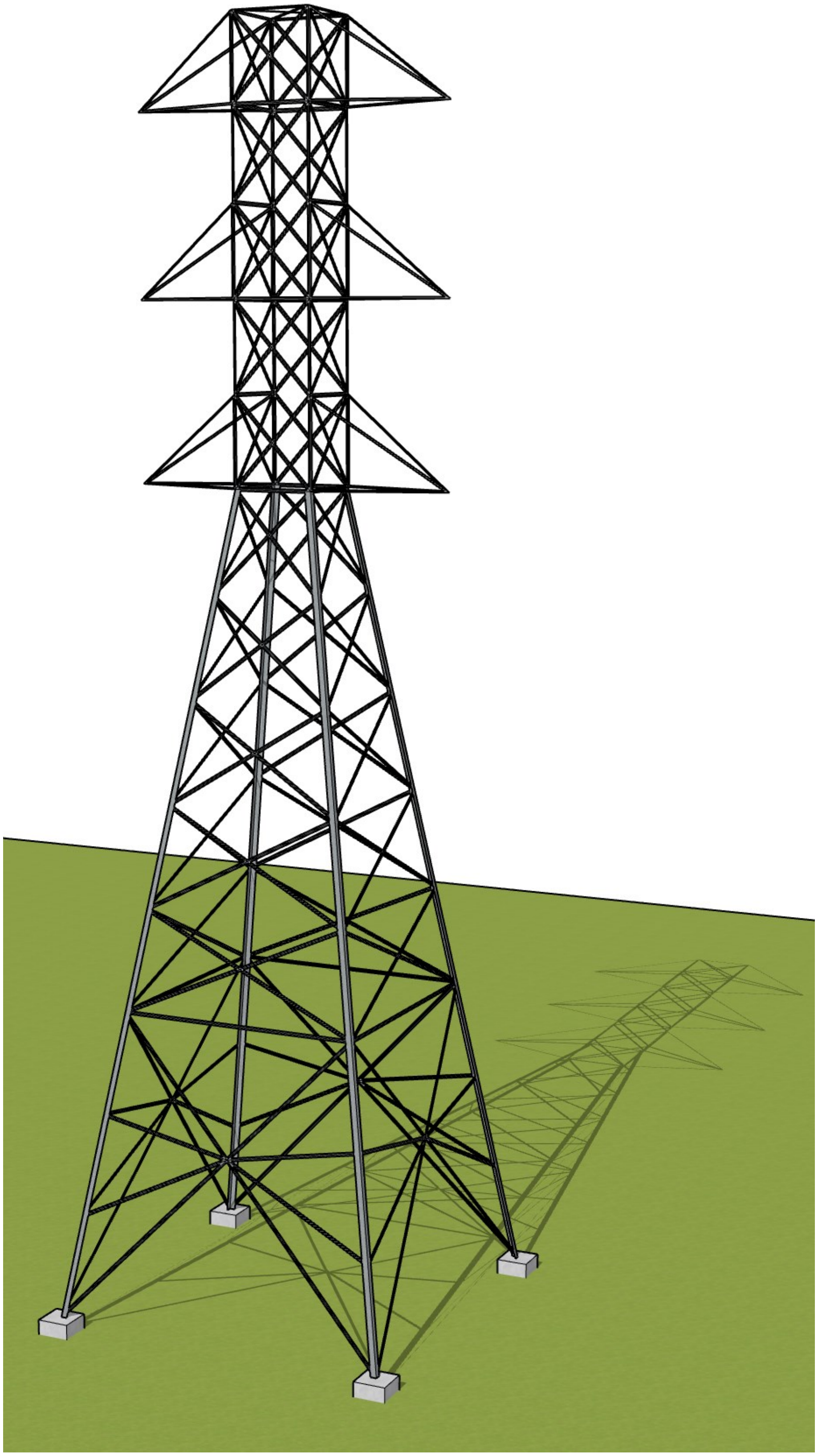
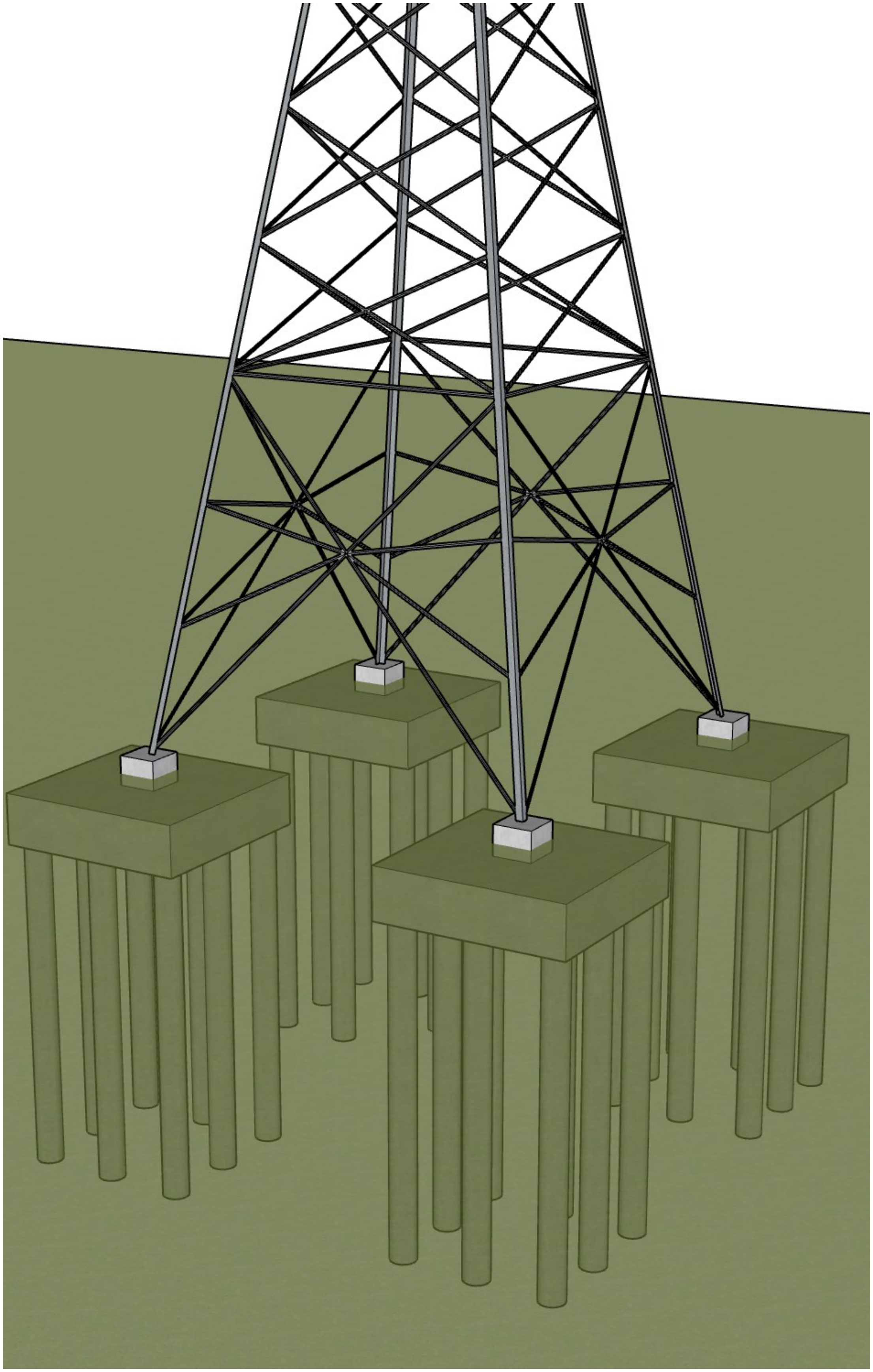
Transmission Tower Reinforced Concrete Pile Cap Foundation





Transmission Tower Reinforced Concrete Pile Cap Foundation

The purpose of a transmission line tower is to support conductors carrying electrical power and one or two ground wires at suitable distances above the ground level and from each other. The transmission line towers cost about 35 to 45 per cent of the total cost of the transmission line. A transmission tower is commonly a space truss and is an indeterminate 3D structure. This case study focuses on the design of transsmission tower foundation using the engineering software program spMats. The tower under study is a galvanized steel tower type 2DT6 for 230kV transmission line with a total height of 100 ft. All the information provided by the sturcutral engineer regarding the transmission tower are shown in the following figures and design data section and will serve as input for foundation design. Because of tower height, significant uplift is expected and a pile supported foundation is selected to resist the design overturning moments. Eight 24" diameter piles are assembled in a pile cap as shown in the following figure.

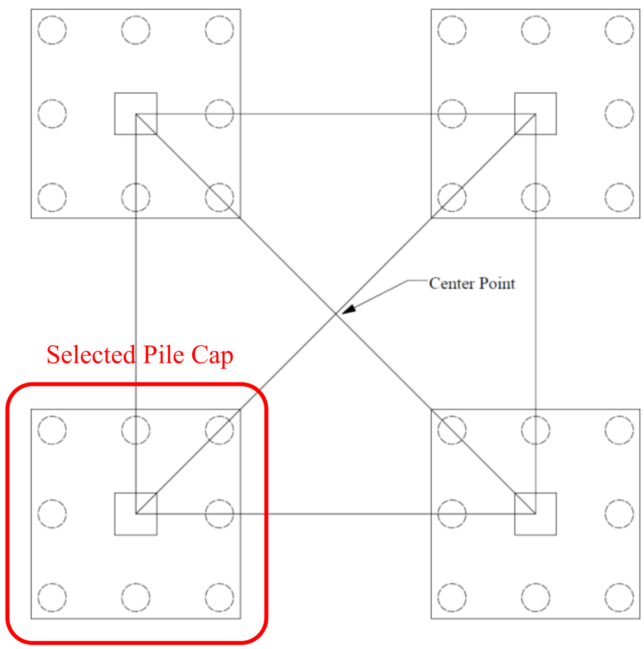


Figure 1 – Transmission Tower Foundation Layout Plan

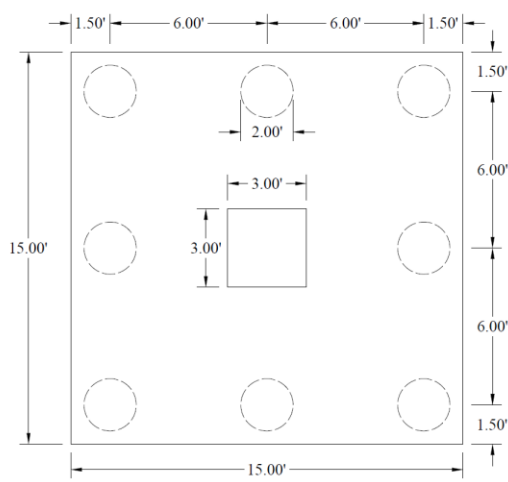


Figure 2 – Transmission Tower Foundation Geometry

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 Pier

Size = 3 ft x 3 ft

Height = 2.3 ft

Weight = 3 kips

Clear Cover = 2 in.

Pile Cap Foundation

f_c' = 3,000 psi

f_y = 60,000 psi

Thickness = 4 ft

Clear Cover = 2 in.

Pile Cap Weight = 133.7 kips

Superimposed Soil Weight = 24.1 kips = 115 psf over the foundation (pile cap) cross-section

Concrete Piles

f_c' = 4,000 psi

f_y = 60,000 psi

Diameter = 2 ft

Clear Cover = 3 in.

Length = 26 ft

Center-to-Center Distance = 6 ft

Number of Piles Per Leg = 8 Piles

Pile embedment = 6 in.

Foundation Loads

F_z = 937.0 kips

M_y = 610 kips-ft (Reversible)

M_x = 568 kips-ft (Reversible)

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 an spMats model created for the transmission tower reinforced concrete foundation (pile cap) in this example.

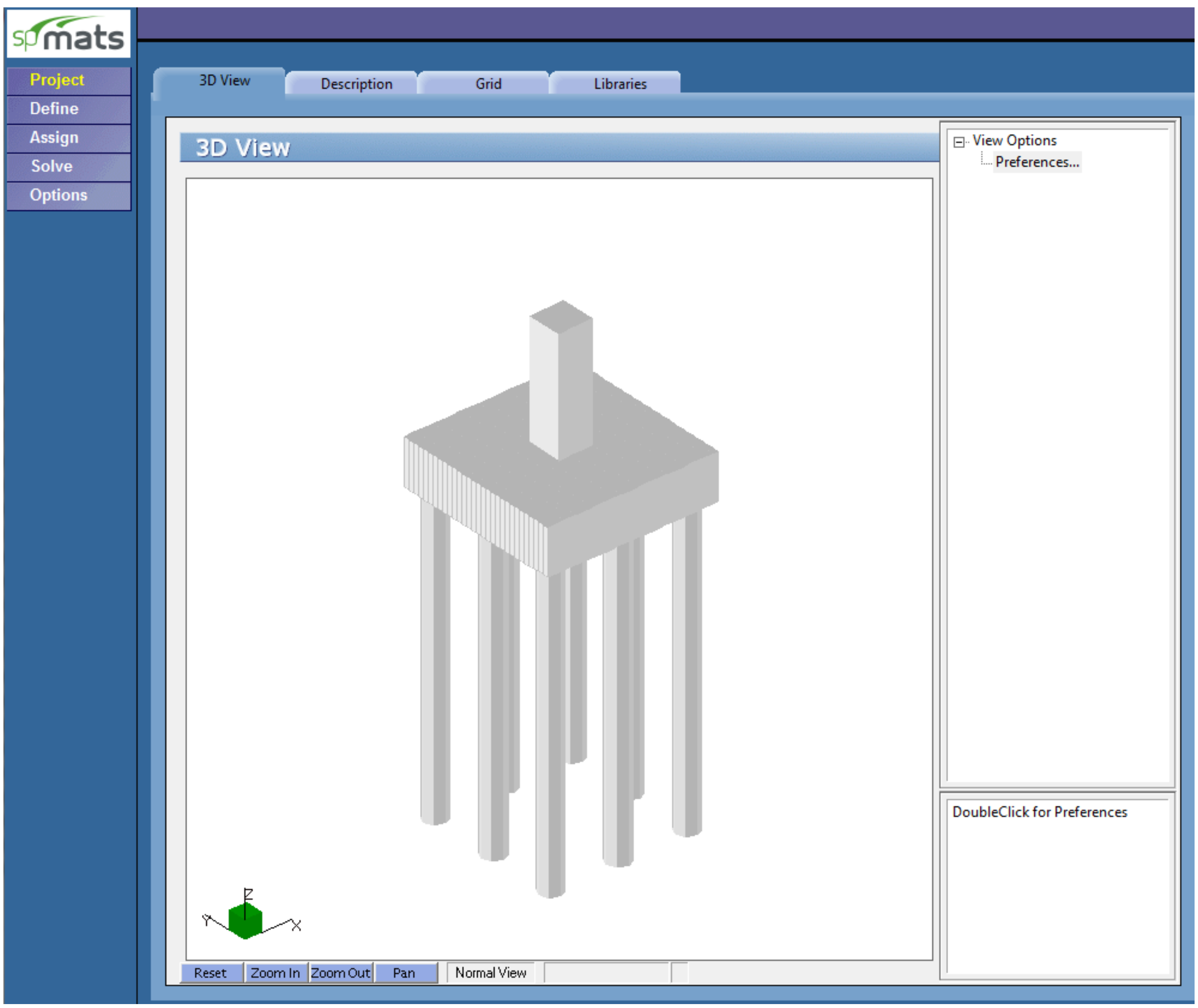


Figure 3 – Transmission Tower Foundation (Pile Cap) Model – 3D View

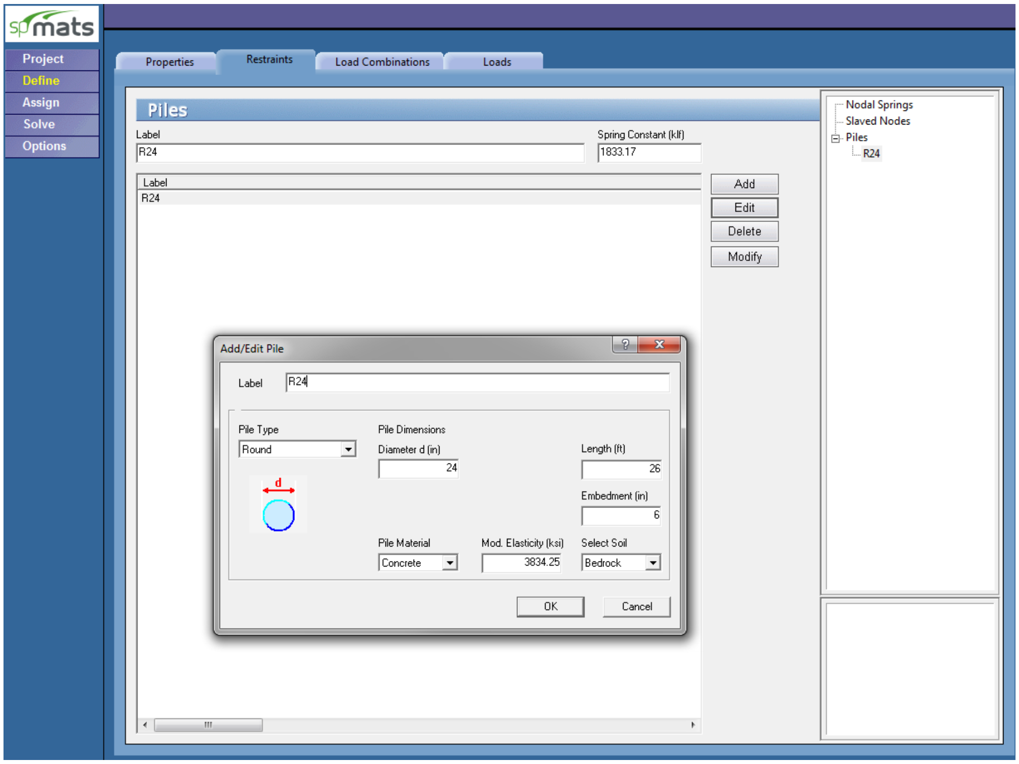


Figure 4 –Defining Piles

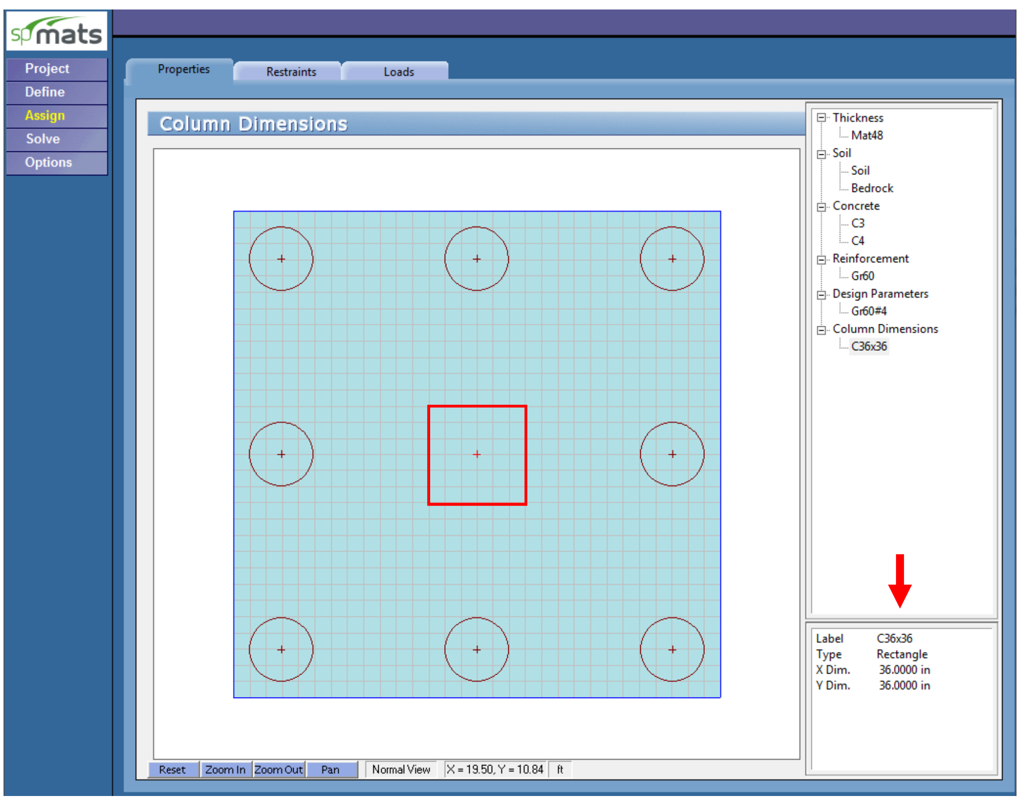


Figure 5 – Assigning Concrete Pier

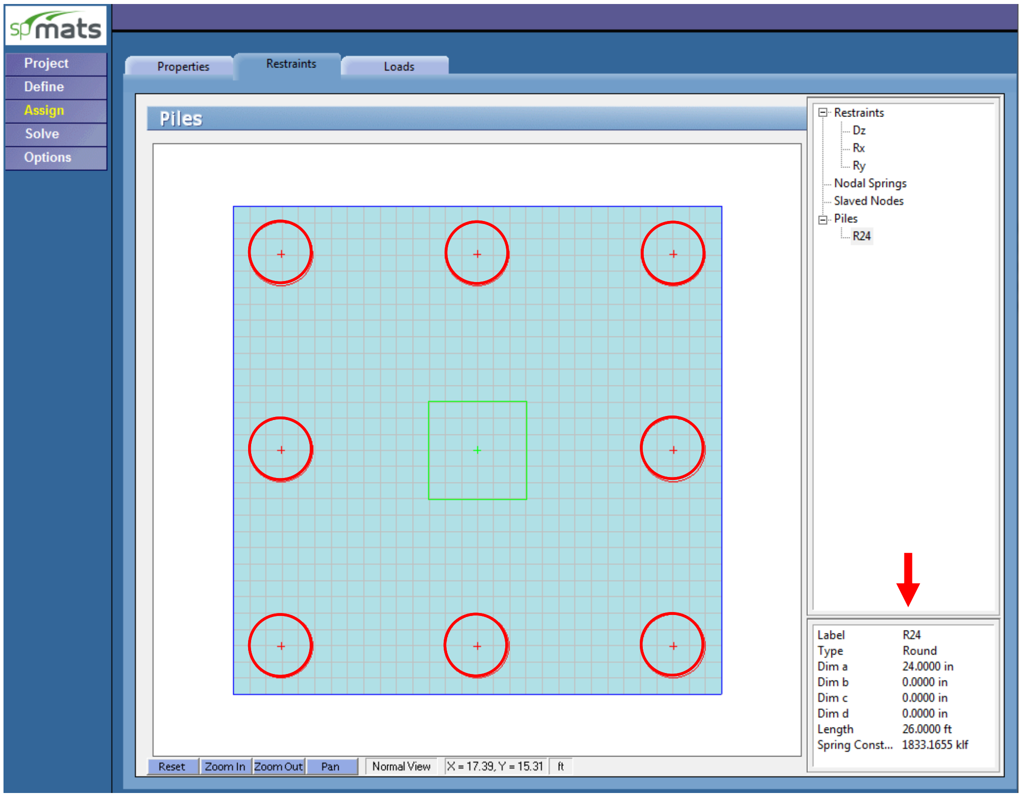


Figure 6 – Assigning Piles

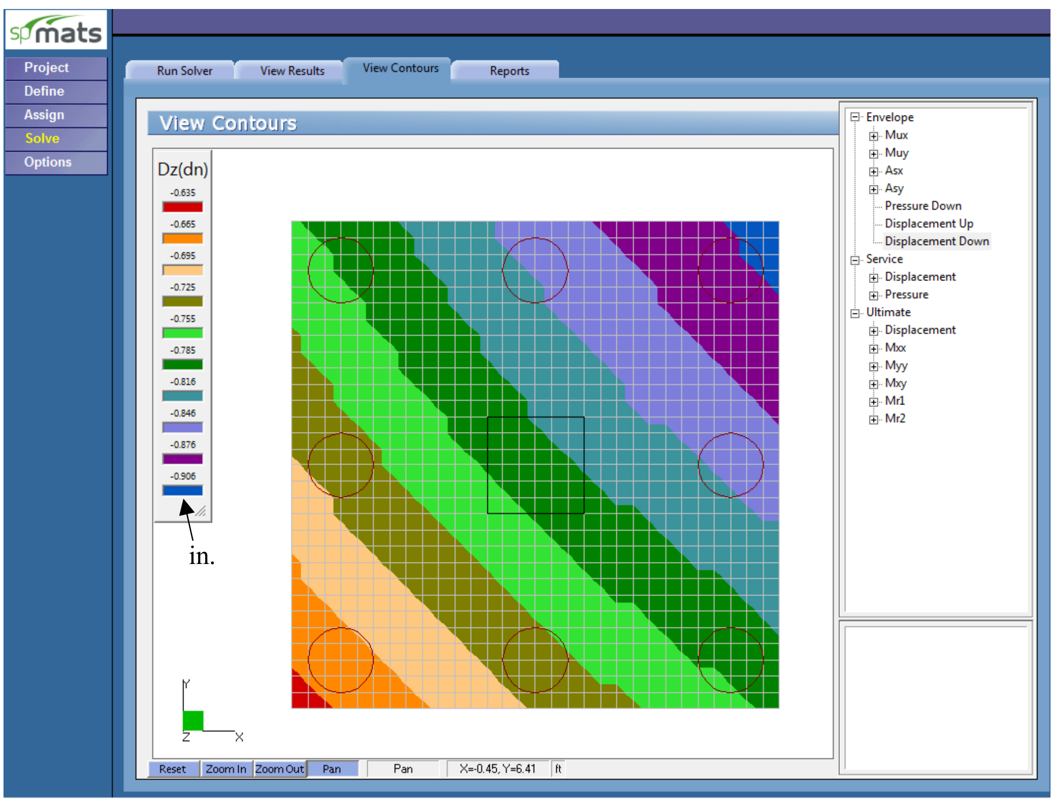


Figure 7 – Transmission Tower Foundation (Pile Cap) Vertical Displacement Contour

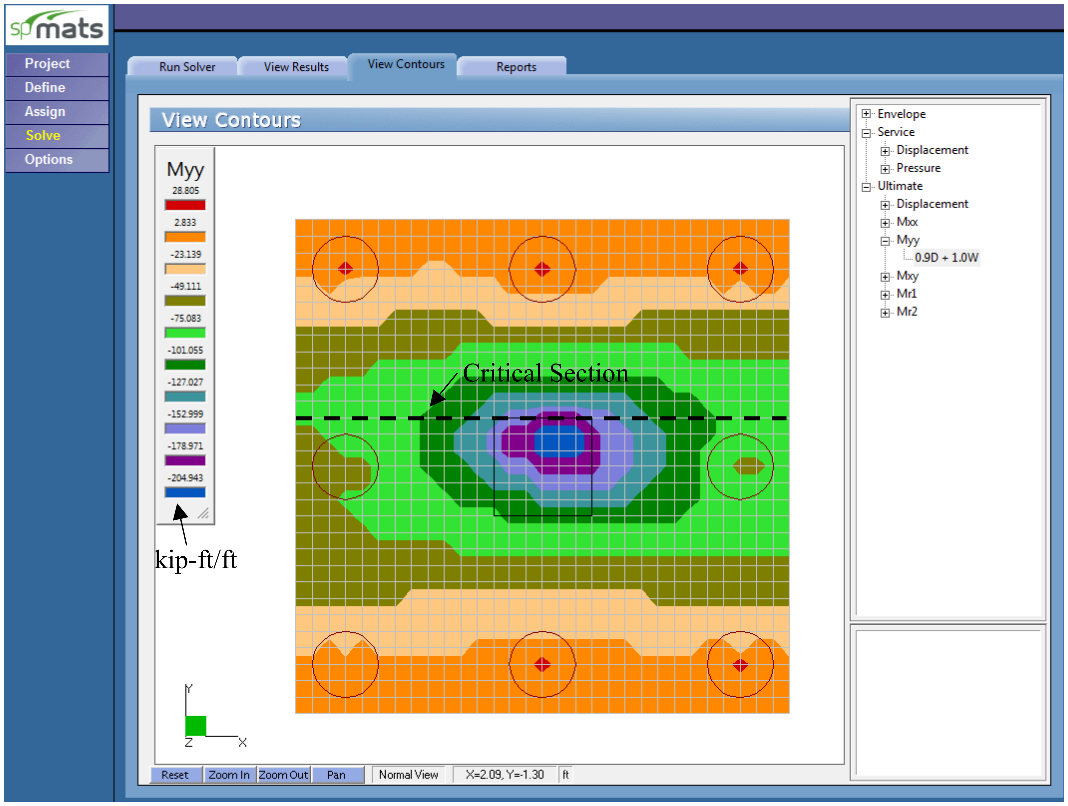


Figure 8 – Transmission Tower Foundation (Pile Cap) Moment Contour along Y-Axis

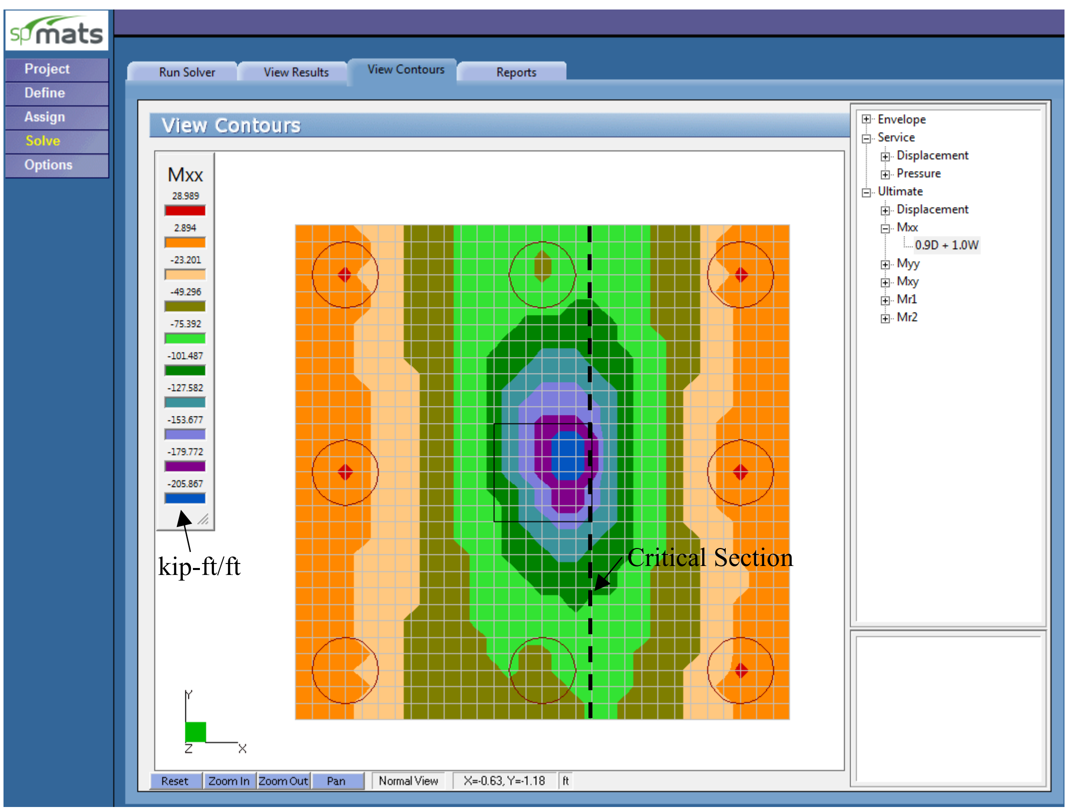


Figure 9 – Transmission Tower Foundation (Pile Cap) Moment Contour along X-Axis - Complete Model

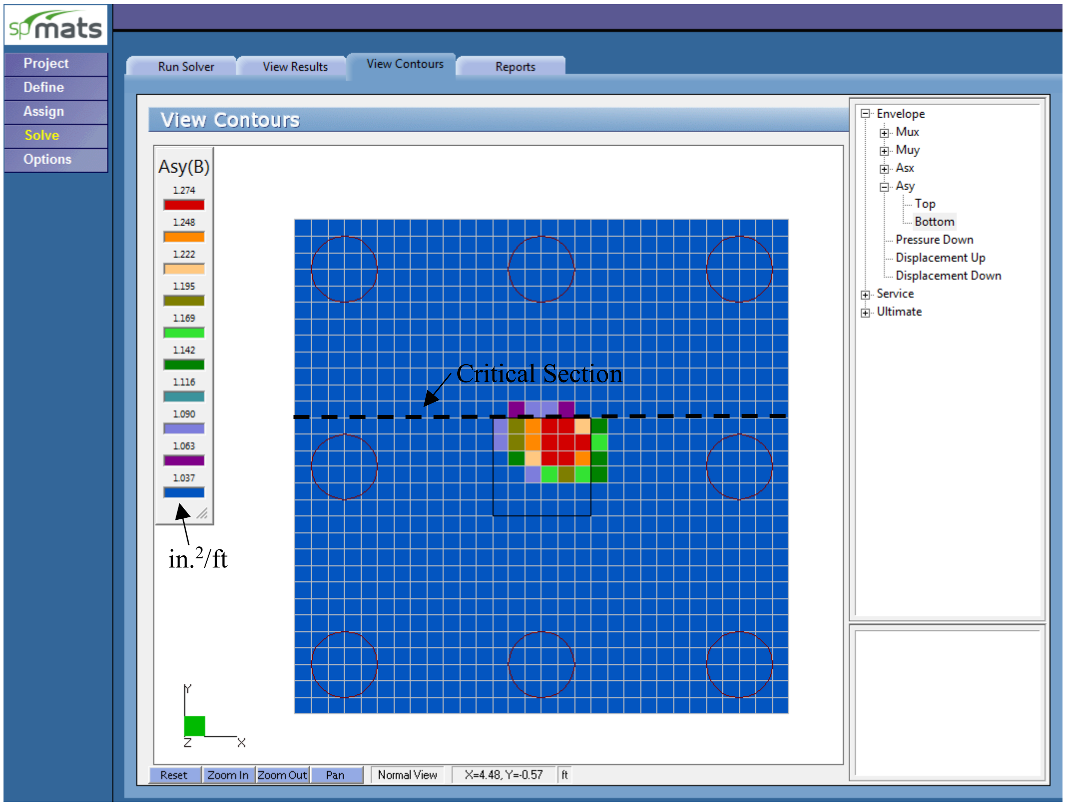


Figure 10 – Required Reinforcement Contour along Y Direction

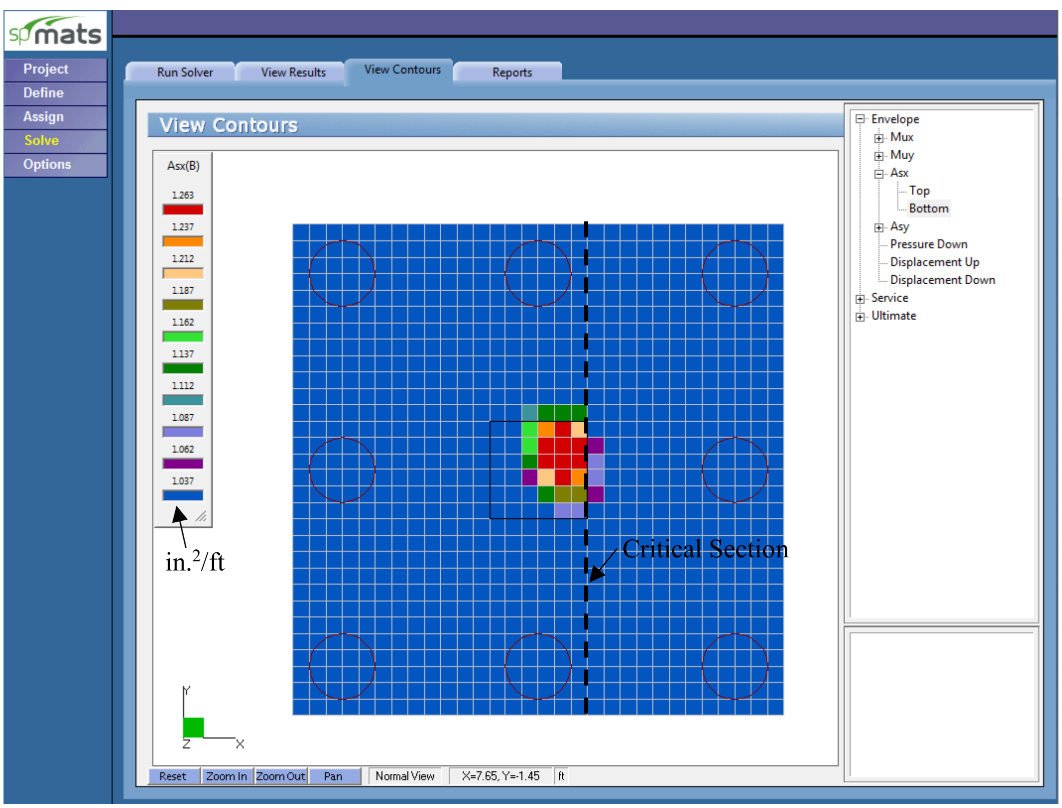


Figure 11 – Required Reinforcement Contour along X Direction

2. Two-Way Punching Shear Check - Piles

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.

```
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
 ----- -------------- -------- -------- -------- -------- -------- --------
   97 R24             Inner       38.75     5.23     5.23     0.00     0.00
  109 R24             Inner       38.75     5.23     5.23    -0.00     0.00
  121 R24             Inner       38.75     5.23     5.23    -0.00     0.00
  469 R24             Inner       38.75     5.23     5.23     0.00    -0.00
  493 R24             Inner       38.75     5.23     5.23    -0.00    -0.00
  841 R24             Inner       38.75     5.23     5.23     0.00    -0.00
  853 R24             Inner       38.75     5.23     5.23    -0.00    -0.00
  865 R24             Inner       38.75     5.23     5.23    -0.00    -0.00

Properties of Resisting Area
----------------------------
 Node Pile Label            Area        Jxx            Jyy          Jxy
 ----- -------------- ---------- ------------ ------------ ------------
   97 R24               7631.13   4218034.00   4218033.50        -0.00
  109 R24               7631.13   4218034.00   4218033.50         0.00
  121 R24               7631.13   4218033.00   4218033.00        -0.00
  469 R24               7631.13   4218034.00   4218033.50         0.00
  493 R24               7631.13   4218033.00   4218032.50         0.00
  841 R24               7631.13   4218033.50   4218033.00         0.00
  853 R24               7631.13   4218033.50   4218033.00        -0.00
  865 R24               7631.13   4218032.50   4218032.50        -0.00

Ultimate Load Combination: 0.9D + 1.0W
--------------------------------------

  Factored Applied Forces:
  ------------------------
   Node  Pile Label          Vu            Mux      Gamma_X        Muy      Gamma_Y
   ----- -------------- ---------- -------------- ------- -------------- -------
     97 R24                 79.96           -0.0   0.400            0.0   0.400
    109 R24                 94.44           -0.0   0.400           -0.0   0.400
    121 R24                107.48           -0.0   0.400           -0.0   0.400
    469 R24                 93.49            0.0   0.400            0.0   0.400
    493 R24                121.13            0.0   0.400            0.0   0.400
    841 R24                105.58            0.0   0.400            0.0   0.400
    853 R24                120.18           -0.0   0.400            0.0   0.400
    865 R24                133.09            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
   -----  -------------- ---------- ---------- ---------- -------- -------- ------
     97 R24                    10.48    3000.00     164.32    -1.85    -1.85   Safe
    109 R24                    12.38    3000.00     164.32    -0.00    -2.61   Safe
    121 R24                    14.08    3000.00     164.32    -0.00    -2.61   Safe
    469 R24                    12.25    3000.00     164.32    -2.61    -0.00   Safe
    493 R24                    15.87    3000.00     164.32     1.19     2.33   Safe
    841 R24                    13.84    3000.00     164.32    -2.61    -0.00   Safe
    853 R24                    15.75    3000.00     164.32     1.54    -2.12   Safe
    865 R24                    17.44    3000.00     164.32     2.12     1.54   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.

```
B3 - REACTIONS:
===============
Units --> Force (kip), Moment (kip-ft)
Service Load Combination: 1.0D + 1.0W
          ___Soil___  __Spring__  ___Pile___  __________Restraints__________  __________Slaved Nodes__________
   Node        Fz          Fz          Fz          Fz          Mx          My          Fz          Mx          My
  -----  ----------  ----------  ----------  ----------  ----------  ----------  ----------  ----------  ----------
     97       0.139           -     101.762           -           -           -           -           -           -
    109       0.152           -     111.188           -           -           -           -           -           -
    121       0.162           -     118.957           -           -           -           -           -           -
    469       0.151           -     110.593           -           -           -           -           -           -
    493       0.174           -     127.869           -           -           -           -           -           -
    841       0.161           -     117.773           -           -           -           -           -           -
    853       0.174           -     127.274           -           -           -           -           -           -
    865       0.184           -     134.967           -           -           -           -           -           -
  Sum of all forces and moments with respect to center of gravity (X, Y) = (7.50, 7.50) ft

  Sum of Reactions          Fz           Mx           My
  ---------------- ------------ ------------ ------------
  Soil                 146.357       30.860      -33.142
  Springs                    -            -            -
  Piles                950.383      288.641     -309.984
  Restraints                 -            -            -
  Slaved Nodes               -            -            -
  ---------------- ------------ ------------ ------------
  Total Reactions     1096.740      319.501     -343.126
  Total Loads        -1096.740     -319.501      343.126
```

Figure 13 – Piles Service Reactions

```
B3 - REACTIONS:
===============
Units --> Force (kip), Moment (kip-ft)
Ultimate Load Combination: 0.9D + 1.0W
          ___Soil___  __Spring__  ___Pile___  __________Restraints__________  __________Slaved Nodes__________
   Node        Fz          Fz          Fz          Fz          Mx          My          Fz          Mx          My
  -----  ----------  ----------  ----------  ----------  ----------  ----------  ----------  ----------  ----------
     97       0.109           -      79.964           -           -           -           -           -           -
    109       0.129           -      94.439           -           -           -           -           -           -
    121       0.147           -     107.475           -           -           -           -           -           -
    469       0.127           -      93.488           -           -           -           -           -           -
    493       0.165           -     121.128           -           -           -           -           -           -
    841       0.144           -     105.581           -           -           -           -           -           -
    853       0.164           -     120.177           -           -           -           -           -           -
    865       0.182           -     133.092           -           -           -           -           -           -
  Sum of all forces and moments with respect to center of gravity (X, Y) = (7.50, 7.50) ft

  Sum of Reactions          Fz           Mx           My
  ---------------- ------------ ------------ ------------
  Soil                 131.721       49.376      -53.027
  Springs                    -            -            -
  Piles                855.345      461.826     -495.975
  Restraints                 -            -            -
  Slaved Nodes               -            -            -
  ---------------- ------------ ------------ ------------
  Total Reactions      987.066      511.202     -549.002
  Total Loads         -987.066     -511.202      549.002
```

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.

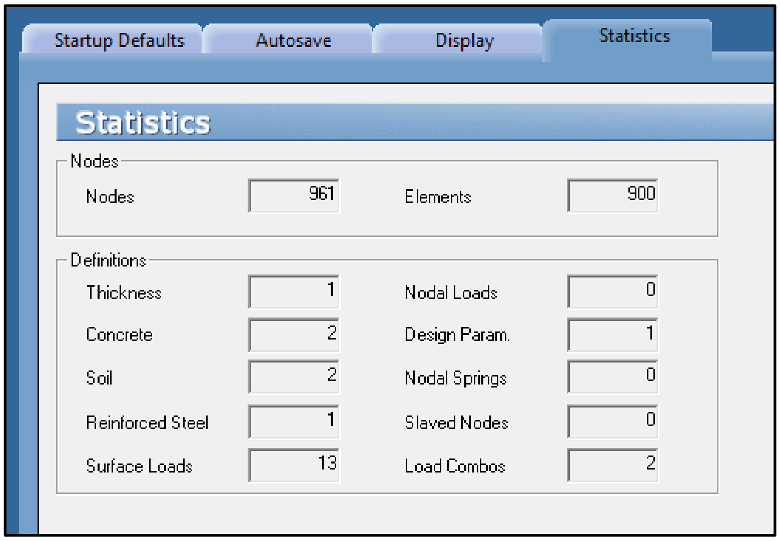


Figure 15 – Model Statistics

5. Column and Pile Design - spColumn

spMats provides the options to export columns and pile 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.

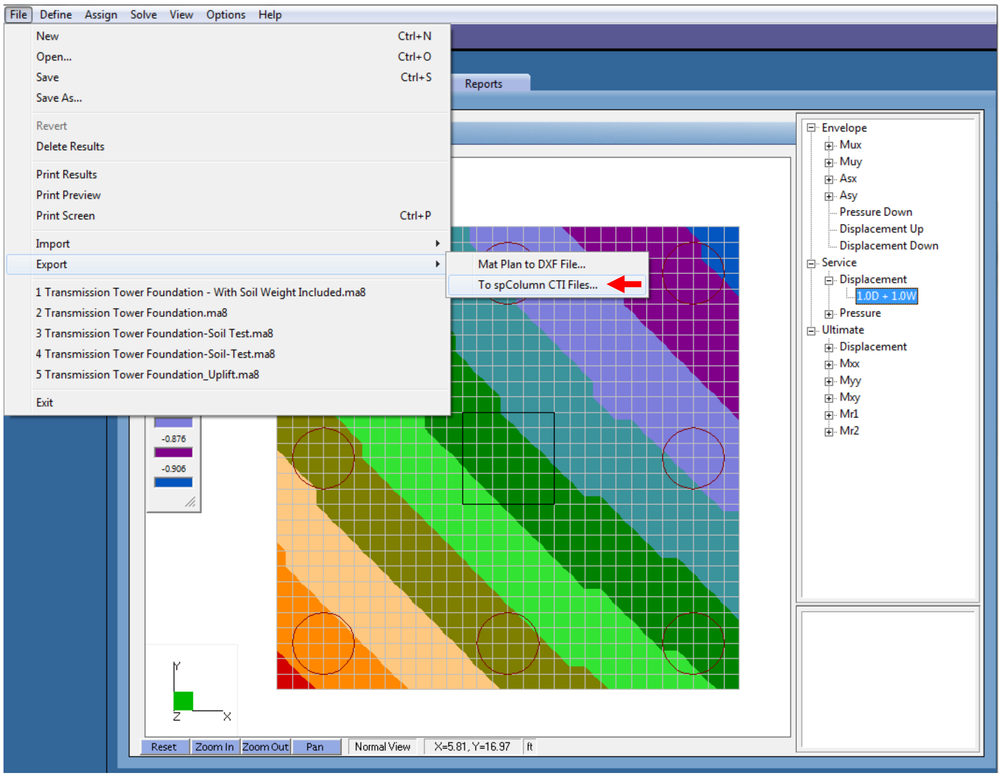


Figure 16 – Exporting CTI Files

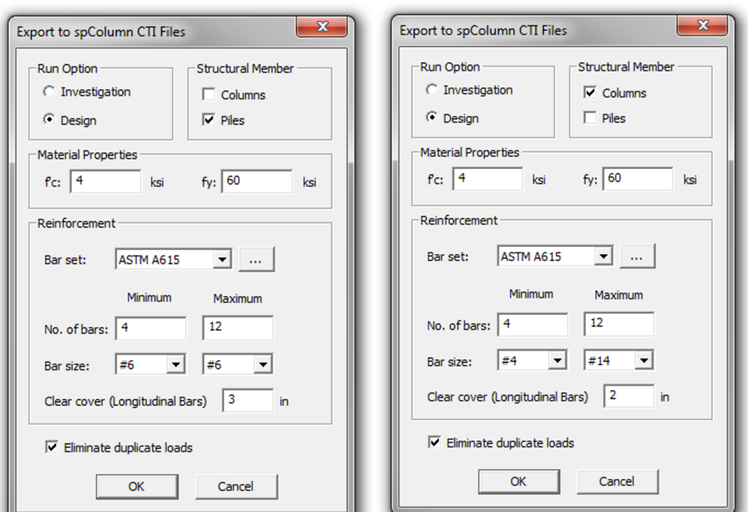


Figure 17 – Exporting CTI Files Dialog Box

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.

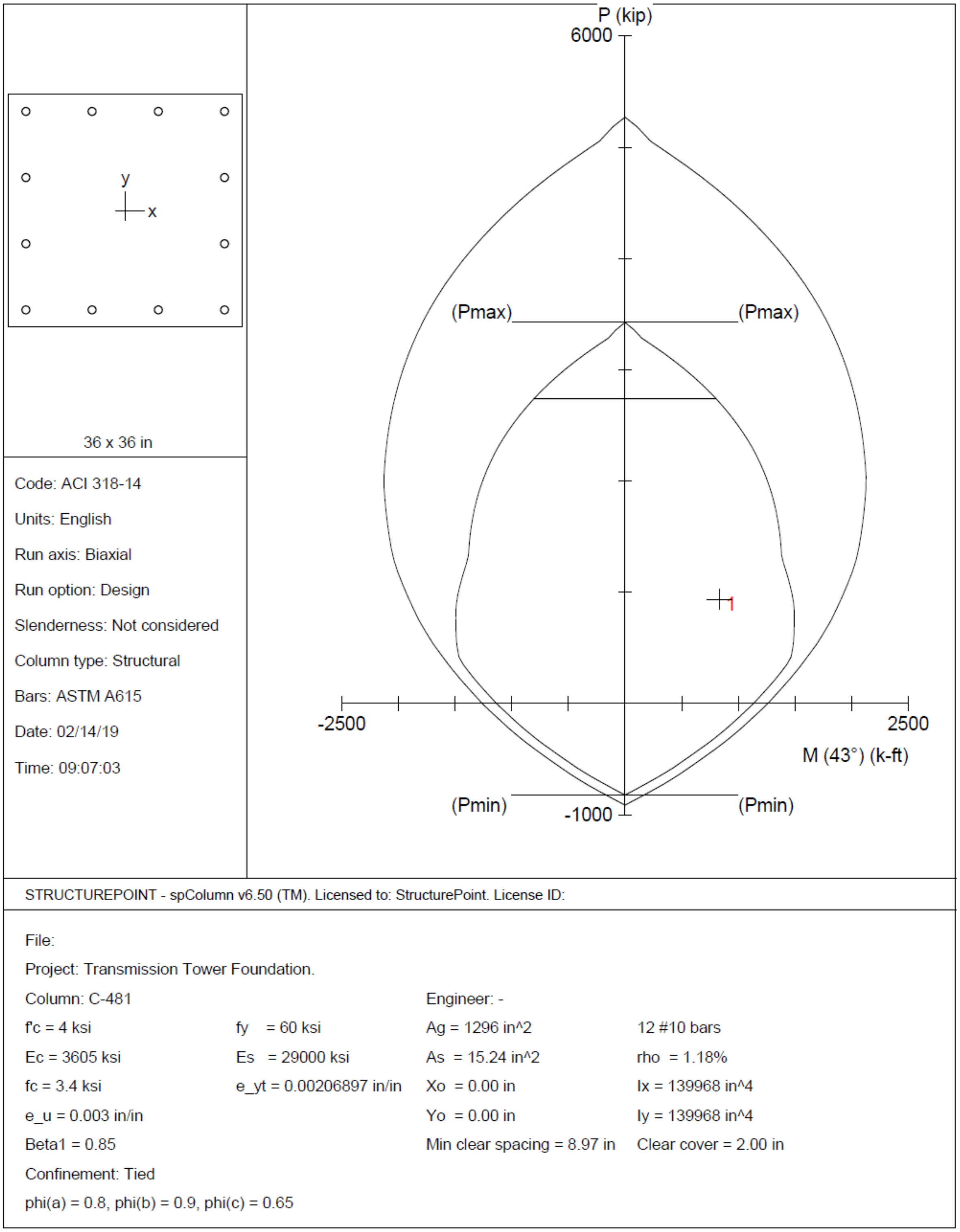


Figure 18 – Concrete Pier Interaction Diagram with Factored Load

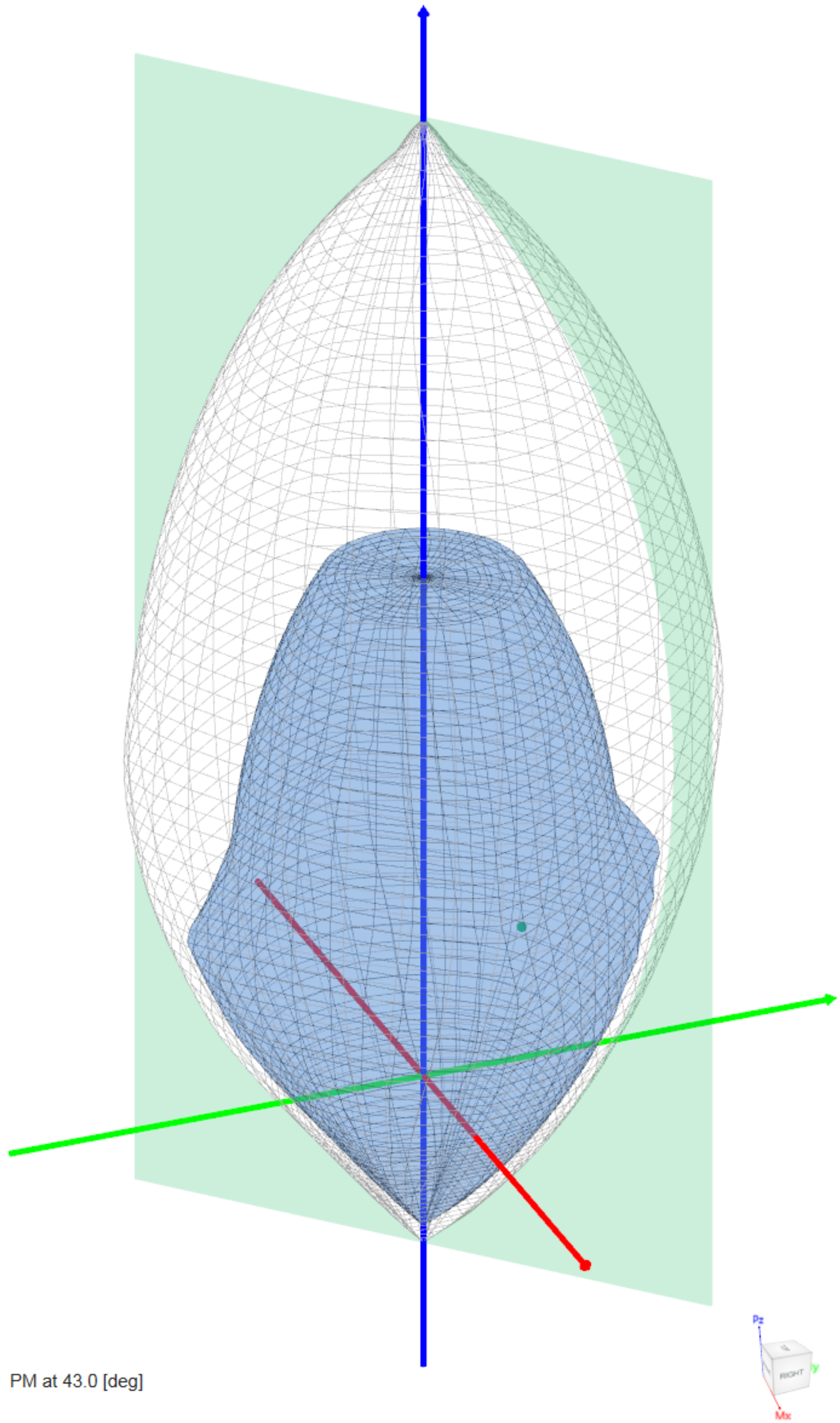


Figure 19 – Column 3D Failure Surfaces

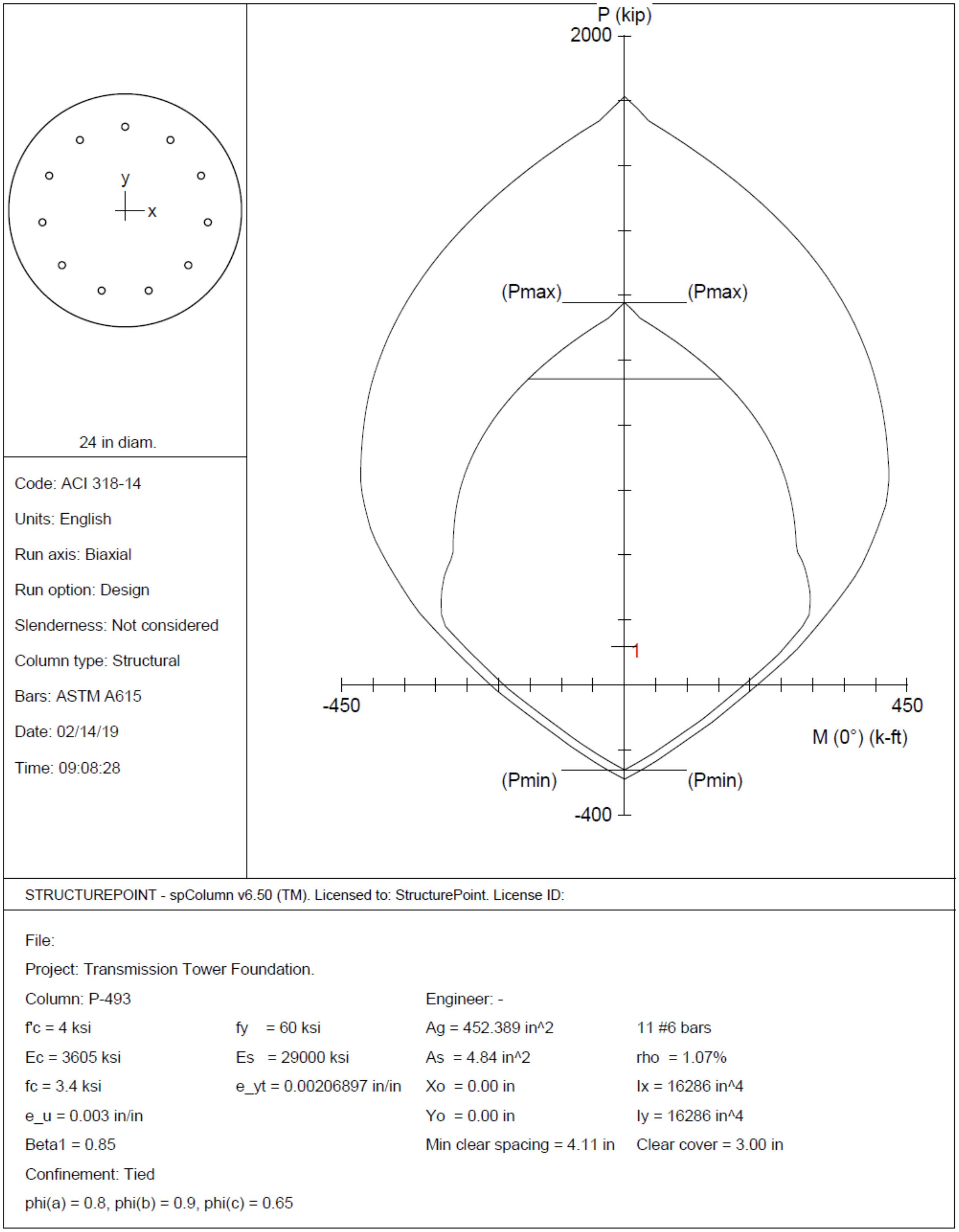


Figure 20 – Pile Interaction Diagram with Reaction Applied

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.

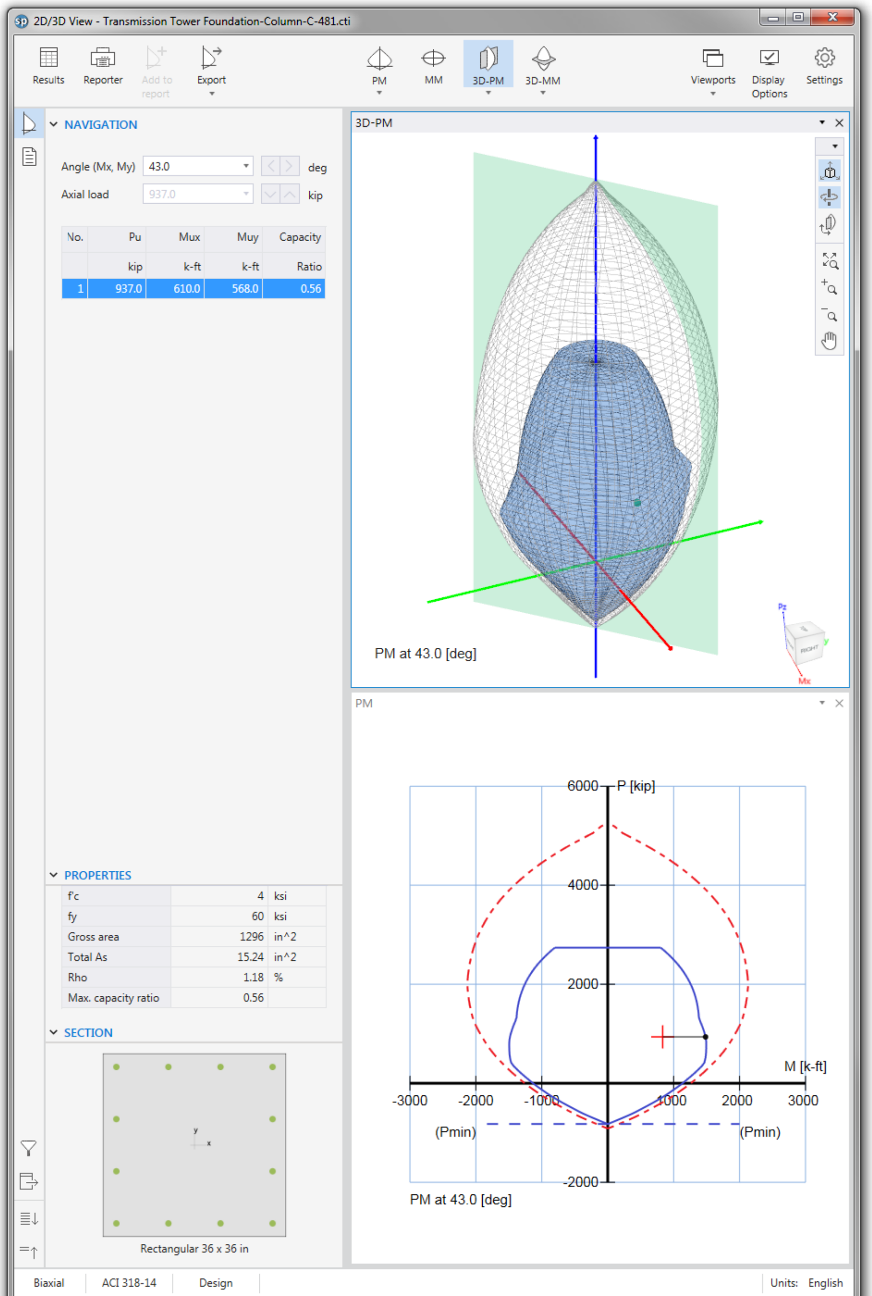


Figure 21 – 2D/3D View for Column

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.

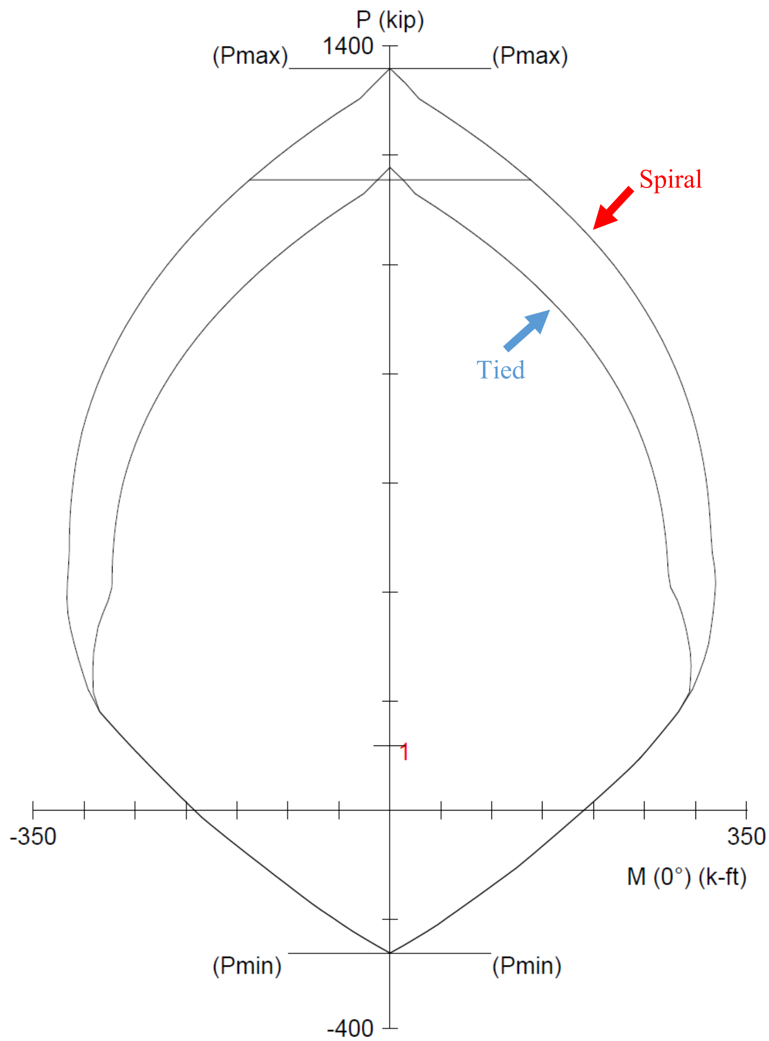


Figure 22 – Tied vs. Spiral Confinement