Industrial Plant Pipe Rack Foundations Analysis and Design
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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 structural 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.
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

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Load*, kips</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$P_1$</td>
</tr>
<tr>
<td>Dead</td>
<td>-6**</td>
</tr>
<tr>
<td>Live</td>
<td>251</td>
</tr>
<tr>
<td>Wind</td>
<td>40</td>
</tr>
</tbody>
</table>

* Load locations are shown in the following figure

** Negative values indicate uplift loads
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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

Type 1

Type 2

Type 3
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.

![Figure 11 - Two-Way Shear Results around Concrete Piers](image-url)
**Figure 12 – Two-Way Shear Results around Piles**

<table>
<thead>
<tr>
<th>Type 1</th>
<th>Type 2</th>
<th>Type 3</th>
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<tbody>
<tr>
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<td>Geometry of Resisting Area</td>
<td>Geometry of Resisting Area</td>
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<tr>
<td>Node Label</td>
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<tr>
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<tr>
<td>171 Pile</td>
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</tr>
<tr>
<td>171 Pile</td>
<td>25.13</td>
<td>300.0</td>
</tr>
</tbody>
</table>
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.

Figure 13 – Piles Service Reactions
**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](image-url)
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.

![Image](image1.png)

Figure 16 – Exporting CTI Files

![Image](image2.png)

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
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