# Your Project Calculations

Project Name: MTSOLAR_JBA2EC44H48L

S3D Model Link:
https://platform.skyciv.com/structural?preload_name=MTSOLAR_JBA2EC44H48L&preload_path=Shared%20Enterprise%20Folder/MT_Solar_Projects/7_2023

Public Model Link:
https://platform.skyciv.com/structural-viewer?project_id=PHbXIL1z54dlKe76PEH7lcUACS12DMH4OPJAnYw6lyZTtGkkZ1H6YtejuOUm1fWm

## Array Specification

| | |
|---|---|
| **Product:** | Beam |
| **Unique ID:** | 5P-19.75-8TOP-XD-57-L-5Hx14W-GLKK |
| **Duty Classification:** | XD |
| **Module Width:** | 40.87 in |
| **Module Length:** | 82.45in |
| **Number of Rows:** | 5 |
| **Number of Columns:** | 14 |
| **Total Number of Modules:** | 70 |
| **Desired Tilt Angle:** | 20 |
| **Front Edge Clearance:** | 8 |
| **Total Array Height at Tilt:** | 13.86 ft |
| **Total Frame Length:** | 96.00 ft |
| **Frame Weight:** | 5231 lbs |
| **Array Dimensions N/S:** | 17.24 ft |
| **Array Dimensions E/W:** | 97.36 ft |
| **Rail Length:** | 206.85 in |
| **Rail Spacing:** | 3.44 ft |
| **Rail Check:** | Not Checked |

## Support Specifications

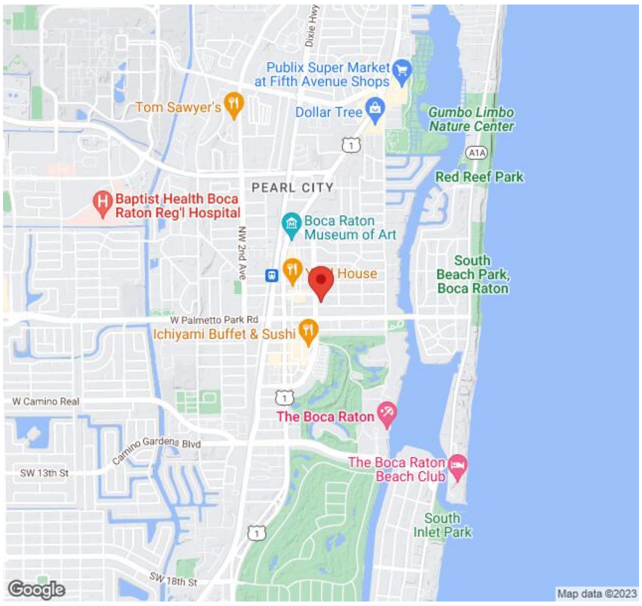
| | |
|---|---|
| **Pole Size:** | 8in Pipe Sch 40 |
| **Pole Length above Grade:** | 10.95 ft |
| **Number of Poles:** | 5 |
| **Pole Spacing:** | 19.75 ft |

## Foundation Specifications

| | |
|---|---|
| **Foundation Type:** | Round |
| **Foundation Dimensions:** | Ø36 in |
| **Foundation Depth (below grade):** | Pile 1: 15.00 ft<br>Pile 2: 15.00 ft<br>Pile 3: 15.00 ft<br>Pile 4: 15.00 ft<br>Pile 5: 15.00 ft |
| **Foundation Volume:** | 19.635 $y^3$ |
| **Foundation Result:** | FAILED Try increasing foundation size and/or type and re-running foundation design check on right panel. |
| **Mount Twist:** | 0.039067 kip |

## Site Info

| | |
|---|---|
| **Risk Category:** | I |
| **Exposure:** | B |
| **Soil Classification:** | sand |
| **Site Location:** | 100 NE Mizner Blvd, Boca Raton, FL 33432, USA |
| **Wind Speed:** | 156 mph |
| **Snow Load:** | 0 psf |
| **Design Uplift Pressure:** | Multiple pressures |
| **Design Downforce Pressure:** | Multiple pressures |
| **Design Snow Pressure:** | 0.000000 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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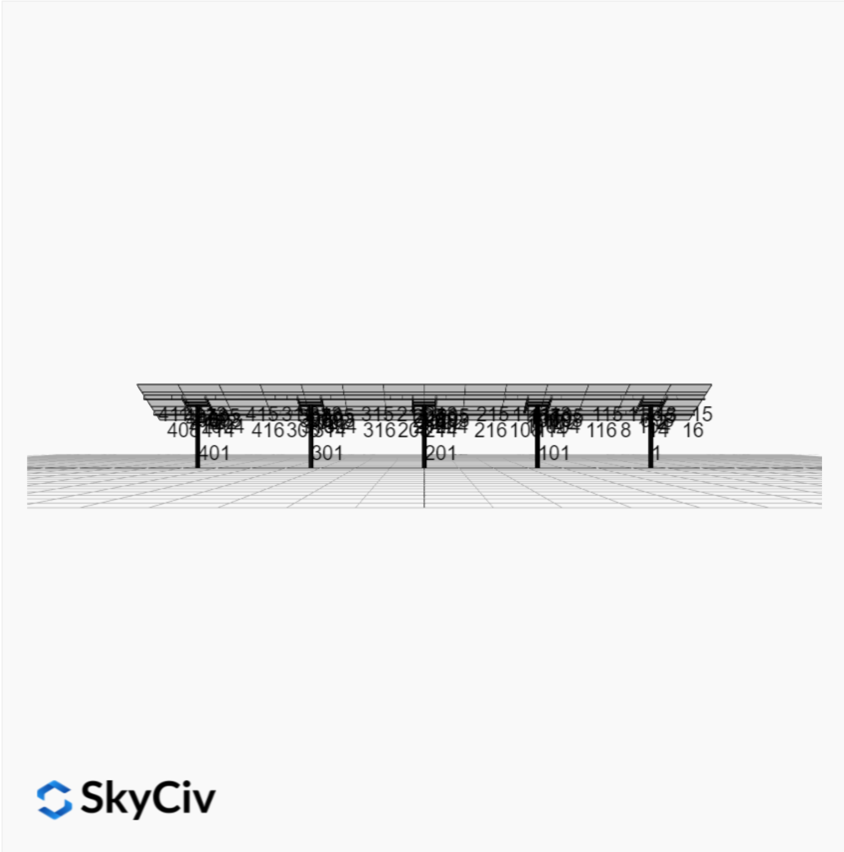
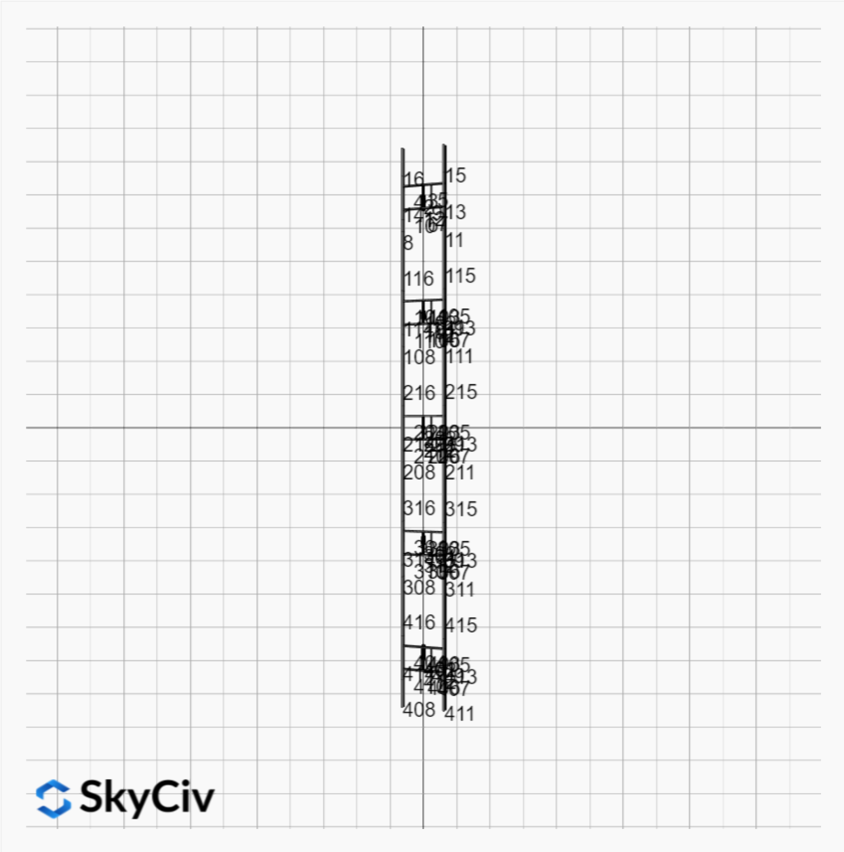
**Design Notes:**

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


401
301
201
101
15
16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15
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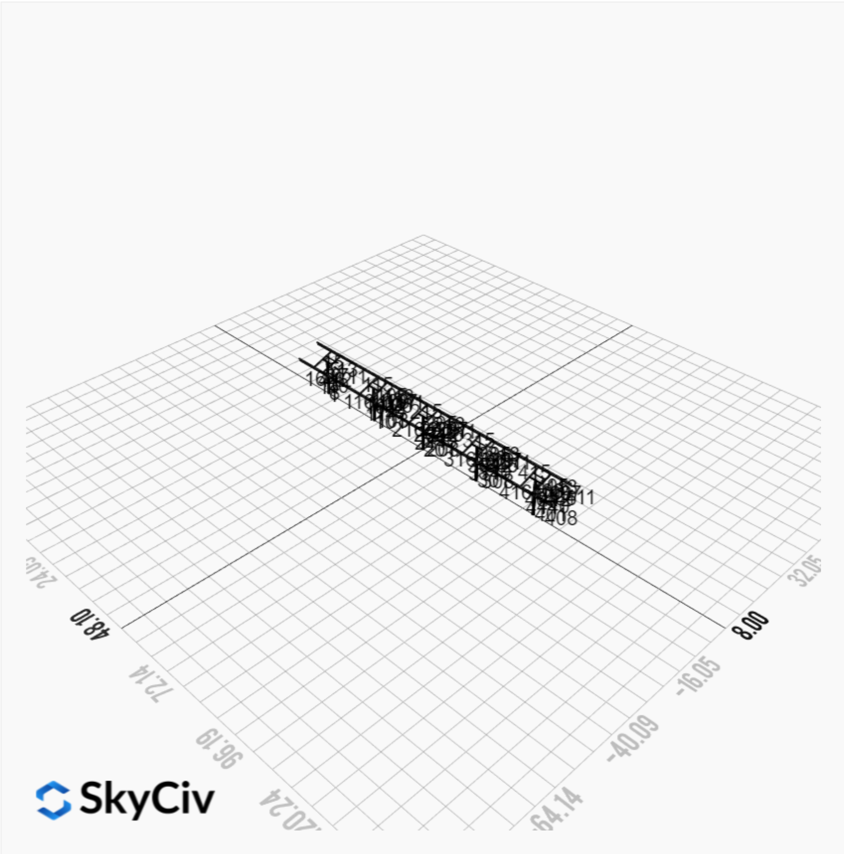
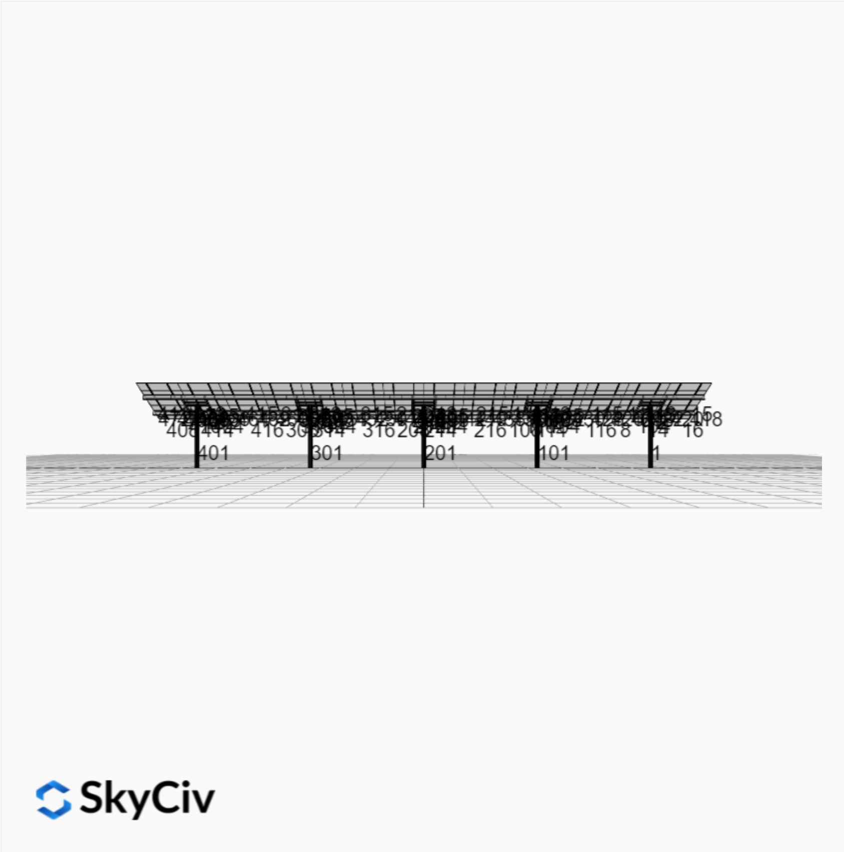
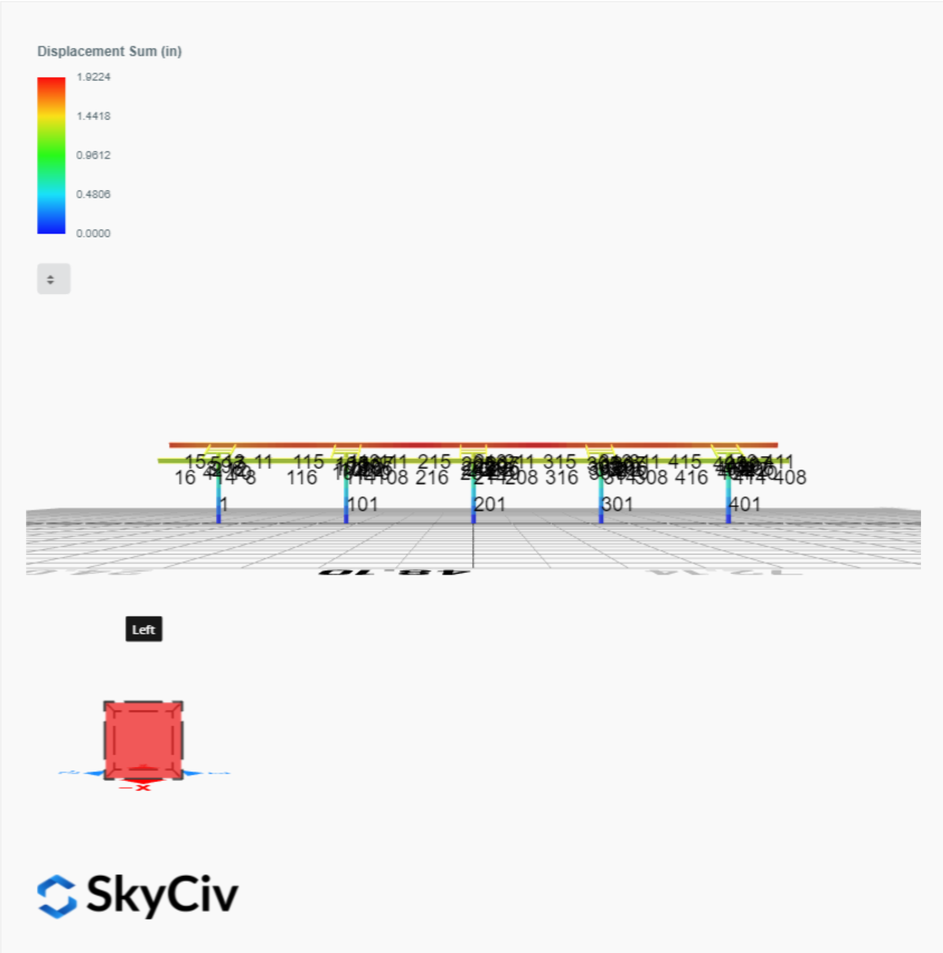
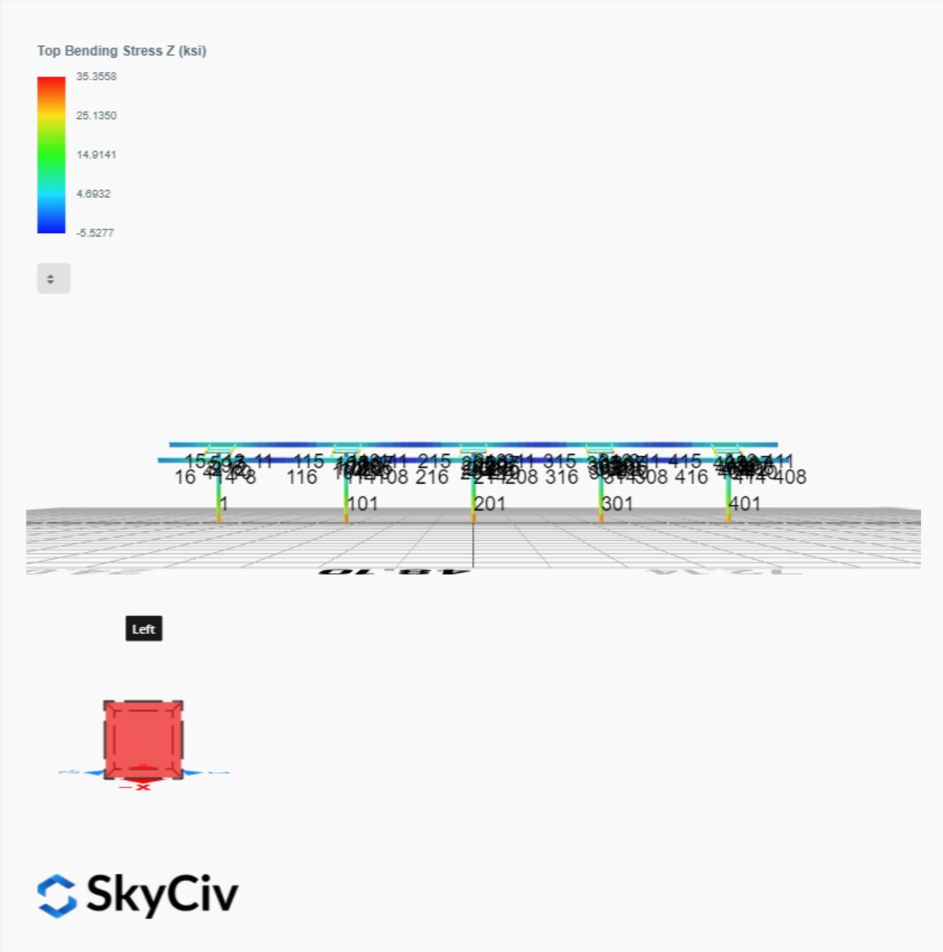
411
SkyCiv

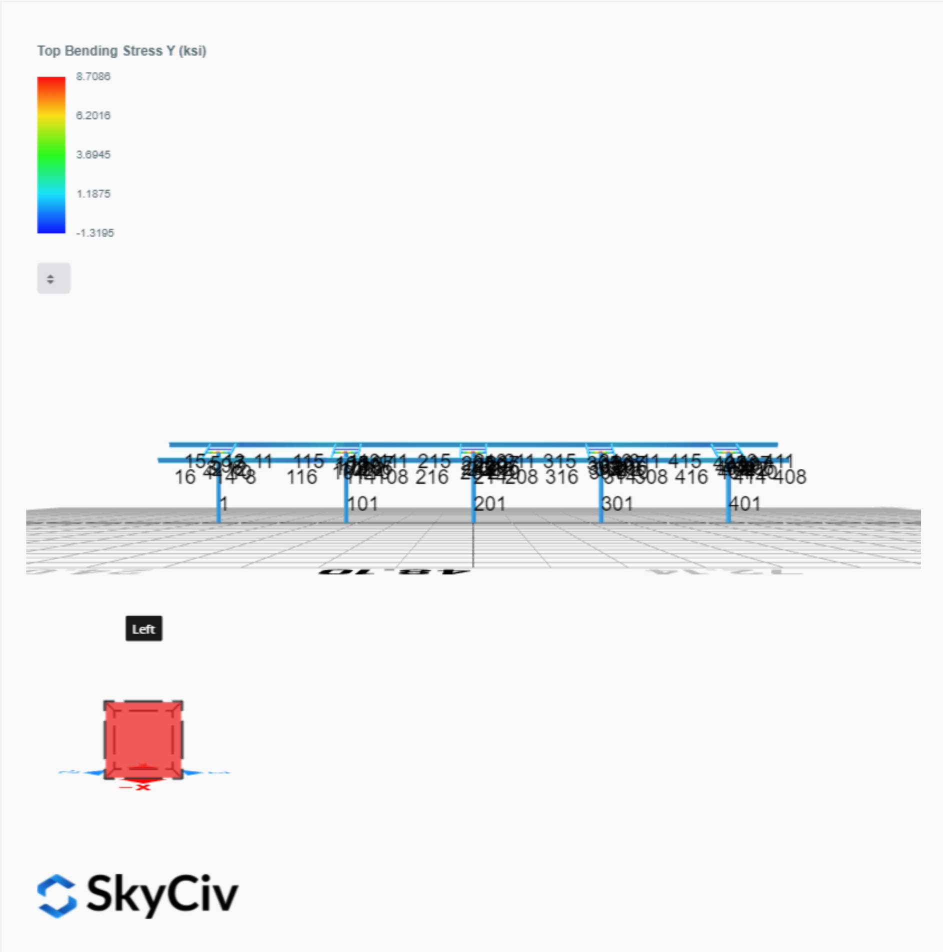

48.10
72.14
96.19
8.00
-16.05
-40.09
SkyCiv

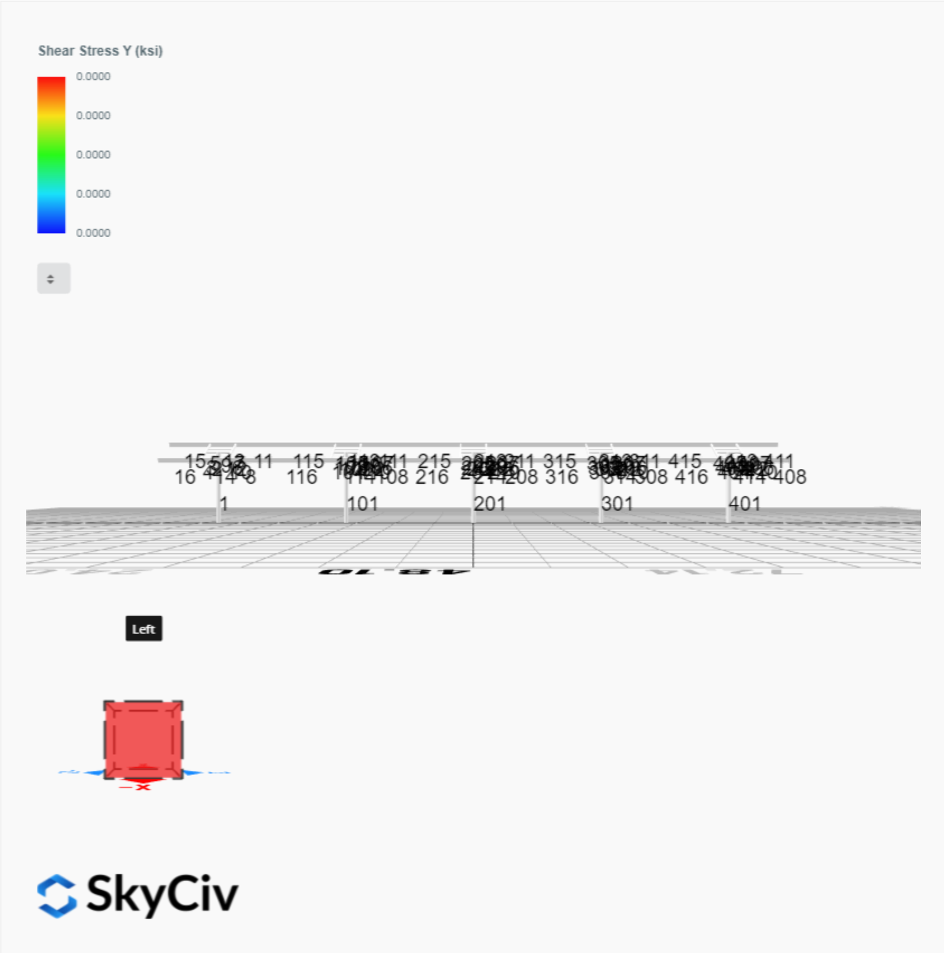

401
301
201
101
SkyCiv

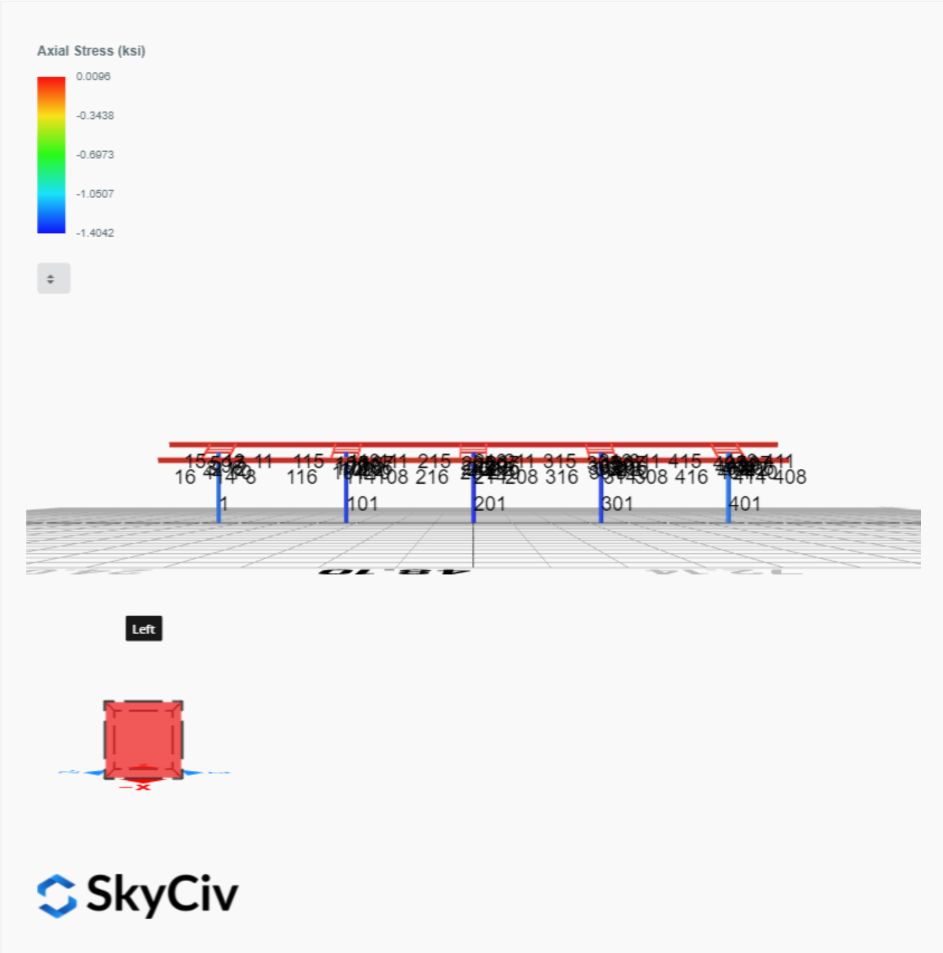
## FEM Results (Envelope Worst Case for each member)




Top Bending Stress Z (ksi)
35.3558
25.1350
14.9141
4.6932
-5.5277
Left


Top Bending Stress Y (ksi)
8.7086
6.2016
3.6945
1.1875
-1.3195
1
101
201
301
401
Left


Shear Stress Y (ksi)
0.0000
0.0000
0.0000
0.0000
0.0000
Left
1
101
201
301
401
SkyCiv


Axial Stress (ksi)
0.0096
-0.3438
-0.6973
-1.0507
-1.4042
1
101
201
301
401
Left

## 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 | -0.0036 | 2.4829 | -0.0043 | -0.0121 | 0.0197 | 0.0676 |
| ULS: 2. D + L | -0.0036 | 2.4829 | -0.0043 | -0.0121 | 0.0197 | 0.0676 |
| ULS: 3. D + (S or Lr or R) | -0.0036 | 2.4829 | -0.0043 | -0.0121 | 0.0197 | 0.0676 |
| ULS: 3. D + (S or Lr or R) | -0.0036 | 2.4829 | -0.0043 | -0.0121 | 0.0197 | 0.0676 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | -0.0036 | 2.4829 | -0.0043 | -0.0121 | 0.0197 | 0.0676 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | -0.0036 | 2.4829 | -0.0043 | -0.0121 | 0.0197 | 0.0676 |
| ULS: 5b. D + 0.7E | -0.0036 | 2.4829 | -0.0043 | -0.0121 | 0.0197 | 0.0676 |
| ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S | -0.0036 | 2.4829 | -0.0043 | -0.0121 | 0.0197 | 0.0676 |
| ULS: 8. 0.6D + 0.7E | -0.0022 | 1.4897 | -0.0026 | -0.0073 | 0.0118 | 0.0406 |
| ULS: 5a. D + 0.6W_Wind downforce Case A only | -2.8484 | 10.2686 | -0.0156 | -0.0486 | 0.0261 | 34.0849 |
| ULS: 5a. D + 0.6W_Wind downforce Case B only | -2.8484 | 10.2686 | -0.0156 | -0.0486 | 0.0261 | 34.0849 |
| ULS: 5a. D + 0.6W_Wind uplift Case A only | 2.4071 | -4.1216 | 0.0078 | 0.0264 | 0.0087 | -23.7848 |
| ULS: 5a. D + 0.6W_Wind uplift Case B only | 2.1015 | -3.2615 | -0.0021 | -0.0040 | 0.0286 | -40.9082 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -2.1372 | 8.3221 | -0.0128 | -0.0395 | 0.0245 | 25.5806 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -2.1372 | 8.3221 | -0.0128 | -0.0395 | 0.0245 | 25.5806 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.8044 | -2.4704 | 0.0048 | 0.0168 | 0.0115 | -17.8217 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.5752 | -1.8254 | -0.0027 | -0.0061 | 0.0264 | -30.6643 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -2.1372 | 8.3221 | -0.0128 | -0.0395 | 0.0245 | 25.5806 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -2.1372 | 8.3221 | -0.0128 | -0.0395 | 0.0245 | 25.5806 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.8044 | -2.4704 | 0.0048 | 0.0168 | 0.0115 | -17.8217 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.5752 | -1.8254 | -0.0027 | -0.0061 | 0.0264 | -30.6643 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case A only | -2.8470 | 9.2754 | -0.0139 | -0.0437 | 0.0182 | 34.0578 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case B only | -2.8470 | 9.2754 | -0.0139 | -0.0437 | 0.0182 | 34.0578 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case A only | 2.4085 | -5.1147 | 0.0095 | 0.0312 | 0.0008 | -23.8118 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case B only | 2.1030 | -4.2547 | -0.0004 | 0.0008 | 0.0207 | -40.9353 |

### 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 | 15.9558 |
| Shear X | -4.7461 |
| Shear Z | -0.0238 |
| Moment X | -0.0747 |
| Moment Y (Twist) | 0.0392 |
| Moment Z | 68.9049 |

### 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 | 10.2686 |
| Shear X | -2.8484 |
| Shear Z | -0.0156 |
| Moment X | -0.0486 |
| Moment Y (Twist) | 0.0286 |
| Moment Z | 40.9353 |

## 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 | 0.0043 | 2.5995 | 0.0027 | 0.0088 | -0.0043 | -0.0081 |
| ULS: 2. D + L | 0.0043 | 2.5995 | 0.0027 | 0.0088 | -0.0043 | -0.0081 |
| ULS: 3. D + (S or Lr or R) | 0.0043 | 2.5995 | 0.0027 | 0.0088 | -0.0043 | -0.0081 |
| ULS: 3. D + (S or Lr or R) | 0.0043 | 2.5995 | 0.0027 | 0.0088 | -0.0043 | -0.0081 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | 0.0043 | 2.5995 | 0.0027 | 0.0088 | -0.0043 | -0.0081 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | 0.0043 | 2.5995 | 0.0027 | 0.0088 | -0.0043 | -0.0081 |
| ULS: 5b. D + 0.7E | 0.0043 | 2.5995 | 0.0027 | 0.0088 | -0.0043 | -0.0081 |

| Name | Fx | Fy | Fz | Mx | My | Mz |
| --- | --- | --- | --- | --- | --- | --- |
| ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S | 0.0043 | 2.5995 | 0.0027 | 0.0088 | -0.0043 | -0.0081 |
| ULS: 8. 0.6D + 0.7E | 0.0026 | 1.5597 | 0.0016 | 0.0053 | -0.0026 | -0.0049 |
| ULS: 5a. D + 0.6W_Wind downforce Case A only | -2.9831 | 10.8282 | 0.0238 | 0.0747 | -0.0435 | 35.6924 |
| ULS: 5a. D + 0.6W_Wind downforce Case B only | -2.9831 | 10.8282 | 0.0238 | 0.0747 | -0.0435 | 35.6924 |
| ULS: 5a. D + 0.6W_Wind uplift Case A only | 2.5413 | -4.3839 | -0.0129 | -0.0399 | 0.0234 | -25.0087 |
| ULS: 5a. D + 0.6W_Wind uplift Case B only | 2.2021 | -3.4646 | -0.0174 | -0.0534 | 0.0372 | -42.7671 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -2.2363 | 8.7710 | 0.0185 | 0.0582 | -0.0337 | 26.7672 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -2.2363 | 8.7710 | 0.0185 | 0.0582 | -0.0337 | 26.7672 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.9071 | -2.6380 | -0.0090 | -0.0277 | 0.0164 | -18.7586 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.6526 | -1.9486 | -0.0124 | -0.0379 | 0.0268 | -32.0773 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -2.2363 | 8.7710 | 0.0185 | 0.0582 | -0.0337 | 26.7672 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -2.2363 | 8.7710 | 0.0185 | 0.0582 | -0.0337 | 26.7672 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.9071 | -2.6380 | -0.0090 | -0.0277 | 0.0164 | -18.7586 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.6526 | -1.9486 | -0.0124 | -0.0379 | 0.0268 | -32.0773 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case A only | -2.9849 | 9.7884 | 0.0227 | 0.0711 | -0.0417 | 35.6956 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case B only | -2.9849 | 9.7884 | 0.0227 | 0.0711 | -0.0417 | 35.6956 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case A only | 2.5396 | -5.4237 | -0.0139 | -0.0434 | 0.0251 | -25.0054 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case B only | 2.2003 | -4.5045 | -0.0185 | -0.0570 | 0.0390 | -42.7638 |

### 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 | 16.8337 |
| Shear X | -4.9791 |
| Shear Z | 0.0386 |
| Moment X | 0.1214 |
| Moment Y (Twist) | 0.0711 |
| Moment Z | 72.0167 |

### 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 | 10.8282 |
| Shear X | -2.9849 |
| Shear Z | 0.0238 |
| Moment X | 0.0747 |
| Moment Y (Twist) | 0.0435 |
| Moment Z | 42.7671 |

## 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 | -0.0015 | 2.6186 | -0.0000 | 0.0000 | 0.0000 | 0.0414 |
| ULS: 2. D + L | -0.0015 | 2.6186 | -0.0000 | 0.0000 | 0.0000 | 0.0414 |
| ULS: 3. D + (S or Lr or R) | -0.0015 | 2.6186 | -0.0000 | 0.0000 | 0.0000 | 0.0414 |
| ULS: 3. D + (S or Lr or R) | -0.0015 | 2.6186 | -0.0000 | 0.0000 | 0.0000 | 0.0414 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | -0.0015 | 2.6186 | -0.0000 | 0.0000 | 0.0000 | 0.0414 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | -0.0015 | 2.6186 | -0.0000 | 0.0000 | 0.0000 | 0.0414 |
| ULS: 5b. D + 0.7E | -0.0015 | 2.6186 | -0.0000 | 0.0000 | 0.0000 | 0.0414 |
| ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S | -0.0015 | 2.6186 | -0.0000 | 0.0000 | 0.0000 | 0.0414 |
| ULS: 8. 0.6D + 0.7E | -0.0009 | 1.5711 | -0.0000 | 0.0000 | 0.0000 | 0.0248 |
| ULS: 5a. D + 0.6W_Wind downforce Case A only | -3.0299 | 10.9587 | -0.0000 | 0.0000 | 0.0000 | 36.2723 |
| ULS: 5a. D + 0.6W_Wind downforce Case B only | -3.0299 | 10.9587 | -0.0000 | 0.0000 | 0.0000 | 36.2723 |
| ULS: 5a. D + 0.6W_Wind uplift Case A only | 2.5700 | -4.4580 | -0.0000 | 0.0000 | 0.0000 | -25.3005 |
| ULS: 5a. D + 0.6W_Wind uplift Case B only | 2.2271 | -3.5311 | -0.0000 | 0.0000 | 0.0000 | -43.3286 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -2.2728 | 8.8737 | -0.0000 | 0.0000 | 0.0000 | 27.2145 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -2.2728 | 8.8737 | -0.0000 | 0.0000 | 0.0000 | 27.2145 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.9272 | -2.6888 | -0.0000 | 0.0000 | 0.0000 | -18.9651 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.6700 | -1.9937 | -0.0000 | 0.0000 | 0.0000 | -32.4861 |

| 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 | -2.2728 | 8.8737 | -0.0000 | 0.0000 | 0.0000 | 27.2145 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -2.2728 | 8.8737 | -0.0000 | 0.0000 | 0.0000 | 27.2145 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.9272 | -2.6888 | -0.0000 | 0.0000 | 0.0000 | -18.9651 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.6700 | -1.9937 | -0.0000 | 0.0000 | 0.0000 | -32.4861 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case A only | -3.0293 | 9.9113 | 0.0000 | 0.0000 | 0.0000 | 36.2557 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case B only | -3.0293 | 9.9113 | 0.0000 | 0.0000 | 0.0000 | 36.2557 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case A only | 2.5706 | -5.5054 | 0.0000 | 0.0000 | 0.0000 | -25.3171 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case B only | 2.2277 | -4.5786 | -0.0000 | 0.0000 | 0.0000 | -43.3452 |

### 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 | 17.0425 |
| Shear X | -5.0489 |
| Shear Z | 0.0000 |
| Moment X | 0.0002 |
| Moment Y (Twist) | 0.0001 |
| Moment Z | 72.9941 |

### 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 | 10.9587 |
| Shear X | -3.0299 |
| Shear Z | -0.0000 |
| Moment X | 0.0000 |
| Moment Y (Twist) | 0.0000 |
| Moment Z | 43.3452 |

## Reaction Forces for Foundation 4 (Node ID#301), (kip, kip-ft)

### ASD Load Combination Results

| Name | Fx | Fy | Fz | Mx | My | Mz |
|---|---|---|---|---|---|---|
| ULS: 1. D | 0.0043 | 2.5995 | -0.0027 | -0.0088 | 0.0043 | -0.0081 |
| ULS: 2. D + L | 0.0043 | 2.5995 | -0.0027 | -0.0088 | 0.0043 | -0.0081 |
| ULS: 3. D + (S or Lr or R) | 0.0043 | 2.5995 | -0.0027 | -0.0088 | 0.0043 | -0.0081 |
| ULS: 3. D + (S or Lr or R) | 0.0043 | 2.5995 | -0.0027 | -0.0088 | 0.0043 | -0.0081 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | 0.0043 | 2.5995 | -0.0027 | -0.0088 | 0.0043 | -0.0081 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | 0.0043 | 2.5995 | -0.0027 | -0.0088 | 0.0043 | -0.0081 |
| ULS: 5b. D + 0.7E | 0.0043 | 2.5995 | -0.0027 | -0.0088 | 0.0043 | -0.0081 |
| ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S | 0.0043 | 2.5995 | -0.0027 | -0.0088 | 0.0043 | -0.0081 |
| ULS: 8. 0.6D + 0.7E | 0.0026 | 1.5597 | -0.0016 | -0.0053 | 0.0026 | -0.0049 |
| ULS: 5a. D + 0.6W_Wind downforce Case A only | -2.9831 | 10.8282 | -0.0238 | -0.0746 | 0.0435 | 35.6924 |
| ULS: 5a. D + 0.6W_Wind downforce Case B only | -2.9831 | 10.8282 | -0.0238 | -0.0746 | 0.0435 | 35.6924 |
| ULS: 5a. D + 0.6W_Wind uplift Case A only | 2.5413 | -4.3839 | 0.0129 | 0.0399 | -0.0234 | -25.0087 |
| ULS: 5a. D + 0.6W_Wind uplift Case B only | 2.2021 | -3.4646 | 0.0174 | 0.0534 | -0.0372 | -42.7671 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -2.2363 | 8.7710 | -0.0185 | -0.0582 | 0.0337 | 26.7672 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -2.2363 | 8.7710 | -0.0185 | -0.0582 | 0.0337 | 26.7672 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.9071 | -2.6380 | 0.0090 | 0.0277 | -0.0164 | -18.7586 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.6526 | -1.9486 | 0.0124 | 0.0379 | -0.0268 | -32.0773 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -2.2363 | 8.7710 | -0.0185 | -0.0582 | 0.0337 | 26.7672 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -2.2363 | 8.7710 | -0.0185 | -0.0582 | 0.0337 | 26.7672 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.9071 | -2.6380 | 0.0090 | 0.0277 | -0.0164 | -18.7586 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.6526 | -1.9486 | 0.0124 | 0.0379 | -0.0268 | -32.0773 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case A only | -2.9849 | 9.7884 | -0.0227 | -0.0711 | 0.0417 | 35.6956 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case B only | -2.9849 | 9.7884 | -0.0227 | -0.0711 | 0.0417 | 35.6956 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case A only | 2.5396 | -5.4237 | 0.0139 | 0.0434 | -0.0251 | -25.0054 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case B only | 2.2003 | -4.5045 | 0.0185 | 0.0570 | -0.0390 | -42.7638 |

### Worst Case Reactions LRFD

### Worst Case Reactions ASD

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 | 16.8337 |
| Shear X | -4.9791 |
| Shear Z | -0.0386 |
| Moment X | -0.1213 |
| Moment Y (Twist) | 0.0711 |
| Moment Z | 72.0167 |

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 | 10.8282 |
| Shear X | -2.9849 |
| Shear Z | -0.0238 |
| Moment X | -0.0746 |
| Moment Y (Twist) | 0.0435 |
| Moment Z | 42.7671 |

## Reaction Forces for Foundation 5 (Node ID#401), (kip, kip-ft)

### ASD Load Combination Results

| Name | Fx | Fy | Fz | Mx | My | Mz |
|---|---|---|---|---|---|---|
| ULS: 1. D | -0.0036 | 2.4829 | 0.0043 | 0.0122 | -0.0197 | 0.0676 |
| ULS: 2. D + L | -0.0036 | 2.4829 | 0.0043 | 0.0122 | -0.0197 | 0.0676 |
| ULS: 3. D + (S or Lr or R) | -0.0036 | 2.4829 | 0.0043 | 0.0122 | -0.0197 | 0.0676 |
| ULS: 3. D + (S or Lr or R) | -0.0036 | 2.4829 | 0.0043 | 0.0122 | -0.0197 | 0.0676 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | -0.0036 | 2.4829 | 0.0043 | 0.0122 | -0.0197 | 0.0676 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | -0.0036 | 2.4829 | 0.0043 | 0.0122 | -0.0197 | 0.0676 |
| ULS: 5b. D + 0.7E | -0.0036 | 2.4829 | 0.0043 | 0.0122 | -0.0197 | 0.0676 |
| ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S | -0.0036 | 2.4829 | 0.0043 | 0.0122 | -0.0197 | 0.0676 |
| ULS: 8. 0.6D + 0.7E | -0.0022 | 1.4897 | 0.0026 | 0.0073 | -0.0118 | 0.0406 |
| ULS: 5a. D + 0.6W_Wind downforce Case A only | -2.8484 | 10.2686 | 0.0156 | 0.0486 | -0.0261 | 34.0849 |
| ULS: 5a. D + 0.6W_Wind downforce Case B only | -2.8484 | 10.2686 | 0.0156 | 0.0486 | -0.0261 | 34.0849 |
| ULS: 5a. D + 0.6W_Wind uplift Case A only | 2.4071 | -4.1216 | -0.0078 | -0.0264 | -0.0087 | -23.7848 |
| ULS: 5a. D + 0.6W_Wind uplift Case B only | 2.1015 | -3.2615 | 0.0021 | 0.0040 | -0.0286 | -40.9082 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -2.1372 | 8.3221 | 0.0128 | 0.0395 | -0.0245 | 25.5806 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -2.1372 | 8.3221 | 0.0128 | 0.0395 | -0.0245 | 25.5806 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.8044 | -2.4704 | -0.0048 | -0.0167 | -0.0115 | -17.8217 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.5752 | -1.8254 | 0.0027 | 0.0061 | -0.0264 | -30.6643 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -2.1372 | 8.3221 | 0.0128 | 0.0395 | -0.0245 | 25.5806 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -2.1372 | 8.3221 | 0.0128 | 0.0395 | -0.0245 | 25.5806 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 1.8044 | -2.4704 | -0.0048 | -0.0167 | -0.0115 | -17.8217 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 1.5752 | -1.8254 | 0.0027 | 0.0061 | -0.0264 | -30.6643 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case A only | -2.8470 | 9.2754 | 0.0139 | 0.0437 | -0.0182 | 34.0578 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case B only | -2.8470 | 9.2754 | 0.0139 | 0.0437 | -0.0182 | 34.0578 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case A only | 2.4085 | -5.1147 | -0.0095 | -0.0312 | -0.0008 | -23.8118 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case B only | 2.1030 | -4.2547 | 0.0004 | -0.0008 | -0.0207 | -40.9353 |

### 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 | 15.9558 |
| Shear X | -4.7461 |
| Shear Z | 0.0238 |
| Moment X | 0.0748 |
| Moment Y (Twist) | 0.0391 |
| Moment Z | 68.9061 |

### 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 | 10.2686 |
| Shear X | -2.8484 |
| Shear Z | 0.0156 |
| Moment X | 0.0486 |
| Moment Y (Twist) | 0.0286 |
| Moment Z | 40.9353 |

## Project Details

Design Code: AISC 360-16 LRFD
Provision: LRFD
Country: United States

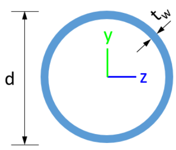
User Name: sales@mtsolar.us
Unit System: imperial

## Design Input Information

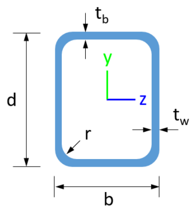
| Design Factors | | | |
|---|---|---|---|
| $\Phi_t$ | $\Phi_c$ | $\Phi_b$ | $\Phi_v$ |
| 0.9 | 0.9 | 0.9 | 0.9 |

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

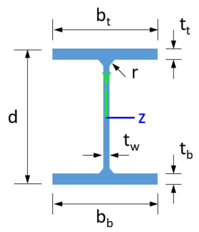
**Section Dimensions**




| ID | Name | d (in) | $t_w$ (in) | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3 | 2in Pipe Sch 120 | 2.38 | 0.25 | | | | | |
| 6 | 4in Pipe Sch 120 | 4.50 | 0.44 | | | | | |
| 9 | 8in Pipe Sch 40 | 8.63 | 0.32 | | | | | |




| ID | Name | d (in) | b (in) | $t_w$ (in) | $t_b$ (in) | r (in) | | |
|---|---|---|---|---|---|---|---|---|
| 17 | HSS5x3x1/4 | 5.00 | 3.00 | 0.23 | 0.23 | 0.23 | | |




| ID | Name | d (in) | $t_w$ (in) | $b_t$ (in) | $b_b$ (in) | $t_t$ (in) | $t_b$ (in) | r (in) |
|---|---|---|---|---|---|---|---|---|
| 20 | W10x12 | 9.87 | 0.19 | 3.96 | 3.96 | 0.21 | 0.21 | 0.30 |

| Section Properties | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ID | Name | A ($in^2$) | J ($in^4$) | $I_{yp}$ ($in^4$) | $I_{zp}$ ($in^4$) | $I_w$ ($in^6$) | $S_{yp}$ ($in^3$) | $S_{zp}$ ($in^3$) |
| 3 | 2in Pipe Sch 120 | 1.67 | 1.91 | 0.96 | 0.96 | 0.00 | 1.13 | 1.13 |
| 6 | 4in Pipe Sch 120 | 5.58 | 23.29 | 11.64 | 11.64 | 0.00 | 7.24 | 7.24 |
| 9 | 8in Pipe Sch 40 | 8.40 | 144.98 | 72.49 | 72.49 | 0.00 | 22.21 | 22.21 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 17 | HSS5x3x1/4 | 3.37 | 11.00 | 4.81 | 10.70 | 62.42 | 3.77 | 5.38 |
| 20 | W10x12 | 3.54 | 0.05 | 2.18 | 53.80 | 50.90 | 1.74 | 12.60 |

| Member Properties | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Member ID | Section ID | $K_zL$ (ft) | $K_yL$ (ft) | $L_b$(ft) | $C_b$ | LST | LSC | LD |
| 1 | 9 | 22.99 | 22.99 | 10.95 | - | 300 | 200 | 1 |
| 2 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 3 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.19,1.19,1.19,1.19,1.19,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.17,1.17,1.18,1.18,1.17,1.17,1.18,1.18,1.18,1.18 | 300 | 200 | 1 |
| 4 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.69,1.69,1.69,1.69,1.69,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.23 | 300 | 200 | 1 |
| 5 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.68,1.68,1.68,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.67 | 300 | 200 | 1 |
| 6 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.19,1.19,1.19,1.19,1.19,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.17,1.18,1.18,1.18,1.17,1.18,1.18,1.18,1.18,1.18 | 300 | 200 | 1 |
| 7 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.68,1.68,1.68,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.67 | 300 | 200 | 1 |
| 8 | 20 | 1.33 | 1.33 | 2.05 | 2.12,2.12,2.12,2.12,2.12,2.12,2.11,2.11,2.12,1.47,2.11,2.11,2.12,1.47,2.12,2.12,2.12,2.28,2.12,2.12,2.12,2.28,2.11,2.11,2.12,1.03 | 300 | 200 | 1 |
| 9 | 3 | 2.60 | 2.60 | 4.00 | - | 300 | 200 | 1 |
| 10 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.69,1.69,1.69,1.69,1.69,1.67,1.67,1.66,1.75,1.67,1.67,1.66,1.75,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.70,1.67,1.67,1.66,2.47 | 300 | 200 | 1 |
| 11 | 20 | 1.33 | 1.33 | 2.05 | 2.12,2.12,2.12,2.12,2.12,2.12,2.19,2.19,2.17,2.33,2.19,2.19,2.17,2.33,2.17,2.17,2.21,2.38,2.17,2.17,2.21,2.38,2.19,2.19,2.17,2.33 | 300 | 200 | 1 |
| 12 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 13 | 20 | 4.88 | 4.00 | 7.50 | 1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09 | 300 | 200 | 1 |
| 14 | 20 | 4.88 | 4.00 | 7.50 | 1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.45,1.09,1.09,1.09,1.45,1.09,1.09,1.09,1.40,1.09,1.09,1.09,1.40,1.09,1.09,1.09,1.03 | 300 | 200 | 1 |
| 15 | 20 | 9.97 | 9.97 | 4.75 | 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 | 20 | 9.97 | 9.97 | 4.75 | 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 | 22.99 | 22.99 | 10.95 | - | 300 | 200 | 1 |
| 102 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 103 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.19,1.19,1.19,1.19,1.19,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.17,1.17,1.18,1.18,1.17,1.17,1.18,1.18,1.18,1.18 | 300 | 200 | 1 |
| 104 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.69,1.69,1.69,1.69,1.69,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.20 | 300 | 200 | 1 |
| 105 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.68,1.68,1.68,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.67 | 300 | 200 | 1 |
| 106 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.19,1.19,1.19,1.19,1.19,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.17,1.18,1.18,1.18,1.17,1.18,1.18,1.18,1.18,1.18 | 300 | 200 | 1 |
| 107 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.68,1.68,1.68,1.67,1.67,1.66,1.67,1.67,1.67,1.66,1.67,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.67 | 300 | 200 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 108 | 20 | 1.33 | 1.33 | 2.05 | 2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.28,2.07,2.07,2.07,2.28,2.07,2.07,2.07,2.08,2.07,2.07,2.07,2.08,2.07,2.07,2.07,1.08 | 300 | 200 | 1 |
| 109 | 3 | 2.60 | 2.60 | 4.00 | - | 300 | 200 | 1 |
| 110 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.69,1.69,1.69,1.69,1.69,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.26 | 300 | 200 | 1 |
| 111 | 20 | 1.33 | 1.33 | 2.05 | 2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.06,2.07,2.07,2.07,2.06,2.07,2.07,2.07,2.06,2.06,2.07,2.07,2.06,2.06,2.07,2.07,2.06,2.07 | 300 | 200 | 1 |
| 112 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 113 | 20 | 4.88 | 4.00 | 7.50 | 1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04 | 300 | 200 | 1 |
| 114 | 20 | 4.88 | 4.00 | 7.50 | 1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.63,1.04,1.04,1.04,1.63,1.04,1.04,1.04,1.03 | 300 | 200 | 1 |
| 115 | 20 | 6.63 | 6.63 | 10.20 | 1.15,1.15,1.15,1.15,1.15,1.15,1.14,1.14,1.14,1.14,1.14,1.14,1.14,1.14,1.14,1.14,1.14,1.14,1.14,1.14,1.14,1.14,1.14,1.14,1.14,1.14 | 300 | 200 | 1 |
| 116 | 20 | 6.63 | 6.63 | 10.20 | 1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.18,1.15,1.15,1.15,1.18,1.15,1.15,1.15,1.14,1.15,1.15,1.15,1.14,1.15,1.15,1.15,1.64 | 300 | 200 | 1 |
| 201 | 9 | 22.99 | 22.99 | 10.95 | - | 300 | 200 | 1 |
| 202 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 203 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.19,1.19,1.19,1.19,1.19,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.17,1.18,1.18,1.18,1.17,1.18,1.18,1.18,1.18,1.18 | 300 | 200 | 1 |
| 204 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.69,1.69,1.69,1.69,1.69,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.20 | 300 | 200 | 1 |
| 205 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.68,1.68,1.68,1.67,1.67,1.66,1.67,1.67,1.67,1.66,1.67,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.67 | 300 | 200 | 1 |
| 206 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.19,1.19,1.19,1.19,1.19,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.17,1.18,1.18,1.18,1.17,1.18,1.18,1.18,1.18,1.18 | 300 | 200 | 1 |
| 207 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.68,1.68,1.68,1.67,1.67,1.66,1.67,1.67,1.67,1.66,1.67,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.67 | 300 | 200 | 1 |
| 208 | 20 | 1.33 | 1.33 | 2.05 | 2.08,2.08,2.08,2.08,2.08,2.08,2.08,2.08,2.08,2.10,2.08,2.08,2.08,2.10,2.08,2.08,2.09,2.08,2.08,2.08,2.09,2.08,2.08,2.08,2.08,1.57 | 300 | 200 | 1 |
| 209 | 3 | 2.60 | 2.60 | 4.00 | - | 300 | 200 | 1 |
| 210 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.69,1.69,1.69,1.69,1.69,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.20 | 300 | 200 | 1 |
| 211 | 20 | 1.33 | 1.33 | 2.05 | 2.08,2.08,2.08,2.08,2.08,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07 | 300 | 200 | 1 |
| 212 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 213 | 20 | 4.88 | 4.00 | 7.50 | 1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04 | 300 | 200 | 1 |
| 214 | 20 | 4.88 | 4.00 | 7.50 | 1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.02,1.04,1.04,1.04,1.02,1.04,1.04,1.04,1.56,1.04,1.04,1.04,1.56,1.04,1.04,1.04,1.00 | 300 | 200 | 1 |
| 215 | 20 | 6.63 | 6.63 | 10.20 | 1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15 | 300 | 200 | 1 |
| 216 | 20 | 6.63 | 6.63 | 10.20 | 1.15,1.15,1.15,1.15,1.15,1.15,1.16,1.16,1.16,1.16,1.16,1.16,1.16,1.16,1.16,1.16,1.16,1.15,1.16,1.16,1.16,1.15,1.16,1.16,1.16,1.18 | 300 | 200 | 1 |
| 301 | 9 | 22.99 | 22.99 | 10.95 | - | 300 | 200 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 302 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 303 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.19,1.19,1.19,1.19,1.19,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.17,1.18,1.18,1.18,1.17,1.18,1.18,1.18,1.18,1.18 | 300 | 200 | 1 |
| 304 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.69,1.69,1.69,1.69,1.69,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.26 | 300 | 200 | 1 |
| 305 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.68,1.68,1.68,1.67,1.67,1.66,1.67,1.67,1.67,1.66,1.67,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.67 | 300 | 200 | 1 |
| 306 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.19,1.19,1.19,1.19,1.19,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.17,1.17,1.18,1.18,1.17,1.17,1.18,1.18,1.18,1.18 | 300 | 200 | 1 |
| 307 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.68,1.68,1.68,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.67 | 300 | 200 | 1 |
| 308 | 20 | 1.33 | 1.33 | 2.05 | 2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,2.07,1.75,2.07,2.07,2.07,1.75,2.07,2.07,2.07,2.06,2.07,2.07,2.07,2.06,2.07,2.07,2.07,2.19 | 300 | 200 | 1 |
| 309 | 3 | 2.60 | 2.60 | 4.00 | - | 300 | 200 | 1 |
| 310 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.69,1.69,1.69,1.69,1.69,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.20 | 300 | 200 | 1 |
| 311 | 20 | 1.33 | 1.33 | 2.05 | 2.08,2.08,2.08,2.08,2.08,2.08,2.06,2.06,2.06,2.06,2.06,2.06,2.06,2.06,2.06,2.06,2.06,2.06,2.06,2.06,2.06,2.06,2.06,2.06,2.06,2.06 | 300 | 200 | 1 |
| 312 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 313 | 20 | 4.88 | 4.00 | 7.50 | 1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04 | 300 | 200 | 1 |
| 314 | 20 | 4.88 | 4.00 | 7.50 | 1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.04,1.63,1.04,1.04,1.04,1.63,1.04,1.04,1.04,1.03 | 300 | 200 | 1 |
| 315 | 20 | 6.63 | 6.63 | 10.20 | 1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.14,1.15,1.15,1.15,1.14,1.15,1.15,1.15,1.15,1.15 | 300 | 200 | 1 |
| 316 | 20 | 6.63 | 6.63 | 10.20 | 1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.15,1.21,1.15,1.15,1.15,1.21,1.15,1.15,1.15,1.16,1.15,1.15,1.15,1.16,1.15,1.15,1.15,1.06 | 300 | 200 | 1 |
| 401 | 9 | 22.99 | 22.99 | 10.95 | - | 300 | 200 | 1 |
| 402 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 403 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.19,1.19,1.19,1.19,1.19,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.17,1.18,1.18,1.18,1.17,1.18,1.18,1.18,1.18,1.18 | 300 | 200 | 1 |
| 404 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.69,1.69,1.69,1.69,1.69,1.67,1.67,1.66,1.75,1.67,1.67,1.66,1.75,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.70,1.67,1.67,1.66,2.47 | 300 | 200 | 1 |
| 405 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.68,1.68,1.68,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.67 | 300 | 200 | 1 |
| 406 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.19,1.19,1.19,1.19,1.19,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.17,1.17,1.18,1.18,1.17,1.17,1.18,1.18,1.18,1.18 | 300 | 200 | 1 |
| 407 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.68,1.68,1.68,1.68,1.68,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.66,1.67,1.67,1.66,1.67 | 300 | 200 | 1 |
| 408 | 20 | 9.97 | 9.97 | 4.75 | 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 |
| 409 | 3 | 2.60 | 2.60 | 4.00 | - | 300 | 200 | 1 |
| 410 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.69,1.69,1.69,1.69,1.69,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.76,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.70,1.67,1.67,1.66,1.23 | 300 | 200 | 1 |
| 411 | 20 | 9.97 | 9.97 | 4.75 | 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 |
| | | | | | | 3 | 2 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 412 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 413 | 20 | 4.88 | 4.00 | 7.50 | 1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09 | 300 | 200 | 1 |
| 414 | 20 | 4.88 | 4.00 | 7.50 | 1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.09,1.45,1.09,1.09,1.09,1.45,1.09,1.09,1.09,1.40,1.09,1.09,1.09,1.40,1.09,1.09,1.09,1.03 | 300 | 200 | 1 |
| 415 | 20 | 6.63 | 6.63 | 10.20 | 1.17,1.17,1.17,1.17,1.17,1.17,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.17,1.17,1.18,1.18,1.17,1.17,1.18,1.18,1.18,1.18,1.17,1.18 | 300 | 200 | 1 |
| 416 | 20 | 6.63 | 6.63 | 10.20 | 1.17,1.17,1.17,1.17,1.17,1.17,1.17,1.17,1.17,2.01,1.17,1.17,1.17,2.01,1.17,1.17,1.17,1.21,1.17,1.17,1.17,1.21,1.17,1.17,1.17,1.35 | 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 | 198.34 | 83.29 | 83.29 | 113.39 | 113.39 |
| 2 | 251.01 | 248.88 | 27.16 | 27.16 | 75.30 | 75.30 |
| 3 | 151.65 | 150.70 | 20.17 | 14.14 | 54.12 | 28.95 |
| 4 | 151.65 | 145.15 | 20.17 | 14.14 | 54.12 | 28.95 |
| 5 | 151.65 | 149.10 | 20.17 | 14.14 | 54.12 | 28.95 |
| 6 | 151.65 | 150.70 | 20.17 | 14.14 | 54.12 | 28.95 |
| 7 | 151.65 | 149.10 | 20.17 | 14.14 | 54.12 | 28.95 |
| 8 | 159.30 | 142.47 | 46.90 | 6.46 | 56.26 | 44.91 |
| 9 | 75.10 | 66.32 | 4.25 | 4.25 | 22.53 | 22.53 |
| 10 | 151.65 | 145.15 | 20.17 | 14.14 | 54.12 | 28.95 |
| 11 | 159.30 | 142.47 | 46.90 | 6.46 | 56.26 | 44.91 |
| 12 | 251.01 | 248.88 | 27.16 | 27.16 | 75.30 | 75.30 |
| 13 | 159.30 | 116.35 | 33.31 | 6.46 | 56.26 | 44.91 |
| 14 | 159.30 | 116.35 | 31.48 | 6.46 | 56.26 | 44.91 |
| 15 | 159.30 | 34.37 | 46.90 | 6.46 | 56.26 | 44.91 |
| 16 | 159.30 | 34.37 | 46.90 | 6.46 | 56.26 | 44.91 |
| 101 | 377.97 | 198.34 | 83.29 | 83.29 | 113.39 | 113.39 |
| 102 | 251.01 | 248.88 | 27.16 | 27.16 | 75.30 | 75.30 |
| 103 | 151.65 | 150.70 | 20.17 | 14.14 | 54.12 | 28.95 |
| 104 | 151.65 | 145.15 | 20.17 | 14.14 | 54.12 | 28.95 |
| 105 | 151.65 | 149.10 | 20.17 | 14.14 | 54.12 | 28.95 |
| 106 | 151.65 | 150.70 | 20.17 | 14.14 | 54.12 | 28.95 |
| 107 | 151.65 | 149.10 | 20.17 | 14.14 | 54.12 | 28.95 |
| 108 | 159.30 | 142.47 | 46.90 | 6.46 | 56.26 | 44.91 |
| 109 | 75.10 | 66.32 | 4.25 | 4.25 | 22.53 | 22.53 |
| 110 | 151.65 | 145.15 | 20.17 | 14.14 | 54.12 | 28.95 |
| 111 | 159.30 | 142.47 | 46.90 | 6.46 | 56.26 | 44.91 |
| 112 | 251.01 | 248.88 | 27.16 | 27.16 | 75.30 | 75.30 |
| 113 | 159.30 | 116.35 | 31.78 | 6.46 | 56.26 | 44.91 |
| 114 | 159.30 | 116.35 | 31.48 | 6.46 | 56.26 | 44.91 |
| 115 | 159.30 | 75.13 | 21.96 | 6.46 | 56.26 | 44.91 |
| 116 | 159.30 | 75.13 | 21.96 | 6.46 | 56.26 | 44.91 |
| 201 | 377.97 | 198.34 | 83.29 | 83.29 | 113.39 | 113.39 |
| 202 | 251.01 | 248.88 | 27.16 | 27.16 | 75.30 | 75.30 |
| 203 | 151.65 | 150.70 | 20.17 | 14.14 | 54.12 | 28.95 |
| 204 | 151.65 | 145.15 | 20.17 | 14.14 | 54.12 | 28.95 |
| 205 | 151.65 | 149.10 | 20.17 | 14.14 | 54.12 | 28.95 |
| 206 | 151.65 | 150.70 | 20.17 | 14.14 | 54.12 | 28.95 |
| 207 | 151.65 | 149.10 | 20.17 | 14.14 | 54.12 | 28.95 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 208 | 159.30 | 142.47 | 46.90 | 6.46 | 56.26 | 44.91 |
| 209 | 75.10 | 66.32 | 4.25 | 4.25 | 22.53 | 22.53 |
| 210 | 151.65 | 145.15 | 20.17 | 14.14 | 54.12 | 28.95 |
| 211 | 159.30 | 142.47 | 46.90 | 6.46 | 56.26 | 44.91 |
| 212 | 251.01 | 248.88 | 27.16 | 27.16 | 75.30 | 75.30 |
| 213 | 159.30 | 116.35 | 31.78 | 6.46 | 56.26 | 44.91 |
| 214 | 159.30 | 116.35 | 30.56 | 6.46 | 56.26 | 44.91 |
| 215 | 159.30 | 75.13 | 22.15 | 6.46 | 56.26 | 44.91 |
| 216 | 159.30 | 75.13 | 22.15 | 6.46 | 56.26 | 44.91 |
| 301 | 377.97 | 198.34 | 83.29 | 83.29 | 113.39 | 113.39 |
| 302 | 251.01 | 248.88 | 27.16 | 27.16 | 75.30 | 75.30 |
| 303 | 151.65 | 150.70 | 20.17 | 14.14 | 54.12 | 28.95 |
| 304 | 151.65 | 145.15 | 20.17 | 14.14 | 54.12 | 28.95 |
| 305 | 151.65 | 149.10 | 20.17 | 14.14 | 54.12 | 28.95 |
| 306 | 151.65 | 150.70 | 20.17 | 14.14 | 54.12 | 28.95 |
| 307 | 151.65 | 149.10 | 20.17 | 14.14 | 54.12 | 28.95 |
| 308 | 159.30 | 142.47 | 46.90 | 6.46 | 56.26 | 44.91 |
| 309 | 75.10 | 66.32 | 4.25 | 4.25 | 22.53 | 22.53 |
| 310 | 151.65 | 145.15 | 20.17 | 14.14 | 54.12 | 28.95 |
| 311 | 159.30 | 142.47 | 46.90 | 6.46 | 56.26 | 44.91 |
| 312 | 251.01 | 248.88 | 27.16 | 27.16 | 75.30 | 75.30 |
| 313 | 159.30 | 116.35 | 31.78 | 6.46 | 56.26 | 44.91 |
| 314 | 159.30 | 116.35 | 31.48 | 6.46 | 56.26 | 44.91 |
| 315 | 159.30 | 75.13 | 21.96 | 6.46 | 56.26 | 44.91 |
| 316 | 159.30 | 75.13 | 20.41 | 6.46 | 56.26 | 44.91 |
| 401 | 377.97 | 198.34 | 83.29 | 83.29 | 113.39 | 113.39 |
| 402 | 251.01 | 248.88 | 27.16 | 27.16 | 75.30 | 75.30 |
| 403 | 151.65 | 150.70 | 20.17 | 14.14 | 54.12 | 28.95 |
| 404 | 151.65 | 145.15 | 20.17 | 14.14 | 54.12 | 28.95 |
| 405 | 151.65 | 149.10 | 20.17 | 14.14 | 54.12 | 28.95 |
| 406 | 151.65 | 150.70 | 20.17 | 14.14 | 54.12 | 28.95 |
| 407 | 151.65 | 149.10 | 20.17 | 14.14 | 54.12 | 28.95 |
| 408 | 159.30 | 34.37 | 46.90 | 6.46 | 56.26 | 44.91 |
| 409 | 75.10 | 66.32 | 4.25 | 4.25 | 22.53 | 22.53 |
| 410 | 151.65 | 145.15 | 20.17 | 14.14 | 54.12 | 28.95 |
| 411 | 159.30 | 34.37 | 46.90 | 6.46 | 56.26 | 44.91 |
| 412 | 251.01 | 248.88 | 27.16 | 27.16 | 75.30 | 75.30 |
| 413 | 159.30 | 116.35 | 33.31 | 6.46 | 56.26 | 44.91 |
| 414 | 159.30 | 116.35 | 31.48 | 6.46 | 56.26 | 44.91 |
| 415 | 159.30 | 75.13 | 22.53 | 6.46 | 56.26 | 44.91 |
| 416 | 159.30 | 75.13 | 22.53 | 6.46 | 56.26 | 44.91 |

## 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 | 0.080 | 0.827 | 0.002 | 0.042 | 0.000 | 0.836 | #16 | 0.470 | Not Required | Pass |
| 2 | 0.001 | 0.504 | 0.163 | 0.104 | 0.032 | 0.667 | #13 | 0.036 | Not Required | Pass |
| 3 | 0.002 | 0.791 | 0.010 | 0.078 | 0.002 | 0.796 | #32 | 0.046 | Not Required | Pass |
| 4 | 0.002 | 0.718 | 0.028 | 0.072 | 0.006 | 0.732 | #13 | 0.082 | Not Required | Pass |
| 5 | 0.002 | 0.493 | 0.029 | 0.079 | 0.007 | 0.498 | #32 | 0.076 | Not Required | Pass |
| 6 | 0.002 | 0.798 | 0.011 | 0.079 | 0.001 | 0.807 | #32 | 0.046 | Not Required | Pass |
| 7 | 0.002 | 0.498 | 0.030 | 0.080 | 0.008 | 0.504 | #32 | 0.076 | Not Required | Pass |
| 8 | 0.000 | 0.048 | 0.036 | 0.046 | 0.003 | 0.063 | #13 | 0.102 | Not Required | Pass |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 9 | 0.003 | 0.078 | 0.030 | 0.001 | 0.000 | 0.109 | #13 | 0.206 | Not Required | Pass |
| 10 | 0.002 | 0.709 | 0.029 | 0.071 | 0.006 | 0.725 | #13 | 0.082 | Not Required | Pass |
| 11 | 0.000 | 0.057 | 0.036 | 0.052 | 0.003 | 0.092 | #16 | 0.102 | Not Required | Pass |
| 12 | 0.001 | 0.498 | 0.162 | 0.103 | 0.031 | 0.659 | #13 | 0.036 | Not Required | Pass |
| 13 | 0.001 | 0.307 | 0.080 | 0.066 | 0.004 | 0.354 | #13 | 0.306 | Not Required | Pass |
| 14 | 0.001 | 0.286 | 0.080 | 0.059 | 0.004 | 0.330 | #13 | 0.204 | Not Required | Pass |
| 15 | 0.000 | 0.111 | 0.043 | 0.039 | 0.003 | 0.145 | #13 | Not Required | Not Required | Pass |
| 16 | 0.000 | 0.099 | 0.043 | 0.035 | 0.003 | 0.136 | #13 | Not Required | Not Required | Pass |
| 101 | 0.085 | 0.865 | 0.004 | 0.044 | 0.000 | 0.875 | #16 | 0.470 | Not Required | Pass |
| 102 | 0.001 | 0.520 | 0.168 | 0.109 | 0.033 | 0.688 | #13 | 0.036 | Not Required | Pass |
| 103 | 0.002 | 0.826 | 0.011 | 0.082 | 0.002 | 0.834 | #32 | 0.046 | Not Required | Pass |
| 104 | 0.002 | 0.752 | 0.028 | 0.075 | 0.006 | 0.773 | #13 | 0.082 | Not Required | Pass |
| 105 | 0.002 | 0.515 | 0.028 | 0.082 | 0.007 | 0.519 | #32 | 0.076 | Not Required | Pass |
| 106 | 0.002 | 0.842 | 0.012 | 0.083 | 0.002 | 0.851 | #32 | 0.046 | Not Required | Pass |
| 107 | 0.002 | 0.526 | 0.028 | 0.084 | 0.007 | 0.529 | #32 | 0.076 | Not Required | Pass |
| 108 | 0.001 | 0.059 | 0.029 | 0.045 | 0.003 | 0.071 | #13 | 0.102 | Not Required | Pass |
| 109 | 0.002 | 0.079 | 0.029 | 0.001 | 0.000 | 0.110 | #13 | 0.206 | Not Required | Pass |
| 110 | 0.002 | 0.759 | 0.027 | 0.076 | 0.006 | 0.773 | #13 | 0.082 | Not Required | Pass |
| 111 | 0.000 | 0.068 | 0.029 | 0.050 | 0.003 | 0.077 | #13 | 0.102 | Not Required | Pass |
| 112 | 0.000 | 0.531 | 0.170 | 0.110 | 0.034 | 0.701 | #13 | 0.036 | Not Required | Pass |
| 113 | 0.001 | 0.246 | 0.076 | 0.064 | 0.004 | 0.293 | #13 | 0.306 | Not Required | Pass |
| 114 | 0.002 | 0.236 | 0.076 | 0.057 | 0.004 | 0.281 | #13 | 0.306 | Not Required | Pass |
| 115 | 0.000 | 0.294 | 0.042 | 0.049 | 0.003 | 0.327 | #13 | 0.507 | Not Required | Pass |
| 116 | 0.000 | 0.265 | 0.042 | 0.044 | 0.003 | 0.301 | #13 | 0.507 | Not Required | Pass |
| 201 | 0.086 | 0.876 | 0.000 | 0.045 | 0.000 | 0.886 | #16 | 0.470 | Not Required | Pass |
| 202 | 0.000 | 0.532 | 0.172 | 0.111 | 0.034 | 0.704 | #13 | 0.036 | Not Required | Pass |
| 203 | 0.002 | 0.847 | 0.012 | 0.084 | 0.002 | 0.856 | #32 | 0.046 | Not Required | Pass |
| 204 | 0.002 | 0.765 | 0.027 | 0.076 | 0.006 | 0.782 | #13 | 0.082 | Not Required | Pass |
| 205 | 0.002 | 0.528 | 0.028 | 0.084 | 0.007 | 0.532 | #32 | 0.076 | Not Required | Pass |
| 206 | 0.002 | 0.847 | 0.012 | 0.084 | 0.002 | 0.856 | #32 | 0.046 | Not Required | Pass |
| 207 | 0.002 | 0.528 | 0.028 | 0.084 | 0.007 | 0.532 | #32 | 0.076 | Not Required | Pass |
| 208 | 0.001 | 0.056 | 0.029 | 0.045 | 0.003 | 0.065 | #13 | 0.102 | Not Required | Pass |
| 209 | 0.002 | 0.078 | 0.030 | 0.001 | 0.000 | 0.109 | #13 | 0.206 | Not Required | Pass |
| 210 | 0.002 | 0.765 | 0.027 | 0.076 | 0.006 | 0.782 | #13 | 0.082 | Not Required | Pass |
| 211 | 0.000 | 0.065 | 0.030 | 0.050 | 0.003 | 0.075 | #16 | 0.102 | Not Required | Pass |
| 212 | 0.000 | 0.532 | 0.172 | 0.111 | 0.034 | 0.704 | #13 | 0.036 | Not Required | Pass |
| 213 | 0.001 | 0.255 | 0.076 | 0.065 | 0.004 | 0.297 | #13 | 0.306 | Not Required | Pass |
| 214 | 0.002 | 0.245 | 0.076 | 0.058 | 0.004 | 0.283 | #13 | 0.306 | Not Required | Pass |
| 215 | 0.001 | 0.313 | 0.042 | 0.050 | 0.003 | 0.342 | #13 | 0.507 | Not Required | Pass |
| 216 | 0.001 | 0.276 | 0.042 | 0.045 | 0.003 | 0.310 | #13 | 0.507 | Not Required | Pass |
| 301 | 0.085 | 0.865 | 0.004 | 0.044 | 0.000 | 0.875 | #16 | 0.470 | Not Required | Pass |
| 302 | 0.000 | 0.531 | 0.170 | 0.110 | 0.034 | 0.701 | #13 | 0.036 | Not Required | Pass |
| 303 | 0.002 | 0.842 | 0.012 | 0.083 | 0.002 | 0.851 | #32 | 0.046 | Not Required | Pass |
| 304 | 0.002 | 0.759 | 0.027 | 0.076 | 0.006 | 0.773 | #13 | 0.082 | Not Required | Pass |
| 305 | 0.002 | 0.526 | 0.028 | 0.084 | 0.007 | 0.529 | #32 | 0.076 | Not Required | Pass |
| 306 | 0.002 | 0.826 | 0.011 | 0.082 | 0.002 | 0.834 | #32 | 0.046 | Not Required | Pass |
| 307 | 0.002 | 0.515 | 0.028 | 0.082 | 0.007 | 0.519 | #32 | 0.076 | Not Required | Pass |
| 308 | 0.000 | 0.057 | 0.033 | 0.044 | 0.003 | 0.067 | #13 | 0.102 | Not Required | Pass |
| 309 | 0.002 | 0.079 | 0.029 | 0.001 | 0.000 | 0.110 | #13 | 0.206 | Not Required | Pass |
| 310 | 0.002 | 0.752 | 0.028 | 0.075 | 0.006 | 0.773 | #13 | 0.082 | Not Required | Pass |
| 311 | 0.000 | 0.066 | 0.033 | 0.049 | 0.003 | 0.080 | #16 | 0.102 | Not Required | Pass |
| 312 | 0.001 | 0.520 | 0.168 | 0.109 | 0.033 | 0.688 | #13 | 0.036 | Not Required | Pass |
| 313 | 0.001 | 0.246 | 0.076 | 0.064 | 0.004 | 0.293 | #13 | 0.306 | Not Required | Pass |
| 314 | 0.002 | 0.236 | 0.076 | 0.057 | 0.004 | 0.281 | #13 | 0.306 | Not Required | Pass |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 315 | 0.001 | 0.313 | 0.042 | 0.050 | 0.003 | 0.341 | #13 | 0.507 | Not Required | Pass |
| 316 | 0.001 | 0.276 | 0.042 | 0.045 | 0.003 | 0.312 | #13 | 0.507 | Not Required | Pass |
| 401 | 0.080 | 0.827 | 0.002 | 0.042 | 0.000 | 0.836 | #16 | 0.470 | Not Required | Pass |
| 402 | 0.001 | 0.498 | 0.162 | 0.103 | 0.031 | 0.659 | #13 | 0.036 | Not Required | Pass |
| 403 | 0.002 | 0.798 | 0.011 | 0.079 | 0.001 | 0.807 | #32 | 0.046 | Not Required | Pass |
| 404 | 0.002 | 0.709 | 0.029 | 0.071 | 0.006 | 0.725 | #13 | 0.082 | Not Required | Pass |
| 405 | 0.002 | 0.498 | 0.030 | 0.080 | 0.008 | 0.504 | #32 | 0.076 | Not Required | Pass |
| 406 | 0.002 | 0.791 | 0.010 | 0.078 | 0.002 | 0.796 | #32 | 0.046 | Not Required | Pass |
| 407 | 0.002 | 0.493 | 0.029 | 0.079 | 0.007 | 0.498 | #32 | 0.076 | Not Required | Pass |
| 408 | 0.000 | 0.099 | 0.043 | 0.035 | 0.003 | 0.136 | #13 | Not Required | Not Required | Pass |
| 409 | 0.003 | 0.078 | 0.030 | 0.001 | 0.000 | 0.109 | #13 | 0.206 | Not Required | Pass |
| 410 | 0.002 | 0.718 | 0.028 | 0.072 | 0.006 | 0.732 | #13 | 0.082 | Not Required | Pass |
| 411 | 0.000 | 0.111 | 0.043 | 0.039 | 0.003 | 0.145 | #13 | Not Required | Not Required | Pass |
| 412 | 0.001 | 0.504 | 0.163 | 0.104 | 0.032 | 0.667 | #13 | 0.036 | Not Required | Pass |
| 413 | 0.001 | 0.307 | 0.080 | 0.066 | 0.004 | 0.354 | #13 | 0.204 | Not Required | Pass |
| 414 | 0.001 | 0.286 | 0.080 | 0.059 | 0.004 | 0.330 | #13 | 0.306 | Not Required | Pass |
| 415 | 0.000 | 0.291 | 0.042 | 0.052 | 0.003 | 0.318 | #13 | 0.507 | Not Required | Pass |
| 416 | 0.000 | 0.261 | 0.042 | 0.046 | 0.003 | 0.297 | #13 | 0.507 | 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/comresssion) |
| $M_n$ | 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 |
|---|---|---|

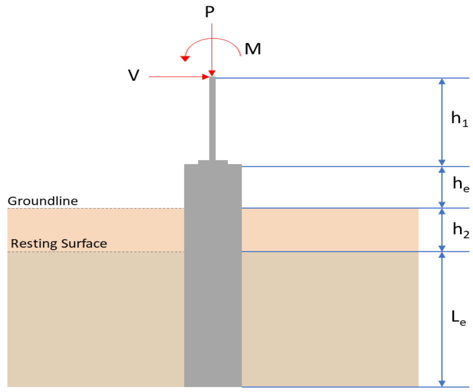
## SkyCiv Foundation Design

Pile Foundation

**Design Information :**

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

### Pile Input




**Geometry**

Pile shape: round
$D = 36\ \mathrm{in}$ - Pile diameter
$L = 15\ \mathrm{ft}$ - Total pile length
$h_1 = 0\ \mathrm{ft}$ - Lateral load height from the top of the pile,
$h_2 = 0\ \mathrm{ft}$ - Depth to resisting surface
$h_e = 0\ \mathrm{ft}$ - 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) | 10.269 | 15.956 |
| $V_x$ (kip) | -2.848 | -4.746 |
| $V_z$ (kip) | -0.016 | -0.024 |
| $M_x$ (kipft) | -0.049 | -0.075 |
| $M_z$ (kipft) | 40.935 | 68.905 |

**Material Properties**

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

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

$H$ - Point of application of the lateral load

$$H = h_1 + h_2 + h_e$$

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

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

**Considering x-direction:**

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-2.848\ \mathrm{kip})}{(36\ \mathrm{in})}$$

$$H_o = -0.94933\ \mathrm{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(40.935 \text{ kipft}) + ((-2.848 \text{ kip}) \times (0 \text{ ft}))}{(36 \text{ in})}$$

$$M_o = 13.645 \text{ kipft/ft}$$

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:
$L_{e,x} = 9.52 \text{ ft}$ - Required depth in x-direction,

**Considering z-direction:**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_z}{D}$$

$$H_o = \frac{(-0.016 \text{ kip})}{(36 \text{ in})}$$

$$H_o = -0.0053333 \text{ kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(0.049 \text{ kipft}) + ((-0.016 \text{ kip}) \times (0 \text{ ft}))}{(36 \text{ in})}$$

$$M_o = 0.016333 \text{ kipft/ft}$$

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:
$L_{e,z} = 1.1395 \text{ ft}$ - Required depth in z-direction,

**Minimum embedded depth required:**

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

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

$$L_{e,req} = MAX[(9.52 \text{ ft}), (1.1395 \text{ ft})]$$

$$L_{e,req} = 9.52 \text{ ft}$$

$L_e$ - Actual embedded length of pile,

$$L_e = L - h_e - h_2$$

$$L_e = (15 \text{ ft}) - (0 \text{ ft}) - (0 \text{ ft})$$

$$L_e = 15 \text{ ft}$$

$Ratio$ - Embedded depth

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

$$Ratio = \frac{(9.52 \text{ ft})}{(15 \text{ ft})}$$

$$Ratio = 0.63467$$

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

**End-bearing Capacity (ASD)**

$A$ - Pile cros-section area

$$A = \pi \left(\frac{D}{2}\right)^2$$

$$A = \pi \times \left(\frac{(36 \text{ in})}{2}\right)^2$$

$$A = 7.0686 \text{ ft}^2$$

$q$ - End-bearing pressure

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

$$q = \frac{(10.269 \text{ kip})}{(7.0686 \text{ ft}^2)}$$

$$q = 1.4528\ \mathrm{kip/ft^2}$$

**Check bearing capacity ratio:**

$Ratio$ - Capacity

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

$$Ratio = \frac{\left(1.4528\ \mathrm{kip/ft^2}\right)}{(2000\ \mathrm{psf})}$$

$$Ratio = 0.72638$$

Status: **PASS**
Ratio: **0.730**

*Czerniak*

**Lateral Soil Pressure (ASD):**

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

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

$$L/D = \frac{(15\ \mathrm{ft})}{(36\ \mathrm{in})}$$

$$L/D = 5$$

Since L/D $\leq$ 10,

Pile is short.

**Considering x-direction:**

$H_o = -0.94933\ \mathrm{kip/ft}$ - Lateral force per length of pile,
$M_o = 13.645\ \mathrm{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (13.645\ \mathrm{kipft/ft}) \times (15\ \mathrm{ft})) + \left(3 \times (-0.94933\ \mathrm{kip/ft}) \times (15\ \mathrm{ft})^2\right)}{(6 \times (13.645\ \mathrm{kipft/ft})) + (4 \times (-0.94933\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))}$$

$$a = 10.513\ \mathrm{ft}$$

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

$$p = \frac{1.178\,[(4\,M_o) + (3\,H_o\,L_e)]^2}{L_e^2\,[(3\,M_o) + (2\,H_o\,L_e)]}$$

$$p = \frac{1.178 \times [(4 \times (13.645\ \mathrm{kipft/ft})) + (3 \times (-0.94933\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]^2}{(15\ \mathrm{ft})^2 \times [(3 \times (13.645\ \mathrm{kipft/ft})) + (2 \times (-0.94933\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]}$$

$$p = 0.059127\ \mathrm{kip/ft^2}$$

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

$$s = \frac{9.425\,[(2\,M_o) + (H_o\,L_e)]}{L_e^2}$$

$$s = \frac{9.425 \times [(2 \times (13.645\ \mathrm{kipft/ft})) + ((-0.94933\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]}{(15\ \mathrm{ft})^2}$$

$$s = 0.54665\ \mathrm{kip/ft^2}$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150\ \mathrm{psf/ft}) \times \frac{(10.513\ \mathrm{ft})}{2}$$

$$p_a = 0.78846\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(0.059127\ \mathrm{kip/ft^2}\right)}{\left(0.78846\ \mathrm{kip/ft^2}\right)}$$

$$Ratio = 0.074991$$

Status: **PASS**
Ratio: **0.070**

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

$$p_s = R\,L_e$$

$$p_s = (150\ \mathrm{psf/ft}) \times (15\ \mathrm{ft})$$

$$p_s = 2.25\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(0.54665\ \mathrm{kip/ft^2}\right)}{\left(2.25\ \mathrm{kip/ft^2}\right)}$$

$$Ratio = 0.24296$$

Status: **PASS**
Ratio: **0.240**

**Considering z-direction:**

$H_o = -0.0053333\ \mathrm{kip/ft}$ - Lateral force per length of pile,
$M_o = 0.016333\ \mathrm{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (0.016333\ \mathrm{kipft/ft}) \times (15\ \mathrm{ft})) + \left(3 \times (-0.0053333\ \mathrm{kip/ft}) \times (15\ \mathrm{ft})^2\right)}{(6 \times (0.016333\ \mathrm{kipft/ft})) + (4 \times (-0.0053333\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))}$$

$$a = 10.957\ \mathrm{ft}$$

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

$$p = \frac{1.178\,\left[(4\,M_o) + (3\,H_o\,L_e)\right]^2}{L_e^2\,\left[(3\,M_o) + (2\,H_o\,L_e)\right]}$$

$$p = \frac{1.178 \times \left[(4 \times (0.016333\ \mathrm{kipft/ft})) + (3 \times (-0.0053333\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))\right]^2}{(15\ \mathrm{ft})^2 \times \left[(3 \times (0.016333\ \mathrm{kipft/ft})) + (2 \times (-0.0053333\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))\right]}$$

$$p = -0.001439\ \mathrm{kip/ft^2}$$

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

$$s = \frac{9.425\,\left[(2\,M_o) + (H_o\,L_e)\right]}{L_e^2}$$

$$s = \frac{9.425 \times \left[(2 \times (0.016333\ \mathrm{kipft/ft})) + ((-0.0053333\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))\right]}{(15\ \mathrm{ft})^2}$$

$$s = -0.0019827\ \mathrm{kip/ft^2}$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150\ \mathrm{psf/ft}) \times \frac{(10.957\ \mathrm{ft})}{2}$$

$$p_a = 0.82177\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(-0.001439\ \mathrm{kip/ft^2}\right)}{\left(0.82177\ \mathrm{kip/ft^2}\right)}$$

$$Ratio = -0.0017511$$

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

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

$$p_s = R\,L_e$$

$$p_s = (150\ \mathrm{psf/ft}) \times (15\ \mathrm{ft})$$

$$p_s = 2.25\ \mathrm{kip/ft^2}$$

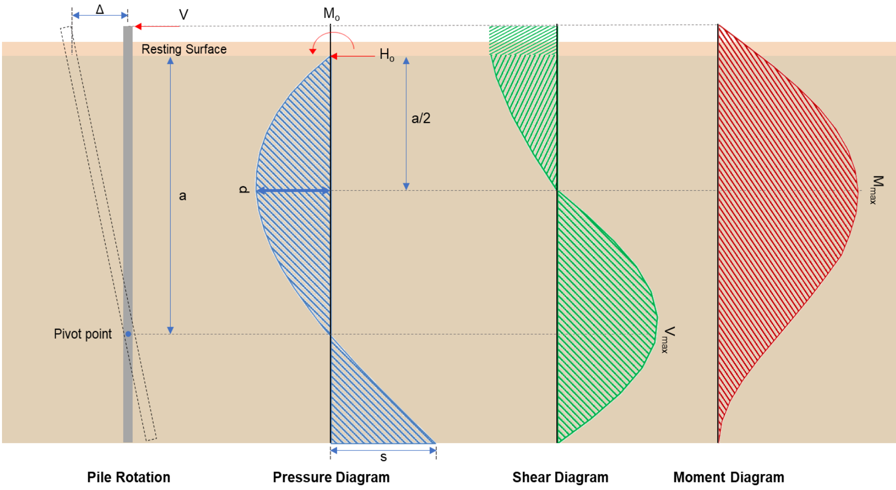
$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(-0.0019827\ \mathrm{kip/ft^2}\right)}{\left(2.25\ \mathrm{kip/ft^2}\right)}$$

$$Ratio = -0.00088122$$

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




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

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-4.746\ \mathrm{kip})}{(36\ \mathrm{in})}$$

$$H_o = -1.582\ \mathrm{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(68.905\ \mathrm{kipft}) + ((-4.746\ \mathrm{kip}) \times (0\ \mathrm{ft}))}{(36\ \mathrm{in})}$$

$$M_o = 22.968\ \mathrm{kipft/ft}$$

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

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

$$E = \frac{(22.968\ \mathrm{kipft/ft})}{(-1.582\ \mathrm{kip/ft})}$$

$$E = 14.519\ \mathrm{ft}$$

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

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

$$a = \frac{(4 \times (22.968\ \mathrm{kipft/ft}) \times (15\ \mathrm{ft})) + \left(3 \times (-1.582\ \mathrm{kip/ft}) \times (15\ \mathrm{ft})^2\right)}{(6 \times (22.968\ \mathrm{kipft/ft})) + (4 \times (-1.582\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))}$$

$$a = 10.51\ \mathrm{ft}$$

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

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

$$V_{max} = ((-1.582\ \mathrm{kip/ft}) \times (36\ \mathrm{in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (14.519\ \mathrm{ft})}{(15\ \mathrm{ft})} + 3\right) \times \left(\frac{(10.51\ \mathrm{ft})}{(15\ \mathrm{ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (14.519\ \mathrm{ft})}{(15\ \mathrm{ft})} + 2\right) \times \left(\frac{(10.51\ \mathrm{ft})}{(15\ \mathrm{ft})}\right)^3\right]\right]$$

$$V_{max} = 11.264 \text{ kip}$$

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

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

$$M_{max} = ((-1.582 \text{ kip/ft}) \times (36 \text{ in}) \times (15 \text{ ft})) \times \left[\left(\frac{(14.519 \text{ ft})}{(15 \text{ ft})} + \frac{(10.51 \text{ ft})}{2 \times (15 \text{ ft})}\right) - \left[\left(\frac{4 \times (14.519 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.51 \text{ ft})}{2 \times (15 \text{ ft})}\right)^3\right] + \left[\left(\frac{3 \times (14.519 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.51 \text{ ft})}{2 \times (15 \text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 78.07 \text{ kipft}$$

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

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_z}{D}$$

$$H_o = \frac{(-0.024 \text{ kip})}{(36 \text{ in})}$$

$$H_o = -0.008 \text{ kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(0.075 \text{ kipft}) + ((-0.024 \text{ kip}) \times (0 \text{ ft}))}{(36 \text{ in})}$$

$$M_o = 0.025 \text{ kipft/ft}$$

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

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

$$E = \frac{(0.025 \text{ kipft/ft})}{(-0.008 \text{ kip/ft})}$$

$$E = 3.125 \text{ ft}$$

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

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

$$a = \frac{(4 \times (0.025 \text{ kipft/ft}) \times (15 \text{ ft})) + \left(3 \times (-0.008 \text{ kip/ft}) \times (15 \text{ ft})^2\right)}{(6 \times (0.025 \text{ kipft/ft})) + (4 \times (-0.008 \text{ kip/ft}) \times (15 \text{ ft}))}$$

$$a = 10.952 \text{ ft}$$

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

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

$$V_{max} = ((-0.008 \text{ kip/ft}) \times (36 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (3.125 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.952 \text{ ft})}{(15 \text{ ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (3.125 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.952 \text{ ft})}{(15 \text{ ft})}\right)^3\right]\right]$$

$$V_{max} = 0.025048 \text{ kip}$$

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

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

$$M_{max} = ((-0.008 \text{ kip/ft}) \times (36 \text{ in}) \times (15 \text{ ft})) \times \left[\left(\frac{(3.125 \text{ ft})}{(15 \text{ ft})} + \frac{(10.952 \text{ ft})}{2 \times (15 \text{ ft})}\right) - \left[\left(\frac{4 \times (3.125 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.952 \text{ ft})}{2 \times (15 \text{ ft})}\right)^3\right] + \left[\left(\frac{3 \times (3.125 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.952 \text{ ft})}{2 \times (15 \text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 0.15607 \text{ kipft}$$

**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* $\alpha = 0.85$ - Alpha factor for axial strength,
$A_g = 1017.9 \text{ in}^2$ - Gross area of concrete,

**Longitudinal reinforcement:**

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

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

$$A_{st,required} = Min\left[\frac{\frac{(15.956 \text{ kip})}{(0.65)\times(0.85)} - \left(0.85 \times (2.5 \text{ ksi}) \times \left(1017.9 \text{ in}^2\right)\right)}{(60 \text{ ksi}) - (0.85 \times (2.5 \text{ ksi}))}, \left(0.08 \times \left(1017.9 \text{ in}^2\right)\right)\right]$$

$$A_{st,required} = -36.874 \text{ in}^2$$

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

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

$$A_{min} = Max\left[\left(-36.874 \text{ in}^2\right), \left(0.0018 \times \left(1017.9 \text{ in}^2\right)\right)\right]$$

$$A_{min} = 1.8322 \text{ in}^2$$

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

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

$$n_{rebar} = \frac{\left(1.8322 \text{ in}^2\right)}{\left(0.3068 \text{ in}^2\right)}$$

$$n_{rebar} = 6$$

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

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

$$A_{st} = (6) \times \frac{\pi \times (0.625 \text{ in})^2}{4}$$

$$A_{st} = 1.8408 \text{ in}^2$$

$Ratio$ - Capacity

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

$$Ratio = \frac{\left(1.8322 \text{ in}^2\right)}{\left(1.8408 \text{ in}^2\right)}$$

$$Ratio = 0.99533$$

Status: **PASS**
Ratio: **1.000**

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

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

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

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

**Ties:**

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

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

$$s_{ties} = Min\left[(16 \times (0.625 \text{ in})), (48 \times (0.375 \text{ in})), (36 \text{ in})\right]$$

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

**Summary:**

Main reinforcement: **6 - #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

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

$$\phi P_N = (0.65) \times 0.85 \times \left[\left(0.85 \times (2.5\text{ ksi}) \times \left[\left(1017.9\text{ in}^2\right) - \left(1.8408\text{ in}^2\right)\right]\right) + \left((60\text{ ksi}) \times \left(1.8408\text{ in}^2\right)\right)\right]$$

$$\phi P_N = 1253.9\text{ kip}$$

$Ratio$ - Capacity

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

$$Ratio = \frac{(15.956\text{ kip})}{(1253.9\text{ kip})}$$

$$Ratio = 0.012725$$

Status: **PASS**
Ratio: **0.010**

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

**Parameters:**

$b_w = 36\text{ in}$ - Effective width,

22.5.2.2 $d$ - Effective depth

$$d = 0.80\, D$$

$$d = 0.80 \times (36\text{ in})$$

$$d = 28.8\text{ in}$$

22.5.5.1.3 $\lambda_s$ - size effect modification factor

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

$$\lambda_s = MIN\left[\sqrt{\frac{2}{1 + \frac{(28.8\text{ in})}{10}}}, 1\right]$$

$$\lambda_s = 0.71796$$

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

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

$$V_{c,max} = 5 \times (0.71796) \times \sqrt{(2500\text{ psi})} \times (36\text{ in}) \times (28.8\text{ in})$$

$$V_{c,max} = 186.09\text{ kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\text{ ksi} \rightarrow 2500\text{ psi}$, $P = 15.956\text{ kip} \rightarrow 15956\text{ lbf}$,

22.5.5.1.1(a) $V_{c,a}$ - Shear strength of concrete (a)

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

$$V_{c,a} = \left[2 \times (0.71796) \times \sqrt{(2500\text{ psi})} + \frac{(15956\text{ lbf})}{6 \times \left(1017.9\text{ in}^2\right)}\right] \times (36\text{ in}) \times (28.8\text{ in})$$

$$V_{c,a} = 77.147\text{ kip}$$

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)

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

$$V_{c,b} = \left[2 \times (0.71796) \times \sqrt{(2500\text{ psi})} + (0.05 \times (2500\text{ psi}))\right] \times (36\text{ in}) \times (28.8\text{ in})$$

$$V_{c,b} = 204.04\text{ kip}$$

$V_c$ - Governing shear strength of concrete

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

$$V_c = Min\left[(186.09\text{ kip}), (77.147\text{ kip}), (204.04\text{ kip})\right]$$

$$V_c = 77.147\ \text{kip}$$

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)

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

$$V_{s,a} = 8 \times \sqrt{(2500\ \text{psi})} \times (36\ \text{in}) \times (28.8\ \text{in})$$

$$V_{s,a} = 414.72\ \text{kip}$$

$A_v$ - 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)

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

$$V_{s,b} = \frac{2 \times \left(0.11045\ \text{in}^2\right) \times (60\ \text{ksi}) \times (28.8\ \text{in})}{(10\ \text{in})}$$

$$V_{s,b} = 38.17\ \text{kip}$$

$V_s$ - Governing shear strength of steel

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

$$V_s = MIN\left[(414.72\ \text{kip}), (38.17\ \text{kip})\right]$$

$$V_s = 38.17\ \text{kip}$$

22.5.1.1 $\phi V_n$ - Allowable shear strength

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

$$\phi V_n = (0.65) \times ((77.147\ \text{kip}) + (38.17\ \text{kip}))$$

$$\phi V_n = 74.956\ \text{kip}$$

**Considering x-direction:**

$V_{max} = 11.264\ \text{kip}$ - Maximum shear force in the x-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(11.264\ \text{kip})}{(74.956\ \text{kip})}$$

$$Ratio = 0.15028$$

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

**Considering z-direction:**

$V_{max} = 0.025048\ \text{kip}$ - Maximum shear force in the z-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(0.025048\ \text{kip})}{(74.956\ \text{kip})}$$

$$Ratio = 0.00033417$$

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

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

$S_m$ - Section modulus

$$S_m = \frac{\pi\, D^3}{32}$$

$$S_m = \frac{\pi \times (36\ \text{in})^3}{32}$$

$$S_m = 4580.4\ \text{in}^3$$

$$S_m = 4580.4 \text{ in}^3$$

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

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

$$\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{(2.5ksi)} \times 4580.442in^3$$

$$\phi M_{n,1} = 62.027kipft$$

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

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

$$\phi M_{n,2} = (0.65) \times 0.85 \times (2.5 \text{ ksi}) \times \left(4580.4 \text{ in}^3\right)$$

$$\phi M_{n,2} = 527.23 \text{ kipft}$$

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

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

$$\phi M_n = MIN[(62.027 \text{ kipft}), (527.23 \text{ kipft})]$$

$$\phi M_n = 62.027 \text{ kipft}$$

**Considering x-direction:**

$M_{max} = 78.07 \text{ kipft}$ - Maximum moment in the x-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(78.07 \text{ kipft})}{(62.027 \text{ kipft})}$$

$$Ratio = 1.2587$$

Status: **FAIL**
Ratio: **1.260**

**Considering z-direction:**

$M_{max} = 0.15607 \text{ kipft}$ - Maximum moment in the z-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(0.15607 \text{ kipft})}{(62.027 \text{ kipft})}$$

$$Ratio = 0.0025161$$

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

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

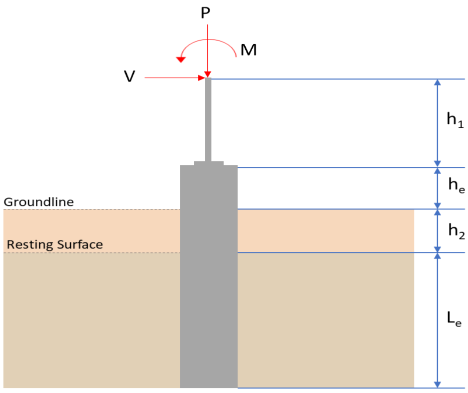
## SkyCiv Foundation Design

Pile Foundation

**Design Information :**

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

### Pile Input




**Geometry**

Pile shape: round
$D = 36\ \mathrm{in}$ - Pile diameter
$L = 15\ \mathrm{ft}$ - Total pile length
$h_1 = 0\ \mathrm{ft}$ - Lateral load height from the top of the pile,
$h_2 = 0\ \mathrm{ft}$ - Depth to resisting surface
$h_e = 0\ \mathrm{ft}$ - Length of pile above the ground

**Tabulation of Soil Parameters**

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

**Tabulation of Loads**

| Load Component | ASD | LRFD |
|---|---|---|
| $P$ (kip) | 10.828 | 16.834 |
| $V_x$ (kip) | -2.985 | -4.979 |
| $V_z$ (kip) | 0.024 | 0.039 |
| $M_x$ (kipft) | 0.075 | 0.121 |
| $M_z$ (kipft) | 42.767 | 72.017 |

**Material Properties**

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

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

$H$ - Point of application of the lateral load

$$H = h_1 + h_2 + h_e$$

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

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

**Considering x-direction:**

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-2.985\ \mathrm{kip})}{(36\ \mathrm{in})}$$

$$H_o = -0.995\ \mathrm{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(42.767 \text{ kipft}) + ((-2.985 \text{ kip}) \times (0 \text{ ft}))}{(36 \text{ in})}$$

$$M_o = 14.256 \text{ kipft/ft}$$

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:
$L_{e,x} = 9.617 \text{ ft}$ - Required depth in x-direction,

**Considering z-direction:**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_z}{D}$$

$$H_o = \frac{(0.024 \text{ kip})}{(36 \text{ in})}$$

$$H_o = 0.008 \text{ kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(0.075 \text{ kipft}) + ((0.024 \text{ kip}) \times (0 \text{ ft}))}{(36 \text{ in})}$$

$$M_o = 0.025 \text{ kipft/ft}$$

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:
$L_{e,z} = 1.6355 \text{ ft}$ - Required depth in z-direction,

**Minimum embedded depth required:**

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

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

$$L_{e,req} = MAX[(9.617 \text{ ft}), (1.6355 \text{ ft})]$$

$$L_{e,req} = 9.617 \text{ ft}$$

$L_e$ - Actual embedded length of pile,

$$L_e = L - h_e - h_2$$

$$L_e = (15 \text{ ft}) - (0 \text{ ft}) - (0 \text{ ft})$$

$$L_e = 15 \text{ ft}$$

$Ratio$ - Embedded depth

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

$$Ratio = \frac{(9.617 \text{ ft})}{(15 \text{ ft})}$$

$$Ratio = 0.64113$$

Status: **PASS**
Ratio: **0.640**

**End-bearing Capacity (ASD)**

$A$ - Pile cros-section area

$$A = \pi \left(\frac{D}{2}\right)^2$$

$$A = \pi \times \left(\frac{(36 \text{ in})}{2}\right)^2$$

$$A = 7.0686 \text{ ft}^2$$

$q$ - End-bearing pressure

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

$$q = \frac{(10.828 \text{ kip})}{(7.0686 \text{ ft}^2)}$$

$$q = 1.5318\ \mathrm{kip/ft^2}$$

**Check bearing capacity ratio:**

$Ratio$ - Capacity

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

$$Ratio = \frac{\left(1.5318\ \mathrm{kip/ft^2}\right)}{(2000\ \mathrm{psf})}$$

$$Ratio = 0.76592$$

Status: **PASS**
Ratio: **0.770**

*Czerniak*

**Lateral Soil Pressure (ASD):**

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

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

$$L/D = \frac{(15\ \mathrm{ft})}{(36\ \mathrm{in})}$$

$$L/D = 5$$

Since L/D $\leq$ 10,

Pile is short.

**Considering x-direction:**

$H_o = -0.995\ \mathrm{kip/ft}$ - Lateral force per length of pile,
$M_o = 14.256\ \mathrm{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (14.256\ \mathrm{kipft/ft}) \times (15\ \mathrm{ft})) + \left(3 \times (-0.995\ \mathrm{kip/ft}) \times (15\ \mathrm{ft})^2\right)}{(6 \times (14.256\ \mathrm{kipft/ft})) + (4 \times (-0.995\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))}$$

$$a = 10.514\ \mathrm{ft}$$

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

$$p = \frac{1.178\ [(4\, M_o) + (3\, H_o\, L_e)]^2}{L_e^2\ [(3\, M_o) + (2\, H_o\, L_e)]}$$

$$p = \frac{1.178 \times [(4 \times (14.256\ \mathrm{kipft/ft})) + (3 \times (-0.995\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]^{\ 2}}{(15\ \mathrm{ft})^2 \times [(3 \times (14.256\ \mathrm{kipft/ft})) + (2 \times (-0.995\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]}$$

$$p = 0.060801\ \mathrm{kip/ft^2}$$

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

$$s = \frac{9.425\ [(2\, M_o) + (H_o\, L_e)]}{L_e^2}$$

$$s = \frac{9.425 \times [(2 \times (14.256\ \mathrm{kipft/ft})) + ((-0.995\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]}{(15\ \mathrm{ft})^2}$$

$$s = 0.56912\ \mathrm{kip/ft^2}$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150\ \mathrm{psf/ft}) \times \frac{(10.514\ \mathrm{ft})}{2}$$

$$p_a = 0.78854\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(0.060801\ \mathrm{kip/ft^2}\right)}{\left(0.78854\ \mathrm{kip/ft^2}\right)}$$

$$Ratio = 0.077106$$

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

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

$$p_s = R\,L_e$$

$$p_s = (150\ \mathrm{psf/ft}) \times (15\ \mathrm{ft})$$

$$p_s = 2.25\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{(0.56912\ \mathrm{kip/ft^2})}{(2.25\ \mathrm{kip/ft^2})}$$

$$Ratio = 0.25294$$

Status: **PASS**
Ratio: **0.250**

**Considering z-direction:**

$H_o = 0.008\ \mathrm{kip/ft}$ - Lateral force per length of pile,
$M_o = 0.025\ \mathrm{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (0.025\ \mathrm{kipft/ft}) \times (15\ \mathrm{ft})) + \left(3 \times (0.008\ \mathrm{kip/ft}) \times (15\ \mathrm{ft})^2\right)}{(6 \times (0.025\ \mathrm{kipft/ft})) + (4 \times (0.008\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))}$$

$$a = 10.952\ \mathrm{ft}$$

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

$$p = \frac{1.178\ [(4\,M_o) + (3\,H_o\,L_e)]^2}{L_e^2\ [(3\,M_o) + (2\,H_o\,L_e)]}$$

$$p = \frac{1.178 \times [(4 \times (0.025\ \mathrm{kipft/ft})) + (3 \times (0.008\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]^2}{(15\ \mathrm{ft})^2 \times [(3 \times (0.025\ \mathrm{kipft/ft})) + (2 \times (0.008\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]}$$

$$p = 0.003517\ \mathrm{kip/ft^2}$$

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

$$s = \frac{9.425\ [(2\,M_o) + (H_o\,L_e)]}{L_e^2}$$

$$s = \frac{9.425 \times [(2 \times (0.025\ \mathrm{kipft/ft})) + ((0.008\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]}{(15\ \mathrm{ft})^2}$$

$$s = 0.0071211\ \mathrm{kip/ft^2}$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150\ \mathrm{psf/ft}) \times \frac{(10.952\ \mathrm{ft})}{2}$$

$$p_a = 0.82143\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{(0.003517\ \mathrm{kip/ft^2})}{(0.82143\ \mathrm{kip/ft^2})}$$

$$Ratio = 0.0042815$$

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

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

$$p_s = R\,L_e$$

$$p_s = (150\ \mathrm{psf/ft}) \times (15\ \mathrm{ft})$$

$$p_s = 2.25\ \mathrm{kip/ft^2}$$

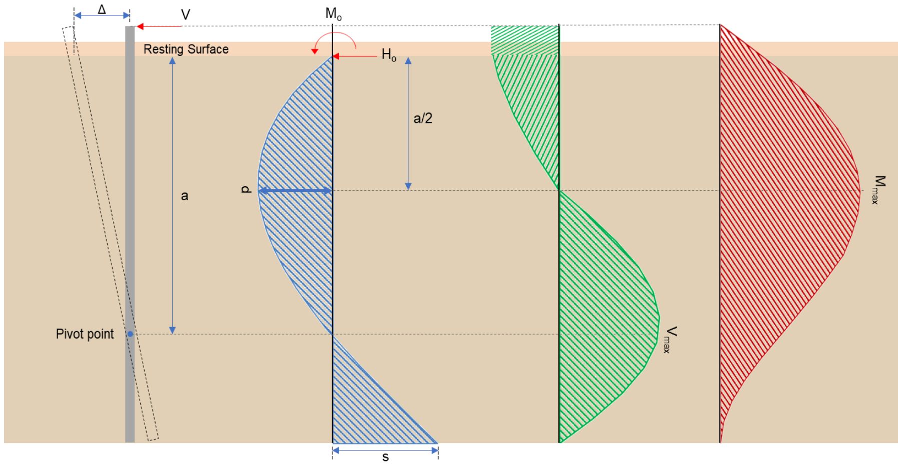
$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{(0.0071211\ \text{kip/ft}^2)}{(2.25\ \text{kip/ft}^2)}$$

$$Ratio = 0.0031649$$

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




Pile Rotation | Pressure Diagram | Shear Diagram | Moment Diagram

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

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-4.979\ \text{kip})}{(36\ \text{in})}$$

$$H_o = -1.6597\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(72.017\ \text{kipft}) + ((-4.979\ \text{kip}) \times (0\ \text{ft}))}{(36\ \text{in})}$$

$$M_o = 24.006\ \text{kipft/ft}$$

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

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

$$E = \frac{(24.006\ \text{kipft/ft})}{(-1.6597\ \text{kip/ft})}$$

$$E = 14.464\ \text{ft}$$

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

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

$$a = \frac{(4 \times (24.006\ \text{kipft/ft}) \times (15\ \text{ft})) + \left(3 \times (-1.6597\ \text{kip/ft}) \times (15\ \text{ft})^2\right)}{(6 \times (24.006\ \text{kipft/ft})) + (4 \times (-1.6597\ \text{kip/ft}) \times (15\ \text{ft}))}$$

$$a = 10.511\ \text{ft}$$

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

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

$$V_{max} = ((-1.6597\ \text{kip/ft}) \times (36\ \text{in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (14.464\ \text{ft})}{(15\ \text{ft})} + 3\right) \times \left(\frac{(10.511\ \text{ft})}{(15\ \text{ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (14.464\ \text{ft})}{(15\ \text{ft})} + 2\right) \times \left(\frac{(10.511\ \text{ft})}{(15\ \text{ft})}\right)^3\right]\right]$$

$$V_{max} = 11.785 \text{ kip}$$

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

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

$$M_{max} = ((-1.6597 \text{ kip/ft}) \times (36 \text{ in}) \times (15 \text{ ft})) \times \left[\left(\frac{(14.464 \text{ ft})}{(15 \text{ ft})} + \frac{(10.511 \text{ ft})}{2 \times (15 \text{ ft})}\right) - \left[\left(\frac{4 \times (14.464 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.511 \text{ ft})}{2 \times (15 \text{ ft})}\right)^3\right] + \left[\left(\frac{3 \times (14.464 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.511 \text{ ft})}{2 \times (15 \text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 81.664 \text{ kipft}$$

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

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_z}{D}$$

$$H_o = \frac{(0.039 \text{ kip})}{(36 \text{ in})}$$

$$H_o = 0.013 \text{ kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(0.121 \text{ kipft}) + ((0.039 \text{ kip}) \times (0 \text{ ft}))}{(36 \text{ in})}$$

$$M_o = 0.040333 \text{ kipft/ft}$$

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

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

$$E = \frac{(0.040333 \text{ kipft/ft})}{(0.013 \text{ kip/ft})}$$

$$E = 3.1026 \text{ ft}$$

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

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

$$a = \frac{(4 \times (0.040333 \text{ kipft/ft}) \times (15 \text{ ft})) + \left(3 \times (0.013 \text{ kip/ft}) \times (15 \text{ ft})^2\right)}{(6 \times (0.040333 \text{ kipft/ft})) + (4 \times (0.013 \text{ kip/ft}) \times (15 \text{ ft}))}$$

$$a = 10.954 \text{ ft}$$

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

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

$$V_{max} = ((0.013 \text{ kip/ft}) \times (36 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (3.1026 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.954 \text{ ft})}{(15 \text{ ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (3.1026 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.954 \text{ ft})}{(15 \text{ ft})}\right)^3\right]\right]$$

$$V_{max} = 0.040603 \text{ kip}$$

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

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

$$M_{max} = ((0.013 \text{ kip/ft}) \times (36 \text{ in}) \times (15 \text{ ft})) \times \left[\left(\frac{(3.1026 \text{ ft})}{(15 \text{ ft})} + \frac{(10.954 \text{ ft})}{2 \times (15 \text{ ft})}\right) - \left[\left(\frac{4 \times (3.1026 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.954 \text{ ft})}{2 \times (15 \text{ ft})}\right)^3\right] + \left[\left(\frac{3 \times (3.1026 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.954 \text{ ft})}{2 \times (15 \text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 0.25286\ \text{kipft}$$

### 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* $\alpha = 0.85$ - Alpha factor for axial strength,
$A_g = 1017.9\ \text{in}^2$ - Gross area of concrete,

**Longitudinal reinforcement:**

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

*22.4.2.2, 10.6.1.1* $A_{st,required}$

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

$$A_{st,required} = Min\left[\frac{\frac{(16.834\ \text{kip})}{(0.65)\times(0.85)} - \left(0.85 \times (2.5\ \text{ksi}) \times \left(1017.9\ \text{in}^2\right)\right)}{(60\ \text{ksi}) - (0.85 \times (2.5\ \text{ksi}))}, \left(0.08 \times \left(1017.9\ \text{in}^2\right)\right)\right]$$

$$A_{st,required} = -36.847\ \text{in}^2$$

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

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

$$A_{min} = Max\left[\left(-36.847\ \text{in}^2\right), \left(0.0018 \times \left(1017.9\ \text{in}^2\right)\right)\right]$$

$$A_{min} = 1.8322\ \text{in}^2$$

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

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

$$n_{rebar} = \frac{\left(1.8322\ \text{in}^2\right)}{\left(0.3068\ \text{in}^2\right)}$$

$$n_{rebar} = 6$$

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

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

$$A_{st} = (6) \times \frac{\pi \times (0.625\ \text{in})^2}{4}$$

$$A_{st} = 1.8408\ \text{in}^2$$

$Ratio$ - Capacity

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

$$Ratio = \frac{\left(1.8322\ \text{in}^2\right)}{\left(1.8408\ \text{in}^2\right)}$$

$$Ratio = 0.99533$$

Status: **PASS**
Ratio: **1.000**

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

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

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

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

**Ties:**

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

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

$$s_{ties} = Min\left[(16 \times (0.625\ \text{in})), (48 \times (0.375\ \text{in})), (36\ \text{in})\right]$$

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

**Summary:**

Main reinforcement: **6 - #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

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

$$\phi P_N = (0.65) \times 0.85 \times \left[\left(0.85 \times (2.5\ \text{ksi}) \times \left[\left(1017.9\ \text{in}^2\right) - \left(1.8408\ \text{in}^2\right)\right]\right) + \left((60\ \text{ksi}) \times \left(1.8408\ \text{in}^2\right)\right)\right]$$

$$\phi P_N = 1253.9\ \text{kip}$$

$Ratio$ - Capacity

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

$$Ratio = \frac{(16.834\ \text{kip})}{(1253.9\ \text{kip})}$$

$$Ratio = 0.013425$$

Status: **PASS**
Ratio: **0.010**

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

**Parameters:**

$b_w = 36\ \text{in}$ - Effective width,
22.5.2.2 $d$ - Effective depth

$$d = 0.80\, D$$

$$d = 0.80 \times (36\ \text{in})$$

$$d = 28.8\ \text{in}$$

22.5.5.1.3 $\lambda_s$ - size effect modification factor

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

$$\lambda_s = MIN\left[\sqrt{\frac{2}{1 + \frac{(28.8\ \text{in})}{10}}}, 1\right]$$

$$\lambda_s = 0.71796$$

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

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

$$V_{c,max} = 5 \times (0.71796) \times \sqrt{(2500\ \text{psi})} \times (36\ \text{in}) \times (28.8\ \text{in})$$

$$V_{c,max} = 186.09\ \text{kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$, $P = 16.834\ \text{kip} \rightarrow 16834\ \text{lbf}$,
22.5.5.1.1(a) $V_{c,a}$ - Shear strength of concrete (a)

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

$$V_{c,a} = \left[2 \times (0.71796) \times \sqrt{(2500\ \text{psi})} + \frac{(16834\ \text{lbf})}{6 \times (1017.9\ \text{in}^2)}\right] \times (36\ \text{in}) \times (28.8\ \text{in})$$

$$V_{c,a} = 77.296\ \text{kip}$$

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)

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

$$V_{c,b} = \left[2 \times (0.71796) \times \sqrt{(2500\ \text{psi})} + (0.05 \times (2500\ \text{psi}))\right] \times (36\ \text{in}) \times (28.8\ \text{in})$$

$$V_{c,b} = 204.04\ \text{kip}$$

$V_c$ - Governing shear strength of concrete

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

$$V_c = Min\left[(186.09\ \text{kip}), (77.296\ \text{kip}), (204.04\ \text{kip})\right]$$

$$V_c = 77.296\ \text{kip}$$

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)

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

$$V_{s,a} = 8 \times \sqrt{(2500\ \text{psi})} \times (36\ \text{in}) \times (28.8\ \text{in})$$

$$V_{s,a} = 414.72\ \text{kip}$$

$A_v$ - 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)

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

$$V_{s,b} = \frac{2 \times \left(0.11045\ \text{in}^2\right) \times (60\ \text{ksi}) \times (28.8\ \text{in})}{(10\ \text{in})}$$

$$V_{s,b} = 38.17\ \text{kip}$$

$V_s$ - Governing shear strength of steel

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

$$V_s = MIN\left[(414.72\ \text{kip}), (38.17\ \text{kip})\right]$$

$$V_s = 38.17\ \text{kip}$$

22.5.1.1 $\phi V_n$ - Allowable shear strength

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

$$\phi V_n = (0.65) \times ((77.296\ \text{kip}) + (38.17\ \text{kip}))$$

$$\phi V_n = 75.053\ \text{kip}$$

**Considering x-direction:**

$V_{max} = 11.785\ \text{kip}$ - Maximum shear force in the x-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(11.785\ \text{kip})}{(75.053\ \text{kip})}$$

$$Ratio = 0.15703$$

Status: **PASS**
Ratio: **0.160**

**Considering z-direction:**

$V_{max} = 0.040603\ \text{kip}$ - Maximum shear force in the z-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(0.040603\ \text{kip})}{(75.053\ \text{kip})}$$

$$Ratio = 0.00054098$$

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

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

$S_m$ - Section modulus

$$S_m = \frac{\pi\, D^3}{32}$$

$$S_m = \frac{\pi \times (36\ \text{in})^3}{32}$$

$$S_m = 4580.4\ \text{in}^3$$

$$S_m = 4580.4 \text{ in}^3$$

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

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

$$\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{(2.5ksi)} \times 4580.442in^3$$

$$\phi M_{n,1} = 62.027kipft$$

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

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

$$\phi M_{n,2} = (0.65) \times 0.85 \times (2.5 \text{ ksi}) \times \left(4580.4 \text{ in}^3\right)$$

$$\phi M_{n,2} = 527.23 \text{ kipft}$$

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

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

$$\phi M_n = MIN[(62.027 \text{ kipft}), (527.23 \text{ kipft})]$$

$$\phi M_n = 62.027 \text{ kipft}$$

**Considering x-direction:**

$M_{max} = 81.664 \text{ kipft}$ - Maximum moment in the x-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(81.664 \text{ kipft})}{(62.027 \text{ kipft})}$$

$$Ratio = 1.3166$$

Status: **FAIL**
Ratio: **1.320**

**Considering z-direction:**

$M_{max} = 0.25286 \text{ kipft}$ - Maximum moment in the z-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(0.25286 \text{ kipft})}{(62.027 \text{ kipft})}$$

$$Ratio = 0.0040766$$

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

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

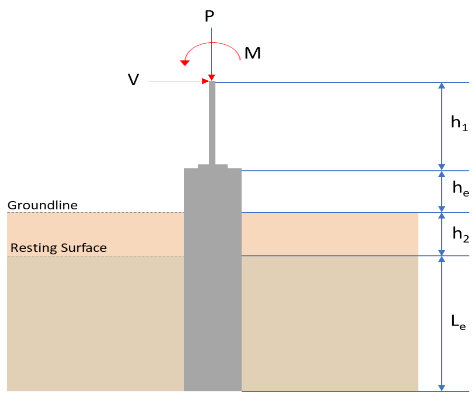
## SkyCiv Foundation Design

Pile Foundation

**Design Information :**

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

### Pile Input




**Geometry**

Pile shape: round
$D = 36\ \text{in}$ - Pile diameter
$L = 15\ \text{ft}$ - 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) | 10.959 | 17.042 |
| $V_x$ (kip) | -3.030 | -5.049 |
| $V_z$ (kip) | 0.000 | 0.000 |
| $M_x$ (kipft) | 0.000 | 0.000 |
| $M_z$ (kipft) | 43.345 | 72.994 |

**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,

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

$$H_o = \frac{(-3.03\ \text{kip})}{(36\ \text{in})}$$

$$H_o = -1.01\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(43.345 \text{ kipft}) + ((-3.03 \text{ kip}) \times (0 \text{ ft}))}{(36 \text{ in})}$$

$$M_o = 14.448 \text{ kipft/ft}$$

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:
$L_{e,x} = 9.6454 \text{ ft}$ - 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,

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

$$L_{e,req} = MAX[(9.6454 \text{ ft}), (0 \text{ ft})]$$

$$L_{e,req} = 9.645 \text{ ft}$$

$L_e$ - Actual embedded length of pile,

$$L_e = L - h_e - h_2$$

$$L_e = (15 \text{ ft}) - (0 \text{ ft}) - (0 \text{ ft})$$

$$L_e = 15 \text{ ft}$$

$Ratio$ - Embedded depth

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

$$Ratio = \frac{(9.645 \text{ ft})}{(15 \text{ ft})}$$

$$Ratio = 0.643$$

Status: **PASS**
Ratio: **0.640**

**End-bearing Capacity (ASD)**

$A$ - Pile cros-section area

$$A = \pi \left(\frac{D}{2}\right)^2$$

$$A = \pi \times \left(\frac{(36 \text{ in})}{2}\right)^2$$

$$A = 7.0686 \text{ ft}^2$$

$q$ - End-bearing pressure

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

$$q = \frac{(10.959 \text{ kip})}{(7.0686 \text{ ft}^2)}$$

$$q = 1.5504 \text{ kip/ft}^2$$

**Check bearing capacity ratio:**

$Ratio$ - Capacity

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

$$Ratio = \frac{(1.5504 \text{ kip/ft}^2)}{(2000 \text{ psf})}$$

$$Ratio = 0.77519$$

Status: **PASS**
Ratio: **0.780**

*Czerniak*

**Lateral Soil Pressure (ASD):**

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

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

$$L/D = \frac{(15 \text{ ft})}{(36 \text{ in})}$$

$$L/D = 5$$

Since L/D $\leq$ 10,

Pile is short.

**Considering x-direction:**

$H_o = -1.01$ kip/ft - Lateral force per length of pile,
$M_o = 14.448$ kipft/ft - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (14.448\ \mathrm{kipft/ft}) \times (15\ \mathrm{ft})) + \left(3 \times (-1.01\ \mathrm{kip/ft}) \times (15\ \mathrm{ft})^2\right)}{(6 \times (14.448\ \mathrm{kipft/ft})) + (4 \times (-1.01\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))}$$

$$a = 10.514\ \mathrm{ft}$$

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

$$p = \frac{1.178\,[(4\,M_o) + (3\,H_o\,L_e)]^2}{L_e^2\,[(3\,M_o) + (2\,H_o\,L_e)]}$$

$$p = \frac{1.178 \times [(4 \times (14.448\ \mathrm{kipft/ft})) + (3 \times (-1.01\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]^{\ 2}}{(15\ \mathrm{ft})^2 \times [(3 \times (14.448\ \mathrm{kipft/ft})) + (2 \times (-1.01\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]}$$

$$p = 0.061148\ \mathrm{kip/ft^2}$$

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

$$s = \frac{9.425\ [(2\,M_o) + (H_o\,L_e)]}{L_e^2}$$

$$s = \frac{9.425 \times [(2 \times (14.448\ \mathrm{kipft/ft})) + ((-1.01\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]}{(15\ \mathrm{ft})^2}$$

$$s = 0.57583\ \mathrm{kip/ft^2}$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150\ \mathrm{psf/ft}) \times \frac{(10.514\ \mathrm{ft})}{2}$$

$$p_a = 0.78857\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(0.061148\ \mathrm{kip/ft^2}\right)}{(0.78857\ \mathrm{kip/ft^2})}$$

$$Ratio = 0.077543$$

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

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

$$p_s = R\,L_e$$

$$p_s = (150\ \mathrm{psf/ft}) \times (15\ \mathrm{ft})$$

$$p_s = 2.25\ \mathrm{kip/ft^2}$$

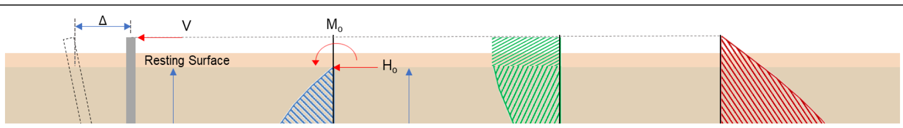
$Ratio$ - Lateral soil capacity

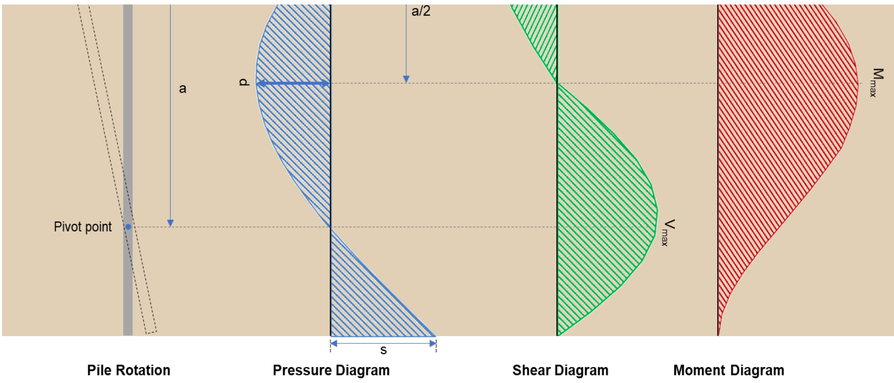
$$Ratio = \frac{s}{p_s}$$

$$Ratio = \frac{\left(0.57583\ \mathrm{kip/ft^2}\right)}{(2.25\ \mathrm{kip/ft^2})}$$

$$Ratio = 0.25593$$

Status: **PASS**
Ratio: **0.260**






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

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-5.049 \text{ kip})}{(36 \text{ in})}$$

$$H_o = -1.683 \text{ kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(72.994 \text{ kipft}) + ((-5.049 \text{ kip}) \times (0 \text{ ft}))}{(36 \text{ in})}$$

$$M_o = 24.331 \text{ kipft/ft}$$

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

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

$$E = \frac{(24.331 \text{ kipft/ft})}{(-1.683 \text{ kip/ft})}$$

$$E = 14.457 \text{ ft}$$

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

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

$$a = \frac{(4 \times (24.331 \text{ kipft/ft}) \times (15 \text{ ft})) + \left(3 \times (-1.683 \text{ kip/ft}) \times (15 \text{ ft})^2\right)}{(6 \times (24.331 \text{ kipft/ft})) + (4 \times (-1.683 \text{ kip/ft}) \times (15 \text{ ft}))}$$

$$a = 10.511 \text{ ft}$$

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

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

$$V_{max} = ((-1.683 \text{ kip/ft}) \times (36 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (14.457 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.511 \text{ ft})}{(15 \text{ ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (14.457 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.511 \text{ ft})}{(15 \text{ ft})}\right)^3\right]\right]$$

$$V_{max} = 11.947 \text{ kip}$$

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

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

$$M_{max} = ((-1.683 \text{ kip/ft}) \times (36 \text{ in}) \times (15 \text{ ft})) \times \left[\left(\frac{(14.457 \text{ ft})}{(15 \text{ ft})} + \frac{(10.511 \text{ ft})}{2 \times (15 \text{ ft})}\right) - \left[\left(\frac{4 \times (14.457 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.511 \text{ ft})}{2 \times (15 \text{ ft})}\right)^3\right] + \left[\left(\frac{3 \times (14.457 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.511 \text{ ft})}{2 \times (15 \text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 82.781 \text{ kipft}$$

**Minimum Reinforcement Check (LRFD)**

**Parameters:**

$f'_{ck} = 2.5$ ksi - Concrete strength,
$f_{yk} = 60$ ksi - Longitudinal reinforcement strength,
$\phi = 0.65$ - Reduction factor for axial strength,
*Table 22.4.2.1* $\alpha = 0.85$ - Alpha factor for axial strength,
$A_g = 1017.9 \text{ in}^2$ - Gross area of concrete,

**Longitudinal reinforcement:**

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

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

$$A_{st,required} = Min\left[\frac{\frac{(17.042 \text{ kip})}{(0.65)\times(0.85)} - \left(0.85 \times (2.5 \text{ ksi}) \times \left(1017.9 \text{ in}^2\right)\right)}{(60 \text{ ksi}) - (0.85 \times (2.5 \text{ ksi}))}, \left(0.08 \times \left(1017.9 \text{ in}^2\right)\right)\right]$$

$$A_{st,required} = -36.84 \text{ in}^2$$

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

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

$$A_{min} = Max\left[\left(-36.84 \text{ in}^2\right), \left(0.0018 \times \left(1017.9 \text{ in}^2\right)\right)\right]$$

$$A_{min} = 1.8322 \text{ in}^2$$

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

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

$$n_{rebar} = \frac{\left(1.8322 \text{ in}^2\right)}{\left(0.3068 \text{ in}^2\right)}$$

$$n_{rebar} = 6$$

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

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

$$A_{st} = (6) \times \frac{\pi \times (0.625 \text{ in})^2}{4}$$

$$A_{st} = 1.8408 \text{ in}^2$$

$Ratio$ - Capacity

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

$$Ratio = \frac{\left(1.8322 \text{ in}^2\right)}{\left(1.8408 \text{ in}^2\right)}$$

$$Ratio = 0.99533$$

Status: **PASS**
Ratio: **1.000**

*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 center-to-center spacing of ties,

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

$$s_{ties} = Min\left[(16 \times (0.625 \text{ in})), (48 \times (0.375 \text{ in})), (36 \text{ in})\right]$$

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

**Summary:**

Main reinforcement: **6 - #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

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

$$\phi P_N = (0.65) \times 0.85 \times \left[\left(0.85 \times (2.5\ \text{ksi}) \times \left[\left(1017.9\ \text{in}^2\right) - \left(1.8408\ \text{in}^2\right)\right]\right) + \left((60\ \text{ksi}) \times \left(1.8408\ \text{in}^2\right)\right)\right]$$

$$\phi P_N = 1253.9\ \text{kip}$$

$Ratio$ - Capacity

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

$$Ratio = \frac{(17.042\ \text{kip})}{(1253.9\ \text{kip})}$$

$$Ratio = 0.013591$$

Status: **PASS**
Ratio: **0.010**

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

**Parameters:**

$b_w = 36\ \text{in}$ - Effective width,

22.5.2.2 $d$ - Effective depth

$$d = 0.80\, D$$

$$d = 0.80 \times (36\ \text{in})$$

$$d = 28.8\ \text{in}$$

22.5.5.1.3 $\lambda_s$ - size effect modification factor

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

$$\lambda_s = MIN\left[\sqrt{\frac{2}{1+\frac{(28.8\ \text{in})}{10}}}, 1\right]$$

$$\lambda_s = 0.71796$$

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

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

$$V_{c,max} = 5 \times (0.71796) \times \sqrt{(2500\ \text{psi})} \times (36\ \text{in}) \times (28.8\ \text{in})$$

$$V_{c,max} = 186.09\ \text{kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$, $P = 17.042\ \text{kip} \rightarrow 17042\ \text{lbf}$,

22.5.5.1.1(a) $V_{c,a}$ - Shear strength of concrete (a)

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

$$V_{c,a} = \left[2 \times (0.71796) \times \sqrt{(2500\ \text{psi})} + \frac{(17042\ \text{lbf})}{6 \times (1017.9\ \text{in}^2)}\right] \times (36\ \text{in}) \times (28.8\ \text{in})$$

$$V_{c,a} = 77.331\ \text{kip}$$

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)

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

$$V_{c,b} = \left[2 \times (0.71796) \times \sqrt{(2500\ \text{psi})} + (0.05 \times (2500\ \text{psi}))\right] \times (36\ \text{in}) \times (28.8\ \text{in})$$

$$V_{c,b} = 204.04\ \text{kip}$$

$V_c$ - Governing shear strength of concrete

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

$$V_c = Min\left[(186.09\ \text{kip}), (77.331\ \text{kip}), (204.04\ \text{kip})\right]$$

$$V_c = 77.331 \text{ kip}$$

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)

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

$$V_{s,a} = 8 \times \sqrt{(2500 \text{ psi})} \times (36 \text{ in}) \times (28.8 \text{ in})$$

$$V_{s,a} = 414.72 \text{ kip}$$

$A_v$ - 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)

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

$$V_{s,b} = \frac{2 \times \left(0.11045 \text{ in}^2\right) \times (60 \text{ ksi}) \times (28.8 \text{ in})}{(10 \text{ in})}$$

$$V_{s,b} = 38.17 \text{ kip}$$

$V_s$ - Governing shear strength of steel

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

$$V_s = MIN\left[(414.72 \text{ kip}), (38.17 \text{ kip})\right]$$

$$V_s = 38.17 \text{ kip}$$

22.5.1.1 $\phi V_n$ - Allowable shear strength

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

$$\phi V_n = (0.65) \times ((77.331 \text{ kip}) + (38.17 \text{ kip}))$$

$$\phi V_n = 75.076 \text{ kip}$$

**Considering x-direction:**

$V_{max} = 11.947 \text{ kip}$ - Maximum shear force in the x-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(11.947 \text{ kip})}{(75.076 \text{ kip})}$$

$$Ratio = 0.15913$$

Status: **PASS**
Ratio: **0.160**

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

$S_m$ - Section modulus

$$S_m = \frac{\pi\, D^3}{32}$$

$$S_m = \frac{\pi \times (36 \text{ in})^3}{32}$$

$$S_m = 4580.4 \text{ in}^3$$

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

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

$$\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{(2.5ksi)} \times 4580.442in^3$$

$$\phi M_{n,1} = 62.027kipft$$

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

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

$$\phi M_{n,2} = (0.65) \times 0.85 \times (2.5 \text{ ksi}) \times \left(4580.4 \text{ in}^3\right)$$

$$\phi M_{n,2} = 527.23 \text{ kipft}$$

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

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

$$\phi M_n = MIN[(62.027 \text{ kipft}), (527.23 \text{ kipft})]$$

$$\phi M_n = 62.027 \text{ kipft}$$

**Considering x-direction:**

$M_{max} = 82.781 \text{ kipft}$ - Maximum moment in the x-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(82.781 \text{ kipft})}{(62.027 \text{ kipft})}$$

$$Ratio = 1.3346$$

Status: **FAIL**
Ratio: **1.330**

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

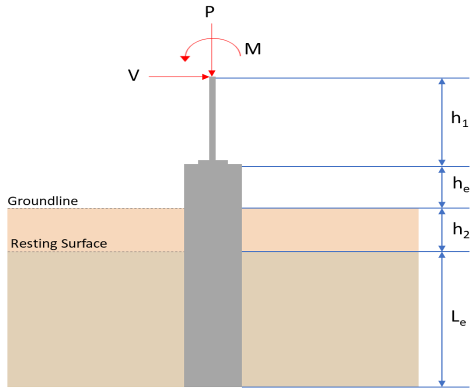
## SkyCiv Foundation Design

Pile Foundation

**Design Information :**

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

### Pile Input




**Geometry**

Pile shape: round
$D = 36\ \text{in}$ - Pile diameter
$L = 15\ \text{ft}$ - 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) | 10.828 | 16.834 |
| $V_x$ (kip) | -2.985 | -4.979 |
| $V_z$ (kip) | -0.024 | -0.039 |
| $M_x$ (kipft) | -0.075 | -0.121 |
| $M_z$ (kipft) | 42.767 | 72.017 |

**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,

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

$$H_o = \frac{(-2.985\ \text{kip})}{(36\ \text{in})}$$

$$H_o = -0.995\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(42.767\ \text{kipft}) + ((-2.985\ \text{kip}) \times (0\ \text{ft}))}{(36\ \text{in})}$$

$$M_o = 14.256\ \text{kipft/ft}$$

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:
$L_{e,x} = 9.617\ \text{ft}$ - Required depth in x-direction,

**Considering z-direction:**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_z}{D}$$

$$H_o = \frac{(-0.024\ \text{kip})}{(36\ \text{in})}$$

$$H_o = -0.008\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(0.075\ \text{kipft}) + ((-0.024\ \text{kip}) \times (0\ \text{ft}))}{(36\ \text{in})}$$

$$M_o = 0.025\ \text{kipft/ft}$$

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:
$L_{e,z} = 1.2938\ \text{ft}$ - Required depth in z-direction,

**Minimum embedded depth required:**

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

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

$$L_{e,req} = MAX[(9.617\ \text{ft}), (1.2938\ \text{ft})]$$

$$L_{e,req} = 9.617\ \text{ft}$$

$L_e$ - Actual embedded length of pile,

$$L_e = L - h_e - h_2$$

$$L_e = (15\ \text{ft}) - (0\ \text{ft}) - (0\ \text{ft})$$

$$L_e = 15\ \text{ft}$$

$Ratio$ - Embedded depth

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

$$Ratio = \frac{(9.617\ \text{ft})}{(15\ \text{ft})}$$

$$Ratio = 0.64113$$

Status: **PASS**
Ratio: **0.640**

**End-bearing Capacity (ASD)**

$A$ - Pile cros-section area

$$A = \pi \left(\frac{D}{2}\right)^2$$

$$A = \pi \times \left(\frac{(36\ \text{in})}{2}\right)^2$$

$$A = 7.0686\ \text{ft}^2$$

$q$ - End-bearing pressure

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

$$q = \frac{(10.828\ \text{kip})}{(7.0686\ \text{ft}^2)}$$

$$q = 1.5318\ \text{kip/ft}^2$$

**Check bearing capacity ratio:**

$Ratio$ - Capacity

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

$$Ratio = \frac{(1.5318\ \text{kip/ft}^2)}{(2000\ \text{psf})}$$

$$Ratio = 0.76592$$

Status: **PASS**
Ratio: **0.770**

Czerniak

**Lateral Soil Pressure (ASD):**

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

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

$$L/D = \frac{(15\ \text{ft})}{(36\ \text{in})}$$

$$L/D = 5$$

Since L/D $\leq$ 10,

Pile is short.

**Considering x-direction:**

$H_o = -0.995\ \text{kip/ft}$ - Lateral force per length of pile,
$M_o = 14.256\ \text{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (14.256\ \text{kipft/ft}) \times (15\ \text{ft})) + \left(3 \times (-0.995\ \text{kip/ft}) \times (15\ \text{ft})^2\right)}{(6 \times (14.256\ \text{kipft/ft})) + (4 \times (-0.995\ \text{kip/ft}) \times (15\ \text{ft}))}$$

$$a = 10.514\ \text{ft}$$

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

$$p = \frac{1.178\, [(4\, M_o) + (3\, H_o\, L_e)]^2}{L_e^2\, [(3\, M_o) + (2\, H_o\, L_e)]}$$

$$p = \frac{1.178 \times [(4 \times (14.256\ \text{kipft/ft})) + (3 \times (-0.995\ \text{kip/ft}) \times (15\ \text{ft}))]^2}{(15\ \text{ft})^2 \times [(3 \times (14.256\ \text{kipft/ft})) + (2 \times (-0.995\ \text{kip/ft}) \times (15\ \text{ft}))]}$$

$$p = 0.060801\ \text{kip/ft}^2$$

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

$$s = \frac{9.425\, [(2\, M_o) + (H_o\, L_e)]}{L_e^2}$$

$$s = \frac{9.425 \times [(2 \times (14.256\ \text{kipft/ft})) + ((-0.995\ \text{kip/ft}) \times (15\ \text{ft}))]}{(15\ \text{ft})^2}$$

$$s = 0.56912\ \text{kip/ft}^2$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150\ \text{psf/ft}) \times \frac{(10.514\ \text{ft})}{2}$$

$$p_a = 0.78854\ \text{kip/ft}^2$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{(0.060801\ \text{kip/ft}^2)}{(0.78854\ \text{kip/ft}^2)}$$

$$Ratio = 0.077106$$

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

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

$$p_s = R\,L_e$$

$$p_s = (150\ \mathrm{psf/ft}) \times (15\ \mathrm{ft})$$

$$p_s = 2.25\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(0.56912\ \mathrm{kip/ft^2}\right)}{\left(2.25\ \mathrm{kip/ft^2}\right)}$$

$$Ratio = 0.25294$$

Status: **PASS**
Ratio: **0.250**

**Considering z-direction:**

$H_o = -0.008\ \mathrm{kip/ft}$ - Lateral force per length of pile,
$M_o = 0.025\ \mathrm{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (0.025\ \mathrm{kipft/ft}) \times (15\ \mathrm{ft})) + \left(3 \times (-0.008\ \mathrm{kip/ft}) \times (15\ \mathrm{ft})^2\right)}{(6 \times (0.025\ \mathrm{kipft/ft})) + (4 \times (-0.008\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))}$$

$$a = 10.952\ \mathrm{ft}$$

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

$$p = \frac{1.178\ [(4\,M_o) + (3\,H_o\,L_e)]^2}{L_e^2\ [(3\,M_o) + (2\,H_o\,L_e)]}$$

$$p = \frac{1.178 \times [(4 \times (0.025\ \mathrm{kipft/ft})) + (3 \times (-0.008\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]^{\ 2}}{(15\ \mathrm{ft})^2 \times [(3 \times (0.025\ \mathrm{kipft/ft})) + (2 \times (-0.008\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]}$$

$$p = -0.002145\ \mathrm{kip/ft^2}$$

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

$$s = \frac{9.425\ [(2\,M_o) + (H_o\,L_e)]}{L_e^2}$$

$$s = \frac{9.425 \times [(2 \times (0.025\ \mathrm{kipft/ft})) + ((-0.008\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]}{(15\ \mathrm{ft})^2}$$

$$s = -0.0029322\ \mathrm{kip/ft^2}$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150\ \mathrm{psf/ft}) \times \frac{(10.952\ \mathrm{ft})}{2}$$

$$p_a = 0.82143\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(-0.002145\ \mathrm{kip/ft^2}\right)}{\left(0.82143\ \mathrm{kip/ft^2}\right)}$$

$$Ratio = -0.0026113$$

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

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

$$p_s = R\,L_e$$

$$p_s = (150\ \mathrm{psf/ft}) \times (15\ \mathrm{ft})$$

$$p_s = 2.25\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

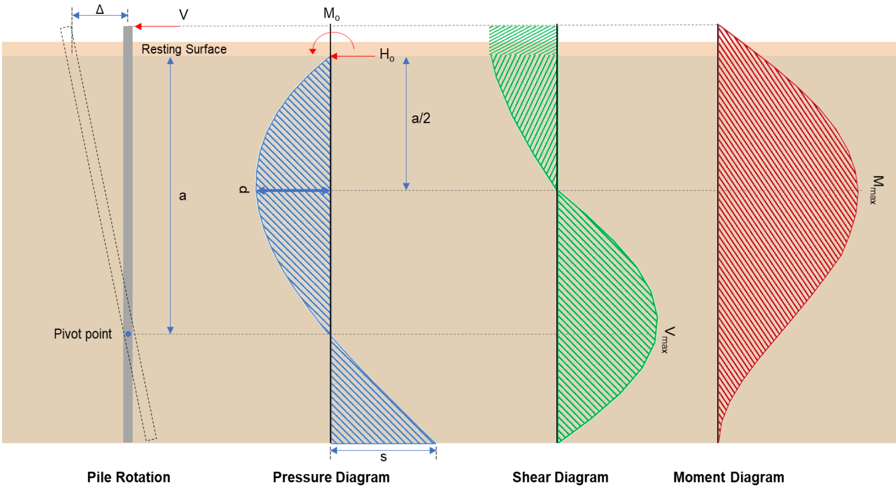
$$Ratio = \frac{s}{\ }$$

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

$$Ratio = \frac{(-0.0029322\ \mathrm{kip/ft^2})}{(2.25\ \mathrm{kip/ft^2})}$$

$$Ratio = -0.0013032$$

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




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

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-4.979\ \mathrm{kip})}{(36\ \mathrm{in})}$$

$$H_o = -1.6597\ \mathrm{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(72.017\ \mathrm{kipft}) + ((-4.979\ \mathrm{kip}) \times (0\ \mathrm{ft}))}{(36\ \mathrm{in})}$$

$$M_o = 24.006\ \mathrm{kipft/ft}$$

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

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

$$E = \frac{(24.006\ \mathrm{kipft/ft})}{(-1.6597\ \mathrm{kip/ft})}$$

$$E = 14.464\ \mathrm{ft}$$

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

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

$$a = \frac{(4 \times (24.006\ \mathrm{kipft/ft}) \times (15\ \mathrm{ft})) + \left(3 \times (-1.6597\ \mathrm{kip/ft}) \times (15\ \mathrm{ft})^2\right)}{(6 \times (24.006\ \mathrm{kipft/ft})) + (4 \times (-1.6597\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))}$$

$$a = 10.511\ \mathrm{ft}$$

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

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

$$V_{max} = ((-1.6597\ \mathrm{kip/ft}) \times (36\ \mathrm{in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (14.464\ \mathrm{ft})}{(15\ \mathrm{ft})} + 3\right) \times \left(\frac{(10.511\ \mathrm{ft})}{(15\ \mathrm{ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (14.464\ \mathrm{ft})}{(15\ \mathrm{ft})} + 2\right) \times \left(\frac{(10.511\ \mathrm{ft})}{(15\ \mathrm{ft})}\right)^3\right]\right]$$

$$V_{max} = 11.785 \text{ kip}$$

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

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

$$M_{max} = ((-1.6597 \text{ kip/ft}) \times (36 \text{ in}) \times (15 \text{ ft})) \times \left[\left(\frac{(14.464 \text{ ft})}{(15 \text{ ft})} + \frac{(10.511 \text{ ft})}{2 \times (15 \text{ ft})}\right) - \left[\left(\frac{4 \times (14.464 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.511 \text{ ft})}{2 \times (15 \text{ ft})}\right)^3\right] + \left[\left(\frac{3 \times (14.464 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.511 \text{ ft})}{2 \times (15 \text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 81.664 \text{ kipft}$$

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

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_z}{D}$$

$$H_o = \frac{(-0.039 \text{ kip})}{(36 \text{ in})}$$

$$H_o = -0.013 \text{ kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(0.121 \text{ kipft}) + ((-0.039 \text{ kip}) \times (0 \text{ ft}))}{(36 \text{ in})}$$

$$M_o = 0.040333 \text{ kipft/ft}$$

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

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

$$E = \frac{(0.040333 \text{ kipft/ft})}{(-0.013 \text{ kip/ft})}$$

$$E = 3.1026 \text{ ft}$$

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

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

$$a = \frac{(4 \times (0.040333 \text{ kipft/ft}) \times (15 \text{ ft})) + \left(3 \times (-0.013 \text{ kip/ft}) \times (15 \text{ ft})^2\right)}{(6 \times (0.040333 \text{ kipft/ft})) + (4 \times (-0.013 \text{ kip/ft}) \times (15 \text{ ft}))}$$

$$a = 10.954 \text{ ft}$$

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

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

$$V_{max} = ((-0.013 \text{ kip/ft}) \times (36 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (3.1026 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.954 \text{ ft})}{(15 \text{ ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (3.1026 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.954 \text{ ft})}{(15 \text{ ft})}\right)^3\right]\right]$$

$$V_{max} = 0.040603 \text{ kip}$$

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

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

$$M_{max} = ((-0.013 \text{ kip/ft}) \times (36 \text{ in}) \times (15 \text{ ft})) \times \left[\left(\frac{(3.1026 \text{ ft})}{(15 \text{ ft})} + \frac{(10.954 \text{ ft})}{2 \times (15 \text{ ft})}\right) - \left[\left(\frac{4 \times (3.1026 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.954 \text{ ft})}{2 \times (15 \text{ ft})}\right)^3\right] + \left[\left(\frac{3 \times (3.1026 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.954 \text{ ft})}{2 \times (15 \text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 0.25286 \text{ kipft}$$

**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* $\alpha = 0.85$ - Alpha factor for axial strength,
$A_g = 1017.9 \text{ in}^2$ - Gross area of concrete,

**Longitudinal reinforcement:**

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

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

$$A_{st,required} = Min\left[\frac{\frac{(16.834 \text{ kip})}{(0.65)\times(0.85)} - \left(0.85 \times (2.5 \text{ ksi}) \times \left(1017.9 \text{ in}^2\right)\right)}{(60 \text{ ksi}) - (0.85 \times (2.5 \text{ ksi}))}, \left(0.08 \times \left(1017.9 \text{ in}^2\right)\right)\right]$$

$$A_{st,required} = -36.847 \text{ in}^2$$

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

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

$$A_{min} = Max\left[\left(-36.847 \text{ in}^2\right), \left(0.0018 \times \left(1017.9 \text{ in}^2\right)\right)\right]$$

$$A_{min} = 1.8322 \text{ in}^2$$

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

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

$$n_{rebar} = \frac{\left(1.8322 \text{ in}^2\right)}{\left(0.3068 \text{ in}^2\right)}$$

$$n_{rebar} = 6$$

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

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

$$A_{st} = (6) \times \frac{\pi \times (0.625 \text{ in})^2}{4}$$

$$A_{st} = 1.8408 \text{ in}^2$$

$Ratio$ - Capacity

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

$$Ratio = \frac{\left(1.8322 \text{ in}^2\right)}{\left(1.8408 \text{ in}^2\right)}$$

$$Ratio = 0.99533$$

Status: **PASS**
Ratio: **1.000**

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

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

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

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

**Ties:**

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

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

$$s_{ties} = Min\left[(16 \times (0.625 \text{ in})), (48 \times (0.375 \text{ in})), (36 \text{ in})\right]$$

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

**Summary:**

| | | |
|---|---|---|
| | Main reinforcement: **6 - #5 (0.625 in)**<br>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

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

$$\phi P_N = (0.65) \times 0.85 \times \left[\left(0.85 \times (2.5\ \text{ksi}) \times \left[\left(1017.9\ \text{in}^2\right) - \left(1.8408\ \text{in}^2\right)\right]\right) + \left((60\ \text{ksi}) \times \left(1.8408\ \text{in}^2\right)\right)\right]$$

$$\phi P_N = 1253.9\ \text{kip}$$

$Ratio$ - Capacity

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

$$Ratio = \frac{(16.834\ \text{kip})}{(1253.9\ \text{kip})}$$

$$Ratio = 0.013425$$

Status: **PASS**
Ratio: **0.010**

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

**Parameters:**

$b_w = 36\ \text{in}$ - Effective width,
22.5.2.2 $d$ - Effective depth

$$d = 0.80\, D$$

$$d = 0.80 \times (36\ \text{in})$$

$$d = 28.8\ \text{in}$$

22.5.5.1.3 $\lambda_s$ - size effect modification factor

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

$$\lambda_s = MIN\left[\sqrt{\frac{2}{1+\frac{(28.8\ \text{in})}{10}}}, 1\right]$$

$$\lambda_s = 0.71796$$

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

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

$$V_{c,max} = 5 \times (0.71796) \times \sqrt{(2500\ \text{psi})} \times (36\ \text{in}) \times (28.8\ \text{in})$$

$$V_{c,max} = 186.09\ \text{kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \rightarrow 2500\ \text{psi}$, $P = 16.834\ \text{kip} \rightarrow 16834\ \text{lbf}$,
22.5.5.1.1(a) $V_{c,a}$ - Shear strength of concrete (a)

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

$$V_{c,a} = \left[2 \times (0.71796) \times \sqrt{(2500\ \text{psi})} + \frac{(16834\ \text{lbf})}{6 \times (1017.9\ \text{in}^2)}\right] \times (36\ \text{in}) \times (28.8\ \text{in})$$

$$V_{c,a} = 77.296\ \text{kip}$$

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)

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

$$V_{c,b} = \left[2 \times (0.71796) \times \sqrt{(2500\ \text{psi})} + (0.05 \times (2500\ \text{psi}))\right] \times (36\ \text{in}) \times (28.8\ \text{in})$$

$$V_{c,b} = 204.04\ \text{kip}$$

$V_c$ - Governing shear strength of concrete

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

$$V_c = Min\left[(186.09\ \text{kip}), (77.296\ \text{kip}), (204.04\ \text{kip})\right]$$

$$V_c = 77.296\ \text{kip}$$

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)

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

$$V_{s,a} = 8 \times \sqrt{(2500\ \text{psi})} \times (36\ \text{in}) \times (28.8\ \text{in})$$

$$V_{s,a} = 414.72\ \text{kip}$$

$A_v$ - 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)

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

$$V_{s,b} = \frac{2 \times \left(0.11045\ \text{in}^2\right) \times (60\ \text{ksi}) \times (28.8\ \text{in})}{(10\ \text{in})}$$

$$V_{s,b} = 38.17\ \text{kip}$$

$V_s$ - Governing shear strength of steel

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

$$V_s = MIN\left[(414.72\ \text{kip}), (38.17\ \text{kip})\right]$$

$$V_s = 38.17\ \text{kip}$$

22.5.1.1 $\phi V_n$ - Allowable shear strength

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

$$\phi V_n = (0.65) \times ((77.296\ \text{kip}) + (38.17\ \text{kip}))$$

$$\phi V_n = 75.053\ \text{kip}$$

**Considering x-direction:**

$V_{max} = 11.785\ \text{kip}$ - Maximum shear force in the x-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(11.785\ \text{kip})}{(75.053\ \text{kip})}$$

$$Ratio = 0.15703$$

Status: **PASS**
Ratio: **0.160**

**Considering z-direction:**

$V_{max} = 0.040603\ \text{kip}$ - Maximum shear force in the z-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(0.040603\ \text{kip})}{(75.053\ \text{kip})}$$

$$Ratio = 0.00054098$$

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

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

$S_m$ - Section modulus

$$S_m = \frac{\pi\, D^3}{32}$$

$$S_m = \frac{\pi \times (36\ \text{in})^3}{32}$$

$$S_m = 4580.4\ \text{in}^3$$

$S_m = 4580.4 \text{ in}^3$

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

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

$$\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{(2.5 ksi)} \times 4580.442 in^3$$

$$\phi M_{n,1} = 62.027 kipft$$

| | | |
|---|---|---|
| 14.5.2.1b | $\phi M_{n,2}$<br>$$\phi M_{n,2} = \phi\, 0.85\, f_{ck}'\, S_m$$<br>$$\phi M_{n,2} = (0.65) \times 0.85 \times (2.5 \text{ ksi}) \times \left(4580.4 \text{ in}^3\right)$$<br>$$\phi M_{n,2} = 527.23 \text{ kipft}$$<br>Therefore,<br>$\phi M_n$ - Allowable flexural strength,<br>$$\phi M_n = MIN[\phi M_{n,1}, \phi M_{n,2}]$$<br>$$\phi M_n = MIN[(62.027 \text{ kipft}), (527.23 \text{ kipft})]$$<br>$$\phi M_n = 62.027 \text{ kipft}$$<br>**Considering x-direction:**<br>$M_{max} = 81.664 \text{ kipft}$ - Maximum moment in the x-direction,<br>$Ratio$ - Capacity<br>$$Ratio = \frac{M_{max}}{\phi M_n}$$<br>$$Ratio = \frac{(81.664 \text{ kipft})}{(62.027 \text{ kipft})}$$<br>$$Ratio = 1.3166$$ | Status: **FAIL**<br>Ratio: **1.320** |
| | **Considering z-direction:**<br>$M_{max} = 0.25286 \text{ kipft}$ - Maximum moment in the z-direction,<br>$Ratio$ - Capacity<br>$$Ratio = \frac{M_{max}}{\phi M_n}$$<br>$$Ratio = \frac{(0.25286 \text{ kipft})}{(62.027 \text{ kipft})}$$<br>$$Ratio = 0.0040766$$ | Status: **PASS**<br>Ratio: **0.000** |

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

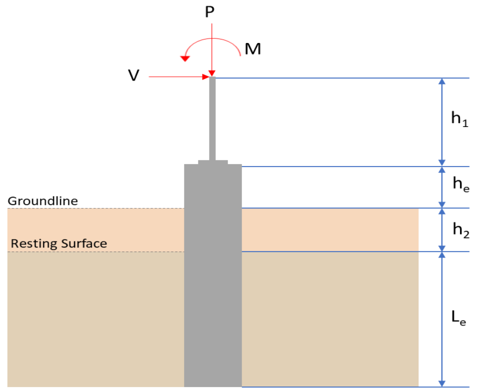
## SkyCiv Foundation Design

Pile Foundation

**Design Information :**

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

### Pile Input




**Geometry**

Pile shape: round
$D = 36\ \text{in}$ - Pile diameter
$L = 15\ \text{ft}$ - 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) | 10.269 | 15.956 |
| $V_x$ (kip) | -2.848 | -4.746 |
| $V_z$ (kip) | 0.016 | 0.024 |
| $M_x$ (kipft) | 0.049 | 0.075 |
| $M_z$ (kipft) | 40.935 | 68.906 |

**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,

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

$$H_o = \frac{(-2.848\ \text{kip})}{(36\ \text{in})}$$

$$H_o = -0.94933\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(40.935 \text{ kipft}) + ((-2.848 \text{ kip}) \times (0 \text{ ft}))}{(36 \text{ in})}$$

$$M_o = 13.645 \text{ kipft/ft}$$

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:
$L_{e,x} = 9.52 \text{ ft}$ - Required depth in x-direction,

**Considering z-direction:**

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_z}{D}$$

$$H_o = \frac{(0.016 \text{ kip})}{(36 \text{ in})}$$

$$H_o = 0.0053333 \text{ kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(0.049 \text{ kipft}) + ((0.016 \text{ kip}) \times (0 \text{ ft}))}{(36 \text{ in})}$$

$$M_o = 0.016333 \text{ kipft/ft}$$

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:
$L_{e,z} = 1.4021 \text{ ft}$ - Required depth in z-direction,

**Minimum embedded depth required:**

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

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

$$L_{e,req} = MAX[(9.52 \text{ ft}), (1.4021 \text{ ft})]$$

$$L_{e,req} = 9.52 \text{ ft}$$

$L_e$ - Actual embedded length of pile,

$$L_e = L - h_e - h_2$$

$$L_e = (15 \text{ ft}) - (0 \text{ ft}) - (0 \text{ ft})$$

$$L_e = 15 \text{ ft}$$

$Ratio$ - Embedded depth

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

$$Ratio = \frac{(9.52 \text{ ft})}{(15 \text{ ft})}$$

$$Ratio = 0.63467$$

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

**End-bearing Capacity (ASD)**

$A$ - Pile cros-section area

$$A = \pi \left(\frac{D}{2}\right)^2$$

$$A = \pi \times \left(\frac{(36 \text{ in})}{2}\right)^2$$

$$A = 7.0686 \text{ ft}^2$$

$q$ - End-bearing pressure

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

$$q = \frac{(10.269 \text{ kip})}{(7.0686 \text{ ft}^2)}$$

$$q = 1.4528 \text{ kip/ft}^2$$

**Check bearing capacity ratio:**

$Ratio$ - Capacity

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

$$Ratio = \frac{\left(1.4528 \text{ kip/ft}^2\right)}{(2000 \text{ psf})}$$

$$Ratio = 0.72638$$

Status: **PASS**
Ratio: **0.730**

*Czerniak*

**Lateral Soil Pressure (ASD):**

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

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

$$L/D = \frac{(15 \text{ ft})}{(36 \text{ in})}$$

$$L/D = 5$$

Since L/D $\leq$ 10,

Pile is short.

**Considering x-direction:**

$H_o = -0.94933 \text{ kip/ft}$ - Lateral force per length of pile,
$M_o = 13.645 \text{ kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (13.645 \text{ kipft/ft}) \times (15 \text{ ft})) + \left(3 \times (-0.94933 \text{ kip/ft}) \times (15 \text{ ft})^2\right)}{(6 \times (13.645 \text{ kipft/ft})) + (4 \times (-0.94933 \text{ kip/ft}) \times (15 \text{ ft}))}$$

$$a = 10.513 \text{ ft}$$

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

$$p = \frac{1.178\, [(4\, M_o) + (3\, H_o\, L_e)]^2}{L_e^2\, [(3\, M_o) + (2\, H_o\, L_e)]}$$

$$p = \frac{1.178 \times [(4 \times (13.645 \text{ kipft/ft})) + (3 \times (-0.94933 \text{ kip/ft}) \times (15 \text{ ft}))]^2}{(15 \text{ ft})^2 \times [(3 \times (13.645 \text{ kipft/ft})) + (2 \times (-0.94933 \text{ kip/ft}) \times (15 \text{ ft}))]}$$

$$p = 0.059127 \text{ kip/ft}^2$$

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

$$s = \frac{9.425\, [(2\, M_o) + (H_o\, L_e)]}{L_e^2}$$

$$s = \frac{9.425 \times [(2 \times (13.645 \text{ kipft/ft})) + ((-0.94933 \text{ kip/ft}) \times (15 \text{ ft}))]}{(15 \text{ ft})^2}$$

$$s = 0.54665 \text{ kip/ft}^2$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150 \text{ psf/ft}) \times \frac{(10.513 \text{ ft})}{2}$$

$$p_a = 0.78846 \text{ kip/ft}^2$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(0.059127 \text{ kip/ft}^2\right)}{\left(0.78846 \text{ kip/ft}^2\right)}$$

$$Ratio = 0.074991$$

Status: **PASS**
Ratio: **0.070**

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

$$p_s = R\,L_e$$

$$p_s = (150\ \mathrm{psf/ft}) \times (15\ \mathrm{ft})$$

$$p_s = 2.25\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(0.54665\ \mathrm{kip/ft^2}\right)}{\left(2.25\ \mathrm{kip/ft^2}\right)}$$

$$Ratio = 0.24296$$

Status: **PASS**
Ratio: **0.240**

**Considering z-direction:**

$H_o = 0.0053333\ \mathrm{kip/ft}$ - Lateral force per length of pile,
$M_o = 0.016333\ \mathrm{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (0.016333\ \mathrm{kipft/ft}) \times (15\ \mathrm{ft})) + \left(3 \times (0.0053333\ \mathrm{kip/ft}) \times (15\ \mathrm{ft})^2\right)}{(6 \times (0.016333\ \mathrm{kipft/ft})) + (4 \times (0.0053333\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))}$$

$$a = 10.957\ \mathrm{ft}$$

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

$$p = \frac{1.178\ [(4\,M_o) + (3\,H_o\,L_e)]^2}{L_e^2\ [(3\,M_o) + (2\,H_o\,L_e)]}$$

$$p = \frac{1.178 \times [(4 \times (0.016333\ \mathrm{kipft/ft})) + (3 \times (0.0053333\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]^2}{(15\ \mathrm{ft})^2 \times [(3 \times (0.016333\ \mathrm{kipft/ft})) + (2 \times (0.0053333\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]}$$

$$p = 0.0023354\ \mathrm{kip/ft^2}$$

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

$$s = \frac{9.425\ [(2\,M_o) + (H_o\,L_e)]}{L_e^2}$$

$$s = \frac{9.425 \times [(2 \times (0.016333\ \mathrm{kipft/ft})) + ((0.0053333\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))]}{(15\ \mathrm{ft})^2}$$

$$s = 0.0047195\ \mathrm{kip/ft^2}$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150\ \mathrm{psf/ft}) \times \frac{(10.957\ \mathrm{ft})}{2}$$

$$p_a = 0.82177\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(0.0023354\ \mathrm{kip/ft^2}\right)}{\left(0.82177\ \mathrm{kip/ft^2}\right)}$$

$$Ratio = 0.0028419$$

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

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

$$p_s = R\,L_e$$

$$p_s = (150\ \mathrm{psf/ft}) \times (15\ \mathrm{ft})$$

$$p_s = 2.25\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

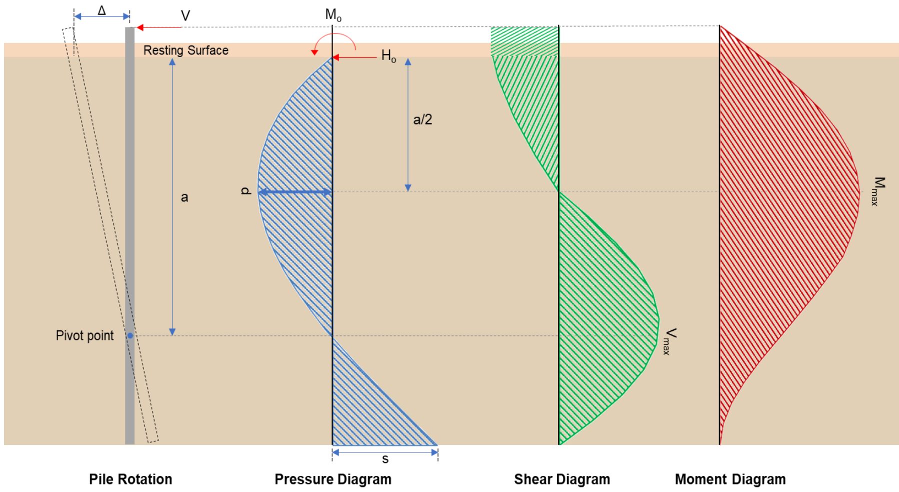
$$Ratio = \frac{s}{\ }$$

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

$$Ratio = \frac{(0.0047195\ \mathrm{kip/ft^2})}{(2.25\ \mathrm{kip/ft^2})}$$

$$Ratio = 0.0020975$$

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




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

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-4.746\ \mathrm{kip})}{(36\ \mathrm{in})}$$

$$H_o = -1.582\ \mathrm{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(68.906\ \mathrm{kipft}) + ((-4.746\ \mathrm{kip}) \times (0\ \mathrm{ft}))}{(36\ \mathrm{in})}$$

$$M_o = 22.969\ \mathrm{kipft/ft}$$

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

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

$$E = \frac{(22.969\ \mathrm{kipft/ft})}{(-1.582\ \mathrm{kip/ft})}$$

$$E = 14.519\ \mathrm{ft}$$

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

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

$$a = \frac{(4 \times (22.969\ \mathrm{kipft/ft}) \times (15\ \mathrm{ft})) + \left(3 \times (-1.582\ \mathrm{kip/ft}) \times (15\ \mathrm{ft})^2\right)}{(6 \times (22.969\ \mathrm{kipft/ft})) + (4 \times (-1.582\ \mathrm{kip/ft}) \times (15\ \mathrm{ft}))}$$

$$a = 10.51\ \mathrm{ft}$$

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

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

$$V_{max} = ((-1.582\ \mathrm{kip/ft}) \times (36\ \mathrm{in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (14.519\ \mathrm{ft})}{(15\ \mathrm{ft})} + 3\right) \times \left(\frac{(10.51\ \mathrm{ft})}{(15\ \mathrm{ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (14.519\ \mathrm{ft})}{(15\ \mathrm{ft})} + 2\right) \times \left(\frac{(10.51\ \mathrm{ft})}{(15\ \mathrm{ft})}\right)^3\right]\right]$$

$$V_{max} = 11.264 \text{ kip}$$

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

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

$$M_{max} = ((-1.582 \text{ kip/ft}) \times (36 \text{ in}) \times (15 \text{ ft})) \times \left[\left(\frac{(14.519 \text{ ft})}{(15 \text{ ft})} + \frac{(10.51 \text{ ft})}{2 \times (15 \text{ ft})}\right) - \left[\left(\frac{4 \times (14.519 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.51 \text{ ft})}{2 \times (15 \text{ ft})}\right)^3\right] + \left[\left(\frac{3 \times (14.519 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.51 \text{ ft})}{2 \times (15 \text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 78.071 \text{ kipft}$$

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

$H_o$ - Lateral force per length of pile,

$$H_o = \frac{V_z}{D}$$

$$H_o = \frac{(0.024 \text{ kip})}{(36 \text{ in})}$$

$$H_o = 0.008 \text{ kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(0.075 \text{ kipft}) + ((0.024 \text{ kip}) \times (0 \text{ ft}))}{(36 \text{ in})}$$

$$M_o = 0.025 \text{ kipft/ft}$$

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

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

$$E = \frac{(0.025 \text{ kipft/ft})}{(0.008 \text{ kip/ft})}$$

$$E = 3.125 \text{ ft}$$

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

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

$$a = \frac{(4 \times (0.025 \text{ kipft/ft}) \times (15 \text{ ft})) + \left(3 \times (0.008 \text{ kip/ft}) \times (15 \text{ ft})^2\right)}{(6 \times (0.025 \text{ kipft/ft})) + (4 \times (0.008 \text{ kip/ft}) \times (15 \text{ ft}))}$$

$$a = 10.952 \text{ ft}$$

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

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

$$V_{max} = ((0.008 \text{ kip/ft}) \times (36 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (3.125 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.952 \text{ ft})}{(15 \text{ ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (3.125 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.952 \text{ ft})}{(15 \text{ ft})}\right)^3\right]\right]$$

$$V_{max} = 0.025048 \text{ kip}$$

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

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

$$M_{max} = ((0.008 \text{ kip/ft}) \times (36 \text{ in}) \times (15 \text{ ft})) \times \left[\left(\frac{(3.125 \text{ ft})}{(15 \text{ ft})} + \frac{(10.952 \text{ ft})}{2 \times (15 \text{ ft})}\right) - \left[\left(\frac{4 \times (3.125 \text{ ft})}{(15 \text{ ft})} + 3\right) \times \left(\frac{(10.952 \text{ ft})}{2 \times (15 \text{ ft})}\right)^3\right] + \left[\left(\frac{3 \times (3.125 \text{ ft})}{(15 \text{ ft})} + 2\right) \times \left(\frac{(10.952 \text{ ft})}{2 \times (15 \text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 0.15607 \text{ kipft}$$

**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* $\alpha = 0.85$ - Alpha factor for axial strength,
$A_g = 1017.9 \text{ in}^2$ - Gross area of concrete,

**Longitudinal reinforcement:**

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

*22.4.2.2, 10.6.1.1* $A_{st,required}$

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

$$A_{st,required} = Min\left[\frac{\frac{(15.956 \text{ kip})}{(0.65)\times(0.85)} - \left(0.85 \times (2.5 \text{ ksi}) \times \left(1017.9 \text{ in}^2\right)\right)}{(60 \text{ ksi}) - (0.85 \times (2.5 \text{ ksi}))}, \left(0.08 \times \left(1017.9 \text{ in}^2\right)\right)\right]$$

$$A_{st,required} = -36.874 \text{ in}^2$$

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

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

$$A_{min} = Max\left[\left(-36.874 \text{ in}^2\right), \left(0.0018 \times \left(1017.9 \text{ in}^2\right)\right)\right]$$

$$A_{min} = 1.8322 \text{ in}^2$$

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

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

$$n_{rebar} = \frac{\left(1.8322 \text{ in}^2\right)}{\left(0.3068 \text{ in}^2\right)}$$

$$n_{rebar} = 6$$

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

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

$$A_{st} = (6) \times \frac{\pi \times (0.625 \text{ in})^2}{4}$$

$$A_{st} = 1.8408 \text{ in}^2$$

$Ratio$ - Capacity

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

$$Ratio = \frac{\left(1.8322 \text{ in}^2\right)}{\left(1.8408 \text{ in}^2\right)}$$

$$Ratio = 0.99533$$

Status: **PASS**
Ratio: **1.000**

*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 center-to-center spacing of ties,

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

$$s_{ties} = Min\left[(16 \times (0.625 \text{ in})), (48 \times (0.375 \text{ in})), (36 \text{ in})\right]$$

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

**Summary:**

Main reinforcement: **6 - #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

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

$$\phi P_N = (0.65) \times 0.85 \times \left[\left(0.85 \times (2.5\text{ ksi}) \times \left[\left(1017.9\text{ in}^2\right) - \left(1.8408\text{ in}^2\right)\right]\right) + \left((60\text{ ksi}) \times \left(1.8408\text{ in}^2\right)\right)\right]$$

$$\phi P_N = 1253.9\text{ kip}$$

$Ratio$ - Capacity

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

$$Ratio = \frac{(15.956\text{ kip})}{(1253.9\text{ kip})}$$

$$Ratio = 0.012725$$

Status: **PASS**
Ratio: **0.010**

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

**Parameters:**

$b_w = 36\text{ in}$ - Effective width,

22.5.2.2 $d$ - Effective depth

$$d = 0.80\, D$$

$$d = 0.80 \times (36\text{ in})$$

$$d = 28.8\text{ in}$$

22.5.5.1.3 $\lambda_s$ - size effect modification factor

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

$$\lambda_s = MIN\left[\sqrt{\frac{2}{1 + \frac{(28.8\text{ in})}{10}}}, 1\right]$$

$$\lambda_s = 0.71796$$

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

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

$$V_{c,max} = 5 \times (0.71796) \times \sqrt{(2500\text{ psi})} \times (36\text{ in}) \times (28.8\text{ in})$$

$$V_{c,max} = 186.09\text{ kip}$$

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\text{ ksi} \rightarrow 2500\text{ psi}$, $P = 15.956\text{ kip} \rightarrow 15956\text{ lbf}$,

22.5.5.1.1(a) $V_{c,a}$ - Shear strength of concrete (a)

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

$$V_{c,a} = \left[2 \times (0.71796) \times \sqrt{(2500\text{ psi})} + \frac{(15956\text{ lbf})}{6 \times \left(1017.9\text{ in}^2\right)}\right] \times (36\text{ in}) \times (28.8\text{ in})$$

$$V_{c,a} = 77.147\text{ kip}$$

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)

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

$$V_{c,b} = \left[2 \times (0.71796) \times \sqrt{(2500\text{ psi})} + (0.05 \times (2500\text{ psi}))\right] \times (36\text{ in}) \times (28.8\text{ in})$$

$$V_{c,b} = 204.04\text{ kip}$$

$V_c$ - Governing shear strength of concrete

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

$$V_c = Min\left[(186.09\text{ kip}), (77.147\text{ kip}), (204.04\text{ kip})\right]$$

$$V_c = 77.147\ \text{kip}$$

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)

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

$$V_{s,a} = 8 \times \sqrt{(2500\ \text{psi})} \times (36\ \text{in}) \times (28.8\ \text{in})$$

$$V_{s,a} = 414.72\ \text{kip}$$

$A_v$ - 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)

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

$$V_{s,b} = \frac{2 \times \left(0.11045\ \text{in}^2\right) \times (60\ \text{ksi}) \times (28.8\ \text{in})}{(10\ \text{in})}$$

$$V_{s,b} = 38.17\ \text{kip}$$

$V_s$ - Governing shear strength of steel

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

$$V_s = MIN\left[(414.72\ \text{kip}), (38.17\ \text{kip})\right]$$

$$V_s = 38.17\ \text{kip}$$

22.5.1.1 $\phi V_n$ - Allowable shear strength

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

$$\phi V_n = (0.65) \times ((77.147\ \text{kip}) + (38.17\ \text{kip}))$$

$$\phi V_n = 74.956\ \text{kip}$$

**Considering x-direction:**

$V_{max} = 11.264\ \text{kip}$ - Maximum shear force in the x-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(11.264\ \text{kip})}{(74.956\ \text{kip})}$$

$$Ratio = 0.15028$$

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

**Considering z-direction:**

$V_{max} = 0.025048\ \text{kip}$ - Maximum shear force in the z-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(0.025048\ \text{kip})}{(74.956\ \text{kip})}$$

$$Ratio = 0.00033417$$

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

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

$S_m$ - Section modulus

$$S_m = \frac{\pi\ D^3}{32}$$

$$S_m = \frac{\pi \times (36\ \text{in})^3}{32}$$

$$S_m = 4580.4\ \text{in}^3$$

| | | |
|---|---|---|
| | $S_m = 4580.4\ \text{in}^3$<br><br>$\lambda = 1$ - Concrete modification factor (Normal concrete),<br>Allowable flexural strength:<br>$M_n$ shall be the lesser of:<br>$\phi M_{n,1}$<br><br>$$\phi M_{n,1} = \phi \times 5 \times \lambda \times \sqrt{(f_c')} \times S_m$$<br>$$\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{(2.5ksi)} \times 4580.442in^3$$<br>$$\phi M_{n,1} = 62.027kipft$$ | |
| *14.5.2.1b* | $\phi M_{n,2}$<br><br>$$\phi M_{n,2} = \phi\ 0.85\ f_{ck}'\ S_m$$<br>$$\phi M_{n,2} = (0.65) \times 0.85 \times (2.5\ \text{ksi}) \times \left(4580.4\ \text{in}^3\right)$$<br>$$\phi M_{n,2} = 527.23\ \text{kipft}$$<br>Therefore,<br>$\phi M_n$ - Allowable flexural strength,<br><br>$$\phi M_n = MIN[\phi M_{n,1}, \phi M_{n,2}]$$<br>$$\phi M_n = MIN[(62.027\ \text{kipft}), (527.23\ \text{kipft})]$$<br>$$\phi M_n = 62.027\ \text{kipft}$$<br>**Considering x-direction:**<br><br>$M_{max} = 78.071\ \text{kipft}$ - Maximum moment in the x-direction,<br>$Ratio$ - Capacity<br><br>$$Ratio = \frac{M_{max}}{\phi M_n}$$<br>$$Ratio = \frac{(78.071\ \text{kipft})}{(62.027\ \text{kipft})}$$<br>$$Ratio = 1.2587$$ | Status: **FAIL**<br>Ratio: **1.260** |
| | **Considering z-direction:**<br><br>$M_{max} = 0.15607\ \text{kipft}$ - Maximum moment in the z-direction,<br>$Ratio$ - Capacity<br><br>$$Ratio = \frac{M_{max}}{\phi M_n}$$<br>$$Ratio = \frac{(0.15607\ \text{kipft})}{(62.027\ \text{kipft})}$$<br>$$Ratio = 0.0025161$$ | Status: **PASS**<br>Ratio: **0.000** |