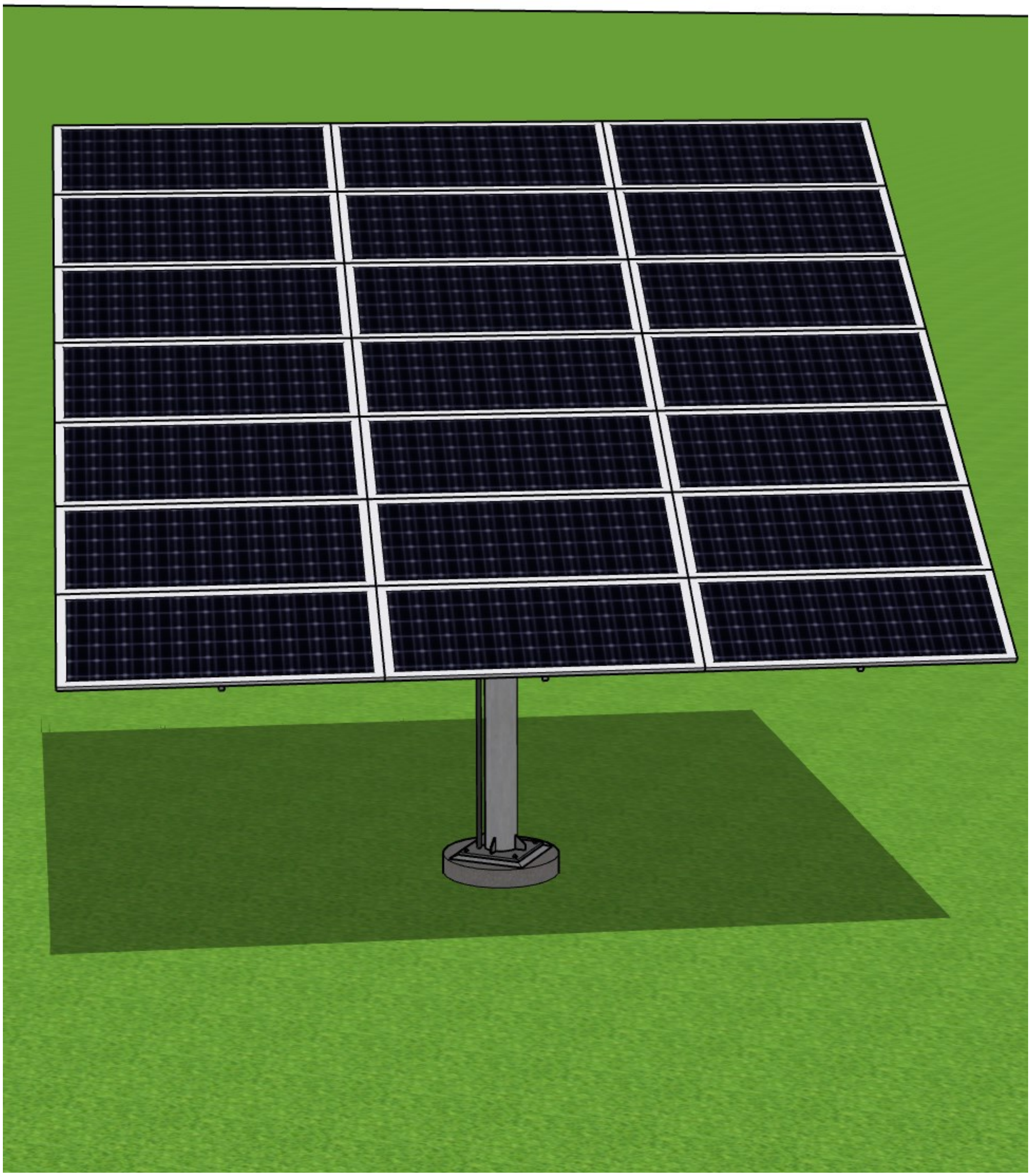
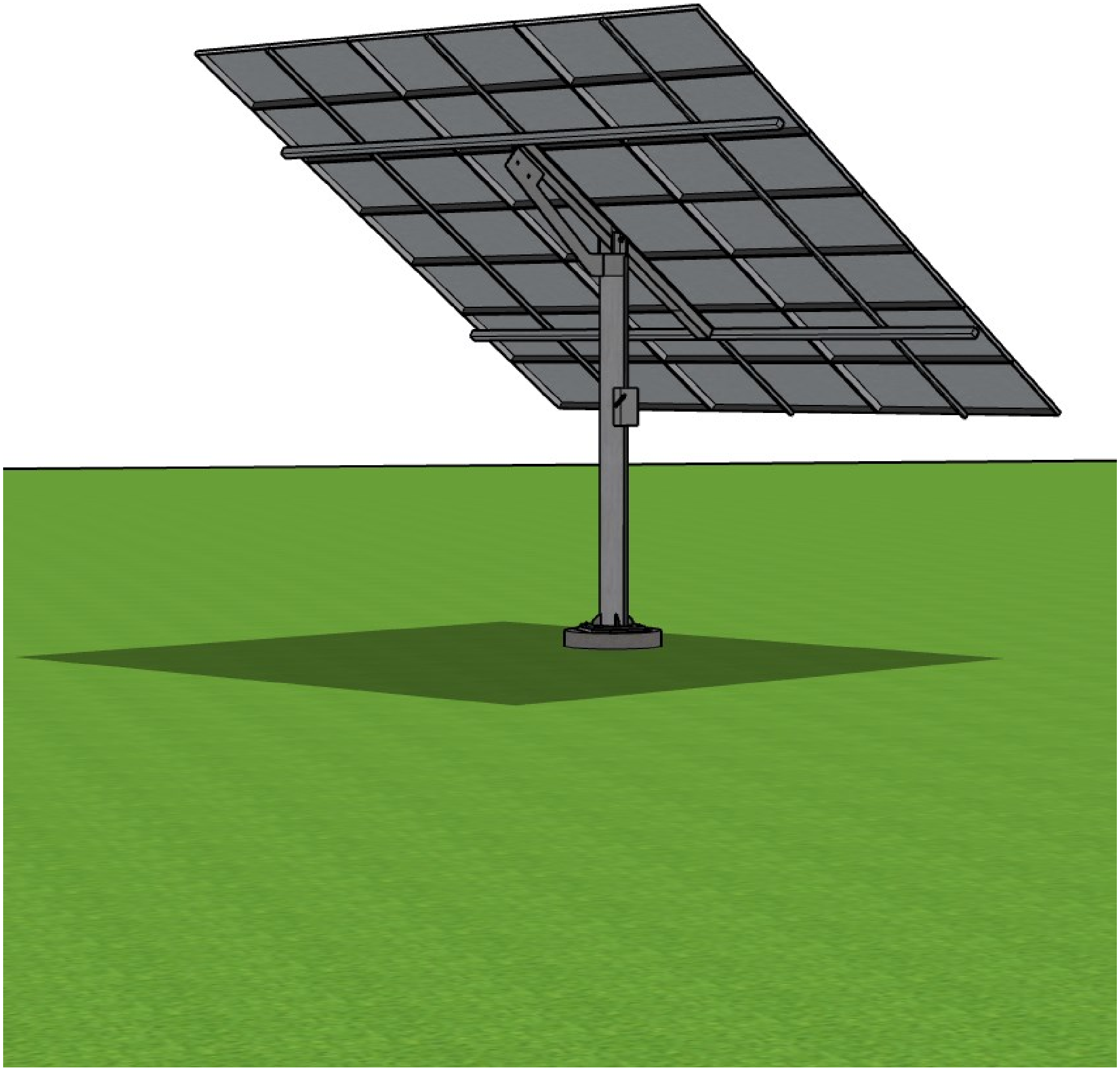
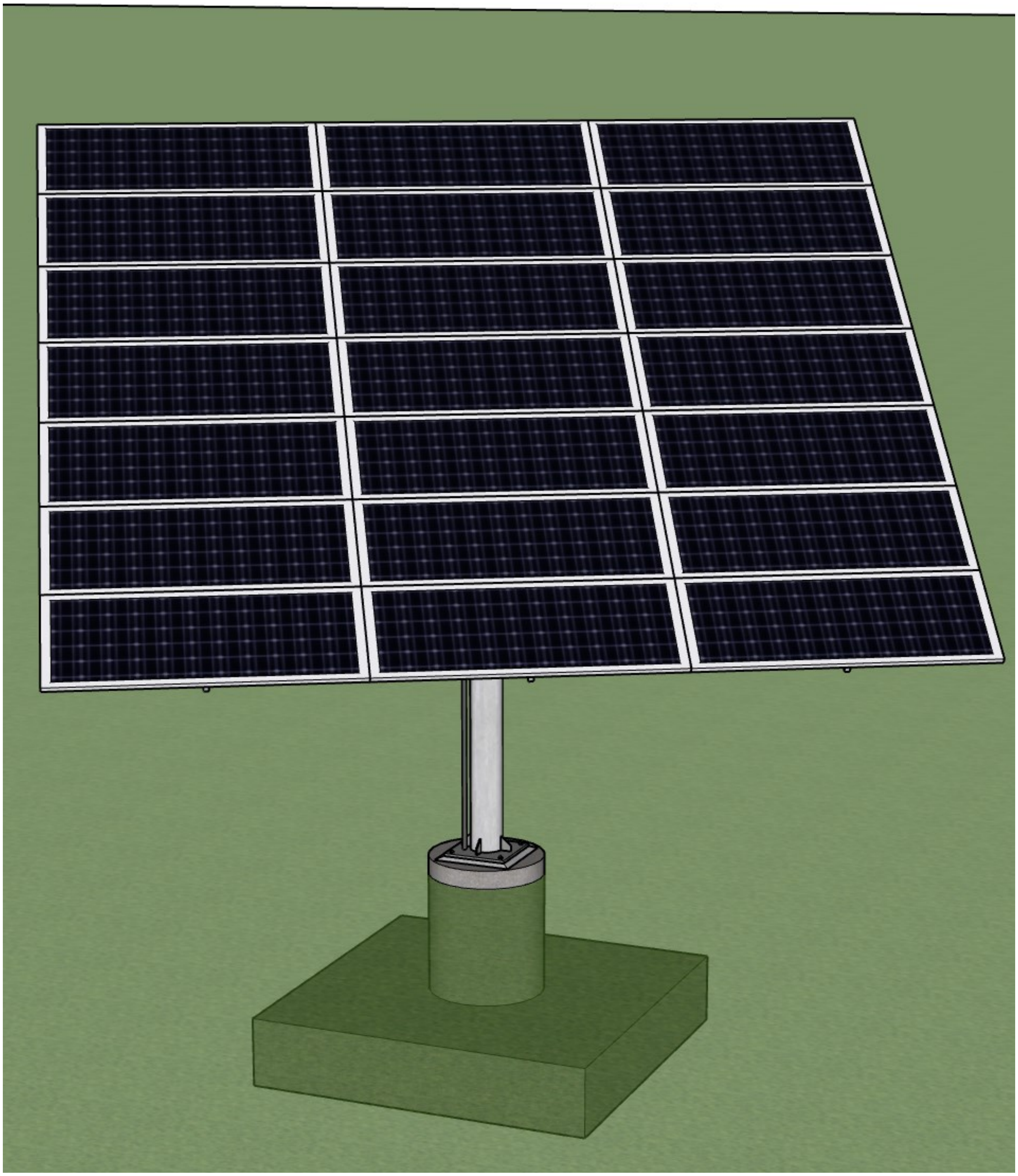
Ground Mounted PV Solar Panel Reinforced Concrete Foundation







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A ground mounted solar panel system is a system of solar panels that are mounted on the ground rather than on the roof of buildings. Photovoltaic solar panels absorb sunlight as a source of energy to generate electricity. A photovoltaic (PV) module is a packaged, and connected photovoltaic solar cells assembled in an array of various sizes. Photovoltaic modules constitute the photovoltaic array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications. The most common application of solar energy collection outside agriculture is solar water heating systems. This case study focuses on the design of a ground mounted PV solar panel foundation using the engineering software program spMats. The selected solar panel is known as Top-of-Pole Mount (TPM), where it is deigned to install quickly and provide a secure mounting structure for PV modules on a single pole. All the information provided by the solar panel provider are shown in the following figure and design data section and will serve as input for detailed foundation analysis and design. Because of available soil conditions at the site, a spread footing foundation is selected to resist applied gravity and wind loads as shown in the following figure. The supporting pole is welded to a base plate anchored to a 36” circular concrete pier.

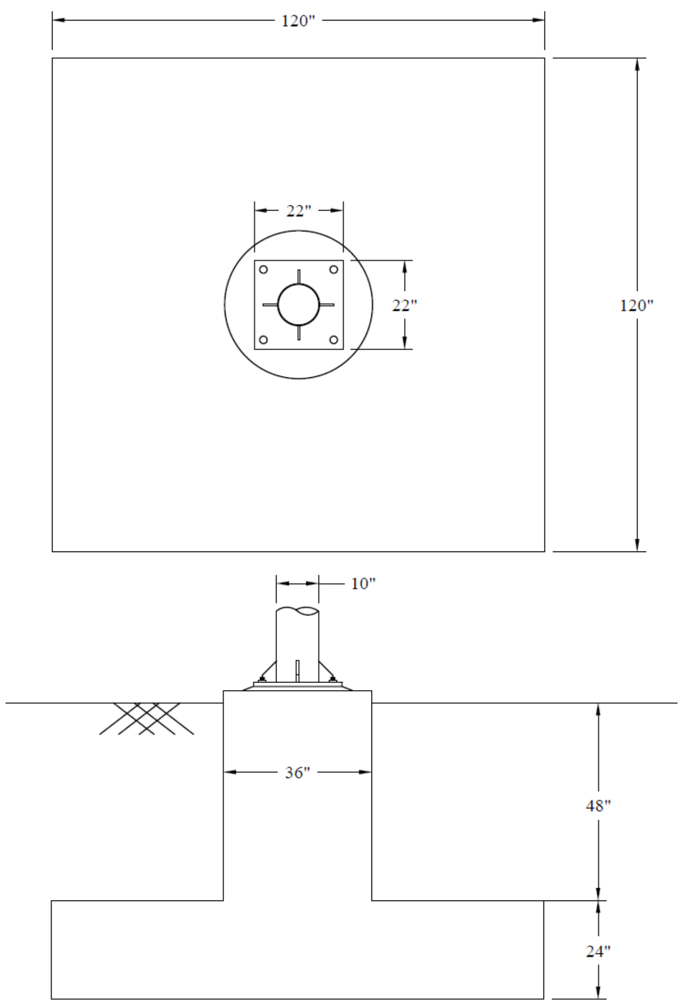


Figure 1 – Solar Panel Foundation Layout Plan

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 = 3.0 ft Diameter

Height = 4.0 ft

Concrete Footing

Size = 10.0 ft x 10.0 ft

f_c' = 4,000 psi

f_y = 60,000 psi

Thickness = 24 in.

Clear Cover = 3 in.

Foundation Loads

P_{DL} = 2.0 kips

$M_{x,wind}$ = 90 kips-ft (Reversible)

$M_{y,wind}$ = Not provided

Supporting/Fill Soil

Type = Sandy soil

Subgrade Modulus = 100 kcf

Allowable Pressure = 2.0 ksf

Unit Weight = 135 pcf

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 and/or supporting soil 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 ground mounted PV solar panel reinforced concrete footing in this example.

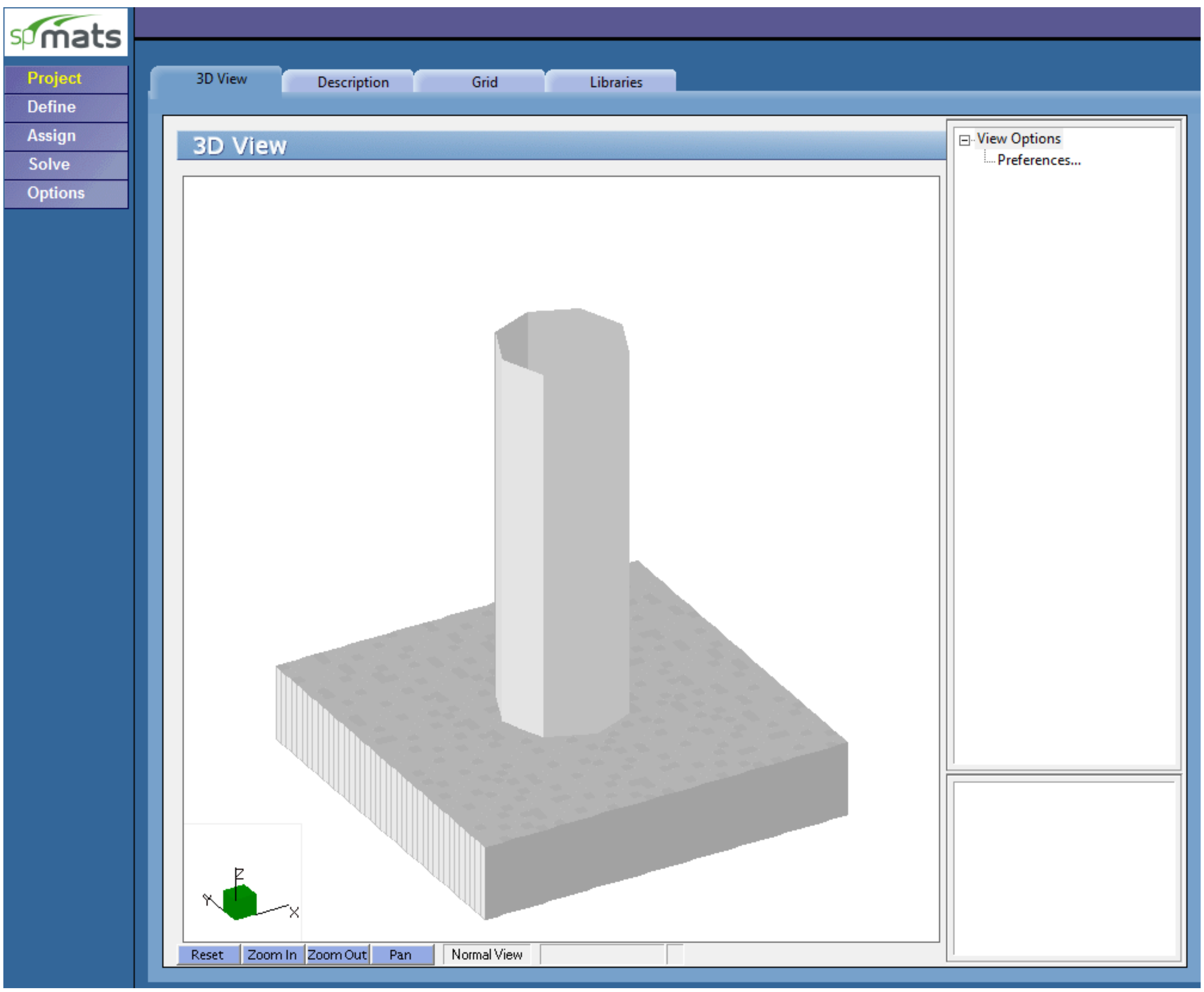


Figure 2 – Solar Panel Foundation Model 3D View

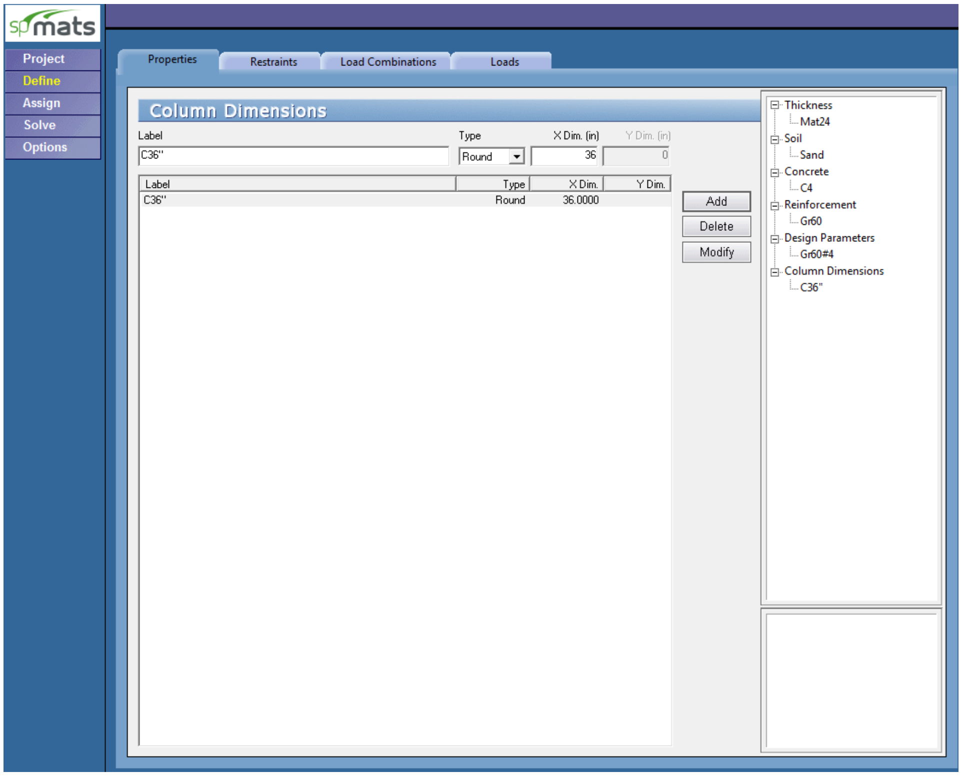


Figure 3 –Defining Concrete Pier

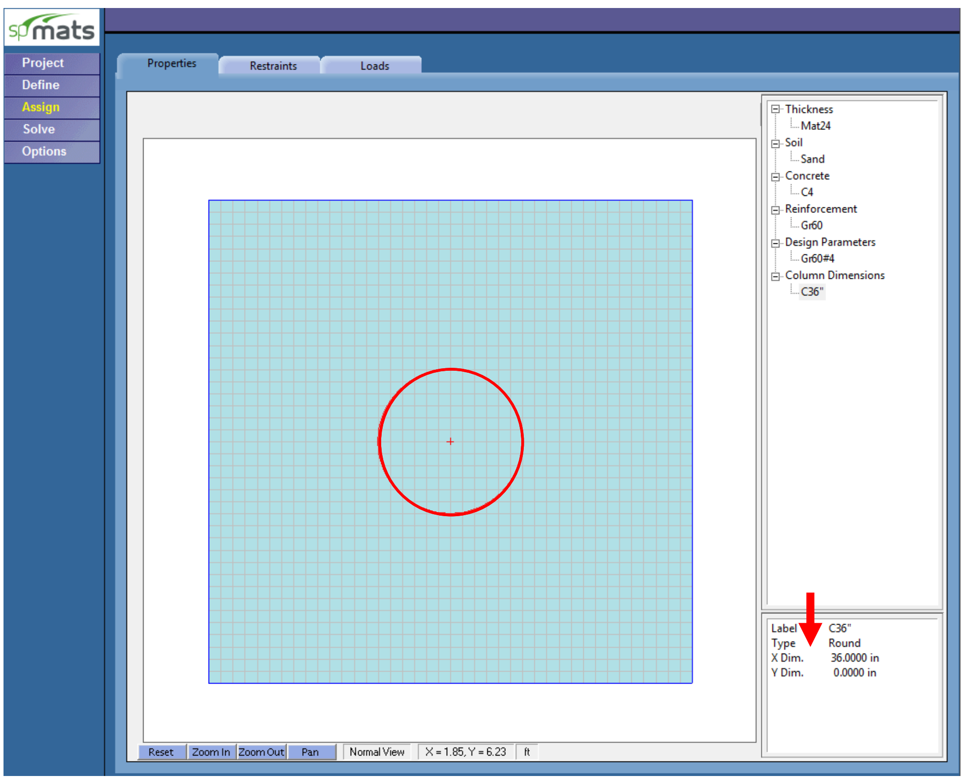


Figure 4 – Assigning Concrete Pier

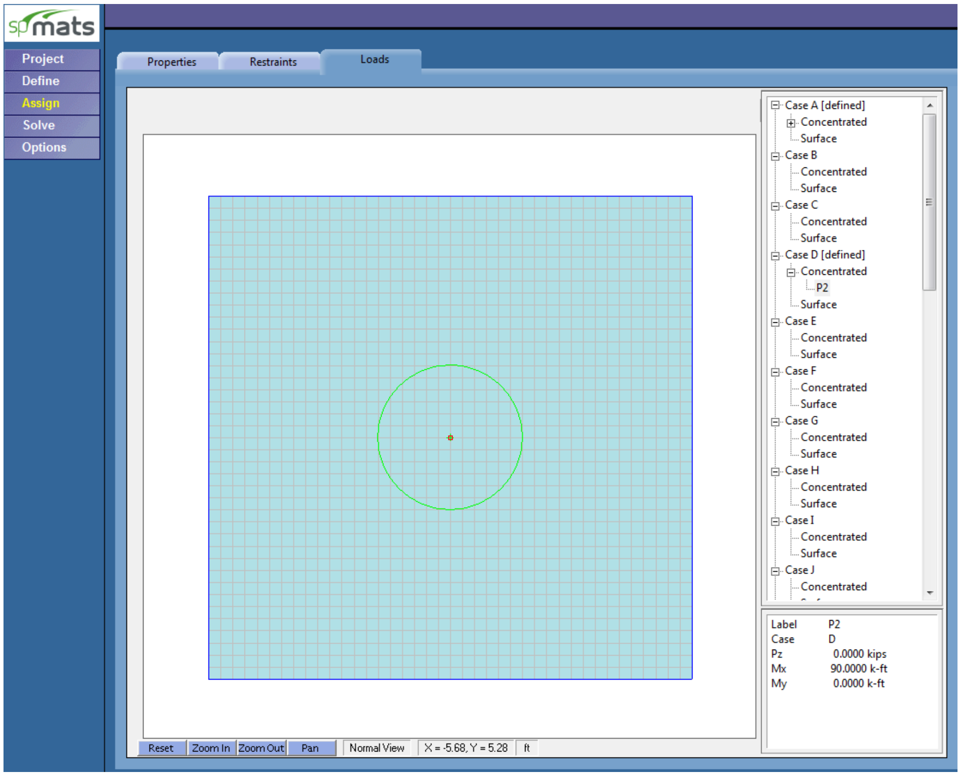


Figure 5 – Assigning Loads

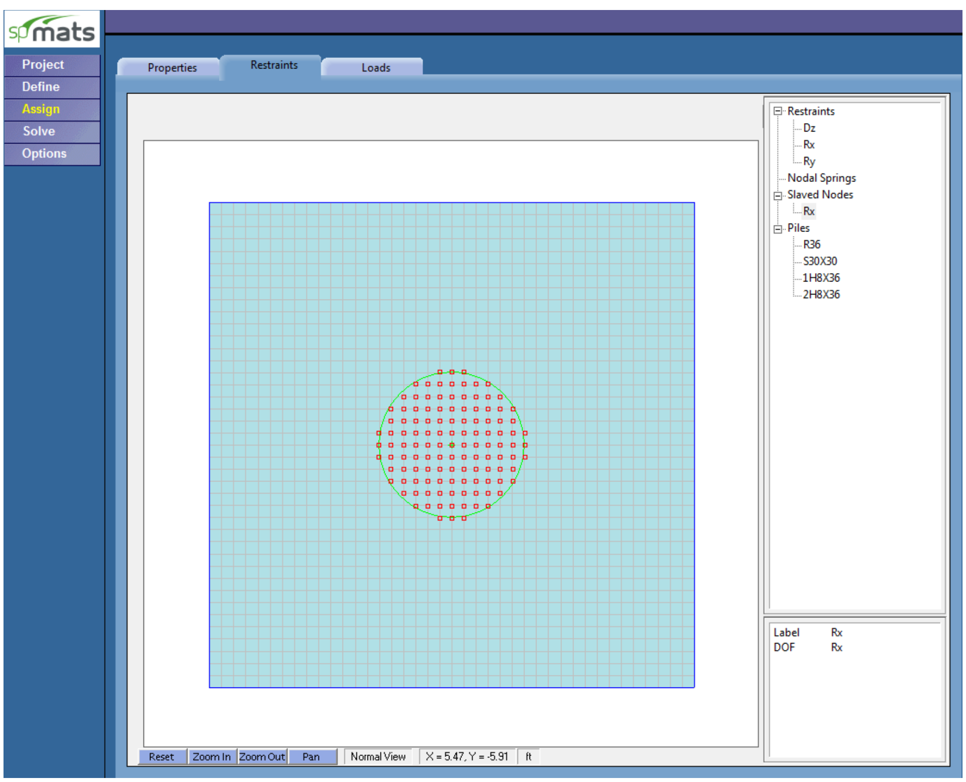


Figure 6 – Assigning Slave Nodes

Slaved nodes are assigned to restrain the rotation about the axis where the moment is applied for the nodes under the concrete pier to simulate the stiffness of the pier above the foundation and to prevent any stress concentrations due to applying the axial load and moments as point loads.

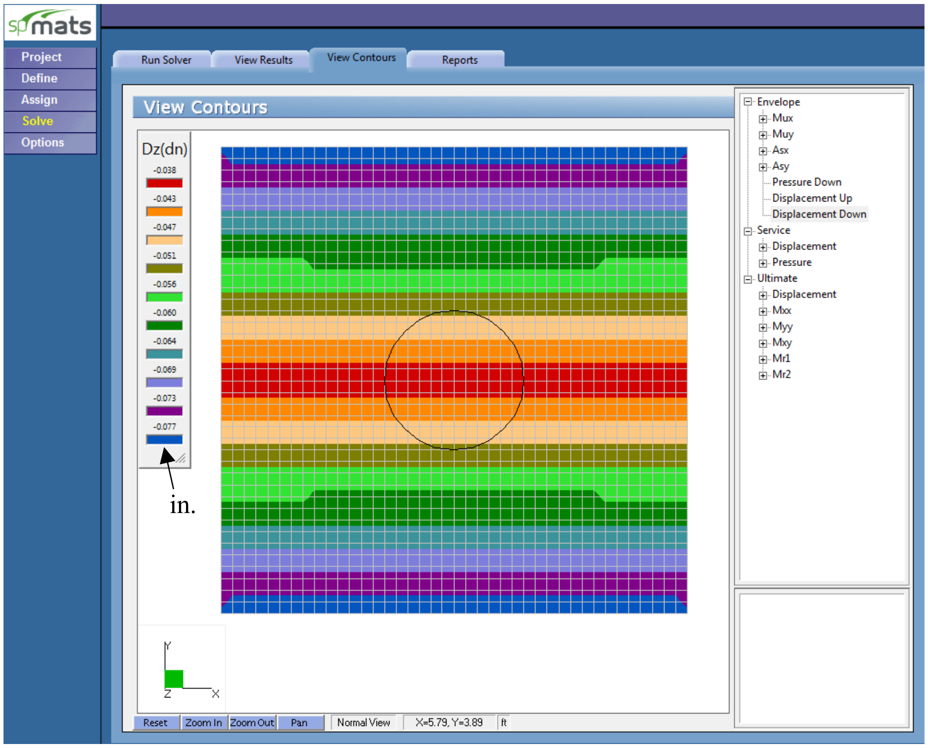


Figure 7 – Vertical (Down) Displacement Contour

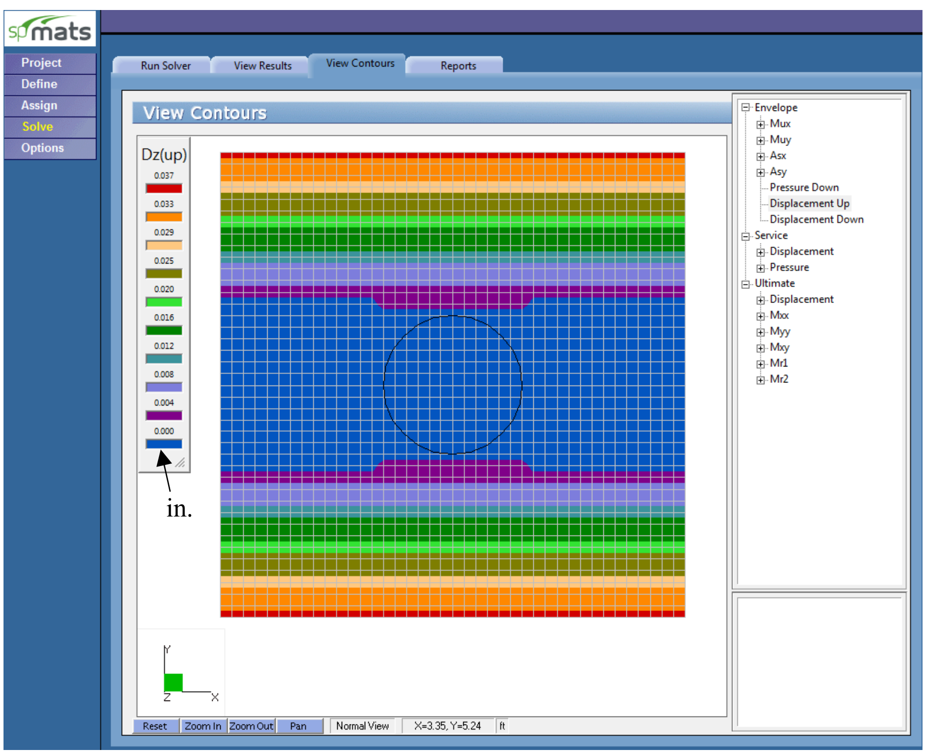


Figure 8 – Vertical (Up) Displacement Contour

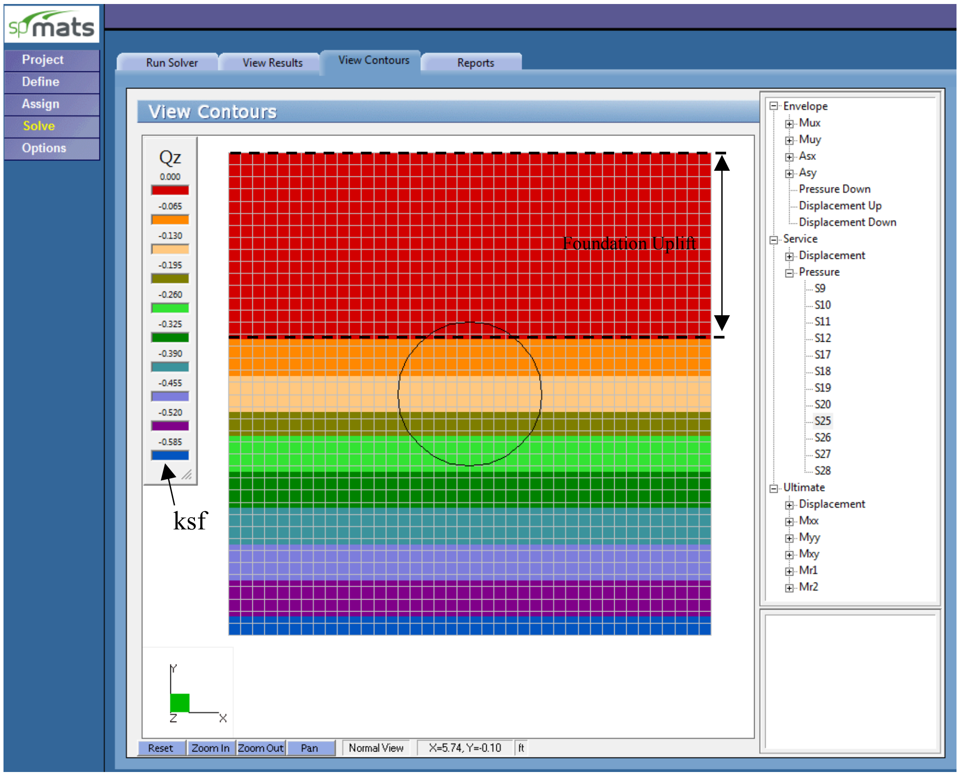


Figure 9 – Foundation Uplift

In some load cases foundation uplift might occur due to overturning moments. spMats solver provides several soil-structure interaction criteria for the user. As such, the model can be solved to control the amount of allowable uplift and the percentage of the cross-sectional area of the foundation that must remain in contact.

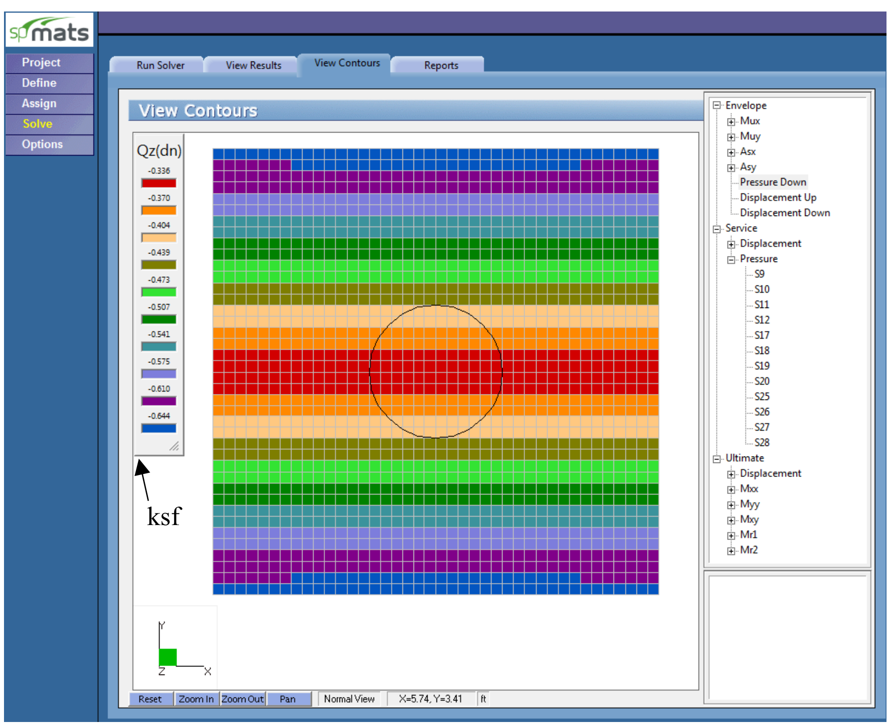


Figure 10 – Soil Pressure Contour

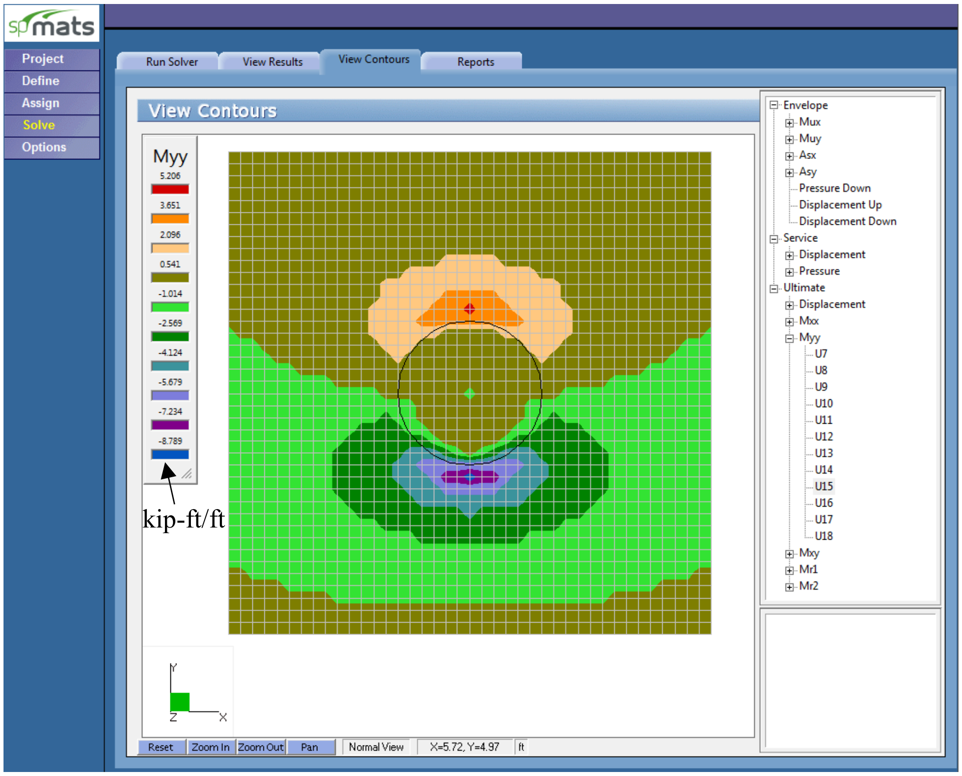


Figure 11 – Moment Contour along Y-Axis

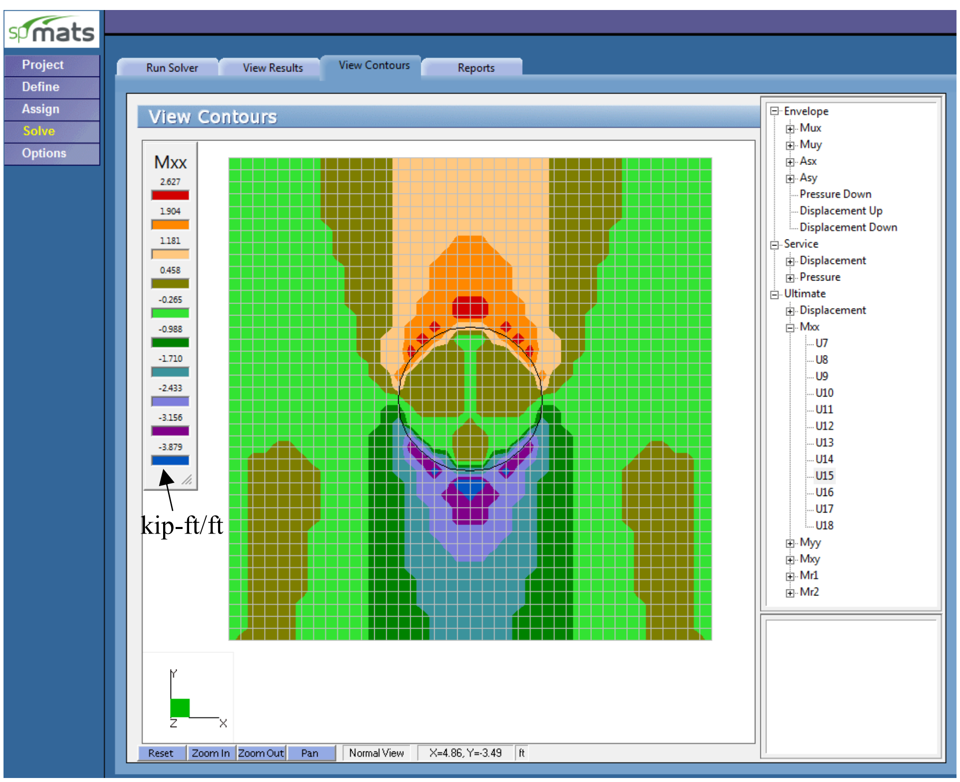


Figure 12 – Moment Contour along X-Axis

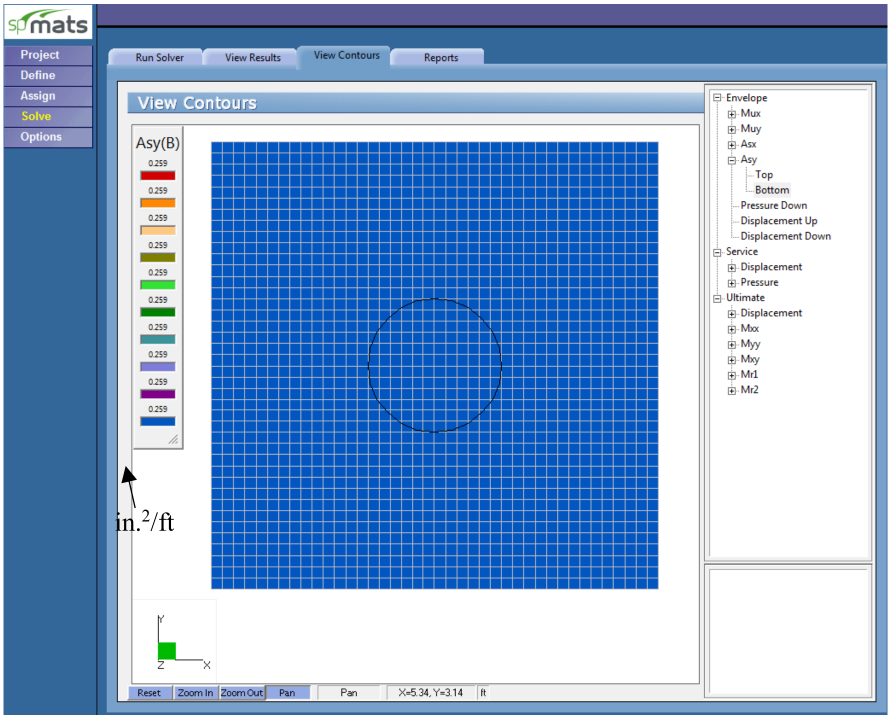


Figure 13 – Required Reinforcement Contour along Y Direction with $A_{s,min}$ Defined

The previous figure shows that the minimum reinforcement governs the entire foundation. The minimum reinforcement code values are the define by default and the user can costumize this value to better understand the foundation behavior as follows:

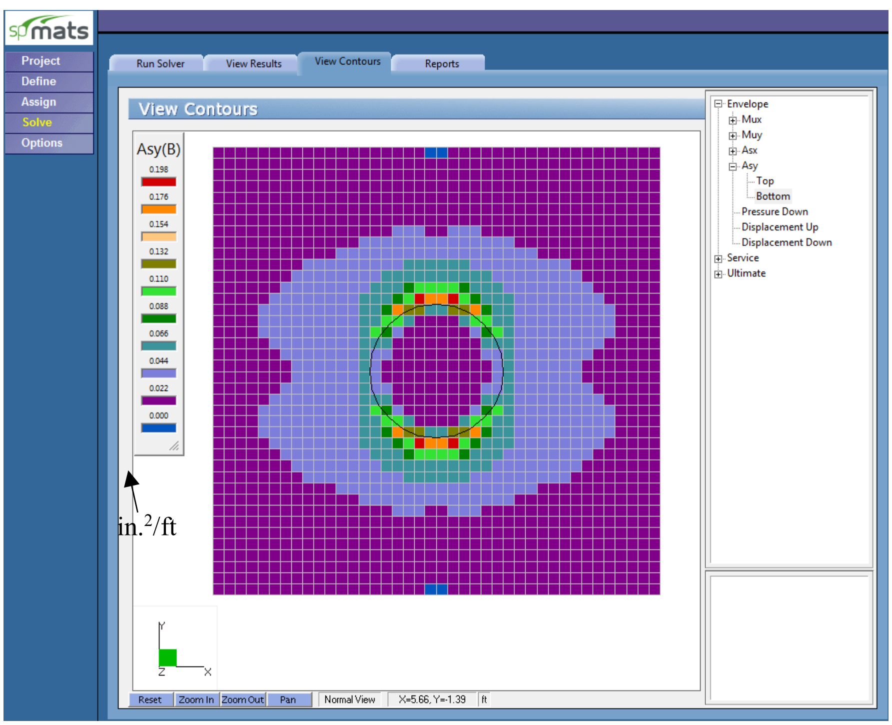


Figure 14 – Required Reinforcement Contour along Y Direction without Defining $A_{s,min}$

2. Two-way (Punching) Shear Check - Pier

```
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
 ----- -------------- --------- --------- --------- --------- --------- ---------
   841 C36"           Inner        20.75      4.73      4.73      0.00    -0.00

Properties of Resisting Area
----------------------------
 Node  Column Label       Area         Jxx          Jyy          Jxy
 ----- -------------- ---------- ------------ ------------ ------------
   841 C36"              3695.62   1547941.25   1547940.88         0.00

Ultimate Load Combination: U11
------------------------------

  Factored Applied Forces:
  ------------------------
   Node  Column Label      Vu            Mux        Gamma_X        Muy        Gamma_Y
  ----- -------------- ---------- --------------- ------- --------------- -------
    841 C36"                -2.40            36.0   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
  ----- -------------- ------------ ---------- ---------- --------- --------- ------
    841 C36"                -8.57    4000.00     189.74     -0.00     -2.36   Safe


B7 - Punching Shear Around Piles (Ultimate Load Combinations):
==============================================================
    * No piles assigned
```

<u>Figure 15 – Two-Way Punching Shear Results around the Column (Pier)</u>

3. Soil Reactions / Pressure

B3 - REACTIONS:
===============
Units --> Force (kip), Moment (kip-ft)
Service Load Combination: S9
Sum of all forces and moments with respect to center of gravity (X, Y) = (0.00, 0.00) ft

Sum of Reactions	Fz	Mx	My
Soil	32.000	-54.000	-0.000
Springs	-	-	-
Piles	-	-	-
Restraints	-	-	-
Slaved Nodes	0.000	-0.000	0.000
Total Reactions	32.000	-54.000	-0.000
Total Loads	-32.000	54.000	-0.000

Figure 16 – Soil Service Reactions

B4 - SOIL DISPLACEMENTS AND PRESSURES:
======================================
Units --> Displacement (in), Pressure (ksf)
Flags --> [x] Indicates allowable pressure is exceeded.
Service Load Combination: S9

Elem	Node	Disp, Dz	Pressure, Qz	Node	Disp, Dz	Pressure, Qz
1	43	-0.0751	-0.626	2	-0.0770	-0.642
	42	-0.0751	-0.626	1	-0.0770	-0.642
2	44	-0.0751	-0.626	3	-0.0771	-0.642
	43	-0.0751	-0.626	2	-0.0770	-0.642
3	45	-0.0751	-0.626	4	-0.0771	-0.642
	44	-0.0751	-0.626	3	-0.0771	-0.642
4	46	-0.0752	-0.626	5	-0.0771	-0.642
	45	-0.0751	-0.626	4	-0.0771	-0.642
5	47	-0.0752	-0.626	6	-0.0771	-0.643
	46	-0.0752	-0.626	5	-0.0771	-0.642
6	48	-0.0752	-0.627	7	-0.0771	-0.643
	47	-0.0752	-0.626	6	-0.0771	-0.643
7	49	-0.0752	-0.627	8	-0.0771	-0.643
	48	-0.0752	-0.627	7	-0.0771	-0.643
8	50	-0.0752	-0.627	9	-0.0772	-0.643
	49	-0.0752	-0.627	8	-0.0771	-0.643
9	51	-0.0752	-0.627	10	-0.0772	-0.643
	50	-0.0752	-0.627	9	-0.0772	-0.643
10	52	-0.0753	-0.627	11	-0.0772	-0.643

Figure 17 – Soil Pressure

4. Foundation 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.

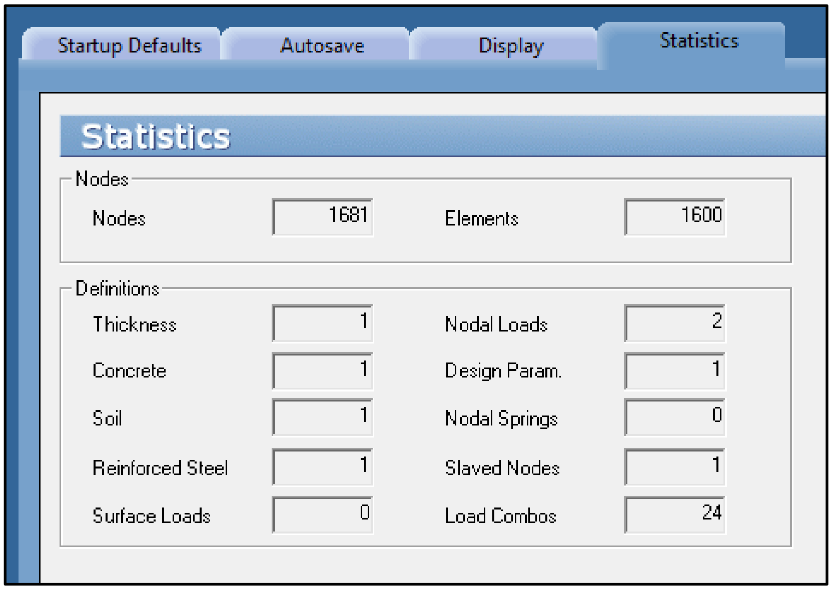


Figure 18 – Model Statistics

5. Column and Pile Design - spColumn

spMats provides the options to export column 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 column.

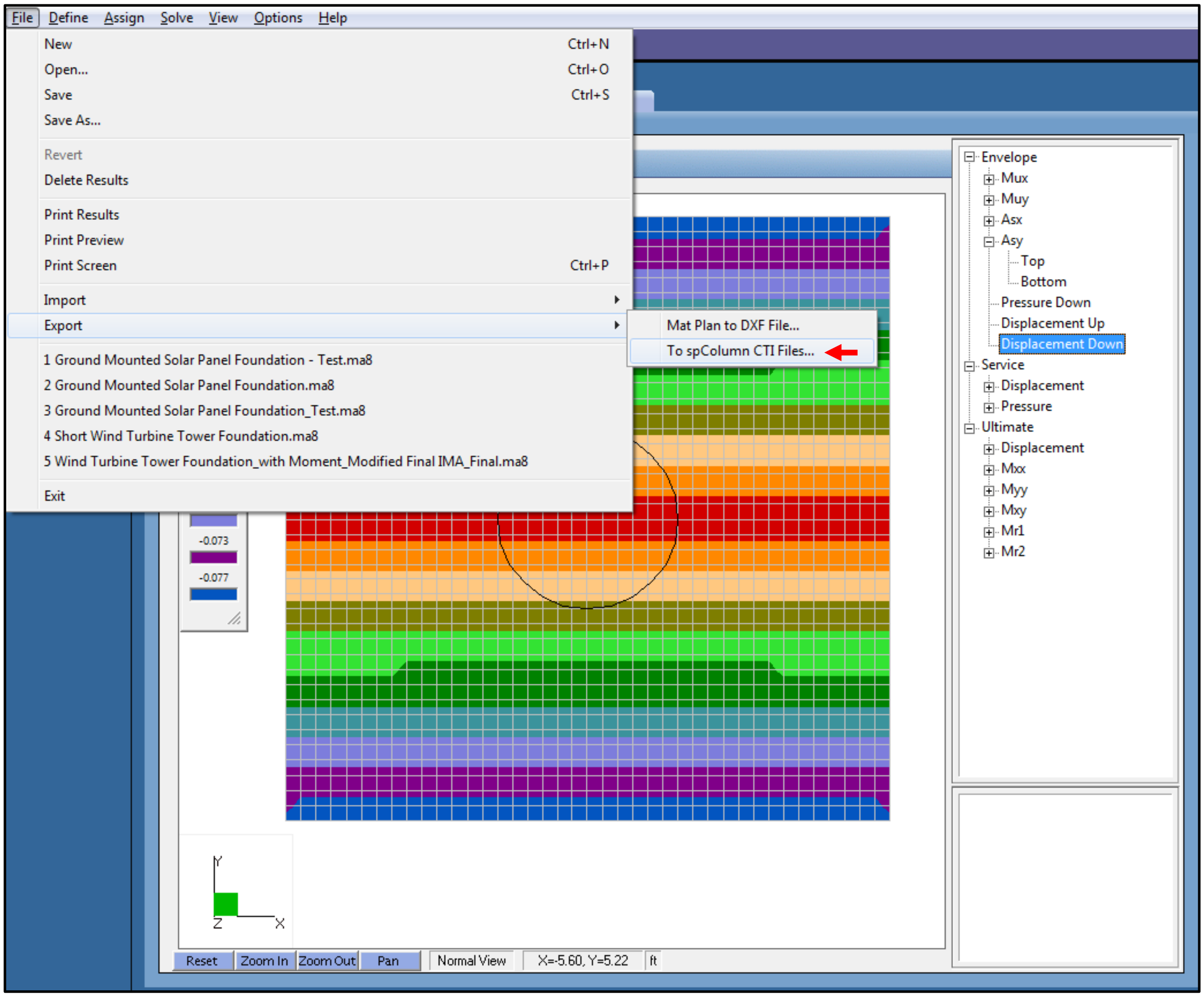


Figure 19 – Exporting CTI Files

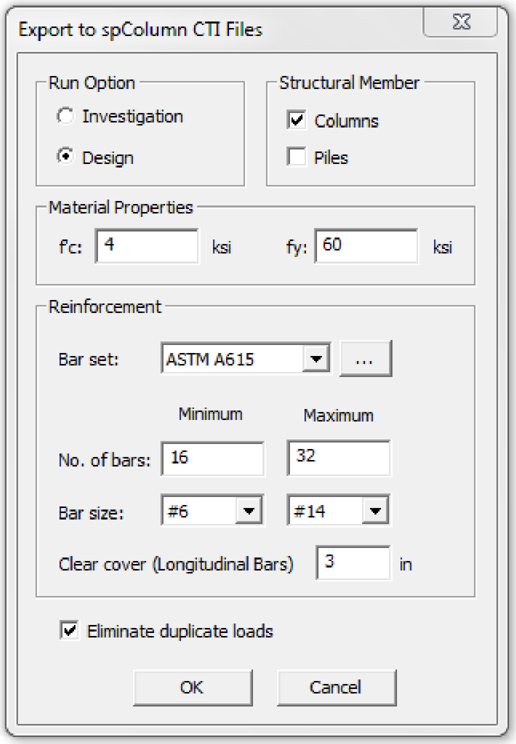
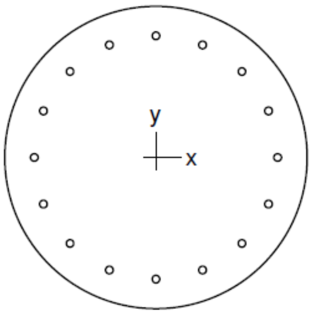


Figure 20 – Exporting CTI Files Dialog Box

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



36 in diam.

Code: ACI 318-14

Units: English

Run axis: Biaxial

Run option: Design

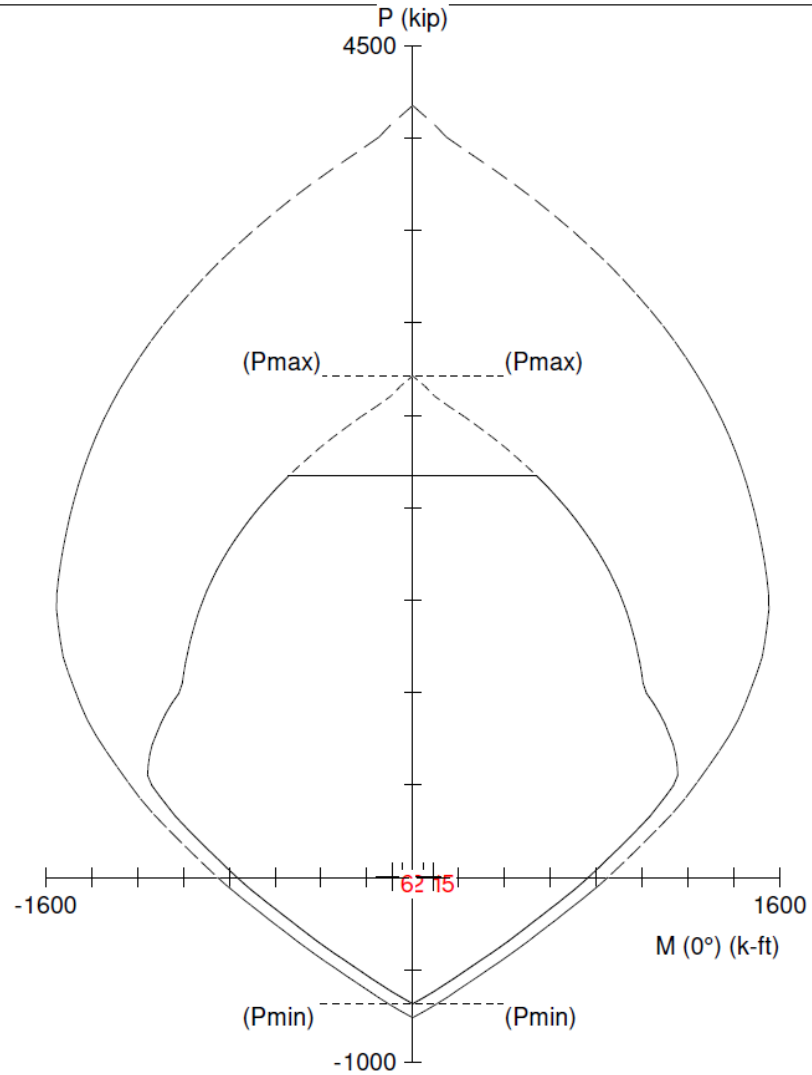
Slenderness: Not considered

Column type: Structural

Bars: ASTM A615

Date: 03/14/19

Time: 10:57:43



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

File:

Project: Ground Mounted Solar Panel Fou

Column: C-841 | Engineer: -

f'c = 4 ksi	fy = 60 ksi	Ag = 1017.88 in^2	16 #8 bars
Ec = 3605 ksi	Es = 29000 ksi	As = 12.64 in^2	rho = 1.24%
fc = 3.4 ksi	e_yt = 0.00206897 in/in	Xo = 0.00 in	Ix = 82448 in^4
e_u = 0.003 in/in		Yo = 0.00 in	Iy = 82448 in^4
Beta1 = 0.85		Min clear spacing = 4.66 in	Clear cover = 3.00 in

Confinement: Tied

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

Figure 21 – Pier Interaction Diagram with Factored Load

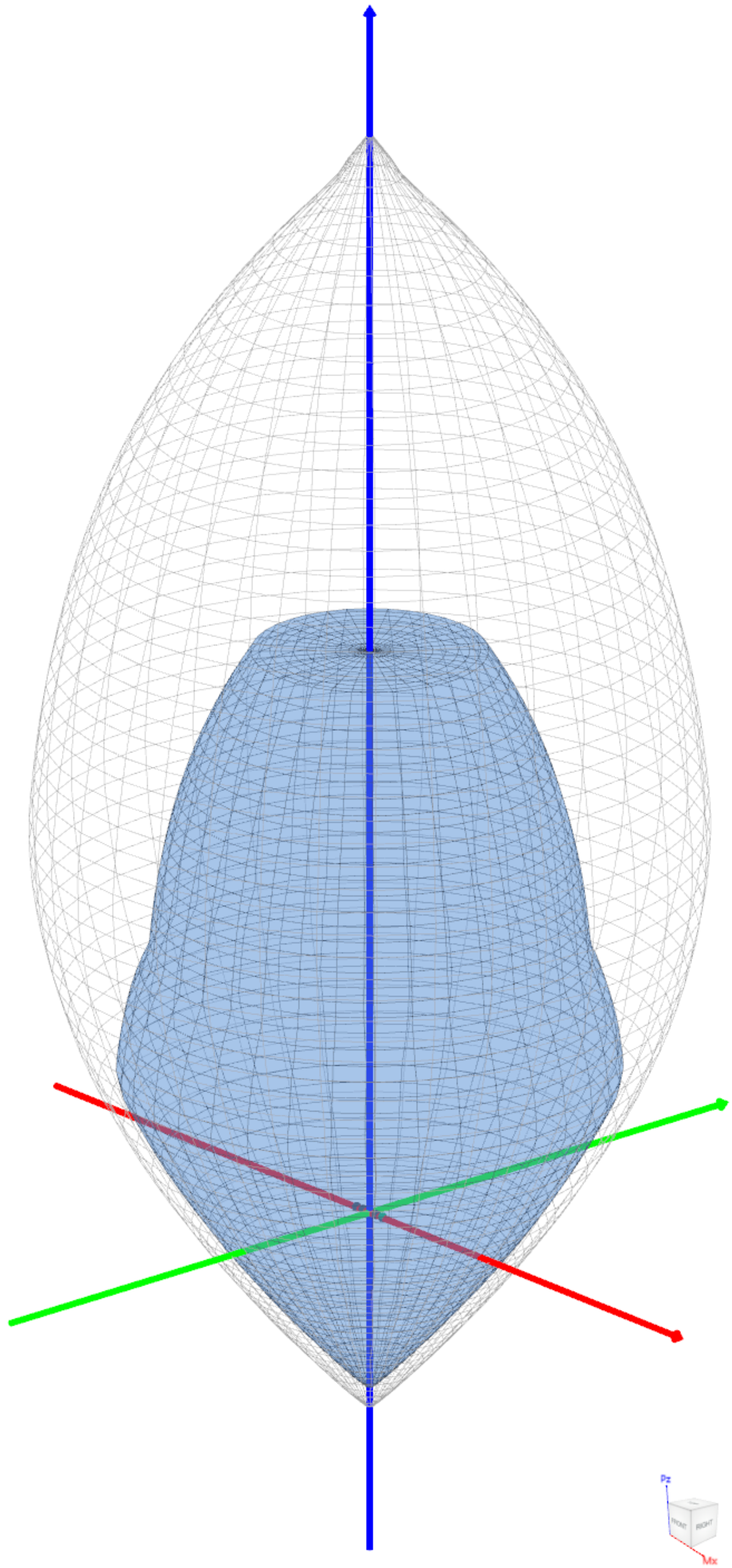


Figure 22 – Pier 3D Failure Surfaces

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.

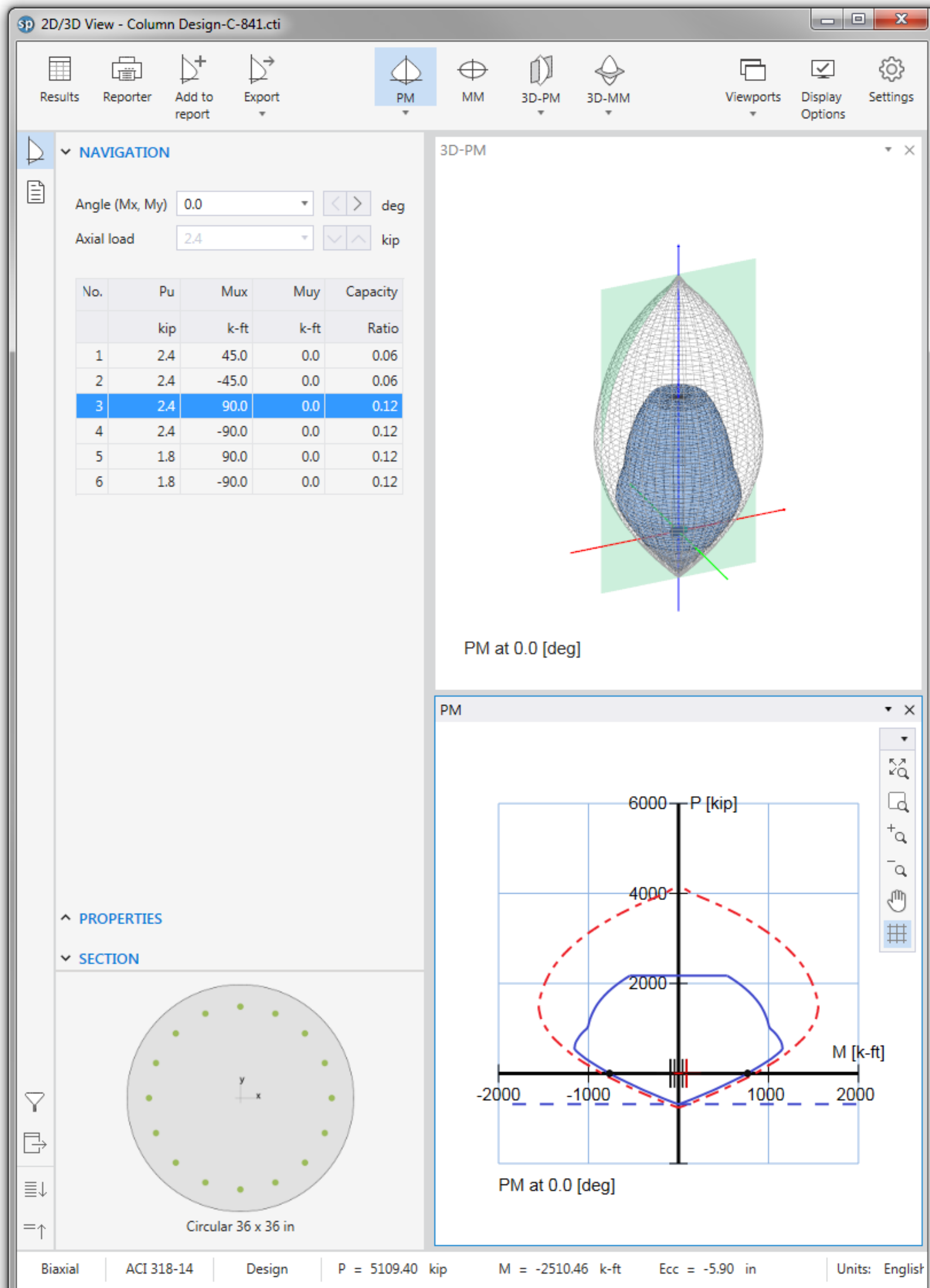


Figure 23 – 2D/3D View for Pier

7. Pier Section Optimization

To further optimize pier design, it was agreed with the builder that 16#6 reinforcement cage can be used for this pier. The following figure illustrate the reduced axial strength capacity is adequate to resist the maximum pier loading. More information about the structural vs architectural columns are provided in "Columns with Low Reinforcement - Architectural Columns" technical article.

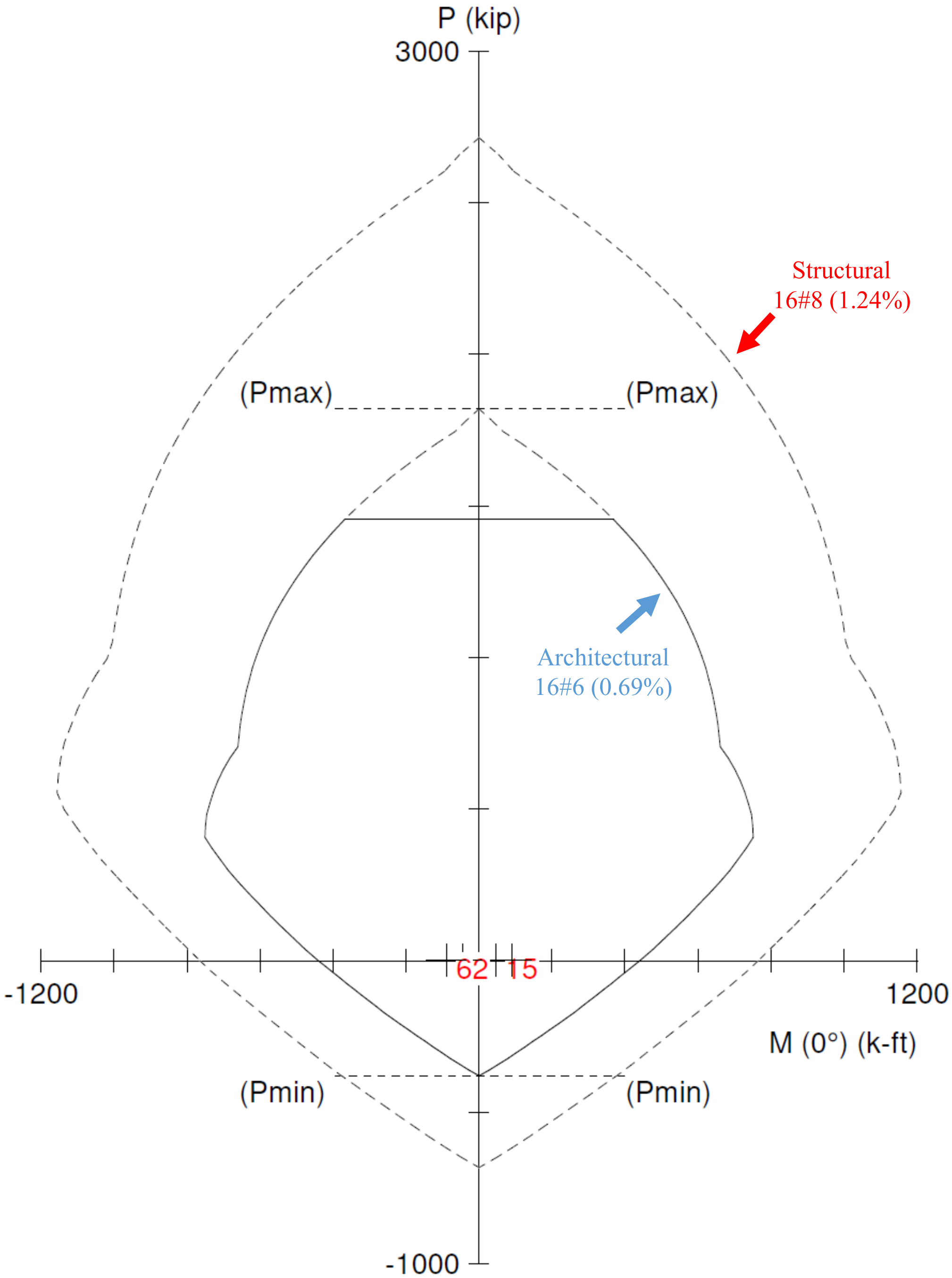


Figure 24 – Superimpose Feature