Design Guide for Insulated Wall Panels using Beam-Spring Modeling Techniques, Part III **2025-09-27**

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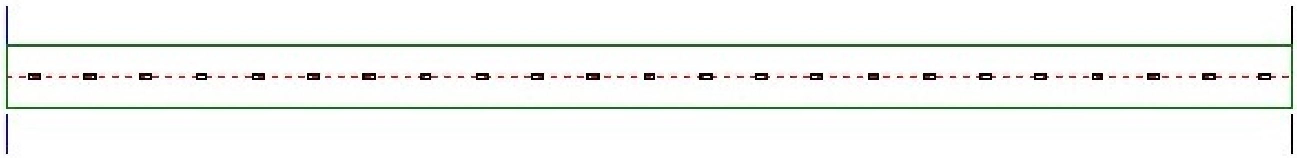
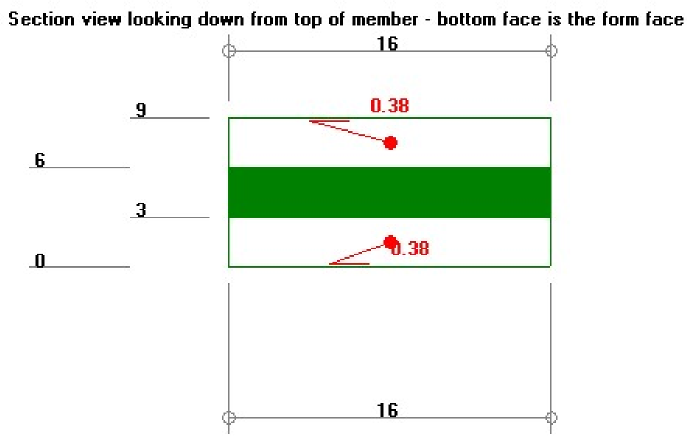
Part 3 – A Design Example:

A sample problem will be run from start to finish, using a basic plane frame analysis program that is similar to STAAD, as well as MASTAN2, an open-source program. A 16" wide section of panel will be used for simplicity. There are two 3" thick concrete wythes with 3" thick insulation between. The panel will be supported at the top (roof) and base (foundation).

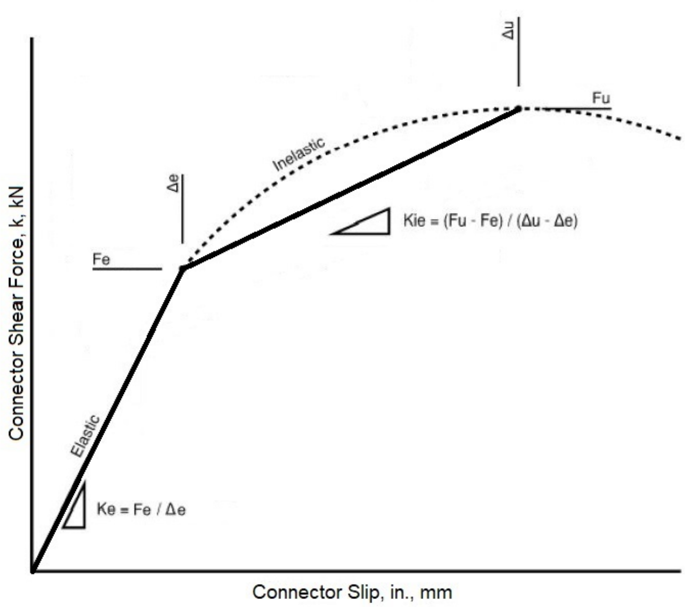


Width = 16", length = 368", view from top-in-form (screed face).

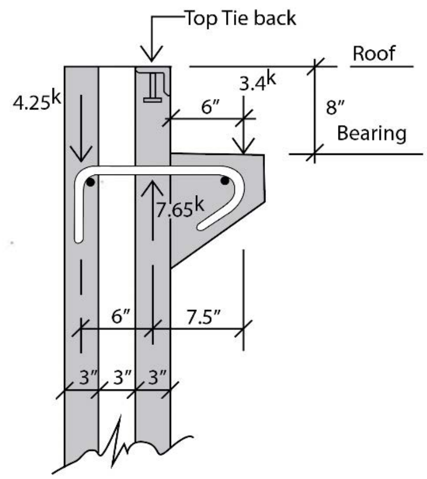


3.1 Initial run input:

Reinforcing consists of 3/8" diameter strands at 16" o.c. top and bottom. These 270 ksi "lo-lax" strands are stressed to 75% pull. Concrete F'c = 6000 psi. Wythe connectors are spaced at 16" o.c. Connector Fe = 2.0k each, Δe = 0.06", Fu = 4.0k each and Δu = 0.20". Based on these values, Ke = 33.33 k/in and Kie = 14.29 k/in.

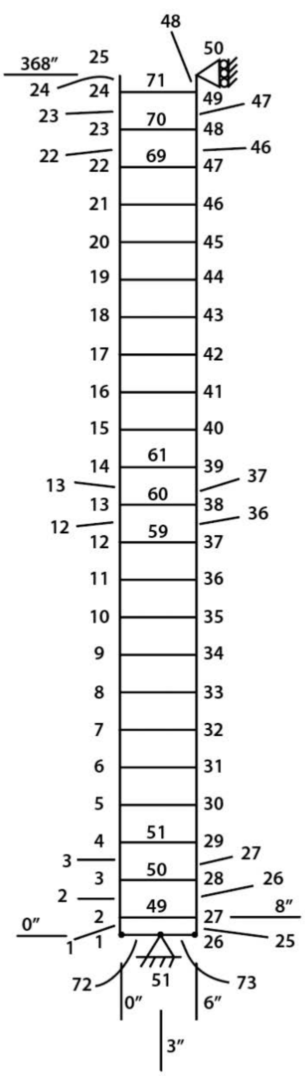


Wind load is 40 psf, or 53.3 plf in suction. A gravity load is applied at 8″ below the roof level, with a 6″ eccentricity from the inside face of wall. The gravity load is assumed to transfer to both wythes through reinforcing.



The load case to be examined is from ACI 318-19 5.3.1d, Dead + Wind + Live + Roof. Load factors are: 1.2*Dead + 1.0*Wind + 0.5*Roof (there is no Live load in this example). The applied gravity load consists of 2k Dead (1.5 klf) + 2k Roof (1.5 klf). The factored reaction would then be 1.2*2.0 + 0.5*2.0 = 3.4k total.

Numbered joints (or nodes) and member elements for design example:



Input file for initial run:

```
/ EDL 3-3-3 Example, Initial Run
JOINT COORDINATES
1 0 0
2 0 8 24 0 360
25 0 368
26 6 0
27 6 8 49 6 360
50 6 368 S
51 3 0 S
JOINT RELEASES
50 M
50 FORCE Y
51 M
MEMBER INCIDENCES
1 1 2 24
25 26 27 48
49 2 27 71
72 1 51
73 51 26
MEMBER RELEASES
72 M 1
73 M 2
MEMBER PROPERTIES
1 THRU 48 48 36 3550
49 THRU 71 1 0.1378 4350
72 0.1 99999 99999
73 0.1 99999 99999
LOADING 1
JOINT LOADS
24 F Y 4.25
49 F Y -7.65
MEMBER LOADS
1 THRU 48 FORCE X UNIFORM -0.005
1 THRU 24 FORCE Y UNIFORM 0.004444
LIST DISPLACEMENTS
FINISH
```

Members 1-48 represent the two concrete wythes. Members 49-71 denote the wythe connectors. Members 72 and 73 are used to link to the pinned rocker support at the base (joint 51). Joint 50 at the top of panel (368”) provides the tieback connection to the roof.

Member Properties: Concrete wythe area is 48 in^2, Moment of Inertia, I = $bd^3/12 = 16*3^3/12 = 36$ in^4. The Modulus of Elasticity, E = 57.619*Sqrt(6000) = 4463 ksi. It is modified by two factors. First, it is multiplied by $\Phi_k = 0.875$ and then divided by 1+ β_d, where $\beta_d = 0.1$ for mostly wind load. (See ACI 318-19, R6.6.4.4.4 and R6.7.1.1.) Therefore the concrete E = 4463*0.875/1.1 = 3550 ksi for the initial run.

For the wythe connector properties, Area is somewhat arbitrarily set to 1.0 in2, since we do not need to find the connector axial tension. Connector Modulus of Elasticity, E is set to 4350 ksi, assuming a glass fiber connector. Moment of Inertia, I, is calculated from the connector elastic stiffness determined by double-shear tests. In this case, Ke = 33.3 k/in. An example of this calculation can be found in Part I of this Design Guide, Section 1.7.2 “Member Properties”. Using E = 4350 ksi, I = $V*l^3/12/E/\Delta = 33.3*6^3/12/4350/1 = 0.1378$ in^4.

Members 72 and 73 are simply rocker components, so are set to be extremely stiff. They are pinned where they join the concrete wythes in order to avoid transmitting any unwanted moments to the wythes.

Joint Loads: Since the bearing connection can transfer load to both wythes, statics can be used to determine the force applied to each wythe. The eccentricity of the load to the inner wythe is 6" + 3"/2 = 7.5". The moment induced is 3.4k*7.5" = 25.5k-in. To balance, the outer wythe tension is therefore 25.5k-in/6" = 4.25k in tension. The inner wythe compression is 4.25+3.4 = 7.65k.

Member Loads: The selfweight of the concrete wythes can be found as follows. 150 pcf/1728 in^3 = 0.0868 pci (pounds per cubic inch). 48 in^3*0.0868*1.2/1000 = 0.005 k/in (with 1.2 load factor applied). Wind load is 53.33 plf / 1000/ 12 which becomes 0.004444 k/in.

3.2 Initial Run Output:

LOADING 1 TITLE – PCFInputFile1.txt Page 2

MEMBER FORCES

MEMBER	JOINT	AXIAL FORCE	SHEAR FORCE	BENDING MOMENT
1	1	3.54	−0.4726525	−1.392272E−13
	2	−3.5	0.4371005	−3.639012
2	2	1.863621	−0.455561	−1.270537
	3	−1.783621	0.384457	−5.449606
3	3	0.1912515	−0.4213442	0.6724855
	4	−0.1112516	0.3502402	−6.845159
4	4	−1.404935	−0.3861257	2.296611
	5	1.484935	0.3150218	−7.90579
5	5	−2.900803	−0.3505045	3.658186
	6	2.980803	0.2794006	−8.697426
6	6	−4.278288	−0.3149503	4.804969
	7	4.358288	0.2438463	−9.27534
7	7	−5.523933	−0.2794004	5.778405
	8	5.603933	0.2082964	−9.679978
8	8	−6.627791	−0.2438483	6.608404
	9	6.707791	0.1727443	−9.941144
9	9	−7.582617	−0.2082962	7.316666
	10	7.662617	0.1371922	−10.08057
10	10	−8.38328	−0.1727443	7.918587
	11	8.46328	0.1016402	−10.11366
11	11	−9.026342	−0.1371922	8.424476
	12	9.106342	6.608825E−02	−10.05072
12	12	−9.509787	−0.1016402	8.840386
	13	9.589787	3.053626E−02	−9.897798
13	13	−9.832847	−6.608824E−02	9.168618
	14	9.912847	−5.015739E−03	−9.657198
14	14	−9.995946	−3.053628E−02	9.407901
	15	10.07595	−4.056776E−02	−9.327648
15	15	−10.00073	5.015664E−03	9.553287
	16	10.08073	−0.0761197	−8.904203
16	16	−9.850216	4.056834E−02	9.595755
	17	9.930216	−0.1116723	−8.377831
17	17	−9.549006	7.612066E−02	9.521463
	18	9.629005	−0.1472247	−7.734699
18	18	−9.10369	0.1116482	9.310645
	19	9.18369	−0.1827522	−6.95544
19	19	−8.523373	0.1472751	8.936395
	20	8.603373	−0.218379	−6.011165
20	20	−7.820411	0.1834546	8.360053
	21	7.900411	−0.2545587	−4.855945
21	21	−7.011419	0.2139833	7.522776
	22	7.091419	−0.2850873	−3.530209
22	22	−6.118622	0.2446682	6.449038
	23	6.198622	−0.3157722	−1.965519
23	23	−5.17166	0.4824289	5.050148
	24	5.25166	−0.553533	3.237551
24	24	−4.21	−3.555197E−02	−0.1422077
	25	4.25	2.970209E−14	−3.036633E−14
25	26	3.54	−0.4772199	8.247049E−14
	27	−3.5	0.4416679	−3.675551

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MEMBER FORCES

MEMBER	JOINT	AXIAL FORCE	SHEAR FORCE	BENDING MOMENT
26	27	5.136379	−0.4232074	−1.233175
	28	−5.056379	0.4232074	−5.538141
27	28	6.648748	−0.3863202	0.7610466
	29	−6.568748	0.3863202	−6.942168
28	29	8.084935	−0.3504347	2.393595
	30	−8.004935	0.3504347	−8.000548
29	30	9.420802	−0.3149519	3.752947
	31	−9.340802	0.3149519	−8.792175
30	31	10.63829	−0.2794021	4.899719
	32	−10.55829	0.2794021	−9.370152
31	32	11.72393	−0.2438481	5.873217
	33	−11.64393	0.2438481	−9.774784
32	33	12.66779	−0.2082962	6.70321
	34	−12.58779	0.2082962	−10.03595
33	34	13.46262	−0.1727443	7.411471
	35	−13.38262	0.1727443	−10.17538
34	35	14.10328	−0.1371922	8.013392
	36	−14.02328	0.1371922	−10.20847
35	36	14.58634	−0.1016402	8.519281
	37	−14.50634	0.1016402	−10.14552
36	37	14.90979	−6.608825E−02	8.935191
	38	−14.82979	6.608825E−02	−9.992603
37	38	15.07285	−3.053626E−02	9.263424
	39	−14.99285	3.053626E−02	−9.752004
38	39	15.07595	5.015753E−03	9.502706
	40	−14.99595	−5.015753E−03	−9.422454
39	40	14.92073	4.056785E−02	9.648092
	41	−14.84073	−4.056785E−02	−8.999006
40	41	14.61022	7.611921E−02	9.690557
	42	−14.53022	−7.611921E−02	−8.472651
41	42	14.149	0.1116708	9.616283
	43	−14.06901	−0.1116708	−7.829549
42	43	13.54369	0.1472473	9.405496
	44	−13.46369	−0.1472473	−7.049538
43	44	12.80337	0.1827244	9.030485
	45	−12.72337	−0.1827244	−6.106897
44	45	11.94041	0.2176488	8.455781
	46	−11.86041	−0.2176488	−4.973398
45	46	10.97142	0.2582242	7.640519
	47	−10.89142	−0.2582242	−3.508929
46	47	9.918621	0.2986433	6.426883
	48	−9.838621	−0.2986433	−1.648595
47	48	8.81166	0.1319865	4.725737
	49	−8.73166	−0.1319865	−2.613951
48	49	7.69	0.7210715	5.768566
	50	−7.65	−0.7210715	−3.325468E−13
49	2	−1.846052E−02	1.636379	4.909549
	27	1.846052E−02	−1.636379	4.908726
50	3	−3.688718E−02	1.592369	4.777121
	28	3.688718E−02	−1.592369	4.777095

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MEMBER FORCES

MEMBER	JOINT	AXIAL FORCE	SHEAR FORCE	BENDING MOMENT
51	4	-3.588553E-02	1.516187	4.548548
	29	3.588553E-02	-1.516187	4.548573
52	5	-3.548278E-02	1.415868	4.247604
	30	3.548278E-02	-1.415868	4.247602
53	6	-3.554974E-02	1.297485	3.892457
	31	3.554974E-02	-1.297485	3.892456
54	7	-0.0355541	1.165645	3.496936
	32	0.0355541	-1.165645	3.496936
55	8	-3.555185E-02	1.023858	3.071574
	33	3.555185E-02	-1.023858	3.071574
56	9	-3.555195E-02	0.8748259	2.624478
	34	3.555195E-02	-0.8748259	2.624478
57	10	-3.555201E-02	0.7206621	2.161986
	35	3.555201E-02	-0.7206621	2.161986
58	11	-3.555201E-02	0.5630627	1.689188
	36	3.555201E-02	-0.5630627	1.689188
59	12	-3.555199E-02	0.4034444	1.210333
	37	3.555199E-02	-0.4034444	1.210333
60	13	-3.555198E-02	0.2430598	0.7291796
	38	3.555198E-02	-0.2430598	0.7291796
61	14	-3.555201E-02	8.309927E-02	0.2492978
	39	3.555201E-02	-8.309927E-02	0.2492978
62	15	-0.0355521	-7.521271E-02	-0.2256381
	40	0.0355521	7.521271E-02	-0.2256381
63	16	-3.555136E-02	-0.2305172	-0.6915515
	41	3.555136E-02	0.2305172	-0.6915515
64	17	-3.555162E-02	-0.3812106	-1.143632
	42	3.555162E-02	0.3812106	-1.143632
65	18	-3.557649E-02	-0.5253153	-1.575945
	43	3.557649E-02	0.5253153	-1.575946
66	19	-3.547714E-02	-0.6603171	-1.980955
	44	3.547714E-02	0.6603171	-1.980947
67	20	-3.492438E-02	-0.782962	-2.348888
	45	3.492438E-02	0.782962	-2.348884
68	21	-0.0405754	-0.888992	-2.666831
	46	0.0405754	0.888992	-2.667121
69	22	-4.041908E-02	-0.9727973	-2.918829
	47	4.041908E-02	0.9727973	-2.917954
70	23	0.1666568	-1.026962	-3.084629
	48	-0.1666568	1.026962	-3.077142
71	24	-0.5890849	-1.04166	-3.095344
	49	0.5890849	1.04166	-3.154615
72	1	-0.4726525	-3.54	0
	51	0.4726525	3.54	-10.62
73	51	0.4772199	3.54	10.62
	26	-0.4772199	-3.54	2.891148E-09

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SUPPORT JOINT REACTIONS

JOINT	X FORCE	Y FORCE	MOMENT
50	0.7210715	-7.65	-3.325468E-13
51	0.9498724	7.079999	-1.445569E-09

RESULTANT JOINT DISPLACEMENTS - SUPPORTS

JOINT	X DISP.	Y DISP.	ROTATION (DEG.)
50	0	-2.034407E-02	-0.5926846
51	0	0	9.190898E-02

RESULTANT JOINT DISPLACEMENTS - FREE JOINTS

JOINT	X DISP.	Y DISP.	ROTATION (DEG.)
1	-1.417972E-04	-4.812344E-03	0.5678717
2	-7.912197E-02	-4.977602E-03	0.5612609
3	-0.2347895	-5.148834E-03	0.5455922
4	-0.3843182	-5.163036E-03	0.5179495
5	-0.5246891	-5.027362E-03	0.4806776
6	-0.6534783	-4.75123E-03	0.435683
7	-0.768744	-4.345757E-03	0.3845026
8	-0.8689324	-3.823322E-03	0.3283797
9	-0.9528069	-3.197239E-03	0.2683432
10	-1.019397	-0.0024815	0.2052664
11	-1.067959	-1.690581E-03	0.139912
12	-1.097954	-8.392818E-04	7.296894E-02
13	-1.109029	5.741156E-05	5.08269E-03
14	-1.101007	9.844392E-04	-6.311786E-02
15	-1.07389	1.926782E-03	-0.1309947
16	-1.027863	2.869574E-03	-0.1978743
17	-0.9633074	3.798232E-03	-0.2630182
18	-0.8808241	4.698609E-03	-0.3255891
19	-0.7812685	5.557172E-03	-0.384609
20	-0.6657969	6.361243E-03	-0.4388998
21	-0.5359347	7.09931E-03	-0.4869802
22	-0.3936476	7.761416E-03	-0.5273029
23	-0.2413398	8.339689E-03	-0.5581625
24	-8.308533E-02	8.829048E-03	-0.5653436
25	-4.166387E-03	9.027638E-03	-0.5651736
26	-1.431674E-04	4.812337E-03	0.5677014
27	-0.0790965	4.647079E-03	0.5610251
28	-0.2347386	4.168546E-03	0.5455849
29	-0.3842688	3.548007E-03	0.5179566
30	-0.5246402	2.792614E-03	0.4806771
31	-0.6534293	1.911788E-03	0.4356829
32	-0.7686949	9.166435E-04	0.3845027
33	-0.8688833	-1.804391E-04	0.3283797
34	-0.9527578	-1.366147E-03	0.2683432

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RESULTANT JOINT DISPLACEMENTS - FREE JOINTS

JOINT	X DISP.	Y DISP.	ROTATION (DEG.)
35	-1.019348	-2.626486E-03	0.2052664
36	-1.06791	-3.946983E-03	0.139912
37	-1.097905	-5.312836E-03	7.296894E-02
38	-1.10898	-6.70906E-03	5.08269E-03
39	-1.100958	-8.120595E-03	-6.311786E-02
40	-1.073841	-9.532421E-03	-0.1309947
41	-1.027814	-1.092967E-02	-0.1978743
42	-0.9632584	-1.229777E-02	-0.2630182
43	-0.880775	-1.362256E-02	-0.3255893
44	-0.7812196	-1.489051E-02	-0.3846068
45	-0.6657487	-1.608895E-02	-0.4388984
46	-0.5358787	-1.720636E-02	-0.4870634
47	-0.3935919	-1.823278E-02	-0.5270519
48	-0.2415697	-1.916035E-02	-0.5560153
49	-0.0822728	-1.998398E-02	-0.5823398

The initial panel node deflections are harvested from this run to use as input for the PΔ runs. The maximum displacement occurs at Joint 13, 1.11" outward due to wind suction.

3.3 PΔ Deflections:

As covered in Part II, PΔ loads consist of gravity loads only, all of which are applied concentric to the compression wythe, the inner wythe in this case. The base rocker is replaced by a pinned support at the bottom of the inner wythe. Self-weight from both wythes is applied to the inner wythe only (0.005 k/in * 2 = 0.01 k/in). β_d = 0.809 for the concrete modulus of elasticity, E, for mostly sustained loads. Therefore, E = 4463*0.875/(1+0.809) = 2159 ksi for the PΔ runs.

The outer wythe is just along for the ride. The resultant PΔ deflection is added to the initial deflection and the run is repeated until convergence is achieved. In this case it took three runs. Final maximum deflection is 1.346" at Joint 13.

PΔ Deflections

```
/ EDL 3-3-3 Example, P-Delta 1
JOINT COORDINATES
1 0 0
2 -0.079 8
3 -0.235 24
4 -0.384 40
5 -0.525 56
6 -0.653 72
7 -0.769 88
8 -0.869 104
9 -0.953 120
10 -1.019 136
11 -1.068 152
12 -1.098 168
13 -1.109 184
14 -1.101 200
15 -1.074 216
16 -1.028 232
17 -0.963 248
18 -0.881 264
19 -0.781 280
20 -0.666 296
21 -0.536 312
22 -0.394 328
23 -0.241 344
24 -0.083 360
25 0 368
26 6 0 S
27 5.921 8
28 5.765 24
29 5.616 40
30 5.475 56
31 5.347 72
32 5.231 88
33 5.131 104
34 5.047 120
35 4.981 136
36 4.932 152
37 4.902 168
38 4.891 184
39 4.899 200
40 4.926 216
41 4.972 232
42 5.037 248
43 5.119 264
44 5.219 280
45 5.334 296
46 5.464 312
47 5.606 328
48 5.758 344
49 5.918 360
50 6 368 S
51 3 0
JOINT RELEASES
26 M
50 M
50 F Y
MEMBER INCIDENCES
1 1 2 24
25 26 27 48
49 2 27 71
72 1 51
73 51 26
MEMBER RELEASES
72 M 1
73 M 2
MEMBER PROPERTIES
1 THRU 48 48 36 2159
49 THRU 71 1 0.1378 4350
72 0.1 99999 99999
73 0.1 99999 99999
LOADING 1
JOINT LOADS
49 F Y -3.4
MEMBER LOADS
25 THRU 48 FORCE X UNIFORM -0.01
LIST DISPLACEMENTS
FINISH
```

```
/ EDL 3-3-3 Example, P-Delta 2
JOINT COORDINATES
1 0 0
2 -0.095 8
3 -0.283 24
4 -0.463 40
5 -0.633 56
6 -0.786 72
7 -0.925 88
8 -1.044 104
9 -1.144 120
10 -1.221 136
11 -1.279 152
12 -1.313 168
13 -1.324 184
14 -1.313 200
15 -1.279 216
16 -1.223 232
17 -1.145 248
18 -1.046 264
19 -0.926 280
20 -0.789 296
21 -0.634 312
22 -0.466 328
23 -0.285 344
24 -0.098 360
25 0 368
26 6 0 S
27 5.905 8
28 5.717 24
29 5.537 40
30 5.367 56
31 5.214 72
32 5.075 88
33 4.956 104
34 4.856 120
35 4.779 136
36 4.721 152
37 4.687 168
38 4.676 184
39 4.687 200
40 4.721 216
41 4.777 232
42 4.855 248
43 4.954 264
44 5.074 280
45 5.211 296
46 5.366 312
47 5.534 328
48 5.715 344
49 5.902 360
50 6 368 S
51 3 0
JOINT RELEASES
26 M
50 M
50 F Y
MEMBER INCIDENCES
1 1 2 24
25 26 27 48
49 2 27 71
72 1 51
73 51 26
MEMBER RELEASES
72 M 1
73 M 2
MEMBER PROPERTIES
1 THRU 48 48 36 2159
49 THRU 71 1 0.1378 4350
72 0.1 99999 99999
73 0.1 99999 99999
LOADING 1
JOINT LOADS
49 F Y -3.4
MEMBER LOADS
25 THRU 48 FORCE X UNIFORM -0.01
LIST DISPLACEMENTS
FINISH
```

```
/ EDL 3-3-3 Example, P-Delta 3
JOINT COORDINATES
1 0 0
2 -0.097 8
3 -0.288 24
4 -0.470 40
5 -0.642 56
6 -0.798 72
7 -0.939 88
8 -1.060 104
9 -1.161 120
10 -1.240 136
11 -1.298 152
12 -1.332 168
13 -1.344 184
14 -1.332 200
15 -1.298 216
16 -1.241 232
17 -1.161 248
18 -1.060 264
19 -0.939 280
20 -0.800 296
21 -0.643 312
22 -0.472 328
23 -0.289 344
24 -0.099 360
25 0 368
26 6 0 S
27 5.903 8
28 5.712 24
29 5.530 40
30 5.358 56
31 5.202 72
32 5.061 88
33 4.940 104
34 4.839 120
35 4.760 136
36 4.702 152
37 4.668 168
38 4.656 184
39 4.668 200
40 4.702 216
41 4.759 232
42 4.839 248
43 4.940 264
44 5.061 280
45 5.200 296
46 5.357 312
47 5.528 328
48 5.711 344
49 5.901 360
50 6 368 S
51 3 0
JOINT RELEASES
26 M
50 M
50 F Y
MEMBER INCIDENCES
1 1 2 24
25 26 27 48
49 2 27 71
72 1 51
73 51 26
MEMBER RELEASES
72 M 1
73 M 2
MEMBER PROPERTIES
1 THRU 48 48 36 2159
49 THRU 71 1 0.1378 4350
72 0.1 99999 99999
73 0.1 99999 99999
LOADING 1
JOINT LOADS
49 F Y -3.4
MEMBER LOADS
25 THRU 48 FORCE X UNIFORM -0.01
LIST DISPLACEMENTS
FINISH
```

3.4 Final run:

The deflection output from the third PΔ run is used as input for the **Final Run**:

```
/ EDL 3-3-3 Example, Final Run
JOINT COORDINATES
1 0 0
2 -0.097 8
3 -0.288 24
4 -0.471 40
5 -0.643 56
6 -0.799 72
7 -0.940 88
8 -1.061 104
9 -1.162 120
10 -1.241 136
11 -1.299 152
12 -1.334 168
13 -1.346 184
14 -1.334 200
15 -1.299 216
16 -1.242 232
17 -1.162 248
18 -1.062 264
19 -0.940 280
20 -0.801 296
21 -0.644 312
22 -0.473 328
23 -0.289 344
24 -0.099 360
25 0 368
26 6 0
27 5.903 8
28 5.712 24
29 5.529 40
30 5.357 56
31 5.201 72
32 5.060 88
33 4.939 104
34 4.838 120
35 4.759 136
36 4.701 152
37 4.666 168
38 4.654 184
39 4.666 200
40 4.701 216
41 4.758 232
42 4.838 248
43 4.938 264
44 5.060 280
45 5.199 296
46 5.356 312
47 5.527 328
48 5.711 344
49 5.901 360
50 6 368 S
51 3 0 S
JOINT RELEASES
50 M
50 FORCE Y
51 M
MEMBER INCIDENCES
1 1 2 24
25 26 27 48
49 2 27 71
72 1 51
73 51 26
MEMBER RELEASES
72 M 1
73 M 2
MEMBER PROPERTIES
1 THRU 48 48 36 3550
49 THRU 71 1 0.1378 4350
72 0.1 99999 99999
73 0.1 99999 99999
LOADING 1
JOINT LOADS
24 F Y 4.25
49 F Y -7.65
MEMBER LOADS
1 THRU 48 FORCE X UNIFORM -0.005
1 THRU 24 FORCE Y UNIFORM 0.004444
LIST DISPLACEMENTS
FINISH
```

LOADING 1 TITLE – PCFFinal.txt Page 3

MEMBER FORCES

MEMBER	JOINT	AXIAL FORCE	SHEAR FORCE	BENDING MOMENT
1	1	3.534297	-0.509571	-4.441759E-14
	2	-3.494294	0.4740164	-3.934639
2	2	1.72907	-0.4877579	-1.360999
	3	-1.649065	0.4166488	-5.874768
3	3	-6.914683E-02	-0.4532472	0.7212045
	4	0.149152	0.3821386	-7.404726
4	4	-1.785038	-0.4155656	2.497751
	5	1.865042	0.3444574	-8.578285
5	5	-3.391869	-0.3769218	3.99799
	6	3.471873	0.3058145	-9.460139
6	6	-4.869578	-0.3380572	5.267212
	7	4.949581	0.2669505	-10.10746
7	7	-6.202804	-0.2989314	6.347605
	8	6.282806	0.2278254	-10.56178
8	8	-7.380287	-0.259381	7.2691
	9	7.460289	0.1882756	-10.85042
9	9	-8.393736	-0.2200421	8.04974
	10	8.473737	0.1489373	-11.00161
10	10	-9.23739	-0.1804871	8.710369
	11	9.31739	0.1093826	-11.02934
11	11	-9.907388	-0.1411455	9.259043
	12	9.987388	7.004131E-02	-10.94854
12	12	-10.40159	-0.1015626	9.705689
	13	10.48159	0.0304586	-10.76186
13	13	-10.71933	-6.222441E-02	10.04844
	14	10.79932	-8.879588E-03	-10.4752
14	14	-10.86139	-2.303201E-02	10.28887
	15	10.94139	-0.0480722	-10.08855
15	15	-10.83001	0.0161074	10.42262
	16	10.91001	-8.721188E-02	-9.596065
16	16	-10.62896	5.467341E-02	10.4392
	17	10.70896	-0.1257782	-8.995574
17	17	-10.26377	0.0936356	10.33111
	18	10.34377	-0.164741	-8.264051
18	18	-9.742187	0.1315787	10.06885
	19	9.822188	-0.2026848	-7.39466
19	19	-9.07451	0.1700647	9.637517
	20	9.154512	-0.2411714	-6.347507
20	20	-8.274648	0.2082674	8.986959
	21	8.354651	-0.2793748	-5.085632
21	21	-7.360659	0.2397282	8.066793
	22	7.440663	-0.3108363	-3.662024
22	22	-6.356648	0.2704734	6.9138
	23	6.436654	-0.341582	-2.017038
23	23	-5.296943	0.5550956	5.448462
	24	5.376949	-0.6262047	4.002612
24	24	-4.209671	-8.814446E-02	-0.5629795
	25	4.249675	5.258977E-02	9.008939E-14
25	26	3.534307	-0.508709	-2.664015E-14
	27	-3.494304	0.4731543	-3.927742

LOADING 1 TITLE – PCFFinal.txt Page 4

MEMBER FORCES

MEMBER	JOINT	AXIAL FORCE	SHEAR FORCE	BENDING MOMENT
26	27	5.259706	-0.4581027	-1.36671
	28	-5.1797	0.4581027	-5.963453
27	28	6.898348	-0.4180902	0.809742
	29	-6.818343	0.4180902	-7.499622
28	29	8.454777	-0.3800786	2.592422
	30	-8.374772	0.3800786	-8.674029
29	30	9.90232	-0.3411044	4.093519
	31	-9.822316	0.3411044	-9.551448
30	31	11.22062	-0.302909	5.358271
	32	-11.14062	0.302909	-10.205
31	32	12.39455	-0.2631889	6.444883
	33	-12.31455	0.2631889	-10.65602
32	33	13.41264	-0.2240939	7.363106
	34	-13.33264	0.2240939	-10.94868
33	34	14.26665	-0.1842525	8.147789
	35	-14.18665	0.1842525	-11.09586
34	35	14.95073	-0.1452042	8.80445
	36	-14.87073	0.1452042	-11.12773
35	36	15.46109	-0.1054588	9.357298
	37	-15.38109	0.1054588	-11.04464
36	37	15.79553	-6.618337E-02	9.801712
	38	-15.71553	6.618337E-02	-10.86065
37	38	15.95341	-2.656688E-02	10.14722
	39	-15.87341	2.656688E-02	-10.57229
38	39	15.93549	1.263923E-02	10.38603
	40	-15.85549	-1.263923E-02	-10.1838
39	40	15.74403	5.136028E-02	10.51797
	41	-15.66403	-5.136028E-02	-9.696201
40	41	15.38277	9.073245E-02	10.53951
	42	-15.30277	-9.073245E-02	-9.087778
41	42	14.85731	0.1286174	10.42352
	43	-14.77731	-0.1286174	-8.365601
42	43	14.17531	0.1678747	10.17066
	44	-14.09531	-0.1678747	-7.484585
43	44	13.34723	0.2050347	9.727735
	45	-13.26723	-0.2050347	-6.447059
44	45	12.38686	0.2425649	9.086803
	46	-12.30686	-0.2425649	-5.205577
45	46	11.31241	0.2856691	8.187408
	47	-11.2324	-0.2856691	-3.616438
46	47	10.1479	0.3291121	6.867451
	48	-10.0679	-0.3291121	-1.601314
47	48	8.927935	0.1169602	5.023823
	49	-8.847929	-0.1169602	-3.152327
48	49	7.68028	0.8330444	6.664858
	50	-7.640277	-0.8330444	-5.542023E-14
49	2	-3.546746E-02	1.765015	5.295639
	27	3.546746E-02	-1.765015	5.294452
50	3	-5.707352E-02	1.717879	5.153563
	28	5.707352E-02	-1.717879	5.153711

LOADING 1 TITLE – PCFFinal.txt Page 5

MEMBER FORCES

MEMBER	JOINT	AXIAL FORCE	SHEAR FORCE	BENDING MOMENT
51	4	-5.091021E-02	1.635696	4.906974
	29	5.091021E-02	-1.635696	4.907199
52	5	-4.548746E-02	1.526801	4.580295
	30	4.548746E-02	-1.526801	4.58051
53	6	-4.130654E-02	1.397684	4.192927
	31	4.130654E-02	-1.397684	4.193177
54	7	-3.527362E-02	1.253329	3.759856
	32	3.527362E-02	-1.253329	3.760119
55	8	-3.063167E-02	1.0976	3.29268
	33	3.063167E-02	-1.0976	3.292919
56	9	-2.611914E-02	0.9335957	2.800684
	34	2.611914E-02	-0.9335957	2.80089
57	10	-2.319703E-02	0.7637759	2.291241
	35	2.319703E-02	-0.7637759	2.291414
58	11	-1.966035E-02	0.5901227	1.7703
	36	1.966035E-02	-0.5901227	1.770437
59	12	-1.747529E-02	0.4142969	1.242852
	37	1.747529E-02	-0.4142969	1.242929
60	13	-1.586509E-02	0.2378077	0.713417
	38	1.586509E-02	-0.2378077	0.7134295
61	14	-1.625185E-02	6.209761E-02	0.1863257
	39	1.625185E-02	-6.209761E-02	0.18626
62	15	-1.731735E-02	-0.1113741	-0.3340719
	40	1.731735E-02	0.1113741	-0.3341725
63	16	-1.826097E-02	-0.2810752	-0.8431386
	41	1.826097E-02	0.2810752	-0.8433126
64	17	-2.153992E-02	-0.4452123	-1.335532
	42	2.153992E-02	0.4452123	-1.335742
65	18	-2.352814E-02	-0.6016427	-1.804796
	43	2.352814E-02	0.6016427	-1.80506
66	19	-2.868064E-02	-0.7476677	-2.242858
	44	2.868064E-02	0.7476677	-2.243149
67	20	-3.124087E-02	-0.8798661	-2.639452
	45	3.124087E-02	0.8798661	-2.639745
68	21	-4.296039E-02	-0.9938321	-2.981161
	46	4.296039E-02	0.9938321	-2.981831
69	22	-4.678384E-02	-1.083798	-3.251776
	47	4.678384E-02	1.083798	-3.251013
70	23	0.2023771	-1.142322	-3.431424
	48	-0.2023771	1.142322	-3.422508
71	24	-0.7260542	-1.158694	-3.439632
	49	0.7260542	1.158694	-3.512531
72	1	-0.4666834	-3.540215	-1.445574E-09
	51	0.4666834	3.540215	-10.62065
73	51	0.4658211	3.540215	10.62065
	26	-0.4658211	-3.540215	-1.445574E-09

LOADING 1 TITLE – PCFFinal.txt Page 6

SUPPORT JOINT REACTIONS

JOINT	X FORCE	Y FORCE	MOMENT
50	0.7384399	-7.65	-5.542023E-14
51	0.9325045	7.080431	-5.782296E-09

Note that the modulus of elasticity, E, is set back to 3550 ksi for mostly wind load (β_d = 0.1).

3.5 The three ultimate strength checks:

The Final Run forces and moments are used to find wythe stresses, connector slip, and panel capacity.

Find the maximum wythe tension stress: First, find the final prestress stress. Fpu = 270 ksi, percent pull = 75%, losses = 12.3%, and strand area = 0.083 in^2. Fps = 270*0.75*0.083*(100-12.3)*10/3/16 = 307 psi.

At the outer wythe member 14, Pu =**10.90k** in tension and Mu = **10.19k"**. Wythe section modulus = 16*3^2/6 = 24 in^3. Outer stress, f_o = (10.9/3/16 + 10.19/24)*1000 – 307 psi = **345 psi** net tension at the extreme fiber. Cracking stress is 7.5 √ f'c = 581 psi > 345 psi, so our assumption to use gross, uncracked wythe section properties is valid. If the member was not prestressed, then 5 √ f'c (387 psi) would be the tension limit for using gross properties, per ACI 318-19, 24.2.3.5.

Check 1: Find the maximum wythe connector slip: Members 49 through 71 represent the wythe connectors. Maximum connector shear was found at Member 49, equaling **1.765 kips**. In Part I, Section 1.7.2, the equation for connector moment of inertia (I) was found to be I = Vl^3/12EΔ. Rearranging this equation to find the slip, Δ, yields Δ = Vl^3/12EI = 1.765*6^3/12/4350/0.1378 = **0.053"**. Maximum elastic slip is **0.06"**, so our assumption to use elastic stiffness for the wythe connectors is valid. Maximum connector shear needs to stay below 0.75*Fu, per the PCI 150 Standard: 0.75*4.0 = 3.0k > 1.765k, ok.

Check 2: Check tension wythe flexural capacity: Here we'll use a simplified procedure instead of a strain compatibility analysis, since there is no net compression. Prestress strand capacity, P_n = # strand * strand area * fps – Pu = 1*0.083in^2*260ksi – 10.9k = **10.7k**. The compression block centroid, a = P_n/ β_1/f'c/b, where β_1 = 0.75 for 6000 psi concrete (see ACI 318-19 Table 22.2.2.4.3), and b is the member width. Therefore, a = 10.7k/ 0.75/6.0ksi/16" = 0.15". ΦMn = Φ*P_n*(d – a/2), where d is the distance from the strand centroid to the extreme fiber of the section. ΦMn = 0.9*10.7k*(1.5" – 0.15"/2) = **13.7k"** > Mu = **10.19k"**. Therefore, wythe flexural capacity is not exceeded. Flexural reserve = 1 – 10.19/13.7 = 26%.

Check 3: Check tension wythe maximum axial tension: For partial-composite truss action to be valid, the tension chord axial force should not exceed the capacity of the chord reinforcing. From the Final Run, Pu = **10.9k** at Member 14. ΦTn = Φ*Aps*fse, where fse is the effective stress in the prestressing strand after all losses. Per ACI 318-19, 22.4.3.1 and 23.7.2.1, fse can be taken as: %Pull*fpu*(1-%loss) + Δfp = 0.75*270ksi*(1 – 0.123) + 60ksi = 238ksi. ΦTn = 0.9*0.083*238 = **17.8k** > Pu = **10.9k**, ok. Axial tension reserve = 1 – 10.9/17.8 = 39%.

In conclusion, the three ultimate strength checks have been satisfied, so this panel has adequate capacity for the applied loads.

3.6 Check results against LECWall:

An identical design was run using the LECWall software. LECWall is a commercial program that uses the beam-spring method for insulated wall panel design.

```
LECWALL 3 - CONCRETE WALL & COLUMN DESIGN  (c) 2025 LOSCH SOFTWARE, LTD  Release 12.6.0d  2025-08-28
=====================================================================================================
0001 Losch Engineering      INPUT DATA                              2025-08-31      11:59:59     Pg. 1
=====================================================================================================
File: EDL 3-3-3 Example.W12    Name:
Job No:    Mark:    Designer:

SECTION DIMENSIONS:

Top Wythe:  Width = 16 in           Thickness = 3 in     Main Structural Wythe:  Top     No. of Wythes = 2
Bot Wythe:  Width = 16 in           Thickness = 3 in     Member Height = 368 in          Insulation Thk = 3 in
Insulation Start from Top = 0 in                         Insulation Stop from Bottom = 0 in
Bott Wythe (no rvls/opngs):  Area = 48 in2          M of I = 36 in4          Centroid from Bottom = 1.50 in
Comp. @ Midp (w/rvls/opngs):  Area = 96 in2         M of I = 936 in4         Centroid from Bottom = 4.50 in

MATERIALS:     F'c (psi)    Ec (ksi)    F'ci (psi)    Eci (ksi)    Conc Wt (pcf)

Top Wythe:       6000         4463        3500          3409         150.0    Superimposed Load = 0.0 psf
Bot Wythe:       6000         4463        3500          3409         150.0    Average Relative Humidity = 70 %
Fy, Reinf Bar Grade = 60 ksi       Fy - WWF Grade = 80 ksi       Fpu, Strand = 270 ksi          Lo-Lax = Yes

STRAND ROWS:                 A          B          C          D          E          F          G          H

Strand Diameter (in) =       0.375      0.375
Strand Area (in2) =          0.083      0.083
% Pull =                      75         75
No. Strand in Row =           1          1
Centr from Bot of Sect(in) = 1.50       7.50
Debond Length, T/B (in) =    0.00/0.00  0.00/0.00

STRAND LOCATIONS FROM LEFT:

Row A        8.00
Row B        8.00
```

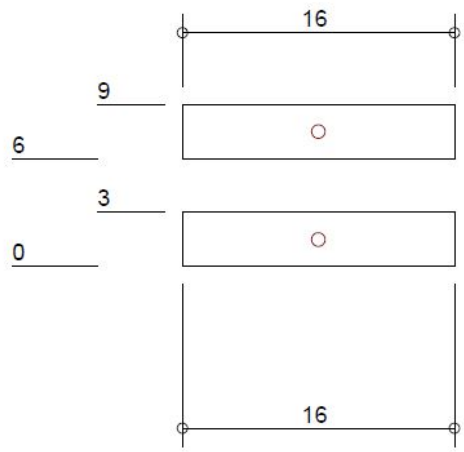
File: EDL 3-3-3 Example.W12 Name:
Job No: Mark: Designer:

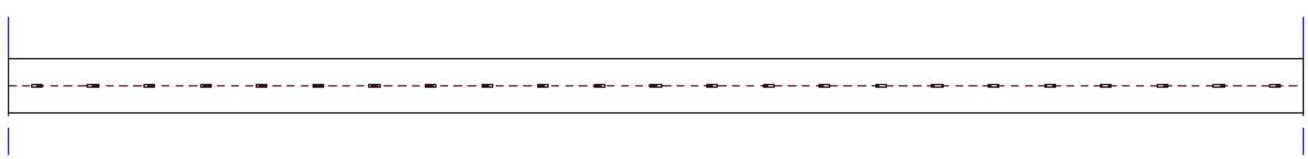
Coefficients:
Initial prestress loss = 1.30% (Calculated)
Outside temp, deg F: 75 Inside: 75

Cracking stress coefficient: 7.500
Inside horiz. surcharge at floor or grade, psf: 0.0
Inside active lateral earth pressure, psf/ft: 0.0
Inside dist. from base to top of retained earth, in: 0.00
Strand dev. length mult. at ends = 1 , at openings = 2
Main structural wythe is inside
Floor tie active for load cases with earth pressure

Final prestress loss = 12.35% (Calculated)
Initial member bow at midheight, in: 0
Seismic coefficient, % = 0
Slenderness effects are included
Outside horiz. surcharge at floor or grade, psf: 0.0
Outside active lateral earth pressure, psf/ft: 0.0
Outside dist. from base to top of retained earth, in: 0.00

Beam-Spring partial composite method used





File: EDL 3-3-3 Example.W12 Name:
Job No: Mark: Designer:

SUPPORT LOCATIONS, INCHES:		SPRING CONSTANTS, INCHES/KIP:
Top support location from top of member, in:	0.00	0
Slab-on-grade connection location from bottom, in:	0.00	0

Panel is supported at the base from both wythes.

WIND LOAD:	Suction		Pressure		Start	Stop
	psf	plf	psf	plf	(elev. from bot., in)	
Row 1	40	53.33	40	53.33	0.00	368.00

CONCENTRATED VERTICAL LOADS, KIPS:

	Pv Location (from bottom, in.)	Eccentricity (from inside face, in.)	Dead	Live	Roof	Wind	Bearing Wythe
Row 1	360.00	6.00	2.00	0.00	2.00	0.00	Both

PARTIAL COMPOSITE CONNECTORS:

Critical span length, in: 368
No. of connectors per lateral row: 1
Additional connectors in first row: 0
Additional connectors in second row: 0
Additional connectors in third row: 0
Longitudinal connector row spacing, in: 16.00

Connector force at elastic limit, Fe, k: 2.000
Connector elastic stiffness, Ke, k/in: 33.33
Connector force at ultimate limit, Fu, k: 4.000
Connector inelastic stiffness, Kie, k/in: 14.29
Connector elastic limit, DeltaE, in: 0.06
Connector inelastic limit, DeltaU, in: 0.2

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0002 Losch Engineering - Debug Mode APPLIED MOMENT & STRESS GRAPHS 2025-07-13 16:32:18

==

File: EDL 3-3-3 Example.W12 Name:
Job No: Mark: Designer:

LOAD CASE 4 ACI 318-14/19 5.3.1d Wind+Live:

Suction at 182.16 in:

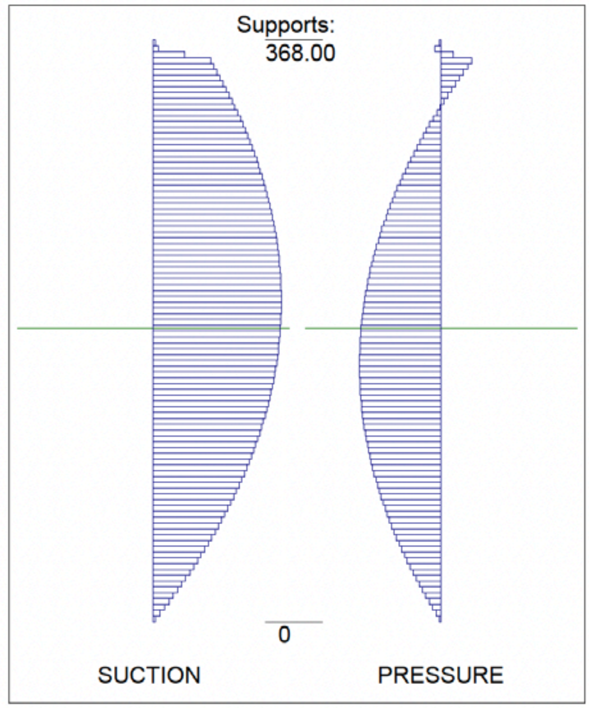
Pu (kips) = 5.24
Mu (kip-in) = 100.07
Outer Stress (psi) = 345.24
Inner Stress (psi) = -1068.04
Section is uncracked
Bow + Defl (in) = 1.33
(Outward deflection is positive)
 Force in 368 in. Conn. in Kips = 0.74
 Force in 0 in. Conn. in Kips = 0.90
(Compression is Negative)

Pressure at 182.16 in:

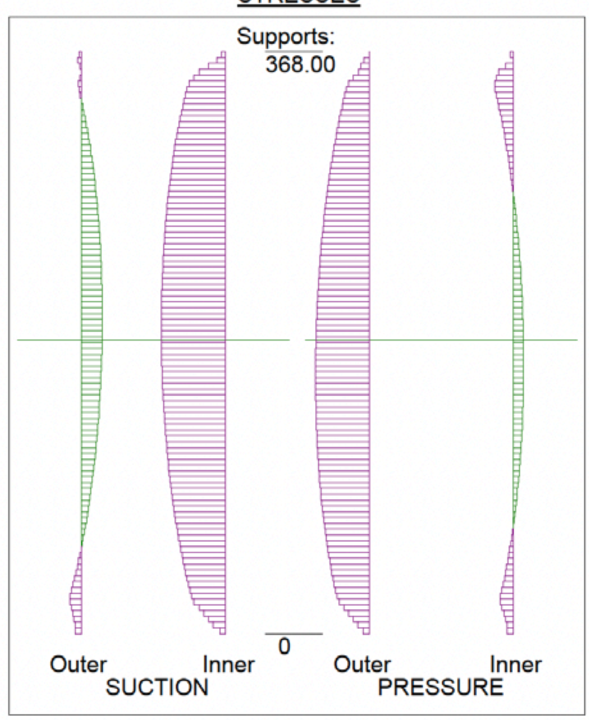
Pu (kips) = 5.24
Mu (kip-in) = -63.21
Inner Stress (psi) = 169.39
Outer Stress (psi) = -892.17
Section is uncracked
Bow + Defl (in) = -1.17
(Outward deflection is positive)
 Force in 368 in. Conn. in Kips = -0.93
 Force in 0 in. Conn. in Kips = -0.70
(Compression is Negative)

Percent composite at ultimate: 100.00
Percent composite for stresses: Calced
Percent composite for deflection: Calced
Cracking stress coefficient: 7.500
Slenderness effects are included

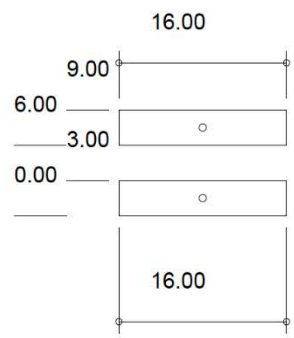
MAGNIFIED MOMENT



STRESSES



File: EDL 3-3-3 Example.W12 Name:
Job No: Mark: Designer:



LOAD CASES:

1 ACI 318-14/19 5.3.1a Dead
2 ACI 318-14/19 5.3.1b Live+T+Earth
3 ACI 318-14/19 5.3.1c Live+Roof+Earth
4 ACI 318-14/19 5.3.1d Wind+Live
5 ACI 318-14/19 5.3.1e Live+Seismic
6 ACI 318-14/19 5.3.1f Wind+Earth
7 ACI 318-14/19 5.3.1f Wind Only
8 ACI 318-14/19 5.3.1c Roof+Wind
9 ACI 318-14/19 5.3.1g Seismic Only
10 Service Dead + Temp
11 Service Dead + Live, ASCE 7-10/16 2.4.1-2
12 Service D + L + R, ASCE 7-10/16 2.4.1-4
13 Service Dead + Wind, ASCE 7-10/16 2.4.1-5
14 User Defined

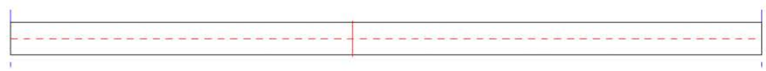
ACI 318 Phi factors used

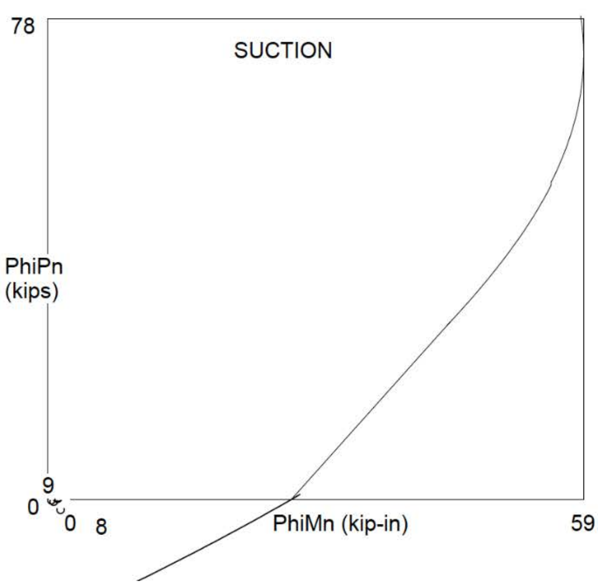
Moment Check - Outer Wythe Only:

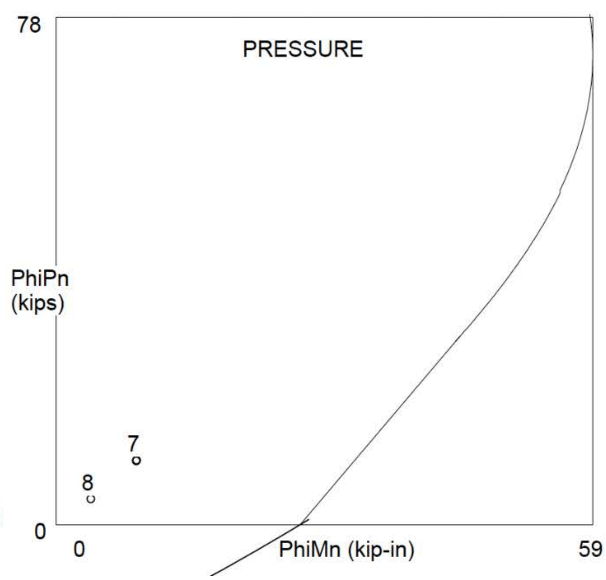
	Pu-S	Mu-S	Phi-Mn S	1.0Mcr S	Pu-P	Mu-P	Phi-Mn P	1.0Mcr P		Pu-S	Mu-S	Phi-Mn S	1.0Mcr S	Pu-P	Mu-P	Phi-Mn P	1.0Mcr P
1	-0.27	0.71	26.71	21.18	-0.09	0.60	26.93	21.26	2	-0.61	0.81	26.29	21.00	-0.45	0.66	26.49	21.08
3	-1.66	1.43	25.03	20.48	-1.36	1.21	25.40	20.63	4	-10.82	10.31	13.24	**15.90**	9.76	-8.86	-33.03	-26.19
5	-0.35	0.66	26.61	21.13	-0.21	0.53	26.77	21.20	6	-10.04	9.63	14.30	**16.29**	9.86	-8.88	-33.09	-26.24
7	-10.04	9.63	14.30	**16.29**	9.86	-8.88	-33.09	-26.24	8	-6.86	6.29	18.48	17.88	3.95	-3.82	-29.46	-23.29
9	-0.12	0.41	26.89	21.25	-0.05	0.34	26.97	21.28									

Section cut location from
left end (in) = 167.44

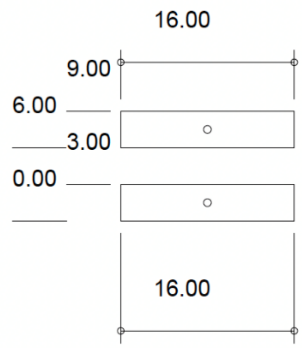
Compr. face not reversed.







File: EDL 3-3-3 Example.W12 Name:
Job No: Mark: Designer:



LOAD CASES:

1 ACI 318-14/19 5.3.1a Dead
2 ACI 318-14/19 5.3.1b Live+T+Earth
3 ACI 318-14/19 5.3.1c Live+Roof+Earth
4 ACI 318-14/19 5.3.1d Wind+Live
5 ACI 318-14/19 5.3.1e Live+Seismic
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12 Service D + L + R, ASCE 7-10/16 2.4.1-4
13 Service Dead + Wind, ASCE 7-10/16 2.4.1-5
14 User Defined

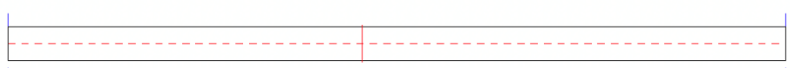
ACI 318 Phi factors used

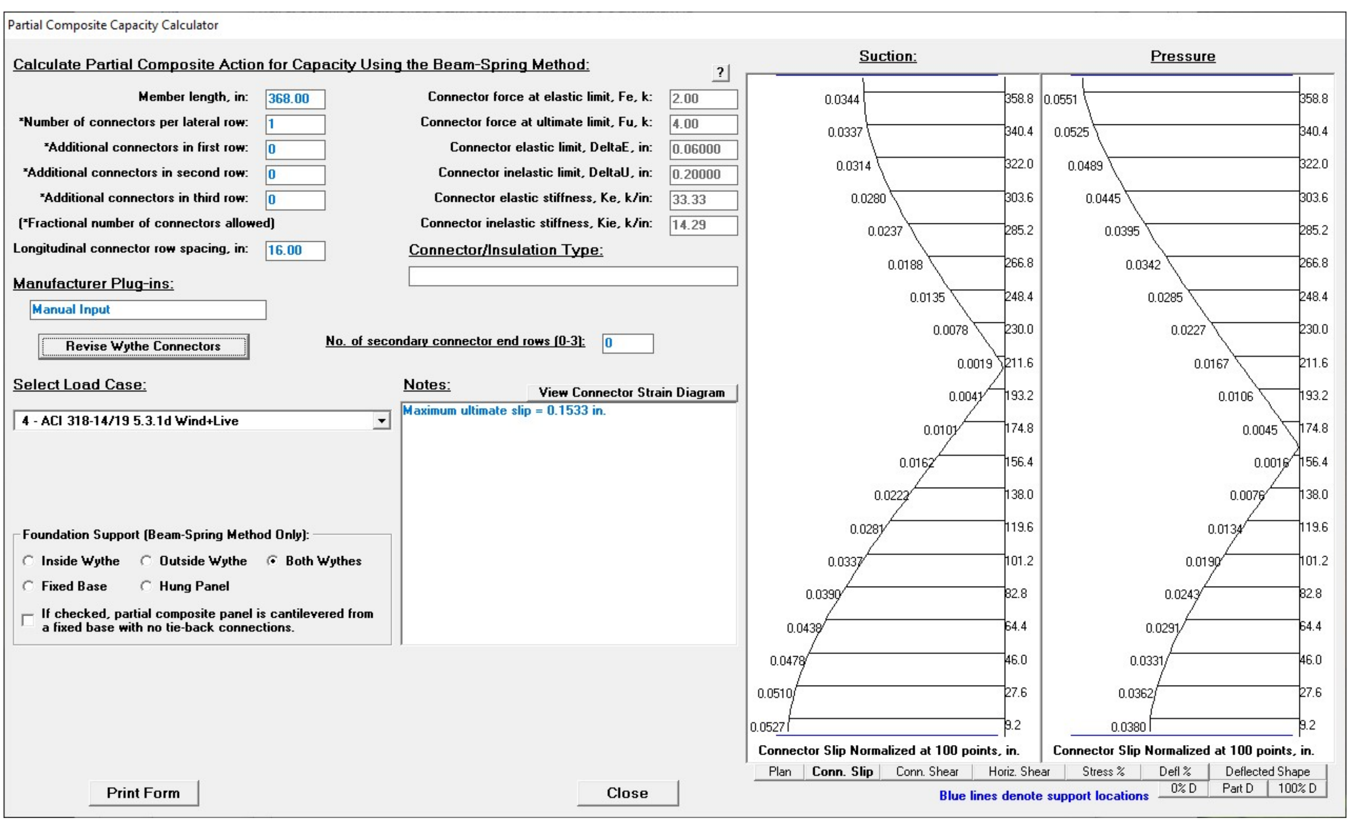
Axial Tension Check - Outer Wythe Only:

	Pu-S	Mu-S	Phi-Tn S	Pu-P	Mu-P	Phi-Tn P		Pu-S	Mu-S	Phi-Tn S	Pu-P	Mu-P	Phi-Tn P
1	-0.27	0.71	-17.74	-0.09	0.60	-17.74	2	-0.61	0.81	-17.74	-0.45	0.66	-17.74
3	-1.66	1.43	-17.74	-1.36	1.21	-17.74	4	-10.82	10.31	-17.74	9.76	-8.86	-17.74
5	-0.35	0.66	-17.74	-0.21	0.53	-17.74	6	-10.04	9.63	-17.74	9.86	-8.88	-17.74
7	-10.04	9.63	-17.74	9.86	-8.88	-17.74	8	-6.86	6.29	-17.74	3.95	-3.82	-17.74
9	-0.12	0.41	-17.74	-0.05	0.34	-17.74							

Section cut location from
left end (in) = 167.44

Compr. face not reversed.





Compare LECWall to manual calculation:	**Manual Check**	**LECWall**	**MASTAN2***
Maximum extreme fiber flexural tension stress, psi:	345	348	316**^**
Maximum deflection, in:	1.35	1.33	1.35
Maximum connector slip, in:	0.053	0.053 (Suction)	0.055
Wythe maximum moment, k-in:	10.19	10.31	9.87
Wythe flexural capacity, k-in:	13.70	13.24	13.70
Wythe maximum axial tension, k:	10.90	10.82	11.30
Wythe axial tension capacity, k:	17.8	17.8	17.8

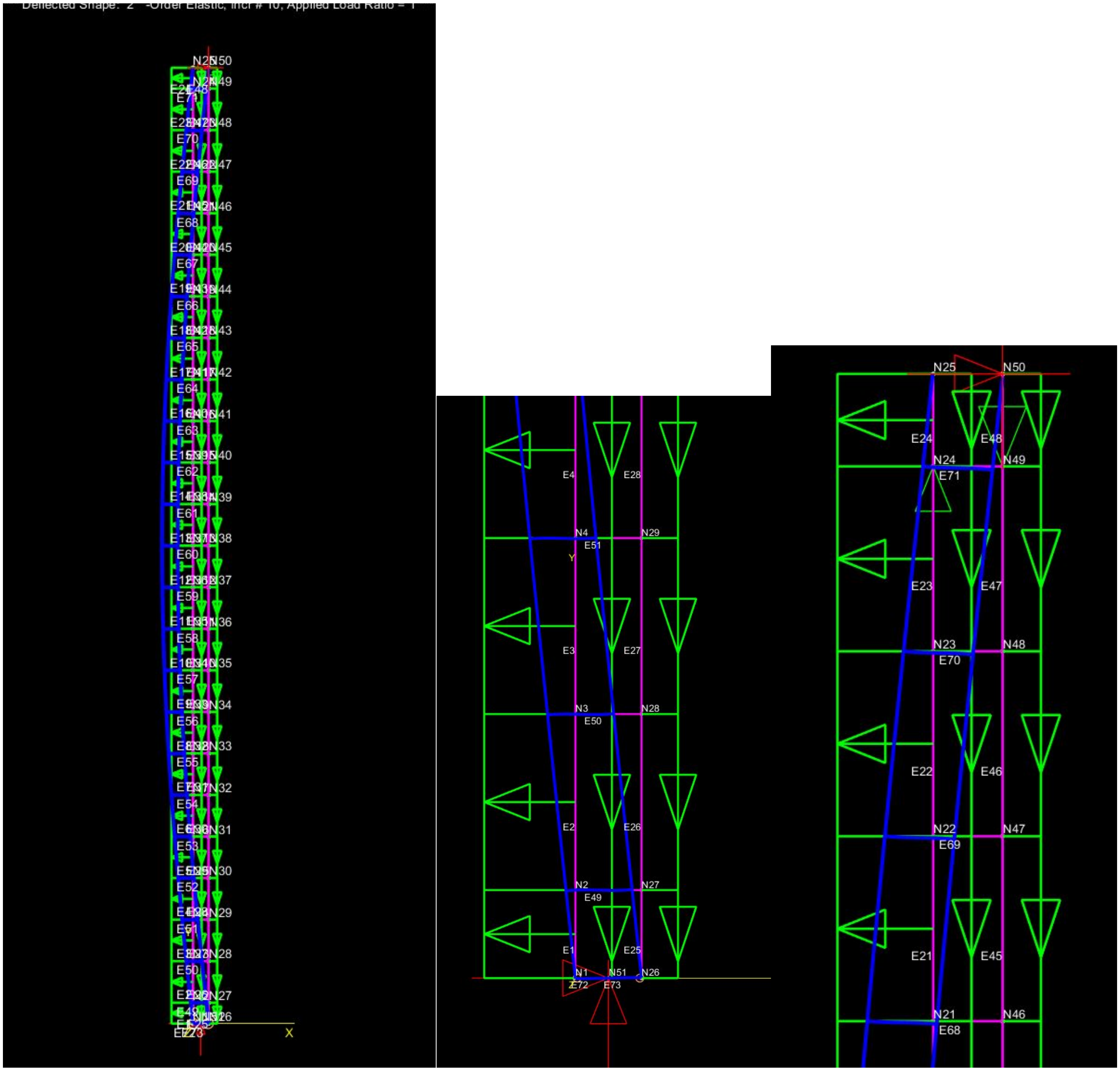
The manual analysis results correlate well with the LECWall run. LECWall divides the connector stiffness into 100 nodes for ease and consistency of analysis. This could be one source of the minor differences. LECWall uses strain compatibility to find flexural capacity, vs the simplified method used for the manual calculation. Insulation effects are not included, as they would act in compression only, which is difficult to model. The insulation effect can provide additional stiffness which is not accounted for with either method.

***MASTAN2** is a popular open-source frame analysis program with built-in 2nd order (PΔ) analysis. The modulus of elasticity was modified using a β_d of 0.6, per ACI 318-19 R6.6.4.4.4. Connector slip $\Delta = Vl^3/12EI$ = $1.84*6^3/12/4350/0.1378$ = **0.055”**. At the outer wythe member 12, Pu =10.86k in tension and Mu = 9.51k”. Wythe section modulus = $16*3^2/6$ = 24 in^3. Outer stress, f_o = (10.86/3/16 + 9.51/24)*1000 – 307 psi = **316 psi** net tension at the extreme fiber.

^The lower wythe moment and flexural stress with MASTAN can be explained by the use of a higher β_d coefficient. The MASTAN run uses an average β_d = 0.6 for 2nd order analysis, while the LECWall and manual checks used a lower β_d of 0.1 for the final run, assuming mostly wind load. A higher β_d lowers the wythe’s effective modulus of elasticity, attracting less moment and flexural stress to the wythes. To be conservative, one could run the MASTAN 2nd order analysis a second time with β_d = 0.1, to find maximum wythe moment and stresses only. Doing so yields a stress of **340 psi**, much closer to the other analyses. The previous MASTAN 2nd order analysis, using β_d = 0.6, would be used to find maximum deflection and wythe axial tension.

The MASTAN2 sample run and printouts can be found at https://www.loschsoft.net/beam-spring.html.

MASTAN2 run:



Deflected Shape: 2 -Order Elastic, Incr # 10, Applied Load Ratio = 1
N25
N50
E24
E48
N24
N49
E71
E23
E47
N23
N48
E70
E22
E46
N22
N47
E69
E21
E45
N21
N46
E68
E4
E28
N4
E51
N29
E3
E27
N3
E50
N28
E2
E26
N2
E49
N27
E1
E25
N1
N51
N26
E72
E73
X
Y