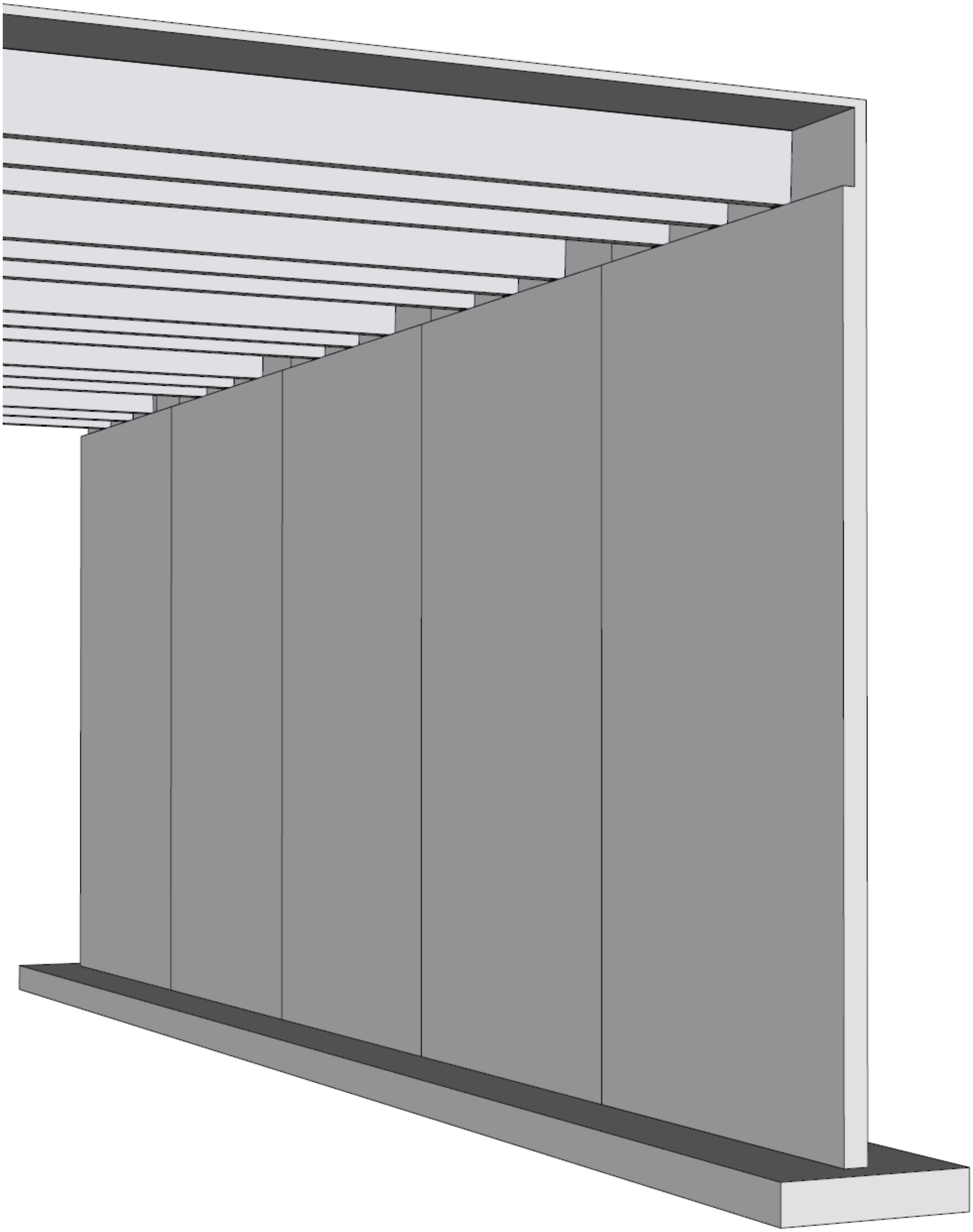
Reinforced Concrete Tilt-Up Wall Panel Analysis and Design (ACI 318-14 – ACI 551)



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Tilt-up is form of construction with increasing popularity owing to its flexibility and economics. Tilt-up concrete is essentially a precast concrete that is site cast instead of traditional factory cast concrete members. A structural reinforced concrete tilt-up wall panel in a single-story warehouse (big-box) building provides gravity and lateral load resistance for the following applied loads from three roof joists bearing in wall pockets in addition to the wind:

Roof dead load	= 2.4 kip per joist
Roof live load	= 2.5 kip per joist
Wind load	= 27.2 psf (Out-of-Plane)

The assumed tilt-up wall panel section and reinforcement are investigated after analysis to verify suitability for the applied loads then compared with numerical analysis results obtained from spWall engineering software program from StructurePoint.

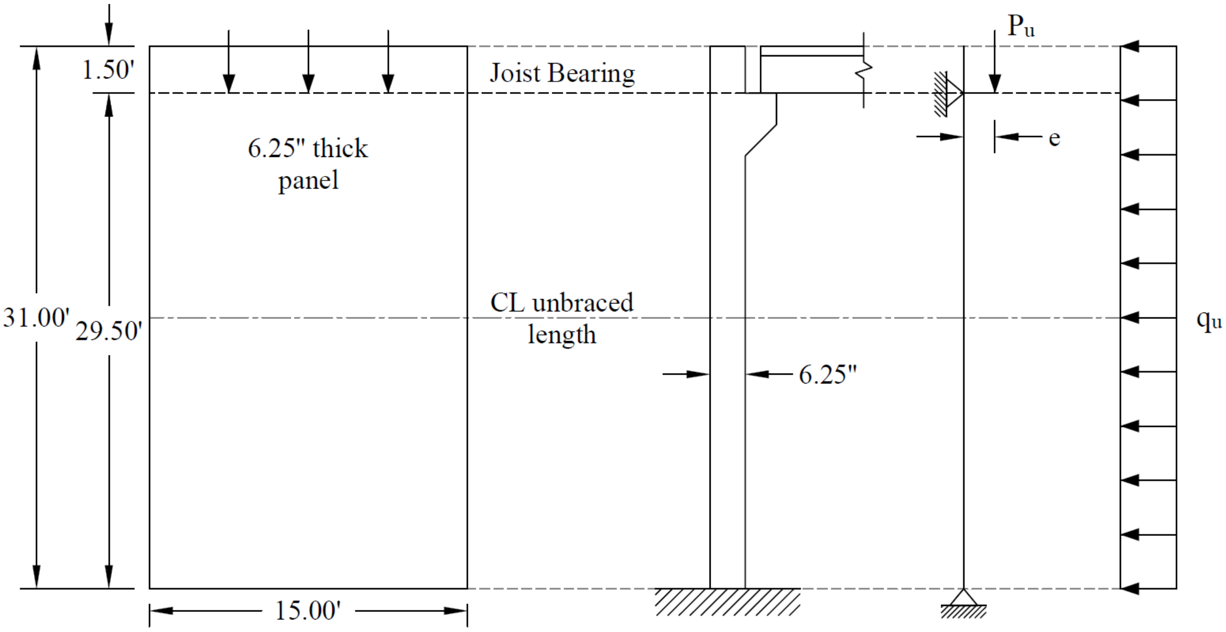


Figure 1 – Reinforced Concrete Tilt-Up Wall Panel Geometry

Contents

Code

Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)

Reference

- Design Guide for Tilt-Up Concrete Panels, ACI 551.2R-15, 2015, Example B.1
- spWall Engineering Software Program Manual v10.00, STRUCTUREPOINT, 2022

Design Data

f_c' = 4,000 psi normal weight concrete (w_c = 150 pcf)

f_y = 60,000 psi

Wall length = l_c = 31 ft – 1.5 ft = 29.5 ft

Assumed wall thickness = 6.25 in.

Assumed eccentricity = e_{cc} = 3 in.

Assumed vertical reinforcement: 16 #6 (single layer)

1. Minimum Vertical Reinforcement

$$\rho_l = \frac{A_{v,vertical}}{b \times h} = \frac{7.04}{(15 \times 12) \times 6.25} = 0.0063$$ ***ACI 318-14 (2.2)***

$$\rho_{l,\min} = 0.0015$$ ***ACI 318-14 (Table 11.6.1)***

$$\rho_l = 0.0063 \geq \rho_{l,\min} = 0.0015 \text{ (o.k)}$$

$$s_{l,\max} = \text{smallest of} \begin{Bmatrix} 3 \times h \\ 18 \text{ in.} \end{Bmatrix} = \text{smallest of} \begin{Bmatrix} 3 \times 6.25 \\ 18 \text{ in.} \end{Bmatrix} = \text{smallest of} \begin{Bmatrix} 18.75 \text{ in.} \\ 18 \text{ in.} \end{Bmatrix} = 18 \text{ in.}$$ ***ACI 318-14 (11.7.2.1)***

$$s_{l,provided} = \frac{15 \times 12}{16} = 11.25 \text{ in.} \leq s_{l,\max} = 18 \text{ in.} \; (\textbf{o.k.})$$

2. Alternative Method for Out-of-Plane Slender Wall Analysis ACI 318 Provisions

The design guide for tilt-up concrete panels ACI 551 states that tilt-up concrete walls can be analyzed using the provisions of Chapter 14 of the ACI 318-11, the same provisions are presented in Chapter 11 of the ACI 318-14. Most walls, and especially slender walls, are widely evaluated using the “Alternative Method for Out-of-Plane Slender Wall Analysis” in Section 11.8 of the ACI 318-14. The method is applicable when the conditions summarized below are met:

- The cross section shall be constant over the height of the wall ***ACI 318-14 (11.8.1.1(a))***
- The wall can be designed as simply supported ***ACI 318-14 (11.8.2.1)***
- Maximum moments and deflections occurring at midspan ***ACI 318-14 (11.8.2.1)***
- The wall must be axially loaded ***ACI 318-14 (11.8.2.1)***
- The wall must be subjected to an out-of-plane uniform lateral load ***ACI 318-14 (11.8.2.1)***
- The wall shall be tension-controlled ***ACI 318-14 (11.8.1.1(b))***
- The reinforcement shall provide design strength greater than cracking strength ***ACI 318-14 (11.8.1.1(c))***
- P_u at the midheight section does not exceed $0.06 f_c' A_g$ ***ACI 318-14 (11.8.1.1(d))***
- Out-of-plane deflection due to service loads including $P\Delta$ effects does not exceed $l_c / 150$ ***ACI 318-14 (11.8.1.1(e))***

3. Tilt-Up Wall Structural Analysis

Using 11.8 provisions, calculate factored loads as follows for each of the considered load combinations:

3.1. Applied loads

$$\text{Wall self-weight} = \frac{6.25}{12}\times 15\times\left(\frac{29.5}{2}+1.5\right)\times 150\times\frac{1\text{ kip}}{1000\text{ lb}} = 19.04\text{ kip}$$

$$P_{DL} = 3\times 2.4 = 7.20\text{ kip}$$

$$P_{LL} = 3\times 2.5 = 7.50\text{ kip}$$

$$w = 27.2\text{ lb/ft}^2$$

3.2. Maximum wall forces

Calculate maximum factored wall forces in accordance with 11.8.3.1 including moment magnification due to second order (P-Δ) effects. Load combination U = 1.2 *D* + 1.6 L_r + 0.5 *W* is considered in this example:

$$P_{ua} = 1.2\times 7.20 + 1.6\times 7.50 = 20.64\text{ kip}$$

$$P_{um} = 20.64 + 1.2\times 19.04 = 43.49\text{ kip}$$

$$w_u = 0.5\times 27.2\times 15\text{ ft}\times\frac{1\text{ kip}}{1000\text{ lb}} = 0.204\text{ kip/ft}$$

$$M_u = \frac{M_{ua}}{1-\dfrac{5\times P_u\times l_c^2}{0.75\times 48\times E_c\times I_{cr}}}$$

ACI 318-14 (Eq. 11.8.3.1(d))

$$M_{ua} = \frac{w_u\times l_c^2}{8}+\frac{P_{ua}\times e}{2} = \frac{0.204\times(29.5)^2}{8}+\frac{20.64\times 3}{2\times 12} = 24.77\text{ ft-kip}$$

Where M_{ua} is the maximum factored moment at midheight of wall due to lateral and eccentric vertical loads, not including PΔ effects. ***ACI 318-14 (11.8.3.1)***

$$E_c = 57{,}000\times\sqrt{f_c^{'}} = 57{,}000\times\sqrt{4{,}000} = 3{,}605{,}000\text{ psi}$$

ACI 318-14 (19.2.2.1(b))

$$I_{cr} = n\times A_{se}\times(d-c)^2+\frac{l_w\times c^3}{3}$$

ACI 318-14 (11.8.3.1(c))

$$n = \frac{E_s}{E_c} = \frac{29{,}000}{3{,}605} = 8.0 > 6.0\ (\textbf{o.k.})$$

ACI 318-14 (11.8.3.1)

Calculate the effective area of longitudinal reinforcement in a slender wall for obtaining an approximate cracked moment of inertia.

$$A_{se} = A_s + \frac{P_{um} \times h}{2 \times f_y \times d} = 7.04 + \frac{43.49 \times 6.25}{2 \times 60 \times (6.25/2)} = 7.76 \text{ in.}^2$$ ***ACI 318-14 (R11.8.3.1)***

The following calculation are performed with the effective area of steel in lieu of the actual area of steel.

$$a = \frac{A_{se} \times f_y}{0.85 \times f_c^{'} \times b} = \frac{7.76 \times 60}{0.85 \times 4 \times (15 \times 12)} = 0.761 \text{ in.}$$

$$c = \frac{a}{\beta_1} = \frac{0.761}{0.85} = 0.896 \text{ in.}$$

$$\frac{c}{d} = \frac{0.896}{3.13} = 0.287 < 0.375 \therefore \text{ tension-controlled}$$ ***ACI 318-14 (R21.2.2)***

$$\phi = 0.9$$ ***ACI 318-14 (Table 21.2.2)***

$$I_{cr} = 8.0 \times 7.76 \times (3.13 - 0.896)^2 + \frac{(15 \times 12) \times 0.896^3}{3} = 353.56 \text{ in.}^4$$ ***ACI 318-14 (11.8.3.1(c))***

$$M_u = \frac{M_{ua}}{1 - \dfrac{P_{um}}{0.75 \times K_b}}$$ ***ACI 318-14 (Eq. 11.8.3.1(d))***

$$K_b = \frac{48 \times E_c \times I_{cr}}{5 \times l_c^2} = \frac{48 \times 3605 \times 353.56}{5 \times (29.5 \times 12)^2} = 97.64 \text{ kip}$$

$$M_u = \frac{24.77}{1 - \dfrac{43.49}{0.75 \times 97.64}} = 61.00 \text{ ft-kip}$$

3.3. Tension-controlled verification ***ACI 318-14 (11.8.1.1(b))***

$$P_n = \frac{P_{um}}{\phi} = \frac{43.49}{0.9} = 48.32 \text{ kips}$$

$$a = \frac{A_{se,w} \times f_y}{0.85 \times f_c^{'} \times l_w} = \frac{\dfrac{P_n \times h}{2 \times d} + A_s \times f_y}{0.85 \times f_c^{'} \times l_w} = \frac{\dfrac{48.32 \times 6.25}{2 \times 3.13} + 7.04 \times 60}{0.85 \times 4 \times 15 \times 12} = 0.769 \text{ in.}$$

$$c = \frac{a}{\beta_1} = \frac{0.769}{0.85} = 0.905 \text{ in.}$$

$$\varepsilon_t = \left(\frac{0.003}{c}\right) \times d_t - 0.003 = \left(\frac{0.003}{0.905}\right) \times 3.13 - 0.003 = 0.0075 > 0.0050$$

Therefore, section is tension controlled ***ACI 318-14 (Table 21.2.2)***

4. Tilt-Up Wall Cracking Moment Capacity (M_{cr})

Determine f_r = Modulus of rapture of concrete and I_g = Moment of inertia of the gross uncracked concrete section to calculate M_{cr}

$$f_r = 7.5\lambda\sqrt{f_c^{'}} = 7.5\times1.0\times\sqrt{4,000} = 474.3 \text{ psi}$$ ***ACI 318-14 (19.2.3.1)***

$$I_g = \frac{l_w h^3}{12} = \frac{(15\times12)\times6.25^3}{12} = 3662 \text{ in.}^4$$

$$y_t = \frac{h}{2} = \frac{6.25}{2} = 3.13 \text{ in.}$$

$$M_{cr} = \frac{f_r I_g}{y_t} = \frac{474.3\times3662}{3.13}\times\frac{1}{1000}\times\frac{1}{12} = 46.32 \text{ ft-kip}$$ ***ACI 318-14 (24.2.3.5(b))***

5. Tilt-Up Wall Flexural Moment Capacity (ϕM_n)

For load combination #1:

$$M_n = A_{se}\times f_y\times\left(d-\frac{a}{2}\right) = 7.76\times60\times\left(3.13-\frac{0.761}{2}\right) = 1278.58 \text{ in.-kip} = 106.55 \text{ ft-kip}$$

It was shown previously that the section is tension controlled → ϕ = 0.9

$$\phi M_n = \phi\times M_n = 0.9\times106.55 = 95.89 \text{ ft-kip} > M_u = 61.00 \text{ ft-kip } (\textbf{o.k.})$$ ***ACI 318-14 (11.5.1.1(b))***

$$\phi M_n = 95.89 \text{ ft-kip} > M_{cr} = 46.32 \text{ ft-kip } (\textbf{o.k.})$$ ***ACI 318-14 (11.8.1.1(c))***

$$\Delta_u = \frac{M_u}{0.75\times K_b} = \frac{61.00\times12}{0.75\times97.64} = 9.995 \text{ in.}$$ ***ACI 318-14 (11.8.3.1(b))***

6. Tilt-Up Wall Vertical Stress Check

$$\frac{P_{um}}{A_g} = \frac{43.49\times1000}{6.25\times(15\times12)} = 38.66 \text{ psi} < 0.06\times f_c^{'} = 0.06\times4,000 = 240 \text{ psi } (\textbf{o.k.})$$ ***ACI 318-14 (11.8.1.1(d))***

7. Tilt-Up Wall Shear Stress Check

In-plane shear is not evaluated since in-plane shear forces are not applied in this example. Out-of-plane shear due to lateral load should be checked against the shear capacity of the wall. By inspection of the maximum shear forces, it can be determined that the maximum shear force is under 10 kips. The wall has a shear capacity approximately 140 kips and no detailed calculations are required by engineering judgement. (See Figure 10 for detailed shear force diagram)

8. Tilt-Up Wall Mid-Height Deflection (Δ_s)

The maximum out-of-plane deflection (Δ_s) due to service lateral and eccentric vertical loads, including PΔ effects, shall not exceed $l_c/150$. Where Δ_s is calculated as follows: ***ACI 318-14 (11.8.1.1(e))***

$$\Delta_s = \begin{cases} \dfrac{2}{3}\Delta_{cr} + \dfrac{M_a - \dfrac{2}{3}M_{cr}}{M_n - \dfrac{2}{3}M_{cr}} \times \left(\Delta_n - \dfrac{2}{3}\Delta_{cr}\right) & \text{When} \quad M_a > \dfrac{2}{3}M_{cr} \\ \left(\dfrac{M_a}{M_{cr}}\right)\Delta_{cr} & \text{When} \quad M_a < \dfrac{2}{3}M_{cr} \end{cases}$$ ***ACI 318-14 (Table 11.8.4.1)***

Where M_a is the maximum moment at mid-height of wall due to service lateral and eccentric vertical loads including $P\Delta$ effects.

$$M_a = M_{sa} + P_s\Delta_s$$

$$M_{sa} = \frac{w_s \times l_c^2}{8} + \frac{P_a \times e}{2} = \frac{\left(0.7 \times \dfrac{27.2}{1.6} \times 15\right) \times (29.5)^2}{8 \times 1000} + \frac{(7.20) \times 3/12}{2} = 20.32 \text{ ft-kip}$$

$$P_s = P_{DL} + \text{wall self-weight} = 7.20 + 19.04 = 26.24 \text{ kip}$$

$$M_{cr} = \frac{f_r I_g}{y_t} = 46.32 \text{ ft-kip (as calculated previously)}$$ ***ACI 318-14 (24.2.3.5(b))***

$$\Delta_{cr} = \frac{5}{48} \times \frac{M_{cr} \times l_c^2}{E_c \times I_g} = \frac{5}{48} \times \frac{46.32 \times 12 \times (29.5 \times 12)^2}{3,605 \times 3662} = 0.550 \text{ in.}$$ ***ACI 318-14 (11.8.4.3(a))***

Δ_s will be calculated by trial-and-error method since Δ_s is a function of M_a and M_a is a function of Δ_s.

$$\text{Assume } M_{sa} < \frac{2}{3}M_{cr}$$

$$\text{Assume } \Delta_s = \left(\frac{M_{sa}}{M_{cr}}\right)\Delta_{cr} = \left(\frac{20.32}{46.32}\right) \times 0.550 = 0.241 \text{ in.}$$

$$M_a = M_{sa} + P_s\Delta_s = 20.32 \times 12 + 26.24 \times 0.241 = 250.14 \text{ in.-kip} = 20.84 \text{ ft-kip}$$

$$\Delta_s = \left(\frac{M_a}{M_{cr}}\right)\Delta_{cr} = \frac{20.84}{46.32} \times 0.550 = 0.247 \text{ in.}$$ ***ACI 318-14 (Table 11.8.4.1)***

No further iterations are required.

$$M_a = 20.84 \text{ ft-kip} < \frac{2}{3}M_{cr} = \frac{2}{3} \times 46.32 = 30.88 \text{ ft-kip} \quad (\textbf{o.k.})$$

$$\Delta_s = 0.247 \text{ in.} < \frac{l_c}{150} = \frac{29.5 \times 12}{150} = 2.36 \text{ in.} \quad (\textbf{o.k.})$$

The wall is adequate with 16 #6 vertical reinforcement and 6.25 in. thickness.

9. Tilt-Up Wall Panel Analysis and Design – spWall Software

spWall is a program for the analysis and design of reinforced concrete shear walls, tilt-up walls, precast walls and Insulate Concrete Form (ICF) walls. It uses a graphical interface that enables the user to easily generate complex wall models. Graphical user interface is provided for:

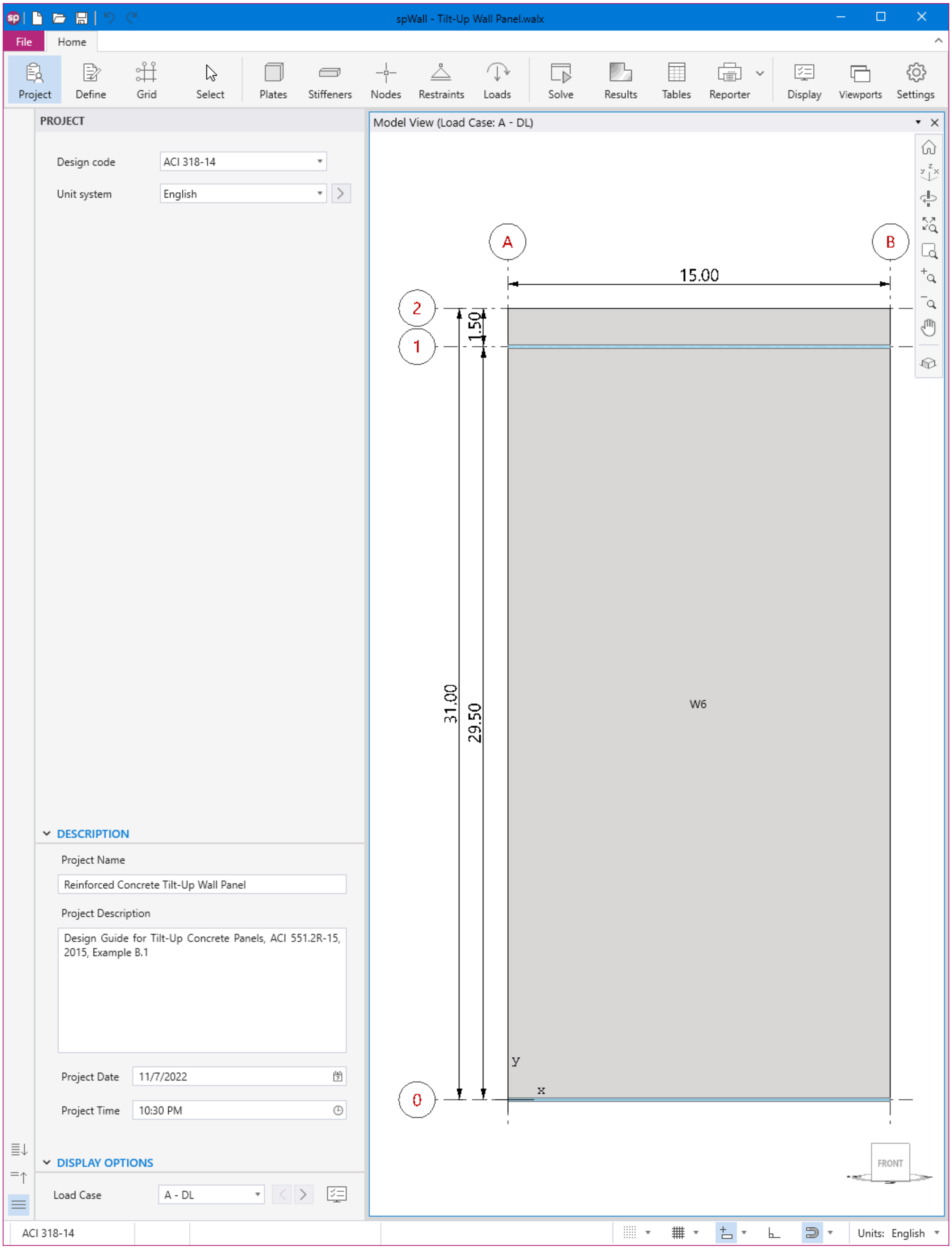
- Wall geometry (including any number of openings and stiffeners)
- Material properties including cracking coefficients
- Wall loads (point, line, and area)
- Support conditions (including translational and rotational spring supports)

spWall uses the Finite Element Method for the structural modeling, analysis, and design of slender and non-slender reinforced concrete walls subject to static loading conditions. The wall is idealized as a mesh of rectangular plate elements and straight-line stiffener elements. Walls of irregular geometry are idealized to conform to geometry with rectangular boundaries. Plate and stiffener properties can vary from one element to another but are assumed by the program to be uniform within each element.

Six degrees of freedom exist at each node: three translations and three rotations relating to the three Cartesian axes. An external load can exist in the direction of each of the degrees of freedom. Sufficient number of nodal degrees of freedom should be restrained in order to achieve stability of the model. The program assembles the global stiffness matrix and load vectors for the finite element model. Then, it solves the equilibrium equations to obtain deflections and rotations at each node. Finally, the program calculates the internal forces and internal moments in each element. At the user's option, the program can perform second order analysis. In this case, the program takes into account the effect of in-plane forces on the out-of-plane deflection with any number of openings and stiffeners.

In spWall, the required flexural reinforcement is computed based on the selected design standard (ACI 318-14 is used in this example), and the user can specify one or two layers of wall reinforcement. In stiffeners and boundary elements, spWall calculates the required shear and torsion steel reinforcement. Wall concrete strength (in-plane and out-of-plane) is calculated for the applied loads and compared with the code permissible shear capacity.

For illustration and comparison purposes, the following figures provide a sample of the input modules and results obtained from an spWall model created for the reinforced concrete wall in this example.



PROJECT

Design code: ACI 318-14

Unit system: English

DESCRIPTION

Project Name: Reinforced Concrete Tilt-Up Wall Panel

Project Description: Design Guide for Tilt-Up Concrete Panels, ACI 551.2R-15, 2015, Example B.1

Project Date: 11/7/2022

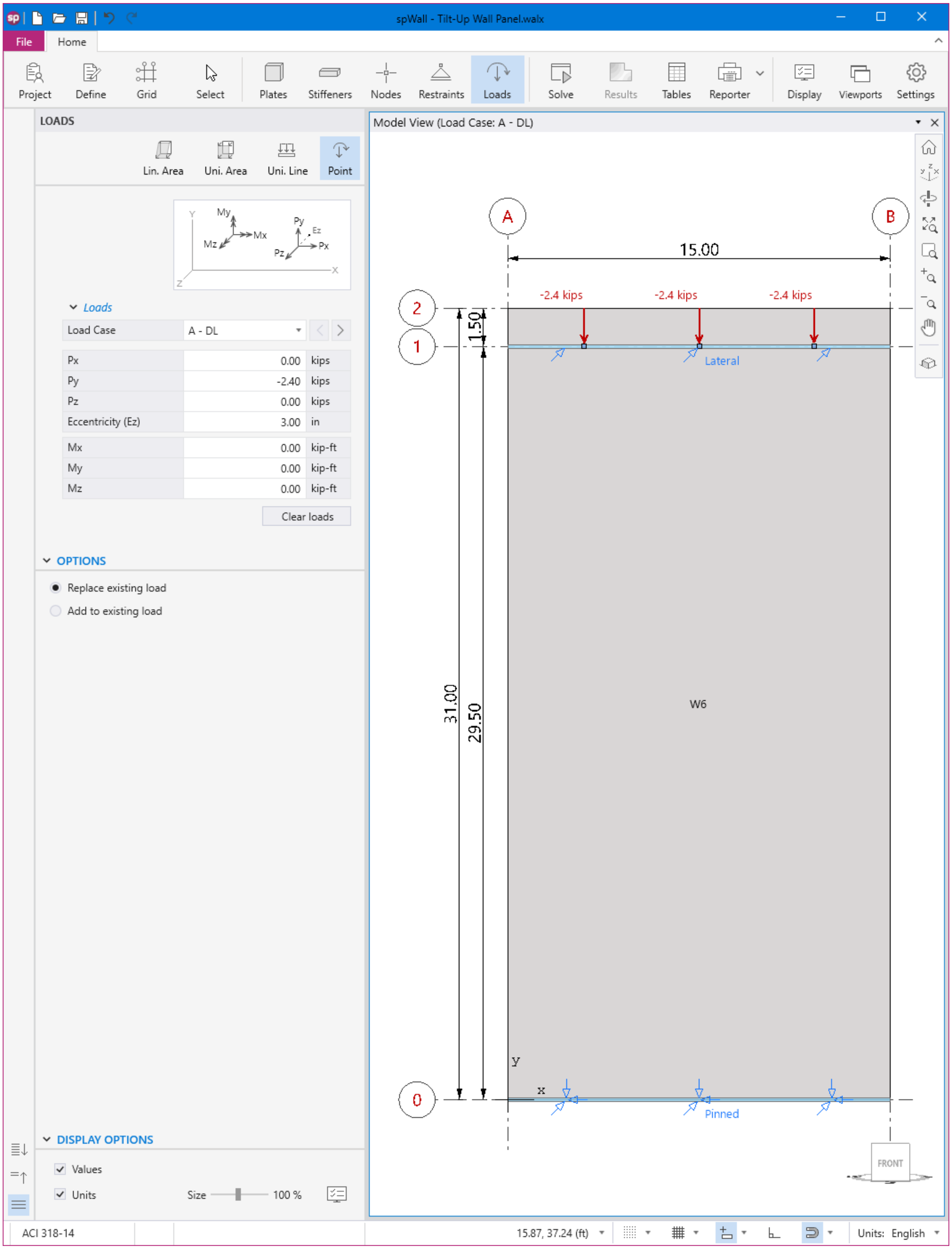
Project Time: 10:30 PM

DISPLAY OPTIONS

Load Case: A - DL

ACI 318-14

Figure 2 – spWall Interface



Loads

Load Case	A - DL	
Px	0.00	kips
Py	-2.40	kips
Pz	0.00	kips
Eccentricity (Ez)	3.00	in
Mx	0.00	kip-ft
My	0.00	kip-ft
Mz	0.00	kip-ft

OPTIONS

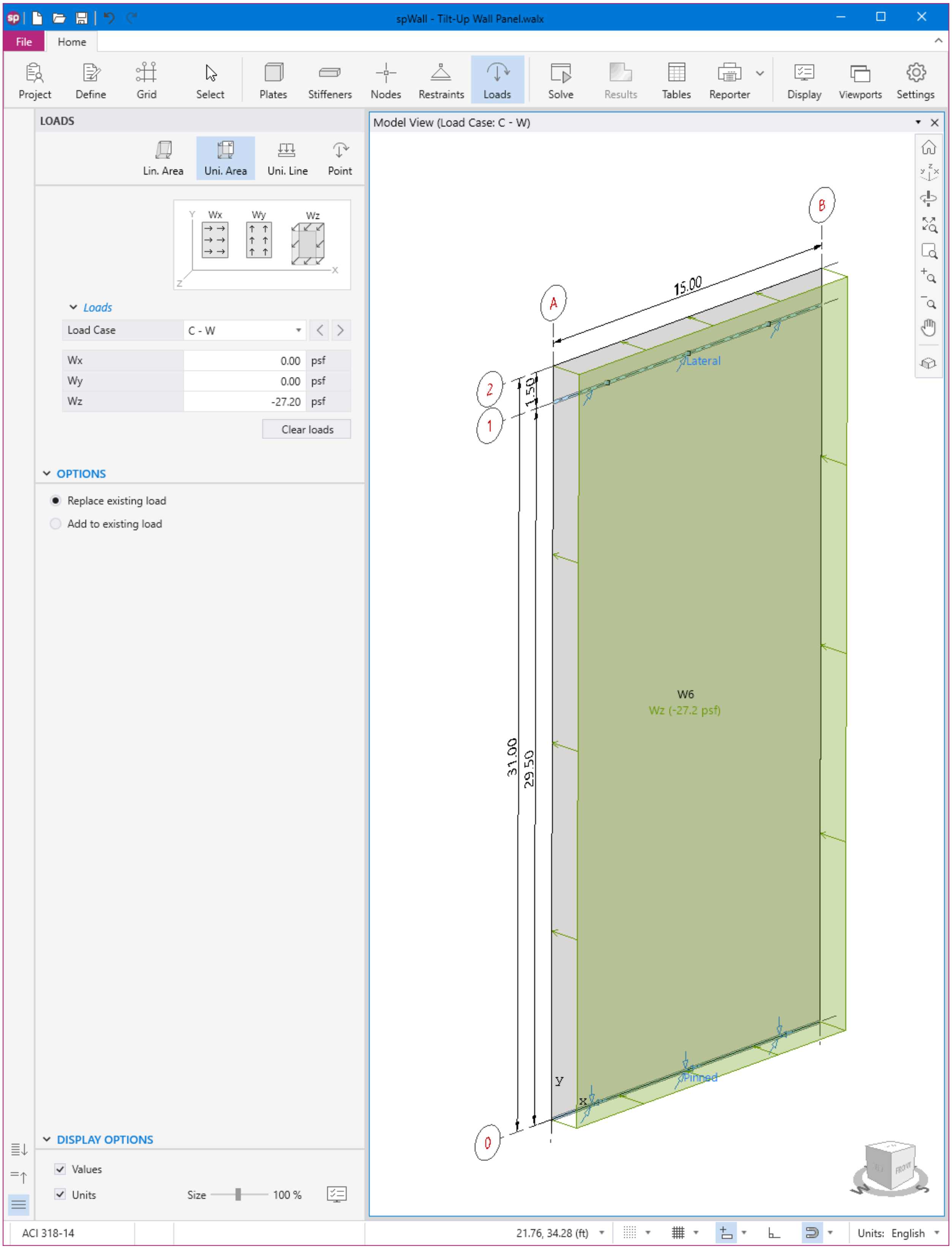
● Replace existing load
○ Add to existing load

DISPLAY OPTIONS

☑ Values
☑ Units
Size 100 %

ACI 318-14
15.87, 37.24 (ft)
Units: English

Figure 3 – Assigning Roof Dead Loads for Tilt-Up Wall (spWall)



Load Case: C - W

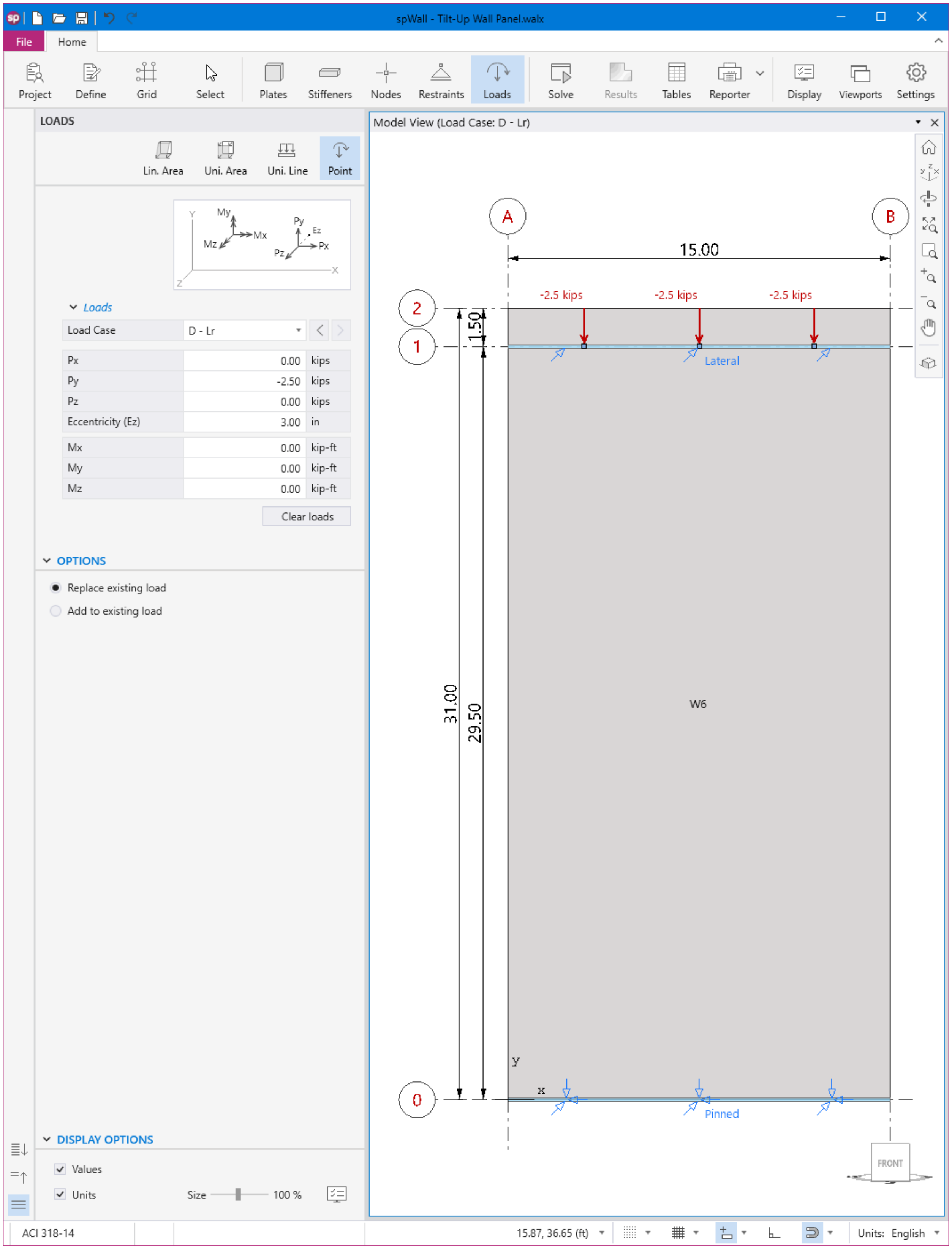
Wx	0.00	psf
Wy	0.00	psf
Wz	-27.20	psf

● Replace existing load
○ Add to existing load

☑ Values
☑ Units Size 100 %

ACI 318-14 21.76, 34.28 (ft) Units: English

Figure 4 – Assigning Wind Loads for Tilt-Up Wall (spWall)



Loads

Load Case	D - Lr	
Px	0.00	kips
Py	-2.50	kips
Pz	0.00	kips
Eccentricity (Ez)	3.00	in
Mx	0.00	kip-ft
My	0.00	kip-ft
Mz	0.00	kip-ft

Clear loads

OPTIONS

● Replace existing load

○ Add to existing load

DISPLAY OPTIONS

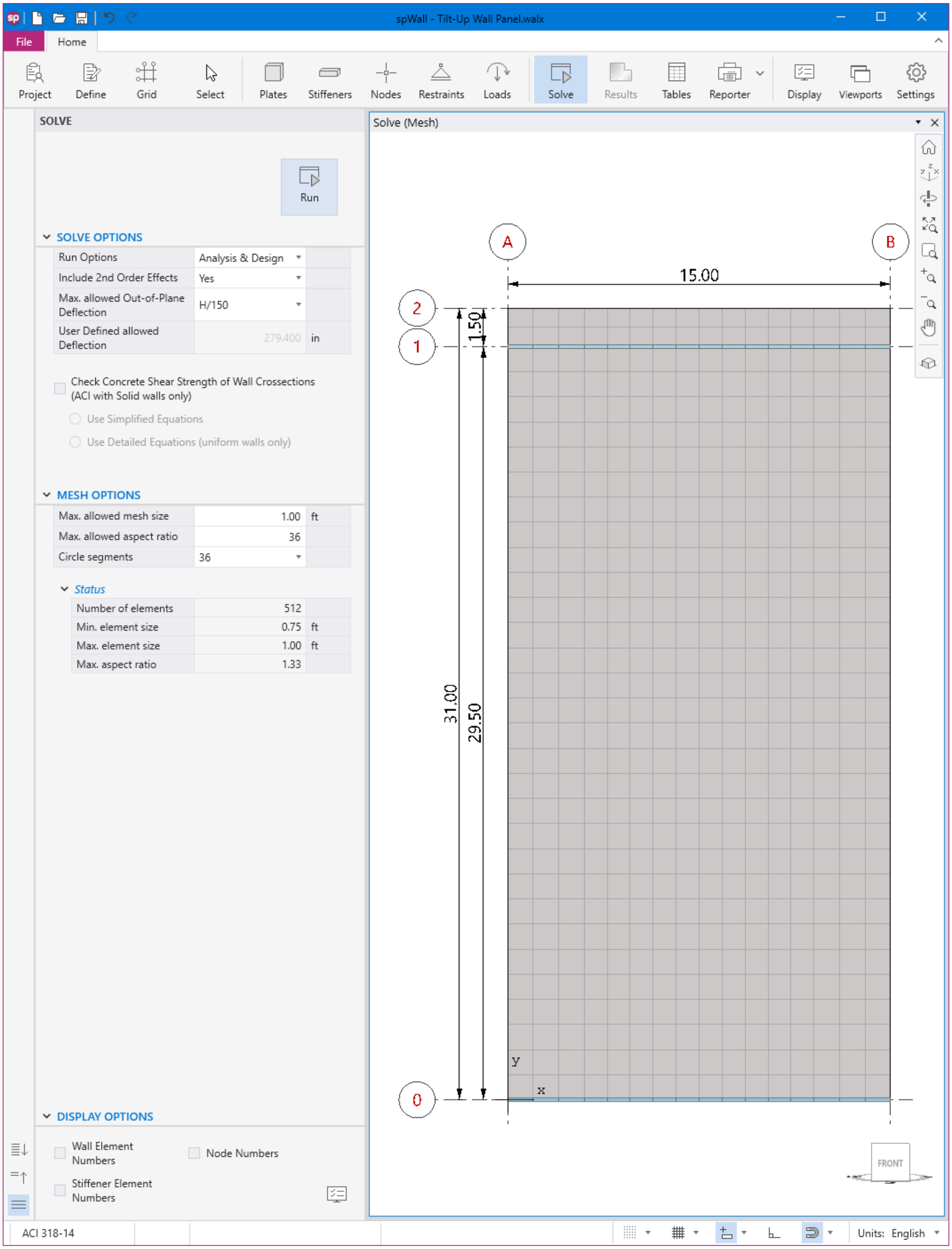
☑ Values

☑ Units

Size 100 %

Units: English

Figure 5 – Assigning Roof Live Loads for Tilt-Up Wall (spWall)



SOLVE

SOLVE OPTIONS

Run Options	Analysis & Design	
Include 2nd Order Effects	Yes	
Max. allowed Out-of-Plane Deflection	H/150	
User Defined allowed Deflection	279.400	in

☐ Check Concrete Shear Strength of Wall Crossections (ACI with Solid walls only)

○ Use Simplified Equations

○ Use Detailed Equations (uniform walls only)

MESH OPTIONS

Max. allowed mesh size	1.00	ft
Max. allowed aspect ratio	36	
Circle segments	36	

Status

Number of elements	512	
Min. element size	0.75	ft
Max. element size	1.00	ft
Max. aspect ratio	1.33	

DISPLAY OPTIONS

☐ Wall Element Numbers ☐ Node Numbers

☐ Stiffener Element Numbers

Figure 6 – Solve and Mesh Options (spWall)

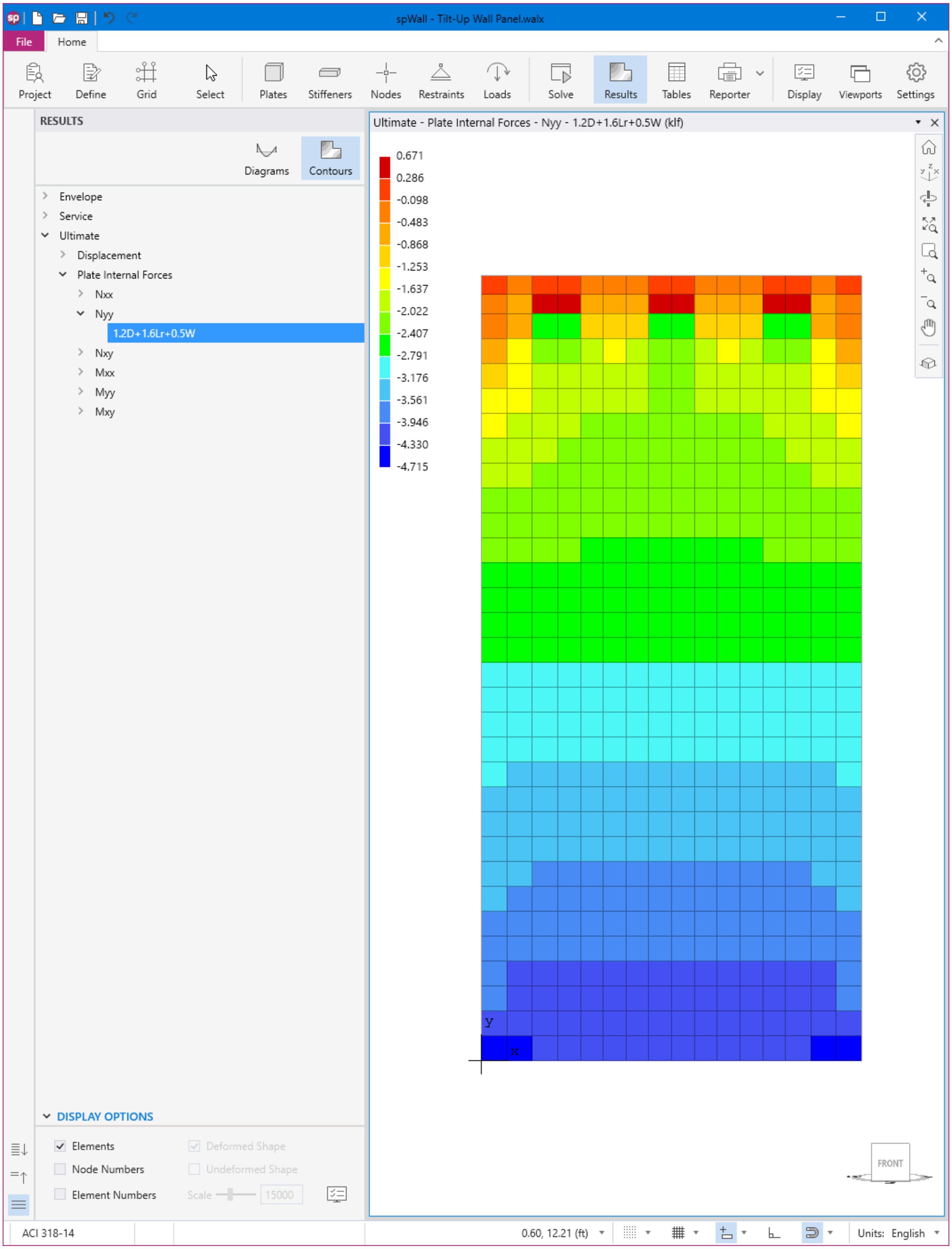
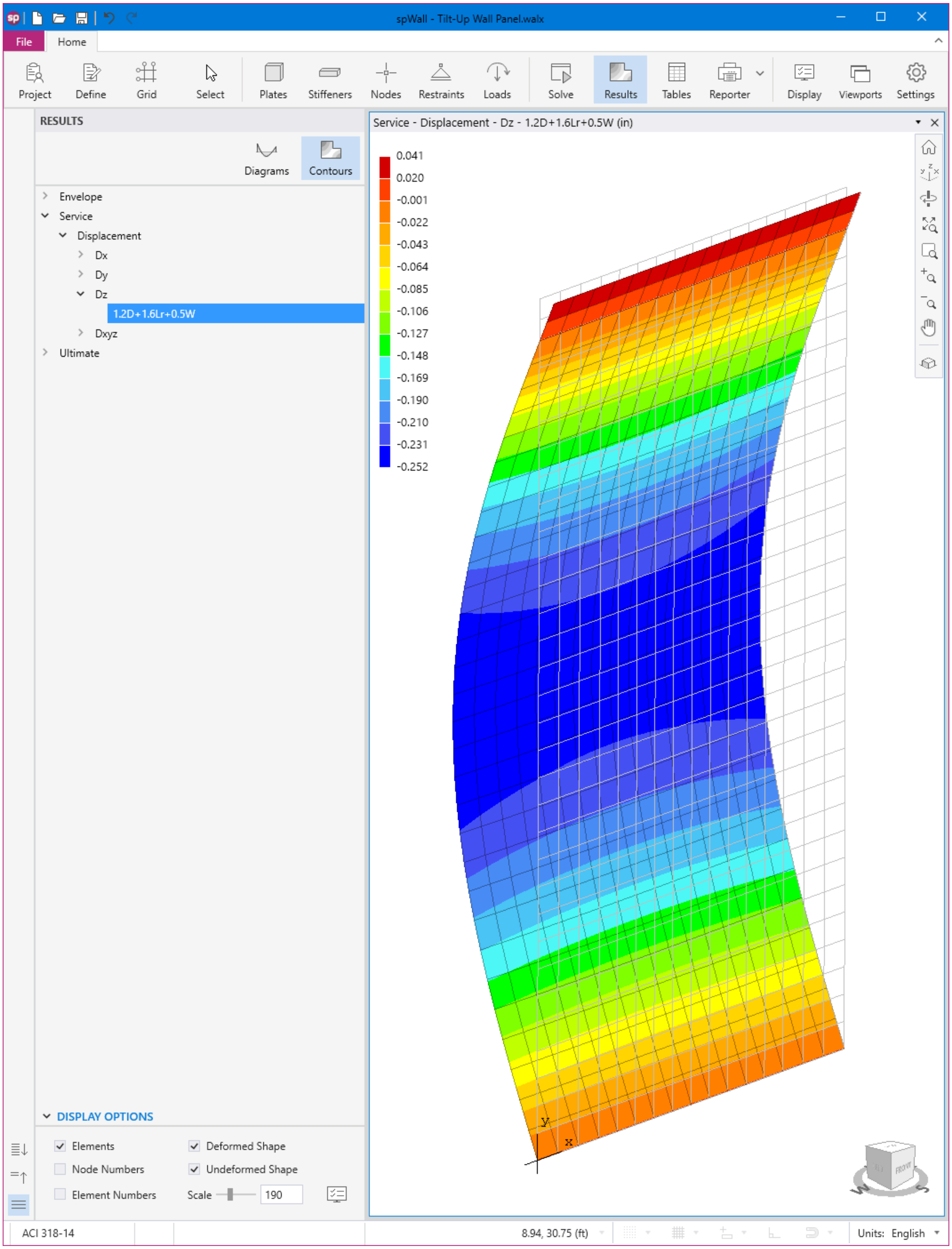


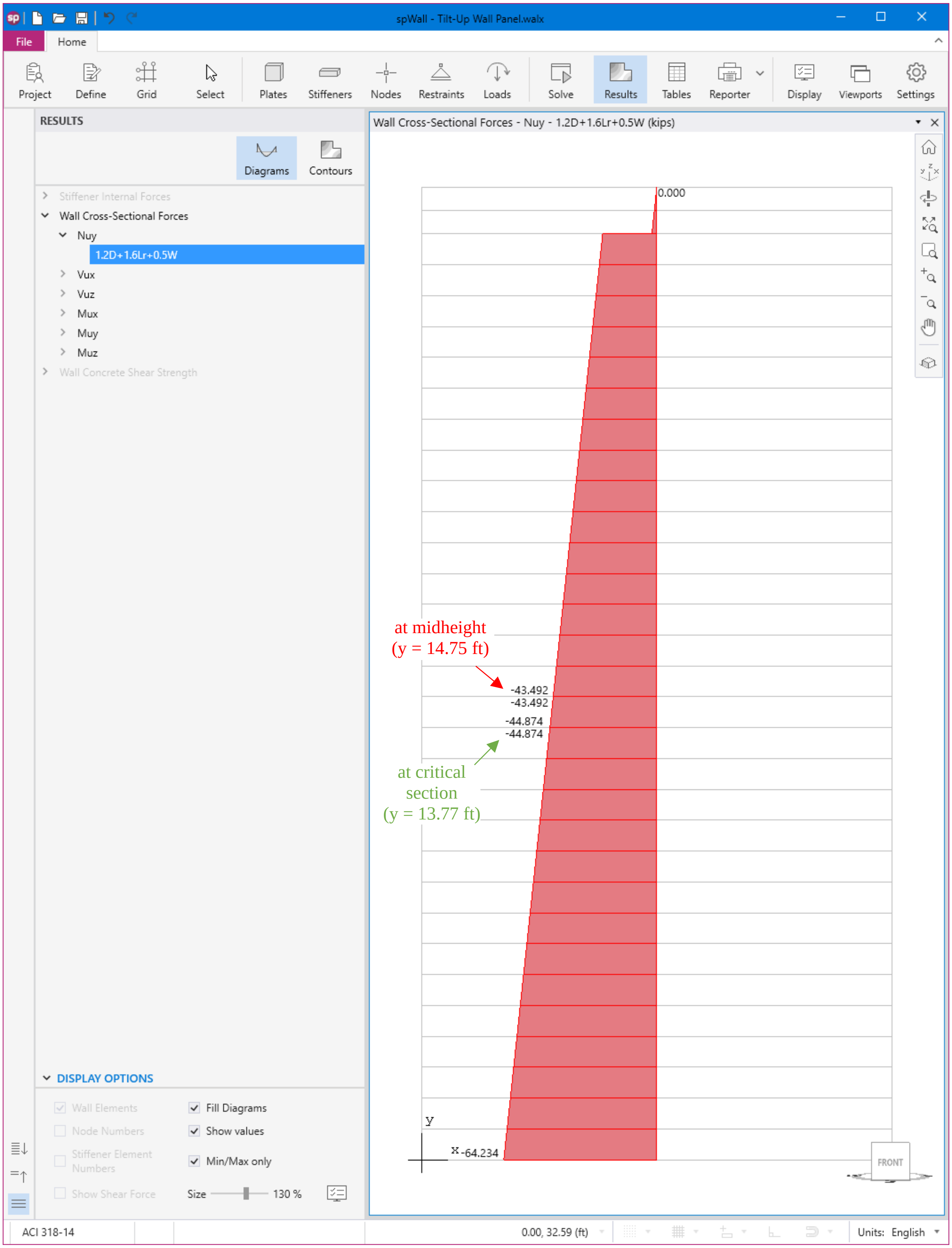
Figure 7 – Factored Axial Forces Contour Normal to Tilt-Up Wall Panel Cross-Section (spWall)



☑ Elements
☐ Node Numbers
☐ Element Numbers
☑ Deformed Shape
☑ Undeformed Shape
Scale 190

ACI 318-14
8.94, 30.75 (ft)
Units: English

Figure 8 – Tilt-Up Wall Panel Lateral Displacement Contour (Out-of-Plane) (spWall)

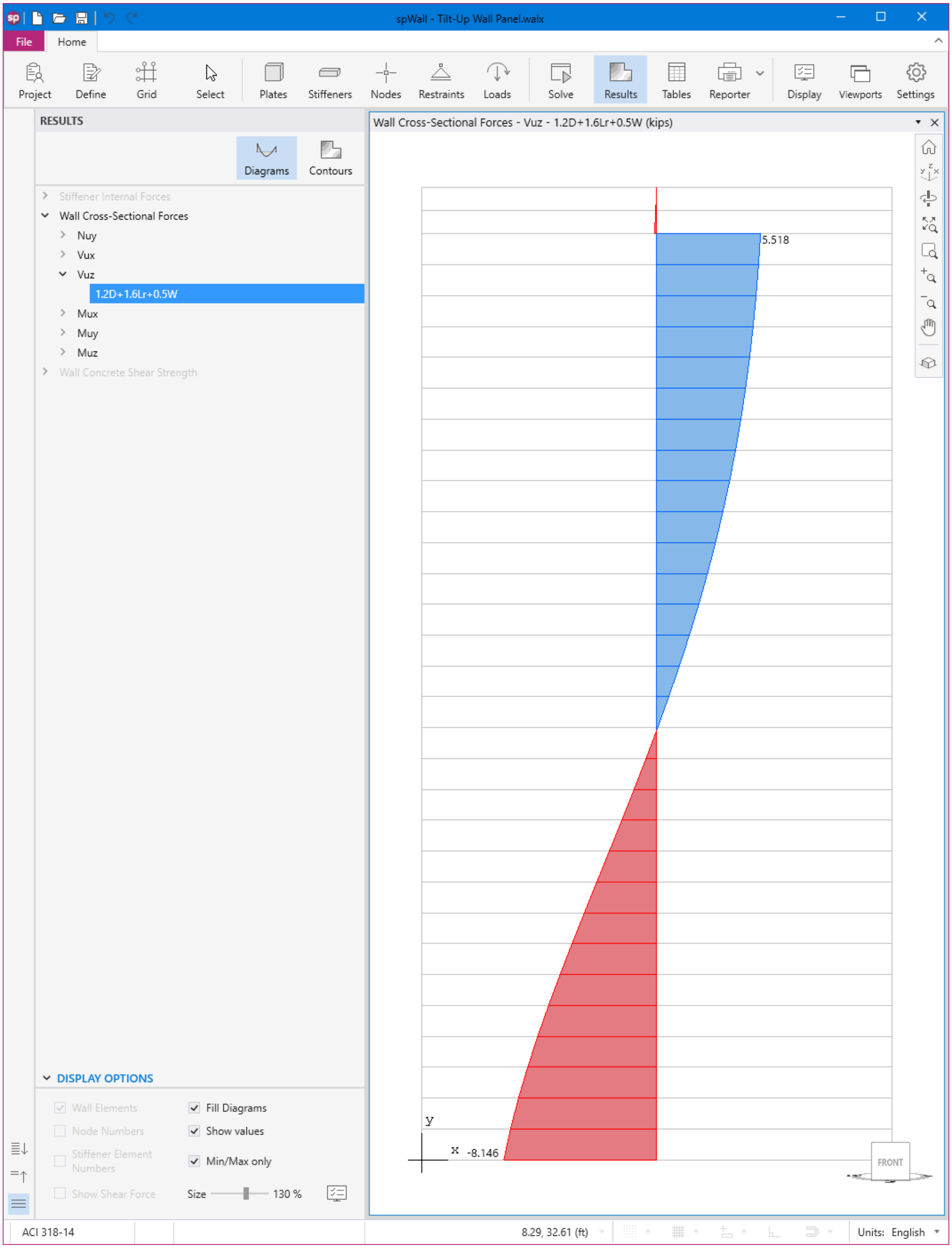


at midheight
(y = 14.75 ft)

at critical
section
(y = 13.77 ft)

☐ Wall Elements ☑ Fill Diagrams
☐ Node Numbers ☑ Show values
☐ Stiffener Element Numbers ☑ Min/Max only
☐ Show Shear Force Size 130 %

Figure 9 – Tilt-Up Wall Panel Axial Load Diagram (spWall)



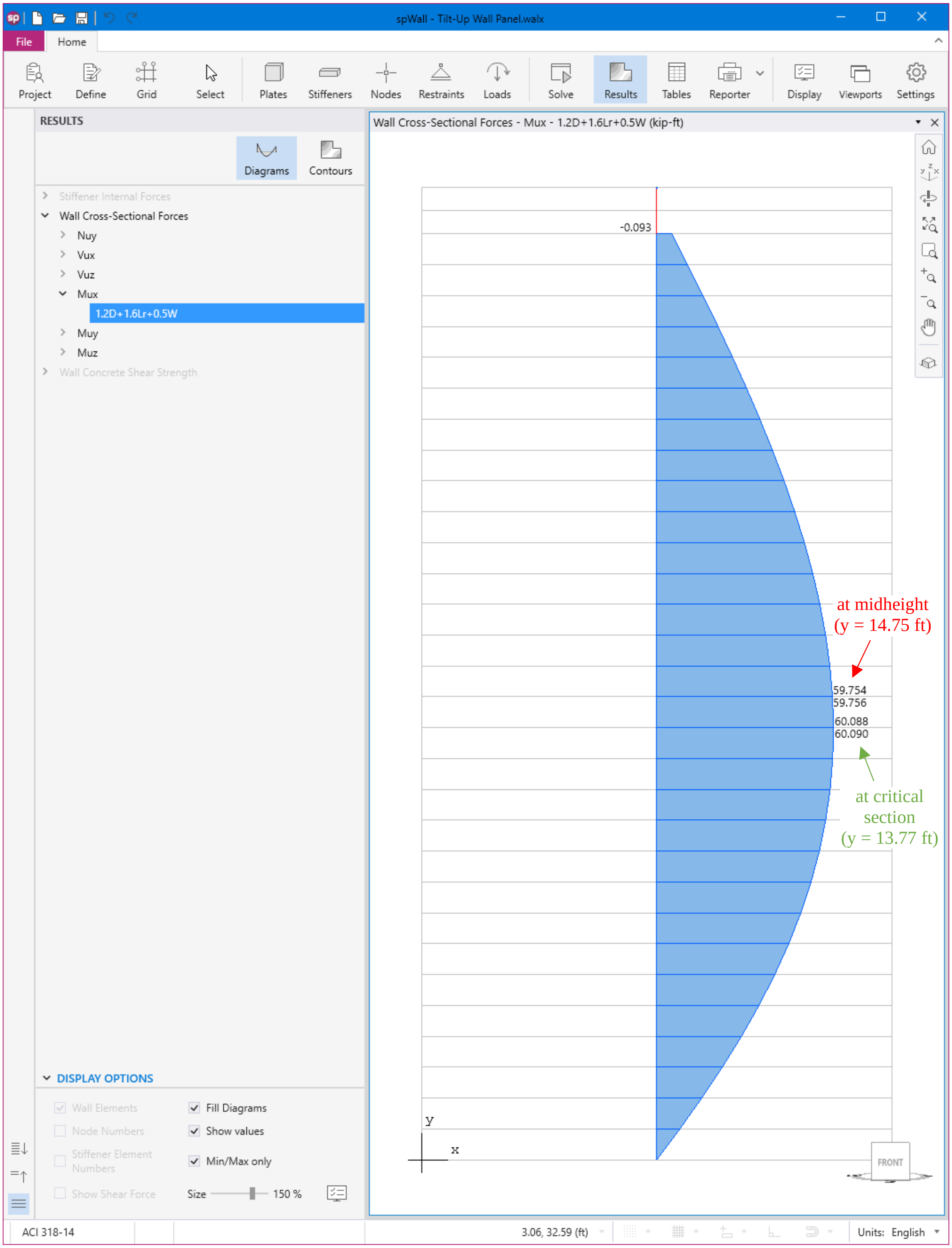
spWall - Tilt-Up Wall Panel.walx

Wall Cross-Sectional Forces - Vuz - 1.2D+1.6Lr+0.5W (kips)

☑ Wall Elements
☐ Node Numbers
☐ Stiffener Element Numbers
☐ Show Shear Force
☑ Fill Diagrams
☑ Show values
☑ Min/Max only
Size 130 %

ACI 318-14
8.29, 32.61 (ft)
Units: English

Figure 10 – Out-of-plane Shear Diagram (spWall)



☑ Wall Elements
☐ Node Numbers
☐ Stiffener Element Numbers
☐ Show Shear Force
☑ Fill Diagrams
☑ Show values
☑ Min/Max only
Size 150 %

at midheight (y = 14.75 ft)

at critical section (y = 13.77 ft)

Figure 11 – Tilt-Up Wall Moment Diagram (spWall)

spWall (TM)

spWall v10.00 (TM)
A Computer Program for Analysis and Design of Reinforced Concrete, Precast, and Tilt-up Walls
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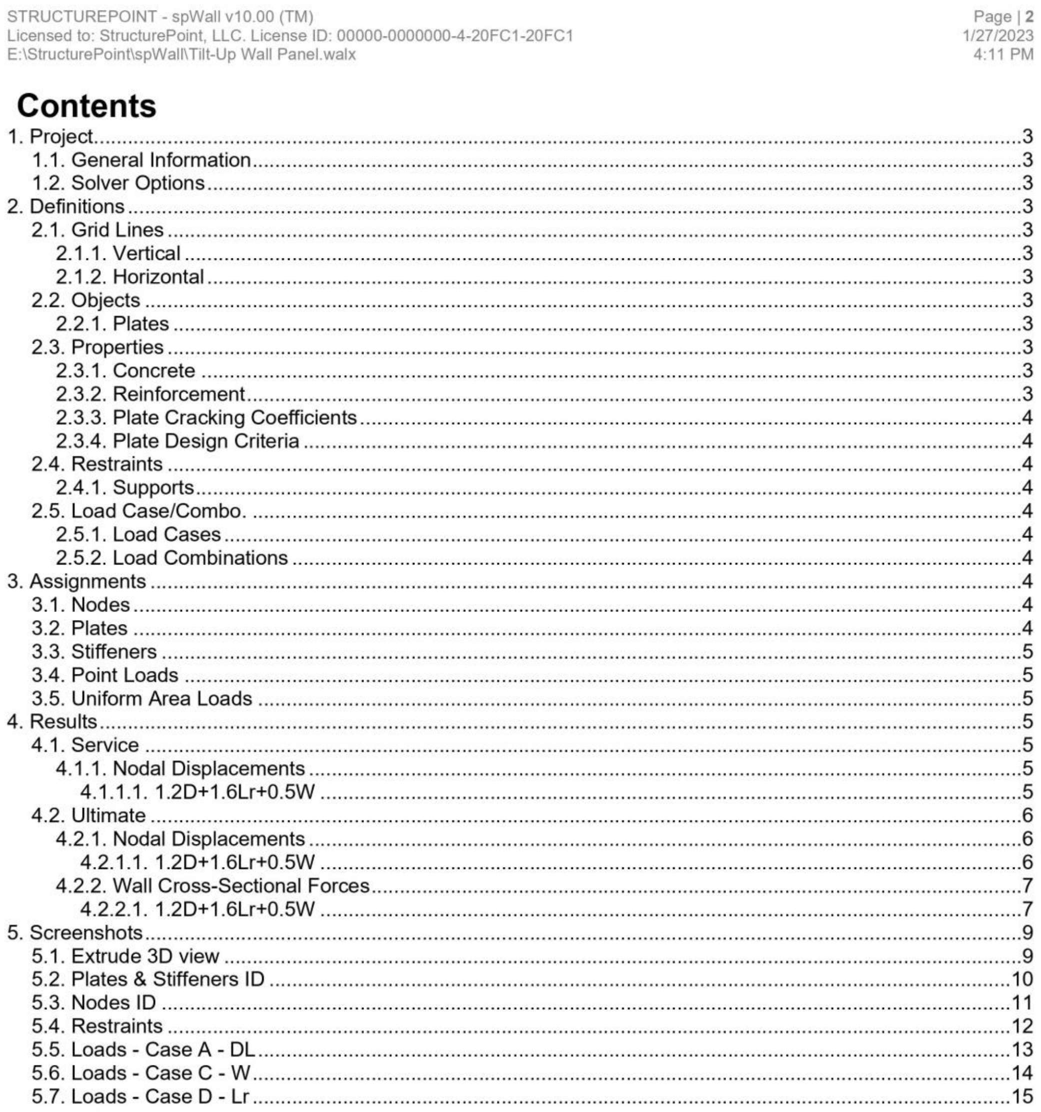

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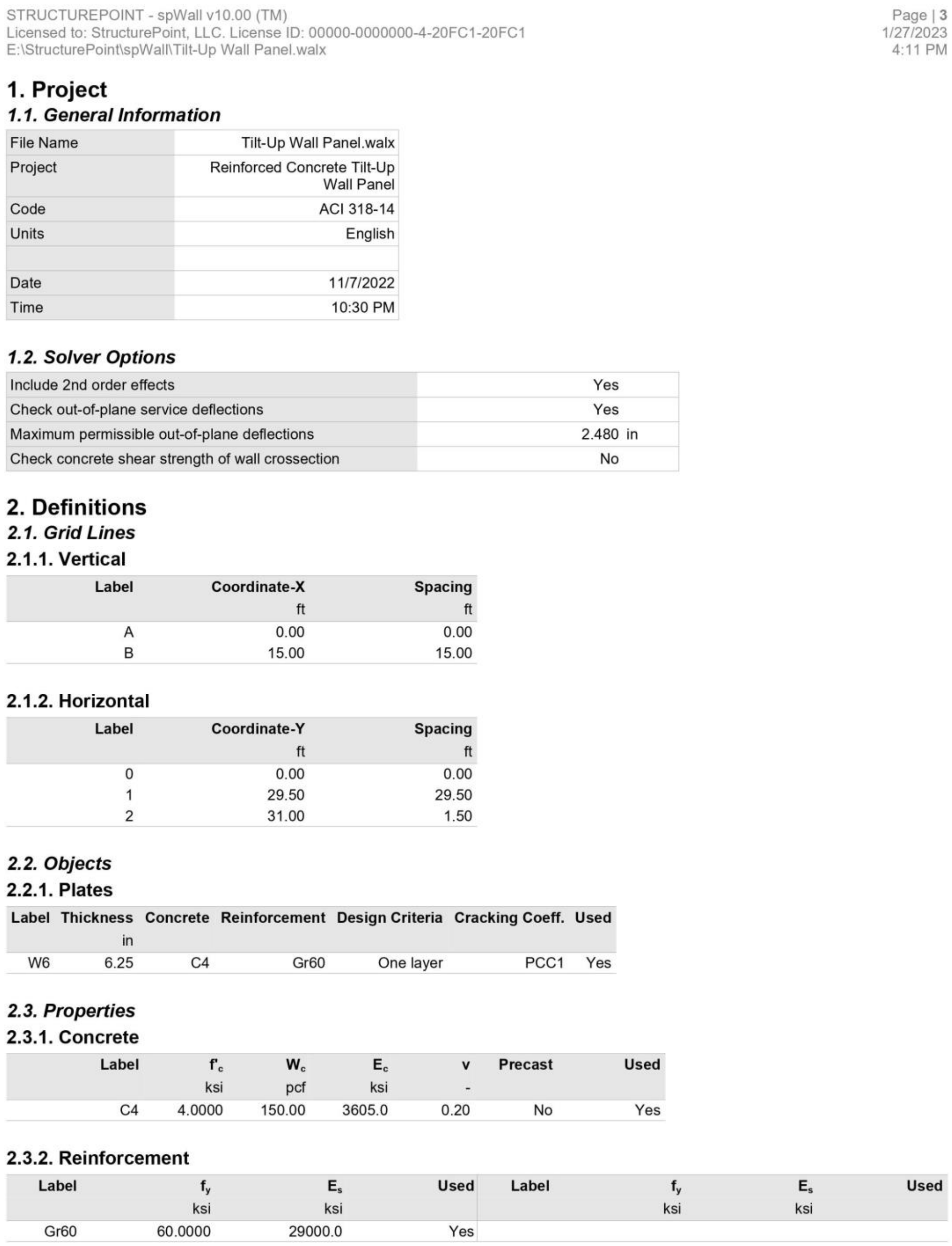

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1. Project

1.1. General Information

File Name	Tilt-Up Wall Panel.walx
Project	Reinforced Concrete Tilt-Up Wall Panel
Code	ACI 318-14
Units	English
Date	11/7/2022
Time	10:30 PM

1.2. Solver Options

Include 2nd order effects	Yes
Check out-of-plane service deflections	Yes
Maximum permissible out-of-plane deflections	2.480 in
Check concrete shear strength of wall crossection	No

2. Definitions

2.1. Grid Lines

2.1.1. Vertical

Label	Coordinate-X ft	Spacing ft
A	0.00	0.00
B	15.00	15.00

2.1.2. Horizontal

Label	Coordinate-Y ft	Spacing ft
0	0.00	0.00
1	29.50	29.50
2	31.00	1.50

2.2. Objects

2.2.1. Plates

Label	Thickness in	Concrete	Reinforcement	Design Criteria	Cracking Coeff.	Used
W6	6.25	C4	Gr60	One layer	PCC1	Yes

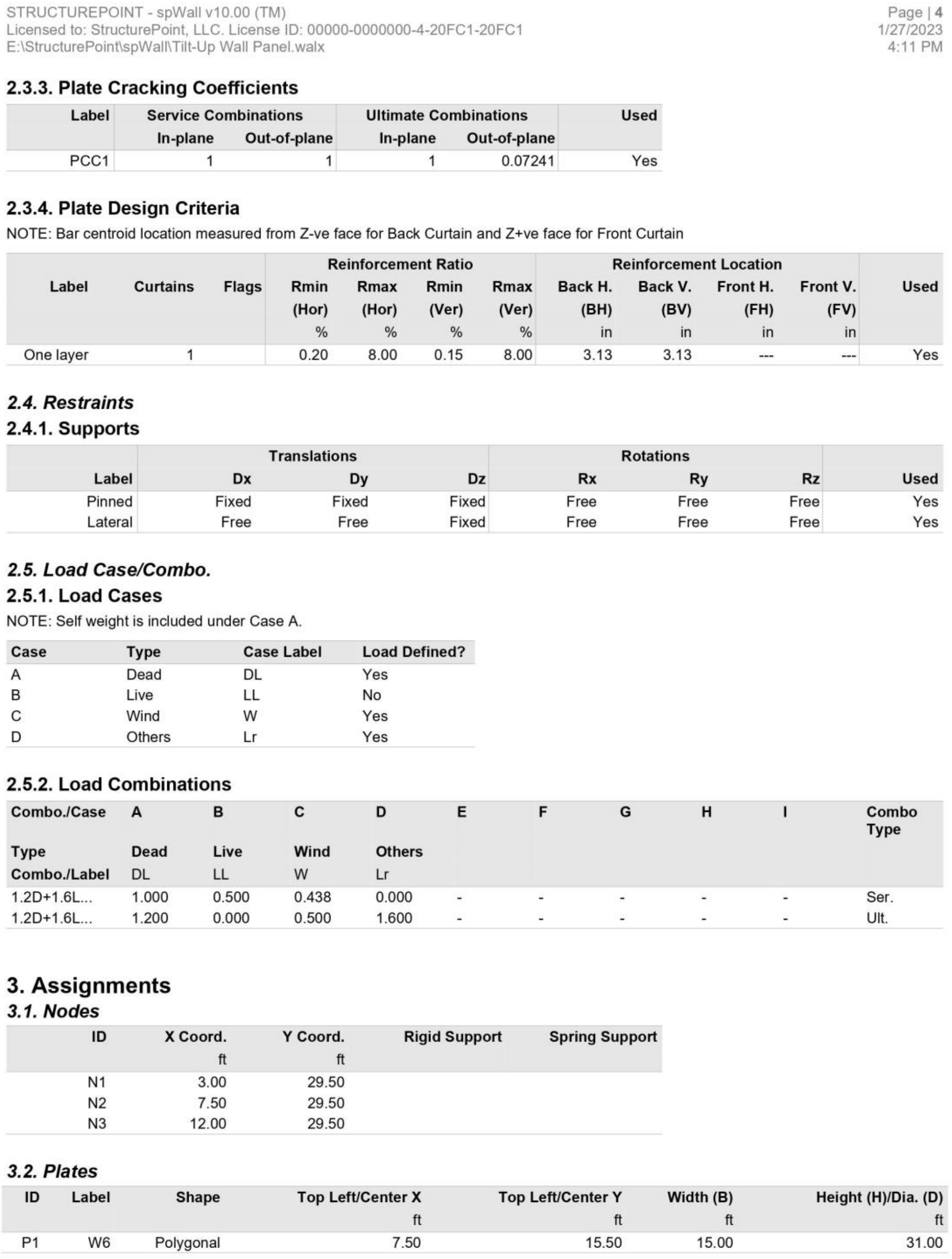
2.3. Properties

2.3.1. Concrete

Label	f'_c ksi	W_c pcf	E_c ksi	v -	Precast	Used
C4	4.0000	150.00	3605.0	0.20	No	Yes

2.3.2. Reinforcement

Label	f_y ksi	E_s ksi	Used	Label	f_y ksi	E_s ksi	Used
Gr60	60.0000	29000.0	Yes				



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2.3.3. Plate Cracking Coefficients

Label	Service Combinations		Ultimate Combinations		Used
	In-plane	Out-of-plane	In-plane	Out-of-plane	
PCC1	1	1	1	0.07241	Yes

2.3.4. Plate Design Criteria

NOTE: Bar centroid location measured from Z-ve face for Back Curtain and Z+ve face for Front Curtain

Label	Curtains	Flags	Reinforcement Ratio				Reinforcement Location				Used
			Rmin (Hor) %	Rmax (Hor) %	Rmin (Ver) %	Rmax (Ver) %	Back H. (BH) in	Back V. (BV) in	Front H. (FH) in	Front V. (FV) in	
One layer	1		0.20	8.00	0.15	8.00	3.13	3.13	---	---	Yes

2.4. Restraints

2.4.1. Supports

Label	Translations			Rotations			Used
	Dx	Dy	Dz	Rx	Ry	Rz	
Pinned	Fixed	Fixed	Fixed	Free	Free	Free	Yes
Lateral	Free	Free	Fixed	Free	Free	Free	Yes

2.5. Load Case/Combo.

2.5.1. Load Cases

NOTE: Self weight is included under Case A.

Case	Type	Case Label	Load Defined?
A	Dead	DL	Yes
B	Live	LL	No
C	Wind	W	Yes
D	Others	Lr	Yes

2.5.2. Load Combinations

Combo./Case	A	B	C	D	E	F	G	H	I	Combo Type
Type	Dead	Live	Wind	Others						
Combo./Label	DL	LL	W	Lr						
1.2D+1.6L...	1.000	0.500	0.438	0.000	-	-	-	-	-	Ser.
1.2D+1.6L...	1.200	0.000	0.500	1.600	-	-	-	-	-	Ult.

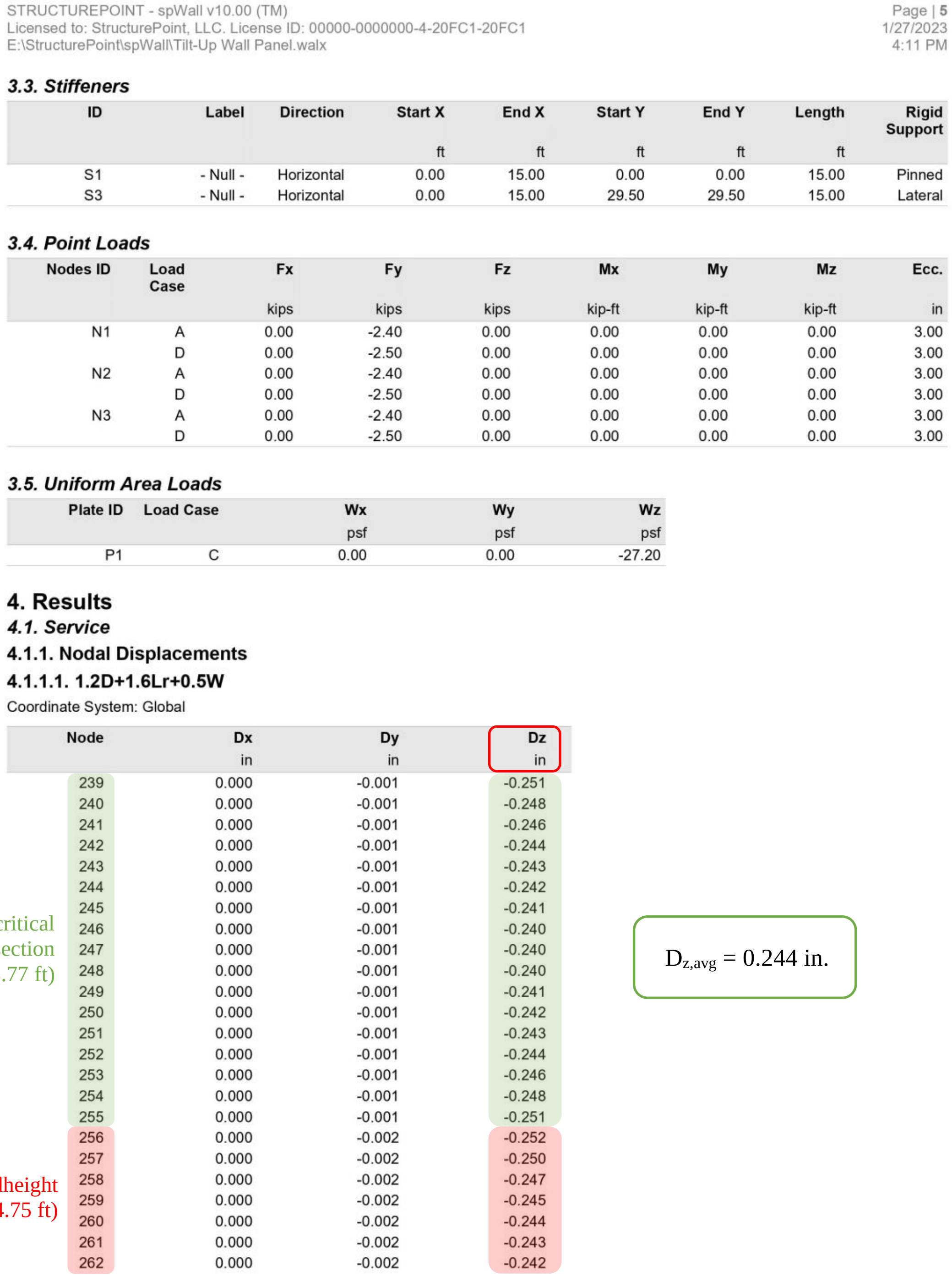
3. Assignments

3.1. Nodes

ID	X Coord. ft	Y Coord. ft	Rigid Support	Spring Support
N1	3.00	29.50		
N2	7.50	29.50		
N3	12.00	29.50		

3.2. Plates

ID	Label	Shape	Top Left/Center X ft	Top Left/Center Y ft	Width (B) ft	Height (H)/Dia. (D) ft
P1	W6	Polygonal	7.50	15.50	15.00	31.00



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3.3. Stiffeners

ID	Label	Direction	Start X ft	End X ft	Start Y ft	End Y ft	Length ft	Rigid Support
S1	- Null -	Horizontal	0.00	15.00	0.00	0.00	15.00	Pinned
S3	- Null -	Horizontal	0.00	15.00	29.50	29.50	15.00	Lateral

3.4. Point Loads

Nodes ID	Load Case	Fx kips	Fy kips	Fz kips	Mx kip-ft	My kip-ft	Mz kip-ft	Ecc. in
N1	A	0.00	-2.40	0.00	0.00	0.00	0.00	3.00
	D	0.00	-2.50	0.00	0.00	0.00	0.00	3.00
N2	A	0.00	-2.40	0.00	0.00	0.00	0.00	3.00
	D	0.00	-2.50	0.00	0.00	0.00	0.00	3.00
N3	A	0.00	-2.40	0.00	0.00	0.00	0.00	3.00
	D	0.00	-2.50	0.00	0.00	0.00	0.00	3.00

3.5. Uniform Area Loads

Plate ID	Load Case	Wx psf	Wy psf	Wz psf
P1	C	0.00	0.00	-27.20

4. Results

4.1. Service

4.1.1. Nodal Displacements

4.1.1.1. 1.2D+1.6Lr+0.5W

Coordinate System: Global

Node	Dx in	Dy in	Dz in
239	0.000	-0.001	-0.251
240	0.000	-0.001	-0.248
241	0.000	-0.001	-0.246
242	0.000	-0.001	-0.244
243	0.000	-0.001	-0.243
244	0.000	-0.001	-0.242
245	0.000	-0.001	-0.241
246	0.000	-0.001	-0.240
247	0.000	-0.001	-0.240
248	0.000	-0.001	-0.240
249	0.000	-0.001	-0.241
250	0.000	-0.001	-0.242
251	0.000	-0.001	-0.243
252	0.000	-0.001	-0.244
253	0.000	-0.001	-0.246
254	0.000	-0.001	-0.248
255	0.000	-0.001	-0.251
256	0.000	-0.002	-0.252
257	0.000	-0.002	-0.250
258	0.000	-0.002	-0.247
259	0.000	-0.002	-0.245
260	0.000	-0.002	-0.244
261	0.000	-0.002	-0.243
262	0.000	-0.002	-0.242

at critical section (y = 13.77 ft)

at midheight (y = 14.75 ft)

$D_{z,avg}$ = 0.244 in.

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Node	Dx in	Dy in	Dz in
263	0.000	-0.002	-0.242
264	0.000	-0.002	-0.242
265	0.000	-0.002	-0.242
266	0.000	-0.002	-0.242
267	0.000	-0.002	-0.243
268	0.000	-0.002	-0.244
269	0.000	-0.002	-0.245
270	0.000	-0.002	-0.247
271	0.000	-0.002	-0.250
272	0.000	-0.002	-0.252

at midheight
(y = 14.75 ft)

$D_{z,avg}$ = 0.245 in.

4.2. Ultimate

4.2.1. Nodal Displacements

4.2.1.1. 1.2D+1.6Lr+0.5W

Coordinate System: Global

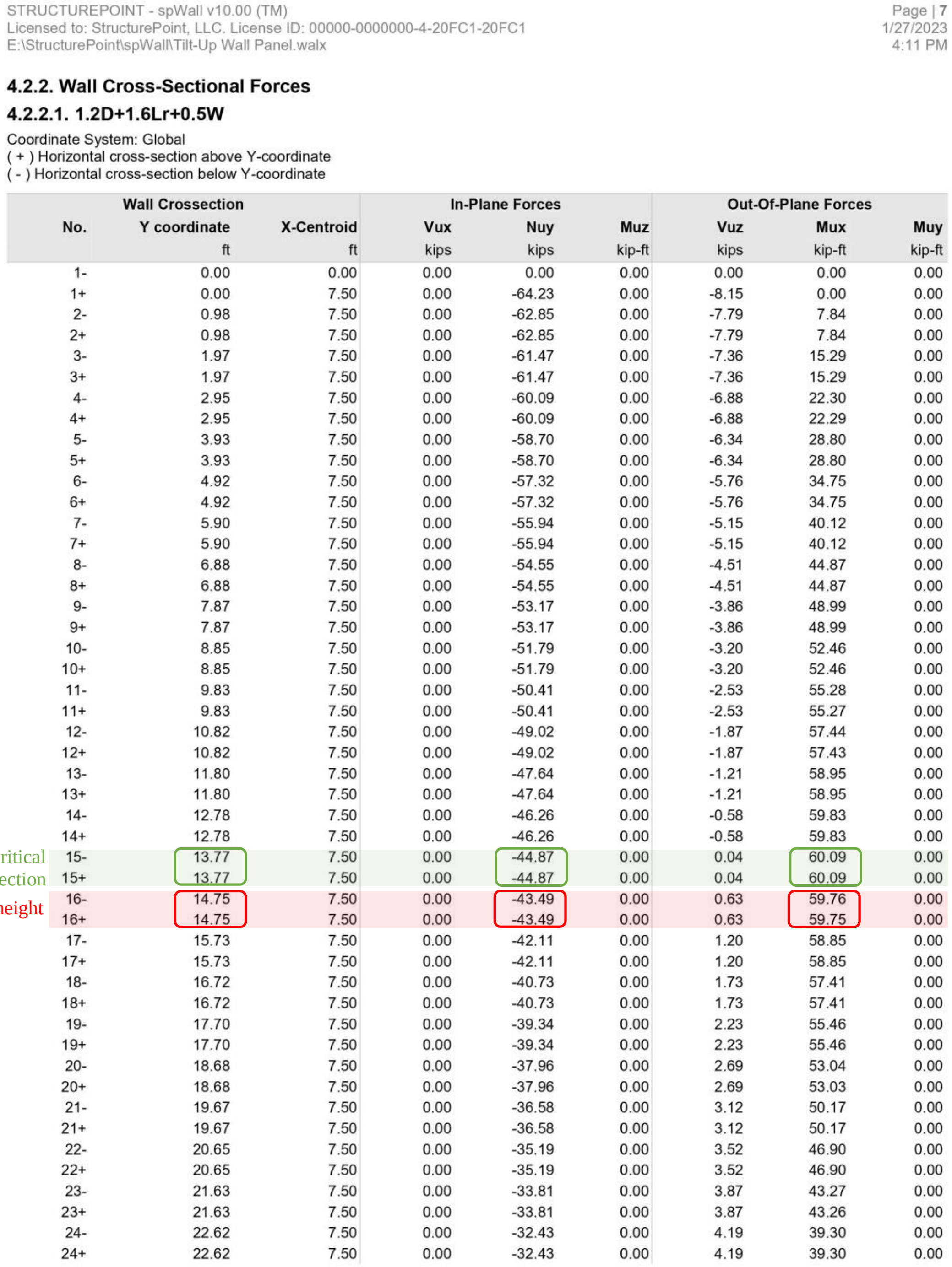
Node	Dx in	Dy in	Dz in
239	0.000	-0.002	-9.890
240	0.000	-0.002	-9.778
241	0.000	-0.002	-9.686
242	0.000	-0.002	-9.612
243	0.000	-0.002	-9.560
244	0.000	-0.002	-9.520
245	0.000	-0.002	-9.492
246	0.000	-0.002	-9.476
247	0.000	-0.002	-9.470
248	0.000	-0.002	-9.476
249	0.000	-0.002	-9.492
250	0.000	-0.002	-9.520
251	0.000	-0.002	-9.560
252	0.000	-0.002	-9.612
253	0.000	-0.002	-9.686
254	0.000	-0.002	-9.778
255	0.000	-0.002	-9.890
256	0.000	-0.002	-9.919
257	0.000	-0.002	-9.807
258	0.000	-0.002	-9.715
259	0.000	-0.002	-9.642
260	0.000	-0.002	-9.589
261	0.000	-0.002	-9.550
262	0.000	-0.002	-9.522
263	0.000	-0.002	-9.505
264	0.000	-0.002	-9.500
265	0.000	-0.002	-9.505
266	0.000	-0.002	-9.522
267	0.000	-0.002	-9.550
268	0.000	-0.002	-9.589
269	0.000	-0.002	-9.642
270	0.000	-0.002	-9.715
271	0.000	-0.002	-9.807
272	0.000	-0.002	-9.919

at critical
section
(y = 13.77 ft)

$D_{z,avg}$ = 9.618 in.

at midheight
(y = 14.75 ft)

$D_{z,avg}$ = 9.647 in.



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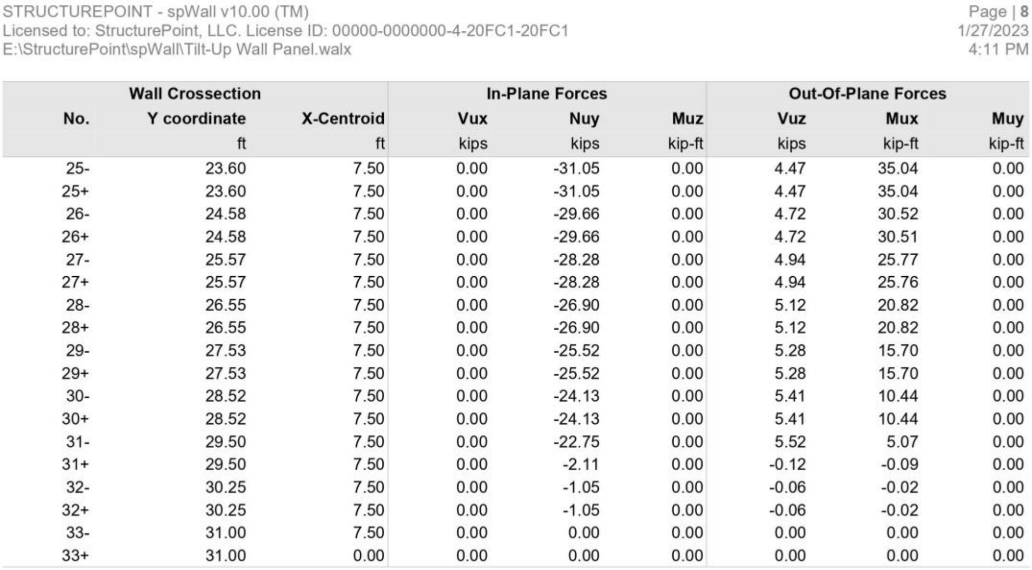
4.2.2. Wall Cross-Sectional Forces

4.2.2.1. 1.2D+1.6Lr+0.5W

Coordinate System: Global
(+) Horizontal cross-section above Y-coordinate
(-) Horizontal cross-section below Y-coordinate

		Wall Crossection			In-Plane Forces			Out-Of-Plane Forces	
	No.	**Y coordinate**	**X-Centroid**	**Vux**	**Nuy**	**Muz**	**Vuz**	**Mux**	**Muy**
		ft	ft	kips	kips	kip-ft	kips	kip-ft	kip-ft
	1-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1+	0.00	7.50	0.00	-64.23	0.00	-8.15	0.00	0.00
	2-	0.98	7.50	0.00	-62.85	0.00	-7.79	7.84	0.00
	2+	0.98	7.50	0.00	-62.85	0.00	-7.79	7.84	0.00
	3-	1.97	7.50	0.00	-61.47	0.00	-7.36	15.29	0.00
	3+	1.97	7.50	0.00	-61.47	0.00	-7.36	15.29	0.00
	4-	2.95	7.50	0.00	-60.09	0.00	-6.88	22.30	0.00
	4+	2.95	7.50	0.00	-60.09	0.00	-6.88	22.29	0.00
	5-	3.93	7.50	0.00	-58.70	0.00	-6.34	28.80	0.00
	5+	3.93	7.50	0.00	-58.70	0.00	-6.34	28.80	0.00
	6-	4.92	7.50	0.00	-57.32	0.00	-5.76	34.75	0.00
	6+	4.92	7.50	0.00	-57.32	0.00	-5.76	34.75	0.00
	7-	5.90	7.50	0.00	-55.94	0.00	-5.15	40.12	0.00
	7+	5.90	7.50	0.00	-55.94	0.00	-5.15	40.12	0.00
	8-	6.88	7.50	0.00	-54.55	0.00	-4.51	44.87	0.00
	8+	6.88	7.50	0.00	-54.55	0.00	-4.51	44.87	0.00
	9-	7.87	7.50	0.00	-53.17	0.00	-3.86	48.99	0.00
	9+	7.87	7.50	0.00	-53.17	0.00	-3.86	48.99	0.00
	10-	8.85	7.50	0.00	-51.79	0.00	-3.20	52.46	0.00
	10+	8.85	7.50	0.00	-51.79	0.00	-3.20	52.46	0.00
	11-	9.83	7.50	0.00	-50.41	0.00	-2.53	55.28	0.00
	11+	9.83	7.50	0.00	-50.41	0.00	-2.53	55.27	0.00
	12-	10.82	7.50	0.00	-49.02	0.00	-1.87	57.44	0.00
	12+	10.82	7.50	0.00	-49.02	0.00	-1.87	57.43	0.00
	13-	11.80	7.50	0.00	-47.64	0.00	-1.21	58.95	0.00
	13+	11.80	7.50	0.00	-47.64	0.00	-1.21	58.95	0.00
	14-	12.78	7.50	0.00	-46.26	0.00	-0.58	59.83	0.00
	14+	12.78	7.50	0.00	-46.26	0.00	-0.58	59.83	0.00
at critical section	15-	13.77	7.50	0.00	-44.87	0.00	0.04	60.09	0.00
	15+	13.77	7.50	0.00	-44.87	0.00	0.04	60.09	0.00
at midheight	16-	14.75	7.50	0.00	-43.49	0.00	0.63	59.76	0.00
	16+	14.75	7.50	0.00	-43.49	0.00	0.63	59.75	0.00
	17-	15.73	7.50	0.00	-42.11	0.00	1.20	58.85	0.00
	17+	15.73	7.50	0.00	-42.11	0.00	1.20	58.85	0.00
	18-	16.72	7.50	0.00	-40.73	0.00	1.73	57.41	0.00
	18+	16.72	7.50	0.00	-40.73	0.00	1.73	57.41	0.00
	19-	17.70	7.50	0.00	-39.34	0.00	2.23	55.46	0.00
	19+	17.70	7.50	0.00	-39.34	0.00	2.23	55.46	0.00
	20-	18.68	7.50	0.00	-37.96	0.00	2.69	53.04	0.00
	20+	18.68	7.50	0.00	-37.96	0.00	2.69	53.03	0.00
	21-	19.67	7.50	0.00	-36.58	0.00	3.12	50.17	0.00
	21+	19.67	7.50	0.00	-36.58	0.00	3.12	50.17	0.00
	22-	20.65	7.50	0.00	-35.19	0.00	3.52	46.90	0.00
	22+	20.65	7.50	0.00	-35.19	0.00	3.52	46.90	0.00
	23-	21.63	7.50	0.00	-33.81	0.00	3.87	43.27	0.00
	23+	21.63	7.50	0.00	-33.81	0.00	3.87	43.26	0.00
	24-	22.62	7.50	0.00	-32.43	0.00	4.19	39.30	0.00
	24+	22.62	7.50	0.00	-32.43	0.00	4.19	39.30	0.00



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	Wall Crossection		In-Plane Forces			Out-Of-Plane Forces		
No.	**Y coordinate**	**X-Centroid**	**Vux**	**Nuy**	**Muz**	**Vuz**	**Mux**	**Muy**
	ft	ft	kips	kips	kip-ft	kips	kip-ft	kip-ft
25-	23.60	7.50	0.00	-31.05	0.00	4.47	35.04	0.00
25+	23.60	7.50	0.00	-31.05	0.00	4.47	35.04	0.00
26-	24.58	7.50	0.00	-29.66	0.00	4.72	30.52	0.00
26+	24.58	7.50	0.00	-29.66	0.00	4.72	30.51	0.00
27-	25.57	7.50	0.00	-28.28	0.00	4.94	25.77	0.00
27+	25.57	7.50	0.00	-28.28	0.00	4.94	25.76	0.00
28-	26.55	7.50	0.00	-26.90	0.00	5.12	20.82	0.00
28+	26.55	7.50	0.00	-26.90	0.00	5.12	20.82	0.00
29-	27.53	7.50	0.00	-25.52	0.00	5.28	15.70	0.00
29+	27.53	7.50	0.00	-25.52	0.00	5.28	15.70	0.00
30-	28.52	7.50	0.00	-24.13	0.00	5.41	10.44	0.00
30+	28.52	7.50	0.00	-24.13	0.00	5.41	10.44	0.00
31-	29.50	7.50	0.00	-22.75	0.00	5.52	5.07	0.00
31+	29.50	7.50	0.00	-2.11	0.00	-0.12	-0.09	0.00
32-	30.25	7.50	0.00	-1.05	0.00	-0.06	-0.02	0.00
32+	30.25	7.50	0.00	-1.05	0.00	-0.06	-0.02	0.00
33-	31.00	7.50	0.00	0.00	0.00	0.00	0.00	0.00
33+	31.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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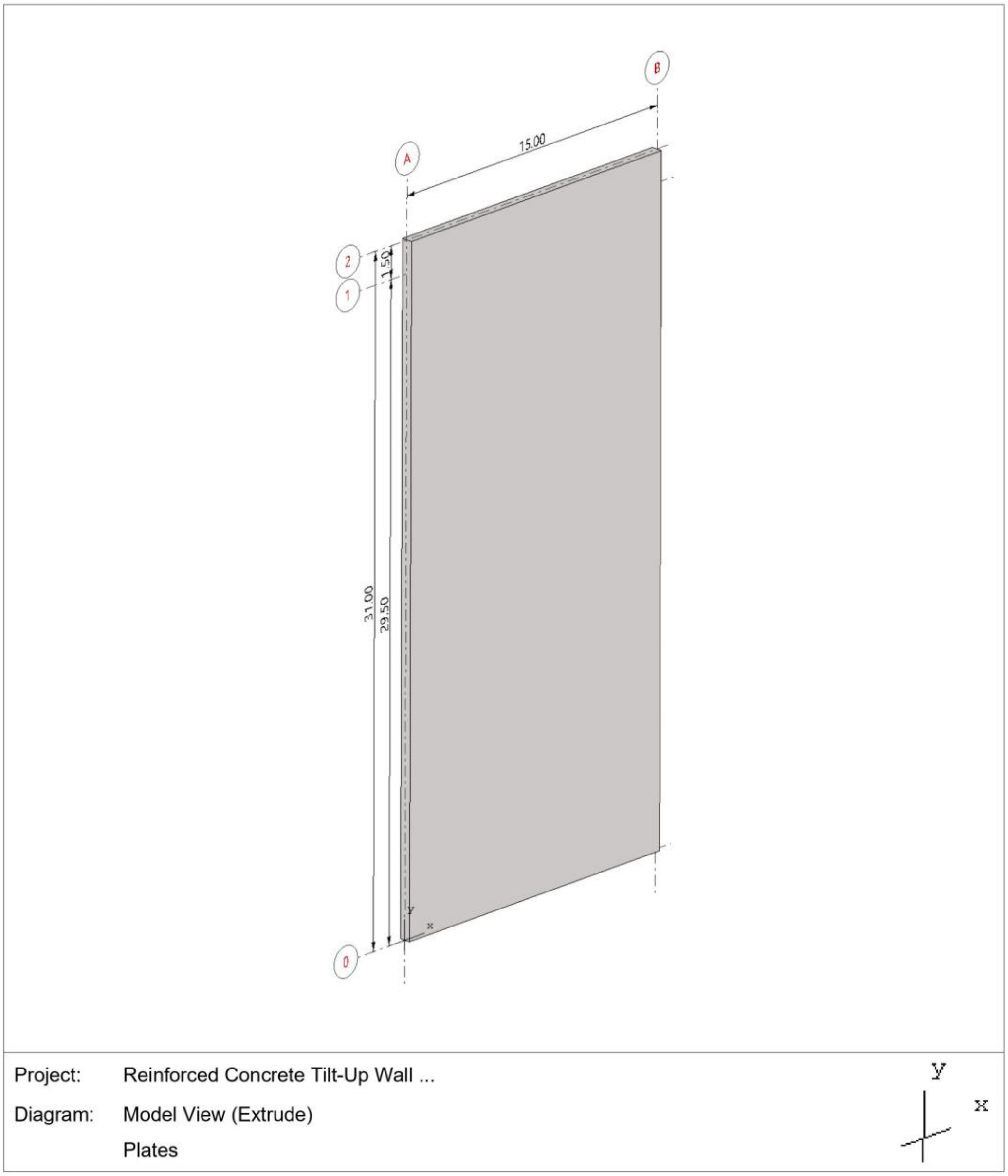
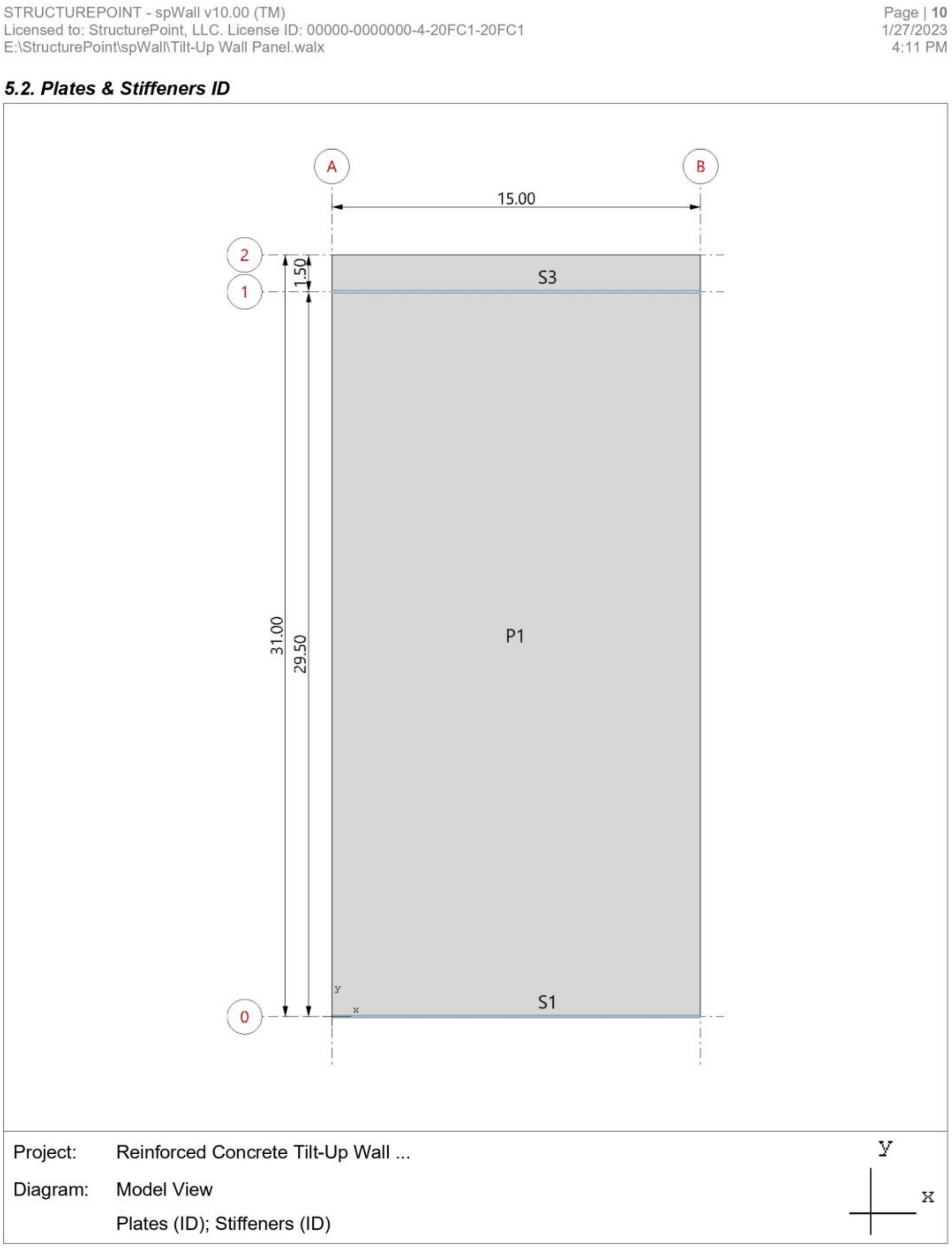
5. Screenshots

5.1. Extrude 3D view



Project:	Reinforced Concrete Tilt-Up Wall ...
Diagram:	Model View (Extrude)
	Plates



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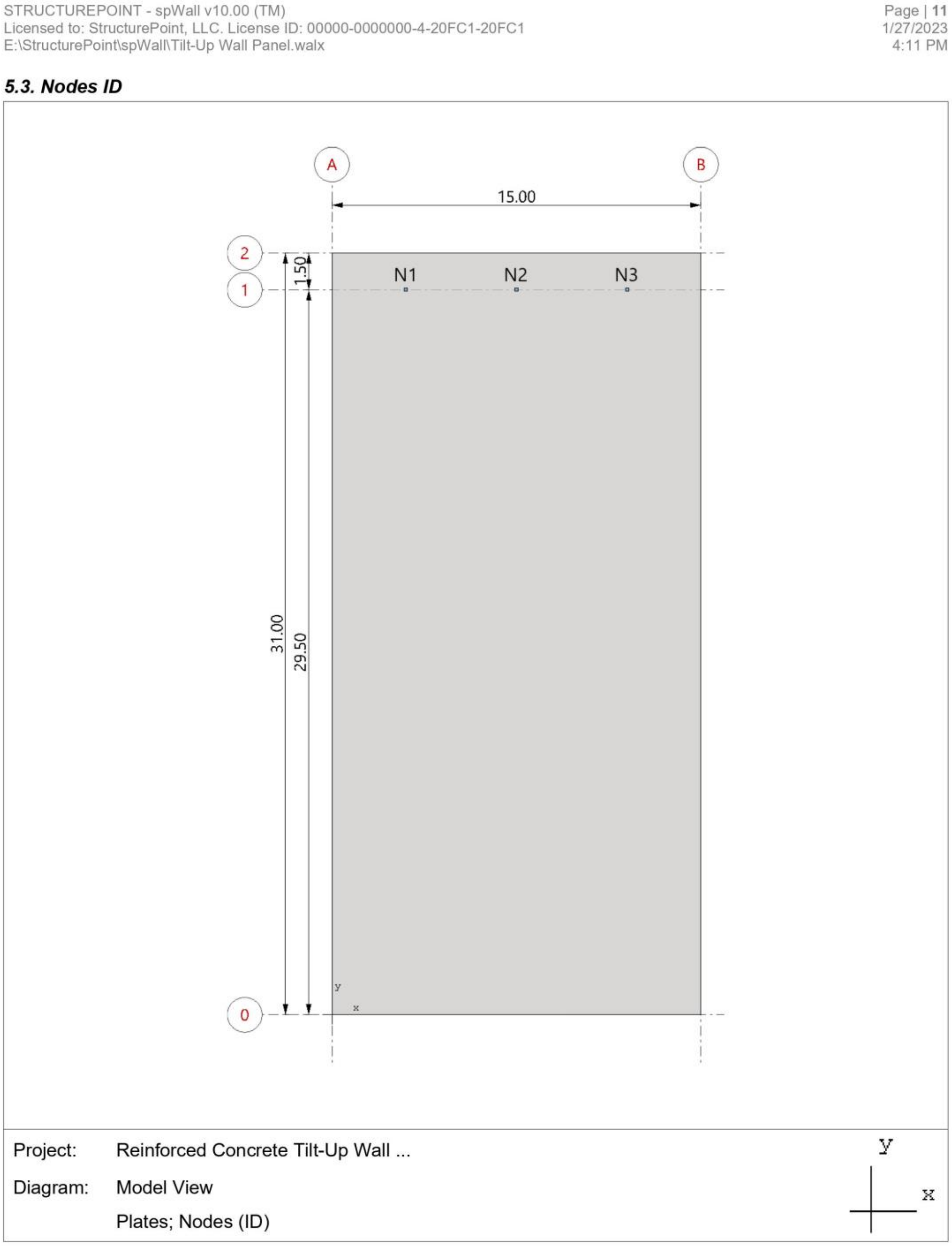
5.2. Plates & Stiffeners ID

Project: Reinforced Concrete Tilt-Up Wall ...
Diagram: Model View
Plates (ID); Stiffeners (ID)



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5.3. Nodes ID

Project: Reinforced Concrete Tilt-Up Wall ...
Diagram: Model View
Plates; Nodes (ID)

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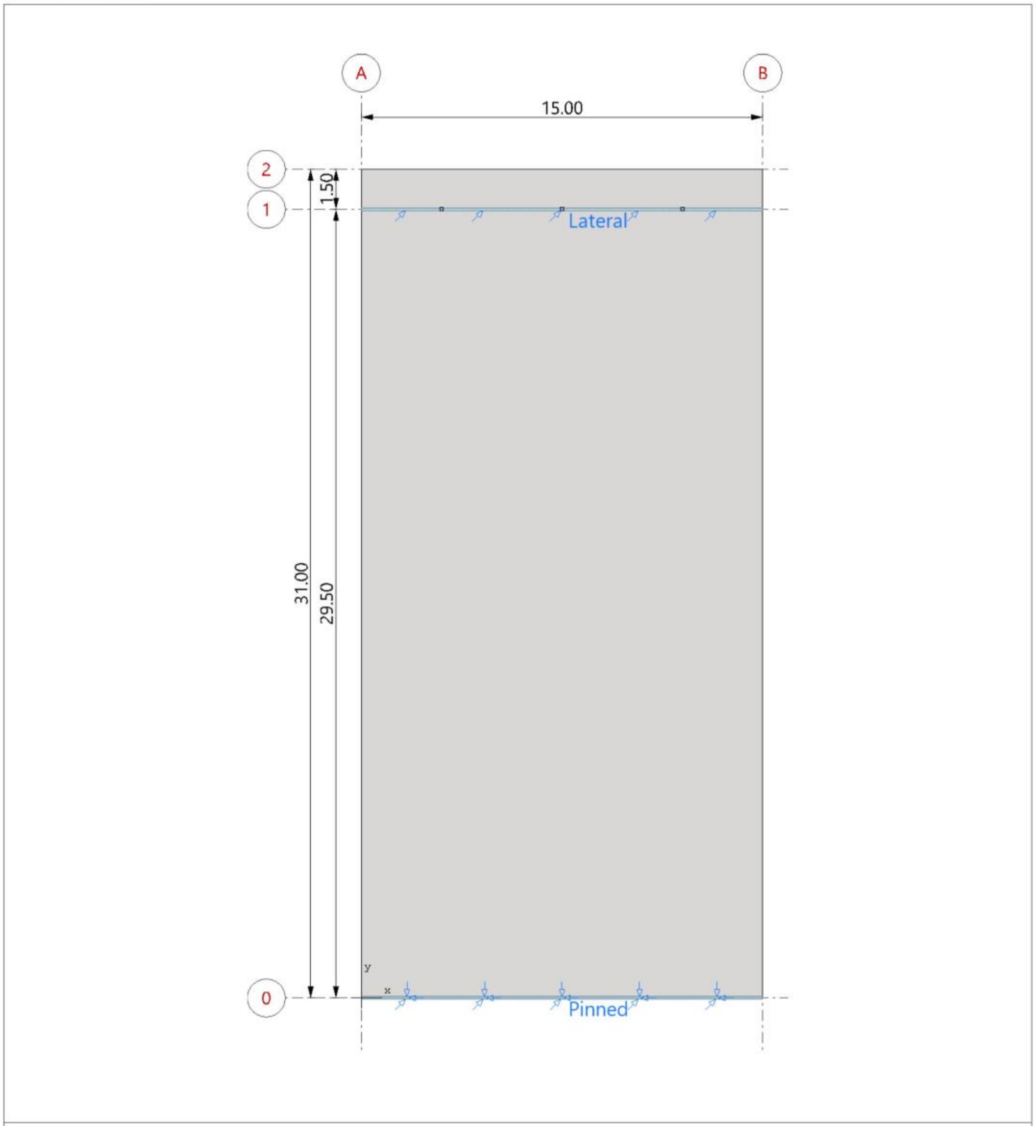
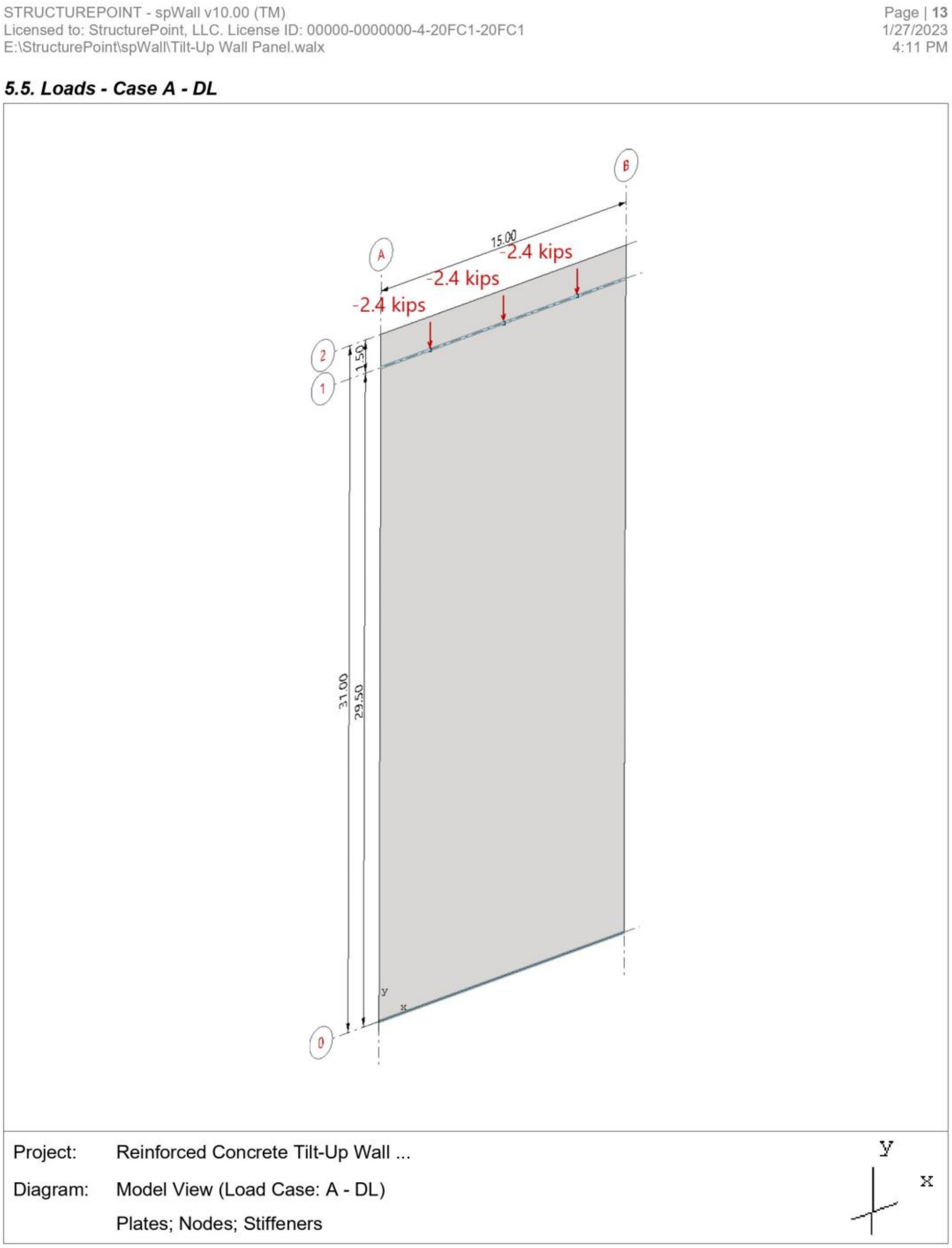
5.4. Restraints



Project:	Reinforced Concrete Tilt-Up Wall ...
Diagram:	Model View
	Plates; Nodes; Stiffeners; Restraints (Label)



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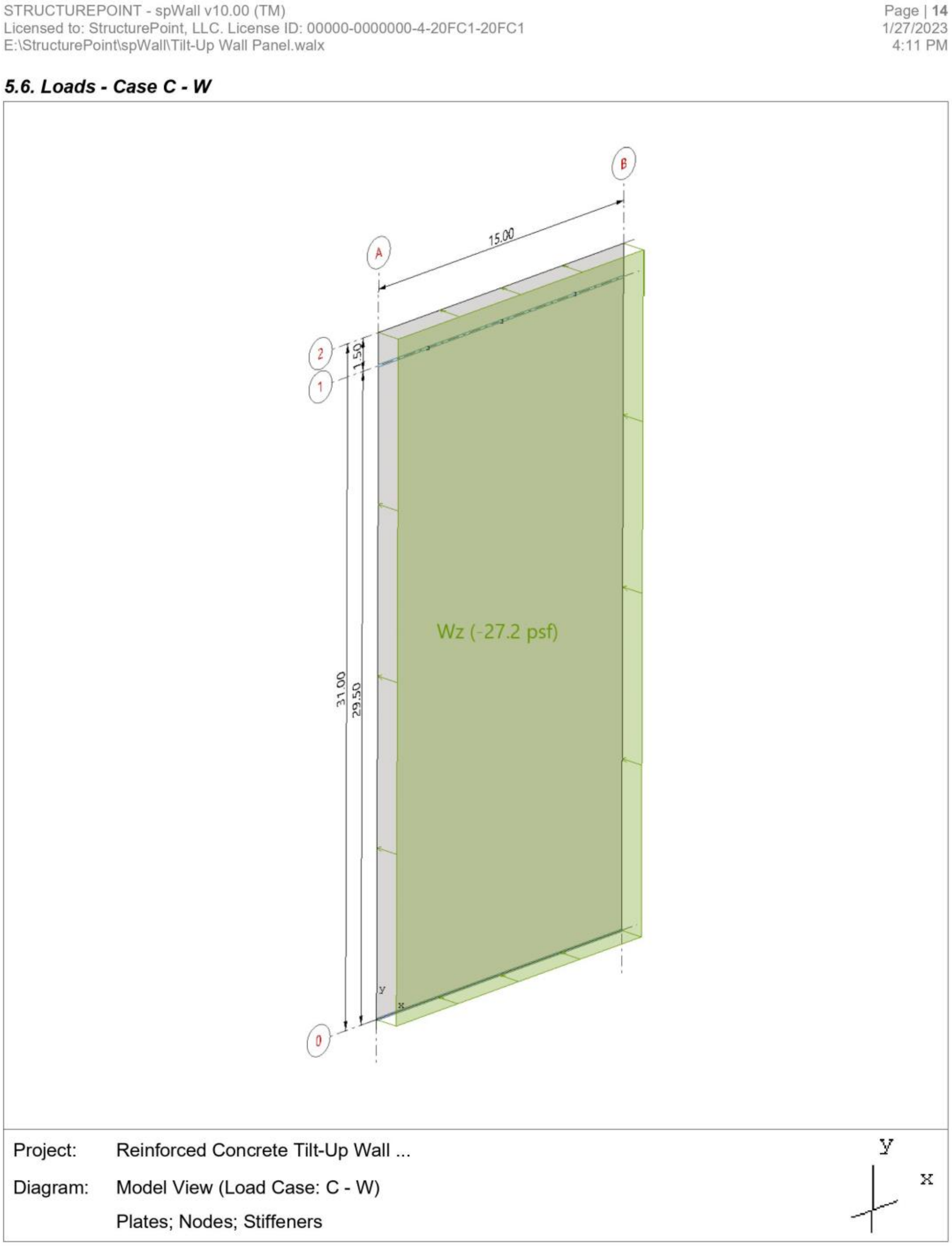
5.5. Loads - Case A - DL

Project: Reinforced Concrete Tilt-Up Wall ...

Diagram: Model View (Load Case: A - DL)

Plates; Nodes; Stiffeners



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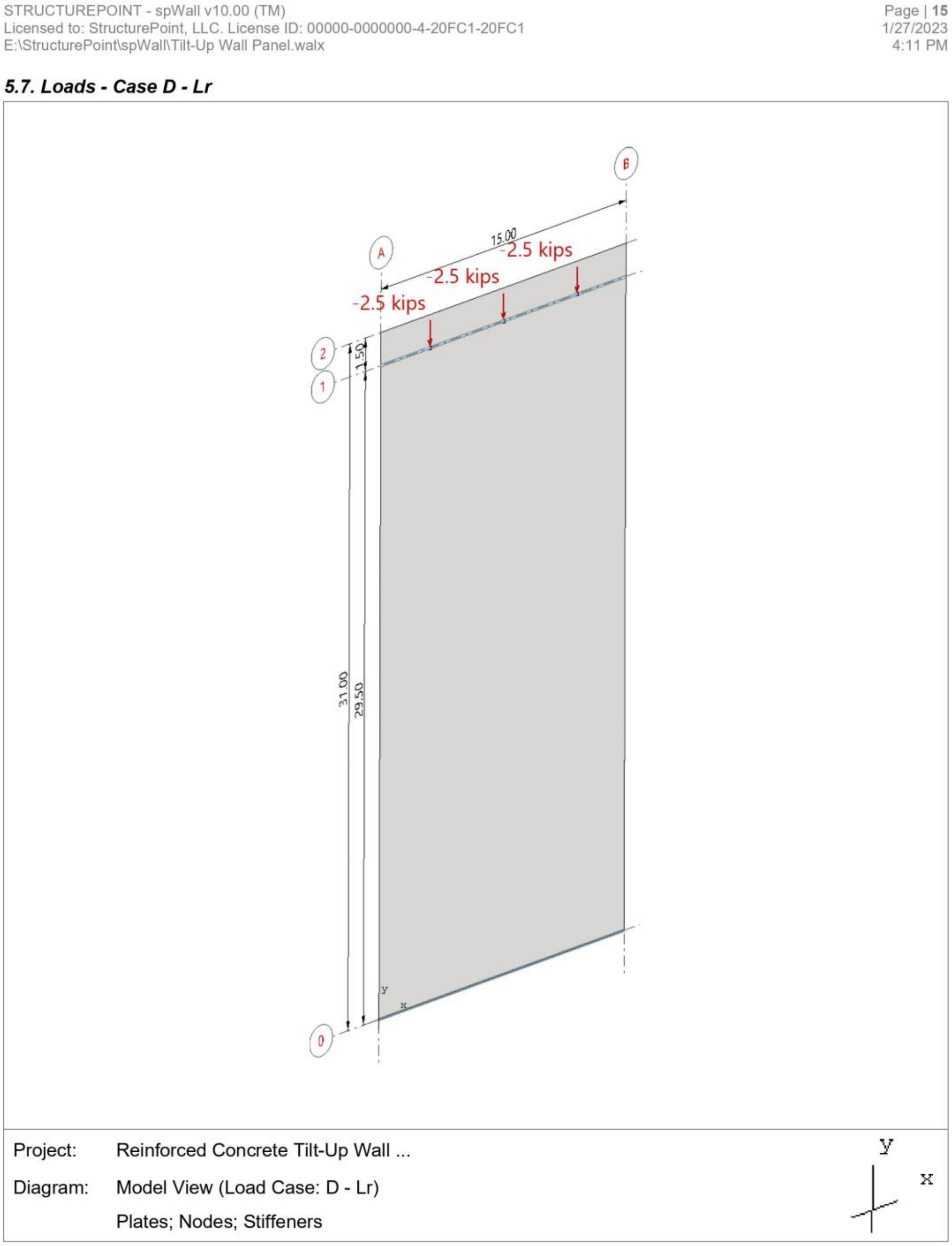
5.6. Loads - Case C - W

Project: Reinforced Concrete Tilt-Up Wall ...

Diagram: Model View (Load Case: C - W)

Plates; Nodes; Stiffeners



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5.7. Loads - Case D - Lr

Project:	Reinforced Concrete Tilt-Up Wall ...
Diagram:	Model View (Load Case: D - Lr)
	Plates; Nodes; Stiffeners

10. Design Results Comparison and Conclusions

Table 1 – Comparison of Tilt-Up Wall Panel Analysis and Design Results

Solution	M_u (kip-ft)	N_u (kips)	$D_{z,service}$ (in.)	$D_{z,ultimate}$ (in.)
Hand (at midheight)	61.00	43.49	0.247	9.995
spWall (at midheight)*	59.76	43.49	0.245	9.647
spWall (at critical section)**	60.09	44.87	0.244	9.618

* Values are taken at midheight (y = 14.75 ft) for comparison purposes with hand calculations.

** Values are taken at critical section (y = 13.77 ft) with maximum moment value.

The results of all the hand calculations illustrated above are in agreement with the automated exact results obtained from the spWall program.

In column and wall analysis, section properties shall be determined by taking into account the influence of axial loads, the presence of cracked regions along the length of the member, and the effect of load duration (creep effects). ACI 318 permits the use of moment of inertia values of 0.70 I_g for uncracked walls and 0.35I_g for cracked walls.

ACI 318-14 (6.6.3.1.1)

In spWall program, these effects are accounted for where the user can input reduced moment of inertia using "cracking coefficient" values for plate and stiffener elements to effectively reduce stiffness. Cracking coefficients for out-of-plane (bending and torsion) and in-plane (axial and shear) stiffness can be entered for plate elements. Because the values of the cracking coefficients can have a large effect on the analysis and design results, the user must take care in selecting values that best represent the state of cracking at the particular loading stage. Cracking coefficients are greater than 0 and less than 1.

At ultimate loads, a wall is normally in a highly cracked state. The user could enter a value of out-of-plane cracking coefficient for plates of $I_{cracked}/I_{gross}$ based on estimated values of A_s. after the analysis and design, if the computed value of A_s greatly differs from the estimated value of A_s, the analysis should be performed again with new values for the cracking coefficients. To account for variations in material properties and workmanship, a factor of 0.75 can be used to reduce the calculated bending stiffness of the concrete section in accordance with ACI 318-14 Chapter 11. ACI 551 states, this bending stiffness reduction factor should be incorporated by all other design methods to comply with the requirements of ACI 318.

At service loads, a wall may or may not be in a highly cracked state. For service load deflection analysis, a wall panel should be modeled with an out-of-plane cracking coefficient of ($I_{effective}/I_{gross}$).

Based on the previous discussion, the ratio between I_{cr} and I_g including a reduction factor of 0.75 is used as the cracking coefficient for the out-of-plane case for ultimate load combinations. In this example, I_{cr} and I_g were found to be equal to 353.56 in.^{4} and 3,662 in.^{4}. Thus, the out-of-plane cracking coefficient for ultimate load combinations can be found as follows:

$$\alpha = \text{ cracking coefficient} = \frac{0.75 \times I_{cr}}{I_g} = \frac{0.75 \times 353.56}{3,662} = 0.07241$$

For the service load combinations, M_a equals 20.84 ft-kip which is less than M_{cr} = 46.32 ft-kip indicating the section is uncracked ($I_{effective} = I_{gross}$) and the cracking coefficient can be set to 1.0

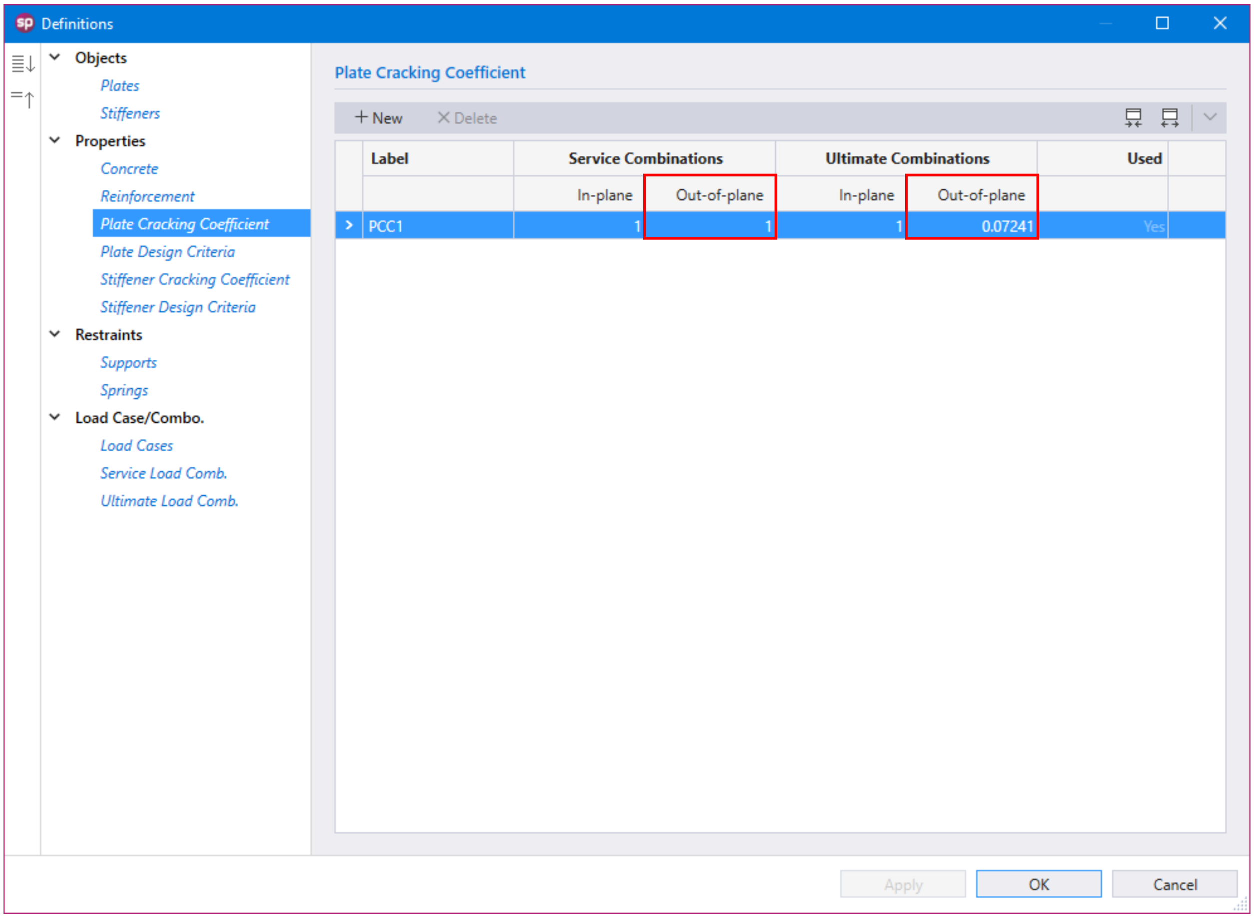

Plate Cracking Coefficient

Label	Service Combinations		Ultimate Combinations		Used
	In-plane	Out-of-plane	In-plane	Out-of-plane	
PCC1	1	1	1	0.07241	Yes

Figure 12 – Defining Cracking Coefficient (spWall)