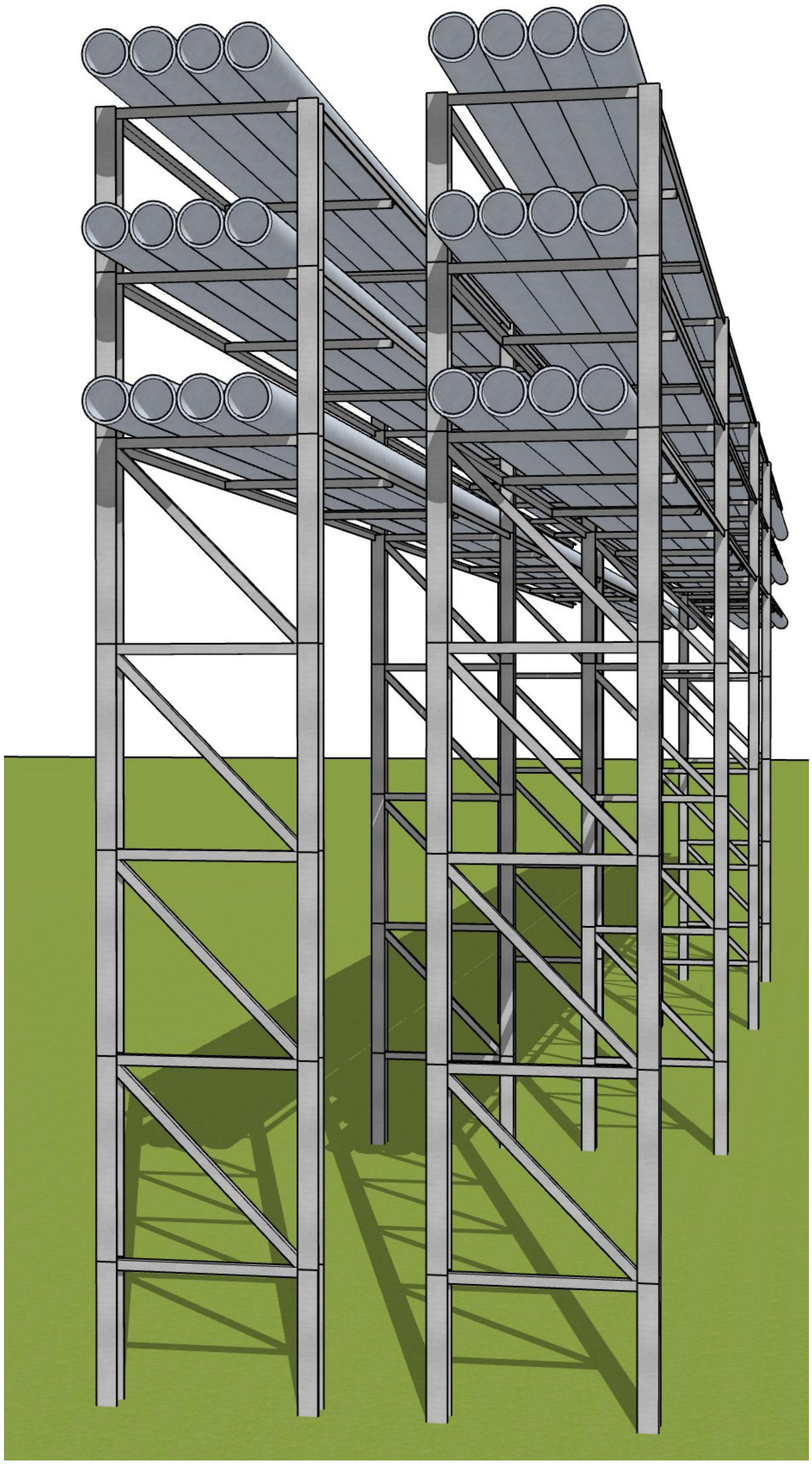
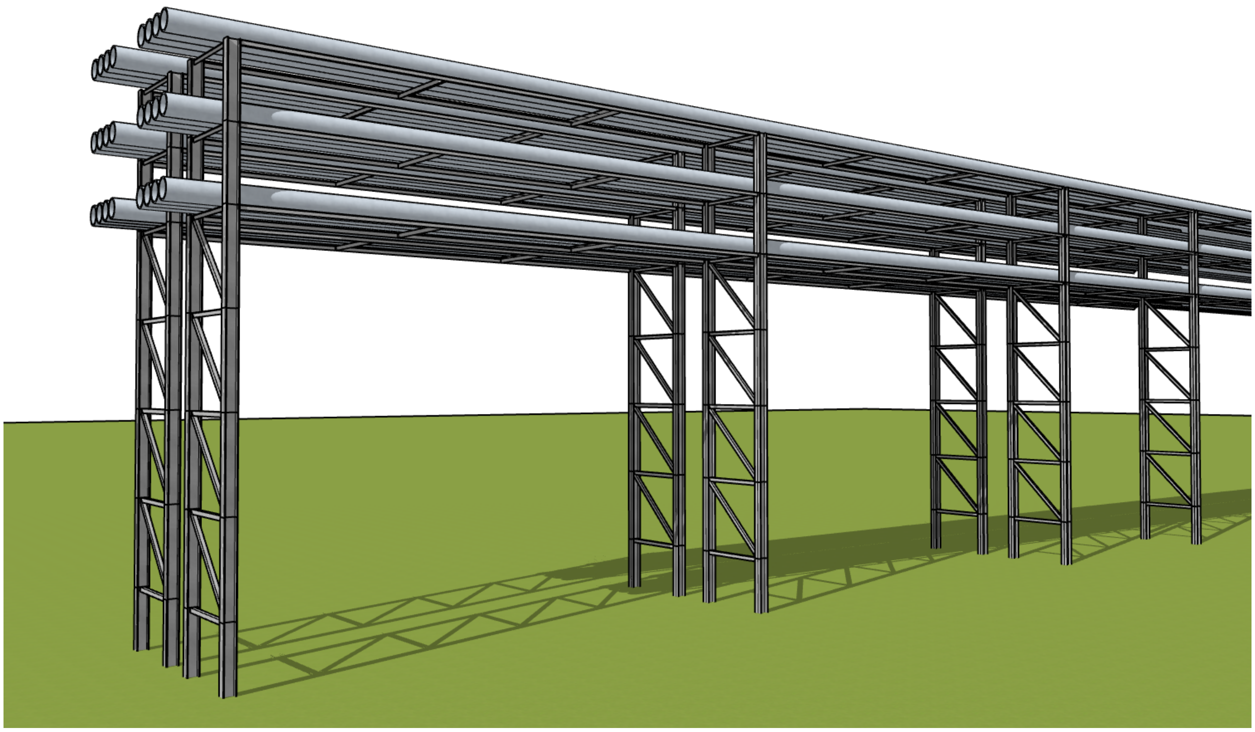
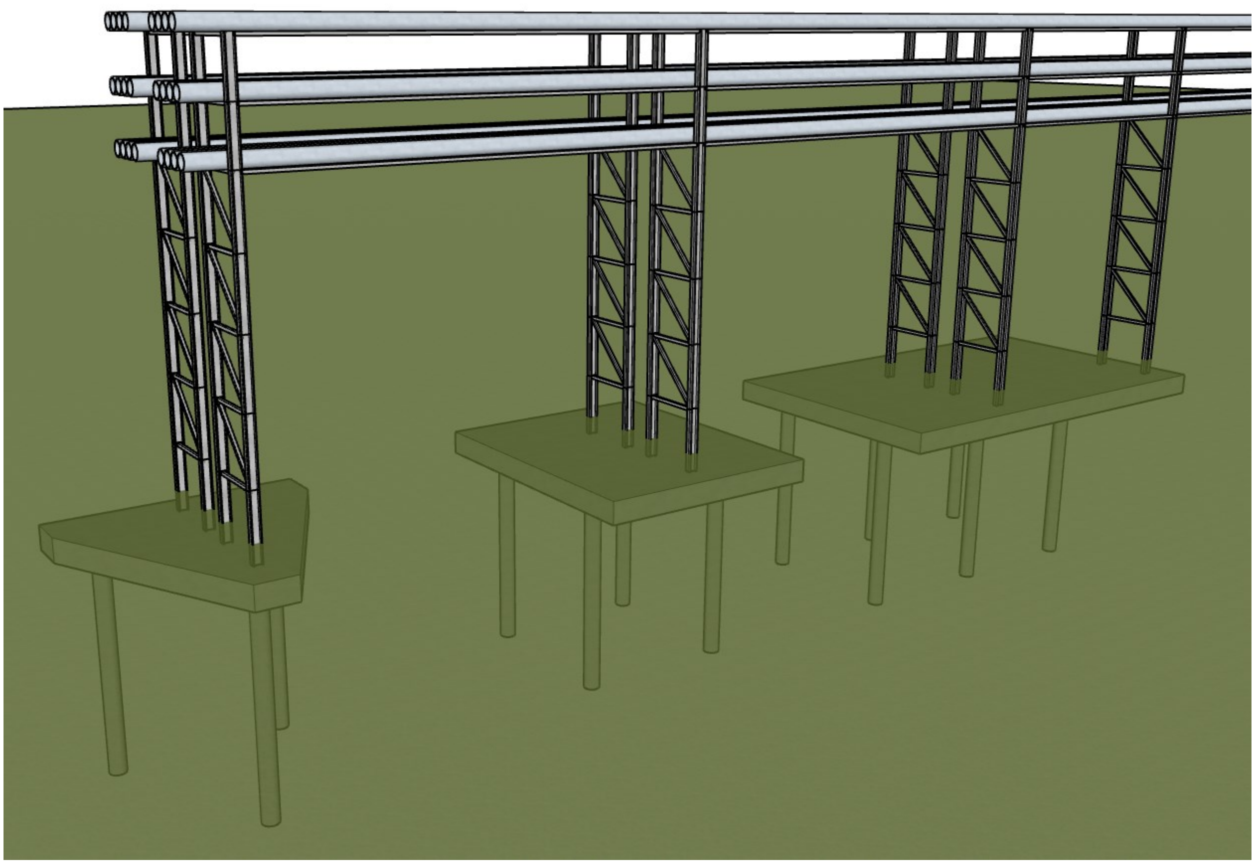
Industrial Plant Pipe Rack Foundations Analysis and Design







Industrial Plant Pipe Rack Foundations Analysis and Design

Industrial pipe racks typically support pipes, power cables and instrument cable trays in petrochemical, chemical, paper mills and power plants. Occasionally, pipe racks may also support mechanical equipment, vessels and valve access platforms. Main pipe racks generally transfer process material between equipment and storage or utility areas where operation specific load cases and temperature effect often complicates the structural analysis and the resulting foundation reactions. Storage racks found in warehouses are not pipe racks, even if they store lengths of pipe. This case study focuses on the design of pipe rack foundations using the engineering software program spMats. All the information provided by the sturcutral engineer regarding the pipe rack foundations are shown in the following figure and design data section and will serve as input for foundation design. Because of poor soil conditions at the site and tower height, significant uplift is expected and a pile supported foundation is selected to resist the design overturning moments. 30” diameter piles are assembled in pile caps as shown in the following figures.

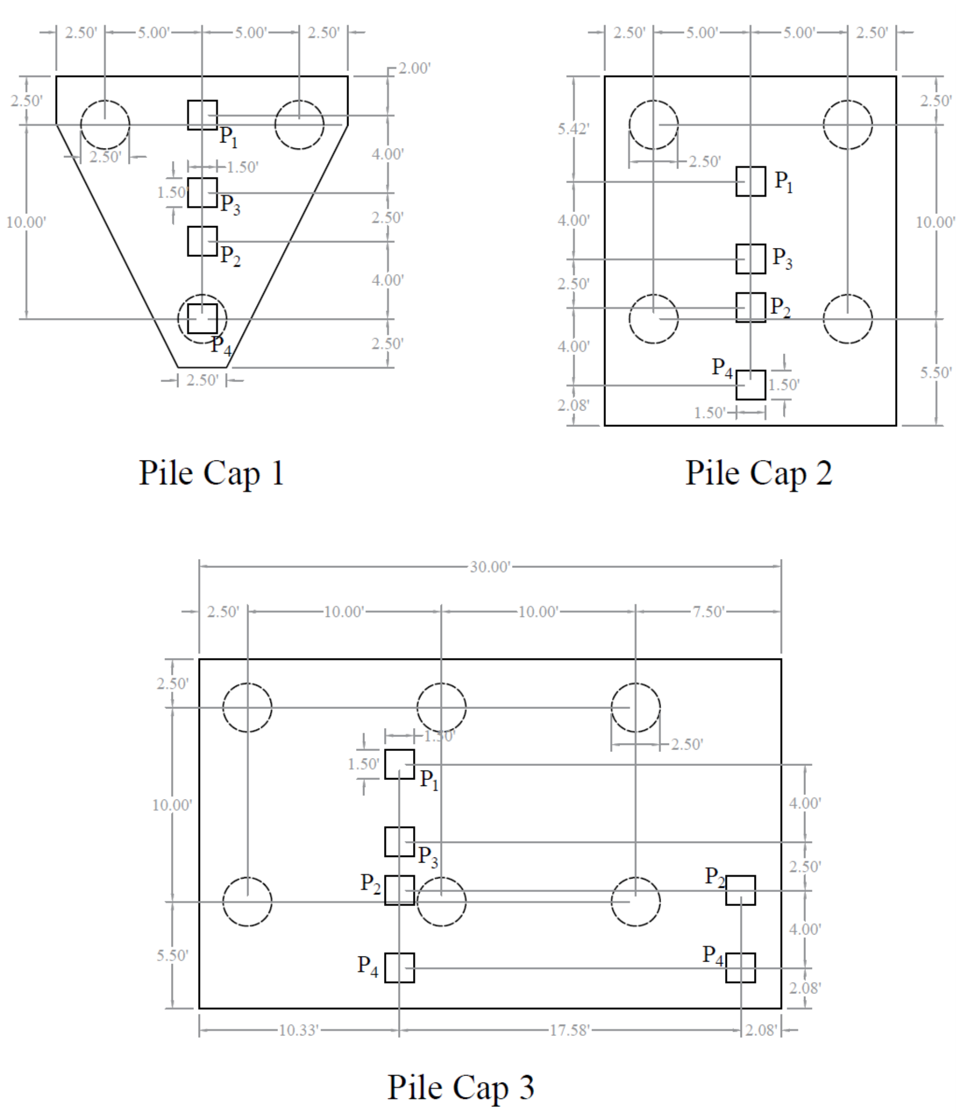


Figure 1 – Industrial Plant Pile Cap Foundations Types

Code

Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)

Reference

spMats Engineering Software Program Manual v8.50, StucturePoint LLC., 2016

Design Data

Concrete Piers

Size = 1.5 ft x 1.5 ft

Pile Cap Foundations

f_c' = 3,000 psi

f_y = 60,000 psi

Thickness = 3 ft

Clear Cover = 2 in.

Concrete Piles

f_c' = 4,000 psi

f_y = 60,000 psi

Diameter = 2.5 ft

Clear Cover = 3 in.

Length = 33 ft

Pile embedment = 6 in.

Foundation Loads

Load Case	Load*, kips			
	P_1	P_2	P_3	P_4
Dead	-6**	65	165	4
Live	251	35	85	-45**
Wind	40	-160**	-35**	160

* Load locations are shown in the following figure
** Negative values indicate uplift loads

Contents

1. Foundation Analysis and Design – spMats Software

spMats uses the Finite Element Method for the structural modeling, analysis and design of reinforced concrete slab systems or mat foundations subject to static loading conditions.

The slab, mat, or footing is idealized as a mesh of rectangular elements interconnected at the corner nodes. The same mesh applies to the underlying soil with the soil stiffness concentrated at the nodes. Slabs of irregular geometry can be idealized to conform to geometry with rectangular boundaries. Even though slab and soil properties can vary between elements, they are assumed uniform within each element. Piles are modeled as springs connected to the nodes of the finite element model. Unlike for springs, however, punching shear check is performed around piles.

For illustration and purposes, the following figures provide a sample of the input modules and results obtained from spMats models created for the industrial plant pipe rack foundations (pile caps) in this example.

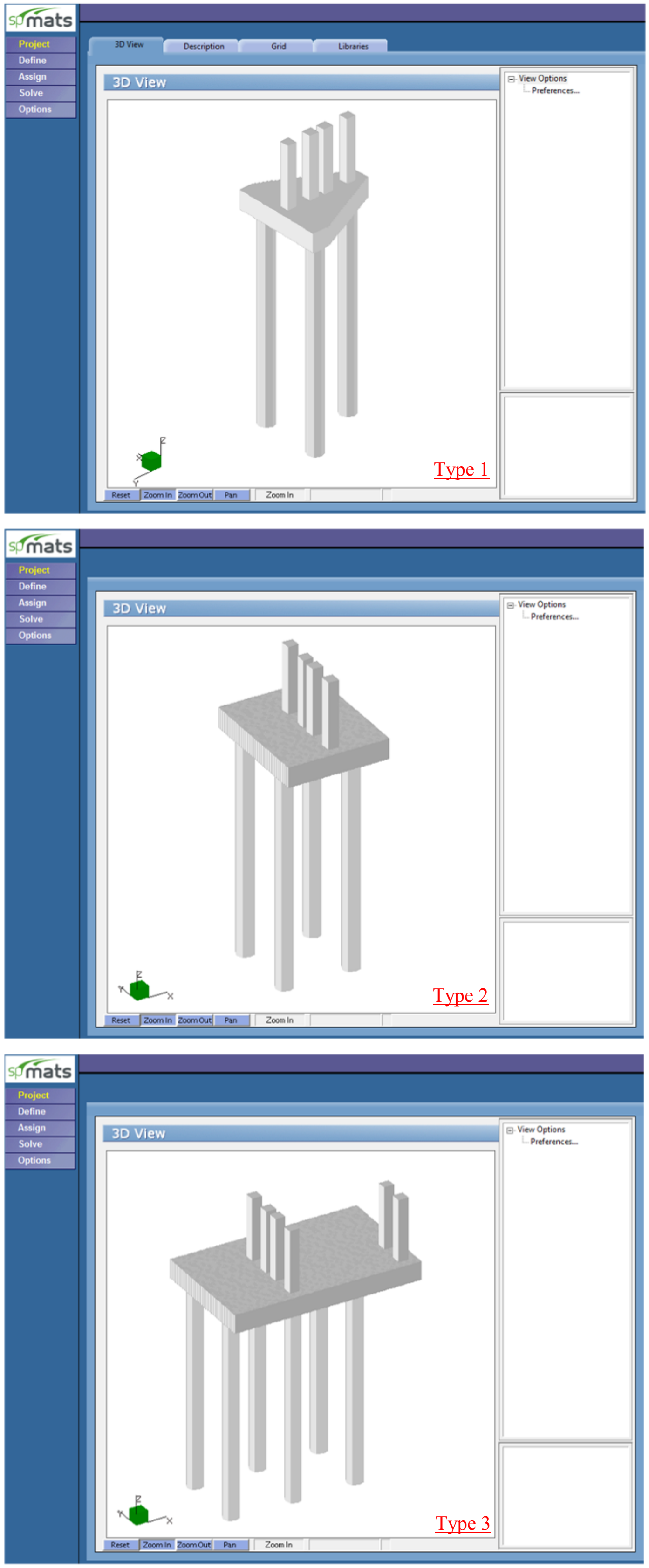


Figure 2 – Pipe Rack Foundation Model - 3D Views

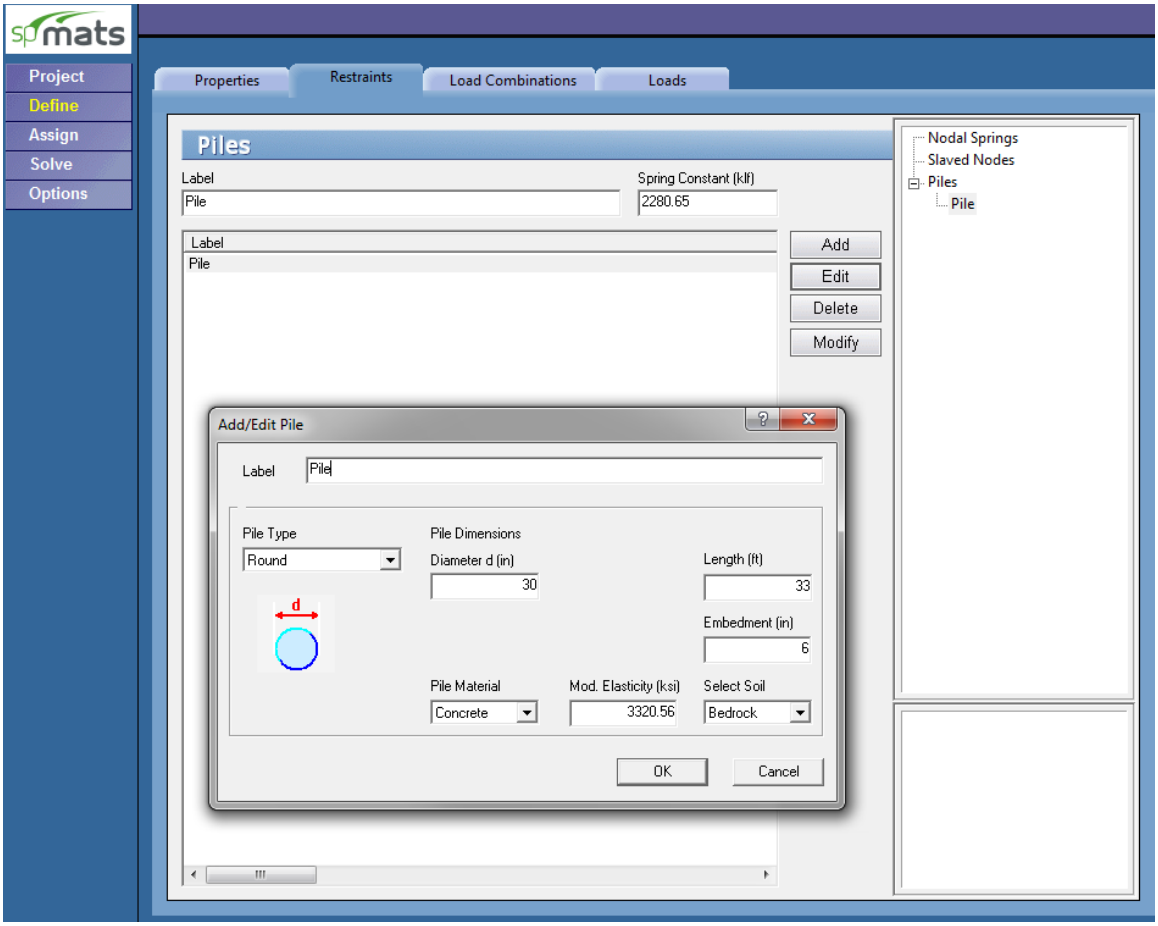


Figure 3 –Defining Piles

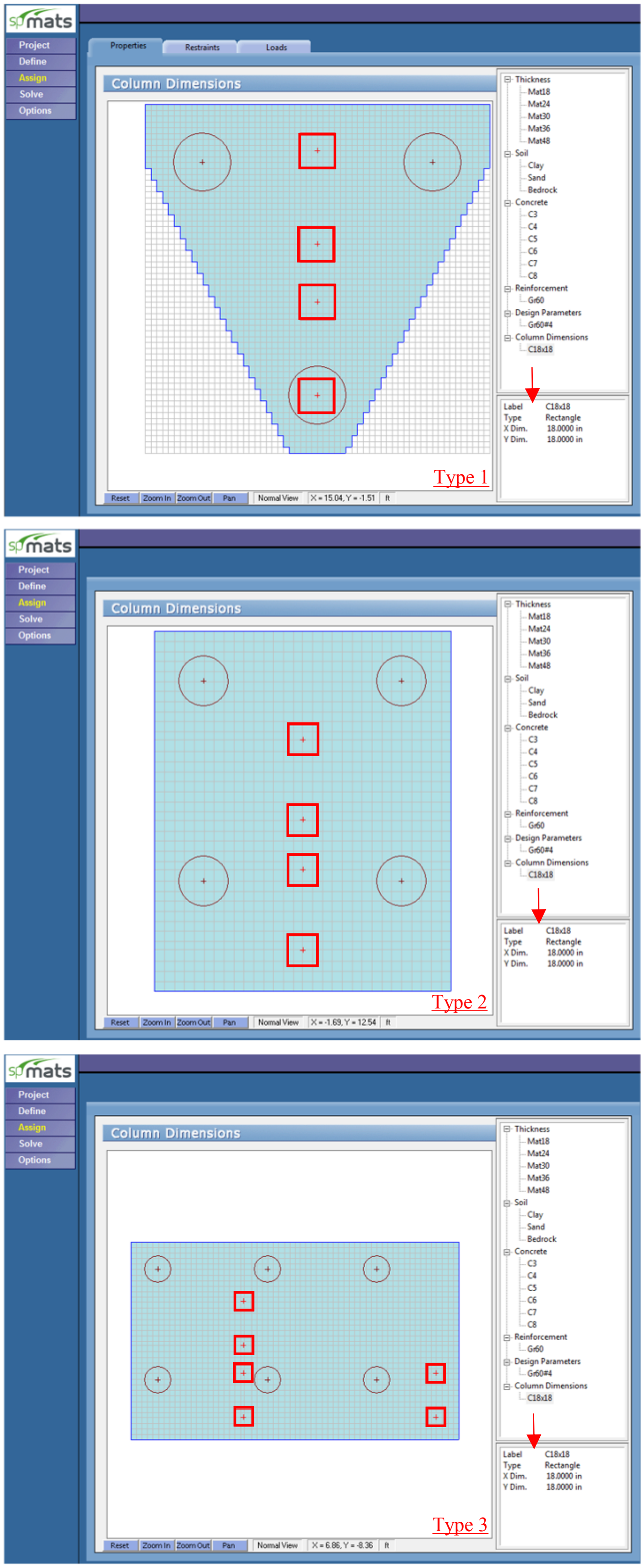


Figure 4 – Assigning Concrete Piers

Figure 5 – Assigning Piles

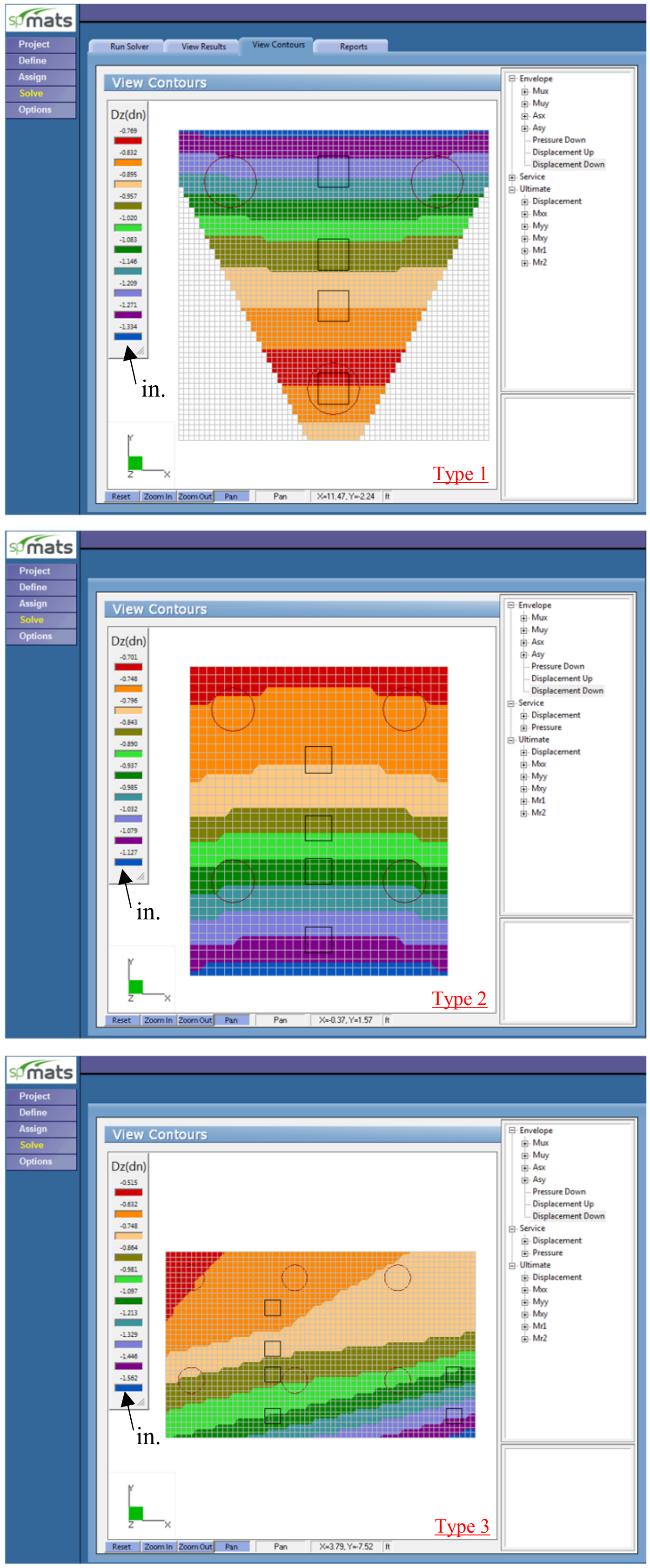


Figure 6 – Vertical Displacement Contours (Note cantilevered corner displacement)

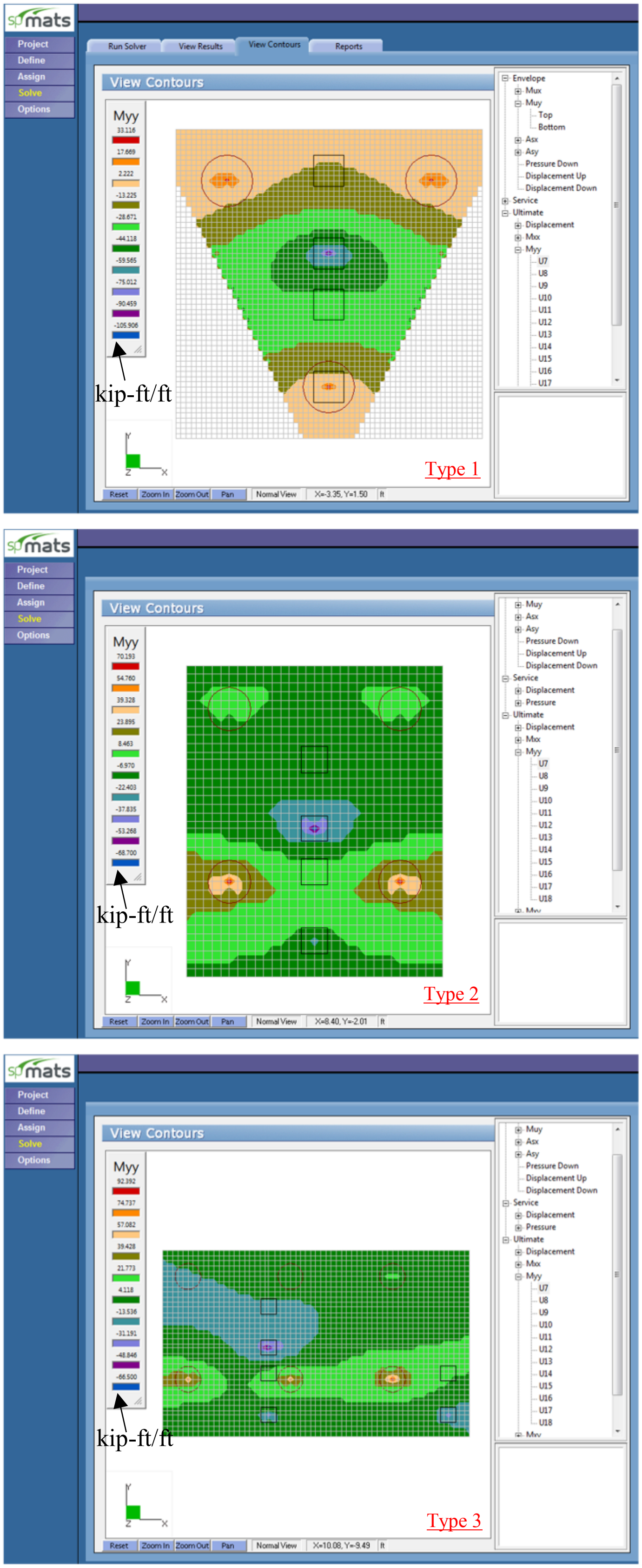


Figure 7 –Moment Contours along Y-Axis

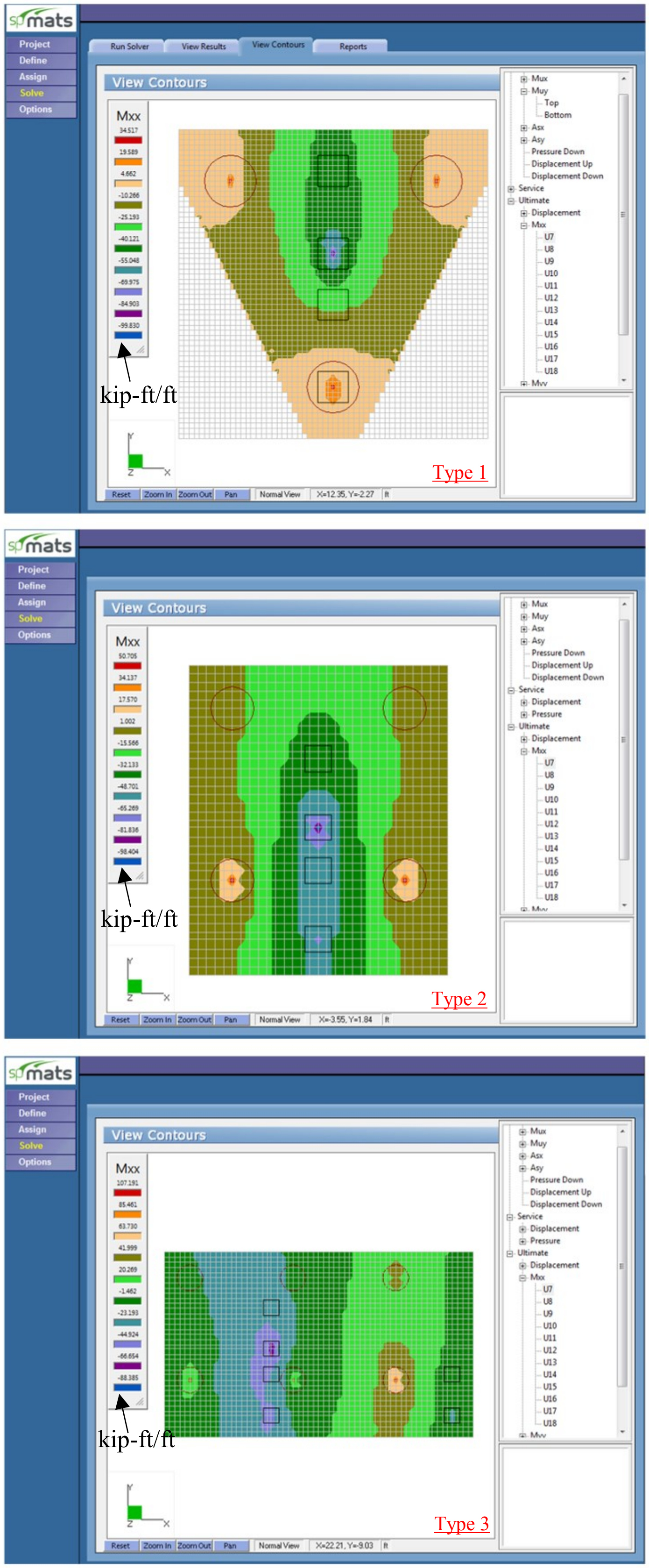


Figure 8 – Moment Contours along X-Axis - Complete Model

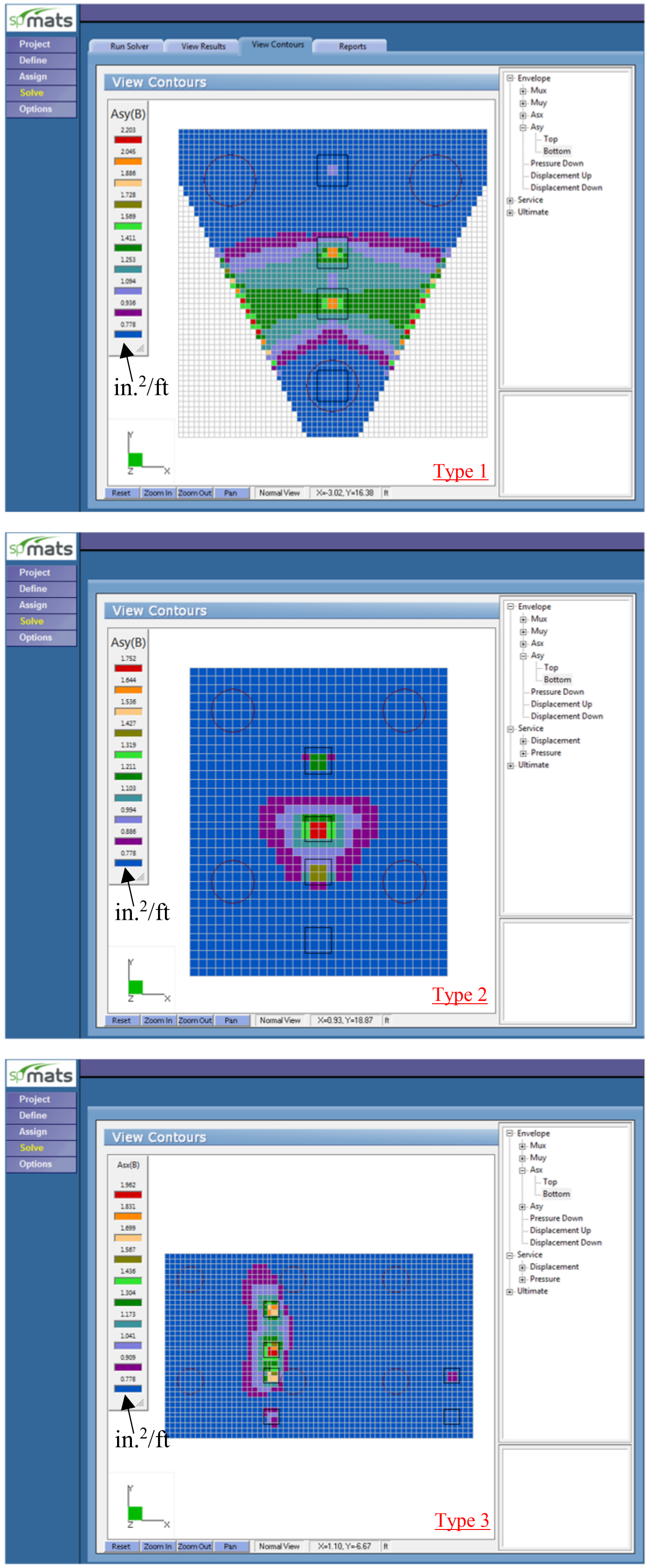


Figure 9 – Required Reinforcement Contours along Y Direction

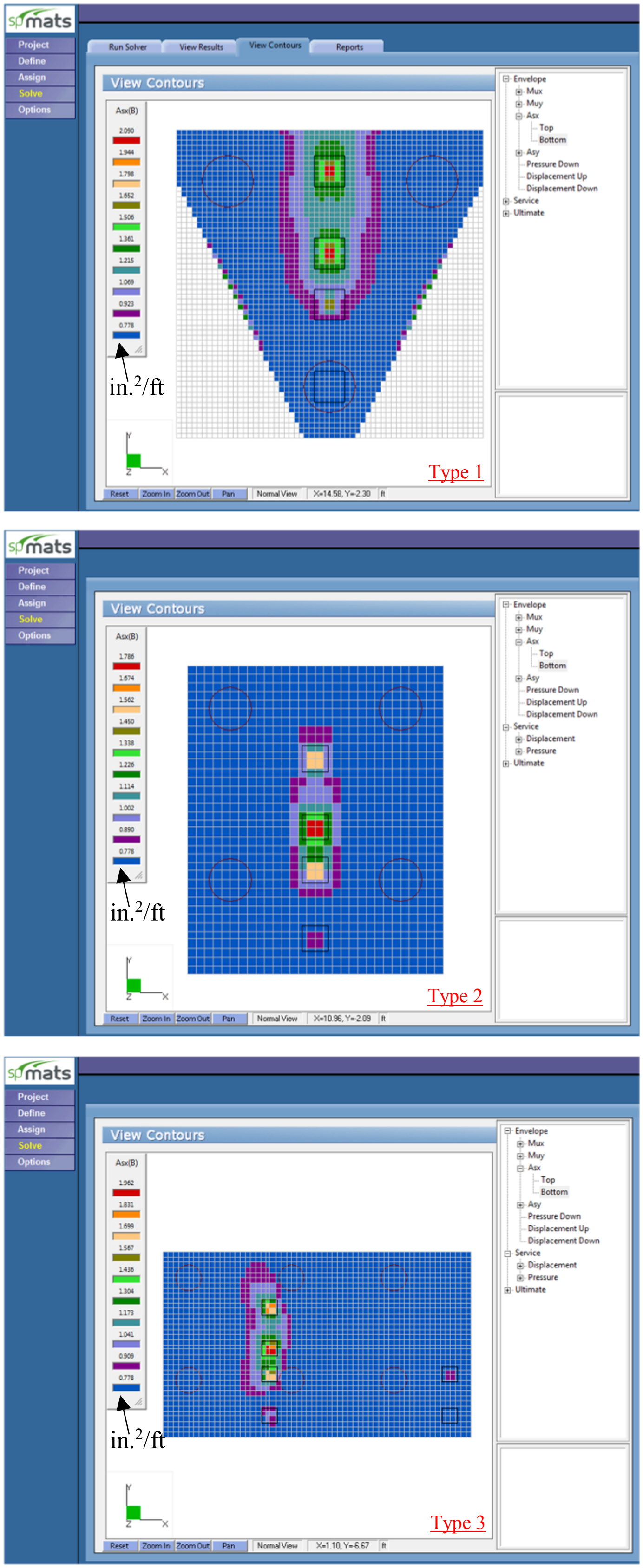


Figure 10 – Required Reinforcement Contours along X Direction

2. Two-way Punching Shear Check

According to ACI 312-14 (R13.2.7.2), if shear perimeters overlap, the modified critical perimeter should be taken as that portion of the smallest envelope of individual shear perimeters that will actually resist the critical shear for group under consideration. spMats reports standard shear perimeter for three conditions (interior, edge, and corner) only considering adequate spacing and edge distance is provided to prevent overlapping or truncated shear perimeter.

Type 1

```
B6 - Punching Shear Around Columns (Ultimate Load Combinations):
==================================================================
Units --> Applied Shear Force Vu (kips), Applied Moments Mux, Muy (k-ft)
          Factored Shear Stress vu (psi), Factored Shear Resistance Phi*vc (psi)
          Concrete Strength f'c (psi), distances X_Offset, Y_Offset (ft)
          Average depth (in), Dimensions Bx, By (ft)
          Area (in^2), Jxx, Jyy, Jxy (in^4)

Geometry of Resisting Area
--------------------------
       _________Column__________ Average  ___Dimensions____  _____Centroid____
 Node      Label        Location  Depth      Bx       By    X_Offset Y_Offset
 ----- ------------- -------- -------- -------- -------- -------- --------
  171 C18x18          Inner       27.75     3.81     3.81    -0.00    -0.00
  643 C18x18          Inner       27.75     3.81     3.81    -0.00    -0.00
 1068 C18x18          Inner       27.75     3.81     3.81    -0.00    -0.00
 1953 C18x18          Inner       27.75     3.81     3.81    -0.00    -0.00

Properties of Resisting Area
----------------------------
 Node  Column Label      Area         Jxx          Jyy          Jxy
 ----- ------------- ---------- ------------ ------------ ------------
  171 C18x18           5078.25   1934456.00   1934456.00        -0.00
  643 C18x18           5078.25   1934456.00   1934456.00        -0.00
 1068 C18x18           5078.25   1934456.00   1934456.00         0.00
 1953 C18x18           5078.25   1934456.00   1934456.00         0.00

Ultimate Load Combination: U7
-----------------------------

  Factored Applied Forces:
  ------------------------
   Node  Column Label       Vu            Mux       Gamma_X       Muy       Gamma_Y
   ----- ------------- ---------- -------------- ------- -------------- -------
    171 C18x18              86.92            0.0   0.400            0.0   0.400
    643 C18x18               2.00           -0.0   0.400            0.0   0.400
   1068 C18x18            -180.50            0.0   0.400            0.0   0.400
   1953 C18x18             -12.80            0.0   0.400            0.0   0.400

  Factored Stress and Capacity:
  -----------------------------
                                                          _Critical Point__
   Node  Column Label       vu         f'c       Phi*vc   X_Offset Y_Offset Status
   ----- ------------- ---------- ---------- ---------- -------- -------- ------
    171 C18x18              17.12    3000.00     164.32     1.91     1.91   Safe
    643 C18x18               0.39    3000.00     164.32     1.91    -1.91   Safe
   1068 C18x18             -35.54    3000.00     164.32     1.91     1.91   Safe
   1953 C18x18              -2.52    3000.00     164.32     1.91    -1.91   Safe
```

Type 2

```
B6 - Punching Shear Around Columns (Ultimate Load Combinations):
==================================================================
Units --> Applied Shear Force Vu (kips), Applied Moments Mux, Muy (k-ft)
          Factored Shear Stress vu (psi), Factored Shear Resistance Phi*vc (psi)
          Concrete Strength f'c (psi), distances X_Offset, Y_Offset (ft)
          Average depth (in), Dimensions Bx, By (ft)
          Area (in^2), Jxx, Jyy, Jxy (in^4)

Geometry of Resisting Area
--------------------------
       _________Column__________ Average  ___Dimensions____  _____Centroid____
 Node      Label        Location  Depth      Bx       By    X_Offset Y_Offset
 ----- ------------- -------- -------- -------- -------- -------- --------
  140 C18x18          Inner       27.75     3.81     3.81    -0.00    -0.00
  388 C18x18          Inner       27.75     3.81     3.81    -0.00    -0.00
  543 C18x18          Inner       27.75     3.81     3.81    -0.00     0.00
  791 C18x18          Inner       27.75     3.81     3.81    -0.00    -0.00

Properties of Resisting Area
----------------------------
 Node  Column Label      Area         Jxx          Jyy          Jxy
 ----- ------------- ---------- ------------ ------------ ------------
  140 C18x18           5078.25   1934456.00   1934456.00         0.00
  388 C18x18           5078.25   1934456.00   1934456.00         0.00
  543 C18x18           5078.25   1934456.00   1934456.00         0.00
  791 C18x18           5078.25   1934456.00   1934456.00         0.00

Ultimate Load Combination: U7
-----------------------------

  Factored Applied Forces:
  ------------------------
   Node  Column Label       Vu            Mux       Gamma_X       Muy       Gamma_Y
   ----- ------------- ---------- -------------- ------- -------------- -------
    140 C18x18             -84.80           -0.0   0.400            0.0   0.400
    388 C18x18               2.00           -0.0   0.400            0.0   0.400
    543 C18x18            -180.50           -0.0   0.400            0.0   0.400
    791 C18x18             -12.80            0.0   0.400            0.0   0.400

  Factored Stress and Capacity:
  -----------------------------
                                                          _Critical Point__
   Node  Column Label       vu         f'c       Phi*vc   X_Offset Y_Offset Status
   ----- ------------- ---------- ---------- ---------- -------- -------- ------
    140 C18x18             -16.70    3000.00     164.32     1.91     1.91   Safe
    388 C18x18               0.39    3000.00     164.32     1.91    -1.91   Safe
    543 C18x18             -35.54    3000.00     164.32     1.91     1.91   Safe
    791 C18x18              -2.52    3000.00     164.32     1.91     1.91   Safe
```

Type 3

```
B6 - Punching Shear Around Columns (Ultimate Load Combinations):
==================================================================
Units --> Applied Shear Force Vu (kips), Applied Moments Mux, Muy (k-ft)
          Factored Shear Stress vu (psi), Factored Shear Resistance Phi*vc (psi)
          Concrete Strength f'c (psi), distances X_Offset, Y_Offset (ft)
          Average depth (in), Dimensions Bx, By (ft)
          Area (in^2), Jxx, Jyy, Jxy (in^4)

Geometry of Resisting Area
--------------------------
       _________Column__________ Average  ___Dimensions____  _____Centroid____
 Node      Label        Location  Depth      Bx       By    X_Offset Y_Offset
 ----- ------------- -------- -------- -------- -------- -------- --------
  266 C18x18          Inner       27.75     3.81     3.81     0.00    -0.00
  301 C18x18          Inner       27.75     3.81     3.81     0.00    -0.00
  754 C18x18          Inner       27.75     3.81     3.81     0.00    -0.00
  789 C18x18          Inner       27.75     3.81     3.81     0.00    -0.00
 1059 C18x18          Inner       27.75     3.81     3.81     0.00     0.00
 1547 C18x18          Inner       27.75     3.81     3.81     0.00    -0.00

Properties of Resisting Area
----------------------------
 Node  Column Label      Area         Jxx          Jyy          Jxy
 ----- ------------- ---------- ------------ ------------ ------------
  266 C18x18           5078.25   1934456.00   1934456.00         0.00
  301 C18x18           5078.25   1934456.00   1934456.00         0.00
  754 C18x18           5078.25   1934456.00   1934456.00         0.00
  789 C18x18           5078.25   1934456.00   1934456.00         0.00
 1059 C18x18           5078.25   1934456.00   1934456.00         0.00
 1547 C18x18           5078.25   1934456.00   1934456.00         0.00

Ultimate Load Combination: U7
-----------------------------

  Factored Applied Forces:
  ------------------------
   Node  Column Label       Vu            Mux       Gamma_X       Muy       Gamma_Y
   ----- ------------- ---------- -------------- ------- -------------- -------
    266 C18x18             -84.80            0.0   0.400            0.0   0.400
    301 C18x18             -84.80            0.0   0.400            0.0   0.400
    754 C18x18               2.00           -0.0   0.400           -0.0   0.400
    789 C18x18               2.00           -0.0   0.400            0.0   0.400
   1059 C18x18            -180.50           -0.0   0.400            0.0   0.400
   1547 C18x18             -12.80            0.0   0.400            0.0   0.400

  Factored Stress and Capacity:
  -----------------------------
                                                          _Critical Point__
   Node  Column Label       vu         f'c       Phi*vc   X_Offset Y_Offset Status
   ----- ------------- ---------- ---------- ---------- -------- -------- ------
    266 C18x18             -16.70    3000.00     164.32     1.91     1.91   Safe
    301 C18x18             -16.70    3000.00     164.32     1.91     1.91   Safe
    754 C18x18               0.39    3000.00     164.32     1.91    -1.91   Safe
    789 C18x18               0.39    3000.00     164.32     1.91    -1.91   Safe
   1059 C18x18             -35.54    3000.00     164.32     1.91     1.91   Safe
   1547 C18x18              -2.52    3000.00     164.32     1.91     1.91   Safe
```

Figure 11 – Two-Way Shear Results around Concrete Piers

Type 1

```
B7 - Punching Shear Around Piles (Ultimate Load Combinations):
===============================================================
Units --> Applied Shear Force Vu (kips), Applied Moments Mux, Muy (k-ft)
          Factored Shear Stress vu (psi), Factored Shear Resistance vc (psi)
          Concrete Strength f'c (psi), distances X_Offset, Y_Offset (ft)
          Average depth (in), Dimensions Bx, By (ft)
          Area (in^2), Jxx, Jyy, Jxy (in^4)

Geometry of Resisting Area
--------------------------
       ___________Pile___________ Average  ___Dimensions____ ______Centroid____
 Node      Label         Location  Depth      Bx       By    X_Offset Y_Offset
----- -------------- -------- -------- -------- -------- -------- --------
  171 Pile            Inner       27.75     4.81     4.81    -0.00    -0.00
 1811 Pile            Inner       27.75     4.81     4.81    -0.00    -0.00
 1851 Pile            Inner       27.75     4.81     4.81    -0.00    -0.00

Properties of Resisting Area
----------------------------
 Node Pile Label          Area        Jxx              Jyy          Jxy
----- -------------- ---------- ------------ ------------ ------------
  171 Pile             5029.43   2249450.50   2249450.00         0.00
 1811 Pile             5029.43   2249450.25   2249450.00         0.00
 1851 Pile             5029.42   2249450.00   2249450.00         0.00

Ultimate Load Combination: U7
-----------------------------

  Factored Applied Forces:
  ------------------------
   Node  Pile Label          Vu            Mux    Gamma_X          Muy    Gamma_Y
  ----- -------------- ---------- -------------- ------- -------------- -------
    171 Pile               86.92           -0.0   0.400            0.0   0.400
   1811 Pile               91.85            0.0   0.400            0.0   0.400
   1851 Pile               91.85            0.0   0.400           -0.0   0.400

  Factored Stress and Capacity:
  -----------------------------
                                                      _Critical Point__
  Node   Pile Label         vu         f'c    Phi*vc  X_Offset Y_Offset Status
  ----- -------------- ---------- ---------- ---------- -------- -------- ------
   171 Pile                17.28    3000.00    164.32    -2.38    -0.38   Safe
  1811 Pile                18.26    3000.00    164.32    -2.41     0.00   Safe
  1851 Pile                18.26    3000.00    164.32     1.41     1.95   Safe
```

Type 2

```
B7 - Punching Shear Around Piles (Ultimate Load Combinations):
===============================================================
Units --> Applied Shear Force Vu (kips), Applied Moments Mux, Muy (k-ft)
          Factored Shear Stress vu (psi), Factored Shear Resistance vc (psi)
          Concrete Strength f'c (psi), distances X_Offset, Y_Offset (ft)
          Average depth (in), Dimensions Bx, By (ft)
          Area (in^2), Jxx, Jyy, Jxy (in^4)

Geometry of Resisting Area
--------------------------
       ___________Pile___________ Average  ___Dimensions____ ______Centroid____
 Node      Label         Location  Depth      Bx       By    X_Offset Y_Offset
----- -------------- -------- -------- -------- -------- -------- --------
  347 Pile            Inner       27.75     4.81     4.81    -0.00    -0.00
  367 Pile            Inner       27.75     4.81     4.81    -0.00    -0.00
  967 Pile            Inner       27.75     4.81     4.81    -0.00    -0.00
  987 Pile            Inner       27.75     4.81     4.81    -0.00    -0.00

Properties of Resisting Area
----------------------------
 Node Pile Label          Area        Jxx              Jyy          Jxy
----- -------------- ---------- ------------ ------------ ------------
  347 Pile             5029.42   2249450.25   2249449.75         0.00
  367 Pile             5029.42   2249450.00   2249450.00         0.00
  967 Pile             5029.43   2249450.25   2249450.00         0.00
  987 Pile             5029.42   2249450.00   2249450.00         0.00

Ultimate Load Combination: U7
-----------------------------

  Factored Applied Forces:
  ------------------------
   Node  Pile Label          Vu            Mux    Gamma_X          Muy    Gamma_Y
  ----- -------------- ---------- -------------- ------- -------------- -------
    347 Pile              167.67           -0.0   0.400            0.0   0.400
    367 Pile              167.67           -0.0   0.400           -0.0   0.400
    967 Pile               43.28            0.0   0.400            0.0   0.400
    987 Pile               43.28            0.0   0.400           -0.0   0.400

  Factored Stress and Capacity:
  -----------------------------
                                                      _Critical Point__
  Node   Pile Label         vu         f'c    Phi*vc  X_Offset Y_Offset Status
  ----- -------------- ---------- ---------- ---------- -------- -------- ------
   347 Pile                33.34    3000.00    164.32    -0.74    -2.29   Safe
   367 Pile                33.34    3000.00    164.32     0.00    -2.41   Safe
   967 Pile                 8.61    3000.00    164.32    -2.41    -0.00   Safe
   987 Pile                 8.61    3000.00    164.32     1.95     1.41   Safe
```

Type 3

```
B7 - Punching Shear Around Piles (Ultimate Load Combinations):
===============================================================
Units --> Applied Shear Force Vu (kips), Applied Moments Mux, Muy (k-ft)
          Factored Shear Stress vu (psi), Factored Shear Resistance vc (psi)
          Concrete Strength f'c (psi), distances X_Offset, Y_Offset (ft)
          Average depth (in), Dimensions Bx, By (ft)
          Area (in^2), Jxx, Jyy, Jxy (in^4)

Geometry of Resisting Area
--------------------------
       ___________Pile___________ Average  ___Dimensions____ ______Centroid____
 Node      Label         Location  Depth      Bx       By    X_Offset Y_Offset
----- -------------- -------- -------- -------- -------- -------- --------
  677 Pile            Inner       27.75     4.81     4.81    -0.00    -0.00
  697 Pile            Inner       27.75     4.81     4.81    -0.00    -0.00
  717 Pile            Inner       27.75     4.81     4.81     0.00    -0.00
 1897 Pile            Inner       27.75     4.81     4.81    -0.00    -0.00
 1917 Pile            Inner       27.75     4.81     4.81    -0.00    -0.00
 1937 Pile            Inner       27.75     4.81     4.81     0.00    -0.00

Properties of Resisting Area
----------------------------
 Node Pile Label          Area        Jxx              Jyy          Jxy
----- -------------- ---------- ------------ ------------ ------------
  677 Pile             5029.42   2249450.25   2249449.75         0.00
  697 Pile             5029.42   2249450.00   2249450.00         0.00
  717 Pile             5029.42   2249449.50   2249449.50         0.00
 1897 Pile             5029.43   2249450.25   2249450.00         0.00
 1917 Pile             5029.42   2249450.00   2249450.00         0.00
 1937 Pile             5029.42   2249449.50   2249449.75         0.00

Ultimate Load Combination: U7
-----------------------------

  Factored Applied Forces:
  ------------------------
   Node  Pile Label          Vu            Mux    Gamma_X          Muy    Gamma_Y
  ----- -------------- ---------- -------------- ------- -------------- -------
    677 Pile              143.97           -0.0   0.400            0.0   0.400
    697 Pile              181.38           -0.0   0.400           -0.0   0.400
    717 Pile              216.62           -0.0   0.400           -0.0   0.400
   1897 Pile                1.85            0.0   0.400            0.0   0.400
   1917 Pile               36.74            0.0   0.400           -0.0   0.400
   1937 Pile               69.94            0.0   0.400           -0.0   0.400

  Factored Stress and Capacity:
  -----------------------------
                                                      _Critical Point__
  Node   Pile Label         vu         f'c    Phi*vc  X_Offset Y_Offset Status
  ----- -------------- ---------- ---------- ---------- -------- -------- ------
   677 Pile                28.62    3000.00    164.32    -0.74    -2.29   Safe
   697 Pile                36.06    3000.00    164.32     0.00    -2.41   Safe
   717 Pile                43.07    3000.00    164.32     2.38    -0.38   Safe
  1897 Pile                 0.37    3000.00    164.32    -2.41    -0.00   Safe
  1917 Pile                 7.30    3000.00    164.32     1.41     1.95   Safe
  1937 Pile                13.91    3000.00    164.32     2.41    -0.00   Safe
```

Figure 12 – Two-Way Shear Results around Piles

3. Pile Reactions

The model results provide a detailed list of the pile reactions indicating the magnitude and direction of the resulting forces on each pile in the foundation model. Whether force is downward compression or upward net tension on the pile, the load combination producing the maximum reaction is denoted in the output results table.

Type 1

```
B3 - REACTIONS:
===============
Units --> Force (kip), Moment (kip-ft)
Service Load Combination: S9
          ___Soil___ __Spring__ ___Pile___ ________________Restraints____________ ____________Slaved Nodes____________
   Node        Fz         Fz         Fz         Fz         Mx         My         Fz         Mx         My
  ----- ---------- ---------- ---------- ---------- ---------- ---------- ---------- ---------- ----------
    171          -          -    152.222          -          -          -          -          -          -
   1811          -          -     72.436          -          -          -          -          -          -
   1851          -          -     72.436          -          -          -          -          -          -

  Sum of all forces and moments with respect to center of gravity (X, Y) = (7.50, 9.27) ft

  Sum of Reactions       Fz           Mx           My
  ---------------- ------------ ------------ ------------
  Soil                        -            -            -
  Springs                     -            -            -
  Piles                 297.094     -563.779       -0.000
  Restraints                  -            -            -
  Slaved Nodes                -            -            -
  ---------------- ------------ ------------ ------------
  Total Reactions       297.094     -563.779       -0.000
  Total Loads          -297.094      563.779       -0.000
```

Type 2

```
B3 - REACTIONS:
===============
Units --> Force (kip), Moment (kip-ft)
Service Load Combination: S9
          ___Soil___ __Spring__ ___Pile___ ________________Restraints____________ ____________Slaved Nodes____________
   Node        Fz         Fz         Fz         Fz         Mx         My         Fz         Mx         My
  ----- ---------- ---------- ---------- ---------- ---------- ---------- ---------- ---------- ----------
    347          -          -    144.439          -          -          -          -          -          -
    367          -          -    144.439          -          -          -          -          -          -
    967          -          -     31.812          -          -          -          -          -          -
    987          -          -     31.812          -          -          -          -          -          -

  Sum of all forces and moments with respect to center of gravity (X, Y) = (7.50, 9.00) ft

  Sum of Reactions       Fz           Mx           My
  ---------------- ------------ ------------ ------------
  Soil                        -            -            -
  Springs                     -            -            -
  Piles                 352.500     -597.520        0.000
  Restraints                  -            -            -
  Slaved Nodes                -            -            -
  ---------------- ------------ ------------ ------------
  Total Reactions       352.500     -597.520        0.000
  Total Loads          -352.500      597.520       -0.000
```

Type 3

```
B3 - REACTIONS:
===============
Units --> Force (kip), Moment (kip-ft)
Service Load Combination: S9
          ___Soil___ __Spring__ ___Pile___ ________________Restraints____________ ____________Slaved Nodes____________
   Node        Fz         Fz         Fz         Fz         Mx         My         Fz         Mx         My
  ----- ---------- ---------- ---------- ---------- ---------- ---------- ---------- ---------- ----------
    677          -          -    123.880          -          -          -          -          -          -
    697          -          -    158.263          -          -          -          -          -          -
    717          -          -    190.647          -          -          -          -          -          -
   1897          -          -      0.000          -          -          -          -          -          -
   1917          -          -     19.886          -          -          -          -          -          -
   1937          -          -     50.324          -          -          -          -          -          -

  Sum of all forces and moments with respect to center of gravity (X, Y) = (15.00, 9.00) ft

  Sum of Reactions       Fz           Mx           My
  ---------------- ------------ ------------ ------------
  Soil                        -            -            -
  Springs                     -            -            -
  Piles                 543.000    -1198.400      186.597
  Restraints                  -            -            -
  Slaved Nodes                -            -            -
  ---------------- ------------ ------------ ------------
  Total Reactions       543.000    -1198.400      186.597
  Total Loads          -543.000     1198.400     -186.597
```

Figure 13 – Piles Service Reactions

B3 - REACTIONS: **Type 1**

Units --> Force (kip), Moment (kip-ft)
Ultimate Load Combination: U7

Node	Soil	Spring	Pile	Restraints			Slaved Nodes		
	Fz	Fz	Fz	Fz	Mx	My	Fz	Mx	My
171	-	-	171.722	-	-	-	-	-	-
1811	-	-	91.845	-	-	-	-	-	-
1851	-	-	91.845	-	-	-	-	-	-

Sum of all forces and moments with respect to center of gravity (X, Y) = (7.50, 9.27) ft

Sum of Reactions	Fz	Mx	My
Soil	-	-	-
Springs	-	-	-
Piles	355.413	-570.634	-0.000
Restraints	-	-	-
Slaved Nodes	-	-	-
Total Reactions	355.413	-570.634	-0.000
Total Loads	-355.413	570.634	-0.000

B3 - REACTIONS: **Type 2**

Units --> Force (kip), Moment (kip-ft)
Ultimate Load Combination: U7

Node	Soil	Spring	Pile	Restraints			Slaved Nodes		
	Fz	Fz	Fz	Fz	Mx	My	Fz	Mx	My
347	-	-	167.666	-	-	-	-	-	-
367	-	-	167.666	-	-	-	-	-	-
967	-	-	43.284	-	-	-	-	-	-
987	-	-	43.284	-	-	-	-	-	-

Sum of all forces and moments with respect to center of gravity (X, Y) = (7.50, 9.00) ft

Sum of Reactions	Fz	Mx	My
Soil	-	-	-
Springs	-	-	-
Piles	421.900	-610.962	0.000
Restraints	-	-	-
Slaved Nodes	-	-	-
Total Reactions	421.900	-610.962	0.000
Total Loads	-421.900	610.962	-0.000

B3 - REACTIONS: **Type 3**

Units --> Force (kip), Moment (kip-ft)
Ultimate Load Combination: U7

Node	Soil	Spring	Pile	Restraints			Slaved Nodes		
	Fz	Fz	Fz	Fz	Mx	My	Fz	Mx	My
677	-	-	143.966	-	-	-	-	-	-
697	-	-	181.383	-	-	-	-	-	-
717	-	-	216.620	-	-	-	-	-	-
1897	-	-	1.851	-	-	-	-	-	-
1917	-	-	36.737	-	-	-	-	-	-
1937	-	-	69.944	-	-	-	-	-	-

Sum of all forces and moments with respect to center of gravity (X, Y) = (15.00, 9.00) ft

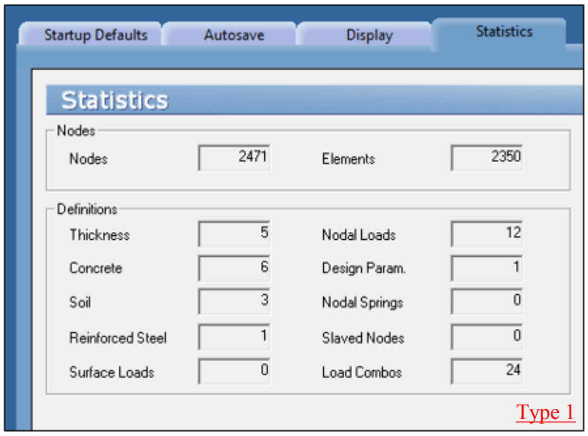
Sum of Reactions	Fz	Mx	My
Soil	-	-	-
Springs	-	-	-
Piles	650.500	-1191.429	218.783
Restraints	-	-	-
Slaved Nodes	-	-	-
Total Reactions	650.500	-1191.429	218.783
Total Loads	-650.500	1191.429	-218.783

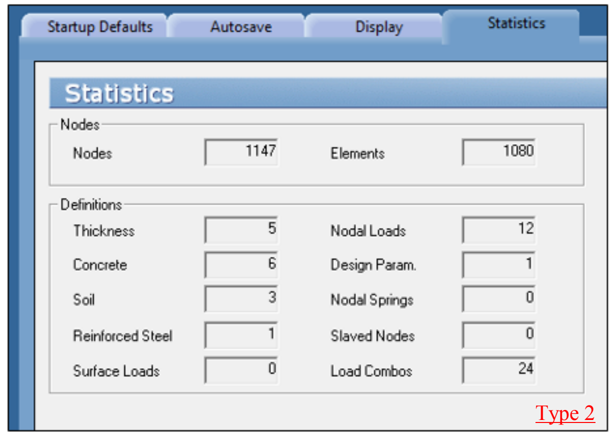
Figure 14 – Piles Ultimate Reactions

Note: Positive and negative reaction values indicate compression and tension forces in piles, respectively.

4. Pile Cap Model Statistics

Since spMats is utilizing finite element analysis to model and design the foundation. It is useful to track the number of elements and nodes used in the model to optimize the model results (accuracy) and running time (processing stage). spMats provides model statistics to keep tracking the mesh sizing as a function of the number of nodes and elements.





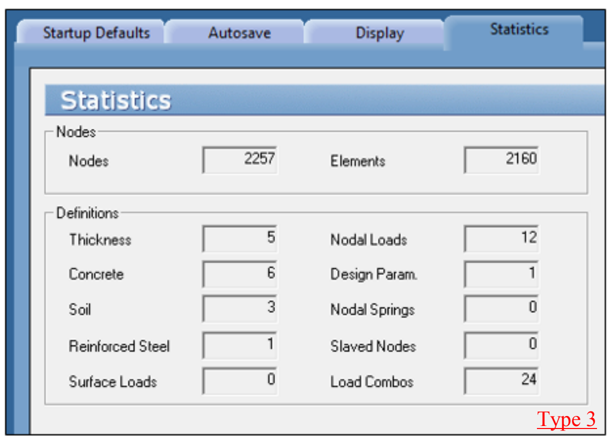


Figure 15 – Model Statistics

5. Column and Pile Design - spColumn

spMats provides the options to export columns and piles information from the foundation model to spColumn. Input (CTI) files are generated by spMats to include the section, materials, and the loads from the foundation model required by spColumn for strength design and investigation of piles and columns. Once the foundation model is completed and successfully executed, the following steps illustrate the design of a sample pile and column.

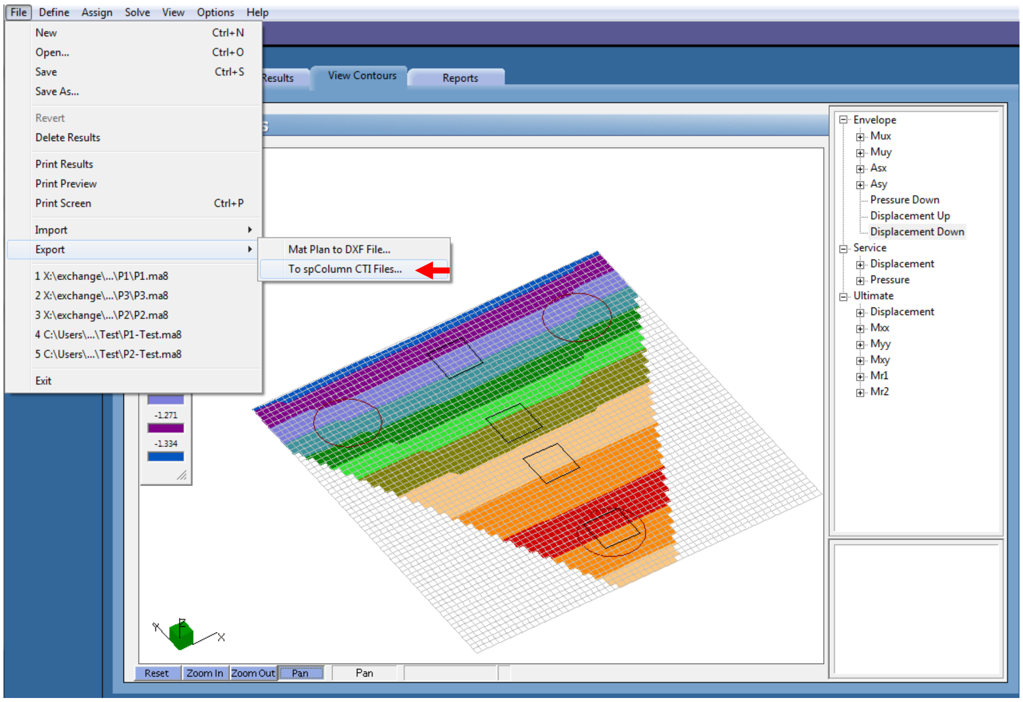


Figure 16 – Exporting CTI Files

Figure 17 – Exporting CTI Files Dialog Box

After exporting spColumn input files, the pile and column design/investigation can proceed/modified to meet project specifications and criteria. In the following a sample pile and column design results are shown as an example.

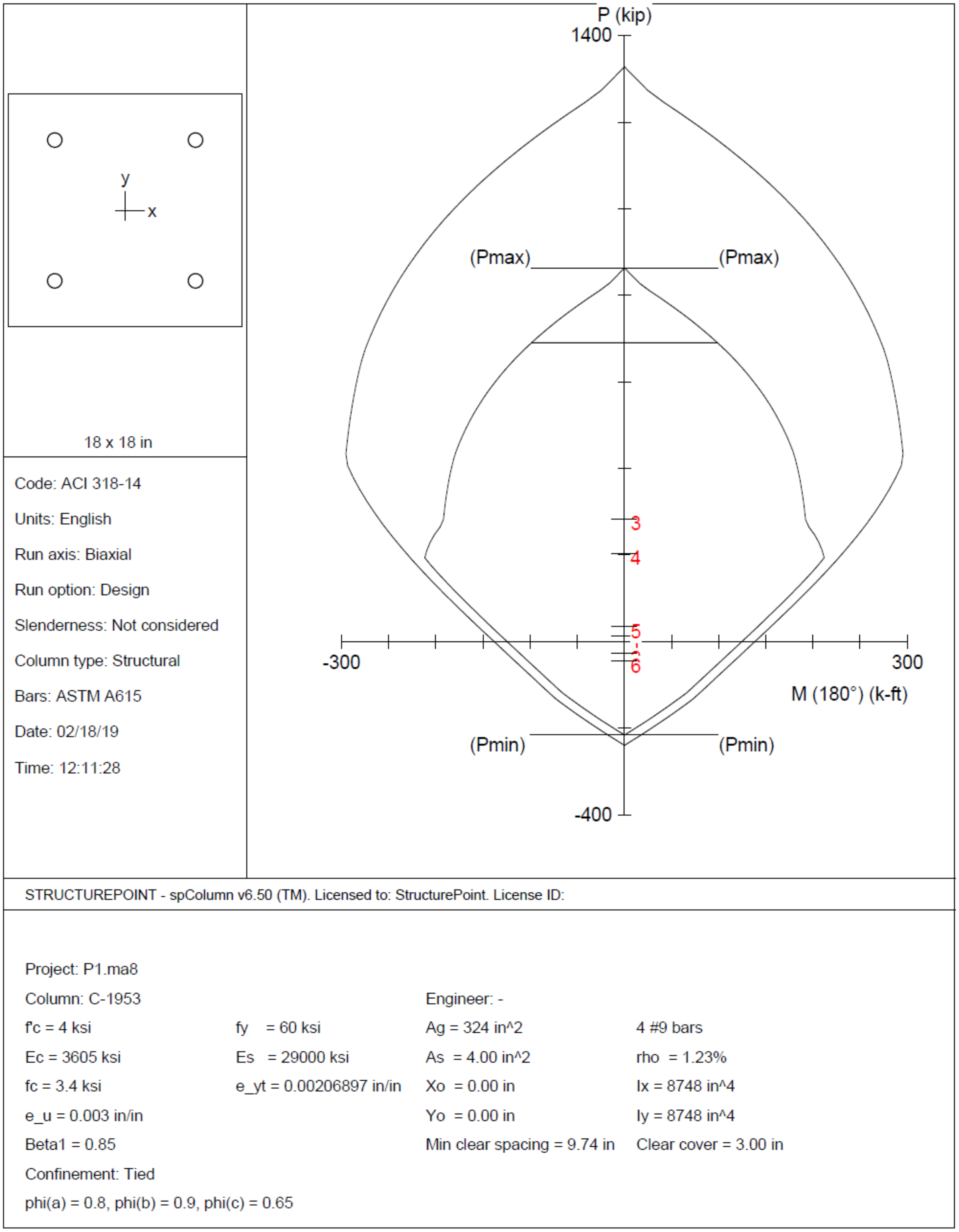


Figure 18 – Pier Interaction Diagram with Factored Load

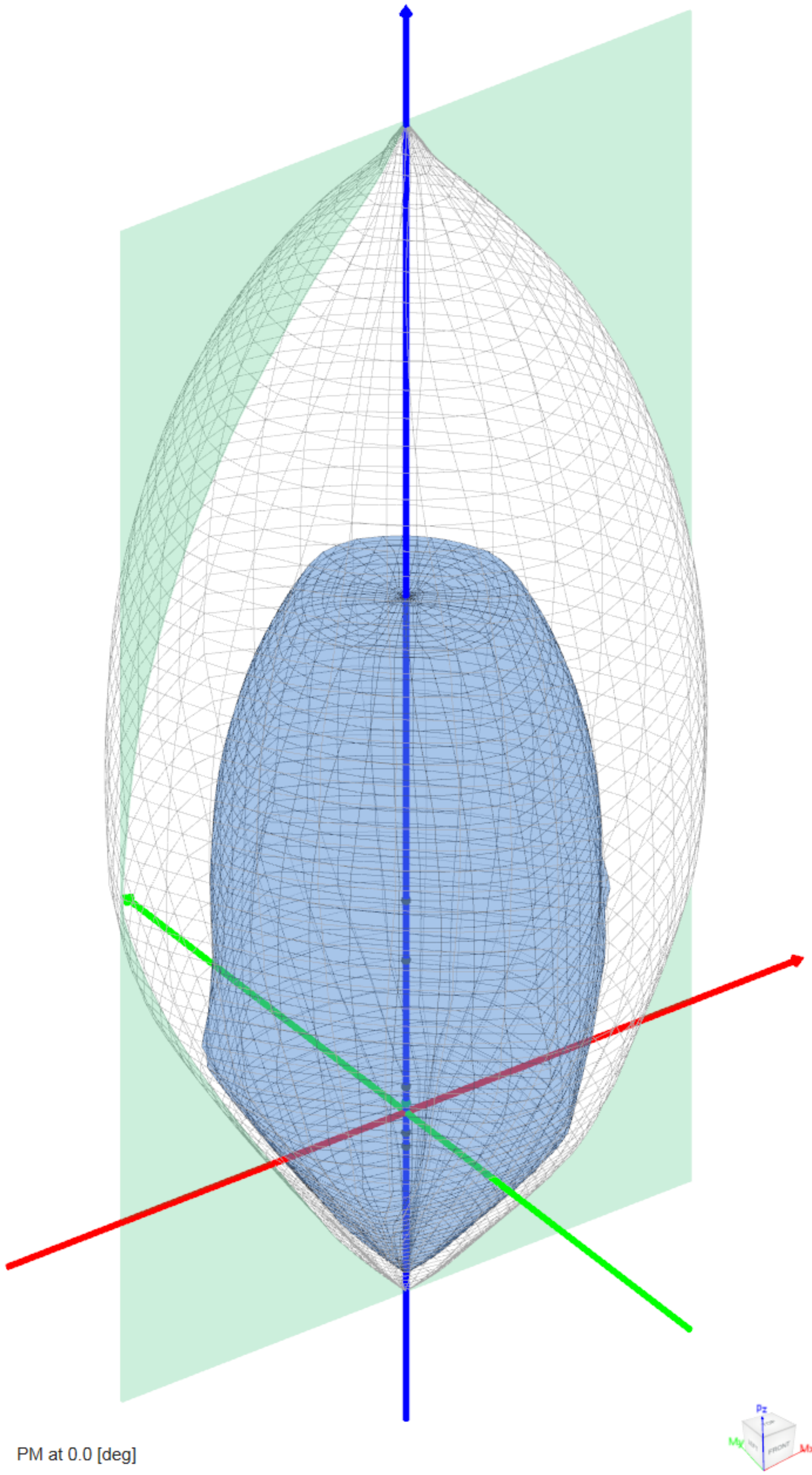
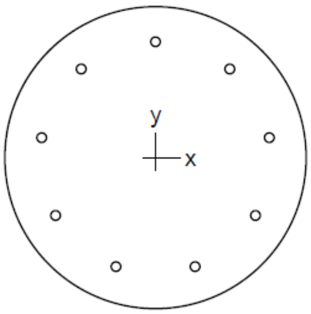


Figure 19 – Column 3D Failure Surfaces



30 in diam.

Code: ACI 318-14

Units: English

Run axis: Biaxial

Run option: Design

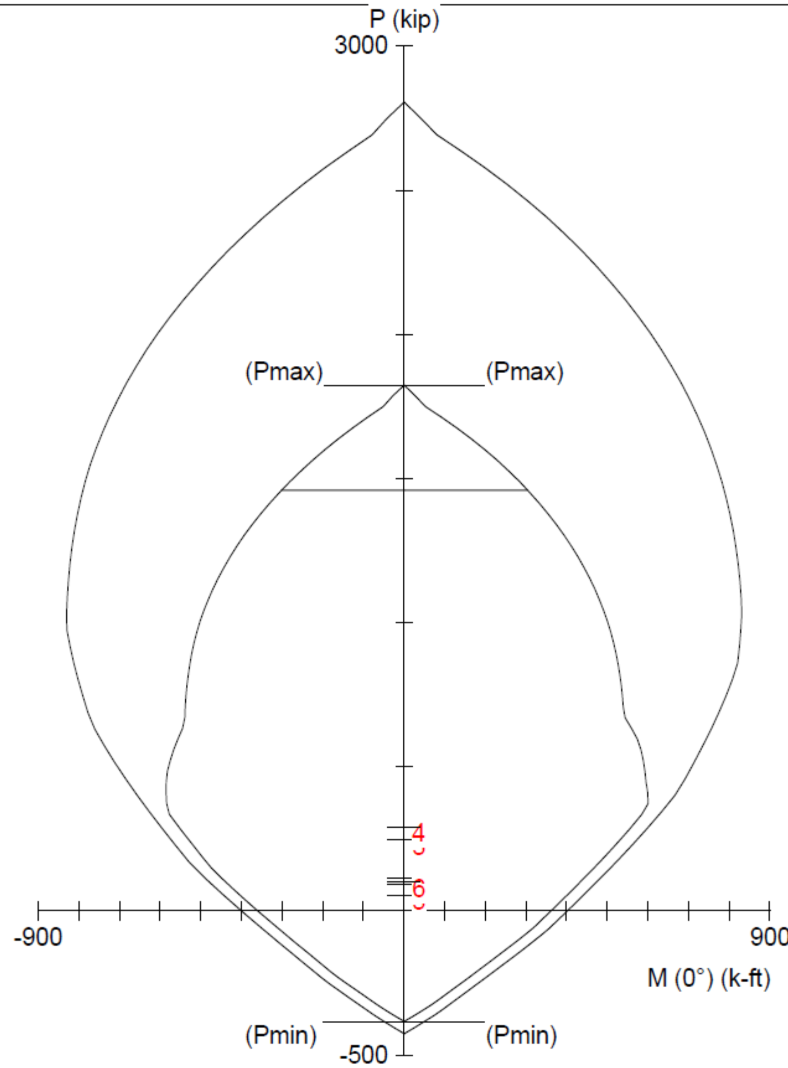
Slenderness: Not considered

Column type: Structural

Bars: ASTM A615

Date: 02/18/19

Time: 12:18:21



STRUCTUREPOINT - spColumn v6.50 (TM). Licensed to: StructurePoint. License ID:

File:

Project: P1.ma8

Column: P-1811		Engineer: -	
f'c = 4 ksi	fy = 60 ksi	Ag = 706.858 in^2	9 #8 bars
Ec = 3605 ksi	Es = 29000 ksi	As = 7.11 in^2	rho = 1.01%
fc = 3.4 ksi	e_yt = 0.00206897 in/in	Xo = 0.00 in	Ix = 39760.8 in^4
e_u = 0.003 in/in		Yo = 0.00 in	Iy = 39760.8 in^4
Beta1 = 0.85		Min clear spacing = 6.87 in	Clear cover = 3.00 in

Confinement: Tied

phi(a) = 0.8, phi(b) = 0.9, phi(c) = 0.65

Figure 20 – Pile Interaction Diagram with Reaction Applied

6. 2D/3D Viewer

2D/3D Viewer is an advanced module of the spColumn program. It enables the user to view and analyze 2D interaction diagrams and contours along with 3D failure surfaces in a multi viewport environment.

2D/3D Viewer is accessed from within spColumn. Once a successful run has been performed, you can open 2D/3D Viewer by selecting the **2D/3D Viewer** command from the **View** menu. Alternatively, 2D/3D Viewer can also be accessed by clicking the 2D/3D Viewer button in the program toolbar.

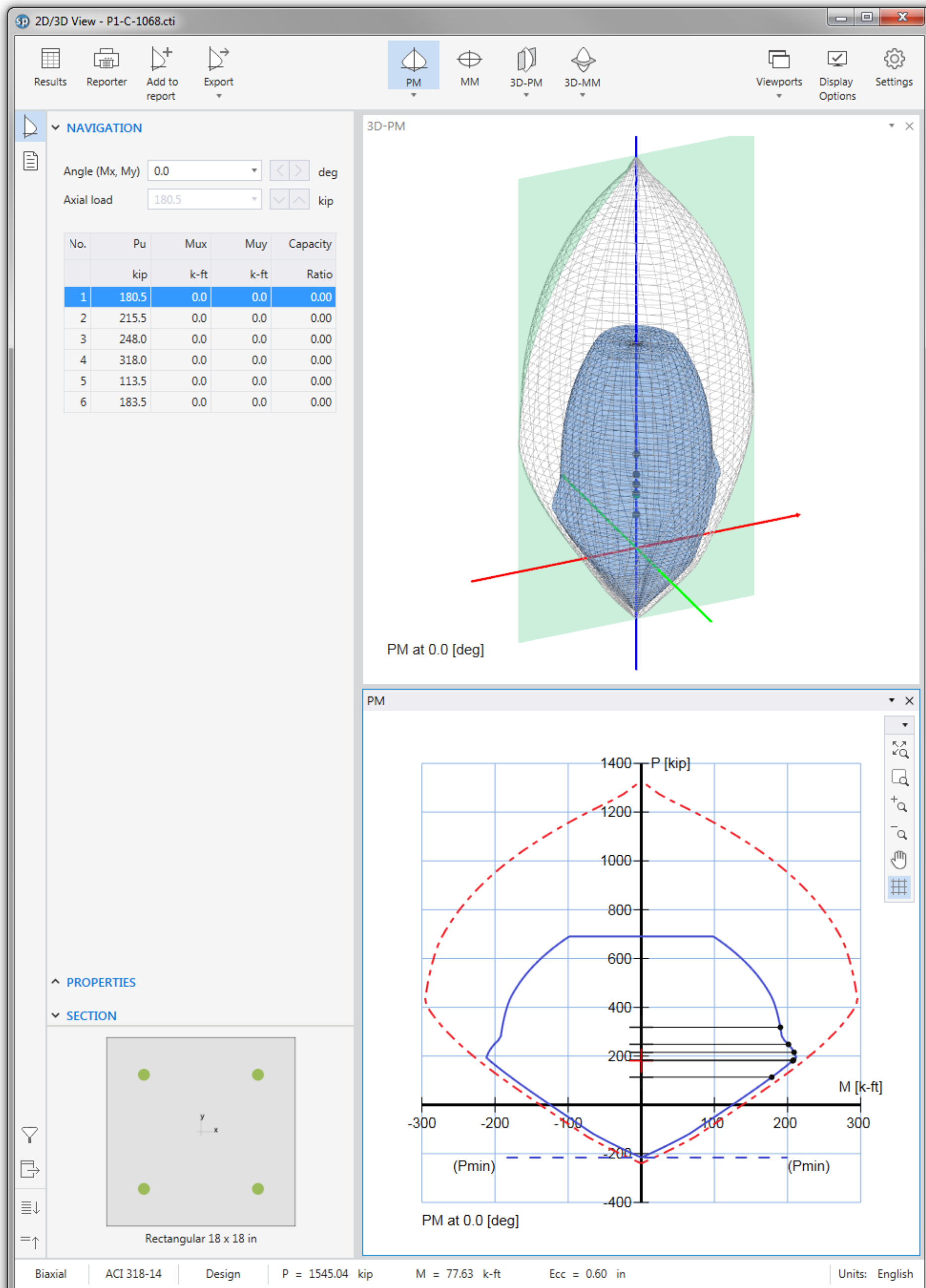


Figure 21 – 2D/3D View for Column

7. Tied vs. Spiral Confinement

The builder was provided two options for confinement to increase field and construction flexibility. The impact of spiral vs tied confinement is illustrated below. Note that pile diameter can be reduced below 30 inches and reactions reevaluated.

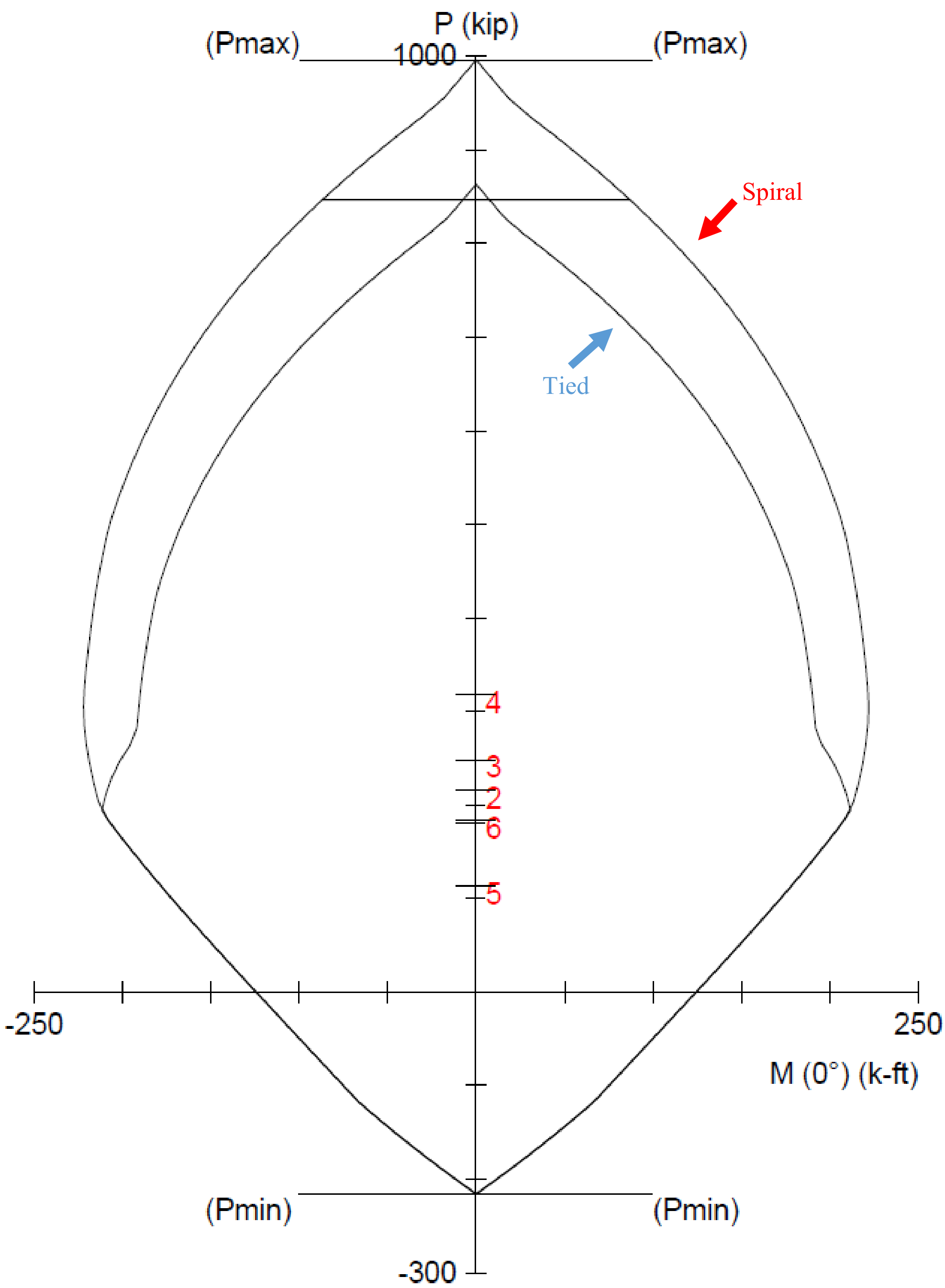


Figure 22 – Tied vs. Spiral Confinement