bar area*

$d_{long.bar} := 1.125 \cdot in$ *longitudinal bar diameter*

$A_{v.bar} := 0.20 \cdot in^2$ *stirrup area* *SM Vol-3 13.6.2*

$d_{v.bar} := 0.5 \cdot in$ *stirrup diameter*

$s_{v1} := 3 \cdot in$ *stirrup spacing, depth = 0 ft-2 ft* *SM Vol-3 13.6.2*

$s_{v2} := 3 \cdot in$ *stirrup spacing, depth = 2 ft-depth.stir*

$s_{v3} := 6 \cdot in$ *stirrup spacing, depth > depth.stir*

$depth_{stir} := 12.0 \cdot ft$ *stirrup depth, see s.v2 and s.v3 above*

$b = 3\,ft$ *shaft diameter*

$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$ *required 1% steel* *SM Vol-3 13.6.2*

$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$ *LRFD 5.7.4.2*

$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot in^2$

$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$ *total area of longitudinal steel*

$CheckLongitudinalReinf := if(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"})$ $CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if(Clearance_{vert.reinf} \geq 6in, \text{"OK"}, \text{"No Good"})$ $CheckReinfClearSpacing = \text{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$V_u := \sqrt{V_x^{\mathbf{2}} + V_z^{\mathbf{2}}} = \mathbf{4.5} \cdot \text{kip}$

$T_u = \mathbf{57} \cdot \text{kip} \cdot \text{ft}$

Effective shear depth

$D_r := b - \mathbf{2} \cdot \left(\text{Cover} + d_{v.bar} + \frac{d_{long.bar}}{\mathbf{2}} \right) = \mathbf{2.3}\,\text{ft}$ $d_e := \frac{b}{\mathbf{2}} + \frac{D_r}{\pi} = \mathbf{2.2}\,\text{ft}$ *LRFD C5.8.2.9-2*

$d_v := \max(\mathbf{0.9} \cdot d_e, \mathbf{0.72} \cdot b) = \mathbf{2.2}\,\text{ft}$

Check Shear Strength

$V_c := \mathbf{0.0316} \cdot (\mathbf{2.0}) \cdot \sqrt{\frac{f_c}{\text{ksi}}} \cdot \left(\frac{b}{\text{in}}\right) \cdot \left(\frac{d_v}{\text{in}}\right) \cdot \text{kip} = \mathbf{117.9} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-3* *LRFD 5.8.3.4.1* *ACI 11.3.3*

$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max(s_{v1}, s_{v2}, s_{v3})} = \mathbf{51.8} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-4*

$\text{ShearRatio} := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -\mathbf{2.2}$

$\text{ShearRatio} := \text{if}(\text{ShearRatio} \le \mathbf{0}, \mathbf{0}, \text{ShearRatio}) = \mathbf{0}$

Check Torsion Strength

$A_{cp} := \pi \cdot \left(\frac{b}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1017.9} \cdot \text{in}^{\mathbf{2}}$ $p_{cp} := \mathbf{2} \cdot \pi \cdot \left(\frac{b}{\mathbf{2}}\right) = \mathbf{113.1} \cdot \text{in}$ *Area and perimeter of concrete cross-section*

$d_{oh} := b - \mathbf{2} \cdot \left(\text{Cover} + \frac{d_{v.bar}}{\mathbf{2}} \right) = \mathbf{29.5} \cdot \text{in}$ $p_h := \pi \cdot d_{oh} = \mathbf{92.7} \cdot \text{in}$ *Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement*

$A_{oh} := \pi \left(\frac{d_{oh}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{683.5} \cdot \text{in}^{\mathbf{2}}$ $A_o := \mathbf{0.85} \cdot A_{oh} = \mathbf{581} \cdot \text{in}^{\mathbf{2}}$

$T_{n1} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD Eqn 5.8.3.6.2-1*

$T_{n2} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD 5.8.3.4.1*

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = 193.7 \cdot kip \cdot ft$$

$\phi_v = 0.9$ $\qquad$ $T_u = 57 \cdot kip \cdot ft$ $\qquad$ $L_{reqdTor} = 7\,ft$

$$Tor2_{sand} := T_u - if\left[2ft > Offset, \left[\pi \cdot b \cdot (2 \cdot ft - Offset) \cdot \gamma_{soil} \cdot \left(\frac{2 \cdot ft - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 55.2 \cdot kip \cdot ft$$

$$Tor3_{sand} := T_u - if\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot (depth_{stir} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -46.8 \cdot kip \cdot ft$$

$$Tor2_{clay} := T_u - if\left[2ft - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (2.0 \cdot ft - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 57 \cdot kip \cdot ft$$

$$Tor3_{clay} := T_u - if\left[depth_{stir} - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (depth_{stir} - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -59.6 \cdot kip \cdot ft$$

$$Tor2 := if(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}) = 57 \cdot kip \cdot ft$$

$$Tor3 := if(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}) = -59.6 \cdot kip \cdot ft$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = 0.15$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = 0.15$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = -0.31$$

$$TorsionRatio := max(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}) = 0.15$$

$$T_{cr} := 0.125 \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{A_{cp}^{\ 2}}{p_{cp} \cdot in}\right)^3 \cdot kip \cdot in = 190.9 \cdot kip \cdot ft$$ *LRFD Eqn 5.8.2.1-4*

$$TorsionRatio := if(T_u \le 0.25 \cdot \phi_{tor} \cdot T_{cr}, 0, TorsionRatio) = 0.1$$ *LRFD Eqn 5.8.2.1-3*

$ShearRatio = 0$

$$CheckShearTorsion := if(ShearRatio + TorsionRatio \le 1, \text{"OK"}, \text{"No Good"})$$

$CheckShearTorsion = \text{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = 0.005359 \cdot ksi$$ $\qquad$ $0.125 \cdot f_c = 0.5 \cdot ksi$ $\qquad$ *LRFD Eqn 5.8.2.9-1*

$s_{max1} := \text{if}\left(0.8 \cdot d_v < 24 \cdot in, 0.8 d_v, 24 \cdot in\right) = 20.7 \cdot in$ LRFD Eqn 5.8.2.7-1

$s_{max2} := \text{if}\left(0.4 \cdot d_v < 12 \cdot in, 0.4 d_v, 12 \cdot in\right) = 10.4 \cdot in$ LRFD Eqn 5.8.2.7-2

$s_{max} := \text{if}\left(v_u < 0.125 \cdot f_c, s_{max1}, s_{max2}\right) = 20.7 \cdot in$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = 6 \cdot in$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \text{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion LRFD Eqn 5.8.3.6.3-1

LRFD 5.8.3.4.1

$M_u = 100.8 \cdot kip \cdot ft$

$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5 \cdot V_s > 0 \cdot kip, \frac{V_u}{\phi_v} - 0.5 \cdot V_s, 0 \cdot kip\right) = 0 \cdot kip$

$$\text{LongReinf}_{shr.tor} := \frac{\frac{M_u}{\phi_v \cdot d_v} + \sqrt{\left(V_{temp}\right)^2 + \left(\frac{0.45 \cdot p_h \cdot T_u}{2 \cdot A_o \cdot \phi_v}\right)^2}}{F_{y.rebar}} = 1.3 \cdot in^2$$

$Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(Num_{bar} \cdot A_{long.bar} \ge \text{LongReinf}_{shr.tor}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \text{"OK"}$

Anchor Bolt Strength Check

$Num_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot in$ *anchor bolt nominal diameter*

$Dia_{anchor.circle} := 24 \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{Dia_{anchor.circle}^{2}}{8} \cdot Num_{anchor} = 576 \cdot in^{2}$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{Dia_{anchor.circle}}{2}} = 48 \cdot in$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 25.2 \cdot kip$$ *anchor tension force*

$$V_{anchor} := \frac{V_u}{Num_{anchor}} + \frac{T_u}{0.5 Dia_{anchor.circle} \cdot Num_{anchor}} = 7.7 \cdot kip$$ *anchor shear force*

$$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}^{2} = 3.1 \cdot in^{2}$$ *anchor bolt nominal area*

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 8 \cdot ksi$$ *anchor tensile stress*

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 2.4 \cdot ksi$$ *anchor shear stress*

$\phi_{anchor} := 0.75$ *resistance factor* *AISC J3-1*

$F_{nt} := 0.75 F_{u.anchor} = 78.8 \cdot ksi$ *nominal tensile stress* *AISC Table J3.2*

$F_{nv} := 0.45 F_{u.anchor} = 47.2 \cdot ksi$ *nominal tensile stress* *AISC Table J3.2*

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot kip$ *design sghear strength*

$CheckAnchorT := if\left(\phi R_{nt} \geq T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$CheckAnchorT = \text{"OK"}$

$CheckAnchorV := if\left(\phi R_{nv} \geq V_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check shear rupture*

$CheckAnchorV = \text{"OK"}$

$$F_{ntv} := \min\left(\left(\begin{matrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{matrix}\right)\right) = 78.8 \cdot ksi$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = 185.6 \cdot kip$

design tension strength modified to include the effects of shearing stress

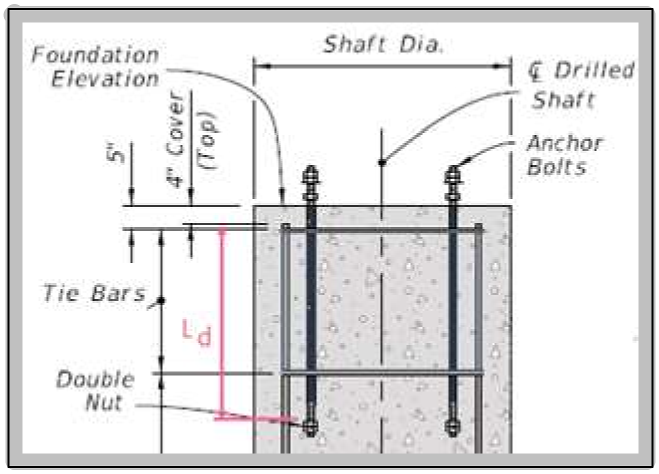
$CheckAnchorTV := if\left[\left(f_{t.anchor} \leq 20\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq 20\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \text{"OK"}, \text{"No Good"}\right]$

$CheckAnchorTV = \text{"OK"}$ *check combined tension and shear rupture*

$CheckAnchorStrength := if\left[(CheckAnchorT = \text{"OK"}) \cdot (CheckAnchorV = \text{"OK"}) \cdot (CheckAnchorTV = \text{"OK"}), \text{"OK"}, \text{"No Good"}\right]$

$CheckAnchorStrength = \text{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = 25.2 \cdot kip$ *tension force in anchor*

$Dia_{bar.circle} = 27.9 \cdot in$ $Dia_{anchor.circle} = 24 \cdot in$

center-to-center distance

$$Dist_{bar.to.bolt} := \frac{Dia_{bar.circle} - Dia_{anchor.circle}}{2} = 1.9 \cdot in$$

$$Num_{bars.per.anchor} := \min\left(\frac{Num_{bar}}{Num_{anchor}}, 3\right) = 1.4$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := 0.9$

$$Num_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot (\phi \cdot F_{y.rebar})} \cdot \frac{Dia_{anchor.circle}}{Dia_{bar.circle}} = 0.4$$

$$AreaRatio := \min\left(\frac{Num_{bars.reqd.per.anchor}}{Num_{bars.per.anchor}}, 1\right) = 0.29$$

2015 AASHTO Development Length of Deformed Bars in Tension 5.11.2.1

$Cover = 3 \cdot in$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half the center-to-center spacing of the bars or wires being developed*

$$c_b := \min\left(\begin{pmatrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{2} \\ \dfrac{\text{Spacing}_{vert.reinf}}{2} \end{pmatrix}\right) = 4 \cdot \text{in}$$

$k_{tr} := 0 \cdot \text{in}$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\begin{bmatrix} 1.0 \\ \max\left(\begin{pmatrix} 0.4 \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{pmatrix}\right) \end{bmatrix}\right] = 0.4$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\begin{pmatrix} 12 \cdot \text{in} \\ \lambda_{rc} \cdot 2.4 \cdot d_{long.bar} \cdot \dfrac{F_{y.rebar}}{\sqrt{f_c \cdot \text{ksi}}} \end{pmatrix}\right) = 32.4 \cdot \text{in}$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$\text{SpacingFactor} := \max\left[\begin{pmatrix} 0.5 \\ \text{Num}_{bars.per.anchor} \cdot 0.5 - 0.5 \end{pmatrix}\right] = 0.5$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf} \cdot \text{SpacingFactor}\right)^2 + \text{Dist}_{bar.to.bolt}^{\ 2}} = 3.9 \cdot \text{in}$$

$$L_{embedment.anchor} := \max\left[\begin{bmatrix} L_{d.bar} \cdot (\text{AreaRatio}) + 12 \cdot \text{in} + L_{embedment.added} \\ 20 \cdot d_{anchor} \end{bmatrix}\right] = 40 \cdot \text{in}$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, \text{in}\right)$

$L_{embedment.anchor} = 40 \cdot \text{in}$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{\mathrm{Dia}_{anchor.circle}}{2} = 12 \cdot \mathrm{in}$$

$$r := \frac{b}{2} = 18 \cdot \mathrm{in}$$

$$c_{a1} := \frac{\sqrt{r_b^{\,2} + 3.25 \cdot \left(r^2 - r_b^{\,2}\right)} - r_b}{3.25} = 4.6 \cdot \mathrm{in}$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\begin{pmatrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{pmatrix}\right) = 16 \cdot \mathrm{in}$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{\mathrm{in}}} \cdot \sqrt{\frac{f_c}{\mathrm{psi}}} \left(\frac{c_{a1}}{\mathrm{in}}\right)^{1.5} \cdot \mathrm{lbf} = 17.5 \cdot \mathrm{kip}$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot \mathrm{deg})}{\mathrm{Num}_{anchor}} = 45 \cdot \mathrm{deg}$$

UF Report Fig 3-7

$$\alpha := 2 \operatorname{asin}\left[\frac{\left(1.5 \cdot c_{a1}\right)}{r}\right] = 45.2 \cdot \mathrm{deg}$$

$$\mathrm{OverlapTest} := \mathrm{if}\left(A_{bolt.sector} \le \alpha, \text{"Overlap of Failure Cones"}, \text{"No Overlap of Failure Cones"}\right) = \text{"Overlap of Failur}$$

$$\mathrm{chord} := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot \mathrm{in}$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{\,2} = 95.9 \cdot \mathrm{in}^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := \mathrm{chord} \cdot 1.5 \cdot c_{a1} = 95.4 \cdot \mathrm{in}^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \mathrm{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot \mathrm{in}^2$$

$\psi_{ecV} := \mathbf{1.0}$ *eccentric load modifier* *ACI D.6.2.5*

$\psi_{edV} := \mathbf{1.0}$ *edge effect modifier* *ACI D.6.2.6*

$\psi_{cV} := \mathbf{1.4}$ *cracked section modifier* *ACI D.6.2.7* *(stirrup spacing <= 4")*

$\psi_{hV} := \mathbf{1.0}$ *member thickness modifier* *ACI D.6.2.8*

$\phi_{breakout} := \mathbf{0.75}$ *strength reduction factor* *ACI D.4.4.c.i* *(shear breakout, condition A)*

$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = \mathbf{194.7} \cdot kip$ *concrete breakout strength - shear*

ACI Eqn D-22 *Shear force ⊥ to edge*

$V_{cbg\_parallel} := \mathbf{2} \cdot V_{cbg} = \mathbf{389.5} \cdot kip$ *ACI D.6.2.1.c* *Shear force ‖ to edge*

$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = \mathbf{389.5} \cdot kip \cdot ft$ *concrete breakout strength - torsion*

$\phi_{breakout} \cdot T_{n.breakout} = \mathbf{292.1} \cdot kip \cdot ft$

$T_u = \mathbf{57} \cdot kip \cdot ft$

$BreakoutTest := if\left(\phi_{breakout} \cdot T_{n.breakout} \geq T_u, \textbf{"OK"}, \textbf{"No Good"}\right)$

$BreakoutTest = \textbf{"OK"}$

$OverlapDesign := if\left(A_{bolt.sector} \leq \alpha, \textbf{"Based on Overlap of Failure Cones"}, \textbf{"Based on No Overlap of Failure Cones"}\right)$

$OverlapDesign = \textbf{"Based on Overlap of Failure Cones"}$

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = \mathbf{1.9} \cdot in$ *center-to-center distance*

$d_{anchor.nut} := \mathbf{1.85} \cdot d_{anchor} = \mathbf{3.7} \cdot in$ *use* $\mathbf{1.85} \cdot d_{anchor}$ *.to account for anchor nut*

$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{\mathbf{2}}\right) = -\mathbf{0.5} \cdot in$

$CheckAnchorageClearance := if\left[\left(Clearance_{bar.to.nut} \geq \mathbf{2} \cdot in\right), \textbf{"OK"}, \textbf{"No Good, increase ped. diameter"}\right]$

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0..48 \qquad r_{ds} := \frac{b}{2}$

$xds_{pt} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yds_{pt} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$xstir.od_{pt} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.od_{pt} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$xstir.id_{pt} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.id_{pt} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$xbar_{pt} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max(xstir.id) - d_{v.bar} \qquad ybar_{pt} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$xboltcircle_{pt} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yboltcircle_{pt} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltr} := \frac{d_{anchor}}{2} = \mathbf{1} \cdot in$

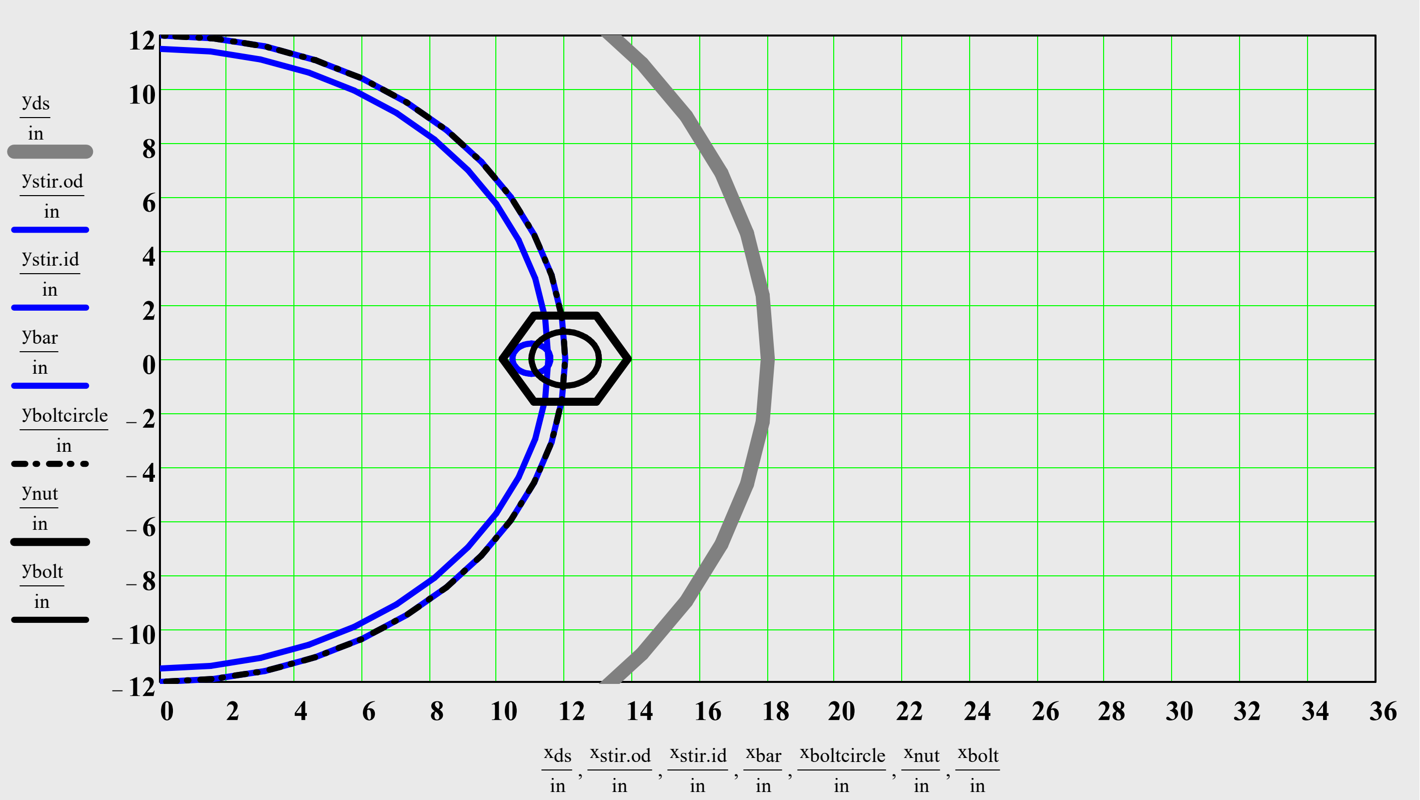
$x_{bolt_{pt}} := r_{boltr} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $y_{bolt_{pt}} := r_{boltr} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$pt := \mathbf{0} .. \mathbf{6}$ $r_{nut} := \frac{d_{anchor} \cdot 1.85}{\mathbf{2}} = \mathbf{1.9} \cdot in$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right]$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$ *enable to rotate nut* $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right]$

$\min\left(x_{bar}\right) - \max\left(x_{nut}\right) = -\mathbf{3.4} \cdot in$



$$\mathrm{Bolts} := \begin{pmatrix} 1 & 1.125 & 1.25 & 1.375 & 1.5 & 1.625 & 1.75 & 1.875 & 2 & 2.25 & 2.5 & 2.75 & 3 \\ 1.5 & 1.688 & 1.875 & 2.063 & 2.25 & 2.438 & 2.625 & 2.938 & 3 & 3.375 & 3.75 & 4.125 & 4.25 \end{pmatrix}\cdot \mathrm{in}$$

$$\left(\mathrm{Bolts}^{T}\right)^{\langle 0\rangle^{T}}\cdot 1.6 - \left(\mathrm{Bolts}^{T}\right)^{\langle 1\rangle^{T}} = \begin{pmatrix} 0.1 & 0.112 & 0.125 & 0.137 & 0.15 & 0.162 & 0.175 & 0.062 & 0.2 & 0.225 & 0.25 & 0.275 & 0.55 \end{pmatrix}\cdot \mathrm{in}$$

$$\left(\mathrm{Bolts}^{T}\right)^{\langle 0\rangle^{T}} - \left(\mathrm{Bolts}^{T}\right)^{\langle 1\rangle^{T}} = \begin{pmatrix} -0.5 & -0.563 & -0.625 & -0.688 & -0.75 & -0.813 & -0.875 & -1.063 & -1 & -1.125 & -1.25 & -1.375 & -1.25 \end{pmatrix}\cdot$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

State Structures Design Office

SUBJECT 079-241-M MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

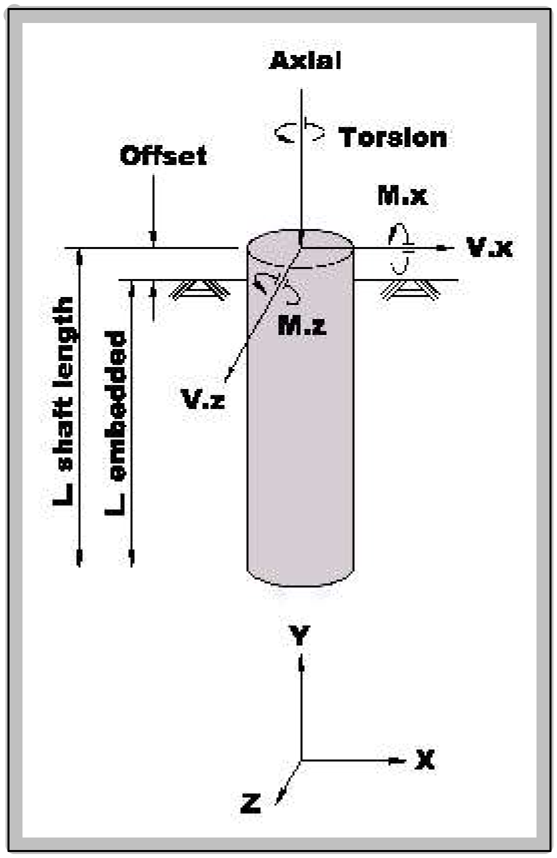
SoilType :=
Sand
Clay

$\phi_{soil} := 32.0 \cdot deg$ *soil friction angle (sand)*

$c_{soil} := 0.0 \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

$N_{blows} := 22$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := 125 \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*



Geometry

$b := 3.0 \cdot ft$ *shaft diameter*

$Offset := 0.50 \cdot ft$ *groundline to top of foundation*

Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := 201.3 \cdot kip \cdot ft$	$V_x := 0.05 \cdot kip$	$Torsion := 0.0 \cdot kip \cdot ft$
$M_z := 0.05 \cdot kip \cdot ft$	$V_z := 6.60 \cdot kip$	$Axial := 14.80 \cdot kip$

StructureType :=
Cantilever Overhead Sign Structure
Mast Arm Signal Structure
Concrete/Steel Strain Poles
Ground Sign

$StructureType = 2$

$\phi_{ot} := if(StructureType = 2, 0.25, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

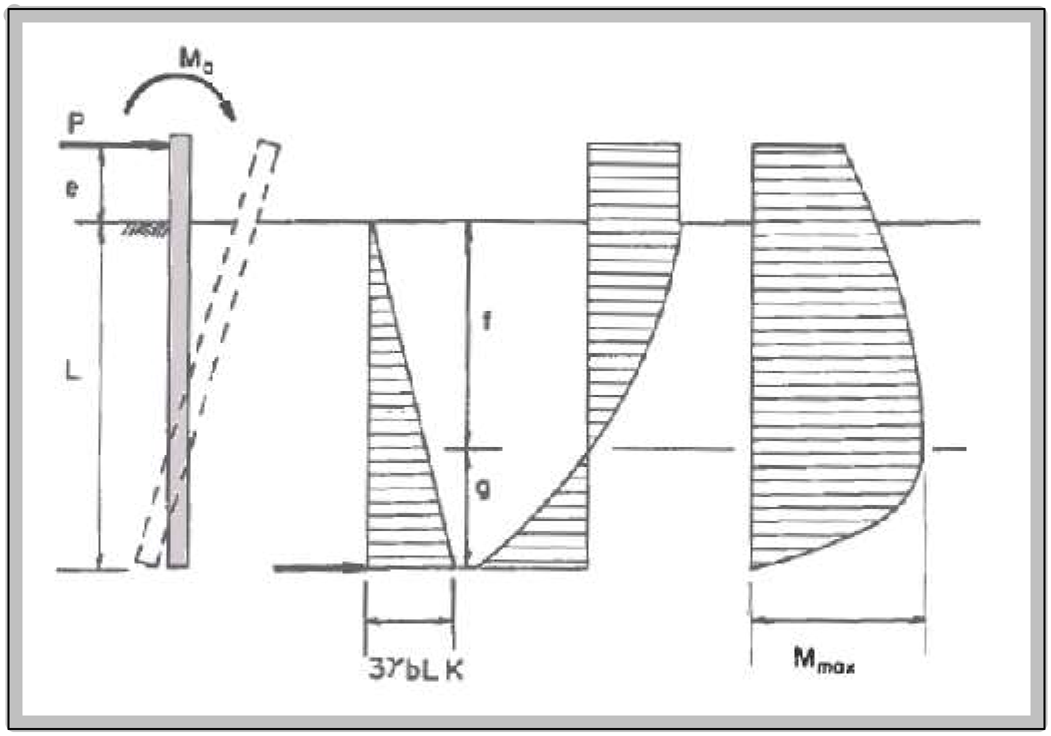
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x^{2} + M_z^{2}} = 201.3 \cdot kip \cdot ft$

$P_u := \sqrt{V_x^{2} + V_z^{2}} = 6.6 \cdot kip$

$T_u := Torsion = 0 \cdot kip \cdot ft$

*short free-head pile in **cohesionless soil** using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(45 \cdot deg + \frac{\phi_{soil}}{2}\right)^{2} = 3.3$ $\qquad$ $e_{sand} := Offset = 0.5 \, ft$

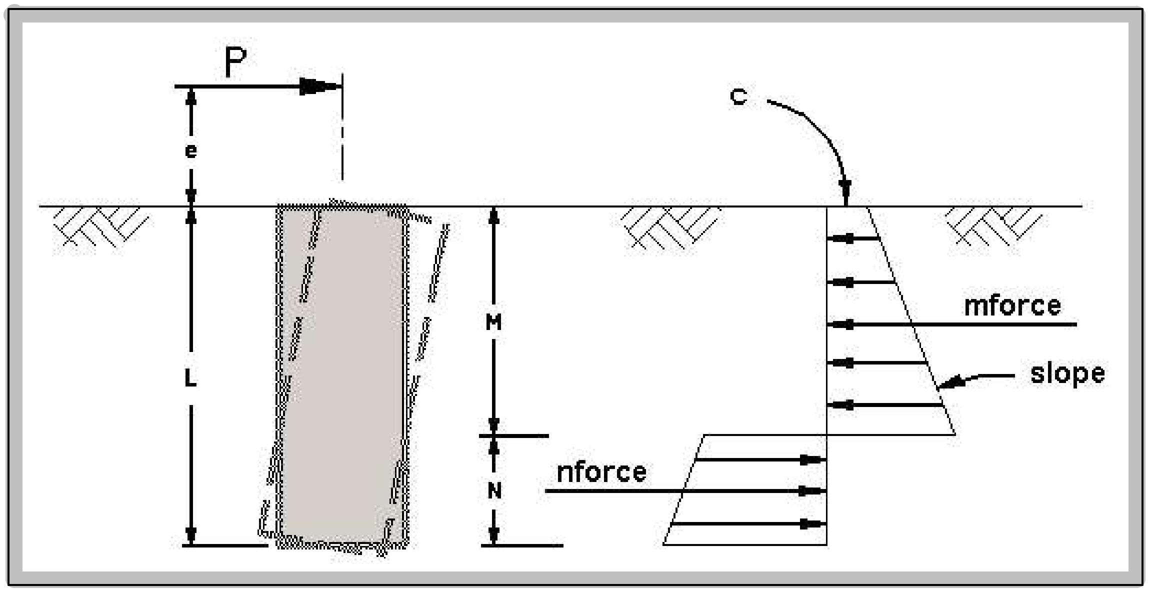
Guess value $\qquad L_{otSand} := 10 \cdot ft$

Given $\qquad P_u \cdot \left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot} \cdot \left[\left(3 \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{1}{2} \cdot L_{otSand}\right) \cdot \left(\frac{1}{3} \cdot L_{otSand}\right)\right]$

$L_{otSand} := Find\left(L_{otSand}\right) = 12.3 \, ft$

$L_{otSand} := ceil\left(\frac{L_{otSand}}{ft}\right) \cdot ft = 13 \, ft$ $\qquad$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}\left(c_{soil} = 0 \cdot ksf, 0.1 \cdot ksf, c_{soil}\right) = 0.1 \cdot ksf$

$\text{Slope} := 8 \cdot \frac{c_{soil}}{3 \cdot b} = 0.1 \cdot \frac{kip}{ft^3}$

$e_{clay} := \frac{M_u}{P_u} + \text{Offset} = 31\,ft$

$\text{nforce}(M,N) := \left[\text{Slope} \cdot (2 \cdot M + N) + 2 \cdot c_{soil}\right] \cdot N \cdot \frac{b}{2}$

$\text{mforce}(M) := (2 \cdot c_{soil} + M \cdot \text{Slope}) \cdot M \cdot \frac{b}{2}$

$\text{m\_arm}(M) := e_{clay} + \frac{M}{3} \cdot \frac{2 \cdot (M \cdot \text{Slope} + c_{soil}) + c_{soil}}{M \cdot \text{Slope} + 2 \cdot c_{soil}}$

$\text{n\_arm}(M,N) := e_{clay} + M + \frac{N}{3} \cdot \frac{2 \cdot (N \cdot \text{Slope} + M \cdot \text{Slope} + c_{soil}) + (M \cdot \text{Slope} + c_{soil})}{\text{Slope} \cdot (2 \cdot M + N) + 2 \cdot c_{soil}}$

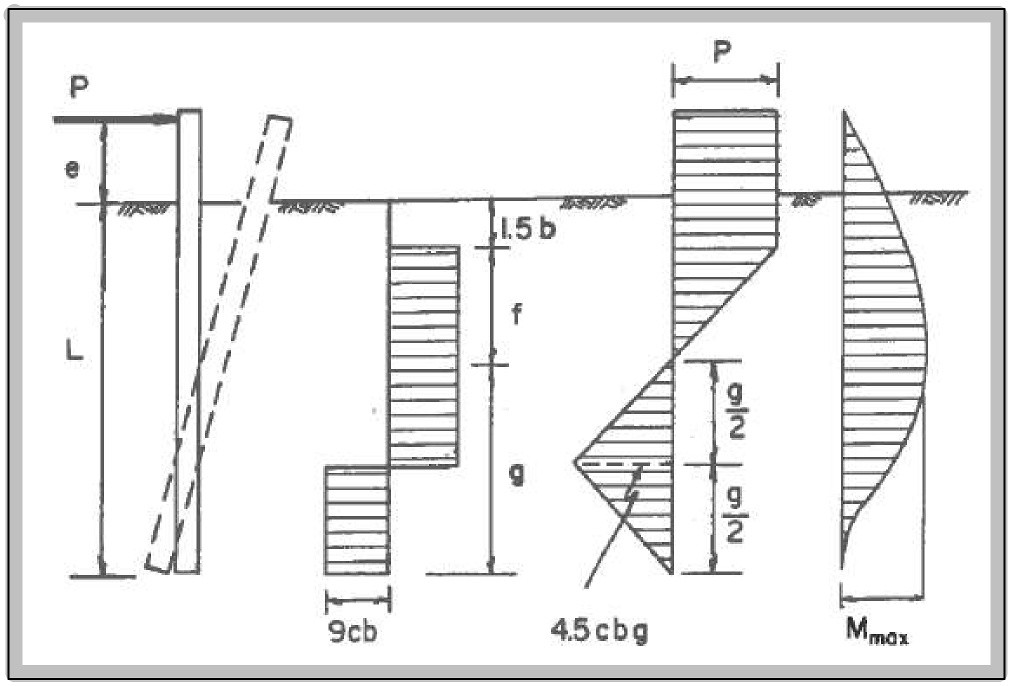
Guess value $M := 4.0 \cdot ft$ $N := 4.0 \cdot ft$

Given $P_u + \phi_{ot} \cdot \text{nforce}(M,N) = \phi_{ot} \cdot \text{mforce}(M)$ $\text{mforce}(M) \cdot \text{m\_arm}(M) = \text{nforce}(M,N) \cdot \text{n\_arm}(M,N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M,N)$ $L_{ot1Clay} := M + N = 37.9\,ft$

$L_{ot1Clay} := \text{ceil}\left(\frac{L_{ot1Clay}}{ft}\right) \cdot ft = 38\,ft$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot \mathbf{9} \cdot c_{soil} \cdot b} = \mathbf{9.8}\,\text{ft}$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + \mathbf{1.5} \cdot b + \mathbf{0.5} \cdot f\right) = \mathbf{266.6} \cdot \text{kip} \cdot \text{ft}$$

$$g := \sqrt{\frac{M_{max.clay}}{\mathbf{2.25} \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = \mathbf{39.7}\,\text{ft}$$

$$L_{ot2Clay} := \left(\mathbf{1.5} \cdot b + f + g\right) = \mathbf{54}\,\text{ft}$$

$$L_{ot2Clay} := \text{ceil}\left(\frac{L_{ot2Clay}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{55}\,\text{ft}$$

(round up to next foot)

$$L_{otClay} := \text{if}\left(L_{ot1Clay} < \mathbf{3} \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = \mathbf{55}\,\text{ft}$$

(If $L_{ot} < 3b$, use Modified Broms method)

$$L_{reqdOT} := \text{if}\left(\text{SoilType} = \textbf{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$L_{reqdOT} = \mathbf{13}\,\text{ft}$

required shaft embedment depth to resist overturning

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = 22$

$$\omega_{fdot} := \text{if}\left(N_{blows} < 5, 0, \text{if}\left(N_{blows} \ge 15, 1.5, 1.5 \cdot \frac{N_{blows}}{15}\right)\right) = 1.5$$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\frac{N_{blows}}{15}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = 13\,\text{ft}$

Given $T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot (L_{torSand}) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right]$

$L_{torSand} := \text{Find}(L_{torSand}) = 1.4 \times 10^{-15}\,\text{ft}$

$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{\text{ft}}\right) \cdot \text{ft} = 1\,\text{ft}$ *(round up to next foot)*

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := 0.55$

$f_{se} := \text{CohesionFactor} \cdot c_{soil} = 0.1 \cdot \text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

Given $T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot (L_{torClay} - 1.5 \cdot \text{ft}) \cdot \frac{b}{2}\right]$

$L_{torClay} := \text{Find}(L_{torClay}) = 1.5\,\text{ft}$

$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{\text{ft}}\right) \cdot \text{ft} = 2\,\text{ft}$ *(round up to next foot)*

$L_{reqdTor} := \text{if}(\text{SoilType} = \text{"Sand"}, L_{torSand}, L_{torClay})$

$L_{reqdTor} = 1\,\text{ft}$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}) = 13\,\text{ft}$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = 13.5\,\text{ft}$ **`Min Shaft embedment depth=14 ft`** *shaft length*

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2 \cdot P_u}{3 \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = 3.8 \, ft$$

$$M_{maxSand} := P_u \cdot \left(e_{sand} + f_{sand}\right) - \frac{P_u \cdot f_{sand}}{3} + M_u = 221.3 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0 \cdot ft$

Given $P_u = \frac{f_{mod} \cdot b}{2} \cdot \left(2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot Slope\right)$

$$f_{mod} := Find\left(f_{mod}\right) = 13 \, ft$$

$$M_{modBroms} := P_u \cdot \left(e_{clay} + f_{mod}\right) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^{2}}{2} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^{3} \cdot Slope}{6} = 259.7 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot \left(e_{clay} + 1.5 \cdot b + 0.5 \cdot f\right) = 266.6 \cdot kip \cdot ft$$

$$M_{maxClay} := if\left(L_{ot1Clay} < 3 \cdot b, M_{modBroms}, M_{Broms}\right) = 266.6 \cdot kip \cdot ft$$ *(If L_{ot} < 3b, use Modified Broms method)*

$$M_{max} := if\left(SoilType = \text{"Sand"}, M_{maxSand}, M_{maxClay}\right) = 221.3 \cdot kip \cdot ft$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$ *reinforcing yield strength*

$f_c := 4.0 \cdot ksi$ *concrete strength* *Spec 346-3*

$Cover := 3 \cdot in$ *cover* *SDG Table 1.4.2-1*

$Num_{bar} := 11$ *number of longitudinal bars*

$A_{long.bar} := 1.0 \cdot in^2$ *longitudinal bar area*

$d_{long.bar} := 1.125 \cdot in$ *longitudinal bar diameter*

$A_{v.bar} := 0.20 \cdot in^2$ *stirrup area* *SM Vol-3 13.6.2*

$d_{v.bar} := 0.5 \cdot in$ *stirrup diameter*

$s_{v1} := 3 \cdot in$ *stirrup spacing, depth = 0 ft-2 ft* *SM Vol-3 13.6.2*

$s_{v2} := 3 \cdot in$ *stirrup spacing, depth = 2 ft-depth.stir*

$s_{v3} := 6 \cdot in$ *stirrup spacing, depth > depth.stir*

$depth_{stir} := 14.0 \cdot ft$ *stirrup depth, see s.v2 and s.v3 above*

$b = 3 \, ft$ *shaft diameter*

$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$ *required 1% steel* *SM Vol-3 13.6.2*

$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$ *LRFD 5.7.4.2*

$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot in^2$

$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$ *total area of longitudinal steel*

$CheckLongitudinalReinf := if(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"})$ $CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if(Clearance_{vert.reinf} \geq 6in, \text{"OK"}, \text{"No Good"})$ $CheckReinfClearSpacing = \text{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$$V_u := \sqrt{V_x^{\mathbf{2}} + V_z^{\mathbf{2}}} = \mathbf{6.6} \cdot \text{kip}$$

$$T_u = \mathbf{0} \cdot \text{kip} \cdot \text{ft}$$

Effective shear depth

$$D_r := b - \mathbf{2} \cdot \left(\text{Cover} + d_{v.bar} + \frac{d_{long.bar}}{\mathbf{2}} \right) = \mathbf{2.3}\,\text{ft} \qquad d_e := \frac{b}{\mathbf{2}} + \frac{D_r}{\pi} = \mathbf{2.2}\,\text{ft}$$

LRFD C5.8.2.9-2

$$d_v := \max(\mathbf{0.9} \cdot d_e, \mathbf{0.72} \cdot b) = \mathbf{2.2}\,\text{ft}$$

Check Shear Strength

$$V_c := \mathbf{0.0316} \cdot (\mathbf{2.0}) \cdot \sqrt{\frac{f_c}{\text{ksi}}} \cdot \left(\frac{b}{\text{in}}\right) \cdot \left(\frac{d_v}{\text{in}}\right) \cdot \text{kip} = \mathbf{117.9} \cdot \text{kip}$$

LRFD Eqn 5.8.3.3-3 *LRFD 5.8.3.4.1* *ACI 11.3.3*

$$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max(s_{v1}, s_{v2}, s_{v3})} = \mathbf{51.8} \cdot \text{kip}$$

LRFD Eqn 5.8.3.3-4

$$\text{ShearRatio} := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -\mathbf{2.1}$$

$$\text{ShearRatio} := \text{if}(\text{ShearRatio} \le \mathbf{0}, \mathbf{0}, \text{ShearRatio}) = \mathbf{0}$$

Check Torsion Strength

$$A_{cp} := \pi \cdot \left(\frac{b}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1017.9} \cdot \text{in}^{\mathbf{2}} \qquad p_{cp} := \mathbf{2} \cdot \pi \cdot \left(\frac{b}{\mathbf{2}}\right) = \mathbf{113.1} \cdot \text{in}$$

Area and perimeter of concrete cross-section

$$d_{oh} := b - \mathbf{2} \cdot \left(\text{Cover} + \frac{d_{v.bar}}{\mathbf{2}} \right) = \mathbf{29.5} \cdot \text{in} \qquad p_h := \pi \cdot d_{oh} = \mathbf{92.7} \cdot \text{in}$$

Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement

$$A_{oh} := \pi \left(\frac{d_{oh}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{683.5} \cdot \text{in}^{\mathbf{2}} \qquad A_o := \mathbf{0.85} \cdot A_{oh} = \mathbf{581} \cdot \text{in}^{\mathbf{2}}$$

$$T_{n1} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$$

LRFD Eqn 5.8.3.6.2-1

$$T_{n2} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$$

LRFD 5.8.3.4.1

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = 193.7 \cdot kip \cdot ft$$

$\phi_v = 0.9$ $\quad T_u = 0 \cdot kip \cdot ft$ $\quad L_{reqdTor} = 1\,ft$

$$Tor2_{sand} := T_u - if\left[2ft > Offset, \left[\pi \cdot b \cdot (2 \cdot ft - Offset) \cdot \gamma_{soil} \cdot \left(\frac{2 \cdot ft - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -3 \cdot kip \cdot ft$$

$$Tor3_{sand} := T_u - if\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot (depth_{stir} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -241.5 \cdot kip \cdot ft$$

$$Tor2_{clay} := T_u - if\left[2ft - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (2.0 \cdot ft - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 0 \cdot kip \cdot ft$$

$$Tor3_{clay} := T_u - if\left[depth_{stir} - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (depth_{stir} - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -9.3 \cdot kip \cdot ft$$

$$Tor2 := if(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}) = -3 \cdot kip \cdot ft$$

$$Tor3 := if(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}) = -241.5 \cdot kip \cdot ft$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = 0$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = -7.7 \times 10^{-3}$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = -1.25$$

$$TorsionRatio := max(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}) = 0$$

$$T_{cr} := 0.125 \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{A_{cp}^{\,2}}{p_{cp} \cdot in^3}\right) \cdot kip \cdot in = 190.9 \cdot kip \cdot ft$$

LRFD Eqn 5.8.2.1-4

$$TorsionRatio := if(T_u \le 0.25 \cdot \phi_{tor} \cdot T_{cr}, 0, TorsionRatio) = 0$$

LRFD Eqn 5.8.2.1-3

$ShearRatio = 0$

$$CheckShearTorsion := if(ShearRatio + TorsionRatio \le 1, \text{"OK"}, \text{"No Good"})$$

$CheckShearTorsion = \text{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = 0.007859 \cdot ksi \qquad 0.125 \cdot f_c = 0.5 \cdot ksi$$

LRFD Eqn 5.8.2.9-1

$s_{max1} := \text{if}\left(\mathbf{0.8} \cdot d_v < \mathbf{24} \cdot \text{in}, \mathbf{0.8} d_v, \mathbf{24} \cdot \text{in}\right) = \mathbf{20.7} \cdot \text{in}$ *LRFD Eqn 5.8.2.7-1*

$s_{max2} := \text{if}\left(\mathbf{0.4} \cdot d_v < \mathbf{12} \cdot \text{in}, \mathbf{0.4} d_v, \mathbf{12} \cdot \text{in}\right) = \mathbf{10.4} \cdot \text{in}$ *LRFD Eqn 5.8.2.7-2*

$s_{max} := \text{if}\left(v_u < \mathbf{0.125} \cdot f_c, s_{max1}, s_{max2}\right) = \mathbf{20.7} \cdot \text{in}$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = \mathbf{6} \cdot \text{in}$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \mathbf{\text{"OK"}}, \mathbf{\text{"No Good"}}\right)$

$\text{CheckMaxSpacingTransvReinf} = \mathbf{\text{"OK"}}$

Check Longitudinal Reinforcement for Combined Shear and Torsion *LRFD Eqn 5.8.3.6.3-1*

LRFD 5.8.3.4.1

$M_u = \mathbf{201.3} \cdot \text{kip} \cdot \text{ft}$

$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5 \cdot V_s > \mathbf{0} \cdot \text{kip}, \frac{V_u}{\phi_v} - 0.5 \cdot V_s, \mathbf{0} \cdot \text{kip}\right) = \mathbf{0} \cdot \text{kip}$

$$\text{LongReinf}_{shr.tor} := \frac{\frac{M_u}{\phi_v \cdot d_v} + \sqrt{\left(V_{temp}\right)^{\mathbf{2}} + \left(\frac{\mathbf{0.45} \cdot p_h \cdot T_u}{\mathbf{2} \cdot A_o \cdot \phi_v}\right)^{\mathbf{2}}}}{F_{y.rebar}} = \mathbf{1.7} \cdot \text{in}^{\mathbf{2}}$$

$\text{Num}_{bar} \cdot A_{long.bar} = \mathbf{11} \cdot \text{in}^{\mathbf{2}}$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(\text{Num}_{bar} \cdot A_{long.bar} \ge \text{LongReinf}_{shr.tor}, \mathbf{\text{"OK"}}, \mathbf{\text{"No Good"}}\right)$

$\text{CheckLongReinf}_{shr.tor} = \mathbf{\text{"OK"}}$

Anchor Bolt Strength Check

$\mathrm{Num}_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot in$ *anchor bolt nominal diameter*

$\mathrm{Dia}_{anchor.circle} := 24 \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{\mathrm{Dia}_{anchor.circle}^{\;2}}{8} \cdot \mathrm{Num}_{anchor} = 576 \cdot in^{2}$$

$$S_{anchor} := \frac{I_{anchor}}{\dfrac{\mathrm{Dia}_{anchor.circle}}{2}} = 48 \cdot in$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 50.3 \cdot kip$$ *anchor tension force*

$$V_{anchor} := \frac{V_u}{\mathrm{Num}_{anchor}} + \frac{T_u}{0.5\mathrm{Dia}_{anchor.circle} \cdot \mathrm{Num}_{anchor}} = 0.8 \cdot kip$$ *anchor shear force*

$$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}^{\;2} = 3.1 \cdot in^{2}$$ *anchor bolt nominal area*

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 16 \cdot ksi$$ *anchor tensile stress*

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 0.3 \cdot ksi$$ *anchor shear stress*

$\phi_{anchor} := 0.75$ *resistance factor* AISC J3-1

$F_{nt} := 0.75 F_{u.anchor} = 78.8 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := 0.45 F_{u.anchor} = 47.2 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot kip$ *design sghear strength*

$\mathrm{CheckAnchorT} := \mathrm{if}\left(\phi R_{nt} \ge T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$\mathrm{CheckAnchorT} = \text{"OK"}$

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check shear rupture*

$\text{CheckAnchorV} = \text{"OK"}$

$$F_{ntv} := \min\left(\left(\begin{matrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{matrix}\right)\right) = 78.8 \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = 185.6 \cdot \text{kip}$

design tension strength modified to include the effects of shearing stress

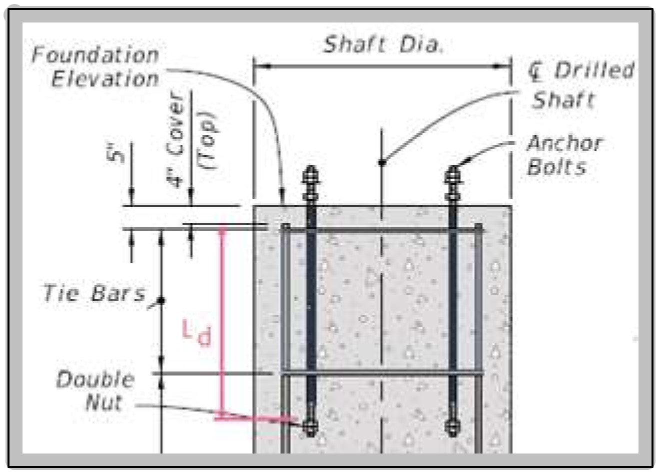
$$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq 20\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq 20\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \text{"OK"}, \text{"No Good"}\right]$$

$\text{CheckAnchorTV} = \text{"OK"}$ *check combined tension and shear rupture*

$$\text{CheckAnchorStrength} := \text{if}\left[(\text{CheckAnchorT} = \text{"OK"}) \cdot (\text{CheckAnchorV} = \text{"OK"}) \cdot (\text{CheckAnchorTV} = \text{"OK"}), \text{"OK"}, \text{"No Good"}\right]$$

$\text{CheckAnchorStrength} = \text{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = 50.3 \cdot \text{kip}$ *tension force in anchor*

$\text{Dia}_{bar.circle} = 27.9 \cdot \text{in}$ $\text{Dia}_{anchor.circle} = 24 \cdot \text{in}$

center-to-center distance

$$\text{Dist}_{bar.to.bolt} := \frac{\text{Dia}_{bar.circle} - \text{Dia}_{anchor.circle}}{2} = 1.9 \cdot \text{in}$$

$$\text{Num}_{bars.per.anchor} := \min\left(\frac{\text{Num}_{bar}}{\text{Num}_{anchor}}, 3\right) = 1.4$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := 0.9$

$$\text{Num}_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{\text{Dia}_{anchor.circle}}{\text{Dia}_{bar.circle}} = 0.8$$

$$\text{AreaRatio} := \min\left(\frac{\text{Num}_{bars.reqd.per.anchor}}{\text{Num}_{bars.per.anchor}}, 1\right) = 0.58$$

2015 AASHTO Development Length of Deformed Bars in Tension **5.11.2.1**

$\text{Cover} = 3 \cdot \text{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half the center-to-center spacing of the bars or wires being developed*

$$c_b := \min\left(\begin{pmatrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{2} \\ \dfrac{\text{Spacing}_{vert.reinf}}{2} \end{pmatrix}\right) = 4 \cdot \text{in}$$

$k_{tr} := 0 \cdot \text{in}$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\begin{bmatrix} 1.0 \\ \max\left(\begin{pmatrix} 0.4 \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{pmatrix}\right) \end{bmatrix}\right] = 0.4$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\begin{pmatrix} 12 \cdot \text{in} \\ \lambda_{rc} \cdot 2.4 \cdot d_{long.bar} \cdot \dfrac{F_{y.rebar}}{\sqrt{f_c \cdot \text{ksi}}} \end{pmatrix}\right) = 32.4 \cdot \text{in}$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$\text{SpacingFactor} := \max\left[\begin{pmatrix} 0.5 \\ \text{Num}_{bars.per.anchor} \cdot 0.5 - 0.5 \end{pmatrix}\right] = 0.5$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf} \cdot \text{SpacingFactor}\right)^2 + \text{Dist}_{bar.to.bolt}^{\;2}} = 3.9 \cdot \text{in}$$

$$L_{embedment.anchor} := \max\left[\begin{bmatrix} L_{d.bar} \cdot (\text{AreaRatio}) + 12 \cdot \text{in} + L_{embedment.added} \\ 20 \cdot d_{anchor} \end{bmatrix}\right] = 40 \cdot \text{in}$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, \text{in}\right)$

$L_{embedment.anchor} = 40 \cdot \text{in}$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^{\,2} + 3.25 \cdot \left(r^2 - r_b^{\,2}\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\left(\begin{array}{c} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{array}\right)\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2\operatorname{asin}\left[\frac{\left(1.5 \cdot c_{a1}\right)}{r}\right] = 45.2 \cdot deg$$

$$OverlapTest := \text{if}\left(A_{bolt.sector} \le \alpha, \text{"Overlap of Failure Cones"}, \text{"No Overlap of Failure Cones"}\right) = \text{"Overlap of Failur}$$

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{\;2} = 95.9 \cdot in^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \text{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$$

$\psi_{ecV} := 1.0$ *eccentric load modifier* ACI D.6.2.5

$\psi_{edV} := 1.0$ *edge effect modifier* ACI D.6.2.6

$\psi_{cV} := 1.4$ *cracked section modifier* ACI D.6.2.7 *(stirrup spacing <= 4")*

$\psi_{hV} := 1.0$ *member thickness modifier* ACI D.6.2.8

$\phi_{breakout} := 0.75$ *strength reduction factor* ACI D.4.4.c.i *(shear breakout, condition A)*

$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = 194.7 \cdot kip$ *concrete breakout strength - shear*

ACI Eqn D-22 *Shear force ⊥ to edge*

$V_{cbg\_parallel} := 2 \cdot V_{cbg} = 389.5 \cdot kip$ ACI D.6.2.1.c *Shear force ‖ to edge*

$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = 389.5 \cdot kip \cdot ft$ *concrete breakout strength - torsion*

$\phi_{breakout} \cdot T_{n.breakout} = 292.1 \cdot kip \cdot ft$

$T_u = 0 \cdot kip \cdot ft$

$BreakoutTest := if\left(\phi_{breakout} \cdot T_{n.breakout} \geq T_u, \text{"OK"}, \text{"No Good"}\right)$

$BreakoutTest = \text{"OK"}$

$OverlapDesign := if\left(A_{bolt.sector} \leq \alpha, \text{"Based on Overlap of Failure Cones"}, \text{"Based on No Overlap of Failure Cones"}\right)$

$OverlapDesign = \text{"Based on Overlap of Failure Cones"}$

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = 1.9 \cdot in$ *center-to-center distance*

$d_{anchor.nut} := 1.85 \cdot d_{anchor} = 3.7 \cdot in$ *use* $1.85 \cdot d_{anchor}$ *.to account for anchor nut*

$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{2}\right) = -0.5 \cdot in$

$CheckAnchorageClearance := if\left[\left(Clearance_{bar.to.nut} \geq 2 \cdot in\right), \text{"OK"}, \text{"No Good, increase ped. diameter"}\right]$

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0..48 \qquad r_{ds} := \frac{b}{2}$

$xds_{pt} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yds_{pt} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$xstir.od_{pt} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.od_{pt} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$xstir.id_{pt} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.id_{pt} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$xbar_{pt} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max(xstir.id) - d_{v.bar} \qquad ybar_{pt} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$xboltcircle_{pt} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yboltcircle_{pt} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltr} := \frac{d_{anchor}}{2} = \mathbf{1} \cdot in$

$x_{bolt_{pt}} := r_{boltr} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$

$y_{bolt_{pt}} := r_{boltr} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$pt := \mathbf{0} .. \mathbf{6}$

$r_{nut} := \frac{d_{anchor} \cdot 1.85}{\mathbf{2}} = \mathbf{1.9} \cdot in$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$

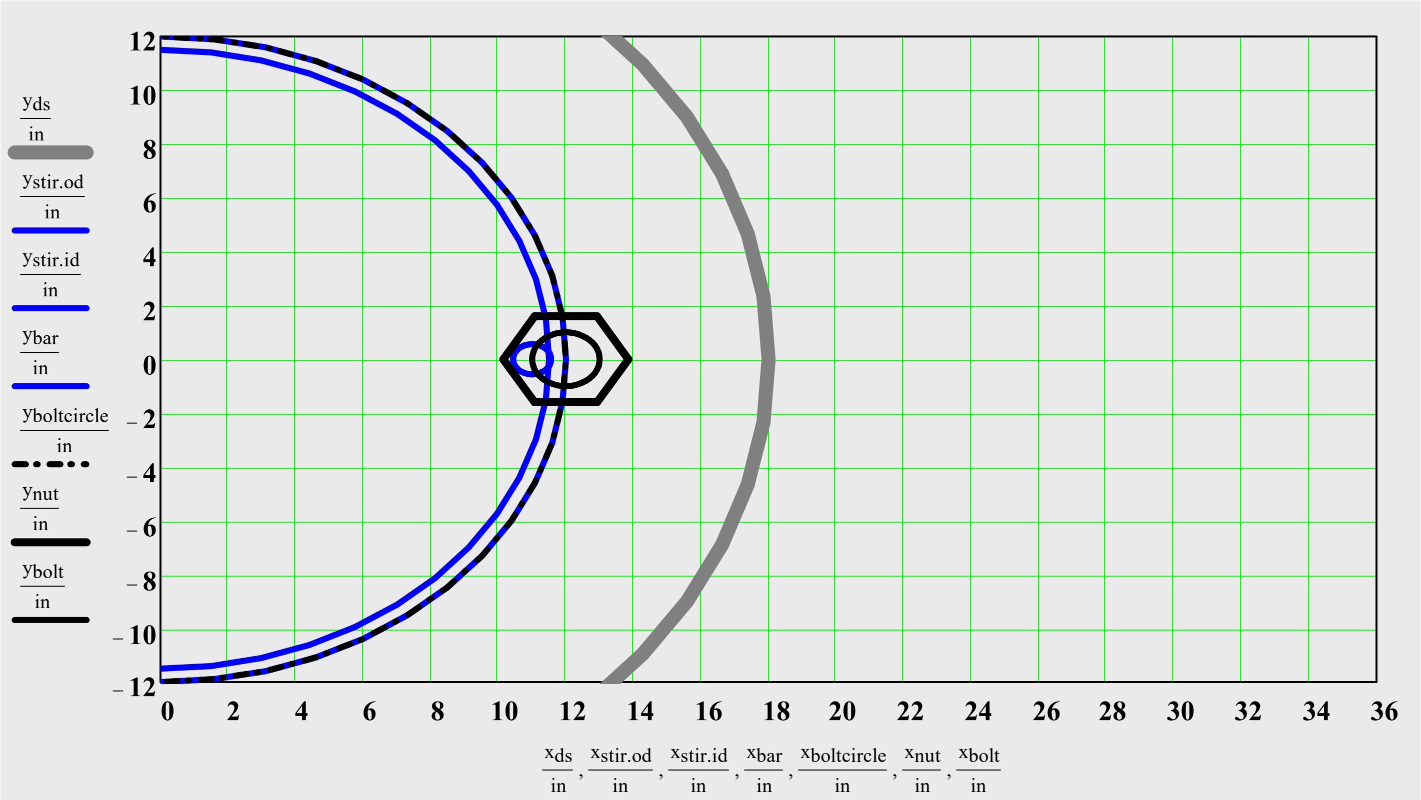
$y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right]$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$

enable to rotate nut

$y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right]$

$\min\left(x_{bar}\right) - \max\left(x_{nut}\right) = -\mathbf{3.4} \cdot in$



$$\mathrm{Bolts} := \begin{pmatrix} \mathbf{1} & \mathbf{1.125} & \mathbf{1.25} & \mathbf{1.375} & \mathbf{1.5} & \mathbf{1.625} & \mathbf{1.75} & \mathbf{1.875} & \mathbf{2} & \mathbf{2.25} & \mathbf{2.5} & \mathbf{2.75} & \mathbf{3} \\ \mathbf{1.5} & \mathbf{1.688} & \mathbf{1.875} & \mathbf{2.063} & \mathbf{2.25} & \mathbf{2.438} & \mathbf{2.625} & \mathbf{2.938} & \mathbf{3} & \mathbf{3.375} & \mathbf{3.75} & \mathbf{4.125} & \mathbf{4.25} \end{pmatrix} \cdot \mathrm{in}$$

$$\left(\mathrm{Bolts}^{T}\right)^{\langle \mathbf{0} \rangle^{T}} \cdot \mathbf{1.6} - \left(\mathrm{Bolts}^{T}\right)^{\langle \mathbf{1} \rangle^{T}} = \begin{pmatrix} \mathbf{0.1} & \mathbf{0.112} & \mathbf{0.125} & \mathbf{0.137} & \mathbf{0.15} & \mathbf{0.162} & \mathbf{0.175} & \mathbf{0.062} & \mathbf{0.2} & \mathbf{0.225} & \mathbf{0.25} & \mathbf{0.275} & \mathbf{0.55} \end{pmatrix} \cdot \mathrm{in}$$

$$\left(\mathrm{Bolts}^{T}\right)^{\langle \mathbf{0} \rangle^{T}} - \left(\mathrm{Bolts}^{T}\right)^{\langle \mathbf{1} \rangle^{T}} = \begin{pmatrix} -\mathbf{0.5} & -\mathbf{0.563} & -\mathbf{0.625} & -\mathbf{0.688} & -\mathbf{0.75} & -\mathbf{0.813} & -\mathbf{0.875} & -\mathbf{1.063} & -\mathbf{1} & -\mathbf{1.125} & -\mathbf{1.25} & -\mathbf{1.375} & -\mathbf{1.25} \end{pmatrix} \cdot$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

FDOT
State Structures Design Office

SUBJECT 079-241-N MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

SoilType :=
● Sand
○ Clay

$\phi_{soil} := 32.0 \cdot deg$ soil friction angle (sand)

$c_{soil} := 0.0 \cdot \frac{kip}{ft^2}$ soil shear strength (clay)

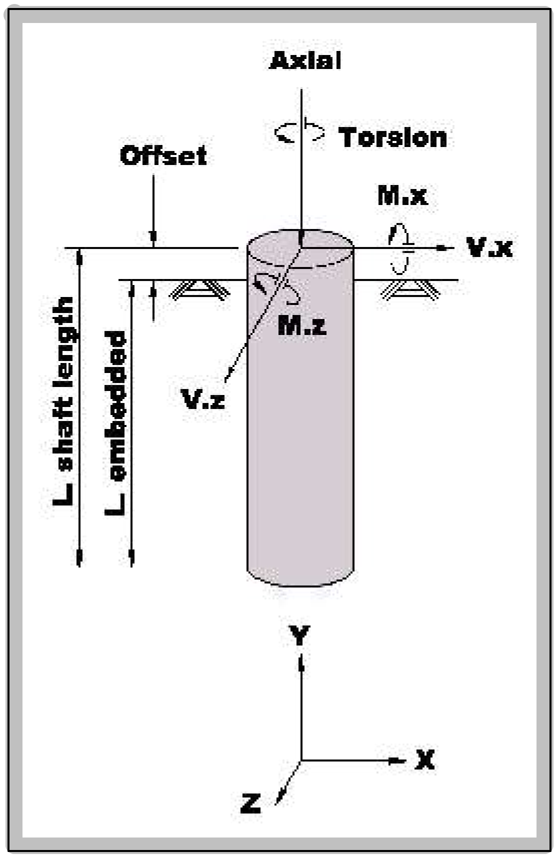
$N_{blows} := 22$ number of blows per foot. If N< 5, contact the district geotech Engineer

$\gamma_{soil} := 125 \cdot pcf$ effective soil weight (typical design value = 45 ~ 50 pcf)

Geometry

$b := 3.0 \cdot ft$ shaft diameter

$Offset := 0.50 \cdot ft$ groundline to top of foundation



Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := 201.3 \cdot kip \cdot ft$ $V_x := 0.05 \cdot kip$ $Torsion := 0.0 \cdot kip \cdot ft$

$M_z := 0.05 \cdot kip \cdot ft$ $V_z := 6.60 \cdot kip$ $Axial := 14.80 \cdot kip$

StructureType :=
○ Cantilever Overhead Sign Structure
○ Mast Arm Signal Structure
● Concrete/Steel Strain Poles
○ Ground Sign

$StructureType = 2$

$\phi_{ot} := if(StructureType = 2, 0.25, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

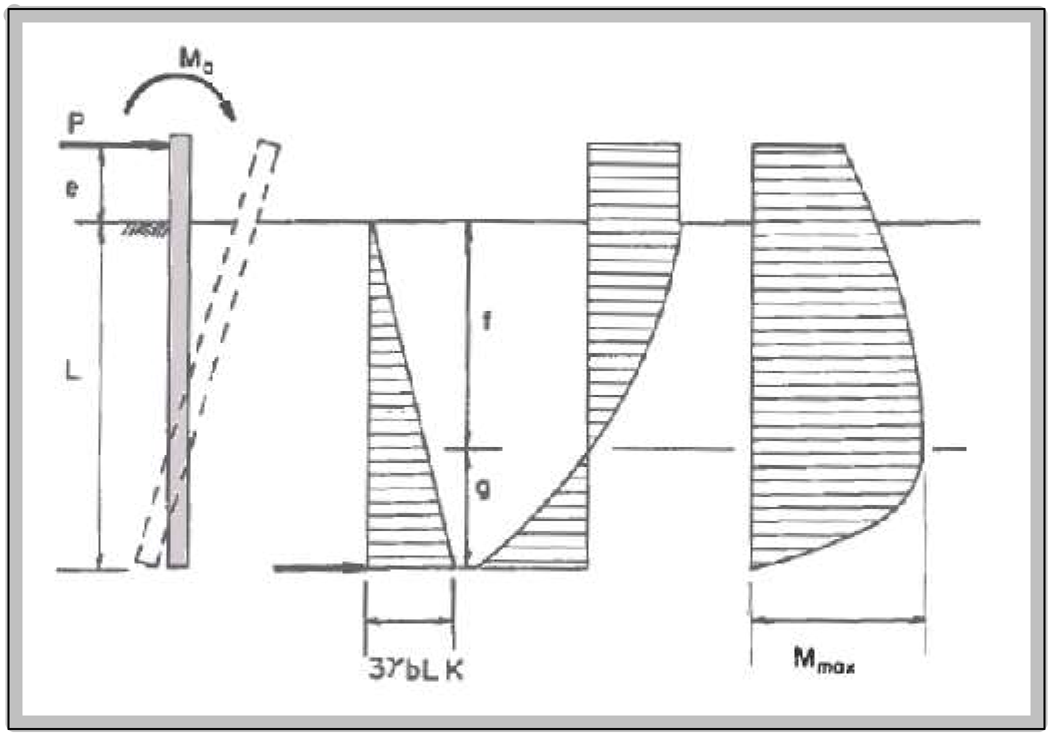
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x^{2} + M_z^{2}} = \mathbf{201.3} \cdot \text{kip} \cdot \text{ft}$

$P_u := \sqrt{V_x^{2} + V_z^{2}} = \mathbf{6.6} \cdot \text{kip}$

$T_u := \text{Torsion} = \mathbf{0} \cdot \text{kip} \cdot \text{ft}$

*short free-head pile in **cohesionless soil** using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(\mathbf{45} \cdot \text{deg} + \frac{\phi_{soil}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{3.3}$ $\qquad e_{sand} := \text{Offset} = \mathbf{0.5}\,\text{ft}$

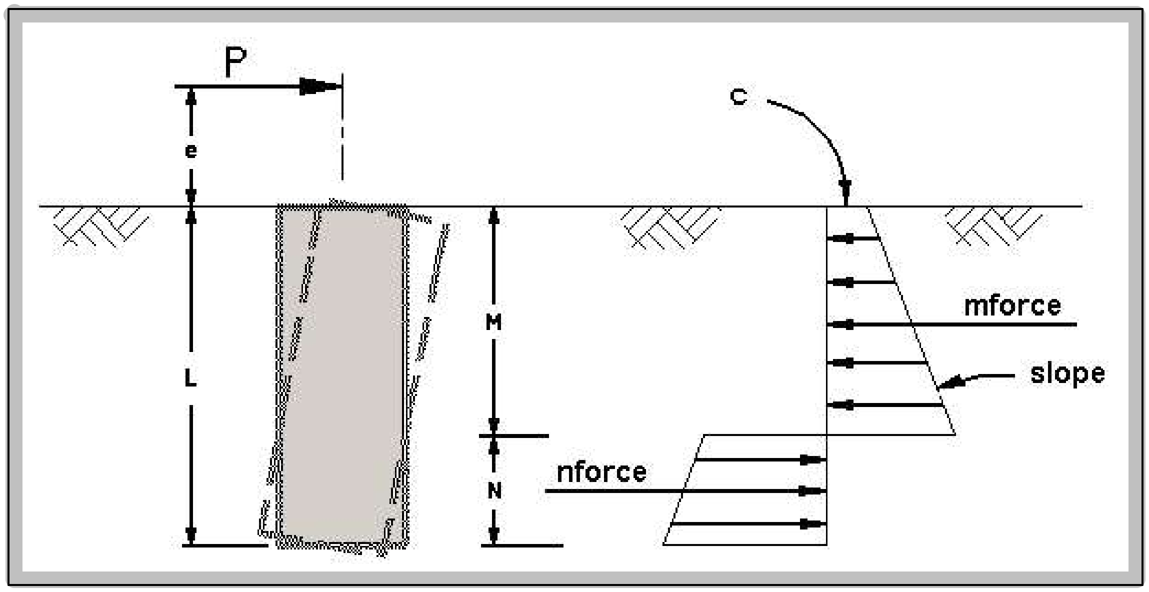
Guess value $\qquad L_{otSand} := \mathbf{10} \cdot \text{ft}$

Given $\qquad P_u \cdot \left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot} \cdot \left[\left(\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{2}} \cdot L_{otSand}\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{3}} \cdot L_{otSand}\right)\right]$

$L_{otSand} := \text{Find}\left(L_{otSand}\right) = \mathbf{12.3}\,\text{ft}$

$L_{otSand} := \text{ceil}\left(\frac{L_{otSand}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{13}\,\text{ft}$ $\qquad$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}\left(c_{soil} = 0 \cdot ksf, 0.1 \cdot ksf, c_{soil}\right) = 0.1 \cdot ksf$

$Slope := 8 \cdot \dfrac{c_{soil}}{3 \cdot b} = 0.1 \cdot \dfrac{kip}{ft^3}$

$e_{clay} := \dfrac{M_u}{P_u} + Offset = 31\,ft$

$nforce(M, N) := \left[Slope \cdot (2 \cdot M + N) + 2 \cdot c_{soil}\right] \cdot N \cdot \dfrac{b}{2}$

$mforce(M) := \left(2 \cdot c_{soil} + M \cdot Slope\right) \cdot M \cdot \dfrac{b}{2}$

$m\_arm(M) := e_{clay} + \dfrac{M}{3} \cdot \dfrac{2 \cdot (M \cdot Slope + c_{soil}) + c_{soil}}{M \cdot Slope + 2 \cdot c_{soil}}$

$n\_arm(M, N) := e_{clay} + M + \dfrac{N}{3} \cdot \dfrac{2 \cdot (N \cdot Slope + M \cdot Slope + c_{soil}) + (M \cdot Slope + c_{soil})}{Slope \cdot (2 \cdot M + N) + 2 \cdot c_{soil}}$

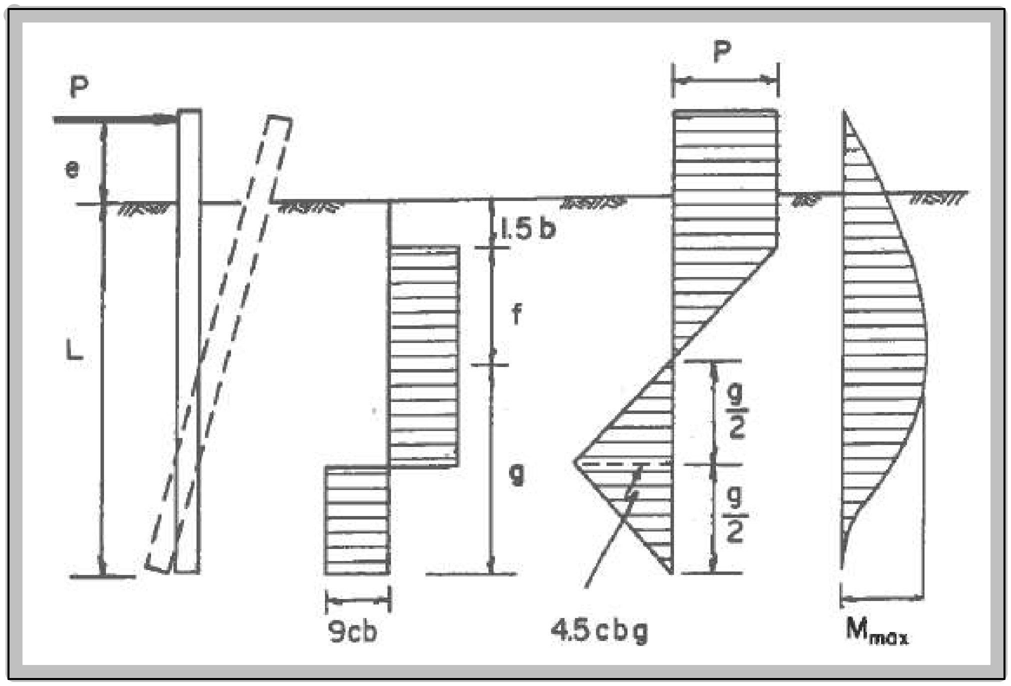
Guess value $M := 4.0 \cdot ft$ $N := 4.0 \cdot ft$

Given $P_u + \phi_{ot} \cdot nforce(M, N) = \phi_{ot} \cdot mforce(M)$ $mforce(M) \cdot m\_arm(M) = nforce(M, N) \cdot n\_arm(M, N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M, N)$ $L_{ot1Clay} := M + N = 37.9\,ft$

$L_{ot1Clay} := \text{ceil}\left(\dfrac{L_{ot1Clay}}{ft}\right) \cdot ft = 38\,ft$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot \mathbf{9} \cdot c_{soil} \cdot b} = \mathbf{9.8} \, ft$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + \mathbf{1.5} \cdot b + \mathbf{0.5} \cdot f \right) = \mathbf{266.6} \cdot kip \cdot ft$$

$$g := \sqrt{\frac{M_{max.clay}}{\mathbf{2.25} \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = \mathbf{39.7} \, ft$$

$$L_{ot2Clay} := \left(\mathbf{1.5} \cdot b + f + g \right) = \mathbf{54} \, ft$$

$$L_{ot2Clay} := ceil\left(\frac{L_{ot2Clay}}{ft} \right) \cdot ft = \mathbf{55} \, ft$$

(round up to next foot)

$$L_{otClay} := if\left(L_{ot1Clay} < \mathbf{3} \cdot b , L_{ot1Clay} , L_{ot2Clay} \right) = \mathbf{55} \, ft$$

(If $L_{ot} < 3b$*, use Modified Broms method)*

$$L_{reqdOT} := if\left(SoilType = \textbf{"Sand"} , L_{otSand} , L_{otClay} \right)$$

$L_{reqdOT} = \mathbf{13} \, ft$

required shaft embedment depth to resist overturning

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = 22$

$$\omega_{fdot} := \text{if}\left(N_{blows} < 5, 0, \text{if}\left(N_{blows} \geq 15, 1.5, 1.5 \cdot \frac{N_{blows}}{15}\right)\right) = 1.5$$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\dfrac{N_{blows}}{15}$ SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = 13\,\text{ft}$

Given $$T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot (L_{torSand}) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right]$$

$L_{torSand} := \text{Find}(L_{torSand}) = 1.4 \times 10^{-15}\,\text{ft}$

$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{\text{ft}}\right) \cdot \text{ft} = 1\,\text{ft}$ *(round up to next foot)*

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := 0.55$

$f_{se} := \text{CohesionFactor} \cdot c_{soil} = 0.1 \cdot \text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

Given $$T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot (L_{torClay} - 1.5 \cdot \text{ft}) \cdot \frac{b}{2}\right]$$

$L_{torClay} := \text{Find}(L_{torClay}) = 1.5\,\text{ft}$

$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{\text{ft}}\right) \cdot \text{ft} = 2\,\text{ft}$ *(round up to next foot)*

$L_{reqdTor} := \text{if}(\text{SoilType} = \text{"Sand"}, L_{torSand}, L_{torClay})$

$L_{reqdTor} = 1\,\text{ft}$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}) = 13\,\text{ft}$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = 13.5\,\text{ft}$ **Min Shaft embedment depth=14 ft** *shaft length*

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2 \cdot P_u}{3 \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = 3.8 \, ft$$

$$M_{maxSand} := P_u \cdot (e_{sand} + f_{sand}) - \frac{P_u \cdot f_{sand}}{3} + M_u = 221.3 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0 \cdot ft$

Given $P_u = \frac{f_{mod} \cdot b}{2} \cdot (2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot Slope)$

$f_{mod} := Find(f_{mod}) = 13 \, ft$

$$M_{modBroms} := P_u \cdot (e_{clay} + f_{mod}) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^2}{2} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^3 \cdot Slope}{6} = 259.7 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot (e_{clay} + 1.5 \cdot b + 0.5 \cdot f) = 266.6 \cdot kip \cdot ft$$

$M_{maxClay} := if(L_{ot1Clay} < 3 \cdot b, M_{modBroms}, M_{Broms}) = 266.6 \cdot kip \cdot ft$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$M_{max} := if(SoilType = \text{"Sand"}, M_{maxSand}, M_{maxClay}) = 221.3 \cdot kip \cdot ft$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$	*reinforcing yield strength*	
$f_c := 4.0 \cdot ksi$	*concrete strength*	Spec 346-3
$Cover := 3 \cdot in$	*cover*	SDG Table 1.4.2-1
$Num_{bar} := 11$	*number of longitudinal bars*	
$A_{long.bar} := 1.0 \cdot in^2$	*longitudinal bar area*	
$d_{long.bar} := 1.125 \cdot in$	*longitudinal bar diameter*	
$A_{v.bar} := 0.20 \cdot in^2$	*stirrup area*	SM Vol-3 13.6.2
$d_{v.bar} := 0.5 \cdot in$	*stirrup diameter*	
$s_{v1} := 3 \cdot in$	*stirrup spacing, depth = 0 ft-2 ft*	SM Vol-3 13.6.2
$s_{v2} := 3 \cdot in$	*stirrup spacing, depth = 2 ft-depth.stir*	
$s_{v3} := 6 \cdot in$	*stirrup spacing, depth > depth.stir*	
$depth_{stir} := 14.0 \cdot ft$	*stirrup depth, see s.v2 and s.v3 above*	
$b = 3\,ft$	*shaft diameter*	
$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$	*required 1% steel*	SM Vol-3 13.6.2
$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$		LRFD 5.7.4.2
$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot in^2$		
$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$	*total area of longitudinal steel*	
$CheckLongitudinalReinf := if(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"})$	$CheckLongitudinalReinf = \text{"OK"}$	

$$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$$

$$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$$

$$Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$$

$CheckReinfClearSpacing := if(Clearance_{vert.reinf} \geq 6in, \text{"OK"}, \text{"No Good"})$	$CheckReinfClearSpacing = \text{"OK"}$	SDG 3.6.10

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$V_u := \sqrt{V_x^{2} + V_z^{2}} = 6.6 \cdot kip$

$T_u = 0 \cdot kip \cdot ft$

Effective shear depth

$D_r := b - 2 \cdot \left(Cover + d_{v.bar} + \frac{d_{long.bar}}{2}\right) = 2.3\, ft$ $d_e := \frac{b}{2} + \frac{D_r}{\pi} = 2.2\, ft$ *LRFD C5.8.2.9-2*

$d_v := \max(0.9 \cdot d_e, 0.72 \cdot b) = 2.2\, ft$

Check Shear Strength

$V_c := 0.0316 \cdot (2.0) \cdot \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{b}{in}\right) \cdot \left(\frac{d_v}{in}\right) \cdot kip = 117.9 \cdot kip$ *LRFD Eqn 5.8.3.3-3* *LRFD 5.8.3.4.1* *ACI 11.3.3*

$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max(s_{v1}, s_{v2}, s_{v3})} = 51.8 \cdot kip$ *LRFD Eqn 5.8.3.3-4*

$ShearRatio := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -2.1$

$ShearRatio := \text{if}(ShearRatio \le 0, 0, ShearRatio) = 0$

Check Torsion Strength

$A_{cp} := \pi \cdot \left(\frac{b}{2}\right)^{2} = 1017.9 \cdot in^{2}$ $p_{cp} := 2 \cdot \pi \cdot \left(\frac{b}{2}\right) = 113.1 \cdot in$ *Area and perimeter of concrete cross-section*

$d_{oh} := b - 2 \cdot \left(Cover + \frac{d_{v.bar}}{2}\right) = 29.5 \cdot in$ $p_h := \pi \cdot d_{oh} = 92.7 \cdot in$ *Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement*

$A_{oh} := \pi \left(\frac{d_{oh}}{2}\right)^{2} = 683.5 \cdot in^{2}$ $A_o := 0.85 \cdot A_{oh} = 581 \cdot in^{2}$

$T_{n1} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = 387.3 \cdot kip \cdot ft$ *LRFD Eqn 5.8.3.6.2-1*

$T_{n2} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = 387.3 \cdot kip \cdot ft$ *LRFD 5.8.3.4.1*

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = 193.7 \cdot kip \cdot ft$$

$\phi_v = 0.9$ $\qquad$ $T_u = 0 \cdot kip \cdot ft$ $\qquad$ $L_{reqdTor} = 1\,ft$

$$Tor2_{sand} := T_u - if\left[2ft > Offset, \left[\pi \cdot b \cdot (2 \cdot ft - Offset) \cdot \gamma_{soil} \cdot \left(\frac{2 \cdot ft - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -3 \cdot kip \cdot ft$$

$$Tor3_{sand} := T_u - if\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot (depth_{stir} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -241.5 \cdot kip \cdot ft$$

$$Tor2_{clay} := T_u - if\left[2ft - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (2.0 \cdot ft - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 0 \cdot kip \cdot ft$$

$$Tor3_{clay} := T_u - if\left[depth_{stir} - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (depth_{stir} - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -9.3 \cdot kip \cdot ft$$

$$Tor2 := if(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}) = -3 \cdot kip \cdot ft$$

$$Tor3 := if(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}) = -241.5 \cdot kip \cdot ft$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = 0$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = -7.7 \times 10^{-3}$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = -1.25$$

$$TorsionRatio := max(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}) = 0$$

$$T_{cr} := 0.125\sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{A_{cp}^{\;2}}{p_{cp} \cdot in}^{3}\right) \cdot kip \cdot in = 190.9 \cdot kip \cdot ft$$

LRFD Eqn 5.8.2.1-4

$$TorsionRatio := if(T_u \le 0.25 \cdot \phi_{tor} \cdot T_{cr}, 0, TorsionRatio) = 0$$

LRFD Eqn 5.8.2.1-3

$ShearRatio = 0$

$$CheckShearTorsion := if(ShearRatio + TorsionRatio \le 1, \text{"OK"}, \text{"No Good"})$$

$CheckShearTorsion = \text{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = 0.007859 \cdot ksi \qquad 0.125 \cdot f_c = 0.5 \cdot ksi$$

LRFD Eqn 5.8.2.9-1

$s_{max1} := \mathrm{if}\left(0.8 \cdot d_v < 24 \cdot in, 0.8 d_v, 24 \cdot in\right) = 20.7 \cdot in$ *LRFD Eqn 5.8.2.7-1*

$s_{max2} := \mathrm{if}\left(0.4 \cdot d_v < 12 \cdot in, 0.4 d_v, 12 \cdot in\right) = 10.4 \cdot in$ *LRFD Eqn 5.8.2.7-2*

$s_{max} := \mathrm{if}\left(v_u < 0.125 \cdot f_c, s_{max1}, s_{max2}\right) = 20.7 \cdot in$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = 6 \cdot in$

$\mathrm{CheckMaxSpacingTransvReinf} := \mathrm{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \text{"OK"}, \text{"No Good"}\right)$

$\mathrm{CheckMaxSpacingTransvReinf} = \text{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion *LRFD Eqn 5.8.3.6.3-1*

LRFD 5.8.3.4.1

$M_u = 201.3 \cdot kip \cdot ft$

$$V_{temp} := \mathrm{if}\left(\frac{V_u}{\phi_v} - 0.5 \cdot V_s > 0 \cdot kip, \frac{V_u}{\phi_v} - 0.5 \cdot V_s, 0 \cdot kip\right) = 0 \cdot kip$$

$$\mathrm{LongReinf}_{shr.tor} := \frac{\frac{M_u}{\phi_v \cdot d_v} + \sqrt{\left(V_{temp}\right)^2 + \left(\frac{0.45 \cdot p_h \cdot T_u}{2 \cdot A_o \cdot \phi_v}\right)^2}}{F_{y.rebar}} = 1.7 \cdot in^2$$

$\mathrm{Num}_{bar} \cdot A_{long.bar} = 11 \cdot in^2$

$\mathrm{CheckLongReinf}_{shr.tor} := \mathrm{if}\left(\mathrm{Num}_{bar} \cdot A_{long.bar} \ge \mathrm{LongReinf}_{shr.tor}, \text{"OK"}, \text{"No Good"}\right)$

$\mathrm{CheckLongReinf}_{shr.tor} = \text{"OK"}$

Anchor Bolt Strength Check

$Num_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot in$ *anchor bolt nominal diameter*

$Dia_{anchor.circle} := 24 \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{Dia_{anchor.circle}^{\,2}}{8} \cdot Num_{anchor} = 576 \cdot in^{2}$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{Dia_{anchor.circle}}{2}} = 48 \cdot in$$

$T_{anchor} := \frac{M_u}{S_{anchor}} = 50.3 \cdot kip$ *anchor tension force*

$V_{anchor} := \frac{V_u}{Num_{anchor}} + \frac{T_u}{0.5 Dia_{anchor.circle} \cdot Num_{anchor}} = 0.8 \cdot kip$ *anchor shear force*

$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}^{\,2} = 3.1 \cdot in^{2}$ *anchor bolt nominal area*

$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 16 \cdot ksi$ *anchor tensile stress*

$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 0.3 \cdot ksi$ *anchor shear stress*

$\phi_{anchor} := 0.75$ *resistance factor* AISC J3-1

$F_{nt} := 0.75 F_{u.anchor} = 78.8 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := 0.45 F_{u.anchor} = 47.2 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot kip$ *design sghear strength*

$CheckAnchorT := if\left(\phi R_{nt} \geq T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$CheckAnchorT = \text{"OK"}$

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check shear rupture*

$\text{CheckAnchorV} = \text{"OK"}$

$$F_{ntv} := \min\left(\begin{pmatrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{pmatrix}\right) = 78.8 \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = 185.6 \cdot \text{kip}$

design tension strength modified to include the effects of shearing stress

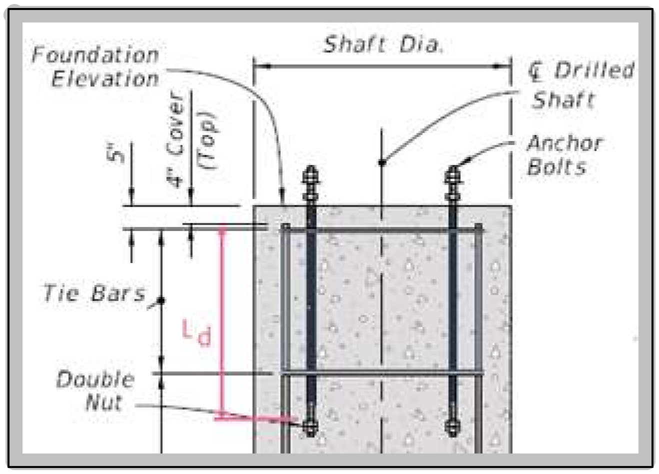
$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq 20\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq 20\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \text{"OK"}, \text{"No Good"}\right]$

$\text{CheckAnchorTV} = \text{"OK"}$ *check combined tension and shear rupture*

$\text{CheckAnchorStrength} := \text{if}\left[(\text{CheckAnchorT} = \text{"OK"}) \cdot (\text{CheckAnchorV} = \text{"OK"}) \cdot (\text{CheckAnchorTV} = \text{"OK"}), \text{"OK"}, \text{"No Good"}\right]$

$\text{CheckAnchorStrength} = \text{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = 50.3 \cdot \text{kip}$ *tension force in anchor*

$\text{Dia}_{bar.circle} = 27.9 \cdot \text{in}$ $\text{Dia}_{anchor.circle} = 24 \cdot \text{in}$

center-to-center distance

$$\text{Dist}_{bar.to.bolt} := \frac{\text{Dia}_{bar.circle} - \text{Dia}_{anchor.circle}}{2} = 1.9 \cdot \text{in}$$

$$\text{Num}_{bars.per.anchor} := \min\left(\frac{\text{Num}_{bar}}{\text{Num}_{anchor}}, 3\right) = 1.4$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := 0.9$

$$\text{Num}_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{\text{Dia}_{anchor.circle}}{\text{Dia}_{bar.circle}} = 0.8$$

$$\text{AreaRatio} := \min\left(\frac{\text{Num}_{bars.reqd.per.anchor}}{\text{Num}_{bars.per.anchor}}, 1\right) = 0.58$$

2015 AASHTO Development Length of Deformed Bars in Tension 5.11.2.1

$\text{Cover} = 3 \cdot \text{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half the center-to-center spacing of the bars or wires being developed*

$$c_b := \min\left(\begin{pmatrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{2} \\ \dfrac{\text{Spacing}_{vert.reinf}}{2} \end{pmatrix}\right) = 4\cdot in$$

$k_{tr} := 0\cdot in$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\begin{bmatrix} 1.0 \\ \max\left(\begin{pmatrix} 0.4 \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{pmatrix}\right) \end{bmatrix}\right] = 0.4$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\begin{pmatrix} 12\cdot in \\ \lambda_{rc}\cdot 2.4\cdot d_{long.bar}\cdot \dfrac{F_{y.rebar}}{\sqrt{f_c\cdot ksi}} \end{pmatrix}\right) = 32.4\cdot in$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$\text{SpacingFactor} := \max\left[\begin{pmatrix} 0.5 \\ \text{Num}_{bars.per.anchor}\cdot 0.5 - 0.5 \end{pmatrix}\right] = 0.5$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf}\cdot \text{SpacingFactor}\right)^2 + \text{Dist}_{bar.to.bolt}^{\ 2}} = 3.9\cdot in$$

$$L_{embedment.anchor} := \max\left[\begin{bmatrix} L_{d.bar}\cdot(\text{AreaRatio}) + 12\cdot in + L_{embedment.added} \\ 20\cdot d_{anchor} \end{bmatrix}\right] = 40\cdot in$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, in\right)$

$L_{embedment.anchor} = 40\cdot in$

`Minimum Anchor Bolts Embedment is 52 in`

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{\mathbf{2}} = \mathbf{12} \cdot in$$

$$r := \frac{b}{\mathbf{2}} = \mathbf{18} \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^{\mathbf{2}} + \mathbf{3.25} \cdot \left(r^{\mathbf{2}} - r_b^{\mathbf{2}}\right)} - r_b}{\mathbf{3.25}} = \mathbf{4.6} \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\begin{pmatrix} \mathbf{8} \cdot d_{anchor} \\ L_{embedment.anchor} \end{pmatrix}\right) = \mathbf{16} \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := \mathbf{13} \cdot \left(\frac{L_e}{d_{anchor}}\right)^{\mathbf{0.2}} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{\mathbf{1.5}} \cdot lbf = \mathbf{17.5} \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(\mathbf{360} \cdot deg)}{Num_{anchor}} = \mathbf{45} \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2\,\mathrm{asin}\left[\frac{(\mathbf{1.5} \cdot c_{a1})}{r}\right] = \mathbf{45.2} \cdot deg$$

$$OverlapTest := if\left(A_{bolt.sector} \le \alpha, \textbf{"Overlap of Failure Cones"}, \textbf{"No Overlap of Failure Cones"}\right) = \textbf{"Overlap of Failur}$$

$$chord := \mathbf{2} \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{\mathbf{2}}\right) = \mathbf{13.8} \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := \mathbf{4.5} \cdot c_{a1}^{\ \mathbf{2}} = \mathbf{95.9} \cdot in^{\mathbf{2}}$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot \mathbf{1.5} \cdot c_{a1} = \mathbf{95.4} \cdot in^{\mathbf{2}}$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := if\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = \mathbf{95.4} \cdot in^{\mathbf{2}}$$

$\psi_{ecV} := \mathbf{1.0}$ *eccentric load modifier* ACI D.6.2.5

$\psi_{edV} := \mathbf{1.0}$ *edge effect modifier* ACI D.6.2.6

$\psi_{cV} := \mathbf{1.4}$ *cracked section modifier* ACI D.6.2.7 *(stirrup spacing <= 4")*

$\psi_{hV} := \mathbf{1.0}$ *member thickness modifier* ACI D.6.2.8

$\phi_{breakout} := \mathbf{0.75}$ *strength reduction factor* ACI D.4.4.c.i *(shear breakout, condition A)*

$$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = \mathbf{194.7} \cdot kip$$

concrete breakout strength - shear

ACI Eqn D-22 *Shear force ⊥ to edge*

$$V_{cbg\_parallel} := \mathbf{2} \cdot V_{cbg} = \mathbf{389.5} \cdot kip$$

ACI D.6.2.1.c *Shear force ∥ to edge*

$$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = \mathbf{389.5} \cdot kip \cdot ft$$

concrete breakout strength - torsion

$$\phi_{breakout} \cdot T_{n.breakout} = \mathbf{292.1} \cdot kip \cdot ft$$

$$T_u = \mathbf{0} \cdot kip \cdot ft$$

BreakoutTest := if$\left(\phi_{breakout} \cdot T_{n.breakout} \geq T_u,\right.$ **"OK"** , **"No Good"**)

BreakoutTest = **"OK"**

OverlapDesign := if$\left(A_{bolt.sector} \leq \alpha,\right.$ **"Based on Overlap of Failure Cones"** , **"Based on No Overlap of Failure Cones"**)

OverlapDesign = **"Based on Overlap of Failure Cones"**

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = \mathbf{1.9} \cdot in$ *center-to-center distance*

$d_{anchor.nut} := \mathbf{1.85} \cdot d_{anchor} = \mathbf{3.7} \cdot in$ *use* $\mathbf{1.85} \cdot d_{anchor}$ *.to account for anchor nut*

$$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{\mathbf{2}}\right) = -\mathbf{0.5} \cdot in$$

CheckAnchorageClearance := if$\left[\left(Clearance_{bar.to.nut} \geq \mathbf{2} \cdot in\right),\right.$ **"OK"** , **"No Good, increase ped. diameter"**]

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0 .. 48 \qquad r_{ds} := \frac{b}{2}$

$x_{ds_{pt}} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{ds_{pt}} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$x_{stir.od_{pt}} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.od_{pt}} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$x_{stir.id_{pt}} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.id_{pt}} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$x_{bar_{pt}} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max(x_{stir.id}) - d_{v.bar} \qquad y_{bar_{pt}} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$x_{boltcircle_{pt}} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{boltcircle_{pt}} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltr} := \frac{d_{anchor}}{2} = 1 \cdot in$

$x_{bolt_{pt}} := r_{boltr} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \left(\max\left(x_{boltcircle}\right)\right)$

$y_{bolt_{pt}} := r_{boltr} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$pt := 0..6$

$r_{nut} := \frac{d_{anchor} \cdot 1.85}{2} = 1.9 \cdot in$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{6} + \frac{2 \cdot \pi}{6}\right] + \left(\max\left(x_{boltcircle}\right)\right)$

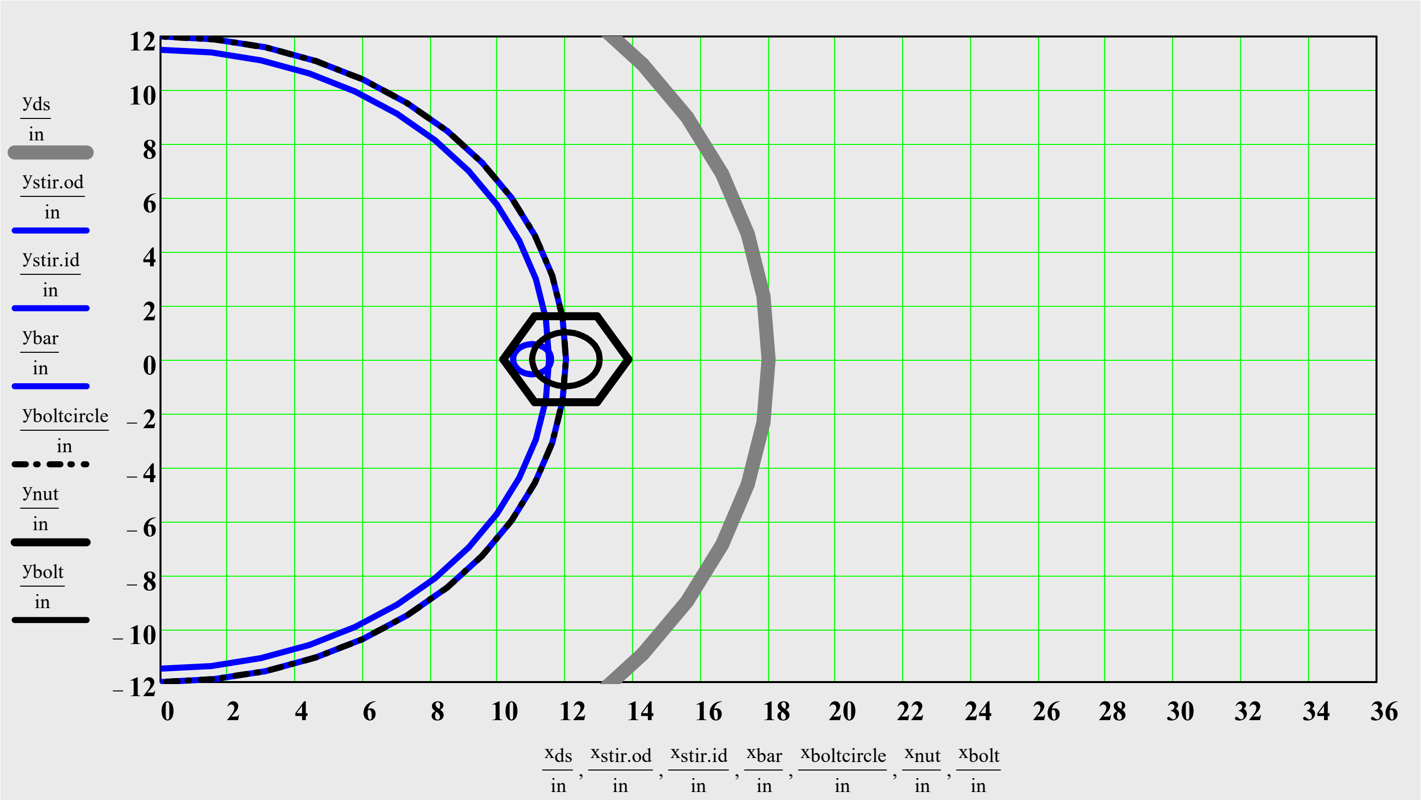
$y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{6}\right) + \frac{2 \cdot \pi}{6}\right]$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{6} + \frac{1 \cdot \pi}{6}\right] + \left(\max\left(x_{boltcircle}\right)\right)$

enable to rotate nut

$y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{6}\right) + \frac{1 \cdot \pi}{6}\right]$

$\min\left(x_{bar}\right) - \max\left(x_{nut}\right) = -3.4 \cdot in$



$$\text{Bolts} := \begin{pmatrix} \mathbf{1} & \mathbf{1.125} & \mathbf{1.25} & \mathbf{1.375} & \mathbf{1.5} & \mathbf{1.625} & \mathbf{1.75} & \mathbf{1.875} & \mathbf{2} & \mathbf{2.25} & \mathbf{2.5} & \mathbf{2.75} & \mathbf{3} \\ \mathbf{1.5} & \mathbf{1.688} & \mathbf{1.875} & \mathbf{2.063} & \mathbf{2.25} & \mathbf{2.438} & \mathbf{2.625} & \mathbf{2.938} & \mathbf{3} & \mathbf{3.375} & \mathbf{3.75} & \mathbf{4.125} & \mathbf{4.25} \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{T}\right)^{\langle \mathbf{0} \rangle^{T}} \cdot \mathbf{1.6} - \left(\text{Bolts}^{T}\right)^{\langle \mathbf{1} \rangle^{T}} = \begin{pmatrix} \mathbf{0.1} & \mathbf{0.112} & \mathbf{0.125} & \mathbf{0.137} & \mathbf{0.15} & \mathbf{0.162} & \mathbf{0.175} & \mathbf{0.062} & \mathbf{0.2} & \mathbf{0.225} & \mathbf{0.25} & \mathbf{0.275} & \mathbf{0.55} \end{pmatrix} \cdot \text{in}$$

$$\left(\text{Bolts}^{T}\right)^{\langle \mathbf{0} \rangle^{T}} - \left(\text{Bolts}^{T}\right)^{\langle \mathbf{1} \rangle^{T}} = \begin{pmatrix} -\mathbf{0.5} & -\mathbf{0.563} & -\mathbf{0.625} & -\mathbf{0.688} & -\mathbf{0.75} & -\mathbf{0.813} & -\mathbf{0.875} & -\mathbf{1.063} & -\mathbf{1} & -\mathbf{1.125} & -\mathbf{1.25} & -\mathbf{1.375} & -\mathbf{1.25} \end{pmatrix} \cdot$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

FDOT
State Structures Design Office

SUBJECT 079-241-O MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

SoilType :=
Sand
Clay

$\phi_{soil} := 32.0 \cdot deg$ *soil friction angle (sand)*

$c_{soil} := 0.0 \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

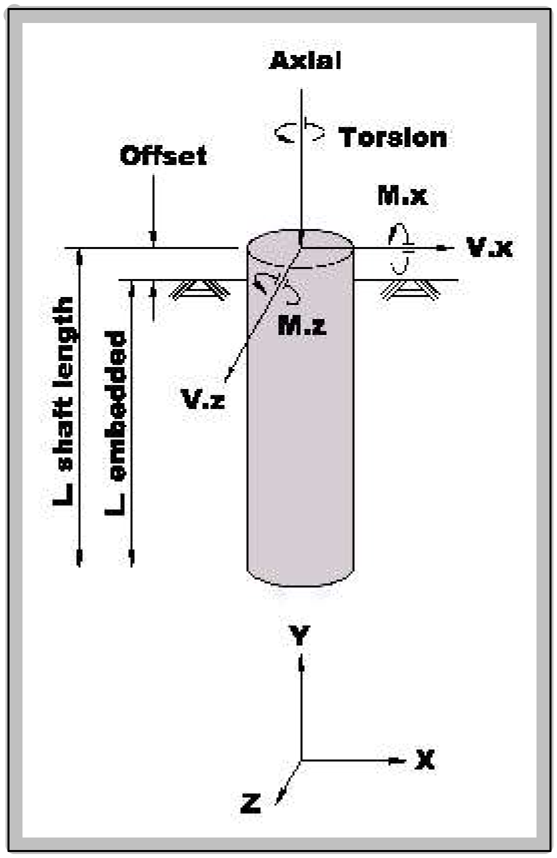
$N_{blows} := 24$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := 125 \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*

Geometry

$b := 3.0 \cdot ft$ *shaft diameter*

$Offset := 0.50 \cdot ft$ *groundline to top of foundation*



Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := 56.70 \cdot kip \cdot ft$ $V_x := 0.05 \cdot kip$ $Torsion := 43.0 \cdot kip \cdot ft$

$M_z := 29.0 \cdot kip \cdot ft$ $V_z := 3.90 \cdot kip$ $Axial := 16.50 \cdot kip$

StructureType :=
Cantilever Overhead Sign Structure
Mast Arm Signal Structure
Concrete/Steel Strain Poles
Ground Sign

$StructureType = 1$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

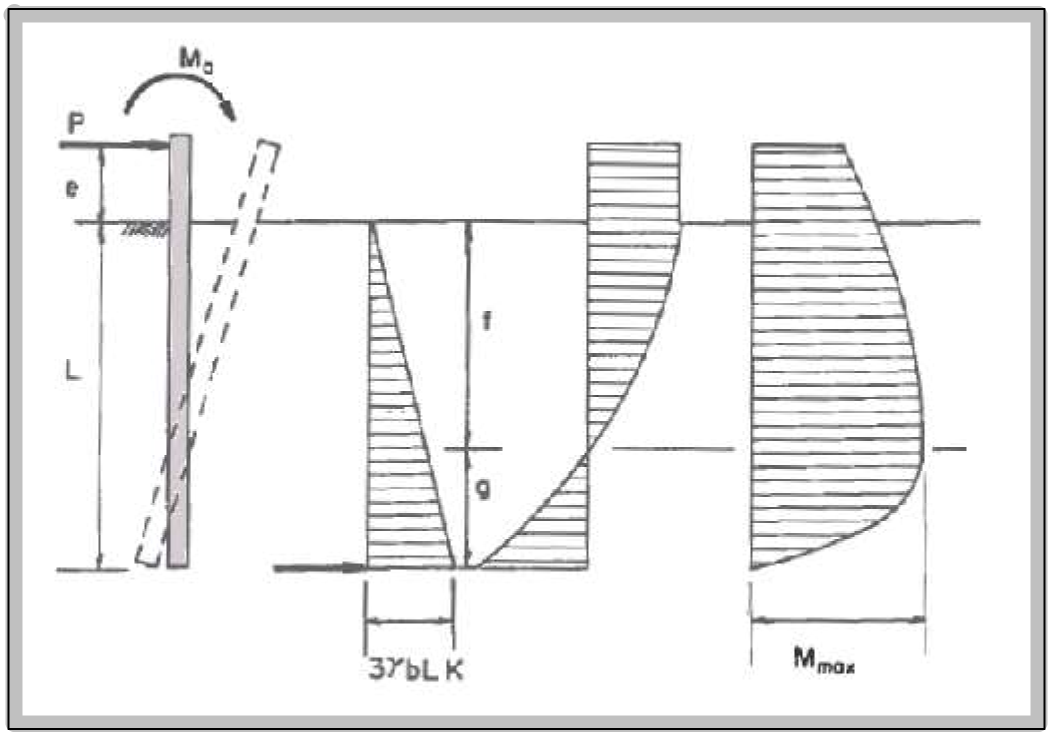
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x^{2} + M_z^{2}} = \mathbf{63.7} \cdot \mathrm{kip} \cdot \mathrm{ft}$

$P_u := \sqrt{V_x^{2} + V_z^{2}} = \mathbf{3.9} \cdot \mathrm{kip}$

$T_u := \mathrm{Torsion} = \mathbf{43} \cdot \mathrm{kip} \cdot \mathrm{ft}$

*short free-head pile in **cohesionless soil** using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(\mathbf{45} \cdot \mathrm{deg} + \frac{\phi_{soil}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{3.3}$ $\quad$ $e_{sand} := \mathrm{Offset} = \mathbf{0.5}\,\mathrm{ft}$

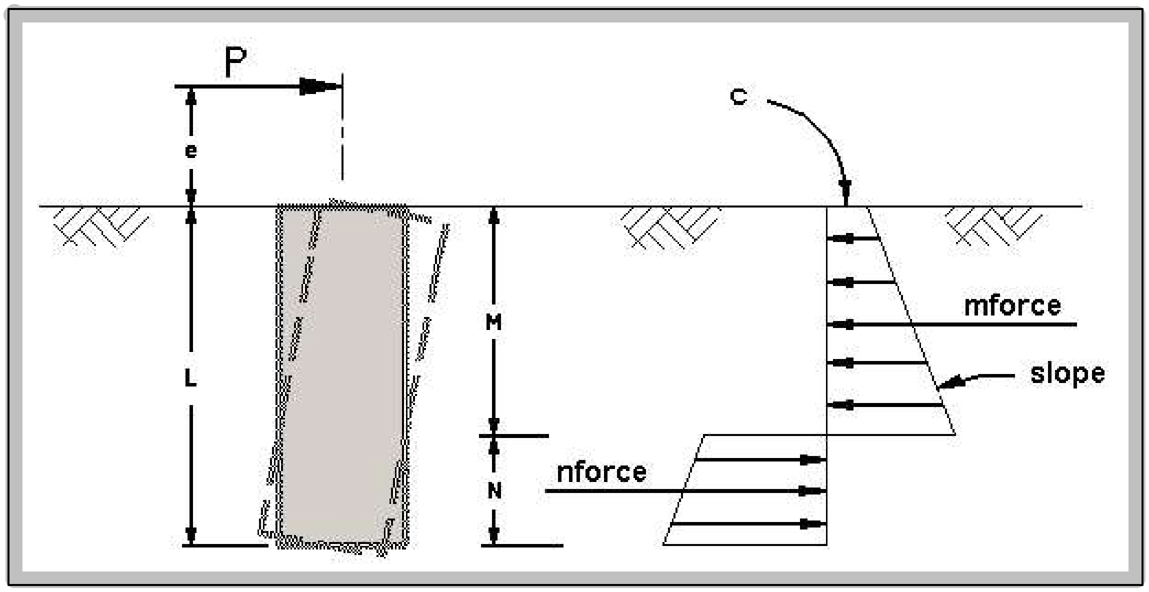
Guess value $\quad L_{otSand} := \mathbf{10} \cdot \mathrm{ft}$

Given $\quad P_u \cdot \left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot} \cdot \left[\left(\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{2}} \cdot L_{otSand}\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{3}} \cdot L_{otSand}\right)\right]$

$L_{otSand} := \mathrm{Find}\left(L_{otSand}\right) = \mathbf{8.7}\,\mathrm{ft}$

$L_{otSand} := \mathrm{ceil}\left(\frac{L_{otSand}}{\mathrm{ft}}\right) \cdot \mathrm{ft} = \mathbf{9}\,\mathrm{ft}$ $\quad$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}\left(c_{soil} = 0\cdot ksf, 0.1\cdot ksf, c_{soil}\right) = 0.1\cdot ksf$

$Slope := 8\cdot\frac{c_{soil}}{3\cdot b} = 0.1\cdot\frac{kip}{ft^3}$

$e_{clay} := \frac{M_u}{P_u} + Offset = 16.8\,ft$

$nforce(M,N) := \left[Slope\cdot(2\cdot M + N) + 2\cdot c_{soil}\right]\cdot N\cdot\frac{b}{2}$

$mforce(M) := \left(2\cdot c_{soil} + M\cdot Slope\right)\cdot M\cdot\frac{b}{2}$

$$m\_arm(M) := e_{clay} + \frac{M}{3}\cdot\frac{2\cdot(M\cdot Slope + c_{soil}) + c_{soil}}{M\cdot Slope + 2\cdot c_{soil}}$$

$$n\_arm(M,N) := e_{clay} + M + \frac{N}{3}\cdot\frac{2\cdot(N\cdot Slope + M\cdot Slope + c_{soil}) + (M\cdot Slope + c_{soil})}{Slope\cdot(2\cdot M + N) + 2\cdot c_{soil}}$$

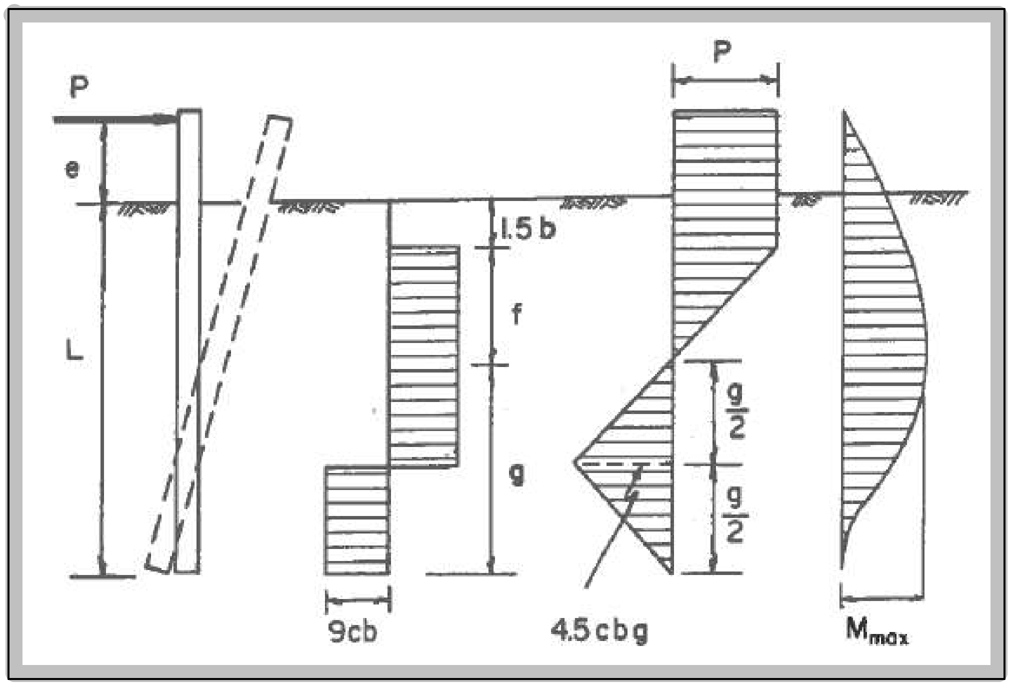
Guess value $M := 4.0\cdot ft$ $N := 4.0\cdot ft$

Given $P_u + \phi_{ot}\cdot nforce(M,N) = \phi_{ot}\cdot mforce(M)$ $mforce(M)\cdot m\_arm(M) = nforce(M,N)\cdot n\_arm(M,N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M,N)$ $L_{ot1Clay} := M + N = 7.9\,ft$

$L_{ot1Clay} := \text{ceil}\left(\frac{L_{ot1Clay}}{ft}\right)\cdot ft = 8\,ft$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$f := \frac{P_u}{\phi_{ot} \cdot 9 \cdot c_{soil} \cdot b} = 5.8\,ft$

$M_{max.clay} := P_u \cdot \left(e_{clay} + 1.5 \cdot b + 0.5 \cdot f\right) = 94.5 \cdot kip \cdot ft$

$g := \sqrt{\frac{M_{max.clay}}{2.25 \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = 23.7\,ft$

$L_{ot2Clay} := \left(1.5 \cdot b + f + g\right) = 33.9\,ft$

$L_{ot2Clay} := ceil\left(\frac{L_{ot2Clay}}{ft}\right) \cdot ft = 34\,ft$ *(round up to next foot)*

$L_{otClay} := if\left(L_{ot1Clay} < 3 \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = 8\,ft$ *(If* $L_{ot} < 3b$*, use Modified Broms method)*

$L_{reqdOT} := if\left(SoilType = \text{"Sand"}, L_{otSand}, L_{otClay}\right)$

$L_{reqdOT} = 9\,ft$ *required shaft embedment depth to resist overturning*

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = \mathbf{24}$

$$\omega_{fdot} := \text{if}\left(N_{blows} < \mathbf{5}, \mathbf{0}, \text{if}\left(N_{blows} \geq \mathbf{15}, \mathbf{1.5}, \mathbf{1.5} \cdot \frac{N_{blows}}{\mathbf{15}}\right)\right) = \mathbf{1.5}$$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\dfrac{N_{blows}}{\mathbf{15}}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = \mathbf{9}\,\text{ft}$

Given $$T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot \left(L_{torSand}\right) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{\mathbf{2}}\right) \cdot \left(\omega_{fdot}\right) \cdot \frac{b}{\mathbf{2}}\right]$$

$L_{torSand} := \text{Find}\left(L_{torSand}\right) = \mathbf{5.7}\,\text{ft}$

$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{6}\,\text{ft}$ *(round up to next foot)*

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := \mathbf{0.55}$

$f_{se} := \text{CohesionFactor} \cdot c_{soil} = \mathbf{0.1} \cdot \text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

Given $$T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot \left(L_{torClay} - \mathbf{1.5} \cdot \text{ft}\right) \cdot \frac{b}{\mathbf{2}}\right]$$

$L_{torClay} := \text{Find}\left(L_{torClay}\right) = \mathbf{56.8}\,\text{ft}$

$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{57}\,\text{ft}$ *(round up to next foot)*

$L_{reqdTor} := \text{if}\left(\text{SoilType} = \mathbf{\text{"Sand"}}, L_{torSand}, L_{torClay}\right)$

$L_{reqdTor} = \mathbf{6}\,\text{ft}$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}\left(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}\right) = \mathbf{9}\,\text{ft}$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = \mathbf{9.5}\,\text{ft}$ *shaft length*

Min Shaft embedment depth=12 ft

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2 \cdot P_u}{3 \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = 2.9 \, ft$$

$$M_{maxSand} := P_u \cdot (e_{sand} + f_{sand}) - \frac{P_u \cdot f_{sand}}{3} + M_u = 73.2 \cdot kip \cdot ft$$

short free-head pile in ***cohesive soil*** *using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0 \cdot ft$

Given $P_u = \frac{f_{mod} \cdot b}{2} \cdot (2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot Slope)$

$$f_{mod} := Find(f_{mod}) = 9.8 \, ft$$

$$M_{modBroms} := P_u \cdot (e_{clay} + f_{mod}) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^2}{2} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^3 \cdot Slope}{6} = 89.8 \cdot kip \cdot ft$$

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot (e_{clay} + 1.5 \cdot b + 0.5 \cdot f) = 94.5 \cdot kip \cdot ft$$

$$M_{maxClay} := if(L_{ot1Clay} < 3 \cdot b, M_{modBroms}, M_{Broms}) = 89.8 \cdot kip \cdot ft$$

(If $L_{ot} < 3b$, use Modified Broms method)

$$M_{max} := if(SoilType = \text{"Sand"}, M_{maxSand}, M_{maxClay}) = 73.2 \cdot kip \cdot ft$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$	*reinforcing yield strength*	
$f_c := 4.0 \cdot ksi$	*concrete strength* Spec 346-3	
$Cover := 3 \cdot in$	*cover* SDG Table 1.4.2-1	
$Num_{bar} := 11$	*number of longitudinal bars*	
$A_{long.bar} := 1.0 \cdot in^2$	*longitudinal bar area*	
$d_{long.bar} := 1.125 \cdot in$	*longitudinal bar diameter*	
$A_{v.bar} := 0.20 \cdot in^2$	*stirrup area*	SM Vol-3 13.6.2
$d_{v.bar} := 0.5 \cdot in$	*stirrup diameter*	
$s_{v1} := 3 \cdot in$	*stirrup spacing, depth = 0 ft-2 ft*	SM Vol-3 13.6.2
$s_{v2} := 3 \cdot in$	*stirrup spacing, depth = 2 ft-depth.stir*	
$s_{v3} := 6 \cdot in$	*stirrup spacing, depth > depth.stir*	
$depth_{stir} := 12.0 \cdot ft$	*stirrup depth, see s.v2 and s.v3 above*	
$b = 3\, ft$	*shaft diameter*	
$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$	*required 1% steel*	SM Vol-3 13.6.2
$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$		LRFD 5.7.4.2
$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot in^2$		
$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$	*total area of longitudinal steel*	

$CheckLongitudinalReinf := if(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"})$ $\quad CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $\quad Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if(Clearance_{vert.reinf} \geq 6in, \text{"OK"}, \text{"No Good"})$ $\quad CheckReinfClearSpacing = \text{"OK"}$ SDG 3.6.10

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$V_u := \sqrt{V_x^{2} + V_z^{2}} = \mathbf{3.9} \cdot \text{kip}$

$T_u = \mathbf{43} \cdot \text{kip} \cdot \text{ft}$

Effective shear depth

$D_r := b - \mathbf{2} \cdot \left(\text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{\mathbf{2}} \right) = \mathbf{2.3}\,\text{ft}$ $d_e := \dfrac{b}{\mathbf{2}} + \dfrac{D_r}{\pi} = \mathbf{2.2}\,\text{ft}$ *LRFD C5.8.2.9-2*

$d_v := \max\left(\mathbf{0.9} \cdot d_e, \mathbf{0.72} \cdot b\right) = \mathbf{2.2}\,\text{ft}$

Check Shear Strength

$V_c := \mathbf{0.0316} \cdot (\mathbf{2.0}) \cdot \sqrt{\dfrac{f_c}{\text{ksi}}} \cdot \left(\dfrac{b}{\text{in}}\right) \cdot \left(\dfrac{d_v}{\text{in}}\right) \cdot \text{kip} = \mathbf{117.9} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-3* *LRFD 5.8.3.4.1* *ACI 11.3.3*

$V_s := \dfrac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max\left(s_{v1}, s_{v2}, s_{v3}\right)} = \mathbf{51.8} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-4*

$\text{ShearRatio} := \dfrac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -\mathbf{2.2}$

$\text{ShearRatio} := \text{if}\left(\text{ShearRatio} \le \mathbf{0}, \mathbf{0}, \text{ShearRatio}\right) = \mathbf{0}$

Check Torsion Strength

$A_{cp} := \pi \cdot \left(\dfrac{b}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1017.9} \cdot \text{in}^{\mathbf{2}}$ $p_{cp} := \mathbf{2} \cdot \pi \cdot \left(\dfrac{b}{\mathbf{2}}\right) = \mathbf{113.1} \cdot \text{in}$ *Area and perimeter of concrete cross-section*

$d_{oh} := b - \mathbf{2} \cdot \left(\text{Cover} + \dfrac{d_{v.bar}}{\mathbf{2}}\right) = \mathbf{29.5} \cdot \text{in}$ $p_h := \pi \cdot d_{oh} = \mathbf{92.7} \cdot \text{in}$ *Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement*

$A_{oh} := \pi \left(\dfrac{d_{oh}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{683.5} \cdot \text{in}^{\mathbf{2}}$ $A_o := \mathbf{0.85} \cdot A_{oh} = \mathbf{581} \cdot \text{in}^{\mathbf{2}}$

$T_{n1} := \dfrac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD Eqn 5.8.3.6.2-1*

$T_{n2} := \dfrac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD 5.8.3.4.1*

$$T_{n3} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = \mathbf{193.7} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$\phi_v = \mathbf{0.9}$ $T_u = \mathbf{43} \cdot \mathrm{kip} \cdot \mathrm{ft}$ $L_{reqdTor} = \mathbf{6}\,\mathrm{ft}$

$$Tor2_{sand} := T_u - \mathrm{if}\left[\mathbf{2}\mathrm{ft} > Offset, \left[\pi \cdot b \cdot (\mathbf{2} \cdot \mathrm{ft} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{\mathbf{2} \cdot \mathrm{ft} - Offset}{\mathbf{2}}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot \mathrm{kip} \cdot \mathrm{ft}\right] = \mathbf{40} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor3_{sand} := T_u - \mathrm{if}\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot (depth_{stir} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{\mathbf{2}}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot \mathrm{kip} \cdot \mathrm{ft}\right] = -\mathbf{132.3} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor2_{clay} := T_u - \mathrm{if}\left[\mathbf{2}\mathrm{ft} - \mathbf{1.5}\mathrm{ft} > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (\mathbf{2.0} \cdot \mathrm{ft} - Offset - \mathbf{1.5} \cdot \mathrm{ft}) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot \mathrm{kip} \cdot \mathrm{ft}\right] = \mathbf{43} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor3_{clay} := T_u - \mathrm{if}\left[depth_{stir} - \mathbf{1.5}\mathrm{ft} > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (depth_{stir} - Offset - \mathbf{1.5} \cdot \mathrm{ft}) \cdot \frac{b}{\mathbf{2}}\right], \mathbf{0} \cdot \mathrm{kip} \cdot \mathrm{ft}\right] = \mathbf{35.2} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor2 := \mathrm{if}(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}) = \mathbf{40} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$Tor3 := \mathrm{if}(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}) = -\mathbf{132.3} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = \mathbf{0.11}$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = \mathbf{0.1}$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = -\mathbf{0.68}$$

$$TorsionRatio := \max(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}) = \mathbf{0.11}$$

$$T_{cr} := \mathbf{0.125}\sqrt{\frac{f_c}{\mathrm{ksi}}} \cdot \left(\frac{A_{cp}{}^{\mathbf{2}}}{p_{cp} \cdot \mathrm{in}^{\mathbf{3}}}\right) \cdot \mathrm{kip} \cdot \mathrm{in} = \mathbf{190.9} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

LRFD Eqn 5.8.2.1-4

$$TorsionRatio := \mathrm{if}(T_u \le \mathbf{0.25} \cdot \phi_{tor} \cdot T_{cr}, \mathbf{0}, TorsionRatio) = \mathbf{0}$$

LRFD Eqn 5.8.2.1-3

$ShearRatio = \mathbf{0}$

$$CheckShearTorsion := \mathrm{if}(ShearRatio + TorsionRatio \le \mathbf{1}, \text{"OK"}, \text{"No Good"})$$

$CheckShearTorsion = \text{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = \mathbf{0.004644} \cdot \mathrm{ksi}$$

$\mathbf{0.125} \cdot f_c = \mathbf{0.5} \cdot \mathrm{ksi}$

LRFD Eqn 5.8.2.9-1

$s_{max1} := \text{if}\left(\mathbf{0.8}\cdot d_v < \mathbf{24}\cdot in, \mathbf{0.8}d_v, \mathbf{24}\cdot in\right) = \mathbf{20.7}\cdot in$ *LRFD Eqn 5.8.2.7-1*

$s_{max2} := \text{if}\left(\mathbf{0.4}\cdot d_v < \mathbf{12}\cdot in, \mathbf{0.4}d_v, \mathbf{12}\cdot in\right) = \mathbf{10.4}\cdot in$ *LRFD Eqn 5.8.2.7-2*

$s_{max} := \text{if}\left(v_u < \mathbf{0.125}\cdot f_c, s_{max1}, s_{max2}\right) = \mathbf{20.7}\cdot in$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = \mathbf{6}\cdot in$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \mathbf{"OK"}, \mathbf{"No\ Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \mathbf{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion *LRFD Eqn 5.8.3.6.3-1*

LRFD 5.8.3.4.1

$M_u = \mathbf{63.7}\cdot kip\cdot ft$

$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5\cdot V_s > \mathbf{0}\cdot kip, \frac{V_u}{\phi_v} - 0.5\cdot V_s, \mathbf{0}\cdot kip\right) = \mathbf{0}\cdot kip$

$$\text{LongReinf}_{shr.tor} := \frac{\frac{M_u}{\phi_v\cdot d_v} + \sqrt{\left(V_{temp}\right)^{\mathbf{2}} + \left(\frac{\mathbf{0.45}\cdot p_h\cdot T_u}{\mathbf{2}\cdot A_o\cdot \phi_v}\right)^{\mathbf{2}}}}{F_{y.rebar}} = \mathbf{0.9}\cdot in^{\mathbf{2}}$$

$\text{Num}_{bar}\cdot A_{long.bar} = \mathbf{11}\cdot in^{\mathbf{2}}$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(\text{Num}_{bar}\cdot A_{long.bar} \ge \text{LongReinf}_{shr.tor}, \mathbf{"OK"}, \mathbf{"No\ Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \mathbf{"OK"}$

Anchor Bolt Strength Check

$\mathrm{Num}_{\mathrm{anchor}} := 8$ *number of anchor bolts*

$d_{\mathrm{anchor}} := 2 \cdot \mathrm{in}$ *anchor bolt nominal diameter*

$\mathrm{Dia}_{\mathrm{anchor.circle}} := 24 \cdot \mathrm{in}$ *anchor bolt circle diameter*

$F_{\mathrm{u.anchor}} := 105 \cdot \mathrm{ksi}$ *anchor bolt specified minimum tensile strength*

$$I_{\mathrm{anchor}} := \frac{\mathrm{Dia}_{\mathrm{anchor.circle}}^{2}}{8} \cdot \mathrm{Num}_{\mathrm{anchor}} = 576 \cdot \mathrm{in}^{2}$$

$$S_{\mathrm{anchor}} := \frac{I_{\mathrm{anchor}}}{\dfrac{\mathrm{Dia}_{\mathrm{anchor.circle}}}{2}} = 48 \cdot \mathrm{in}$$

$T_{\mathrm{anchor}} := \dfrac{M_u}{S_{\mathrm{anchor}}} = 15.9 \cdot \mathrm{kip}$ *anchor tension force*

$V_{\mathrm{anchor}} := \dfrac{V_u}{\mathrm{Num}_{\mathrm{anchor}}} + \dfrac{T_u}{0.5\mathrm{Dia}_{\mathrm{anchor.circle}} \cdot \mathrm{Num}_{\mathrm{anchor}}} = 5.9 \cdot \mathrm{kip}$ *anchor shear force*

$A_{\mathrm{b.anchor}} := \dfrac{1}{4} \pi \cdot d_{\mathrm{anchor}}^{2} = 3.1 \cdot \mathrm{in}^{2}$ *anchor bolt nominal area*

$f_{\mathrm{t.anchor}} := \dfrac{T_{\mathrm{anchor}}}{A_{\mathrm{b.anchor}}} = 5.1 \cdot \mathrm{ksi}$ *anchor tensile stress*

$f_{\mathrm{v.anchor}} := \dfrac{V_{\mathrm{anchor}}}{A_{\mathrm{b.anchor}}} = 1.9 \cdot \mathrm{ksi}$ *anchor shear stress*

$\phi_{\mathrm{anchor}} := 0.75$ *resistance factor* *AISC J3-1*

$F_{\mathrm{nt}} := 0.75 F_{\mathrm{u.anchor}} = 78.8 \cdot \mathrm{ksi}$ *nominal tensile stress* *AISC Table J3.2*

$F_{\mathrm{nv}} := 0.45 F_{\mathrm{u.anchor}} = 47.2 \cdot \mathrm{ksi}$ *nominal tensile stress* *AISC Table J3.2*

$\phi R_{\mathrm{nt}} := \phi_{\mathrm{anchor}} \cdot F_{\mathrm{nt}} \cdot A_{\mathrm{b.anchor}} = 185.6 \cdot \mathrm{kip}$ *design tension strength*

$\phi R_{\mathrm{nv}} := \phi_{\mathrm{anchor}} \cdot F_{\mathrm{nv}} \cdot A_{\mathrm{b.anchor}} = 111.3 \cdot \mathrm{kip}$ *design sghear strength*

$\mathrm{CheckAnchorT} := \mathrm{if}\left(\phi R_{\mathrm{nt}} \geq T_{\mathrm{anchor}}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$\mathrm{CheckAnchorT} = \text{"OK"}$

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check shear rupture*

$\text{CheckAnchorV} = \text{"OK"}$

$$F_{ntv} := \min\left(\left(\begin{matrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{matrix}\right)\right) = 78.8 \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = 185.6 \cdot \text{kip}$ *design tension strength modified to include the effects of shearing stress*

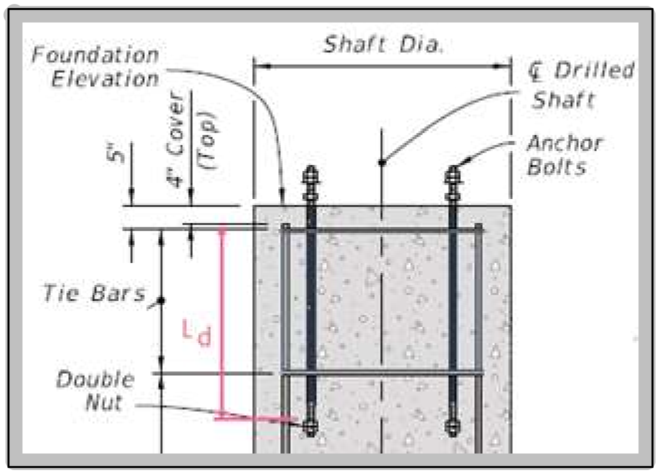
$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq 20\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq 20\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \text{"OK"}, \text{"No Good"}\right]$

$\text{CheckAnchorTV} = \text{"OK"}$ *check combined tension and shear rupture*

$\text{CheckAnchorStrength} := \text{if}\left[\left(\text{CheckAnchorT} = \text{"OK"}\right) \cdot \left(\text{CheckAnchorV} = \text{"OK"}\right) \cdot \left(\text{CheckAnchorTV} = \text{"OK"}\right), \text{"OK"}, \text{"No Good"}\right]$

$\text{CheckAnchorStrength} = \text{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = 15.9 \cdot \text{kip}$ *tension force in anchor*

$\text{Dia}_{bar.circle} = 27.9 \cdot \text{in}$ $\text{Dia}_{anchor.circle} = 24 \cdot \text{in}$

center-to-center distance

$$\text{Dist}_{bar.to.bolt} := \frac{\text{Dia}_{bar.circle} - \text{Dia}_{anchor.circle}}{2} = 1.9 \cdot \text{in}$$

$$\text{Num}_{bars.per.anchor} := \min\left(\frac{\text{Num}_{bar}}{\text{Num}_{anchor}}, 3\right) = 1.4$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := 0.9$

$$\text{Num}_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{\text{Dia}_{anchor.circle}}{\text{Dia}_{bar.circle}} = 0.25$$

$$\text{AreaRatio} := \min\left(\frac{\text{Num}_{bars.reqd.per.anchor}}{\text{Num}_{bars.per.anchor}}, 1\right) = 0.18$$

2015 AASHTO Development Length of Deformed Bars in Tension 5.11.2.1

$\text{Cover} = 3 \cdot \text{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half the center-to-center spacing of the bars or wires being developed*

$$c_b := \min\left(\begin{pmatrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{2} \\ \dfrac{\text{Spacing}_{vert.reinf}}{2} \end{pmatrix}\right) = \mathbf{4}\cdot \text{in}$$

$k_{tr} := \mathbf{0}\cdot \text{in}$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\begin{bmatrix} \mathbf{1.0} \\ \max\left(\begin{pmatrix} \mathbf{0.4} \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{pmatrix}\right) \end{bmatrix}\right] = \mathbf{0.4}$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\begin{pmatrix} \mathbf{12}\cdot \text{in} \\ \lambda_{rc}\cdot \mathbf{2.4}\cdot d_{long.bar}\cdot \dfrac{F_{y.rebar}}{\sqrt{f_c\cdot \text{ksi}}} \end{pmatrix}\right) = \mathbf{32.4}\cdot \text{in}$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$\text{SpacingFactor} := \max\left[\begin{pmatrix} \mathbf{0.5} \\ \text{Num}_{bars.per.anchor}\cdot \mathbf{0.5} - \mathbf{0.5} \end{pmatrix}\right] = \mathbf{0.5}$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf}\cdot \text{SpacingFactor}\right)^{\mathbf{2}} + \text{Dist}_{bar.to.bolt}^{\ \mathbf{2}}} = \mathbf{3.9}\cdot \text{in}$$

$$L_{embedment.anchor} := \max\left[\begin{bmatrix} L_{d.bar}\cdot(\text{AreaRatio}) + \mathbf{12}\cdot \text{in} + L_{embedment.added} \\ \mathbf{20}\cdot d_{anchor} \end{bmatrix}\right] = \mathbf{40}\cdot \text{in}$$

Note: $20 d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, \text{in}\right)$

$L_{embedment.anchor} = \mathbf{40}\cdot \text{in}$

`Minimum Anchor Bolts Embedment is 52 in`

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^{2} + 3.25 \cdot \left(r^{2} - r_b^{2}\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\left(\begin{matrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{matrix}\right)\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2 \text{asin}\left[\frac{(1.5 \cdot c_{a1})}{r}\right] = 45.2 \cdot deg$$

$$\text{OverlapTest} := \text{if}\left(A_{bolt.sector} \le \alpha, \text{"Overlap of Failure Cones"}, \text{"No Overlap of Failure Cones"}\right) = \text{"Overlap of Failur}$$

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{2} = 95.9 \cdot in^{2}$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^{2}$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \text{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^{2}$$

$\psi_{ecV} := \mathbf{1.0}$ *eccentric load modifier* *ACI D.6.2.5*

$\psi_{edV} := \mathbf{1.0}$ *edge effect modifier* *ACI D.6.2.6*

$\psi_{cV} := \mathbf{1.4}$ *cracked section modifier* *ACI D.6.2.7* *(stirrup spacing <= 4")*

$\psi_{hV} := \mathbf{1.0}$ *member thickness modifier* *ACI D.6.2.8*

$\phi_{breakout} := \mathbf{0.75}$ *strength reduction factor* *ACI D.4.4.c.i* *(shear breakout, condition A)*

$$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = \mathbf{194.7} \cdot kip$$

concrete breakout strength - shear

ACI Eqn D-22 *Shear force ⊥ to edge*

$$V_{cbg\_parallel} := \mathbf{2} \cdot V_{cbg} = \mathbf{389.5} \cdot kip$$

ACI D.6.2.1.c *Shear force ∥ to edge*

$$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = \mathbf{389.5} \cdot kip \cdot ft$$

concrete breakout strength - torsion

$$\phi_{breakout} \cdot T_{n.breakout} = \mathbf{292.1} \cdot kip \cdot ft$$

$$T_u = \mathbf{43} \cdot kip \cdot ft$$

BreakoutTest := if($\phi_{breakout} \cdot T_{n.breakout} \geq T_u$, **"OK"** , **"No Good"**)

BreakoutTest = **"OK"**

OverlapDesign := if($A_{bolt.sector} \leq \alpha$, **"Based on Overlap of Failure Cones"** , **"Based on No Overlap of Failure Cones"**)

OverlapDesign = **"Based on Overlap of Failure Cones"**

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = \mathbf{1.9} \cdot in$ *center-to-center distance*

$d_{anchor.nut} := \mathbf{1.85} \cdot d_{anchor} = \mathbf{3.7} \cdot in$ *use* $\mathbf{1.85} \cdot d_{anchor}$ *.to account for anchor nut*

$$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{\mathbf{2}}\right) = -\mathbf{0.5} \cdot in$$

CheckAnchorageClearance := if[($Clearance_{bar.to.nut} \geq \mathbf{2} \cdot in$), **"OK"** , **"No Good, increase ped. diameter"**]

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0 .. 48 \qquad r_{ds} := \frac{b}{2}$

$x_{ds_{pt}} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{ds_{pt}} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$x_{stir.od_{pt}} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.od_{pt}} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$x_{stir.id_{pt}} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{stir.id_{pt}} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$x_{bar_{pt}} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max(x_{stir.id}) - d_{v.bar} \qquad y_{bar_{pt}} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$x_{boltcircle_{pt}} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad y_{boltcircle_{pt}} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$$r_{boltr} := \frac{d_{anchor}}{2} = \mathbf{1} \cdot in$$

$$x_{bolt_{pt}} := r_{boltr} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$$

$$y_{bolt_{pt}} := r_{boltr} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$$

$pt := \mathbf{0} .. \mathbf{6}$

$$r_{nut} := \frac{d_{anchor} \cdot 1.85}{\mathbf{2}} = \mathbf{1.9} \cdot in$$

$$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$$

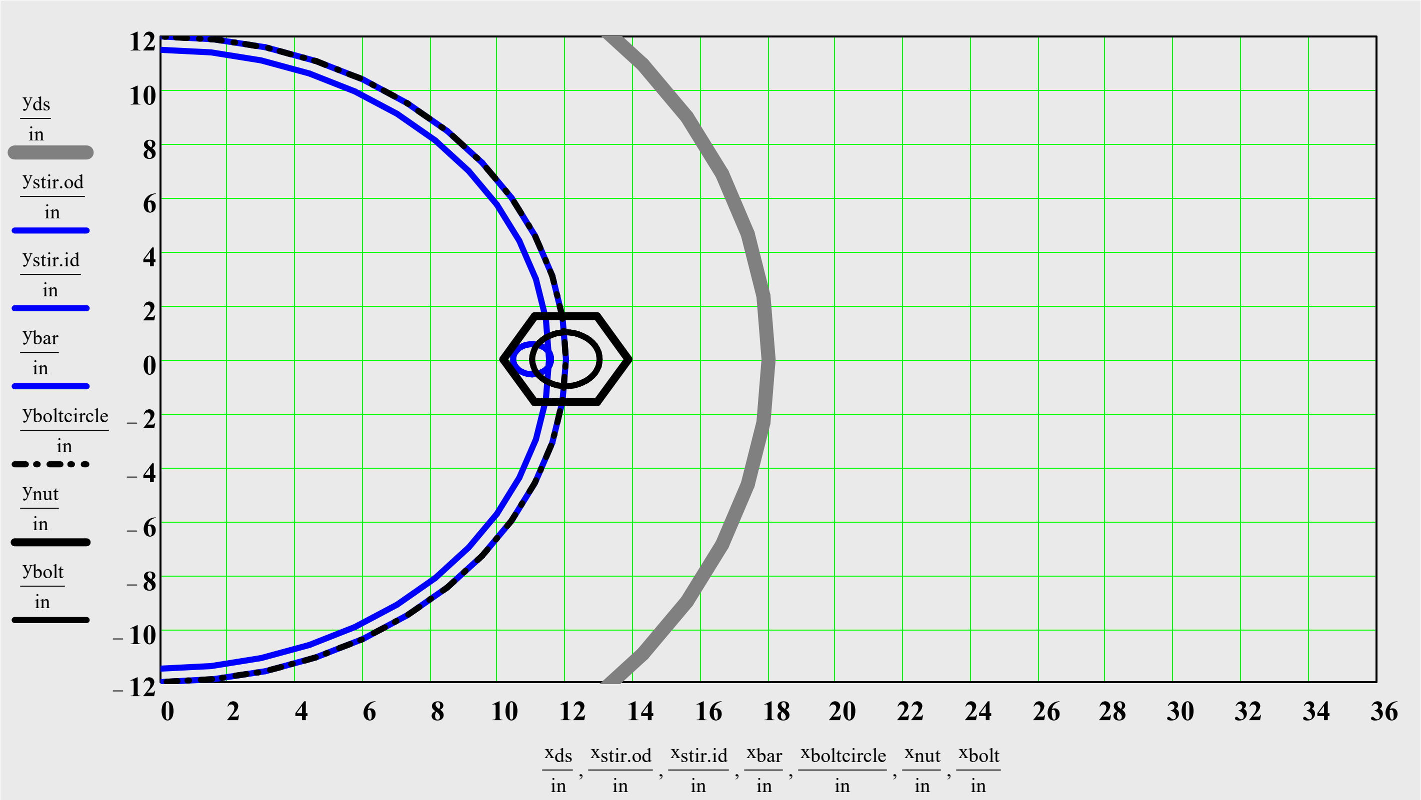
$$y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right]$$

$$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right)$$

enable to rotate nut

$$y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right]$$

$$\min\left(x_{bar}\right) - \max\left(x_{nut}\right) = -\mathbf{3.4} \cdot in$$



$$\mathrm{Bolts} := \begin{pmatrix} \mathbf{1} & \mathbf{1.125} & \mathbf{1.25} & \mathbf{1.375} & \mathbf{1.5} & \mathbf{1.625} & \mathbf{1.75} & \mathbf{1.875} & \mathbf{2} & \mathbf{2.25} & \mathbf{2.5} & \mathbf{2.75} & \mathbf{3} \\ \mathbf{1.5} & \mathbf{1.688} & \mathbf{1.875} & \mathbf{2.063} & \mathbf{2.25} & \mathbf{2.438} & \mathbf{2.625} & \mathbf{2.938} & \mathbf{3} & \mathbf{3.375} & \mathbf{3.75} & \mathbf{4.125} & \mathbf{4.25} \end{pmatrix} \cdot \mathrm{in}$$

$$\left(\mathrm{Bolts}^{T}\right)^{\langle \mathbf{0} \rangle^{T}} \cdot \mathbf{1.6} - \left(\mathrm{Bolts}^{T}\right)^{\langle \mathbf{1} \rangle^{T}} = \begin{pmatrix} \mathbf{0.1} & \mathbf{0.112} & \mathbf{0.125} & \mathbf{0.137} & \mathbf{0.15} & \mathbf{0.162} & \mathbf{0.175} & \mathbf{0.062} & \mathbf{0.2} & \mathbf{0.225} & \mathbf{0.25} & \mathbf{0.275} & \mathbf{0.55} \end{pmatrix} \cdot \mathrm{in}$$

$$\left(\mathrm{Bolts}^{T}\right)^{\langle \mathbf{0} \rangle^{T}} - \left(\mathrm{Bolts}^{T}\right)^{\langle \mathbf{1} \rangle^{T}} = \begin{pmatrix} -\mathbf{0.5} & -\mathbf{0.563} & -\mathbf{0.625} & -\mathbf{0.688} & -\mathbf{0.75} & -\mathbf{0.813} & -\mathbf{0.875} & -\mathbf{1.063} & -\mathbf{1} & -\mathbf{1.125} & -\mathbf{1.25} & -\mathbf{1.375} & -\mathbf{1.25} \end{pmatrix} \cdot$$

Drilled Shaft Foundation for Sign, Signal, and Lighting Support Structures v1.1

State Structures Design Office

SUBJECT 079-241-P MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

SoilType :=
- **Sand**
- Clay

$\phi_{soil} := 32.0 \cdot deg$ *soil friction angle (sand)*

$c_{soil} := 0.0 \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

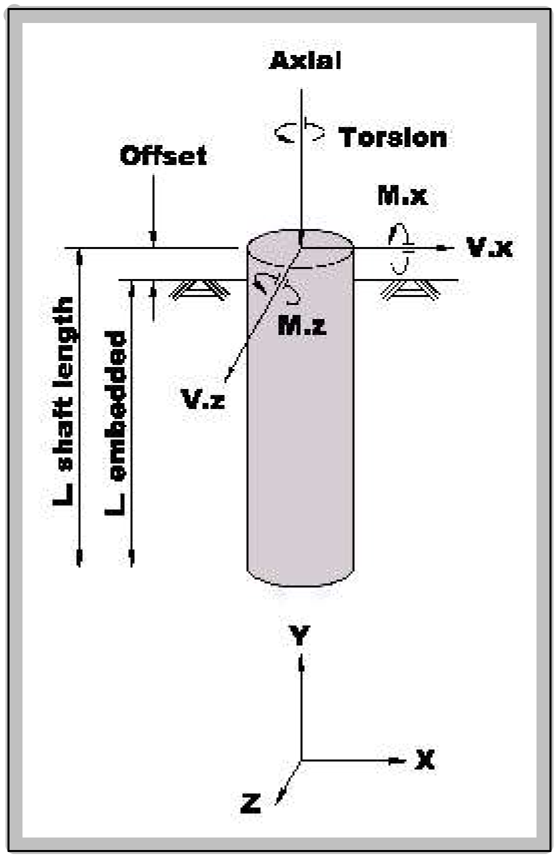
$N_{blows} := 24$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := 125 \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*

Geometry

$b := 3.0 \cdot ft$ *shaft diameter*

$Offset := 0.50 \cdot ft$ *groundline to top of foundation*



Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_X := 31.60 \cdot kip \cdot ft$ $V_X := 0.05 \cdot kip$ $Torsion := 56.30 \cdot kip \cdot ft$

$M_Z := 87.60 \cdot kip \cdot ft$ $V_Z := 4.80 \cdot kip$ $Axial := 17.60 \cdot kip$

StructureType :=
- Cantilever Overhead Sign Structure
- **Mast Arm Signal Structure**
- Concrete/Steel Strain Poles
- Ground Sign

$StructureType = 1$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

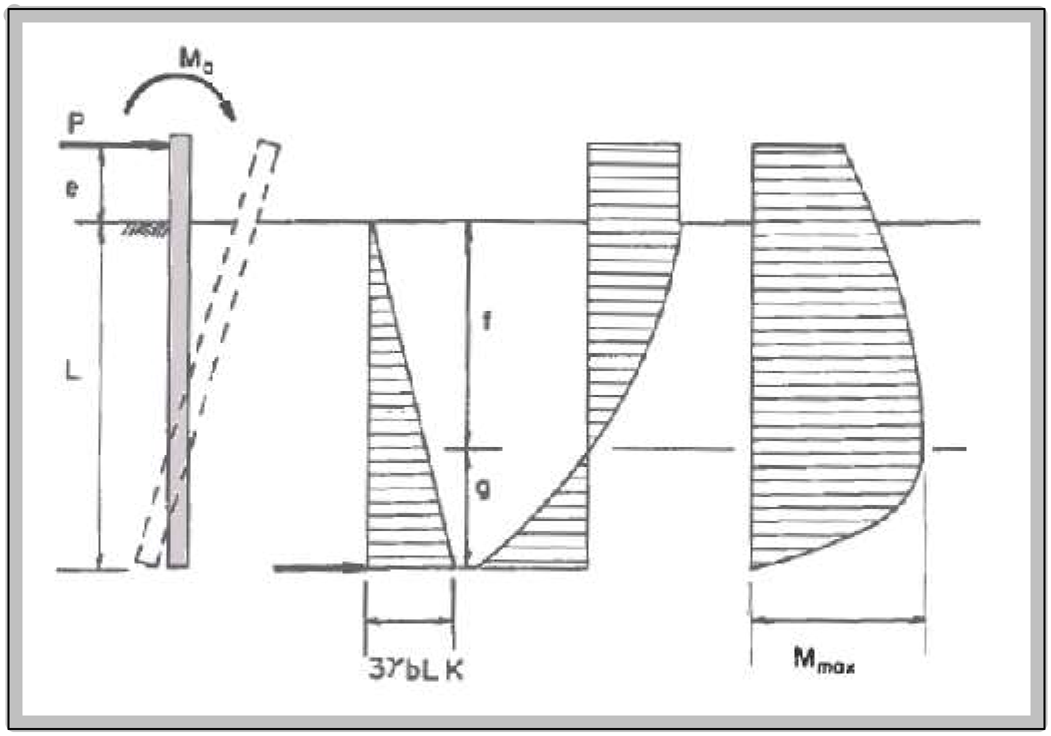
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x^2 + M_z^2} = \mathbf{93.1} \cdot kip \cdot ft$

$P_u := \sqrt{V_x^2 + V_z^2} = \mathbf{4.8} \cdot kip$

$T_u := Torsion = \mathbf{56.3} \cdot kip \cdot ft$

*short free-head pile in **cohesionless soil** using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(\mathbf{45} \cdot deg + \frac{\phi_{soil}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{3.3}$ $\qquad$ $e_{sand} := Offset = \mathbf{0.5} ft$

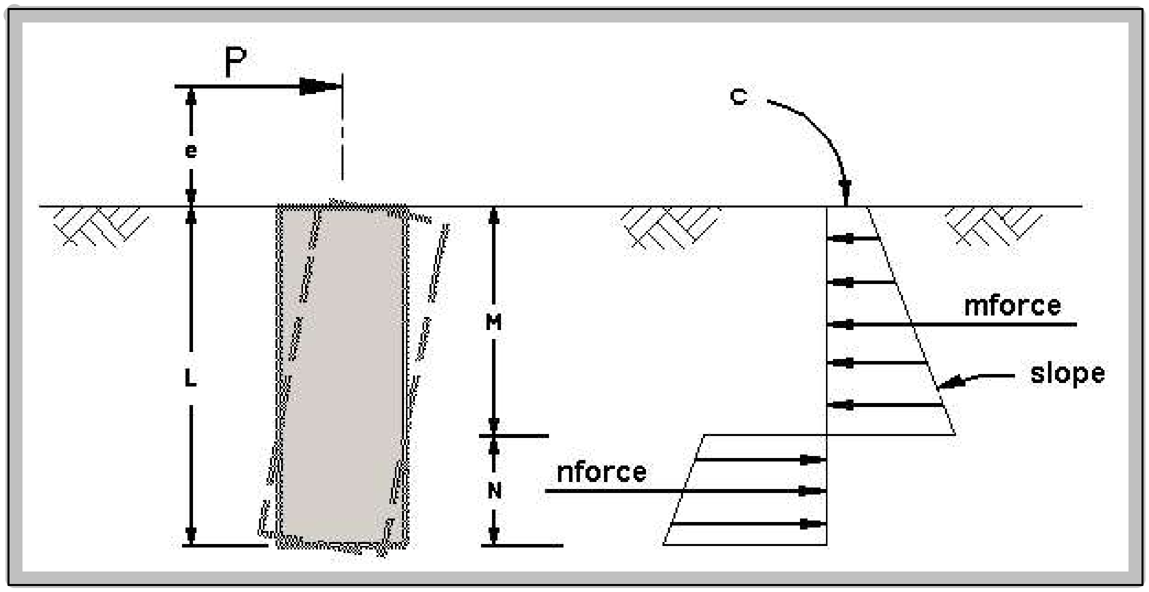
Guess value $\qquad L_{otSand} := \mathbf{10} \cdot ft$

Given $\qquad P_u \cdot \left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot} \cdot \left[\left(\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{2}} \cdot L_{otSand}\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{3}} \cdot L_{otSand}\right)\right]$

$L_{otSand} := Find\left(L_{otSand}\right) = \mathbf{9.8} ft$

$L_{otSand} := ceil\left(\frac{L_{otSand}}{ft}\right) \cdot ft = \mathbf{10} ft$ $\qquad$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}\left(c_{soil} = 0 \cdot \text{ksf}, 0.1 \cdot \text{ksf}, c_{soil}\right) = 0.1 \cdot \text{ksf}$

$\text{Slope} := 8 \cdot \frac{c_{soil}}{3 \cdot b} = 0.1 \cdot \frac{\text{kip}}{\text{ft}^3}$

$e_{clay} := \frac{M_u}{P_u} + \text{Offset} = 19.9\,\text{ft}$

$\text{nforce}(M,N) := \left[\text{Slope} \cdot (2 \cdot M + N) + 2 \cdot c_{soil}\right] \cdot N \cdot \frac{b}{2}$

$\text{mforce}(M) := \left(2 \cdot c_{soil} + M \cdot \text{Slope}\right) \cdot M \cdot \frac{b}{2}$

$\text{m\_arm}(M) := e_{clay} + \frac{M}{3} \cdot \frac{2 \cdot (M \cdot \text{Slope} + c_{soil}) + c_{soil}}{M \cdot \text{Slope} + 2 \cdot c_{soil}}$

$\text{n\_arm}(M,N) := e_{clay} + M + \frac{N}{3} \cdot \frac{2 \cdot (N \cdot \text{Slope} + M \cdot \text{Slope} + c_{soil}) + (M \cdot \text{Slope} + c_{soil})}{\text{Slope} \cdot (2 \cdot M + N) + 2 \cdot c_{soil}}$

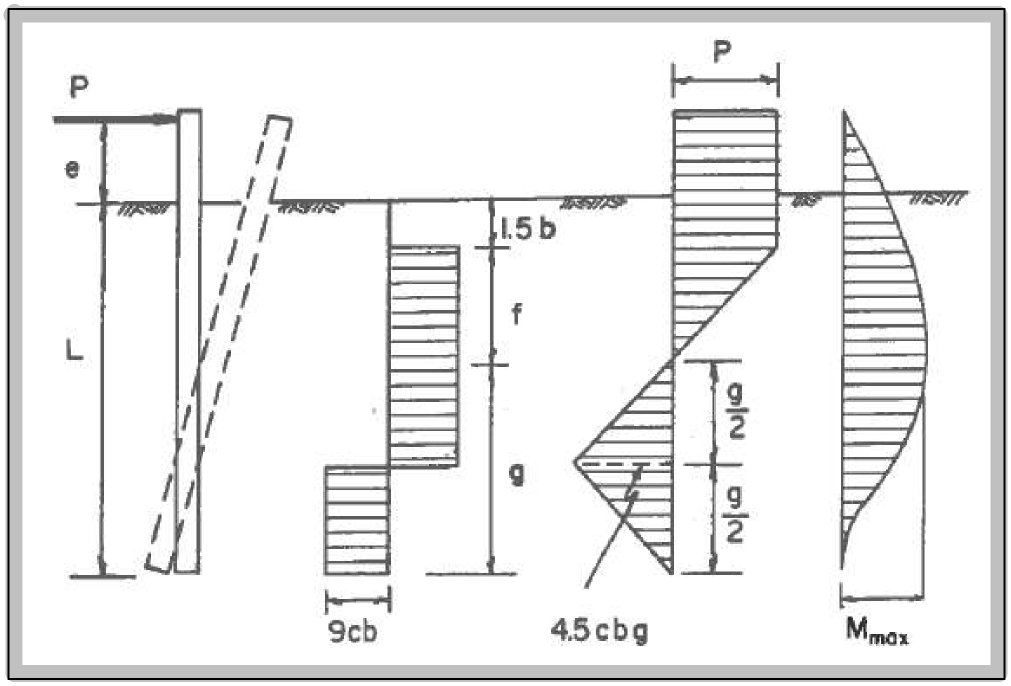
Guess value $M := 4.0 \cdot \text{ft}$ $N := 4.0 \cdot \text{ft}$

Given $P_u + \phi_{ot} \cdot \text{nforce}(M,N) = \phi_{ot} \cdot \text{mforce}(M)$ $\text{mforce}(M) \cdot \text{m\_arm}(M) = \text{nforce}(M,N) \cdot \text{n\_arm}(M,N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M,N)$ $L_{ot1Clay} := M + N = 9.4\,\text{ft}$

$L_{ot1Clay} := \text{ceil}\left(\frac{L_{ot1Clay}}{\text{ft}}\right) \cdot \text{ft} = 10\,\text{ft}$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$f := \frac{P_u}{\phi_{ot} \cdot \mathbf{9} \cdot c_{soil} \cdot b} = \mathbf{7.1}\,\text{ft}$

$M_{max.clay} := P_u \cdot \left(e_{clay} + \mathbf{1.5} \cdot b + \mathbf{0.5} \cdot f\right) = \mathbf{134.2} \cdot \text{kip} \cdot \text{ft}$

$g := \sqrt{\frac{M_{max.clay}}{\mathbf{2.25} \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = \mathbf{28.2}\,\text{ft}$

$L_{ot2Clay} := \left(\mathbf{1.5} \cdot b + f + g\right) = \mathbf{39.8}\,\text{ft}$

$L_{ot2Clay} := \text{ceil}\left(\frac{L_{ot2Clay}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{40}\,\text{ft}$ *(round up to next foot)*

$L_{otClay} := \text{if}\left(L_{ot1Clay} < \mathbf{3} \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = \mathbf{40}\,\text{ft}$ *(If L_{ot} < 3b, use Modified Broms method)*

$L_{reqdOT} := \text{if}\left(\text{SoilType} = \textbf{"Sand"}, L_{otSand}, L_{otClay}\right)$

$L_{reqdOT} = \mathbf{10}\,\text{ft}$ *required shaft embedment depth to resist overturning*

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = 24$

$\omega_{fdot} := \text{if}\left(N_{blows} < 5, 0, \text{if}\left(N_{blows} \geq 15, 1.5, 1.5 \cdot \frac{N_{blows}}{15}\right)\right) = 1.5$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\frac{N_{blows}}{15}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = 10\,ft$

Given $T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot (L_{torSand}) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right]$

$L_{torSand} := \text{Find}(L_{torSand}) = 6.5\,ft$

$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{ft}\right) \cdot ft = 7\,ft$ *(round up to next foot)*

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := 0.55$

$f_{se} := \text{CohesionFactor} \cdot c_{soil} = 0.1 \cdot ksf$

Guess value $L_{torClay} := L_{reqdOT}$

Given $T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot (L_{torClay} - 1.5 \cdot ft) \cdot \frac{b}{2}\right]$

$L_{torClay} := \text{Find}(L_{torClay}) = 73.9\,ft$

$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{ft}\right) \cdot ft = 74\,ft$ *(round up to next foot)*

$L_{reqdTor} := \text{if}(\text{SoilType} = \text{"Sand"}, L_{torSand}, L_{torClay})$

$L_{reqdTor} = 7\,ft$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}) = 10\,ft$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = 10.5\,ft$ *shaft length*

Min Shaft embedment depth=12 ft

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{2 \cdot P_u}{3 \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = 3.2\,ft$$

$$M_{maxSand} := P_u \cdot (e_{sand} + f_{sand}) - \frac{P_u \cdot f_{sand}}{3} + M_u = 105.9 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := 4.0 \cdot ft$

Given $P_u = \frac{f_{mod} \cdot b}{2} \cdot (2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot Slope)$

$f_{mod} := Find(f_{mod}) = 10.9\,ft$

$$M_{modBroms} := P_u \cdot (e_{clay} + f_{mod}) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^{2}}{2} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^{3} \cdot Slope}{6} = 129 \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot (e_{clay} + 1.5 \cdot b + 0.5 \cdot f) = 134.2 \cdot kip \cdot ft$$

$M_{maxClay} := if(L_{ot1Clay} < 3 \cdot b, M_{modBroms}, M_{Broms}) = 134.2 \cdot kip \cdot ft$ *(If $L_{ot} < 3b$, use Modified Broms method)*

$M_{max} := if(SoilType = \text{"Sand"}, M_{maxSand}, M_{maxClay}) = 105.9 \cdot kip \cdot ft$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$ *reinforcing yield strength*

$f_c := 4.0 \cdot ksi$ *concrete strength* *Spec 346-3*

$Cover := 3 \cdot in$ *cover* *SDG Table 1.4.2-1*

$Num_{bar} := 11$ *number of longitudinal bars*

$A_{long.bar} := 1.0 \cdot in^2$ *longitudinal bar area*

$d_{long.bar} := 1.125 \cdot in$ *longitudinal bar diameter*

$A_{v.bar} := 0.20 \cdot in^2$ *stirrup area* *SM Vol-3 13.6.2*

$d_{v.bar} := 0.5 \cdot in$ *stirrup diameter*

$s_{v1} := 3 \cdot in$ *stirrup spacing, depth = 0 ft-2 ft* *SM Vol-3 13.6.2*

$s_{v2} := 3 \cdot in$ *stirrup spacing, depth = 2 ft-depth.stir*

$s_{v3} := 6 \cdot in$ *stirrup spacing, depth > depth.stir*

$depth_{stir} := 12.0 \cdot ft$ *stirrup depth, see s.v2 and s.v3 above*

$b = 3\,ft$ *shaft diameter*

$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$ *required 1% steel* *SM Vol-3 13.6.2*

$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$ *LRFD 5.7.4.2*

$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot in^2$

$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$ *total area of longitudinal steel*

$CheckLongitudinalReinf := if(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"})$ $CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if(Clearance_{vert.reinf} \geq 6in, \text{"OK"}, \text{"No Good"})$ $CheckReinfClearSpacing = \text{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$$V_u := \sqrt{V_x^{\mathbf{2}} + V_z^{\mathbf{2}}} = \mathbf{4.8} \cdot \mathrm{kip}$$

$$T_u = \mathbf{56.3} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

Effective shear depth

$$D_r := b - \mathbf{2} \cdot \left(\mathrm{Cover} + d_{v.bar} + \frac{d_{long.bar}}{\mathbf{2}} \right) = \mathbf{2.3}\,\mathrm{ft} \qquad d_e := \frac{b}{\mathbf{2}} + \frac{D_r}{\pi} = \mathbf{2.2}\,\mathrm{ft}$$

LRFD C5.8.2.9-2

$$d_v := \max\left(\mathbf{0.9} \cdot d_e, \mathbf{0.72} \cdot b\right) = \mathbf{2.2}\,\mathrm{ft}$$

Check Shear Strength

$$V_c := \mathbf{0.0316} \cdot (\mathbf{2.0}) \cdot \sqrt{\frac{f_c}{\mathrm{ksi}}} \cdot \left(\frac{b}{\mathrm{in}}\right) \cdot \left(\frac{d_v}{\mathrm{in}}\right) \cdot \mathrm{kip} = \mathbf{117.9} \cdot \mathrm{kip}$$

LRFD Eqn 5.8.3.3-3 *LRFD 5.8.3.4.1* *ACI 11.3.3*

$$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max\left(s_{v1}, s_{v2}, s_{v3}\right)} = \mathbf{51.8} \cdot \mathrm{kip}$$

LRFD Eqn 5.8.3.3-4

$$\mathrm{ShearRatio} := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -\mathbf{2.2}$$

$$\mathrm{ShearRatio} := \mathrm{if}\left(\mathrm{ShearRatio} \le \mathbf{0}, \mathbf{0}, \mathrm{ShearRatio}\right) = \mathbf{0}$$

Check Torsion Strength

$$A_{cp} := \pi \cdot \left(\frac{b}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1017.9} \cdot \mathrm{in}^{\mathbf{2}} \qquad p_{cp} := \mathbf{2} \cdot \pi \cdot \left(\frac{b}{\mathbf{2}}\right) = \mathbf{113.1} \cdot \mathrm{in}$$

Area and perimeter of concrete cross-section

$$d_{oh} := b - \mathbf{2} \cdot \left(\mathrm{Cover} + \frac{d_{v.bar}}{\mathbf{2}} \right) = \mathbf{29.5} \cdot \mathrm{in} \qquad p_h := \pi \cdot d_{oh} = \mathbf{92.7} \cdot \mathrm{in}$$

Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement

$$A_{oh} := \pi \left(\frac{d_{oh}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{683.5} \cdot \mathrm{in}^{\mathbf{2}} \qquad A_o := \mathbf{0.85} \cdot A_{oh} = \mathbf{581} \cdot \mathrm{in}^{\mathbf{2}}$$

$$T_{n1} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = \mathbf{387.3} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

LRFD Eqn 5.8.3.6.2-1

$$T_{n2} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = \mathbf{387.3} \cdot \mathrm{kip} \cdot \mathrm{ft}$$

LRFD 5.8.3.4.1

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = 193.7 \cdot kip \cdot ft$$

$\phi_v = 0.9$ $T_u = 56.3 \cdot kip \cdot ft$ $L_{reqdTor} = 7\,ft$

$$Tor2_{sand} := T_u - if\left[2ft > Offset, \left[\pi \cdot b \cdot (2 \cdot ft - Offset) \cdot \gamma_{soil} \cdot \left(\frac{2 \cdot ft - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 53.3 \cdot kip \cdot ft$$

$$Tor3_{sand} := T_u - if\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot (depth_{stir} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -119 \cdot kip \cdot ft$$

$$Tor2_{clay} := T_u - if\left[2ft - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (2.0 \cdot ft - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 56.3 \cdot kip \cdot ft$$

$$Tor3_{clay} := T_u - if\left[depth_{stir} - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (depth_{stir} - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 48.5 \cdot kip \cdot ft$$

$$Tor2 := if(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}) = 53.3 \cdot kip \cdot ft$$

$$Tor3 := if(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}) = -119 \cdot kip \cdot ft$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = 0.15$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = 0.14$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = -0.61$$

$$TorsionRatio := max(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}) = 0.15$$

$$T_{cr} := 0.125 \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{A_{cp}^{\;2}}{\frac{p_{cp} \cdot in}{3}}\right) \cdot kip \cdot in = 190.9 \cdot kip \cdot ft$$ *LRFD Eqn 5.8.2.1-4*

$$TorsionRatio := if(T_u \le 0.25 \cdot \phi_{tor} \cdot T_{cr}, 0, TorsionRatio) = 0.1$$ *LRFD Eqn 5.8.2.1-3*

$ShearRatio = 0$

$$CheckShearTorsion := if(ShearRatio + TorsionRatio \le 1, \text{"OK"}, \text{"No Good"})$$

$CheckShearTorsion = \text{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = 0.005716 \cdot ksi$$ $0.125 \cdot f_c = 0.5 \cdot ksi$ *LRFD Eqn 5.8.2.9-1*

$s_{max1} := \mathrm{if}\left(\mathbf{0.8} \cdot d_v < \mathbf{24} \cdot in, \mathbf{0.8} d_v, \mathbf{24} \cdot in\right) = \mathbf{20.7} \cdot in$ *LRFD Eqn 5.8.2.7-1*

$s_{max2} := \mathrm{if}\left(\mathbf{0.4} \cdot d_v < \mathbf{12} \cdot in, \mathbf{0.4} d_v, \mathbf{12} \cdot in\right) = \mathbf{10.4} \cdot in$ *LRFD Eqn 5.8.2.7-2*

$s_{max} := \mathrm{if}\left(v_u < \mathbf{0.125} \cdot f_c, s_{max1}, s_{max2}\right) = \mathbf{20.7} \cdot in$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = \mathbf{6} \cdot in$

$\mathrm{CheckMaxSpacingTransvReinf} := \mathrm{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \textbf{"OK"}, \textbf{"No Good"}\right)$

CheckMaxSpacingTransvReinf = **"OK"**

Check Longitudinal Reinforcement for Combined Shear and Torsion *LRFD Eqn 5.8.3.6.3-1*

LRFD 5.8.3.4.1

$M_u = \mathbf{93.1} \cdot kip \cdot ft$

$$V_{temp} := \mathrm{if}\left(\frac{V_u}{\phi_v} - 0.5 \cdot V_s > \mathbf{0} \cdot kip, \frac{V_u}{\phi_v} - 0.5 \cdot V_s, \mathbf{0} \cdot kip\right) = \mathbf{0} \cdot kip$$

$$\mathrm{LongReinf}_{shr.tor} := \frac{\frac{M_u}{\phi_v \cdot d_v} + \sqrt{\left(V_{temp}\right)^{\mathbf{2}} + \left(\frac{\mathbf{0.45} \cdot p_h \cdot T_u}{\mathbf{2} \cdot A_o \cdot \phi_v}\right)^{\mathbf{2}}}}{F_{y.rebar}} = \mathbf{1.2} \cdot in^{\mathbf{2}}$$

$\mathrm{Num}_{bar} \cdot A_{long.bar} = \mathbf{11} \cdot in^{\mathbf{2}}$

$\mathrm{CheckLongReinf}_{shr.tor} := \mathrm{if}\left(\mathrm{Num}_{bar} \cdot A_{long.bar} \ge \mathrm{LongReinf}_{shr.tor}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$\mathrm{CheckLongReinf}_{shr.tor}$ = **"OK"**

Anchor Bolt Strength Check

$\mathrm{Num}_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot in$ *anchor bolt nominal diameter*

$\mathrm{Dia}_{anchor.circle} := 24 \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{\mathrm{Dia}_{anchor.circle}^{\;2}}{8} \cdot \mathrm{Num}_{anchor} = 576 \cdot in^{2}$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{\mathrm{Dia}_{anchor.circle}}{2}} = 48 \cdot in$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 23.3 \cdot kip$$

anchor tension force

$$V_{anchor} := \frac{V_u}{\mathrm{Num}_{anchor}} + \frac{T_u}{0.5\mathrm{Dia}_{anchor.circle} \cdot \mathrm{Num}_{anchor}} = 7.6 \cdot kip$$

anchor shear force

$$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}^{\;2} = 3.1 \cdot in^{2}$$

anchor bolt nominal area

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 7.4 \cdot ksi$$

anchor tensile stress

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 2.4 \cdot ksi$$

anchor shear stress

$\phi_{anchor} := 0.75$ *resistance factor* AISC J3-1

$F_{nt} := 0.75 F_{u.anchor} = 78.8 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := 0.45 F_{u.anchor} = 47.2 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot kip$ *design sghear strength*

$\mathrm{CheckAnchorT} := \mathrm{if}\left(\phi R_{nt} \geq T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$\mathrm{CheckAnchorT} = \text{"OK"}$

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check shear rupture*

$\text{CheckAnchorV} = \text{"OK"}$

$$F_{ntv} := \min\left(\left(\begin{matrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{matrix}\right)\right) = 78.8 \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = 185.6 \cdot \text{kip}$

design tension strength modified to include the effects of shearing stress

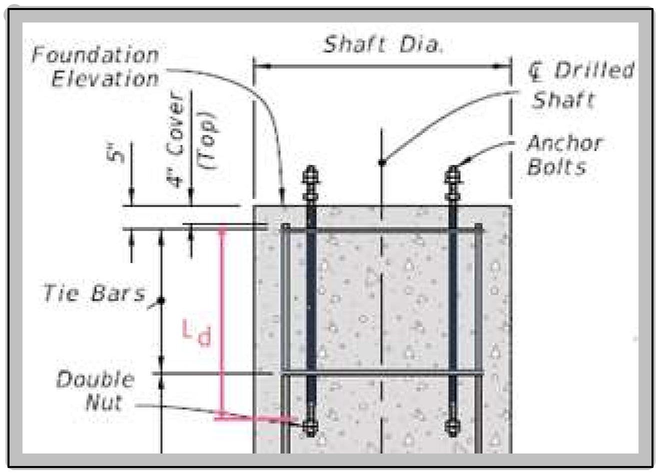
$$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq 20\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq 20\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \text{"OK"}, \text{"No Good"}\right]$$

$\text{CheckAnchorTV} = \text{"OK"}$ *check combined tension and shear rupture*

$$\text{CheckAnchorStrength} := \text{if}\left[(\text{CheckAnchorT} = \text{"OK"}) \cdot (\text{CheckAnchorV} = \text{"OK"}) \cdot (\text{CheckAnchorTV} = \text{"OK"}), \text{"OK"}, \text{"No Good"}\right]$$

$\text{CheckAnchorStrength} = \text{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = 23.3 \cdot \text{kip}$ *tension force in anchor*

$\text{Dia}_{bar.circle} = 27.9 \cdot \text{in}$ $\text{Dia}_{anchor.circle} = 24 \cdot \text{in}$

center-to-center distance

$$\text{Dist}_{bar.to.bolt} := \frac{\text{Dia}_{bar.circle} - \text{Dia}_{anchor.circle}}{2} = 1.9 \cdot \text{in}$$

$$\text{Num}_{bars.per.anchor} := \min\left(\frac{\text{Num}_{bar}}{\text{Num}_{anchor}}, 3\right) = 1.4$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := 0.9$

$$\text{Num}_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{\text{Dia}_{anchor.circle}}{\text{Dia}_{bar.circle}} = 0.37$$

$$\text{AreaRatio} := \min\left(\frac{\text{Num}_{bars.reqd.per.anchor}}{\text{Num}_{bars.per.anchor}}, 1\right) = 0.27$$

2015 AASHTO Development Length of Deformed Bars in Tension 5.11.2.1

$\text{Cover} = 3 \cdot \text{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half the center-to-center spacing of the bars or wires being developed*

$$c_b := \min\left(\left(\begin{matrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{2} \\ \dfrac{\text{Spacing}_{vert.reinf}}{2} \end{matrix}\right)\right) = 4 \cdot in$$

$k_{tr} := 0 \cdot in$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\left[\begin{matrix} 1.0 \\ \max\left(\left(\begin{matrix} 0.4 \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{matrix}\right)\right) \end{matrix}\right]\right] = 0.4$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\left(\begin{matrix} 12 \cdot in \\ \lambda_{rc} \cdot 2.4 \cdot d_{long.bar} \cdot \dfrac{F_{y.rebar}}{\sqrt{f_c \cdot ksi}} \end{matrix}\right)\right) = 32.4 \cdot in$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$\text{SpacingFactor} := \max\left[\left(\begin{matrix} 0.5 \\ \text{Num}_{bars.per.anchor} \cdot 0.5 - 0.5 \end{matrix}\right)\right] = 0.5$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf} \cdot \text{SpacingFactor}\right)^2 + \text{Dist}_{bar.to.bolt}^{\;2}} = 3.9 \cdot in$$

$$L_{embedment.anchor} := \max\left[\left[\begin{matrix} L_{d.bar} \cdot (\text{AreaRatio}) + 12 \cdot in + L_{embedment.added} \\ 20 \cdot d_{anchor} \end{matrix}\right]\right] = 40 \cdot in$$

Note: $20 d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, in\right)$

$L_{embedment.anchor} = 40 \cdot in$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^{\,2} + 3.25 \cdot \left(r^2 - r_b^{\,2}\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\left(\begin{array}{c} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{array}\right)\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2\,asin\left[\frac{(1.5 \cdot c_{a1})}{r}\right] = 45.2 \cdot deg$$

OverlapTest := if$\left(A_{bolt.sector} \le \alpha\right.$, **"Overlap of Failure Cones"** , **"No Overlap of Failure Cones"**$\left.\right)$ = **"Overlap of Failur**

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{\,2} = 95.9 \cdot in^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \mathrm{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$$

$\psi_{ecV} := 1.0$	*eccentric load modifier*	*ACI D.6.2.5*	
$\psi_{edV} := 1.0$	*edge effect modifier*	*ACI D.6.2.6*	
$\psi_{cV} := 1.4$	*cracked section modifier*	*ACI D.6.2.7*	*(stirrup spacing <= 4")*
$\psi_{hV} := 1.0$	*member thickness modifier*	*ACI D.6.2.8*	
$\phi_{breakout} := 0.75$	*strength reduction factor*	*ACI D.4.4.c.i*	*(shear breakout, condition A)*

$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = \mathbf{194.7} \cdot kip$ — *concrete breakout strength - shear*

ACI Eqn D-22 — *Shear force ⊥ to edge*

$V_{cbg\_parallel} := 2 \cdot V_{cbg} = \mathbf{389.5} \cdot kip$ — *ACI D.6.2.1.c* — *Shear force ∥ to edge*

$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = \mathbf{389.5} \cdot kip \cdot ft$ — *concrete breakout strength - torsion*

$\phi_{breakout} \cdot T_{n.breakout} = \mathbf{292.1} \cdot kip \cdot ft$

$T_u = \mathbf{56.3} \cdot kip \cdot ft$

BreakoutTest := if$\left(\phi_{breakout} \cdot T_{n.breakout} \geq T_u\right.$, **"OK"** , **"No Good"**)

BreakoutTest = **"OK"**

OverlapDesign := if$\left(A_{bolt.sector} \leq \alpha\right.$, **"Based on Overlap of Failure Cones"** , **"Based on No Overlap of Failure Cones"**)

OverlapDesign = **"Based on Overlap of Failure Cones"**

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = \mathbf{1.9} \cdot in$ — *center-to-center distance*

$d_{anchor.nut} := \mathbf{1.85} \cdot d_{anchor} = \mathbf{3.7} \cdot in$ — *use* $\mathbf{1.85} \cdot d_{anchor}$ *.to account for anchor nut*

$$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{\mathbf{2}}\right) = -\mathbf{0.5} \cdot in$$

CheckAnchorageClearance := if[($Clearance_{bar.to.nut} \geq \mathbf{2} \cdot in$), **"OK"** , **"No Good, increase ped. diameter"**]

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := \mathbf{2} \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -\mathbf{1.3} \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := \mathbf{0} .. \mathbf{48}$ $\quad r_{ds} := \frac{b}{\mathbf{2}}$

$xds_{pt} := r_{ds} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$ $\quad yds_{pt} := r_{ds} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$r_{v.od} := \frac{b}{\mathbf{2}} - \mathbf{6} \cdot in$ $\quad r_{v.id} := \frac{b}{\mathbf{2}} - \mathbf{6} \cdot in - d_{v.bar}$

$xstir.od_{pt} := r_{v.od} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$ $\quad ystir.od_{pt} := r_{v.od} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$xstir.id_{pt} := r_{v.id} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$ $\quad ystir.id_{pt} := r_{v.id} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$r_{bar} := \frac{d_{long.bar}}{\mathbf{2}} = \mathbf{0.6} \cdot in$

$xbar_{pt} := r_{bar} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] + \max(xstir.id) - d_{v.bar}$ $\quad ybar_{pt} := r_{bar} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{\mathbf{2}} = \mathbf{12} \cdot in$

$xboltcircle_{pt} := r_{boltcircle} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$ $\quad yboltcircle_{pt} := r_{boltcircle} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$r_{boltr} := \frac{d_{anchor}}{2} = \mathbf{1} \cdot in$

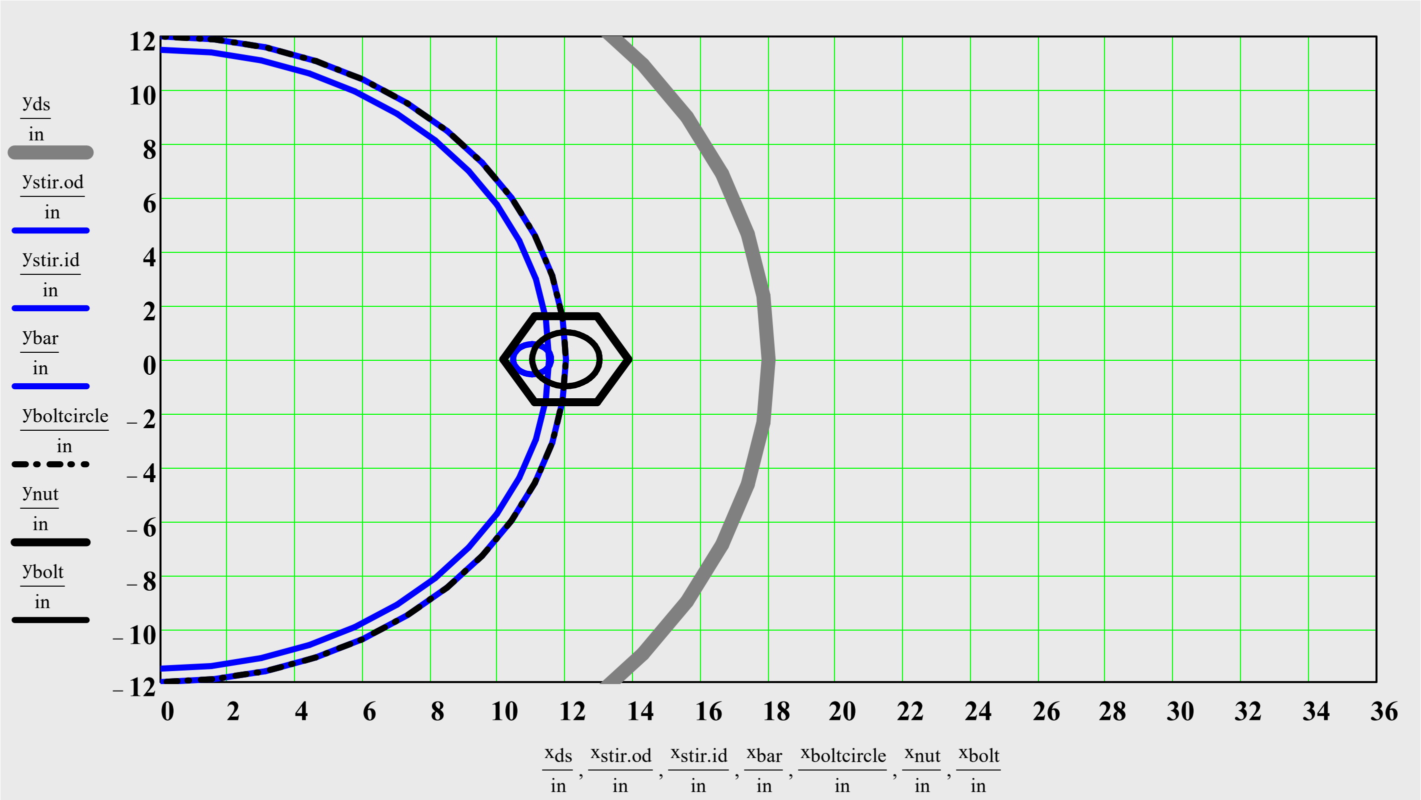
$x_{bolt_{pt}} := r_{boltr} \cdot \cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{48}} + \frac{\mathbf{2}\cdot\pi}{\mathbf{48}}\right] + (\max(x_{boltcircle}))$ $y_{bolt_{pt}} := r_{boltr}\cdot\sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2}\cdot\pi}{\mathbf{48}}\right]$

$pt := \mathbf{0}..\mathbf{6}$ $r_{nut} := \frac{d_{anchor}\cdot 1.85}{\mathbf{2}} = \mathbf{1.9}\cdot in$

$x_{nut_{pt}} := r_{nut}\cdot\cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{6}} + \frac{\mathbf{2}\cdot\pi}{\mathbf{6}}\right] + (\max(x_{boltcircle}))$ $y_{nut_{pt}} := r_{nut}\cdot\sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{2}\cdot\pi}{\mathbf{6}}\right]$

$x_{nut_{pt}} := r_{nut}\cdot\cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{6}} + \frac{\mathbf{1}\cdot\pi}{\mathbf{6}}\right] + (\max(x_{boltcircle}))$ *enable to rotate nut* $y_{nut_{pt}} := r_{nut}\cdot\sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{1}\cdot\pi}{\mathbf{6}}\right]$

$\min(x_{bar}) - \max(x_{nut}) = -\mathbf{3.4}\cdot in$



$$\mathrm{Bolts} := \begin{pmatrix} \mathbf{1} & \mathbf{1.125} & \mathbf{1.25} & \mathbf{1.375} & \mathbf{1.5} & \mathbf{1.625} & \mathbf{1.75} & \mathbf{1.875} & \mathbf{2} & \mathbf{2.25} & \mathbf{2.5} & \mathbf{2.75} & \mathbf{3} \\ \mathbf{1.5} & \mathbf{1.688} & \mathbf{1.875} & \mathbf{2.063} & \mathbf{2.25} & \mathbf{2.438} & \mathbf{2.625} & \mathbf{2.938} & \mathbf{3} & \mathbf{3.375} & \mathbf{3.75} & \mathbf{4.125} & \mathbf{4.25} \end{pmatrix} \cdot \mathrm{in}$$

$$\left(\mathrm{Bolts}^{T}\right)^{\langle \mathbf{0} \rangle T} \cdot \mathbf{1.6} - \left(\mathrm{Bolts}^{T}\right)^{\langle \mathbf{1} \rangle T} = \begin{pmatrix} \mathbf{0.1} & \mathbf{0.112} & \mathbf{0.125} & \mathbf{0.137} & \mathbf{0.15} & \mathbf{0.162} & \mathbf{0.175} & \mathbf{0.062} & \mathbf{0.2} & \mathbf{0.225} & \mathbf{0.25} & \mathbf{0.275} & \mathbf{0.55} \end{pmatrix} \cdot \mathrm{in}$$

$$\left(\mathrm{Bolts}^{T}\right)^{\langle \mathbf{0} \rangle T} - \left(\mathrm{Bolts}^{T}\right)^{\langle \mathbf{1} \rangle T} = \begin{pmatrix} -\mathbf{0.5} & -\mathbf{0.563} & -\mathbf{0.625} & -\mathbf{0.688} & -\mathbf{0.75} & -\mathbf{0.813} & -\mathbf{0.875} & -\mathbf{1.063} & -\mathbf{1} & -\mathbf{1.125} & -\mathbf{1.25} & -\mathbf{1.375} & -\mathbf{1.25} \end{pmatrix} \cdot$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

FDOT
State Structures Design Office

SUBJECT 079-24-Q MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

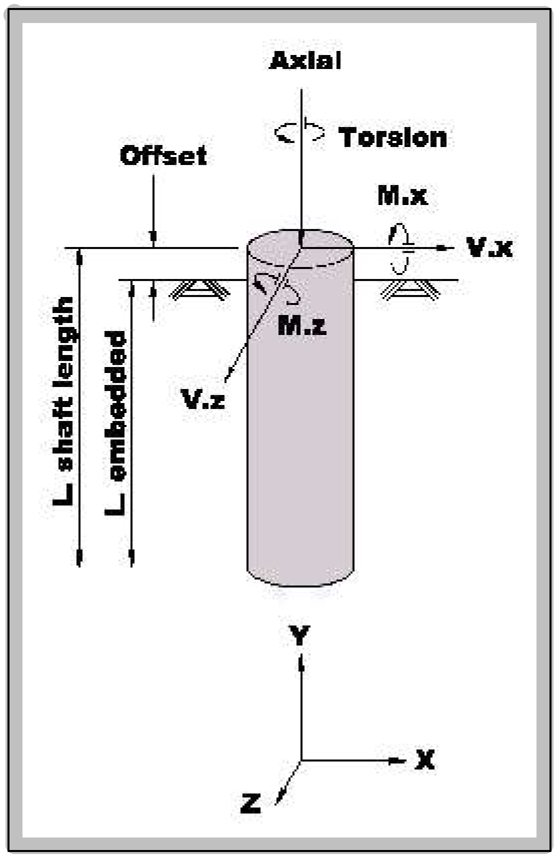
SoilType :=
- Sand
- Clay

$\phi_{soil} := 0 \cdot deg$ *soil friction angle (sand)*

$c_{soil} := 1.5 \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

$N_{blows} := 14$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := 70 \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*



Geometry

$b := 3.0 \cdot ft$ *shaft diameter*

$Offset := 0.50 \cdot ft$ *groundline to top of foundation*

Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := 120.20 \cdot kip \cdot ft$ $V_x := 0.05 \cdot kip$ $Torsion := 177.0 \cdot kip \cdot ft$

$M_z := 107.20 \cdot kip \cdot ft$ $V_z := 7.80 \cdot kip$ $Axial := 29.7 \cdot kip$

StructureType :=
- Cantilever Overhead Sign Structure
- Mast Arm Signal Structure
- Concrete/Steel Strain Poles
- Ground Sign

$StructureType = 1$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

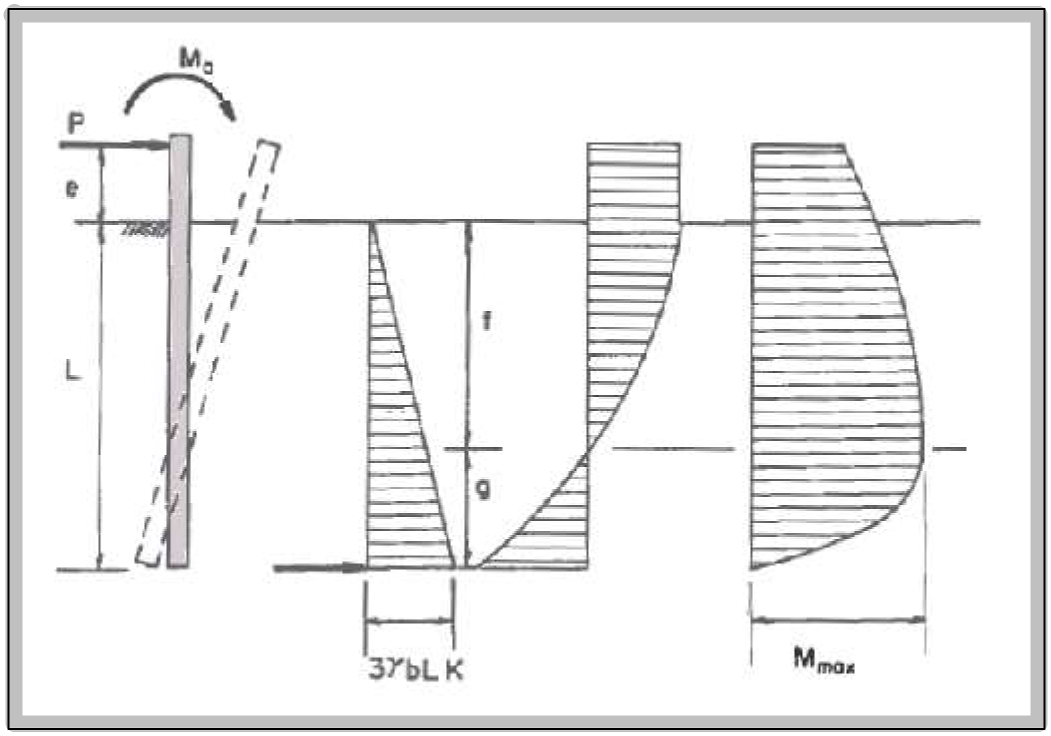
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x^{2} + M_z^{2}} = \mathbf{161.1} \cdot kip \cdot ft$

$P_u := \sqrt{V_x^{2} + V_z^{2}} = \mathbf{7.8} \cdot kip$

$T_u :=$ Torsion $= \mathbf{177} \cdot kip \cdot ft$

*short free-head pile in **cohesionless soil** using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(\mathbf{45} \cdot deg + \frac{\phi_{soil}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1}$ $\qquad e_{sand} :=$ Offset $= \mathbf{0.5}\, ft$

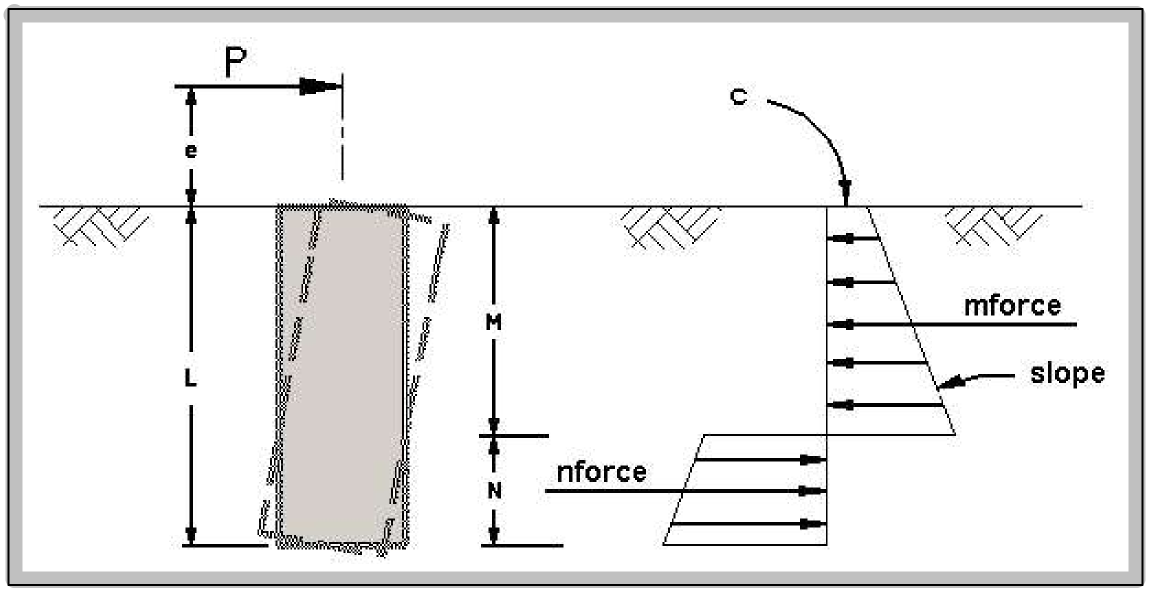
Guess value $\qquad L_{otSand} := \mathbf{10} \cdot ft$

Given $\qquad P_u \cdot (e_{sand} + L_{otSand}) + M_u = \phi_{ot} \cdot \left[(\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p) \cdot \left(\frac{\mathbf{1}}{\mathbf{2}} \cdot L_{otSand}\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{3}} \cdot L_{otSand}\right) \right]$

$L_{otSand} := \mathrm{Find}(L_{otSand}) = \mathbf{23.7}\, ft$

$L_{otSand} := \mathrm{ceil}\left(\frac{L_{otSand}}{ft}\right) \cdot ft = \mathbf{24}\, ft$ $\qquad$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}\left(c_{soil} = 0 \cdot ksf, 0.1 \cdot ksf, c_{soil}\right) = 1.5 \cdot ksf$

$\text{Slope} := 8 \cdot \dfrac{c_{soil}}{3 \cdot b} = 1.3 \cdot \dfrac{kip}{ft^3}$

$e_{clay} := \dfrac{M_u}{P_u} + \text{Offset} = 21.1 \, ft$

$\text{nforce}(M,N) := \left[\text{Slope} \cdot (2 \cdot M + N) + 2 \cdot c_{soil}\right] \cdot N \cdot \dfrac{b}{2}$

$\text{mforce}(M) := \left(2 \cdot c_{soil} + M \cdot \text{Slope}\right) \cdot M \cdot \dfrac{b}{2}$

$\text{m\_arm}(M) := e_{clay} + \dfrac{M}{3} \cdot \dfrac{2 \cdot (M \cdot \text{Slope} + c_{soil}) + c_{soil}}{M \cdot \text{Slope} + 2 \cdot c_{soil}}$

$\text{n\_arm}(M,N) := e_{clay} + M + \dfrac{N}{3} \cdot \dfrac{2 \cdot (N \cdot \text{Slope} + M \cdot \text{Slope} + c_{soil}) + (M \cdot \text{Slope} + c_{soil})}{\text{Slope} \cdot (2 \cdot M + N) + 2 \cdot c_{soil}}$

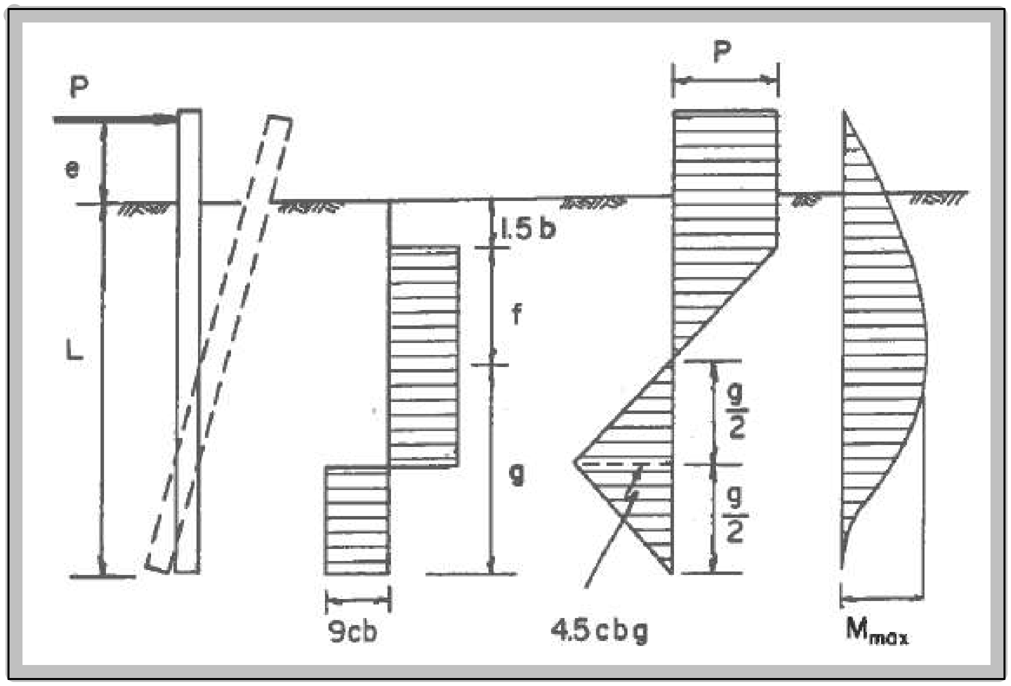
Guess value $M := 4.0 \cdot ft$ $N := 4.0 \cdot ft$

Given $P_u + \phi_{ot} \cdot \text{nforce}(M,N) = \phi_{ot} \cdot \text{mforce}(M)$ $\text{mforce}(M) \cdot \text{m\_arm}(M) = \text{nforce}(M,N) \cdot \text{n\_arm}(M,N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := \text{Find}(M,N)$ $L_{ot1Clay} := M + N = 4.8 \, ft$

$L_{ot1Clay} := \text{ceil}\left(\dfrac{L_{ot1Clay}}{ft}\right) \cdot ft = 5 \, ft$ *(round up to next foot)*

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$$f := \frac{P_u}{\phi_{ot} \cdot \mathbf{9} \cdot c_{soil} \cdot b} = \mathbf{0.8}\ ft$$

$$M_{max.clay} := P_u \cdot \left(e_{clay} + \mathbf{1.5} \cdot b + \mathbf{0.5} \cdot f\right) = \mathbf{203.1} \cdot kip \cdot ft$$

$$g := \sqrt{\frac{M_{max.clay}}{\mathbf{2.25} \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = \mathbf{9}\ ft$$

$$L_{ot2Clay} := \left(\mathbf{1.5} \cdot b + f + g\right) = \mathbf{14.2}\ ft$$

$$L_{ot2Clay} := \text{ceil}\left(\frac{L_{ot2Clay}}{ft}\right) \cdot ft = \mathbf{15}\ ft$$

(round up to next foot)

$$L_{otClay} := \text{if}\left(L_{ot1Clay} < \mathbf{3} \cdot b, L_{ot1Clay}, L_{ot2Clay}\right) = \mathbf{5}\ ft$$

(If $L_{ot} < 3b$, use Modified Broms method)

$$L_{reqdOT} := \text{if}\left(SoilType = \mathbf{"Sand"}, L_{otSand}, L_{otClay}\right)$$

$$L_{reqdOT} = \mathbf{5}\ ft$$

required shaft embedment depth to resist overturning

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = \mathbf{14}$

$$\omega_{fdot} := \text{if}\left(N_{blows} < \mathbf{5}, \mathbf{0}, \text{if}\left(N_{blows} \geq \mathbf{15}, \mathbf{1.5}, \mathbf{1.5} \cdot \frac{N_{blows}}{\mathbf{15}}\right)\right) = \mathbf{1.4}$$

load transfer ratio, If 5<N<15, ω_{fdot} is reduced by a factor of $\dfrac{N_{blows}}{\mathbf{15}}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = \mathbf{5}\,\text{ft}$

$$\text{Given} \qquad T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot (L_{torSand}) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{\mathbf{2}}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{\mathbf{2}}\right]$$

$L_{torSand} := \text{Find}(L_{torSand}) = \mathbf{16}\,\text{ft}$

$L_{torSand} := \text{ceil}\left(\dfrac{L_{torSand}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{16}\,\text{ft}$ *(round up to next foot)*

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := \mathbf{0.55}$

$f_{se} := \text{CohesionFactor} \cdot c_{soil} = \mathbf{0.8} \cdot \text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

$$\text{Given} \qquad T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot \left(L_{torClay} - \mathbf{1.5} \cdot \text{ft}\right) \cdot \frac{b}{\mathbf{2}}\right]$$

$L_{torClay} := \text{Find}(L_{torClay}) = \mathbf{16.7}\,\text{ft}$

$L_{torClay} := \text{ceil}\left(\dfrac{L_{torClay}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{17}\,\text{ft}$ *(round up to next foot)*

$L_{reqdTor} := \text{if}\left(\text{SoilType} = \textbf{"Sand"}, L_{torSand}, L_{torClay}\right)$

$L_{reqdTor} = \mathbf{17}\,\text{ft}$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}\left(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}\right) = \mathbf{17}\,\text{ft}$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = \mathbf{17.5}\,\text{ft}$ *shaft length*

Min Shaft embedment depth=20 ft

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{\mathbf{2}\cdot P_u}{\mathbf{3}\cdot \gamma_{soil}\cdot b\cdot K_p\cdot \phi_{ot}}} = \mathbf{10}\,ft$$

$$M_{maxSand} := P_u\cdot\left(e_{sand} + f_{sand}\right) - \frac{P_u\cdot f_{sand}}{\mathbf{3}} + M_u = \mathbf{216.7}\cdot kip\cdot ft$$

short free-head pile in ***cohesive soil*** *using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := \mathbf{4.0}\cdot ft$

Given $P_u = \frac{f_{mod}\cdot b}{\mathbf{2}}\cdot\left(2\phi_{ot}\cdot c_{soil} + \phi_{ot}\cdot f_{mod}\cdot Slope\right)$

$f_{mod} := Find\left(f_{mod}\right) = \mathbf{3}\,ft$

$$M_{modBroms} := P_u\cdot\left(e_{clay} + f_{mod}\right) - \frac{\phi_{ot}\cdot c_{soil}\cdot b\cdot f_{mod}^{\mathbf{2}}}{\mathbf{2}} - \frac{\phi_{ot}\cdot b\cdot f_{mod}^{\mathbf{3}}\cdot Slope}{\mathbf{6}} = \mathbf{178.8}\cdot kip\cdot ft$$

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*

$$M_{Broms} := P_u\cdot\left(e_{clay} + \mathbf{1.5}\cdot b + \mathbf{0.5}\cdot f\right) = \mathbf{203.1}\cdot kip\cdot ft$$

$M_{maxClay} := if\left(L_{ot1Clay} < \mathbf{3}\cdot b, M_{modBroms}, M_{Broms}\right) = \mathbf{178.8}\cdot kip\cdot ft$ *(If* $L_{ot} < 3b$*, use Modified Broms method)*

$$M_{max} := if\left(SoilType = \mathbf{"Sand"}, M_{maxSand}, M_{maxClay}\right) = \mathbf{178.8}\cdot kip\cdot ft$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$	*reinforcing yield strength*	
$f_c := 4.0 \cdot ksi$	*concrete strength* Spec 346-3	
$Cover := 3 \cdot in$	*cover* SDG Table 1.4.2-1	
$Num_{bar} := 11$	*number of longitudinal bars*	
$A_{long.bar} := 1.0 \cdot in^2$	*longitudinal bar area*	
$d_{long.bar} := 1.125 \cdot in$	*longitudinal bar diameter*	
$A_{v.bar} := 0.20 \cdot in^2$	*stirrup area*	SM Vol-3 13.6.2
$d_{v.bar} := 0.5 \cdot in$	*stirrup diameter*	
$s_{v1} := 3 \cdot in$	*stirrup spacing, depth = 0 ft-2 ft*	SM Vol-3 13.6.2
$s_{v2} := 3 \cdot in$	*stirrup spacing, depth = 2 ft-depth.stir*	
$s_{v3} := 6 \cdot in$	*stirrup spacing, depth > depth.stir*	
$depth_{stir} := 19.0 \cdot ft$	*stirrup depth, see s.v2 and s.v3 above*	
$b = 3\,ft$	*shaft diameter*	
$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$	*required 1% steel*	SM Vol-3 13.6.2
$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$		LRFD 5.7.4.2
$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot in^2$		
$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$	*total area of longitudinal steel*	

$CheckLongitudinalReinf := if(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"})$ $CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if(Clearance_{vert.reinf} \geq 6in, \text{"OK"}, \text{"No Good"})$ $CheckReinfClearSpacing = \text{"OK"}$ SDG 3.6.10

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$V_u := \sqrt{V_x^2 + V_z^2} = \mathbf{7.8} \cdot \text{kip}$

$T_u = \mathbf{177} \cdot \text{kip} \cdot \text{ft}$

Effective shear depth

$D_r := b - \mathbf{2} \cdot \left(\text{Cover} + d_{v.bar} + \frac{d_{long.bar}}{\mathbf{2}}\right) = \mathbf{2.3}\,\text{ft}$ $d_e := \frac{b}{\mathbf{2}} + \frac{D_r}{\pi} = \mathbf{2.2}\,\text{ft}$ *LRFD C5.8.2.9-2*

$d_v := \max\left(\mathbf{0.9} \cdot d_e, \mathbf{0.72} \cdot b\right) = \mathbf{2.2}\,\text{ft}$

Check Shear Strength

$V_c := \mathbf{0.0316} \cdot (\mathbf{2.0}) \cdot \sqrt{\frac{f_c}{\text{ksi}}} \cdot \left(\frac{b}{\text{in}}\right) \cdot \left(\frac{d_v}{\text{in}}\right) \cdot \text{kip} = \mathbf{117.9} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-3* *LRFD 5.8.3.4.1* *ACI 11.3.3*

$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max\left(s_{v1}, s_{v2}, s_{v3}\right)} = \mathbf{51.8} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-4*

$\text{ShearRatio} := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -\mathbf{2.1}$

$\text{ShearRatio} := \text{if}\left(\text{ShearRatio} \le \mathbf{0}, \mathbf{0}, \text{ShearRatio}\right) = \mathbf{0}$

Check Torsion Strength

$A_{cp} := \pi \cdot \left(\frac{b}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1017.9} \cdot \text{in}^{\mathbf{2}}$ $p_{cp} := \mathbf{2} \cdot \pi \cdot \left(\frac{b}{\mathbf{2}}\right) = \mathbf{113.1} \cdot \text{in}$ *Area and perimeter of concrete cross-section*

$d_{oh} := b - \mathbf{2} \cdot \left(\text{Cover} + \frac{d_{v.bar}}{\mathbf{2}}\right) = \mathbf{29.5} \cdot \text{in}$ $p_h := \pi \cdot d_{oh} = \mathbf{92.7} \cdot \text{in}$ *Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement*

$A_{oh} := \pi \left(\frac{d_{oh}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{683.5} \cdot \text{in}^{\mathbf{2}}$ $A_o := \mathbf{0.85} \cdot A_{oh} = \mathbf{581} \cdot \text{in}^{\mathbf{2}}$

$T_{n1} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD Eqn 5.8.3.6.2-1*

$T_{n2} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD 5.8.3.4.1*

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = 193.7 \cdot kip \cdot ft$$

$\phi_v = 0.9$ $T_u = 177 \cdot kip \cdot ft$ $L_{reqdTor} = 17\,ft$

$$Tor2_{sand} := T_u - if\left[2ft > Offset, \left[\pi \cdot b \cdot (2 \cdot ft - Offset) \cdot \gamma_{soil} \cdot \left(\frac{2 \cdot ft - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 175.4 \cdot kip \cdot ft$$

$$Tor3_{sand} := T_u - if\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot (depth_{stir} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -60.1 \cdot kip \cdot ft$$

$$Tor2_{clay} := T_u - if\left[2ft - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (2.0 \cdot ft - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 177 \cdot kip \cdot ft$$

$$Tor3_{clay} := T_u - if\left[depth_{stir} - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (depth_{stir} - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -21.3 \cdot kip \cdot ft$$

$$Tor2 := if(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}) = 177 \cdot kip \cdot ft$$

$$Tor3 := if(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}) = -21.3 \cdot kip \cdot ft$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = 0.46$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = 0.46$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = -0.11$$

$$TorsionRatio := max(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}) = 0.46$$

$$T_{cr} := 0.125 \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{A_{cp}^{\,2}}{p_{cp} \cdot in^{3}}\right) \cdot kip \cdot in = 190.9 \cdot kip \cdot ft$$

LRFD Eqn 5.8.2.1-4

$$TorsionRatio := if(T_u \le 0.25 \cdot \phi_{tor} \cdot T_{cr}, 0, TorsionRatio) = 0.5$$

LRFD Eqn 5.8.2.1-3

$ShearRatio = 0$

$$CheckShearTorsion := if(ShearRatio + TorsionRatio \le 1, \text{"OK"}, \text{"No Good"})$$

$CheckShearTorsion = \text{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = 0.009288 \cdot ksi$$

$0.125 \cdot f_c = 0.5 \cdot ksi$

LRFD Eqn 5.8.2.9-1

$s_{max1} := \text{if}\left(0.8 \cdot d_v < 24 \cdot \text{in}, 0.8 d_v, 24 \cdot \text{in}\right) = 20.7 \cdot \text{in}$ *LRFD Eqn 5.8.2.7-1*

$s_{max2} := \text{if}\left(0.4 \cdot d_v < 12 \cdot \text{in}, 0.4 d_v, 12 \cdot \text{in}\right) = 10.4 \cdot \text{in}$ *LRFD Eqn 5.8.2.7-2*

$s_{max} := \text{if}\left(v_u < 0.125 \cdot f_c, s_{max1}, s_{max2}\right) = 20.7 \cdot \text{in}$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = 6 \cdot \text{in}$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \text{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion *LRFD Eqn 5.8.3.6.3-1*

LRFD 5.8.3.4.1

$M_u = 161.1 \cdot \text{kip} \cdot \text{ft}$

$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5 \cdot V_s > 0 \cdot \text{kip}, \frac{V_u}{\phi_v} - 0.5 \cdot V_s, 0 \cdot \text{kip}\right) = 0 \cdot \text{kip}$

$$\text{LongReinf}_{shr.tor} := \frac{\frac{M_u}{\phi_v \cdot d_v} + \sqrt{\left(V_{temp}\right)^2 + \left(\frac{0.45 \cdot p_h \cdot T_u}{2 \cdot A_o \cdot \phi_v}\right)^2}}{F_{y.rebar}} = 2.8 \cdot \text{in}^2$$

$\text{Num}_{bar} \cdot A_{long.bar} = 11 \cdot \text{in}^2$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(\text{Num}_{bar} \cdot A_{long.bar} \ge \text{LongReinf}_{shr.tor}, \text{"OK"}, \text{"No Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \text{"OK"}$

Anchor Bolt Strength Check

$Num_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot in$ *anchor bolt nominal diameter*

$Dia_{anchor.circle} := 24 \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{Dia_{anchor.circle}^{\;2}}{8} \cdot Num_{anchor} = 576 \cdot in^2$$

$$S_{anchor} := \frac{I_{anchor}}{\frac{Dia_{anchor.circle}}{2}} = 48 \cdot in$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 40.3 \cdot kip$$ *anchor tension force*

$$V_{anchor} := \frac{V_u}{Num_{anchor}} + \frac{T_u}{0.5 Dia_{anchor.circle} \cdot Num_{anchor}} = 23.1 \cdot kip$$ *anchor shear force*

$$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}^{\;2} = 3.1 \cdot in^2$$ *anchor bolt nominal area*

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 12.8 \cdot ksi$$ *anchor tensile stress*

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 7.4 \cdot ksi$$ *anchor shear stress*

$\phi_{anchor} := 0.75$ *resistance factor* AISC J3-1

$F_{nt} := 0.75 F_{u.anchor} = 78.8 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := 0.45 F_{u.anchor} = 47.2 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot kip$ *design sghear strength*

$CheckAnchorT := if\left(\phi R_{nt} \geq T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$CheckAnchorT = \text{"OK"}$

$\mathrm{CheckAnchorV} := \mathrm{if}\left(\phi R_{nv} \geq V_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check shear rupture*

$\mathrm{CheckAnchorV} = \text{"OK"}$

$F_{ntv} := \mathbf{min}\left(\left(\begin{matrix} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{matrix}\right)\right) = 78.8 \cdot \mathrm{ksi}$ *nominal tensile stress modified to include the effects of shearing stress*

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = 185.6 \cdot \mathrm{kip}$ *design tension strength modified to include the effects of shearing stress*

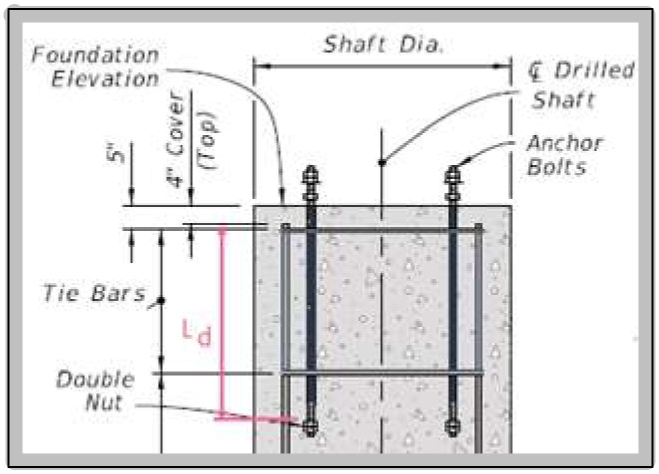
$\mathrm{CheckAnchorTV} := \mathrm{if}\left[\left(f_{t.anchor} \leq 20\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq 20\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \text{"OK"}, \text{"No Good"}\right]$

$\mathrm{CheckAnchorTV} = \text{"OK"}$ *check combined tension and shear rupture*

$\mathrm{CheckAnchorStrength} := \mathrm{if}\left[\left(\mathrm{CheckAnchorT} = \text{"OK"}\right) \cdot \left(\mathrm{CheckAnchorV} = \text{"OK"}\right) \cdot \left(\mathrm{CheckAnchorTV} = \text{"OK"}\right), \text{"OK"}, \text{"No Good"}\right]$

$\mathrm{CheckAnchorStrength} = \text{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = 40.3 \cdot \mathrm{kip}$ *tension force in anchor*

$\mathrm{Dia}_{bar.circle} = 27.9 \cdot \mathrm{in}$ $\mathrm{Dia}_{anchor.circle} = 24 \cdot \mathrm{in}$

center-to-center distance

$\mathrm{Dist}_{bar.to.bolt} := \dfrac{\mathrm{Dia}_{bar.circle} - \mathrm{Dia}_{anchor.circle}}{2} = 1.9 \cdot \mathrm{in}$

$\mathrm{Num}_{bars.per.anchor} := \min\left(\dfrac{\mathrm{Num}_{bar}}{\mathrm{Num}_{anchor}}, 3\right) = 1.4$ *Use a maximum of three rebar per anchor bolt (conservative)*

$\phi := 0.9$

$\mathrm{Num}_{bars.reqd.per.anchor} := \dfrac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \dfrac{\mathrm{Dia}_{anchor.circle}}{\mathrm{Dia}_{bar.circle}} = 0.64$

$\mathrm{AreaRatio} := \min\left(\dfrac{\mathrm{Num}_{bars.reqd.per.anchor}}{\mathrm{Num}_{bars.per.anchor}}, 1\right) = 0.47$

2015 AASHTO Development Length of Deformed Bars in Tension 5.11.2.1

$\mathrm{Cover} = 3 \cdot \mathrm{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half the center-to-center spacing of the bars or wires being developed*

$$c_b := \min\left(\begin{pmatrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{\mathbf{2}} \\ \dfrac{\text{Spacing}_{vert.reinf}}{\mathbf{2}} \end{pmatrix}\right) = \mathbf{4}\cdot in$$

$k_{tr} := \mathbf{0}\cdot in$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\begin{bmatrix} \mathbf{1.0} \\ \max\left(\begin{pmatrix} \mathbf{0.4} \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{pmatrix}\right) \end{bmatrix}\right] = \mathbf{0.4}$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\begin{pmatrix} \mathbf{12}\cdot in \\ \lambda_{rc}\cdot\mathbf{2.4}\cdot d_{long.bar}\cdot\dfrac{F_{y.rebar}}{\sqrt{f_c\cdot ksi}} \end{pmatrix}\right) = \mathbf{32.4}\cdot in$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$\text{SpacingFactor} := \max\left[\begin{pmatrix} \mathbf{0.5} \\ \text{Num}_{bars.per.anchor}\cdot\mathbf{0.5} - \mathbf{0.5} \end{pmatrix}\right] = \mathbf{0.5}$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf}\cdot\text{SpacingFactor}\right)^{\mathbf{2}} + \text{Dist}_{bar.to.bolt}{}^{\mathbf{2}}} = \mathbf{3.9}\cdot in$$

$$L_{embedment.anchor} := \max\left[\begin{bmatrix} L_{d.bar}\cdot(\text{AreaRatio}) + \mathbf{12}\cdot in + L_{embedment.added} \\ \mathbf{20}\cdot d_{anchor} \end{bmatrix}\right] = \mathbf{40}\cdot in$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, in\right)$

$L_{embedment.anchor} = \mathbf{40}\cdot in$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$r_b := \dfrac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$r := \dfrac{b}{2} = 18 \cdot in$

$c_{a1} := \dfrac{\sqrt{r_b^{\,2} + 3.25 \cdot \left(r^2 - r_b^{\,2}\right)} - r_b}{3.25} = 4.6 \cdot in$ *adjusted cover*

UF Report Eqn 3-2

$L_e := \min\left(\begin{pmatrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{pmatrix}\right) = 16 \cdot in$ *load bearing length of anchor for shear*

ACI D.6.2.2

$V_b := 13 \cdot \left(\dfrac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\dfrac{d_{anchor}}{in}} \cdot \sqrt{\dfrac{f_c}{psi}} \left(\dfrac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$ *shear break-out strength (single anchor)*
UF Report Eqn 2-11

$A_{bolt.sector} := \dfrac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$ *UF Report Fig 3-7*

$\alpha := 2\text{asin}\left[\dfrac{(1.5 \cdot c_{a1})}{r}\right] = 45.2 \cdot deg$

OverlapTest := if($A_{bolt.sector} \le \alpha$, **"Overlap of Failure Cones"** , **"No Overlap of Failure Cones"**) = **"Overlap of Failur**

$chord := 2 \cdot r \cdot \sin\left(\dfrac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$ *UF Report Fig 3-7*

$A_{Vco} := 4.5 \cdot c_{a1}^{\,2} = 95.9 \cdot in^2$ *projected concrete failure area (single anchor)*

ACI Eqn D-23

$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$ *projected concrete failure area (group)*

ACI D.6.2.1

$A_{Vc} := \text{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$

$\psi_{ecV} := 1.0$ *eccentric load modifier* *ACI D.6.2.5*

$\psi_{edV} := 1.0$ *edge effect modifier* *ACI D.6.2.6*

$\psi_{cV} := 1.4$ *cracked section modifier* *ACI D.6.2.7* *(stirrup spacing <= 4")*

$\psi_{hV} := 1.0$ *member thickness modifier* *ACI D.6.2.8*

$\phi_{breakout} := 0.75$ *strength reduction factor* *ACI D.4.4.c.i* *(shear breakout, condition A)*

$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = \mathbf{194.7} \cdot kip$ *concrete breakout strength - shear*

ACI Eqn D-22 *Shear force ⊥ to edge*

$V_{cbg\_parallel} := \mathbf{2} \cdot V_{cbg} = \mathbf{389.5} \cdot kip$ *ACI D.6.2.1.c* *Shear force ∥ to edge*

$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = \mathbf{389.5} \cdot kip \cdot ft$ *concrete breakout strength - torsion*

$\phi_{breakout} \cdot T_{n.breakout} = \mathbf{292.1} \cdot kip \cdot ft$

$T_u = \mathbf{177} \cdot kip \cdot ft$

$BreakoutTest := if\left(\phi_{breakout} \cdot T_{n.breakout} \geq T_u, \text{"OK"}, \text{"No Good"}\right)$

$BreakoutTest = $ **"OK"**

$OverlapDesign := if\left(A_{bolt.sector} \leq \alpha, \text{"Based on Overlap of Failure Cones"}, \text{"Based on No Overlap of Failure Cones"}\right)$

$OverlapDesign = $ **"Based on Overlap of Failure Cones"**

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = \mathbf{1.9} \cdot in$ *center-to-center distance*

$d_{anchor.nut} := \mathbf{1.85} \cdot d_{anchor} = \mathbf{3.7} \cdot in$ *use* $\mathbf{1.85} \cdot d_{anchor}$ *.to account for anchor nut*

$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{\mathbf{2}}\right) = -\mathbf{0.5} \cdot in$

$CheckAnchorageClearance := if\left[\left(Clearance_{bar.to.nut} \geq \mathbf{2} \cdot in\right), \text{"OK"}, \text{"No Good, increase ped. diameter"}\right]$

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0 .. 48 \qquad r_{ds} := \frac{b}{2}$

$xds_{pt} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yds_{pt} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$xstir.od_{pt} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.od_{pt} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$xstir.id_{pt} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.id_{pt} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$xbar_{pt} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max(xstir.id) - d_{v.bar} \qquad ybar_{pt} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$xboltcircle_{pt} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yboltcircle_{pt} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltr} := \frac{d_{anchor}}{2} = \mathbf{1} \cdot in$

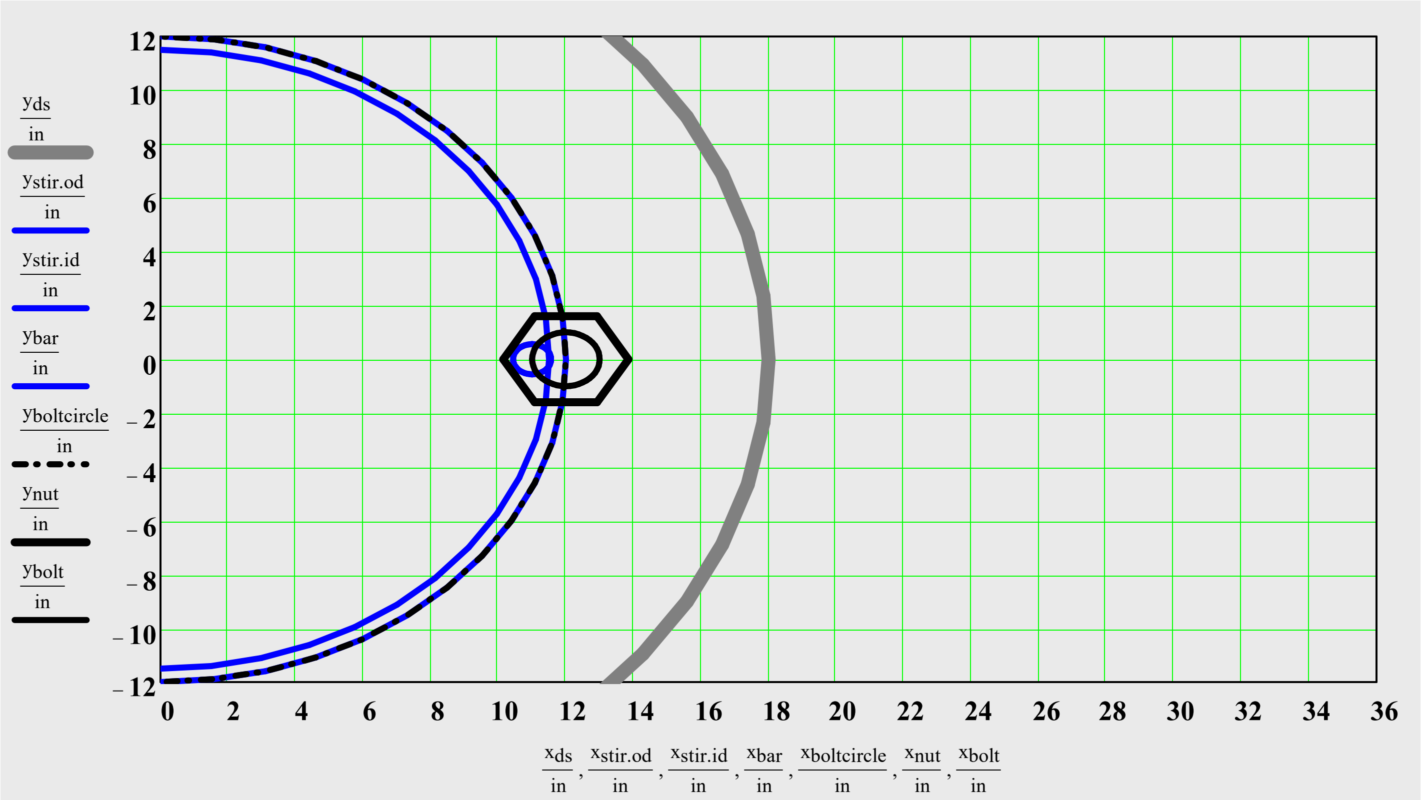
$x_{bolt_{pt}} := r_{boltr} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{48}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right] + (\max(x_{boltcircle}))$ $y_{bolt_{pt}} := r_{boltr} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{48}}\right]$

$pt := \mathbf{0} .. \mathbf{6}$ $r_{nut} := \frac{d_{anchor} \cdot 1.85}{\mathbf{2}} = \mathbf{1.9} \cdot in$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right] + (\max(x_{boltcircle}))$ $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{2} \cdot \pi}{\mathbf{6}}\right]$

$x_{nut_{pt}} := r_{nut} \cdot \cos\left[(\mathbf{2} \cdot \pi) \cdot \frac{pt}{\mathbf{6}} + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right] + (\max(x_{boltcircle}))$ *enable to rotate nut* $y_{nut_{pt}} := r_{nut} \cdot \sin\left[\left(\mathbf{2} \cdot \pi \cdot \frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{1} \cdot \pi}{\mathbf{6}}\right]$

$\min(x_{bar}) - \max(x_{nut}) = -\mathbf{3.4} \cdot in$



$$Bolts := \begin{pmatrix} \mathbf{1} & \mathbf{1.125} & \mathbf{1.25} & \mathbf{1.375} & \mathbf{1.5} & \mathbf{1.625} & \mathbf{1.75} & \mathbf{1.875} & \mathbf{2} & \mathbf{2.25} & \mathbf{2.5} & \mathbf{2.75} & \mathbf{3} \\ \mathbf{1.5} & \mathbf{1.688} & \mathbf{1.875} & \mathbf{2.063} & \mathbf{2.25} & \mathbf{2.438} & \mathbf{2.625} & \mathbf{2.938} & \mathbf{3} & \mathbf{3.375} & \mathbf{3.75} & \mathbf{4.125} & \mathbf{4.25} \end{pmatrix} \cdot in$$

$$\left(Bolts^T\right)^{\langle \mathbf{0} \rangle^T} \cdot \mathbf{1.6} - \left(Bolts^T\right)^{\langle \mathbf{1} \rangle^T} = (\mathbf{0.1} \ \ \mathbf{0.112} \ \ \mathbf{0.125} \ \ \mathbf{0.137} \ \ \mathbf{0.15} \ \ \mathbf{0.162} \ \ \mathbf{0.175} \ \ \mathbf{0.062} \ \ \mathbf{0.2} \ \ \mathbf{0.225} \ \ \mathbf{0.25} \ \ \mathbf{0.275} \ \ \mathbf{0.55}) \cdot in$$

$$\left(Bolts^T\right)^{\langle \mathbf{0} \rangle^T} - \left(Bolts^T\right)^{\langle \mathbf{1} \rangle^T} = (-\mathbf{0.5} \ \ -\mathbf{0.563} \ \ -\mathbf{0.625} \ \ -\mathbf{0.688} \ \ -\mathbf{0.75} \ \ -\mathbf{0.813} \ \ -\mathbf{0.875} \ \ -\mathbf{1.063} \ \ -\mathbf{1} \ \ -\mathbf{1.125} \ \ -\mathbf{1.25} \ \ -\mathbf{1.375} \ \ -\mathbf{1.25}) \cdot$$

Drilled Shaft Foundation for
Sign, Signal, and Lighting Support Structures v1.1

State Structures Design Office

SUBJECT 079-241-R MERIDEN
LOCATION MERIDEN, CT

DESIGNED BY BA DATE 3-6-2020
CHECKED BY RHS DATE 1-7-2021

Program Changes

SoilType :=
[✓ Sand]
Clay

$\phi_{soil} := 32.0 \cdot deg$ *soil friction angle (sand)*

$c_{soil} := 0.0 \cdot \frac{kip}{ft^2}$ *soil shear strength (clay)*

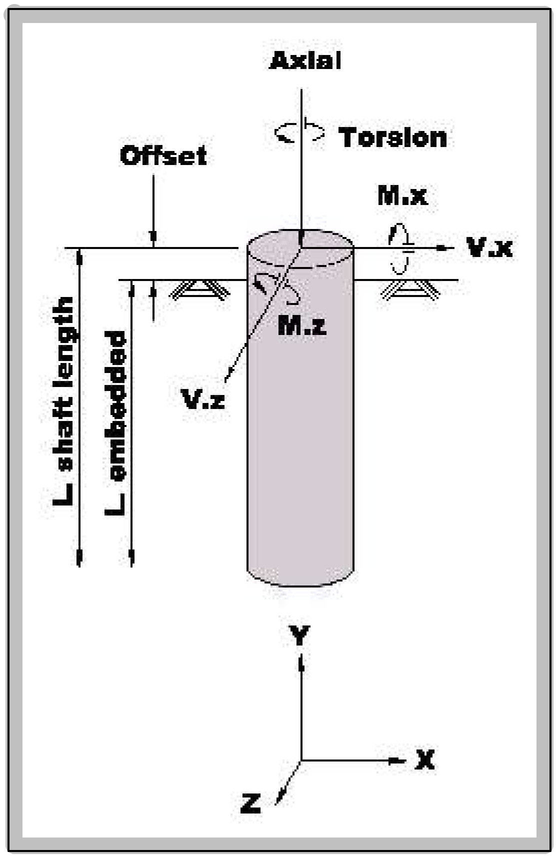
$N_{blows} := 10$ *number of blows per foot. If N< 5, contact the district geotech Engineer*

$\gamma_{soil} := 69 \cdot pcf$ *effective soil weight (typical design value = 45 ~ 50 pcf)*

Geometry

$b := 3.0 \cdot ft$ *shaft diameter*

$Offset := 0.50 \cdot ft$ *groundline to top of foundation*



Applied Loads (Extreme I) `Actual Loads Increased by 10%`

$M_x := 41.7 \cdot kip \cdot ft$ $V_x := 0.05 \cdot kip$ $Torsion := 14.9 \cdot kip \cdot ft$

$M_z := 7.10 \cdot kip \cdot ft$ $V_z := 2.60 \cdot kip$ $Axial := 16.50 \cdot kip$

StructureType :=
Cantilever Overhead Sign Structure
[✓ Mast Arm Signal Structure]
Concrete/Steel Strain Poles
Ground Sign

$StructureType = 1$

$\phi_{ot} := if(StructureType = 2, 0.8, 0.25)$ $\phi_{ot} = 0.3$ *ϕ factor against overturning [SM Vol-3 13.6.1.1]*

$\phi_{tor} := if(StructureType = 0, 0.9, 1.0)$ $\phi_{tor} = 1$ *ϕ factor against torsion [SM Vol-3 13.6.1.1]*

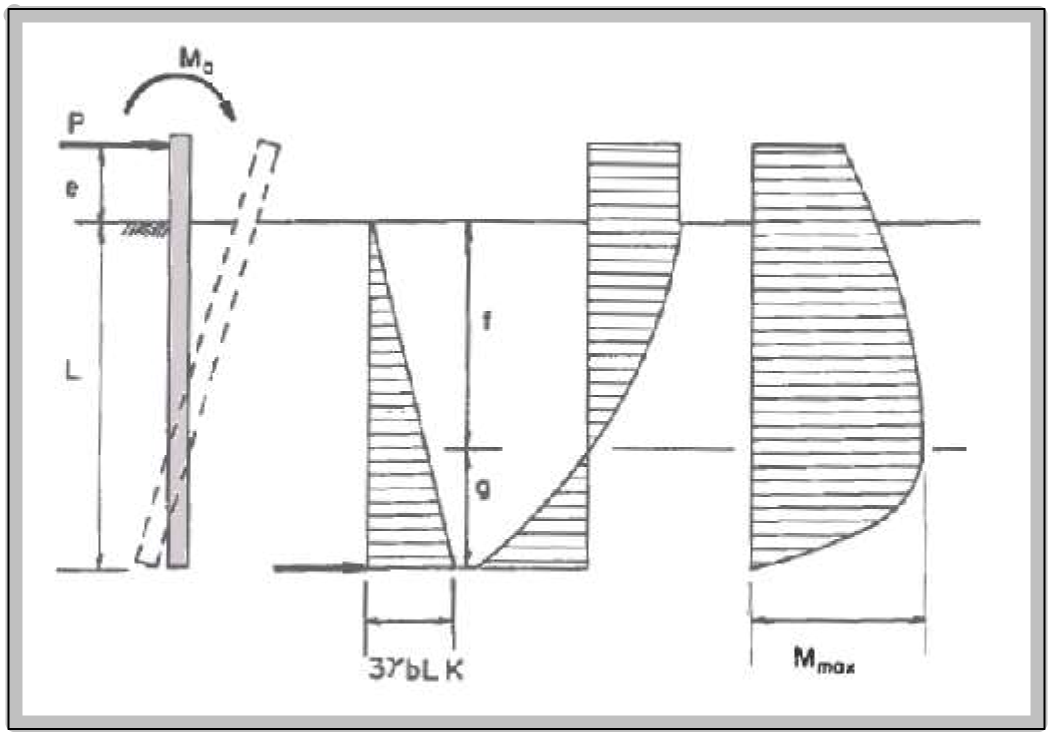
Shaft Depth Required to Resist Overturning

$M_u := \sqrt{M_x^{\mathbf{2}} + M_z^{\mathbf{2}}} = \mathbf{42.3} \cdot \text{kip} \cdot \text{ft}$

$P_u := \sqrt{V_x^{\mathbf{2}} + V_z^{\mathbf{2}}} = \mathbf{2.6} \cdot \text{kip}$

$T_u := \text{Torsion} = \mathbf{14.9} \cdot \text{kip} \cdot \text{ft}$

short free-head pile in ***cohesionless soil*** *using Broms method*



Deflection, load, shear and moment diagram for a short pile in cohesionless soil that is unrestrained against rotation.

$K_p := \tan\left(\mathbf{45} \cdot \text{deg} + \frac{\phi_{soil}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{3.3}$ $\quad$ $e_{sand} := \text{Offset} = \mathbf{0.5} \, \text{ft}$

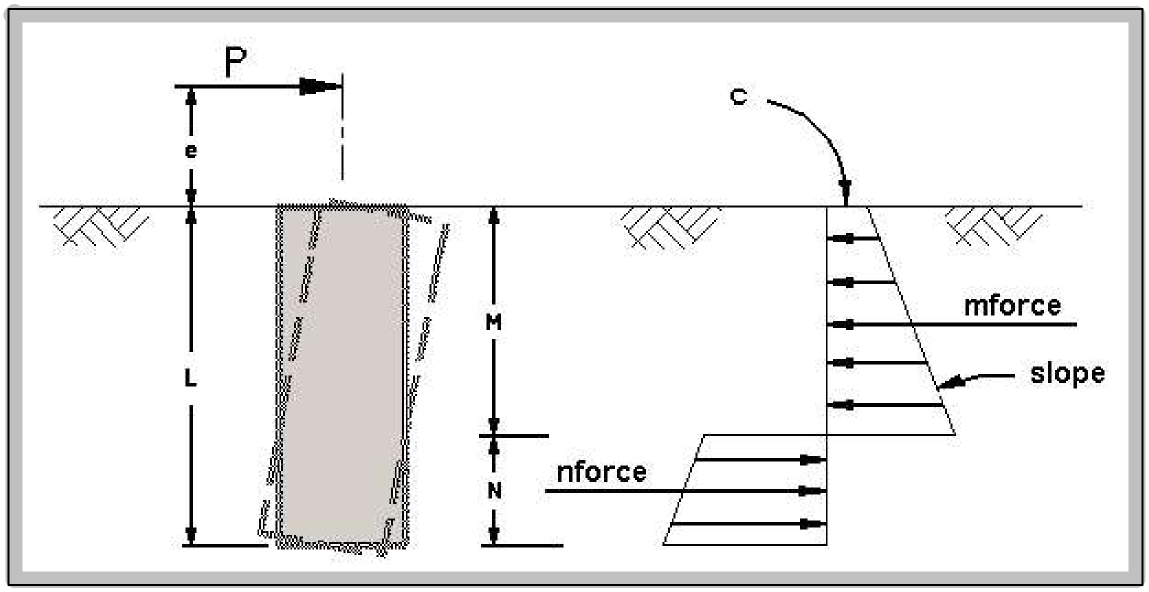
Guess value $\quad L_{otSand} := \mathbf{10} \cdot \text{ft}$

Given $\quad P_u \cdot \left(e_{sand} + L_{otSand}\right) + M_u = \phi_{ot} \cdot \left[\left(\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot L_{otSand} \cdot K_p\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{2}} \cdot L_{otSand}\right) \cdot \left(\frac{\mathbf{1}}{\mathbf{3}} \cdot L_{otSand}\right)\right]$

$L_{otSand} := \text{Find}\left(L_{otSand}\right) = \mathbf{9.3} \, \text{ft}$

$L_{otSand} := \text{ceil}\left(\frac{L_{otSand}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{10} \, \text{ft}$ $\quad$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Modified Broms method for L < 3b (see reference file for derivation)*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$c_{soil} := \text{if}\left(c_{soil} = 0\cdot ksf, 0.1\cdot ksf, c_{soil}\right) = 0.1\cdot ksf$

$Slope := 8\cdot\dfrac{c_{soil}}{3\cdot b} = 0.1\cdot\dfrac{kip}{ft^{3}}$

$e_{clay} := \dfrac{M_u}{P_u} + Offset = 16.8\,ft$

$nforce(M,N) := \left[Slope\cdot(2\cdot M + N) + 2\cdot c_{soil}\right]\cdot N\cdot\dfrac{b}{2}$

$mforce(M) := \left(2\cdot c_{soil} + M\cdot Slope\right)\cdot M\cdot\dfrac{b}{2}$

$m\_arm(M) := e_{clay} + \dfrac{M}{3}\cdot\dfrac{2\cdot(M\cdot Slope + c_{soil}) + c_{soil}}{M\cdot Slope + 2\cdot c_{soil}}$

$n\_arm(M,N) := e_{clay} + M + \dfrac{N}{3}\cdot\dfrac{2\cdot(N\cdot Slope + M\cdot Slope + c_{soil}) + (M\cdot Slope + c_{soil})}{Slope\cdot(2\cdot M + N) + 2\cdot c_{soil}}$

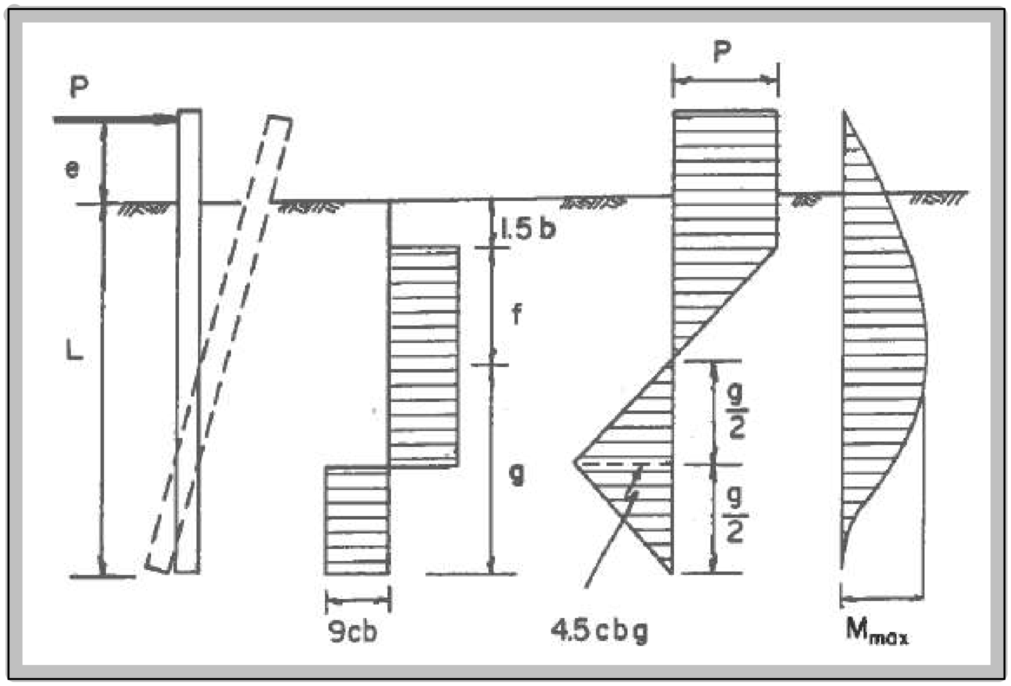
Guess value $M := 4.0\cdot ft$ $N := 4.0\cdot ft$

Given $P_u + \phi_{ot}\cdot nforce(M,N) = \phi_{ot}\cdot mforce(M)$ $mforce(M)\cdot m\_arm(M) = nforce(M,N)\cdot n\_arm(M,N)$

$\begin{pmatrix} M \\ N \end{pmatrix} := Find(M,N)$ $L_{ot1Clay} := M + N = 7.1\,ft$

$L_{ot1Clay} := ceil\left(\dfrac{L_{ot1Clay}}{ft}\right)\cdot ft = 8\,ft$ *(round up to next foot)*

short free-head pile in ***cohesive soil*** *using Regular Broms method for L > 3b*



Deflection, load, shear and moment diagram for a short pile in cohesive soil that is unrestrained against rotation.

$M_{max.clay}$ *equation is derived from the integration of the upper part of the shear diagram to the point of zero shear.*

$f := \dfrac{P_u}{\phi_{ot} \cdot \mathbf{9} \cdot c_{soil} \cdot b} = \mathbf{3.9} \, ft$

$M_{max.clay} := P_u \cdot \left(e_{clay} + \mathbf{1.5} \cdot b + \mathbf{0.5} \cdot f \right) = \mathbf{60.3} \cdot kip \cdot ft$

$g := \sqrt{\dfrac{M_{max.clay}}{\mathbf{2.25} \cdot \phi_{ot} \cdot c_{soil} \cdot b}} = \mathbf{18.9} \, ft$

$L_{ot2Clay} := \left(\mathbf{1.5} \cdot b + f + g \right) = \mathbf{27.3} \, ft$

$L_{ot2Clay} := ceil\left(\dfrac{L_{ot2Clay}}{ft} \right) \cdot ft = \mathbf{28} \, ft$ *(round up to next foot)*

$L_{otClay} := if\left(L_{ot1Clay} < \mathbf{3} \cdot b, L_{ot1Clay}, L_{ot2Clay} \right) = \mathbf{8} \, ft$ *(If* $L_{ot} < 3b$*, use Modified Broms method)*

$L_{reqdOT} := if\left(SoilType = \textbf{"Sand"}, L_{otSand}, L_{otClay} \right)$

$L_{reqdOT} = \mathbf{10} \, ft$ *required shaft embedment depth to resist overturning*

Shaft Depth Required to Resist Torsion

*short free-head pile in **cohesionless soil***

NOTE: ω_{fdot} is based upon concrete soil interaction. This torsion methodology is not to be used with permanent casing.

$N_{blows} = \mathbf{10}$

$\omega_{fdot} := \text{if}\left(N_{blows} < \mathbf{5}, \mathbf{0}, \text{if}\left(N_{blows} \geq \mathbf{15}, \mathbf{1.5}, \mathbf{1.5} \cdot \frac{N_{blows}}{\mathbf{15}}\right)\right) = \mathbf{1}$

load transfer ratio, If 5<N<15, ω_{fdot} *is reduced by a factor of* $\frac{N_{blows}}{\mathbf{15}}$

SM Vol-3 13.6

Guess value $L_{torSand} := L_{reqdOT} = \mathbf{10}\,\text{ft}$

Given $T_u = \phi_{tor} \cdot \left[\pi \cdot b \cdot (L_{torSand}) \cdot \gamma_{soil} \cdot \left(\frac{L_{torSand}}{\mathbf{2}}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{\mathbf{2}}\right]$

$L_{torSand} := \text{Find}(L_{torSand}) = \mathbf{5.5}\,\text{ft}$

$L_{torSand} := \text{ceil}\left(\frac{L_{torSand}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{6}\,\text{ft}$ *(round up to next foot)*

*short free-head pile in **cohesive soil***

$\text{CohesionFactor} := \mathbf{0.55}$

$f_{se} := \text{CohesionFactor} \cdot c_{soil} = \mathbf{0.1} \cdot \text{ksf}$

Guess value $L_{torClay} := L_{reqdOT}$

Given $T_u = \phi_{tor} \cdot \left[f_{se} \cdot (\pi \cdot b) \cdot (L_{torClay} - \mathbf{1.5} \cdot \text{ft}) \cdot \frac{b}{\mathbf{2}}\right]$

$L_{torClay} := \text{Find}(L_{torClay}) = \mathbf{20.7}\,\text{ft}$

$L_{torClay} := \text{ceil}\left(\frac{L_{torClay}}{\text{ft}}\right) \cdot \text{ft} = \mathbf{21}\,\text{ft}$ *(round up to next foot)*

$L_{reqdTor} := \text{if}(\text{SoilType} = \mathbf{"Sand"}, L_{torSand}, L_{torClay})$

$L_{reqdTor} = \mathbf{6}\,\text{ft}$ *required shaft embedment depth to resist torsion*

$L_{embedded} := \text{if}(L_{reqdTor} > L_{reqdOT}, L_{reqdTor}, L_{reqdOT}) = \mathbf{10}\,\text{ft}$

$L_{shaft.length} := L_{embedded} + \text{Offset}$

$L_{shaft.length} = \mathbf{10.5}\,\text{ft}$ **Min Shaft embedment depth=12 ft** *shaft length*

Maximum Moment in Shaft

short free-head pile in cohesionless soil using Broms method

$$f_{sand} := \sqrt{\frac{\mathbf{2} \cdot P_u}{\mathbf{3} \cdot \gamma_{soil} \cdot b \cdot K_p \cdot \phi_{ot}}} = \mathbf{3.2}\,ft$$

$$M_{maxSand} := P_u \cdot (e_{sand} + f_{sand}) - \frac{P_u \cdot f_{sand}}{\mathbf{3}} + M_u = \mathbf{49.2} \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Modified Broms method for L < 3b (see reference file for derivation)*

Guess value $f_{mod} := \mathbf{4.0} \cdot ft$

Given $P_u = \frac{f_{mod} \cdot b}{\mathbf{2}} \cdot (2\phi_{ot} \cdot c_{soil} + \phi_{ot} \cdot f_{mod} \cdot Slope)$

$f_{mod} := Find(f_{mod}) = \mathbf{7.8}\,ft$

$$M_{modBroms} := P_u \cdot (e_{clay} + f_{mod}) - \frac{\phi_{ot} \cdot c_{soil} \cdot b \cdot f_{mod}^{\mathbf{2}}}{\mathbf{2}} - \frac{\phi_{ot} \cdot b \cdot f_{mod}^{\mathbf{3}} \cdot Slope}{\mathbf{6}} = \mathbf{56.3} \cdot kip \cdot ft$$

*short free-head pile in **cohesive soil** using Regular Broms method for L > 3b*

$$M_{Broms} := P_u \cdot (e_{clay} + \mathbf{1.5} \cdot b + \mathbf{0.5} \cdot f) = \mathbf{60.3} \cdot kip \cdot ft$$

$$M_{maxClay} := if(L_{ot1Clay} < \mathbf{3} \cdot b, M_{modBroms}, M_{Broms}) = \mathbf{56.3} \cdot kip \cdot ft$$

(If $L_{ot} < 3b$, use Modified Broms method)

$$M_{max} := if(SoilType = \mathbf{"Sand"}, M_{maxSand}, M_{maxClay}) = \mathbf{49.2} \cdot kip \cdot ft$$

Minimum Reinforcing and Spacing

$F_{y.rebar} := 60 \cdot ksi$ *reinforcing yield strength*

$f_c := 4.0 \cdot ksi$ *concrete strength* *Spec 346-3*

$Cover := 3 \cdot in$ *cover* *SDG Table 1.4.2-1*

$Num_{bar} := 11$ *number of longitudinal bars*

$A_{long.bar} := 1.0 \cdot in^2$ *longitudinal bar area*

$d_{long.bar} := 1.125 \cdot in$ *longitudinal bar diameter*

$A_{v.bar} := 0.20 \cdot in^2$ *stirrup area* *SM Vol-3 13.6.2*

$d_{v.bar} := 0.5 \cdot in$ *stirrup diameter*

$s_{v1} := 3 \cdot in$ *stirrup spacing, depth = 0 ft-2 ft* *SM Vol-3 13.6.2*

$s_{v2} := 3 \cdot in$ *stirrup spacing, depth = 2 ft-depth.stir*

$s_{v3} := 6 \cdot in$ *stirrup spacing, depth > depth.stir*

$depth_{stir} := 12.0 \cdot ft$ *stirrup depth, see s.v2 and s.v3 above*

$b = 3\, ft$ *shaft diameter*

$A_{req1} := 0.01 \cdot \frac{\pi \cdot b^2}{4} = 10.2 \cdot in^2$ *required 1% steel* *SM Vol-3 13.6.2*

$A_{req2} := \min\left(0.135 \cdot \frac{\pi \cdot b^2}{4} \cdot \frac{f_c}{F_{y.rebar}}, 0.015 \cdot \frac{\pi \cdot b^2}{4}\right) = 9.2 \cdot in^2$ *LRFD 5.7.4.2*

$A_{req} := \max(A_{req1}, A_{req2}) = 10.2 \cdot in^2$

$A_{long} := Num_{bar} \cdot A_{long.bar} = 11 \cdot in^2$ *total area of longitudinal steel*

$CheckLongitudinalReinf := if(A_{long} \geq A_{req}, \text{"OK"}, \text{"No Good"})$ $CheckLongitudinalReinf = \text{"OK"}$

$Dia_{bar.circle} := b - 2 \cdot Cover - 2 \cdot d_{v.bar} - d_{long.bar} = 27.9 \cdot in$

$Spacing_{vert.reinf} := Dia_{bar.circle} \cdot \frac{\pi}{Num_{bar}} = 8 \cdot in$ $Clearance_{vert.reinf} := Spacing_{vert.reinf} - d_{long.bar} = 6.84 \cdot in$

$CheckReinfClearSpacing := if(Clearance_{vert.reinf} \geq 6in, \text{"OK"}, \text{"No Good"})$ $CheckReinfClearSpacing = \text{"OK"}$ *SDG 3.6.10*

Check Shear and Torsion

$\phi_v := \mathbf{0.90}$ *Shear Resistance Factor* *LRFD 5.5.4.2.1*

$V_u := \sqrt{V_x^{\mathbf{2}} + V_z^{\mathbf{2}}} = \mathbf{2.6} \cdot \text{kip}$

$T_u = \mathbf{14.9} \cdot \text{kip} \cdot \text{ft}$

Effective shear depth

$D_r := b - \mathbf{2} \cdot \left(\text{Cover} + d_{v.bar} + \frac{d_{long.bar}}{\mathbf{2}} \right) = \mathbf{2.3}\,\text{ft}$ $d_e := \frac{b}{\mathbf{2}} + \frac{D_r}{\pi} = \mathbf{2.2}\,\text{ft}$ *LRFD C5.8.2.9-2*

$d_v := \max\left(\mathbf{0.9} \cdot d_e, \mathbf{0.72} \cdot b\right) = \mathbf{2.2}\,\text{ft}$

Check Shear Strength

$V_c := \mathbf{0.0316} \cdot (\mathbf{2.0}) \cdot \sqrt{\frac{f_c}{\text{ksi}}} \cdot \left(\frac{b}{\text{in}}\right) \cdot \left(\frac{d_v}{\text{in}}\right) \cdot \text{kip} = \mathbf{117.9} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-3* *LRFD 5.8.3.4.1* *ACI 11.3.3*

$V_s := \frac{A_{v.bar} \cdot F_{y.rebar} \cdot d_v}{\max\left(s_{v1}, s_{v2}, s_{v3}\right)} = \mathbf{51.8} \cdot \text{kip}$ *LRFD Eqn 5.8.3.3-4*

$\text{ShearRatio} := \frac{V_u - \phi_v \cdot V_c}{\phi_v \cdot V_s} = -\mathbf{2.2}$

$\text{ShearRatio} := \text{if}\left(\text{ShearRatio} \le \mathbf{0}, \mathbf{0}, \text{ShearRatio}\right) = \mathbf{0}$

Check Torsion Strength

$A_{cp} := \pi \cdot \left(\frac{b}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{1017.9} \cdot \text{in}^{\mathbf{2}}$ $p_{cp} := \mathbf{2} \cdot \pi \cdot \left(\frac{b}{\mathbf{2}}\right) = \mathbf{113.1} \cdot \text{in}$ *Area and perimeter of concrete cross-section*

$d_{oh} := b - \mathbf{2} \cdot \left(\text{Cover} + \frac{d_{v.bar}}{\mathbf{2}}\right) = \mathbf{29.5} \cdot \text{in}$ $p_h := \pi \cdot d_{oh} = \mathbf{92.7} \cdot \text{in}$ *Diameter, perimeter and area enclosed by the centerline of the outermost closed transverse torsion reinforcement*

$A_{oh} := \pi \left(\frac{d_{oh}}{\mathbf{2}}\right)^{\mathbf{2}} = \mathbf{683.5} \cdot \text{in}^{\mathbf{2}}$ $A_o := \mathbf{0.85} \cdot A_{oh} = \mathbf{581} \cdot \text{in}^{\mathbf{2}}$

$T_{n1} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v1}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD Eqn 5.8.3.6.2-1*

$T_{n2} := \frac{\mathbf{2} \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v2}} = \mathbf{387.3} \cdot \text{kip} \cdot \text{ft}$ *LRFD 5.8.3.4.1*

$$T_{n3} := \frac{2 \cdot A_o \cdot A_{v.bar} \cdot F_{y.rebar}}{s_{v3}} = 193.7 \cdot kip \cdot ft$$

$\phi_v = 0.9$ $\quad$ $T_u = 14.9 \cdot kip \cdot ft$ $\quad$ $L_{reqdTor} = 6\,ft$

$$Tor2_{sand} := T_u - \text{if}\left[2ft > Offset, \left[\pi \cdot b \cdot (2 \cdot ft - Offset) \cdot \gamma_{soil} \cdot \left(\frac{2 \cdot ft - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 13.8 \cdot kip \cdot ft$$

$$Tor3_{sand} := T_u - \text{if}\left[depth_{stir} > Offset, \left[\pi \cdot b \cdot (depth_{stir} - Offset) \cdot \gamma_{soil} \cdot \left(\frac{depth_{stir} - Offset}{2}\right) \cdot (\omega_{fdot}) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = -49.6 \cdot kip \cdot ft$$

$$Tor2_{clay} := T_u - \text{if}\left[2ft - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (2.0 \cdot ft - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 14.9 \cdot kip \cdot ft$$

$$Tor3_{clay} := T_u - \text{if}\left[depth_{stir} - 1.5ft > Offset, \left[f_{se} \cdot (\pi \cdot b) \cdot (depth_{stir} - Offset - 1.5 \cdot ft) \cdot \frac{b}{2}\right], 0 \cdot kip \cdot ft\right] = 7.1 \cdot kip \cdot ft$$

$$Tor2 := \text{if}(SoilType = \text{"Sand"}, Tor2_{sand}, Tor2_{clay}) = 13.8 \cdot kip \cdot ft$$

$$Tor3 := \text{if}(SoilType = \text{"Sand"}, Tor3_{sand}, Tor3_{clay}) = -49.6 \cdot kip \cdot ft$$

$$TorsionRatio_{n1} := \frac{T_u}{\phi_{tor} \cdot T_{n1}} = 0.04$$

$$TorsionRatio_{n2} := \frac{Tor2}{\phi_{tor} \cdot T_{n2}} = 0.04$$

$$TorsionRatio_{n3} := \frac{Tor3}{\phi_{tor} \cdot T_{n3}} = -0.26$$

$$TorsionRatio := \max(TorsionRatio_{n1}, TorsionRatio_{n2}, TorsionRatio_{n3}) = 0.04$$

$$T_{cr} := 0.125 \sqrt{\frac{f_c}{ksi}} \cdot \left(\frac{A_{cp}^{\;2}}{p_{cp} \cdot in^3}\right) \cdot kip \cdot in = 190.9 \cdot kip \cdot ft$$

LRFD Eqn 5.8.2.1-4

$$TorsionRatio := \text{if}(T_u \le 0.25 \cdot \phi_{tor} \cdot T_{cr}, 0, TorsionRatio) = 0$$

LRFD Eqn 5.8.2.1-3

$ShearRatio = 0$

$$CheckShearTorsion := \text{if}(ShearRatio + TorsionRatio \le 1, \text{"OK"}, \text{"No Good"})$$

$CheckShearTorsion = \text{"OK"}$

Check Maximum Spacing Transverse Reinforcement

$$v_u := \frac{V_u}{\phi_v \cdot b \cdot d_v} = 0.003097 \cdot ksi \qquad 0.125 \cdot f_c = 0.5 \cdot ksi$$

LRFD Eqn 5.8.2.9-1

$s_{max1} := \text{if}\left(\mathbf{0.8} \cdot d_v < \mathbf{24} \cdot \text{in}, \mathbf{0.8} d_v, \mathbf{24} \cdot \text{in}\right) = \mathbf{20.7} \cdot \text{in}$ *LRFD Eqn 5.8.2.7-1*

$s_{max2} := \text{if}\left(\mathbf{0.4} \cdot d_v < \mathbf{12} \cdot \text{in}, \mathbf{0.4} d_v, \mathbf{12} \cdot \text{in}\right) = \mathbf{10.4} \cdot \text{in}$ *LRFD Eqn 5.8.2.7-2*

$s_{max} := \text{if}\left(v_u < \mathbf{0.125} \cdot f_c, s_{max1}, s_{max2}\right) = \mathbf{20.7} \cdot \text{in}$

$\max\left(s_{v1}, s_{v2}, s_{v3}\right) = \mathbf{6} \cdot \text{in}$

$\text{CheckMaxSpacingTransvReinf} := \text{if}\left(\max\left(s_{v1}, s_{v2}, s_{v3}\right) \le s_{max}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$\text{CheckMaxSpacingTransvReinf} = \textbf{"OK"}$

Check Longitudinal Reinforcement for Combined Shear and Torsion *LRFD Eqn 5.8.3.6.3-1*

LRFD 5.8.3.4.1

$M_u = \mathbf{42.3} \cdot \text{kip} \cdot \text{ft}$

$V_{temp} := \text{if}\left(\frac{V_u}{\phi_v} - 0.5 \cdot V_s > \mathbf{0} \cdot \text{kip}, \frac{V_u}{\phi_v} - 0.5 \cdot V_s, \mathbf{0} \cdot \text{kip}\right) = \mathbf{0} \cdot \text{kip}$

$$\text{LongReinf}_{shr.tor} := \frac{\frac{M_u}{\phi_v \cdot d_v} + \sqrt{\left(V_{temp}\right)^{\mathbf{2}} + \left(\frac{\mathbf{0.45} \cdot p_h \cdot T_u}{\mathbf{2} \cdot A_o \cdot \phi_v}\right)^{\mathbf{2}}}}{F_{y.rebar}} = \mathbf{0.5} \cdot \text{in}^{\mathbf{2}}$$

$\text{Num}_{bar} \cdot A_{long.bar} = \mathbf{11} \cdot \text{in}^{\mathbf{2}}$

$\text{CheckLongReinf}_{shr.tor} := \text{if}\left(\text{Num}_{bar} \cdot A_{long.bar} \ge \text{LongReinf}_{shr.tor}, \textbf{"OK"}, \textbf{"No Good"}\right)$

$\text{CheckLongReinf}_{shr.tor} = \textbf{"OK"}$

Anchor Bolt Strength Check

$Num_{anchor} := 8$ *number of anchor bolts*

$d_{anchor} := 2 \cdot in$ *anchor bolt nominal diameter*

$Dia_{anchor.circle} := 24 \cdot in$ *anchor bolt circle diameter*

$F_{u.anchor} := 105 \cdot ksi$ *anchor bolt specified minimum tensile strength*

$$I_{anchor} := \frac{Dia_{anchor.circle}^{\,2}}{8} \cdot Num_{anchor} = 576 \cdot in^2$$

$$S_{anchor} := \frac{I_{anchor}}{\dfrac{Dia_{anchor.circle}}{2}} = 48 \cdot in$$

$$T_{anchor} := \frac{M_u}{S_{anchor}} = 10.6 \cdot kip$$

anchor tension force

$$V_{anchor} := \frac{V_u}{Num_{anchor}} + \frac{T_u}{0.5 Dia_{anchor.circle} \cdot Num_{anchor}} = 2.2 \cdot kip$$

anchor shear force

$$A_{b.anchor} := \frac{1}{4} \pi \cdot d_{anchor}^{\,2} = 3.1 \cdot in^2$$

anchor bolt nominal area

$$f_{t.anchor} := \frac{T_{anchor}}{A_{b.anchor}} = 3.4 \cdot ksi$$

anchor tensile stress

$$f_{v.anchor} := \frac{V_{anchor}}{A_{b.anchor}} = 0.7 \cdot ksi$$

anchor shear stress

$\phi_{anchor} := 0.75$ *resistance factor* AISC J3-1

$F_{nt} := 0.75 F_{u.anchor} = 78.8 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$F_{nv} := 0.45 F_{u.anchor} = 47.2 \cdot ksi$ *nominal tensile stress* AISC Table J3.2

$\phi R_{nt} := \phi_{anchor} \cdot F_{nt} \cdot A_{b.anchor} = 185.6 \cdot kip$ *design tension strength*

$\phi R_{nv} := \phi_{anchor} \cdot F_{nv} \cdot A_{b.anchor} = 111.3 \cdot kip$ *design sghear strength*

$CheckAnchorT := if\left(\phi R_{nt} \geq T_{anchor}, \text{"OK"}, \text{"No Good"}\right)$ *check tensile rupture*

$CheckAnchorT = \text{"OK"}$

$\text{CheckAnchorV} := \text{if}\left(\phi R_{nv} \geq V_{anchor}, \textbf{"OK"}, \textbf{"No Good"}\right)$

check shear rupture

$\text{CheckAnchorV} = \textbf{"OK"}$

$$F_{ntv} := \textbf{min}\left(\left(\begin{array}{c} F_{nt} \\ 1.3F_{nt} - \dfrac{F_{nt}}{\phi_{anchor} \cdot F_{nv}} \cdot f_{v.anchor} \end{array}\right)\right) = \textbf{78.8} \cdot \text{ksi}$$

nominal tensile stress modified to include the effects of shearing stress

$\phi R_{ntv} := \phi_{anchor} \cdot F_{ntv} \cdot A_{b.anchor} = \textbf{185.6} \cdot \text{kip}$

design tension strength modified to include the effects of shearing stress

$\text{CheckAnchorTV} := \text{if}\left[\left(f_{t.anchor} \leq \textbf{20}\% \cdot F_{nt}\right) + \left(f_{v.anchor} \leq \textbf{20}\% \cdot F_{nv}\right) + \left(\phi R_{ntv} \geq T_{anchor}\right), \textbf{"OK"}, \textbf{"No Good"}\right]$

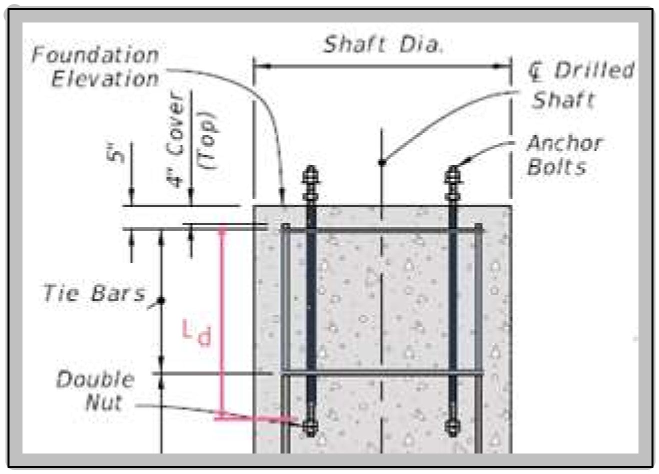
$\text{CheckAnchorTV} = \textbf{"OK"}$

check combined tension and shear rupture

$\text{CheckAnchorStrength} := \text{if}\left[\left(\text{CheckAnchorT} = \textbf{"OK"}\right) \cdot \left(\text{CheckAnchorV} = \textbf{"OK"}\right) \cdot \left(\text{CheckAnchorTV} = \textbf{"OK"}\right), \textbf{"OK"}, \textbf{"No Good"}\right]$

$\text{CheckAnchorStrength} = \textbf{"OK"}$

Anchor Bolt Embedment



$T_{anchor} = \textbf{10.6} \cdot \text{kip}$ *tension force in anchor*

$\text{Dia}_{bar.circle} = \textbf{27.9} \cdot \text{in}$ $\text{Dia}_{anchor.circle} = \textbf{24} \cdot \text{in}$

center-to-center distance

$$\text{Dist}_{bar.to.bolt} := \frac{\text{Dia}_{bar.circle} - \text{Dia}_{anchor.circle}}{\textbf{2}} = \textbf{1.9} \cdot \text{in}$$

$$\text{Num}_{bars.per.anchor} := \min\left(\frac{\text{Num}_{bar}}{\text{Num}_{anchor}}, \textbf{3}\right) = \textbf{1.4}$$

Use a maximum of three rebar per anchor bolt (conservative)

$\phi := \textbf{0.9}$

$$\text{Num}_{bars.reqd.per.anchor} := \frac{T_{anchor}}{A_{long.bar} \cdot \left(\phi \cdot F_{y.rebar}\right)} \cdot \frac{\text{Dia}_{anchor.circle}}{\text{Dia}_{bar.circle}} = \textbf{0.17}$$

$$\text{AreaRatio} := \min\left(\frac{\text{Num}_{bars.reqd.per.anchor}}{\text{Num}_{bars.per.anchor}}, \textbf{1}\right) = \textbf{0.12}$$

2015 AASHTO Development Length of Deformed Bars in Tension 5.11.2.1

$\text{Cover} = \textbf{3} \cdot \text{in}$

$c_b =$ *the smaller of the distance from center of bar or wire being developed to the nearest concrete surface and one half the center-to-center spacing of the bars or wires being developed*

$$c_b := \min\left(\left(\begin{matrix} \text{Cover} + d_{v.bar} + \dfrac{d_{long.bar}}{2} \\ \dfrac{\text{Spacing}_{vert.reinf}}{2} \end{matrix}\right)\right) = 4 \cdot in$$

$k_{tr} := 0 \cdot in$ *assume no transverse bars:*

$$\lambda_{rc} := \min\left[\left[\begin{matrix} 1.0 \\ \max\left(\left(\begin{matrix} 0.4 \\ \dfrac{d_{long.bar}}{c_b + k_{tr}} \end{matrix}\right)\right) \end{matrix}\right]\right] = 0.4$$

LRFD Eqn 5.11.2.1.3-1

$$L_{d.bar} := \max\left(\left(\begin{matrix} 12 \cdot in \\ \lambda_{rc} \cdot 2.4 \cdot d_{long.bar} \cdot \dfrac{F_{y.rebar}}{\sqrt{f_c \cdot ksi}} \end{matrix}\right)\right) = 32.4 \cdot in$$

tension development length ***LRFD Eqn 5.11.2.1.1-2***

$$\text{SpacingFactor} := \max\left[\left(\begin{matrix} 0.5 \\ \text{Num}_{bars.per.anchor} \cdot 0.5 - 0.5 \end{matrix}\right)\right] = 0.5$$

$$L_{embedment.added} := \sqrt{\left(\text{Clearance}_{vert.reinf} \cdot \text{SpacingFactor}\right)^2 + \text{Dist}_{bar.to.bolt}^{\;2}} = 3.9 \cdot in$$

$$L_{embedment.anchor} := \max\left[\left[\begin{matrix} L_{d.bar} \cdot (\text{AreaRatio}) + 12 \cdot in + L_{embedment.added} \\ 20 \cdot d_{anchor} \end{matrix}\right]\right] = 40 \cdot in$$

Note: $20d_{anchor.bolt}$ *minimum embedment is in AASHTO LTS,3rd Ed. 1994, Section 3, 1.3.4 and still a good rule of thumb.*

$L_{embedment.anchor} := \text{Ceil}\left(L_{embedment.anchor}, in\right)$

$L_{embedment.anchor} = 40 \cdot in$

Minimum Anchor Bolts Embedment is 52 in

Anchor Bolt Shear Break-Out Strength

References:
ACI 318-05 Appendix D.
FDOT/University of Florida Report BD545 RPWO #54,
Anchor Embedment Requirements for Signal/Sign Structures, July 2007.

$$r_b := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$$

$$r := \frac{b}{2} = 18 \cdot in$$

$$c_{a1} := \frac{\sqrt{r_b^{\,2} + 3.25 \cdot \left(r^2 - r_b^{\,2}\right)} - r_b}{3.25} = 4.6 \cdot in$$

adjusted cover

UF Report Eqn 3-2

$$L_e := \min\left(\left(\begin{matrix} 8 \cdot d_{anchor} \\ L_{embedment.anchor} \end{matrix}\right)\right) = 16 \cdot in$$

load bearing length of anchor for shear

ACI D.6.2.2

$$V_b := 13 \cdot \left(\frac{L_e}{d_{anchor}}\right)^{0.2} \cdot \sqrt{\frac{d_{anchor}}{in}} \cdot \sqrt{\frac{f_c}{psi}} \left(\frac{c_{a1}}{in}\right)^{1.5} \cdot lbf = 17.5 \cdot kip$$

shear break-out strength (single anchor)
UF Report Eqn 2-11

$$A_{bolt.sector} := \frac{(360 \cdot deg)}{Num_{anchor}} = 45 \cdot deg$$

UF Report Fig 3-7

$$\alpha := 2\,\mathrm{asin}\left[\frac{\left(1.5 \cdot c_{a1}\right)}{r}\right] = 45.2 \cdot deg$$

$$OverlapTest := \mathrm{if}\left(A_{bolt.sector} \le \alpha, \text{"Overlap of Failure Cones"}, \text{"No Overlap of Failure Cones"}\right) = \text{"Overlap of Failur}$$

$$chord := 2 \cdot r \cdot \sin\left(\frac{A_{bolt.sector}}{2}\right) = 13.8 \cdot in$$

UF Report Fig 3-7

$$A_{Vco} := 4.5 \cdot c_{a1}^{\;2} = 95.9 \cdot in^2$$

projected concrete failure area (single anchor)

ACI Eqn D-23

$$A_{Vc} := chord \cdot 1.5 \cdot c_{a1} = 95.4 \cdot in^2$$

projected concrete failure area (group)

ACI D.6.2.1

$$A_{Vc} := \mathrm{if}\left(A_{Vc} > A_{Vco}, A_{Vco}, A_{Vc}\right) = 95.4 \cdot in^2$$

$\psi_{ecV} := \mathbf{1.0}$ *eccentric load modifier* *ACI D.6.2.5*

$\psi_{edV} := \mathbf{1.0}$ *edge effect modifier* *ACI D.6.2.6*

$\psi_{cV} := \mathbf{1.4}$ *cracked section modifier* *ACI D.6.2.7* *(stirrup spacing <= 4")*

$\psi_{hV} := \mathbf{1.0}$ *member thickness modifier* *ACI D.6.2.8*

$\phi_{breakout} := \mathbf{0.75}$ *strength reduction factor* *ACI D.4.4.c.i* *(shear breakout, condition A)*

$V_{cbg} := Num_{anchor} \cdot \left(\frac{A_{Vc}}{A_{Vco}}\right) \cdot \left(\psi_{ecV} \cdot \psi_{edV} \cdot \psi_{cV} \cdot \psi_{hV}\right) \cdot V_b = \mathbf{194.7} \cdot kip$ *concrete breakout strength - shear*

ACI Eqn D-22 *Shear force ⊥ to edge*

$V_{cbg\_parallel} := \mathbf{2} \cdot V_{cbg} = \mathbf{389.5} \cdot kip$ *ACI D.6.2.1.c* *Shear force ∥ to edge*

$T_{n.breakout} := V_{cbg\_parallel} \cdot r_b = \mathbf{389.5} \cdot kip \cdot ft$ *concrete breakout strength - torsion*

$\phi_{breakout} \cdot T_{n.breakout} = \mathbf{292.1} \cdot kip \cdot ft$

$T_u = \mathbf{14.9} \cdot kip \cdot ft$

BreakoutTest := if($\phi_{breakout} \cdot T_{n.breakout} \geq T_u$, **"OK"** , **"No Good"**)

BreakoutTest = **"OK"**

OverlapDesign := if($A_{bolt.sector} \leq \alpha$, **"Based on Overlap of Failure Cones"** , **"Based on No Overlap of Failure Cones"**)

OverlapDesign = **"Based on Overlap of Failure Cones"**

Clearance Between Vertical Reinforcement and Anchor Bolt Nut

$Dist_{bar.to.bolt} = \mathbf{1.9} \cdot in$ *center-to-center distance*

$d_{anchor.nut} := \mathbf{1.85} \cdot d_{anchor} = \mathbf{3.7} \cdot in$ *use* $\mathbf{1.85} \cdot d_{anchor}$ *.to account for anchor nut*

$$Clearance_{bar.to.nut} := Dist_{bar.to.bolt} - \left(\frac{d_{anchor.nut} + d_{long.bar}}{\mathbf{2}}\right) = -\mathbf{0.5} \cdot in$$

CheckAnchorageClearance := if[($Clearance_{bar.to.nut} \geq \mathbf{2} \cdot in$), **"OK"** , **"No Good, increase ped. diameter"**]

CSL tubes can be relocated plus/minus 2 inches from planned position (see Specifications)

$d_{csl.tube} := 2 \cdot in$

$Clearance_{csl.to.nut} := Dist_{bar.to.bolt} + 0.5 \cdot d_{long.bar} - d_{csl.tube} - 0.5 \cdot d_{anchor.nut} = -1.3 \cdot in$

References

LRFD = AASHTO LRFD Bridge Design Specifications

LTS = AASHTO LRFD Luminaire, Traffic Signal, and Sign Structure Specifications.

SM = FDOT Structures Manual

SDG = FDOT Structures Design Guidelines

Spec = FDOT Standard Specifications

ACI = ACI 318 Structural Concrete Building Code

UF Report = FDOT/University of Florida Report BD545 RPWO #54

find coordinates to draw Plan view of plate clearance

$pt := 0 .. 48 \qquad r_{ds} := \frac{b}{2}$

$xds_{pt} := r_{ds} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yds_{pt} := r_{ds} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{v.od} := \frac{b}{2} - 6 \cdot in \qquad r_{v.id} := \frac{b}{2} - 6 \cdot in - d_{v.bar}$

$xstir.od_{pt} := r_{v.od} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.od_{pt} := r_{v.od} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$xstir.id_{pt} := r_{v.id} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad ystir.id_{pt} := r_{v.id} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{bar} := \frac{d_{long.bar}}{2} = 0.6 \cdot in$

$xbar_{pt} := r_{bar} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] + \max(xstir.id) - d_{v.bar} \qquad ybar_{pt} := r_{bar} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$r_{boltcircle} := \frac{Dia_{anchor.circle}}{2} = 12 \cdot in$

$xboltcircle_{pt} := r_{boltcircle} \cdot \cos\left[(2 \cdot \pi) \cdot \frac{pt}{48} + \frac{2 \cdot \pi}{48}\right] \qquad yboltcircle_{pt} := r_{boltcircle} \cdot \sin\left[\left(2 \cdot \pi \cdot \frac{pt}{48}\right) + \frac{2 \cdot \pi}{48}\right]$

$$r_{boltr} := \frac{d_{anchor}}{2} = \mathbf{1}\cdot in$$

$$x_{bolt_{pt}} := r_{boltr}\cdot\cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{48}} + \frac{\mathbf{2}\cdot\pi}{\mathbf{48}}\right] + \left(\max\left(x_{boltcircle}\right)\right) \qquad y_{bolt_{pt}} := r_{boltr}\cdot\sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{48}}\right) + \frac{\mathbf{2}\cdot\pi}{\mathbf{48}}\right]$$

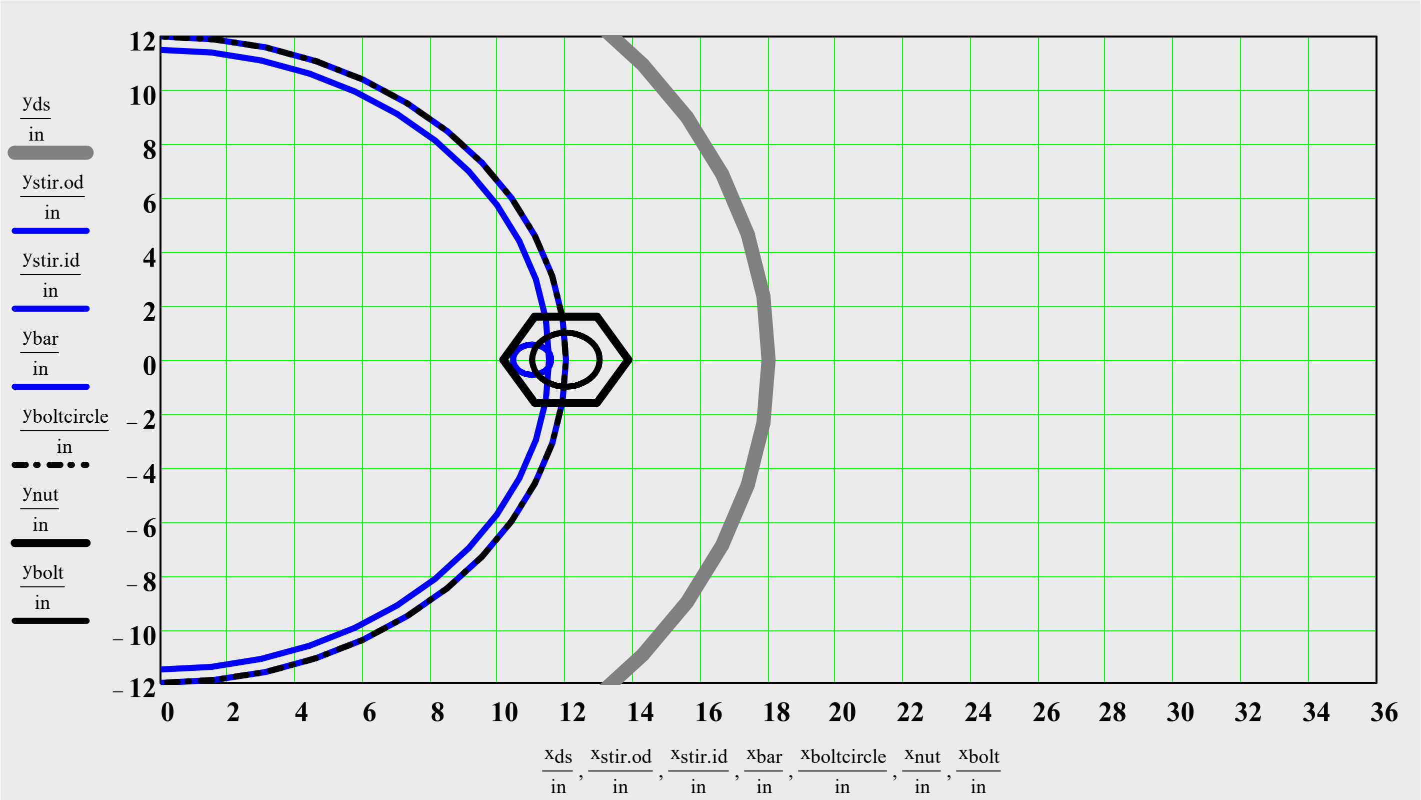
$$pt := \mathbf{0}\,..\,\mathbf{6} \qquad r_{nut} := \frac{d_{anchor}\cdot 1.85}{\mathbf{2}} = \mathbf{1.9}\cdot in$$

$$x_{nut_{pt}} := r_{nut}\cdot\cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{6}} + \frac{\mathbf{2}\cdot\pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right) \qquad y_{nut_{pt}} := r_{nut}\cdot\sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{2}\cdot\pi}{\mathbf{6}}\right]$$

$$x_{nut_{pt}} := r_{nut}\cdot\cos\left[(\mathbf{2}\cdot\pi)\cdot\frac{pt}{\mathbf{6}} + \frac{\mathbf{1}\cdot\pi}{\mathbf{6}}\right] + \left(\max\left(x_{boltcircle}\right)\right) \qquad y_{nut_{pt}} := r_{nut}\cdot\sin\left[\left(\mathbf{2}\cdot\pi\cdot\frac{pt}{\mathbf{6}}\right) + \frac{\mathbf{1}\cdot\pi}{\mathbf{6}}\right]$$

enable to rotate nut

$$\min\left(x_{bar}\right) - \max\left(x_{nut}\right) = -\mathbf{3.4}\cdot in$$



$$Bolts := \begin{pmatrix} \mathbf{1} & \mathbf{1.125} & \mathbf{1.25} & \mathbf{1.375} & \mathbf{1.5} & \mathbf{1.625} & \mathbf{1.75} & \mathbf{1.875} & \mathbf{2} & \mathbf{2.25} & \mathbf{2.5} & \mathbf{2.75} & \mathbf{3} \\ \mathbf{1.5} & \mathbf{1.688} & \mathbf{1.875} & \mathbf{2.063} & \mathbf{2.25} & \mathbf{2.438} & \mathbf{2.625} & \mathbf{2.938} & \mathbf{3} & \mathbf{3.375} & \mathbf{3.75} & \mathbf{4.125} & \mathbf{4.25} \end{pmatrix}\cdot in$$

$$\left(Bolts^{T}\right)^{\langle\mathbf{0}\rangle^{T}}\cdot\mathbf{1.6} - \left(Bolts^{T}\right)^{\langle\mathbf{1}\rangle^{T}} = \begin{pmatrix} \mathbf{0.1} & \mathbf{0.112} & \mathbf{0.125} & \mathbf{0.137} & \mathbf{0.15} & \mathbf{0.162} & \mathbf{0.175} & \mathbf{0.062} & \mathbf{0.2} & \mathbf{0.225} & \mathbf{0.25} & \mathbf{0.275} & \mathbf{0.55} \end{pmatrix}\cdot in$$

$$\left(Bolts^{T}\right)^{\langle\mathbf{0}\rangle^{T}} - \left(Bolts^{T}\right)^{\langle\mathbf{1}\rangle^{T}} = \begin{pmatrix} -\mathbf{0.5} & -\mathbf{0.563} & -\mathbf{0.625} & -\mathbf{0.688} & -\mathbf{0.75} & -\mathbf{0.813} & -\mathbf{0.875} & -\mathbf{1.063} & -\mathbf{1} & -\mathbf{1.125} & -\mathbf{1.25} & -\mathbf{1.375} & -\mathbf{1.25} \end{pmatrix}\cdot$$