

Your Project Calculations



Project Name: Cincinnati Children's Hospital PV Study-RevA-JB

S3D Model Link:

https://platform.skyciv.com/structural?preload_name=Cincinnati%20Children's%20Hospital%20PV%20Study-RevA-JB&preload_path=Shared%20Enterprise%20Folder/MT_Solar_Projects/1_2024

Public Model Link:

https://platform.skyciv.com/structural-viewer?project_id=5OKEOGXoITxcooJDRFRc0vdtVsbvAe58Gh6fRTaLzhr8X5u0ZhMbMi6aL4iKqVM

Array Specification

Product:	Beam
Unique ID:	4P-19.75-6TOP-HD-72-L-5Hx10W-1K36
Duty Classification:	HD
Module Width:	45.00 in
Module Length:	96.00in
Number of Rows:	5
Number of Columns:	10
Total Number of Modules:	50
Desired Tilt Angle:	5
Front Edge Clearance:	12
Total Array Height at Tilt:	13.64 ft
Total Frame Length:	78.75 ft
Frame Weight:	3408 lbs
Array Dimensions N/S:	18.96 ft
Array Dimensions E/W:	80.83 ft
Rail Length:	227.50 in
Rail Spacing:	4.00 ft
Rail Check:	Not Checked

Support Specifications

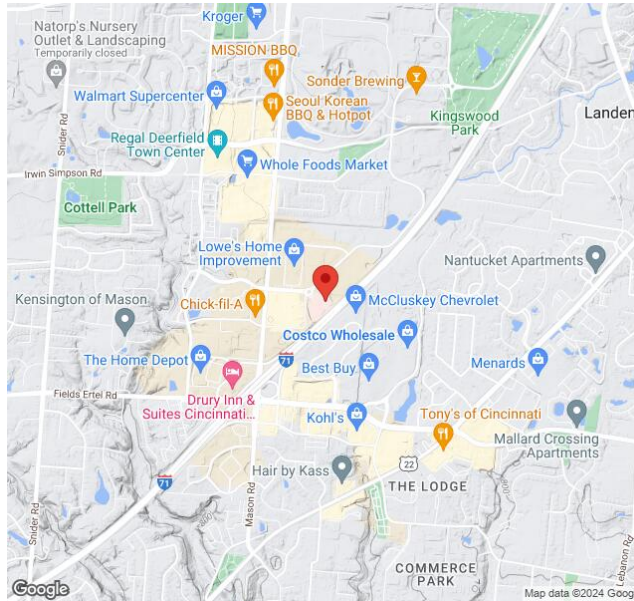
Pole Size:	6in Pipe Sch 40
Pole Length above Grade:	12.83 ft
Number of Poles:	4
Pole Spacing:	19.75 ft

Foundation Specifications

Foundation Type:	Square
Foundation Dimensions:	48 x 48 in
Foundation Depth (below grade):	Pile 1: 4.50 ft Pile 2: 4.50 ft Pile 3: 4.50 ft Pile 4: 4.50 ft
Foundation Volume:	10.667 y ³
Foundation Result:	PASSED
Mount Twist:	0.062865 kip

Site Info

Risk Category:	I
Exposure:	B
Soil Classification:	sand
Site Location:	9560 Children's Dr, Mason, OH 45040, USA
Wind Speed:	100 mph
Snow Load:	20 psf
Design Uplift Pressure:	Multiple pressures
Design Downforce Pressure:	Multiple pressures
Design Snow Pressure:	0.012096 ksf



Design Disclaimer

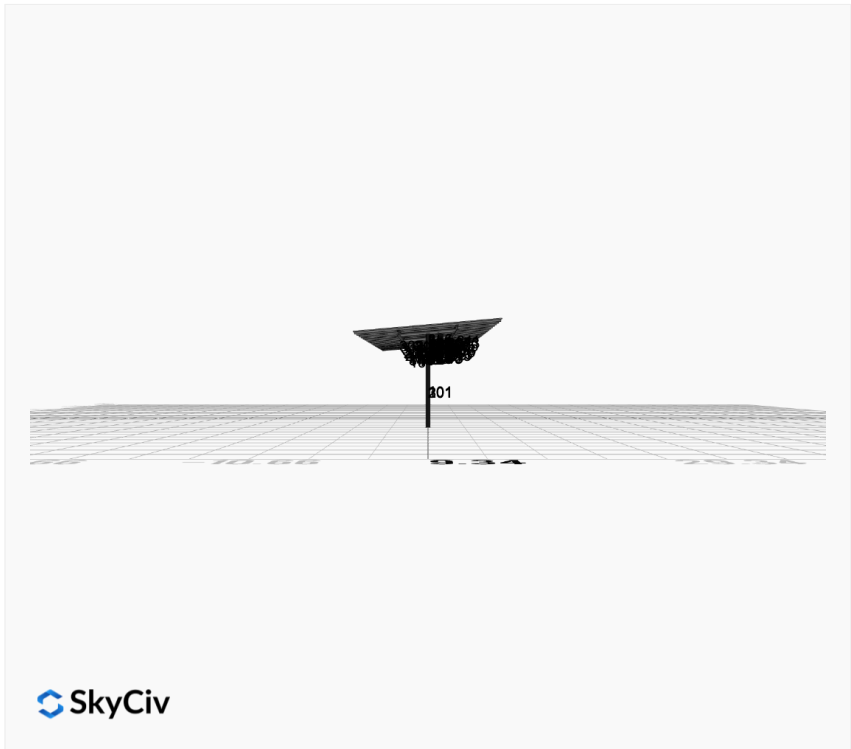
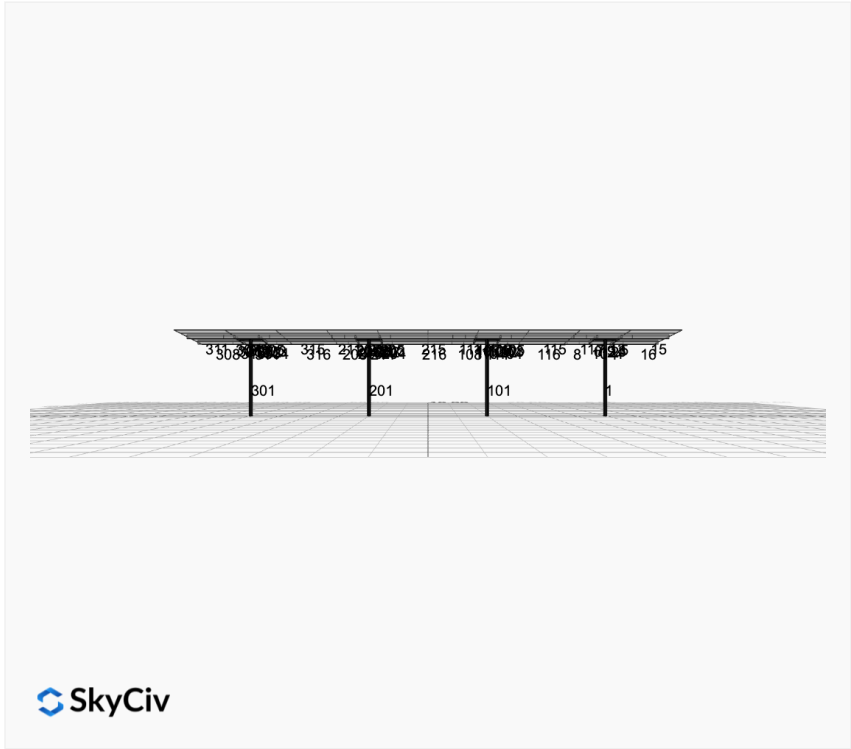
This software should be used for preliminary designs and should not be used as a final design unless reviewed, verified and designed by a qualified structural engineer.

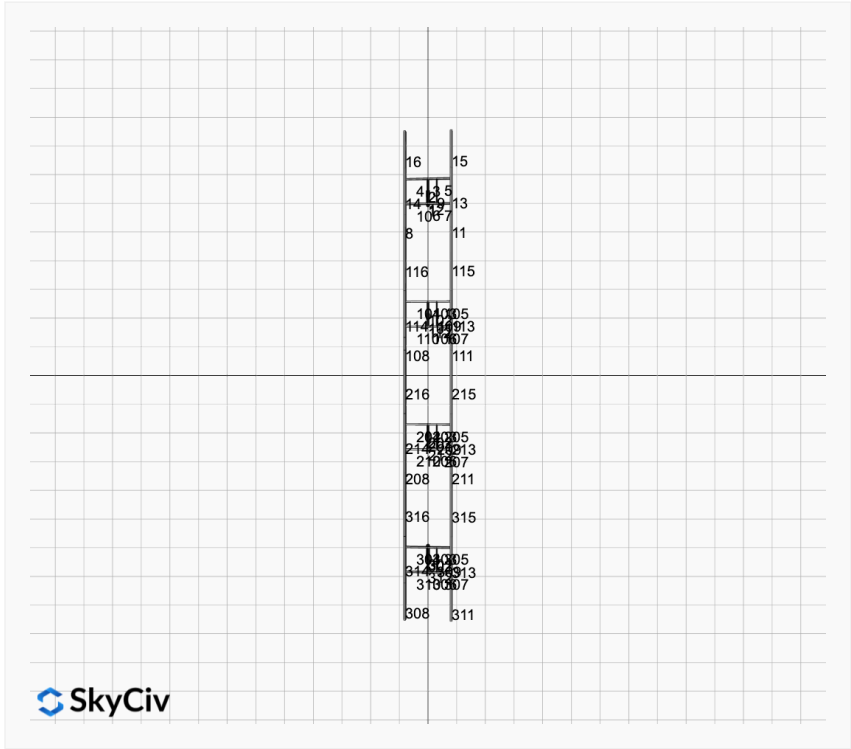
AutoDesigner Input

```
{"wind_speed_override":null,"snow_load_override":null,"direct_snow_load":false,"add_angle_brace":false,"product_type":"Beam","project_id":"Cincinnati Children's Hospital PV Study-RevA-JB","site_address":"9560 Children's Dr, Mason, OH 45040, USA","module_width":45,"module_length":96,"number_rows":5,"number_columns":10,"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":12,"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}
```

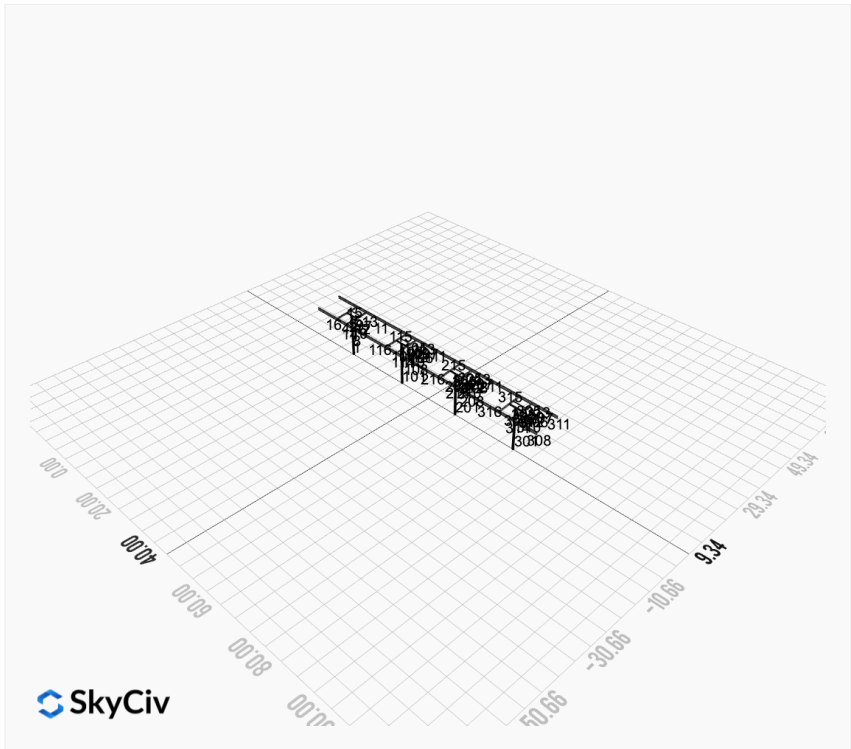
Design Notes:

- AISC Deflection checks are set to L/1 due to structure design intent
- Foundation Soil Parameters used in this Autodesign are all estimates, proper geotechnical reports are required to confirm soil profiles
- Wind speeds, snow loads and other site specific results are based on ASCE 7 2016
- Steel frame design checks are based on AISC 360 2016 (LRFD)
- Foundation Design and Sizing is approximate only





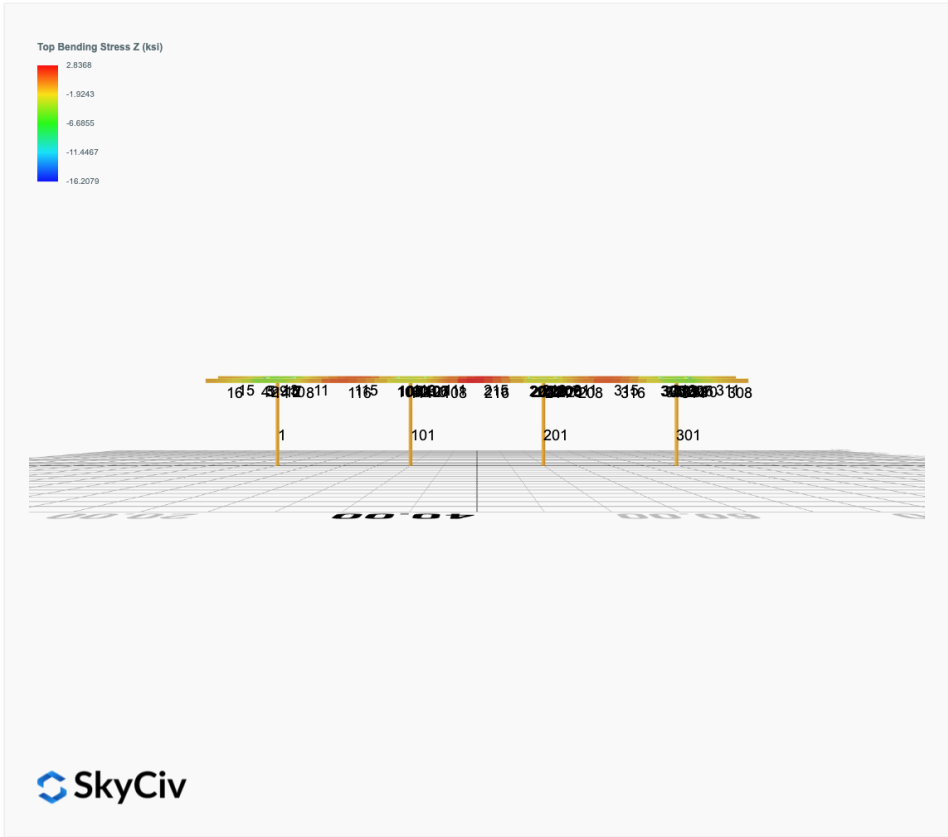
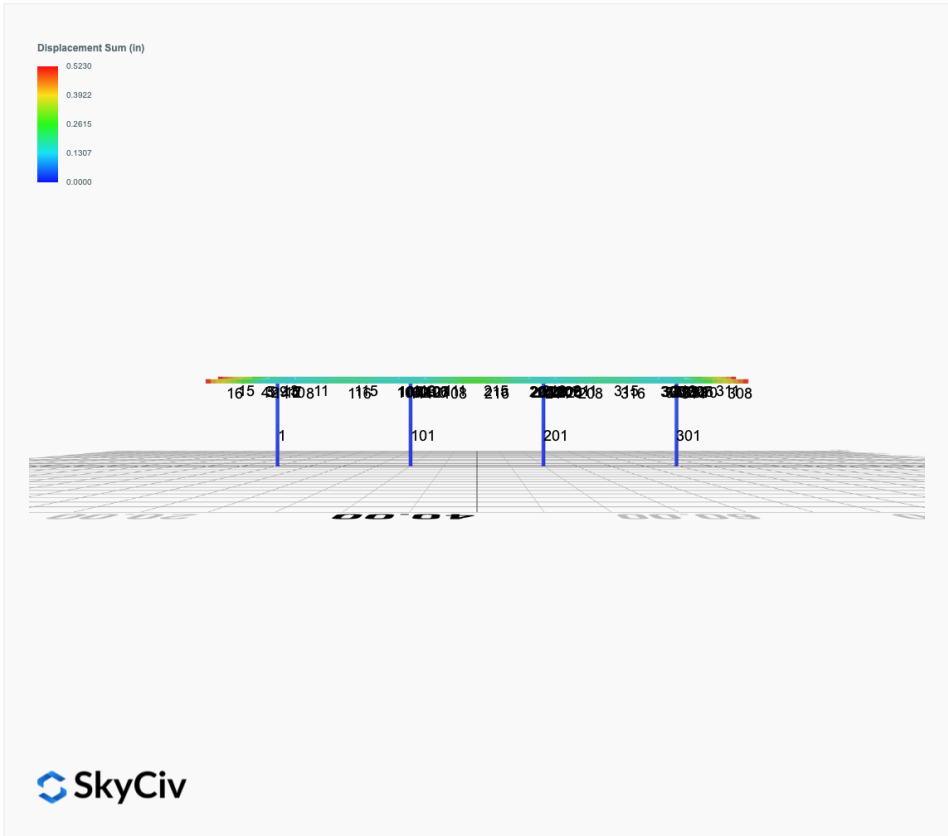
SkyCiv

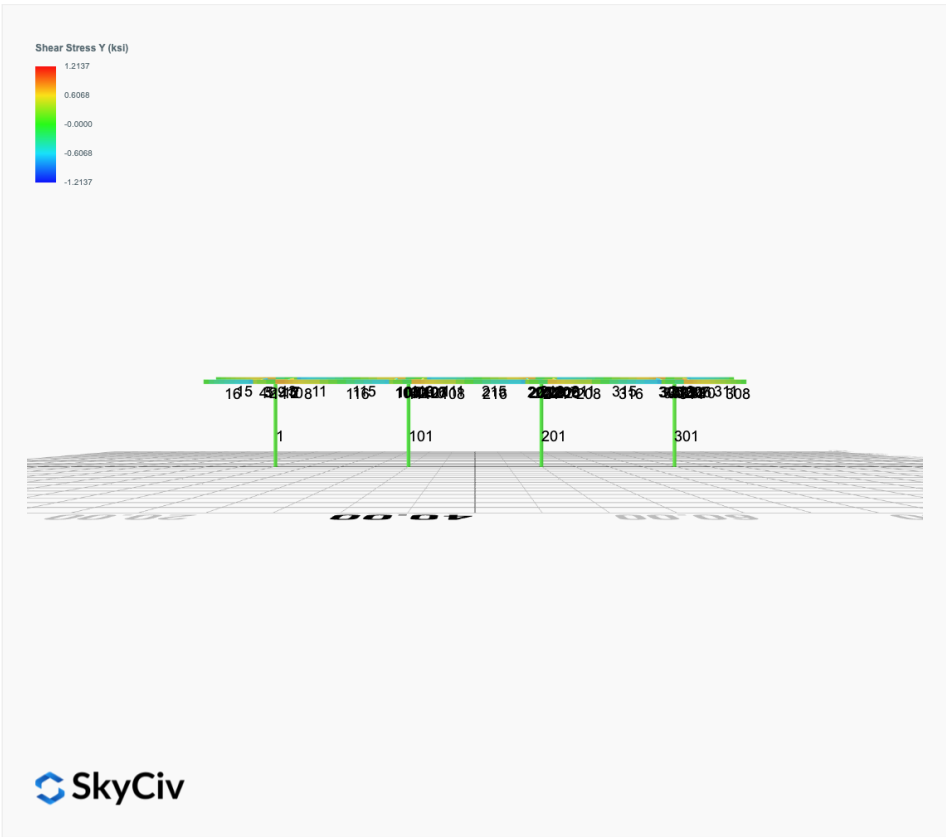
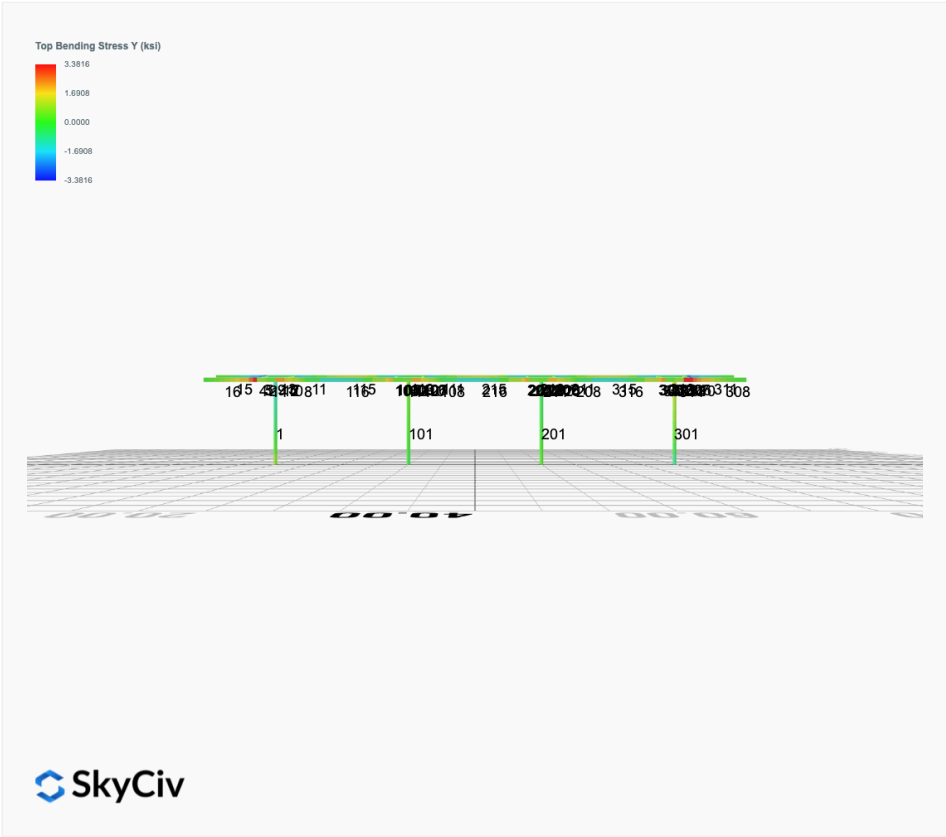


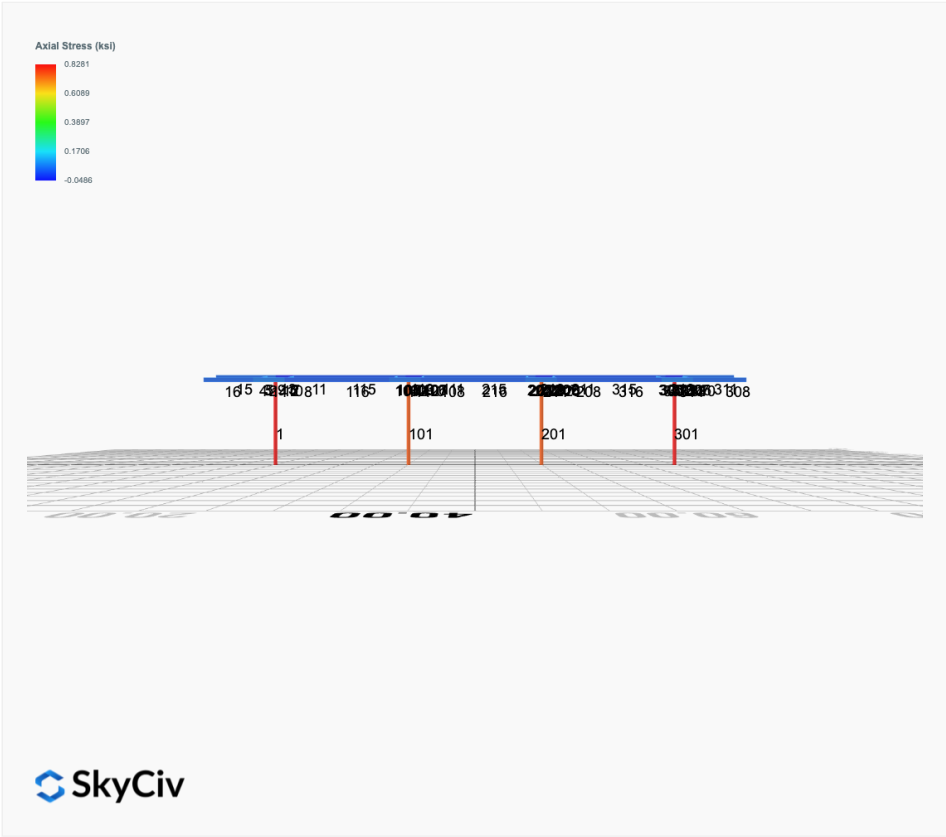
SkyCiv



FEM Results (Envelope Worst Case for each member)







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	-0.0039	2.5921	-0.0459	-0.1889	0.0106	0.0730
ULS: 2. D + L	-0.0039	2.5921	-0.0459	-0.1889	0.0106	0.0730
ULS: 3. D + (S or Lr or R)	-0.0124	7.2141	-0.1451	-0.5983	0.0334	0.1733
ULS: 3. D + (S or Lr or R)	-0.0039	2.5921	-0.0459	-0.1889	0.0106	0.0730
ULS: 4. D + 0.75L + 0.75(S or Lr or R)	-0.0103	6.0586	-0.1203	-0.4960	0.0277	0.1482
ULS: 4. D + 0.75L + 0.75(S or Lr or R)	-0.0039	2.5921	-0.0459	-0.1889	0.0106	0.0730
ULS: 5b. D + 0.7E	-0.0039	2.5921	-0.0459	-0.1889	0.0106	0.0730
ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S	-0.0103	6.0586	-0.1203	-0.4960	0.0277	0.1482
ULS: 8. 0.6D + 0.7E	-0.0024	1.5553	-0.0275	-0.1134	0.0063	0.0438
ULS: 5a. D + 0.6W_Wind downforce Case A only	-0.2245	5.1386	-0.1009	-0.4157	0.0263	3.4953
ULS: 5a. D + 0.6W_Wind downforce Case B only	-0.2245	5.1386	-0.1009	-0.4157	0.0263	3.4953
ULS: 5a. D + 0.6W_Wind uplift Case A only	0.0575	1.9046	-0.0316	-0.1302	0.0072	1.8142
ULS: 5a. D + 0.6W_Wind uplift Case B only	0.1325	0.9759	-0.0101	-0.0425	-0.0010	-7.1365
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only	-0.1757	7.9685	-0.1615	-0.6661	0.0395	2.7150
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only	-0.1757	7.9685	-0.1615	-0.6661	0.0395	2.7150
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only	0.0358	5.5430	-0.1096	-0.4519	0.0252	1.4541
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only	0.0921	4.8464	-0.0934	-0.3861	0.0190	-5.2589
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only	-0.1693	4.5020	-0.0871	-0.3590	0.0224	2.6398
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only	-0.1693	4.5020	-0.0871	-0.3590	0.0224	2.6398
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only	0.0422	2.0765	-0.0352	-0.1449	0.0080	1.3789
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only	0.0984	1.3799	-0.0191	-0.0791	0.0019	-5.3341
ULS: 7. 0.6D + 0.6W_Wind downforce Case A only	-0.2229	4.1018	-0.0825	-0.3401	0.0221	3.4662
ULS: 7. 0.6D + 0.6W_Wind downforce Case B only	-0.2229	4.1018	-0.0825	-0.3401	0.0221	3.4662
ULS: 7. 0.6D + 0.6W_Wind uplift Case A only	0.0591	0.8678	-0.0132	-0.0547	0.0030	1.7850
ULS: 7. 0.6D + 0.6W_Wind uplift Case B only	0.1341	-0.0610	0.0082	0.0331	-0.0052	-7.1657

Worst Case Reactions LRFD

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

Result	Value (kip, kip-ft)
Axial	12.6281
Shear X	-0.3759
Shear Z	-0.2606
Moment X	-1.0832
Moment Y (Twist)	0.0628
Moment Z	12.7655

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	7.9685
Shear X	-0.2245
Shear Z	-0.1615
Moment X	-0.6661
Moment Y (Twist)	0.0395
Moment Z	7.1657

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	0.0039	2.4768	0.0116	0.0478	-0.0026	-0.0141
ULS: 2. D + L	0.0039	2.4768	0.0116	0.0478	-0.0026	-0.0141
ULS: 3. D + (S or Lr or R)	0.0124	6.8499	0.0365	0.1513	-0.0083	-0.1045
ULS: 3. D + (S or Lr or R)	0.0039	2.4768	0.0116	0.0478	-0.0026	-0.0141
ULS: 4. D + 0.75L + 0.75(S or Lr or R)	0.0103	5.7566	0.0303	0.1254	-0.0069	-0.0819
ULS: 4. D + 0.75L + 0.75(S or Lr or R)	0.0039	2.4768	0.0116	0.0478	-0.0026	-0.0141
ULS: 5b. D + 0.7E	0.0039	2.4768	0.0116	0.0478	-0.0026	-0.0141

Name	Fx	Fy	Fz	Mx	My	Mz
ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S	0.0103	5.7566	0.0303	0.1254	-0.0069	-0.0819
ULS: 8. 0.6D + 0.7E	0.0024	1.4861	0.0069	0.0287	-0.0016	-0.0085
ULS: 5a. D + 0.6W_Wind downforce Case A only	-0.2090	4.8851	0.0254	0.1051	-0.0055	3.3013
ULS: 5a. D + 0.6W_Wind downforce Case B only	-0.2090	4.8851	0.0254	0.1051	-0.0055	3.3013
ULS: 5a. D + 0.6W_Wind uplift Case A only	0.0594	1.8272	0.0076	0.0318	-0.0011	1.7131
ULS: 5a. D + 0.6W_Wind uplift Case B only	0.1427	0.9470	0.0031	0.0128	-0.0022	-7.0832
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only	-0.1495	7.5629	0.0406	0.1685	-0.0091	2.4046
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only	-0.1495	7.5629	0.0406	0.1685	-0.0091	2.4046
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only	0.0519	5.2695	0.0273	0.1134	-0.0058	1.2134
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only	0.1143	4.6093	0.0239	0.0992	-0.0065	-5.3838
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only	-0.1558	4.2830	0.0219	0.0908	-0.0048	2.4724
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only	-0.1558	4.2830	0.0219	0.0908	-0.0048	2.4724
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only	0.0456	1.9896	0.0086	0.0358	-0.0015	1.2813
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only	0.1080	1.3295	0.0052	0.0216	-0.0023	-5.3159
ULS: 7. 0.6D + 0.6W_Wind downforce Case A only	-0.2106	3.8944	0.0208	0.0860	-0.0045	3.3069
ULS: 7. 0.6D + 0.6W_Wind downforce Case B only	-0.2106	3.8944	0.0208	0.0860	-0.0045	3.3069
ULS: 7. 0.6D + 0.6W_Wind uplift Case A only	0.0579	0.8365	0.0030	0.0126	-0.0001	1.7187
ULS: 7. 0.6D + 0.6W_Wind uplift Case B only	0.1411	-0.0437	-0.0015	-0.0063	-0.0011	-7.0776

Worst Case Reactions LRFD

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

Result	Value (kip, kip-ft)
Axial	11.9758
Shear X	-0.3549
Shear Z	0.0655
Moment X	0.2735
Moment Y (Twist)	0.0144
Moment Z	12.7004

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	7.5629
Shear X	-0.2106
Shear Z	0.0406
Moment X	0.1685
Moment Y (Twist)	0.0091
Moment Z	7.0832

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	0.0039	2.4768	-0.0116	-0.0478	0.0026	-0.0141
ULS: 2. D + L	0.0039	2.4768	-0.0116	-0.0478	0.0026	-0.0141
ULS: 3. D + (S or Lr or R)	0.0124	6.8499	-0.0365	-0.1513	0.0083	-0.1045
ULS: 3. D + (S or Lr or R)	0.0039	2.4768	-0.0116	-0.0478	0.0026	-0.0141
ULS: 4. D + 0.75L + 0.75(S or Lr or R)	0.0103	5.7566	-0.0303	-0.1254	0.0069	-0.0819
ULS: 4. D + 0.75L + 0.75(S or Lr or R)	0.0039	2.4768	-0.0116	-0.0478	0.0026	-0.0141
ULS: 5b. D + 0.7E	0.0039	2.4768	-0.0116	-0.0478	0.0026	-0.0141
ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S	0.0103	5.7566	-0.0303	-0.1254	0.0069	-0.0819
ULS: 8. 0.6D + 0.7E	0.0024	1.4861	-0.0069	-0.0287	0.0016	-0.0085
ULS: 5a. D + 0.6W_Wind downforce Case A only	-0.2090	4.8851	-0.0254	-0.1051	0.0055	3.3013
ULS: 5a. D + 0.6W_Wind downforce Case B only	-0.2090	4.8851	-0.0254	-0.1051	0.0055	3.3013
ULS: 5a. D + 0.6W_Wind uplift Case A only	0.0594	1.8272	-0.0076	-0.0317	0.0011	1.7131
ULS: 5a. D + 0.6W_Wind uplift Case B only	0.1427	0.9470	-0.0031	-0.0128	0.0022	-7.0832
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only	-0.1495	7.5629	-0.0406	-0.1684	0.0091	2.4046
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only	-0.1495	7.5629	-0.0406	-0.1684	0.0091	2.4046
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only	0.0519	5.2695	-0.0273	-0.1134	0.0058	1.2134
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only	0.1143	4.6093	-0.0239	-0.0992	0.0065	-5.3838

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	-0.1558	4.2830	-0.0219	-0.0908	0.0048	2.4724
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only	-0.1558	4.2830	-0.0219	-0.0908	0.0048	2.4724
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only	0.0456	1.9896	-0.0086	-0.0358	0.0015	1.2813
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only	0.1080	1.3295	-0.0052	-0.0216	0.0023	-5.3159
ULS: 7. 0.6D + 0.6W_Wind downforce Case A only	-0.2106	3.8944	-0.0208	-0.0860	0.0045	3.3069
ULS: 7. 0.6D + 0.6W_Wind downforce Case B only	-0.2106	3.8944	-0.0208	-0.0860	0.0045	3.3069
ULS: 7. 0.6D + 0.6W_Wind uplift Case A only	0.0579	0.8365	-0.0030	-0.0126	0.0001	1.7187
ULS: 7. 0.6D + 0.6W_Wind uplift Case B only	0.1411	-0.0437	0.0015	0.0063	0.0011	-7.0776

Worst Case Reactions LRFD

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

Result	Value (kip, kip-ft)
Axial	11.9758
Shear X	-0.3549
Shear Z	-0.0655
Moment X	-0.2735
Moment Y (Twist)	0.0144
Moment Z	12.7005

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	7.5629
Shear X	-0.2106
Shear Z	-0.0406
Moment X	-0.1684
Moment Y (Twist)	0.0091
Moment Z	7.0832

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

ASD Load Combination Results

Name	Fx	Fy	Fz	Mx	My	Mz
ULS: 1. D	-0.0039	2.5921	0.0459	0.1889	-0.0106	0.0730
ULS: 2. D + L	-0.0039	2.5921	0.0459	0.1889	-0.0106	0.0730
ULS: 3. D + (S or Lr or R)	-0.0124	7.2141	0.1451	0.5983	-0.0334	0.1733
ULS: 3. D + (S or Lr or R)	-0.0039	2.5921	0.0459	0.1889	-0.0106	0.0730
ULS: 4. D + 0.75L + 0.75(S or Lr or R)	-0.0103	6.0586	0.1203	0.4960	-0.0277	0.1482
ULS: 4. D + 0.75L + 0.75(S or Lr or R)	-0.0039	2.5921	0.0459	0.1889	-0.0106	0.0730
ULS: 5b. D + 0.7E	-0.0039	2.5921	0.0459	0.1889	-0.0106	0.0730
ULS: 6b. D + 0.75L + 0.75(0.7)E + 0.75S	-0.0103	6.0586	0.1203	0.4960	-0.0277	0.1482
ULS: 8. 0.6D + 0.7E	-0.0024	1.5553	0.0275	0.1134	-0.0063	0.0438
ULS: 5a. D + 0.6W_Wind downforce Case A only	-0.2245	5.1386	0.1009	0.4157	-0.0263	3.4953
ULS: 5a. D + 0.6W_Wind downforce Case B only	-0.2245	5.1386	0.1009	0.4157	-0.0263	3.4953
ULS: 5a. D + 0.6W_Wind uplift Case A only	0.0575	1.9046	0.0316	0.1302	-0.0072	1.8142
ULS: 5a. D + 0.6W_Wind uplift Case B only	0.1325	0.9759	0.0101	0.0425	0.0010	-7.1365
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only	-0.1757	7.9685	0.1615	0.6661	-0.0395	2.7150
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only	-0.1757	7.9685	0.1615	0.6661	-0.0395	2.7150
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only	0.0358	5.5430	0.1096	0.4520	-0.0252	1.4541
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only	0.0921	4.8464	0.0934	0.3861	-0.0190	-5.2589
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case A only	-0.1693	4.5020	0.0871	0.3590	-0.0224	2.6398
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind downforce Case B only	-0.1693	4.5020	0.0871	0.3590	-0.0224	2.6398
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case A only	0.0422	2.0765	0.0352	0.1449	-0.0080	1.3789
ULS: 6a. D + 0.75L + 0.75(0.6)W + 0.75(S or Lr or R)_Wind uplift Case B only	0.0984	1.3799	0.0191	0.0791	-0.0019	-5.3341
ULS: 7. 0.6D + 0.6W_Wind downforce Case A only	-0.2229	4.1018	0.0825	0.3401	-0.0221	3.4662
ULS: 7. 0.6D + 0.6W_Wind downforce Case B only	-0.2229	4.1018	0.0825	0.3401	-0.0221	3.4662
ULS: 7. 0.6D + 0.6W_Wind uplift Case A only	0.0591	0.8678	0.0132	0.0547	-0.0030	1.7850
ULS: 7. 0.6D + 0.6W_Wind uplift Case B only	0.1341	-0.0610	-0.0082	-0.0331	0.0052	-7.1657

Worst Case Reactions LRFD

Worst Case Reactions ASD

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

Result	Value (kip, kip-ft)
Axial	12.6281
Shear X	-0.3759
Shear Z	0.2606
Moment X	1.0833
Moment Y (Twist)	0.0629
Moment Z	12.7656

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	7.9685
Shear X	-0.2245
Shear Z	0.1615
Moment X	0.6661
Moment Y (Twist)	0.0395
Moment Z	7.1657

Project Details

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

User Name: sales@mtsolar.us
 Project Name: Cincinnati Children's Hospital PV Study-RevA-JB
 Unit System: imperial



Design Input Information

Design Factors			
Φ_t	Φ_c	Φ_b	Φ_v
0.9	0.9	0.9	0.9

Design Materials			
ID	E (ksi)	F _y (ksi)	F _u (ksi)
1	29000	50	65

Section Dimensions

ID	Name	d (in)	t _w (in)				
2	2in Pipe Sch 80	2.38	0.22				
5	4in Pipe Sch 80	4.50	0.34				
7	6in Pipe Sch 40	6.63	0.28				

ID	Name	d (in)	b (in)	t _w (in)	t _b (in)	r (in)	
16	HSS5x3x3/16	5.00	3.00	0.17	0.17	0.17	

ID	Name	d (in)	t _w (in)	b _t (in)	b _b (in)	t _t (in)	t _b (in)	r (in)
19	W8x10	7.89	0.17	3.94	3.94	0.20	0.20	0.30

Section Properties								
ID	Name	A (in ²)	J (in ⁴)	I _{yp} (in ⁴)	I _{zp} (in ⁴)	I _w (in ⁶)	S _{yp} (in ³)	S _{zp} (in ³)
2	2in Pipe Sch 80	1.48	1.74	0.87	0.87	0.00	1.02	1.02
5	4in Pipe Sch 80	4.41	19.22	9.61	9.61	0.00	5.85	5.85

103	116.10	115.41	15.79	11.10	42.08	23.28
104	116.10	111.33	15.79	11.10	42.08	23.28
105	116.10	114.23	15.79	11.10	42.08	23.28
106	116.10	115.41	15.79	11.10	42.08	23.28
107	116.10	114.23	15.79	11.10	42.08	23.28
108	133.20	126.01	32.87	6.12	40.24	43.62
109	66.48	58.89	3.82	3.82	19.94	19.94
110	116.10	111.33	15.79	11.10	42.08	23.28
111	133.20	126.01	32.87	6.12	40.24	43.62
112	198.33	196.72	21.95	21.95	59.50	59.50
113	133.20	104.94	24.11	6.12	40.24	43.62
114	133.20	104.94	23.63	6.12	40.24	43.62
115	133.20	69.16	17.99	6.12	40.24	43.62
116	133.20	69.16	17.56	6.12	40.24	43.62
201	251.16	60.86	42.30	42.30	75.35	75.35
202	198.33	196.72	21.95	21.95	59.50	59.50
203	116.10	115.41	15.79	11.10	42.08	23.28
204	116.10	111.33	15.79	11.10	42.08	23.28
205	116.10	114.23	15.79	11.10	42.08	23.28
206	116.10	115.41	15.79	11.10	42.08	23.28
207	116.10	114.23	15.79	11.10	42.08	23.28
208	133.20	126.01	32.87	6.12	40.24	43.62
209	66.48	58.89	3.82	3.82	19.94	19.94
210	116.10	111.33	15.79	11.10	42.08	23.28
211	133.20	126.01	32.87	6.12	40.24	43.62
212	198.33	196.72	21.95	21.95	59.50	59.50
213	133.20	104.94	24.11	6.12	40.24	43.62
214	133.20	104.94	23.63	6.12	40.24	43.62
215	133.20	69.16	17.59	6.12	40.24	43.62
216	133.20	69.16	16.85	6.12	40.24	43.62
301	251.16	60.86	42.30	42.30	75.35	75.35
302	198.33	196.72	21.95	21.95	59.50	59.50
303	116.10	115.41	15.79	11.10	42.08	23.28
304	116.10	111.33	15.79	11.10	42.08	23.28
305	116.10	114.23	15.79	11.10	42.08	23.28
306	116.10	115.41	15.79	11.10	42.08	23.28
307	116.10	114.23	15.79	11.10	42.08	23.28
308	133.20	20.65	32.87	6.12	40.24	43.62
309	66.48	58.89	3.82	3.82	19.94	19.94
310	116.10	111.33	15.79	11.10	42.08	23.28
311	133.20	20.65	32.87	6.12	40.24	43.62
312	198.33	196.72	21.95	21.95	59.50	59.50
313	133.20	104.94	24.78	6.12	40.24	43.62
314	133.20	104.94	24.75	6.12	40.24	43.62
315	133.20	69.16	18.22	6.12	40.24	43.62
316	133.20	69.16	19.03	6.12	40.24	43.62

Design Ratio

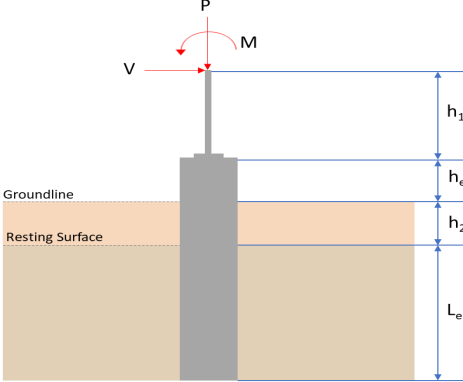
Member ID	P	M _z	M _y	V _y	V _z	(P,M _z ,M _y)	Worst LC	KL/r	δ	Status
1	0.208	0.302	0.053	0.005	0.003	0.329	#16	0.720	Not Required	Pass
2	0.000	0.559	0.023	0.111	0.003	0.581	#21	0.053	Not Required	Pass
3	0.002	0.776	0.021	0.079	0.003	0.798	#21	0.045	Not Required	Pass

4	0.002	0.762	0.036	0.077	0.007	0.774	#21	0.080	Not Required	Pass
5	0.002	0.481	0.050	0.078	0.013	0.497	#21	0.074	Not Required	Pass
6	0.002	0.678	0.008	0.068	0.004	0.683	#21	0.045	Not Required	Pass
7	0.002	0.421	0.030	0.068	0.007	0.427	#21	0.074	Not Required	Pass
8	0.001	0.104	0.033	0.050	0.003	0.137	#21	0.095	Not Required	Pass
9	0.004	0.107	0.021	0.002	0.001	0.130	#21	0.204	Not Required	Pass
10	0.001	0.668	0.044	0.067	0.010	0.705	#21	0.080	Not Required	Pass
11	0.001	0.104	0.031	0.050	0.003	0.135	#21	0.063	Not Required	Pass
12	0.002	0.456	0.021	0.096	0.003	0.476	#21	0.035	Not Required	Pass
13	0.002	0.370	0.105	0.063	0.004	0.469	#21	0.190	Not Required	Pass
14	0.001	0.371	0.105	0.062	0.004	0.463	#21	0.190	Not Required	Pass
15	0.000	0.164	0.063	0.045	0.003	0.228	#21	Not Required	Not Required	Pass
16	0.000	0.162	0.063	0.044	0.003	0.225	#21	Not Required	Not Required	Pass
101	0.197	0.300	0.013	0.005	0.001	0.323	#16	0.720	Not Required	Pass
102	0.001	0.456	0.019	0.096	0.003	0.474	#21	0.035	Not Required	Pass
103	0.002	0.678	0.009	0.068	0.001	0.687	#21	0.045	Not Required	Pass
104	0.002	0.662	0.030	0.067	0.007	0.685	#21	0.080	Not Required	Pass
105	0.002	0.420	0.028	0.068	0.007	0.426	#21	0.074	Not Required	Pass
106	0.002	0.702	0.015	0.071	0.003	0.718	#21	0.045	Not Required	Pass
107	0.002	0.435	0.032	0.070	0.008	0.444	#21	0.074	Not Required	Pass
108	0.001	0.072	0.026	0.045	0.003	0.082	#21	0.095	Not Required	Pass
109	0.002	0.076	0.011	0.001	0.000	0.089	#21	0.204	Not Required	Pass
110	0.002	0.688	0.027	0.069	0.006	0.705	#21	0.080	Not Required	Pass
111	0.001	0.070	0.027	0.046	0.003	0.080	#21	0.063	Not Required	Pass
112	0.000	0.482	0.020	0.100	0.003	0.500	#21	0.053	Not Required	Pass
113	0.002	0.212	0.070	0.059	0.004	0.258	#21	0.190	Not Required	Pass
114	0.001	0.209	0.069	0.058	0.004	0.250	#21	0.286	Not Required	Pass
115	0.001	0.185	0.039	0.041	0.003	0.224	#21	0.316	Not Required	Pass
116	0.001	0.184	0.039	0.040	0.003	0.222	#21	0.473	Not Required	Pass
201	0.197	0.300	0.013	0.005	0.001	0.323	#16	0.720	Not Required	Pass
202	0.000	0.482	0.020	0.100	0.003	0.500	#21	0.053	Not Required	Pass
203	0.002	0.702	0.015	0.071	0.003	0.718	#21	0.045	Not Required	Pass
204	0.002	0.688	0.027	0.069	0.006	0.705	#21	0.080	Not Required	Pass
205	0.002	0.435	0.032	0.070	0.008	0.444	#21	0.074	Not Required	Pass
206	0.002	0.678	0.009	0.068	0.001	0.687	#21	0.045	Not Required	Pass
207	0.002	0.420	0.028	0.068	0.007	0.426	#21	0.074	Not Required	Pass
208	0.001	0.048	0.025	0.040	0.003	0.062	#21	0.095	Not Required	Pass
209	0.002	0.076	0.011	0.001	0.000	0.089	#21	0.204	Not Required	Pass
210	0.002	0.662	0.030	0.067	0.007	0.685	#21	0.080	Not Required	Pass
211	0.001	0.047	0.025	0.041	0.003	0.061	#21	0.063	Not Required	Pass
212	0.001	0.456	0.019	0.096	0.003	0.474	#21	0.035	Not Required	Pass
213	0.002	0.212	0.070	0.059	0.004	0.258	#21	0.190	Not Required	Pass
214	0.001	0.209	0.069	0.058	0.004	0.250	#21	0.286	Not Required	Pass
215	0.001	0.271	0.038	0.046	0.003	0.310	#21	0.316	Not Required	Pass
216	0.001	0.273	0.039	0.045	0.003	0.312	#21	0.473	Not Required	Pass
301	0.208	0.302	0.053	0.005	0.003	0.329	#16	0.720	Not Required	Pass
302	0.002	0.456	0.021	0.096	0.003	0.476	#21	0.035	Not Required	Pass
303	0.002	0.678	0.008	0.068	0.004	0.683	#21	0.045	Not Required	Pass
304	0.001	0.668	0.044	0.067	0.010	0.705	#21	0.080	Not Required	Pass
305	0.002	0.421	0.030	0.068	0.007	0.427	#21	0.074	Not Required	Pass
306	0.002	0.776	0.021	0.079	0.003	0.798	#21	0.045	Not Required	Pass
307	0.002	0.481	0.050	0.078	0.013	0.497	#21	0.074	Not Required	Pass
308	0.000	0.162	0.063	0.044	0.003	0.225	#21	Not Required	Not Required	Pass
309	0.004	0.107	0.021	0.002	0.001	0.130	#21	0.204	Not Required	Pass

309	0.004	0.107	0.021	0.002	0.001	0.100	#21	0.204	Not Required	Pass
310	0.002	0.762	0.036	0.077	0.007	0.774	#21	0.080	Not Required	Pass
311	0.000	0.164	0.063	0.045	0.003	0.228	#21	Not Required	Not Required	Pass
312	0.000	0.559	0.023	0.111	0.003	0.581	#21	0.053	Not Required	Pass
313	0.002	0.370	0.105	0.063	0.004	0.469	#21	0.190	Not Required	Pass
314	0.001	0.371	0.105	0.062	0.004	0.463	#21	0.286	Not Required	Pass
315	0.001	0.167	0.040	0.050	0.003	0.204	#21	0.316	Not Required	Pass
316	0.001	0.166	0.039	0.050	0.003	0.199	#21	0.473	Not Required	Pass

Definitions

Φ_t	Safety factor for tensile
Φ_c	Safety factor for compression
Φ_b	Safety factor for flexure
Φ_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/compression)
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																										
	<p>SkyCiv Foundation Design Pile Foundation</p> <p>Design Information : Design code : IBC 2021 (International Building Code) Unit System : Imperial</p>																											
	<p>Pile Input</p>  <p>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 resting surface $h_e = 0$ ft - Length of pile above the ground</p> <p>Tabulation of Soil Parameters</p> <table border="1" data-bbox="416 1102 1193 1191"> <thead> <tr> <th>Layer</th> <th>Label</th> <th>Allowable Bearing Pressure (q_a) (psf)</th> <th>Allowable Lateral Pressure (R) (psf/ft)</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>Sand, silty sand, clayey sand, silty gravel & clayey gravel</td> <td>2000.000</td> <td>150.000</td> </tr> </tbody> </table> <p>Tabulation of Loads</p> <table border="1" data-bbox="676 1288 933 1458"> <thead> <tr> <th>Load Component</th> <th>ASD</th> <th>LRFD</th> </tr> </thead> <tbody> <tr> <td>P (kip)</td> <td>7.968</td> <td>12.628</td> </tr> <tr> <td>V_x (kip)</td> <td>-0.224</td> <td>-0.376</td> </tr> <tr> <td>V_z (kip)</td> <td>-0.162</td> <td>-0.261</td> </tr> <tr> <td>M_x (kipft)</td> <td>-0.666</td> <td>-1.083</td> </tr> <tr> <td>M_z (kipft)</td> <td>7.166</td> <td>12.765</td> </tr> </tbody> </table> <p>Material Properties $f'_{ck} = 2.5$ ksi - Concrete strength,</p>	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	Load Component	ASD	LRFD	P (kip)	7.968	12.628	V_x (kip)	-0.224	-0.376	V_z (kip)	-0.162	-0.261	M_x (kipft)	-0.666	-1.083	M_z (kipft)	7.166	12.765	
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																									
Load Component	ASD	LRFD																										
P (kip)	7.968	12.628																										
V_x (kip)	-0.224	-0.376																										
V_z (kip)	-0.162	-0.261																										
M_x (kipft)	-0.666	-1.083																										
M_z (kipft)	7.166	12.765																										
	<p>Required depth to resist lateral loads (ASD) H - Point of application of the lateral load</p> $H = h_1 + h_2 + h_e$ $H = (0 \text{ ft}) + (0 \text{ ft}) + (0 \text{ ft})$ $H = 0 \text{ ft}$ <p>Considering x-direction: H_o - Lateral force per length of pile,</p> $H_o = \frac{V_x}{1.57 D}$ $H_o = \frac{(-0.224 \text{ kip})}{1.57 \times (48 \text{ in})}$ $H_o = -0.035669 \text{ kip/ft}$ <p>M_o - Moment per length of pile,</p> $M_o = \frac{M_z + (V_x H)}{1.57 D}$																											

$$M_o = \frac{(7.166 \text{ kipft}) + ((-0.224 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 1.1411 \text{ kipft/ft}$$

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:

$L_{e,x} = 4.3443 \text{ ft}$ - Required depth in x-direction,

Considering z-direction:

H_o - Lateral force per length of pile,

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

$$H_o = \frac{(-0.162 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = -0.025796 \text{ kip/ft}$$

M_o - Moment per length of pile,

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

$$M_o = \frac{(0.666 \text{ kipft}) + ((-0.162 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 0.10605 \text{ kipft/ft}$$

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:

$L_{e,z} = 1.788 \text{ ft}$ - Required depth in z-direction,

Minimum embedded depth required:

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

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

$$L_{e,req} = \text{MAX}[(4.3443 \text{ ft}), (1.788 \text{ ft})]$$

$$L_{e,req} = 4.344 \text{ ft}$$

L_e - Actual embedded length of pile,

$$L_e = L - h_c - h_2$$

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

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

Ratio - Embedded depth

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

$$\text{Ratio} = \frac{(4.344 \text{ ft})}{(4.5 \text{ ft})}$$

$$\text{Ratio} = 0.96533$$

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

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

$$q = \frac{(7.968 \text{ kip})}{(16 \text{ ft}^2)}$$

$$q = 0.498 \text{ kip/ft}^2$$

$$q = 0.498 \text{ kip/ft}$$

Check bearing capacity ratio:

Ratio - Capacity

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

$$Ratio = \frac{(0.498 \text{ kip/ft}^2)}{(2000 \text{ psf})}$$

$$Ratio = 0.249$$

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

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:

$H_o = -0.035669 \text{ kip/ft}$ - Lateral force per length of pile,

$M_o = 1.1411 \text{ kipft/ft}$ - Overturning moment per length of pile,

a - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (1.1411 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (-0.035669 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (1.1411 \text{ kipft/ft})) + (4 \times (-0.035669 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.0322 \text{ ft}$$

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

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

$$p = \frac{0.75 \times [(4 \times (1.1411 \text{ kipft/ft})) + (3 \times (-0.035669 \text{ kip/ft}) \times (4.5 \text{ ft}))]^2}{(4.5 \text{ ft})^2 \times [(3 \times (1.1411 \text{ kipft/ft})) + (2 \times (-0.035669 \text{ kip/ft}) \times (4.5 \text{ ft}))]}$$

$$p = 0.19901 \text{ kip/ft}^2$$

s - Earth pressure against the pile at distance L_e ,

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

$$s = \frac{6 \times [(2 \times (1.1411 \text{ kipft/ft})) + ((-0.035669 \text{ kip/ft}) \times (4.5 \text{ ft}))]}{(4.5 \text{ ft})^2}$$

$$s = 0.62864 \text{ kip/ft}^2$$

Check lateral soil pressure capacity:

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

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

$$p_a = (150 \text{ psf/ft}) \times \frac{(3.0322 \text{ ft})}{2}$$

$$p_a = 0.22741 \text{ kip/ft}^2$$

Ratio - Lateral soil capacity

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

$$Ratio = \frac{(0.19901 \text{ kip/ft}^2)}{(0.22741 \text{ kip/ft}^2)}$$

$$Ratio = 0.87512$$

p_a - Allowable lateral soil pressure at depth L_e ,

Status: **PASS**
Ratio: **0.880**

$$p_s = R L_e$$

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

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

Ratio - Lateral soil capacity

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

$$\text{Ratio} = \frac{(0.62864 \text{ kip/ft}^2)}{(0.675 \text{ kip/ft}^2)}$$

$$\text{Ratio} = 0.93132$$

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

Considering z-direction:

$H_o = -0.025796 \text{ kip/ft}$ - Lateral force per length of pile,

$M_o = 0.10605 \text{ kipft/ft}$ - Overturning moment per length of pile,

a - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (0.10605 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (-0.025796 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (0.10605 \text{ kipft/ft})) + (4 \times (-0.025796 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.1582 \text{ ft}$$

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

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

$$p = \frac{0.75 \times [(4 \times (0.10605 \text{ kipft/ft})) + (3 \times (-0.025796 \text{ kip/ft}) \times (4.5 \text{ ft}))]^2}{(4.5 \text{ ft})^2 \times [(3 \times (0.10605 \text{ kipft/ft})) + (2 \times (-0.025796 \text{ kip/ft}) \times (4.5 \text{ ft}))]}$$

$$p = 0.002485 \text{ kip/ft}^2$$

s - Earth pressure against the pile at distance L_e ,

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

$$s = \frac{6 \times [(2 \times (0.10605 \text{ kipft/ft})) + ((-0.025796 \text{ kip/ft}) \times (4.5 \text{ ft}))]}{(4.5 \text{ ft})^2}$$

$$s = 0.02845 \text{ kip/ft}^2$$

Check lateral soil pressure capacity:

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

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

$$p_a = (150 \text{ psf/ft}) \times \frac{(3.1582 \text{ ft})}{2}$$

$$p_a = 0.23687 \text{ kip/ft}^2$$

Ratio - Lateral soil capacity

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

$$\text{Ratio} = \frac{(0.002485 \text{ kip/ft}^2)}{(0.23687 \text{ kip/ft}^2)}$$

$$\text{Ratio} = 0.010491$$

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

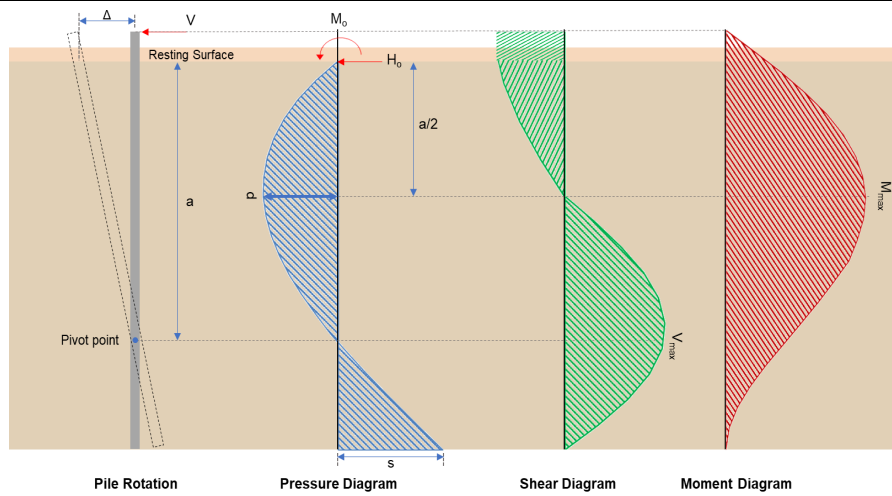
$$\text{Ratio} = \frac{s}{p_s}$$

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

$$Ratio = \frac{(0.02845 \text{ kip/ft}^2)}{(0.675 \text{ kip/ft}^2)}$$

$$Ratio = 0.042148$$

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



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

H_o - Lateral force per length of pile,

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

$$H_o = \frac{(-0.376 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = -0.059873 \text{ kip/ft}$$

M_o - Moment per length of pile,

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

$$M_o = \frac{(12.765 \text{ kipft}) + ((-0.376 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 2.0326 \text{ kipft/ft}$$

E - Distance from lateral load to resisting surface,

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

$$E = \frac{(2.0326 \text{ kipft/ft})}{(-0.059873 \text{ kip/ft})}$$

$$E = 33.949 \text{ ft}$$

a - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (2.0326 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (-0.059873 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (2.0326 \text{ kipft/ft})) + (4 \times (-0.059873 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.0304 \text{ ft}$$

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

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

$$V_{max} = ((-0.059873 \text{ kip/ft}) \times (48 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (33.949 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.0304 \text{ ft})}{(4.5 \text{ ft})} \right)^2 \right] + \left[4 \times \left(\frac{3 \times (33.949 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.0304 \text{ ft})}{(4.5 \text{ ft})} \right)^3 \right] \right]$$

$$V_{max} = 3.364 \text{ kip}$$

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

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

$$M_{max} = ((-0.059873 \text{ kip/ft}) \times (48 \text{ in}) \times (4.5 \text{ ft})) \times \left[\left(\frac{(33.949 \text{ ft})}{(4.5 \text{ ft})} + \frac{(3.0304 \text{ ft})}{2 \times (4.5 \text{ ft})} \right) - \left[\left(\frac{4 \times (33.949 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.0304 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^3 \right] + \left[\left(\frac{3 \times (33.949 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.0304 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^4 \right] \right]$$

$$M_{max} = 7.4697 \text{ kipft}$$

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

H_o - Lateral force per length of pile,

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

$$H_o = \frac{(-0.261 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = -0.041561 \text{ kip/ft}$$

M_o - Moment per length of pile,

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

$$M_o = \frac{(1.083 \text{ kipft}) + ((-0.261 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 0.17245 \text{ kipft/ft}$$

E - Distance from lateral load to resisting surface,

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

$$E = \frac{(0.17245 \text{ kipft/ft})}{(-0.041561 \text{ kip/ft})}$$

$$E = 4.1494 \text{ ft}$$

a - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (0.17245 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (-0.041561 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (0.17245 \text{ kipft/ft})) + (4 \times (-0.041561 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.1574 \text{ ft}$$

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

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

$$V_{max} = ((-0.041561 \text{ kip/ft}) \times (48 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (4.1494 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.1574 \text{ ft})}{(4.5 \text{ ft})} \right)^2 \right] + \left[4 \times \left(\frac{3 \times (4.1494 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.1574 \text{ ft})}{(4.5 \text{ ft})} \right)^3 \right] \right]$$

$$V_{max} = 0.38113 \text{ kip}$$

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

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

$$M_{max} = ((-0.041561 \text{ kip/ft}) \times (48 \text{ in}) \times (4.5 \text{ ft})) \times \left[\left(\frac{(4.1494 \text{ ft})}{(4.5 \text{ ft})} + \frac{(3.1574 \text{ ft})}{2 \times (4.5 \text{ ft})} \right) - \left[\left(\frac{4 \times (4.1494 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.1574 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^3 \right] + \left[\left(\frac{3 \times (4.1494 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.1574 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^4 \right] \right]$$

$$M_{max} = 0.79023 \text{ kipft}$$

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,
 $\alpha = 0.8$ - Alpha factor for axial strength,
 $A_g = 2304 \text{ in}^2$ - Gross area of concrete,

Table 22.4.2.1

Longitudinal reinforcement:

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

22.4.2.2, 10.6.1.1

$A_{st,required}$

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

$$A_{st,required} = \text{Min} \left[\frac{\frac{(12.628 \text{ kip})}{(0.65) \times (0.8)} - (0.85 \times (2.5 \text{ ksi}) \times (2304 \text{ in}^2))}{(60 \text{ ksi}) - (0.85 \times (2.5 \text{ ksi}))}, (0.08 \times (2304 \text{ in}^2)) \right]$$

$$A_{st,required} = -84.177 \text{ in}^2$$

A_{min} - Governing minimum reinforcement area,

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

$$A_{min} = \text{Max} [(-84.177 \text{ in}^2), (0.0018 \times (2304 \text{ in}^2))]$$

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

n_{rebar} - Required number of reinforcement,

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

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

$$n_{rebar} = 14$$

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

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

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

$$\text{Ratio} = 0.96556$$

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

25.2.3 s_{rebar} - Minimum spacing of reinforcement,

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

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

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

Ties:

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

25.7.2.1 s_{ties} - Maximum spacing of ties,

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

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

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

Summary:

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

Ties: #3(0.375 in) - 10 in

Axial Compression Strength (ACI 318-19, LRFD)

22.4.2.2

ϕP_N - Allowable axial compressive strength

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

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

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

Ratio - Capacity

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

$$\text{Ratio} = \frac{(12.628 \text{ kip})}{(2675.2 \text{ kip})}$$

$$\text{Ratio} = 0.0047204$$

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

Shear Strength (ACI 318-19, LRFD)

Parameters:

22.5.2.2

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

$$d = 0.80 D$$

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

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

22.5.5.1.3

λ_s - size effect modification factor

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

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

$$\lambda_s = 0.64282$$

22.5.5.1.1

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

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

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

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

22.5.5.1.1(a)

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5 \text{ ksi} \rightarrow 2500 \text{ psi}$, $P = 12.628 \text{ kip} \rightarrow 12628 \text{ lbf}$,
 $V_{c,a}$ - Shear strength of concrete (a)

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

$$V_{c,a} = \left[2 \times (0.64282) \times \sqrt{(2500 \text{ psi})} + \frac{(12628 \text{ lbf})}{6 \times (2304 \text{ in}^2)} \right] \times (48 \text{ in}) \times (38.4 \text{ in})$$

$$V_{c,a} = 120.17 \text{ kip}$$

22.5.5.1.2

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

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

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

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

V_c - Governing shear strength of concrete

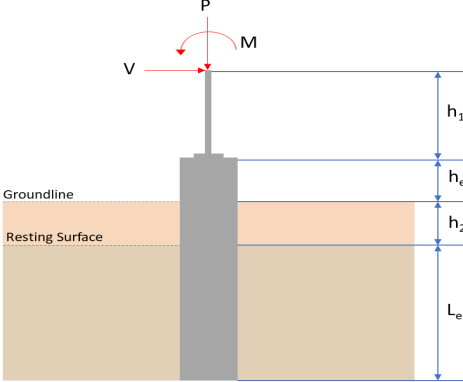
$$V_c = \text{Min}[V_{c,max}, V_{c,a}, V_{c,b}]$$

$$V_c = \text{Min}[(296.21 \text{ kip}), (120.17 \text{ kip}), (348.89 \text{ kip})]$$

$$V_c = 120.17 \text{ kip}$$

<p>22.5.1.2</p>	<p>The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5 \text{ ksi} \rightarrow 2500 \text{ psi}$.</p> <p>$V_{s,a}$ - Shear strength of steel (a)</p> $V_{s,a} = 8 \sqrt{f'_{ck}} b_w d$ $V_{s,a} = 8 \times \sqrt{(2500 \text{ psi})} \times (48 \text{ in}) \times (38.4 \text{ in})$ $V_{s,a} = 737.28 \text{ kip}$ <p>A_v - Ties rebar area,</p> $A_v = \frac{\pi d_{ties}^2}{4}$ $A_v = \frac{\pi \times (0.375 \text{ in})^2}{4}$ $A_v = 0.11045 \text{ in}^2$ <p>22.5.8.5.3 $V_{s,b}$ - Shear strength of steel (b)</p> $V_{s,b} = \frac{2 A_v f_{ytik} d}{s_{ties}}$ $V_{s,b} = \frac{2 \times (0.11045 \text{ in}^2) \times (60 \text{ ksi}) \times (38.4 \text{ in})}{(10 \text{ in})}$ $V_{s,b} = 50.894 \text{ kip}$ <p>V_s - Governing shear strength of steel</p> $V_s = \text{MIN}[V_{s,a}, V_{s,b}]$ $V_s = \text{MIN}[(737.28 \text{ kip}), (50.894 \text{ kip})]$ $V_s = 50.894 \text{ kip}$ <p>22.5.1.1 ϕV_n - Allowable shear strength</p> $\phi V_n = \phi (V_c + V_s)$ $\phi V_n = (0.65) \times ((120.17 \text{ kip}) + (50.894 \text{ kip}))$ $\phi V_n = 111.19 \text{ kip}$ <p>Considering x-direction:</p> <p>$V_{max} = 3.364 \text{ kip}$ - Maximum shear force in the x-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{V_{max}}{\phi V_n}$ $\text{Ratio} = \frac{(3.364 \text{ kip})}{(111.19 \text{ kip})}$ $\text{Ratio} = 0.030254$ <p>Considering z-direction:</p> <p>$V_{max} = 0.38113 \text{ kip}$ - Maximum shear force in the z-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{V_{max}}{\phi V_n}$ $\text{Ratio} = \frac{(0.38113 \text{ kip})}{(111.19 \text{ kip})}$ $\text{Ratio} = 0.0034277$	<p>Status: PASS Ratio: 0.030</p> <p>Status: PASS Ratio: 0.000</p>
	<p>Flexural Strength (ACI 318-19, LRFD)</p> <p>S_m - Section modulus</p> $S_m = \frac{b D^2}{6}$ $S_m = \frac{(48 \text{ in}) \times (48 \text{ in})^2}{6}$ $S_m = 18432 \text{ in}^3$	

<p>14.5.2.1b</p>	<p>$\lambda = 1$ - Concrete modification factor (Normal concrete), Allowable flexural strength: M_n shall be the lesser of: $\phi M_{n,1}$</p> $\phi M_{n,1} = \phi \times 5 \times \lambda \times \sqrt{f'_c} \times S_m$ $\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{2.5 \text{ksi}} \times 18432.001 \text{in}^3$ $\phi M_{n,1} = 249.600 \text{kipft}$ <p>$\phi M_{n,2}$</p> $\phi M_{n,2} = \phi \times 0.85 \times f'_c \times S_m$ $\phi M_{n,2} = (0.65) \times 0.85 \times (2.5 \text{ksi}) \times (18432 \text{in}^3)$ $\phi M_{n,2} = 2121.6 \text{kipft}$ <p>Therefore, ϕM_n - Allowable flexural strength,</p> $\phi M_n = \text{MIN}[\phi M_{n,1}, \phi M_{n,2}]$ $\phi M_n = \text{MIN}[(249.6 \text{kipft}), (2121.6 \text{kipft})]$ $\phi M_n = 249.6 \text{kipft}$ <p>Considering x-direction: $M_{max} = 7.4697 \text{kipft}$ - Maximum moment in the x-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{M_{max}}{\phi M_n}$ $\text{Ratio} = \frac{(7.4697 \text{kipft})}{(249.6 \text{kipft})}$ $\text{Ratio} = 0.029927$	<p>Status: PASS Ratio: 0.030</p>
	<p>Considering z-direction: $M_{max} = 0.79023 \text{kipft}$ - Maximum moment in the z-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{M_{max}}{\phi M_n}$ $\text{Ratio} = \frac{(0.79023 \text{kipft})}{(249.6 \text{kipft})}$ $\text{Ratio} = 0.003166$	<p>Status: PASS Ratio: 0.000</p>

REFERENCES	CALCULATIONS	RESULTS																										
	<p>SkyCiv Foundation Design Pile Foundation</p> <p>Design Information : Design code : IBC 2021 (International Building Code) Unit System : Imperial</p>																											
	<p>Pile Input</p>  <p>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 resting surface $h_e = 0$ ft - Length of pile above the ground</p> <p>Tabulation of Soil Parameters</p> <table border="1" data-bbox="416 1102 1193 1191"> <thead> <tr> <th>Layer</th> <th>Label</th> <th>Allowable Bearing Pressure (q_a) (psf)</th> <th>Allowable Lateral Pressure (R) (psf/ft)</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>Sand, silty sand, clayey sand, silty gravel & clayey gravel</td> <td>2000.000</td> <td>150.000</td> </tr> </tbody> </table> <p>Tabulation of Loads</p> <table border="1" data-bbox="676 1285 933 1458"> <thead> <tr> <th>Load Component</th> <th>ASD</th> <th>LRFD</th> </tr> </thead> <tbody> <tr> <td>P (kip)</td> <td>7.563</td> <td>11.976</td> </tr> <tr> <td>V_x (kip)</td> <td>-0.211</td> <td>-0.355</td> </tr> <tr> <td>V_z (kip)</td> <td>0.041</td> <td>0.065</td> </tr> <tr> <td>M_x (kipft)</td> <td>0.168</td> <td>0.273</td> </tr> <tr> <td>M_z (kipft)</td> <td>7.083</td> <td>12.700</td> </tr> </tbody> </table> <p>Material Properties $f'_{ck} = 2.5$ ksi - Concrete strength,</p>	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	Load Component	ASD	LRFD	P (kip)	7.563	11.976	V_x (kip)	-0.211	-0.355	V_z (kip)	0.041	0.065	M_x (kipft)	0.168	0.273	M_z (kipft)	7.083	12.700	
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																									
Load Component	ASD	LRFD																										
P (kip)	7.563	11.976																										
V_x (kip)	-0.211	-0.355																										
V_z (kip)	0.041	0.065																										
M_x (kipft)	0.168	0.273																										
M_z (kipft)	7.083	12.700																										
	<p>Required depth to resist lateral loads (ASD) H - Point of application of the lateral load</p> $H = h_1 + h_2 + h_e$ $H = (0 \text{ ft}) + (0 \text{ ft}) + (0 \text{ ft})$ $H = 0 \text{ ft}$ <p>Considering x-direction: H_o - Lateral force per length of pile,</p> $H_o = \frac{V_x}{1.57 D}$ $H_o = \frac{(-0.211 \text{ kip})}{1.57 \times (48 \text{ in})}$ $H_o = -0.033599 \text{ kip/ft}$ <p>M_o - Moment per length of pile,</p> $M_o = \frac{M_z + (V_x H)}{1.57 D}$																											

$$M_o = \frac{(7.083 \text{ kipft}) + ((-0.211 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 1.1279 \text{ kipft/ft}$$

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:

$L_{e,x} = 4.3354 \text{ ft}$ - Required depth in x-direction,

Considering z-direction:

H_o - Lateral force per length of pile,

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

$$H_o = \frac{(0.041 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = 0.0065287 \text{ kip/ft}$$

M_o - Moment per length of pile,

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

$$M_o = \frac{(0.168 \text{ kipft}) + ((0.041 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 0.026752 \text{ kipft/ft}$$

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:

$L_{e,z} = 1.3898 \text{ ft}$ - Required depth in z-direction,

Minimum embedded depth required:

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

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

$$L_{e,req} = \text{MAX}[(4.3354 \text{ ft}), (1.3898 \text{ ft})]$$

$$L_{e,req} = 4.335 \text{ ft}$$

L_e - Actual embedded length of pile,

$$L_e = L - h_c - h_2$$

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

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

Ratio - Embedded depth

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

$$\text{Ratio} = \frac{(4.335 \text{ ft})}{(4.5 \text{ ft})}$$

$$\text{Ratio} = 0.96333$$

Status: **PASS**
Ratio: **0.960**

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

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

$$q = \frac{(7.563 \text{ kip})}{(16 \text{ ft}^2)}$$

$$q = 0.47268 \text{ kip/ft}^2$$

$$q = 0.41209 \text{ kip/ft}$$

Check bearing capacity ratio:

Ratio - Capacity

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

$$\text{Ratio} = \frac{(0.47269 \text{ kip/ft}^2)}{(2000 \text{ psf})}$$

$$\text{Ratio} = 0.23634$$

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

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:

$H_o = -0.033599 \text{ kip/ft}$ - Lateral force per length of pile,

$M_o = 1.1279 \text{ kipft/ft}$ - Overturning moment per length of pile,

a - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (1.1279 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (-0.033599 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (1.1279 \text{ kipft/ft})) + (4 \times (-0.033599 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.0308 \text{ ft}$$

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

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

$$p = \frac{0.75 \times [(4 \times (1.1279 \text{ kipft/ft})) + (3 \times (-0.033599 \text{ kip/ft}) \times (4.5 \text{ ft}))]^2}{(4.5 \text{ ft})^2 \times [(3 \times (1.1279 \text{ kipft/ft})) + (2 \times (-0.033599 \text{ kip/ft}) \times (4.5 \text{ ft}))]}$$

$$p = 0.19793 \text{ kip/ft}^2$$

s - Earth pressure against the pile at distance L_e ,

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

$$s = \frac{6 \times [(2 \times (1.1279 \text{ kipft/ft})) + ((-0.033599 \text{ kip/ft}) \times (4.5 \text{ ft}))]}{(4.5 \text{ ft})^2}$$

$$s = 0.62357 \text{ kip/ft}^2$$

Check lateral soil pressure capacity:

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

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

$$p_a = (150 \text{ psf/ft}) \times \frac{(3.0308 \text{ ft})}{2}$$

$$p_a = 0.22731 \text{ kip/ft}^2$$

Ratio - Lateral soil capacity

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

$$\text{Ratio} = \frac{(0.19793 \text{ kip/ft}^2)}{(0.22731 \text{ kip/ft}^2)}$$

$$\text{Ratio} = 0.87076$$

p_a - Allowable lateral soil pressure at depth L_e ,

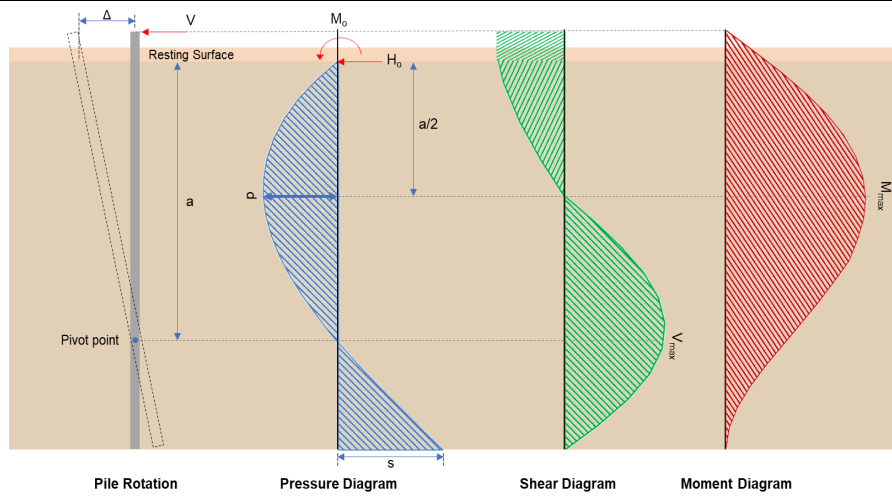
Status: **PASS**
Ratio: **0.870**

	$p_s = R L_e$ $p_s = (150 \text{ psf/ft}) \times (4.5 \text{ ft})$ $p_s = 0.675 \text{ kip/ft}^2$ <p>Ratio - Lateral soil capacity</p> $\text{Ratio} = \frac{s}{p_s}$ $\text{Ratio} = \frac{(0.62357 \text{ kip/ft}^2)}{(0.675 \text{ kip/ft}^2)}$ $\text{Ratio} = 0.9238$	<p>Status: PASS Ratio: 0.920</p>
	<p>Considering z-direction:</p> <p>$H_o = 0.0065287 \text{ kip/ft}$ - Lateral force per length of pile, $M_o = 0.026752 \text{ kipft/ft}$ - Overturning moment per length of pile, a - Distance from resting surface to pivot point,</p> $a = \frac{(4 M_o L_e) + (3 H_o L_e^2)}{(6 M_o) + (4 H_o L_e)}$ $a = \frac{(4 \times (0.026752 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (0.0065287 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (0.026752 \text{ kipft/ft})) + (4 \times (0.0065287 \text{ kip/ft}) \times (4.5 \text{ ft}))}$ $a = 3.1585 \text{ ft}$ <p>p - Earth pressure against the pile at distance $a/2$ from resting surface,</p> $p = \frac{0.75 [(4 M_o) + (3 H_o L_e)]^2}{L_e^2 [(3 M_o) + (2 H_o L_e)]}$ $p = \frac{0.75 \times [(4 \times (0.026752 \text{ kipft/ft})) + (3 \times (0.0065287 \text{ kip/ft}) \times (4.5 \text{ ft}))]^2}{(4.5 \text{ ft})^2 \times [(3 \times (0.026752 \text{ kipft/ft})) + (2 \times (0.0065287 \text{ kip/ft}) \times (4.5 \text{ ft}))]}$ $p = 0.010146 \text{ kip/ft}^2$ <p>s - Earth pressure against the pile at distance L_e,</p> $s = \frac{6 [(2 M_o) + (H_o L_e)]}{L_e^2}$ $s = \frac{6 \times [(2 \times (0.026752 \text{ kipft/ft})) + ((0.0065287 \text{ kip/ft}) \times (4.5 \text{ ft}))]}{(4.5 \text{ ft})^2}$ $s = 0.024558 \text{ kip/ft}^2$ <p>Check lateral soil pressure capacity:</p> <p>p_a - Allowable lateral soil pressure at depth $a/2$,</p> $p_a = R \frac{a}{2}$ $p_a = (150 \text{ psf/ft}) \times \frac{(3.1585 \text{ ft})}{2}$ $p_a = 0.23689 \text{ kip/ft}^2$ <p>Ratio - Lateral soil capacity</p> $\text{Ratio} = \frac{p}{p_a}$ $\text{Ratio} = \frac{(0.010146 \text{ kip/ft}^2)}{(0.23689 \text{ kip/ft}^2)}$ $\text{Ratio} = 0.04283$ <p>p_s - Allowable lateral soil pressure at depth L_e,</p> $p_s = R L_e$ $p_s = (150 \text{ psf/ft}) \times (4.5 \text{ ft})$ $p_s = 0.675 \text{ kip/ft}^2$ <p>Ratio - Lateral soil capacity</p> $\text{Ratio} = \frac{s}{p_s}$	<p>Status: PASS Ratio: 0.040</p>

$$Ratio = \frac{(0.024558 \text{ kip/ft}^2)}{(0.675 \text{ kip/ft}^2)}$$

$$Ratio = 0.036382$$

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



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

H_o - Lateral force per length of pile,

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

$$H_o = \frac{(-0.355 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = -0.056529 \text{ kip/ft}$$

M_o - Moment per length of pile,

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

$$M_o = \frac{(12.7 \text{ kipft}) + ((-0.355 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 2.0223 \text{ kipft/ft}$$

E - Distance from lateral load to resisting surface,

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

$$E = \frac{(2.0223 \text{ kipft/ft})}{(-0.056529 \text{ kip/ft})}$$

$$E = 35.775 \text{ ft}$$

a - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (2.0223 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (-0.056529 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (2.0223 \text{ kipft/ft})) + (4 \times (-0.056529 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.029 \text{ ft}$$

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

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

$$V_{max} = ((-0.056529 \text{ kip/ft}) \times (48 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (35.775 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.029 \text{ ft})}{(4.5 \text{ ft})} \right)^2 \right] + \left[4 \times \left(\frac{3 \times (35.775 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.029 \text{ ft})}{(4.5 \text{ ft})} \right)^3 \right] \right]$$

$$V_{max} = 3.3391 \text{ kip}$$

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

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

$$M_{max} = ((-0.056529 \text{ kip/ft}) \times (48 \text{ in}) \times (4.5 \text{ ft})) \times \left[\left(\frac{(35.775 \text{ ft})}{(4.5 \text{ ft})} + \frac{(3.029 \text{ ft})}{2 \times (4.5 \text{ ft})} \right) - \left[\left(\frac{4 \times (35.775 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.029 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^3 + \left[\left(\frac{3 \times (35.775 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.029 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^4 \right] \right] \right]$$

$$M_{max} = 7.4192 \text{ kipft}$$

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

H_o - Lateral force per length of pile,

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

$$H_o = \frac{(0.065 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = 0.01035 \text{ kip/ft}$$

M_o - Moment per length of pile,

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

$$M_o = \frac{(0.273 \text{ kipft}) + ((0.065 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 0.043471 \text{ kipft/ft}$$

E - Distance from lateral load to resisting surface,

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

$$E = \frac{(0.043471 \text{ kipft/ft})}{(0.01035 \text{ kip/ft})}$$

$$E = 4.2 \text{ ft}$$

a - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (0.043471 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (0.01035 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (0.043471 \text{ kipft/ft})) + (4 \times (0.01035 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.1563 \text{ ft}$$

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

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

$$V_{max} = ((0.01035 \text{ kip/ft}) \times (48 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (4.2 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.1563 \text{ ft})}{(4.5 \text{ ft})} \right)^2 + 4 \times \left(\frac{3 \times (4.2 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.1563 \text{ ft})}{(4.5 \text{ ft})} \right)^3 \right] \right]$$

$$V_{max} = 0.095738 \text{ kip}$$

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

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

$$M_{max} = ((0.01035 \text{ kip/ft}) \times (48 \text{ in}) \times (4.5 \text{ ft})) \times \left[\left(\frac{(4.2 \text{ ft})}{(4.5 \text{ ft})} + \frac{(3.1563 \text{ ft})}{2 \times (4.5 \text{ ft})} \right) - \left[\left(\frac{4 \times (4.2 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.1563 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^3 + \left[\left(\frac{3 \times (4.2 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.1563 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^4 \right] \right] \right]$$

$$M_{max} = 0.19864 \text{ kipft}$$

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,
 $\alpha = 0.8$ - Alpha factor for axial strength,
 $A_g = 2304 \text{ in}^2$ - Gross area of concrete,

Table 22.4.2.1

Longitudinal reinforcement:

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

22.4.2.2, 10.6.1.1

$A_{st,required}$

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

$$A_{st,required} = \text{Min} \left[\frac{\frac{(11.976 \text{ kip})}{(0.65) \times (0.8)} - (0.85 \times (2.5 \text{ ksi}) \times (2304 \text{ in}^2))}{(60 \text{ ksi}) - (0.85 \times (2.5 \text{ ksi}))}, (0.08 \times (2304 \text{ in}^2)) \right]$$

$$A_{st,required} = -84.198 \text{ in}^2$$

A_{min} - Governing minimum reinforcement area,

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

$$A_{min} = \text{Max} [(-84.198 \text{ in}^2), (0.0018 \times (2304 \text{ in}^2))]$$

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

n_{rebar} - Required number of reinforcement,

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

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

$$n_{rebar} = 14$$

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

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

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

$$\text{Ratio} = 0.96556$$

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

25.2.3

s_{rebar} - Minimum spacing of reinforcement,

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

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

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

Ties:

25.7.2.2

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

25.7.2.1

s_{ties} - Maximum spacing of ties,

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

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

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

Summary:

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

Ties: #3(0.375 in) - 10 in

Axial Compression Strength (ACI 318-19, LRFD)

22.4.2.2

ϕP_N - Allowable axial compressive strength

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

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

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

Ratio - Capacity

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

$$\text{Ratio} = \frac{(11.976 \text{ kip})}{(2675.2 \text{ kip})}$$

$$\text{Ratio} = 0.0044767$$

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

Shear Strength (ACI 318-19, LRFD)

Parameters:

22.5.2.2

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

$$d = 0.80 D$$

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

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

22.5.5.1.3

λ_s - size effect modification factor

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

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

$$\lambda_s = 0.64282$$

22.5.5.1.1

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

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

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

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

22.5.5.1.1(a)

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5 \text{ ksi} \rightarrow 2500 \text{ psi}$, $P = 11.976 \text{ kip} \rightarrow 11976 \text{ lbf}$,
 $V_{c,a}$ - Shear strength of concrete (a)

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

$$V_{c,a} = \left[2 \times (0.64282) \times \sqrt{(2500 \text{ psi})} + \frac{(11976 \text{ lbf})}{6 \times (2304 \text{ in}^2)} \right] \times (48 \text{ in}) \times (38.4 \text{ in})$$

$$V_{c,a} = 120.08 \text{ kip}$$

22.5.5.1.2

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

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

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

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

V_c - Governing shear strength of concrete

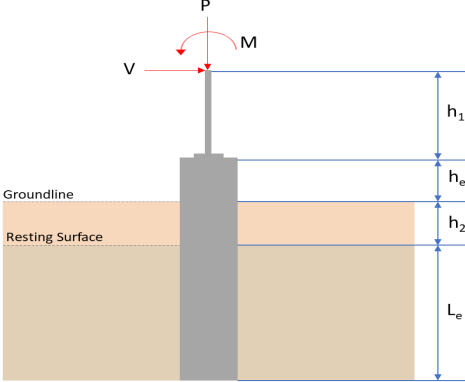
$$V_c = \text{Min}[V_{c,max}, V_{c,a}, V_{c,b}]$$

$$V_c = \text{Min}[(296.21 \text{ kip}), (120.08 \text{ kip}), (348.89 \text{ kip})]$$

$$V_c = 120.08 \text{ kip}$$

<p>22.5.1.2</p>	<p>The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5 \text{ ksi} \rightarrow 2500 \text{ psi}$.</p> <p>$V_{s,a}$ - Shear strength of steel (a)</p> $V_{s,a} = 8 \sqrt{f'_{ck}} b_w d$ $V_{s,a} = 8 \times \sqrt{(2500 \text{ psi})} \times (48 \text{ in}) \times (38.4 \text{ in})$ $V_{s,a} = 737.28 \text{ kip}$ <p>A_v - Ties rebar area,</p> $A_v = \frac{\pi d_{ties}^2}{4}$ $A_v = \frac{\pi \times (0.375 \text{ in})^2}{4}$ $A_v = 0.11045 \text{ in}^2$ <p>22.5.8.5.3 $V_{s,b}$ - Shear strength of steel (b)</p> $V_{s,b} = \frac{2 A_v f_{ytik} d}{s_{ties}}$ $V_{s,b} = \frac{2 \times (0.11045 \text{ in}^2) \times (60 \text{ ksi}) \times (38.4 \text{ in})}{(10 \text{ in})}$ $V_{s,b} = 50.894 \text{ kip}$ <p>V_s - Governing shear strength of steel</p> $V_s = \text{MIN}[V_{s,a}, V_{s,b}]$ $V_s = \text{MIN}[(737.28 \text{ kip}), (50.894 \text{ kip})]$ $V_s = 50.894 \text{ kip}$ <p>22.5.1.1 ϕV_n - Allowable shear strength</p> $\phi V_n = \phi (V_c + V_s)$ $\phi V_n = (0.65) \times ((120.08 \text{ kip}) + (50.894 \text{ kip}))$ $\phi V_n = 111.13 \text{ kip}$ <p>Considering x-direction:</p> <p>$V_{max} = 3.3391 \text{ kip}$ - Maximum shear force in the x-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{V_{max}}{\phi V_n}$ $\text{Ratio} = \frac{(3.3391 \text{ kip})}{(111.13 \text{ kip})}$ $\text{Ratio} = 0.030045$ <p>Considering z-direction:</p> <p>$V_{max} = 0.095738 \text{ kip}$ - Maximum shear force in the z-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{V_{max}}{\phi V_n}$ $\text{Ratio} = \frac{(0.095738 \text{ kip})}{(111.13 \text{ kip})}$ $\text{Ratio} = 0.00086146$	<p>Status: PASS Ratio: 0.030</p> <p>Status: PASS Ratio: 0.000</p>
	<p>Flexural Strength (ACI 318-19, LRFD)</p> <p>S_m - Section modulus</p> $S_m = \frac{b D^2}{6}$ $S_m = \frac{(48 \text{ in}) \times (48 \text{ in})^2}{6}$ $S_m = 18432 \text{ in}^3$	

<p>14.5.2.1b</p>	<p>$\lambda = 1$ - Concrete modification factor (Normal concrete), Allowable flexural strength: M_n shall be the lesser of: $\phi M_{n,1}$</p> $\phi M_{n,1} = \phi \times 5 \times \lambda \times \sqrt{f'_c} \times S_m$ $\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{2.5 \text{ksi}} \times 18432.001 \text{in}^3$ $\phi M_{n,1} = 249.600 \text{kipft}$ <p>$\phi M_{n,2}$</p> $\phi M_{n,2} = \phi \times 0.85 \times f'_c \times S_m$ $\phi M_{n,2} = (0.65) \times 0.85 \times (2.5 \text{ksi}) \times (18432 \text{in}^3)$ $\phi M_{n,2} = 2121.6 \text{kipft}$ <p>Therefore, ϕM_n - Allowable flexural strength,</p> $\phi M_n = \text{MIN}[\phi M_{n,1}, \phi M_{n,2}]$ $\phi M_n = \text{MIN}[(249.6 \text{kipft}), (2121.6 \text{kipft})]$ $\phi M_n = 249.6 \text{kipft}$ <p>Considering x-direction: $M_{max} = 7.4192 \text{kipft}$ - Maximum moment in the x-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{M_{max}}{\phi M_n}$ $\text{Ratio} = \frac{(7.4192 \text{kipft})}{(249.6 \text{kipft})}$ $\text{Ratio} = 0.029724$	<p>Status: PASS Ratio: 0.030</p>
	<p>Considering z-direction: $M_{max} = 0.19864 \text{kipft}$ - Maximum moment in the z-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{M_{max}}{\phi M_n}$ $\text{Ratio} = \frac{(0.19864 \text{kipft})}{(249.6 \text{kipft})}$ $\text{Ratio} = 0.00079584$	<p>Status: PASS Ratio: 0.000</p>

REFERENCES	CALCULATIONS	RESULTS																										
	<p>SkyCiv Foundation Design Pile Foundation</p> <p>Design Information : Design code : IBC 2021 (International Building Code) Unit System : Imperial</p>																											
	<p>Pile Input</p>  <p>Geometry</p> <p>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 resting surface $h_e = 0$ ft - Length of pile above the ground</p> <p>Tabulation of Soil Parameters</p> <table border="1" data-bbox="416 1102 1193 1193"> <thead> <tr> <th>Layer</th> <th>Label</th> <th>Allowable Bearing Pressure (q_a) (psf)</th> <th>Allowable Lateral Pressure (R) (psf/ft)</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>Sand, silty sand, clayey sand, silty gravel & clayey gravel</td> <td>2000.000</td> <td>150.000</td> </tr> </tbody> </table> <p>Tabulation of Loads</p> <table border="1" data-bbox="676 1288 935 1458"> <thead> <tr> <th>Load Component</th> <th>ASD</th> <th>LRFD</th> </tr> </thead> <tbody> <tr> <td>P (kip)</td> <td>7.563</td> <td>11.976</td> </tr> <tr> <td>V_x (kip)</td> <td>-0.211</td> <td>-0.355</td> </tr> <tr> <td>V_z (kip)</td> <td>-0.041</td> <td>-0.065</td> </tr> <tr> <td>M_x (kipft)</td> <td>-0.168</td> <td>-0.273</td> </tr> <tr> <td>M_z (kipft)</td> <td>7.083</td> <td>12.700</td> </tr> </tbody> </table> <p>Material Properties</p> <p>$f'_{ck} = 2.5$ ksi - Concrete strength,</p>	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	Load Component	ASD	LRFD	P (kip)	7.563	11.976	V_x (kip)	-0.211	-0.355	V_z (kip)	-0.041	-0.065	M_x (kipft)	-0.168	-0.273	M_z (kipft)	7.083	12.700	
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																									
Load Component	ASD	LRFD																										
P (kip)	7.563	11.976																										
V_x (kip)	-0.211	-0.355																										
V_z (kip)	-0.041	-0.065																										
M_x (kipft)	-0.168	-0.273																										
M_z (kipft)	7.083	12.700																										
	<p>Required depth to resist lateral loads (ASD)</p> <p>H - Point of application of the lateral load</p> $H = h_1 + h_2 + h_e$ $H = (0 \text{ ft}) + (0 \text{ ft}) + (0 \text{ ft})$ $H = 0 \text{ ft}$ <p>Considering x-direction:</p> <p>H_o - Lateral force per length of pile,</p> $H_o = \frac{V_x}{1.57 D}$ $H_o = \frac{(-0.211 \text{ kip})}{1.57 \times (48 \text{ in})}$ $H_o = -0.033599 \text{ kip/ft}$ <p>M_o - Moment per length of pile,</p> $M_o = \frac{M_x + (V_x H)}{1.57 D}$																											

$$M_o = \frac{(7.083 \text{ kipft}) + ((-0.211 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 1.1279 \text{ kipft/ft}$$

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:

$L_{e,x} = 4.3354 \text{ ft}$ - Required depth in x-direction,

Considering z-direction:

H_o - Lateral force per length of pile,

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

$$H_o = \frac{(-0.041 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = -0.0065287 \text{ kip/ft}$$

M_o - Moment per length of pile,

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

$$M_o = \frac{(0.168 \text{ kipft}) + ((-0.041 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 0.026752 \text{ kipft/ft}$$

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:

$L_{e,z} = 1.1875 \text{ ft}$ - Required depth in z-direction,

Minimum embedded depth required:

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

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

$$L_{e,req} = \text{MAX}[(4.3354 \text{ ft}), (1.1875 \text{ ft})]$$

$$L_{e,req} = 4.335 \text{ ft}$$

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

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

$$\text{Ratio} = \frac{(4.335 \text{ ft})}{(4.5 \text{ ft})}$$

$$\text{Ratio} = 0.96333$$

Status: **PASS**
Ratio: **0.960**

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

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

$$q = \frac{(7.563 \text{ kip})}{(16 \text{ ft}^2)}$$

$$q = 0.47268 \text{ kip/ft}^2$$

$$q = 0.41209 \text{ kip/ft}$$

Check bearing capacity ratio:

Ratio - Capacity

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

$$\text{Ratio} = \frac{(0.47269 \text{ kip/ft}^2)}{(2000 \text{ psf})}$$

$$\text{Ratio} = 0.23634$$

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

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:

$H_o = -0.033599 \text{ kip/ft}$ - Lateral force per length of pile,

$M_o = 1.1279 \text{ kipft/ft}$ - Overturning moment per length of pile,

a - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (1.1279 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (-0.033599 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (1.1279 \text{ kipft/ft})) + (4 \times (-0.033599 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.0308 \text{ ft}$$

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

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

$$p = \frac{0.75 \times [(4 \times (1.1279 \text{ kipft/ft})) + (3 \times (-0.033599 \text{ kip/ft}) \times (4.5 \text{ ft}))]^2}{(4.5 \text{ ft})^2 \times [(3 \times (1.1279 \text{ kipft/ft})) + (2 \times (-0.033599 \text{ kip/ft}) \times (4.5 \text{ ft}))]}$$

$$p = 0.19793 \text{ kip/ft}^2$$

s - Earth pressure against the pile at distance L_e ,

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

$$s = \frac{6 \times [(2 \times (1.1279 \text{ kipft/ft})) + ((-0.033599 \text{ kip/ft}) \times (4.5 \text{ ft}))]}{(4.5 \text{ ft})^2}$$

$$s = 0.62357 \text{ kip/ft}^2$$

Check lateral soil pressure capacity:

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

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

$$p_a = (150 \text{ psf/ft}) \times \frac{(3.0308 \text{ ft})}{2}$$

$$p_a = 0.22731 \text{ kip/ft}^2$$

Ratio - Lateral soil capacity

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

$$\text{Ratio} = \frac{(0.19793 \text{ kip/ft}^2)}{(0.22731 \text{ kip/ft}^2)}$$

$$\text{Ratio} = 0.87076$$

p_a - Allowable lateral soil pressure at depth L_e ,

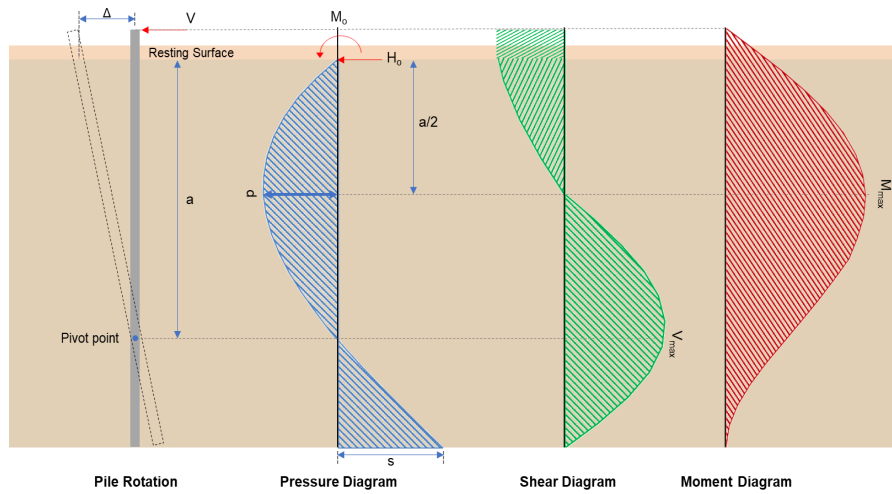
Status: **PASS**
Ratio: **0.870**

	$p_s = R L_e$ $p_s = (150 \text{ psf/ft}) \times (4.5 \text{ ft})$ $p_s = 0.675 \text{ kip/ft}^2$ <p>Ratio - Lateral soil capacity</p> $\text{Ratio} = \frac{s}{p_s}$ $\text{Ratio} = \frac{(0.62357 \text{ kip/ft}^2)}{(0.675 \text{ kip/ft}^2)}$ $\text{Ratio} = 0.9238$	<p>Status: PASS Ratio: 0.920</p>
	<p>Considering z-direction:</p> <p>$H_o = -0.0065287 \text{ kip/ft}$ - Lateral force per length of pile, $M_o = 0.026752 \text{ kipft/ft}$ - Overturning moment per length of pile, a - Distance from resting surface to pivot point,</p> $a = \frac{(4 M_o L_e) + (3 H_o L_e^2)}{(6 M_o) + (4 H_o L_e)}$ $a = \frac{(4 \times (0.026752 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (-0.0065287 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (0.026752 \text{ kipft/ft})) + (4 \times (-0.0065287 \text{ kip/ft}) \times (4.5 \text{ ft}))}$ $a = 3.1585 \text{ ft}$ <p>p - Earth pressure against the pile at distance $a/2$ from resting surface,</p> $p = \frac{0.75 [(4 M_o) + (3 H_o L_e)]^2}{L_e^2 [(3 M_o) + (2 H_o L_e)]}$ $p = \frac{0.75 \times [(4 \times (0.026752 \text{ kipft/ft})) + (3 \times (-0.0065287 \text{ kip/ft}) \times (4.5 \text{ ft}))]^2}{(4.5 \text{ ft})^2 \times [(3 \times (0.026752 \text{ kipft/ft})) + (2 \times (-0.0065287 \text{ kip/ft}) \times (4.5 \text{ ft}))]}$ $p = 0.00061345 \text{ kip/ft}^2$ <p>s - Earth pressure against the pile at distance L_e,</p> $s = \frac{6 [(2 M_o) + (H_o L_e)]}{L_e^2}$ $s = \frac{6 \times [(2 \times (0.026752 \text{ kipft/ft})) + ((-0.0065287 \text{ kip/ft}) \times (4.5 \text{ ft}))]}{(4.5 \text{ ft})^2}$ $s = 0.0071479 \text{ kip/ft}^2$ <p>Check lateral soil pressure capacity:</p> <p>p_a - Allowable lateral soil pressure at depth $a/2$,</p> $p_a = R \frac{a}{2}$ $p_a = (150 \text{ psf/ft}) \times \frac{(3.1585 \text{ ft})}{2}$ $p_a = 0.23689 \text{ kip/ft}^2$ <p>Ratio - Lateral soil capacity</p> $\text{Ratio} = \frac{p}{p_a}$ $\text{Ratio} = \frac{(0.00061345 \text{ kip/ft}^2)}{(0.23689 \text{ kip/ft}^2)}$ $\text{Ratio} = 0.0025896$ <p>p_s - Allowable lateral soil pressure at depth L_e,</p> $p_s = R L_e$ $p_s = (150 \text{ psf/ft}) \times (4.5 \text{ ft})$ $p_s = 0.675 \text{ kip/ft}^2$ <p>Ratio - Lateral soil capacity</p> $\text{Ratio} = \frac{s}{p_s}$	<p>Status: PASS Ratio: 0.000</p>

$$\text{Ratio} = \frac{(0.0071479 \text{ kip/ft}^2)}{(0.675 \text{ kip/ft}^2)}$$

$$\text{Ratio} = 0.010589$$

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



Shear force and Bending moment (x-direction, LRF)

H_o - Lateral force per length of pile,

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

$$H_o = \frac{(-0.355 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = -0.056529 \text{ kip/ft}$$

M_o - Moment per length of pile,

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

$$M_o = \frac{(12.7 \text{ kipft}) + ((-0.355 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 2.0223 \text{ kipft/ft}$$

E - Distance from lateral load to resisting surface,

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

$$E = \frac{(2.0223 \text{ kipft/ft})}{(-0.056529 \text{ kip/ft})}$$

$$E = 35.775 \text{ ft}$$

a - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (2.0223 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (-0.056529 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (2.0223 \text{ kipft/ft})) + (4 \times (-0.056529 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.029 \text{ ft}$$

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

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

$$V_{max} = ((-0.056529 \text{ kip/ft}) \times (48 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (35.775 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.029 \text{ ft})}{(4.5 \text{ ft})} \right)^2 \right] + \left[4 \times \left(\frac{3 \times (35.775 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.029 \text{ ft})}{(4.5 \text{ ft})} \right)^3 \right] \right]$$

$$V_{max} = 3.3391 \text{ kip}$$

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

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

$$M_{max} = ((-0.056529 \text{ kip/ft}) \times (48 \text{ in}) \times (4.5 \text{ ft})) \times \left[\left(\frac{(35.775 \text{ ft})}{(4.5 \text{ ft})} + \frac{(3.029 \text{ ft})}{2 \times (4.5 \text{ ft})} \right) - \left[\left(\frac{4 \times (35.775 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.029 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^3 + \left[\left(\frac{3 \times (35.775 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.029 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^4 \right] \right] \right]$$

$$M_{max} = 7.4192 \text{ kipft}$$

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

H_o - Lateral force per length of pile,

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

$$H_o = \frac{(-0.065 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = -0.01035 \text{ kip/ft}$$

M_o - Moment per length of pile,

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

$$M_o = \frac{(0.273 \text{ kipft}) + ((-0.065 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 0.043471 \text{ kipft/ft}$$

E - Distance from lateral load to resisting surface,

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

$$E = \frac{(0.043471 \text{ kipft/ft})}{(-0.01035 \text{ kip/ft})}$$

$$E = 4.2 \text{ ft}$$

a - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (0.043471 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (-0.01035 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (0.043471 \text{ kipft/ft})) + (4 \times (-0.01035 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.1563 \text{ ft}$$

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

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

$$V_{max} = ((-0.01035 \text{ kip/ft}) \times (48 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (4.2 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.1563 \text{ ft})}{(4.5 \text{ ft})} \right)^2 + 4 \times \left(\frac{3 \times (4.2 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.1563 \text{ ft})}{(4.5 \text{ ft})} \right)^3 \right] \right]$$

$$V_{max} = 0.095738 \text{ kip}$$

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

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

$$M_{max} = ((-0.01035 \text{ kip/ft}) \times (48 \text{ in}) \times (4.5 \text{ ft})) \times \left[\left(\frac{(4.2 \text{ ft})}{(4.5 \text{ ft})} + \frac{(3.1563 \text{ ft})}{2 \times (4.5 \text{ ft})} \right) - \left[\left(\frac{4 \times (4.2 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.1563 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^3 + \left[\left(\frac{3 \times (4.2 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.1563 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^4 \right] \right] \right]$$

$$M_{max} = 0.19864 \text{ kipft}$$

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,
 $\alpha = 0.8$ - Alpha factor for axial strength,
 $A_g = 2304 \text{ in}^2$ - Gross area of concrete,

Table 22.4.2.1

Longitudinal reinforcement:

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

22.4.2.2, 10.6.1.1

$A_{st,required}$

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

$$A_{st,required} = \text{Min} \left[\frac{\frac{(11.976 \text{ kip})}{(0.65) \times (0.8)} - (0.85 \times (2.5 \text{ ksi}) \times (2304 \text{ in}^2))}{(60 \text{ ksi}) - (0.85 \times (2.5 \text{ ksi}))}, (0.08 \times (2304 \text{ in}^2)) \right]$$

$$A_{st,required} = -84.198 \text{ in}^2$$

A_{min} - Governing minimum reinforcement area,

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

$$A_{min} = \text{Max} [(-84.198 \text{ in}^2), (0.0018 \times (2304 \text{ in}^2))]$$

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

n_{rebar} - Required number of reinforcement,

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

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

$$n_{rebar} = 14$$

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

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

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

$$\text{Ratio} = 0.96556$$

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

25.2.3

s_{rebar} - Minimum spacing of reinforcement,

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

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

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

Ties:

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

25.7.2.1 s_{ties} - Maximum spacing of ties,

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

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

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

Summary:

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

Ties: #3(0.375 in) - 10 in

Axial Compression Strength (ACI 318-19, LRFD)

22.4.2.2

ϕP_N - Allowable axial compressive strength

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

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

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

Ratio - Capacity

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

$$\text{Ratio} = \frac{(11.976 \text{ kip})}{(2675.2 \text{ kip})}$$

$$\text{Ratio} = 0.0044767$$

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

Shear Strength (ACI 318-19, LRFD)

Parameters:

22.5.2.2

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

$$d = 0.80 D$$

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

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

22.5.5.1.3

λ_s - size effect modification factor

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

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

$$\lambda_s = 0.64282$$

22.5.5.1.1

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

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

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

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

22.5.5.1.1(a)

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5 \text{ ksi} \rightarrow 2500 \text{ psi}$, $P = 11.976 \text{ kip} \rightarrow 11976 \text{ lbf}$,
 $V_{c,a}$ - Shear strength of concrete (a)

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

$$V_{c,a} = \left[2 \times (0.64282) \times \sqrt{(2500 \text{ psi})} + \frac{(11976 \text{ lbf})}{6 \times (2304 \text{ in}^2)} \right] \times (48 \text{ in}) \times (38.4 \text{ in})$$

$$V_{c,a} = 120.08 \text{ kip}$$

22.5.5.1.2

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

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

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

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

V_c - Governing shear strength of concrete

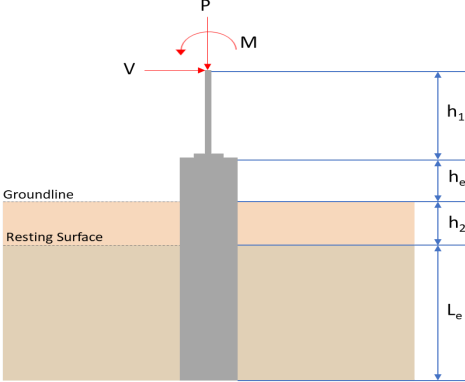
$$V_c = \text{Min}[V_{c,max}, V_{c,a}, V_{c,b}]$$

$$V_c = \text{Min}[(296.21 \text{ kip}), (120.08 \text{ kip}), (348.89 \text{ kip})]$$

$$V_c = 120.08 \text{ kip}$$

<p>22.5.1.2</p>	<p>The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5 \text{ ksi} \rightarrow 2500 \text{ psi}$.</p> <p>$V_{s,a}$ - Shear strength of steel (a)</p> $V_{s,a} = 8 \sqrt{f'_{ck}} b_w d$ $V_{s,a} = 8 \times \sqrt{(2500 \text{ psi})} \times (48 \text{ in}) \times (38.4 \text{ in})$ $V_{s,a} = 737.28 \text{ kip}$ <p>A_v - Ties rebar area,</p> $A_v = \frac{\pi d_{ties}^2}{4}$ $A_v = \frac{\pi \times (0.375 \text{ in})^2}{4}$ $A_v = 0.11045 \text{ in}^2$ <p>22.5.8.5.3 $V_{s,b}$ - Shear strength of steel (b)</p> $V_{s,b} = \frac{2 A_v f_{yt} d}{s_{ties}}$ $V_{s,b} = \frac{2 \times (0.11045 \text{ in}^2) \times (60 \text{ ksi}) \times (38.4 \text{ in})}{(10 \text{ in})}$ $V_{s,b} = 50.894 \text{ kip}$ <p>V_s - Governing shear strength of steel</p> $V_s = \text{MIN}[V_{s,a}, V_{s,b}]$ $V_s = \text{MIN}[(737.28 \text{ kip}), (50.894 \text{ kip})]$ $V_s = 50.894 \text{ kip}$ <p>22.5.1.1 ϕV_n - Allowable shear strength</p> $\phi V_n = \phi (V_c + V_s)$ $\phi V_n = (0.65) \times ((120.08 \text{ kip}) + (50.894 \text{ kip}))$ $\phi V_n = 111.13 \text{ kip}$ <p>Considering x-direction:</p> <p>$V_{max} = 3.3391 \text{ kip}$ - Maximum shear force in the x-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{V_{max}}{\phi V_n}$ $\text{Ratio} = \frac{(3.3391 \text{ kip})}{(111.13 \text{ kip})}$ $\text{Ratio} = 0.030045$ <p>Considering z-direction:</p> <p>$V_{max} = 0.095738 \text{ kip}$ - Maximum shear force in the z-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{V_{max}}{\phi V_n}$ $\text{Ratio} = \frac{(0.095738 \text{ kip})}{(111.13 \text{ kip})}$ $\text{Ratio} = 0.00086146$	<p>Status: PASS Ratio: 0.030</p> <p>Status: PASS Ratio: 0.000</p>
	<p>Flexural Strength (ACI 318-19, LRFD)</p> <p>S_m - Section modulus</p> $S_m = \frac{b D^2}{6}$ $S_m = \frac{(48 \text{ in}) \times (48 \text{ in})^2}{6}$ $S_m = 18432 \text{ in}^3$	

<p>14.5.2.1b</p>	<p>$\lambda = 1$ - Concrete modification factor (Normal concrete), Allowable flexural strength: M_n shall be the lesser of: $\phi M_{n,1}$</p> $\phi M_{n,1} = \phi \times 5 \times \lambda \times \sqrt{f'_c} \times S_m$ $\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{2.5 \text{ksi}} \times 18432.001 \text{in}^3$ $\phi M_{n,1} = 249.600 \text{kipft}$ <p>$\phi M_{n,2}$</p> $\phi M_{n,2} = \phi \times 0.85 \times f'_c \times S_m$ $\phi M_{n,2} = (0.65) \times 0.85 \times (2.5 \text{ksi}) \times (18432 \text{in}^3)$ $\phi M_{n,2} = 2121.6 \text{kipft}$ <p>Therefore, ϕM_n - Allowable flexural strength,</p> $\phi M_n = \text{MIN}[\phi M_{n,1}, \phi M_{n,2}]$ $\phi M_n = \text{MIN}[(249.6 \text{kipft}), (2121.6 \text{kipft})]$ $\phi M_n = 249.6 \text{kipft}$ <p>Considering x-direction: $M_{max} = 7.4192 \text{kipft}$ - Maximum moment in the x-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{M_{max}}{\phi M_n}$ $\text{Ratio} = \frac{(7.4192 \text{kipft})}{(249.6 \text{kipft})}$ $\text{Ratio} = 0.029724$	<p>Status: PASS Ratio: 0.030</p>
	<p>Considering z-direction: $M_{max} = 0.19864 \text{kipft}$ - Maximum moment in the z-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{M_{max}}{\phi M_n}$ $\text{Ratio} = \frac{(0.19864 \text{kipft})}{(249.6 \text{kipft})}$ $\text{Ratio} = 0.00079584$	<p>Status: PASS Ratio: 0.000</p>

REFERENCES	CALCULATIONS	RESULTS																										
	<p>SkyCiv Foundation Design Pile Foundation</p> <p>Design Information : Design code : IBC 2021 (International Building Code) Unit System : Imperial</p>																											
	<p>Pile Input</p>  <p>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 resting surface $h_e = 0$ ft - Length of pile above the ground</p> <p>Tabulation of Soil Parameters</p> <table border="1" data-bbox="416 1102 1193 1193"> <thead> <tr> <th>Layer</th> <th>Label</th> <th>Allowable Bearing Pressure (q_n) (psf)</th> <th>Allowable Lateral Pressure (R) (psf/ft)</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>Sand, silty sand, clayey sand, silty gravel & clayey gravel</td> <td>2000.000</td> <td>150.000</td> </tr> </tbody> </table> <p>Tabulation of Loads</p> <table border="1" data-bbox="676 1288 935 1458"> <thead> <tr> <th>Load Component</th> <th>ASD</th> <th>LRFD</th> </tr> </thead> <tbody> <tr> <td>P (kip)</td> <td>7.968</td> <td>12.628</td> </tr> <tr> <td>V_x (kip)</td> <td>-0.224</td> <td>-0.376</td> </tr> <tr> <td>V_z (kip)</td> <td>0.162</td> <td>0.261</td> </tr> <tr> <td>M_x (kipft)</td> <td>0.666</td> <td>1.083</td> </tr> <tr> <td>M_z (kipft)</td> <td>7.166</td> <td>12.766</td> </tr> </tbody> </table> <p>Material Properties $f'_{ck} = 2.5$ ksi - Concrete strength,</p>	Layer	Label	Allowable Bearing Pressure (q_n) (psf)	Allowable Lateral Pressure (R) (psf/ft)	1	Sand, silty sand, clayey sand, silty gravel & clayey gravel	2000.000	150.000	Load Component	ASD	LRFD	P (kip)	7.968	12.628	V_x (kip)	-0.224	-0.376	V_z (kip)	0.162	0.261	M_x (kipft)	0.666	1.083	M_z (kipft)	7.166	12.766	
Layer	Label	Allowable Bearing Pressure (q_n) (psf)	Allowable Lateral Pressure (R) (psf/ft)																									
1	Sand, silty sand, clayey sand, silty gravel & clayey gravel	2000.000	150.000																									
Load Component	ASD	LRFD																										
P (kip)	7.968	12.628																										
V_x (kip)	-0.224	-0.376																										
V_z (kip)	0.162	0.261																										
M_x (kipft)	0.666	1.083																										
M_z (kipft)	7.166	12.766																										
	<p>Required depth to resist lateral loads (ASD) H - Point of application of the lateral load</p> $H = h_1 + h_2 + h_e$ $H = (0 \text{ ft}) + (0 \text{ ft}) + (0 \text{ ft})$ $H = 0 \text{ ft}$ <p>Considering x-direction: H_o - Lateral force per length of pile,</p> $H_o = \frac{V_x}{1.57 D}$ $H_o = \frac{(-0.224 \text{ kip})}{1.57 \times (48 \text{ in})}$ $H_o = -0.035669 \text{ kip/ft}$ <p>M_o - Moment per length of pile,</p> $M_o = \frac{M_z + (V_x H)}{1.57 D}$																											

$$M_o = \frac{(7.166 \text{ kipft}) + ((-0.224 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 1.1411 \text{ kipft/ft}$$

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:

$L_{e,x} = 4.3443 \text{ ft}$ - Required depth in x-direction,

Considering z-direction:

H_o - Lateral force per length of pile,

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

$$H_o = \frac{(0.162 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = 0.025796 \text{ kip/ft}$$

M_o - Moment per length of pile,

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

$$M_o = \frac{(0.666 \text{ kipft}) + ((0.162 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 0.10605 \text{ kipft/ft}$$

Required depth of embedment in earth:

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

Solving the cubic equation:

$L_{e,z} = 2.2914 \text{ ft}$ - Required depth in z-direction,

Minimum embedded depth required:

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

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

$$L_{e,req} = \text{MAX}[(4.3443 \text{ ft}), (2.2914 \text{ ft})]$$

$$L_{e,req} = 4.344 \text{ ft}$$

L_e - Actual embedded length of pile,

$$L_e = L - h_c - h_2$$

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

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

Ratio - Embedded depth

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

$$\text{Ratio} = \frac{(4.344 \text{ ft})}{(4.5 \text{ ft})}$$

$$\text{Ratio} = 0.96533$$

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

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

$$q = \frac{(7.968 \text{ kip})}{(16 \text{ ft}^2)}$$

$$q = 0.498 \text{ kip/ft}^2$$

$$q = 0.498 \text{ kip/ft}$$

Check bearing capacity ratio:

Ratio - Capacity

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

$$Ratio = \frac{(0.498 \text{ kip/ft}^2)}{(2000 \text{ psf})}$$

$$Ratio = 0.249$$

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

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:

$H_o = -0.035669 \text{ kip/ft}$ - Lateral force per length of pile,

$M_o = 1.1411 \text{ kipft/ft}$ - Overturning moment per length of pile,

a - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (1.1411 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (-0.035669 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (1.1411 \text{ kipft/ft})) + (4 \times (-0.035669 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.0322 \text{ ft}$$

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

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

$$p = \frac{0.75 \times [(4 \times (1.1411 \text{ kipft/ft})) + (3 \times (-0.035669 \text{ kip/ft}) \times (4.5 \text{ ft}))]^2}{(4.5 \text{ ft})^2 \times [(3 \times (1.1411 \text{ kipft/ft})) + (2 \times (-0.035669 \text{ kip/ft}) \times (4.5 \text{ ft}))]}$$

$$p = 0.19901 \text{ kip/ft}^2$$

s - Earth pressure against the pile at distance L_e ,

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

$$s = \frac{6 \times [(2 \times (1.1411 \text{ kipft/ft})) + ((-0.035669 \text{ kip/ft}) \times (4.5 \text{ ft}))]}{(4.5 \text{ ft})^2}$$

$$s = 0.62864 \text{ kip/ft}^2$$

Check lateral soil pressure capacity:

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

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

$$p_a = (150 \text{ psf/ft}) \times \frac{(3.0322 \text{ ft})}{2}$$

$$p_a = 0.22741 \text{ kip/ft}^2$$

Ratio - Lateral soil capacity

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

$$Ratio = \frac{(0.19901 \text{ kip/ft}^2)}{(0.22741 \text{ kip/ft}^2)}$$

$$Ratio = 0.87512$$

p_a - Allowable lateral soil pressure at depth L_e ,

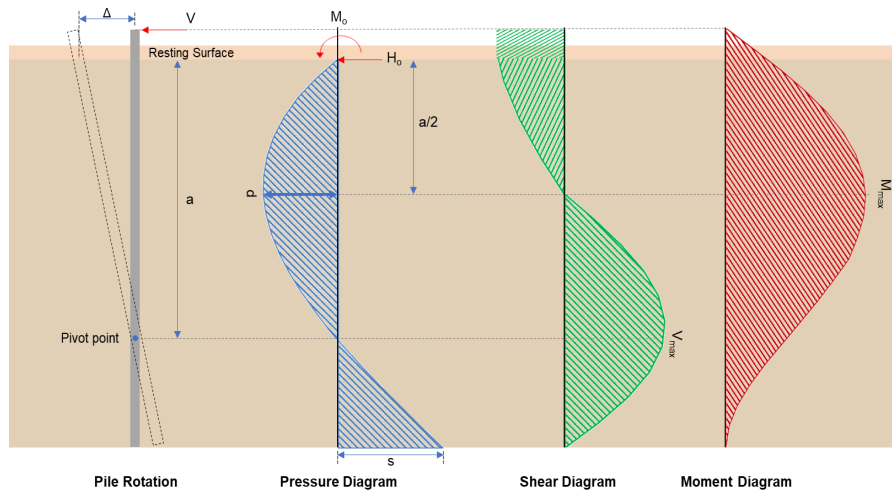
Status: **PASS**
Ratio: **0.880**

	$p_s = R L_e$ $p_s = (150 \text{ psf/ft}) \times (4.5 \text{ ft})$ $p_s = 0.675 \text{ kip/ft}^2$ <p>Ratio - Lateral soil capacity</p> $\text{Ratio} = \frac{s}{p_s}$ $\text{Ratio} = \frac{(0.62864 \text{ kip/ft}^2)}{(0.675 \text{ kip/ft}^2)}$ $\text{Ratio} = 0.93132$	<p>Status: PASS Ratio: 0.930</p>
	<p>Considering z-direction:</p> <p>$H_o = 0.025796 \text{ kip/ft}$ - Lateral force per length of pile, $M_o = 0.10605 \text{ kipft/ft}$ - Overturning moment per length of pile, a - Distance from resting surface to pivot point,</p> $a = \frac{(4 M_o L_e) + (3 H_o L_e^2)}{(6 M_o) + (4 H_o L_e)}$ $a = \frac{(4 \times (0.10605 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (0.025796 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (0.10605 \text{ kipft/ft})) + (4 \times (0.025796 \text{ kip/ft}) \times (4.5 \text{ ft}))}$ $a = 3.1582 \text{ ft}$ <p>p - Earth pressure against the pile at distance $a/2$ from resting surface,</p> $p = \frac{0.75 [(4 M_o) + (3 H_o L_e)]^2}{L_e^2 [(3 M_o) + (2 H_o L_e)]}$ $p = \frac{0.75 \times [(4 \times (0.10605 \text{ kipft/ft})) + (3 \times (0.025796 \text{ kip/ft}) \times (4.5 \text{ ft}))]^2}{(4.5 \text{ ft})^2 \times [(3 \times (0.10605 \text{ kipft/ft})) + (2 \times (0.025796 \text{ kip/ft}) \times (4.5 \text{ ft}))]}$ $p = 0.040157 \text{ kip/ft}^2$ <p>s - Earth pressure against the pile at distance L_e,</p> $s = \frac{6 [(2 M_o) + (H_o L_e)]}{L_e^2}$ $s = \frac{6 \times [(2 \times (0.10605 \text{ kipft/ft})) + ((0.025796 \text{ kip/ft}) \times (4.5 \text{ ft}))]}{(4.5 \text{ ft})^2}$ $s = 0.09724 \text{ kip/ft}^2$ <p>Check lateral soil pressure capacity:</p> <p>p_a - Allowable lateral soil pressure at depth $a/2$,</p> $p_a = R \frac{a}{2}$ $p_a = (150 \text{ psf/ft}) \times \frac{(3.1582 \text{ ft})}{2}$ $p_a = 0.23687 \text{ kip/ft}^2$ <p>Ratio - Lateral soil capacity</p> $\text{Ratio} = \frac{p}{p_a}$ $\text{Ratio} = \frac{(0.040157 \text{ kip/ft}^2)}{(0.23687 \text{ kip/ft}^2)}$ $\text{Ratio} = 0.16954$ <p>p_s - Allowable lateral soil pressure at depth L_e,</p> $p_s = R L_e$ $p_s = (150 \text{ psf/ft}) \times (4.5 \text{ ft})$ $p_s = 0.675 \text{ kip/ft}^2$ <p>Ratio - Lateral soil capacity</p> $\text{Ratio} = \frac{s}{p_s}$	<p>Status: PASS Ratio: 0.170</p>

$$Ratio = \frac{(0.09724 \text{ kip/ft}^2)}{(0.675 \text{ kip/ft}^2)}$$

$$Ratio = 0.14406$$

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



Shear force and Bending moment (x-direction, LRF)

H_o - Lateral force per length of pile,

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

$$H_o = \frac{(-0.376 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = -0.059873 \text{ kip/ft}$$

M_o - Moment per length of pile,

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

$$M_o = \frac{(12.766 \text{ kipft}) + ((-0.376 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 2.0328 \text{ kipft/ft}$$

E - Distance from lateral load to resisting surface,

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

$$E = \frac{(2.0328 \text{ kipft/ft})}{(-0.059873 \text{ kip/ft})}$$

$$E = 33.952 \text{ ft}$$

a - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (2.0328 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (-0.059873 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (2.0328 \text{ kipft/ft})) + (4 \times (-0.059873 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.0304 \text{ ft}$$

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

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

$$V_{max} = ((-0.059873 \text{ kip/ft}) \times (48 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (33.952 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.0304 \text{ ft})}{(4.5 \text{ ft})} \right)^2 \right] + \left[4 \times \left(\frac{3 \times (33.952 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.0304 \text{ ft})}{(4.5 \text{ ft})} \right)^3 \right] \right]$$

$$V_{max} = 3.3642 \text{ kip}$$

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

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

$$M_{max} = ((-0.059873 \text{ kip/ft}) \times (48 \text{ in}) \times (4.5 \text{ ft})) \times \left[\left(\frac{(33.952 \text{ ft})}{(4.5 \text{ ft})} + \frac{(3.0304 \text{ ft})}{2 \times (4.5 \text{ ft})} \right) - \left[\left(\frac{4 \times (33.952 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.0304 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^3 + \left[\left(\frac{3 \times (33.952 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.0304 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^4 \right] \right] \right]$$

$$M_{max} = 7.4703 \text{ kipft}$$

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

H_o - Lateral force per length of pile,

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

$$H_o = \frac{(0.261 \text{ kip})}{1.57 \times (48 \text{ in})}$$

$$H_o = 0.041561 \text{ kip/ft}$$

M_o - Moment per length of pile,

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

$$M_o = \frac{(1.083 \text{ kipft}) + ((0.261 \text{ kip}) \times (0 \text{ ft}))}{1.57 \times (48 \text{ in})}$$

$$M_o = 0.17245 \text{ kipft/ft}$$

E - Distance from lateral load to resisting surface,

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

$$E = \frac{(0.17245 \text{ kipft/ft})}{(0.041561 \text{ kip/ft})}$$

$$E = 4.1494 \text{ ft}$$

a - Distance from resting surface to pivot point,

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

$$a = \frac{(4 \times (0.17245 \text{ kipft/ft}) \times (4.5 \text{ ft})) + (3 \times (0.041561 \text{ kip/ft}) \times (4.5 \text{ ft})^2)}{(6 \times (0.17245 \text{ kipft/ft})) + (4 \times (0.041561 \text{ kip/ft}) \times (4.5 \text{ ft}))}$$

$$a = 3.1574 \text{ ft}$$

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

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

$$V_{max} = ((0.041561 \text{ kip/ft}) \times (48 \text{ in})) \times \left[1 - \left[3 \times \left(\frac{4 \times (4.1494 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.1574 \text{ ft})}{(4.5 \text{ ft})} \right)^2 + 4 \times \left(\frac{3 \times (4.1494 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.1574 \text{ ft})}{(4.5 \text{ ft})} \right)^3 \right] \right]$$

$$V_{max} = 0.38113 \text{ kip}$$

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

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

$$M_{max} = ((0.041561 \text{ kip/ft}) \times (48 \text{ in}) \times (4.5 \text{ ft})) \times \left[\left(\frac{(4.1494 \text{ ft})}{(4.5 \text{ ft})} + \frac{(3.1574 \text{ ft})}{2 \times (4.5 \text{ ft})} \right) - \left[\left(\frac{4 \times (4.1494 \text{ ft})}{(4.5 \text{ ft})} + 3 \right) \times \left(\frac{(3.1574 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^3 + \left[\left(\frac{3 \times (4.1494 \text{ ft})}{(4.5 \text{ ft})} + 2 \right) \times \left(\frac{(3.1574 \text{ ft})}{2 \times (4.5 \text{ ft})} \right)^4 \right] \right] \right]$$

$$M_{max} = 0.79023 \text{ kipft}$$

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,
 $\alpha = 0.8$ - Alpha factor for axial strength,
 $A_g = 2304 \text{ in}^2$ - Gross area of concrete,

Table 22.4.2.1

Longitudinal reinforcement:

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

22.4.2.2, 10.6.1.1

$A_{st,required}$

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

$$A_{st,required} = \text{Min} \left[\frac{\frac{(12.628 \text{ kip})}{(0.65)(0.8)} - (0.85 \times (2.5 \text{ ksi}) \times (2304 \text{ in}^2))}{(60 \text{ ksi}) - (0.85 \times (2.5 \text{ ksi}))}, (0.08 \times (2304 \text{ in}^2)) \right]$$

$$A_{st,required} = -84.177 \text{ in}^2$$

A_{min} - Governing minimum reinforcement area,

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

$$A_{min} = \text{Max} [(-84.177 \text{ in}^2), (0.0018 \times (2304 \text{ in}^2))]$$

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

n_{rebar} - Required number of reinforcement,

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

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

$$n_{rebar} = 14$$

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

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

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

$$\text{Ratio} = 0.96556$$

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

25.2.3 s_{rebar} - Minimum spacing of reinforcement,

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

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

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

Ties:

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

25.7.2.1 s_{ties} - Maximum spacing of ties,

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

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

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

Summary:

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

Ties: #3(0.375 in) - 10 in

Axial Compression Strength (ACI 318-19, LRFD)

22.4.2.2

ϕP_N - Allowable axial compressive strength

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

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

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

Ratio - Capacity

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

$$\text{Ratio} = \frac{(12.628 \text{ kip})}{(2675.2 \text{ kip})}$$

$$\text{Ratio} = 0.0047204$$

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

Shear Strength (ACI 318-19, LRFD)

Parameters:

22.5.2.2

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

$$d = 0.80 D$$

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

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

22.5.5.1.3

λ_s - size effect modification factor

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

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

$$\lambda_s = 0.64282$$

22.5.5.1.1

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

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

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

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

22.5.5.1.1(a)

The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5 \text{ ksi} \rightarrow 2500 \text{ psi}$, $P = 12.628 \text{ kip} \rightarrow 12628 \text{ lbf}$,
 $V_{c,a}$ - Shear strength of concrete (a)

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

$$V_{c,a} = \left[2 \times (0.64282) \times \sqrt{(2500 \text{ psi})} + \frac{(12628 \text{ lbf})}{6 \times (2304 \text{ in}^2)} \right] \times (48 \text{ in}) \times (38.4 \text{ in})$$

$$V_{c,a} = 120.17 \text{ kip}$$

22.5.5.1.2

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

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

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

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

V_c - Governing shear strength of concrete

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

$$V_c = \text{Min}[(296.21 \text{ kip}), (120.17 \text{ kip}), (348.89 \text{ kip})]$$

$$V_c = 120.17 \text{ kip}$$

<p>22.5.1.2</p>	<p>The following variables were converted to be consistent with empirical formula $f'_{ck} = 2.5 \text{ ksi} \rightarrow 2500 \text{ psi}$.</p> <p>$V_{s,a}$ - Shear strength of steel (a)</p> $V_{s,a} = 8 \sqrt{f'_{ck}} b_w d$ $V_{s,a} = 8 \times \sqrt{(2500 \text{ psi})} \times (48 \text{ in}) \times (38.4 \text{ in})$ $V_{s,a} = 737.28 \text{ kip}$ <p>A_v - Ties rebar area,</p> $A_v = \frac{\pi d_{ties}^2}{4}$ $A_v = \frac{\pi \times (0.375 \text{ in})^2}{4}$ $A_v = 0.11045 \text{ in}^2$ <p>22.5.8.5.3 $V_{s,b}$ - Shear strength of steel (b)</p> $V_{s,b} = \frac{2 A_v f_{yt} d}{s_{ties}}$ $V_{s,b} = \frac{2 \times (0.11045 \text{ in}^2) \times (60 \text{ ksi}) \times (38.4 \text{ in})}{(10 \text{ in})}$ $V_{s,b} = 50.894 \text{ kip}$ <p>V_s - Governing shear strength of steel</p> $V_s = \text{MIN}[V_{s,a}, V_{s,b}]$ $V_s = \text{MIN}[(737.28 \text{ kip}), (50.894 \text{ kip})]$ $V_s = 50.894 \text{ kip}$ <p>22.5.1.1 ϕV_n - Allowable shear strength</p> $\phi V_n = \phi (V_c + V_s)$ $\phi V_n = (0.65) \times ((120.17 \text{ kip}) + (50.894 \text{ kip}))$ $\phi V_n = 111.19 \text{ kip}$ <p>Considering x-direction:</p> <p>$V_{max} = 3.3642 \text{ kip}$ - Maximum shear force in the x-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{V_{max}}{\phi V_n}$ $\text{Ratio} = \frac{(3.3642 \text{ kip})}{(111.19 \text{ kip})}$ $\text{Ratio} = 0.030256$ <p>Considering z-direction:</p> <p>$V_{max} = 0.38113 \text{ kip}$ - Maximum shear force in the z-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{V_{max}}{\phi V_n}$ $\text{Ratio} = \frac{(0.38113 \text{ kip})}{(111.19 \text{ kip})}$ $\text{Ratio} = 0.0034277$	<p>Status: PASS Ratio: 0.030</p> <p>Status: PASS Ratio: 0.000</p>
	<p>Flexural Strength (ACI 318-19, LRFD)</p> <p>S_m - Section modulus</p> $S_m = \frac{b D^2}{6}$ $S_m = \frac{(48 \text{ in}) \times (48 \text{ in})^2}{6}$ $S_m = 18432 \text{ in}^3$	

<p>14.5.2.1b</p>	<p>$\lambda = 1$ - Concrete modification factor (Normal concrete), Allowable flexural strength: M_n shall be the lesser of: $\phi M_{n,1}$</p> $\phi M_{n,1} = \phi \times 5 \times \lambda \times \sqrt{f'_c} \times S_m$ $\phi M_{n,1} = 0.65 \times 5 \times 1 \times \sqrt{2.5 \text{ksi}} \times 18432.001 \text{in}^3$ $\phi M_{n,1} = 249.600 \text{kipft}$ <p>$\phi M_{n,2}$</p> $\phi M_{n,2} = \phi \times 0.85 \times f'_c \times S_m$ $\phi M_{n,2} = (0.65) \times 0.85 \times (2.5 \text{ksi}) \times (18432 \text{in}^3)$ $\phi M_{n,2} = 2121.6 \text{kipft}$ <p>Therefore, ϕM_n - Allowable flexural strength,</p> $\phi M_n = \text{MIN}[\phi M_{n,1}, \phi M_{n,2}]$ $\phi M_n = \text{MIN}[(249.6 \text{kipft}), (2121.6 \text{kipft})]$ $\phi M_n = 249.6 \text{kipft}$ <p>Considering x-direction: $M_{max} = 7.4703 \text{kipft}$ - Maximum moment in the x-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{M_{max}}{\phi M_n}$ $\text{Ratio} = \frac{(7.4703 \text{kipft})}{(249.6 \text{kipft})}$ $\text{Ratio} = 0.02993$	<p>Status: PASS Ratio: 0.030</p>
	<p>Considering z-direction: $M_{max} = 0.79023 \text{kipft}$ - Maximum moment in the z-direction, Ratio - Capacity</p> $\text{Ratio} = \frac{M_{max}}{\phi M_n}$ $\text{Ratio} = \frac{(0.79023 \text{kipft})}{(249.6 \text{kipft})}$ $\text{Ratio} = 0.003166$	<p>Status: PASS Ratio: 0.000</p>