Commentary on Multi-Story Tilt-Up Panel Design Using ACI 318-14 – ACI 551.2R-15

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 provisions from 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 wall can be designed as simply supported   *ACI 318-14 (11.8.2.1)*
- The 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 cross section shall be constant over the height of the wall   *ACI 318-14 (11.8.1.1(a))*
- 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))*
- The concentrated loads application limits shall be met   *ACI 318-14 (11.8.2.2)*
- P_u at the midheight section does not exceed $0.06f_c' A_g$ *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))

For multi-story panels, ACI 551 utilized the alternative analysis method even though some of the conditions above are not met. An investigation of StructurePoint Design Example Solution (based on Example B.5 solution in ACI 551.2R-15) was compared with a detailed FEA model using the engineering software program spWall. The results of the comparison identified two important issues summarized in this article along with StructurePoint's observations and recommendations.

Issue #1:   **Proper calculation of moment magnification**

Using the same moment magnification factor (magnifier) for the maximum <u>negative</u> moment section based on the properties of the maximum <u>positive</u> moment section within the same span is not valid. In some cases, this will underestimate the second order design moment at the negative section.

Recommendation: Calculate the moment magnification factor separately for positive and negative moments and repeat for each wall segment or conservatively use the highest magnification factor. This procedure should be repeated for all load combinations under consideration.

Illustration: In the Example, this issue is illustrated in Figures 1 and 2 for Load Combination 1 (1.2D + 1.6L_r + 0.5W) where:

Current Procedure $M_{u,negative}$ = -9.33 kip-ft (Using positive moment magnification factor from span 3).

Recommended Procedure $M_{u,negative}$ = -13.73 kip-ft (Using the correct negative moment magnification factor from span 1 where the max negative moment occurs, see the following table).

Issue #2:   **Proper location of maximum design moments**

For multi-story tilt-up panels such as the panel discussed in the Example, the location of maximum positive and negative moment can vary between first and second order analyses. Thus, locating and magnifying the maximum moment based on first order analysis to estimate the maximum second order moment may be incorrect for some cases. This can lead to underestimating maximum moments and deflections as shown in Figure 2.

Recommendation: Perform the ACI 551 procedure for each wall span individually and evaluate maximum positive and negative design moment values separately after considering moment magnification due to second order effects.

Illustration: In the Example, this issue is illustrated for Load Combination 1 (1.2D + 1.6L_r + 0.5W) where in table 1 the maximum positive design moment moved to Span 1 after second order analysis (magnification) while the maximum negative design moment remained in span 1.

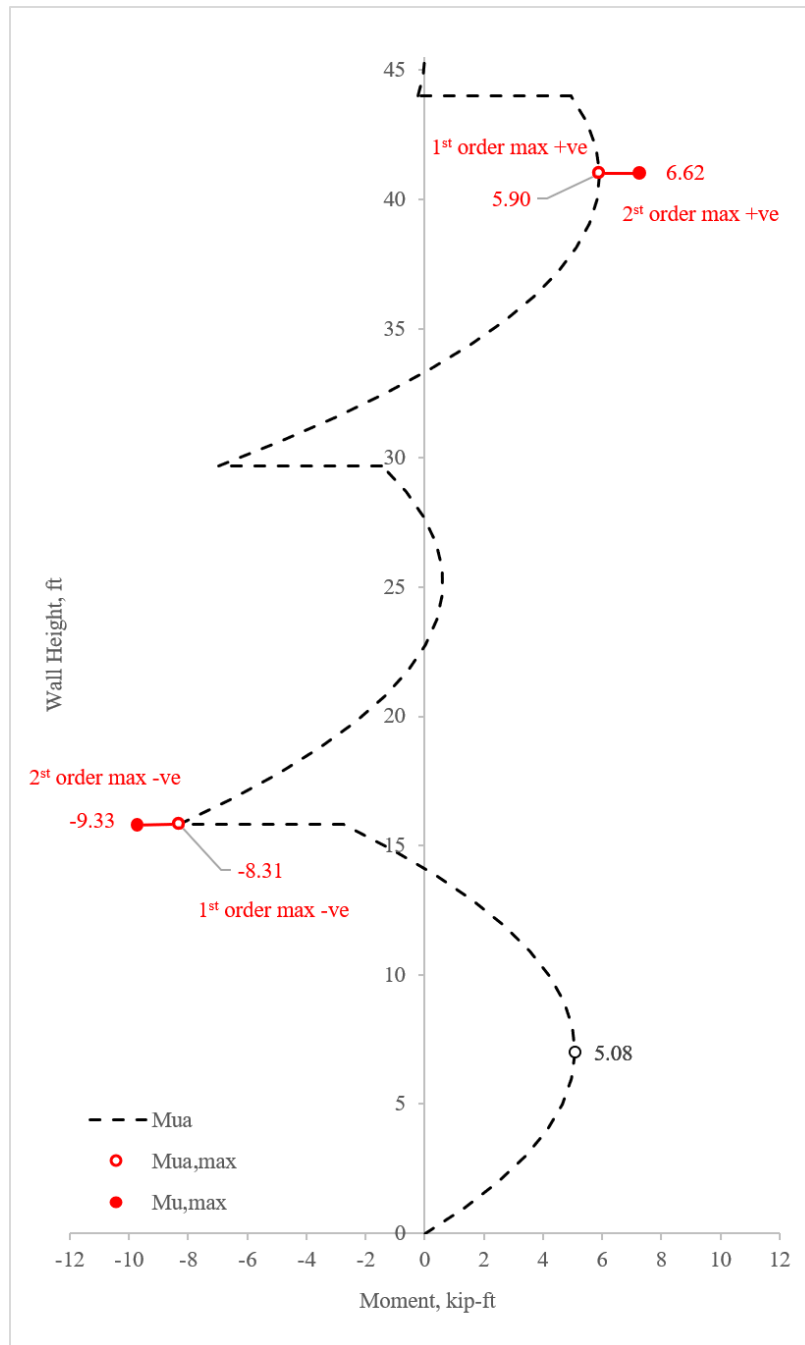|	Table 1 - Comparison of Design Moments					
Method	Maximum Positive (issue 2)			Maximum Negative (issue 1)		
	M_{ua} kip-ft	M_u kip-ft	Location	M_{ua} kip-ft	M_u kip-ft	Location
Current Procedure	+5.90	+6.62	Span 3	-8.31	-9.33	Span 1
Recommended Procedure	+5.08	+10.05	*Span 1*	-8.31	-13.73	Span 1

Figure 1 – First Order Moment Diagram and Second Order Maximum Moments (Current Procedure)
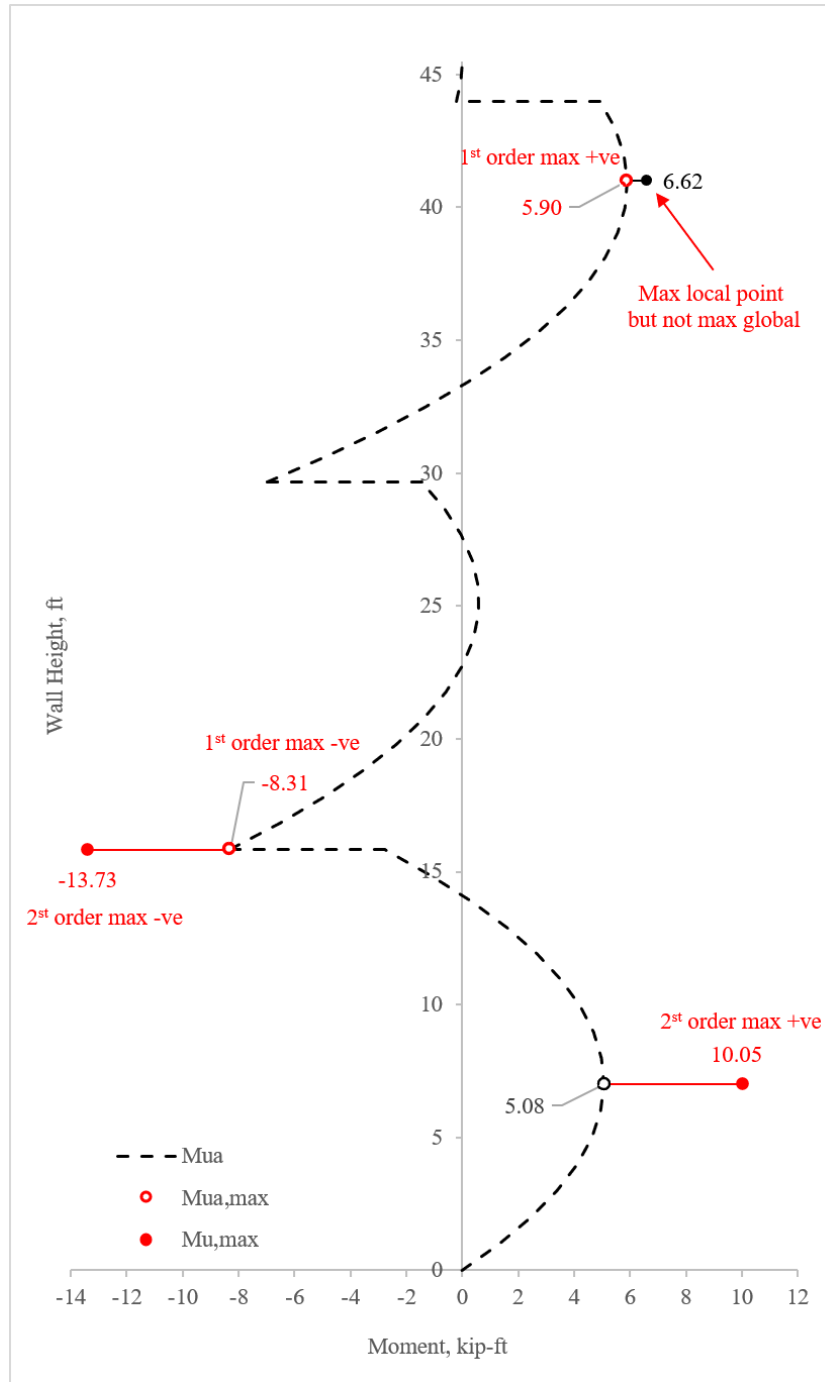
Figure 2 – First Order Moment Diagram and Second Order Maximum Moments (Recommended Procedure)

Conclusions and Observation

The information presented for first order and recommended second order moments has been verified using an FEA spWall model of the multi-story tilt-up wall panel as shown in the following figure.
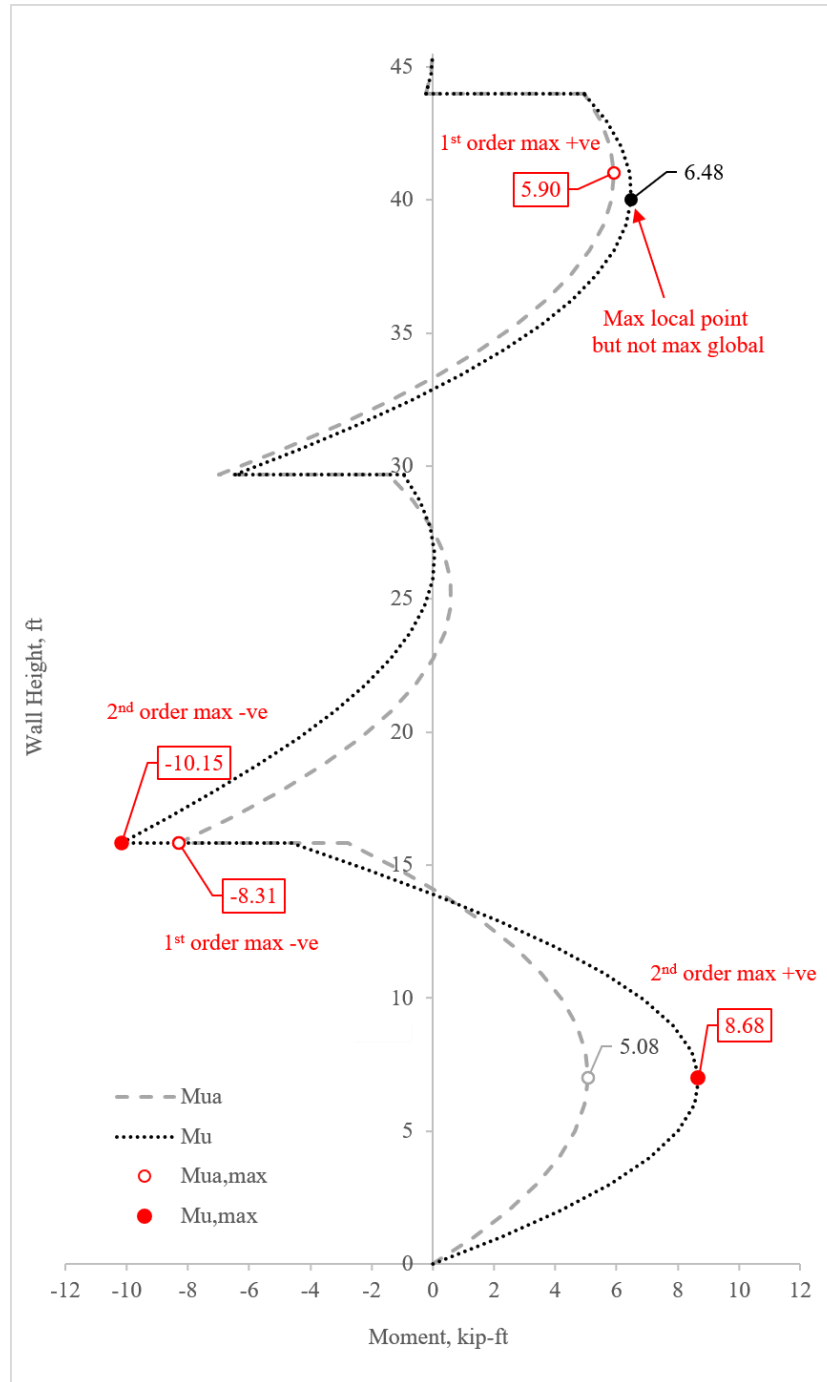

Figure 3 – First and Second Order Moment Diagrams (Using FEA - spWall)

The results indicate good agreement with the ACI 551 procedure when the recommended corrections are implemented. It is worth noting that the magnified positive and negative moments are slightly conservative in comparison with the corresponding FEA value as can be seen in the following table.

Table 2 - Comparison of Recommended Procedure with FEA (Bending Moments)								
Method	Maximum Positive				Maximum Negative			
	M_{ua} kip-ft	M_u kip-ft	Magnifier	Location	M_{ua} kip-ft	M_u kip-ft	Magnifier	Location
Recommended Procedure	+5.08	+10.05	1.98	Span 1	-8.31	-13.73	1.65	Span 1
FEA spWall	+5.08	+8.68	1.71	Span 1	-8.31	-10.15	1.22	Span 1