



#### 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 <u>spWall</u> engineering software program from <u>StructurePoint</u>.



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
- <u>Cracking Coefficient and Effective Flexural Stiffness of Concrete Walls, STRUCTUREPOINT</u>, 2023
- <u>spWall Engineering Software Program Manual v10.00</u>, <u>STRUCTUREPOINT</u>, 2022

## Design Data

 $f_c'$ = 6,000 psi normal weight concrete ( $w_c = 150 \text{ pcf}$ ) $f_y$ = 60,000 psi $E_c$ = 4,415 ksi $t_{wall}$ = 14 in.

 $w_{wind} = 1 \text{ kip/ft}$ 

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 <sup>†</sup>	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									





 251
 252
 253
 254
 255

 246
 247
 248
 249
 250

 241
 242
 243
 244
 245



Figure 2 – Elements Locations (spWall)



#### Shear Wall Analysis – spWall Software

<u>spWall</u> 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 <u>spWall</u>, 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, <u>spWall</u> 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 <u>spWall</u> model created for the reinforced concrete shear wall in case study.





<b>9</b>   [	6		C.		sp	Wall - Shear \	Wall Latera	l Stability in H	ligh-Rise E	Buildings - 0.5E	l Corner.w	alx			- 🛛	×
File Pro	ا م ject	lome Define	o ↓ Grid	↓ Select	Plates		 Nodes	 Restraints	↓ Loads	Solve	Results	Tables	Reporter	Display	Viewports	ہ Settings
Pro	PRO	ECRIPTION Project Date Project Time	ACI 31 English Interal Stability i ption encrete Shear and Hoonhee 2/13/2023 1:40 PM	8-14 h	e Buildings	E Loads, national,	Nodes	A Restraints	Loads	Jead)	Results	Tables 50.00 W14_1		Usplay	Viewports	Settings
=↑ ≡	L	ad Case	A - De	ad	• <					0		x			- are FRO	
AC	1318-	14										· #	• <mark>†</mark> • E		· Units:	English 🔻

Figure 3 – spWall Interface







Figure 4 – Assigning Supports (spWall)





sp	Def	nitions						- 🗆	×						
≣↓	~	Objects	Plate Cracking Coefficier	nt											
=↑		Plates	+ New X Delete												
	~	Properties	+ New X Delete	→+ +→	$ $ $\sim$										
		Concrete	Label	Service Com	binations	Ultimate Con	nbinations	Used							
		Reinforcement		In-plane	Out-of-plane	In-plane	Out-of-plane								
		Plate Cracking Coefficient	Cracked_0.50	0.5	0.5	0.35	0.35	Yes							
		Plate Design Criteria	Uncracked	1	1	1	1	Yes							
		Stiffener Cracking Coefficient	Cracked_0.86	0.86	0.86	0.35	0.35	No							
		Stiffener Design Criteria	Cracked_0.87	0.87	0.87	0.35	0.35	No							
	~	Restraints	Cracked_0.88	0.88	0.88	0.35	0.35	No							
		Supports	Cracked_0.89	0.89	0.89	0.35	0.35	No							
		Springs	Cracked_0.90	0.9	0.9	0.35	0.35	No							
		Load Cases Service Load Comb. Ultimate Load Comb.													
						Appl	ОК	Cano	el						

Figure 5 – Defining Clacking Coefficients (Sp W at
--

<b>SP</b>   [	। । 🕞 🔠 । ५ ९	I		sp\	Vall - Shear \	Wall Latera	al Stability in H	ligh-Rise Bui	ldings - 0.5El (	Corner.v	valx			- 🗆	×
File	Home								-						^
Proi	ect Define	Grid		Plates	Stiffeners	 I Nodes	Restraints	↓ Loads	Solve	Result	s Tables	Reporter	∑= Display	Viewports	ැටූ Settings
	SELECT					Model	View (Load (	aco: A - Do	ad)						• •
×	SELLET					woder	view (Load C	.ase: A - Dei	30)	$\sim$		$\sim$			• •
$\stackrel{\uparrow}{\leftarrow_{\downarrow}} \rightarrow$	DI ATT				~					( <u>A</u> )	)	Y			ນປ ະ
	Label	1	W14	*	>				$\bigcirc$	+	50.00				<12
	No. of selected								$\cup$	1					49 10
	✓ Section														56
	Type		Solid							2		2			La
000	Thickness			14.00	in										+a
															-a
	Concrete		C6		>										1
ß	Reinforcement		Gr60	*	>										<u></u>
E7/1	Design Criteria	1	2C#4	*	>										~
<i>V</i> →	Cracking Coeff		Cracked_0.50	*	>										
	✓ Position &	Size													
	Top Left X			0.00	ft										
	Top Left Y			150.00	ft					1		A			
	Width			10.00	ft										
	Height			150.00	ft										
	<ul> <li>Uniform Al</li> </ul>	rea Loads													
	∧ Linear Area	a Loads													
											W14_1				
										100	~	8 00			
											52	1 02			
											- <b>–</b>				
										\$		A			
											10 1501	ft			
= 1										2		R			
≣↓		NS								7	7			FRO	INT
=↑	Load Case	Δ - Γ	Dead		, (%=)				( <b>b</b> )-	<u> </u>	x			• et	
	2000 0050	A-1									- S D	yzRxyz			
AC	1 318-14							-14.58	B, 539.51 (ft)	*	* #	• 🗄 •	L 🗩	<ul> <li>Units:</li> </ul>	English 👻

Figure 6 – Assigning Cracking Coefficient (Cracked Wall Portion) (spWall)





Figure 7 - Assigning Cracking Coefficient (Uncracked Wall Portion) (spWall)









Figure 8 - Assigning Lateral Wind Loads (spWall)



<b>99</b>	6	<u>ר ₪</u>	Ċ		sj	oWall - Shear	Wall Later	al Stability in	High-Rise B	uildings - 0.5	El Corner.wal	x			- 0	×
File	à	Home		Ģ		-		<u> </u>	$\longrightarrow$					¥ <u>=</u>		^ نې
Pro	ject	Define	Grid	Select	Plates	Stiffeners	Nodes	Restraints	Loads	Solve	Results	Tables	Reporter	Display	Viewports	Settings
Prc	<pre>v v v v v v v v v v v v v v v v v v v</pre>	Define SULTS Envelope ✓ Service D D X (+ D y (+ D y (+ D z (+)))))))))))))))))))))))))))))))))))	Grid isplacement ve) ve) ve) ve) ve) ve) rej nforcement	Select	med Shape formed Shape	Stiffeners	Nodes	Restraints pe - Service .795 .809 .824 .839 .853 .868 .883 .897 .912 .927 .941 .956 .971 .925 .000	Loads	Solve ents - Dx (+v (1				Display	Viewports FR	•     ×       ·     ×       ·     ·    · </td
AC	1 3 1 8	3-14									-		÷		Units:	English 🔻

Figure 9 – Shear Wall Lateral Displacement Contour (spWall)





## **Results Comparison and Conclusions**



Table 2 – Results Comparison										
Mathad	Lateral Displacement, in.									
Method	Reference	spWall	Difference (%)							
1.0EI	14.17	12.41	14.19							
ACI 318	14.80	12.67	16.79							
Proposed	15.40	13.03	18.22							
0.5EI	16.67	13.80	20.84							







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 <u>spWall</u>.