# Your Project Calculations

Project Name: JAM72-D30-545MB 28-panel

S3D Model Link:
https://platform.skyciv.com/structural?preload_name=JAM72-D30-545MB%2028-panel&preload_path=Shared%20Enterprise%20Folder/MT_Solar_Projects/8_2023

Public Model Link:
https://platform.skyciv.com/structural-viewer?project_id=uZn5rXLCJrzONs47Q7waDKzuVihR4MWkHFA2s2XThQcXcXDkPewKyr3SEh3ooyMY

## Array Specification

| | |
|---|---|
| **Product:** | Beam |
| **Unique ID:** | 3P-19.75-8TOP-HD-24-L-4Hx7W-6G7L |
| **Duty Classification:** | HD |
| **Module Width:** | 44.72 in |
| **Module Length:** | 89.76in |
| **Number of Rows:** | 4 |
| **Number of Columns:** | 7 |
| **Total Number of Modules:** | 28 |
| **Desired Tilt Angle:** | 45 |
| **Front Edge Clearance:** | 5 |
| **Total Array Height at Tilt:** | 15.60 ft |
| **Total Frame Length:** | 51.00 ft |
| **Frame Weight:** | 2548 lbs |
| **Array Dimensions N/S:** | 15.07 ft |
| **Array Dimensions E/W:** | 52.94 ft |
| **Rail Length:** | 180.88 in |
| **Rail Spacing:** | 3.74 ft |
| **Rail Check:** | Not Checked |

## Support Specifications

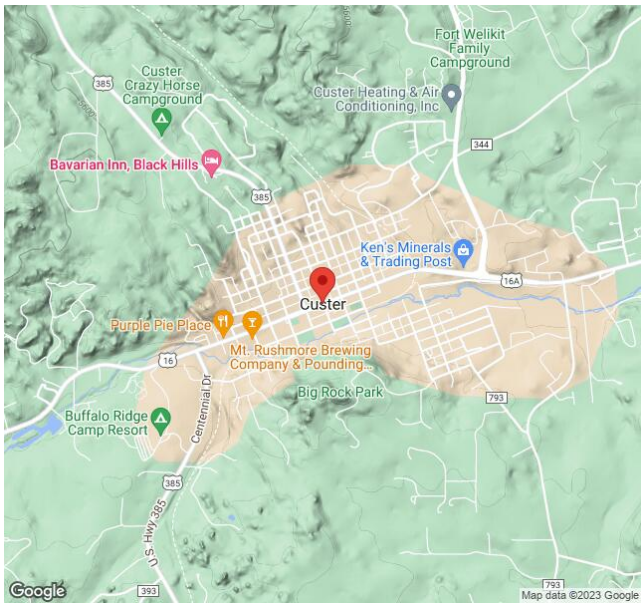
| | |
|---|---|
| **Pole Size:** | 8in Pipe Sch 40 |
| **Pole Length above Grade:** | 10.33 ft |
| **Number of Poles:** | 3 |
| **Pole Spacing:** | 19.75 ft |

## Foundation Specifications

| | |
|---|---|
| **Foundation Type:** | Square |
| **Foundation Dimensions:** | 48 x 48 in |
| **Foundation Depth (below grade):** | Pile 1: 6.25 ft<br>Pile 2: 6.75 ft<br>Pile 3: 6.25 ft |
| **Foundation Volume:** | 11.407 $y^3$ |
| **Foundation Result:** | PASSED |
| **Mount Twist:** | 1.616321 kip |

## Site Info

| | |
|---|---|
| **Risk Category:** | I |
| **Exposure:** | B |
| **Soil Classification:** | sand |
| **Site Location:** | Custer, SD 57730, USA |
| **Wind Speed:** | 105 mph |
| **Snow Load:** | 30 psf |
| **Design Uplift Pressure:** | Multiple pressures |
| **Design Downforce Pressure:** | Multiple pressures |
| **Design Snow Pressure:** | 0.008247 ksf |




### Design Disclaimer

This software should be used for preliminary designs and should not be used as a final design unless reviewed, verified and designed by a qualified structural engineer.

### AutoDesigner Input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{"product_type":"Beam","project_id":"JAM72-D30-545MB 28-panel","site_address":"Custer, SD 57730,
USA","module_width":44.72,"module_length":89.76,"number_rows":"4","number_columns":7,"pole_mount_section":"4_40","core_pipe_widt
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,"foundation_size":48,"check_rails":false,"wind_speed_override":105,"snow_load_override":30,"direct_snow_load":false}
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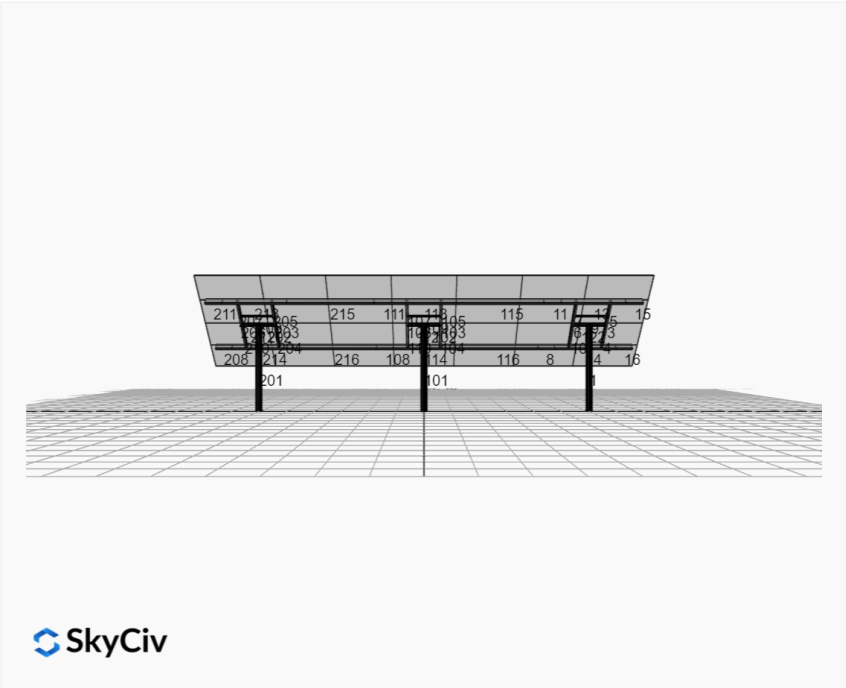
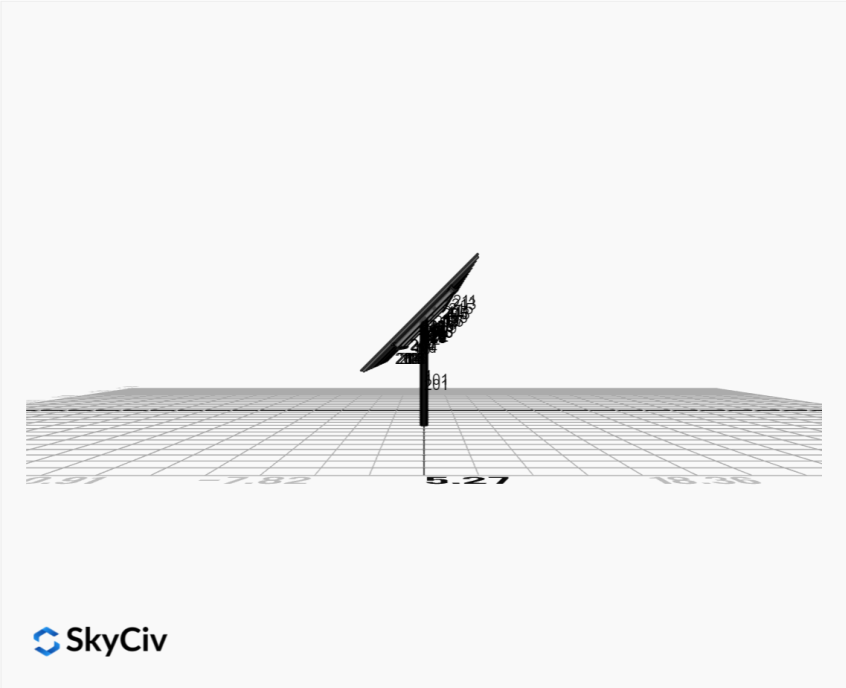
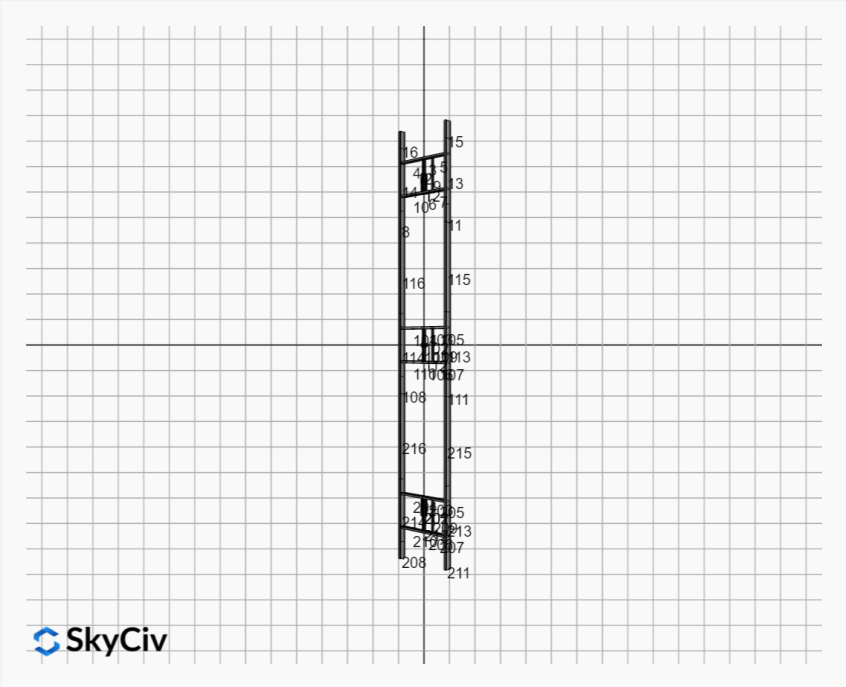
**Design Notes:**

- AISC Deflection checks are set to L/1 due to structure design intent
- Foundation Design and Sizing is approximate only




SkyCiv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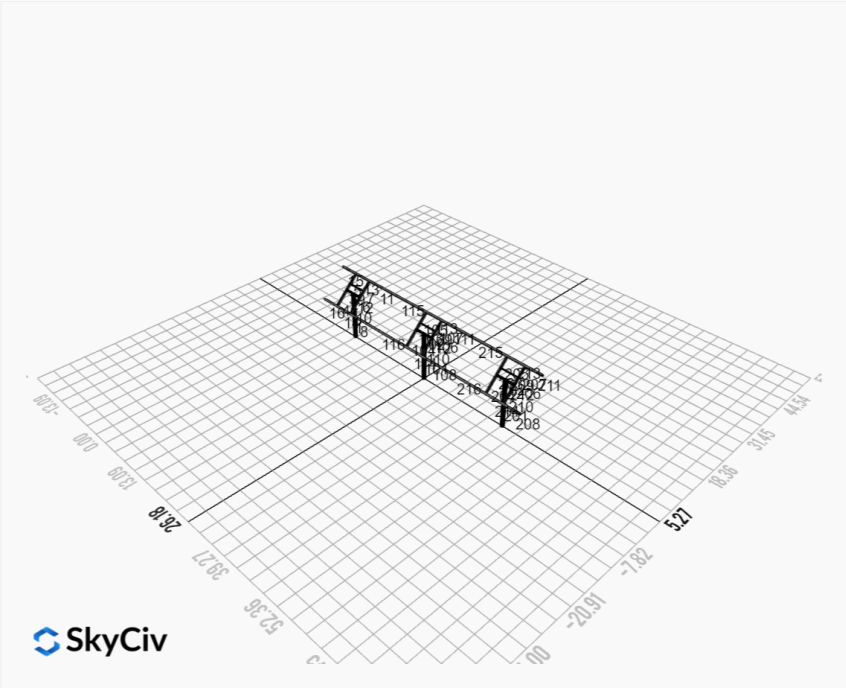
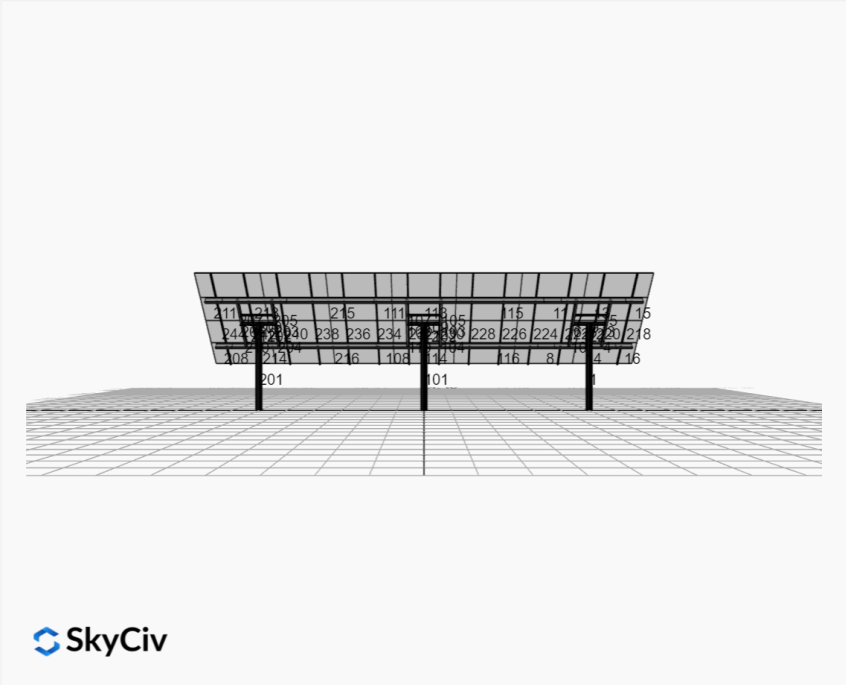
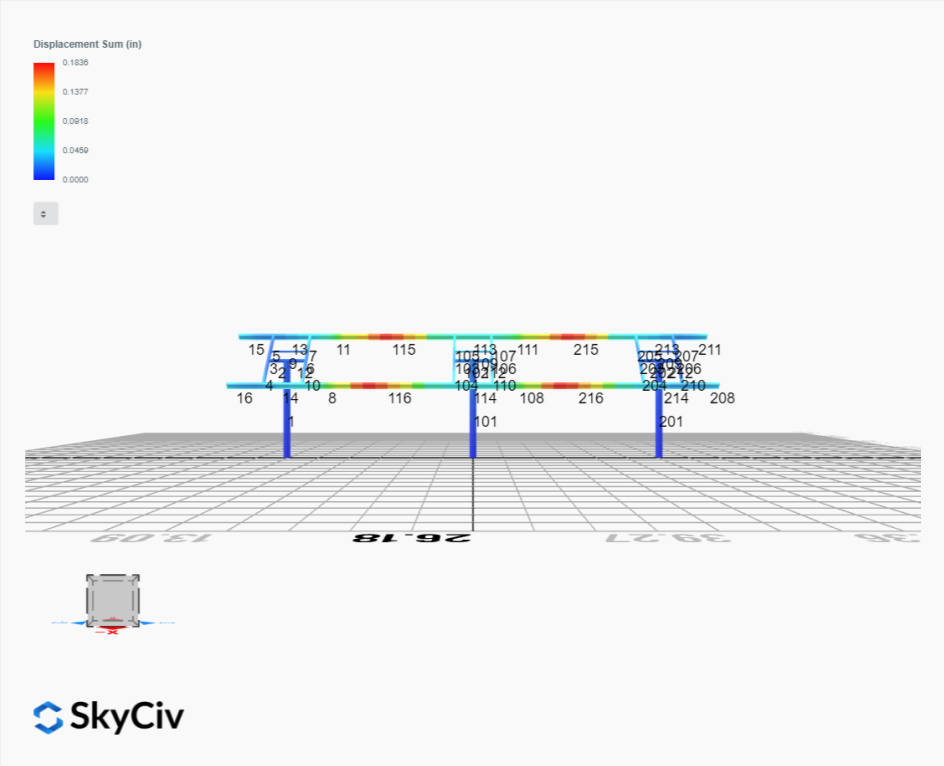
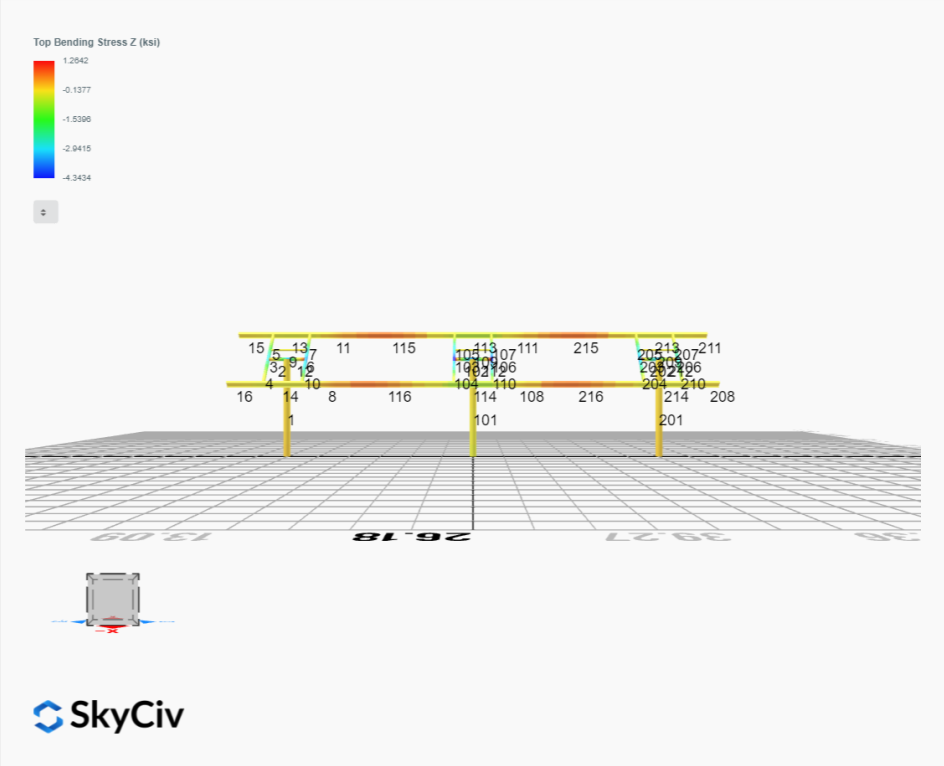
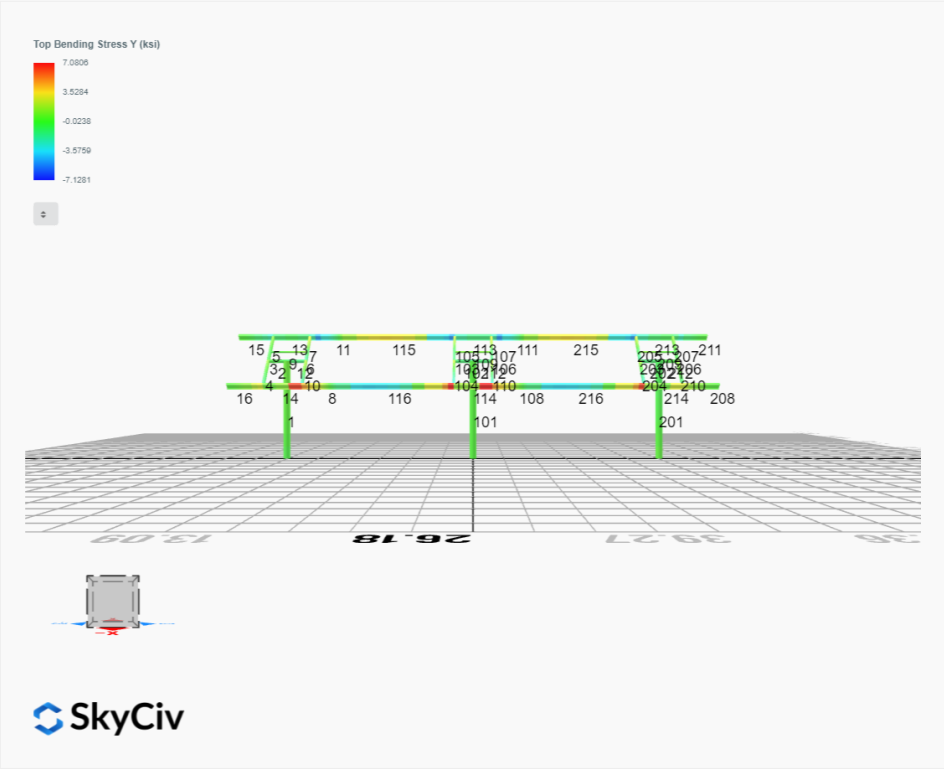

SkyCiv

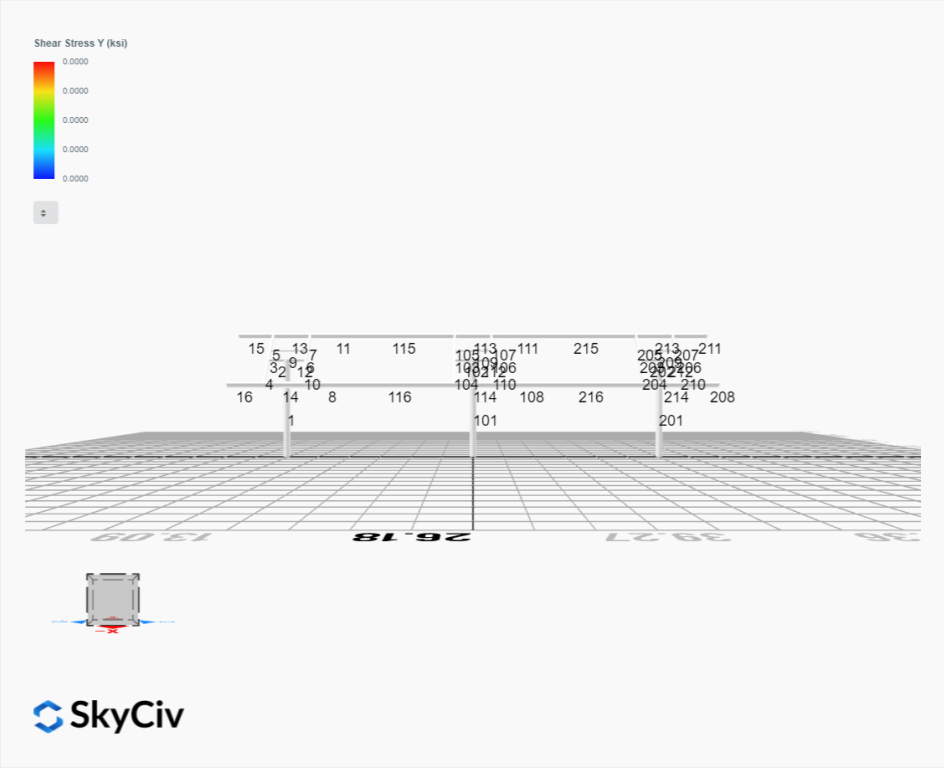

SkyCiv

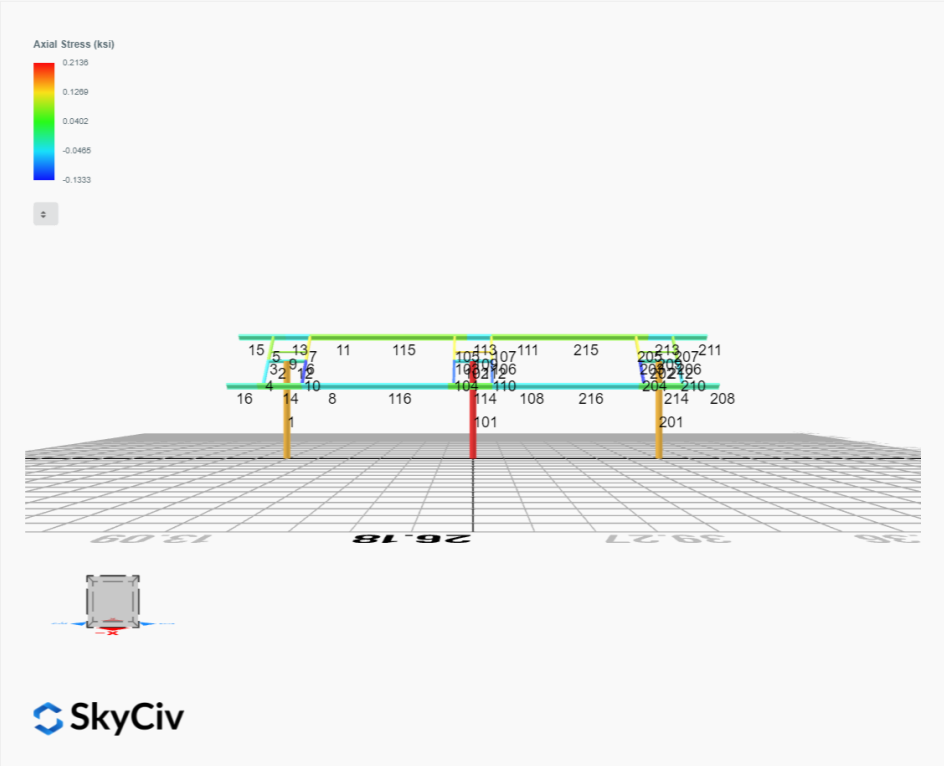
## FEM Results (Envelope Worst Case for each member)




Top Bending Stress Y (ksi)
7.0806
3.5284
-0.0238
-3.5759
-7.1281
SkyCiv


Shear Stress Y (ksi)
0.0000
0.0000
0.0000
0.0000
0.0000
SkyCiv


Axial Stress (ksi)
0.2136
0.1269
0.0402
-0.0465
-0.1333
15
5
13
7
11
115
105
113
107
111
215
205
213
207
211
3
2
9
16
12
6
1
96
206
4
10
110
204
210
16
14
8
116
114
108
216
214
208
1
101
201
26.18

## Reaction Forces for Foundation 1 (Node ID#1), (kip, kip-ft)

### ASD Load Combination Results

| Name | Fx | Fy | Fz | Mx | My | Mz |
|---|---|---|---|---|---|---|
| ULS: 1. D | 0.0264 | 1.8983 | 0.0771 | 0.2268 | -0.0841 | -0.2255 |
| ULS: 2. D + L | 0.0264 | 1.8983 | 0.0771 | 0.2268 | -0.0841 | -0.2255 |
| ULS: 3. D + (S or Lr or R) | 0.0519 | 3.2426 | 0.1518 | 0.4467 | -0.1658 | -0.4628 |
| ULS: 3. D + (S or Lr or R) | 0.0264 | 1.8983 | 0.0771 | 0.2268 | -0.0841 | -0.2255 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | 0.0455 | 2.9065 | 0.1332 | 0.3917 | -0.1454 | -0.4035 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | 0.0264 | 1.8983 | 0.0771 | 0.2268 | -0.0841 | -0.2255 |
| ULS: 5b. D + 0.7E | 0.0264 | 1.8983 | 0.0771 | 0.2268 | -0.0841 | -0.2255 |
| ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S | 0.0455 | 2.9065 | 0.1332 | 0.3917 | -0.1454 | -0.4035 |
| ULS: 8. 0.6D + 0.7E | 0.0158 | 1.1390 | 0.0463 | 0.1361 | -0.0505 | -0.1353 |
| ULS: 5a. D + 0.6W_Wind downforce Case A only | -2.2939 | 4.1826 | 0.2919 | 0.8136 | -0.9646 | 25.0142 |
| ULS: 5a. D + 0.6W_Wind downforce Case B only | -2.2939 | 4.1826 | 0.2919 | 0.8136 | -0.9646 | 25.0142 |
| ULS: 5a. D + 0.6W_Wind uplift Case A only | 1.6987 | 0.2497 | -0.0724 | -0.1815 | 0.5286 | -17.0282 |
| ULS: 5a. D + 0.6W_Wind uplift Case B only | 1.5210 | 0.4324 | -0.0704 | -0.1756 | 0.5252 | -19.9015 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -1.6947 | 4.6198 | 0.2942 | 0.8318 | -0.8057 | 18.5263 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -1.6947 | 4.6198 | 0.2942 | 0.8318 | -0.8057 | 18.5263 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.2998 | 1.6701 | 0.0210 | 0.0854 | 0.3142 | -13.0055 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.1665 | 1.8071 | 0.0225 | 0.0899 | 0.3116 | -15.1604 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -1.7138 | 3.6116 | 0.2382 | 0.6669 | -0.7444 | 18.7043 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -1.7138 | 3.6116 | 0.2382 | 0.6669 | -0.7444 | 18.7043 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.2806 | 0.6619 | -0.0350 | -0.0794 | 0.3755 | -12.8275 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.1474 | 0.7989 | -0.0335 | -0.0750 | 0.3729 | -14.9825 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case A only | -2.3044 | 3.4233 | 0.2611 | 0.7229 | -0.9309 | 25.1044 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case B only | -2.3044 | 3.4233 | 0.2611 | 0.7229 | -0.9309 | 25.1044 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case A only | 1.6881 | -0.5096 | -0.1033 | -0.2723 | 0.5623 | -16.9380 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case B only | 1.5105 | -0.3269 | -0.1012 | -0.2663 | 0.5588 | -19.8113 |

### Worst Case Reactions LRFD

These calculations are taken directly from the FEA via SkyCiv and are used in the Concrete Checks of the Foundatino Module.
Note: Worst case values are assumed as downforce wind load cases.

| Result | Value (kip, kip-ft) |
|---|---|
| Axial | 6.7585 |
| Shear X | -3.8671 |
| Shear Z | 0.4899 |
| Moment X | 1.3663 |
| Moment Y (Twist) | 1.6161 |
| Moment Z | 42.0758 |

### Worst Case Reactions ASD

These results are taken from the worst case values in the above table and are used in the Soil Checks in the Foundation Module.
Note: Worst case values are assumed as downforce wind load cases.

| Result | Value (kip, kip-ft) |
|---|---|
| Axial | 4.6198 |
| Shear X | -2.3044 |
| Shear Z | 0.2942 |
| Moment X | 0.8318 |
| Moment Y (Twist) | 0.9646 |
| Moment Z | 25.1044 |

## Reaction Forces for Foundation 2 (Node ID#101), (kip, kip-ft)

### ASD Load Combination Results

| Name | Fx | Fy | Fz | Mx | My | Mz |
|---|---|---|---|---|---|---|
| ULS: 1. D | -0.0528 | 2.3640 | 0.0000 | -0.0000 | 0.0000 | 0.5185 |
| ULS: 2. D + L | -0.0528 | 2.3640 | 0.0000 | -0.0000 | 0.0000 | 0.5185 |
| ULS: 3. D + (S or Lr or R) | -0.1039 | 4.1585 | 0.0000 | -0.0000 | 0.0000 | 1.0026 |
| ULS: 3. D + (S or Lr or R) | -0.0528 | 2.3640 | 0.0000 | -0.0000 | 0.0000 | 0.5185 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | -0.0911 | 3.7098 | 0.0000 | -0.0000 | 0.0000 | 0.8816 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | -0.0528 | 2.3640 | 0.0000 | -0.0000 | 0.0000 | 0.5185 |
| ULS: 5b. D + 0.7E | -0.0528 | 2.3640 | 0.0000 | -0.0000 | 0.0000 | 0.5185 |

| Name | Fx | Fy | Fz | Mx | My | Mz |
|---|---|---|---|---|---|---|
| ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S | -0.0911 | 3.7098 | 0.0000 | -0.0000 | 0.0000 | 0.8816 |
| ULS: 8. 0.6D + 0.7E | -0.0317 | 1.4184 | 0.0000 | -0.0000 | 0.0000 | 0.3111 |
| ULS: 5a. D + 0.6W_Wind downforce Case A only | -3.1051 | 5.4881 | 0.0000 | -0.0000 | 0.0000 | 33.0003 |
| ULS: 5a. D + 0.6W_Wind downforce Case B only | -3.1051 | 5.4881 | 0.0000 | -0.0000 | 0.0000 | 33.0003 |
| ULS: 5a. D + 0.6W_Wind uplift Case A only | 2.1678 | 0.0960 | 0.0000 | -0.0000 | 0.0000 | -21.2055 |
| ULS: 5a. D + 0.6W_Wind uplift Case B only | 1.8683 | 0.3854 | 0.0000 | -0.0000 | 0.0000 | -24.2595 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -2.3803 | 6.0529 | 0.0000 | -0.0000 | 0.0000 | 25.2429 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -2.3803 | 6.0529 | 0.0000 | -0.0000 | 0.0000 | 25.2429 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.5743 | 2.0089 | 0.0000 | -0.0000 | 0.0000 | -15.4114 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.3497 | 2.2259 | 0.0000 | -0.0000 | 0.0000 | -17.7019 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -2.3420 | 4.7071 | 0.0000 | -0.0000 | 0.0000 | 24.8798 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -2.3420 | 4.7071 | 0.0000 | -0.0000 | 0.0000 | 24.8798 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.6126 | 0.6630 | 0.0000 | -0.0000 | 0.0000 | -15.7745 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.3881 | 0.8800 | 0.0000 | -0.0000 | 0.0000 | -18.0650 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case A only | -3.0840 | 4.5425 | 0.0000 | -0.0000 | 0.0000 | 32.7929 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case B only | -3.0840 | 4.5425 | 0.0000 | -0.0000 | 0.0000 | 32.7929 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case A only | 2.1889 | -0.8496 | 0.0000 | -0.0000 | 0.0000 | -21.4128 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case B only | 1.8894 | -0.5602 | 0.0000 | -0.0000 | 0.0000 | -24.4669 |

### Worst Case Reactions LRFD

These calculations are taken directly from the FEA via SkyCiv and are used in the Concrete Checks of the Foundatino Module.
Note: Worst case values are assumed as downforce wind load cases.

| Result | Value (kip, kip-ft) |
|---|---|
| Axial | 8.9387 |
| Shear X | -5.1725 |
| Shear Z | 0.0000 |
| Moment X | 0.0002 |
| Moment Y (Twist) | 0.0002 |
| Moment Z | 55.5251 |

### Worst Case Reactions ASD

These results are taken from the worst case values in the above table and are used in the Soil Checks in the Foundation Module.
Note: Worst case values are assumed as downforce wind load cases.

| Result | Value (kip, kip-ft) |
|---|---|
| Axial | 6.0529 |
| Shear X | -3.1051 |
| Shear Z | 0.0000 |
| Moment X | -0.0000 |
| Moment Y (Twist) | 0.0000 |
| Moment Z | 33.0003 |

## Reaction Forces for Foundation 3 (Node ID#201), (kip, kip-ft)

### ASD Load Combination Results

| Name | Fx | Fy | Fz | Mx | My | Mz |
|---|---|---|---|---|---|---|
| ULS: 1. D | 0.0264 | 1.8983 | -0.0771 | -0.2269 | 0.0841 | -0.2255 |
| ULS: 2. D + L | 0.0264 | 1.8983 | -0.0771 | -0.2269 | 0.0841 | -0.2255 |
| ULS: 3. D + (S or Lr or R) | 0.0519 | 3.2425 | -0.1518 | -0.4467 | 0.1659 | -0.4627 |
| ULS: 3. D + (S or Lr or R) | 0.0264 | 1.8983 | -0.0771 | -0.2269 | 0.0841 | -0.2255 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | 0.0455 | 2.9065 | -0.1332 | -0.3918 | 0.1454 | -0.4034 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | 0.0264 | 1.8983 | -0.0771 | -0.2269 | 0.0841 | -0.2255 |
| ULS: 5b. D + 0.7E | 0.0264 | 1.8983 | -0.0771 | -0.2269 | 0.0841 | -0.2255 |
| ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S | 0.0455 | 2.9065 | -0.1332 | -0.3918 | 0.1454 | -0.4034 |
| ULS: 8. 0.6D + 0.7E | 0.0158 | 1.1390 | -0.0463 | -0.1361 | 0.0505 | -0.1353 |
| ULS: 5a. D + 0.6W_Wind downforce Case A only | -2.2939 | 4.1826 | -0.2919 | -0.8136 | 0.9646 | 25.0142 |
| ULS: 5a. D + 0.6W_Wind downforce Case B only | -2.2939 | 4.1826 | -0.2919 | -0.8136 | 0.9646 | 25.0142 |
| ULS: 5a. D + 0.6W_Wind uplift Case A only | 1.6987 | 0.2497 | 0.0724 | 0.1815 | -0.5286 | -17.0282 |
| ULS: 5a. D + 0.6W_Wind uplift Case B only | 1.5210 | 0.4324 | 0.0704 | 0.1756 | -0.5252 | -19.9015 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -1.6947 | 4.6198 | -0.2942 | -0.8318 | 0.8058 | 18.5263 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -1.6947 | 4.6198 | -0.2942 | -0.8318 | 0.8058 | 18.5263 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.2997 | 1.6701 | -0.0210 | -0.0855 | -0.3141 | -13.0055 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.1665 | 1.8071 | -0.0225 | -0.0899 | -0.3115 | -15.1604 |

| Name | Fx | Fy | Fz | Mx | My | Mz |
|---|---|---|---|---|---|---|
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -1.7138 | 3.6116 | -0.2382 | -0.6669 | 0.7445 | 18.7043 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -1.7138 | 3.6116 | -0.2382 | -0.6669 | 0.7445 | 18.7043 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.2806 | 0.6618 | 0.0350 | 0.0794 | -0.3754 | -12.8275 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.1474 | 0.7989 | 0.0335 | 0.0750 | -0.3729 | -14.9825 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case A only | -2.3044 | 3.4233 | -0.2611 | -0.7229 | 0.9309 | 25.1044 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case B only | -2.3044 | 3.4233 | -0.2611 | -0.7229 | 0.9309 | 25.1044 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case A only | 1.6881 | -0.5096 | 0.1033 | 0.2722 | -0.5623 | -16.9380 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case B only | 1.5105 | -0.3269 | 0.1012 | 0.2663 | -0.5588 | -19.8113 |

### Worst Case Reactions LRFD

These calculations are taken directly from the FEA via SkyCiv and are used in the Concrete Checks of the Foundatino Module.
Note: Worst case values are assumed as downforce wind load cases.

| Result | Value (kip, kip-ft) |
|---|---|
| Axial | 6.7585 |
| Shear X | -3.8671 |
| Shear Z | -0.4899 |
| Moment X | -1.3666 |
| Moment Y (Twist) | 1.6163 |
| Moment Z | 42.0766 |

### Worst Case Reactions ASD

These results are taken from the worst case values in the above table and are used in the Soil Checks in the Foundation Module.
Note: Worst case values are assumed as downforce wind load cases.

| Result | Value (kip, kip-ft) |
|---|---|
| Axial | 4.6198 |
| Shear X | -2.3044 |
| Shear Z | -0.2942 |
| Moment X | -0.8318 |
| Moment Y (Twist) | 0.9646 |
| Moment Z | 25.1044 |

## Project Details

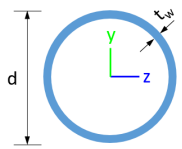
| | |
|---|---|
| Design Code: | AISC 360-16 LRFD |
| Provision: | LRFD |
| Country: | United States |
| User Name: | sales@mtsolar.us |
| Project Name: | JAM72-D30-545MB 28-panel |
| Unit System: | imperial |

## Design Input Information

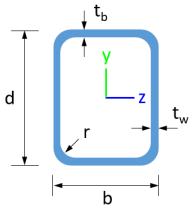
| Design Factors | | | |
|---|---|---|---|
| $\Phi_t$ | $\Phi_c$ | $\Phi_b$ | $\Phi_v$ |
| 0.9 | 0.9 | 0.9 | 0.9 |

| Design Materials | | | |
|---|---|---|---|
| ID | E (ksi) | $F_y$ (ksi) | $F_u$ (ksi) |
| 1 | 29000 | 50 | 65 |

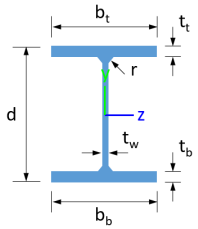
**Section Dimensions**




| ID | Name | d (in) | $t_w$ (in) | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2 | 2in Pipe Sch 80 | 2.38 | 0.22 | | | | | |
| 5 | 4in Pipe Sch 80 | 4.50 | 0.34 | | | | | |
| 9 | 8in Pipe Sch 40 | 8.63 | 0.32 | | | | | |




| ID | Name | d (in) | b (in) | $t_w$ (in) | $t_b$ (in) | r (in) | | |
|---|---|---|---|---|---|---|---|---|
| 16 | HSS5x3x3/16 | 5.00 | 3.00 | 0.17 | 0.17 | 0.17 | | |




| ID | Name | d (in) | $t_w$ (in) | $b_t$ (in) | $b_b$ (in) | $t_t$ (in) | $t_b$ (in) | r (in) |
|---|---|---|---|---|---|---|---|---|
| 19 | W8x10 | 7.89 | 0.17 | 3.94 | 3.94 | 0.20 | 0.20 | 0.30 |

**Section Properties**

| ID | Name | A ($in^2$) | J ($in^4$) | $I_{yp}$ ($in^4$) | $I_{zp}$ ($in^4$) | $I_w$ ($in^6$) | $S_{yp}$ ($in^3$) | $S_{zp}$ ($in^3$) |
|---|---|---|---|---|---|---|---|---|
| 2 | 2in Pipe Sch 80 | 1.48 | 1.74 | 0.87 | 0.87 | 0.00 | 1.02 | 1.02 |
| 5 | 4in Pipe Sch 80 | 4.41 | 19.22 | 9.61 | 9.61 | 0.00 | 5.85 | 5.85 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9 | 8in Pipe Sch 40 | 8.40 | 144.98 | 72.49 | 72.49 | 0.00 | 22.21 | 22.21 |
| 16 | HSS5x3x3/16 | 2.58 | 8.64 | 3.85 | 8.53 | 92.39 | 2.96 | 4.21 |
| 19 | W8x10 | 2.96 | 0.04 | 2.09 | 30.80 | 30.90 | 1.66 | 8.87 |

| Member Properties | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Member ID | Section ID | $K_zL$ (ft) | $K_yL$ (ft) | $L_b$(ft) | $C_b$ | LST | LSC | LD |
| 1 | 9 | 21.69 | 21.69 | 10.33 | - | 300 | 200 | 1 |
| 2 | 5 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 3 | 16 | 0.92 | 0.92 | 1.42 | 1.18,1.18,1.18,1.18,1.18,1.18,1.17,1.17,1.16,1.16,1.17,1.17,1.16,1.16,1.17,1.17,1.19,2.07,1.17,1.17,1.14,1.16,1.17,1.17,1.16,1.17 | 300 | 200 | 1 |
| 4 | 16 | 2.44 | 2.44 | 3.75 | 1.69,1.69,1.69,1.68,1.69,1.69,1.67,1.67,1.65,1.76,1.67,1.67,1.66,1.43,1.67,1.67,1.72,1.68,1.68,1.68,1.63,1.73,1.67,1.67,1.66,1.61 | 300 | 200 | 1 |
| 5 | 16 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.67,1.68,1.68,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.69,1.22,1.67,1.67,1.63,1.65,1.67,1.67,1.66,1.66 | 300 | 200 | 1 |
| 6 | 16 | 0.92 | 0.92 | 1.42 | 1.19,1.19,1.19,1.19,1.19,1.19,1.19,1.19,1.18,1.18,1.19,1.19,1.18,1.18,1.19,1.19,1.20,1.01,1.19,1.19,1.17,1.18,1.19,1.19,1.18,1.18 | 300 | 200 | 1 |
| 7 | 16 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.67,1.68,1.68,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.69,1.50,1.67,1.67,1.65,1.66,1.67,1.67,1.66,1.66 | 300 | 200 | 1 |
| 8 | 19 | 1.33 | 1.33 | 2.05 | 1.32,1.32,1.32,1.32,1.32,1.32,1.31,1.31,1.31,1.14,1.31,1.31,1.31,1.13,1.31,1.31,1.35,1.37,1.31,1.31,1.31,1.74,1.31,1.31,1.31,1.18 | 300 | 200 | 1 |
| 9 | 2 | 2.60 | 2.60 | 4.00 | - | 300 | 200 | 1 |
| 10 | 16 | 2.44 | 2.44 | 3.75 | 1.69,1.68,1.69,1.68,1.68,1.69,1.67,1.67,1.66,1.46,1.67,1.67,1.66,1.63,1.67,1.67,1.70,1.68,1.67,1.67,1.64,1.74,1.67,1.67,1.66,1.65 | 300 | 200 | 1 |
| 11 | 19 | 1.33 | 1.33 | 2.05 | 1.35,1.36,1.35,1.36,1.36,1.35,1.39,1.39,1.42,1.45,1.39,1.39,1.41,1.44,1.38,1.38,1.28,1.44,1.39,1.39,1.45,1.48,1.39,1.39,1.40,1.43 | 300 | 200 | 1 |
| 12 | 5 | 4.20 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 13 | 19 | 4.88 | 4.00 | 7.50 | 1.16,1.16,1.16,1.16,1.16,1.16,1.15,1.15,1.12,1.20,1.15,1.15,1.12,1.18,1.15,1.15,1.24,3.49,1.15,1.15,1.11,1.25,1.15,1.15,1.13,1.18 | 300 | 200 | 1 |
| 14 | 19 | 4.88 | 4.00 | 7.50 | 1.16,1.16,1.16,1.16,1.16,1.16,1.15,1.15,1.17,1.82,1.15,1.15,1.17,1.51,1.15,1.15,1.14,1.25,1.15,1.15,1.18,1.72,1.15,1.15,1.17,1.36 | 300 | 200 | 1 |
| 15 | 19 | 4.20 | 4.20 | 2.00 | 2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33 | 300 | 200 | 1 |
| 16 | 19 | 4.20 | 4.20 | 2.00 | 2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33 | 300 | 200 | 1 |
| 101 | 9 | 21.69 | 21.69 | 10.33 | - | 300 | 200 | 1 |
| 102 | 5 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 103 | 16 | 0.92 | 0.92 | 1.42 | 1.19,1.18,1.19,1.18,1.18,1.19,1.18,1.18,1.17,1.17,1.18,1.18,1.17,1.18,1.18,1.18,1.19,1.23,1.18,1.18,1.16,1.17,1.18,1.18,1.18,1.18 | 300 | 200 | 1 |
| 104 | 16 | 2.44 | 2.44 | 3.75 | 1.68,1.68,1.68,1.67,1.68,1.68,1.67,1.67,1.66,1.12,1.67,1.67,1.66,1.63,1.67,1.67,1.70,1.68,1.67,1.67,1.64,1.72,1.67,1.67,1.66,1.65 | 300 | 200 | 1 |
| 105 | 16 | 1.52 | 1.52 | 2.33 | 1.68,1.67,1.68,1.67,1.68,1.68,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.68,1.74,1.67,1.67,1.65,1.66,1.67,1.67,1.66,1.66 | 300 | 200 | 1 |
| 106 | 16 | 0.92 | 0.92 | 1.42 | 1.19,1.18,1.19,1.18,1.18,1.19,1.18,1.18,1.17,1.17,1.18,1.18,1.17,1.18,1.18,1.18,1.19,1.23,1.18,1.18,1.16,1.17,1.18,1.18,1.18,1.18 | 300 | 200 | 1 |
| 107 | 16 | 1.52 | 1.52 | 2.33 | 1.68,1.67,1.68,1.67,1.68,1.68,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.68,1.74,1.67,1.67,1.65,1.66,1.67,1.67,1.66,1.66 | 30 | 20 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | [illegible] | [illegible] | 0 | 0 | |
| 108 | 19 | 1.33 | 1.33 | 2.05 | 2.09,2.09,2.09,2.09,2.09,2.09,2.08,2.08,1.95,1.22,2.08,2.08,2.02,2.31,2.08,2.08,2.27,2.09,2.08,2.08,1.83,2.04,2.08,2.08,2.05,2.14 | 300 | 200 | 1 |
| 109 | 2 | 2.60 | 2.60 | 4.00 | - | 300 | 200 | 1 |
| 110 | 16 | 2.44 | 2.44 | 3.75 | 1.68,1.68,1.68,1.67,1.68,1.68,1.67,1.67,1.66,1.12,1.67,1.67,1.66,1.63,1.67,1.67,1.70,1.68,1.67,1.67,1.64,1.72,1.67,1.67,1.66,1.65 | 300 | 200 | 1 |
| 111 | 19 | 1.33 | 1.33 | 2.05 | 1.93,1.93,1.93,1.93,1.93,1.93,1.50,1.50,1.31,1.33,1.48,1.48,1.36,1.36,1.59,1.59,1.81,1.11,1.52,1.52,1.21,1.28,1.47,1.47,1.39,1.38 | 300 | 200 | 1 |
| 112 | 5 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 113 | 19 | 4.88 | 4.00 | 7.50 | 1.04,1.04,1.04,1.04,1.04,1.04,1.05,1.05,1.08,1.09,1.05,1.05,1.07,1.08,1.05,1.05,1.02,1.00,1.05,1.05,2.21,1.25,1.05,1.05,1.06,1.07 | 300 | 200 | 1 |
| 114 | 19 | 4.88 | 4.00 | 7.50 | 1.03,1.03,1.03,1.03,1.03,1.03,1.03,1.03,1.04,1.01,1.03,1.03,1.04,1.02,1.03,1.03,1.03,1.04,1.03,1.03,1.04,1.30,1.03,1.03,1.04,1.02 | 300 | 200 | 1 |
| 115 | 19 | 6.63 | 6.63 | 10.20 | 1.15,1.15,1.15,1.15,1.15,1.15,1.11,1.11,1.08,1.09,1.11,1.11,1.09,1.09,1.12,1.12,1.34,1.80,1.12,1.12,1.07,1.07,1.11,1.11,1.10,1.10 | 300 | 200 | 1 |
| 116 | 19 | 6.63 | 6.63 | 10.20 | 1.17,1.17,1.17,1.17,1.17,1.17,1.16,1.16,1.15,2.41,1.16,1.16,1.15,1.24,1.16,1.16,1.22,1.16,1.16,1.16,1.14,1.14,1.16,1.16,1.15,1.21 | 300 | 200 | 1 |
| 201 | 9 | 21.69 | 21.69 | 10.33 | - | 300 | 200 | 1 |
| 202 | 5 | 4.20 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 203 | 16 | 0.92 | 0.92 | 1.42 | 1.19,1.19,1.19,1.19,1.19,1.19,1.19,1.19,1.18,1.18,1.19,1.19,1.18,1.18,1.19,1.19,1.20,1.01,1.19,1.19,1.17,1.18,1.19,1.19,1.18,1.18 | 300 | 200 | 1 |
| 204 | 16 | 2.44 | 2.44 | 3.75 | 1.69,1.68,1.69,1.68,1.68,1.69,1.67,1.67,1.66,1.46,1.67,1.67,1.66,1.63,1.67,1.67,1.70,1.68,1.67,1.67,1.64,1.74,1.67,1.67,1.66,1.65 | 300 | 200 | 1 |
| 205 | 16 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.67,1.68,1.68,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.69,1.50,1.67,1.67,1.65,1.66,1.67,1.67,1.66,1.66 | 300 | 200 | 1 |
| 206 | 16 | 0.92 | 0.92 | 1.42 | 1.18,1.18,1.18,1.18,1.18,1.18,1.17,1.17,1.16,1.16,1.17,1.17,1.16,1.16,1.17,1.17,1.19,2.07,1.17,1.17,1.14,1.16,1.17,1.17,1.16,1.17 | 300 | 200 | 1 |
| 207 | 16 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.67,1.68,1.68,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.69,1.22,1.67,1.67,1.63,1.65,1.67,1.67,1.66,1.66 | 300 | 200 | 1 |
| 208 | 19 | 4.20 | 4.20 | 2.00 | 2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33 | 300 | 200 | 1 |
| 209 | 2 | 2.60 | 2.60 | 4.00 | - | 300 | 200 | 1 |
| 210 | 16 | 2.44 | 2.44 | 3.75 | 1.69,1.69,1.69,1.68,1.69,1.69,1.67,1.67,1.65,1.76,1.67,1.67,1.66,1.43,1.67,1.67,1.72,1.68,1.68,1.68,1.63,1.73,1.67,1.67,1.66,1.61 | 300 | 200 | 1 |
| 211 | 19 | 4.20 | 4.20 | 2.00 | 2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33,2.33 | 300 | 200 | 1 |
| 212 | 5 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 213 | 19 | 4.88 | 4.00 | 7.50 | 1.16,1.16,1.16,1.16,1.16,1.16,1.15,1.15,1.12,1.20,1.15,1.15,1.12,1.18,1.15,1.15,1.24,3.50,1.15,1.15,1.11,1.25,1.15,1.15,1.13,1.18 | 300 | 200 | 1 |
| 214 | 19 | 4.88 | 4.00 | 7.50 | 1.16,1.16,1.16,1.16,1.16,1.16,1.15,1.15,1.17,1.83,1.15,1.15,1.17,1.51,1.15,1.15,1.14,1.25,1.15,1.15,1.18,1.72,1.15,1.15,1.17,1.36 | 300 | 200 | 1 |
| 215 | 19 | 6.63 | 6.63 | 10.20 | 1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.11,1.11,1.10,1.10,1.10,1.11,1.09,1.09,1.11,2.21,1.09,1.09,1.12,1.12,1.10,1.10,1.10,1.10 | 300 | 200 | 1 |
| 216 | 19 | 6.63 | 6.63 | 10.20 | 1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,2.12,1.09,1.09,1.09,1.08,1.09,1.09,1.10,1.09,1.09,1.09,1.08,1.13,1.09,1.09,1.09,1.08 | 300 | 200 | 1 |

## Member Design Capacity

| Member ID | $\Phi_t P_n$ (kip) | $\Phi_c P_n$ (kip) | $\Phi_b M_{zn}$ (k-ft) | $\Phi_b M_{yn}$ (k-ft) | $\Phi_v V_{yn}$ (kip) | $\Phi_v V_{zn}$ (kip) |
|---|---|---|---|---|---|---|
| 1 | 377.97 | 212.89 | 83.29 | 83.29 | 113.39 | 113.39 |
| 2 | 198.33 | 196.72 | 21.95 | 21.95 | 59.50 | 59.50 |
| 3 | 116.10 | 115.41 | 15.79 | 11.10 | 42.08 | 23.28 |
| 4 | 116.10 | 111.33 | 15.79 | 11.10 | 42.08 | 23.28 |
| 5 | 116.10 | 114.23 | 15.79 | 11.10 | 42.08 | 23.28 |
| 6 | 116.10 | 115.41 | 15.79 | 11.10 | 42.08 | 23.28 |
| 7 | 116.10 | 114.23 | 15.79 | 11.10 | 42.08 | 23.28 |
| 8 | 133.20 | 126.01 | 32.87 | 6.12 | 40.24 | 43.62 |
| 9 | 66.48 | 58.89 | 3.82 | 3.82 | 19.94 | 19.94 |
| 10 | 116.10 | 111.33 | 15.79 | 11.10 | 42.08 | 23.28 |
| 11 | 133.20 | 126.01 | 32.87 | 6.12 | 40.24 | 43.62 |
| 12 | 198.33 | 182.14 | 21.95 | 21.95 | 59.50 | 59.50 |
| 13 | 133.20 | 104.94 | 25.44 | 6.12 | 40.24 | 43.62 |
| 14 | 133.20 | 104.94 | 26.12 | 6.12 | 40.24 | 43.62 |
| 15 | 133.20 | 102.39 | 32.87 | 6.12 | 40.24 | 43.62 |
| 16 | 133.20 | 102.39 | 32.87 | 6.12 | 40.24 | 43.62 |
| 101 | 377.97 | 212.89 | 83.29 | 83.29 | 113.39 | 113.39 |
| 102 | 198.33 | 196.72 | 21.95 | 21.95 | 59.50 | 59.50 |
| 103 | 116.10 | 115.41 | 15.79 | 11.10 | 42.08 | 23.28 |
| 104 | 116.10 | 111.33 | 15.79 | 11.10 | 42.08 | 23.28 |
| 105 | 116.10 | 114.23 | 15.79 | 11.10 | 42.08 | 23.28 |
| 106 | 116.10 | 115.41 | 15.79 | 11.10 | 42.08 | 23.28 |
| 107 | 116.10 | 114.23 | 15.79 | 11.10 | 42.08 | 23.28 |
| 108 | 133.20 | 126.01 | 32.87 | 6.12 | 40.24 | 43.62 |
| 109 | 66.48 | 58.89 | 3.82 | 3.82 | 19.94 | 19.94 |
| 110 | 116.10 | 111.33 | 15.79 | 11.10 | 42.08 | 23.28 |
| 111 | 133.20 | 126.01 | 32.87 | 6.12 | 40.24 | 43.62 |
| 112 | 198.33 | 196.72 | 21.95 | 21.95 | 59.50 | 59.50 |
| 113 | 133.20 | 104.94 | 22.92 | 6.12 | 40.24 | 43.62 |
| 114 | 133.20 | 104.94 | 23.14 | 6.12 | 40.24 | 43.62 |
| 115 | 133.20 | 69.16 | 16.56 | 6.12 | 40.24 | 43.62 |
| 116 | 133.20 | 69.16 | 17.64 | 6.12 | 40.24 | 43.62 |
| 201 | 377.97 | 212.89 | 83.29 | 83.29 | 113.39 | 113.39 |
| 202 | 198.33 | 182.14 | 21.95 | 21.95 | 59.50 | 59.50 |
| 203 | 116.10 | 115.41 | 15.79 | 11.10 | 42.08 | 23.28 |
| 204 | 116.10 | 111.33 | 15.79 | 11.10 | 42.08 | 23.28 |
| 205 | 116.10 | 114.23 | 15.79 | 11.10 | 42.08 | 23.28 |
| 206 | 116.10 | 115.41 | 15.79 | 11.10 | 42.08 | 23.28 |
| 207 | 116.10 | 114.23 | 15.79 | 11.10 | 42.08 | 23.28 |
| 208 | 133.20 | 102.39 | 32.87 | 6.12 | 40.24 | 43.62 |
| 209 | 66.48 | 58.89 | 3.82 | 3.82 | 19.94 | 19.94 |
| 210 | 116.10 | 111.33 | 15.79 | 11.10 | 42.08 | 23.28 |
| 211 | 133.20 | 102.39 | 32.87 | 6.12 | 40.24 | 43.62 |
| 212 | 198.33 | 196.72 | 21.95 | 21.95 | 59.50 | 59.50 |
| 213 | 133.20 | 104.94 | 25.44 | 6.12 | 40.24 | 43.62 |
| 214 | 133.20 | 104.94 | 26.12 | 6.12 | 40.24 | 43.62 |
| 215 | 133.20 | 69.16 | 16.87 | 6.12 | 40.24 | 43.62 |
| 216 | 133.20 | 69.16 | 16.71 | 6.12 | 40.24 | 43.62 |

## Design Ratio

## Design Ratio

| Member ID | P | $M_z$ | $M_y$ | $V_y$ | $V_z$ | $(P,M_z,M_y)$ | Worst LC | KL/r | δ | Status |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.032 | 0.505 | 0.044 | 0.034 | 0.004 | 0.537 | #13 | 0.443 | Not Required | Pass |
| 2 | 0.002 | 0.155 | 0.130 | 0.041 | 0.028 | 0.286 | #13 | 0.053 | Not Required | Pass |
| 3 | 0.005 | 0.362 | 0.018 | 0.035 | 0.001 | 0.369 | #13 | 0.045 | Not Required | Pass |
| 4 | 0.004 | 0.323 | 0.059 | 0.033 | 0.015 | 0.381 | #13 | 0.080 | Not Required | Pass |
| 5 | 0.004 | 0.224 | 0.040 | 0.036 | 0.010 | 0.227 | #13 | 0.074 | Not Required | Pass |
| 6 | 0.008 | 0.544 | 0.076 | 0.056 | 0.020 | 0.599 | #13 | 0.045 | Not Required | Pass |
| 7 | 0.008 | 0.338 | 0.125 | 0.054 | 0.031 | 0.357 | #13 | 0.074 | Not Required | Pass |
| 8 | 0.003 | 0.092 | 0.114 | 0.030 | 0.013 | 0.136 | #13 | 0.095 | Not Required | Pass |
| 9 | 0.004 | 0.044 | 0.062 | 0.003 | 0.003 | 0.106 | #13 | 0.204 | Not Required | Pass |
| 10 | 0.009 | 0.468 | 0.120 | 0.047 | 0.026 | 0.479 | #13 | 0.080 | Not Required | Pass |
| 11 | 0.004 | 0.097 | 0.116 | 0.036 | 0.013 | 0.137 | #13 | 0.095 | Not Required | Pass |
| 12 | 0.001 | 0.323 | 0.204 | 0.067 | 0.038 | 0.527 | #13 | 0.171 | Not Required | Pass |
| 13 | 0.004 | 0.093 | 0.295 | 0.047 | 0.016 | 0.334 | #21 | 0.286 | Not Required | Pass |
| 14 | 0.003 | 0.076 | 0.292 | 0.039 | 0.016 | 0.310 | #24 | 0.190 | Not Required | Pass |
| 15 | 0.000 | 0.015 | 0.029 | 0.012 | 0.004 | 0.040 | #21 | Not Required | Not Required | Pass |
| 16 | 0.000 | 0.013 | 0.029 | 0.011 | 0.004 | 0.039 | #21 | Not Required | Not Required | Pass |
| 101 | 0.042 | 0.667 | 0.000 | 0.046 | 0.000 | 0.688 | #13 | 0.443 | Not Required | Pass |
| 102 | 0.002 | 0.322 | 0.230 | 0.072 | 0.043 | 0.553 | #13 | 0.035 | Not Required | Pass |
| 103 | 0.008 | 0.587 | 0.049 | 0.059 | 0.008 | 0.619 | #13 | 0.045 | Not Required | Pass |
| 104 | 0.008 | 0.560 | 0.129 | 0.056 | 0.027 | 0.619 | #13 | 0.080 | Not Required | Pass |
| 105 | 0.008 | 0.364 | 0.134 | 0.058 | 0.034 | 0.388 | #13 | 0.074 | Not Required | Pass |
| 106 | 0.008 | 0.587 | 0.049 | 0.059 | 0.008 | 0.619 | #13 | 0.045 | Not Required | Pass |
| 107 | 0.008 | 0.364 | 0.134 | 0.058 | 0.034 | 0.388 | #13 | 0.074 | Not Required | Pass |
| 108 | 0.003 | 0.054 | 0.124 | 0.037 | 0.013 | 0.146 | #21 | 0.095 | Not Required | Pass |
| 109 | 0.011 | 0.038 | 0.044 | 0.001 | 0.000 | 0.085 | #13 | 0.204 | Not Required | Pass |
| 110 | 0.008 | 0.560 | 0.129 | 0.056 | 0.027 | 0.619 | #13 | 0.080 | Not Required | Pass |
| 111 | 0.004 | 0.088 | 0.126 | 0.038 | 0.013 | 0.129 | #21 | 0.095 | Not Required | Pass |
| 112 | 0.002 | 0.322 | 0.230 | 0.072 | 0.043 | 0.553 | #13 | 0.035 | Not Required | Pass |
| 113 | 0.004 | 0.135 | 0.307 | 0.049 | 0.016 | 0.407 | #21 | 0.286 | Not Required | Pass |
| 114 | 0.006 | 0.182 | 0.306 | 0.047 | 0.016 | 0.434 | #21 | 0.286 | Not Required | Pass |
| 115 | 0.007 | 0.285 | 0.161 | 0.038 | 0.013 | 0.395 | #13 | 0.473 | Not Required | Pass |
| 116 | 0.004 | 0.235 | 0.162 | 0.037 | 0.013 | 0.345 | #21 | 0.473 | Not Required | Pass |
| 201 | 0.032 | 0.505 | 0.044 | 0.034 | 0.004 | 0.537 | #13 | 0.443 | Not Required | Pass |
| 202 | 0.001 | 0.323 | 0.204 | 0.067 | 0.038 | 0.527 | #13 | 0.171 | Not Required | Pass |
| 203 | 0.008 | 0.544 | 0.076 | 0.056 | 0.020 | 0.599 | #13 | 0.045 | Not Required | Pass |
| 204 | 0.009 | 0.468 | 0.120 | 0.047 | 0.026 | 0.479 | #13 | 0.080 | Not Required | Pass |
| 205 | 0.008 | 0.337 | 0.125 | 0.054 | 0.030 | 0.357 | #13 | 0.074 | Not Required | Pass |
| 206 | 0.005 | 0.362 | 0.018 | 0.035 | 0.001 | 0.369 | #13 | 0.045 | Not Required | Pass |
| 207 | 0.004 | 0.224 | 0.040 | 0.036 | 0.010 | 0.227 | #13 | 0.074 | Not Required | Pass |
| 208 | 0.000 | 0.013 | 0.029 | 0.011 | 0.004 | 0.039 | #21 | Not Required | Not Required | Pass |
| 209 | 0.004 | 0.044 | 0.062 | 0.003 | 0.003 | 0.106 | #13 | 0.204 | Not Required | Pass |
| 210 | 0.004 | 0.323 | 0.059 | 0.033 | 0.015 | 0.381 | #13 | 0.080 | Not Required | Pass |
| 211 | 0.000 | 0.015 | 0.029 | 0.012 | 0.004 | 0.040 | #21 | Not Required | Not Required | Pass |
| 212 | 0.002 | 0.155 | 0.130 | 0.041 | 0.028 | 0.286 | #13 | 0.053 | Not Required | Pass |
| 213 | 0.004 | 0.093 | 0.295 | 0.047 | 0.016 | 0.334 | #21 | 0.190 | Not Required | Pass |
| 214 | 0.003 | 0.076 | 0.292 | 0.039 | 0.016 | 0.310 | #24 | 0.286 | Not Required | Pass |
| 215 | 0.007 | 0.300 | 0.161 | 0.036 | 0.013 | 0.398 | #13 | 0.473 | Not Required | Pass |
| 216 | 0.004 | 0.253 | 0.161 | 0.030 | 0.013 | 0.355 | #13 | 0.473 | Not Required | Pass |

## Definitions

| | |
|---|---|
| $\Phi_t$ | Safety factor for tensile |
| $\Phi_c$ | Safety factor for compression |
| $\Phi_b$ | Safety factor for flexure |
| $\Phi_v$ | Safety factor for shear |
| E | Modulus of elasticity |
| $F_y$ | Specified minimum yield stress |
| $F_u$ | Specified minimum tensile strength |
| A | Cross-sectional area |
| J | Torsional constant |
| $I_{yp}$ | Moment of inertia about the Y axes |
| $I_{zp}$ | Moment of inertia about the Z axes |
| $I_w$ | Warping constant |
| $S_{yp}$ | Plastic section modulus about the Y axis |
| $S_{zp}$ | Plastic section modulus about the Z axis |
| KL | Effective length |
| $C_b$ | Buckling modification factor (from all load combinations) |
| $L_b$ | Length between braced points |
| LST | Limited slenderness for tension |
| LSC | Limited slenderness for compression |
| LD | Limited deflection |
| $P_n$ | Nominal axial strength (tension/comression) |
| $M_n$ | Nominal flexural strength (about Z/Y axis) |
| $V_n$ | Nominal shear strength (along Z/Y axis) |
| P | Design ratio in case of axial force |
| $M_z$ | Design ratio in case of bending about Z axis |
| $M_y$ | Design ratio in case of bending about Y axis |
| $V_y$ | Design ratio in case of shear along Y axis |
| $V_z$ | Design ratio in case of shear along Z axis |
| $(P,M_z,M_y)$ | Design ratio in case of axial force and bending action |
| KL/r | Design ratio in case of section slenderness |
| δ | Design ratio in case of member deflection |
| OK | Capacity is provided |
| NG | Capacity is not provided |

| REFERENCES | CALCULATIONS | RESULTS |
|---|---|---|

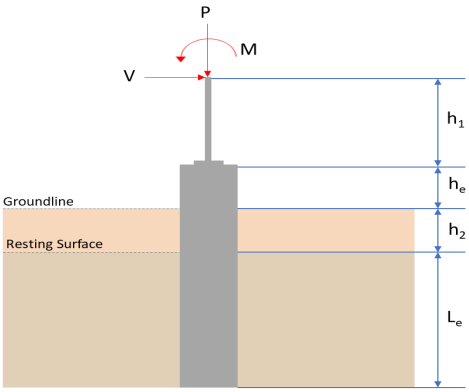
## SkyCiv Foundation Design

Pile Foundation

**Design Information :**

Design code : IBC 2021 (International Building Code)
Unit System : Imperial

### Pile Input




**Geometry**

Pile shape: rectangular
$b = 48\ \text{in}$ - Pile width
$D = 48\ \text{in}$ - Pile depth
$L = 6.25\ \text{ft}$ - Total pile length
$h_1 = 0\ \text{ft}$ - Lateral load height from the top of the pile,
$h_2 = 0\ \text{ft}$ - Depth to resisting surface
$h_e = 0\ \text{ft}$ - Length of pile above the ground

**Tabulation of Soil Parameters**

| Layer | Label | Allowable Bearing Pressure $(q_a)$ $(\text{psf})$ | Allowable Lateral Pressure $(R)$ $(\text{psf/ft})$ |
|---|---|---|---|
| 1 | Sand, silty sand, clayey sand, silty gravel & clayey gravel | 2000.000 | 150.000 |

**Tabulation of Loads**

| Load Component | ASD | LRFD |
|---|---|---|
| $P$ (kip) | 4.620 | 6.758 |
| $V_x$ (kip) | -2.304 | -3.867 |
| $V_z$ (kip) | 0.294 | 0.490 |
| $M_x$ (kipft) | 0.832 | 1.366 |
| $M_z$ (kipft) | 25.104 | 42.076 |

**Material Properties**

$f'_{ck} = 2.5\ \text{ksi}$ - Concrete strength,

### Required depth to resist lateral loads (ASD)

$H$ - Point of application of the lateral load

$$H = h_1 + h_2 + h_e$$

$$H = (0\ \text{ft}) + (0\ \text{ft}) + (0\ \text{ft})$$

$$H = 0\ \text{ft}$$

**Considering x-direction:**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_x}{1.57\ D}$$

$$H_o = \frac{(-2.304\ \text{kip})}{1.57 \times (48\ \text{in})}$$

$$H_o = -0.36688\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

$$M_o = \frac{M_z + (V_x\ H)}{1.57\ D}$$

$$M_o = \frac{(25.104\ \text{kipft}) + ((-2.304\ \text{kip}) \times (0\ \text{ft}))}{1.57 \times (48\ \text{in})}$$

$$M_o = 3.9975\ \text{kipft/ft}$$

Required depth of embedment in earth:

$$L_x^3 - \left(14.14 \times \frac{H_o \times L_x}{R}\right) - \left(18.85 \times \frac{M_o}{R}\right) = 0$$

Solving the cubic equation:
$L_{e,x} = 5.7756\ \text{ft}$ - Required depth in x-direction,

**Considering z-direction:**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_z}{1.57\,b}$$

$$H_o = \frac{(0.294\ \text{kip})}{1.57 \times (48\ \text{in})}$$

$$H_o = 0.046815\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

$$M_o = \frac{M_x + (V_z\,H)}{1.57\,b}$$

$$M_o = \frac{(0.832\ \text{kipft}) + ((0.294\ \text{kip}) \times (0\ \text{ft}))}{1.57 \times (48\ \text{in})}$$

$$M_o = 0.13248\ \text{kipft/ft}$$

Required depth of embedment in earth:

$$L_z^3 - \left(14.14 \times \frac{H_o \times L_z}{R}\right) - \left(18.85 \times \frac{M_o}{R}\right) = 0$$

Solving the cubic equation:
$L_{e,z} = 2.6185\ \text{ft}$ - Required depth in z-direction,

**Minimum embedded depth required:**

$L_{e,req}$ - Depth of pile required,

$$L_{e,req} = MAX[L_{e,x}, L_{e,z}]$$

$$L_{e,req} = MAX[(5.7756\ \text{ft}), (2.6185\ \text{ft})]$$

$$L_{e,req} = 5.776\ \text{ft}$$

$L_e$ - Actual embedded length of pile,

$$L_e = L - h_e - h_2$$

$$L_e = (6.25\ \text{ft}) - (0\ \text{ft}) - (0\ \text{ft})$$

$$L_e = 6.25\ \text{ft}$$

$Ratio$ - Embedded depth

$$Ratio = \frac{L_{e,req}}{L_e}$$

$$Ratio = \frac{(5.776\ \text{ft})}{(6.25\ \text{ft})}$$

$$Ratio = 0.92416$$

Status: **PASS**
Ratio: **0.920**

**End-bearing Capacity (ASD)**

$A$ - Pile cross-section area

$$A = b\,D$$

$$A = (48\ \text{in}) \times (48\ \text{in})$$

$$A = 16\ \text{ft}^2$$

$q$ - End-bearing pressure

$$q = \frac{P_v}{A}$$

$$q = \frac{(4.62\ \text{kip})}{(16\ \text{ft}^2)}$$

$$q = 0.28875\ \text{kip/ft}^2$$

$$q = 0.28875 \text{ kip/ft}$$

**Check bearing capacity ratio:**

$Ratio$ - Capacity

$$Ratio = \frac{q}{q_a}$$

$$Ratio = \frac{(0.28875 \text{ kip/ft}^2)}{(2000 \text{ psf})}$$

$$Ratio = 0.14438$$

Status: **PASS**
Ratio: **0.140**

*Czerniak*

**Lateral Soil Pressure (ASD):**

$L/D$ - Length to least lateral dimension ratio,

$$L/D = \frac{L}{D}$$

$$L/D = \frac{(6.25 \text{ ft})}{(48 \text{ in})}$$

$$L/D = 1.5625$$

Since L/D $\leq$ 10,

Pile is short.

**Considering x-direction:**

$H_o = -0.36688 \text{ kip/ft}$ - Lateral force per length of pile,
$M_o = 3.9975 \text{ kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

$$a = \frac{(4\, M_o\, L_e) + (3\, H_o\, L_e^2)}{(6\, M_o) + (4\, H_o\, L_e)}$$

$$a = \frac{(4 \times (3.9975 \text{ kipft/ft}) \times (6.25 \text{ ft})) + \left(3 \times (-0.36688 \text{ kip/ft}) \times (6.25 \text{ ft})^2\right)}{(6 \times (3.9975 \text{ kipft/ft})) + (4 \times (-0.36688 \text{ kip/ft}) \times (6.25 \text{ ft}))}$$

$$a = 4.3107 \text{ ft}$$

$p$ - Earth pressure against the pile at distance a/2 from resting surface,

$$p = \frac{0.75\, [(4\, M_o) + (3\, H_o\, L_e)]^2}{L_e^2\, [(3\, M_o) + (2\, H_o\, L_e)]}$$

$$p = \frac{0.75 \times [(4 \times (3.9975 \text{ kipft/ft})) + (3 \times (-0.36688 \text{ kip/ft}) \times (6.25 \text{ ft}))]^{\ 2}}{(6.25 \text{ ft})^2 \times [(3 \times (3.9975 \text{ kipft/ft})) + (2 \times (-0.36688 \text{ kip/ft}) \times (6.25 \text{ ft}))]}$$

$$p = 0.21518 \text{ kip/ft}^2$$

$s$ - Earth pressure against the pile at distance $L_e$,

$$s = \frac{6\, [(2\, M_o) + (H_o\, L_e)]}{L_e^2}$$

$$s = \frac{6 \times [(2 \times (3.9975 \text{ kipft/ft})) + ((-0.36688 \text{ kip/ft}) \times (6.25 \text{ ft}))]}{(6.25 \text{ ft})^2}$$

$$s = 0.87581 \text{ kip/ft}^2$$

**Check lateral soil pressure capacity:**

$p_a$ - Allowable lateral soil pressure at depth a/2,

$$p_a = R\, \frac{a}{2}$$

$$p_a = (150 \text{ psf/ft}) \times \frac{(4.3107 \text{ ft})}{2}$$

$$p_a = 0.32331 \text{ kip/ft}^2$$

$Ratio$ - Lateral soil capacity

$$Ratio = \frac{p}{p_a}$$

$$Ratio = \frac{(0.21518 \text{ kip/ft}^2)}{(0.32331 \text{ kip/ft}^2)}$$

$$Ratio = 0.66558$$

Status: **PASS**
Ratio: **0.670**

$p_s$ - Allowable lateral soil pressure at depth $L_e$,

$$p_s = R\,L_e$$

$$p_s = (150\ \text{psf/ft}) \times (6.25\ \text{ft})$$

$$p_s = 0.9375\ \text{kip/ft}^2$$

$Ratio$ - Lateral soil capacity

$$Ratio = \frac{s}{p_s}$$

$$Ratio = \frac{(0.87581\ \text{kip/ft}^2)}{(0.9375\ \text{kip/ft}^2)}$$

$$Ratio = 0.9342$$

Status: **PASS**
Ratio: **0.930**

**Considering z-direction:**

$H_o = 0.046815\ \text{kip/ft}$ - Lateral force per length of pile,
$M_o = 0.13248\ \text{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

$$a = \frac{(4\,M_o\,L_e) + (3\,H_o\,L_e^2)}{(6\,M_o) + (4\,H_o\,L_e)}$$

$$a = \frac{(4 \times (0.13248\ \text{kipft/ft}) \times (6.25\ \text{ft})) + \left(3 \times (0.046815\ \text{kip/ft}) \times (6.25\ \text{ft})^2\right)}{(6 \times (0.13248\ \text{kipft/ft})) + (4 \times (0.046815\ \text{kip/ft}) \times (6.25\ \text{ft}))}$$

$$a = 4.4768\ \text{ft}$$

$p$ - Earth pressure against the pile at distance a/2 from resting surface,

$$p = \frac{0.75\,[(4\,M_o) + (3\,H_o\,L_e)]^2}{L_e^2\,[(3\,M_o) + (2\,H_o\,L_e)]}$$

$$p = \frac{0.75 \times [(4 \times (0.13248\ \text{kipft/ft})) + (3 \times (0.046815\ \text{kip/ft}) \times (6.25\ \text{ft}))]^{\ 2}}{(6.25\ \text{ft})^2 \times [(3 \times (0.13248\ \text{kipft/ft})) + (2 \times (0.046815\ \text{kip/ft}) \times (6.25\ \text{ft}))]}$$

$$p = 0.03872\ \text{kip/ft}^2$$

$s$ - Earth pressure against the pile at distance $L_e$,

$$s = \frac{6\,[(2\,M_o) + (H_o\,L_e)]}{L_e^2}$$

$$s = \frac{6 \times [(2 \times (0.13248\ \text{kipft/ft})) + ((0.046815\ \text{kip/ft}) \times (6.25\ \text{ft}))]}{(6.25\ \text{ft})^2}$$

$$s = 0.085642\ \text{kip/ft}^2$$

**Check lateral soil pressure capacity:**

$p_a$ - Allowable lateral soil pressure at depth a/2,

$$p_a = R\,\frac{a}{2}$$

$$p_a = (150\ \text{psf/ft}) \times \frac{(4.4768\ \text{ft})}{2}$$

$$p_a = 0.33576\ \text{kip/ft}^2$$

$Ratio$ - Lateral soil capacity

$$Ratio = \frac{p}{p_a}$$

$$Ratio = \frac{(0.03872\ \text{kip/ft}^2)}{(0.33576\ \text{kip/ft}^2)}$$

$$Ratio = 0.11532$$

Status: **PASS**
Ratio: **0.120**

$p_s$ - Allowable lateral soil pressure at depth $L_e$,

$$p_s = R\,L_e$$

$$p_s = (150\ \text{psf/ft}) \times (6.25\ \text{ft})$$

$$p_s = 0.9375\ \text{kip/ft}^2$$

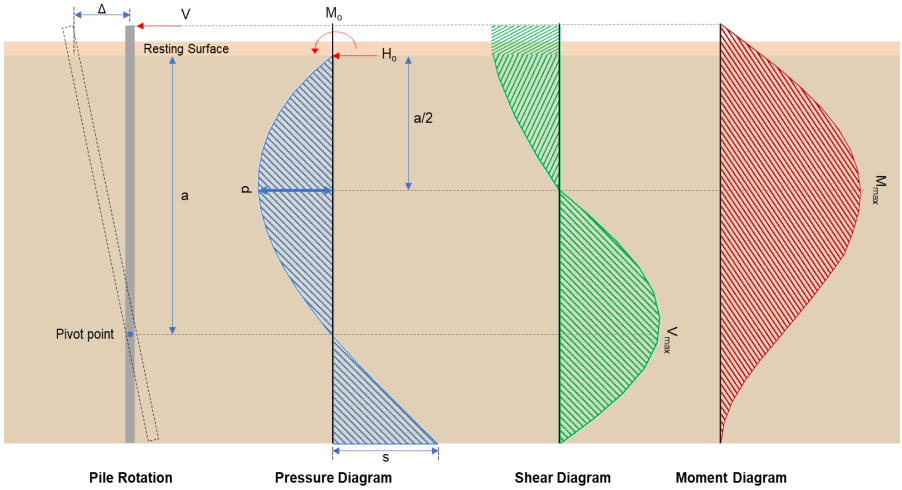
$Ratio$ - Lateral soil capacity

$$Ratio = \frac{s}{p_s}$$

$$Ratio = \frac{(0.085642\ \text{kip/ft}^2)}{(0.9375\ \text{kip/ft}^2)}$$

$$Ratio = 0.091351$$

Status: **PASS**
Ratio: **0.090**




**Shear force and Bending moment (x-direction, LRFD)**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_x}{1.57\ D}$$

$$H_o = \frac{(-3.867\ \text{kip})}{1.57 \times (48\ \text{in})}$$

$$H_o = -0.61576\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

$$M_o = \frac{M_z + (V_x\ H)}{1.57\ D}$$

$$M_o = \frac{(42.076\ \text{kipft}) + ((-3.867\ \text{kip}) \times (0\ \text{ft}))}{1.57 \times (48\ \text{in})}$$

$$M_o = 6.7\ \text{kipft/ft}$$

$E$ - Distance from lateral load to resisting surface,

$$E = \frac{M_o}{H_o}$$

$$E = \frac{(6.7\ \text{kipft/ft})}{(-0.61576\ \text{kip/ft})}$$

$$E = 10.881\ \text{ft}$$

$a$ - Distance from resting surface to pivot point,

$$a = \frac{(4\ M_o\ L_e) + (3\ H_o\ L_e^2)}{(6\ M_o) + (4\ H_o\ L_e)}$$

$$a = \frac{(4 \times (6.7\ \text{kipft/ft}) \times (6.25\ \text{ft})) + \left(3 \times (-0.61576\ \text{kip/ft}) \times (6.25\ \text{ft})^2\right)}{(6 \times (6.7\ \text{kipft/ft})) + (4 \times (-0.61576\ \text{kip/ft}) \times (6.25\ \text{ft}))}$$

$$a = 4.3109\ \text{ft}$$

$V_{max}$ - Max shear force located at depth a,

$$V_{max} = (H_o\ D)\left[1 - \left[3\left(\frac{4\ E}{L_e} + 3\right)\left(\frac{a}{L_e}\right)^2\right] + \left[4\left(\frac{3\ E}{L_e} + 2\right)\left(\frac{a}{L_e}\right)^3\right]\right]$$

$$V_{max} = ((-0.61576\ \text{kip/ft}) \times (48\ \text{in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (10.881\ \text{ft})}{(6.25\ \text{ft})} + 3\right) \times \left(\frac{(4.3109\ \text{ft})}{(6.25\ \text{ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (10.881\ \text{ft})}{(6.25\ \text{ft})} + 2\right) \times \left(\frac{(4.3109\ \text{ft})}{(6.25\ \text{ft})}\right)^3\right]\right]$$

$$V_{max} = 9.2123\ \text{kip}$$

$M_{max}$ - Max bending moment located at depth a/2,

$$M_{max} = (H_o\ D\ L_e)\ \left[\left(\frac{E}{L_e} + \frac{a}{2\ L_e}\right) - \left[\left(\frac{4\ E}{L_e} + 3\right)\ \left(\frac{a}{2\ L_e}\right)^3\right] + \left[\left(\frac{3\ E}{L_e} + 2\right)\ \left(\frac{a}{2\ L_e}\right)^4\right]\right]$$

$$M_{max} = ((-0.61576\ \text{kip/ft}) \times (48\ \text{in}) \times (6.25\ \text{ft})) \times \left[\left(\frac{(10.881\ \text{ft})}{(6.25\ \text{ft})} + \frac{(4.3109\ \text{ft})}{2 \times (6.25\ \text{ft})}\right) - \left[\left(\frac{4 \times (10.881\ \text{ft})}{(6.25\ \text{ft})} + 3\right) \times \left(\frac{(4.3109\ \text{ft})}{2 \times (6.25\ \text{ft})}\right)^3\right] + \left[\left(\frac{3 \times (10.881\ \text{ft})}{(6.25\ \text{ft})} + 2\right) \times \left(\frac{(4.3109\ \text{ft})}{2 \times (6.25\ \text{ft})}\right)^4\right]\right]$$

$$M_{max} = 27.39\ \text{kipft}$$

**Shear force and Bending moment (z-direction, LRFD)**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_z}{1.57\ b}$$

$$H_o = \frac{(0.49\ \text{kip})}{1.57 \times (48\ \text{in})}$$

$$H_o = 0.078025\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

$$M_o = \frac{M_x + (V_z\ H)}{1.57\ b}$$

$$M_o = \frac{(1.366\ \text{kipft}) + ((0.49\ \text{kip}) \times (0\ \text{ft}))}{1.57 \times (48\ \text{in})}$$

$$M_o = 0.21752\ \text{kipft/ft}$$

$E$ - Distance from lateral load to resisting surface,

$$E = \frac{M_o}{H_o}$$

$$E = \frac{(0.21752\ \text{kipft/ft})}{(0.078025\ \text{kip/ft})}$$

$$E = 2.7878\ \text{ft}$$

$a$ - Distance from resting surface to pivot point,

$$a = \frac{(4\ M_o\ L_e) + \left(3\ H_o\ L_e^2\right)}{(6\ M_o) + (4\ H_o\ L_e)}$$

$$a = \frac{(4 \times (0.21752\ \text{kipft/ft}) \times (6.25\ \text{ft})) + \left(3 \times (0.078025\ \text{kip/ft}) \times (6.25\ \text{ft})^2\right)}{(6 \times (0.21752\ \text{kipft/ft})) + (4 \times (0.078025\ \text{kip/ft}) \times (6.25\ \text{ft}))}$$

$$a = 4.4787\ \text{ft}$$

$V_{max}$ - Max shear force located at depth a,

$$V_{max} = (H_o\ b)\ \left[1 - \left[3\ \left(\frac{4\ E}{L_e} + 3\right)\ \left(\frac{a}{L_e}\right)^2\right] + \left[4\ \left(\frac{3\ E}{L_e} + 2\right)\ \left(\frac{a}{L_e}\right)^3\right]\right]$$

$$V_{max} = ((0.078025\ \text{kip/ft}) \times (48\ \text{in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (2.7878\ \text{ft})}{(6.25\ \text{ft})} + 3\right) \times \left(\frac{(4.4787\ \text{ft})}{(6.25\ \text{ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (2.7878\ \text{ft})}{(6.25\ \text{ft})} + 2\right) \times \left(\frac{(4.4787\ \text{ft})}{(6.25\ \text{ft})}\right)^3\right]\right]$$

$$V_{max} = 0.45464\ \text{kip}$$

$M_{max}$ - Max bending moment located at depth a/2,

$$M_{max} = (H_o\ b\ L_e)\ \left[\left(\frac{E}{L_e} + \frac{a}{2\ L_e}\right) - \left[\left(\frac{4\ E}{L_e} + 3\right)\ \left(\frac{a}{2\ L_e}\right)^3\right] + \left[\left(\frac{3\ E}{L_e} + 2\right)\ \left(\frac{a}{2\ L_e}\right)^4\right]\right]$$

$$M_{max} = ((0.078025\ \text{kip/ft}) \times (48\ \text{in}) \times (6.25\ \text{ft})) \times \left[\left(\frac{(2.7878\ \text{ft})}{(6.25\ \text{ft})} + \frac{(4.4787\ \text{ft})}{2 \times (6.25\ \text{ft})}\right) - \left[\left(\frac{4 \times (2.7878\ \text{ft})}{(6.25\ \text{ft})} + 3\right) \times \left(\frac{(4.4787\ \text{ft})}{2 \times (6.25\ \text{ft})}\right)^3\right] + \left[\left(\frac{3 \times (2.7878\ \text{ft})}{(6.25\ \text{ft})} + 2\right) \times \left(\frac{(4.4787\ \text{ft})}{2 \times (6.25\ \text{ft})}\right)^4\right]\right]$$

$$M_{max} = 1.247 \text{ kipft}$$

**Minimum Reinforcement Check (LRFD)**

**Parameters:**

$f'_{ck} = 2.5 \text{ ksi}$ - Concrete strength,
$f_{yk} = 60 \text{ ksi}$ - Longitudinal reinforcement strength,
$\phi = 0.65$ - Reduction factor for axial strength,
*Table 22.4.2.1* $\alpha = 0.8$ - Alpha factor for axial strength,
$A_g = 2304 \text{ in}^2$ - Gross area of concrete,

**Longitudinal reinforcement:**

Required reinforcement due to axial load, $A_{st,required}$
*22.4.2.2, 10.6.1.1* $A_{st,required}$

$$A_{st,required} = Min\left[\frac{\frac{P}{\phi\,\alpha} - \left(0.85\,f'_{ck}\,A_g\right)}{f_{yk} - \left(0.85\,f'_{ck}\right)}, \left(0.08\,A_g\right)\right]$$

$$A_{st,required} = Min\left[\frac{\frac{(6.758 \text{ kip})}{(0.65)\times(0.8)} - \left(0.85 \times (2.5 \text{ ksi}) \times \left(2304 \text{ in}^2\right)\right)}{(60 \text{ ksi}) - (0.85 \times (2.5 \text{ ksi}))}, \left(0.08 \times \left(2304 \text{ in}^2\right)\right)\right]$$

$$A_{st,required} = -84.372 \text{ in}^2$$

$A_{min}$ - Governing minimum reinforcement area,

$$A_{min} = Max\left[A_{st,required}, \left(0.0018\,A_g\right)\right]$$

$$A_{min} = Max\left[\left(-84.372 \text{ in}^2\right), \left(0.0018 \times \left(2304 \text{ in}^2\right)\right)\right]$$

$$A_{min} = 4.1472 \text{ in}^2$$

$n_{rebar}$ - Required number of reinforcement,

$$n_{rebar} = \frac{A_{min}}{A_{rebar}}$$

$$n_{rebar} = \frac{\left(4.1472 \text{ in}^2\right)}{\left(0.3068 \text{ in}^2\right)}$$

$$n_{rebar} = 14$$

$A_{st}$ - Actual total reinforcement area,

$$A_{st} = n_{rebar}\,\frac{\pi\,d_{bar}^2}{4}$$

$$A_{st} = (14) \times \frac{\pi \times (0.625 \text{ in})^2}{4}$$

$$A_{st} = 4.2951 \text{ in}^2$$

$Ratio$ - Capacity

$$Ratio = \frac{A_{min}}{A_{st}}$$

$$Ratio = \frac{\left(4.1472 \text{ in}^2\right)}{\left(4.2951 \text{ in}^2\right)}$$

$$Ratio = 0.96556$$

Status: **PASS**
Ratio: **0.970**

*25.2.3* $s_{rebar}$ - Minimum spacing of reinforcement,

$$s_{rebar} = Max\left[1.5, \left(1.5\,d_{bar}\right)\right]$$

$$s_{rebar} = Max\left[1.5, \left(1.5 \times (0.625 \text{ in})\right)\right]$$

$$s_{rebar} = 1.5 \text{ in}$$

**Ties:**

*25.7.2.2* Since longitudinal reinforcement is $\leq$ No. 10ø: Use #3(0.375 in)
*25.7.2.1* $s_{ties}$ - Maximum spacing of ties,

$$s_{ties} = Min\left[\left(16\,d_{bar}\right), \left(48\,d_{ties}\right), Min\left(D, b\right)\right]$$

$$s_{ties} = Min\left[\left(16 \times (0.625 \text{ in})\right), \left(48 \times (0.375 \text{ in})\right), Min\left((48 \text{ in}), (48 \text{ in})\right)\right]$$

$$s_{ties} = 10 \text{ in}$$

**Summary:**

Main reinforcement: **14 - #5 (0.625 in)**

Ties: **#3(0.375 in) - 10 in**

**Axial Compression Strength (ACI 318-19, LRFD)**

22.4.2.2 $\phi P_N$ - Allowable axial compressive strength

$$\phi P_N = \phi\, 0.80\, \left[\left(0.85\, f'_{ck}\, \left[A_g - A_{st}\right]\right) + \left(f_{yk}\, A_{st}\right)\right]$$

$$\phi P_N = (0.65) \times 0.80 \times \left[\left(0.85 \times (2.5\ \text{ksi}) \times \left[\left(2304\ \text{in}^2\right) - \left(4.2951\ \text{in}^2\right)\right]\right) + \left((60\ \text{ksi}) \times \left(4.2951\ \text{in}^2\right)\right)\right]$$

$$\phi P_N = 2675.2\ \text{kip}$$

$Ratio$ - Capacity

$$Ratio = \frac{P}{\phi P_N}$$

$$Ratio = \frac{(6.758\ \text{kip})}{(2675.2\ \text{kip})}$$

$$Ratio = 0.0025262$$

Status: **PASS**
Ratio: **0.000**

**Shear Strength (ACI 318-19, LRFD)**

**Parameters:**

$b_w = 48\ \text{in}$ - Effective width,
22.5.2.2 $d$ - Effective depth

$$d = 0.80\, D$$

$$d = 0.80 \times (48\ \text{in})$$

$$d = 38.4\ \text{in}$$

22.5.5.1.3 $\lambda_s$ - size effect modification factor

$$\lambda_s = MIN\left[\sqrt{\frac{2}{1 + \frac{d}{10}}}, 1\right]$$

$$\lambda_s = MIN\left[\sqrt{\frac{2}{1 + \frac{(38.4\ \text{in})}{10}}}, 1\right]$$

$$\lambda_s = 0.64282$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$,
22.5.5.1.1 $V_{c,max}$ - Max shear strength of concrete

$$V_{c,max} = 5\, \lambda_s\, \sqrt{f'_{ck}}\, b_w\, d$$

$$V_{c,max} = 5 \times (0.64282) \times \sqrt{(2500\ \text{psi})} \times (48\ \text{in}) \times (38.4\ \text{in})$$

$$V_{c,max} = 296.21\ \text{kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$, $P = 6.758\ \text{kip} \rightarrow 6758\ \text{lbf}$,
22.5.5.1.1(a) $V_{c,a}$ - Shear strength of concrete (a)

$$V_{c,a} = \left[2\, \lambda_s\, \sqrt{f'_{ck}} + \frac{P}{6\, A_g}\right]\, b_w\, d$$

$$V_{c,a} = \left[2 \times (0.64282) \times \sqrt{(2500\ \text{psi})} + \frac{(6758\ \text{lbf})}{6 \times (2304\ \text{in}^2)}\right] \times (48\ \text{in}) \times (38.4\ \text{in})$$

$$V_{c,a} = 119.39\ \text{kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$,
22.5.5.1.2 $V_{c,b}$ - Shear strength of concrete (b)

$$V_{c,b} = \left[2\, \lambda_s\, \sqrt{f'_{ck}} + \left(0.05\, f'_{ck}\right)\right]\, b_w\, d$$

$$V_{c,b} = \left[2 \times (0.64282) \times \sqrt{(2500\ \text{psi})} + (0.05 \times (2500\ \text{psi}))\right] \times (48\ \text{in}) \times (38.4\ \text{in})$$

$$V_{c,b} = 348.89\ \text{kip}$$

$V_c$ - Governing shear strength of concrete

$$V_c = Min\left[V_{c,max}, V_{c,a}, V_{c,b}\right]$$

$$V_c = Min\left[(296.21\ \text{kip}), (119.39\ \text{kip}), (348.89\ \text{kip})\right]$$

$$V_c = 119.39\ \text{kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$,

22.5.1.2 $V_{s,a}$ - Shear strength of steel (a)

$$V_{s,a} = 8\sqrt{f'_{ck}}\, b_w\, d$$

$$V_{s,a} = 8 \times \sqrt{(2500\ \text{psi})} \times (48\ \text{in}) \times (38.4\ \text{in})$$

$$V_{s,a} = 737.28\ \text{kip}$$

$A_v$ - Ties rebar area,

$$A_v = \frac{\pi\, d_{ties}^2}{4}$$

$$A_v = \frac{\pi \times (0.375\ \text{in})^2}{4}$$

$$A_v = 0.11045\ \text{in}^2$$

22.5.8.5.3 $V_{s,b}$ - Shear strength of steel (b)

$$V_{s,b} = \frac{2\, A_v\, f_{ywk}\, d}{s_{ties}}$$

$$V_{s,b} = \frac{2 \times \left(0.11045\ \text{in}^2\right) \times (60\ \text{ksi}) \times (38.4\ \text{in})}{(10\ \text{in})}$$

$$V_{s,b} = 50.894\ \text{kip}$$

$V_s$ - Governing shear strength of steel

$$V_s = MIN\left[V_{s,a}, V_{s,b}\right]$$

$$V_s = MIN\left[(737.28\ \text{kip}), (50.894\ \text{kip})\right]$$

$$V_s = 50.894\ \text{kip}$$

22.5.1.1 $\phi V_n$ - Allowable shear strength

$$\phi V_n = \phi\ (V_c + V_s)$$

$$\phi V_n = (0.65) \times ((119.39\ \text{kip}) + (50.894\ \text{kip}))$$

$$\phi V_n = 110.68\ \text{kip}$$

**Considering x-direction:**

$V_{max} = 9.2123\ \text{kip}$ - Maximum shear force in the x-direction,
$Ratio$ - Capacity

$$Ratio = \frac{V_{max}}{\phi V_n}$$

$$Ratio = \frac{(9.2123\ \text{kip})}{(110.68\ \text{kip})}$$

$$Ratio = 0.083232$$

Status: **PASS**
Ratio: **0.080**

**Considering z-direction:**

$V_{max} = 0.45464\ \text{kip}$ - Maximum shear force in the z-direction,
$Ratio$ - Capacity

$$Ratio = \frac{V_{max}}{\phi V_n}$$

$$Ratio = \frac{(0.45464\ \text{kip})}{(110.68\ \text{kip})}$$

$$Ratio = 0.0041076$$

Status: **PASS**
Ratio: **0.000**

**Flexural Strength (ACI 318-19, LRFD)**

$S_m$ - Section modulus

$$S_m = \frac{b\, D^2}{6}$$

$$S_m = \frac{(48\ \text{in}) \times (48\ \text{in})^2}{6}$$

$$S_m = 18432\ \text{in}^3$$

| | | |
|---|---|---|
| 14.5.2.1b | $\lambda = 1$ - Concrete modification factor (Normal concrete),<br>Allowable flexural strength:<br>$M_n$ shall be the lesser of:<br>$\phi M_{n,1}$<br>$$\phi M_{n,1} = \phi \times 5 \times \lambda \times \sqrt{(f'_c)} \times S_m$$<br>$$\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{(2.5ksi)} \times 18432.001in^3$$<br>$$\phi M_{n,1} = 249.600kipft$$<br>$\phi M_{n,2}$<br>$$\phi M_{n,2} = \phi\, 0.85\, f'_{ck}\, S_m$$<br>$$\phi M_{n,2} = (0.65) \times 0.85 \times (2.5 \text{ ksi}) \times \left(18432 \text{ in}^3\right)$$<br>$$\phi M_{n,2} = 2121.6 \text{ kipft}$$<br>Therefore,<br>$\phi M_n$ - Allowable flexural strength,<br>$$\phi M_n = MIN[\phi M_{n,1}, \phi M_{n,2}]$$<br>$$\phi M_n = MIN[(249.6 \text{ kipft}), (2121.6 \text{ kipft})]$$<br>$$\phi M_n = 249.6 \text{ kipft}$$<br>**Considering x-direction:**<br>$M_{max} = 27.39 \text{ kipft}$ - Maximum moment in the x-direction,<br>$Ratio$ - Capacity<br>$$Ratio = \frac{M_{max}}{\phi M_n}$$<br>$$Ratio = \frac{(27.39 \text{ kipft})}{(249.6 \text{ kipft})}$$<br>$$Ratio = 0.10974$$ | Status: **PASS**<br>Ratio: **0.110** |
| | **Considering z-direction:**<br>$M_{max} = 1.247 \text{ kipft}$ - Maximum moment in the z-direction,<br>$Ratio$ - Capacity<br>$$Ratio = \frac{M_{max}}{\phi M_n}$$<br>$$Ratio = \frac{(1.247 \text{ kipft})}{(249.6 \text{ kipft})}$$<br>$$Ratio = 0.0049961$$ | Status: **PASS**<br>Ratio: **0.000** |

| REFERENCES | CALCULATIONS | RESULTS |
|---|---|---|

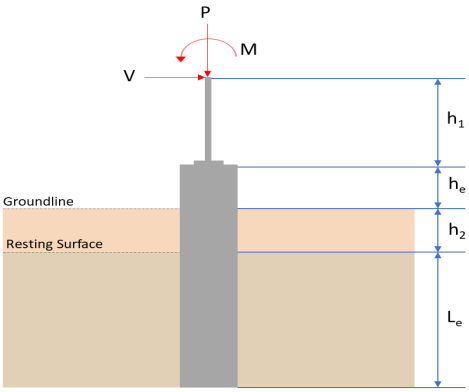
## SkyCiv Foundation Design

Pile Foundation

**Design Information :**

Design code : IBC 2021 (International Building Code)
Unit System : Imperial

### Pile Input




**Geometry**

Pile shape: rectangular
$b = 48\ \text{in}$ - Pile width
$D = 48\ \text{in}$ - Pile depth
$L = 6.25\ \text{ft}$ - Total pile length
$h_1 = 0\ \text{ft}$ - Lateral load height from the top of the pile,
$h_2 = 0\ \text{ft}$ - Depth to resisting surface
$h_e = 0\ \text{ft}$ - Length of pile above the ground

**Tabulation of Soil Parameters**

| Layer | Label | Allowable Bearing Pressure $(q_a)$ (psf) | Allowable Lateral Pressure $(R)$ (psf/ft) |
|---|---|---|---|
| 1 | Sand, silty sand, clayey sand, silty gravel & clayey gravel | 2000.000 | 150.000 |

**Tabulation of Loads**

| Load Component | ASD | LRFD |
|---|---|---|
| $P$ (kip) | 4.620 | 6.758 |
| $V_x$ (kip) | -2.304 | -3.867 |
| $V_z$ (kip) | -0.294 | -0.490 |
| $M_x$ (kipft) | -0.832 | -1.367 |
| $M_z$ (kipft) | 25.104 | 42.077 |

**Material Properties**

$f'_{ck} = 2.5\ \text{ksi}$ - Concrete strength,

### Required depth to resist lateral loads (ASD)

$H$ - Point of application of the lateral load

$$H = h_1 + h_2 + h_e$$

$$H = (0\ \text{ft}) + (0\ \text{ft}) + (0\ \text{ft})$$

$$H = 0\ \text{ft}$$

**Considering x-direction:**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_x}{1.57\ D}$$

$$H_o = \frac{(-2.304\ \text{kip})}{1.57 \times (48\ \text{in})}$$

$$H_o = -0.36688\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

$$M_o = \frac{M_z + (V_x\ H)}{1.57\ D}$$

$$M_o = \frac{(25.104\ \text{kipft}) + ((-2.304\ \text{kip}) \times (0\ \text{ft}))}{1.57 \times (48\ \text{in})}$$

$$M_o = 3.9975\ \text{kipft/ft}$$

Required depth of embedment in earth:

$$L_x^3 - \left(14.14 \times \frac{H_o \times L_x}{R}\right) - \left(18.85 \times \frac{M_o}{R}\right) = 0$$

Solving the cubic equation:
$L_{e,x} = 5.7756\ \text{ft}$ - Required depth in x-direction,

**Considering z-direction:**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_z}{1.57\,b}$$

$$H_o = \frac{(-0.294\ \text{kip})}{1.57 \times (48\ \text{in})}$$

$$H_o = -0.046815\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

$$M_o = \frac{M_x + (V_z\,H)}{1.57\,b}$$

$$M_o = \frac{(0.832\ \text{kipft}) + ((-0.294\ \text{kip}) \times (0\ \text{ft}))}{1.57 \times (48\ \text{in})}$$

$$M_o = 0.13248\ \text{kipft/ft}$$

Required depth of embedment in earth:

$$L_z^3 - \left(14.14 \times \frac{H_o \times L_z}{R}\right) - \left(18.85 \times \frac{M_o}{R}\right) = 0$$

Solving the cubic equation:
$L_{e,z} = 1.7766\ \text{ft}$ - Required depth in z-direction,

**Minimum embedded depth required:**

$L_{e,req}$ - Depth of pile required,

$$L_{e,req} = MAX[L_{e,x}, L_{e,z}]$$

$$L_{e,req} = MAX[(5.7756\ \text{ft}), (1.7766\ \text{ft})]$$

$$L_{e,req} = 5.776\ \text{ft}$$

$L_e$ - Actual embedded length of pile,

$$L_e = L - h_e - h_2$$

$$L_e = (6.25\ \text{ft}) - (0\ \text{ft}) - (0\ \text{ft})$$

$$L_e = 6.25\ \text{ft}$$

$Ratio$ - Embedded depth

$$Ratio = \frac{L_{e,req}}{L_e}$$

$$Ratio = \frac{(5.776\ \text{ft})}{(6.25\ \text{ft})}$$

$$Ratio = 0.92416$$

Status: **PASS**
Ratio: **0.920**

**End-bearing Capacity (ASD)**

$A$ - Pile cross-section area

$$A = b\,D$$

$$A = (48\ \text{in}) \times (48\ \text{in})$$

$$A = 16\ \text{ft}^2$$

$q$ - End-bearing pressure

$$q = \frac{P_v}{A}$$

$$q = \frac{(4.62\ \text{kip})}{(16\ \text{ft}^2)}$$

$$q = 0.28875\ \text{kip/ft}^2$$

$$q = 0.28875 \text{ kip/ft}$$

**Check bearing capacity ratio:**

$Ratio$ - Capacity

$$Ratio = \frac{q}{q_a}$$

$$Ratio = \frac{(0.28875 \text{ kip/ft}^2)}{(2000 \text{ psf})}$$

$$Ratio = 0.14438$$

Status: **PASS**
Ratio: **0.140**

*Czerniak*

**Lateral Soil Pressure (ASD):**

$L/D$ - Length to least lateral dimension ratio,

$$L/D = \frac{L}{D}$$

$$L/D = \frac{(6.25 \text{ ft})}{(48 \text{ in})}$$

$$L/D = 1.5625$$

Since L/D $\leq$ 10,

Pile is short.

**Considering x-direction:**

$H_o = -0.36688 \text{ kip/ft}$ - Lateral force per length of pile,
$M_o = 3.9975 \text{ kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

$$a = \frac{(4\, M_o\, L_e) + (3\, H_o\, L_e^2)}{(6\, M_o) + (4\, H_o\, L_e)}$$

$$a = \frac{(4 \times (3.9975 \text{ kipft/ft}) \times (6.25 \text{ ft})) + \left(3 \times (-0.36688 \text{ kip/ft}) \times (6.25 \text{ ft})^2\right)}{(6 \times (3.9975 \text{ kipft/ft})) + (4 \times (-0.36688 \text{ kip/ft}) \times (6.25 \text{ ft}))}$$

$$a = 4.3107 \text{ ft}$$

$p$ - Earth pressure against the pile at distance a/2 from resting surface,

$$p = \frac{0.75\, [(4\, M_o) + (3\, H_o\, L_e)]^2}{L_e^2\, [(3\, M_o) + (2\, H_o\, L_e)]}$$

$$p = \frac{0.75 \times [(4 \times (3.9975 \text{ kipft/ft})) + (3 \times (-0.36688 \text{ kip/ft}) \times (6.25 \text{ ft}))]^{\ 2}}{(6.25 \text{ ft})^2 \times [(3 \times (3.9975 \text{ kipft/ft})) + (2 \times (-0.36688 \text{ kip/ft}) \times (6.25 \text{ ft}))]}$$

$$p = 0.21518 \text{ kip/ft}^2$$

$s$ - Earth pressure against the pile at distance $L_e$,

$$s = \frac{6\, [(2\, M_o) + (H_o\, L_e)]}{L_e^2}$$

$$s = \frac{6 \times [(2 \times (3.9975 \text{ kipft/ft})) + ((-0.36688 \text{ kip/ft}) \times (6.25 \text{ ft}))]}{(6.25 \text{ ft})^2}$$

$$s = 0.87581 \text{ kip/ft}^2$$

**Check lateral soil pressure capacity:**

$p_a$ - Allowable lateral soil pressure at depth a/2,

$$p_a = R\, \frac{a}{2}$$

$$p_a = (150 \text{ psf/ft}) \times \frac{(4.3107 \text{ ft})}{2}$$

$$p_a = 0.32331 \text{ kip/ft}^2$$

$Ratio$ - Lateral soil capacity

$$Ratio = \frac{p}{p_a}$$

$$Ratio = \frac{(0.21518 \text{ kip/ft}^2)}{(0.32331 \text{ kip/ft}^2)}$$

$$Ratio = 0.66558$$

Status: **PASS**
Ratio: **0.670**

$p_s$ - Allowable lateral soil pressure at depth $L_e$,

$$p_s = R\,L_e$$

$$p_s = (150\ \text{psf/ft}) \times (6.25\ \text{ft})$$

$$p_s = 0.9375\ \text{kip/ft}^2$$

$Ratio$ - Lateral soil capacity

$$Ratio = \frac{s}{p_s}$$

$$Ratio = \frac{(0.87581\ \text{kip/ft}^2)}{(0.9375\ \text{kip/ft}^2)}$$

$$Ratio = 0.9342$$

Status: **PASS**
Ratio: **0.930**

**Considering z-direction:**

$H_o = -0.046815\ \text{kip/ft}$ - Lateral force per length of pile,
$M_o = 0.13248\ \text{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

$$a = \frac{(4\,M_o\,L_e) + (3\,H_o\,L_e^2)}{(6\,M_o) + (4\,H_o\,L_e)}$$

$$a = \frac{(4 \times (0.13248\ \text{kipft/ft}) \times (6.25\ \text{ft})) + \left(3 \times (-0.046815\ \text{kip/ft}) \times (6.25\ \text{ft})^2\right)}{(6 \times (0.13248\ \text{kipft/ft})) + (4 \times (-0.046815\ \text{kip/ft}) \times (6.25\ \text{ft}))}$$

$$a = 4.4768\ \text{ft}$$

$p$ - Earth pressure against the pile at distance a/2 from resting surface,

$$p = \frac{0.75\,[(4\,M_o) + (3\,H_o\,L_e)]^2}{L_e^2\,[(3\,M_o) + (2\,H_o\,L_e)]}$$

$$p = \frac{0.75 \times [(4 \times (0.13248\ \text{kipft/ft})) + (3 \times (-0.046815\ \text{kip/ft}) \times (6.25\ \text{ft}))]^{\ 2}}{(6.25\ \text{ft})^2 \times [(3 \times (0.13248\ \text{kipft/ft})) + (2 \times (-0.046815\ \text{kip/ft}) \times (6.25\ \text{ft}))]}$$

$$p = -0.012375\ \text{kip/ft}^2$$

$s$ - Earth pressure against the pile at distance $L_e$,

$$s = \frac{6\,[(2\,M_o) + (H_o\,L_e)]}{L_e^2}$$

$$s = \frac{6 \times [(2 \times (0.13248\ \text{kipft/ft})) + ((-0.046815\ \text{kip/ft}) \times (6.25\ \text{ft}))]}{(6.25\ \text{ft})^2}$$

$$s = -0.0042436\ \text{kip/ft}^2$$

**Check lateral soil pressure capacity:**

$p_a$ - Allowable lateral soil pressure at depth a/2,

$$p_a = R\,\frac{a}{2}$$

$$p_a = (150\ \text{psf/ft}) \times \frac{(4.4768\ \text{ft})}{2}$$

$$p_a = 0.33576\ \text{kip/ft}^2$$

$Ratio$ - Lateral soil capacity

$$Ratio = \frac{p}{p_a}$$

$$Ratio = \frac{(-0.012375\ \text{kip/ft}^2)}{(0.33576\ \text{kip/ft}^2)}$$

$$Ratio = -0.036855$$

Status: **PASS**
Ratio: **-0.040**

$p_s$ - Allowable lateral soil pressure at depth $L_e$,

$$p_s = R\,L_e$$

$$p_s = (150\ \text{psf/ft}) \times (6.25\ \text{ft})$$

$$p_s = 0.9375\ \text{kip/ft}^2$$

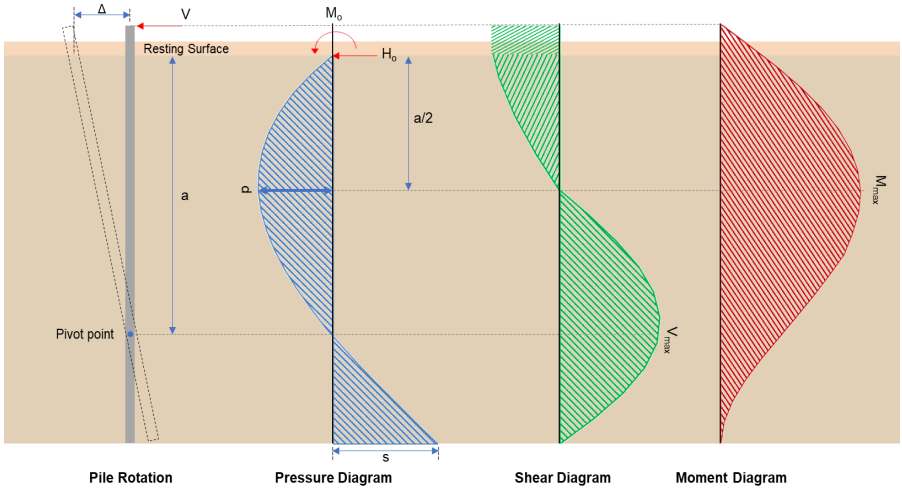
$Ratio$ - Lateral soil capacity

$$Ratio = \frac{s}{p_s}$$

$$Ratio = \frac{(-0.0042436\ \text{kip/ft}^2)}{(0.9375\ \text{kip/ft}^2)}$$

$$Ratio = -0.0045265$$

Status: **PASS**
Ratio: **0.000**




**Shear force and Bending moment (x-direction, LRFD)**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_x}{1.57\ D}$$

$$H_o = \frac{(-3.867\ \text{kip})}{1.57 \times (48\ \text{in})}$$

$$H_o = -0.61576\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

$$M_o = \frac{M_z + (V_x\ H)}{1.57\ D}$$

$$M_o = \frac{(42.077\ \text{kipft}) + ((-3.867\ \text{kip}) \times (0\ \text{ft}))}{1.57 \times (48\ \text{in})}$$

$$M_o = 6.7002\ \text{kipft/ft}$$

$E$ - Distance from lateral load to resisting surface,

$$E = \frac{M_o}{H_o}$$

$$E = \frac{(6.7002\ \text{kipft/ft})}{(-0.61576\ \text{kip/ft})}$$

$$E = 10.881\ \text{ft}$$

$a$ - Distance from resting surface to pivot point,

$$a = \frac{(4\ M_o\ L_e) + (3\ H_o\ L_e^2)}{(6\ M_o) + (4\ H_o\ L_e)}$$

$$a = \frac{(4 \times (6.7002\ \text{kipft/ft}) \times (6.25\ \text{ft})) + \left(3 \times (-0.61576\ \text{kip/ft}) \times (6.25\ \text{ft})^2\right)}{(6 \times (6.7002\ \text{kipft/ft})) + (4 \times (-0.61576\ \text{kip/ft}) \times (6.25\ \text{ft}))}$$

$$a = 4.3109\ \text{ft}$$

$V_{max}$ - Max shear force located at depth a,

$$V_{max} = (H_o\ D) \left[1 - \left[3 \left(\frac{4\ E}{L_e} + 3\right) \left(\frac{a}{L_e}\right)^2\right] + \left[4 \left(\frac{3\ E}{L_e} + 2\right) \left(\frac{a}{L_e}\right)^3\right]\right]$$

$$V_{max} = ((-0.61576\ \text{kip/ft}) \times (48\ \text{in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (10.881\ \text{ft})}{(6.25\ \text{ft})} + 3\right) \times \left(\frac{(4.3109\ \text{ft})}{(6.25\ \text{ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (10.881\ \text{ft})}{(6.25\ \text{ft})} + 2\right) \times \left(\frac{(4.3109\ \text{ft})}{(6.25\ \text{ft})}\right)^3\right]\right]$$

$$V_{max} = 9.2124\ \text{kip}$$

$M_{max}$ - Max bending moment located at depth a/2,

$$M_{max} = (H_o\, D\, L_e) \left[\left(\frac{E}{L_e} + \frac{a}{2\, L_e}\right) - \left[\left(\frac{4\, E}{L_e} + 3\right) \left(\frac{a}{2\, L_e}\right)^3\right] + \left[\left(\frac{3\, E}{L_e} + 2\right) \left(\frac{a}{2\, L_e}\right)^4\right]\right]$$

$$M_{max} = ((-0.61576\ \text{kip/ft}) \times (48\ \text{in}) \times (6.25\ \text{ft})) \times \left[\left(\frac{(10.881\ \text{ft})}{(6.25\ \text{ft})} + \frac{(4.3109\ \text{ft})}{2 \times (6.25\ \text{ft})}\right) - \left[\left(\frac{4 \times (10.881\ \text{ft})}{(6.25\ \text{ft})} + 3\right) \times \left(\frac{(4.3109\ \text{ft})}{2 \times (6.25\ \text{ft})}\right)^3\right] + \left[\left(\frac{3 \times (10.881\ \text{ft})}{(6.25\ \text{ft})} + 2\right) \times \left(\frac{(4.3109\ \text{ft})}{2 \times (6.25\ \text{ft})}\right)^4\right]\right]$$

$$M_{max} = 27.391\ \text{kipft}$$

**Shear force and Bending moment (z-direction, LRFD)**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_z}{1.57\, b}$$

$$H_o = \frac{(-0.49\ \text{kip})}{1.57 \times (48\ \text{in})}$$

$$H_o = -0.078025\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

$$M_o = \frac{M_x + (V_z\, H)}{1.57\, b}$$

$$M_o = \frac{(1.367\ \text{kipft}) + ((-0.49\ \text{kip}) \times (0\ \text{ft}))}{1.57 \times (48\ \text{in})}$$

$$M_o = 0.21768\ \text{kipft/ft}$$

$E$ - Distance from lateral load to resisting surface,

$$E = \frac{M_o}{H_o}$$

$$E = \frac{(0.21768\ \text{kipft/ft})}{(-0.078025\ \text{kip/ft})}$$

$$E = 2.7898\ \text{ft}$$

$a$ - Distance from resting surface to pivot point,

$$a = \frac{(4\, M_o\, L_e) + \left(3\, H_o\, L_e^2\right)}{(6\, M_o) + (4\, H_o\, L_e)}$$

$$a = \frac{(4 \times (0.21768\ \text{kipft/ft}) \times (6.25\ \text{ft})) + \left(3 \times (-0.078025\ \text{kip/ft}) \times (6.25\ \text{ft})^2\right)}{(6 \times (0.21768\ \text{kipft/ft})) + (4 \times (-0.078025\ \text{kip/ft}) \times (6.25\ \text{ft}))}$$

$$a = 4.4786\ \text{ft}$$

$V_{max}$ - Max shear force located at depth a,

$$V_{max} = (H_o\, b) \left[1 - \left[3 \left(\frac{4\, E}{L_e} + 3\right) \left(\frac{a}{L_e}\right)^2\right] + \left[4 \left(\frac{3\, E}{L_e} + 2\right) \left(\frac{a}{L_e}\right)^3\right]\right]$$

$$V_{max} = ((-0.078025\ \text{kip/ft}) \times (48\ \text{in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (2.7898\ \text{ft})}{(6.25\ \text{ft})} + 3\right) \times \left(\frac{(4.4786\ \text{ft})}{(6.25\ \text{ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (2.7898\ \text{ft})}{(6.25\ \text{ft})} + 2\right) \times \left(\frac{(4.4786\ \text{ft})}{(6.25\ \text{ft})}\right)^3\right]\right]$$

$$V_{max} = 0.45482\ \text{kip}$$

$M_{max}$ - Max bending moment located at depth a/2,

$$M_{max} = (H_o\, b\, L_e) \left[\left(\frac{E}{L_e} + \frac{a}{2\, L_e}\right) - \left[\left(\frac{4\, E}{L_e} + 3\right) \left(\frac{a}{2\, L_e}\right)^3\right] + \left[\left(\frac{3\, E}{L_e} + 2\right) \left(\frac{a}{2\, L_e}\right)^4\right]\right]$$

$$M_{max} = ((-0.078025\ \text{kip/ft}) \times (48\ \text{in}) \times (6.25\ \text{ft})) \times \left[\left(\frac{(2.7898\ \text{ft})}{(6.25\ \text{ft})} + \frac{(4.4786\ \text{ft})}{2 \times (6.25\ \text{ft})}\right) - \left[\left(\frac{4 \times (2.7898\ \text{ft})}{(6.25\ \text{ft})} + 3\right) \times \left(\frac{(4.4786\ \text{ft})}{2 \times (6.25\ \text{ft})}\right)^3\right] + \left[\left(\frac{3 \times (2.7898\ \text{ft})}{(6.25\ \text{ft})} + 2\right) \times \left(\frac{(4.4786\ \text{ft})}{2 \times (6.25\ \text{ft})}\right)^4\right]\right]$$

$$M_{max} = 1.2476 \text{ kipft}$$

**Minimum Reinforcement Check (LRFD)**

**Parameters:**

$f'_{ck} = 2.5 \text{ ksi}$ - Concrete strength,
$f_{yk} = 60 \text{ ksi}$ - Longitudinal reinforcement strength,
$\phi = 0.65$ - Reduction factor for axial strength,
*Table 22.4.2.1* $\alpha = 0.8$ - Alpha factor for axial strength,
$A_g = 2304 \text{ in}^2$ - Gross area of concrete,

**Longitudinal reinforcement:**

Required reinforcement due to axial load, $A_{st,required}$
*22.4.2.2, 10.6.1.1* $A_{st,required}$

$$A_{st,required} = Min\left[\frac{\frac{P}{\phi\,\alpha} - \left(0.85\,f'_{ck}\,A_g\right)}{f_{yk} - \left(0.85\,f'_{ck}\right)}, \left(0.08\,A_g\right)\right]$$

$$A_{st,required} = Min\left[\frac{\frac{(6.758 \text{ kip})}{(0.65)\times(0.8)} - \left(0.85 \times (2.5 \text{ ksi}) \times \left(2304 \text{ in}^2\right)\right)}{(60 \text{ ksi}) - (0.85 \times (2.5 \text{ ksi}))}, \left(0.08 \times \left(2304 \text{ in}^2\right)\right)\right]$$

$$A_{st,required} = -84.372 \text{ in}^2$$

$A_{min}$ - Governing minimum reinforcement area,

$$A_{min} = Max\left[A_{st,required}, \left(0.0018\,A_g\right)\right]$$

$$A_{min} = Max\left[\left(-84.372 \text{ in}^2\right), \left(0.0018 \times \left(2304 \text{ in}^2\right)\right)\right]$$

$$A_{min} = 4.1472 \text{ in}^2$$

$n_{rebar}$ - Required number of reinforcement,

$$n_{rebar} = \frac{A_{min}}{A_{rebar}}$$

$$n_{rebar} = \frac{\left(4.1472 \text{ in}^2\right)}{\left(0.3068 \text{ in}^2\right)}$$

$$n_{rebar} = 14$$

$A_{st}$ - Actual total reinforcement area,

$$A_{st} = n_{rebar}\,\frac{\pi\,d_{bar}^2}{4}$$

$$A_{st} = (14) \times \frac{\pi \times (0.625 \text{ in})^2}{4}$$

$$A_{st} = 4.2951 \text{ in}^2$$

$Ratio$ - Capacity

$$Ratio = \frac{A_{min}}{A_{st}}$$

$$Ratio = \frac{\left(4.1472 \text{ in}^2\right)}{\left(4.2951 \text{ in}^2\right)}$$

$$Ratio = 0.96556$$

Status: **PASS**
Ratio: **0.970**

*25.2.3* $s_{rebar}$ - Minimum spacing of reinforcement,

$$s_{rebar} = Max\left[1.5, \left(1.5\,d_{bar}\right)\right]$$

$$s_{rebar} = Max\left[1.5, \left(1.5 \times (0.625 \text{ in})\right)\right]$$

$$s_{rebar} = 1.5 \text{ in}$$

**Ties:**

*25.7.2.2* Since longitudinal reinforcement is $\leq$ No. 10ø: Use #3(0.375 in)
*25.7.2.1* $s_{ties}$ - Maximum spacing of ties,

$$s_{ties} = Min\left[\left(16\,d_{bar}\right), \left(48\,d_{ties}\right), Min\left(D, b\right)\right]$$

$$s_{ties} = Min\left[\left(16 \times (0.625 \text{ in})\right), \left(48 \times (0.375 \text{ in})\right), Min\left((48 \text{ in}), (48 \text{ in})\right)\right]$$

$$s_{ties} = 10 \text{ in}$$

**Summary:**

Main reinforcement: **14 - #5 (0.625 in)**

Ties: **#3(0.375 in) - 10 in**

**Axial Compression Strength (ACI 318-19, LRFD)**

22.4.2.2 $\phi P_N$ - Allowable axial compressive strength

$$\phi P_N = \phi\ 0.80\ \left[\left(0.85\ f'_{ck}\ \left[A_g - A_{st}\right]\right) + \left(f_{yk}\ A_{st}\right)\right]$$

$$\phi P_N = (0.65) \times 0.80 \times \left[\left(0.85 \times (2.5\ \text{ksi}) \times \left[\left(2304\ \text{in}^2\right) - \left(4.2951\ \text{in}^2\right)\right]\right) + \left((60\ \text{ksi}) \times \left(4.2951\ \text{in}^2\right)\right)\right]$$

$$\phi P_N = 2675.2\ \text{kip}$$

$Ratio$ - Capacity

$$Ratio = \frac{P}{\phi P_N}$$

$$Ratio = \frac{(6.758\ \text{kip})}{(2675.2\ \text{kip})}$$

$$Ratio = 0.0025262$$

Status: **PASS**
Ratio: **0.000**

**Shear Strength (ACI 318-19, LRFD)**

**Parameters:**

$b_w = 48\ \text{in}$ - Effective width,
22.5.2.2 $d$ - Effective depth

$$d = 0.80\ D$$

$$d = 0.80 \times (48\ \text{in})$$

$$d = 38.4\ \text{in}$$

22.5.5.1.3 $\lambda_s$ - size effect modification factor

$$\lambda_s = MIN\left[\sqrt{\frac{2}{1 + \frac{d}{10}}}, 1\right]$$

$$\lambda_s = MIN\left[\sqrt{\frac{2}{1 + \frac{(38.4\ \text{in})}{10}}}, 1\right]$$

$$\lambda_s = 0.64282$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$,
22.5.5.1.1 $V_{c,max}$ - Max shear strength of concrete

$$V_{c,max} = 5\ \lambda_s\ \sqrt{f'_{ck}}\ b_w\ d$$

$$V_{c,max} = 5 \times (0.64282) \times \sqrt{(2500\ \text{psi})} \times (48\ \text{in}) \times (38.4\ \text{in})$$

$$V_{c,max} = 296.21\ \text{kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$, $P = 6.758\ \text{kip} \rightarrow 6758\ \text{lbf}$,
22.5.5.1.1(a) $V_{c,a}$ - Shear strength of concrete (a)

$$V_{c,a} = \left[2\ \lambda_s\ \sqrt{f'_{ck}} + \frac{P}{6\ A_g}\right]\ b_w\ d$$

$$V_{c,a} = \left[2 \times (0.64282) \times \sqrt{(2500\ \text{psi})} + \frac{(6758\ \text{lbf})}{6 \times (2304\ \text{in}^2)}\right] \times (48\ \text{in}) \times (38.4\ \text{in})$$

$$V_{c,a} = 119.39\ \text{kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$,
22.5.5.1.2 $V_{c,b}$ - Shear strength of concrete (b)

$$V_{c,b} = \left[2\ \lambda_s\ \sqrt{f'_{ck}} + \left(0.05\ f'_{ck}\right)\right]\ b_w\ d$$

$$V_{c,b} = \left[2 \times (0.64282) \times \sqrt{(2500\ \text{psi})} + (0.05 \times (2500\ \text{psi}))\right] \times (48\ \text{in}) \times (38.4\ \text{in})$$

$$V_{c,b} = 348.89\ \text{kip}$$

$V_c$ - Governing shear strength of concrete

$$V_c = Min\left[V_{c,max}, V_{c,a}, V_{c,b}\right]$$

$$V_c = Min\left[(296.21\ \text{kip}), (119.39\ \text{kip}), (348.89\ \text{kip})\right]$$

$$V_c = 119.39\ \text{kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$,

22.5.1.2 $V_{s,a}$ - Shear strength of steel (a)

$$V_{s,a} = 8\sqrt{f'_{ck}}\, b_w\, d$$

$$V_{s,a} = 8 \times \sqrt{(2500\ \text{psi})} \times (48\ \text{in}) \times (38.4\ \text{in})$$

$$V_{s,a} = 737.28\ \text{kip}$$

$A_v$ - Ties rebar area,

$$A_v = \frac{\pi\, d_{ties}^2}{4}$$

$$A_v = \frac{\pi \times (0.375\ \text{in})^2}{4}$$

$$A_v = 0.11045\ \text{in}^2$$

22.5.8.5.3 $V_{s,b}$ - Shear strength of steel (b)

$$V_{s,b} = \frac{2\, A_v\, f_{ywk}\, d}{s_{ties}}$$

$$V_{s,b} = \frac{2 \times \left(0.11045\ \text{in}^2\right) \times (60\ \text{ksi}) \times (38.4\ \text{in})}{(10\ \text{in})}$$

$$V_{s,b} = 50.894\ \text{kip}$$

$V_s$ - Governing shear strength of steel

$$V_s = MIN\left[V_{s,a}, V_{s,b}\right]$$

$$V_s = MIN\left[(737.28\ \text{kip}), (50.894\ \text{kip})\right]$$

$$V_s = 50.894\ \text{kip}$$

22.5.1.1 $\phi V_n$ - Allowable shear strength

$$\phi V_n = \phi\ (V_c + V_s)$$

$$\phi V_n = (0.65) \times ((119.39\ \text{kip}) + (50.894\ \text{kip}))$$

$$\phi V_n = 110.68\ \text{kip}$$

**Considering x-direction:**

$V_{max} = 9.2124\ \text{kip}$ - Maximum shear force in the x-direction,
$Ratio$ - Capacity

$$Ratio = \frac{V_{max}}{\phi V_n}$$

$$Ratio = \frac{(9.2124\ \text{kip})}{(110.68\ \text{kip})}$$

$$Ratio = 0.083233$$

Status: **PASS**
Ratio: **0.080**

**Considering z-direction:**

$V_{max} = 0.45482\ \text{kip}$ - Maximum shear force in the z-direction,
$Ratio$ - Capacity

$$Ratio = \frac{V_{max}}{\phi V_n}$$

$$Ratio = \frac{(0.45482\ \text{kip})}{(110.68\ \text{kip})}$$

$$Ratio = 0.0041092$$

Status: **PASS**
Ratio: **0.000**

**Flexural Strength (ACI 318-19, LRFD)**

$S_m$ - Section modulus

$$S_m = \frac{b\, D^2}{6}$$

$$S_m = \frac{(48\ \text{in}) \times (48\ \text{in})^2}{6}$$

$$S_m = 18432\ \text{in}^3$$

| | | |
|---|---|---|
| | $\lambda = 1$ - Concrete modification factor (Normal concrete),<br>Allowable flexural strength:<br>$M_n$ shall be the lesser of:<br>$\phi M_{n,1}$<br>$$\phi M_{n,1} = \phi \times 5 \times \lambda \times \sqrt{(f'_c)} \times S_m$$<br>$$\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{(2.5ksi)} \times 18432.001in^3$$<br>$$\phi M_{n,1} = 249.600kipft$$ | |
| *14.5.2.1b* | $\phi M_{n,2}$<br>$$\phi M_{n,2} = \phi\, 0.85\, f'_{ck}\, S_m$$<br>$$\phi M_{n,2} = (0.65) \times 0.85 \times (2.5 \text{ ksi}) \times \left(18432 \text{ in}^3\right)$$<br>$$\phi M_{n,2} = 2121.6 \text{ kipft}$$<br>Therefore,<br>$\phi M_n$ - Allowable flexural strength,<br>$$\phi M_n = MIN[\phi M_{n,1}, \phi M_{n,2}]$$<br>$$\phi M_n = MIN[(249.6 \text{ kipft}), (2121.6 \text{ kipft})]$$<br>$$\phi M_n = 249.6 \text{ kipft}$$<br>**Considering x-direction:**<br>$M_{max} = 27.391 \text{ kipft}$ - Maximum moment in the x-direction,<br>$Ratio$ - Capacity<br>$$Ratio = \frac{M_{max}}{\phi M_n}$$<br>$$Ratio = \frac{(27.391 \text{ kipft})}{(249.6 \text{ kipft})}$$<br>$$Ratio = 0.10974$$ | Status: **PASS**<br>Ratio: **0.110** |
| | **Considering z-direction:**<br>$M_{max} = 1.2476 \text{ kipft}$ - Maximum moment in the z-direction,<br>$Ratio$ - Capacity<br>$$Ratio = \frac{M_{max}}{\phi M_n}$$<br>$$Ratio = \frac{(1.2476 \text{ kipft})}{(249.6 \text{ kipft})}$$<br>$$Ratio = 0.0049983$$ | Status: **PASS**<br>Ratio: **0.000** |

| REFERENCES | CALCULATIONS | RESULTS |
|---|---|---|

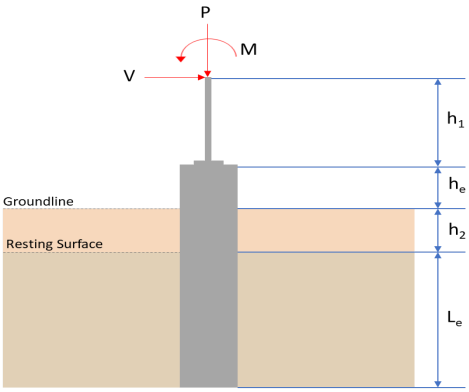
## SkyCiv Foundation Design

Pile Foundation

**Design Information :**

Design code : IBC 2021 (International Building Code)
Unit System : Imperial

### Pile Input




**Geometry**

Pile shape: rectangular
$b = 48\ \text{in}$ - Pile width
$D = 48\ \text{in}$ - Pile depth
$L = 6.75\ \text{ft}$ - Total pile length
$h_1 = 0\ \text{ft}$ - Lateral load height from the top of the pile,
$h_2 = 0\ \text{ft}$ - Depth to resisting surface
$h_e = 0\ \text{ft}$ - Length of pile above the ground

**Tabulation of Soil Parameters**

| Layer | Label | Allowable Bearing Pressure $(q_a)$ $(\text{psf})$ | Allowable Lateral Pressure $(R)$ $(\text{psf/ft})$ |
|---|---|---|---|
| 1 | Sand, silty sand, clayey sand, silty gravel & clayey gravel | 2000.000 | 150.000 |

**Tabulation of Loads**

| Load Component | ASD | LRFD |
|---|---|---|
| $P$ (kip) | 6.053 | 8.939 |
| $V_x$ (kip) | -3.105 | -5.172 |
| $V_z$ (kip) | 0.000 | 0.000 |
| $M_x$ (kipft) | 0.000 | 0.000 |
| $M_z$ (kipft) | 33.000 | 55.525 |

**Material Properties**

$f'_{ck} = 2.5\ \text{ksi}$ - Concrete strength,

### Required depth to resist lateral loads (ASD)

$H$ - Point of application of the lateral load

$$H = h_1 + h_2 + h_e$$

$$H = (0\ \text{ft}) + (0\ \text{ft}) + (0\ \text{ft})$$

$$H = 0\ \text{ft}$$

**Considering x-direction:**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_x}{1.57\ D}$$

$$H_o = \frac{(-3.105\ \text{kip})}{1.57 \times (48\ \text{in})}$$

$$H_o = -0.49443\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

$$M_o = \frac{M_z + (V_x\ H)}{1.57\ D}$$

$$M_o = \frac{(33\ \text{kipft}) + ((-3.105\ \text{kip}) \times (0\ \text{ft}))}{1.57 \times (48\ \text{in})}$$

$$M_o = 5.2548\ \text{kipft/ft}$$

Required depth of embedment in earth:

$$L_x^3 - \left(14.14 \times \frac{H_o \times L_x}{R}\right) - \left(18.85 \times \frac{M_o}{R}\right) = 0$$

Solving the cubic equation:
$L_{e,x} = 6.1871\ \text{ft}$ - Required depth in x-direction,

**Considering z-direction:**

$L_{e,z} = 0\ \text{ft}$ - Required depth in z-direction,

**Minimum embedded depth required:**

$L_{e,req}$ - Depth of pile required,

$$L_{e,req} = MAX[L_{e,x}, L_{e,z}]$$

$$L_{e,req} = MAX[(6.1871\ \text{ft}), (0\ \text{ft})]$$

$$L_{e,req} = 6.187\ \text{ft}$$

$L_e$ - Actual embedded length of pile,

$$L_e = L - h_e - h_2$$

$$L_e = (6.75\ \text{ft}) - (0\ \text{ft}) - (0\ \text{ft})$$

$$L_e = 6.75\ \text{ft}$$

$Ratio$ - Embedded depth

$$Ratio = \frac{L_{e,req}}{L_e}$$

$$Ratio = \frac{(6.187\ \text{ft})}{(6.75\ \text{ft})}$$

$$Ratio = 0.91659$$

Status: **PASS**
Ratio: **0.920**

**End-bearing Capacity (ASD)**

$A$ - Pile cross-section area

$$A = b\,D$$

$$A = (48\ \text{in}) \times (48\ \text{in})$$

$$A = 16\ \text{ft}^2$$

$q$ - End-bearing pressure

$$q = \frac{P_v}{A}$$

$$q = \frac{(6.053\ \text{kip})}{(16\ \text{ft}^2)}$$

$$q = 0.37831\ \text{kip/ft}^2$$

**Check bearing capacity ratio:**

$Ratio$ - Capacity

$$Ratio = \frac{q}{q_a}$$

$$Ratio = \frac{(0.37831\ \text{kip/ft}^2)}{(2000\ \text{psf})}$$

$$Ratio = 0.18916$$

Status: **PASS**
Ratio: **0.190**

*Czerniak*

**Lateral Soil Pressure (ASD):**

$L/D$ - Length to least lateral dimension ratio,

$$L/D = \frac{L}{D}$$

$$L/D = \frac{(6.75\ \text{ft})}{(48\ \text{in})}$$

$$L/D = 1.6875$$

Since L/D $\leq$ 10,

Pile is short.

**Considering x-direction:**

$H_o = -0.49443\ \text{kip/ft}$ - Lateral force per length of pile,
$M_o = 5.2548\ \text{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

$$a = \frac{(4\ M_o\ L_e) + \left(3\ H_o\ L_e^2\right)}{(6\ M_o) + (4\ H_o\ L_e)}$$

$$a = \frac{(4 \times (5.2548\ \text{kipft/ft}) \times (6.75\ \text{ft})) + \left(3 \times (-0.49443\ \text{kip/ft}) \times (6.75\ \text{ft})^2\right)}{(6 \times (5.2548\ \text{kipft/ft})) + (4 \times (-0.49443\ \text{kip/ft}) \times (6.75\ \text{ft}))}$$

$$a = 4.6673\ \text{ft}$$

$p$ - Earth pressure against the pile at distance a/2 from resting surface,

$$p = \frac{0.75\ [(4\ M_o) + (3\ H_o\ L_e)]^2}{L_e^2\ [(3\ M_o) + (2\ H_o\ L_e)]}$$

$$p = \frac{0.75 \times [(4 \times (5.2548\ \text{kipft/ft})) + (3 \times (-0.49443\ \text{kip/ft}) \times (6.75\ \text{ft}))]^{\ 2}}{(6.75\ \text{ft})^2 \times [(3 \times (5.2548\ \text{kipft/ft})) + (2 \times (-0.49443\ \text{kip/ft}) \times (6.75\ \text{ft}))]}$$

$$p = 0.2194\ \text{kip/ft}^2$$

$s$ - Earth pressure against the pile at distance $L_e$,

$$s = \frac{6\ [(2\ M_o) + (H_o\ L_e)]}{L_e^2}$$

$$s = \frac{6 \times [(2 \times (5.2548\ \text{kipft/ft})) + ((-0.49443\ \text{kip/ft}) \times (6.75\ \text{ft}))]}{(6.75\ \text{ft})^2}$$

$$s = 0.94448\ \text{kip/ft}^2$$

**Check lateral soil pressure capacity:**

$p_a$ - Allowable lateral soil pressure at depth a/2,

$$p_a = R\ \frac{a}{2}$$

$$p_a = (150\ \text{psf/ft}) \times \frac{(4.6673\ \text{ft})}{2}$$

$$p_a = 0.35005\ \text{kip/ft}^2$$

$Ratio$ - Lateral soil capacity

$$Ratio = \frac{p}{p_a}$$

$$Ratio = \frac{\left(0.2194\ \text{kip/ft}^2\right)}{\left(0.35005\ \text{kip/ft}^2\right)}$$

$$Ratio = 0.62678$$

Status: **PASS**
Ratio: **0.630**

$p_s$ - Allowable lateral soil pressure at depth $L_e$,

$$p_s = R\ L_e$$

$$p_s = (150\ \text{psf/ft}) \times (6.75\ \text{ft})$$

$$p_s = 1.0125\ \text{kip/ft}^2$$

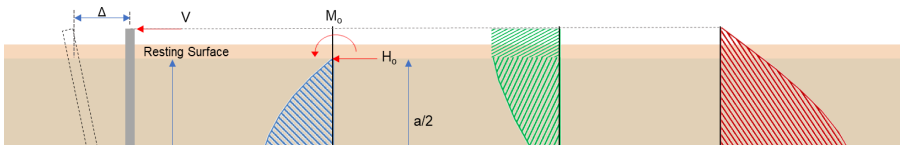
$Ratio$ - Lateral soil capacity

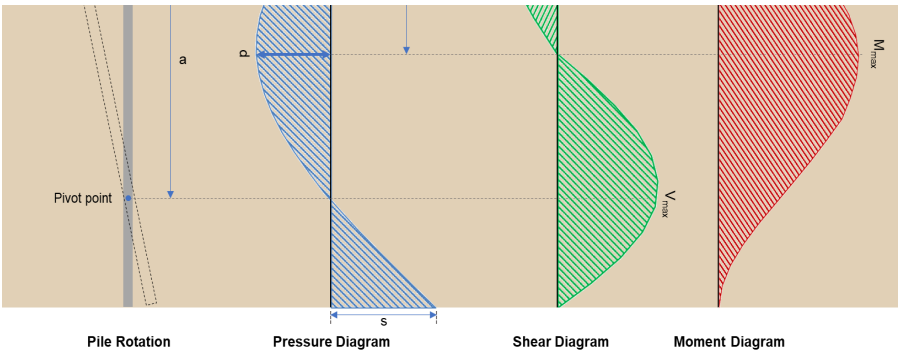
$$Ratio = \frac{s}{p_s}$$

$$Ratio = \frac{\left(0.94448\ \text{kip/ft}^2\right)}{\left(1.0125\ \text{kip/ft}^2\right)}$$

$$Ratio = 0.93282$$

Status: **PASS**
Ratio: **0.930**






**Shear force and Bending moment (x-direction, LRFD)**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_x}{1.57\,D}$$

$$H_o = \frac{(-5.172\text{ kip})}{1.57 \times (48\text{ in})}$$

$$H_o = -0.82357\text{ kip/ft}$$

$M_o$ - Moment per length of pile,

$$M_o = \frac{M_z + (V_x\,H)}{1.57\,D}$$

$$M_o = \frac{(55.525\text{ kipft}) + ((-5.172\text{ kip}) \times (0\text{ ft}))}{1.57 \times (48\text{ in})}$$

$$M_o = 8.8416\text{ kipft/ft}$$

$E$ - Distance from lateral load to resisting surface,

$$E = \frac{M_o}{H_o}$$

$$E = \frac{(8.8416\text{ kipft/ft})}{(-0.82357\text{ kip/ft})}$$

$$E = 10.736\text{ ft}$$

$a$ - Distance from resting surface to pivot point,

$$a = \frac{(4\,M_o\,L_e) + \left(3\,H_o\,L_e^2\right)}{(6\,M_o) + (4\,H_o\,L_e)}$$

$$a = \frac{(4 \times (8.8416\text{ kipft/ft}) \times (6.75\text{ ft})) + \left(3 \times (-0.82357\text{ kip/ft}) \times (6.75\text{ ft})^2\right)}{(6 \times (8.8416\text{ kipft/ft})) + (4 \times (-0.82357\text{ kip/ft}) \times (6.75\text{ ft}))}$$

$$a = 4.6661\text{ ft}$$

$V_{max}$ - Max shear force located at depth a,

$$V_{max} = (H_o\,D)\left[1 - \left[3\left(\frac{4\,E}{L_e} + 3\right)\left(\frac{a}{L_e}\right)^2\right] + \left[4\left(\frac{3\,E}{L_e} + 2\right)\left(\frac{a}{L_e}\right)^3\right]\right]$$

$$V_{max} = ((-0.82357\text{ kip/ft}) \times (48\text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (10.736\text{ ft})}{(6.75\text{ ft})} + 3\right) \times \left(\frac{(4.6661\text{ ft})}{(6.75\text{ ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (10.736\text{ ft})}{(6.75\text{ ft})} + 2\right) \times \left(\frac{(4.6661\text{ ft})}{(6.75\text{ ft})}\right)^3\right]\right]$$

$$V_{max} = 11.443\text{ kip}$$

$M_{max}$ - Max bending moment located at depth a/2,

$$M_{max} = (H_o\,D\,L_e)\left[\left(\frac{E}{L_e} + \frac{a}{2\,L_e}\right) - \left[\left(\frac{4\,E}{L_e} + 3\right)\left(\frac{a}{2\,L_e}\right)^3\right] + \left[\left(\frac{3\,E}{L_e} + 2\right)\left(\frac{a}{2\,L_e}\right)^4\right]\right]$$

$$M_{max} = ((-0.82357\text{ kip/ft}) \times (48\text{ in}) \times (6.75\text{ ft})) \times \left[\left(\frac{(10.736\text{ ft})}{(6.75\text{ ft})} + \frac{(4.6661\text{ ft})}{2 \times (6.75\text{ ft})}\right) - \left[\left(\frac{4 \times (10.736\text{ ft})}{(6.75\text{ ft})} + 3\right) \times \left(\frac{(4.6661\text{ ft})}{2 \times (6.75\text{ ft})}\right)^3\right] + \left[\left(\frac{3 \times (10.736\text{ ft})}{(6.75\text{ ft})} + 2\right) \times \left(\frac{(4.6661\text{ ft})}{2 \times (6.75\text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 36.605 \text{ kipft}$$

**Minimum Reinforcement Check (LRFD)**

**Parameters:**

$f'_{ck} = 2.5 \text{ ksi}$ - Concrete strength,
$f_{yk} = 60 \text{ ksi}$ - Longitudinal reinforcement strength,
$\phi = 0.65$ - Reduction factor for axial strength,
*Table 22.4.2.1* $\alpha = 0.8$ - Alpha factor for axial strength,
$A_g = 2304 \text{ in}^2$ - Gross area of concrete,

**Longitudinal reinforcement:**

Required reinforcement due to axial load, $A_{st,required}$
*22.4.2.2, 10.6.1.1* $A_{st,required}$

$$A_{st,required} = Min\left[\frac{\frac{P}{\phi\,\alpha} - \left(0.85\,f'_{ck}\,A_g\right)}{f_{yk} - \left(0.85\,f'_{ck}\right)}, \left(0.08\,A_g\right)\right]$$

$$A_{st,required} = Min\left[\frac{\frac{(8.939 \text{ kip})}{(0.65)\times(0.8)} - \left(0.85 \times (2.5 \text{ ksi}) \times \left(2304 \text{ in}^2\right)\right)}{(60 \text{ ksi}) - (0.85 \times (2.5 \text{ ksi}))}, \left(0.08 \times \left(2304 \text{ in}^2\right)\right)\right]$$

$$A_{st,required} = -84.299 \text{ in}^2$$

$A_{min}$ - Governing minimum reinforcement area,

$$A_{min} = Max\left[A_{st,required}, \left(0.0018\,A_g\right)\right]$$

$$A_{min} = Max\left[\left(-84.299 \text{ in}^2\right), \left(0.0018 \times \left(2304 \text{ in}^2\right)\right)\right]$$

$$A_{min} = 4.1472 \text{ in}^2$$

$n_{rebar}$ - Required number of reinforcement,

$$n_{rebar} = \frac{A_{min}}{A_{rebar}}$$

$$n_{rebar} = \frac{\left(4.1472 \text{ in}^2\right)}{\left(0.3068 \text{ in}^2\right)}$$

$$n_{rebar} = 14$$

$A_{st}$ - Actual total reinforcement area,

$$A_{st} = n_{rebar}\,\frac{\pi\,d_{bar}^2}{4}$$

$$A_{st} = (14) \times \frac{\pi \times (0.625 \text{ in})^2}{4}$$

$$A_{st} = 4.2951 \text{ in}^2$$

$Ratio$ - Capacity

$$Ratio = \frac{A_{min}}{A_{st}}$$

$$Ratio = \frac{\left(4.1472 \text{ in}^2\right)}{\left(4.2951 \text{ in}^2\right)}$$

$$Ratio = 0.96556$$

Status: **PASS**
Ratio: **0.970**

*25.2.3* $s_{rebar}$ - Minimum spacing of reinforcement,

$$s_{rebar} = Max\left[1.5, \left(1.5\,d_{bar}\right)\right]$$

$$s_{rebar} = Max\left[1.5, (1.5 \times (0.625 \text{ in}))\right]$$

$$s_{rebar} = 1.5 \text{ in}$$

**Ties:**

*25.7.2.2* Since longitudinal reinforcement is $\leq$ No. 10ø: Use #3(0.375 in)
*25.7.2.1* $s_{ties}$ - Maximum spacing of ties,

$$s_{ties} = Min\left[\left(16\,d_{bar}\right), \left(48\,d_{ties}\right), Min\left(D, b\right)\right]$$

$$s_{ties} = Min\left[(16 \times (0.625 \text{ in})), (48 \times (0.375 \text{ in})), Min\left((48 \text{ in}), (48 \text{ in})\right)\right]$$

$$s_{ties} = 10 \text{ in}$$

**Summary:**

Main reinforcement: **14 - #5 (0.625 in)**

Ties: **#3(0.375 in) - 10 in**

**Axial Compression Strength (ACI 318-19, LRFD)**

22.4.2.2 $\phi P_N$ - Allowable axial compressive strength

$$\phi P_N = \phi\, 0.80\, \left[\left(0.85\, f'_{ck}\, \left[A_g - A_{st}\right]\right) + \left(f_{yk}\, A_{st}\right)\right]$$

$$\phi P_N = (0.65) \times 0.80 \times \left[\left(0.85 \times (2.5\ \text{ksi}) \times \left[\left(2304\ \text{in}^2\right) - \left(4.2951\ \text{in}^2\right)\right]\right) + \left((60\ \text{ksi}) \times \left(4.2951\ \text{in}^2\right)\right)\right]$$

$$\phi P_N = 2675.2\ \text{kip}$$

$Ratio$ - Capacity

$$Ratio = \frac{P}{\phi P_N}$$

$$Ratio = \frac{(8.939\ \text{kip})}{(2675.2\ \text{kip})}$$

$$Ratio = 0.0033415$$

Status: **PASS**
Ratio: **0.000**

**Shear Strength (ACI 318-19, LRFD)**

**Parameters:**

$b_w = 48\ \text{in}$ - Effective width,
22.5.2.2 $d$ - Effective depth

$$d = 0.80\, D$$

$$d = 0.80 \times (48\ \text{in})$$

$$d = 38.4\ \text{in}$$

22.5.5.1.3 $\lambda_s$ - size effect modification factor

$$\lambda_s = MIN\left[\sqrt{\frac{2}{1 + \frac{d}{10}}}, 1\right]$$

$$\lambda_s = MIN\left[\sqrt{\frac{2}{1 + \frac{(38.4\ \text{in})}{10}}}, 1\right]$$

$$\lambda_s = 0.64282$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$,
22.5.5.1.1 $V_{c,max}$ - Max shear strength of concrete

$$V_{c,max} = 5\, \lambda_s\, \sqrt{f'_{ck}}\, b_w\, d$$

$$V_{c,max} = 5 \times (0.64282) \times \sqrt{(2500\ \text{psi})} \times (48\ \text{in}) \times (38.4\ \text{in})$$

$$V_{c,max} = 296.21\ \text{kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$, $P = 8.939\ \text{kip} \rightarrow 8939\ \text{lbf}$,
22.5.5.1.1(a) $V_{c,a}$ - Shear strength of concrete (a)

$$V_{c,a} = \left[2\, \lambda_s\, \sqrt{f'_{ck}} + \frac{P}{6\, A_g}\right]\, b_w\, d$$

$$V_{c,a} = \left[2 \times (0.64282) \times \sqrt{(2500\ \text{psi})} + \frac{(8939\ \text{lbf})}{6 \times (2304\ \text{in}^2)}\right] \times (48\ \text{in}) \times (38.4\ \text{in})$$

$$V_{c,a} = 119.68\ \text{kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$,
22.5.5.1.2 $V_{c,b}$ - Shear strength of concrete (b)

$$V_{c,b} = \left[2\, \lambda_s\, \sqrt{f'_{ck}} + \left(0.05\, f'_{ck}\right)\right]\, b_w\, d$$

$$V_{c,b} = \left[2 \times (0.64282) \times \sqrt{(2500\ \text{psi})} + (0.05 \times (2500\ \text{psi}))\right] \times (48\ \text{in}) \times (38.4\ \text{in})$$

$$V_{c,b} = 348.89\ \text{kip}$$

$V_c$ - Governing shear strength of concrete

$$V_c = Min\left[V_{c,max}, V_{c,a}, V_{c,b}\right]$$

$$V_c = Min\left[(296.21\ \text{kip}), (119.68\ \text{kip}), (348.89\ \text{kip})\right]$$

$$V_c = 119.68\ \text{kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$,

22.5.1.2 $V_{s,a}$ - Shear strength of steel (a)

$$V_{s,a} = 8\sqrt{f'_{ck}}\, b_w\, d$$

$$V_{s,a} = 8 \times \sqrt{(2500\ \text{psi})} \times (48\ \text{in}) \times (38.4\ \text{in})$$

$$V_{s,a} = 737.28\ \text{kip}$$

$A_v$ - Ties rebar area,

$$A_v = \frac{\pi\, d_{ties}^2}{4}$$

$$A_v = \frac{\pi \times (0.375\ \text{in})^2}{4}$$

$$A_v = 0.11045\ \text{in}^2$$

22.5.8.5.3 $V_{s,b}$ - Shear strength of steel (b)

$$V_{s,b} = \frac{2\, A_v\, f_{ywk}\, d}{s_{ties}}$$

$$V_{s,b} = \frac{2 \times \left(0.11045\ \text{in}^2\right) \times (60\ \text{ksi}) \times (38.4\ \text{in})}{(10\ \text{in})}$$

$$V_{s,b} = 50.894\ \text{kip}$$

$V_s$ - Governing shear strength of steel

$$V_s = MIN\left[V_{s,a}, V_{s,b}\right]$$

$$V_s = MIN\left[(737.28\ \text{kip}), (50.894\ \text{kip})\right]$$

$$V_s = 50.894\ \text{kip}$$

22.5.1.1 $\phi V_n$ - Allowable shear strength

$$\phi V_n = \phi\ (V_c + V_s)$$

$$\phi V_n = (0.65) \times ((119.68\ \text{kip}) + (50.894\ \text{kip}))$$

$$\phi V_n = 110.87\ \text{kip}$$

**Considering x-direction:**

$V_{max} = 11.443\ \text{kip}$ - Maximum shear force in the x-direction,
$Ratio$ - Capacity

$$Ratio = \frac{V_{max}}{\phi V_n}$$

$$Ratio = \frac{(11.443\ \text{kip})}{(110.87\ \text{kip})}$$

$$Ratio = 0.10321$$

Status: **PASS**
Ratio: **0.100**

**Flexural Strength (ACI 318-19, LRFD)**

$S_m$ - Section modulus

$$S_m = \frac{b\, D^2}{6}$$

$$S_m = \frac{(48\ \text{in}) \times (48\ \text{in})^2}{6}$$

$$S_m = 18432\ \text{in}^3$$

$\lambda = 1$ - Concrete modification factor (Normal concrete),
Allowable flexural strength:
$M_n$ shall be the lesser of:
$\phi M_{n,1}$

$$\phi M_{n,1} = \phi \times 5 \times \lambda \times \sqrt{(f'_c)} \times S_m$$

$$\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{(2.5ksi)} \times 18432.001in^3$$

$$\phi M_{n,1} = 249.600kipft$$

14.5.2.1b $\phi M_{n,2}$

$$\phi M_{n,2} = \phi\, 0.85\, f'_c\, S_m$$

$$\phi M_{n,2} = \phi\, 0.85\, f_{ck}\, Sm$$

$$\phi M_{n,2} = (0.65) \times 0.85 \times (2.5 \text{ ksi}) \times \left(18432 \text{ in}^3\right)$$

$$\phi M_{n,2} = 2121.6 \text{ kipft}$$

Therefore,
$\phi M_n$ - Allowable flexural strength,

$$\phi M_n = MIN[\phi M_{n,1}, \phi M_{n,2}]$$

$$\phi M_n = MIN[(249.6 \text{ kipft}), (2121.6 \text{ kipft})]$$

$$\phi M_n = 249.6 \text{ kipft}$$

**Considering x-direction:**

$M_{max} = 36.605 \text{ kipft}$ - Maximum moment in the x-direction,
$Ratio$ - Capacity

$$Ratio = \frac{M_{max}}{\phi M_n}$$

$$Ratio = \frac{(36.605 \text{ kipft})}{(249.6 \text{ kipft})}$$

$$Ratio = 0.14665$$

Status: **PASS**
Ratio: **0.150**