Benchmarking Traditional PTI Design Against Advanced Finite Element Method on a Ribbed 40x70 Slab-on-Ground and Design of a Wafflemat Using FEM Approach

Florian Aalami

PT-Structures

Anna Olveda

WAFFLEMAT™
A SMARTSENSE STRUCTURAL SYSTEM

pti POST-TENSIONING CONVENTION
April 30 - May 3, 2023 | Miami, FL, USA

ENGINEERING

RCEP

REGISTERED CONTINUING EDUCATION PROGRAM

"The Post-Tensioning Institute has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP."

Copyright Materials

Learning Objectives

At the end of this presentation, you will be able to…

- Assess differences between traditional PTI and FEM design methods for slab-on-ground foundations
- Understand FEM design approach
- Evaluate a Wafflemat design
- Confidently apply FEM-based design method to non-traditional slabs

Demand for cost-effective and well performing foundations on expansive soils is very high, however, the existing PTI method of design is very restrictive and does not allow for the implementation of innovative foundation solutions.

Existing Design Methodology Extremely Limited

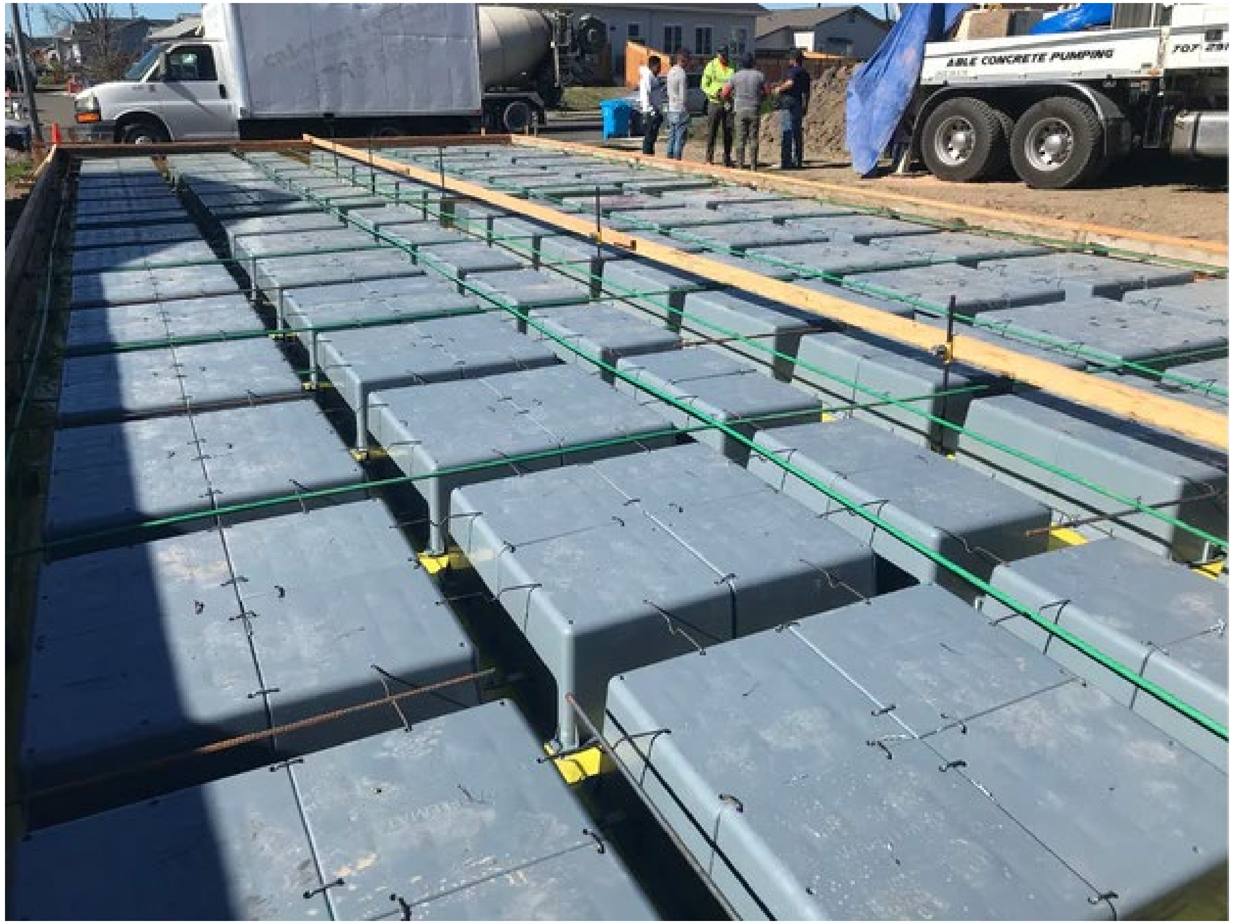
- Prescriptive and not performance-based
- Limited to rectangular shapes
- Overly conservative – worst-case rectangle governs
- Maximum allowable difference in beam depths not greater than 1.2
- Moment calculation discontinuity for Center Lift $e_m > 5$ ft
- Is not set up to analyze and check any other configuration…

PTISlab 3.5 Software Limitations

The PTI design method has been implemented by many companies using their own spreadsheets. For our comparison, we chose PTISlab 3.5 as one of the commonly used and commercially available implementations of the PTI design method.

- Can only model rectangular slabs
- Cannot model beams spaced closer than 6 ft apart
- No flexibility in tendon profiling or placement
- No flexibility in detailed load modeling

An alternative design approach needs to be accepted so that new, innovative solutions can be evaluated and approved.



We are not the first to recognize the need for a more flexible and improved design methodology.

PTI Journal *Industry News*

SLAB-ON-GROUND ALTERNATIVE DESIGN (SOGAD): A BLEND OF ART AND SCIENCE

By

JACK W. GRAVES JR., BRIAN M. JUEDES, AND RYNE C. STOKER

POST-TENSIONING INSTITUTE ®

Authorized reprint from: July 2012 issue of the PTI Journal

Leveraging Capabilities of Advanced Finite Element Analysis

A finite element analysis may be performed in lieu of the specific structural design formulas and procedures for slabs on expansive soils presented in this chapter. The finite element model should consider the interaction of the concrete foundation and the soil (see 1.2). The expansive characteristics of the soil should be established using the criteria specified in Chapter 3.

PTI Section 6.1.13

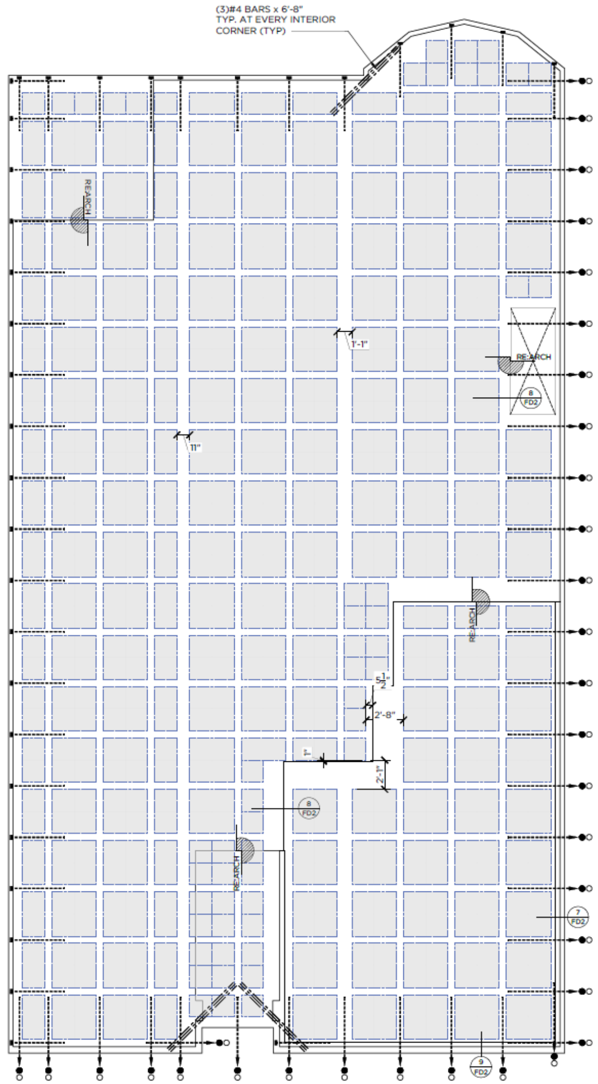
Agenda

- Detailed comparison of PTISlab 3.5 vs FEM design for ribbed 40 x 70 slab
- Parametric study of different soil conditions
- Proposed design method using FEM
- Use of new design method to check and design 40 x 70 Wafflemat slab
- Concluding remarks

Outline of Design Procedure using GTK PTISlab Software

- Soil bearing pressure check
  - Based on Load/Area
- Center lift design checks
  - Bending stress
  - Stiffness
  - Shear stress
  - Cracked moment capacity
- Edge lift design checks
  - Bending stress
  - Stiffness
  - Shear stress
  - Cracked moment capacity

Project: 40x70 Foundation



Short Direction

Long Direction

PVR 4.5” with a 2ft embedment depth

Select Soil Parameters:	Edge Lift	Center Lift
Edge Moisture Distance, ft (em)	3.5	6.7
Differential Soil Movement, inches (ym)	2.1	1.5

PTISlab 3.5 Input Data: Ribbed Foundation Analysis Model

Slab Dimensions : 40.00 FT x 70.00 FT x 4.00 Inches

Material Properties

Concrete Strength, f'_c :	4,000 PSI
Tendon Strength, F_{pu} :	270 KSI
Tendon Diameter :	1 / 2 Inch

Material Quantities

Concrete Volume :	69.8 Cubic Yards
Prestressing Tendon :	1,392 Linear Feet
Number of End Anchorages :	52

In the LONG direction ...

	Type I Beam	Type II Beam
Quantity of Beams :	2	3
Depth of Beams :	28.0 Inches	24.0 Inches
Width of Beams :	10.0 Inches	10.0 Inches
Tendons per Beam :	1	1
Beam Tendon Centroid :	2.25 Inches	2.25 Inches

Beam Spacing : 10.00 Feet O.C.

Number of Slab Tendons :	5
Slab Tendon Spacing :	9.00 Feet O.C.
Slab Tendon Centroid :	2.25 Inches from top of slab

In the SHORT direction ...

	Type I Beam	Type II Beam
Quantity of Beams :	2	6
Depth of Beams :	28.0 Inches	24.0 Inches
Width of Beams :	10.0 Inches	10.0 Inches
Tendons per Beam :	1	1
Beam Tendon Centroid :	2.25 Inches	2.25 Inches

Beam Spacing : 10.00 Feet O.C.

Number of Slab Tendons :	8
Slab Tendon Spacing :	9.43 Feet O.C.
Slab Tendon Centroid :	2.25 Inches from top of slab

Soil Properties

Allowable Bearing Pressure : 1,500.0 PSF

	Center Lift	Edge Lift
Edge Moisture Variation Distance, e_m :	6.70 Feet	3.50 Feet
Differential Soil Movement, y_m :	1.500 Inches	2.100 Inches

Load, Deflection and Subgrade Properties

Slab Loading

Uniform Superimposed Total Load :	40.00 PSF
Total Perimeter Load :	1,200.00 PLF

Stiffness Coefficients

Center Lift :	480
Edge Lift :	960

Prestress Calculation

Subgrade Friction calculated by method prescribed in PTI Manual

Prestress Loss : 15.0 KSI

Subgrade Friction Coefficient : 0.75

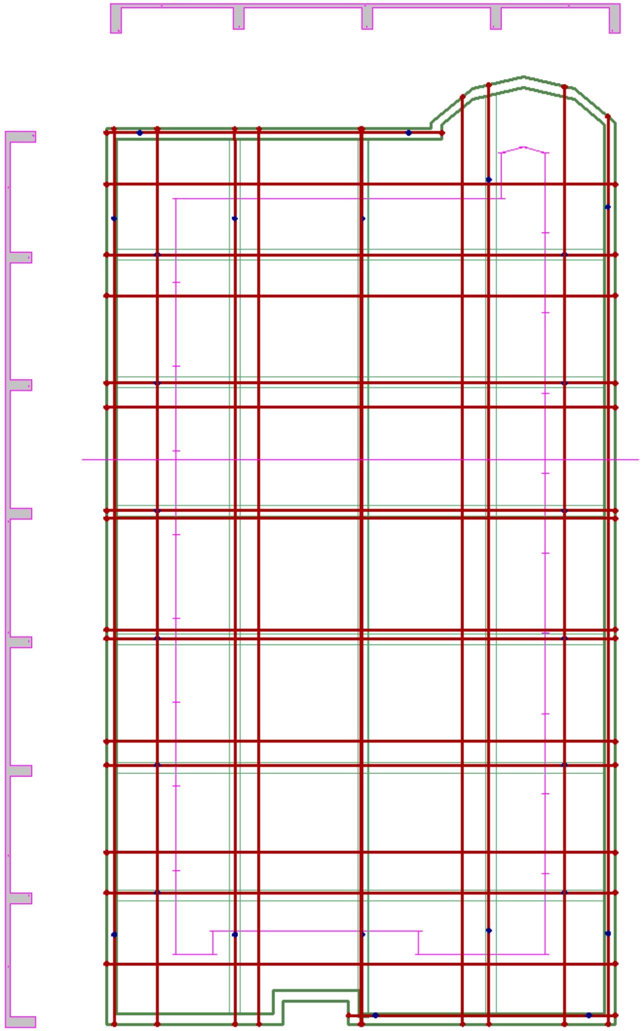
PTISlab 3.5 Analysis Parameters: Ribbed Foundation Analysis Model

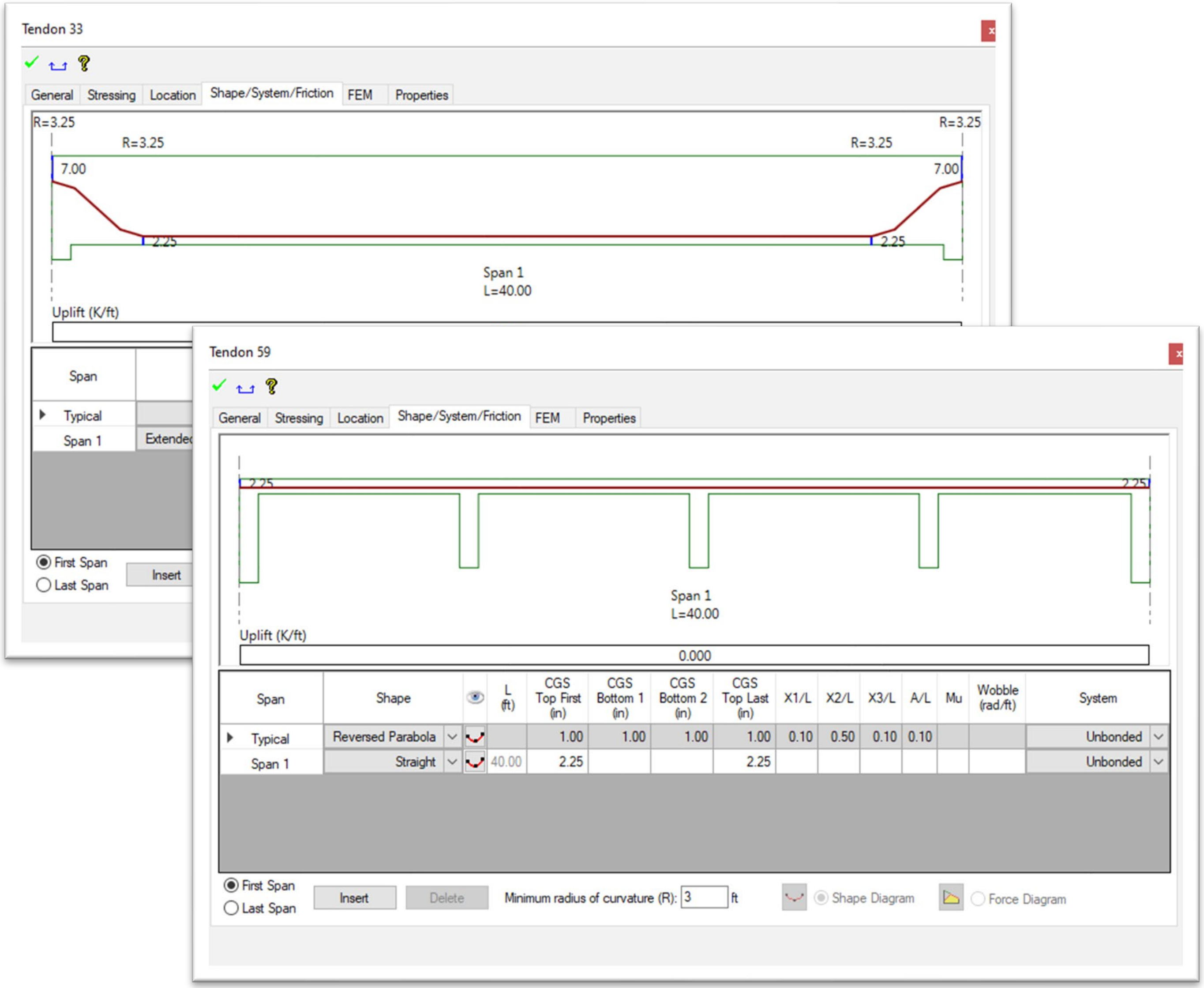
	Short Direction	Long Direction
Cross Sectional Area ($Inch^2$) :	5,053	3,010
Moment of Inertia ($Inch^4$) :	245,897	161,491
Section Modulus, Top ($Inch^3$) :	39,560	24,203
Section Modulus, Bottom ($Inch^3$) :	12,977	8,441
Center of Gravity of Concrete - from top (Inch) :	6.22	6.67
Center of Gravity of Prestressing Tendons - from top (Inch) :	12.58	12.90
Eccentricity of Prestress (Inch) :	-6.37	-6.23
Beta Distance (Feet) :	11.55	10.40
Equivalent Beam Depth (Inches) :	25.16	25.80

Note: All Calculations above and other reported values which depend on depths use the equivalent depths as shown above.

Jacking Force : 33.05 KIPS

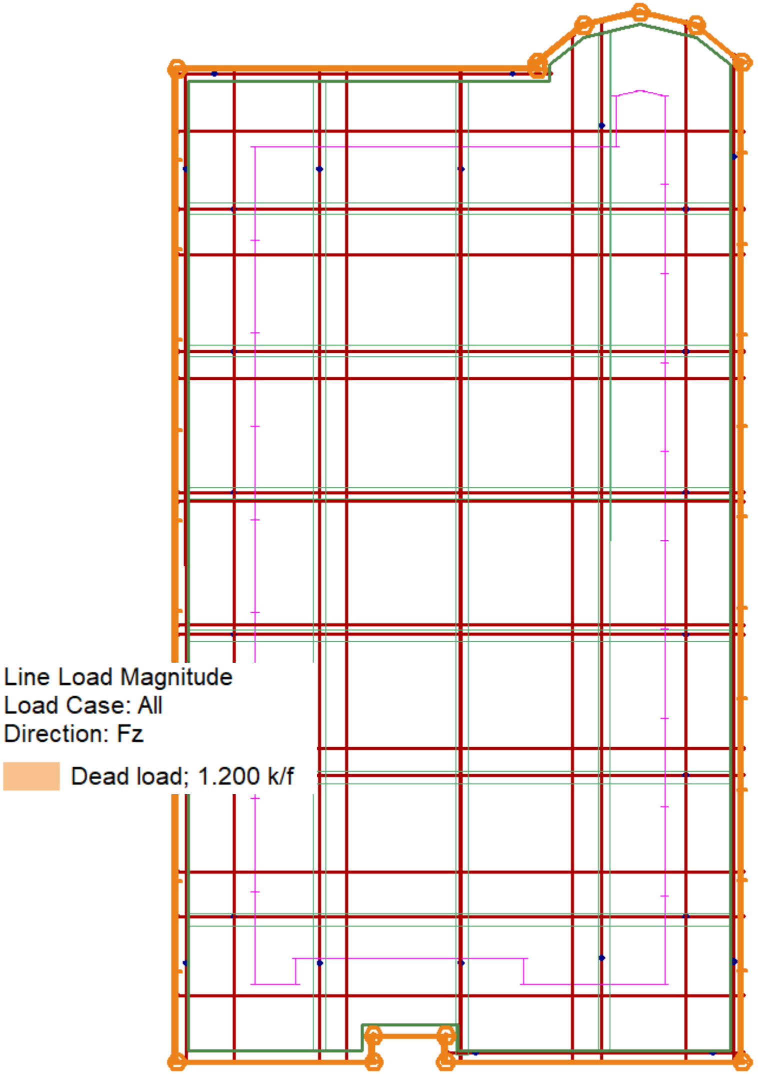
3D Finite Element Ribbed Foundation Analysis Model

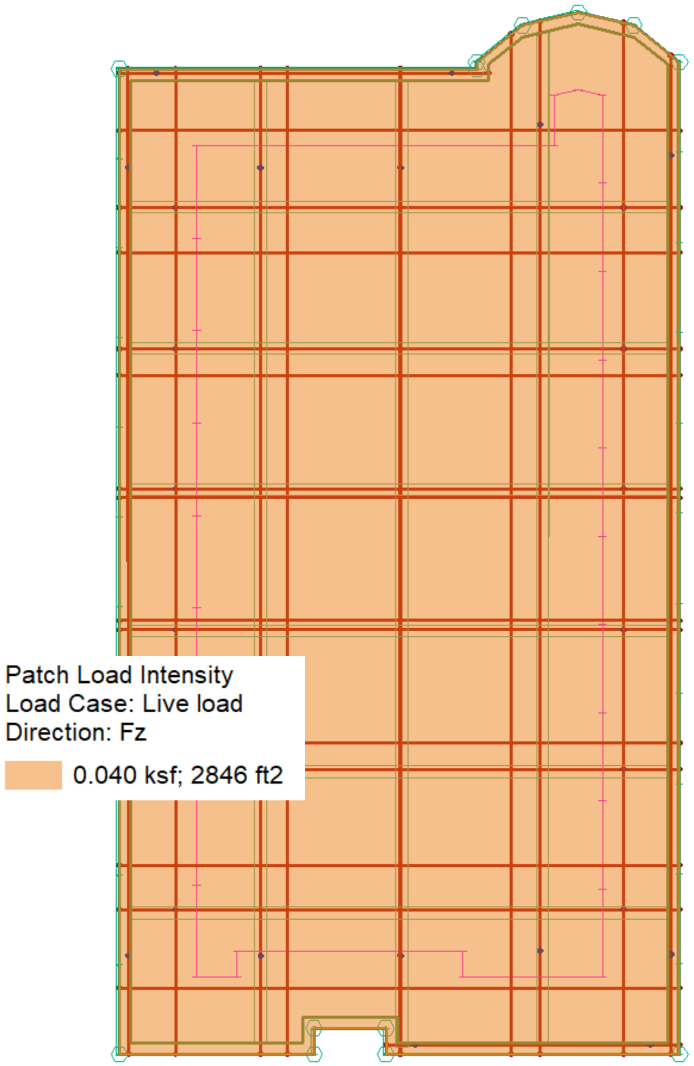


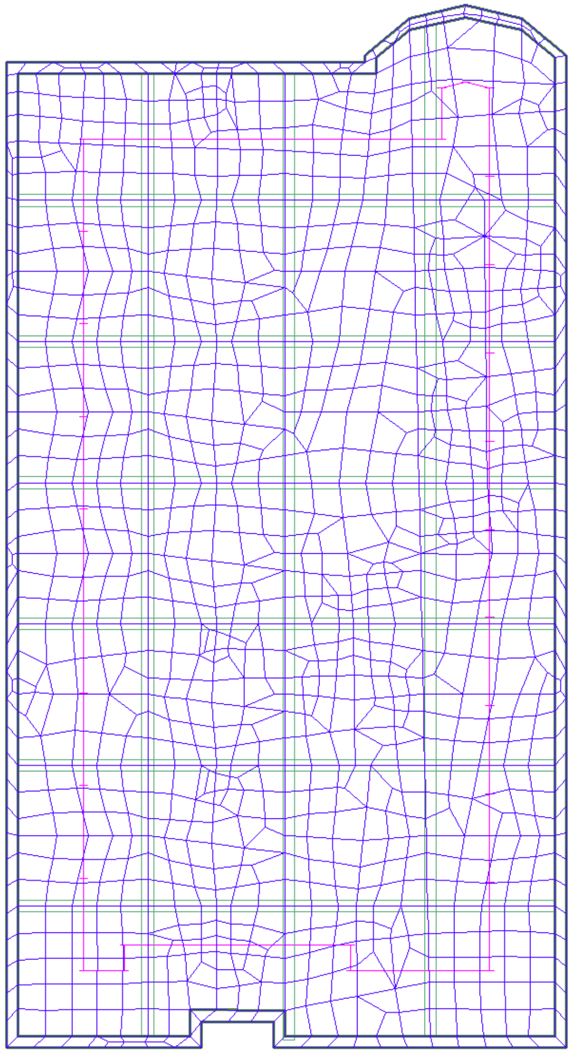


Span	Shape	L (ft)	CGS Top First (in)	CGS Bottom 1 (in)	CGS Bottom 2 (in)	CGS Top Last (in)	X1/L	X2/L	X3/L	A/L	Mu	Wobble (rad/ft)	System
Typical	Reversed Parabola		1.00	1.00	1.00	1.00	0.10	0.50	0.10	0.10			Unbonded
Span 1	Straight	40.00	2.25			2.25							Unbonded

3D Finite Element Ribbed Foundation Analysis Model







PTISlab - Soil Bearing Analysis

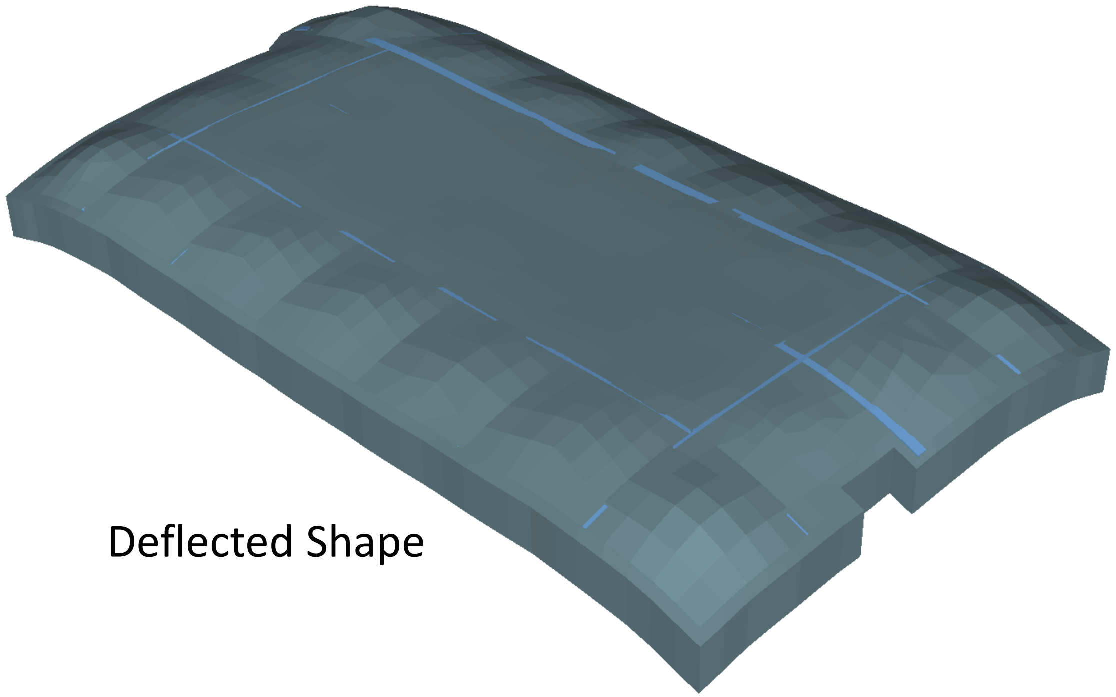
- Assumes uniform soil support
- Equally distributes all load to supporting soil
- Max pressure on soil 163 PSF << allowable 1,500 PSF

Soil Bearing Analysis

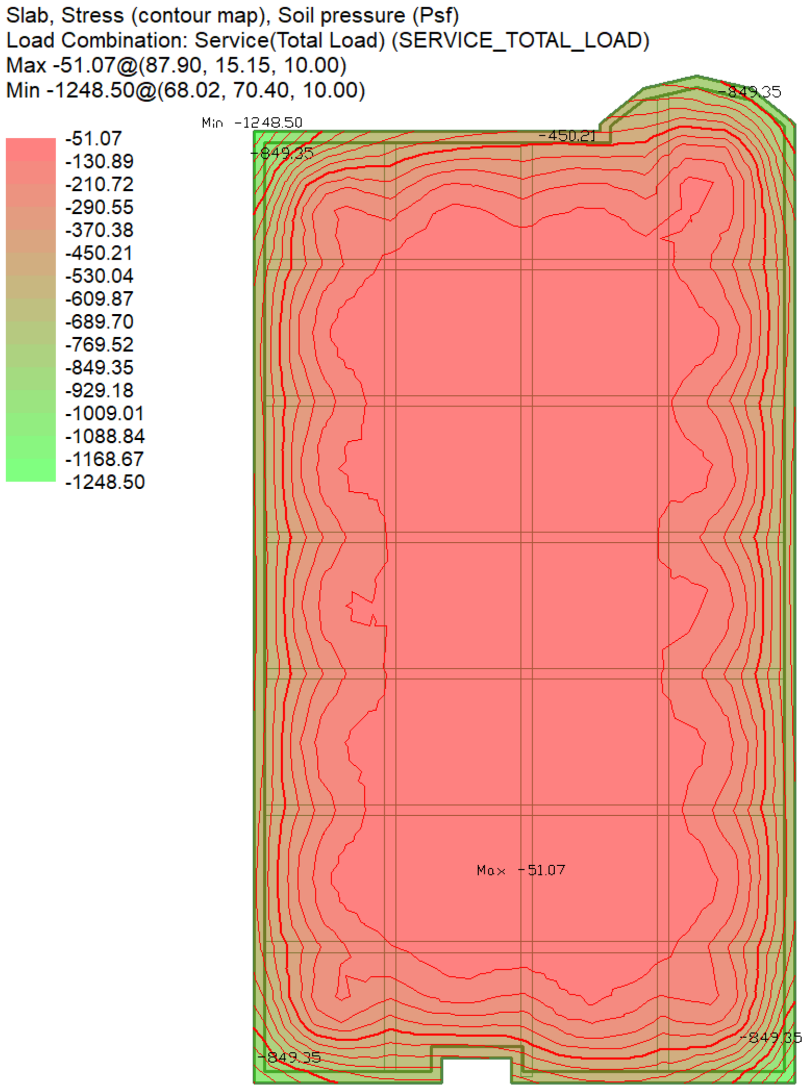
Total Applied Load	385,266	LB
Bearing Area	2,367	FT^2
Applied Pressure on Soil	163	PSF
Soil Pressure Safety Factor	0.00	

FEM - Soil Bearing Analysis

- Assumes uniform soil support
- Max pressure on soil 1,249 PSF < allowable 1,500 PSF



Deflected Shape



PTISlab – Effective Prestress Calculations

- Effective PT force/tendon at Beta distance
  - Short direction
    - **22.93 kips**
  - Long direction
    - **23.58 kips**
  - We assume the same valued in the FEM model

Prestress Summary

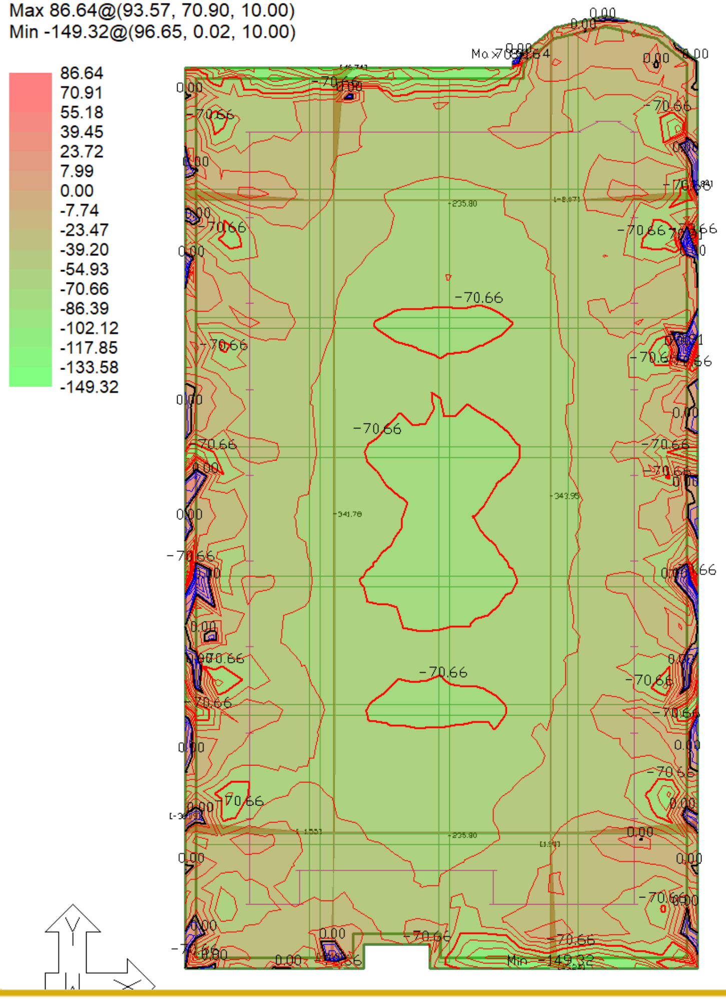
Subgrade Friction calculated by method prescribed in PTI Manual

	Short Direction	Long Direction
Number of Slab Tendons	8	5
Number of Beam Tendons	8	5
Spacing of Slab Tendons (Feet)	9.43	9.00
Center of Gravity of Concrete (from top of slab) (Inch)	6.22	6.67
Center of Gravity of Tendons (from top of slab) (Inch)	12.58	12.90
Eccentricity of Prestressing (Inch)	-6.37	-6.23
Minimum Effective Prestress Force (K)	323.5	163.7
Beta Distance Effective Prestress Force (K)	366.8	235.8
Minimum Effective Prestress (PSI)	64	54
Beta Distance Effective Prestress (PSI)	73	78

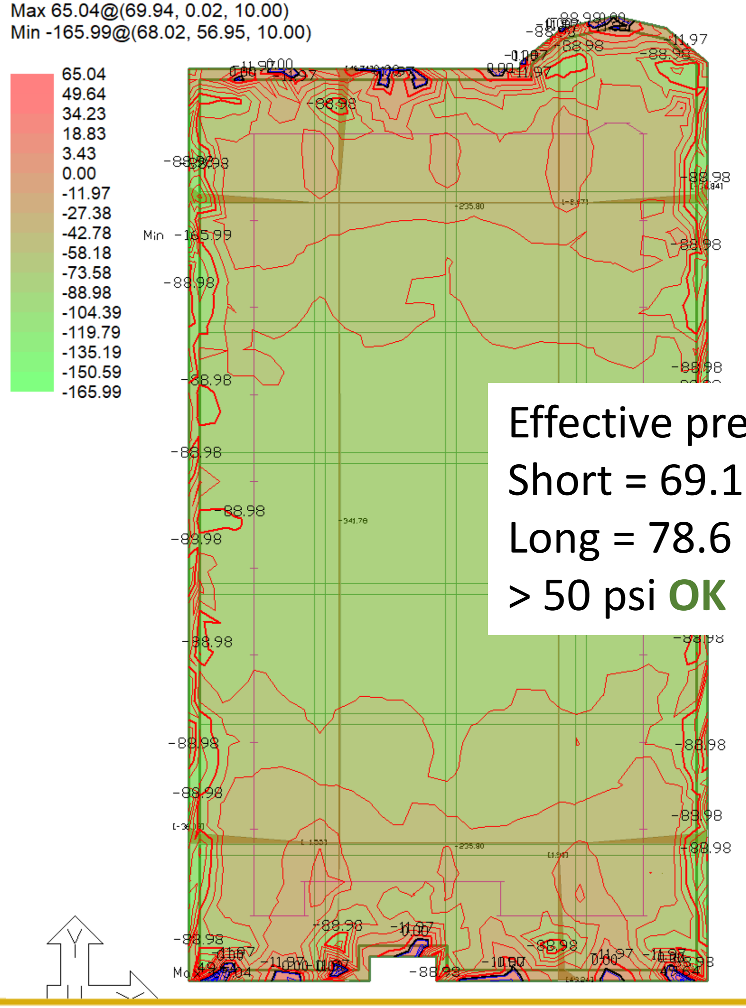
FEM – Effective Prestress Calculations

Exact same PT force applied to FEM model as in PTSlab.

Slab, Stress (contour map), Mid-depth along XX (Psi)
Load Combination: Effective PT (NO_CODE_CHECK)
Max 86.64@(93.57, 70.90, 10.00)
Min -149.32@(96.65, 0.02, 10.00)

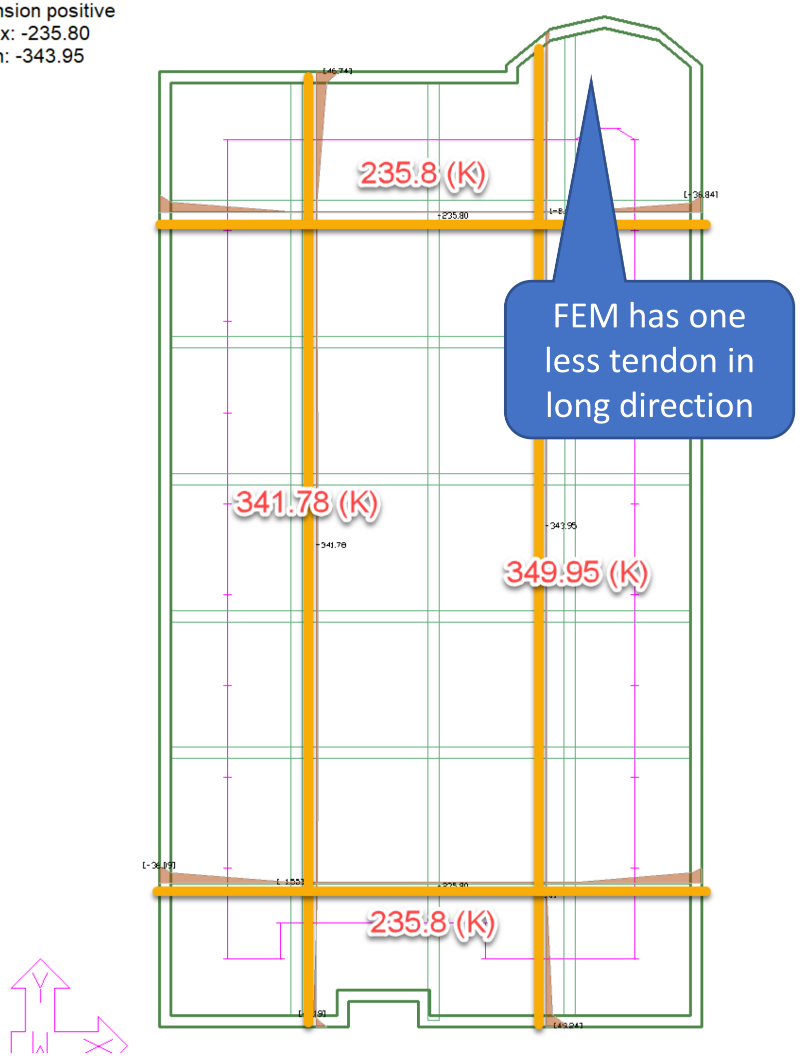


Slab, Stress (contour map), Mid-depth along YY (Psi)
Load Combination: Effective PT (NO_CODE_CHECK)
Max 65.04@(69.94, 0.02, 10.00)
Min -165.99@(68.02, 56.95, 10.00)

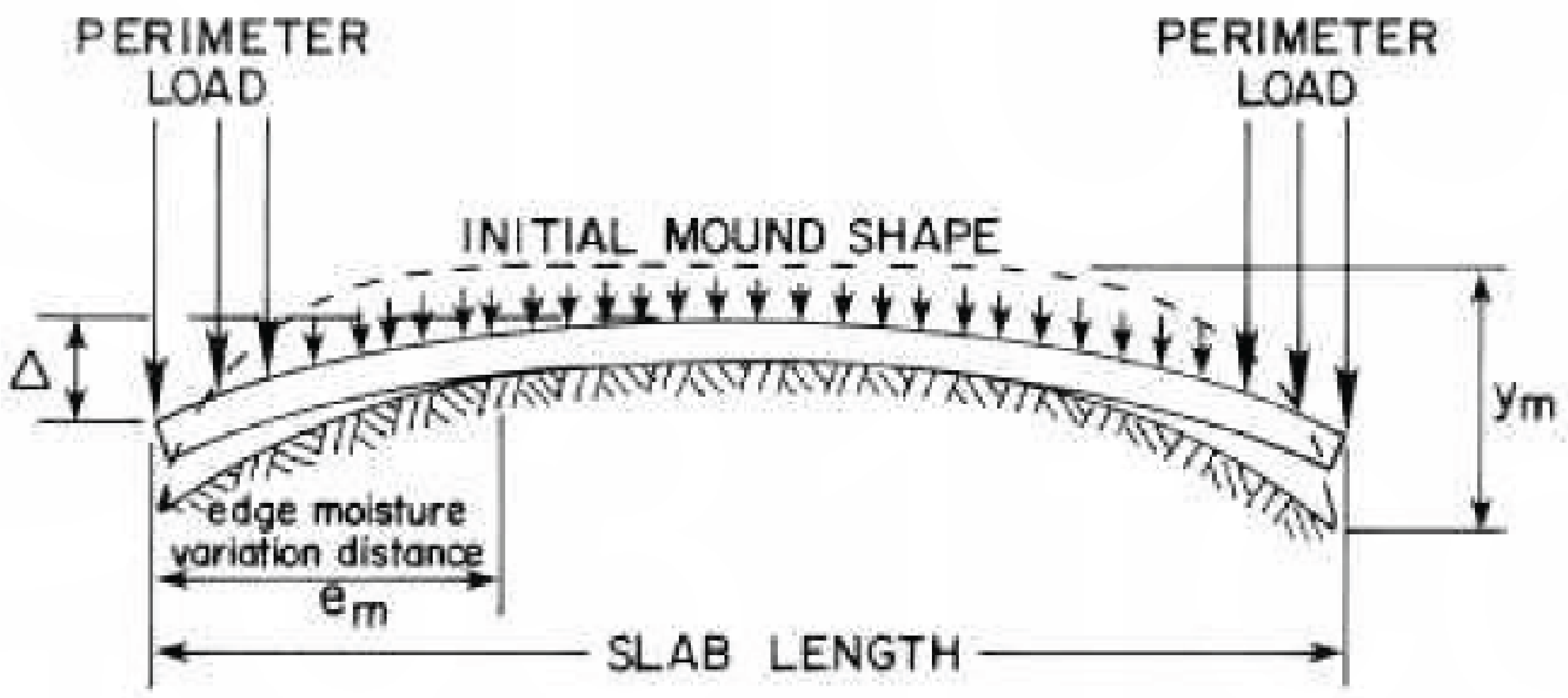


Effective prestress:
Short = 69.16 psi
Long = 78.6 psi
> 50 psi **OK**

Manual Design Sections, Actions, Axial (Kip)
Load Combination: Effective PT (NO_CODE_CHECK)
Tension positive
Max: -235.80
Min: -343.95



Center Lift Mode



PTI Figure 3.5

PTISlab – Moment Analysis – Center Lift Mode

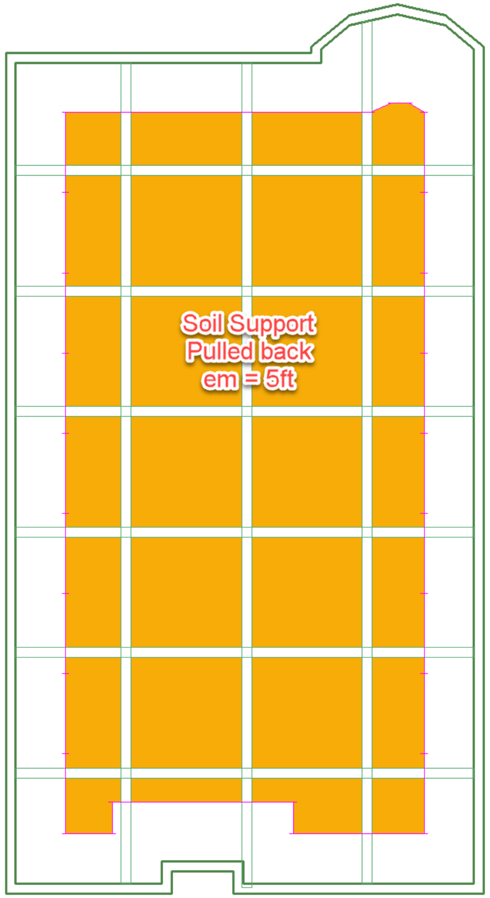
Moment Analysis - Center Lift Mode

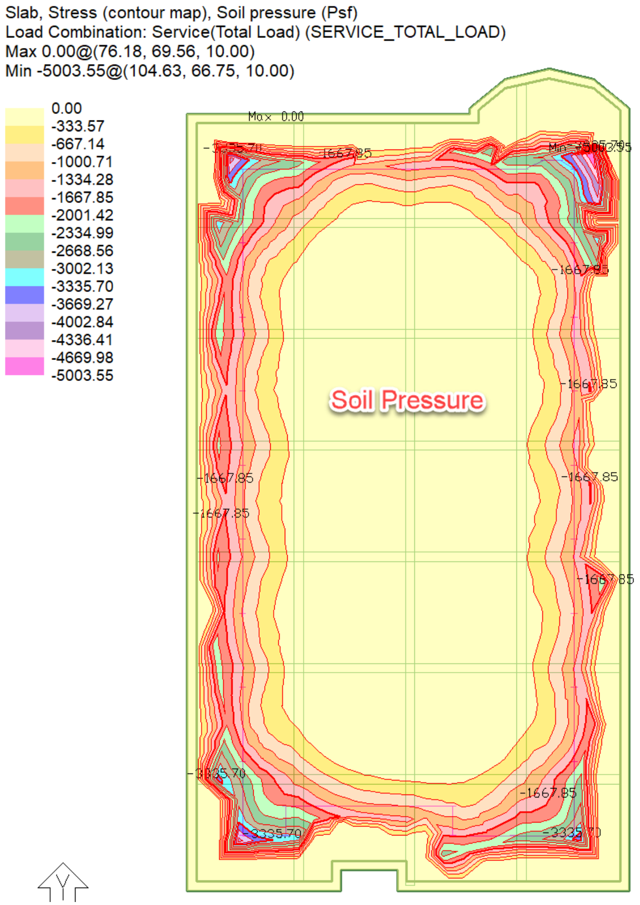
Maximum Moment, Short Dir.	(calculated with Em=5.0 per PTI 4.3.2)	10.10 FT-K/FT
Maximum Moment, Long Dir.	(calculated with Em=5.0 per PTI 4.3.2)	9.62 FT-K/FT

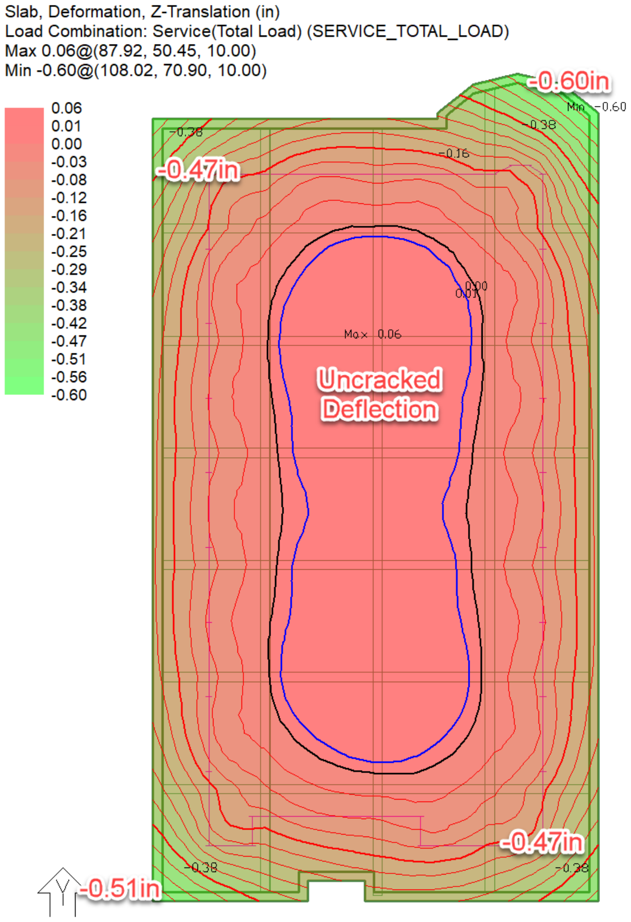
	Tension in Top Fiber (KSI)			Compression in Bottom Fiber (KSI)	
	Short Direction	Long Direction		Short Direction	Long Direction
Allowable Stress	-0.379	-0.379	Allowable Stress	1.800	1.800
Actual Stress	-0.167	-0.150	Actual Stress	0.307	0.301

FEM– Center Lift Mode – Analysis Method

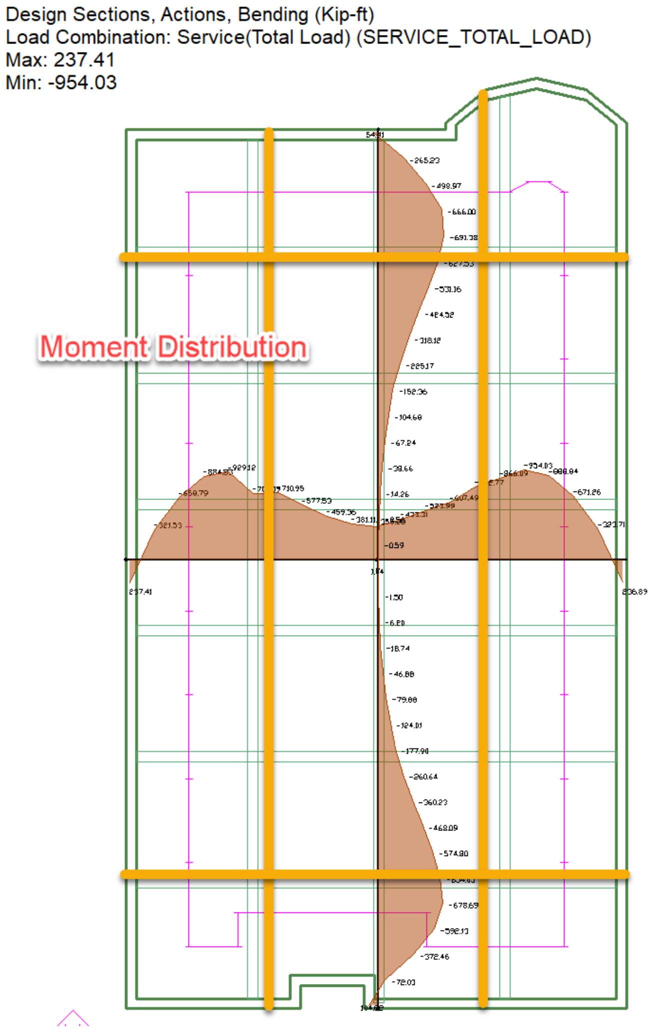
To simulate Center Lift Mode, soil support is removed the distance of em (5ft) from perimeter of slab.

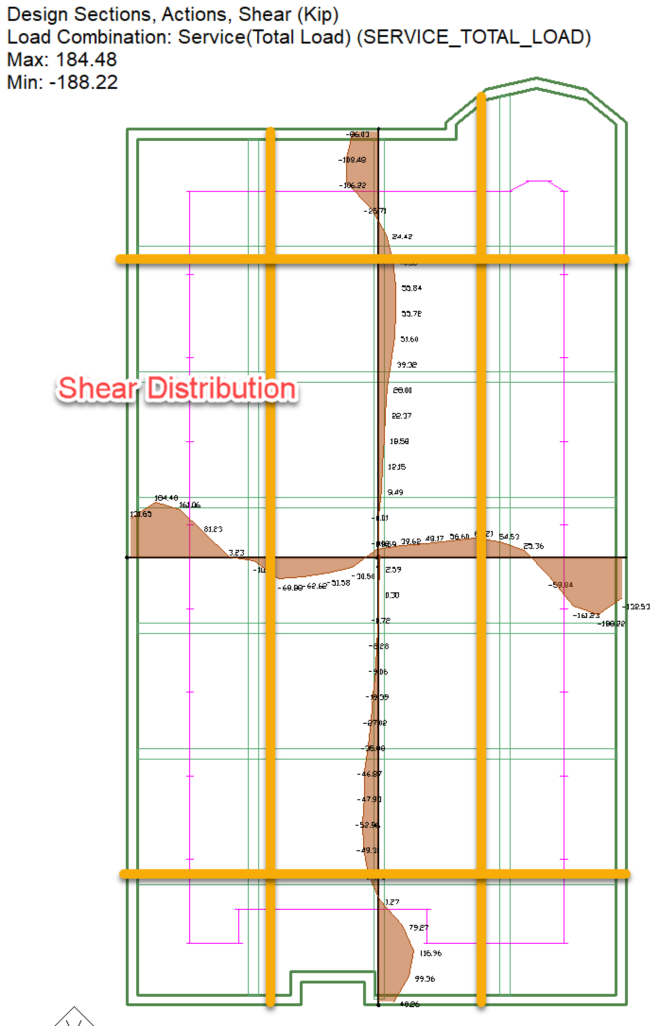






FEM – Moment Analysis – Center Lift Mode

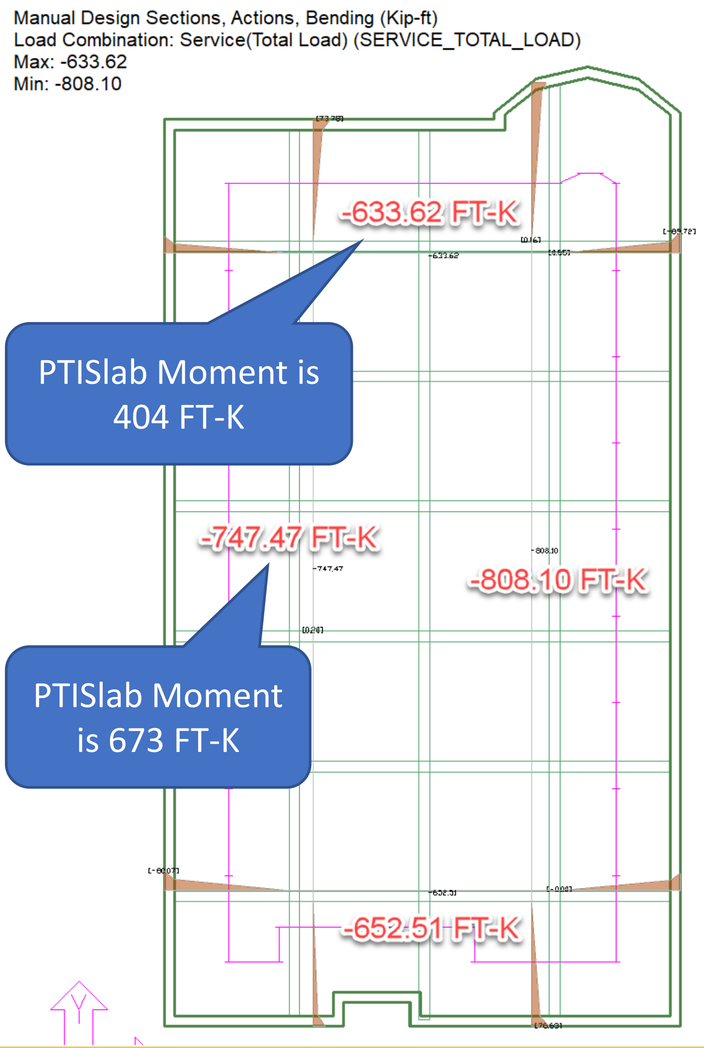


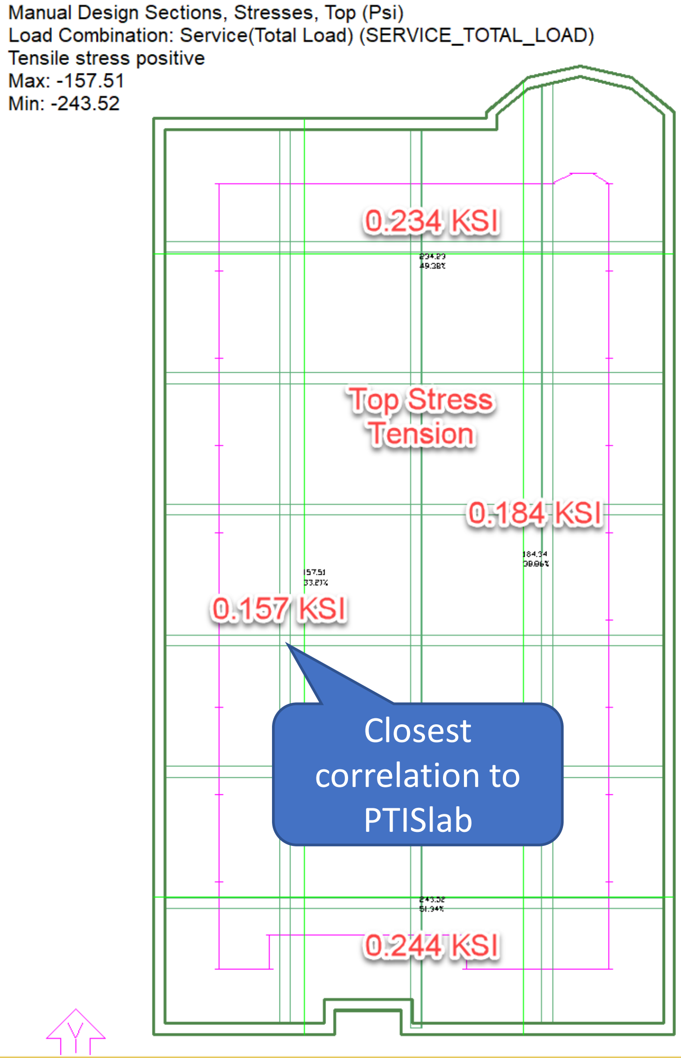


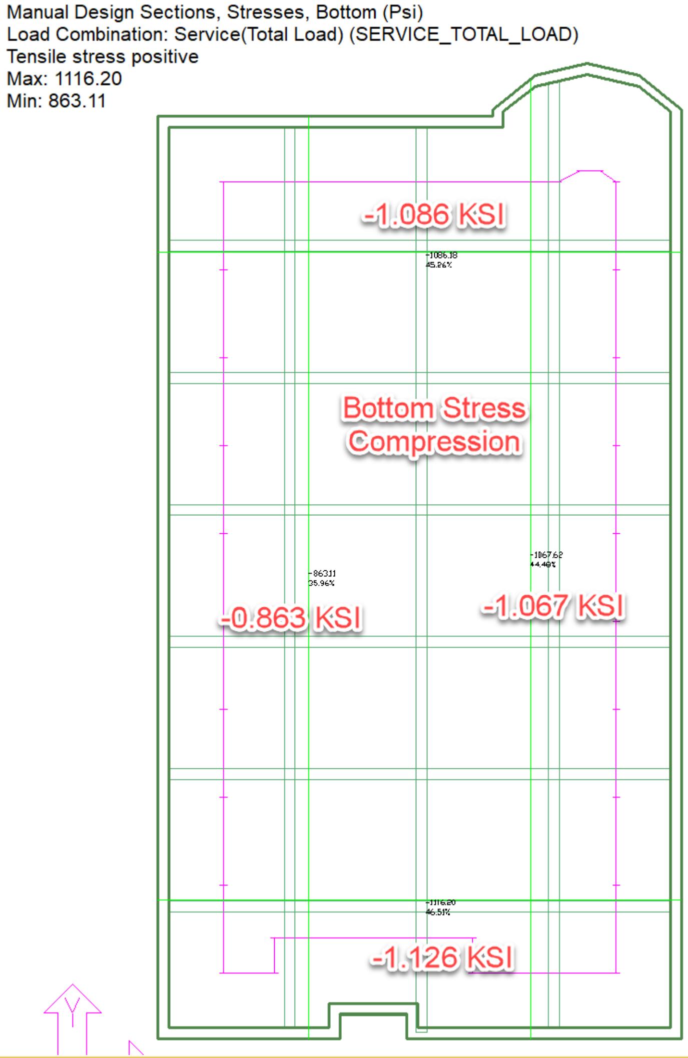
Maximum moments and shears don't coincide with Beta distance.

FEM – Moment Analysis @ Beta – Center Lift Mode

Stresses @ beta distance pass.





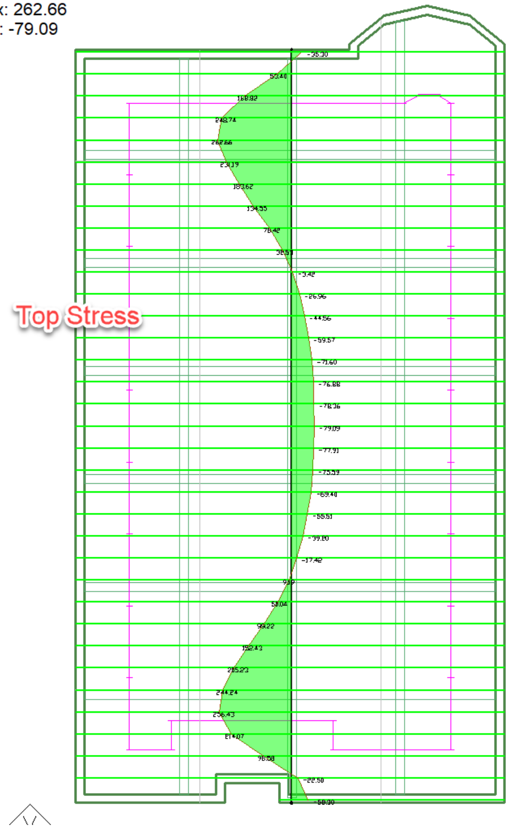


FEM – Moment Analysis @ All Sections – Center Lift Mode

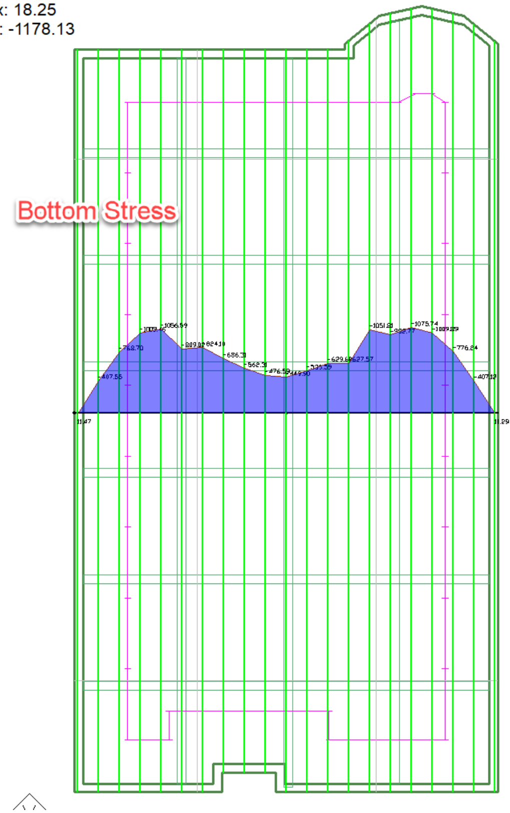
All slab stresses are within allowable limits if integrated over entire slab width.

Design Sections, Stresses, Top (Psi)
Load Combination: Service(Total Load) (SERVICE_TOTAL_LOAD)
Tensile stress positive
Max: 262.66
Min: -79.09

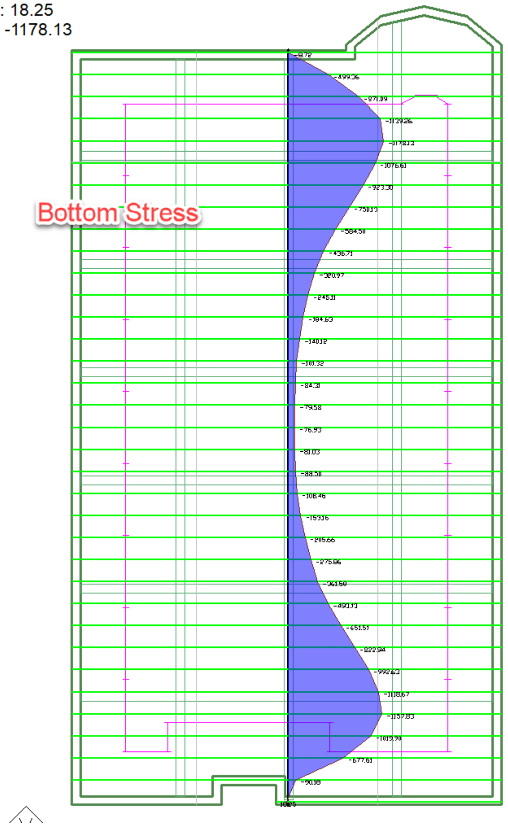
Design Sections, Stresses, Top (Psi)
Load Combination: Service(Total Load) (SERVICE_TOTAL_LOAD)
Tensile stress positive
Max: 262.66
Min: -79.09



Design Sections, Stresses, Bottom (Psi)
Load Combination: Service(Total Load) (SERVICE_TOTAL_LOAD)
Tensile stress positive
Max: 18.25
Min: -1178.13

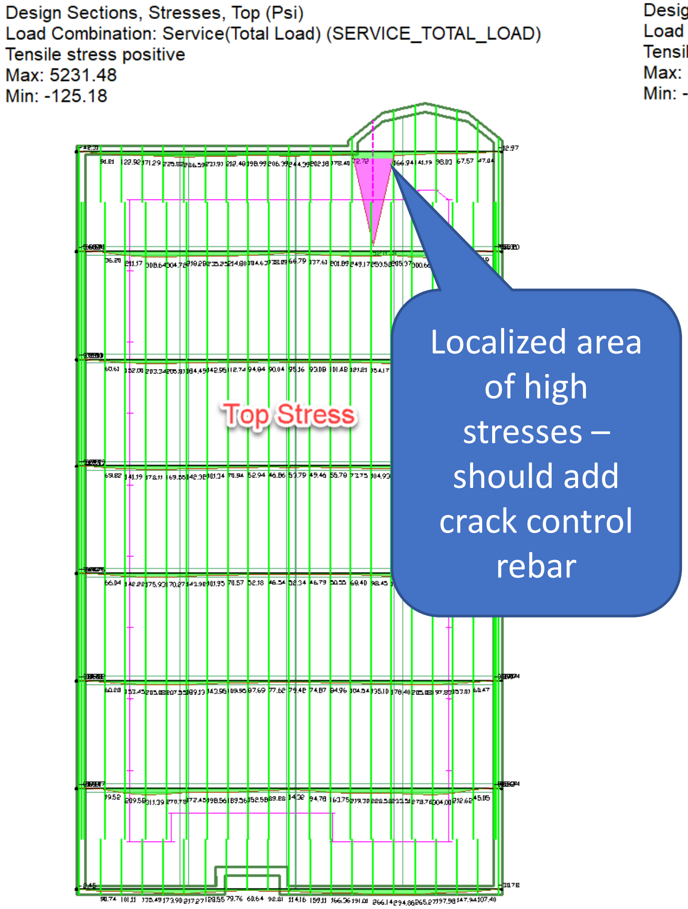


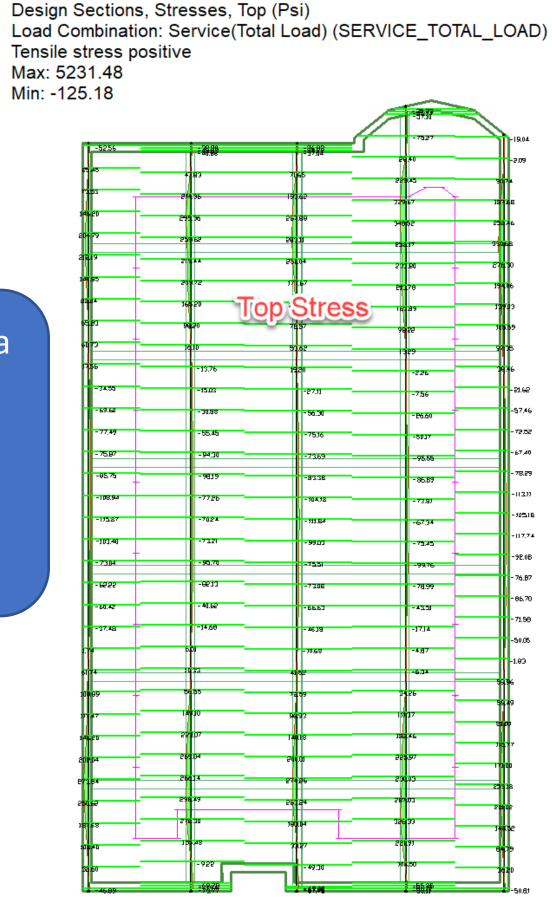
Design Sections, Stresses, Bottom (Psi)
Load Combination: Service(Total Load) (SERVICE_TOTAL_LOAD)
Tensile stress positive
Max: 18.25
Min: -1178.13

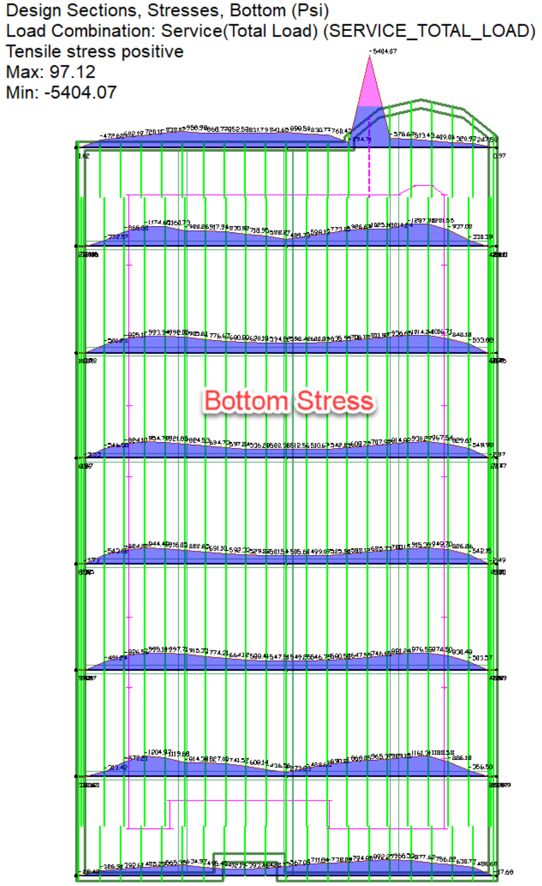


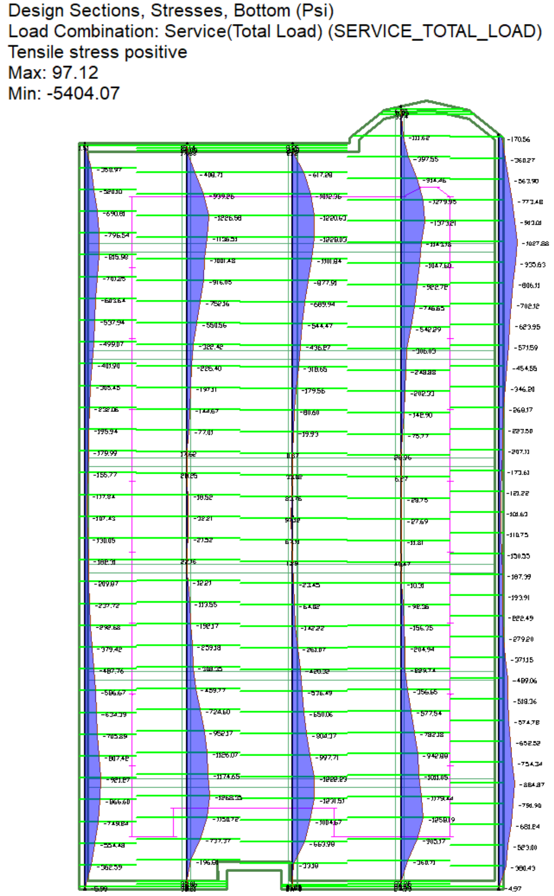
FEM – Moment Analysis @ Detailed – Center Lift Mode

FEM can provide more detailed and localized stress distribution, a useful guide for added rebar placement.









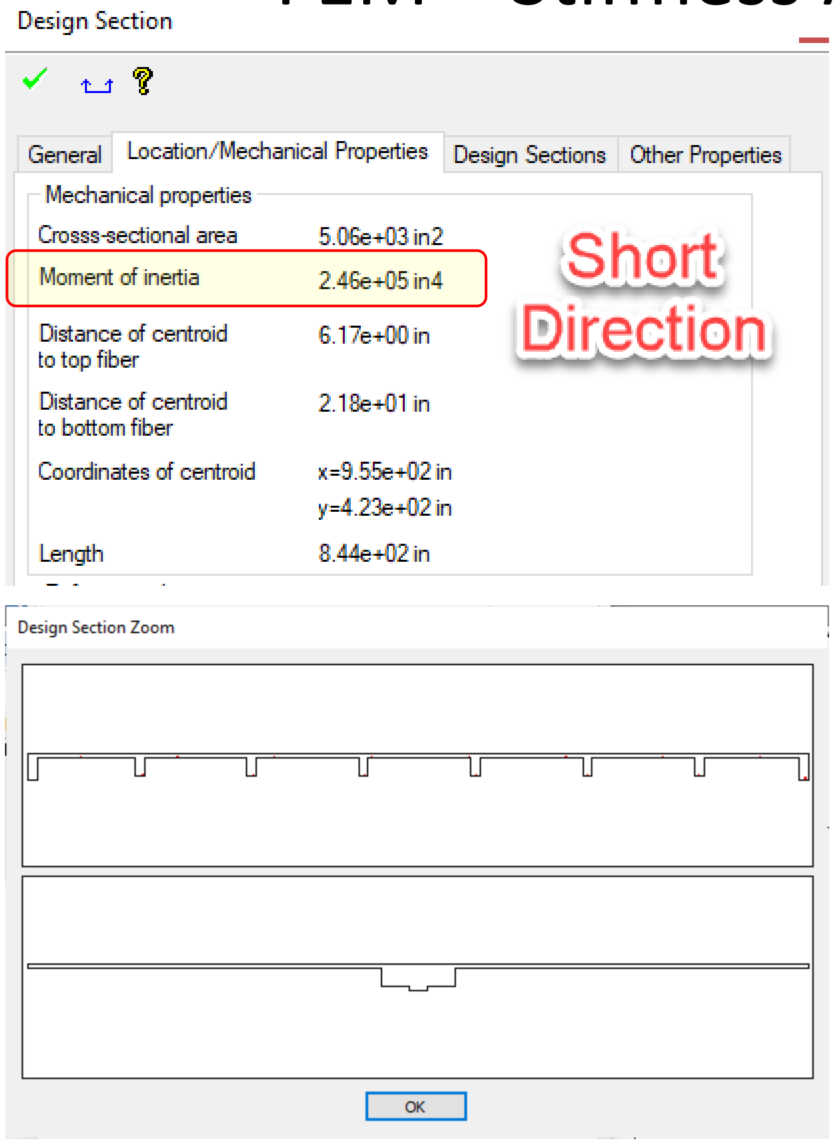
PTISlab – Stiffness Analysis – Center Lift Mode

Stiffness Analysis - Center Lift Mode

Based on a Stiffness Coefficient of 480

	Short Direction	Long Direction
Available Moment of Inertia (Inch^4)	245,897	161,491
Required Moment of Inertia (Inch^4)	108,632	92,193
Required Moment of Inertia controlled by	Width	6*Beta

FEM – Stiffness Analysis – Based on I – Center Lift Mode

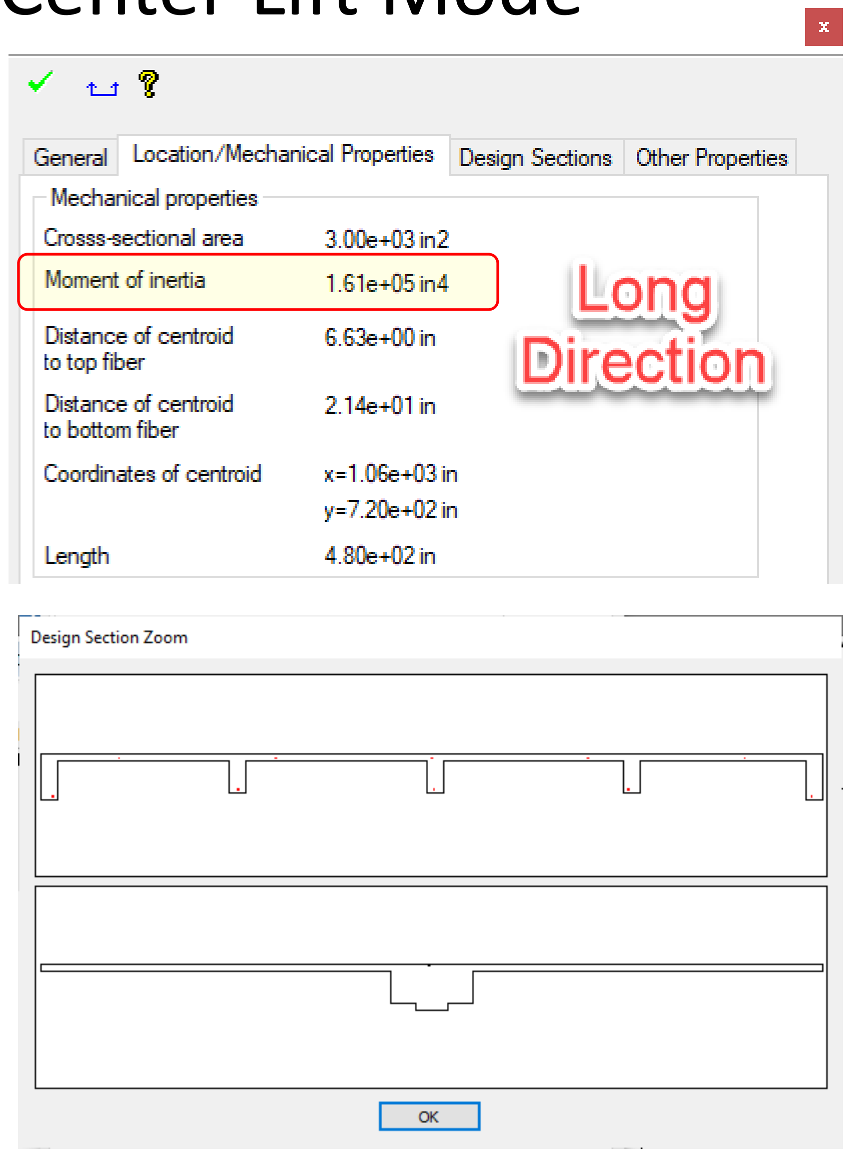


Short direction:

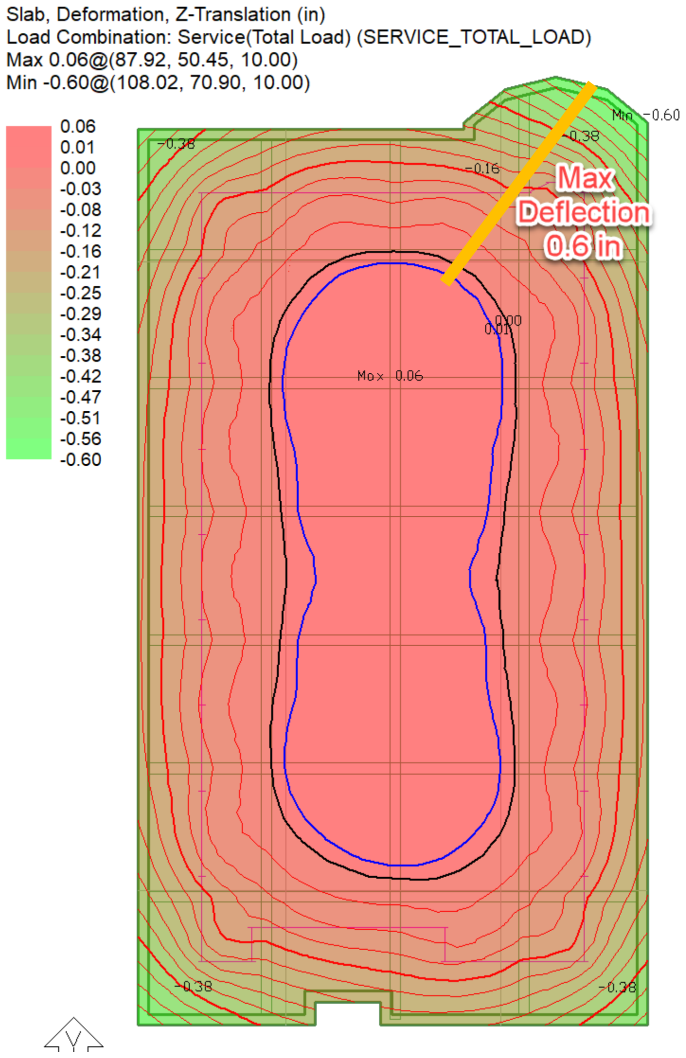
- Required 108,632 (in4)
- Available 246,000 (in4)
- **OK**

Long direction:

- Required 92,193 (in4)
- Available 161,000 (in4)
- **OK**



FEM – Stiffness Analysis – Based on Deflection – Center Lift Mode



Can use actual deflection to check deflection criteria.

- Stiffness coefficient 480
- Max allowable deflection 0.9 in
  (based on 18 ft cantilever deflection)

- Max deflection 0.6 in **OK**

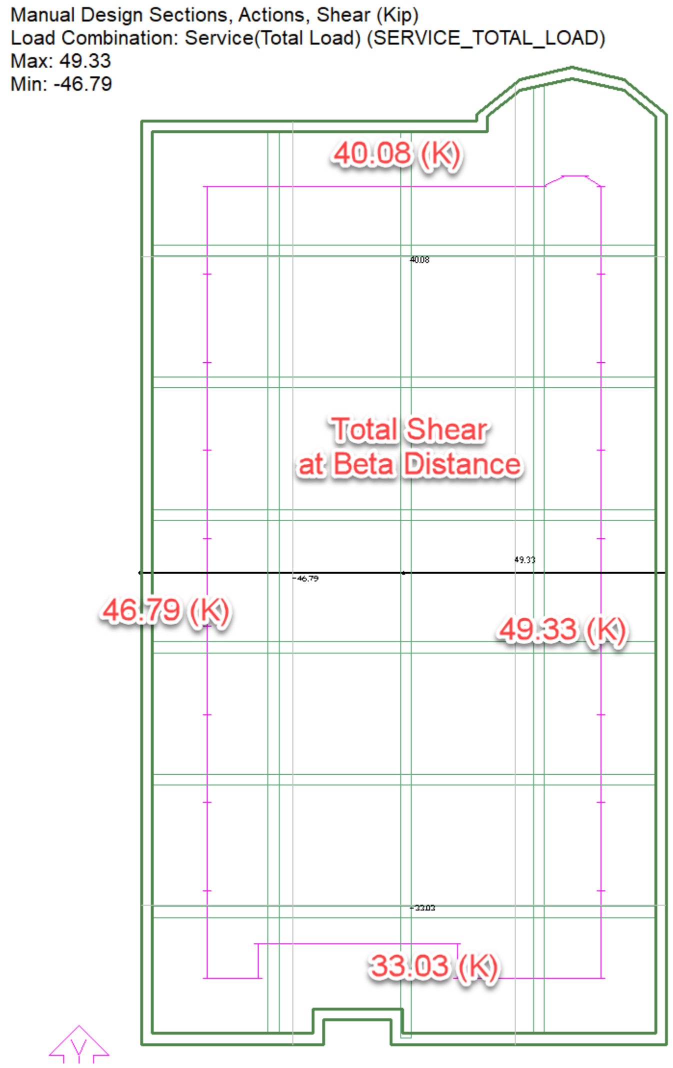
PTISlab – Shear Analysis – Center Lift Mode

Shear Analysis - Center Lift Mode

Maximum Shear, Short Direction	2.37 K/FT	
Maximum Shear, Long Direction	2.22 K/FT	

	Short Direction	Long Direction
Allowable Shear Stress (PSI)	166	167
Actual Shear Stress (PSI)	12	12

FEM – Shear Analysis – Center Lift Mode



Allowable shear stress:

- Short direction 165 psi
- Long direction 167 psi

Max shear capacity:

- Short direction 331 K
- Long direction 214 K

Shear @ Beta

- Short direction 47 K **OK**
- Long direction 41 K **OK**

Max shear demand

- Short direction 188 K **OK**
- Long direction 117 K **OK**

PTISlab – Cracked Section Analysis – Center Lift Mode

Cracked Section Analysis - Center Lift Mode

	Short Direction	Long Direction
Cracked Section Capacity (FT-K)	399.7	256.9
0.5 Moment (FT-K)	353.6	192.4

FEM – Cracked Section Analysis – Center Lift Mode

Short direction:

Design section moment capacity

Positive moment	400.20 k-ft
Negative moment	-387.74 k-ft

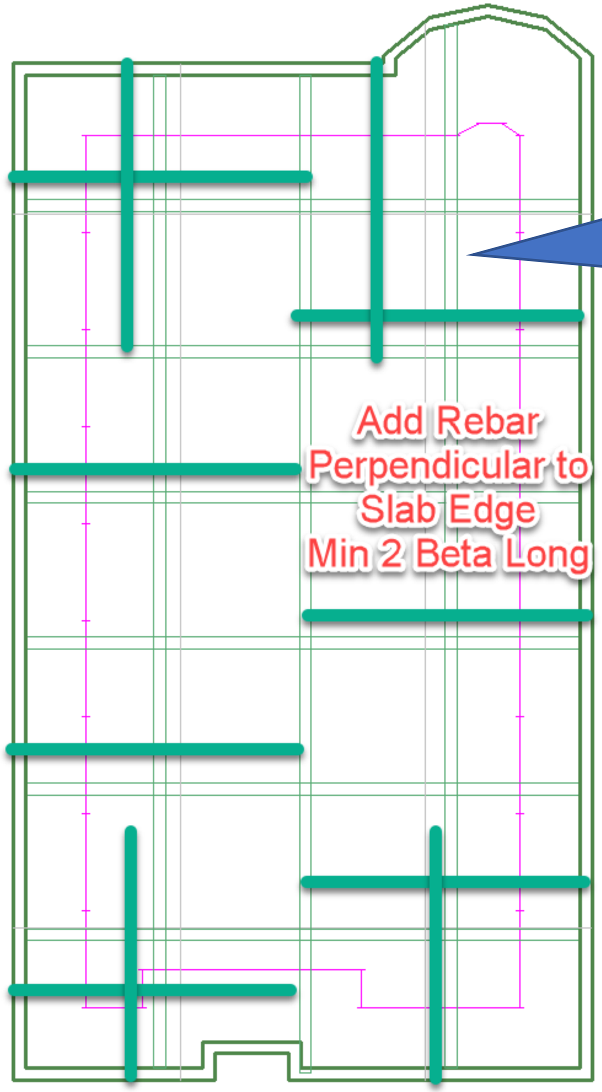
0.5 M @ Beta	404 K-FT **NG**
0.5 M Max	477 K-FT **NG**

Long direction:

Design section moment capacity

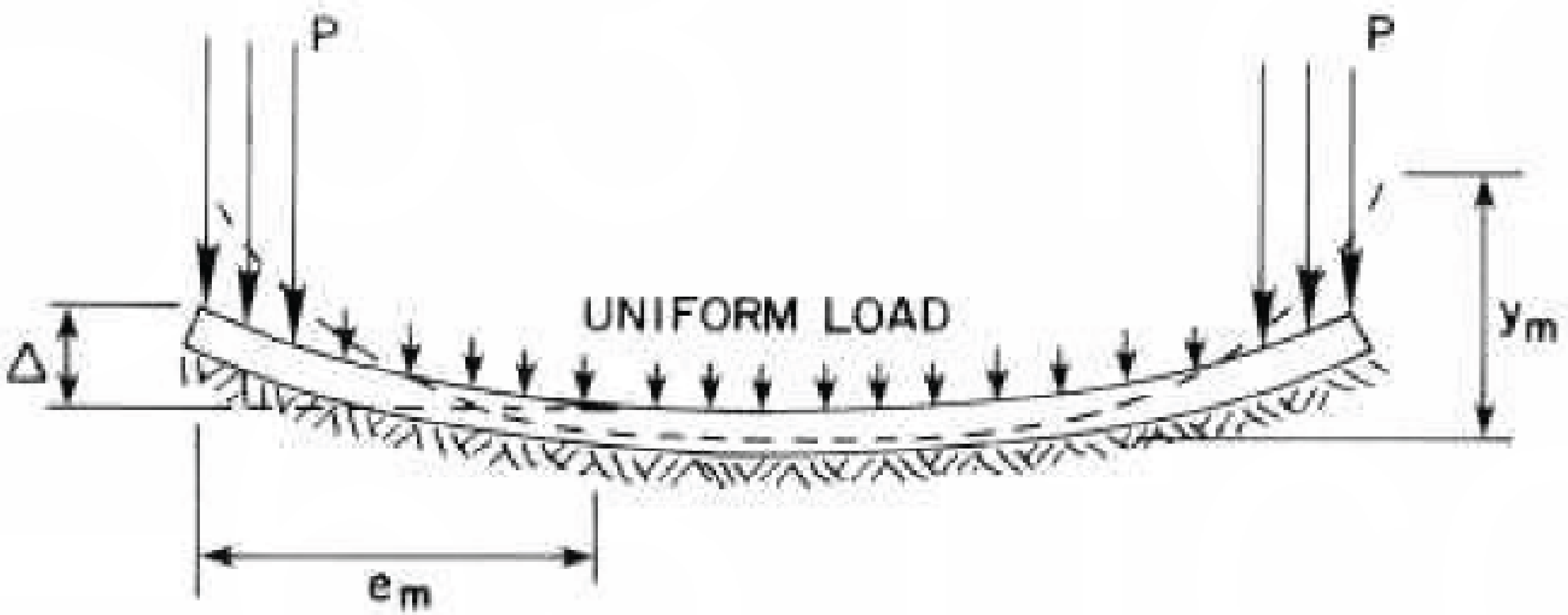
Positive moment	299.97 k-ft
Negative moment	-548.30 k-ft

0.5 M @ Beta	327 K-FT **NG**
0.5 M Max	345 K-FT **NG**



To meet PTI 6.9, add rebar or increase PT

Edge Lift Mode



PTI Figure 3.5

PTISlab – Moment Analysis – Edge Lift Mode

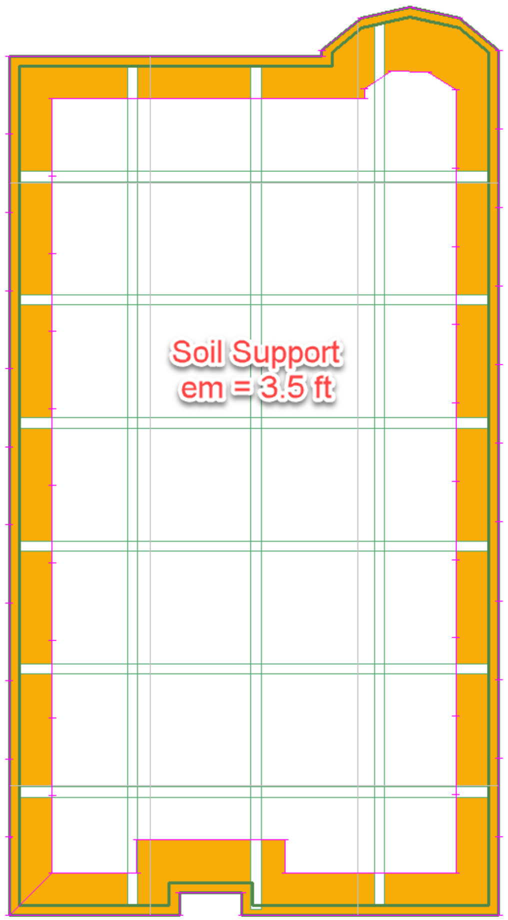
Moment Analysis - Edge Lift Mode

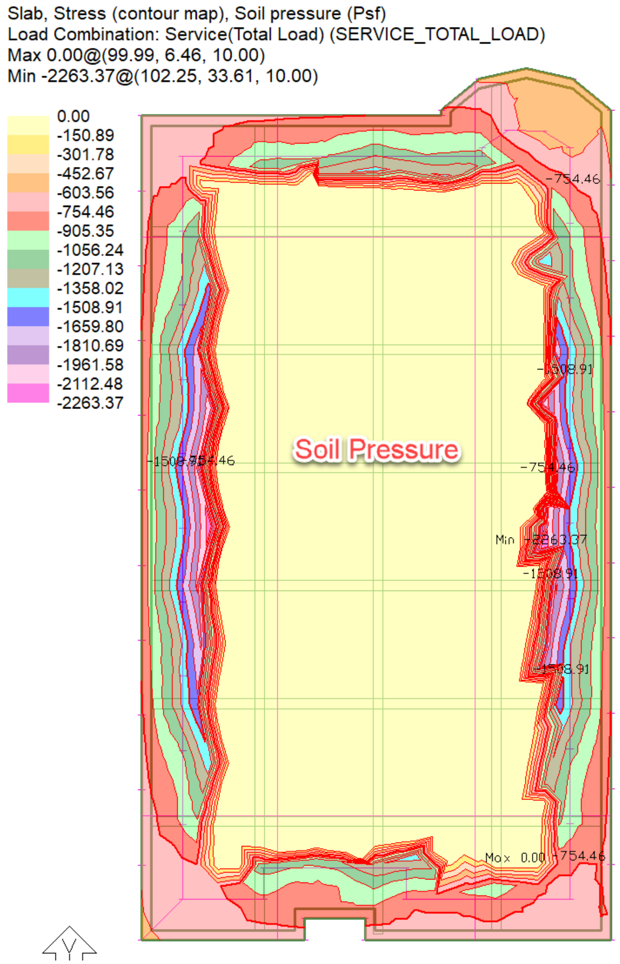
Maximum Moment, Short Direction	8.44	FT-K/FT
Maximum Moment, Long Direction	7.01	FT-K/FT

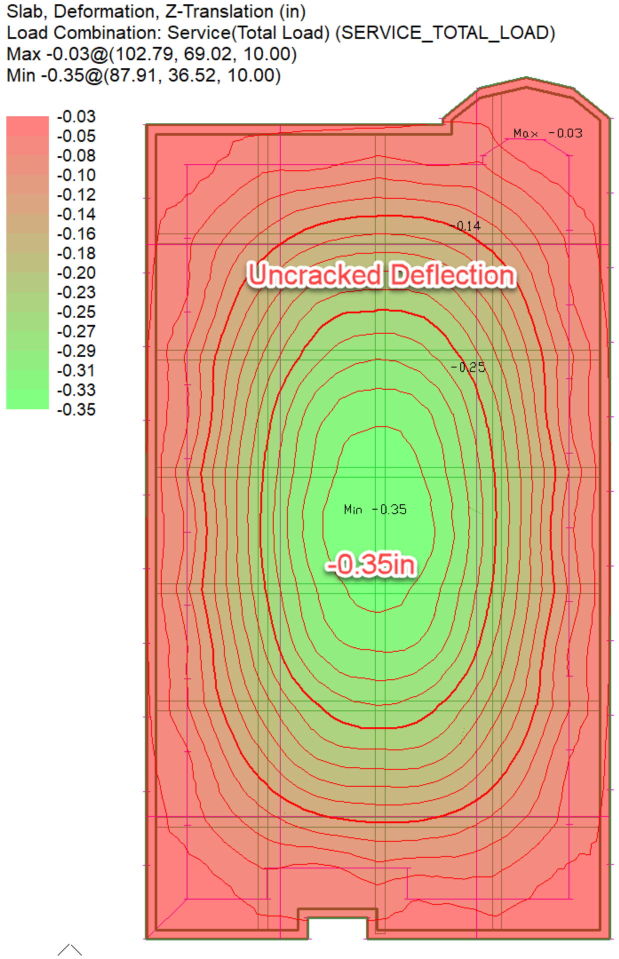
	Tension in Bottom Fiber (KSI)			Compression in Top Fiber (KSI)	
	Short Direction	Long Direction		Short Direction	Long Direction
Allowable Stress	-0.379	-0.379	Allowable Stress	1.800	1.800
Actual Stress	-0.294	-0.146	Actual Stress	0.193	0.157

FEM– Edge Lift Mode – Analysis Method

To simulate Edge Lift Mode, heaving soil support is limited to outer distance em (3ft) from perimeter of slab.

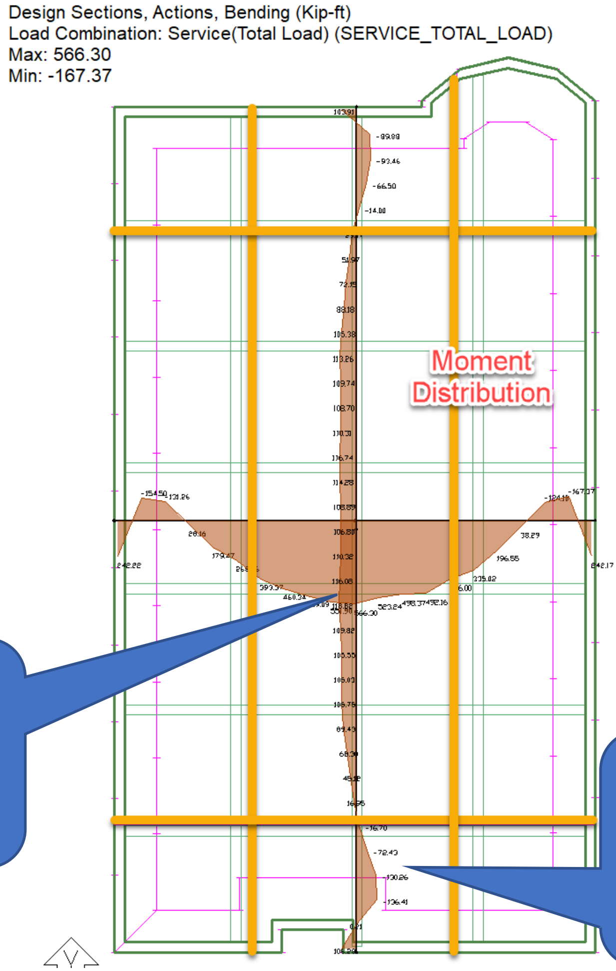






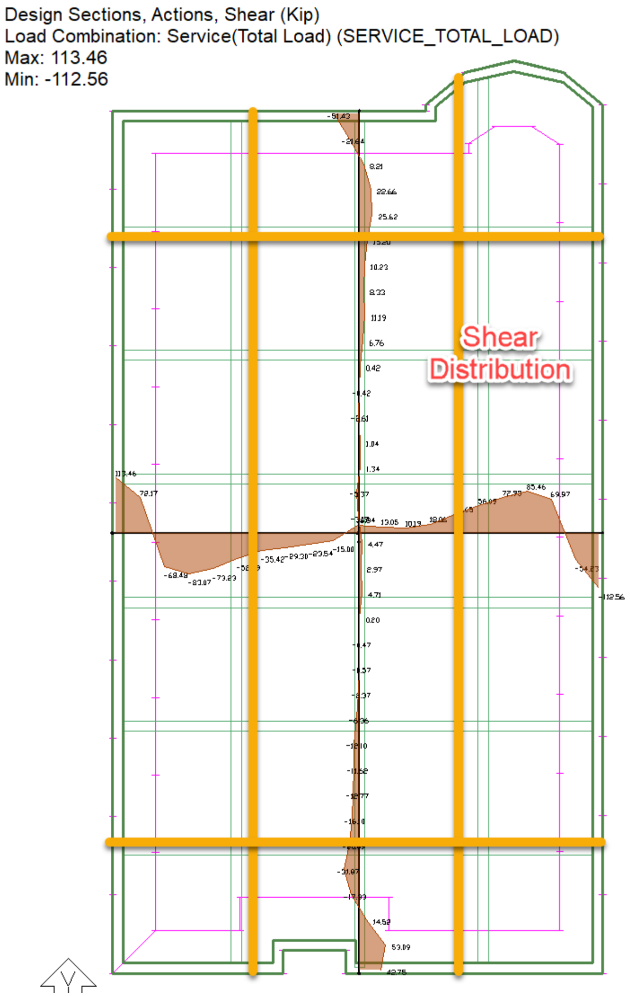
FEM – Moment Analysis – Edge Lift Mode

Maximum moments and shears don’t coincide with Beta distance.



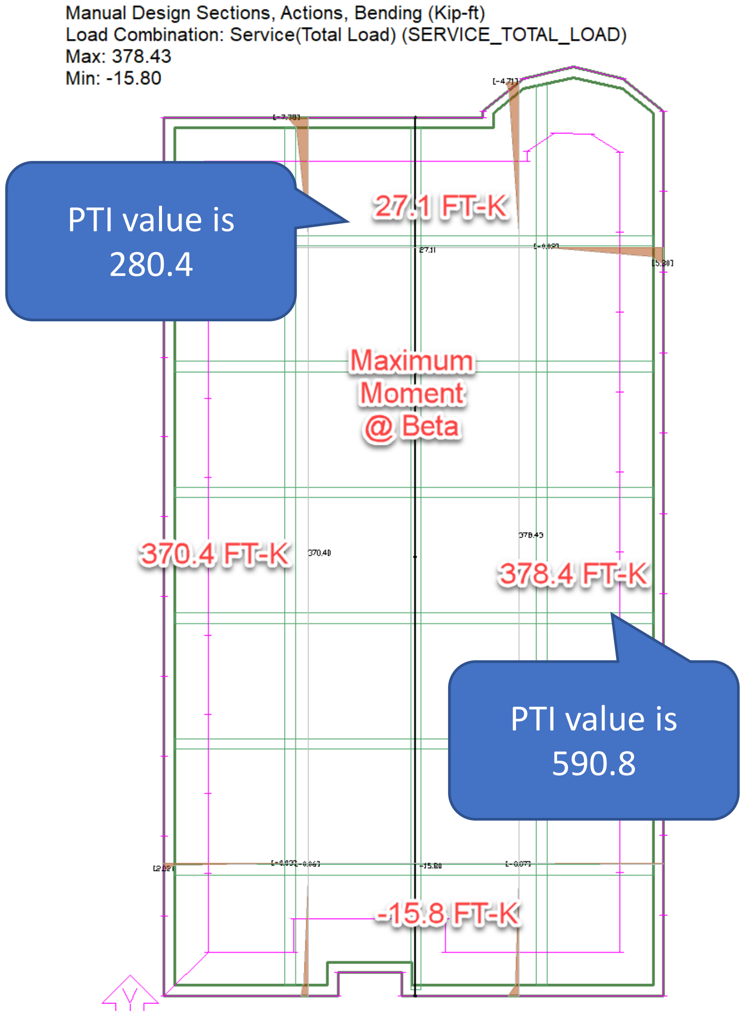
FEM Max value is 566.3 PTI value is 590.8

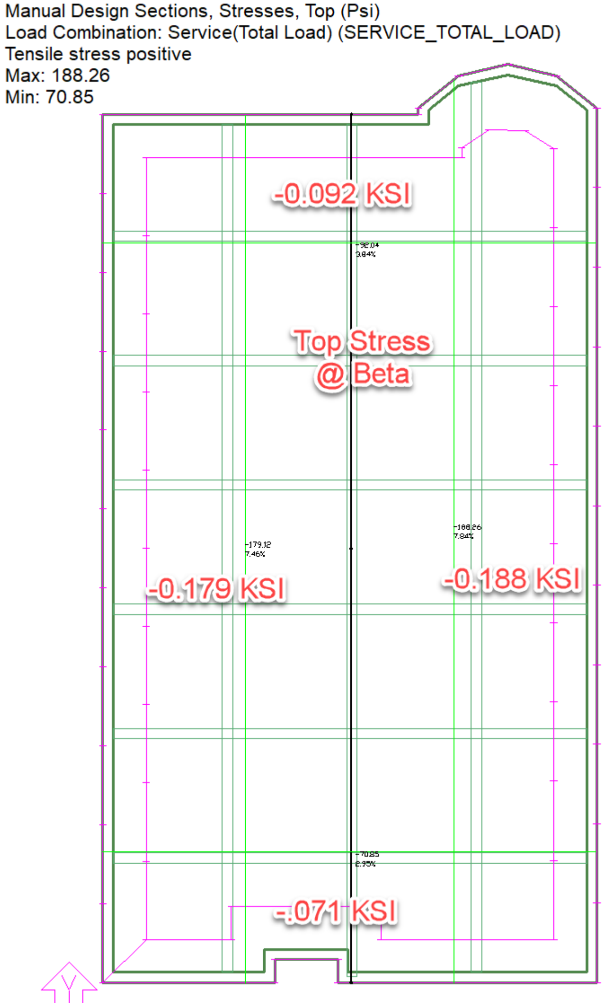
FEM Max value is 130.3 PTI value is 280.4

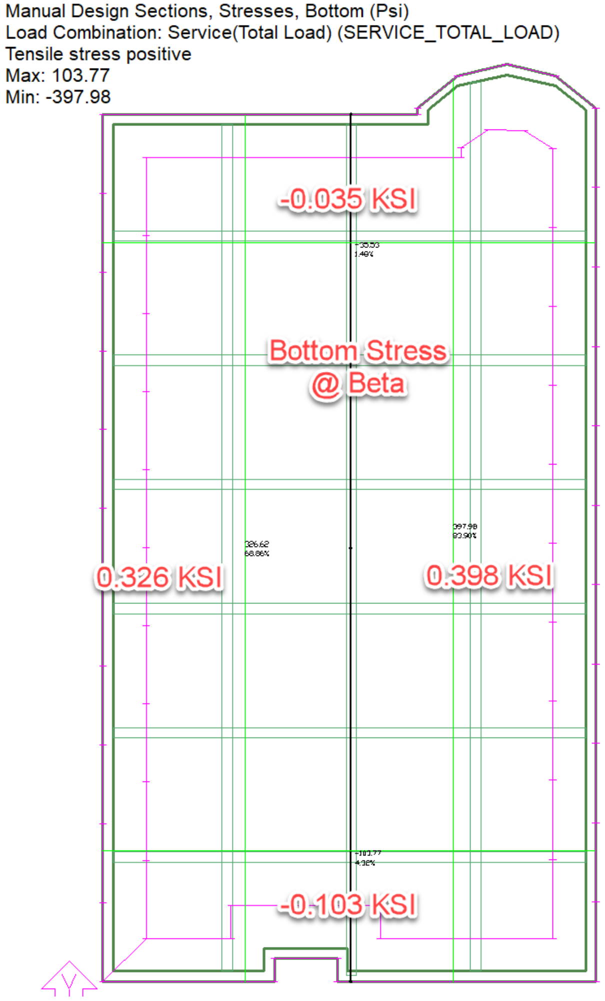


FEM – Moment Analysis @ Beta – Edge Lift Mode

Stresses @ beta distance pass.

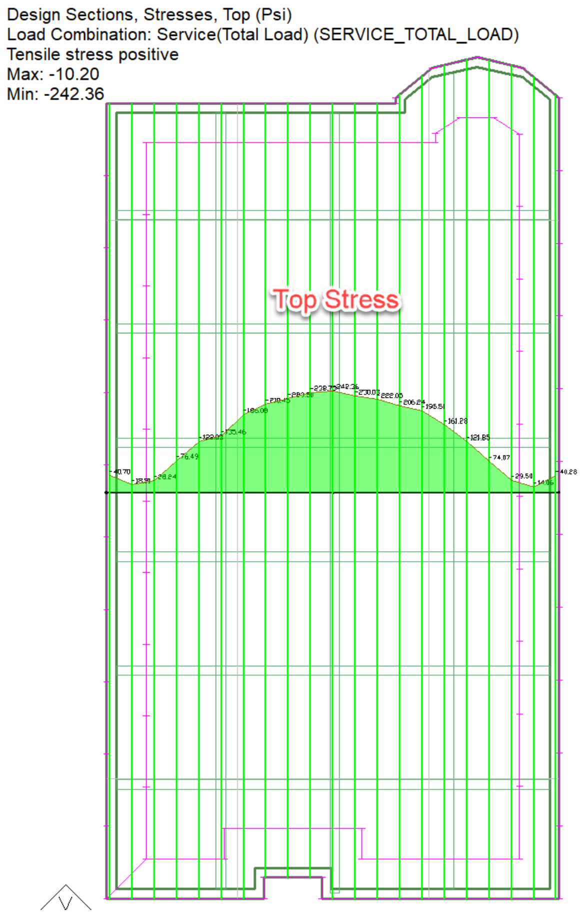


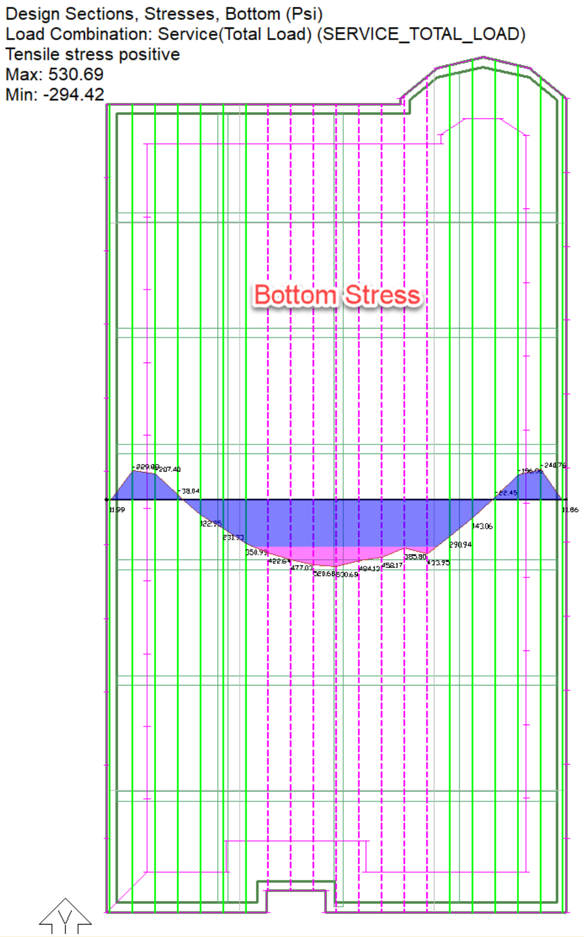


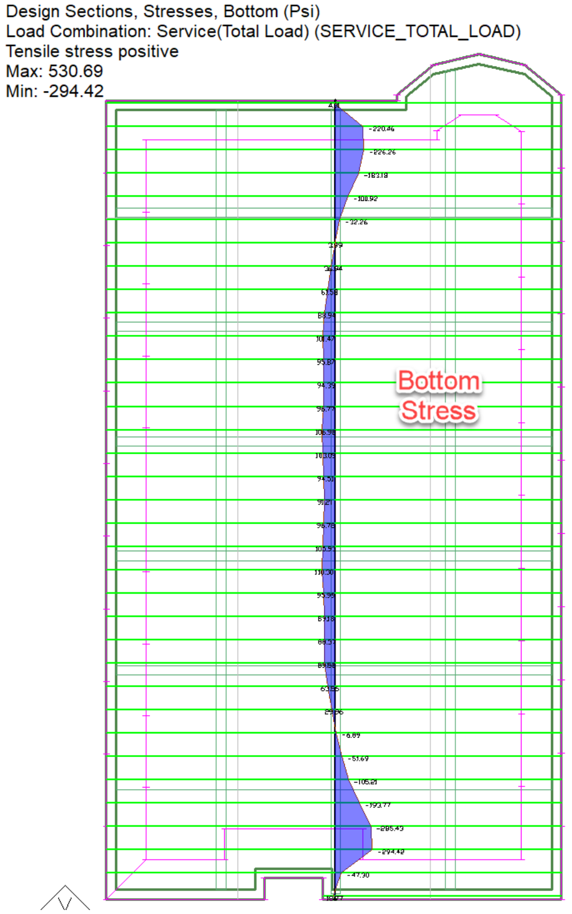


FEM – Moment Analysis @ All Sections – Edge Lift Mode

When checking stress distribution in slab, short direction bottom stresses in beams exceed cracking stress.

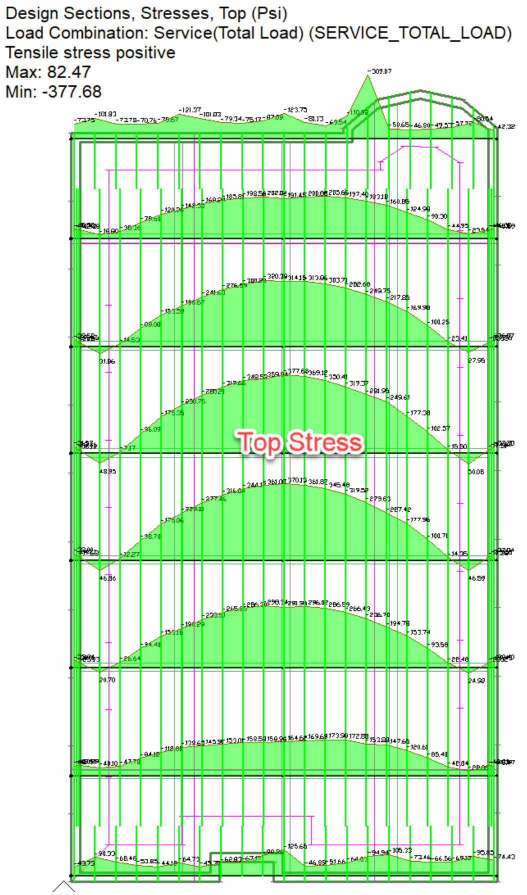


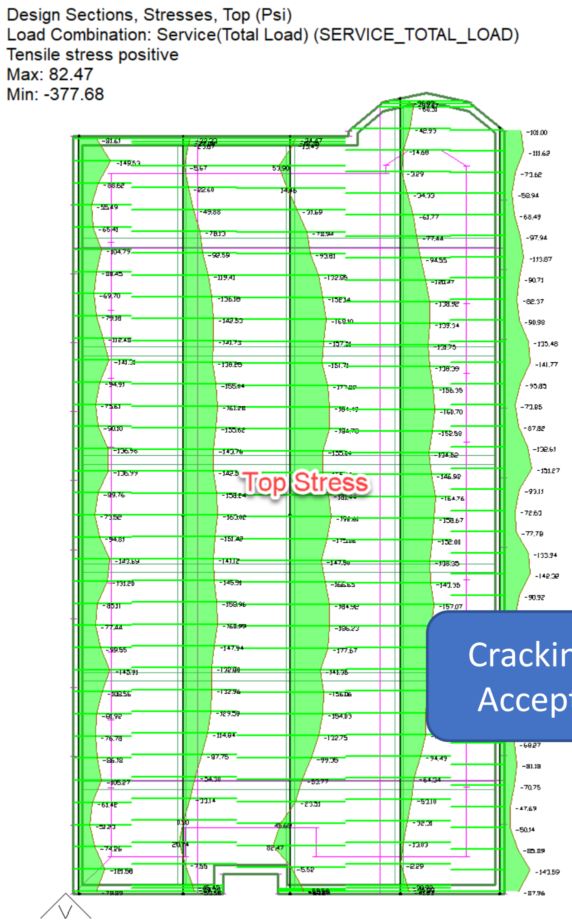


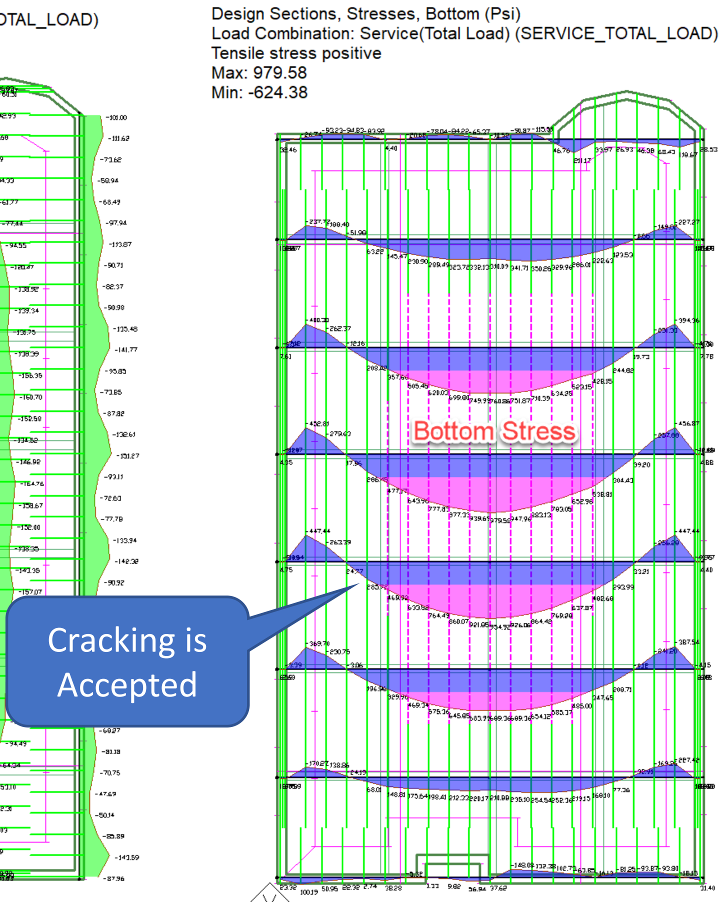


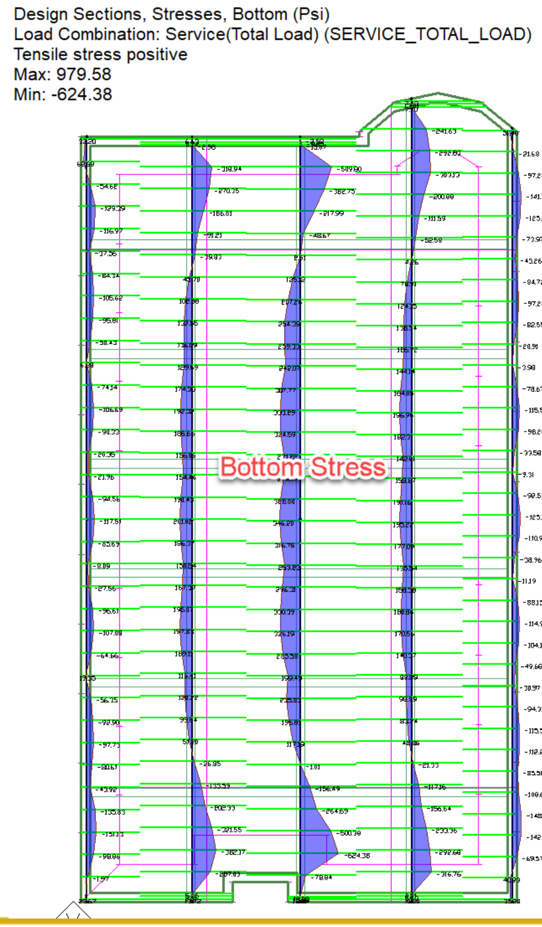
FEM – Moment Analysis @ Detailed – Edge Lift Mode

FEM can provide more detailed and localized stress distribution, a useful guide for added rebar placement.









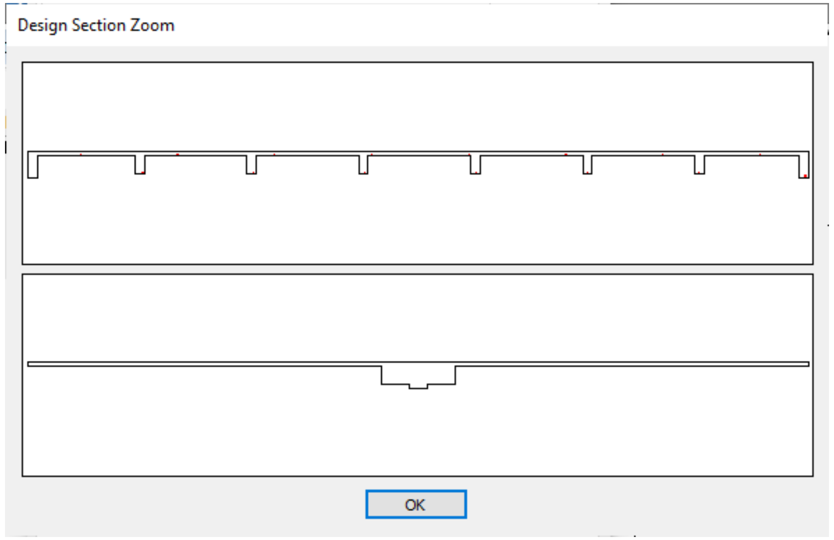
PTISlab – Stiffness Analysis – Edge Lift Mode

Stiffness Analysis - Edge Lift Mode

Based on a Stiffness Coefficient of 960

	Short Direction	Long Direction
Available Moment of Inertia (Inch^4)	245,897	161,491
Required Moment of Inertia (Inch^4)	181,583	134,309
Required Moment of Inertia controlled by	Width	6*Beta

FEM – Stiffness Analysis – Using Required I – Edge Lift Mode

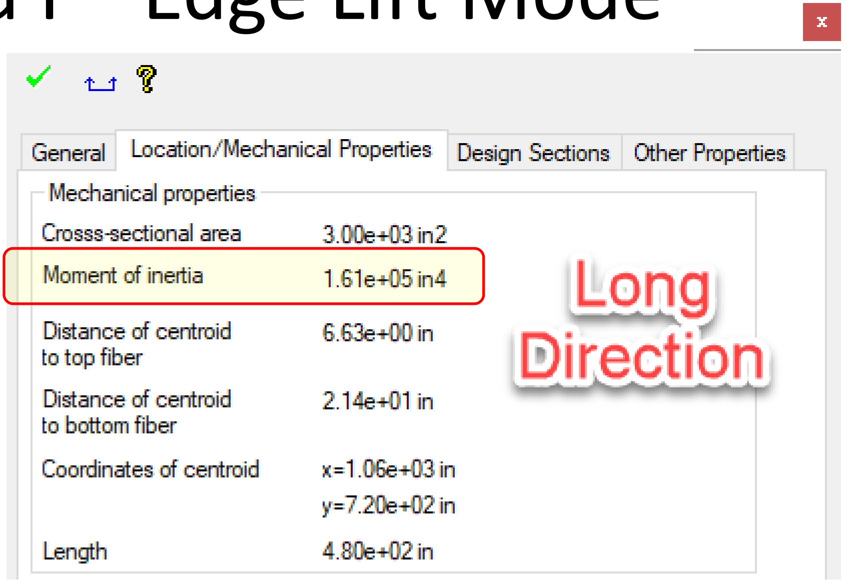


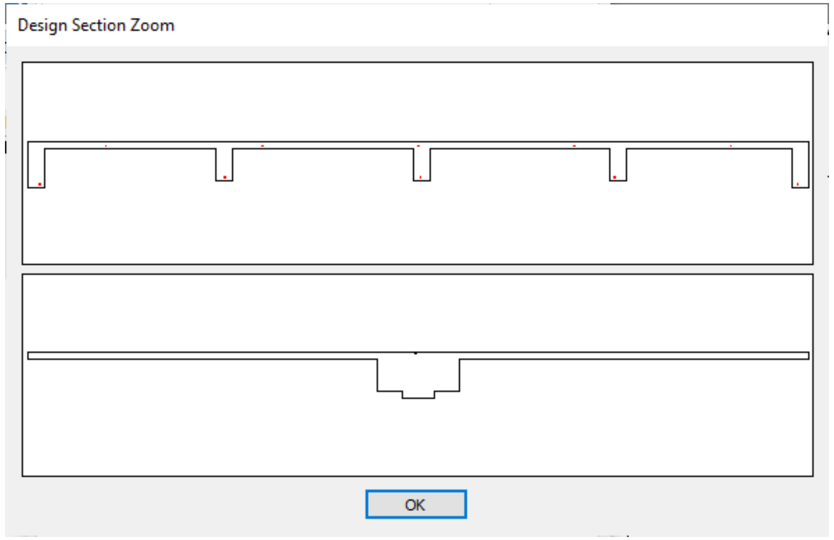
Short direction:

- Required 181,583 (in4)
- Available 246,000 (in4)
- **OK**

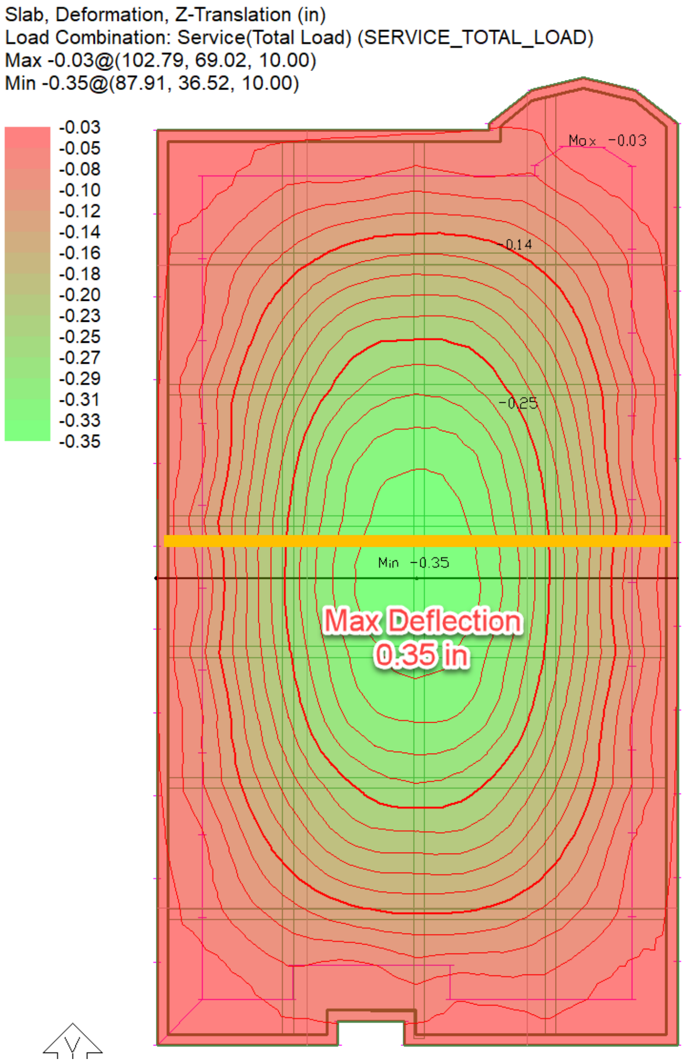
Long direction:

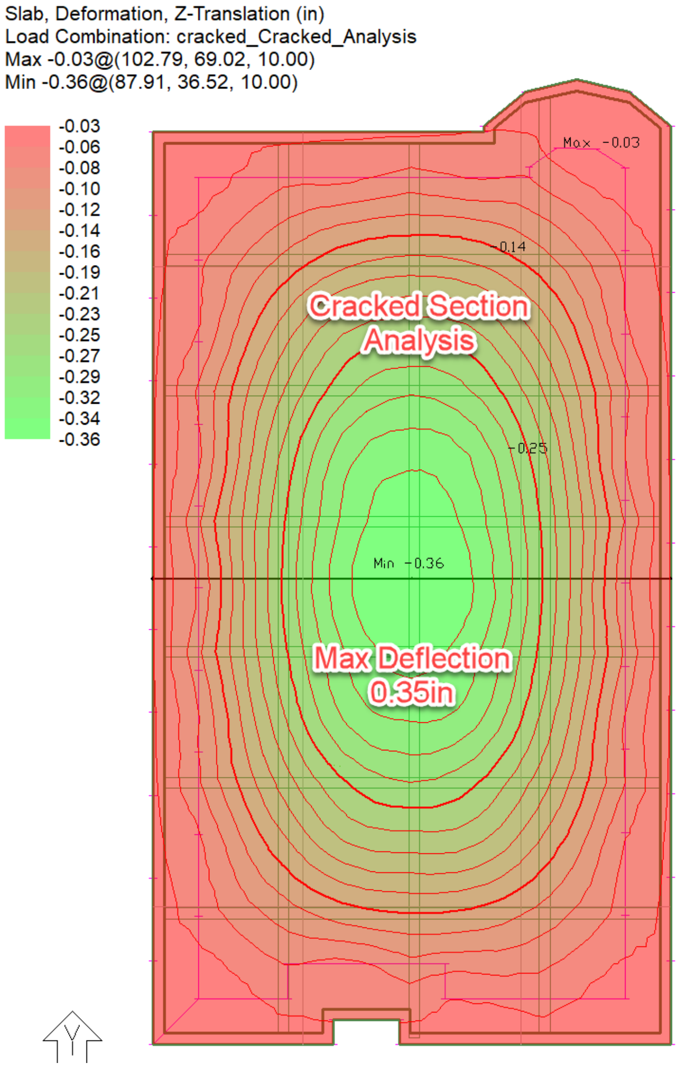
- Required 134,309 (in4)
- Available 161,000 (in4)
- **OK**





FEM – Stiffness Analysis – Using Deflection – Center Lift Mode





Use actual deflection to check deflection criteria.

- Stiffness coefficient 480
- Max allowable deflection 1.0 in

- Max deflection (uncracked) 0.35 in **OK**
- Max deflection (cracked) 0.36 in **OK**

PTISlab – Shear Analysis – Edge Lift Mode

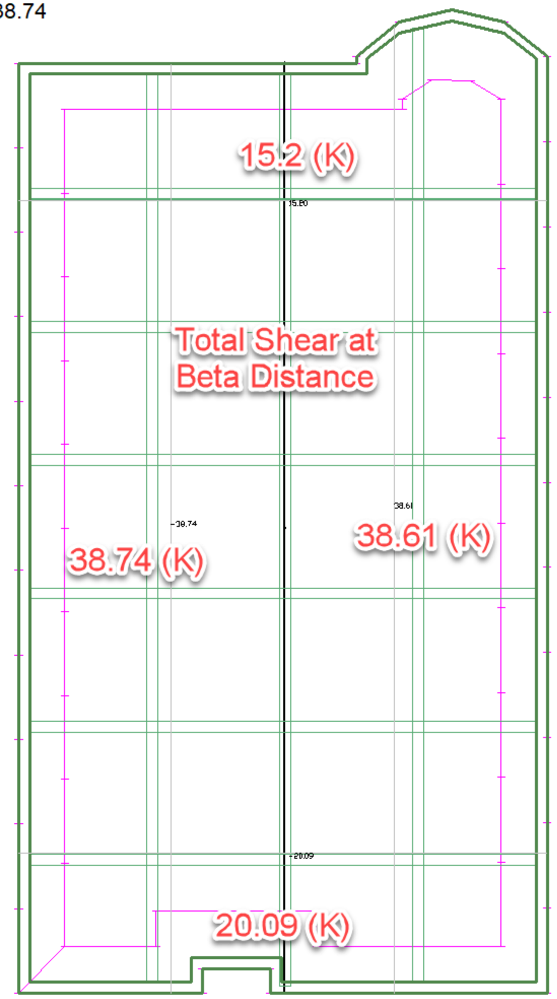
Shear Analysis - Edge Lift Mode

Maximum Shear, Short Direction	3.76 K/FT	
Maximum Shear, Long Direction	3.95 K/FT	

	Short Direction	Long Direction
Allowable Shear Stress (PSI)	166	167
Actual Shear Stress (PSI)	131	123

FEM – Shear Analysis – Edge Lift Mode

Manual Design Sections, Actions, Shear (Kip)
Load Combination: Service(Total Load) (SERVICE_TOTAL_LOAD)
Max: 38.61
Min: -38.74



Allowable shear stress:

- Short direction 165 psi
- Long direction 167 psi

Max shear capacity:

- Short direction 331 K
- Long direction 214 K

Shear @ Beta

- Short direction 39 K **OK**
- Long direction 21 K **OK**

Max shear demand

- Short direction 112 K **OK**
- Long direction 53 K **OK**

PTISlab – Cracked Section Analysis – Edge Lift Mode

Cracked Section Analysis - Edge Lift Mode

	Short Direction	Long Direction
Cracked Section Capacity (FT-K)	406.0	260.8
0.5 Moment (FT-K)	295.5	140.2

FEM – Cracked Section Analysis – Edge Lift Mode

Short direction:

Design section moment capacity

Positive moment	400.20 k-ft
Negative moment	-387.74 k-ft

0.5 M @ Beta	189 K-FT OK
0.5 M Max	283 K-FT OK

Long direction:

Design section moment capacity

Positive moment	299.97 k-ft
Negative moment	-548.30 k-ft

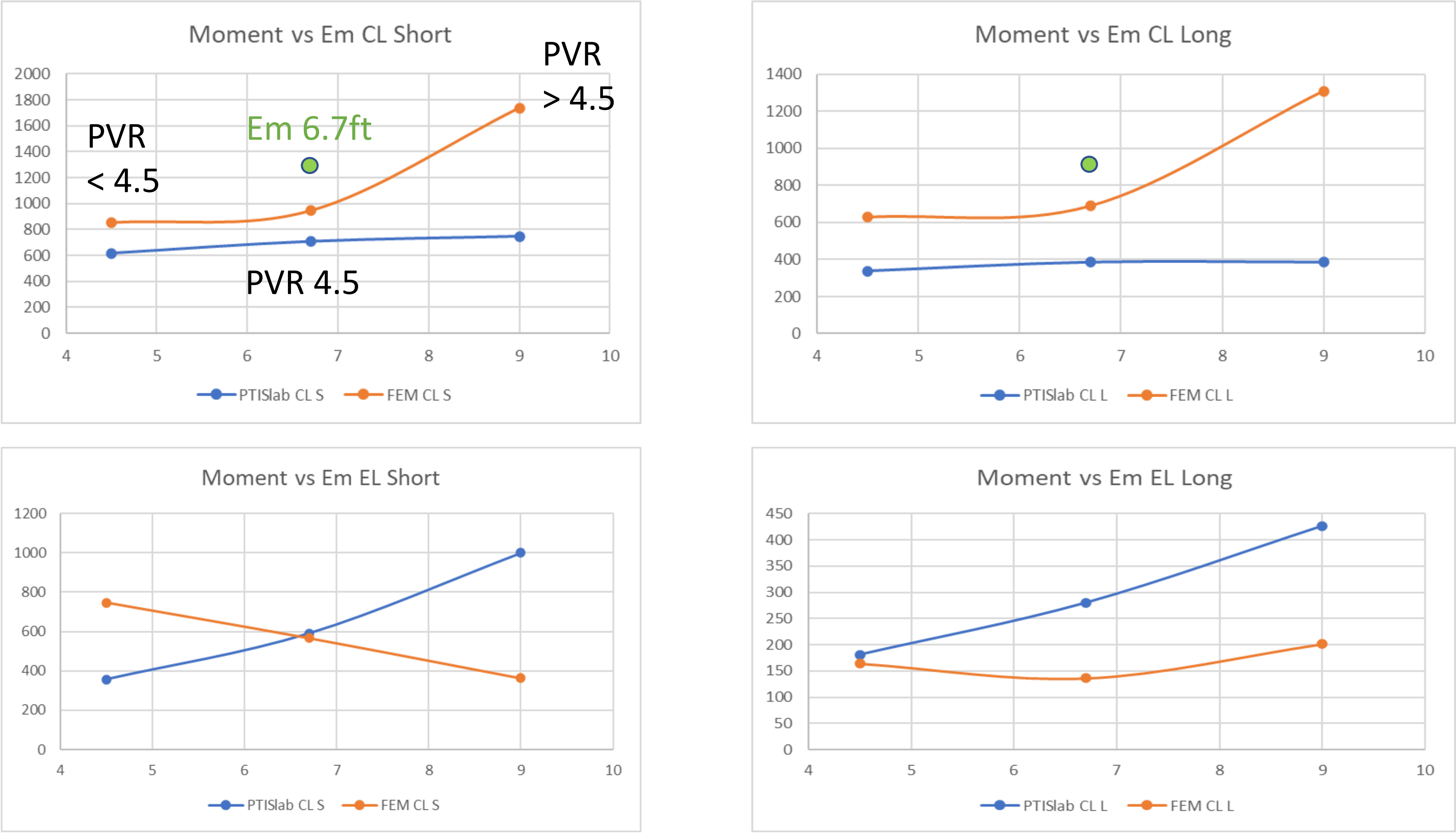
0.5 M @ Beta	14 K-FT OK
0.5 M Max	-68 K-FT OK

Summary Table Comparing Design Values

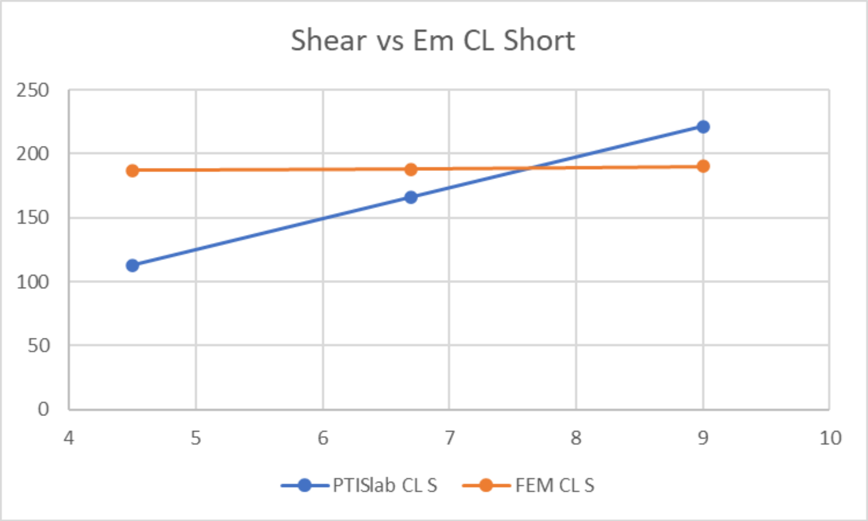
General Design Criteria	PTISlab 3.5	FEM CL Em Limited to 5ft	FEM CL Em 6.7ft
Soil Bearing (uniform) PSF	163	1249	Same
Effective Prestress PSI	64 / 54	69 / 78	Same
Center Lift Mode Design Criteria			
Max Moment @ Beta Short FT-K	707	808	1226
Max Moment @ Beta Long FT-K	384.8	653	928
Max Total Moment Short FT-K	707	946	1227
Max Total Moment Long FT-K	384.8	689	928
Stiffness Check Approach	Rq'd Moment of Inertia	0.6 in Deflection	1.02 in Deflection
Max Shear @ Beta Short K	166	49	29
Max Shear @ Beta Long K	89	40	33
Max Total Shear Short K	166	188	189
Max Total Shear Long K	89	117	122
Edge Lift Mode Design Criteria			
Max Moment @ Beta Short FT-K	591	378	n.a.
Max Moment @ Beta Long FT-K	280	27	n.a.
Max Total Moment Short FT-K	591	566	n.a.
Max Total Moment Long FT-K	280	136	n.a.
Stiffness Check Approach	Req'd Moment of Inertia	0.36 in Deflection	n.a.
Max Shear @ Beta Short K	263	39	n.a.
Max Shear @ Beta Long K	158	20	n.a.
Max Total Shear Short K	263	85	n.a.
Max Total Shear Long K	158	53	n.a.

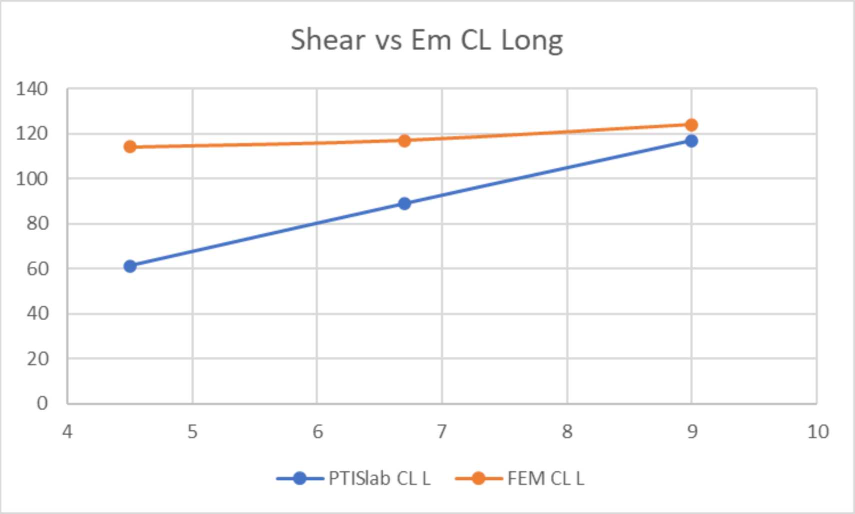
- FEM values higher for soil bearing
- FEM higher for Center Lift (not limited to e_m = 5ft)
- PTISlab higher for Edge Lift (Soil / Slab interaction less understood)

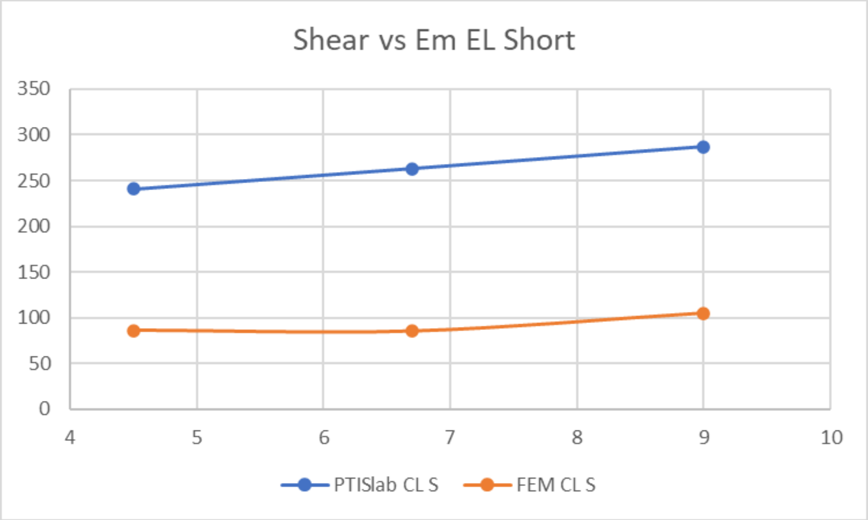
Parametric Study for Different E_m Soil Conditions - Moment

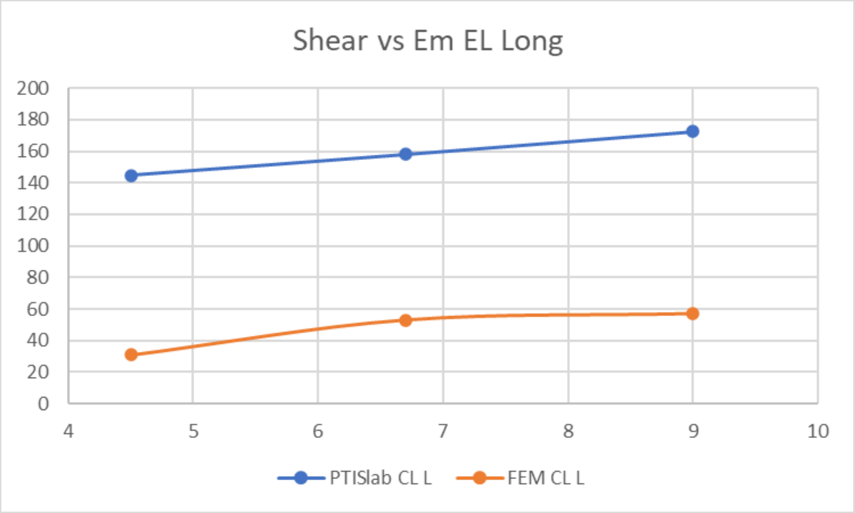


Parametric Study for Different E_m Soil Conditions - Shear

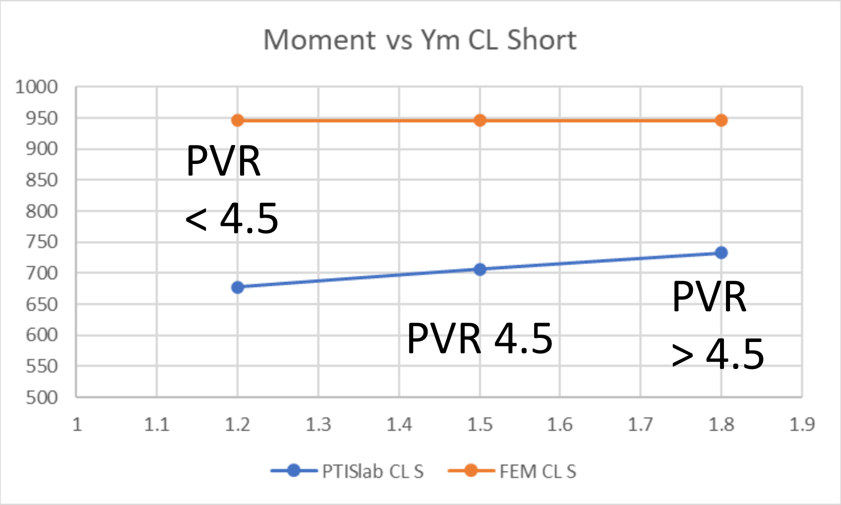


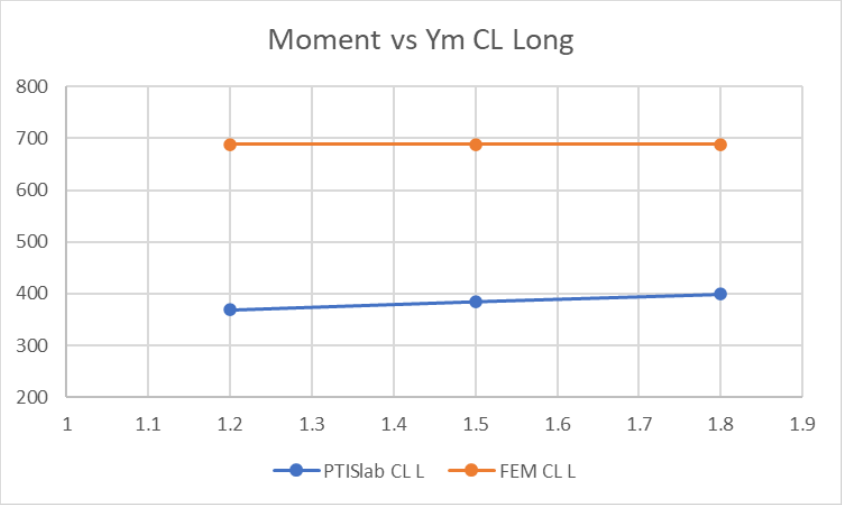


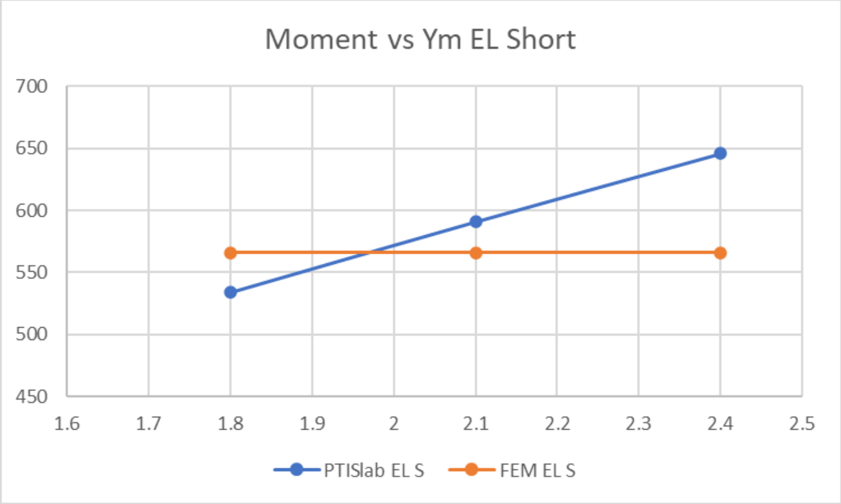


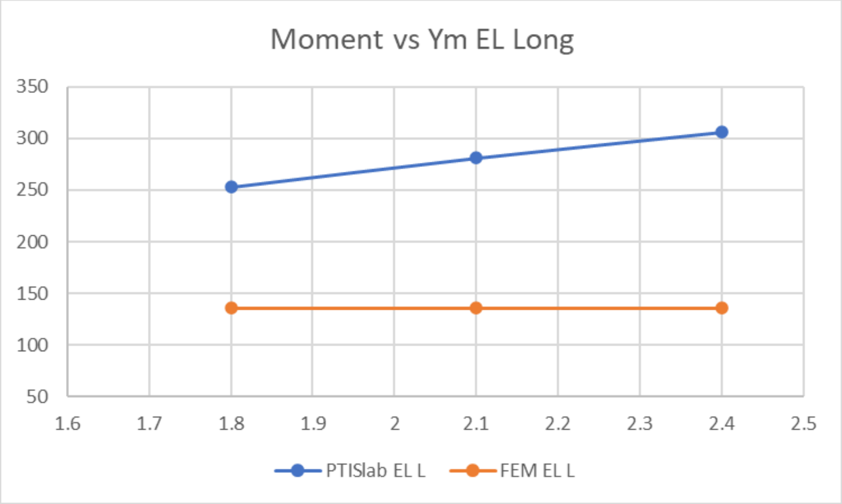


Parametric Study for Different Y_m Soil Conditions - Moment

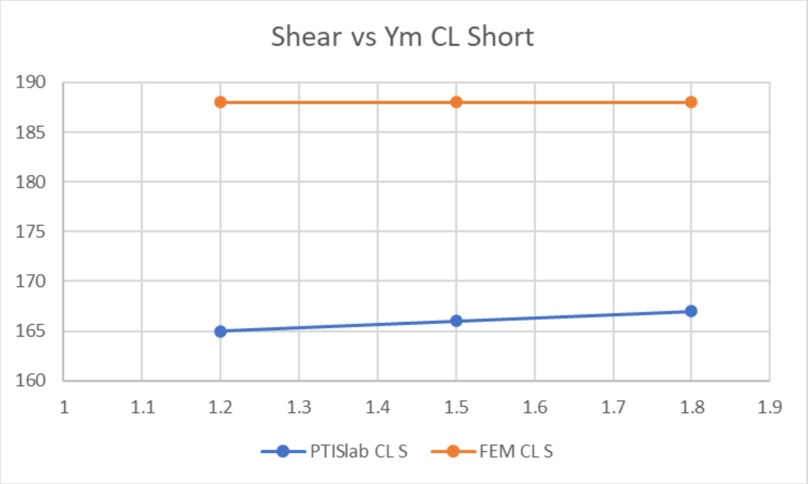


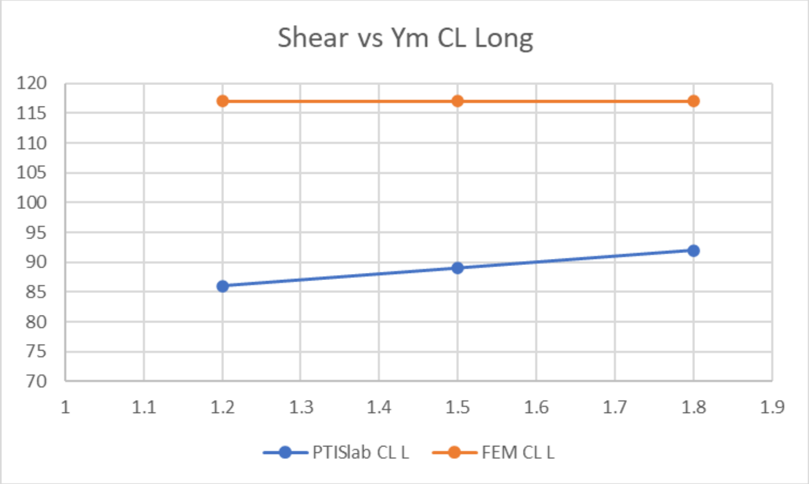


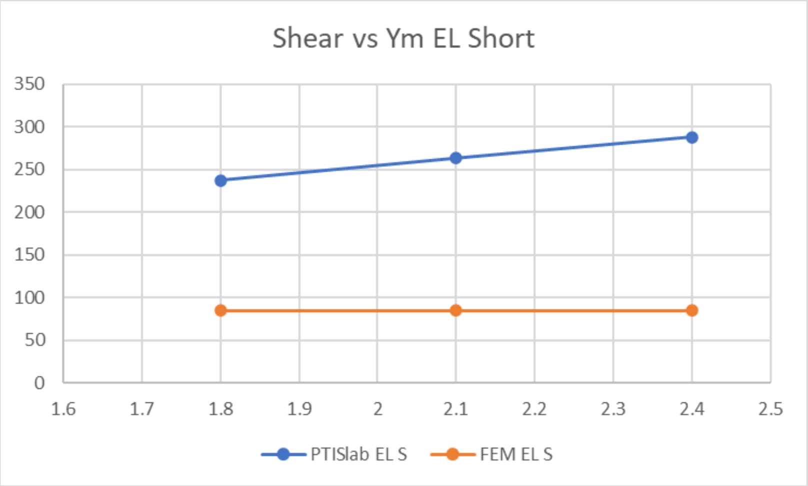


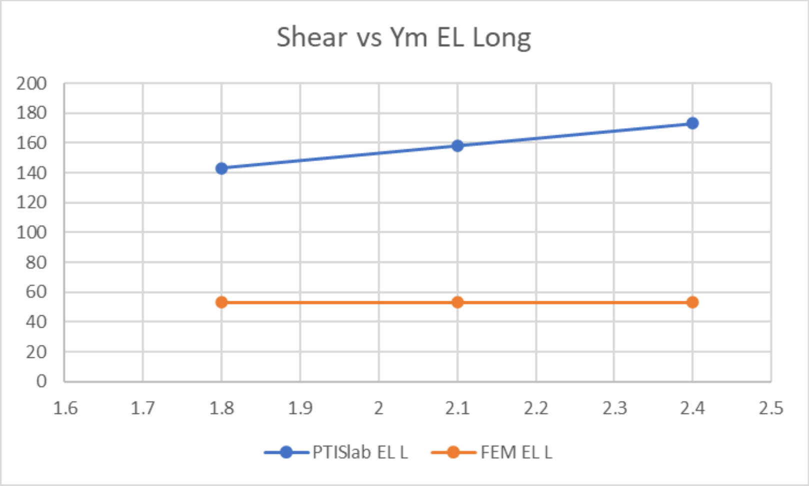


Parametric Study for Different Y_m Soil Conditions - Shear





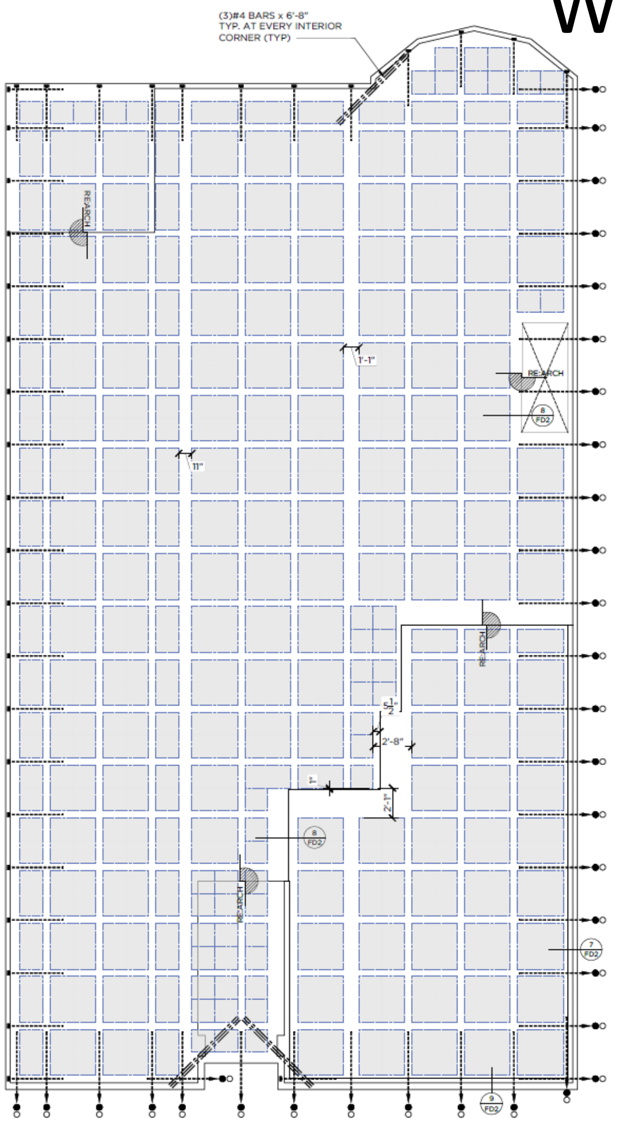




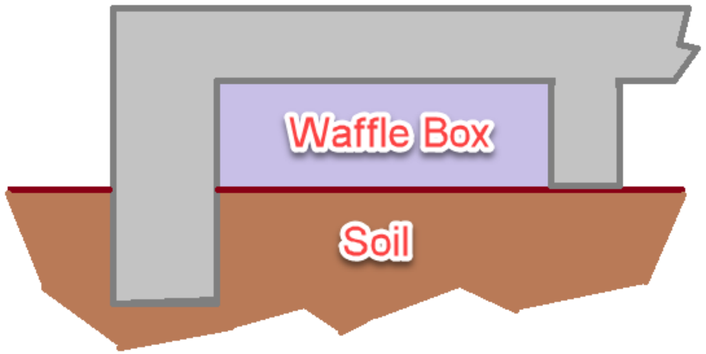
Best Practice for Using FEM to Design Slab-on-Ground Foundations

- Create base model with geometry, loading and tendons
- Reduce effective PT force to account for losses
- Check soil bearing pressure
- Check min 50 psi effective prestress requirement
- Model design strips to allow checking of slab at multiple sections
- Create Center Lift model by removing soil em from perimeter
    - Check moment stresses
    - Check stiffness
    - Check shear
    - Check cracking moment
- Create Edge Lift model by removing soil em from perimeter or by applying edge displacement
    - Calculated deflection limited to ym
    - Run through all design checks

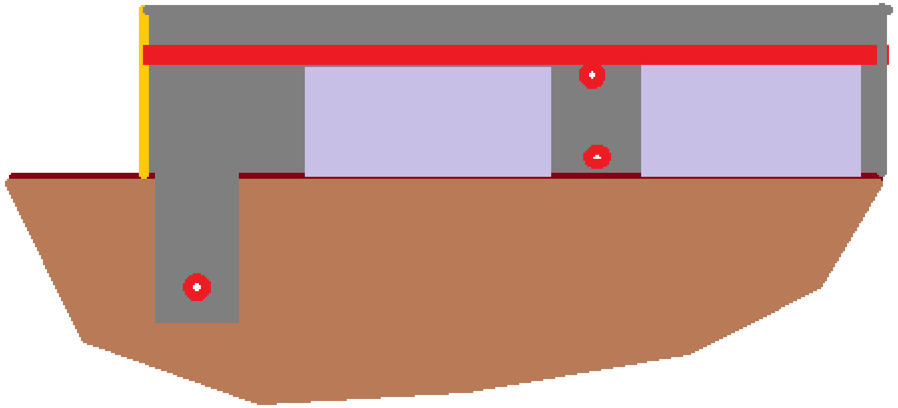
Wafflemat Foundation Designed using FEM



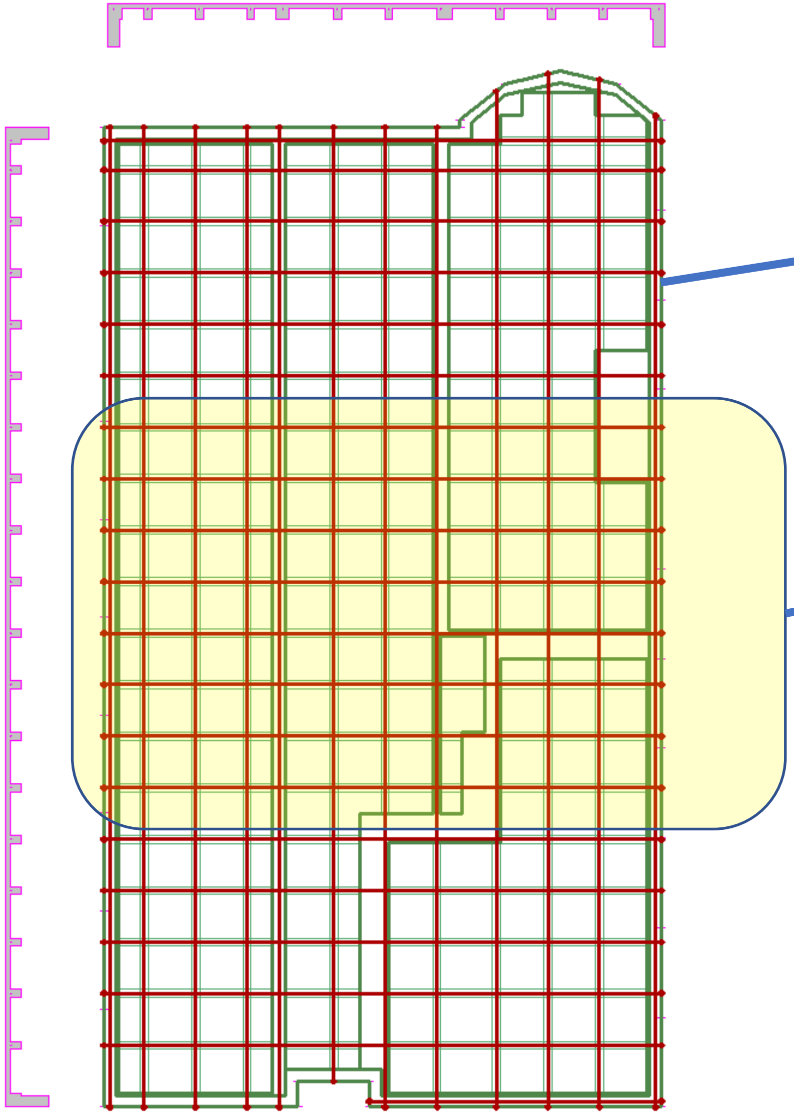
- 36.5 in perimeter beams
- 4 in slab
- 8.5 in boxes
- 12.5 in interior beams

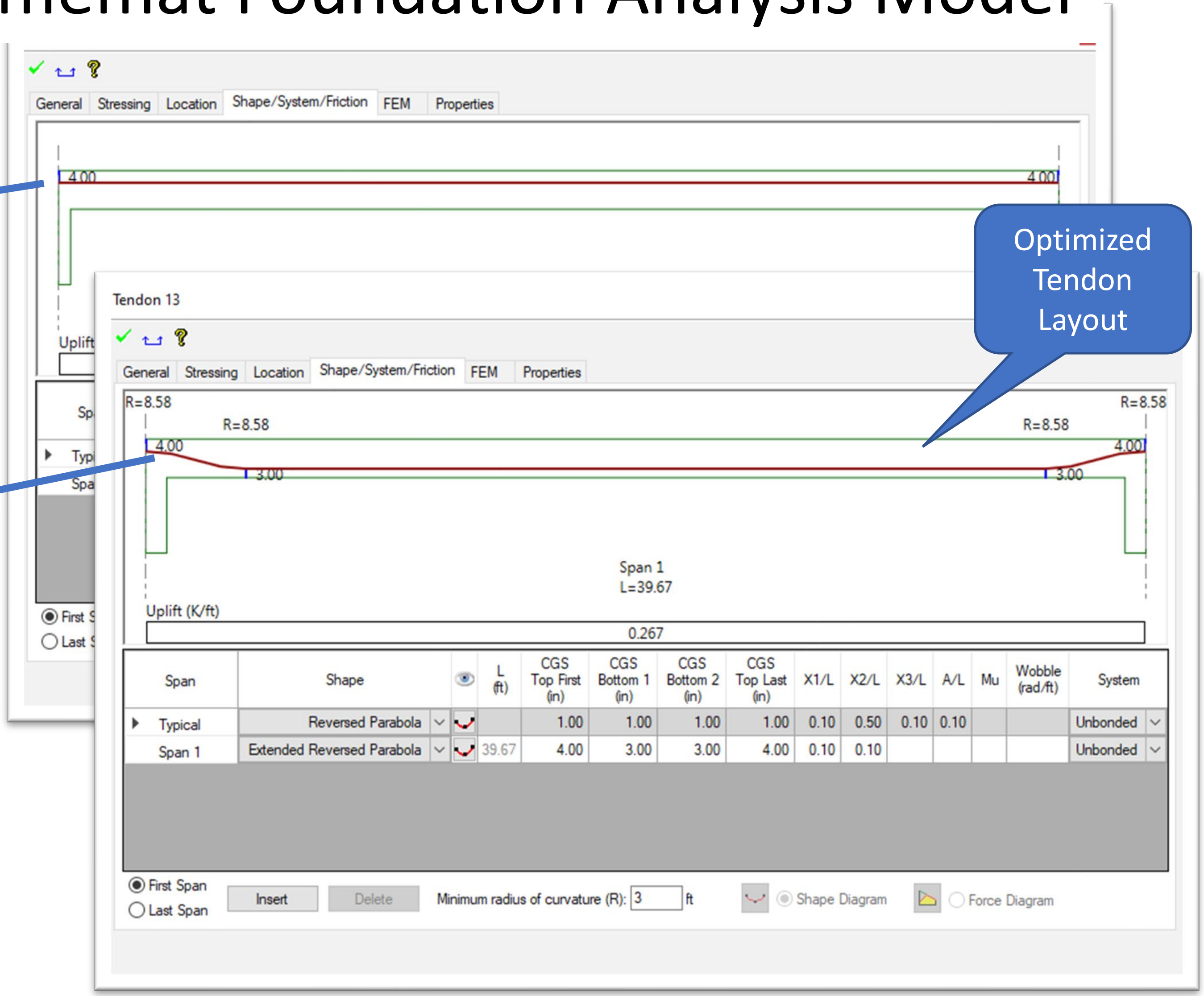


Wafflemat Construction Sequence



FEM Wafflemat Foundation Analysis Model

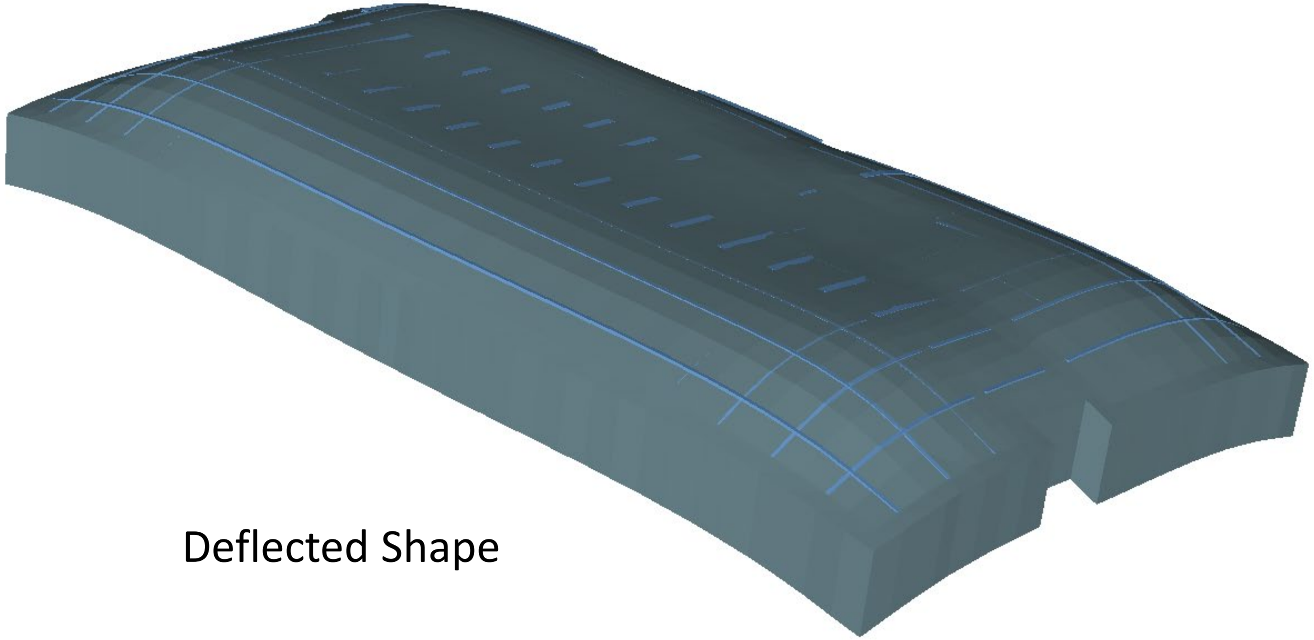




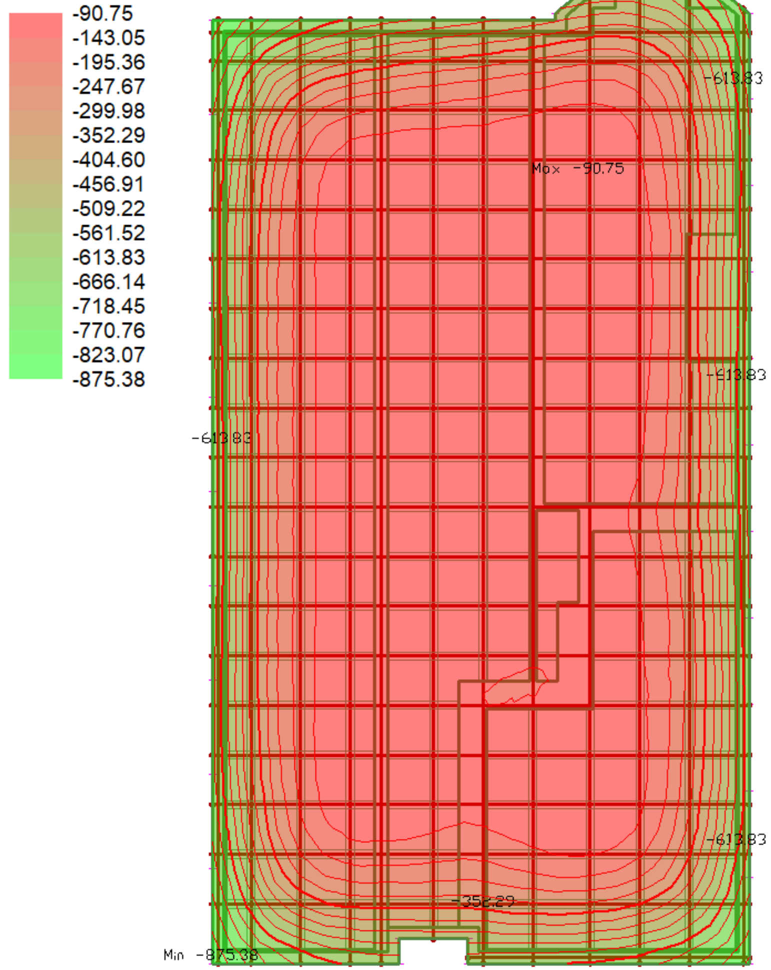
Span	Shape		L (ft)	CGS Top First (in)	CGS Bottom 1 (in)	CGS Bottom 2 (in)	CGS Top Last (in)	X1/L	X2/L	X3/L	A/L	Mu	Wobble (rad/ft)	System
Typical	Reversed Parabola			1.00	1.00	1.00	1.00	0.10	0.50	0.10	0.10			Unbonded
Span 1	Extended Reversed Parabola		39.67	4.00	3.00	3.00	4.00	0.10	0.10					Unbonded

FEM - Soil Bearing Analysis

- Assumes uniform soil support
- Max pressure on soil 875 PSF < allowable 1,500 PSF **OK**



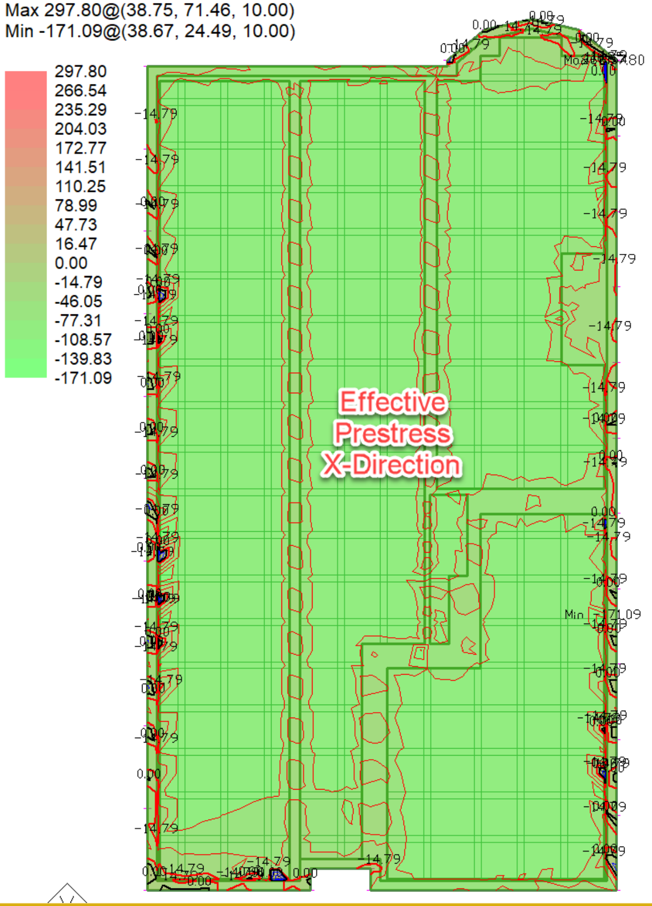
Deflected Shape



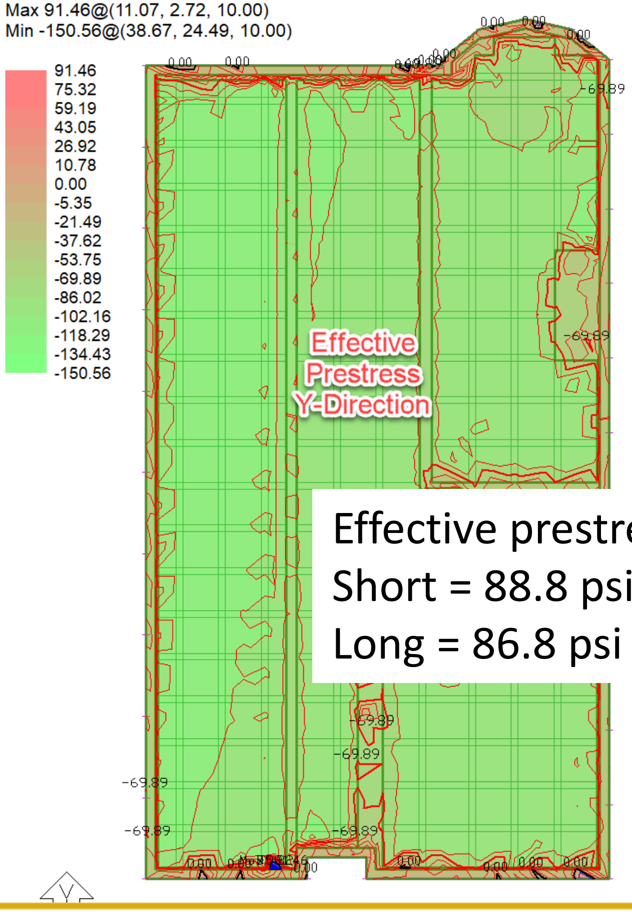
FEM – Effective Prestress Calculations

Reduced PT force applied to model.

Slab, Stress (contour map), Mid-depth along XX (Psi)
Load Combination: PT Only (SERVICE_TOTAL_LOAD)
Max 297.80@(38.75, 71.46, 10.00)
Min -171.09@(38.67, 24.49, 10.00)

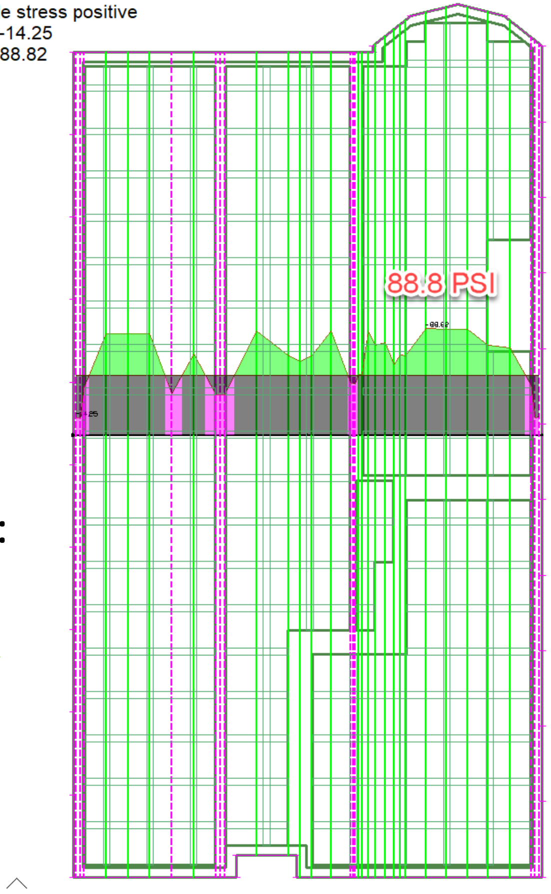


Slab, Stress (contour map), Mid-depth along YY (Psi)
Load Combination: PT Only (SERVICE_TOTAL_LOAD)
Max 91.46@(11.07, 2.72, 10.00)
Min -150.56@(38.67, 24.49, 10.00)

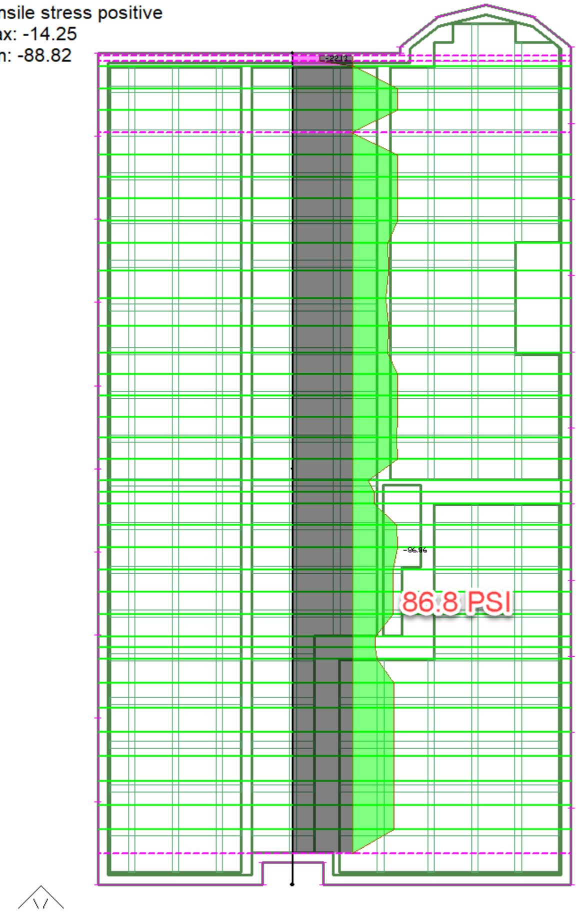


Effective prestress:
Short = 88.8 psi
Long = 86.8 psi **OK**

Design Sections, Stresses, P/A (Precompression FEM) (Psi)
Load Combination: PT Only (SERVICE_TOTAL_LOAD)
Minimum allowable 50.00
Tensile stress positive
Max: -14.25
Min: -88.82



Design Sections, Stresses, P/A (Precompression FEM) (Psi)
Load Combination: PT Only (SERVICE_TOTAL_LOAD)
Minimum allowable 50.00
Tensile stress positive
Max: -14.25
Min: -88.82

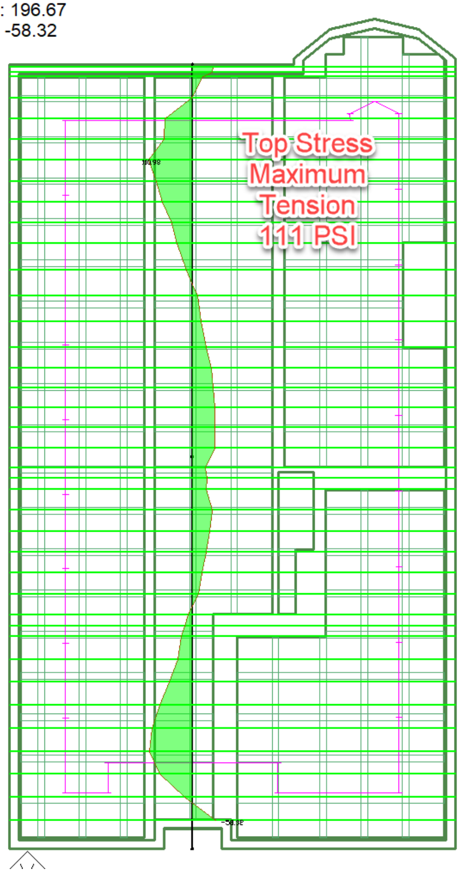


FEM – Moment Analysis – Center Lift Mode

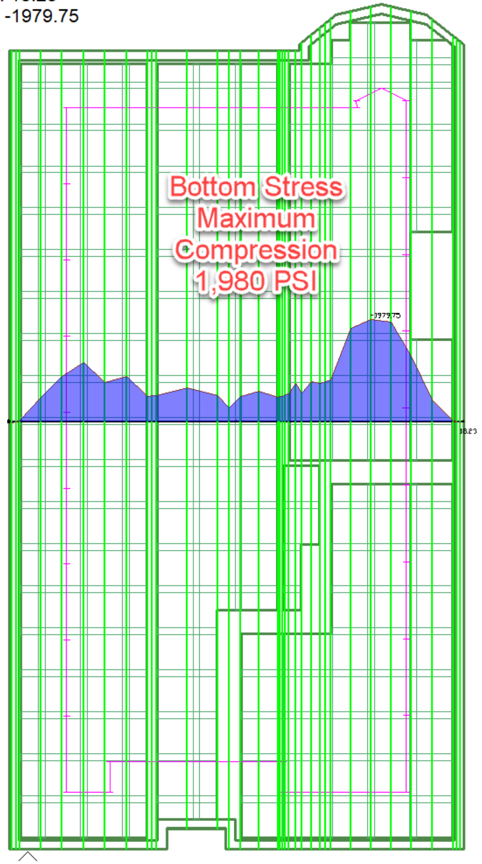
All stresses are within limits – **OK**.

Design Sections, Stresses, Top (Psi)
Load Combination: Service(Total Load) (SERVICE_TOTAL_LOAD)
Tensile stress positive
Max: 196.67
Min: -58.32

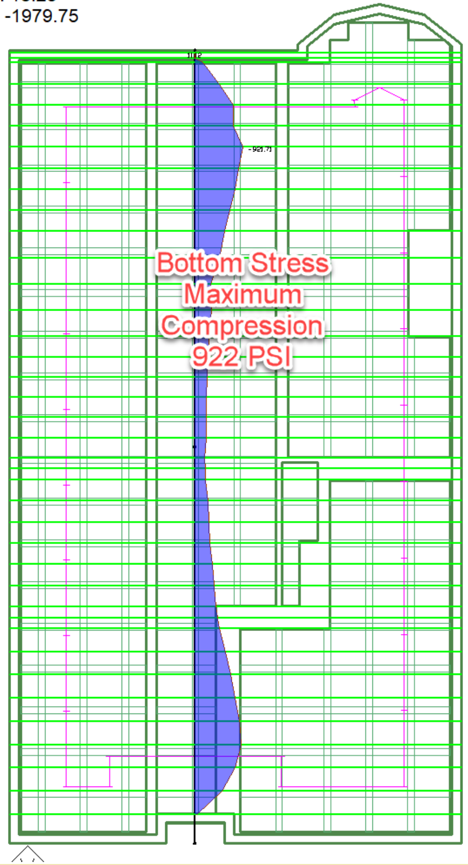
Design Sections, Stresses, Top (Psi)
Load Combination: Service(Total Load) (SERVICE_TOTAL_LOAD)
Tensile stress positive
Max: 196.67
Min: -58.32



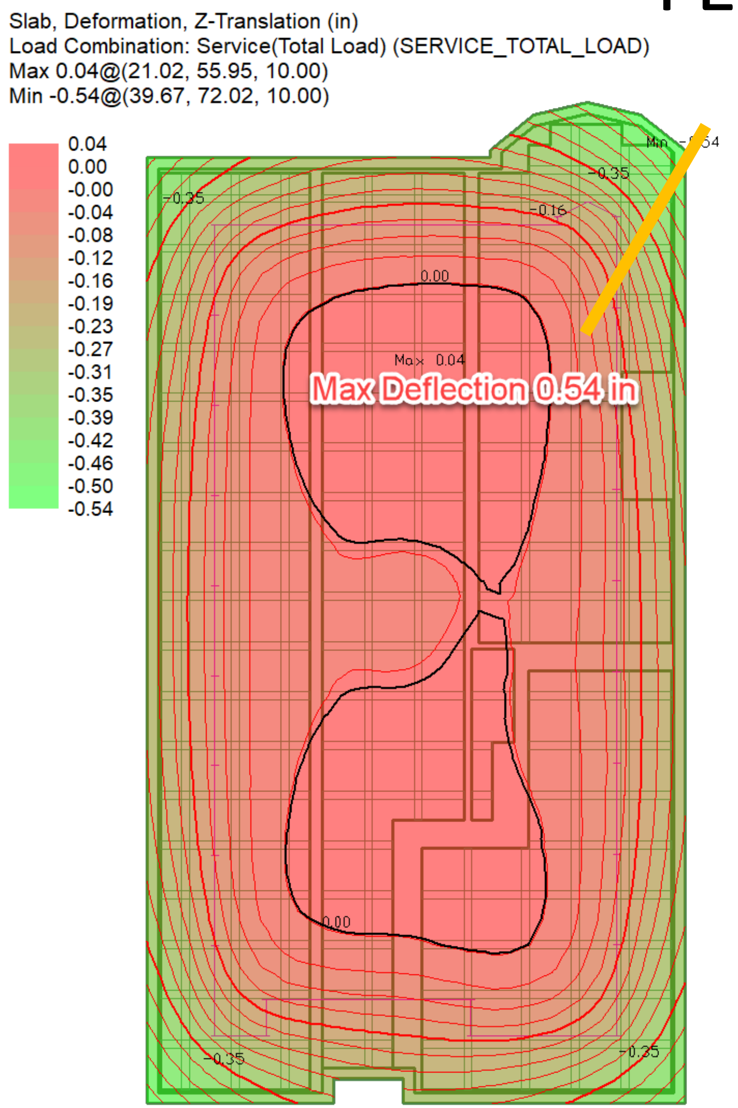
Design Sections, Stresses, Bottom (Psi)
Load Combination: Service(Total Load) (SERVICE_TOTAL_LOAD)
Tensile stress positive
Max: 18.23
Min: -1979.75



Design Sections, Stresses, Bottom (Psi)
Load Combination: Service(Total Load) (SERVICE_TOTAL_LOAD)
Tensile stress positive
Max: 18.23
Min: -1979.75



FEM – Stiffness Analysis – Center Lift Mode



Deflection check:

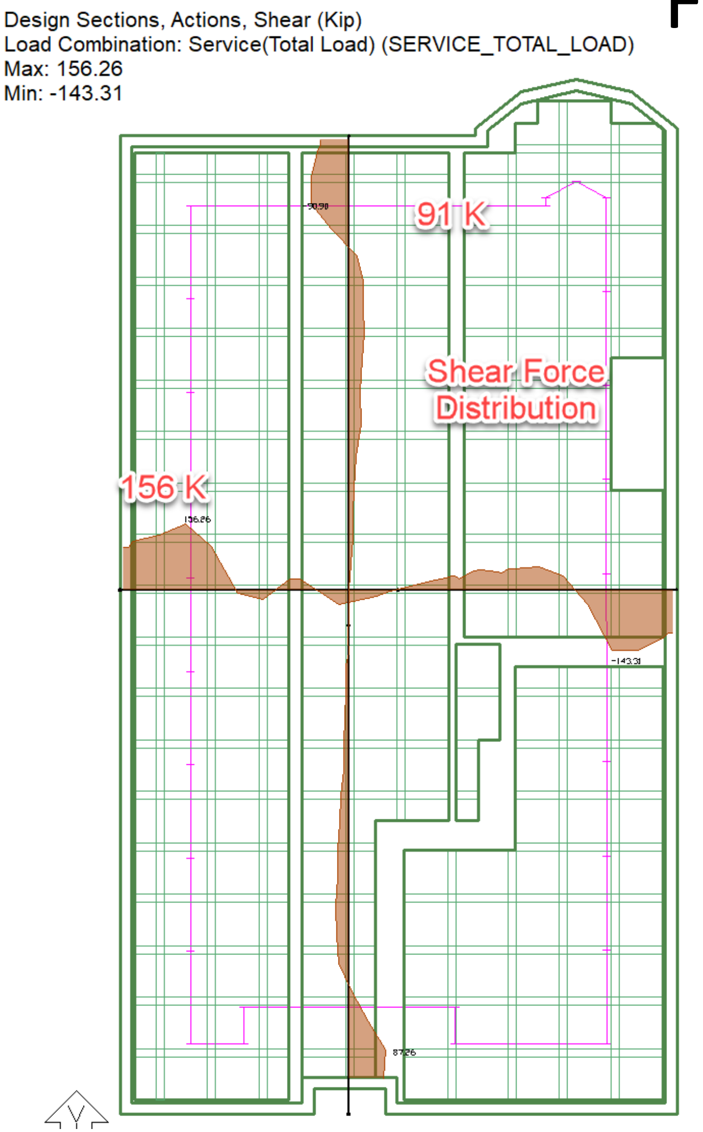
- Cantilever length at max deflection = 16 ft
- Max allowable deflection based on L / 480 = 0.8 in
- Max calculated deflection 0.54 in < 0.8 in **OK**

Stiffness comparison (moments of inertia Inch^4):

- Short direction
  - Traditional ribbed slab 245,897
  - Wafflemat 258,000
- Long direction
  - Traditional ribbed slab 161,491
  - Wafflemat 226,000

- Wafflemat is stiffer in both directions compared to conforming ribbed slab **OK**

FEM – Shear Analysis – Center Lift Mode



Allowable shear stress:

- Short direction 169 psi
- Long direction 169 psi

Max shear capacity:

- Short direction 391 K
- Long direction 335 K

Max shear demand

- Short direction 156 K **OK**
- Long direction 91 K **OK**

FEM – Cracked Section Analysis – Center Lift Mode

Short direction:

Design section moment capacity

Positive moment	171.04 k-ft
Negative moment	-1063.56 k-ft

0.5 M Max -402 K-FT **OK**

Long direction:

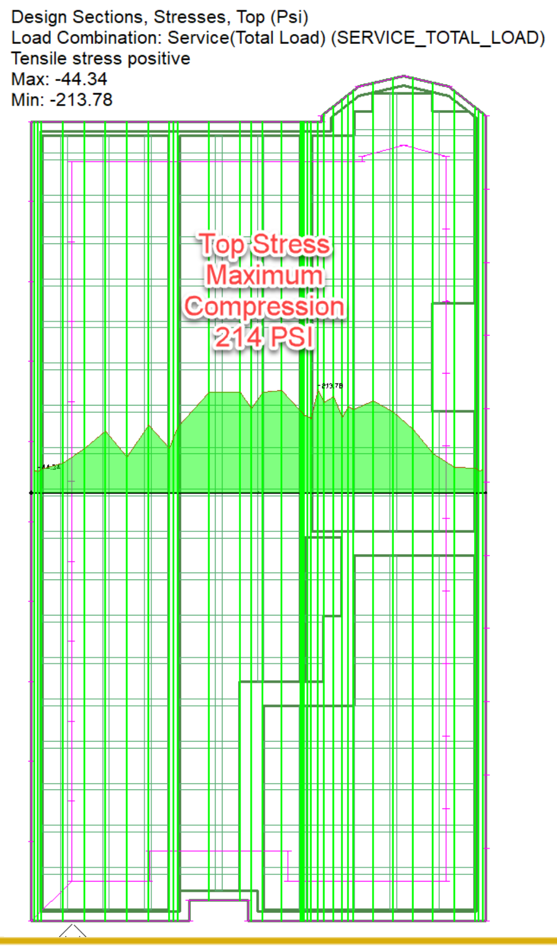
Design section moment capacity

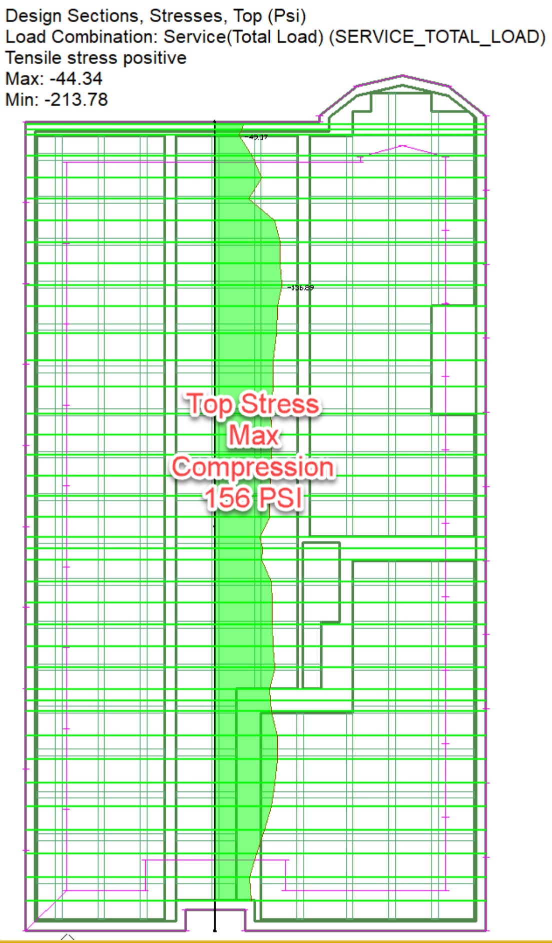
Positive moment	111.00 k-ft
Negative moment	-1020.78 k-ft

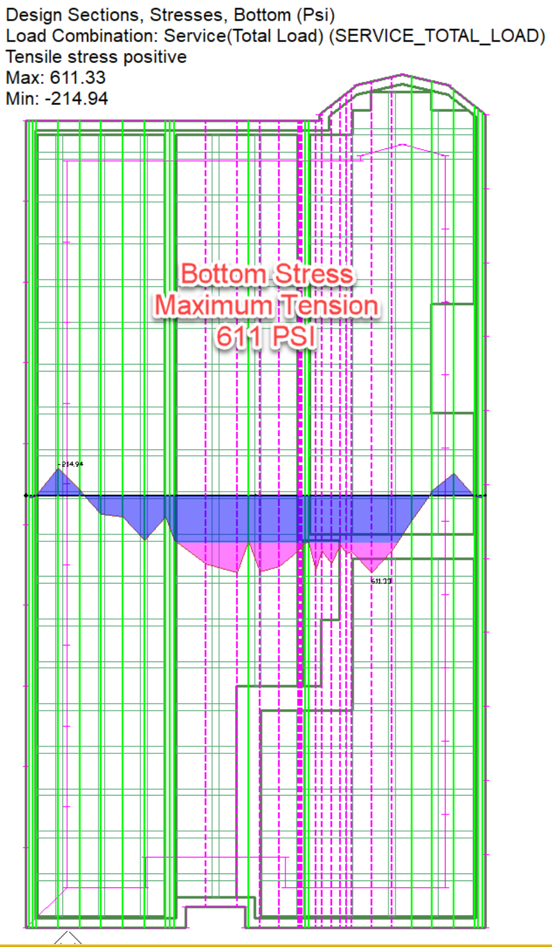
0.5 M Max -267 K-FT **OK**

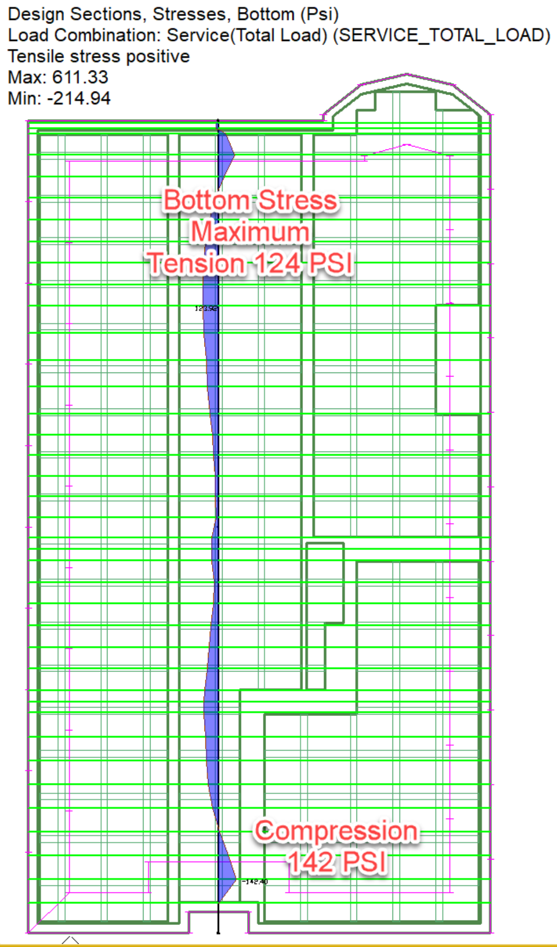
FEM – Moment Analysis – Edge Lift Mode

Bottom tension stresses in Short direction exceed allowable – same as traditional ribbed slab – check cracked deflection.

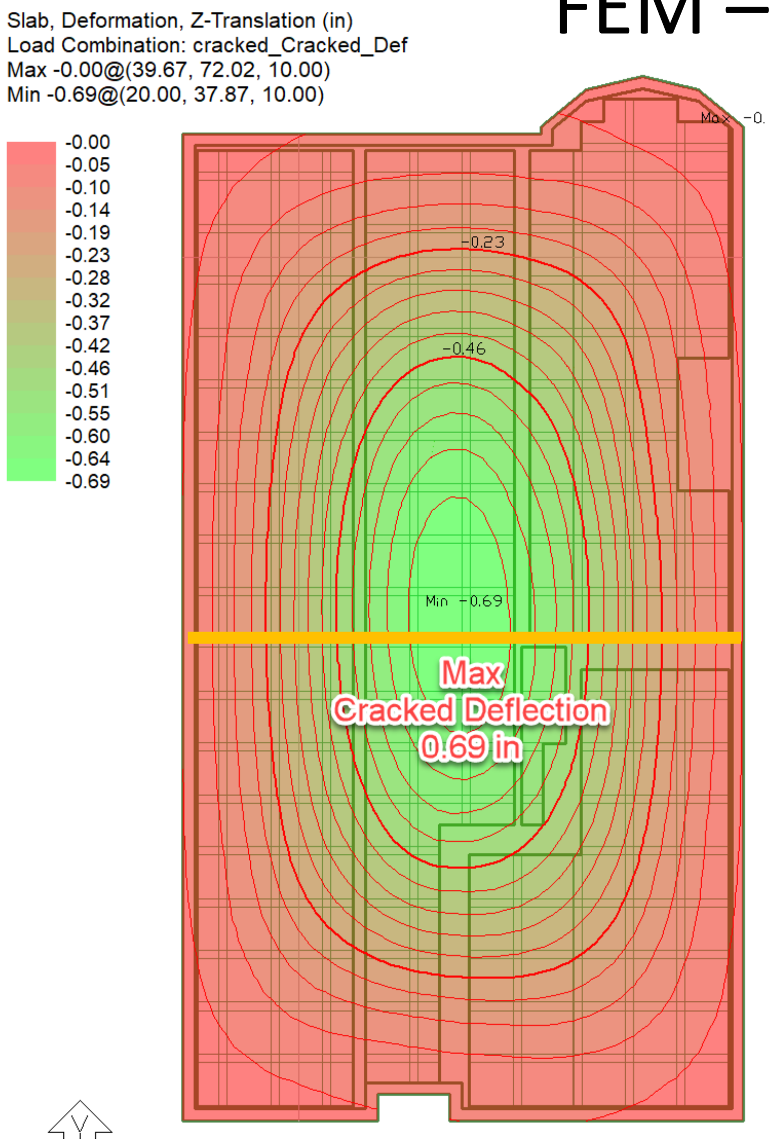








FEM – Stiffness Analysis – Edge Lift Mode



Deflection check:

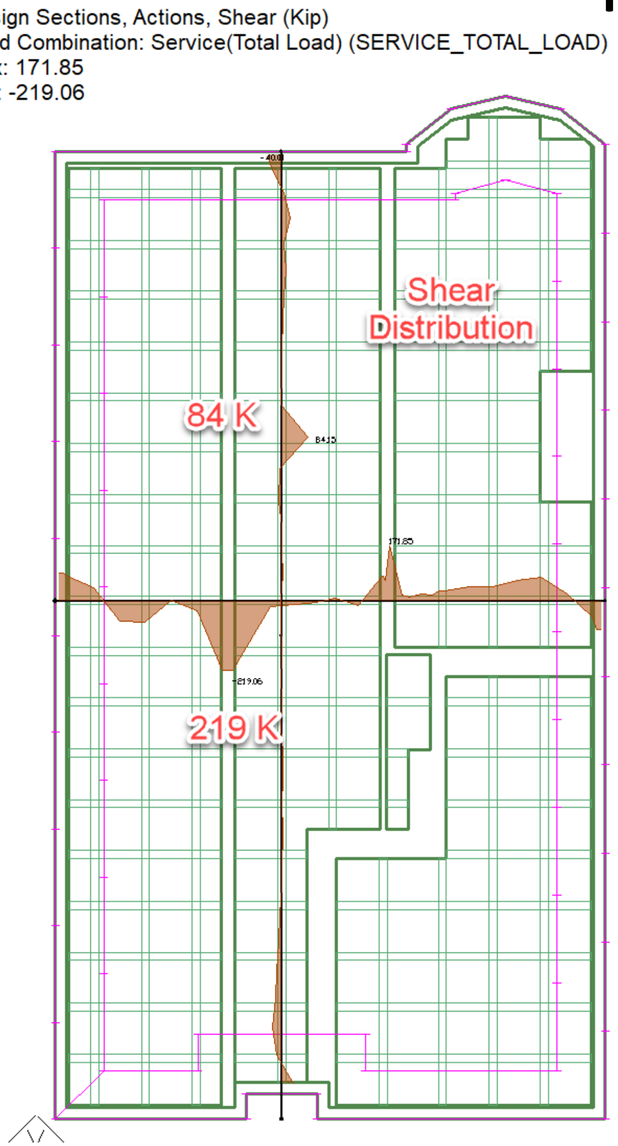
- Span = 40 ft
- Max allowable deflection based on L / 480 = 1.0 in
- Max calculated deflection 0.69 in < 1.0 in **OK**

Stiffness comparison (moments of inertia Inch^4):

- Short direction
  - Traditional ribbed slab 245,897
  - Wafflemat 258,000 **OK**
- Long direction
  - Traditional ribbed slab 161,491
  - Wafflemat 226,000 **OK**

- Wafflemat is stiffer in both directions compared to conforming ribbed slab

FEM – Shear Analysis – Edge Lift Mode



Allowable shear stress:

- Short direction 169 psi
- Long direction 169 psi

Max shear capacity:

- Short direction 391 K
- Long direction 335 K

Max shear demand

- Short direction 219 K **OK**
- Long direction 84 K **OK**

FEM – Cracked Section Analysis – Edge Lift Mode

Short direction:

Design section moment capacity

Positive moment	298.93 k-ft
Negative moment	-958.83 k-ft

0.5 M Max 271 K-FT **OK**

Long direction:

Design section moment capacity

Positive moment	136.37 k-ft
Negative moment	-993.49 k-ft

0.5 M Max 60 K-FT **OK**

Concluding Remarks

- The FEM method of analysis and design is a valid option for slab-on-ground designs
- We benchmarked the PTISlab method against the FEM method for a 40x70 ribbed slab
- A best practices design methodology based on FEM was presented
- Using the FEM method, we successfully analyzed and validated a wafflemat design

This concludes the Educational Content of this activity.

Florian Aalami
florian@ptstructures.com

PT-Structures

Anna Olveda
anna@wafflemat.com

WAFFLEMAT™
A SMARTSENSE STRUCTURAL SYSTEM