

A guide to using LECWall for partially composite slender wall analysis:

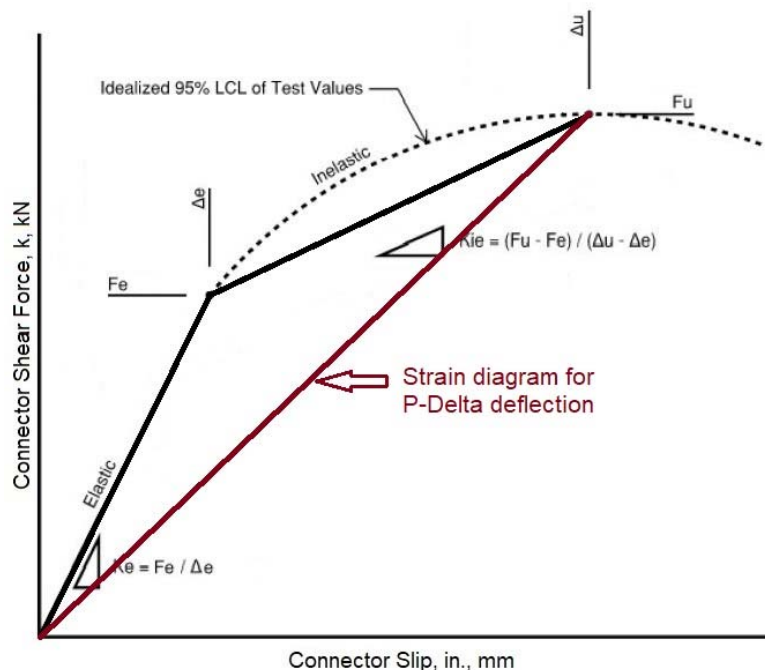
Main reference: *Tilt-Up Partially Composite Insulated Wall Panels* - A research report prepared for the Tilt-Up Concrete Association in 2022. Prepared by: Marc Maguire, PhD, Assistant Professor, Salam Al-Rubaye, PhD Candidate, Graduate Research Assistant, Durham School of Architectural Engineering and Construction, University of Nebraska-Lincoln.

From the Report: "This research project was initiated to investigate the behavior of load-bearing concrete insulated wall (CIP) panels for use in tilt-up construction. The primary objective was to understand the inelastic behavior of these panels so that engineers could perform a proper second-order analysis for combined axial and out-of-plane loading."

Five connector types were tested in double-shear, and then 40 ft. long panels were constructed using each system type. These were then tested to failure and deflections noted.

A slender wall analysis is generally required for mild-reinforced, load-bearing, unbraced slender walls. For a classic ACI slender wall analysis, maximum cracked-section deflection is estimated under ultimate lateral and eccentric gravity loads. An iterative "P-Delta" analysis is then used to magnify this deflection, which is then applied to find the maximum moment in the panel.

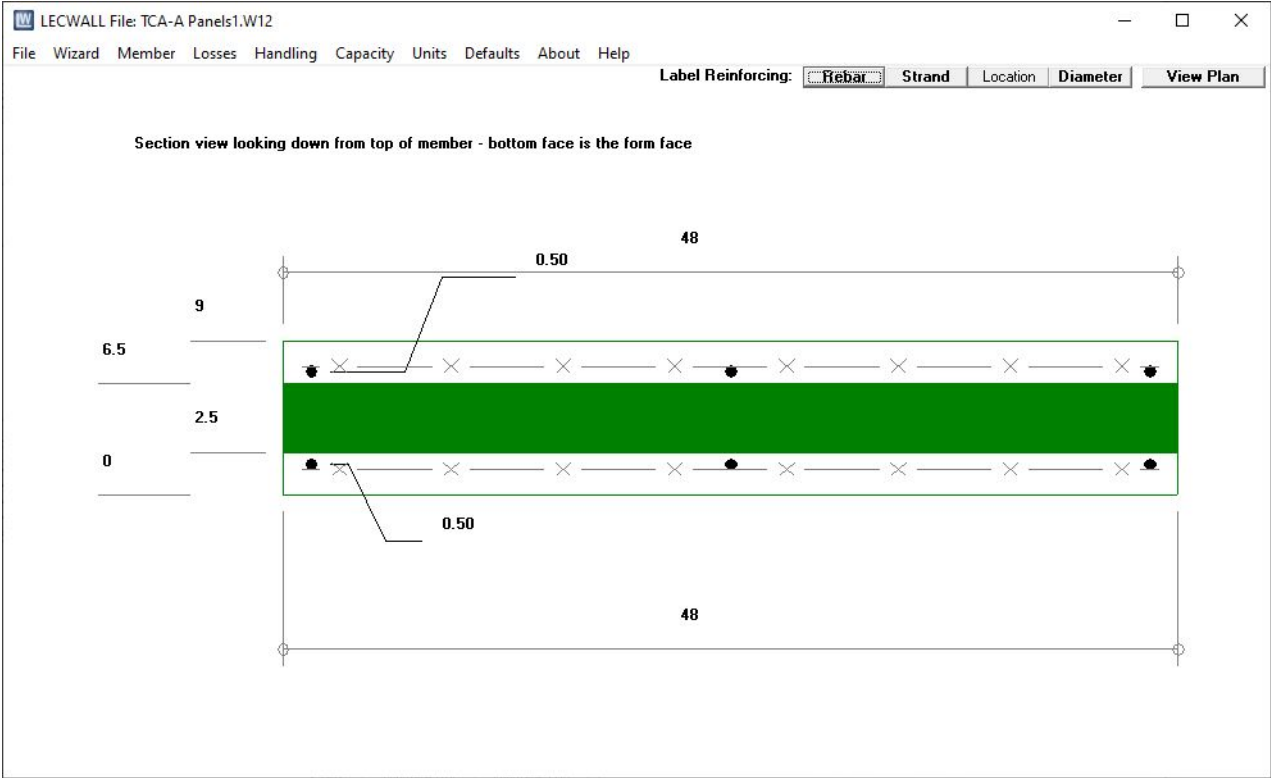
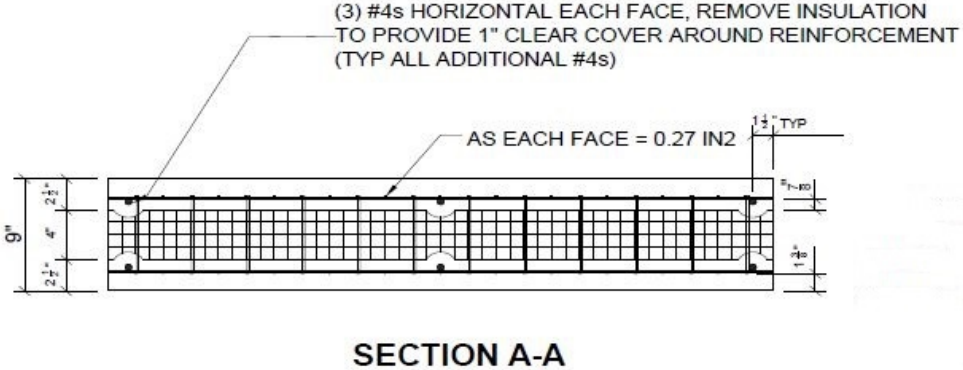
LECWall can be used to perform this type of analysis. Make sure you have the latest update first. (Select *Check for Updates* from the startup screen.) To use, select the *Pre-cracked* option from the Capacity screen. This will change the following: Instead of I-gross or I-effective, I-cracked will be used for the middle 2/3 of the panel length (it is assumed that the L/6 portions at the ends remain uncracked). For partially composite panels using Beam-Spring analysis, both wythes are considered to be fully cracked for the deflection calculation. In addition, cracked concrete area is substituted instead of A-gross (it is estimated to be $\frac{1}{4}$ A-gross for both wythes). Lastly, the wythe connectors are assumed to be in the full inelastic range for deflection (see graph):



When the *Pre-cracked* option is selected, the P-Delta deflections estimated by LECWall compare favorably to the TCA research report results for the five connector system types.

The following example outlines this procedure for the Group “A” partially composite insulated panels tested in the TCA report (Innstruct):

Since we are trying to duplicate the TCA tests, $F'c = 3790$ psi and $Fy = 85$ ksi for the rebar and 60 ksi for the WWF. The panel is 40 ft. long by 4 ft. wide.



From pg. 98 of the Report, average $Fu = 2.82$ ksf, $\Delta u = 0.06$ in., $Ke = 102$ k/in, $\Delta e = 0.014$ in and $Fe = 102 * 0.014 = 1.43$ ksf. (Generally, the lower-bound values should be used instead of the average, but in this case we are trying to match the test conditions.) The values are per sq ft, so for a default 16" spacing, 5.333 connectors are required in each row ($48 / 5.333 * 16 = 144$ in²):

Partial Composite Wythe Connector Properties

Partial Composite Wythe Connector Properties:

Member length, in:

*Number of connectors per lateral row:

*Additional connectors in first row:

*Additional connectors in second row:

*Additional connectors in third row:

(*Fractional number of connectors allowed)

Longitudinal connector row spacing, in:

Manufacturer Plug-ins:

Connector force at elastic limit, Fe, k:

Connector force at ultimate limit, Fu, k:

Connector elastic limit, DeltaE, in:

Connector inelastic limit, DeltaU, in:

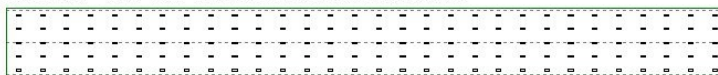
Connector elastic stiffness, Ke, k/in:

Connector inelastic stiffness, Kie, k/in:

Connector Phi for ultimate limit:

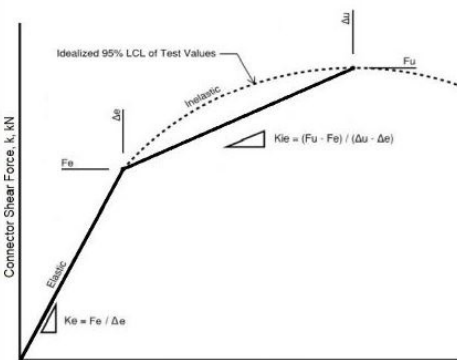
Notes:

Member Length = 480 in. Width = 48 in. (Select Advanced Layout to edit row-by-row.)



Plan Ultimate Bot Ultimate Top

Connector Shear Force, k, kN



Connector Slip, in., mm

Solid Zones If checked, end solid zones are counted on where possible to provide composite action for ultimate strength.

Maximum % Composite Equivalent:

Ultimate: Top Pressure % Bottom Suction %

Tension force from reinforcement, k:

Advanced Layout

Total number of connectors:

Print Form

<< Back Cancel Close Next >>

Wind load is applied, 38.75 psf Suction, 25.5 psf Pressure. Any gravity loads should also be applied, but we don't have any, just the panel self-weight, which can still be significant for P-Delta effects.

Applied Wind, Seismic and Earth Loads

Wind Load:

	Suction		Pressure		Start	Stop
	psf	plf	psf	plf		
1.	38.75	155	25.5	102	0	480
2.	0	0	0	0	0	0
3.	0	0	0	0	0	0
4.	0	0	0	0	0	0
5.	0	0	0	0	0	0
6.	0	0	0	0	0	0

(Member height is 480 in.)

Seismic Load:

Percent of panel dead weight to be applied as Seismic Load:

Earth Pressure:

Pressure From:

	Inside	Outside
Horizontal component of surcharge at top of retained earth (psf):	<input type="text" value="0"/>	<input type="text" value="0"/>
Active lateral pressure per unit of depth (psf/ft):	<input type="text" value="0"/>	<input type="text" value="0"/>
Distance from bottom of wall to top of retained earth (in):	<input type="text" value="0"/>	<input type="text" value="0"/>

Slab on grade floor tie not active for load cases with earth pressure and no wind or seismic load

Go to Applied Dead and Live Loads

<< Back Cancel Close Next >>

Check wind under service loads for cracking (the *Pre-cracked* option is not active for service load cases):

Input:

Supports Applied Loads

Bow & Temperature

Manual Input: Calculated:

0 % composite at ultimate 100.0

0 % composite for stresses Calcd

0 % composite for deflection Calcd

Composite Calculation:

Beam-Spring Method Manual % Comp. Input

Revise Wythe Connectors

Beam-Spring Graphs

Cracking stress coefficient: 7.5

Member is pre-cracked

Load Case 13:

1	2	3	4	5	6	7
8	9	10	11	12	13	14

Service Dead + Wind, ASCE 7-10 2.4.1-5

Show Moment Diagrams

Show Stresses

Show Shear Diagrams

Show Connection Forces

Max Tension Stress Envelope

Max Compr Stress Envelope

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Output:

Suction at 237.60 in:

Pu (kips) = 5.00
Mu (kip-in) = 228.40
Vu (kips) = 0.06

Outer Stress (psi) = 372.08
Inner Stress (psi) = -413.62
Service tension exceeded
Bow + Deflection (in) = 1.02
(Outward deflection is positive)
of Iterations = 3
Converge = True
(Compression is Negative)

Second-order effects ratio = 1.02

Pressure at 237.60 in:

Pu (kips) = 5.00
Mu (kip-in) = -150.45
Vu (kips) = -0.04

Outer Stress (psi) = -279.24
Inner Stress (psi) = 237.80
Section is uncracked
Bow + Deflection (in) = -0.70
(Outward deflection is positive)
of Iterations = 2
Converge = True
(Compression is Negative)

Cracking Stress

Maximum Connection Forces

Edit Load Cases

Close

Stresses

Outer Inner Outer Inner

SUCTION PRESSURE

Click on graph for values at any point

Show Stresses at Insulation Face

Print Moment and Stress Diagrams

Print Shear Diagrams

Sections Print Input Print All

Interaction Curves

Interaction Curves

Next >>

Service deflection is 1.02" (L/470, ok), compared to 0.57" in the TCA report. Tension stress is 372 psi (6 SQFC), less than 7.5 SQFC = 461 psi cracking stress, but greater than 5 SQFC = 307 psi, so could be a concern for appearance.

Next, check Ultimate Wind as a Pre-cracked member:

Wall & Column Capacity Under Design Loadings File: TCA-A Panels1.W12

Input:

Supports Applied Loads

Bow & Temperature

Manual Input: Calculated:

0 % composite at ultimate 100.0

0 % composite for stresses Calced

0 % composite for deflection Calced

Composite Calculation:

Beam-Spring Method

Manual % Comp. Input

Cracking stress coefficient: 7.5

Member is pre-cracked

Load Case 4:

1	2	3	4	5	6	7
8	9	10	11	12	13	14

ACI 318-14/19 5.3.1d Wind+Live

Show Moment Diagrams

Show Stresses

Show Shear Diagrams

Show Connection Forces

Max Tension Stress Envelope

Max Compr Stress Envelope

<< Back

Output:

Suction at 237.60 in:

Pu (kips) = 6.00
Mu (kip-in) = 416.28
Vu (kips) = 0.16

Outer Stress (psi) = 659.17
Inner Stress (psi) = -709.16

SECTION IS CRACKED

Bow + Deflection (in) = 7.27 (Outward deflection is positive)

of Iterations = 5
Converge = True
(Compression is Negative)

Second-order effects ratio = 1.12

Pressure at 237.60 in:

Pu (kips) = 6.00
Mu (kip-in) = -275.56
Vu (kips) = -0.11

Outer Stress (psi) = -475.14
Inner Stress (psi) = 425.31

Section is pre-cracked

Bow + Deflection (in) = -5.02 (Outward deflection is positive)

of Iterations = 4
Converge = True
(Compression is Negative)

Cracking Stress

Maximum Connection Forces

Edit Load Cases

Close

Stresses

Outer Inner Outer Inner

SUCTION PRESSURE

Click on graph for values at any point

Show Stresses at Insulation Face

Print Moment and Stress Diagrams

Print Shear Diagrams

Sections Print Input Print All

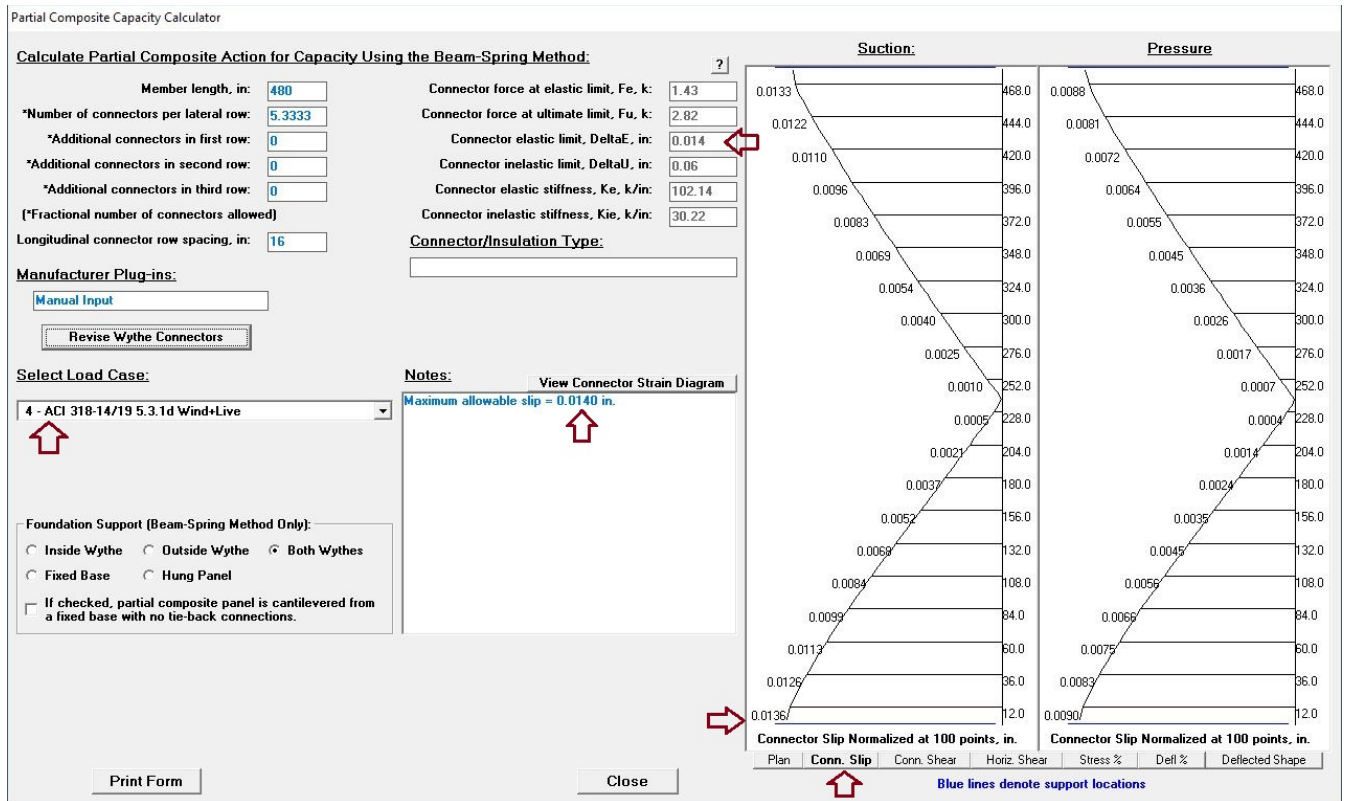
Interaction Curves

Interaction Curves

Next >>

Deflection with P-Delta magnification is 7.27", compared to 5.7" in the TCA report. LECWall applies a Phi-k stiffness factor of 0.875 to EI (per ACI 318). Without that, deflection would be 7.27*0.875 = 6.36", still greater than 5.7". The *Second-order effects ratio* shows that deflections were magnified 12% by P-Delta effects. ACI limits second-order effects to 40% maximum.

Click on "Beam-Spring Graphs" to check the maximum connector slip:



Maximum allowable slip to remain in the elastic range is 0.014", compared to 0.0136" actual, so ok. (This provides a factor of safety to ensure that the connectors stay in the elastic range under service loads.) If exceeded, it doesn't necessarily mean that the member has failed, just that it exceeds the limits of the Beam-Spring elastic analysis used by LECWall. If exceeded by a significant amount, the LECWall analysis could over-estimate the connector stiffness, as some connectors would be in the inelastic range. The cure is to simply add more connectors where slip is exceeded (use the Advanced Layout option on the Connectors screen, if needed).

Click on *Interaction Curves* from the Capacity screen to check the member capacity (Use *Auto-Check* to find the critical locations along the span).

Interaction Curves

Section cut location from left end (in): **237.6001**

100.0 % Comp. Suction
100.0 % Comp. Pressure

Wythe in Tension: Composite: 0% 100%

Top: A B
Bottom: C D

Auto-Check ?

Strand
Rebar
WwF

STRAND:
Row As d

A
B
C
D
E
F
G
H

Print Input
Print Diagram

Print 1.0*M-Cr ?

Member Length = 480 in. Width = 48 in. Not to scale or proportion

Click on plan or use slider to select locations along the span.

Load Cases to Show:

All 1 2 3 4 5 6 7
8 9 10 11 12 13 14

? Compr Face Not Reversed

Solid zones are not counted on to provide composite action for ultimate strength.

100% Comp: Partial Composite:
0% Comp:

Check also: Outer Wythe Check Inner Wythe Check

Done

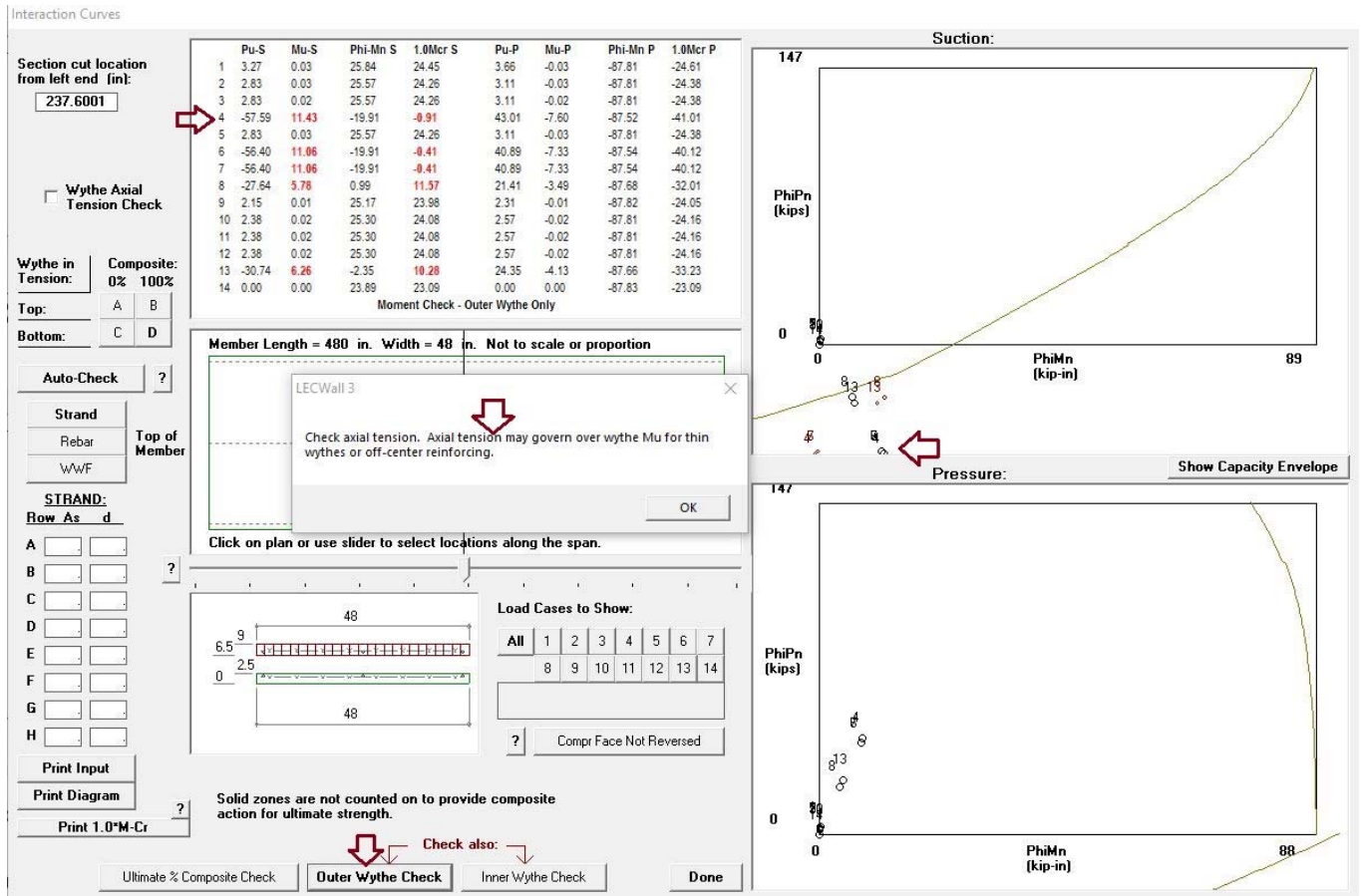
Table:

	Pu	Mu-S	Phi-Mn S	1.0Mer S	Mu-P	Phi-Mn P	1.0Mer P
1	7.00	1.34	443.25	49.09	-1.34	-443.25	-49.09
2	6.00	0.98	440.94	48.67	-0.98	-440.94	-48.67
3	6.00	0.98	440.94	48.67	-0.98	-440.94	-48.67
4	6.00	0.98	440.94	264.78	-275.56	-440.94	-264.78
5	6.00	0.98	440.94	48.67	-0.98	-440.94	-48.67
6	4.50	402.97	437.49	261.38	-266.08	-437.49	-261.38
7	4.50	402.97	437.49	261.38	-266.08	-437.49	-261.38
8	6.00	210.44	440.94	264.78	-126.86	-440.94	-264.78
9	4.50	0.54	437.49	48.05	-0.54	-437.49	-48.05
10	5.00	0.68	438.64	48.26	-0.68	-438.64	-48.26
11	5.00	0.68	438.64	48.26	-0.68	-438.64	-48.26
12	5.00	0.68	438.64	48.26	-0.68	-438.64	-48.26
13	5.00	228.40	438.64	274.31	-150.45	-438.64	-274.31
14	0.00	0.00	427.13	46.17	0.00	-427.13	46.17

Suction:

Pressure:

The % Composite check looks ok, but this is misleading, as the individual wythe checks are usually more accurate. Checking the Outer Wythe:



Here it is not surprising that the outer wythe fails in flexure. The wythes are very thin and the reinforcing is located off-center toward the insulation face, so the moment arm is small. By this criteria the member capacity would be much less than expected or shown by the TCA tests. As such, we can assume that the outer wythe yields when cracked and forms one or more plastic hinges. The flexural stiffness of the wythe becomes very small and it essentially becomes a tension chord. It is necessary to check the axial tension in the wythes. To do this, select *Wythe Axial Tension Check* at the upper left of the window:

Interaction Curves

Section cut location from left end (in):
237.6001

Wythe Axial Tension Check

Wythe in Tension: Composite: 0% 100%

Top: A B
Bottom: C D

Auto-Check ?

Strand
Rebar
WWF

STRAND:
Row As d

A
B
C
D
E
F
G
H

Print Input
Print Diagram ?
Print 1.0*M-Cr

	Pu-S	Mu-S	Phi-Tn S	Pu-P	Mu-P	Phi-Tn P
1	3.26	0.00	-60.55	3.67	0.00	-60.55
2	2.82	0.00	-60.55	3.12	0.00	-60.55
3	2.82	0.00	-60.55	3.12	0.00	-60.55
4	-60.29	0.03	-60.55	44.94	-2.63	-60.55
5	2.82	0.00	-60.55	3.12	0.00	-60.55
6	-59.02	0.03	-60.55	42.76	-2.50	-60.55
7	-59.02	0.03	-60.55	42.76	-2.50	-60.55
8	-29.16	0.02	-60.55	22.37	-0.77	-60.55
9	2.14	0.00	-60.55	2.31	0.00	-60.55
10	2.38	0.02	-60.55	2.57	-0.02	-60.55
11	2.38	0.02	-60.55	2.57	-0.02	-60.55
12	2.38	0.02	-60.55	2.57	-0.02	-60.55
13	-31.62	0.05	-60.55	24.35	-4.13	-60.55
14	0.00	0.00	-60.55	0.00	0.00	-60.55

Axial Tension Check - Outer Wythe Only

Member Length = 480 in. Width = 48 in. Not to scale or proportion

Click on plan or use slider to select locations along the span.

Load Cases to Show:

All	1	2	3	4	5	6	7
	8	9	10	11	12	13	14

Compr Face Not Reversed

Solid zones are not counted on to provide composite action for ultimate strength.

Check also: Outer Wythe Check Inner Wythe Check

Ultimate % Composite Check **Outer Wythe Check** Inner Wythe Check Done

The axial tension is 60.29k, slightly less than the Phi-Tn tension capacity of 60.55k. The loading we have chosen corresponds almost exactly to the tension wythe capacity, how about that? Therefore, the member moment capacity (without 0.9 Phi) according to LECWall is 462 k-in, compared to 680 k-in actual from page 108 of the TCA Report (LECWAll 416 k-in max with 0.9 Phi). Conservative, but not excessively so. The LECWall capacity based on maximum connector slip is 426 k-in and Phi-Mn capacity based on the Percent Composite check is 441 k-in, but axial tension would govern (416 k-in max for Phi-Mn).

Conservative results were also obtained with the other four connector systems (B-E) when the *Pre-cracked* option was selected.