Reinforced Concrete Shear Wall Lateral Displacement and Stability in High-Rise Buildings (ACI 318-14/19)

A structural reinforced concrete shear wall in a 50-story building provides lateral and gravity load resistance for the applied load as shown in the figure below. Shear wall lateral displacement is investigated using different cracking coefficient equations using spWall engineering software program from StructurePoint.

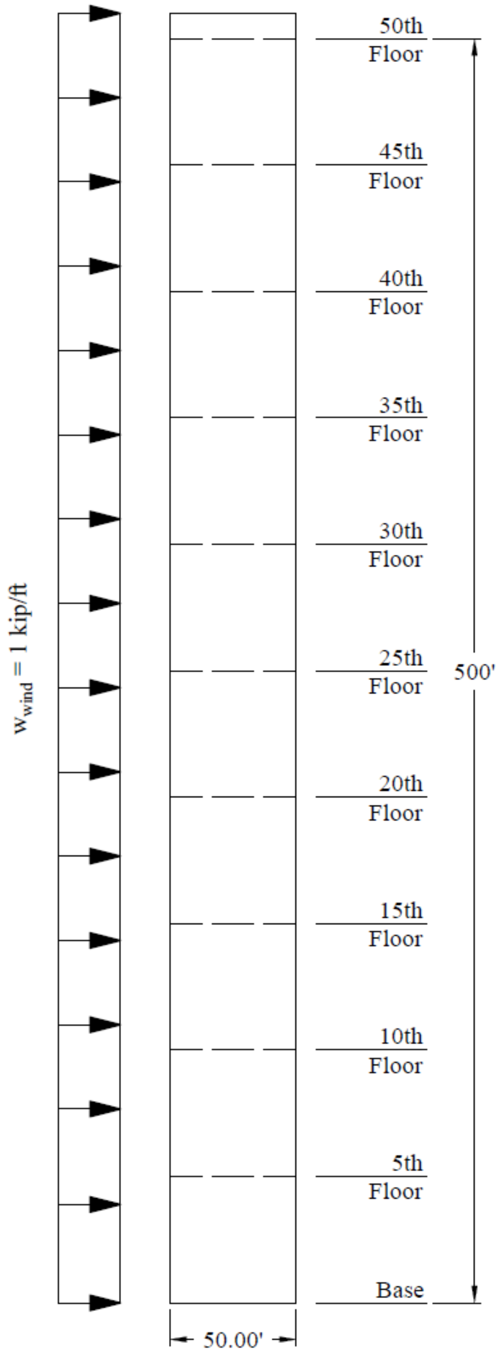


Figure 1 – Reinforced Concrete Shear Wall Geometry and Loading

Code

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

Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)

Reference

High-Rise Concrete Shear Walls Subject to Service Loads, Neil Wexler and Hoonhee Jeoung, Concrete International, 2019

Effective Flexural Stiffness for Cracked Moment of Inertia of Concrete Walls, STRUCTUREPOINT, 2019

spWall Engineering Software Program Manual v5.01, STRUCTUREPOINT, 2016

Design Data

f_c' = 6,000 psi normal weight concrete (w_c = 150 pcf) f_y = 60,000 psi

E_c = 4,415 ksi t_{wall} = 14 in.

w_{wind} = 1 kip/ft

Reference assumed that the wall carries only self-weight (no floor loads). The reference provided the following cracking coefficients in their presentation.

Table 1 - Cracking Coefficient Calculation Methods for Lateral Analysis

Element†	Proposed*	ACI 318 Table 6.6.3.1.1(b) & Section 6.6.3.2.2*	ACI 318 Uncracked	ACI 318 Simplified Cracked
remaining elements	1.00	1.00	1.00	0.50
71	1.00	0.90	1.00	0.50
66	0.96	0.90	1.00	0.50
63	0.91	0.89	1.00	0.50
56	0.86	0.89	1.00	0.50
51	0.93	0.89	1.00	0.50
46	0.79	0.89	1.00	0.50
41	0.77	0.88	1.00	0.50
36	0.75	0.88	1.00	0.50
31	0.73	0.88	1.00	0.50
26	0.71	0.87	1.00	0.50
21	0.69	0.87	1.00	0.50
16	0.68	0.87	1.00	0.50
11	0.67	0.87	1.00	0.50
6	0.66	0.86	1.00	0.50
1	0.65	0.86	1.00	0.50

* Detailed calculations can be found in the reference

† Elements locations are shown in the following Figure

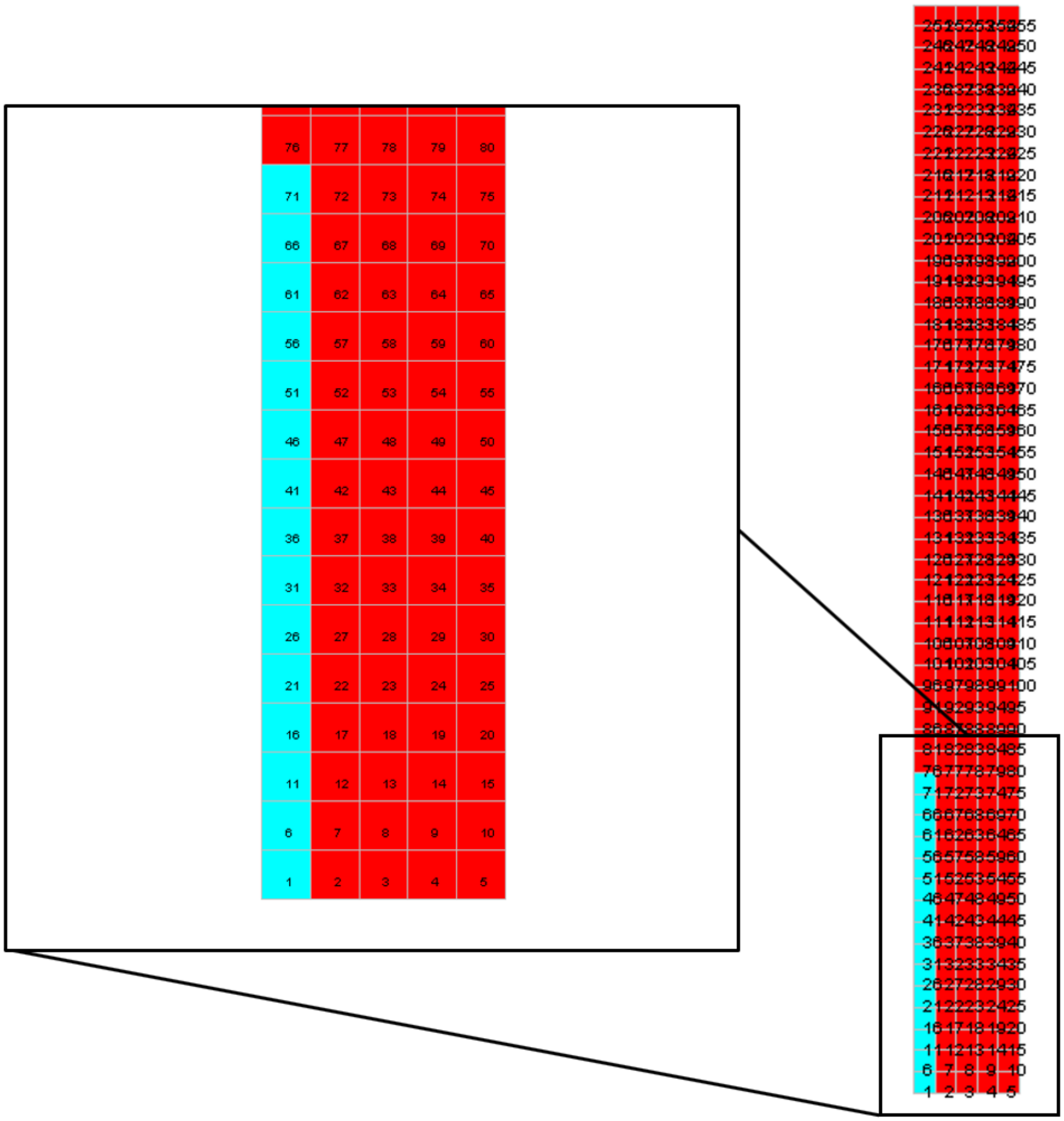


Figure 2 – Elements Locations (spWall)

Shear Wall Analysis – spWall Software

spWall is a program for the analysis and design of reinforced concrete shear walls, tilt-up walls, precast wall 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.

After the Finite Element Analysis (FEA) is completed in spWall, the required flexural reinforcement is computed based on the selected design standard (ACI 318-14 and ACI 318-19 are used in this example), and the user can specify one or two layers of shear wall reinforcement. In stiffeners and boundary elements, spWall calculates the required shear and torsion steel reinforcement. Shear 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 the FEA results obtained from an spWall model created for the reinforced concrete shear wall in case study.

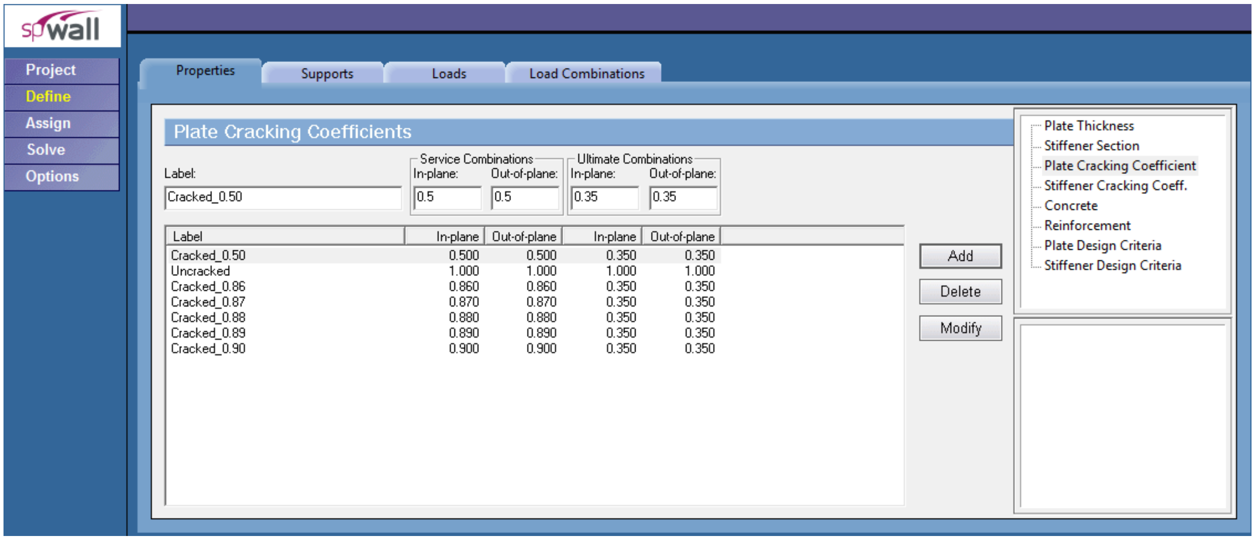


Figure 3 – Defining Cracking Coefficients (spWall)

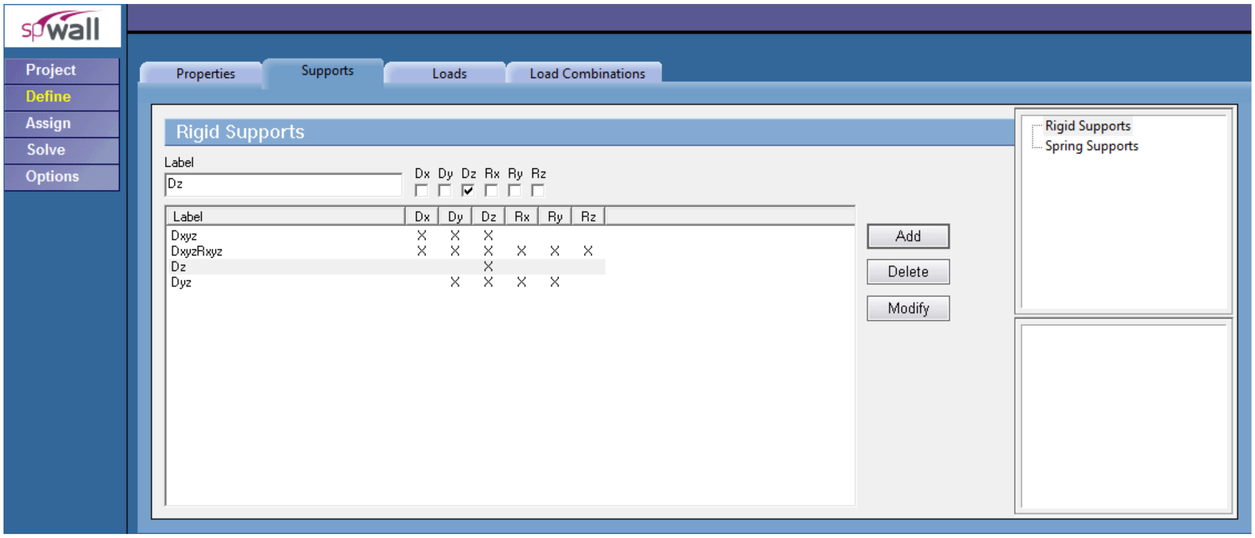


Figure 4 – Defining Supports (spWall)

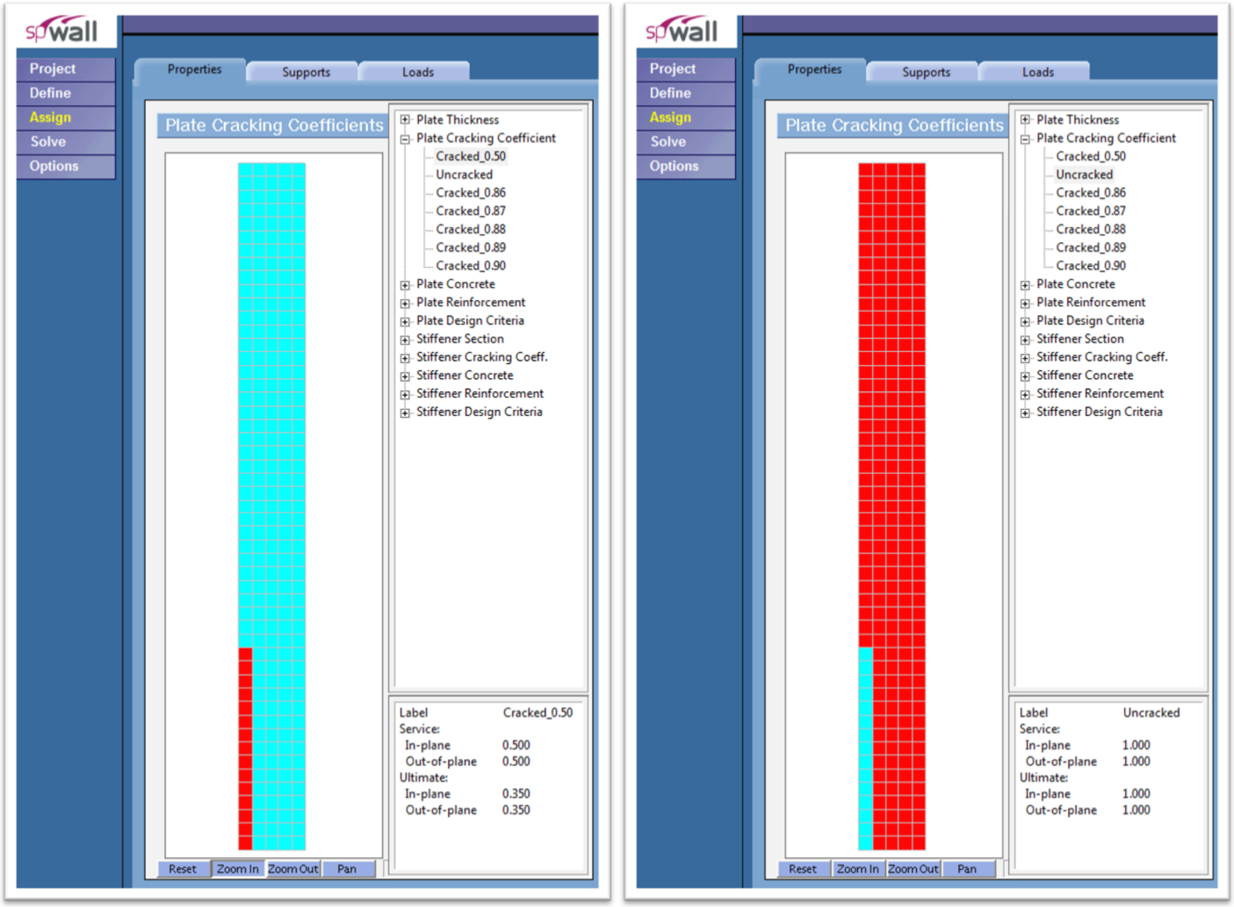


Figure 5 – Assigning Cracking Coefficients (spWall)

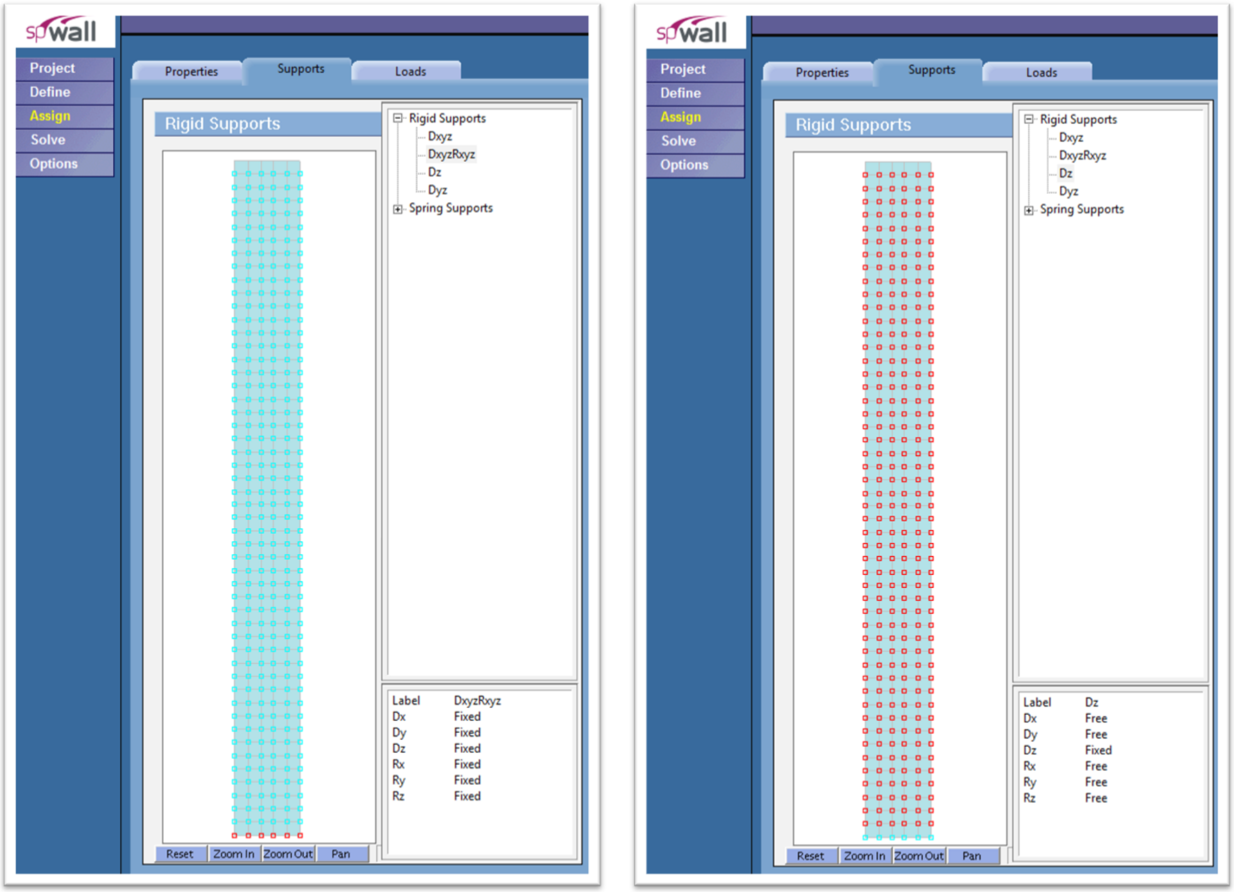


Figure 6 – Assigning Supports (spWall)

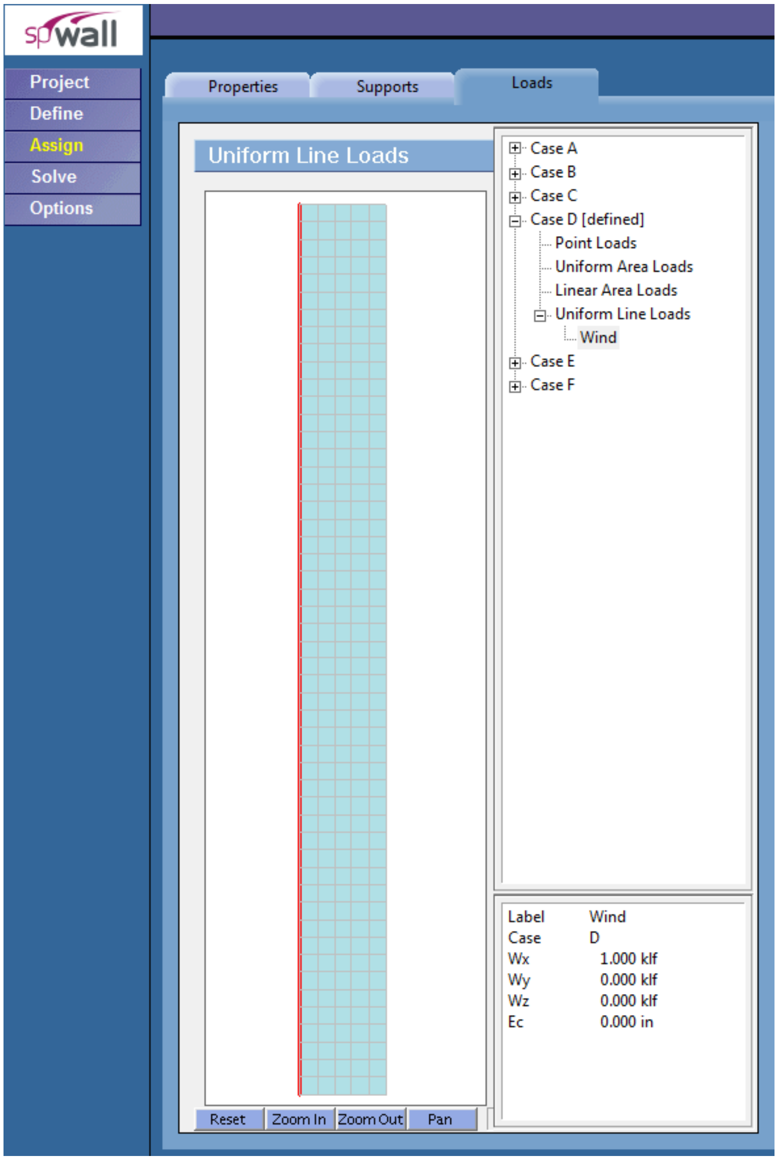


Figure 7 – Applying Lateral Wind Loads (spWall)

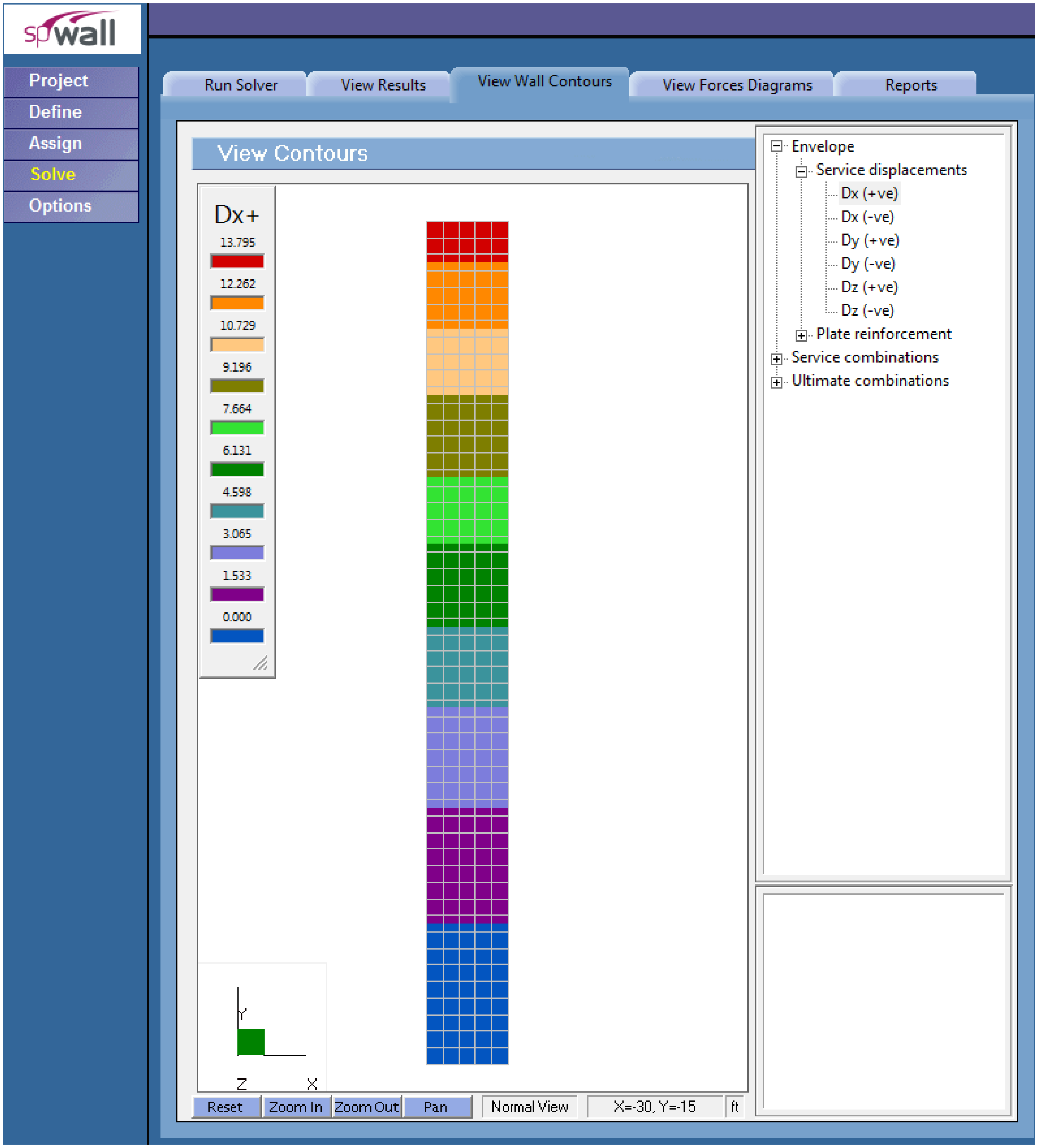


Figure 8 – Shear Wall Lateral Displacement Contour Sample

Results Comparison and Conclusions

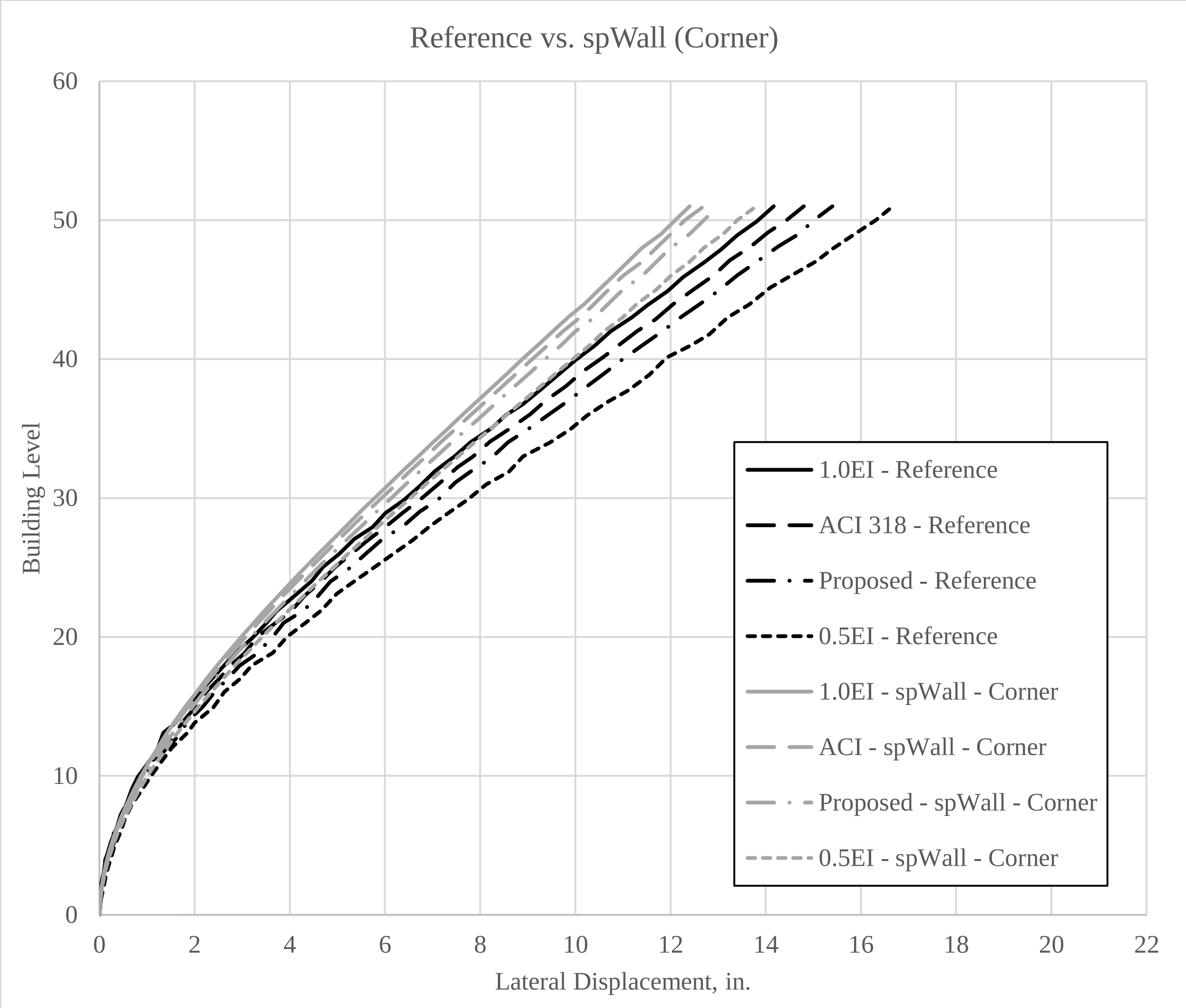
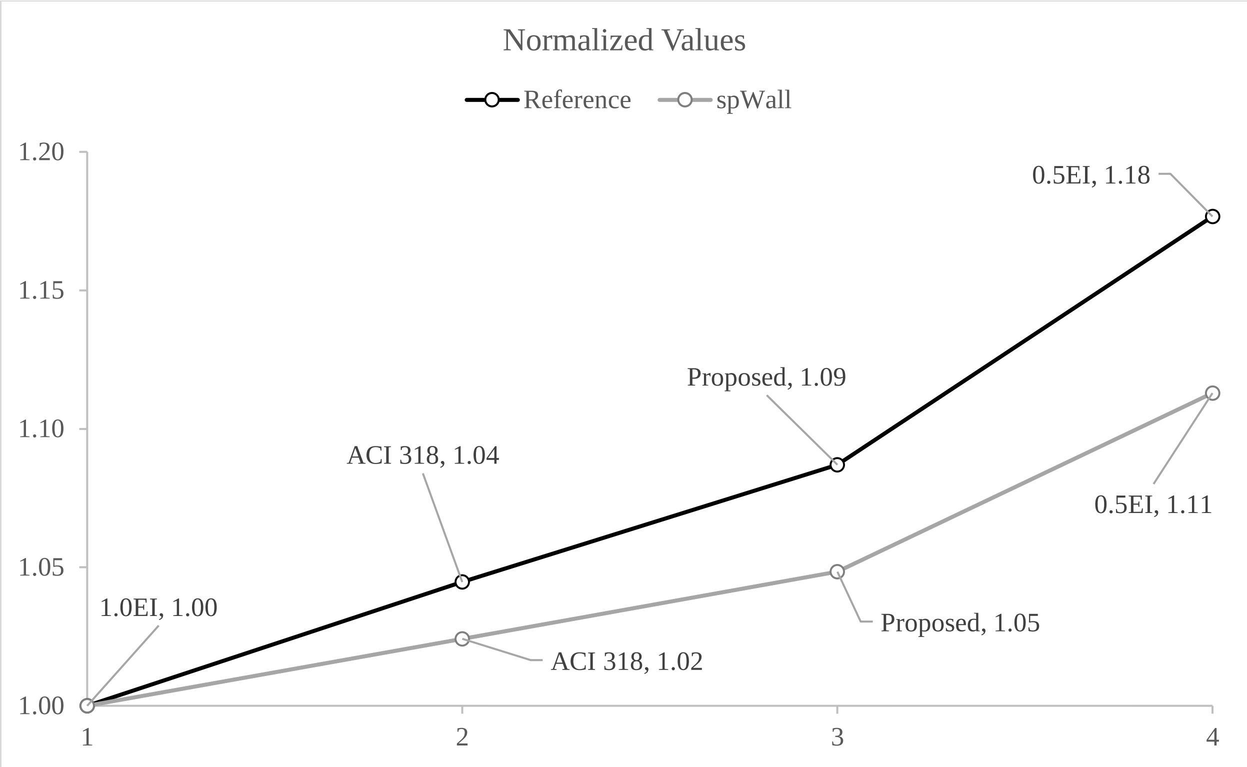


Table 2 – Results Comparison			
Method	Lateral Displacement, in.		
	Reference	spWall	Difference (%)
1.0EI	14.17	12.40	14.25
ACI 318	14.80	12.70	16.54
Proposed	15.40	13.00	18.46
0.5EI	16.67	13.80	20.80



Using reduced stiffness in critical region (heel of shear wall) has significant effect on the lateral displacement of shear walls and need to be considered. The reduced stiffness can be calculated using different ACI 318 provisions or using more detailed analysis (as provided by the reference), but the value shall not exceed the stiffness of gross section. This emphasis on the critical region is easily evaluated given the availability of a basic finite element analysis tool such as spWall.