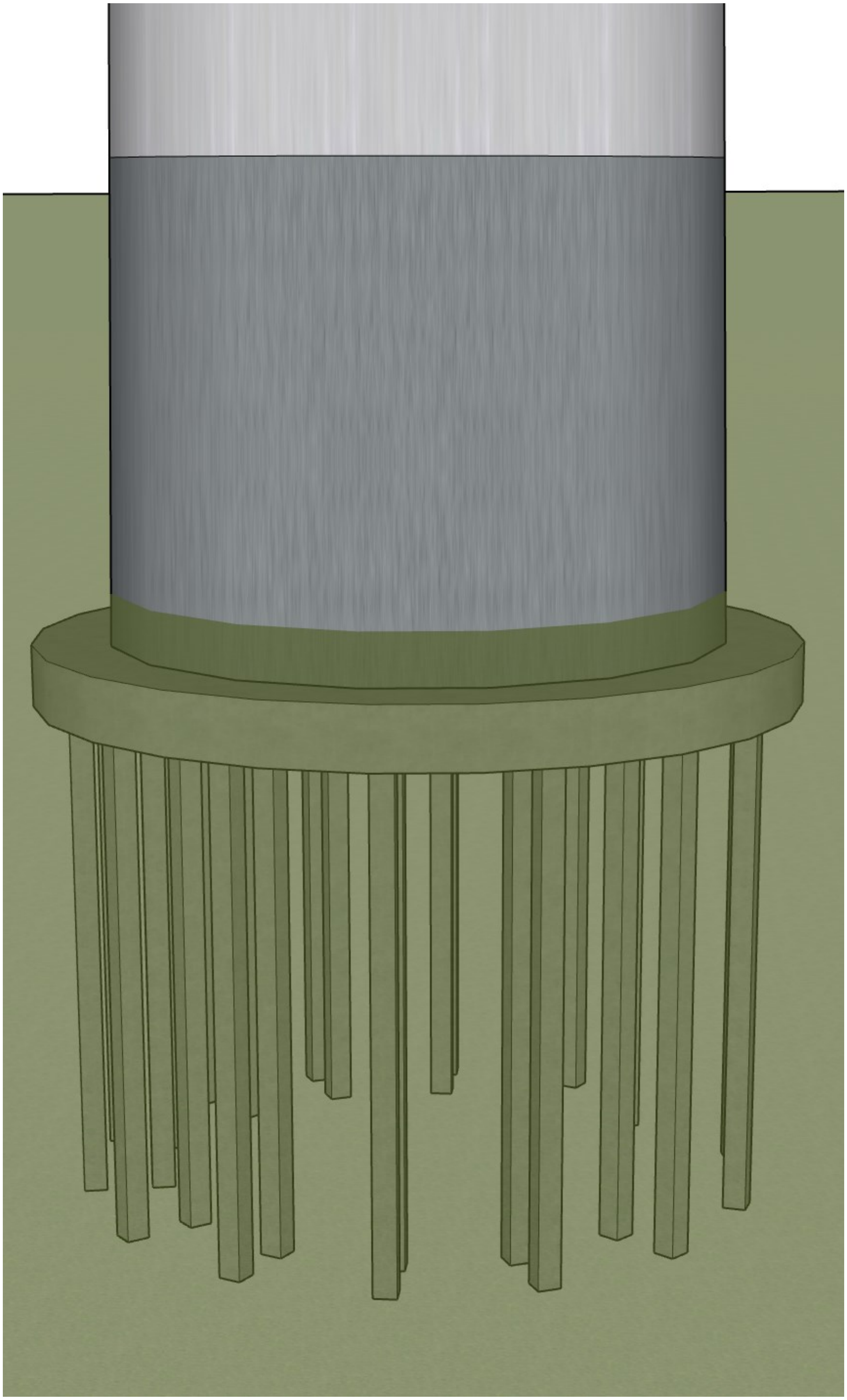
Tall Wind Turbine Pile Supported Concrete Foundation



Tall Wind Turbine Tower Pile Supported Concrete Foundation Analysis and Designes

A wind turbine, or alternatively referred to as a wind energy converter, is a device that converts the wind's kinetic energy into electrical energy.

Wind turbines are manufactured in a wide range of vertical and horizontal configurations. The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs. Larger turbines can be used for making contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid.

Arrays of large turbines, known as wind farms, are becoming an increasingly important source of intermittent renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels. One assessment claimed that, as of 2009, wind had the "lowest relative greenhouse gas emissions, the least water consumption demands and the most favourable social impacts" compared to photovoltaic, hydro, geothermal, coal and gas.

Wind turbines with generating capacity from as little as 0.1 MW to as high as 4.0 MW are offered by vendors like Siemens, GE, Mitsubishi, EWT, Vestas, etc.

This case study focuses on the design of a 2.0 MW tall wind turbine tower foundation using the engineering software program spMats. The tower under study is a 425 ft high and 40 ft diameter base with a blade length of 240 ft. Because of its height, the tower lower part is constructed as a reinforced concrete hollow circular section and transitions to steel section in the upper part. All the information provided by the wind turbine provider are shown in the following figure and design data and will serve as input for the foundation analysis and design. Because of the tower height and the significant overturning moment generated, a pile supported foundation was recommended with an optimized arrangement of piles to best resist uplift forces as shown in the following figure.

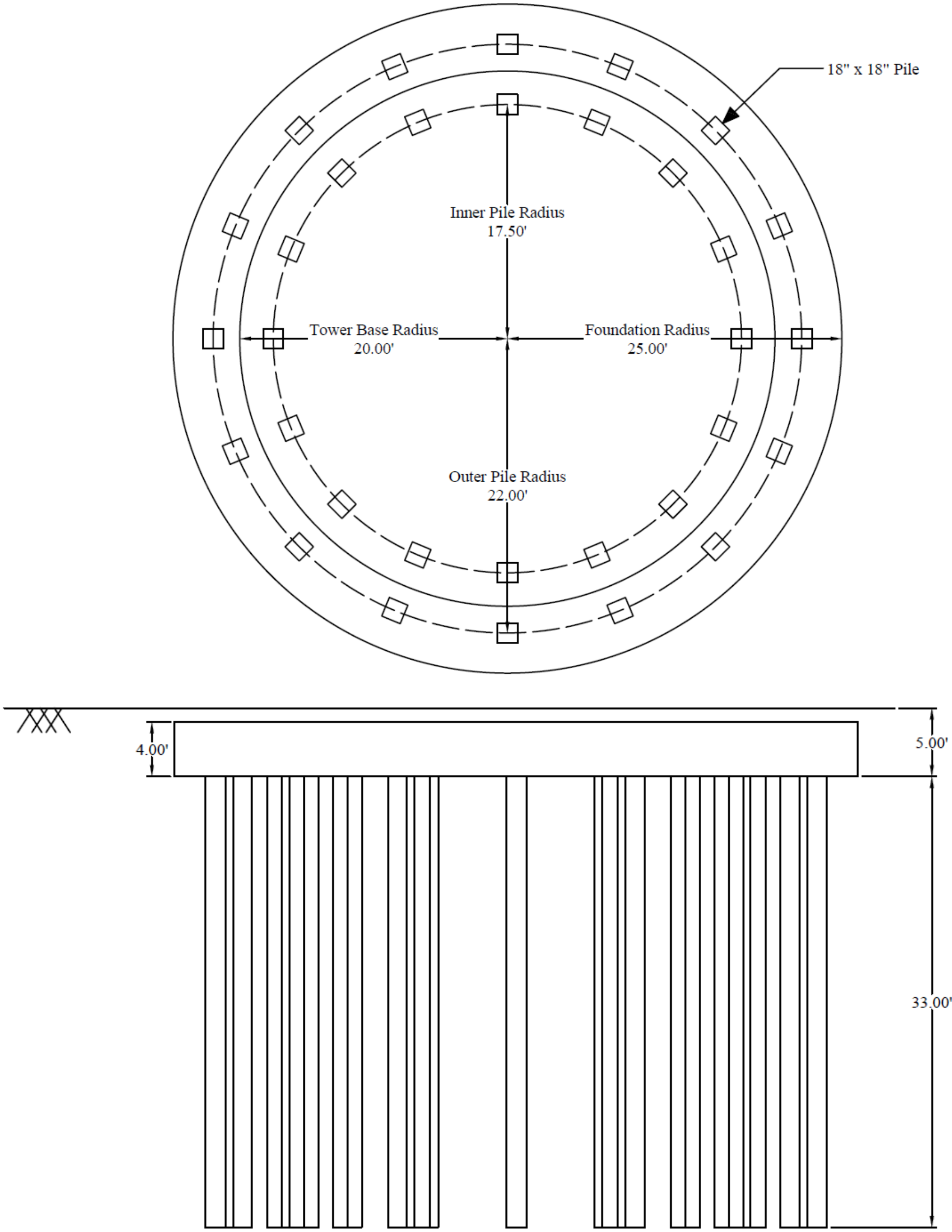


Figure 1 – Wind Turbine Tower Pile Supported Foundation

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 Piles

Dimensions = 18” x 18” x 33’

f_c' = 4,000 psi normal weight concrete

f_y = 60,000 psi (8 #9 longitudinal reinforcement)

16 inner piles at 17.5 ft radius

16 outer piles at 22 ft radius.

Piles arranged with center-to-center spacing of at least three pile diameters to avoid group effect.

Bottom of concrete mat foudnations is located at a depth of 5.0 ft below the ground surface.

Concrete Foundation – Pile Cap

Radius = 25 ft

Thickness = 4 ft

f_c' = 3,000 psi normal weight concrete

f_y = 60,000 psi

Foundation Loads

Dead load, D = 400 kips

Live load, L = 270 kips

Surcharge load = 100 psf

Soil Backfill

Depth = 6 in.

Density = 120 lb/ft^3

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 wind turbine tower reinforced concrete pile supported foundation in this example.

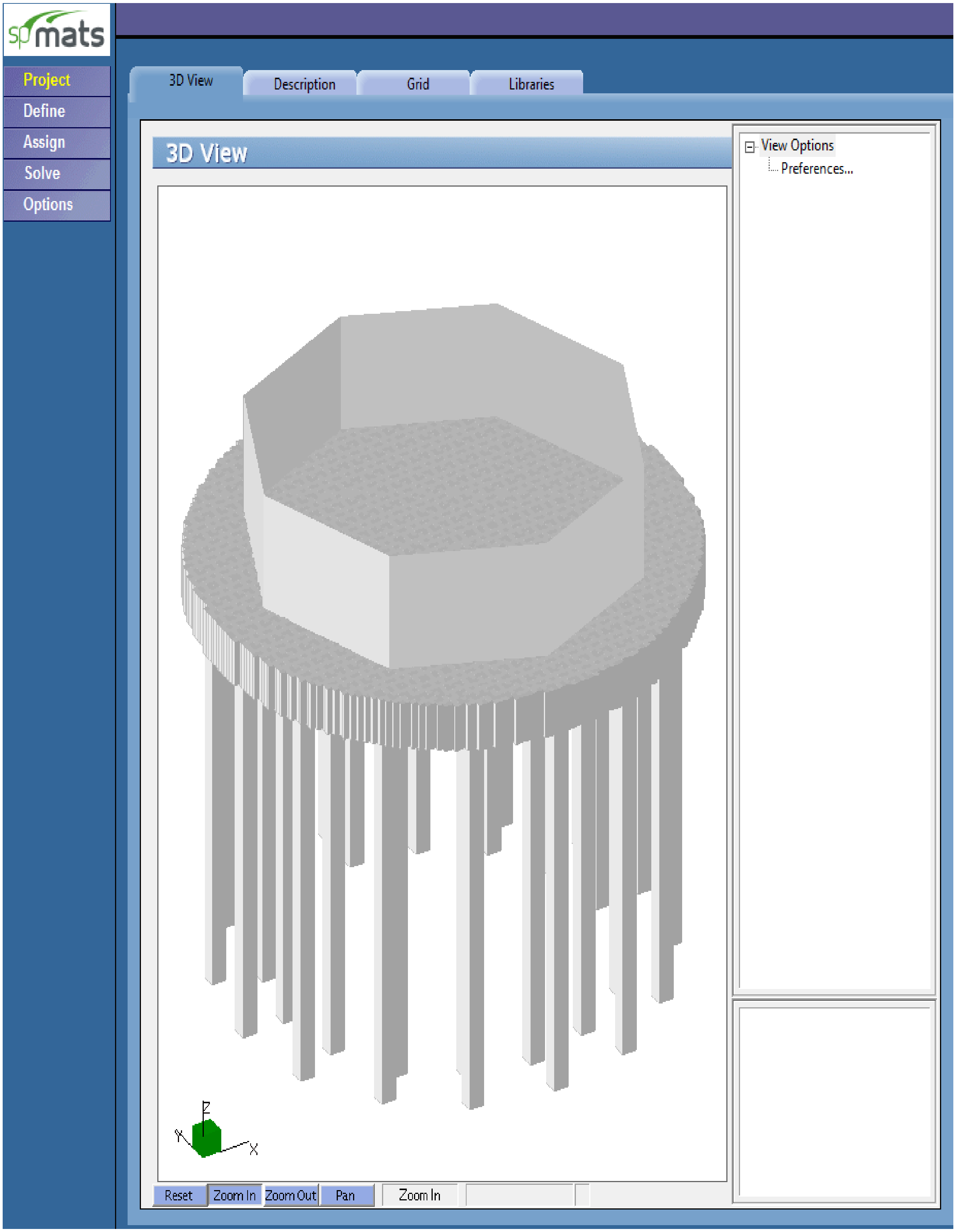


Figure 2 – Wind Turbine Tower Foundation Model 3D View

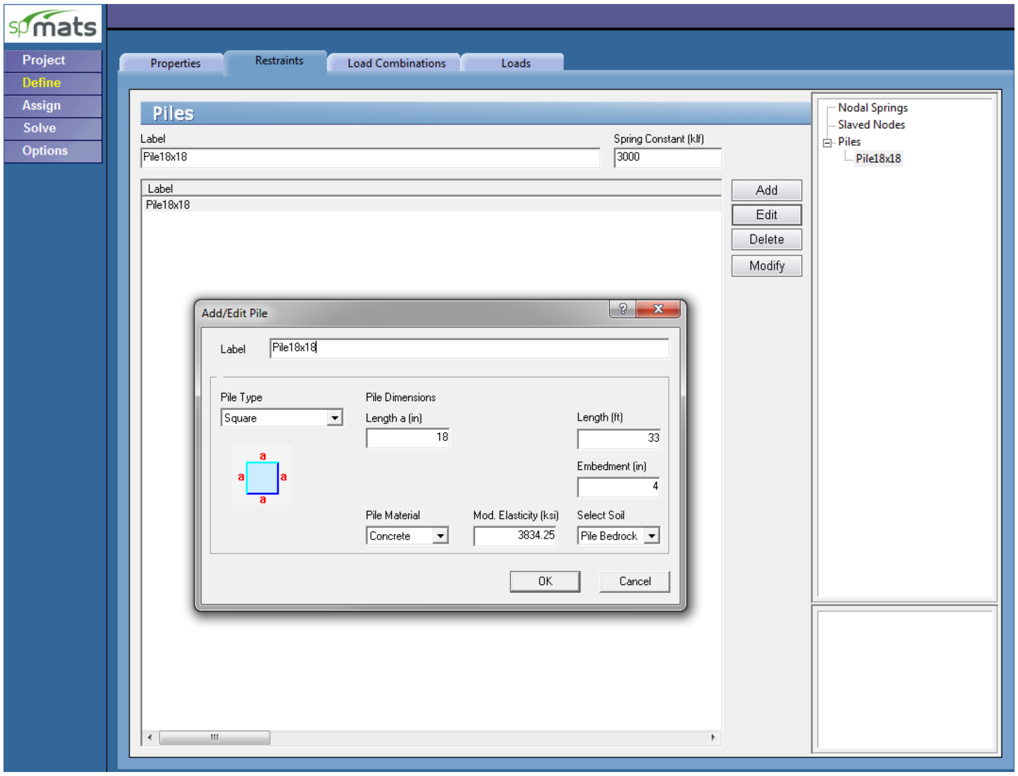


Figure 3 –Defining Piles

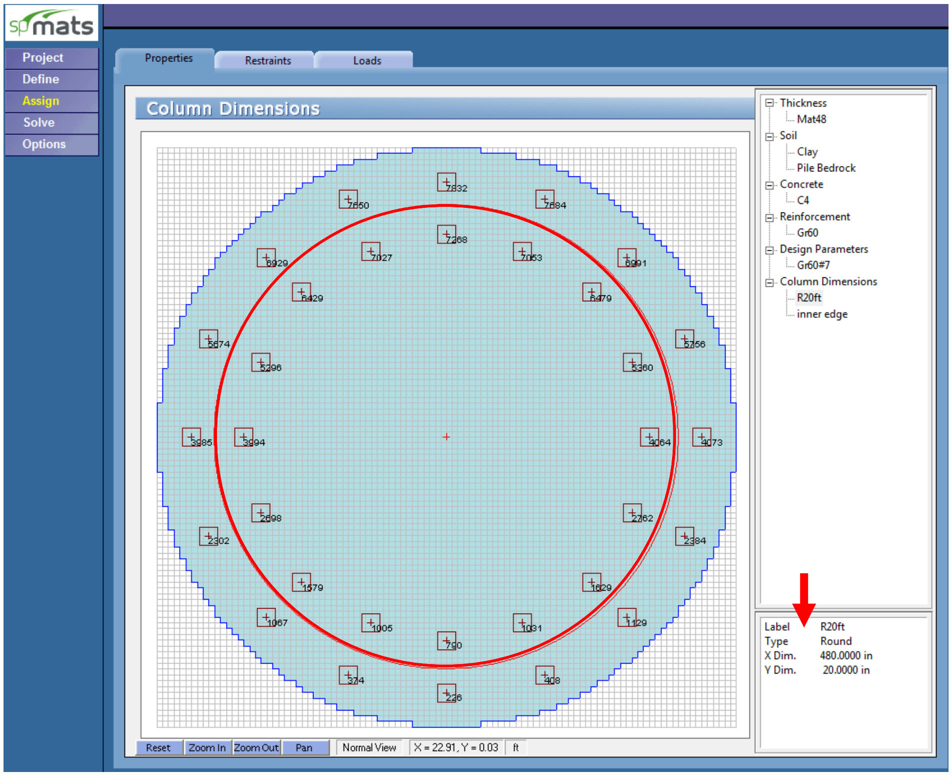


Figure 4 – Assigning Column

Column is assigned to represent the 40' diameter wind turbine tower base and to facilitate pile and load placement.

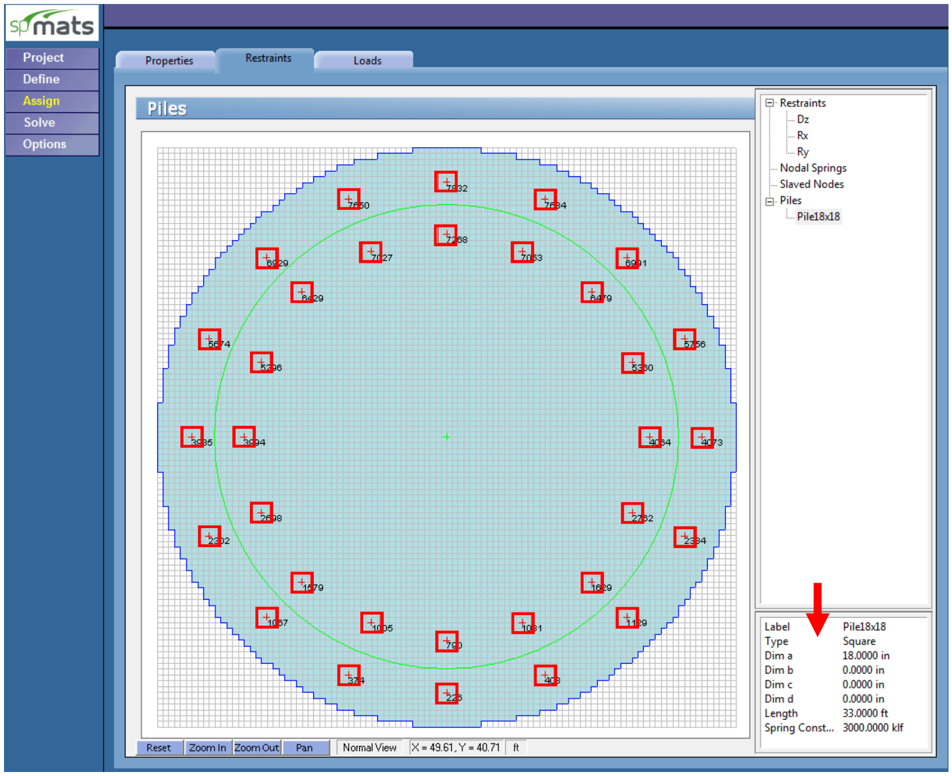


Figure 5 – Assigning Piles

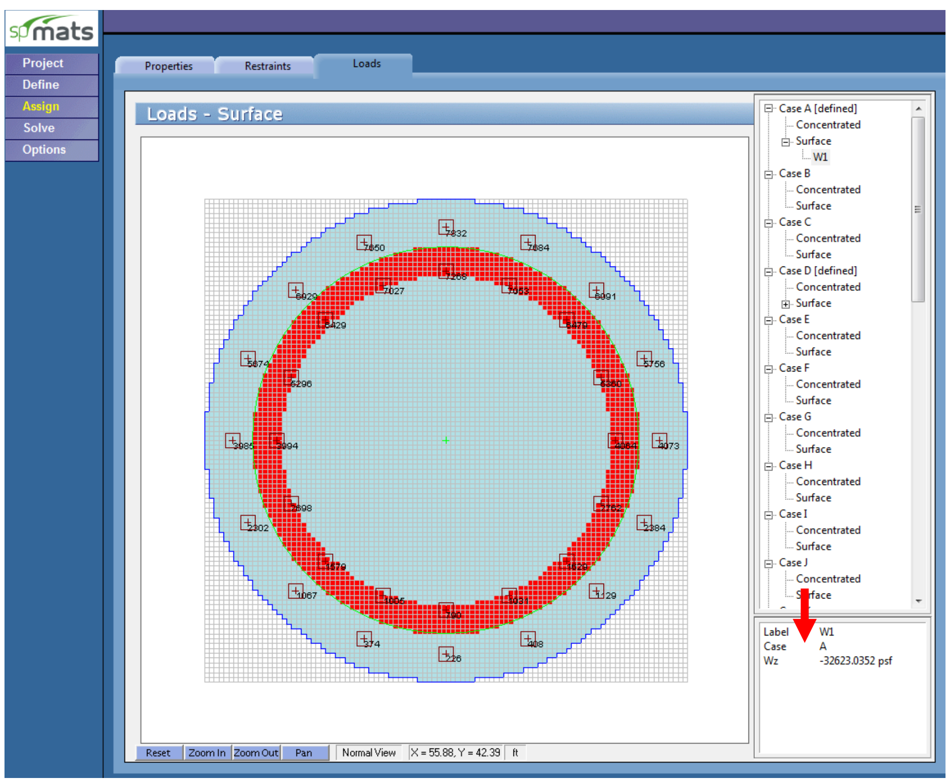


Figure 6 – Assigning Gravity Loads

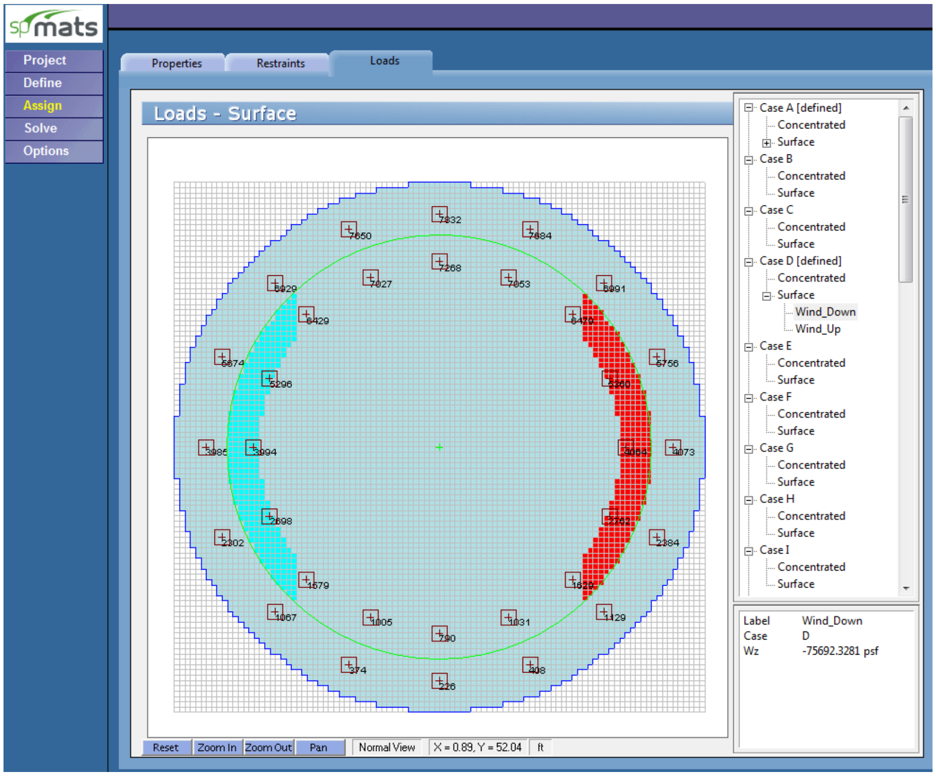


Figure 7 – Assigning Wind Load Overturning Momonets

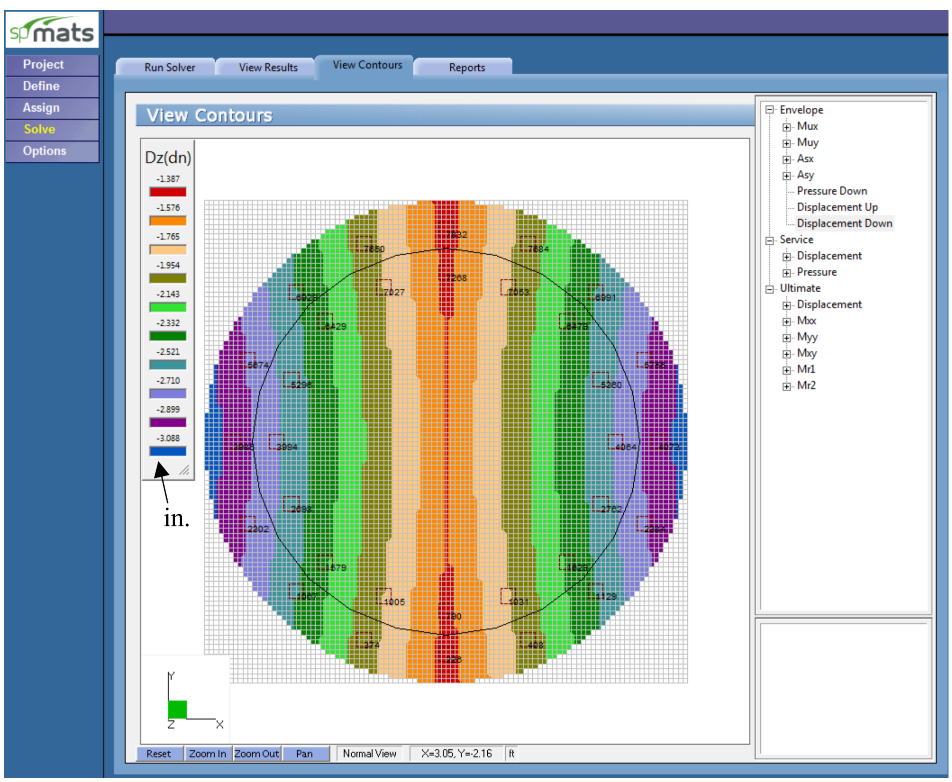


Figure 8 – Vertical Downward Displacement Contour

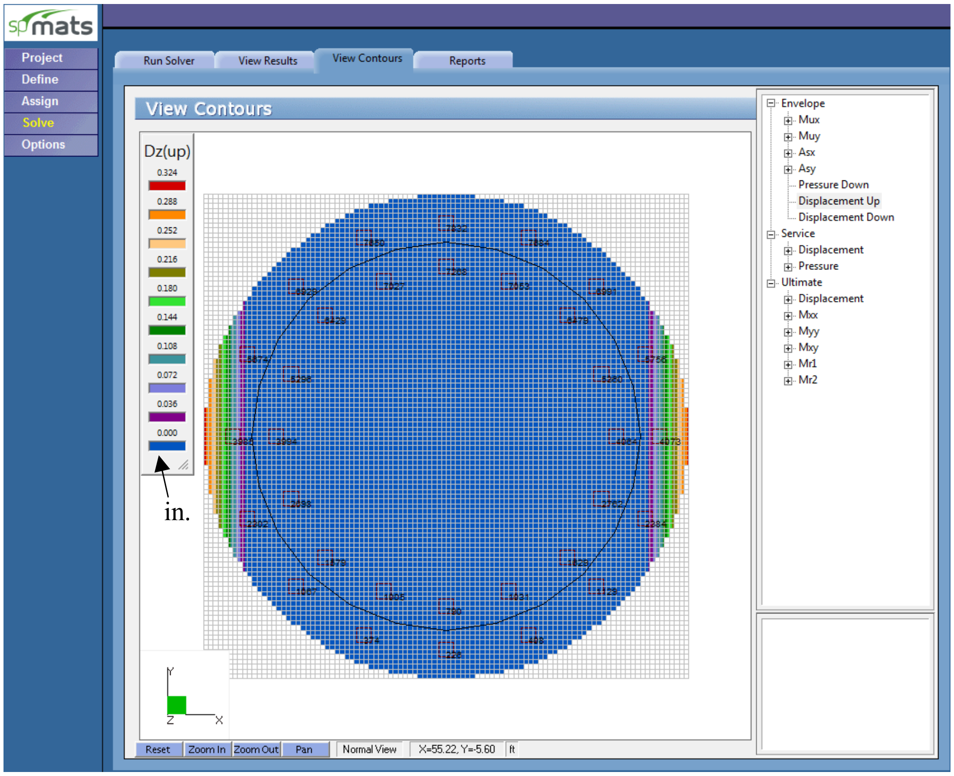


Figure 9 – Vertical Upward Displacement Contour

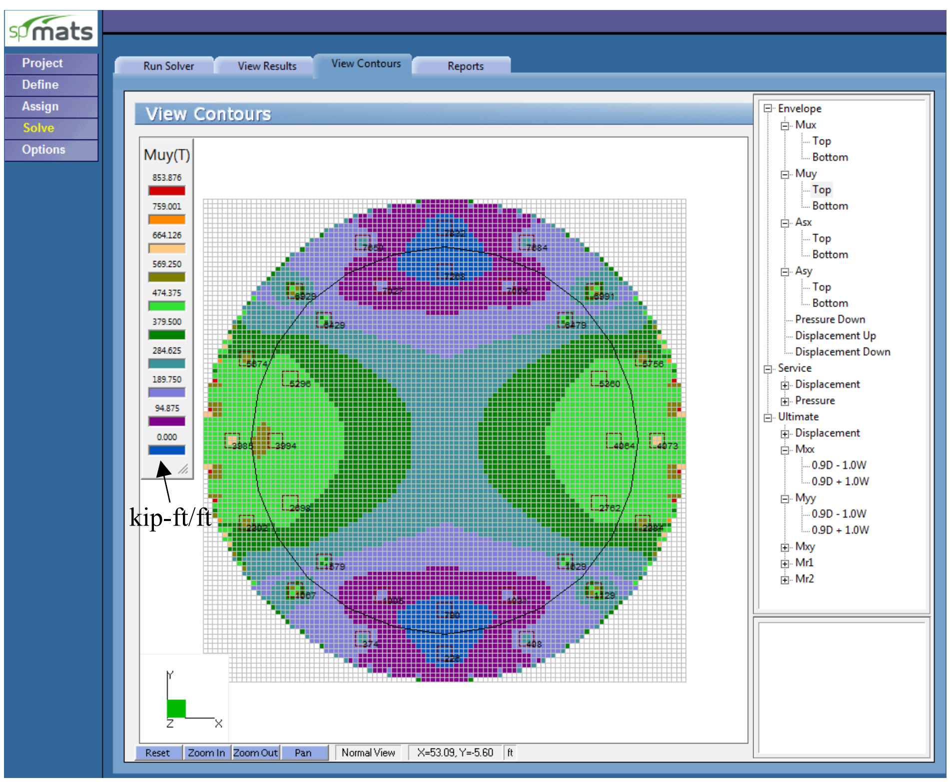


Figure 10 – Moment Contour along Y-Axis

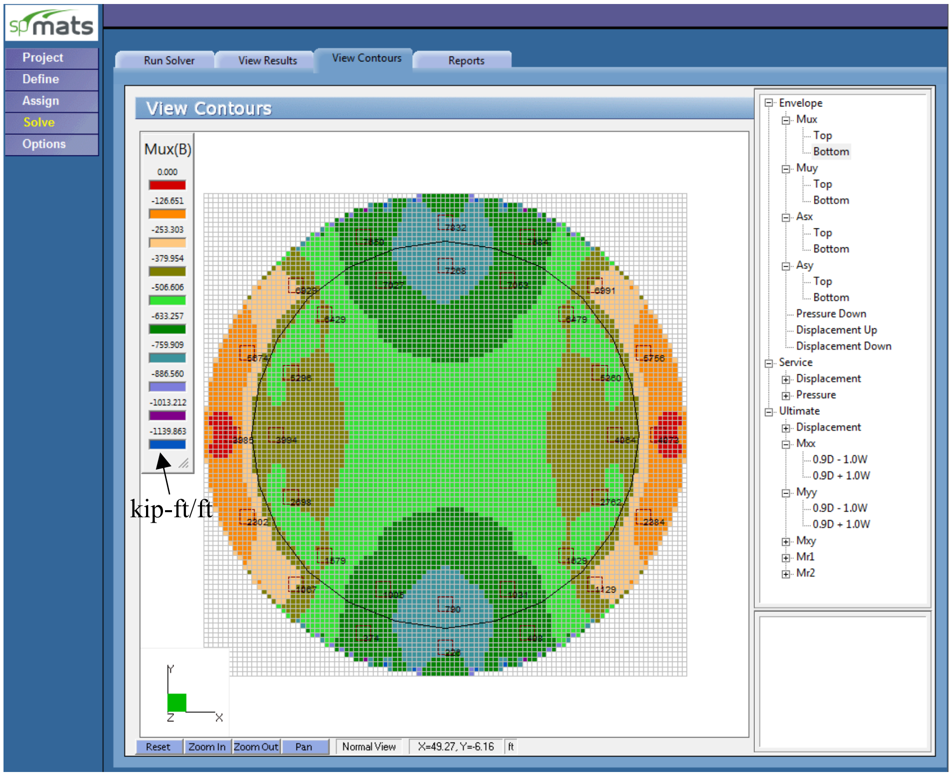


Figure 11 – Moment Contour along X-Axis - Complete Model

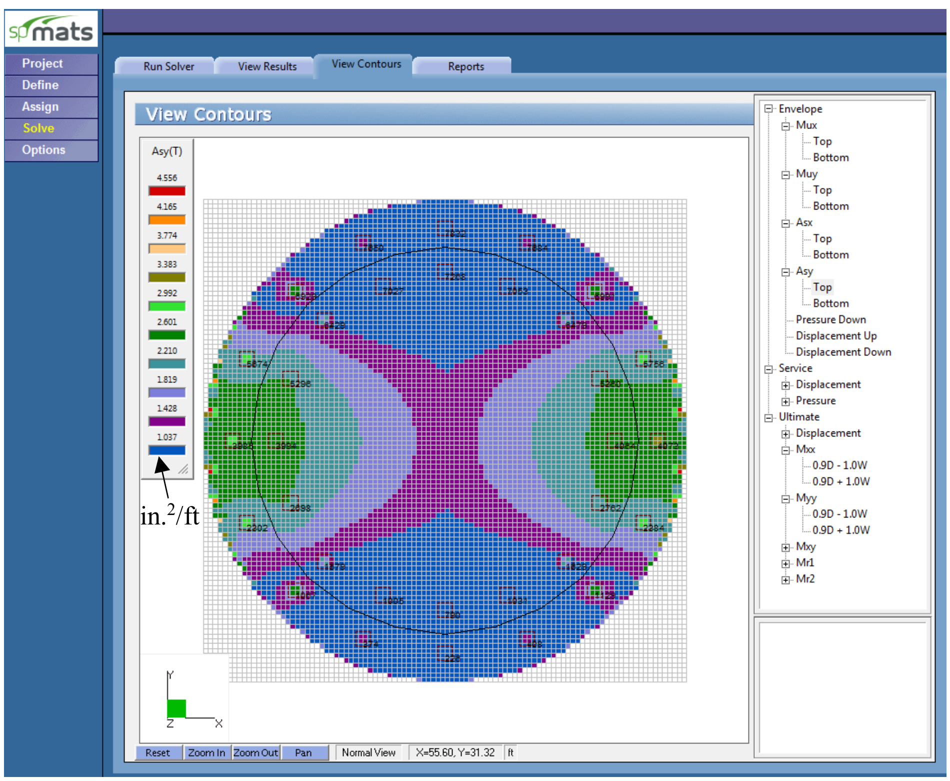


Figure 12 – Required Reinforcement Contour along Y Direction

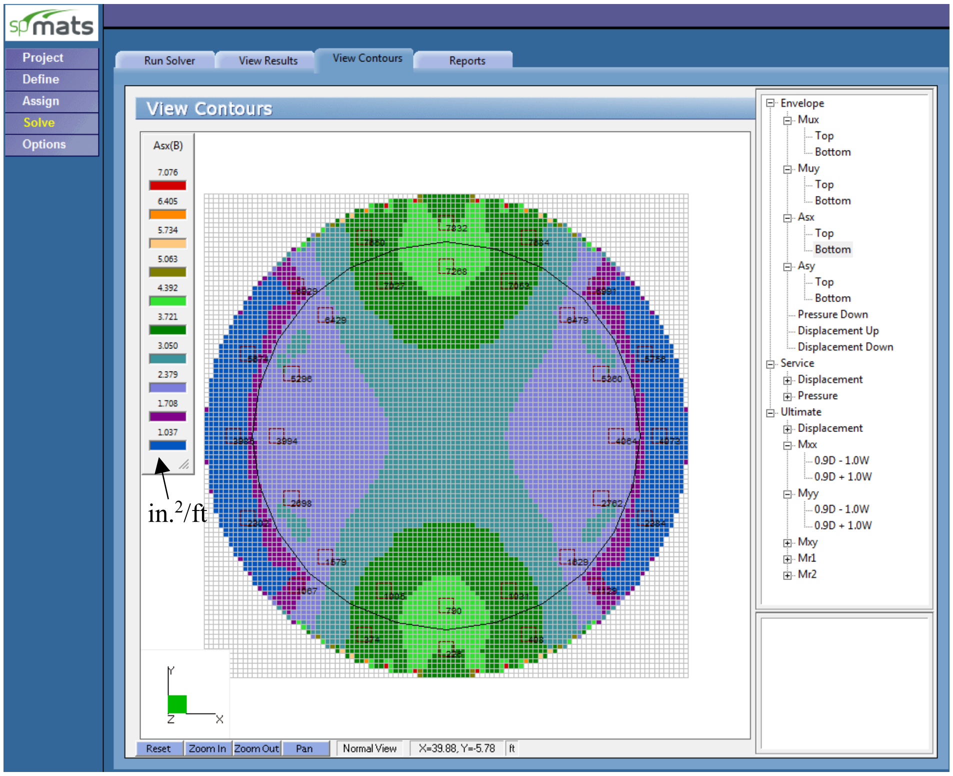


Figure 13 – Required Reinforcement Contour along X Direction

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.

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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
----- --------------  -------- -------- -------- -------- -------- --------
  226 Pile18x18        Inner       41.00     4.92     4.92    -0.00     0.00
  374 Pile18x18        Inner       41.00     4.92     4.92     0.00    -0.00
  408 Pile18x18        Inner       41.00     4.92     4.92    -0.00    -0.00
  790 Pile18x18        Inner       41.00     4.92     4.92    -0.00    -0.00
 1005 Pile18x18        Inner       41.00     4.92     4.92     0.00    -0.00
 1031 Pile18x18        Inner       41.00     4.92     4.92    -0.00    -0.00
 1067 Pile18x18        Inner       41.00     4.92     4.92     0.00     0.00
 1129 Pile18x18        Inner       41.00     4.92     4.92     0.00     0.00
 1579 Pile18x18        Inner       41.00     4.92     4.92    -0.00    -0.00
 1629 Pile18x18        Inner       41.00     4.92     4.92    -0.00    -0.00
 2302 Pile18x18        Inner       41.00     4.92     4.92    -0.00     0.00
 2384 Pile18x18        Inner       41.00     4.92     4.92     0.00     0.00
 2698 Pile18x18        Inner       41.00     4.92     4.92    -0.00     0.00
 2762 Pile18x18        Inner       41.00     4.92     4.92     0.00     0.00
 3985 Pile18x18        Inner       41.00     4.92     4.92     0.00    -0.00
 3994 Pile18x18        Inner       41.00     4.92     4.92    -0.00    -0.00
 4064 Pile18x18        Inner       41.00     4.92     4.92    -0.00    -0.00
 4073 Pile18x18        Inner       41.00     4.92     4.92     0.00    -0.00
 5296 Pile18x18        Inner       41.00     4.92     4.92    -0.00    -0.00
 5360 Pile18x18        Inner       41.00     4.92     4.92     0.00    -0.00
 5674 Pile18x18        Inner       41.00     4.92     4.92    -0.00    -0.00
 5756 Pile18x18        Inner       41.00     4.92     4.92     0.00    -0.00
 6429 Pile18x18        Inner       41.00     4.92     4.92    -0.00    -0.00
 6479 Pile18x18        Inner       41.00     4.92     4.92    -0.00    -0.00
 6929 Pile18x18        Inner       41.00     4.92     4.92     0.00     0.00
 6991 Pile18x18        Inner       41.00     4.92     4.92     0.00     0.00
 7027 Pile18x18        Inner       41.00     4.92     4.92     0.00     0.00
 7053 Pile18x18        Inner       41.00     4.92     4.92    -0.00     0.00
 7268 Pile18x18        Inner       41.00     4.92     4.92    -0.00    -0.00
 7650 Pile18x18        Inner       41.00     4.92     4.92     0.00     0.00
 7684 Pile18x18        Inner       41.00     4.92     4.92    -0.00     0.00
 7832 Pile18x18        Inner       41.00     4.92     4.92    -0.00     0.00

Properties of Resisting Area
------------------------------
 Node Pile Label           Area        Jxx            Jyy           Jxy
----- --------------  ----------  ------------ ------------ ------------
  226 Pile18x18          9676.00    6291415.50   6291415.50         0.00
  374 Pile18x18          9676.00    6291415.50   6291415.50         0.00
  408 Pile18x18          9676.00    6291415.50   6291415.50         0.00
  790 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 1005 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 1031 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 1067 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 1129 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 1579 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 1629 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 2302 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 2384 Pile18x18          9676.00    6291415.50   6291415.50        -0.00
 2698 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 2762 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 3985 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 3994 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 4064 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 4073 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 5296 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 5360 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 5674 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 5756 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 6429 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 6479 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 6929 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 6991 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 7027 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 7053 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 7268 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 7650 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 7684 Pile18x18          9676.00    6291415.50   6291415.50         0.00
 7832 Pile18x18          9676.00    6291415.50   6291415.50         0.00
```

Ultimate Load Combination: 0.9D - 1.0W

Factored Applied Forces:

Node	Pile Label	Vu	Mux	Gamma_X	Muy	Gamma_Y
226	Pile18x18	-94.54	-0.0	0.400	0.0	0.400
374	Pile18x18	436.33	0.0	0.400	-0.0	0.400
408	Pile18x18	-675.99	0.0	0.400	0.0	0.400
790	Pile18x18	-113.18	-0.0	0.400	0.0	0.400
1005	Pile18x18	297.62	0.0	0.400	-0.0	0.400
1031	Pile18x18	-558.82	0.0	0.400	0.0	0.400
1067	Pile18x18	846.29	0.0	0.400	-0.0	0.400
1129	Pile18x18	-1203.45	-0.0	0.400	0.0	0.400
1579	Pile18x18	659.13	0.0	0.400	-0.0	0.400
1629	Pile18x18	-1001.12	-0.0	0.400	0.0	0.400
2302	Pile18x18	1131.65	0.0	0.400	0.0	0.400
2384	Pile18x18	-1603.37	0.0	0.400	0.0	0.400
2698	Pile18x18	862.47	0.0	0.400	0.0	0.400
2762	Pile18x18	-1279.82	0.0	0.400	0.0	0.400
3985	Pile18x18	1214.66	0.0	0.400	-0.0	0.400
3994	Pile18x18	948.95	0.0	0.400	-0.0	0.400
4064	Pile18x18	-1399.60	-0.0	0.400	0.0	0.400
4073	Pile18x18	-1730.06	-0.0	0.400	0.0	0.400
5296	Pile18x18	861.70	0.0	0.400	0.0	0.400
5360	Pile18x18	-1280.30	-0.0	0.400	0.0	0.400
5674	Pile18x18	1130.59	0.0	0.400	0.0	0.400
5756	Pile18x18	-1603.98	-0.0	0.400	0.0	0.400
6429	Pile18x18	657.77	0.0	0.400	-0.0	0.400
6479	Pile18x18	-1002.06	-0.0	0.400	0.0	0.400
6929	Pile18x18	844.56	0.0	0.400	-0.0	0.400
6991	Pile18x18	-1204.59	-0.0	0.400	0.0	0.400
7027	Pile18x18	296.12	0.0	0.400	-0.0	0.400
7053	Pile18x18	-560.08	-0.0	0.400	0.0	0.400
7268	Pile18x18	-114.66	-0.0	0.400	0.0	0.400
7650	Pile18x18	434.39	0.0	0.400	-0.0	0.400
7684	Pile18x18	-677.57	-0.0	0.400	0.0	0.400
7832	Pile18x18	-96.37	-0.0	0.400	0.0	0.400

Factored Stress and Capacity:

Node	Pile Label	vu	f'c	Phi*vc	_Critical Point__ X_Offset	Y_Offset	Status
226	Pile18x18	-9.77	4000.00	189.74	2.46	2.46	Safe
374	Pile18x18	45.09	4000.00	189.74	2.46	2.46	Safe
408	Pile18x18	-69.86	4000.00	189.74	2.46	2.46	Safe
790	Pile18x18	-11.70	4000.00	189.74	2.46	2.46	Safe
1005	Pile18x18	30.76	4000.00	189.74	2.46	2.46	Safe
1031	Pile18x18	-57.75	4000.00	189.74	2.46	2.46	Safe
1067	Pile18x18	87.46	4000.00	189.74	2.46	2.46	Safe
1129	Pile18x18	-124.37	4000.00	189.74	2.46	2.46	Safe
1579	Pile18x18	68.12	4000.00	189.74	2.46	2.46	Safe
1629	Pile18x18	-103.46	4000.00	189.74	2.46	2.46	Safe
2302	Pile18x18	116.95	4000.00	189.74	2.46	2.46	Safe
2384	Pile18x18	-165.71	4000.00	189.74	2.46	2.46	Safe
2698	Pile18x18	89.14	4000.00	189.74	2.46	2.46	Safe
2762	Pile18x18	-132.27	4000.00	189.74	2.46	2.46	Safe
3985	Pile18x18	125.53	4000.00	189.74	2.46	2.46	Safe
3994	Pile18x18	98.07	4000.00	189.74	2.46	2.46	Safe
4064	Pile18x18	-144.65	4000.00	189.74	2.46	2.46	Safe
4073	Pile18x18	-178.80	4000.00	189.74	2.46	2.46	Safe
5296	Pile18x18	89.06	4000.00	189.74	2.46	2.46	Safe
5360	Pile18x18	-132.32	4000.00	189.74	2.46	2.46	Safe
5674	Pile18x18	116.84	4000.00	189.74	2.46	2.46	Safe
5756	Pile18x18	-165.77	4000.00	189.74	2.46	2.46	Safe
6429	Pile18x18	67.98	4000.00	189.74	2.46	2.46	Safe
6479	Pile18x18	-103.56	4000.00	189.74	2.46	2.46	Safe
6929	Pile18x18	87.28	4000.00	189.74	2.46	2.46	Safe
6991	Pile18x18	-124.49	4000.00	189.74	2.46	2.46	Safe
7027	Pile18x18	30.60	4000.00	189.74	2.46	2.46	Safe
7053	Pile18x18	-57.88	4000.00	189.74	2.46	2.46	Safe
7268	Pile18x18	-11.85	4000.00	189.74	2.46	2.46	Safe
7650	Pile18x18	44.89	4000.00	189.74	2.46	2.46	Safe
7684	Pile18x18	-70.03	4000.00	189.74	2.46	2.46	Safe
7832	Pile18x18	-9.96	4000.00	189.74	2.46	2.46	Safe

Figure 14 – 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 + 0.5L - 1

	Soil	Spring	Pile	Restraints			Slaved Nodes		
Node	Fz	Fz	Fz	Fz	Mx	My	Fz	Mx	My
226	-	-	351.628	-	-	-	-	-	-
374	-	-	488.463	-	-	-	-	-	-
408	-	-	213.920	-	-	-	-	-	-
790	-	-	357.890	-	-	-	-	-	-
1005	-	-	464.871	-	-	-	-	-	-
1031	-	-	251.316	-	-	-	-	-	-
1067	-	-	608.441	-	-	-	-	-	-
1129	-	-	94.104	-	-	-	-	-	-
1579	-	-	566.951	-	-	-	-	-	-
1629	-	-	147.742	-	-	-	-	-	-
2302	-	-	698.162	-	-	-	-	-	-
2384	-	-	2.664	-	-	-	-	-	-
2698	-	-	631.258	-	-	-	-	-	-
2762	-	-	83.818	-	-	-	-	-	-
3985	-	-	726.576	-	-	-	-	-	-
3994	-	-	658.079	-	-	-	-	-	-
4064	-	-	55.920	-	-	-	-	-	-
4073	-	-	-25.776	-	-	-	-	-	-
5296	-	-	630.854	-	-	-	-	-	-
5360	-	-	83.677	-	-	-	-	-	-
5674	-	-	697.594	-	-	-	-	-	-
5756	-	-	2.499	-	-	-	-	-	-
6429	-	-	566.267	-	-	-	-	-	-
6479	-	-	147.442	-	-	-	-	-	-
6929	-	-	607.550	-	-	-	-	-	-
6991	-	-	93.759	-	-	-	-	-	-
7027	-	-	464.171	-	-	-	-	-	-
7053	-	-	250.858	-	-	-	-	-	-
7268	-	-	357.277	-	-	-	-	-	-
7650	-	-	487.545	-	-	-	-	-	-
7684	-	-	213.366	-	-	-	-	-	-
7832	-	-	350.871	-	-	-	-	-	-

Sum of all forces and moments with respect to center of gravity (X, Y) = (25.00, 25.00) ft

Sum of Reactions	Fz	Mx	My
Soil	-	-	-
Springs	-	-	-
Piles	11329.756	-117.295	106960.781
Restraints	-	-	-
Slaved Nodes	-	-	-
Total Reactions	11329.756	-117.295	106960.781
Total Loads	-11329.756	117.295	-106960.781

Figure 15 – Piles Service Reactions

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

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
226	-	-	-94.542	-	-	-	-	-	-
374	-	-	436.332	-	-	-	-	-	-
408	-	-	0.000	-	-	-	-	-	-
790	-	-	-113.183	-	-	-	-	-	-
1005	-	-	297.623	-	-	-	-	-	-
1031	-	-	0.000	-	-	-	-	-	-
1067	-	-	846.291	-	-	-	-	-	-
1129	-	-	0.000	-	-	-	-	-	-
1579	-	-	659.131	-	-	-	-	-	-
1629	-	-	0.000	-	-	-	-	-	-
2302	-	-	1131.652	-	-	-	-	-	-
2384	-	-	0.000	-	-	-	-	-	-
2698	-	-	862.472	-	-	-	-	-	-
2762	-	-	0.000	-	-	-	-	-	-
3985	-	-	1214.659	-	-	-	-	-	-
3994	-	-	948.951	-	-	-	-	-	-
4064	-	-	0.000	-	-	-	-	-	-
4073	-	-	0.000	-	-	-	-	-	-
5296	-	-	861.700	-	-	-	-	-	-
5360	-	-	0.000	-	-	-	-	-	-
5674	-	-	1130.591	-	-	-	-	-	-
5756	-	-	0.000	-	-	-	-	-	-
6429	-	-	657.774	-	-	-	-	-	-
6479	-	-	0.000	-	-	-	-	-	-
6929	-	-	844.557	-	-	-	-	-	-
6991	-	-	0.000	-	-	-	-	-	-
7027	-	-	296.119	-	-	-	-	-	-
7053	-	-	0.000	-	-	-	-	-	-
7268	-	-	-114.656	-	-	-	-	-	-
7650	-	-	434.389	-	-	-	-	-	-
7684	-	-	0.000	-	-	-	-	-	-
7832	-	-	-96.370	-	-	-	-	-	-

Sum of all forces and moments with respect to center of gravity (X, Y) = (25.00, 25.00) ft

Sum of Reactions	Fz	Mx	My
Soil	-	-	-
Springs	-	-	-
Piles	10203.490	-187.764	171221.797
Restraints	-	-	-
Slaved Nodes	-	-	-
Total Reactions	10203.490	-187.764	171221.797
Total Loads	-10203.490	187.764	-171221.797

Figure 16 – 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.

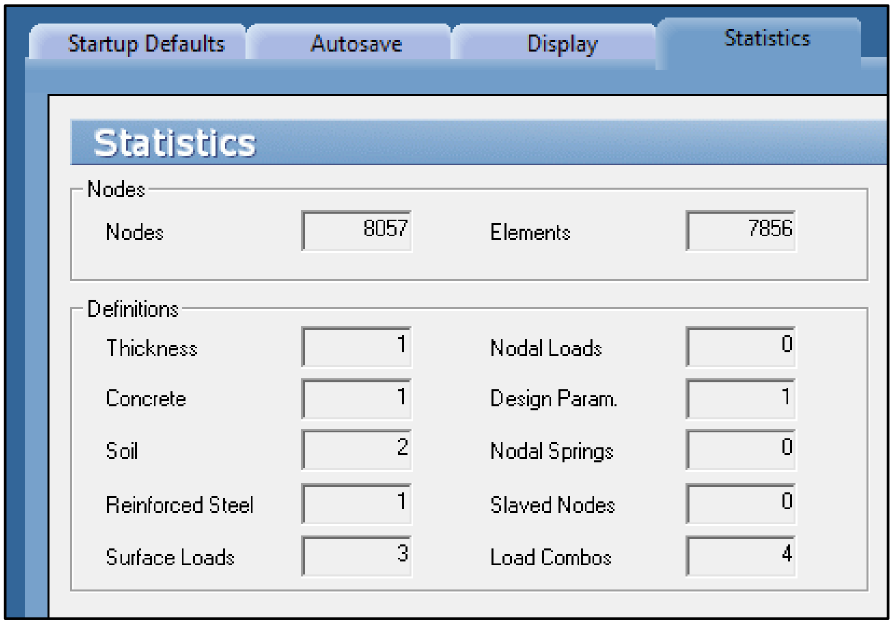


Figure 17 – Model Statistics

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.

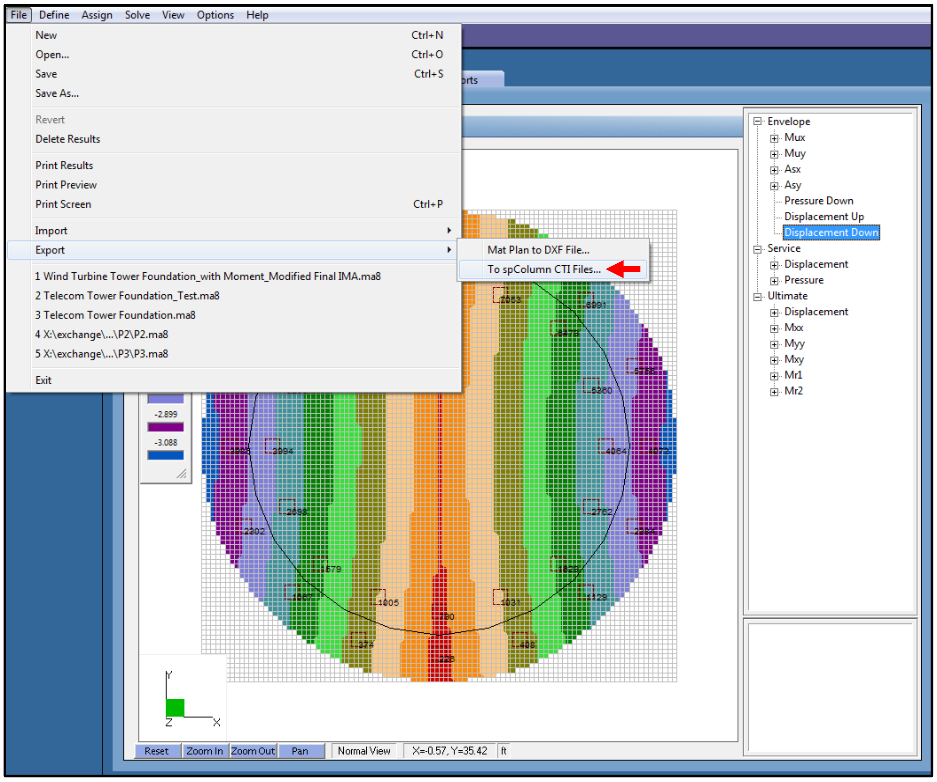


Figure 18 – Exporting Column Design CTI Files

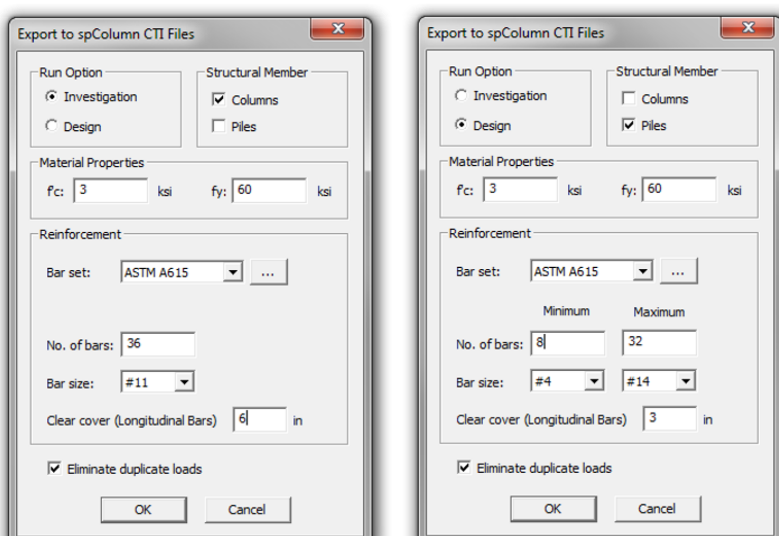


Figure 19 – Exporting Column Design CTI Files Dialog Box

After exporting spColumn input files, the pile and column design/investigation can proceed/modified to meet project specifications and criteria. In the following, the wind turbine concrete circular base section capacity results are shown as an example.

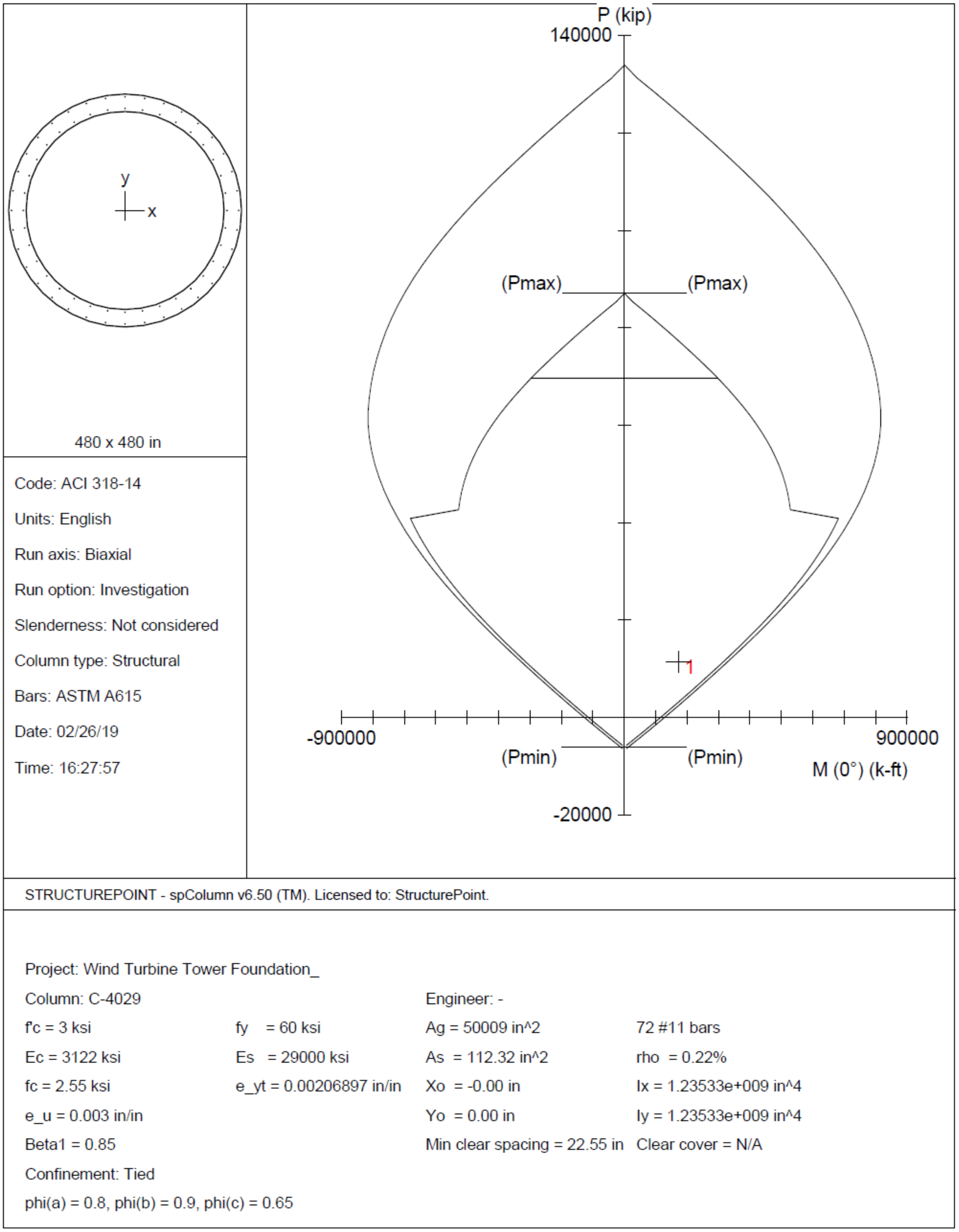


Figure 20 – Wind Turbine Concrete Tower Design Capacity with Factored Load

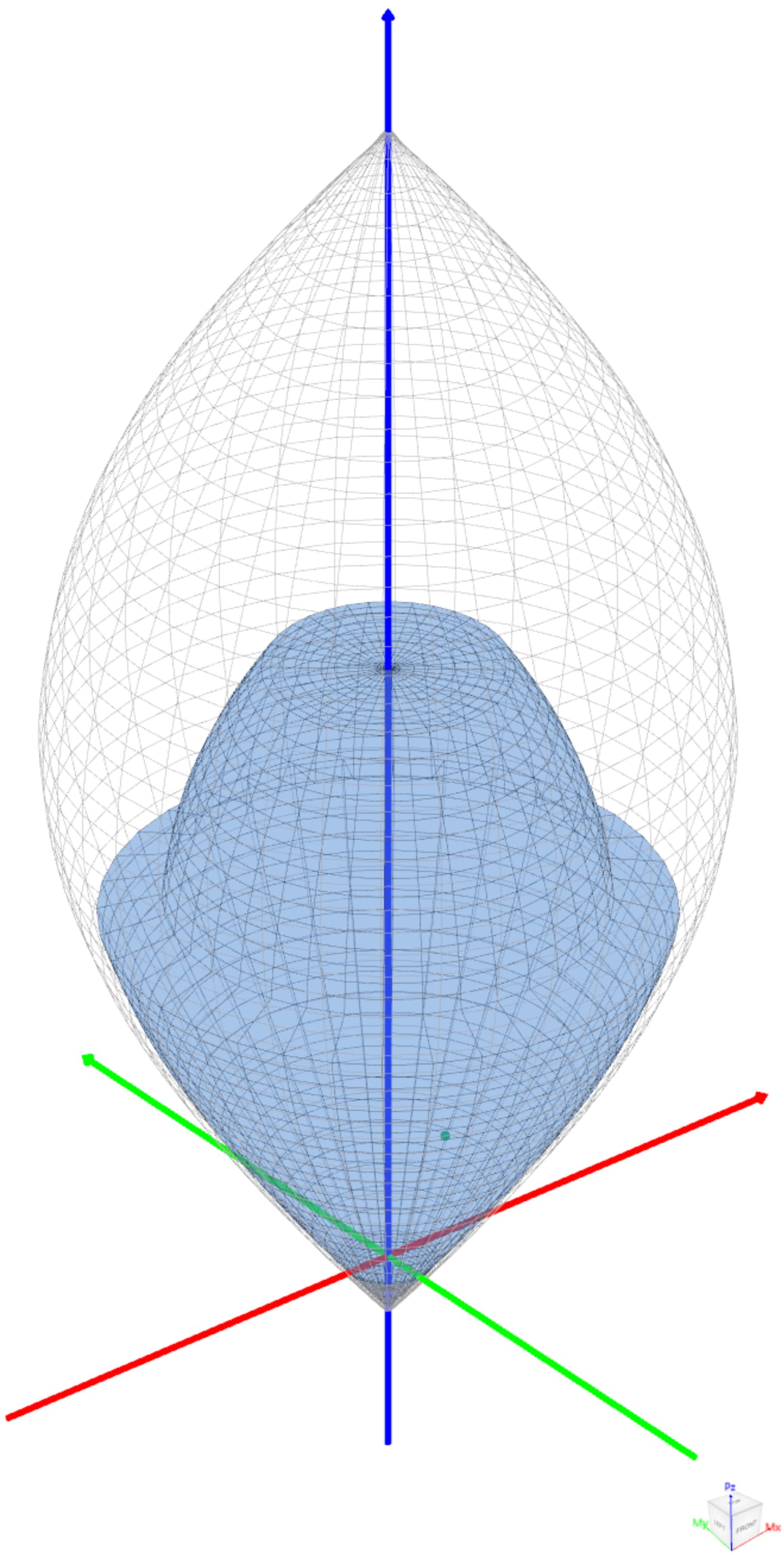
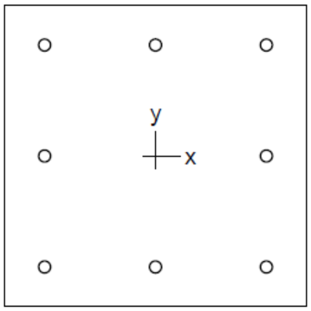


Figure 21 – Wind Turbine Tower Concrete Base 3D Failure Surface



18 x 18 in

Code: ACI 318-14

Units: English

Run axis: Biaxial

Run option: Design

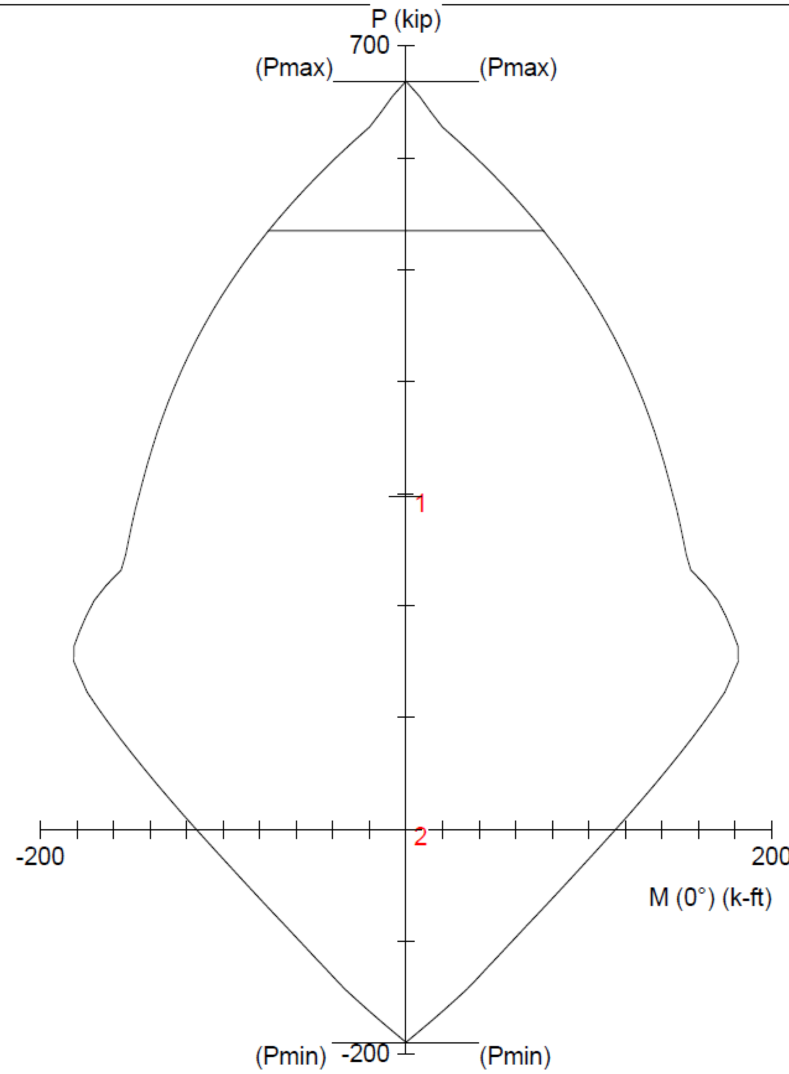
Slenderness: Not considered

Column type: Structural

Bars: ASTM A615

Date: 02/26/19

Time: 16:41:11



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

File:

Project: Wind Turbine Tower Foundation_

Column: P-1005		Engineer: -	
f'c = 3 ksi	fy = 60 ksi	Ag = 324 in^2	8 #6 bars
Ec = 3122 ksi	Es = 29000 ksi	As = 3.52 in^2	rho = 1.09%
fc = 2.55 ksi	e_yt = 0.00206897 in/in	Xo = 0.00 in	Ix = 8748 in^4
e_u = 0.003 in/in		Yo = 0.00 in	Iy = 8748 in^4
Beta1 = 0.85		Min clear spacing = 5.88 in	Clear cover = 2.00 in
Confinement: Tied			
phi(a) = 0.8, phi(b) = 0.9, phi(c) = 0.65			

Figure 22 – Pile Design Capacity 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.

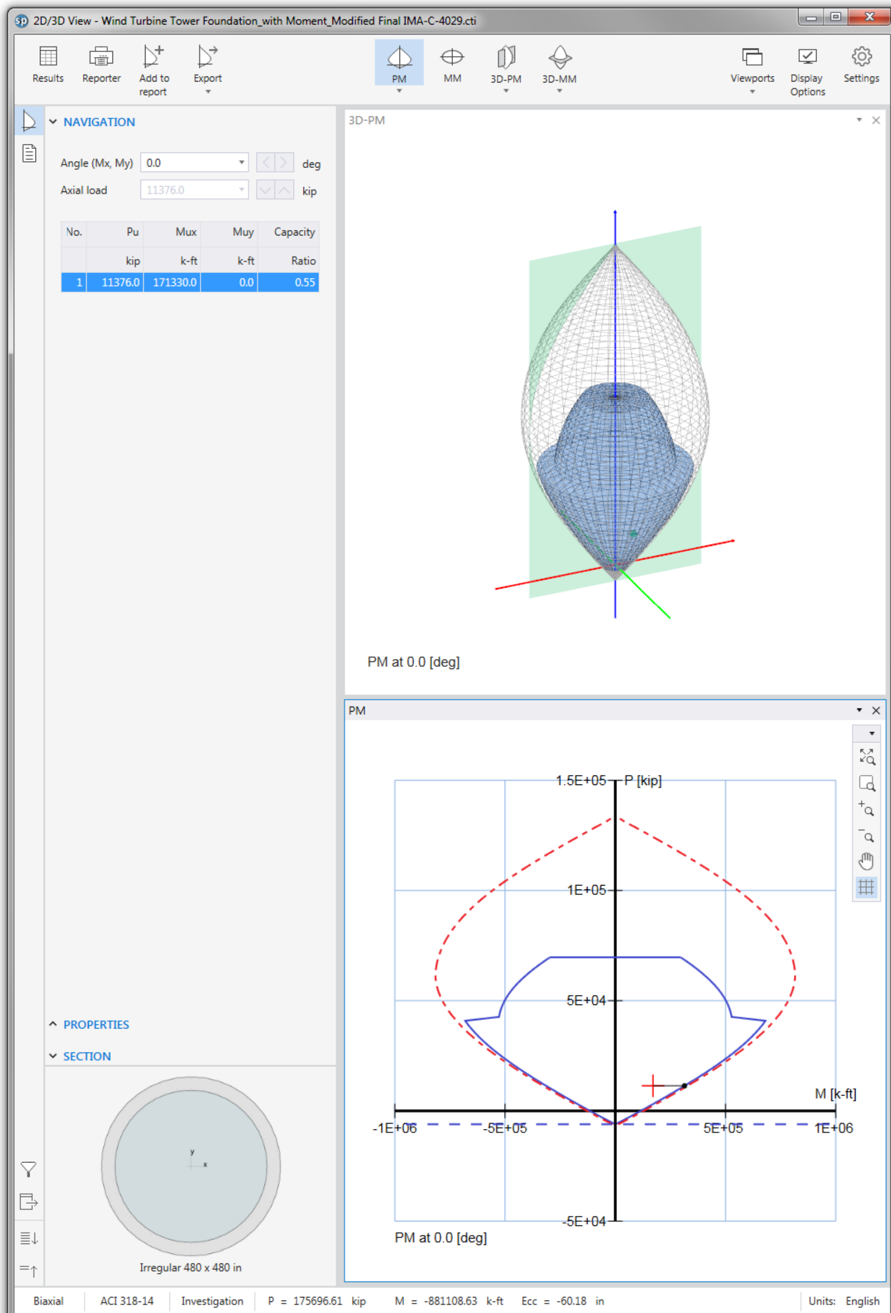


Figure 23 – 2D/3D View for Turbine Tower