# Your Project Calculations

Project Name: KopkesGreenhouse-JB-RevA

S3D Model Link:
https://platform.skyciv.com/structural?preload_name=KopkesGreenhouse-JB-RevA&preload_path=Shared%20Enterprise%20Folder/MT_Solar_Projects/8_2023

Public Model Link:
https://platform.skyciv.com/structural-viewer?project_id=cLUWqf0BD2C7uthu3Wr2sUmJUlKR2w0pnXNHmiZZ6xg0sOZ6ZBx2QipBDYhosoeU

## Array Specification

| | |
|---|---|
| **Product:** | Beam |
| **Unique ID:** | 3P-22.5-6TOP-XD-45-L-5Hx8W-717B |
| **Duty Classification:** | XD |
| **Module Width:** | 44.65 in |
| **Module Length:** | 89.72in |
| **Number of Rows:** | 5 |
| **Number of Columns:** | 8 |
| **Total Number of Modules:** | 40 |
| **Desired Tilt Angle:** | 5 |
| **Front Edge Clearance:** | 10 |
| **Total Array Height at Tilt:** | 11.63 ft |
| **Total Frame Length:** | 60.00 ft |
| **Frame Weight:** | 2874 lbs |
| **Array Dimensions N/S:** | 18.81 ft |
| **Array Dimensions E/W:** | 60.48 ft |
| **Rail Length:** | 225.73 in |
| **Rail Spacing:** | 3.74 ft |
| **Rail Check:** | Not Checked |

## Support Specifications

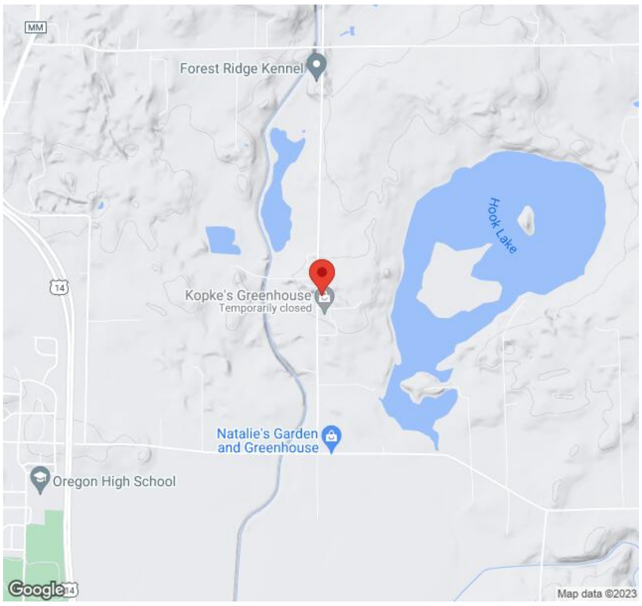
| | |
|---|---|
| **Pole Size:** | 6in Pipe Sch 40 |
| **Pole Length above Grade:** | 10.82 ft |
| **Number of Poles:** | 3 |
| **Pole Spacing:** | 22.5 ft |

## Foundation Specifications

| | |
|---|---|
| **Foundation Type:** | Square |
| **Foundation Dimensions:** | 48 x 48 in |
| **Foundation Depth (below grade):** | Pile 1: 4.50 ft<br>Pile 2: 4.50 ft<br>Pile 3: 4.50 ft |
| **Foundation Volume:** | 8.000 $y^3$ |
| **Foundation Result:** | PASSED |
| **Mount Twist:** | 0.048662 kip |

## Site Info

| | |
|---|---|
| **Risk Category:** | I |
| **Exposure:** | B |
| **Soil Classification:** | sand |
| **Site Location:** | 1828 Sand Hill Rd, Oregon, WI 53575, USA |
| **Wind Speed:** | 100 mph |
| **Snow Load:** | 30 psf |
| **Design Uplift Pressure:** | Multiple pressures |
| **Design Downforce Pressure:** | Multiple pressures |
| **Design Snow Pressure:** | 0.018144 ksf |




**Design Disclaimer**

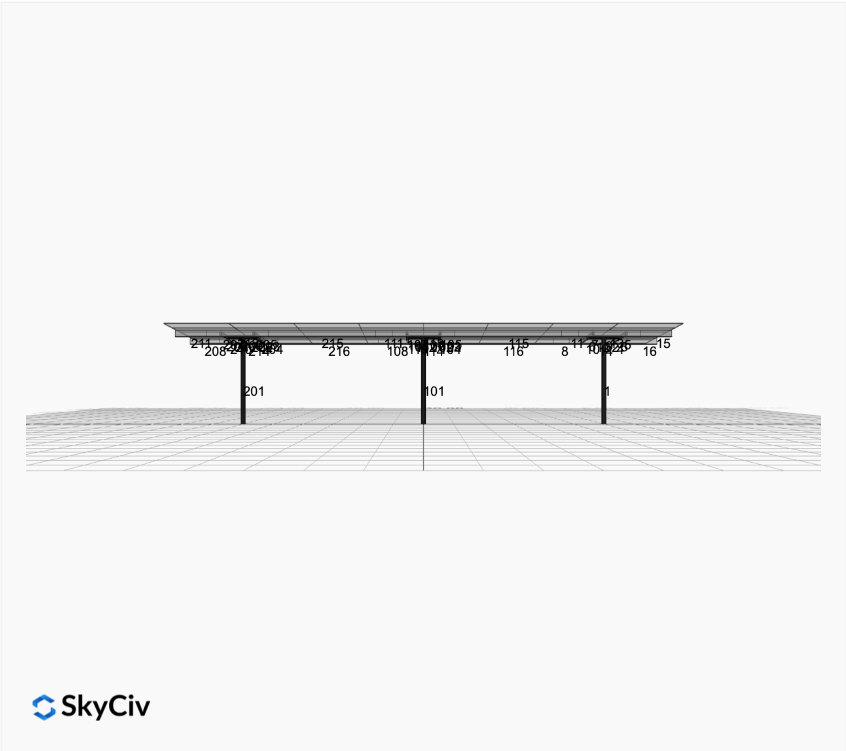
This software should be used for preliminary designs and should not be used as a final design unless reviewed, verified and designed by a qualified structural engineer.

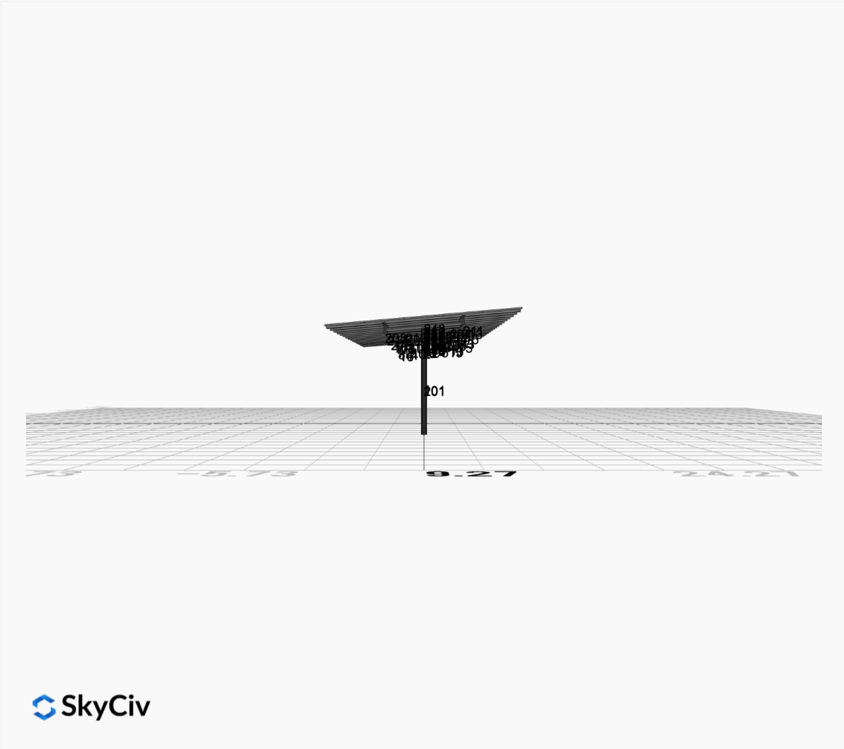
### AutoDesigner Input

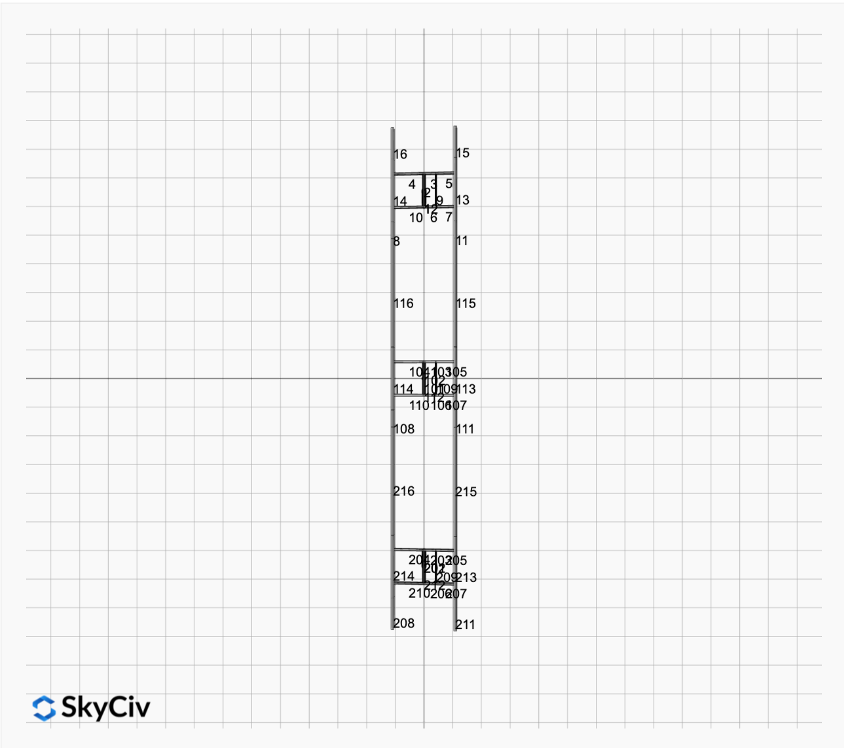
{"wind_speed_override":null,"snow_load_override":null,"direct_snow_load":false,"product_type":"Beam","project_id":"KopkesGreenhouse-JB-RevA","site_address":"1828 Sand Hill Rd, Oregon, WI 53575, USA","module_width":44.6456693,"module_length":89.7244094,"number_rows":"5","number_columns":8,"pole_mount_section":"4_40","core_pipe_width":65,"core_pipe_section":"2_40","adjuster_section":"2_40","core_beam_height":65,"core_beam_section":"HSS3x2x1/8","main_pipe_section":"2_12GA","pole_spacing":"15","tilt_angle":5,"ground_clearance":10,"risk_category":"I","exposure_category":"B","frame_duty_override":"auto","pole_override":"auto","soil_type":"sand","customer_foundation_override":"48_Square","foundation_type":"Square","foundation_size":48,"check_rails":false}

**Design Notes:**

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




201
9.27
SkyCiv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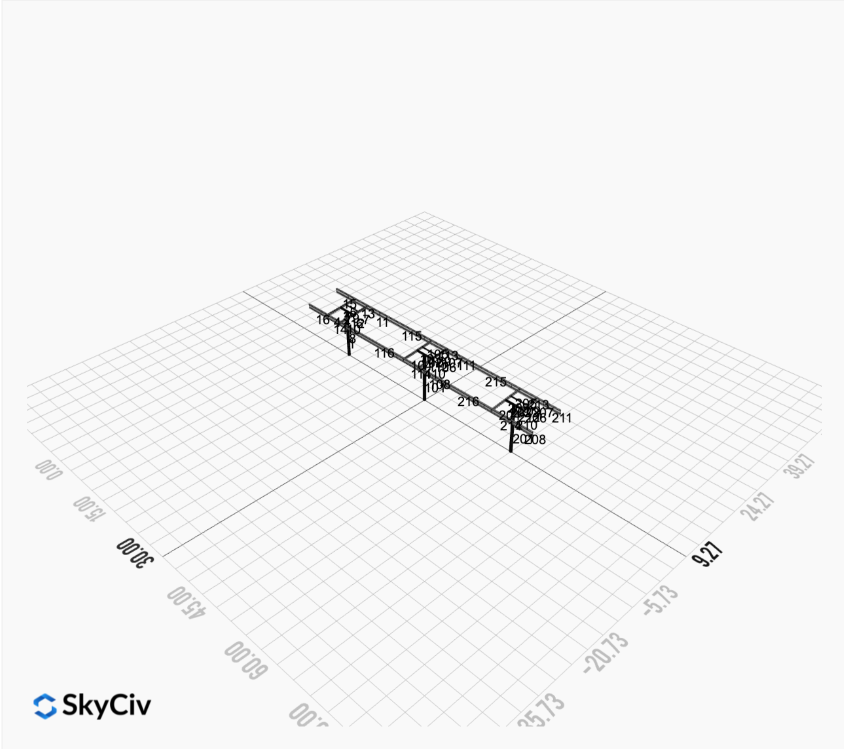
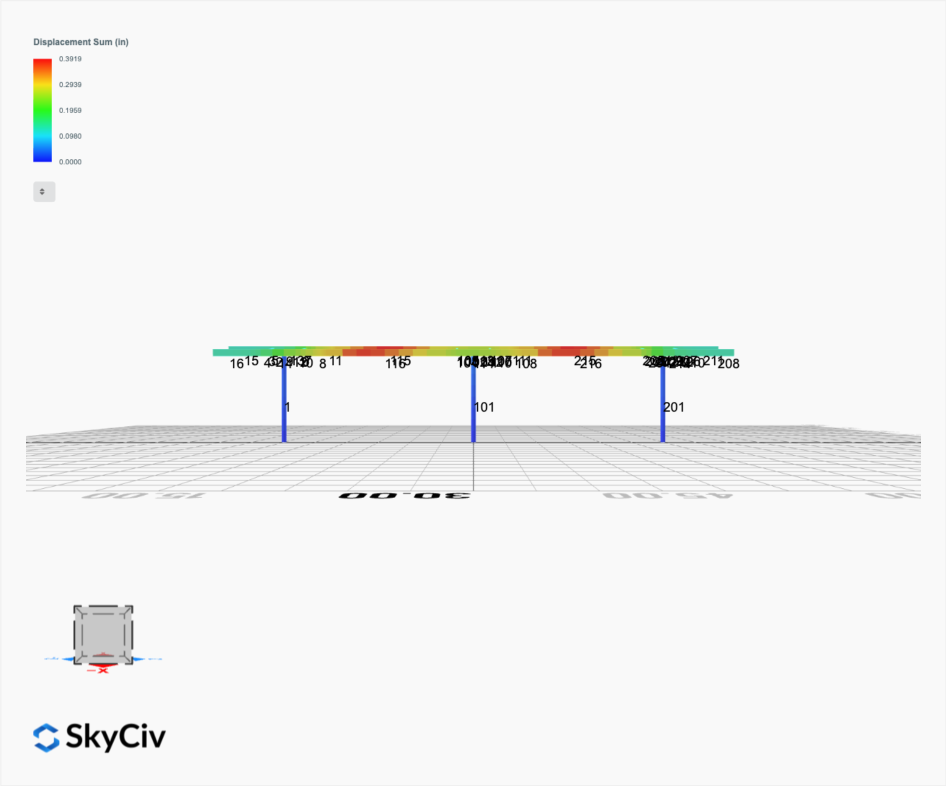
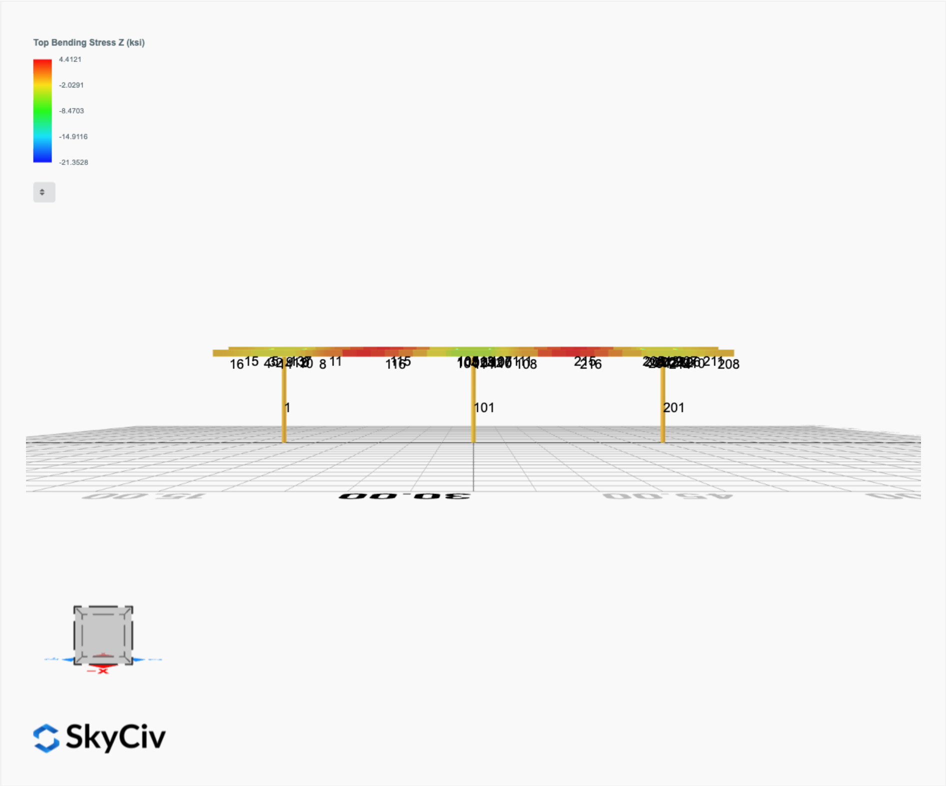
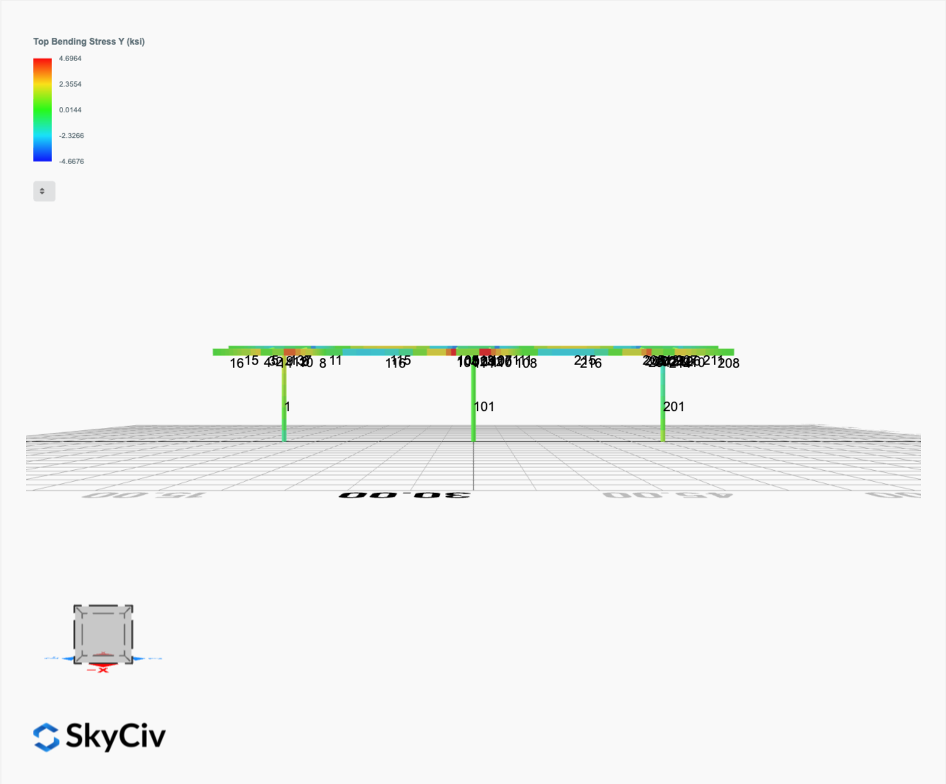
208
211
SkyCiv

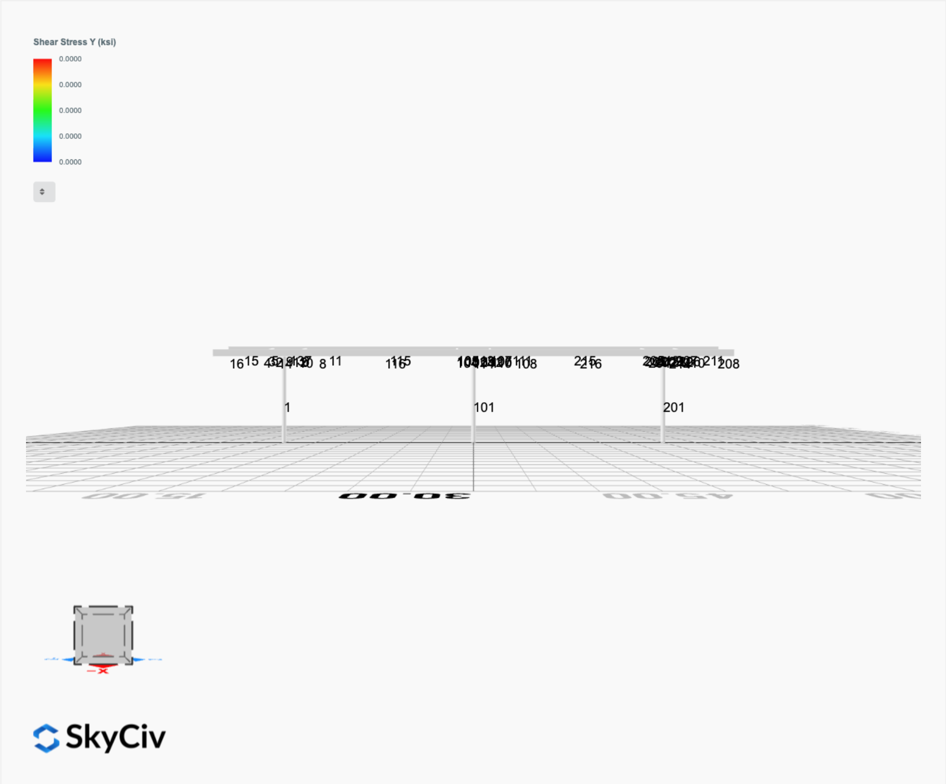


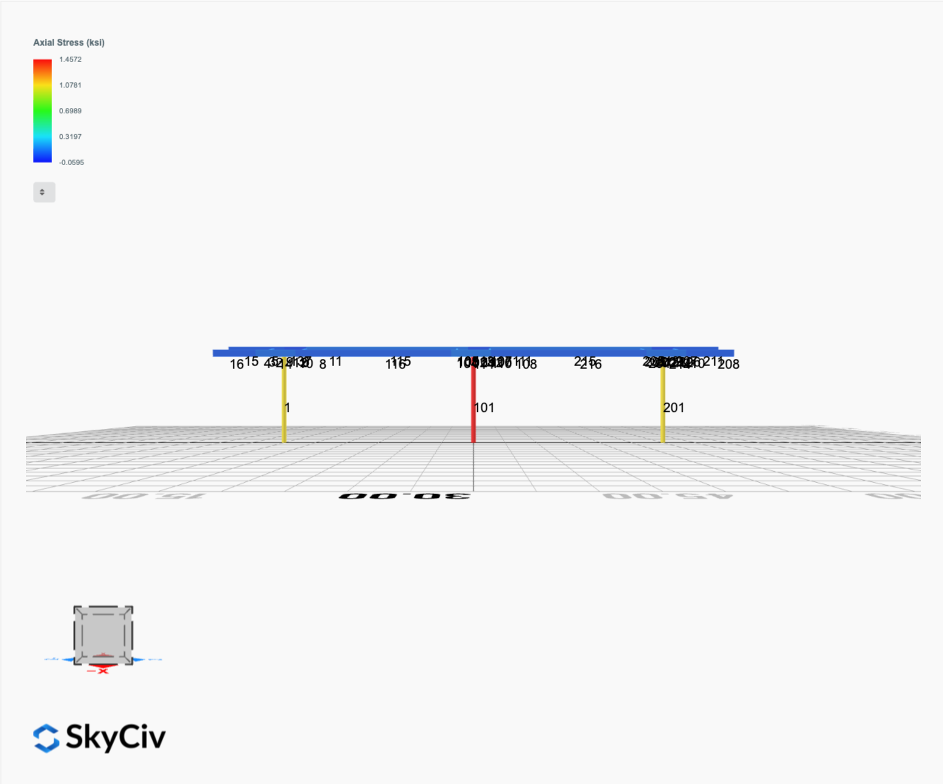
# FEM Results (Envelope Worst Case for each member)




Top Bending Stress Y (ksi)
4.6964
2.3554
0.0144
-2.3266
-4.6676
1
101
201
30.00
SkyCiv


Shear Stress Y (ksi)
0.0000
0.0000
0.0000
0.0000
0.0000
1
101
201
30.00
SkyCiv


Axial Stress (ksi)
1.4572
1.0781
0.6989
0.3197
-0.0595
1
101
201
30.00
SkyCiv

## 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 | 0.0054 | 2.4236 | 0.0551 | 0.1885 | -0.0054 | -0.0141 |
| ULS: 2. D + L | 0.0054 | 2.4236 | 0.0551 | 0.1885 | -0.0054 | -0.0141 |
| ULS: 3. D + (S or Lr or R) | 0.0224 | 8.5569 | 0.2293 | 0.7870 | -0.0224 | -0.1564 |
| ULS: 3. D + (S or Lr or R) | 0.0054 | 2.4236 | 0.0551 | 0.1885 | -0.0054 | -0.0141 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | 0.0182 | 7.0236 | 0.1857 | 0.6374 | -0.0181 | -0.1209 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | 0.0054 | 2.4236 | 0.0551 | 0.1885 | -0.0054 | -0.0141 |
| ULS: 5b. D + 0.7E | 0.0054 | 2.4236 | 0.0551 | 0.1885 | -0.0054 | -0.0141 |
| ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S | 0.0182 | 7.0236 | 0.1857 | 0.6374 | -0.0181 | -0.1209 |
| ULS: 8. 0.6D + 0.7E | 0.0033 | 1.4541 | 0.0330 | 0.1131 | -0.0032 | -0.0085 |
| ULS: 5a. D + 0.6W_Wind downforce Case A only | -0.1923 | 4.6274 | 0.1190 | 0.4070 | -0.0222 | 2.6544 |
| ULS: 5a. D + 0.6W_Wind downforce Case B only | -0.1923 | 4.6274 | 0.1190 | 0.4070 | -0.0222 | 2.6544 |
| ULS: 5a. D + 0.6W_Wind uplift Case A only | 0.0540 | 1.8310 | 0.0400 | 0.1372 | -0.0030 | 1.7829 |
| ULS: 5a. D + 0.6W_Wind uplift Case B only | 0.1401 | 1.0202 | 0.0104 | 0.0369 | 0.0095 | -6.6014 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -0.1301 | 8.6765 | 0.2337 | 0.8012 | -0.0308 | 1.8806 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -0.1301 | 8.6765 | 0.2337 | 0.8012 | -0.0308 | 1.8806 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 0.0546 | 6.5792 | 0.1745 | 0.5989 | -0.0164 | 1.2269 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 0.1192 | 5.9711 | 0.1523 | 0.5236 | -0.0070 | -5.0613 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -0.1429 | 4.0764 | 0.1031 | 0.3524 | -0.0180 | 1.9873 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -0.1429 | 4.0764 | 0.1031 | 0.3524 | -0.0180 | 1.9873 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 0.0418 | 1.9791 | 0.0438 | 0.1501 | -0.0036 | 1.3336 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 0.1064 | 1.3711 | 0.0216 | 0.0748 | 0.0058 | -4.9546 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case A only | -0.1945 | 3.6580 | 0.0970 | 0.3316 | -0.0201 | 2.6601 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case B only | -0.1945 | 3.6580 | 0.0970 | 0.3316 | -0.0201 | 2.6601 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case A only | 0.0518 | 0.8616 | 0.0180 | 0.0618 | -0.0009 | 1.7885 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case B only | 0.1379 | 0.0508 | -0.0116 | -0.0385 | 0.0116 | -6.5958 |

### 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 | 14.5580 |
| Shear X | -0.3296 |
| Shear Z | 0.4001 |
| Moment X | 1.3804 |
| Moment Y (Twist) | 0.0484 |
| Moment Z | 11.7630 |

### 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 | 8.6765 |
| Shear X | -0.1945 |
| Shear Z | 0.2337 |
| Moment X | 0.8012 |
| Moment Y (Twist) | 0.0308 |
| Moment Z | 6.6014 |

## 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 | -0.0108 | 3.0577 | -0.0000 | 0.0000 | 0.0000 | 0.1273 |
| ULS: 2. D + L | -0.0108 | 3.0577 | -0.0000 | 0.0000 | 0.0000 | 0.1273 |
| ULS: 3. D + (S or Lr or R) | -0.0449 | 11.1911 | 0.0000 | -0.0000 | 0.0000 | 0.4429 |
| ULS: 3. D + (S or Lr or R) | -0.0108 | 3.0577 | -0.0000 | 0.0000 | 0.0000 | 0.1273 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | -0.0364 | 9.1577 | 0.0000 | -0.0000 | 0.0000 | 0.3640 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | -0.0108 | 3.0577 | -0.0000 | 0.0000 | 0.0000 | 0.1273 |
| ULS: 5b. D + 0.7E | -0.0108 | 3.0577 | -0.0000 | 0.0000 | 0.0000 | 0.1273 |

| Name | Fx | Fy | Fz | Mx | My | Mz |
|---|---|---|---|---|---|---|
| ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S | -0.0364 | 9.1577 | 0.0000 | -0.0000 | 0.0000 | 0.3640 |
| ULS: 8. 0.6D + 0.7E | -0.0065 | 1.8346 | -0.0000 | 0.0000 | 0.0000 | 0.0764 |
| ULS: 5a. D + 0.6W_Wind downforce Case A only | -0.2564 | 5.9776 | -0.0000 | 0.0000 | 0.0000 | 3.3012 |
| ULS: 5a. D + 0.6W_Wind downforce Case B only | -0.2564 | 5.9776 | -0.0000 | 0.0000 | 0.0000 | 3.3012 |
| ULS: 5a. D + 0.6W_Wind uplift Case A only | 0.0651 | 2.2655 | -0.0000 | 0.0000 | 0.0000 | 2.0347 |
| ULS: 5a. D + 0.6W_Wind uplift Case B only | 0.1268 | 1.2120 | -0.0000 | 0.0000 | 0.0000 | -7.2247 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -0.2205 | 11.3476 | 0.0000 | -0.0000 | 0.0000 | 2.7444 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -0.2205 | 11.3476 | 0.0000 | -0.0000 | 0.0000 | 2.7444 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 0.0206 | 8.5636 | 0.0000 | -0.0000 | 0.0000 | 1.7945 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 0.0669 | 7.7734 | 0.0000 | -0.0000 | 0.0000 | -5.1500 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -0.1950 | 5.2476 | -0.0000 | 0.0000 | 0.0000 | 2.5077 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -0.1950 | 5.2476 | -0.0000 | 0.0000 | 0.0000 | 2.5077 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 0.0461 | 2.4636 | -0.0000 | 0.0000 | 0.0000 | 1.5579 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 0.0924 | 1.6734 | -0.0000 | 0.0000 | 0.0000 | -5.3867 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case A only | -0.2521 | 4.7545 | -0.0000 | -0.0000 | 0.0000 | 3.2502 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case B only | -0.2521 | 4.7545 | -0.0000 | -0.0000 | 0.0000 | 3.2502 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case A only | 0.0694 | 1.0424 | -0.0000 | 0.0000 | 0.0000 | 1.9838 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case B only | 0.1312 | -0.0111 | -0.0000 | 0.0000 | 0.0000 | -7.2757 |

### 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 | 19.1163 |
| Shear X | -0.4375 |
| Shear Z | -0.0000 |
| Moment X | 0.0000 |
| Moment Y (Twist) | 0.0001 |
| Moment Z | 12.8068 |

### 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 | 11.3476 |
| Shear X | -0.2564 |
| Shear Z | 0.0000 |
| Moment X | -0.0000 |
| Moment Y (Twist) | 0.0000 |
| Moment Z | 7.2757 |

## 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 | 0.0054 | 2.4236 | -0.0551 | -0.1885 | 0.0054 | -0.0141 |
| ULS: 2. D + L | 0.0054 | 2.4236 | -0.0551 | -0.1885 | 0.0054 | -0.0141 |
| ULS: 3. D + (S or Lr or R) | 0.0224 | 8.5569 | -0.2293 | -0.7870 | 0.0225 | -0.1564 |
| ULS: 3. D + (S or Lr or R) | 0.0054 | 2.4236 | -0.0551 | -0.1885 | 0.0054 | -0.0141 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | 0.0182 | 7.0236 | -0.1857 | -0.6374 | 0.0182 | -0.1208 |
| ULS: 4. D + 0.75L + 0.75(S or Lr or R) | 0.0054 | 2.4236 | -0.0551 | -0.1885 | 0.0054 | -0.0141 |
| ULS: 5b. D + 0.7E | 0.0054 | 2.4236 | -0.0551 | -0.1885 | 0.0054 | -0.0141 |
| ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S | 0.0182 | 7.0236 | -0.1857 | -0.6374 | 0.0182 | -0.1208 |
| ULS: 8. 0.6D + 0.7E | 0.0033 | 1.4541 | -0.0330 | -0.1131 | 0.0032 | -0.0085 |
| ULS: 5a. D + 0.6W_Wind downforce Case A only | -0.1923 | 4.6274 | -0.1190 | -0.4070 | 0.0222 | 2.6544 |
| ULS: 5a. D + 0.6W_Wind downforce Case B only | -0.1923 | 4.6274 | -0.1190 | -0.4070 | 0.0222 | 2.6544 |
| ULS: 5a. D + 0.6W_Wind uplift Case A only | 0.0540 | 1.8310 | -0.0400 | -0.1372 | 0.0030 | 1.7829 |
| ULS: 5a. D + 0.6W_Wind uplift Case B only | 0.1401 | 1.0202 | -0.0104 | -0.0369 | -0.0095 | -6.6014 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only | -0.1301 | 8.6765 | -0.2337 | -0.8012 | 0.0308 | 1.8806 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -0.1301 | 8.6765 | -0.2337 | -0.8012 | 0.0308 | 1.8806 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 0.0546 | 6.5792 | -0.1745 | -0.5989 | 0.0164 | 1.2269 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 0.1192 | 5.9711 | -0.1523 | -0.5236 | 0.0071 | -5.0613 |

| 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 | -0.1429 | 4.0764 | -0.1031 | -0.3524 | 0.0180 | 1.9873 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only | -0.1429 | 4.0764 | -0.1031 | -0.3524 | 0.0180 | 1.9873 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only | 0.0418 | 1.9791 | -0.0438 | -0.1501 | 0.0036 | 1.3336 |
| ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only | 0.1064 | 1.3711 | -0.0216 | -0.0748 | -0.0058 | -4.9546 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case A only | -0.1945 | 3.6580 | -0.0970 | -0.3316 | 0.0201 | 2.6601 |
| ULS: 7. 0.6D + 0.6W_Wind downforce Case B only | -0.1945 | 3.6580 | -0.0970 | -0.3316 | 0.0201 | 2.6601 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case A only | 0.0518 | 0.8616 | -0.0180 | -0.0618 | 0.0009 | 1.7885 |
| ULS: 7. 0.6D + 0.6W_Wind uplift Case B only | 0.1379 | 0.0508 | 0.0116 | 0.0385 | -0.0116 | -6.5958 |

### 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 | 14.5580 |
| Shear X | -0.3296 |
| Shear Z | -0.4001 |
| Moment X | -1.3804 |
| Moment Y (Twist) | 0.0487 |
| Moment Z | 11.7631 |

### 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 | 8.6765 |
| Shear X | -0.1945 |
| Shear Z | -0.2337 |
| Moment X | -0.8012 |
| Moment Y (Twist) | 0.0308 |
| Moment Z | 6.6014 |

## Project Details

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

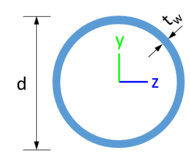
User Name: sales@mtsolar.us
Unit System: imperial

## Design Input Information

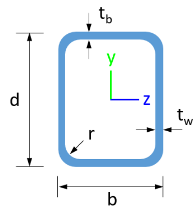
| Design Factors | | | |
|---|---|---|---|
| $\Phi_t$ | $\Phi_c$ | $\Phi_b$ | $\Phi_v$ |
| 0.9 | 0.9 | 0.9 | 0.9 |

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

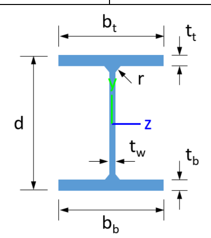
**Section Dimensions**




| 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 | | | | | |
| 7 | 6in Pipe Sch 40 | 6.63 | 0.28 | | | | | |




| 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 |
| 7 | 6in Pipe Sch 40 | 5.58 | 56.28 | 28.14 | 28.14 | 0.00 | 11.28 | 11.28 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 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 | 7 | 22.72 | 22.72 | 10.82 | - | 300 | 200 | 1 |
| 2 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 3 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.18,1.19,1.18,1.18,1.19,1.18,1.18,1.18,1.22,1.18,1.18,1.18,1.16,1.18,1.18,1.18,1.18,1.18,1.18,1.19,1.45,1.18,1.18,1.18,1.17 | 300 | 200 | 1 |
| 4 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.68,1.69,1.67,1.68,1.69,1.67,1.67,1.68,1.68,1.68,1.68,1.81,1.69,1.67,1.67,1.67,1.67,1.68,1.68,1.70,1.69,1.67,1.67,1.49,1.69 | 300 | 200 | 1 |
| 5 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.67,1.68,1.67,1.68,1.68,1.67,1.67,1.67,1.71,1.67,1.67,1.68,1.65,1.67,1.67,1.67,1.67,1.67,1.67,1.68,2.16,1.67,1.67,1.68,1.66 | 300 | 200 | 1 |
| 6 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.18,1.19,1.18,1.19,1.19,1.18,1.18,1.18,1.20,1.18,1.18,1.19,1.17,1.18,1.18,1.18,1.18,1.19,1.19,1.19,1.50,1.18,1.18,1.19,1.18 | 300 | 200 | 1 |
| 7 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.67,1.68,1.67,1.67,1.68,1.67,1.67,1.67,1.71,1.67,1.67,1.68,1.66,1.67,1.67,1.67,1.67,1.67,1.67,1.68,1.16,1.67,1.67,1.68,1.66 | 300 | 200 | 1 |
| 8 | 20 | 1.33 | 1.33 | 2.05 | 1.53,1.53,1.53,1.53,1.53,1.53,1.52,1.52,1.46,1.67,1.52,1.52,1.15,1.95,1.53,1.53,1.52,1.56,1.52,1.52,1.45,1.70,1.52,1.52,2.20,2.09 | 300 | 200 | 1 |
| 9 | 3 | 2.60 | 2.60 | 4.00 | - | 300 | 200 | 1 |
| 10 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.68,1.69,1.67,1.68,1.69,1.67,1.67,1.68,1.68,1.67,1.67,1.79,1.69,1.67,1.67,1.67,1.67,1.68,1.68,1.70,1.69,1.67,1.67,1.53,1.69 | 300 | 200 | 1 |
| 11 | 20 | 1.33 | 1.33 | 2.05 | 1.55,1.55,1.55,1.55,1.55,1.57,1.57,1.61,1.13,1.57,1.57,1.69,2.02,1.56,1.56,1.57,1.52,1.57,1.57,1.62,1.19,1.57,1.57,1.75,1.88 | 300 | 200 | 1 |
| 12 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 13 | 20 | 4.88 | 4.00 | 7.50 | 1.13,1.13,1.13,1.13,1.13,1.13,1.13,1.13,1.13,1.08,1.13,1.13,1.13,1.18,1.13,1.13,1.13,1.13,1.13,1.13,1.13,3.61,1.13,1.13,1.14,1.14 | 300 | 200 | 1 |
| 14 | 20 | 4.88 | 4.00 | 7.50 | 1.12,1.12,1.12,1.12,1.12,1.12,1.12,1.11,1.14,1.12,1.12,1.05,1.15,1.13,1.13,1.12,1.13,1.12,1.12,1.11,1.14,1.12,1.12,1.98,1.23 | 300 | 200 | 1 |
| 15 | 20 | 7.88 | 7.88 | 3.75 | 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 | 7.88 | 7.88 | 3.75 | 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 | 7 | 22.72 | 22.72 | 10.82 | - | 300 | 200 | 1 |
| 102 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 103 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.18,1.19,1.18,1.18,1.19,1.18,1.18,1.18,1.19,1.18,1.18,1.19,1.17,1.18,1.18,1.18,1.18,1.18,1.18,1.19,1.26,1.18,1.18,1.19,1.17 | 300 | 200 | 1 |
| 104 | 17 | 2.44 | 2.44 | 3.75 | 1.68,1.67,1.68,1.67,1.68,1.68,1.67,1.67,1.68,1.67,1.67,1.67,1.74,1.68,1.67,1.67,1.67,1.67,1.68,1.68,1.69,1.68,1.67,1.67,1.46,1.69 | 300 | 200 | 1 |
| 105 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.67,1.68,1.67,1.67,1.68,1.67,1.67,1.67,1.69,1.67,1.67,1.68,1.66,1.67,1.67,1.67,1.67,1.67,1.67,1.68,1.79,1.67,1.67,1.68,1.66 | 300 | 200 | 1 |
| 106 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.18,1.19,1.18,1.18,1.19,1.18,1.18,1.18,1.19,1.18,1.18,1.19,1.17,1.18,1.18,1.18,1.18,1.18,1.18,1.19,1.26,1.18,1.18,1.19,1.17 | 300 | 200 | 1 |
| 107 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.67,1.68,1.67,1.67,1.68,1.67,1.67,1.67,1.69,1.67,1.67,1.68,1.66,1.67,1.67,1.67,1.67,1.67,1.67,1.68,1.79,1.67,1.67,1.68,1.66 | 300 | 200 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 108 | 20 | 1.33 | 1.33 | 2.05 | 2.24,2.24,2.24,2.23,2.24,2.24,2.22,2.22,1.97,2.13,2.22,2.22,1.29,1.61,2.23,2.23,2.22,2.27,2.22,2.22,1.90,2.11,2.21,2.21,1.09,1.41 | 300 | 200 | 1 |
| 109 | 3 | 2.60 | 2.60 | 4.00 | - | 300 | 200 | 1 |
| 110 | 17 | 2.44 | 2.44 | 3.75 | 1.68,1.67,1.68,1.67,1.68,1.68,1.67,1.67,1.68,1.67,1.67,1.67,1.74,1.68,1.67,1.67,1.67,1.67,1.68,1.68,1.69,1.68,1.67,1.67,1.46,1.69 | 300 | 200 | 1 |
| 111 | 20 | 1.33 | 1.33 | 2.05 | 2.26,2.26,2.26,2.26,2.26,2.28,2.28,2.35,1.26,2.29,2.29,2.11,1.49,2.27,2.27,2.28,2.21,2.28,2.28,2.34,1.10,2.29,2.29,2.08,1.66 | 300 | 200 | 1 |
| 112 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 113 | 20 | 4.88 | 4.00 | 7.50 | 1.02,1.02,1.02,1.02,1.02,1.02,1.02,1.02,1.03,1.01,1.02,1.02,1.03,1.11,1.02,1.02,1.02,1.02,1.02,1.03,1.00,1.02,1.02,1.03,1.05 | 300 | 200 | 1 |
| 114 | 20 | 4.88 | 4.00 | 7.50 | 1.02,1.02,1.02,1.02,1.02,1.02,1.02,1.02,1.02,1.03,1.02,1.02,1.01,1.06,1.02,1.02,1.02,1.02,1.02,1.02,1.03,1.02,1.02,1.03,1.19 | 300 | 200 | 1 |
| 115 | 20 | 8.42 | 8.42 | 12.95 | 1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.18,1.17,2.29,1.18,1.18,1.15,1.10,1.18,1.18,1.18,1.20,1.18,1.18,1.16,2.13,1.18,1.18,1.14,1.11 | 300 | 200 | 1 |
| 116 | 20 | 8.42 | 8.42 | 12.95 | 1.19,1.19,1.19,1.19,1.19,1.19,1.19,1.19,1.22,1.15,1.20,1.20,2.09,1.11,1.19,1.19,1.19,1.18,1.19,1.19,1.22,1.15,1.20,1.20,1.11,1.10 | 300 | 200 | 1 |
| 201 | 7 | 22.72 | 22.72 | 10.82 | - | 300 | 200 | 1 |
| 202 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 203 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.18,1.19,1.18,1.19,1.19,1.18,1.18,1.18,1.20,1.18,1.18,1.19,1.17,1.18,1.18,1.18,1.18,1.19,1.19,1.19,1.50,1.18,1.18,1.19,1.18 | 300 | 200 | 1 |
| 204 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.68,1.69,1.67,1.68,1.69,1.67,1.67,1.68,1.68,1.67,1.67,1.79,1.69,1.67,1.67,1.67,1.67,1.68,1.68,1.70,1.69,1.67,1.67,1.53,1.69 | 300 | 200 | 1 |
| 205 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.67,1.68,1.67,1.67,1.68,1.67,1.67,1.67,1.71,1.67,1.67,1.68,1.66,1.67,1.67,1.67,1.67,1.67,1.67,1.68,1.16,1.67,1.67,1.68,1.66 | 300 | 200 | 1 |
| 206 | 17 | 0.92 | 0.92 | 1.42 | 1.19,1.18,1.19,1.18,1.18,1.19,1.18,1.18,1.18,1.22,1.18,1.18,1.18,1.16,1.18,1.18,1.18,1.18,1.18,1.18,1.19,1.45,1.18,1.18,1.18,1.17 | 300 | 200 | 1 |
| 207 | 17 | 1.52 | 1.52 | 2.33 | 1.68,1.67,1.68,1.67,1.68,1.68,1.67,1.67,1.67,1.71,1.67,1.67,1.68,1.65,1.67,1.67,1.67,1.67,1.67,1.67,1.68,2.16,1.67,1.67,1.68,1.66 | 300 | 200 | 1 |
| 208 | 20 | 7.88 | 7.88 | 3.75 | 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 |
| 209 | 3 | 2.60 | 2.60 | 4.00 | - | 300 | 200 | 1 |
| 210 | 17 | 2.44 | 2.44 | 3.75 | 1.69,1.68,1.69,1.67,1.68,1.69,1.67,1.67,1.68,1.68,1.68,1.68,1.81,1.69,1.67,1.67,1.67,1.67,1.68,1.68,1.70,1.69,1.67,1.67,1.49,1.69 | 300 | 200 | 1 |
| 211 | 20 | 7.88 | 7.88 | 3.75 | 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 |
| 212 | 6 | 1.30 | 1.30 | 2.00 | - | 300 | 200 | 1 |
| 213 | 20 | 4.88 | 4.00 | 7.50 | 1.13,1.13,1.13,1.13,1.13,1.13,1.13,1.13,1.13,1.08,1.13,1.13,1.13,1.18,1.13,1.13,1.13,1.13,1.13,1.13,1.13,3.62,1.13,1.13,1.14,1.14 | 300 | 200 | 1 |
| 214 | 20 | 4.88 | 4.00 | 7.50 | 1.12,1.12,1.12,1.12,1.12,1.12,1.12,1.12,1.11,1.14,1.12,1.12,1.05,1.15,1.13,1.13,1.12,1.13,1.12,1.12,1.11,1.14,1.12,1.12,1.98,1.23 | 300 | 200 | 1 |
| 215 | 20 | 8.42 | 8.42 | 12.95 | 1.12,1.12,1.12,1.12,1.12,1.12,1.12,1.12,1.12,1.46,1.12,1.12,1.11,1.14,1.12,1.12,1.12,1.12,1.12,1.12,1.12,2.31,1.12,1.12,1.12,1.13 | 300 | 200 | 1 |
| 216 | 20 | 8.42 | 8.42 | 12.95 | 1.12,1.12,1.12,1.12,1.12,1.12,1.12,1.12,1.12,1.11,1.12,1.12,1.27,1.13,1.12,1.12,1.12,1.12,1.12,1.12,1.12,1.11,1.12,1.12,1.27,1.14 | 300 | 200 | 1 |

## Member Design Capacity

## 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 | 251.16 | 85.52 | 42.30 | 42.30 | 75.35 | 75.35 |
| 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 | 33.01 | 6.46 | 56.26 | 44.91 |
| 14 | 159.30 | 116.35 | 32.09 | 6.46 | 56.26 | 44.91 |
| 15 | 159.30 | 55.15 | 46.90 | 6.46 | 56.26 | 44.91 |
| 16 | 159.30 | 55.15 | 46.90 | 6.46 | 56.26 | 44.91 |
| 101 | 251.16 | 85.52 | 42.30 | 42.30 | 75.35 | 75.35 |
| 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 | 30.56 | 6.46 | 56.26 | 44.91 |
| 114 | 159.30 | 116.35 | 30.87 | 6.46 | 56.26 | 44.91 |
| 115 | 159.30 | 48.27 | 14.61 | 6.46 | 56.26 | 44.91 |
| 116 | 159.30 | 48.27 | 14.61 | 6.46 | 56.26 | 44.91 |
| 201 | 251.16 | 85.52 | 42.30 | 42.30 | 75.35 | 75.35 |
| 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 | 55.15 | 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 | 55.15 | 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 | 33.01 | 6.46 | 56.26 | 44.91 |
| 214 | 159.30 | 116.35 | 32.09 | 6.46 | 56.26 | 44.91 |
| 215 | 159.30 | 48.27 | 14.74 | 6.46 | 56.26 | 44.91 |
| 216 | 159.30 | 48.27 | 14.74 | 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 | 0.170 | 0.278 | 0.069 | 0.004 | 0.005 | 0.306 | #16 | 0.607 | Not Required | Pass |
| 2 | 0.001 | 0.404 | 0.015 | 0.087 | 0.002 | 0.419 | #21 | 0.036 | Not Required | Pass |
| 3 | 0.002 | 0.608 | 0.009 | 0.060 | 0.004 | 0.617 | #21 | 0.046 | Not Required | Pass |
| 4 | 0.001 | 0.598 | 0.034 | 0.060 | 0.009 | 0.631 | #21 | 0.082 | Not Required | Pass |
| 5 | 0.002 | 0.377 | 0.020 | 0.060 | 0.005 | 0.378 | #21 | 0.076 | Not Required | Pass |
| 6 | 0.002 | 0.713 | 0.030 | 0.072 | 0.006 | 0.743 | #21 | 0.046 | Not Required | Pass |
| 7 | 0.002 | 0.441 | 0.054 | 0.071 | 0.015 | 0.459 | #21 | 0.076 | Not Required | Pass |
| 8 | 0.001 | 0.102 | 0.060 | 0.046 | 0.005 | 0.111 | #21 | 0.102 | Not Required | Pass |
| 9 | 0.004 | 0.086 | 0.027 | 0.002 | 0.002 | 0.114 | #21 | 0.206 | Not Required | Pass |
| 10 | 0.003 | 0.695 | 0.039 | 0.070 | 0.007 | 0.707 | #21 | 0.082 | Not Required | Pass |
| 11 | 0.002 | 0.102 | 0.064 | 0.047 | 0.005 | 0.108 | #21 | 0.102 | Not Required | Pass |
| 12 | 0.000 | 0.512 | 0.019 | 0.103 | 0.002 | 0.528 | #21 | 0.054 | Not Required | Pass |
| 13 | 0.003 | 0.198 | 0.131 | 0.059 | 0.006 | 0.268 | #21 | 0.306 | Not Required | Pass |
| 14 | 0.002 | 0.197 | 0.127 | 0.058 | 0.006 | 0.254 | #24 | 0.204 | Not Required | Pass |
| 15 | 0.000 | 0.058 | 0.032 | 0.026 | 0.002 | 0.090 | #21 | Not Required | Not Required | Pass |
| 16 | 0.000 | 0.058 | 0.032 | 0.026 | 0.002 | 0.090 | #21 | Not Required | Not Required | Pass |
| 101 | 0.224 | 0.303 | 0.000 | 0.006 | 0.000 | 0.330 | #16 | 0.607 | Not Required | Pass |
| 102 | 0.001 | 0.610 | 0.024 | 0.125 | 0.003 | 0.635 | #21 | 0.054 | Not Required | Pass |
| 103 | 0.002 | 0.868 | 0.012 | 0.087 | 0.001 | 0.879 | #21 | 0.046 | Not Required | Pass |
| 104 | 0.002 | 0.862 | 0.050 | 0.086 | 0.010 | 0.893 | #21 | 0.082 | Not Required | Pass |
| 105 | 0.002 | 0.538 | 0.051 | 0.086 | 0.013 | 0.553 | #21 | 0.076 | Not Required | Pass |
| 106 | 0.002 | 0.868 | 0.012 | 0.087 | 0.001 | 0.879 | #21 | 0.046 | Not Required | Pass |
| 107 | 0.002 | 0.538 | 0.051 | 0.086 | 0.013 | 0.553 | #21 | 0.076 | Not Required | Pass |
| 108 | 0.001 | 0.087 | 0.068 | 0.056 | 0.005 | 0.155 | #21 | 0.102 | Not Required | Pass |
| 109 | 0.006 | 0.094 | 0.011 | 0.001 | 0.000 | 0.108 | #21 | 0.206 | Not Required | Pass |
| 110 | 0.002 | 0.862 | 0.050 | 0.086 | 0.010 | 0.893 | #21 | 0.082 | Not Required | Pass |
| 111 | 0.002 | 0.079 | 0.067 | 0.056 | 0.005 | 0.148 | #21 | 0.102 | Not Required | Pass |
| 112 | 0.001 | 0.610 | 0.024 | 0.125 | 0.003 | 0.635 | #21 | 0.054 | Not Required | Pass |
| 113 | 0.003 | 0.344 | 0.135 | 0.069 | 0.006 | 0.454 | #21 | 0.306 | Not Required | Pass |
| 114 | 0.003 | 0.359 | 0.136 | 0.068 | 0.006 | 0.465 | #21 | 0.306 | Not Required | Pass |
| 115 | 0.006 | 0.590 | 0.068 | 0.056 | 0.005 | 0.661 | #21 | 0.644 | Not Required | Pass |
| 116 | 0.002 | 0.570 | 0.070 | 0.056 | 0.005 | 0.641 | #21 | 0.644 | Not Required | Pass |
| 201 | 0.170 | 0.278 | 0.069 | 0.004 | 0.005 | 0.306 | #16 | 0.607 | Not Required | Pass |
| 202 | 0.000 | 0.512 | 0.019 | 0.103 | 0.002 | 0.528 | #21 | 0.054 | Not Required | Pass |
| 203 | 0.002 | 0.713 | 0.030 | 0.072 | 0.006 | 0.743 | #21 | 0.046 | Not Required | Pass |
| 204 | 0.003 | 0.695 | 0.039 | 0.070 | 0.007 | 0.707 | #21 | 0.082 | Not Required | Pass |
| 205 | 0.002 | 0.441 | 0.054 | 0.071 | 0.015 | 0.459 | #21 | 0.076 | Not Required | Pass |
| 206 | 0.002 | 0.608 | 0.009 | 0.060 | 0.004 | 0.617 | #21 | 0.046 | Not Required | Pass |
| 207 | 0.002 | 0.377 | 0.020 | 0.060 | 0.005 | 0.378 | #21 | 0.076 | Not Required | Pass |
| 208 | 0.000 | 0.058 | 0.032 | 0.026 | 0.002 | 0.090 | #21 | Not Required | Not Required | Pass |
| 209 | 0.004 | 0.086 | 0.027 | 0.002 | 0.002 | 0.114 | #21 | 0.206 | Not Required | Pass |
| 210 | 0.001 | 0.598 | 0.034 | 0.060 | 0.009 | 0.631 | #21 | 0.082 | Not Required | Pass |
| 211 | 0.000 | 0.058 | 0.032 | 0.026 | 0.002 | 0.090 | #21 | Not Required | Not Required | Pass |
| 212 | 0.001 | 0.404 | 0.015 | 0.087 | 0.002 | 0.419 | #21 | 0.036 | Not Required | Pass |
| 213 | 0.003 | 0.198 | 0.131 | 0.059 | 0.006 | 0.268 | #21 | 0.204 | Not Required | Pass |
| 214 | 0.002 | 0.197 | 0.127 | 0.058 | 0.006 | 0.254 | #24 | 0.306 | Not Required | Pass |
| 215 | 0.006 | 0.620 | 0.068 | 0.047 | 0.005 | 0.690 | #21 | 0.644 | Not Required | Pass |
| 216 | 0.002 | 0.605 | 0.069 | 0.046 | 0.005 | 0.675 | #21 | 0.644 | Not Required | Pass |

## Definitions

| | |
|---|---|
| $\Phi_t$ | Safety factor for tensile |

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

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

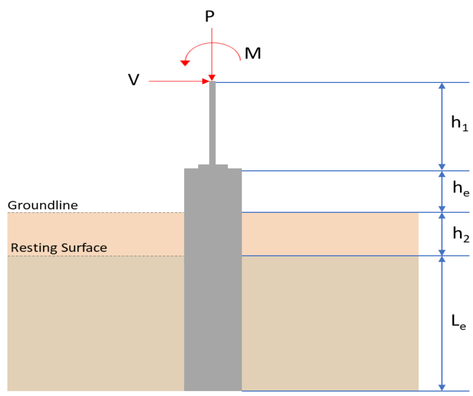
## SkyCiv Foundation Design

Pile Foundation

**Design Information :**

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

### Pile Input




**Geometry**

Pile shape: rectangular
$b = 48 \text{ in}$ - Pile width
$D = 48 \text{ in}$ - Pile depth
$L = 4.5 \text{ ft}$ - 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) | 8.676 | 14.558 |
| $V_x$ (kip) | -0.195 | -0.330 |
| $V_z$ (kip) | 0.234 | 0.400 |
| $M_x$ (kipft) | 0.801 | 1.380 |
| $M_z$ (kipft) | 6.601 | 11.763 |

**Material Properties**

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

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

$H$ - Point of application of the lateral load

$$H = h_1 + h_2 + h_e$$

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

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

**Considering x-direction:**

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-0.195 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = -0.031051 \text{ kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(6.601\ \mathrm{kipft}) + ((-0.195\ \mathrm{kip}) \times (0\ \mathrm{ft}))}{1.57 \times (48\ \mathrm{in})}$$

$$M_o = 1.0511\ \mathrm{kipft/ft}$$

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:
$L_{e,x} = 4.2394\ \mathrm{ft}$ - Required depth in x-direction,

**Considering z-direction:**

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(0.234\ \mathrm{kip})}{1.57 \times (48\ \mathrm{in})}$$

$$H_o = 0.037261\ \mathrm{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(0.801\ \mathrm{kipft}) + ((0.234\ \mathrm{kip}) \times (0\ \mathrm{ft}))}{1.57 \times (48\ \mathrm{in})}$$

$$M_o = 0.12755\ \mathrm{kipft/ft}$$

Required depth of embedment in earth:

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

Solving the cubic equation:
$L_{e,z} = 2.5101\ \mathrm{ft}$ - Required depth in z-direction,

**Minimum embedded depth required:**

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

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

$$L_{e,req} = MAX[(4.2394\ \mathrm{ft}), (2.5101\ \mathrm{ft})]$$

$$L_{e,req} = 4.239\ \mathrm{ft}$$

$L_e$ - Actual embedded length of pile,

$$L_e = L - h_e - h_2$$

$$L_e = (4.5\ \mathrm{ft}) - (0\ \mathrm{ft}) - (0\ \mathrm{ft})$$

$$L_e = 4.5\ \mathrm{ft}$$

$Ratio$ - Embedded depth

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

$$Ratio = \frac{(4.239\ \mathrm{ft})}{(4.5\ \mathrm{ft})}$$

$$Ratio = 0.942$$

Status: **PASS**
Ratio: **0.940**

**End-bearing Capacity (ASD)**

$A$ - Pile cross-section area

$$A = b\,D$$

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

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

$q$ - End-bearing pressure

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

$$q = \frac{(8.676\ \mathrm{kip})}{(16\ \mathrm{ft}^2)}$$

$$q = 0.54225\ \mathrm{kip/ft}^2$$

$q = 0.54225\ \mathrm{kip/ft}$

**Check bearing capacity ratio:**

$Ratio$ - Capacity

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

$$Ratio = \frac{\left(0.54225\ \mathrm{kip/ft^2}\right)}{\left(2000\ \mathrm{psf}\right)}$$

$$Ratio = 0.27113$$

Status: **PASS**
Ratio: **0.270**

*Czerniak*

**Lateral Soil Pressure (ASD):**

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

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

$$L/D = \frac{(4.5\ \mathrm{ft})}{(48\ \mathrm{in})}$$

$$L/D = 1.125$$

Since L/D $\leq$ 10,

Pile is short.

**Considering x-direction:**

$H_o = -0.031051\ \mathrm{kip/ft}$ - Lateral force per length of pile,
$M_o = 1.0511\ \mathrm{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (1.0511\ \mathrm{kipft/ft}) \times (4.5\ \mathrm{ft})) + \left(3 \times (-0.031051\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft})^2\right)}{(6 \times (1.0511\ \mathrm{kipft/ft})) + (4 \times (-0.031051\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))}$$

$$a = 3.0305\ \mathrm{ft}$$

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

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

$$p = \frac{0.75 \times [(4 \times (1.0511\ \mathrm{kipft/ft})) + (3 \times (-0.031051\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))]^2}{(4.5\ \mathrm{ft})^2 \times [(3 \times (1.0511\ \mathrm{kipft/ft})) + (2 \times (-0.031051\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))]}$$

$$p = 0.18465\ \mathrm{kip/ft^2}$$

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

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

$$s = \frac{6 \times [(2 \times (1.0511\ \mathrm{kipft/ft})) + ((-0.031051\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))]}{(4.5\ \mathrm{ft})^2}$$

$$s = 0.58148\ \mathrm{kip/ft^2}$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150\ \mathrm{psf/ft}) \times \frac{(3.0305\ \mathrm{ft})}{2}$$

$$p_a = 0.22729\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(0.18465\ \mathrm{kip/ft^2}\right)}{\left(0.22729\ \mathrm{kip/ft^2}\right)}$$

$$Ratio = 0.81242$$

Status: **PASS**
Ratio: **0.810**

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

$$p_s = R\,L_e$$

$$p_s = (150\ \text{psf/ft}) \times (4.5\ \text{ft})$$

$$p_s = 0.675\ \text{kip/ft}^2$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(0.58148\ \text{kip/ft}^2\right)}{\left(0.675\ \text{kip/ft}^2\right)}$$

$$Ratio = 0.86145$$

Status: **PASS**
Ratio: **0.860**

**Considering z-direction:**

$H_o = 0.037261\ \text{kip/ft}$ - Lateral force per length of pile,
$M_o = 0.12755\ \text{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (0.12755\ \text{kipft/ft}) \times (4.5\ \text{ft})) + \left(3 \times (0.037261\ \text{kip/ft}) \times (4.5\ \text{ft})^2\right)}{(6 \times (0.12755\ \text{kipft/ft})) + (4 \times (0.037261\ \text{kip/ft}) \times (4.5\ \text{ft}))}$$

$$a = 3.1751\ \text{ft}$$

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

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

$$p = \frac{0.75 \times [(4 \times (0.12755\ \text{kipft/ft})) + (3 \times (0.037261\ \text{kip/ft}) \times (4.5\ \text{ft}))]^2}{(4.5\ \text{ft})^2 \times [(3 \times (0.12755\ \text{kipft/ft})) + (2 \times (0.037261\ \text{kip/ft}) \times (4.5\ \text{ft}))]}$$

$$p = 0.052957\ \text{kip/ft}^2$$

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

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

$$s = \frac{6 \times [(2 \times (0.12755\ \text{kipft/ft})) + ((0.037261\ \text{kip/ft}) \times (4.5\ \text{ft}))]}{(4.5\ \text{ft})^2}$$

$$s = 0.12527\ \text{kip/ft}^2$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150\ \text{psf/ft}) \times \frac{(3.1751\ \text{ft})}{2}$$

$$p_a = 0.23814\ \text{kip/ft}^2$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(0.052957\ \text{kip/ft}^2\right)}{\left(0.23814\ \text{kip/ft}^2\right)}$$

$$Ratio = 0.22238$$

Status: **PASS**
Ratio: **0.220**

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

$$p_s = R\,L_e$$

$$p_s = (150\ \text{psf/ft}) \times (4.5\ \text{ft})$$

$$p_s = 0.675\ \text{kip/ft}^2$$

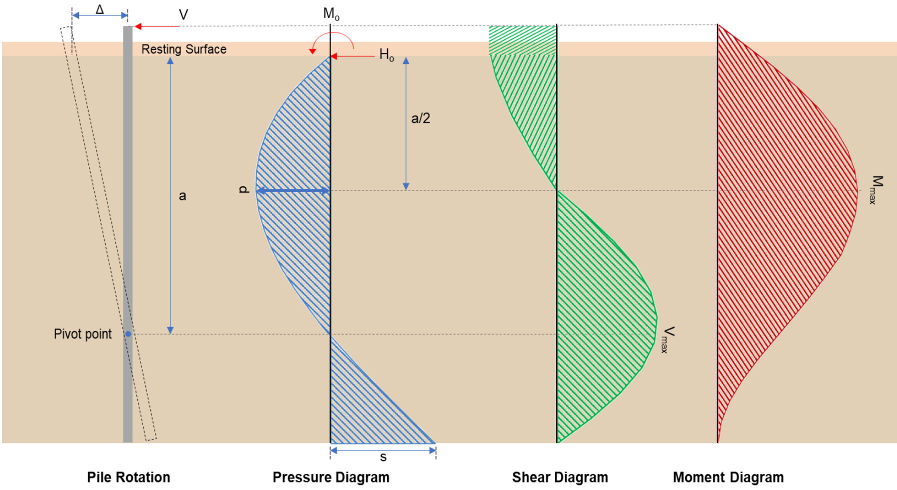
$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{(0.12527\ \mathrm{kip/ft^2})}{(0.675\ \mathrm{kip/ft^2})}$$

$$Ratio = 0.18558$$

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




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

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-0.33\ \mathrm{kip})}{1.57 \times (48\ \mathrm{in})}$$

$$H_o = -0.052548\ \mathrm{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(11.763\ \mathrm{kipft}) + ((-0.33\ \mathrm{kip}) \times (0\ \mathrm{ft}))}{1.57 \times (48\ \mathrm{in})}$$

$$M_o = 1.8731\ \mathrm{kipft/ft}$$

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

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

$$E = \frac{(1.8731\ \mathrm{kipft/ft})}{(-0.052548\ \mathrm{kip/ft})}$$

$$E = 35.645\ \mathrm{ft}$$

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

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

$$a = \frac{(4 \times (1.8731\ \mathrm{kipft/ft}) \times (4.5\ \mathrm{ft})) + \left(3 \times (-0.052548\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft})^2\right)}{(6 \times (1.8731\ \mathrm{kipft/ft})) + (4 \times (-0.052548\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))}$$

$$a = 3.0291\ \mathrm{ft}$$

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

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

$$V_{max} = ((-0.052548\ \mathrm{kip/ft}) \times (48\ \mathrm{in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (35.645\ \mathrm{ft})}{(4.5\ \mathrm{ft})} + 3\right) \times \left(\frac{(3.0291\ \mathrm{ft})}{(4.5\ \mathrm{ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (35.645\ \mathrm{ft})}{(4.5\ \mathrm{ft})} + 2\right) \times \left(\frac{(3.0291\ \mathrm{ft})}{(4.5\ \mathrm{ft})}\right)^3\right]\right]$$

$$V_{max} = 3.0932\ \mathrm{kip}$$

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

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

$$M_{max} = ((-0.052548 \text{ kip/ft}) \times (48 \text{ in}) \times (4.5 \text{ ft})) \times \left[\left(\frac{(35.645 \text{ ft})}{(4.5 \text{ ft})} + \frac{(3.0291 \text{ ft})}{2 \times (4.5 \text{ ft})}\right) - \left[\left(\frac{4 \times (35.645 \text{ ft})}{(4.5 \text{ ft})} + 3\right) \times \left(\frac{(3.0291 \text{ ft})}{2 \times (4.5 \text{ ft})}\right)^3\right] + \left[\left(\frac{3 \times (35.645 \text{ ft})}{(4.5 \text{ ft})} + 2\right) \times \left(\frac{(3.0291 \text{ ft})}{2 \times (4.5 \text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 6.8726 \text{ kipft}$$

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

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(0.4 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = 0.063694 \text{ kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(1.38 \text{ kipft}) + ((0.4 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 0.21975 \text{ kipft/ft}$$

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

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

$$E = \frac{(0.21975 \text{ kipft/ft})}{(0.063694 \text{ kip/ft})}$$

$$E = 3.45 \text{ ft}$$

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

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

$$a = \frac{(4 \times (0.21975 \text{ kipft/ft}) \times (4.5 \text{ ft})) + \left(3 \times (0.063694 \text{ kip/ft}) \times (4.5 \text{ ft})^2\right)}{(6 \times (0.21975 \text{ kipft/ft})) + (4 \times (0.063694 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.1744 \text{ ft}$$

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

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

$$V_{max} = ((0.063694 \text{ kip/ft}) \times (48 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (3.45 \text{ ft})}{(4.5 \text{ ft})} + 3\right) \times \left(\frac{(3.1744 \text{ ft})}{(4.5 \text{ ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (3.45 \text{ ft})}{(4.5 \text{ ft})} + 2\right) \times \left(\frac{(3.1744 \text{ ft})}{(4.5 \text{ ft})}\right)^3\right]\right]$$

$$V_{max} = 0.51438 \text{ kip}$$

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

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

$$M_{max} = ((0.063694 \text{ kip/ft}) \times (48 \text{ in}) \times (4.5 \text{ ft})) \times \left[\left(\frac{(3.45 \text{ ft})}{(4.5 \text{ ft})} + \frac{(3.1744 \text{ ft})}{2 \times (4.5 \text{ ft})}\right) - \left[\left(\frac{4 \times (3.45 \text{ ft})}{(4.5 \text{ ft})} + 3\right) \times \left(\frac{(3.1744 \text{ ft})}{2 \times (4.5 \text{ ft})}\right)^3\right] + \left[\left(\frac{3 \times (3.45 \text{ ft})}{(4.5 \text{ ft})} + 2\right) \times \left(\frac{(3.1744 \text{ ft})}{2 \times (4.5 \text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 1.0545 \text{ kipft}$$

**Minimum Reinforcement Check (LRFD)**

**Parameters:**

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

**Longitudinal reinforcement:**

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

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

$$A_{st,required} = Min\left[\frac{\frac{(14.558 \text{ kip})}{(0.65)\times(0.8)} - \left(0.85 \times (2.5 \text{ ksi}) \times \left(2304 \text{ in}^2\right)\right)}{(60 \text{ ksi}) - (0.85 \times (2.5 \text{ ksi}))}, \left(0.08 \times \left(2304 \text{ in}^2\right)\right)\right]$$

$$A_{st,required} = -84.112 \text{ in}^2$$

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

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

$$A_{min} = Max\left[\left(-84.112 \text{ in}^2\right), \left(0.0018 \times \left(2304 \text{ in}^2\right)\right)\right]$$

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

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

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

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

$$n_{rebar} = 14$$

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

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

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

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

$Ratio$ - Capacity

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

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

$$Ratio = 0.96556$$

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

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

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

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

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

**Ties:**

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

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

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

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

**Summary:**

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

| | | | |
|---|---|---|---|
| | Ties: **#3(0.375 in) - 10 in** | | |
| 22.4.2.2 | **Axial Compression Strength (ACI 318-19, LRFD)**<br>$\phi P_N$ - Allowable axial compressive strength<br>$$\phi P_N = \phi\ 0.80\ \left[\left(0.85\ f'_{ck}\ [A_g - A_{st}]\right) + (f_{yk}\ A_{st})\right]$$<br>$$\phi P_N = (0.65) \times 0.80 \times \left[\left(0.85 \times (2.5\ \text{ksi}) \times \left[\left(2304\ \text{in}^2\right) - \left(4.2951\ \text{in}^2\right)\right]\right) + \left((60\ \text{ksi}) \times \left(4.2951\ \text{in}^2\right)\right)\right]$$<br>$$\phi P_N = 2675.2\ \text{kip}$$<br>$Ratio$ - Capacity<br>$$Ratio = \frac{P}{\phi P_N}$$<br>$$Ratio = \frac{(14.558\ \text{kip})}{(2675.2\ \text{kip})}$$<br>$$Ratio = 0.0054419$$ | Status: **PASS**<br>Ratio: **0.010** | |
| 22.5.2.2<br>22.5.5.1.3<br>22.5.5.1.1<br>22.5.5.1.1(a)<br>22.5.5.1.2 | **Shear Strength (ACI 318-19, LRFD)**<br>**Parameters:**<br>$b_w = 48\ \text{in}$ - Effective width,<br>$d$ - Effective depth<br>$$d = 0.80\ D$$<br>$$d = 0.80 \times (48\ \text{in})$$<br>$$d = 38.4\ \text{in}$$<br>$\lambda_s$ - size effect modification factor<br>$$\lambda_s = MIN\left[\sqrt{\frac{2}{1+\frac{d}{10}}}, 1\right]$$<br>$$\lambda_s = MIN\left[\sqrt{\frac{2}{1+\frac{(38.4\ \text{in})}{10}}}, 1\right]$$<br>$$\lambda_s = 0.64282$$<br>The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \to 2500\ \text{psi}$,<br>$V_{c,max}$ - Max shear strength of concrete<br>$$V_{c,max} = 5\ \lambda_s\ \sqrt{f'_{ck}}\ b_w\ d$$<br>$$V_{c,max} = 5 \times (0.64282) \times \sqrt{(2500\ \text{psi})} \times (48\ \text{in}) \times (38.4\ \text{in})$$<br>$$V_{c,max} = 296.21\ \text{kip}$$<br>The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \to 2500\ \text{psi}$, $P = 14.558\ \text{kip} \to 14558\ \text{lbf}$,<br>$V_{c,a}$ - Shear strength of concrete (a)<br>$$V_{c,a} = \left[2\ \lambda_s\ \sqrt{f'_{ck}} + \frac{P}{6\ A_g}\right]\ b_w\ d$$<br>$$V_{c,a} = \left[2 \times (0.64282) \times \sqrt{(2500\ \text{psi})} + \frac{(14558\ \text{lbf})}{6 \times (2304\ \text{in}^2)}\right] \times (48\ \text{in}) \times (38.4\ \text{in})$$<br>$$V_{c,a} = 120.43\ \text{kip}$$<br>The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \text{ksi} \to 2500\ \text{psi}$,<br>$V_{c,b}$ - Shear strength of concrete (b)<br>$$V_{c,b} = \left[2\ \lambda_s\ \sqrt{f'_{ck}} + \left(0.05\ f'_{ck}\right)\right]\ b_w\ d$$<br>$$V_{c,b} = \left[2 \times (0.64282) \times \sqrt{(2500\ \text{psi})} + (0.05 \times (2500\ \text{psi}))\right] \times (48\ \text{in}) \times (38.4\ \text{in})$$<br>$$V_{c,b} = 348.89\ \text{kip}$$<br>$V_c$ - Governing shear strength of concrete<br>$$V_c = Min\left[V_{c,max}, V_{c,a}, V_{c,b}\right]$$<br>$$V_c = Min\left[(296.21\ \text{kip}), (120.43\ \text{kip}), (348.89\ \text{kip})\right]$$<br>$$V_c = 120.43\ \text{kip}$$ | | |

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

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

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

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

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

$A_v$ - Ties rebar area,

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

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

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

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

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

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

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

$V_s$ - Governing shear strength of steel

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

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

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

22.5.1.1 $\phi V_n$ - Allowable shear strength

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

$$\phi V_n = (0.65) \times ((120.43\text{ kip}) + (50.894\text{ kip}))$$

$$\phi V_n = 111.36\text{ kip}$$

**Considering x-direction:**

$V_{max} = 3.0932\text{ kip}$ - Maximum shear force in the x-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(3.0932\text{ kip})}{(111.36\text{ kip})}$$

$$Ratio = 0.027777$$

Status: **PASS**
Ratio: **0.030**

**Considering z-direction:**

$V_{max} = 0.51438\text{ kip}$ - Maximum shear force in the z-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(0.51438\text{ kip})}{(111.36\text{ kip})}$$

$$Ratio = 0.0046191$$

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

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

$S_m$ - Section modulus

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

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

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

| | | |
|---|---|---|
| | $\lambda = 1$ - Concrete modification factor (Normal concrete),<br>Allowable flexural strength:<br>$M_n$ shall be the lesser of:<br>$\phi M_{n,1}$<br>$$\phi M_{n,1} = \phi \times 5 \times \lambda \times \sqrt{(f_c')} \times S_m$$<br>$$\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{(2.5ksi)} \times 18432.001in^3$$<br>$$\phi M_{n,1} = 249.600kipft$$ | |
| *14.5.2.1b* | $\phi M_{n,2}$<br>$$\phi M_{n,2} = \phi\, 0.85\, f'_{ck}\, S_m$$<br>$$\phi M_{n,2} = (0.65) \times 0.85 \times (2.5 \text{ ksi}) \times \left(18432 \text{ in}^3\right)$$<br>$$\phi M_{n,2} = 2121.6 \text{ kipft}$$<br>Therefore,<br>$\phi M_n$ - Allowable flexural strength,<br>$$\phi M_n = MIN[\phi M_{n,1}, \phi M_{n,2}]$$<br>$$\phi M_n = MIN[(249.6 \text{ kipft}), (2121.6 \text{ kipft})]$$<br>$$\phi M_n = 249.6 \text{ kipft}$$<br>**Considering x-direction:**<br>$M_{max} = 6.8726 \text{ kipft}$ - Maximum moment in the x-direction,<br>$Ratio$ - Capacity<br>$$Ratio = \frac{M_{max}}{\phi M_n}$$<br>$$Ratio = \frac{(6.8726 \text{ kipft})}{(249.6 \text{ kipft})}$$<br>$$Ratio = 0.027534$$ | Status: **PASS**<br>Ratio: **0.030** |
| | **Considering z-direction:**<br>$M_{max} = 1.0545 \text{ kipft}$ - Maximum moment in the z-direction,<br>$Ratio$ - Capacity<br>$$Ratio = \frac{M_{max}}{\phi M_n}$$<br>$$Ratio = \frac{(1.0545 \text{ kipft})}{(249.6 \text{ kipft})}$$<br>$$Ratio = 0.0042246$$ | Status: **PASS**<br>Ratio: **0.000** |

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

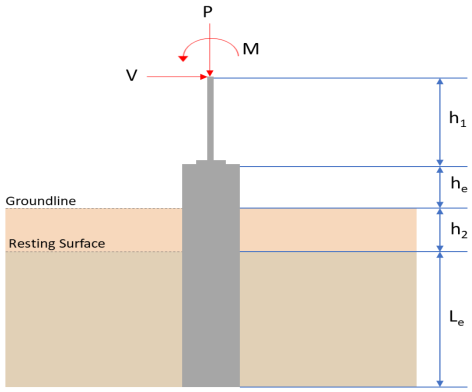
## SkyCiv Foundation Design

Pile Foundation

**Design Information :**

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

### Pile Input




**Geometry**

Pile shape: rectangular
$b = 48$ in - Pile width
$D = 48$ in - Pile depth
$L = 4.5$ ft - Total pile length
$h_1 = 0$ ft - Lateral load height from the top of the pile,
$h_2 = 0$ ft - Depth to resisting surface
$h_e = 0$ 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) | 11.348 | 19.116 |
| $V_x$ (kip) | -0.256 | -0.438 |
| $V_z$ (kip) | 0.000 | 0.000 |
| $M_x$ (kipft) | 0.000 | 0.000 |
| $M_z$ (kipft) | 7.276 | 12.807 |

**Material Properties**

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

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

$H$ - Point of application of the lateral load

$$H = h_1 + h_2 + h_e$$

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

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

**Considering x-direction:**

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-0.256 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = -0.040764 \text{ kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(7.276 \text{ kipft}) + ((-0.256 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 1.1586 \text{ kipft/ft}$$

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:
$L_{e,x} = 4.3456 \text{ ft}$ - 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,

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

$$L_{e,req} = MAX[(4.3456 \text{ ft}), (0 \text{ ft})]$$

$$L_{e,req} = 4.346 \text{ ft}$$

$L_e$ - Actual embedded length of pile,

$$L_e = L - h_e - h_2$$

$$L_e = (4.5 \text{ ft}) - (0 \text{ ft}) - (0 \text{ ft})$$

$$L_e = 4.5 \text{ ft}$$

$Ratio$ - Embedded depth

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

$$Ratio = \frac{(4.346 \text{ ft})}{(4.5 \text{ ft})}$$

$$Ratio = 0.96578$$

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

**End-bearing Capacity (ASD)**

$A$ - Pile cross-section area

$$A = b\,D$$

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

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

$q$ - End-bearing pressure

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

$$q = \frac{(11.348 \text{ kip})}{(16 \text{ ft}^2)}$$

$$q = 0.70925 \text{ kip/ft}^2$$

**Check bearing capacity ratio:**

$Ratio$ - Capacity

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

$$Ratio = \frac{(0.70925 \text{ kip/ft}^2)}{(2000 \text{ psf})}$$

$$Ratio = 0.35463$$

Status: **PASS**
Ratio: **0.350**

*Czerniak*

**Lateral Soil Pressure (ASD):**

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

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

$$L/D = \frac{(4.5 \text{ ft})}{(48 \text{ in})}$$

$$L/D = 1.125$$

Since L/D $\leq$ 10,

Pile is short.

**Considering x-direction:**

$H_o = -0.040764\ \mathrm{kip/ft}$ - Lateral force per length of pile,
$M_o = 1.1586\ \mathrm{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (1.1586\ \mathrm{kipft/ft}) \times (4.5\ \mathrm{ft})) + \left(3 \times (-0.040764\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft})^2\right)}{(6 \times (1.1586\ \mathrm{kipft/ft})) + (4 \times (-0.040764\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))}$$

$$a = 3.0358\ \mathrm{ft}$$

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

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

$$p = \frac{0.75 \times [(4 \times (1.1586\ \mathrm{kipft/ft})) + (3 \times (-0.040764\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))]^2}{(4.5\ \mathrm{ft})^2 \times [(3 \times (1.1586\ \mathrm{kipft/ft})) + (2 \times (-0.040764\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))]}$$

$$p = 0.19871\ \mathrm{kip/ft^2}$$

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

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

$$s = \frac{6 \times [(2 \times (1.1586\ \mathrm{kipft/ft})) + ((-0.040764\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))]}{(4.5\ \mathrm{ft})^2}$$

$$s = 0.63222\ \mathrm{kip/ft^2}$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150\ \mathrm{psf/ft}) \times \frac{(3.0358\ \mathrm{ft})}{2}$$

$$p_a = 0.22769\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{(0.19871\ \mathrm{kip/ft^2})}{(0.22769\ \mathrm{kip/ft^2})}$$

$$Ratio = 0.87273$$

Status: **PASS**
Ratio: **0.870**

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

$$p_s = R\, L_e$$

$$p_s = (150\ \mathrm{psf/ft}) \times (4.5\ \mathrm{ft})$$

$$p_s = 0.675\ \mathrm{kip/ft^2}$$

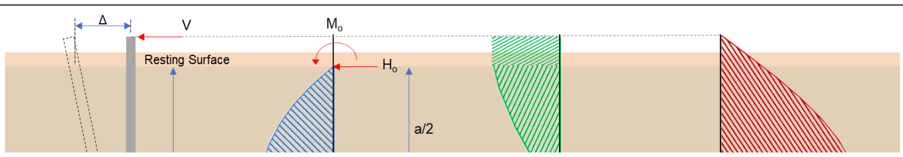
$Ratio$ - Lateral soil capacity

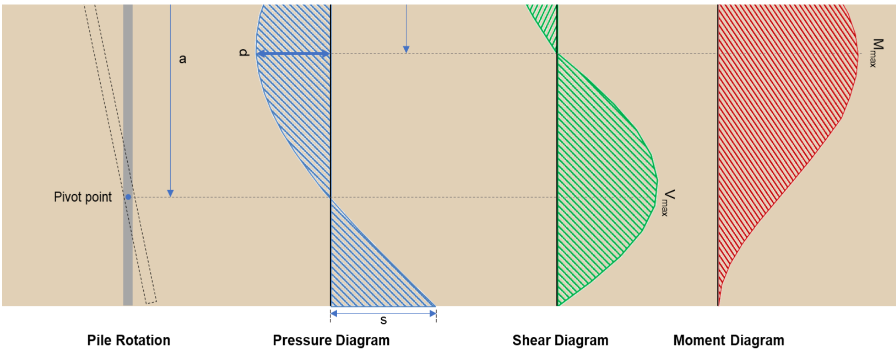
$$Ratio = \frac{s}{p_s}$$

$$Ratio = \frac{(0.63222\ \mathrm{kip/ft^2})}{(0.675\ \mathrm{kip/ft^2})}$$

$$Ratio = 0.93663$$

Status: **PASS**
Ratio: **0.940**






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

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-0.438\text{ kip})}{1.57 \times (48\text{ in})}$$

$$H_o = -0.069745\text{ kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(12.807\text{ kipft}) + ((-0.438\text{ kip}) \times (0\text{ ft}))}{1.57 \times (48\text{ in})}$$

$$M_o = 2.0393\text{ kipft/ft}$$

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

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

$$E = \frac{(2.0393\text{ kipft/ft})}{(-0.069745\text{ kip/ft})}$$

$$E = 29.24\text{ ft}$$

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

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

$$a = \frac{(4 \times (2.0393\text{ kipft/ft}) \times (4.5\text{ ft})) + \left(3 \times (-0.069745\text{ kip/ft}) \times (4.5\text{ ft})^2\right)}{(6 \times (2.0393\text{ kipft/ft})) + (4 \times (-0.069745\text{ kip/ft}) \times (4.5\text{ ft}))}$$

$$a = 3.0349\text{ ft}$$

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

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

$$V_{max} = ((-0.069745\text{ kip/ft}) \times (48\text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (29.24\text{ ft})}{(4.5\text{ ft})} + 3\right) \times \left(\frac{(3.0349\text{ ft})}{(4.5\text{ ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (29.24\text{ ft})}{(4.5\text{ ft})} + 2\right) \times \left(\frac{(3.0349\text{ ft})}{(4.5\text{ ft})}\right)^3\right]\right]$$

$$V_{max} = 3.3997\text{ kip}$$

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

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

$$M_{max} = ((-0.069745\text{ kip/ft}) \times (48\text{ in}) \times (4.5\text{ ft})) \times \left[\left(\frac{(29.24\text{ ft})}{(4.5\text{ ft})} + \frac{(3.0349\text{ ft})}{2 \times (4.5\text{ ft})}\right) - \left[\left(\frac{4 \times (29.24\text{ ft})}{(4.5\text{ ft})} + 3\right) \times \left(\frac{(3.0349\text{ ft})}{2 \times (4.5\text{ ft})}\right)^3\right] + \left[\left(\frac{3 \times (29.24\text{ ft})}{(4.5\text{ ft})} + 2\right) \times \left(\frac{(3.0349\text{ ft})}{2 \times (4.5\text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 7.534 \text{ kipft}$$

**Minimum Reinforcement Check (LRFD)**

**Parameters:**

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

$f_{yk} = 60 \text{ ksi}$ - Longitudinal reinforcement strength,

$\phi = 0.65$ - Reduction factor for axial strength,

*Table 22.4.2.1* $\alpha = 0.8$ - Alpha factor for axial strength,

$A_g = 2304 \text{ in}^2$ - Gross area of concrete,

**Longitudinal reinforcement:**

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

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

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

$$A_{st,required} = Min\left[\frac{\frac{(19.116 \text{ kip})}{(0.65)\times(0.8)} - \left(0.85 \times (2.5 \text{ ksi}) \times \left(2304 \text{ in}^2\right)\right)}{(60 \text{ ksi}) - (0.85 \times (2.5 \text{ ksi}))}, \left(0.08 \times \left(2304 \text{ in}^2\right)\right)\right]$$

$$A_{st,required} = -83.961 \text{ in}^2$$

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

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

$$A_{min} = Max\left[\left(-83.961 \text{ in}^2\right), \left(0.0018 \times \left(2304 \text{ in}^2\right)\right)\right]$$

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

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

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

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

$$n_{rebar} = 14$$

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

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

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

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

$Ratio$ - Capacity

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

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

$$Ratio = 0.96556$$

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

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

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

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

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

**Ties:**

*25.7.2.2* Since longitudinal reinforcement is $\leq$ No. 10ø: Use #3(0.375 in)

*25.7.2.1* $s_{ties}$ - Maximum spacing of ties,

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

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

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

**Summary:**

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

| | | |
|---|---|---|
| | Ties: **#3(0.375 in) - 10 in** | |
| 22.4.2.2 | **Axial Compression Strength (ACI 318-19, LRFD)**<br>$\phi P_N$ - Allowable axial compressive strength<br>$$\phi P_N = \phi\, 0.80\ \left[\left(0.85\, f'_{ck}\ \left[A_g - A_{st}\right]\right) + \left(f_{yk}\, A_{st}\right)\right]$$<br>$$\phi P_N = (0.65) \times 0.80 \times \left[\left(0.85 \times (2.5\ \mathrm{ksi}) \times \left[\left(2304\ \mathrm{in}^2\right) - \left(4.2951\ \mathrm{in}^2\right)\right]\right) + \left((60\ \mathrm{ksi}) \times \left(4.2951\ \mathrm{in}^2\right)\right)\right]$$<br>$$\phi P_N = 2675.2\ \mathrm{kip}$$<br>$Ratio$ - Capacity<br>$$Ratio = \frac{P}{\phi P_N}$$<br>$$Ratio = \frac{(19.116\ \mathrm{kip})}{(2675.2\ \mathrm{kip})}$$<br>$$Ratio = 0.0071457$$ | Status: **PASS**<br>Ratio: **0.010** |
| 22.5.2.2<br>22.5.5.1.3<br>22.5.5.1.1<br>22.5.5.1.1(a)<br>22.5.5.1.2 | **Shear Strength (ACI 318-19, LRFD)**<br>**Parameters:**<br>$b_w = 48\ \mathrm{in}$ - Effective width,<br>$d$ - Effective depth<br>$$d = 0.80\, D$$<br>$$d = 0.80 \times (48\ \mathrm{in})$$<br>$$d = 38.4\ \mathrm{in}$$<br>$\lambda_s$ - size effect modification factor<br>$$\lambda_s = MIN\left[\sqrt{\frac{2}{1+\frac{d}{10}}}, 1\right]$$<br>$$\lambda_s = MIN\left[\sqrt{\frac{2}{1+\frac{(38.4\ \mathrm{in})}{10}}}, 1\right]$$<br>$$\lambda_s = 0.64282$$<br>The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \mathrm{ksi} \rightarrow 2500\ \mathrm{psi}$,<br>$V_{c,max}$ - Max shear strength of concrete<br>$$V_{c,max} = 5\ \lambda_s\ \sqrt{f'_{ck}}\ b_w\ d$$<br>$$V_{c,max} = 5 \times (0.64282) \times \sqrt{(2500\ \mathrm{psi})} \times (48\ \mathrm{in}) \times (38.4\ \mathrm{in})$$<br>$$V_{c,max} = 296.21\ \mathrm{kip}$$<br>The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \mathrm{ksi} \rightarrow 2500\ \mathrm{psi}$, $P = 19.116\ \mathrm{kip} \rightarrow 19116\ \mathrm{lbf}$,<br>$V_{c,a}$ - Shear strength of concrete (a)<br>$$V_{c,a} = \left[2\ \lambda_s\ \sqrt{f'_{ck}} + \frac{P}{6\ A_g}\right]\ b_w\ d$$<br>$$V_{c,a} = \left[2 \times (0.64282) \times \sqrt{(2500\ \mathrm{psi})} + \frac{(19116\ \mathrm{lbf})}{6 \times (2304\ \mathrm{in}^2)}\right] \times (48\ \mathrm{in}) \times (38.4\ \mathrm{in})$$<br>$$V_{c,a} = 121.03\ \mathrm{kip}$$<br>The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\ \mathrm{ksi} \rightarrow 2500\ \mathrm{psi}$,<br>$V_{c,b}$ - Shear strength of concrete (b)<br>$$V_{c,b} = \left[2\ \lambda_s\ \sqrt{f'_{ck}} + \left(0.05\ f'_{ck}\right)\right]\ b_w\ d$$<br>$$V_{c,b} = \left[2 \times (0.64282) \times \sqrt{(2500\ \mathrm{psi})} + (0.05 \times (2500\ \mathrm{psi}))\right] \times (48\ \mathrm{in}) \times (38.4\ \mathrm{in})$$<br>$$V_{c,b} = 348.89\ \mathrm{kip}$$<br>$V_c$ - Governing shear strength of concrete<br>$$V_c = Min\left[V_{c,max}, V_{c,a}, V_{c,b}\right]$$<br>$$V_c = Min\left[(296.21\ \mathrm{kip}), (121.03\ \mathrm{kip}), (348.89\ \mathrm{kip})\right]$$<br>$$V_c = 121.03\ \mathrm{kip}$$ | |

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

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

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

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

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

$A_v$ - Ties rebar area,

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

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

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

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

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

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

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

$V_s$ - Governing shear strength of steel

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

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

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

22.5.1.1 $\phi V_n$ - Allowable shear strength

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

$$\phi V_n = (0.65) \times ((121.03 \text{ kip}) + (50.894 \text{ kip}))$$

$$\phi V_n = 111.75 \text{ kip}$$

**Considering x-direction:**

$V_{max} = 3.3997 \text{ kip}$ - Maximum shear force in the x-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(3.3997 \text{ kip})}{(111.75 \text{ kip})}$$

$$Ratio = 0.030422$$

Status: **PASS**
Ratio: **0.030**

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

$S_m$ - Section modulus

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Considering x-direction:**

$M_{max} = 7.534\ \mathrm{kipft}$ - Maximum moment in the x-direction,
$Ratio$ - Capacity

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

$$Ratio = \frac{(7.534\ \mathrm{kipft})}{(249.6\ \mathrm{kipft})}$$

$$Ratio = 0.030184$$

Status: **PASS**
Ratio: **0.030**

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

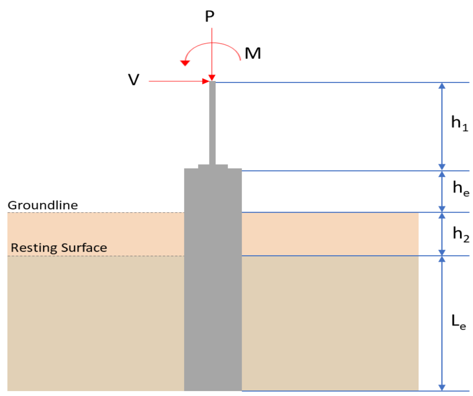
## SkyCiv Foundation Design

Pile Foundation

**Design Information :**

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

### Pile Input




**Geometry**

Pile shape: rectangular
$b = 48\ \mathrm{in}$ - Pile width
$D = 48\ \mathrm{in}$ - Pile depth
$L = 4.5\ \mathrm{ft}$ - 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) | 8.676 | 14.558 |
| $V_x$ (kip) | -0.195 | -0.330 |
| $V_z$ (kip) | -0.234 | -0.400 |
| $M_x$ (kipft) | -0.801 | -1.380 |
| $M_z$ (kipft) | 6.601 | 11.763 |

**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,

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

$$H_o = \frac{(-0.195\ \mathrm{kip})}{1.57 \times (48\ \mathrm{in})}$$

$$H_o = -0.031051\ \mathrm{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(6.601\ \text{kipft}) + ((-0.195\ \text{kip}) \times (0\ \text{ft}))}{1.57 \times (48\ \text{in})}$$

$$M_o = 1.0511\ \text{kipft/ft}$$

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:
$L_{e,x} = 4.2394\ \text{ft}$ - Required depth in x-direction,

**Considering z-direction:**

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-0.234\ \text{kip})}{1.57 \times (48\ \text{in})}$$

$$H_o = -0.037261\ \text{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(0.801\ \text{kipft}) + ((-0.234\ \text{kip}) \times (0\ \text{ft}))}{1.57 \times (48\ \text{in})}$$

$$M_o = 0.12755\ \text{kipft/ft}$$

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:
$L_{e,z} = 1.8287\ \text{ft}$ - Required depth in z-direction,

**Minimum embedded depth required:**

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

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

$$L_{e,req} = MAX[(4.2394\ \text{ft}), (1.8287\ \text{ft})]$$

$$L_{e,req} = 4.239\ \text{ft}$$

$L_e$ - Actual embedded length of pile,

$$L_e = L - h_e - h_2$$

$$L_e = (4.5\ \text{ft}) - (0\ \text{ft}) - (0\ \text{ft})$$

$$L_e = 4.5\ \text{ft}$$

$Ratio$ - Embedded depth

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

$$Ratio = \frac{(4.239\ \text{ft})}{(4.5\ \text{ft})}$$

$$Ratio = 0.942$$

Status: **PASS**
Ratio: **0.940**

**End-bearing Capacity (ASD)**

$A$ - Pile cross-section area

$$A = b\, D$$

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

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

$q$ - End-bearing pressure

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

$$q = \frac{(8.676\ \text{kip})}{(16\ \text{ft}^2)}$$

$$q = 0.54225\ \text{kip/ft}^2$$

$$q = 0.54225 \text{ kip/ft}^2$$

**Check bearing capacity ratio:**

$Ratio$ - Capacity

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

$$Ratio = \frac{\left(0.54225 \text{ kip/ft}^2\right)}{(2000 \text{ psf})}$$

$$Ratio = 0.27113$$

Status: **PASS**
Ratio: **0.270**

*Czerniak*

**Lateral Soil Pressure (ASD):**

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

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

$$L/D = \frac{(4.5 \text{ ft})}{(48 \text{ in})}$$

$$L/D = 1.125$$

Since L/D $\leq$ 10,

Pile is short.

**Considering x-direction:**

$H_o = -0.031051 \text{ kip/ft}$ - Lateral force per length of pile,
$M_o = 1.0511 \text{ kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (1.0511 \text{ kipft/ft}) \times (4.5 \text{ ft})) + \left(3 \times (-0.031051 \text{ kip/ft}) \times (4.5 \text{ ft})^2\right)}{(6 \times (1.0511 \text{ kipft/ft})) + (4 \times (-0.031051 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.0305 \text{ ft}$$

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

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

$$p = \frac{0.75 \times [(4 \times (1.0511 \text{ kipft/ft})) + (3 \times (-0.031051 \text{ kip/ft}) \times (4.5 \text{ ft}))]^{\,2}}{(4.5 \text{ ft})^2 \times [(3 \times (1.0511 \text{ kipft/ft})) + (2 \times (-0.031051 \text{ kip/ft}) \times (4.5 \text{ ft}))]}$$

$$p = 0.18465 \text{ kip/ft}^2$$

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

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

$$s = \frac{6 \times [(2 \times (1.0511 \text{ kipft/ft})) + ((-0.031051 \text{ kip/ft}) \times (4.5 \text{ ft}))]}{(4.5 \text{ ft})^2}$$

$$s = 0.58148 \text{ kip/ft}^2$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150 \text{ psf/ft}) \times \frac{(3.0305 \text{ ft})}{2}$$

$$p_a = 0.22729 \text{ kip/ft}^2$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{\left(0.18465 \text{ kip/ft}^2\right)}{\left(0.22729 \text{ kip/ft}^2\right)}$$

$$Ratio = 0.81242$$

Status: **PASS**
Ratio: **0.810**

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

$$p_s = R\,L_e$$

$$p_s = (150\ \mathrm{psf/ft}) \times (4.5\ \mathrm{ft})$$

$$p_s = 0.675\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{(0.58148\ \mathrm{kip/ft^2})}{(0.675\ \mathrm{kip/ft^2})}$$

$$Ratio = 0.86145$$

Status: **PASS**
Ratio: **0.860**

**Considering z-direction:**

$H_o = -0.037261\ \mathrm{kip/ft}$ - Lateral force per length of pile,
$M_o = 0.12755\ \mathrm{kipft/ft}$ - Overturning moment per length of pile,
$a$ - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (0.12755\ \mathrm{kipft/ft}) \times (4.5\ \mathrm{ft})) + \left(3 \times (-0.037261\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft})^2\right)}{(6 \times (0.12755\ \mathrm{kipft/ft})) + (4 \times (-0.037261\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))}$$

$$a = 3.1751\ \mathrm{ft}$$

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

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

$$p = \frac{0.75 \times [(4 \times (0.12755\ \mathrm{kipft/ft})) + (3 \times (-0.037261\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))]^2}{(4.5\ \mathrm{ft})^2 \times [(3 \times (0.12755\ \mathrm{kipft/ft})) + (2 \times (-0.037261\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))]}$$

$$p = 0.000040211\ \mathrm{kip/ft^2}$$

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

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

$$s = \frac{6 \times [(2 \times (0.12755\ \mathrm{kipft/ft})) + ((-0.037261\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))]}{(4.5\ \mathrm{ft})^2}$$

$$s = 0.025902\ \mathrm{kip/ft^2}$$

**Check lateral soil pressure capacity:**

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

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

$$p_a = (150\ \mathrm{psf/ft}) \times \frac{(3.1751\ \mathrm{ft})}{2}$$

$$p_a = 0.23814\ \mathrm{kip/ft^2}$$

$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{(0.000040211\ \mathrm{kip/ft^2})}{(0.23814\ \mathrm{kip/ft^2})}$$

$$Ratio = 0.00016886$$

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

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

$$p_s = R\,L_e$$

$$p_s = (150\ \mathrm{psf/ft}) \times (4.5\ \mathrm{ft})$$

$$p_s = 0.675\ \mathrm{kip/ft^2}$$

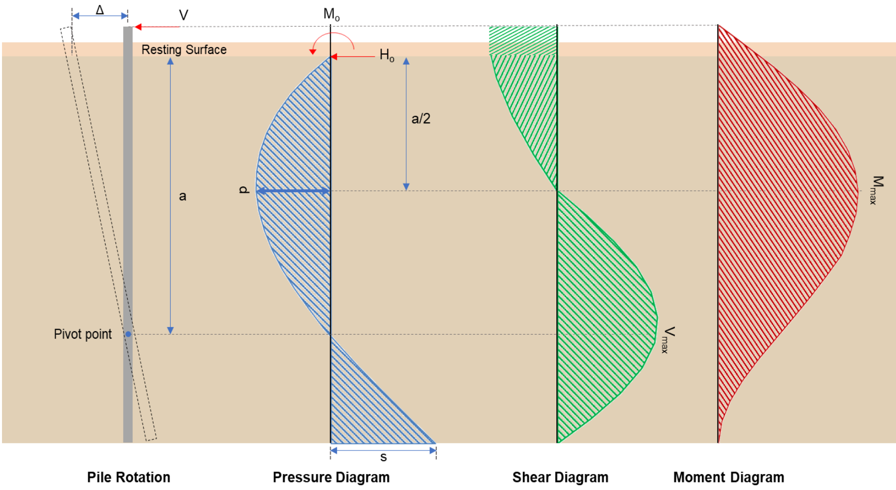
$Ratio$ - Lateral soil capacity

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

$$Ratio = \frac{(0.025902\ \mathrm{kip/ft^2})}{(0.675\ \mathrm{kip/ft^2})}$$

$$Ratio = 0.038374$$

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




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

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-0.33\ \mathrm{kip})}{1.57 \times (48\ \mathrm{in})}$$

$$H_o = -0.052548\ \mathrm{kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(11.763\ \mathrm{kipft}) + ((-0.33\ \mathrm{kip}) \times (0\ \mathrm{ft}))}{1.57 \times (48\ \mathrm{in})}$$

$$M_o = 1.8731\ \mathrm{kipft/ft}$$

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

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

$$E = \frac{(1.8731\ \mathrm{kipft/ft})}{(-0.052548\ \mathrm{kip/ft})}$$

$$E = 35.645\ \mathrm{ft}$$

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

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

$$a = \frac{(4 \times (1.8731\ \mathrm{kipft/ft}) \times (4.5\ \mathrm{ft})) + \left(3 \times (-0.052548\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft})^2\right)}{(6 \times (1.8731\ \mathrm{kipft/ft})) + (4 \times (-0.052548\ \mathrm{kip/ft}) \times (4.5\ \mathrm{ft}))}$$

$$a = 3.0291\ \mathrm{ft}$$

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

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

$$V_{max} = ((-0.052548\ \mathrm{kip/ft}) \times (48\ \mathrm{in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (35.645\ \mathrm{ft})}{(4.5\ \mathrm{ft})} + 3\right) \times \left(\frac{(3.0291\ \mathrm{ft})}{(4.5\ \mathrm{ft})}\right)^2\right] + \left[4 \times \left(\frac{3 \times (35.645\ \mathrm{ft})}{(4.5\ \mathrm{ft})} + 2\right) \times \left(\frac{(3.0291\ \mathrm{ft})}{(4.5\ \mathrm{ft})}\right)^3\right]\right]$$

$$V_{max} = 3.0932\ \mathrm{kip}$$

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

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

$$M_{max} = ((-0.052548\text{ kip/ft})\times(48\text{ in})\times(4.5\text{ ft}))\times\left[\left(\frac{(35.645\text{ ft})}{(4.5\text{ ft})}+\frac{(3.0291\text{ ft})}{2\times(4.5\text{ ft})}\right) - \left[\left(\frac{4\times(35.645\text{ ft})}{(4.5\text{ ft})}+3\right)\times\left(\frac{(3.0291\text{ ft})}{2\times(4.5\text{ ft})}\right)^3\right]+\left[\left(\frac{3\times(35.645\text{ ft})}{(4.5\text{ ft})}+2\right)\times\left(\frac{(3.0291\text{ ft})}{2\times(4.5\text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 6.8726\text{ kipft}$$

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

$H_o$ - Lateral force per length of pile,

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

$$H_o = \frac{(-0.4\text{ kip})}{1.57\times(48\text{ in})}$$

$$H_o = -0.063694\text{ kip/ft}$$

$M_o$ - Moment per length of pile,

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

$$M_o = \frac{(1.38\text{ kipft}) + ((-0.4\text{ kip})\times(0\text{ ft}))}{1.57\times(48\text{ in})}$$

$$M_o = 0.21975\text{ kipft/ft}$$

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

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

$$E = \frac{(0.21975\text{ kipft/ft})}{(-0.063694\text{ kip/ft})}$$

$$E = 3.45\text{ ft}$$

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

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

$$a = \frac{(4\times(0.21975\text{ kipft/ft})\times(4.5\text{ ft})) + \left(3\times(-0.063694\text{ kip/ft})\times(4.5\text{ ft})^2\right)}{(6\times(0.21975\text{ kipft/ft})) + (4\times(-0.063694\text{ kip/ft})\times(4.5\text{ ft}))}$$

$$a = 3.1744\text{ ft}$$

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

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

$$V_{max} = ((-0.063694\text{ kip/ft})\times(48\text{ in}))\times\left[1-\left[3\times\left(\frac{4\times(3.45\text{ ft})}{(4.5\text{ ft})}+3\right)\times\left(\frac{(3.1744\text{ ft})}{(4.5\text{ ft})}\right)^2\right]+\left[4\times\left(\frac{3\times(3.45\text{ ft})}{(4.5\text{ ft})}+2\right)\times\left(\frac{(3.1744\text{ ft})}{(4.5\text{ ft})}\right)^3\right]\right]$$

$$V_{max} = 0.51438\text{ kip}$$

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

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

$$M_{max} = ((-0.063694\text{ kip/ft})\times(48\text{ in})\times(4.5\text{ ft}))\times\left[\left(\frac{(3.45\text{ ft})}{(4.5\text{ ft})}+\frac{(3.1744\text{ ft})}{2\times(4.5\text{ ft})}\right) - \left[\left(\frac{4\times(3.45\text{ ft})}{(4.5\text{ ft})}+3\right)\times\left(\frac{(3.1744\text{ ft})}{2\times(4.5\text{ ft})}\right)^3\right]+\left[\left(\frac{3\times(3.45\text{ ft})}{(4.5\text{ ft})}+2\right)\times\left(\frac{(3.1744\text{ ft})}{2\times(4.5\text{ ft})}\right)^4\right]\right]$$

$$M_{max} = 1.0545 \text{ kipft}$$

**Minimum Reinforcement Check (LRFD)**

**Parameters:**

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

**Longitudinal reinforcement:**

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

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

$$A_{st,required} = Min\left[\frac{\frac{(14.558\text{ kip})}{(0.65)\times(0.8)} - \left(0.85\times(2.5\text{ ksi})\times\left(2304\text{ in}^2\right)\right)}{(60\text{ ksi}) - (0.85\times(2.5\text{ ksi}))}, \left(0.08\times\left(2304\text{ in}^2\right)\right)\right]$$

$$A_{st,required} = -84.112 \text{ in}^2$$

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

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

$$A_{min} = Max\left[\left(-84.112\text{ in}^2\right), \left(0.0018\times\left(2304\text{ in}^2\right)\right)\right]$$

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

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

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

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

$$n_{rebar} = 14$$

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

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

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

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

$Ratio$ - Capacity

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

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

$$Ratio = 0.96556$$

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

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

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

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

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

**Ties:**

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

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

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

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

**Summary:**

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

| | | |
|---|---|---|
| | Ties: **#3(0.375 in) - 10 in** | |
| 22.4.2.2 | **Axial Compression Strength (ACI 318-19, LRFD)**<br>$\phi P_N$ - Allowable axial compressive strength<br>$$\phi P_N = \phi\, 0.80\, \left[\left(0.85\, f'_{ck}\, [A_g - A_{st}]\right) + (f_{yk}\, A_{st})\right]$$<br>$$\phi P_N = (0.65) \times 0.80 \times \left[\left(0.85 \times (2.5\text{ ksi}) \times \left[\left(2304\text{ in}^2\right) - \left(4.2951\text{ in}^2\right)\right]\right) + \left((60\text{ ksi}) \times \left(4.2951\text{ in}^2\right)\right)\right]$$<br>$$\phi P_N = 2675.2\text{ kip}$$<br>$Ratio$ - Capacity<br>$$Ratio = \frac{P}{\phi P_N}$$<br>$$Ratio = \frac{(14.558\text{ kip})}{(2675.2\text{ kip})}$$<br>$$Ratio = 0.0054419$$ | Status: **PASS**<br>Ratio: **0.010** |
| 22.5.2.2<br>22.5.5.1.3<br>22.5.5.1.1<br>22.5.5.1.1(a)<br>22.5.5.1.2 | **Shear Strength (ACI 318-19, LRFD)**<br>**Parameters:**<br>$b_w = 48\text{ in}$ - Effective width,<br>$d$ - Effective depth<br>$$d = 0.80\, D$$<br>$$d = 0.80 \times (48\text{ in})$$<br>$$d = 38.4\text{ in}$$<br>$\lambda_s$ - size effect modification factor<br>$$\lambda_s = MIN\left[\sqrt{\frac{2}{1+\frac{d}{10}}}, 1\right]$$<br>$$\lambda_s = MIN\left[\sqrt{\frac{2}{1+\frac{(38.4\text{ in})}{10}}}, 1\right]$$<br>$$\lambda_s = 0.64282$$<br>The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\text{ ksi} \rightarrow 2500\text{ psi}$,<br>$V_{c,max}$ - Max shear strength of concrete<br>$$V_{c,max} = 5\, \lambda_s\, \sqrt{f'_{ck}}\, b_w\, d$$<br>$$V_{c,max} = 5 \times (0.64282) \times \sqrt{(2500\text{ psi})} \times (48\text{ in}) \times (38.4\text{ in})$$<br>$$V_{c,max} = 296.21\text{ kip}$$<br>The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\text{ ksi} \rightarrow 2500\text{ psi}$, $P = 14.558\text{ kip} \rightarrow 14558\text{ lbf}$,<br>$V_{c,a}$ - Shear strength of concrete (a)<br>$$V_{c,a} = \left[2\, \lambda_s\, \sqrt{f'_{ck}} + \frac{P}{6\, A_g}\right]\, b_w\, d$$<br>$$V_{c,a} = \left[2 \times (0.64282) \times \sqrt{(2500\text{ psi})} + \frac{(14558\text{ lbf})}{6 \times (2304\text{ in}^2)}\right] \times (48\text{ in}) \times (38.4\text{ in})$$<br>$$V_{c,a} = 120.43\text{ kip}$$<br>The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5\text{ ksi} \rightarrow 2500\text{ psi}$,<br>$V_{c,b}$ - Shear strength of concrete (b)<br>$$V_{c,b} = \left[2\, \lambda_s\, \sqrt{f'_{ck}} + \left(0.05\, f'_{ck}\right)\right]\, b_w\, d$$<br>$$V_{c,b} = \left[2 \times (0.64282) \times \sqrt{(2500\text{ psi})} + (0.05 \times (2500\text{ psi}))\right] \times (48\text{ in}) \times (38.4\text{ in})$$<br>$$V_{c,b} = 348.89\text{ kip}$$<br>$V_c$ - Governing shear strength of concrete<br>$$V_c = Min\left[V_{c,max}, V_{c,a}, V_{c,b}\right]$$<br>$$V_c = Min\left[(296.21\text{ kip}), (120.43\text{ kip}), (348.89\text{ kip})\right]$$<br>$$V_c = 120.43\text{ kip}$$ | |

| | | |
|---|---|---|
| | 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)<br>$$V_{s,a} = 8\sqrt{f'_{ck}}\, b_w\, d$$<br>$$V_{s,a} = 8 \times \sqrt{(2500\ \text{psi})} \times (48\ \text{in}) \times (38.4\ \text{in})$$<br>$$V_{s,a} = 737.28\ \text{kip}$$ | |
| | $A_v$ - Ties rebar area,<br>$$A_v = \frac{\pi\, d_{ties}^2}{4}$$<br>$$A_v = \frac{\pi \times (0.375\ \text{in})^2}{4}$$<br>$$A_v = 0.11045\ \text{in}^2$$ | |
| 22.5.8.5.3 | $V_{s,b}$ - Shear strength of steel (b)<br>$$V_{s,b} = \frac{2\, A_v\, f_{ywk}\, d}{s_{ties}}$$<br>$$V_{s,b} = \frac{2 \times \left(0.11045\ \text{in}^2\right) \times (60\ \text{ksi}) \times (38.4\ \text{in})}{(10\ \text{in})}$$<br>$$V_{s,b} = 50.894\ \text{kip}$$ | |
| | $V_s$ - Governing shear strength of steel<br>$$V_s = MIN\left[V_{s,a}, V_{s,b}\right]$$<br>$$V_s = MIN\left[(737.28\ \text{kip}), (50.894\ \text{kip})\right]$$<br>$$V_s = 50.894\ \text{kip}$$ | |
| 22.5.1.1 | $\phi V_n$ - Allowable shear strength<br>$$\phi V_n = \phi\ (V_c + V_s)$$<br>$$\phi V_n = (0.65) \times ((120.43\ \text{kip}) + (50.894\ \text{kip}))$$<br>$$\phi V_n = 111.36\ \text{kip}$$ | |
| | **Considering x-direction:**<br>$V_{max} = 3.0932\ \text{kip}$ - Maximum shear force in the x-direction,<br>$Ratio$ - Capacity<br>$$Ratio = \frac{V_{max}}{\phi V_n}$$<br>$$Ratio = \frac{(3.0932\ \text{kip})}{(111.36\ \text{kip})}$$<br>$$Ratio = 0.027777$$ | Status: **PASS**<br>Ratio: **0.030** |
| | **Considering z-direction:**<br>$V_{max} = 0.51438\ \text{kip}$ - Maximum shear force in the z-direction,<br>$Ratio$ - Capacity<br>$$Ratio = \frac{V_{max}}{\phi V_n}$$<br>$$Ratio = \frac{(0.51438\ \text{kip})}{(111.36\ \text{kip})}$$<br>$$Ratio = 0.0046191$$ | Status: **PASS**<br>Ratio: **0.000** |
| | **Flexural Strength (ACI 318-19, LRFD)**<br>$S_m$ - Section modulus<br>$$S_m = \frac{b\, D^2}{6}$$<br>$$S_m = \frac{(48\ \text{in}) \times (48\ \text{in})^2}{6}$$<br>$$S_m = 18432\ \text{in}^3$$ | |

| | | |
|---|---|---|
| | $\lambda = 1$ - Concrete modification factor (Normal concrete),<br>Allowable flexural strength:<br>$M_n$ shall be the lesser of:<br>$\phi M_{n,1}$<br>$$\phi M_{n,1} = \phi \times 5 \times \lambda \times \sqrt{(f_c')} \times S_m$$<br>$$\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{(2.5ksi)} \times 18432.001in^3$$<br>$$\phi M_{n,1} = 249.600kipft$$ | |
| *14.5.2.1b* | $\phi M_{n,2}$<br>$$\phi M_{n,2} = \phi\, 0.85\, f'_{ck}\, S_m$$<br>$$\phi M_{n,2} = (0.65) \times 0.85 \times (2.5 \text{ ksi}) \times \left(18432 \text{ in}^3\right)$$<br>$$\phi M_{n,2} = 2121.6 \text{ kipft}$$<br>Therefore,<br>$\phi M_n$ - Allowable flexural strength,<br>$$\phi M_n = MIN[\phi M_{n,1}, \phi M_{n,2}]$$<br>$$\phi M_n = MIN[(249.6 \text{ kipft}), (2121.6 \text{ kipft})]$$<br>$$\phi M_n = 249.6 \text{ kipft}$$<br>**Considering x-direction:**<br>$M_{max} = 6.8726 \text{ kipft}$ - Maximum moment in the x-direction,<br>$Ratio$ - Capacity<br>$$Ratio = \frac{M_{max}}{\phi M_n}$$<br>$$Ratio = \frac{(6.8726 \text{ kipft})}{(249.6 \text{ kipft})}$$<br>$$Ratio = 0.027534$$ | Status: **PASS**<br>Ratio: **0.030** |
| | **Considering z-direction:**<br>$M_{max} = 1.0545 \text{ kipft}$ - Maximum moment in the z-direction,<br>$Ratio$ - Capacity<br>$$Ratio = \frac{M_{max}}{\phi M_n}$$<br>$$Ratio = \frac{(1.0545 \text{ kipft})}{(249.6 \text{ kipft})}$$<br>$$Ratio = 0.0042246$$ | Status: **PASS**<br>Ratio: **0.000** |