COMPARISONS OF CONCRETE SLENDER WALL SOFTWARE WITH FULL-SCALE EXPERIMENTS

GLORIANA MOUA

PRESENTATION OVERVIEW

1. PROJECT GOALS AND PURPOSE
2. 1982 FULL-SCALE TESTING
3. RESULTS AND IMPACT OF TESTING
4. COMPARISON WITH CURRECT DESIGN SOFTWARE
5. CONCLUDING SUMMARY

MY PROJECT GOALS

1. Understand ACI design provisions and how they were derived from the original full-scale testing.

2. Try to duplicate panel test results in multiple different software programs.

3. Analyze and compare results. If software results vary from original testing, pinpoint user assumptions that may have caused results to differ.

4. See which software programs could be contributors to the discrepancies within the engineering community.

PROJECT PURPOSE

Ensure life safety

- Current design provisions were empirically derived from experimental full-scale testing

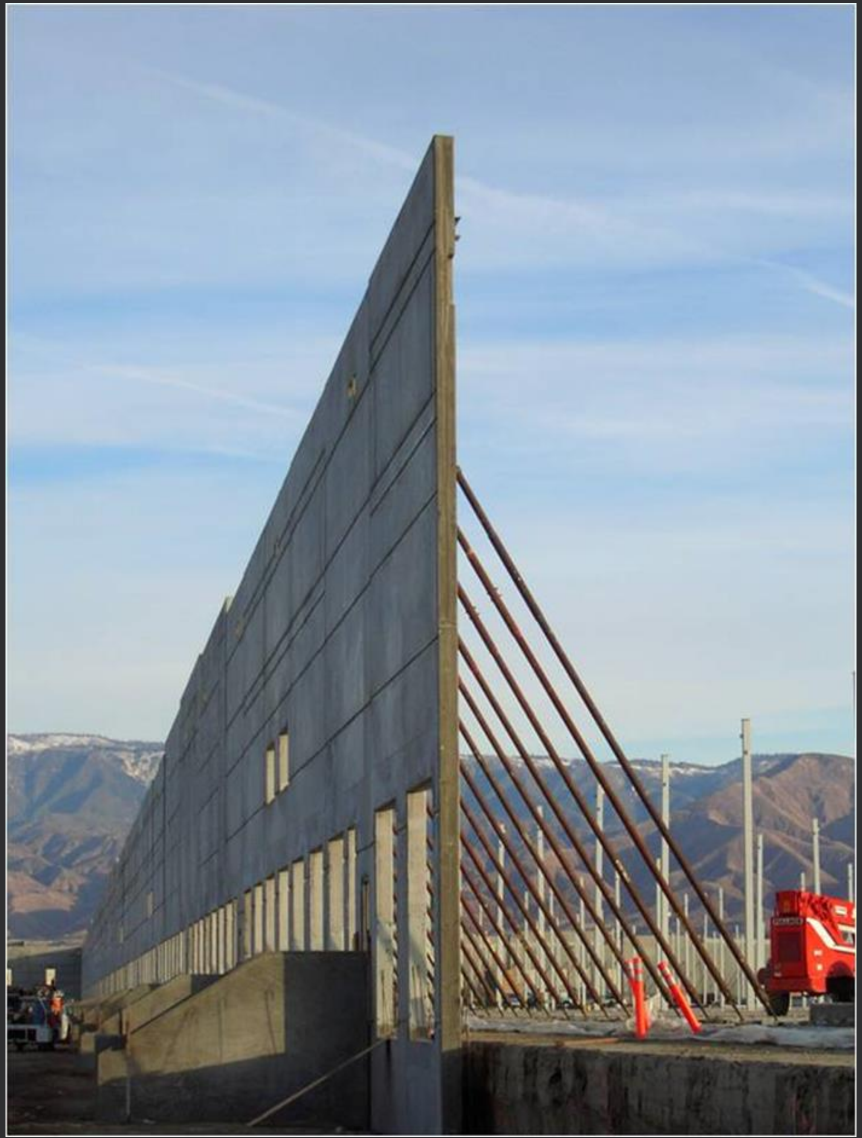


Photo Source: John Lawson

1980-82 ACI-SEASC

- WHAT WAS THE REASONING FOR TESTING?

  There was an increase in concrete and masonry walls usage due to economy, architectural appearance, fire safety and ease of construction.

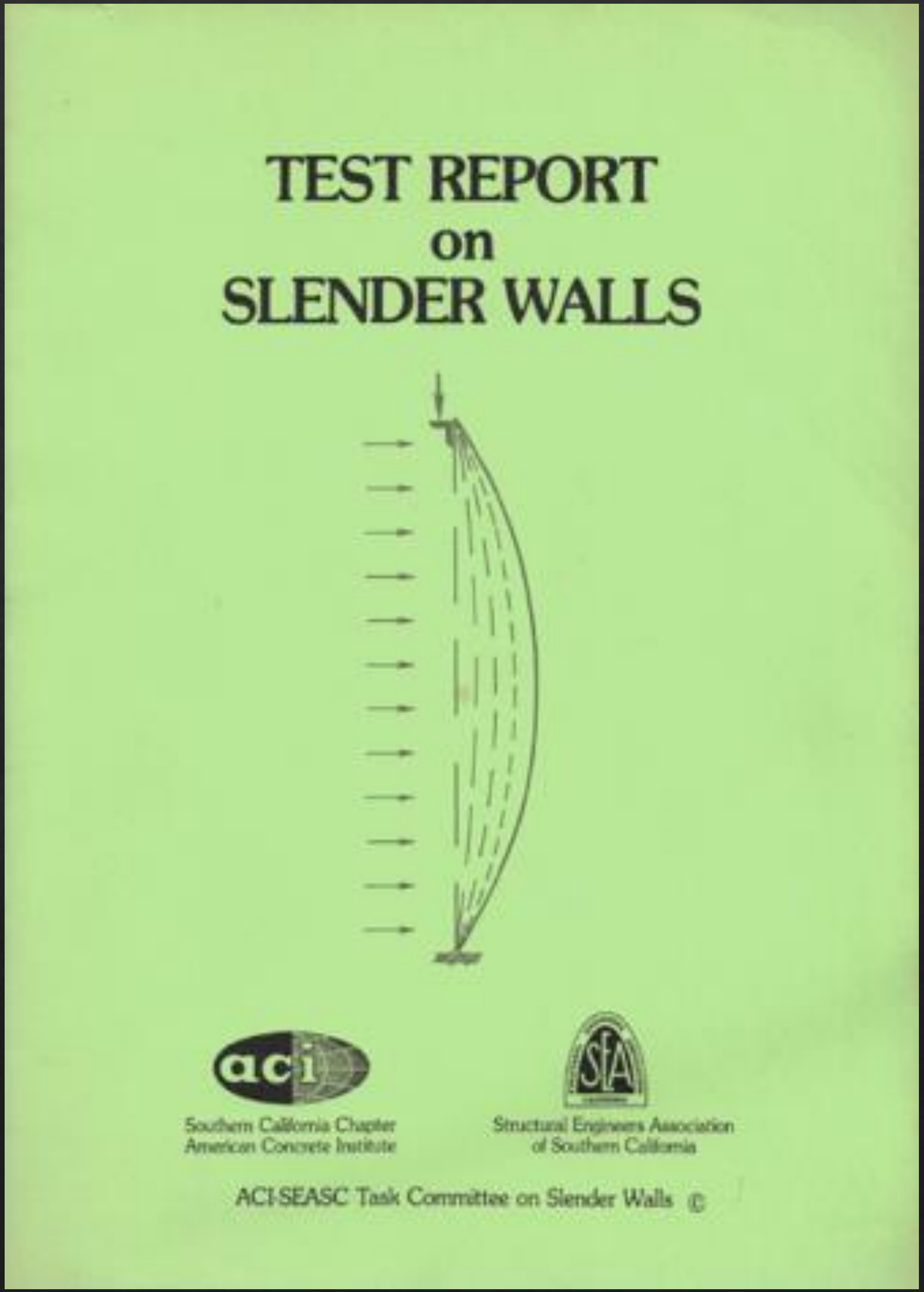
- WHAT WERE THE GOALS FOR TESTING?

  Analyze behavior of slender walls when subjected to both lateral and eccentric axial loads.

- WHAT WERE THE RESULTS?

  1. A fixed limitation of height-to-thickness ratio was not necessary for slender wall designs.

  2. Each case should be analyzed based off strength and deflection of wall, including P-delta effects.



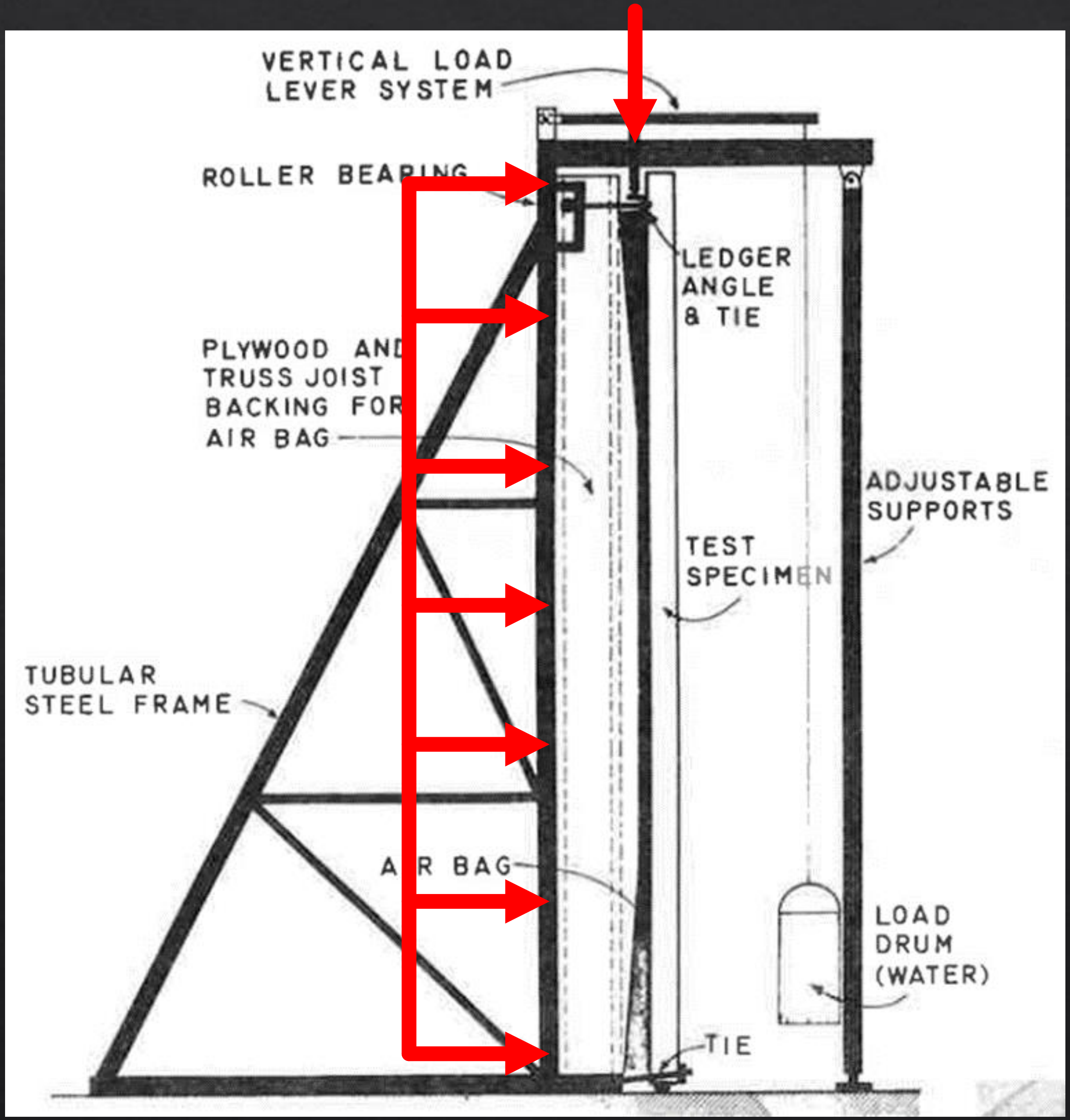
TEST REPORT
on
SLENDER WALLS

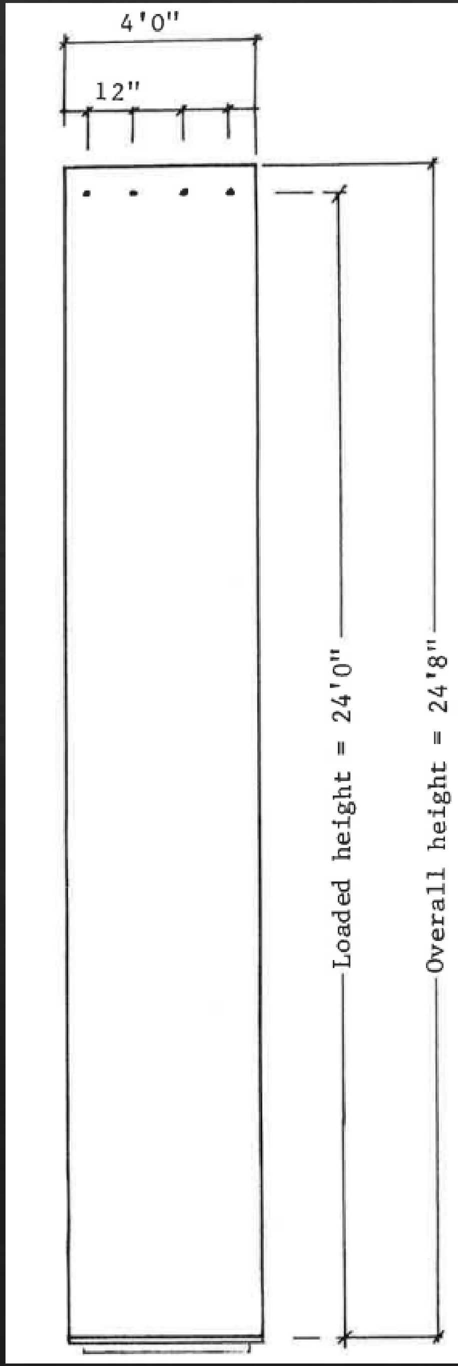
aci
Southern California Chapter
American Concrete Institute

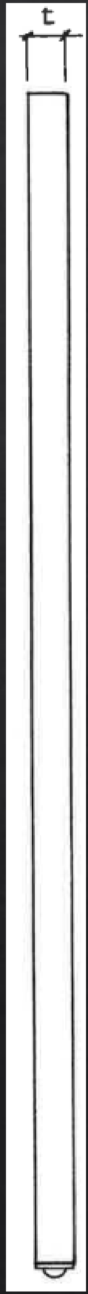
SEA
Structural Engineers Association
of Southern California

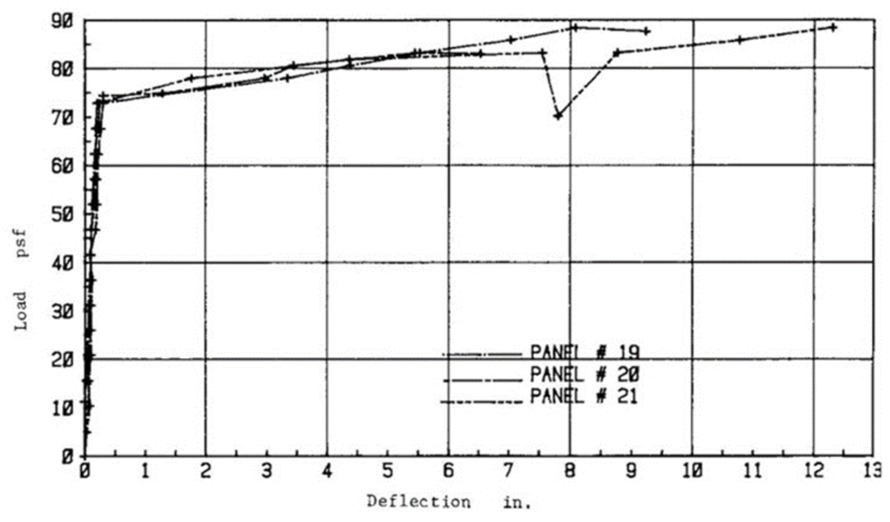
ACI-SEASC Task Committee on Slender Walls ©

TEST SETUP

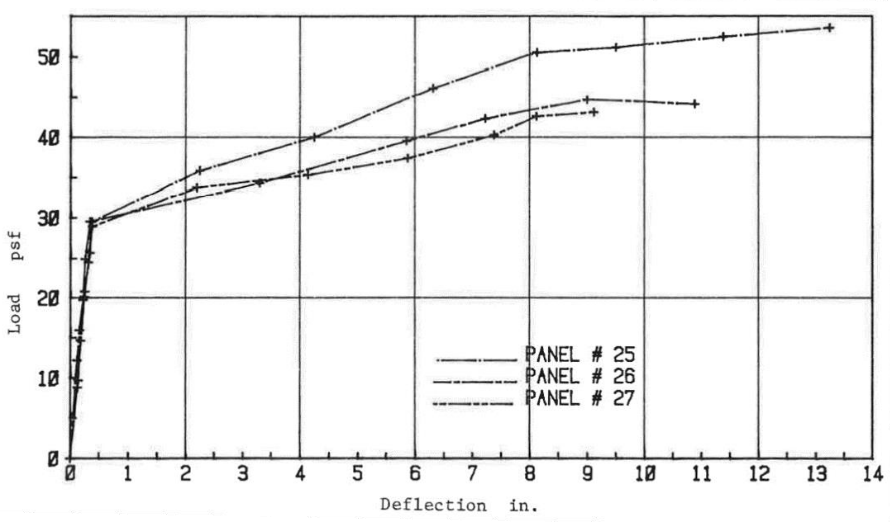

VERTICAL LOAD
LEVER SYSTEM
ROLLER BEARING
LEDGER
ANGLE
& TIE
PLYWOOD AND
TRUSS JOIST
BACKING FOR
AIR BAG
ADJUSTABLE
SUPPORTS
TEST
SPECIMEN
TUBULAR
STEEL FRAME
AIR BAG
LOAD
DRUM
(WATER)
TIE


4'0"
12"
Loaded height = 24'0"
Overall height = 24'8"


t



9-1/2" PANEL



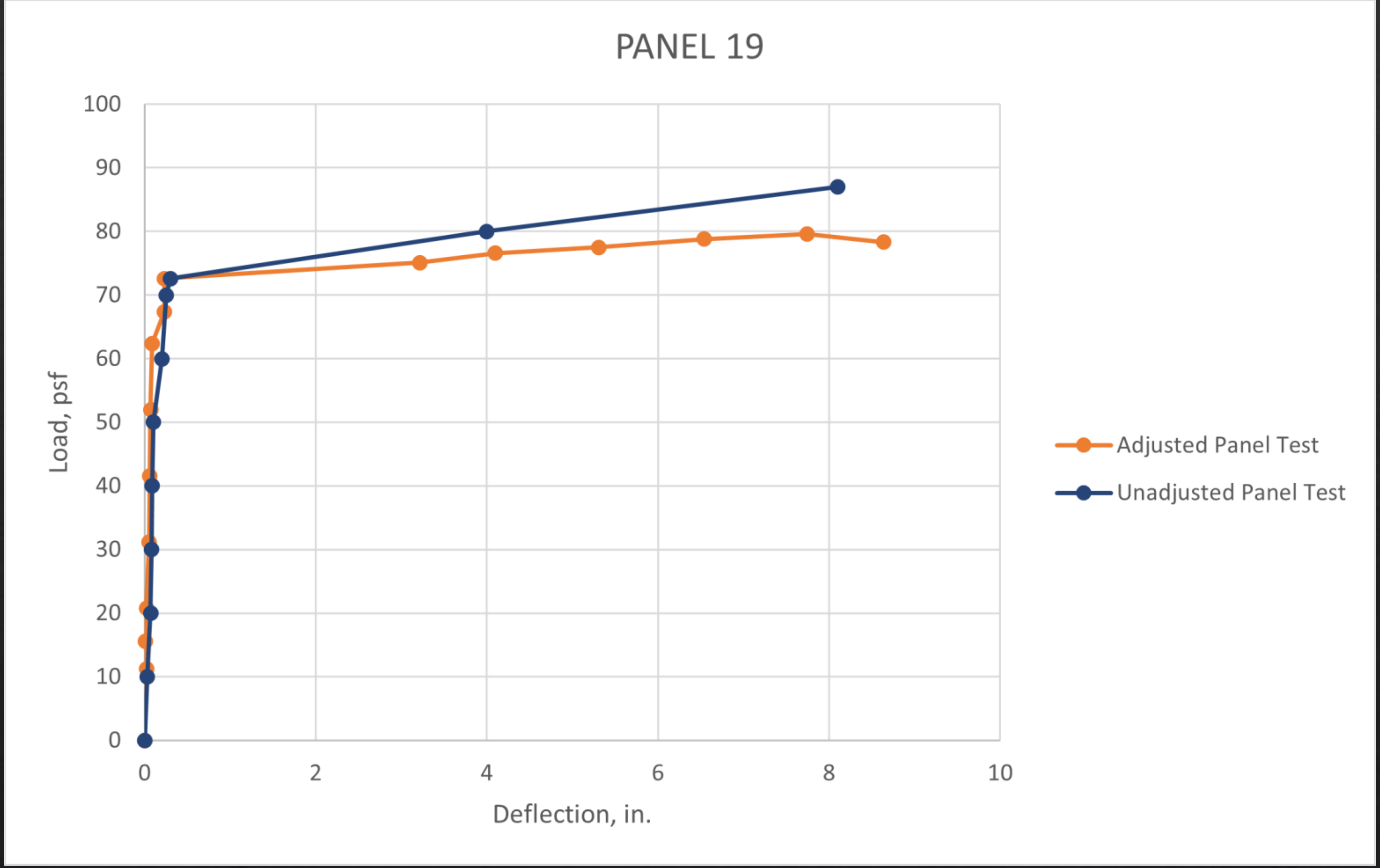
5-3/4" PANEL

TEST PANEL DEFLECTION

TEST PANEL CRACKING

SUMMARY REPORT

- Written by SEAOSC Slender Wall Task Group in 2006
- Incorporates adjustments as a result of lack of contact area in original testing.



ACI 318-19 SEC. 11.8

11.8—Alternative method for out-of-plane slender wall analysis

11.8.1 *General*

11.8.1.1 It shall be permitted to analyze out-of-plane slenderness effects in accordance with this section for walls satisfying (a) through (e):

(a) Cross section is constant over the height of the wall
(b) Wall is tension-controlled for out-of-plane moment effect
(c) ϕM_n is at least M_{cr}, where M_{cr} is calculated using f_r as provided in 19.2.3
(d) P_u at the midheight section does not exceed $0.06 f_c' A_g$

11.8.3 *Factored moment*

11.8.3.1 M_u at midheight of wall due to combined flexure and axial loads shall include the effects of wall deflection in accordance with (a) or (b):

(a) By iterative calculation using

$$M_u = M_{ua} + P_u\Delta_u \qquad (11.8.3.1a)$$

where M_{ua} is the maximum factored moment at midheight of wall due to lateral and eccentric vertical loads, not including $P\Delta$ effects.

Δ_u shall be calculated by:

$$\Delta_u = \frac{5M_u\ell_c^2}{(0.75)48E_cI_{cr}} \qquad (11.8.3.1b)$$

where I_{cr} shall be calculated by:

$$I_{cr} = \frac{E_s}{E_c}\left(A_s + \frac{P_u}{f_y}\frac{h}{2d}\right)(d-c)^2 + \frac{\ell_w c^3}{3} \qquad (11.8.3.1c)$$

and the value of E_s/E_c shall be at least 6.

(b) By direct calculation using:

$$M_u = \frac{M_{ua}}{\left(1 - \frac{5P_u\ell_c^2}{(0.75)48E_cI_{cr}}\right)} \qquad (11.8.3.1d)$$

11.8.4.1 Out-of-plane deflection due to service loads, Δ_s, shall be calculated in accordance with Table 11.8.4.1, where M_a is calculated by 11.8.4.2.

Table 11.8.4.1—Calculation of Δ_s

M_a	Δ_s	
$\leq(2/3)M_{cr}$	$\Delta_s = \left(\frac{M_a}{M_{cr}}\right)\Delta_{cr}$	(a)
$>(2/3)M_{cr}$	$\Delta_s = (2/3)\Delta_{cr} + \frac{(M_a - (2/3)M_{cr})}{(M_n - (2/3)M_{cr})}(\Delta_n - (2/3)\Delta_{cr})$	(b)

11.8.4.2 The maximum moment M_a at midheight of wall due to service lateral and eccentric vertical loads, including $P_s\Delta_s$ effects, shall be calculated by Eq. (11.8.4.2) with iteration of deflections.

$$M_a = M_{sa} + P_s\Delta_s \qquad (11.8.4.2)$$

11.8.4.3 Δ_{cr} and Δ_n shall be calculated by (a) and (b):

(a) $\Delta_{cr} = \frac{5M_{cr}\ell_c^2}{48E_cI_g}$ (11.8.4.3a)

(b) $\Delta_n = \frac{5M_n\ell_c^2}{48E_cI_{cr}}$ (11.8.4.3b)

CONCERNS

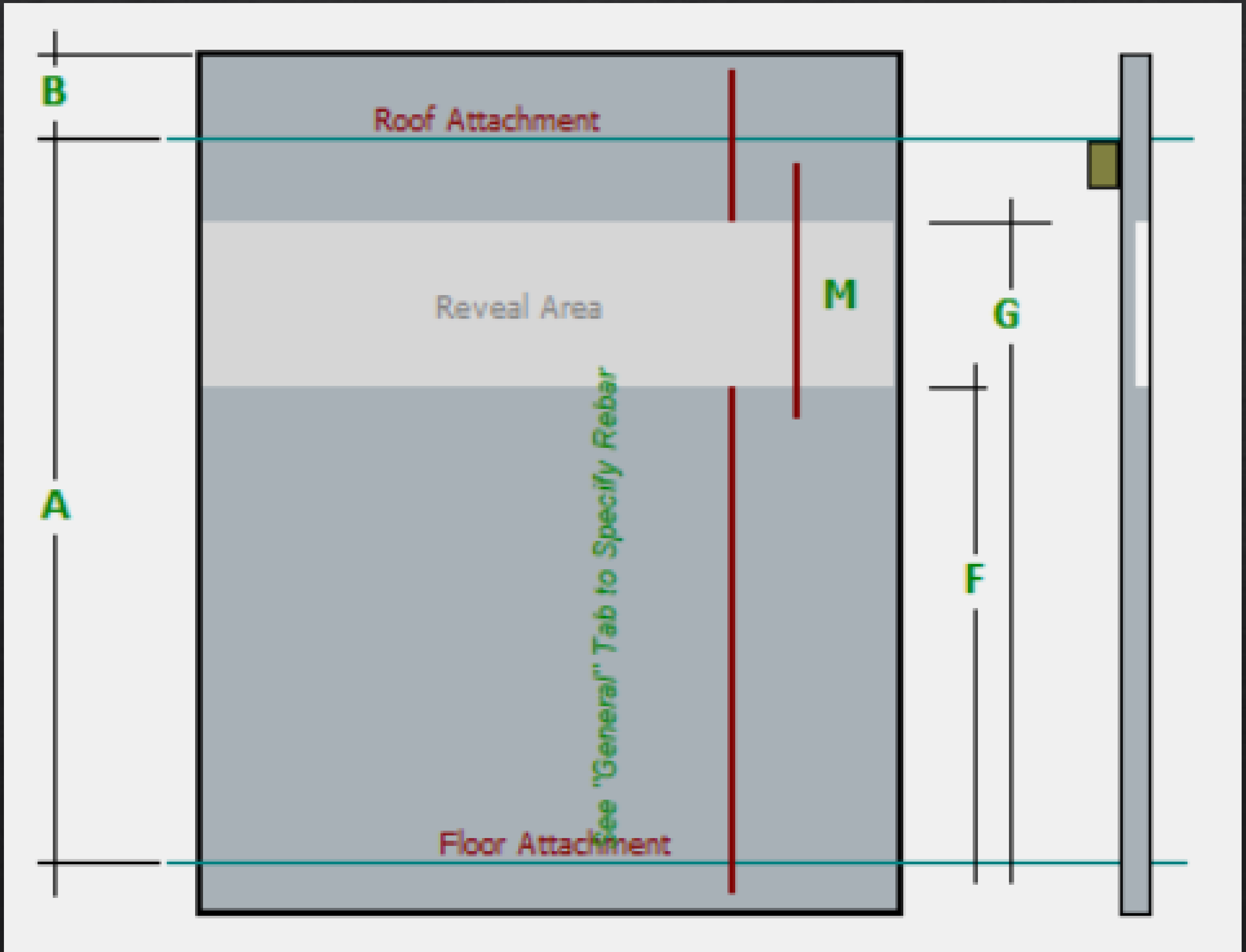
1. Concerned program results aren't agreeing with original experimental testing and could pose safety issues to designs.

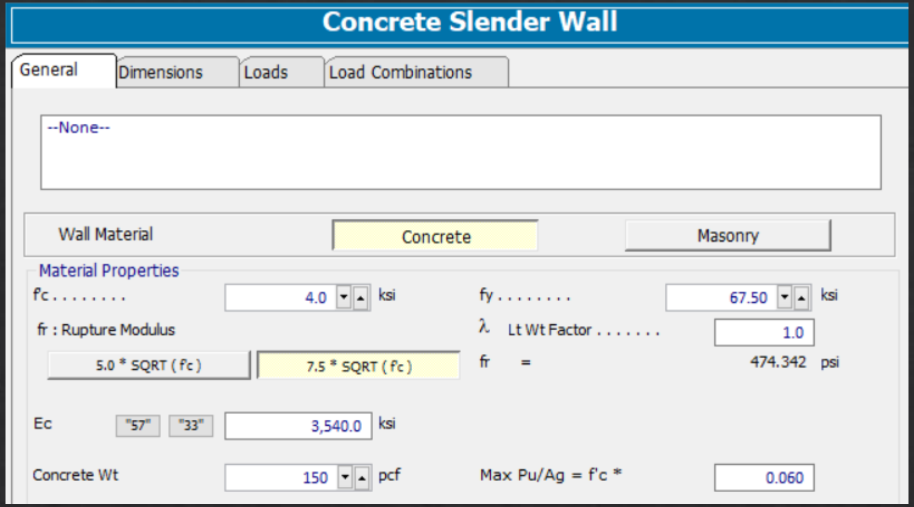
2. The ACI Committee 551 questions whether it is appropriate to deviate from the approved ACI provisions when designing any slender or tilt up walls.

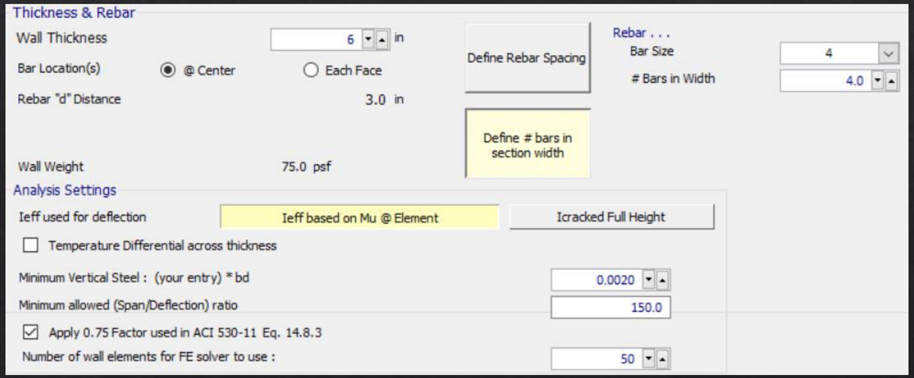
   Slender walls are very sensitive to inaccuracies which can lead to a quick strength and stiffness reduction resulting in large deflections.

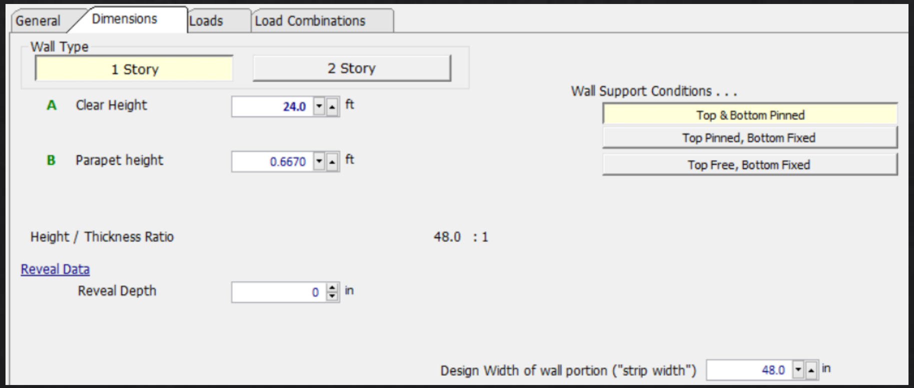
SOFTWARE

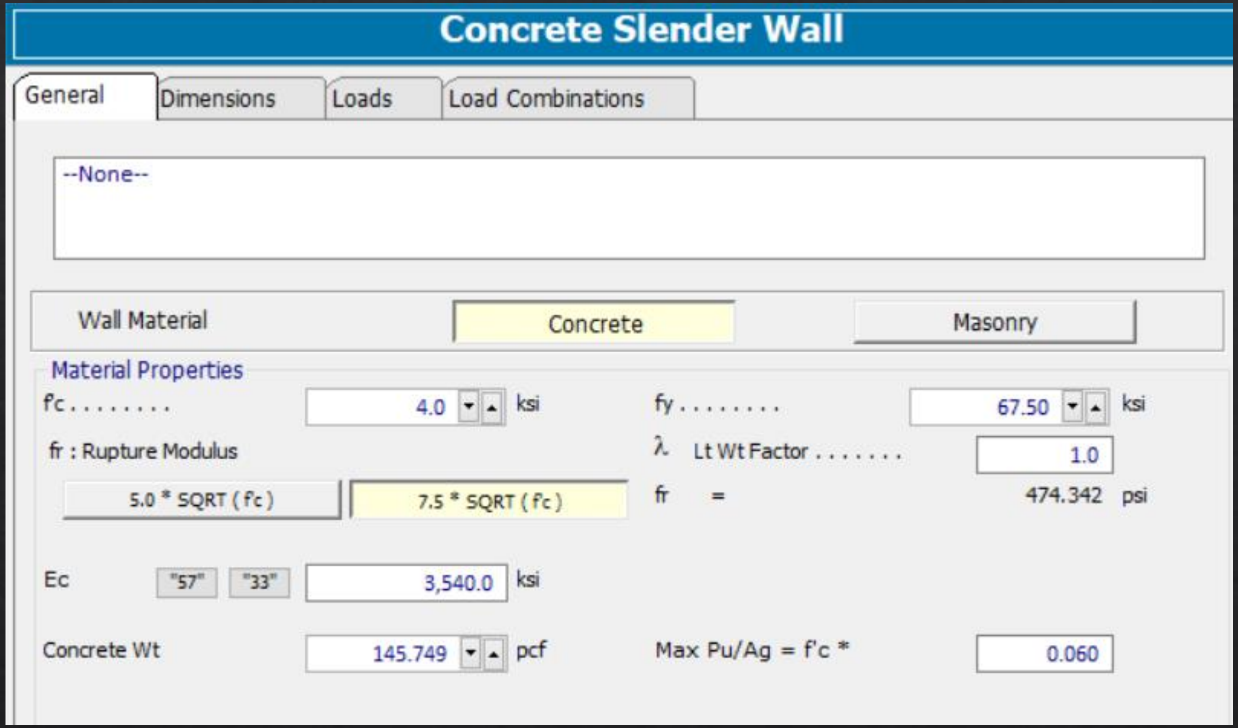
Software X

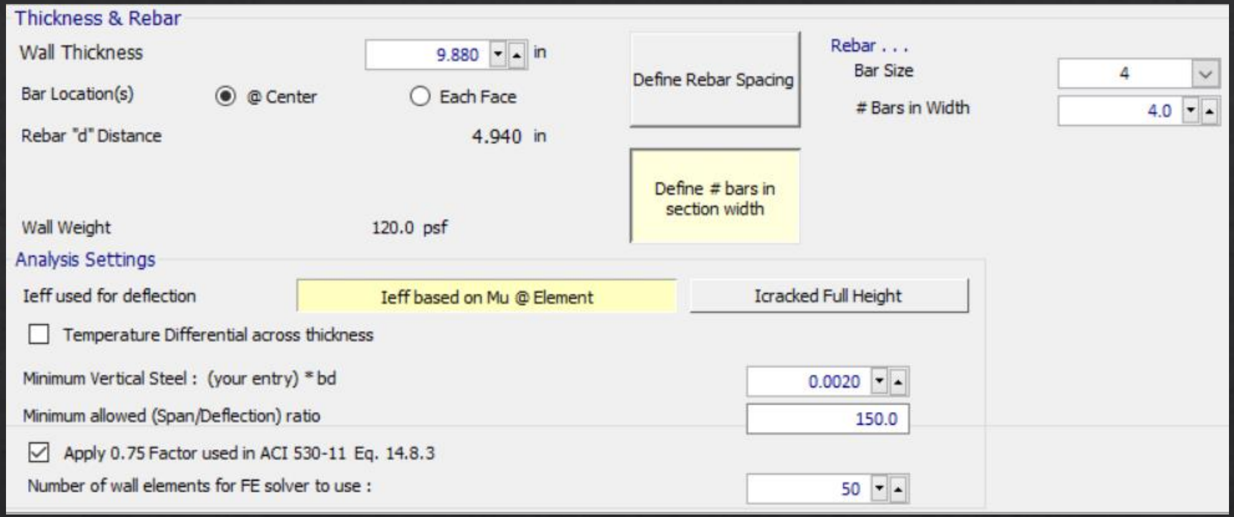

B
Roof Attachment
Reveal Area
M
G
A
See "General" Tab to Specify Rebar
F
Floor Attachment

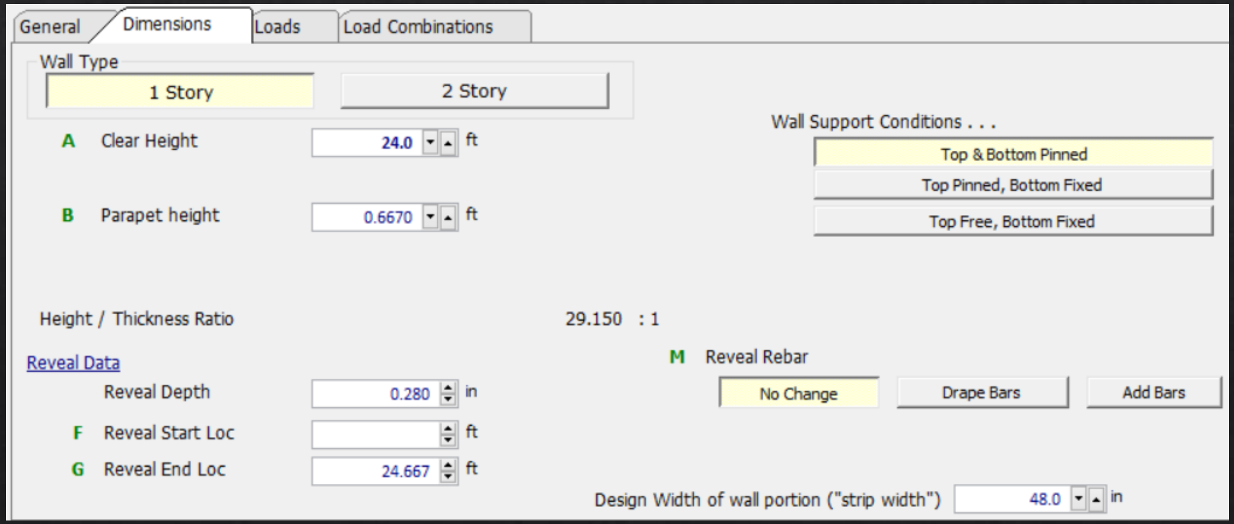

Concrete Slender Wall
General
Dimensions
Loads
Load Combinations
--None--
Wall Material
Concrete
Masonry
Material Properties
f'c . . . .
4.0
ksi
fy . . . .
67.50
ksi
fr : Rupture Modulus
λ Lt Wt Factor . . . .
1.0
5.0 * SQRT (f'c)
7.5 * SQRT (f'c)
fr =
474.342
psi
Ec
"57"
"33"
3,540.0
ksi
Concrete Wt
150
pcf
Max Pu/Ag = f'c *
0.060


Thickness & Rebar
Wall Thickness
6
in
Define Rebar Spacing
Rebar . . .
Bar Size
4
Bars in Width
4.0
Bar Location(s)
@ Center
Each Face
Rebar "d" Distance
3.0 in
Define # bars in section width
Wall Weight
75.0 psf
Analysis Settings
Ieff used for deflection
Ieff based on Mu @ Element
Icracked Full Height
Temperature Differential across thickness
Minimum Vertical Steel : (your entry) * bd
0.0020
Minimum allowed (Span/Deflection) ratio
150.0
Apply 0.75 Factor used in ACI 530-11 Eq. 14.8.3
Number of wall elements for FE solver to use :
50

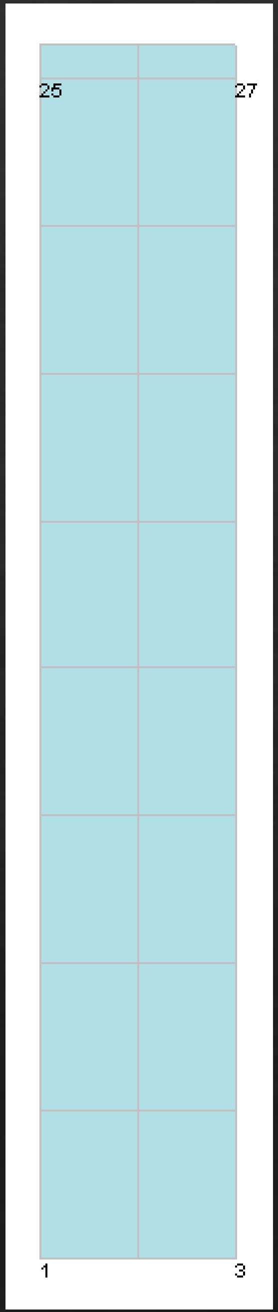

General
Dimensions
Loads
Load Combinations
Wall Type
1 Story
2 Story
A Clear Height
24.0
ft
B Parapet height
0.6670
ft
Wall Support Conditions . . .
Top & Bottom Pinned
Top Pinned, Bottom Fixed
Top Free, Bottom Fixed
Height / Thickness Ratio
48.0 : 1
Reveal Data
Reveal Depth
0
in
Design Width of wall portion ("strip width")
48.0
in

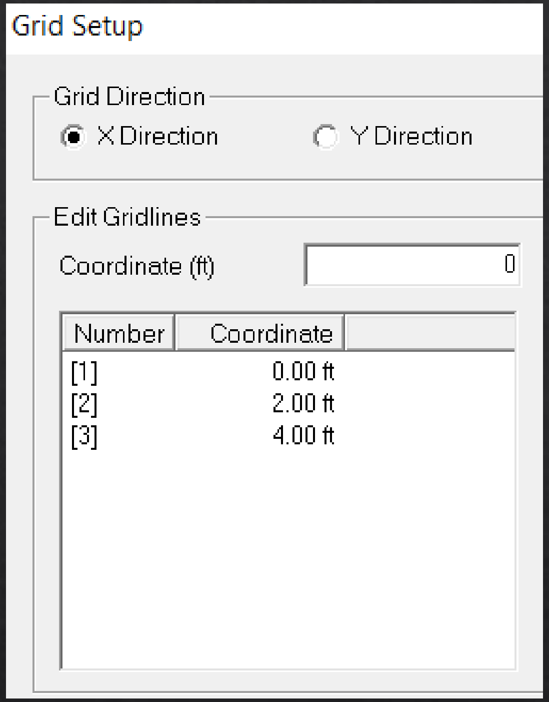

Concrete Slender Wall
General
Dimensions
Loads
Load Combinations
--None--
Wall Material
Concrete
Masonry
Material Properties
f'c . . . .
4.0
ksi
fy . . . .
67.50
ksi
fr : Rupture Modulus
λ Lt Wt Factor . . . .
1.0
5.0 * SQRT (f'c)
7.5 * SQRT (f'c)
fr =
474.342 psi
Ec
"57"
"33"
3,540.0
ksi
Concrete Wt
145.749
pcf
Max Pu/Ag = f'c *
0.060


Thickness & Rebar
Wall Thickness
9.880
in
Define Rebar Spacing
Rebar . . .
Bar Size
4
Bars in Width
4.0
Bar Location(s)
@ Center
Each Face
Rebar "d" Distance
4.940 in
Define # bars in section width
Wall Weight
120.0 psf
Analysis Settings
Ieff used for deflection
Ieff based on Mu @ Element
Icracked Full Height
Temperature Differential across thickness
Minimum Vertical Steel : (your entry) * bd
0.0020
Minimum allowed (Span/Deflection) ratio
150.0
Apply 0.75 Factor used in ACI 530-11 Eq. 14.8.3
Number of wall elements for FE solver to use :
50


General
Dimensions
Loads
Load Combinations
Wall Type
1 Story
2 Story
Wall Support Conditions . . .
Top & Bottom Pinned
Top Pinned, Bottom Fixed
Top Free, Bottom Fixed
A Clear Height
24.0
ft
B Parapet height
0.6670
ft
Height / Thickness Ratio
29.150 : 1
Reveal Data
M Reveal Rebar
No Change
Drape Bars
Add Bars
Reveal Depth
0.280
in
F Reveal Start Loc
ft
G Reveal End Loc
24.667
ft
Design Width of wall portion ("strip width")
48.0
in

Software Y


25
27
1
3


Grid Setup
Grid Direction
X Direction
Y Direction
Edit Gridlines
Coordinate (ft)
0
Number
Coordinate
[1] 0.00 ft
[2] 2.00 ft
[3] 4.00 ft

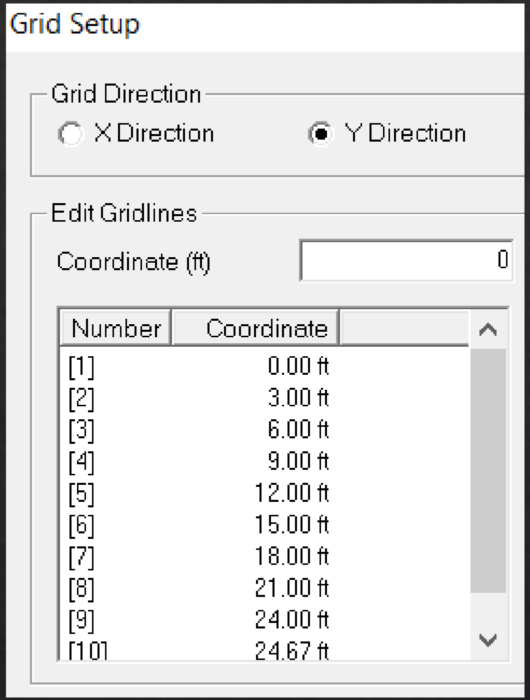

Grid Setup
Grid Direction
X Direction
Y Direction
Edit Gridlines
Coordinate (ft)
0
Number
Coordinate
[1] 0.00 ft
[2] 3.00 ft
[3] 6.00 ft
[4] 9.00 ft
[5] 12.00 ft
[6] 15.00 ft
[7] 18.00 ft
[8] 21.00 ft
[9] 24.00 ft
[10] 24.67 ft

Plate Thickness

Label: W9.6

Thickness (in): 9.6

Label	Thickness
W9.6	9.60
W6	6.00

Reinforcement

Label: Gr67.5

fy (ksi): 67.5

Es (ksi): 28600

Label	fy	Es
Gr67.5	67.50	28600.00

Plate Design Criteria

Label: W9.6_1C#4

Reinforcement Layout

- (•) One curtain
- ( ) Two curtains
- [ ] Allow one curtain in thick walls [Chk-1]

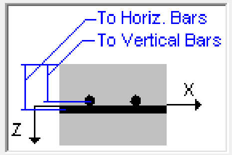
Reinforcement Ratios (%)

	Horizontal	Vertical
Minimum:	0.1	0.1735
Maximum	0.2	0.1737

[ ] Allow minimum below code [Chk-2]

Reinforcement Location (in)

	Horizontal	Vertical
Curtain 1	4.16	4.66



Label	Curtai...	[Chk...	Rmin (H)	Rmax (H)	Rmin (V)	Rmax (V)	[Chk...	Ct-1 (H)	Ct-1 (V)	Ct-2 (H)	Ct-2 (V)
W9.6_1C#4	One	No	0.100	0.200	0.174	0.174	No	4.16	4.66		
W6_1C#4	One	No	0.100	0.200	0.278	0.278	No	3.85	3.35		
W6_2C#4	One	No	0.100	0.200	0.278	0.278	No	3.50	3.00		

Uniform Line Loads

Label: Vertical6

Load Case: Case A

Eccentricity (in): 6

Forces (klf)

Wx	Wy	Wz
0	-0.32	0

Label	Case	Wx	Wy	Wz	Ec
Vertical9.6	A	0.000	-0.320	0.000	7.800
Vertical6	A	0.000	-0.320	0.000	6.000

Stiffener Cracking Coefficients

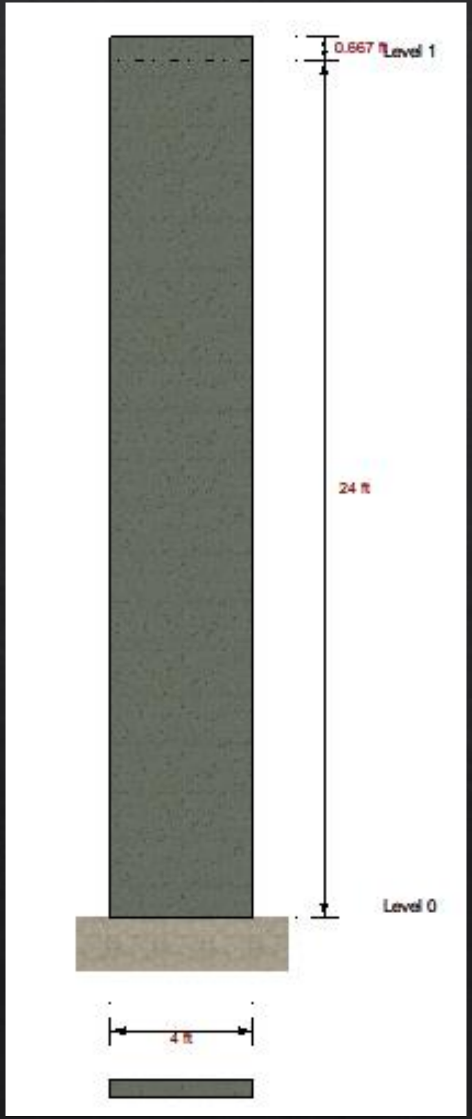
Label: SCC1

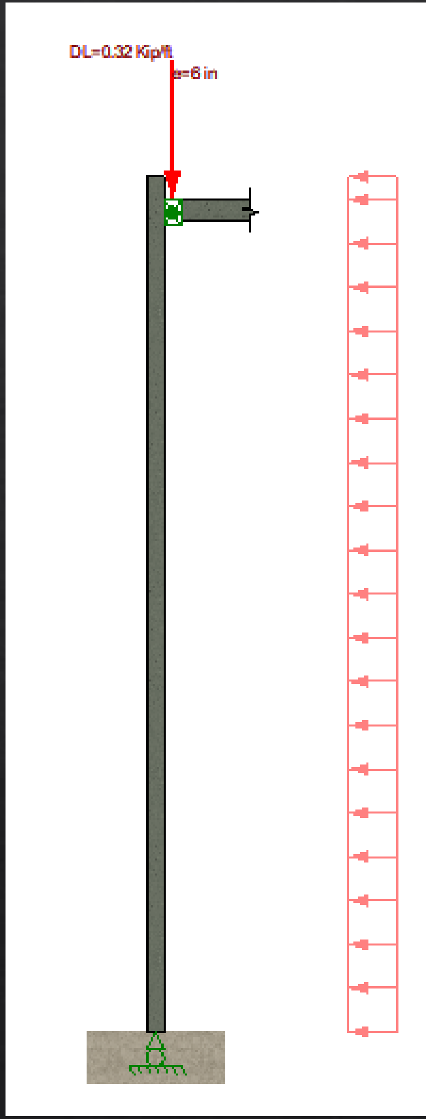
Cracking coefficients

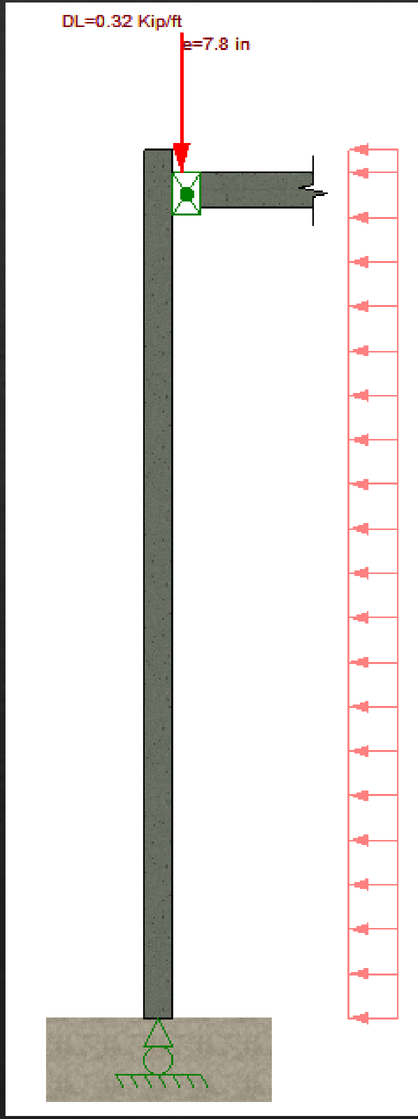
Area:	Inertia (Iy):	Inertia (Iz):	Torsion (J):
1	0.35	0.35	0.35

Label	Area	Inertia (Iy)	Inertia (Iz)	Torsion (J)
SCC1	1.000	0.350	0.350	0.350

Software Z



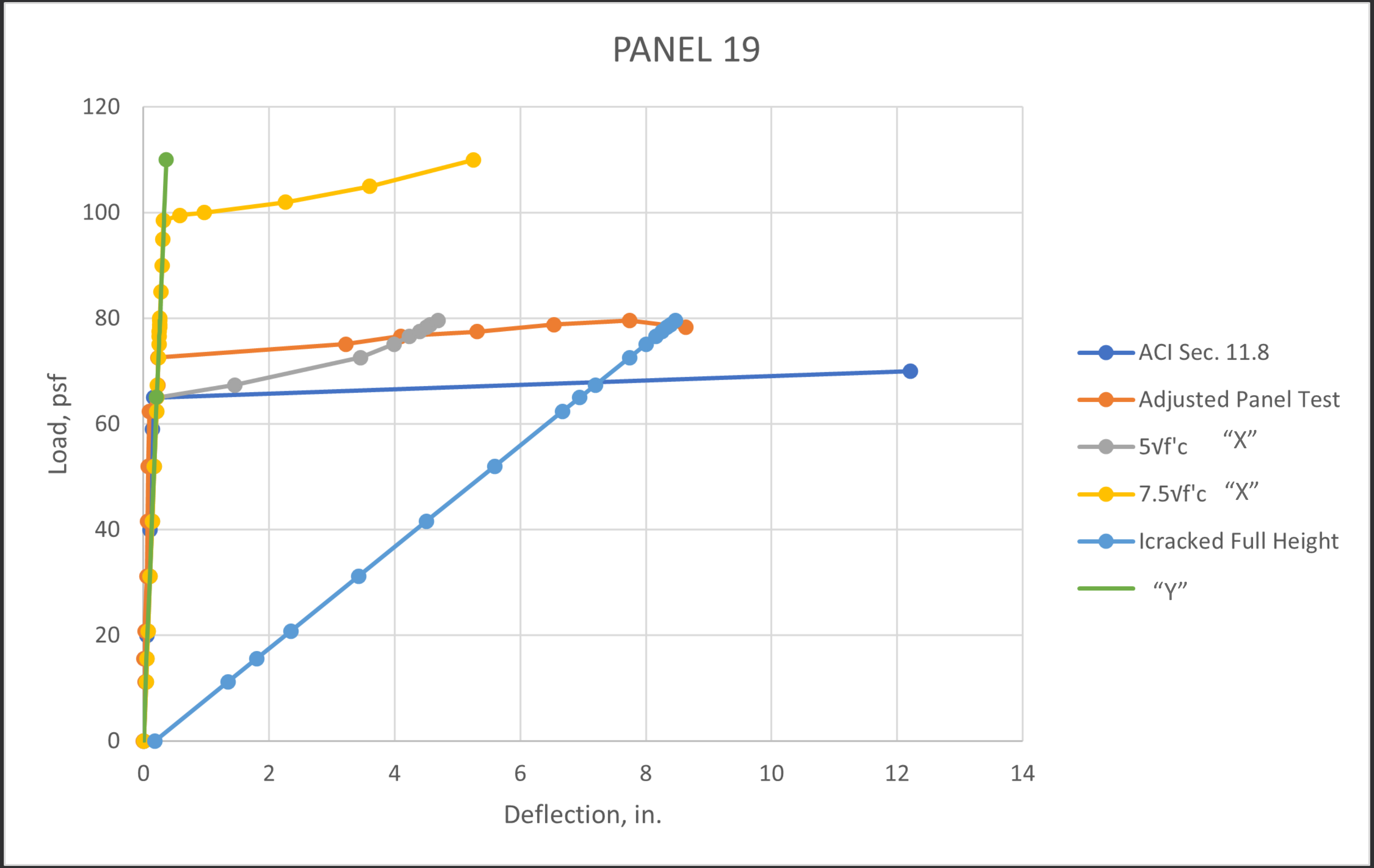


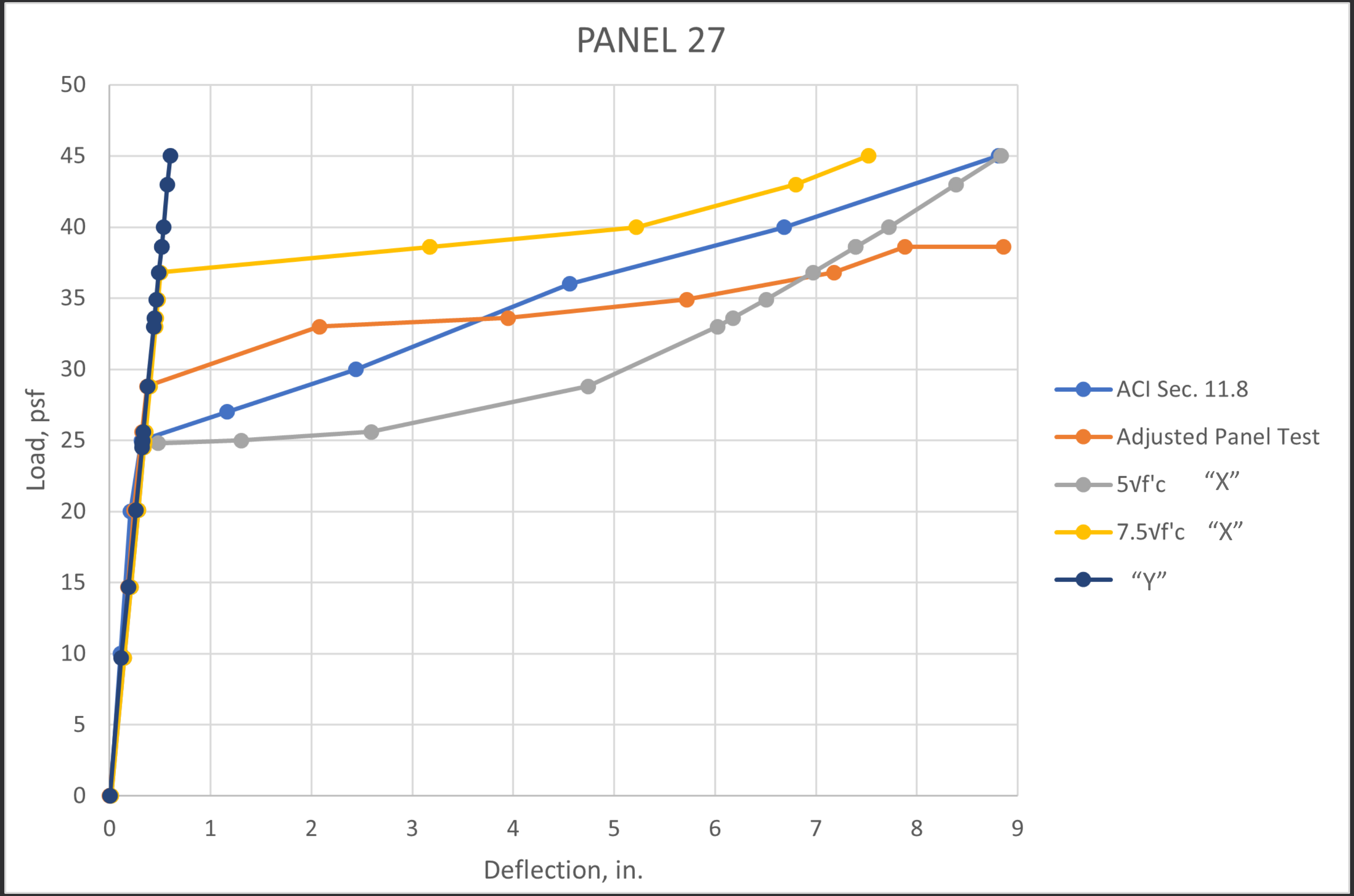


Property	Value
Units system	English
Analysis method	Simplified
Design code	ACI 318-19
Geometry	
Number of levels	1
Height	24 ft
Parapet height	0.667 ft
Length	4 ft
Thickness	6 in
Bottom panel	0 ft
Fixity at foundation level	Pinned
Level restraints	Pinned
Openings	<Openings>
Additional strips	<Strips>
Materials	
Material	Senior Project
Lightweight concrete	☐

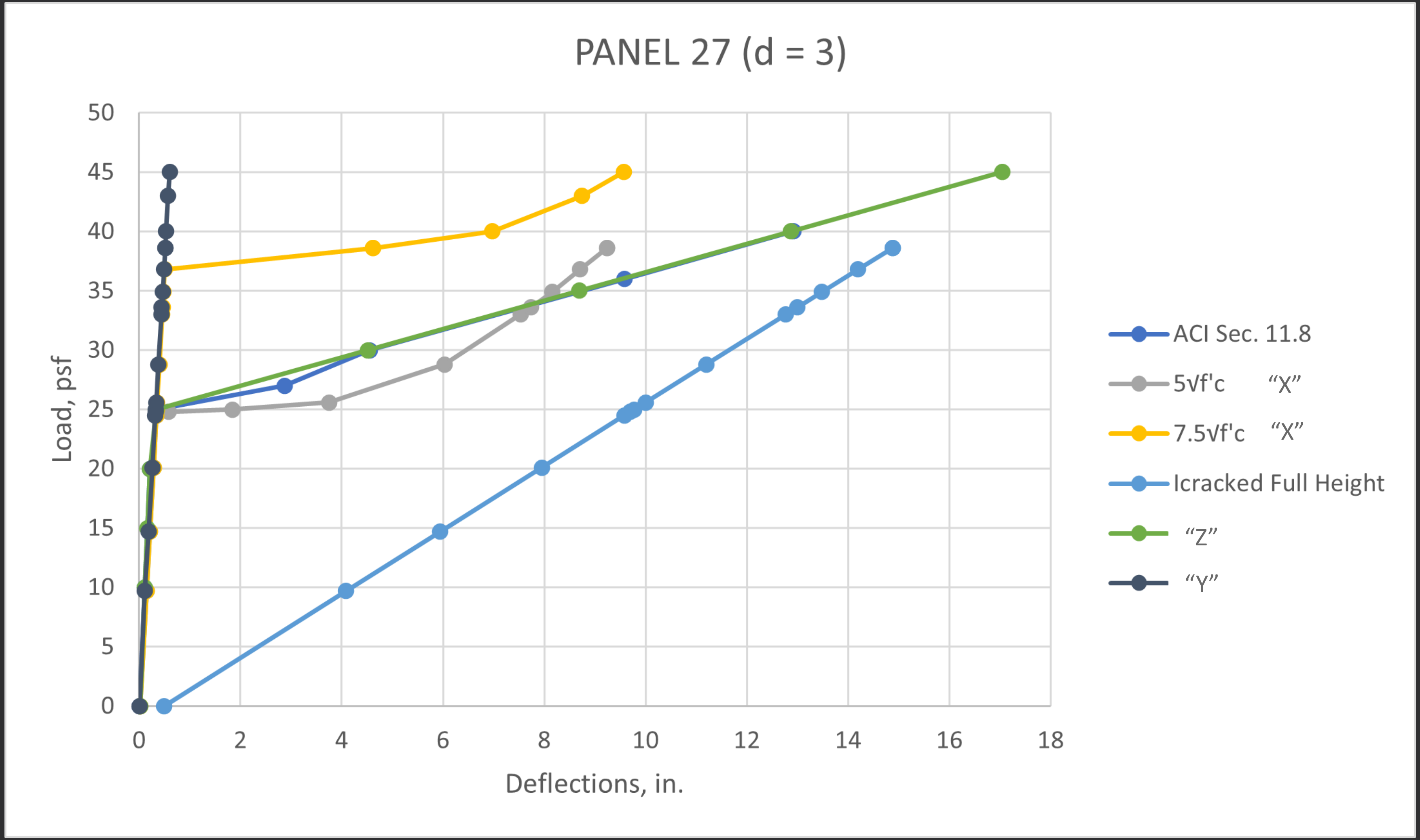
COMPARISONS

Service Level Deflection

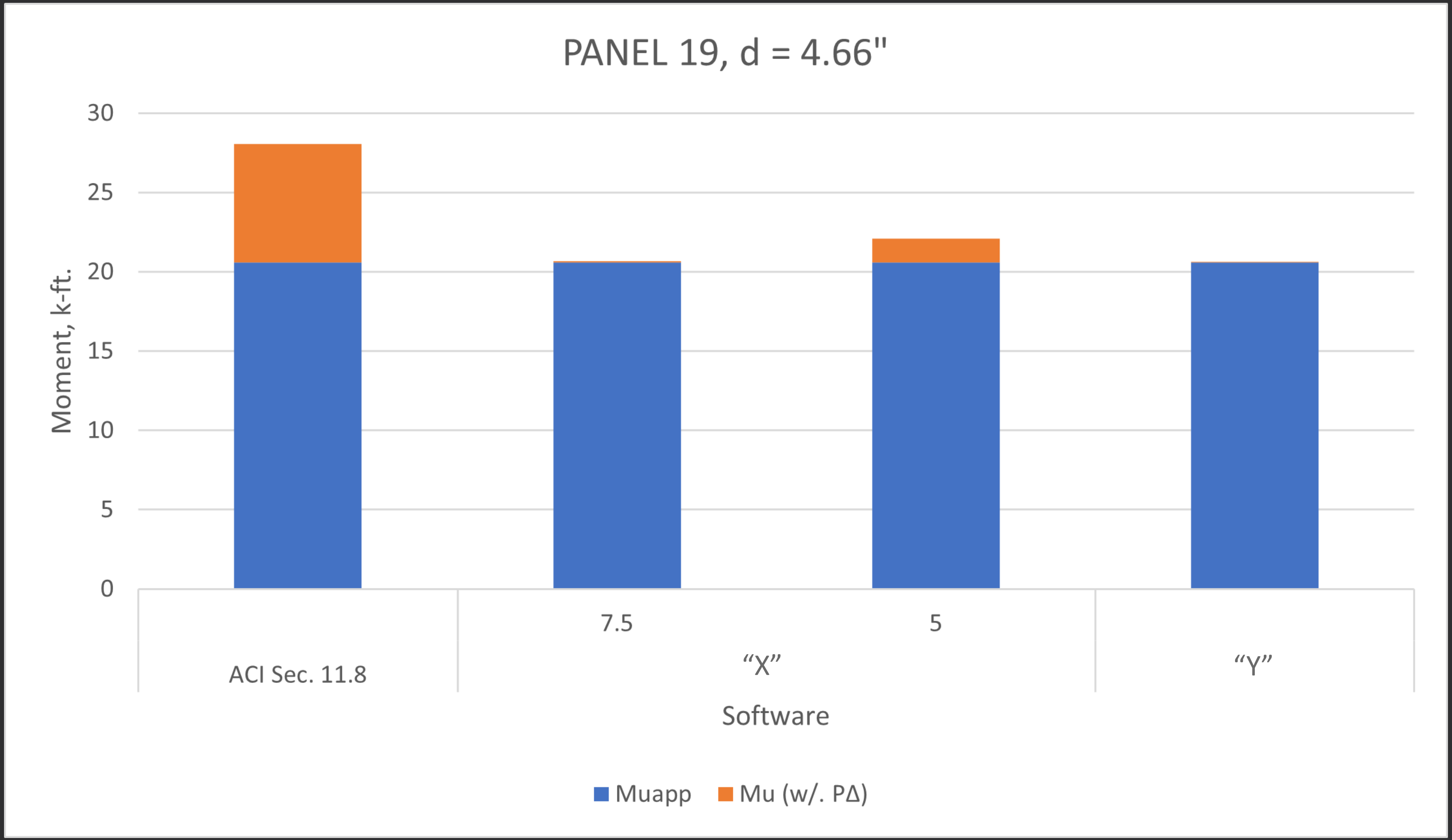


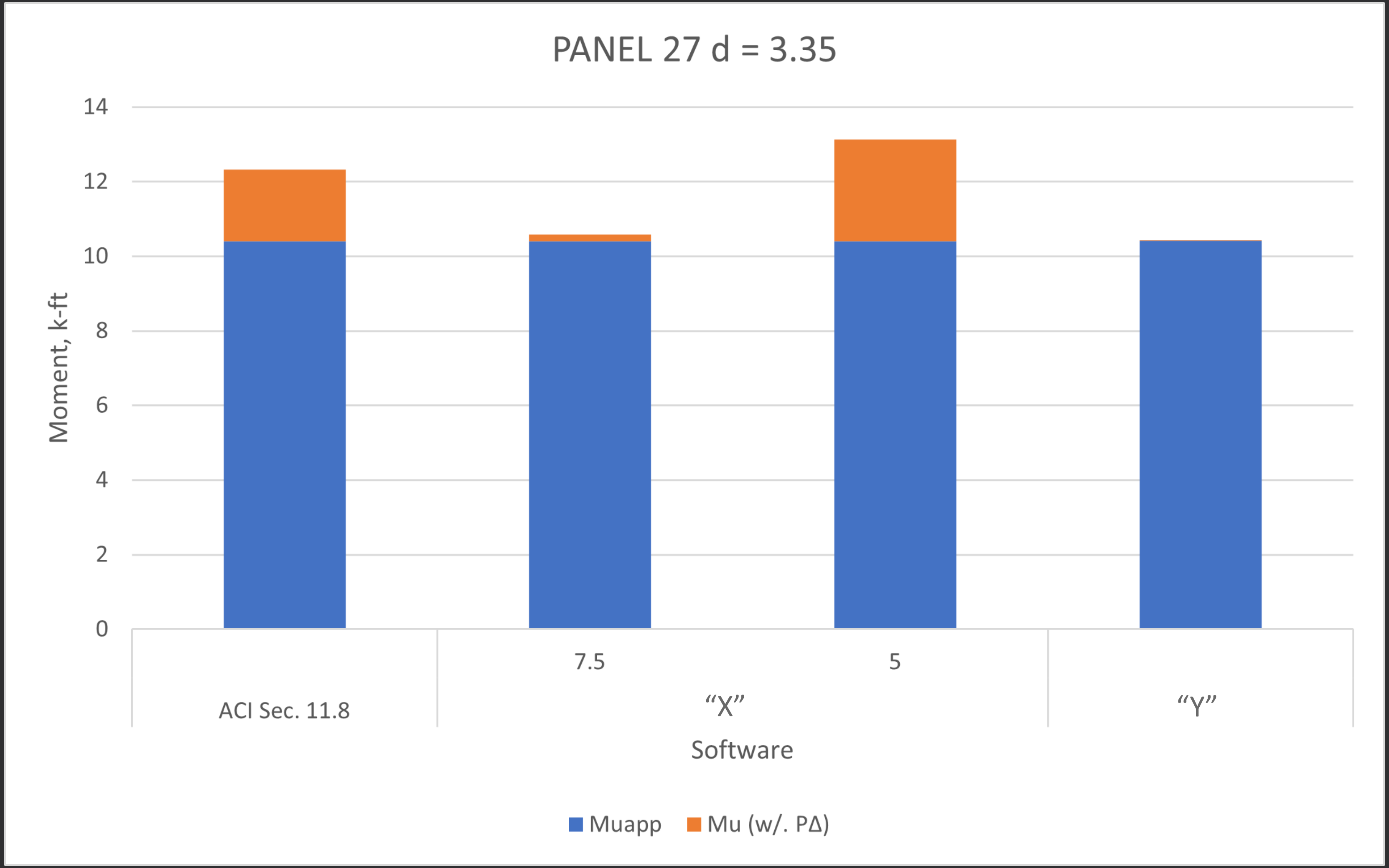


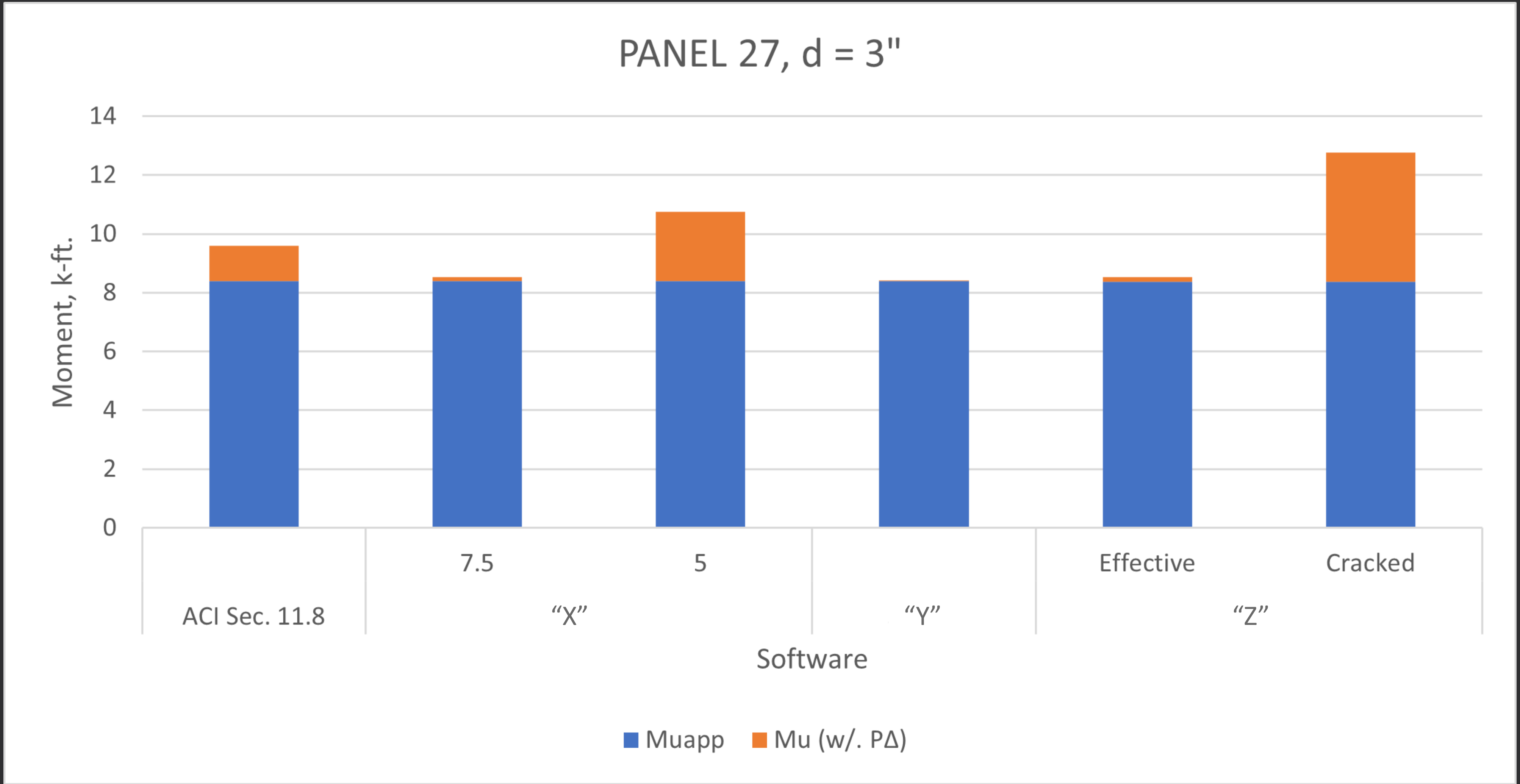
PANEL 27
Load, psf
Deflection, in.
0
5
10
15
20
25
30
35
40
45
50
0
1
2
3
4
5
6
7
8
9
ACI Sec. 11.8
Adjusted Panel Test
5√f'c “X”
7.5√f'c “X”
“Y”


PANEL 27 (d = 3)
Load, psf
Deflections, in.
0
5
10
15
20
25
30
35
40
45
50
0
2
4
6
8
10
12
14
16
18
ACI Sec. 11.8
5√f'c “X”
7.5√f'c “X”
Icracked Full Height
“Z”
“Y”

Moment


PANEL 19, d = 4.66"
Moment, k-ft.
30
25
20
15
10
5
0
ACI Sec. 11.8
7.5
5
"X"
"Y"
Software
Muapp
Mu (w/. PΔ)


PANEL 27 d = 3.35
14
12
10
8
6
4
2
0
Moment, k-ft
7.5
5
ACI Sec. 11.8
“X”
“Y”
Software
Muapp
Mu (w/. PΔ)



PANEL 27, d = 3"
Moment, k-ft.
14
12
10
8
6
4
2
0
ACI Sec. 11.8
7.5
5
"X"
"Y"
Effective
Cracked
"Z"
Software
Muapp
Mu (w/. PΔ)

CONCLUDING SUMMARY

1. It’s important to understand the true behavior of slender walls.

2. Different software will require users to make assumptions.

3. Decide whether the assumptions are appropriate and adjust accordingly.

4. Know that software is a tool and can be used incorrectly.

QUESTIONS??