

Technical Report 3: Lateral System Analysis and Confirmation Design

SMILOW CANCER CENTER – YALE-NEW HAVEN HOSPITAL

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TABLE of CONTENTS

i.	Executive Summary	1
ii.	Introduction + Background Information	2
iii.	Analysis: Loads and Load Cases	8
iv.	Analysis: Distribution of Lateral Loads	8
v.	Analysis: Strength and Serviceability Checks	22
vi.	Discussion and Conclusion	27
vii.	Appendix	
	- Shear Wall Sections	A1
	- Shear Wall Strength Check	A3
	- Shear Wall Deflection Calculation	A6
	- Tabulated Load Values from Tech Report 1	A7

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EXECUTIVE SUMMARY

The Lateral System Analysis and Confirmation Design Report (Tech Report 3) is a study of the lateral resisting system of Smilow Cancer Center. The 16-story, 240-ft building located in New Haven, CT is one of the most comprehensive hospitals of its kind in the region. The structure of the building consists of concrete slab on metal deck floor system supported on a steel framing system (moment, lateral braced, and gravity frames) and four reinforced concrete shear walls. The whole structure sits on a 4-foot thick mat slab foundation which increases to 8 feet thick at shear wall locations.

For this report, the lateral system was simplified down to the four 18-inch thick shear walls which were assumed to be much stiffer compared to the six moment frames. Hence, all of the calculated lateral loads from Tech Report 1 were distributed solely to the shear walls. Load distribution was carried out using the principle of relative stiffness, with elements absorbing load proportionate to their stiffness. After determining load distribution factors, each element was analyzed using a combination of computer modeling and old-fashioned hand calculations.

The results of these calculations illustrate an apparent overdesign of the lateral system, with shear wall capacities significantly exceeding applied loads. Of course, certain assumptions and simplifications made in the analysis of the elements could be the reason for the discrepancy. Also, there may be other guidelines considered by the structural engineers that were not considered as a part of this report, partly for simplification and partly because they were not available.

In any case, Tech Report 3 is a valuable in-depth study of the lateral system of the structure. With a deeper understanding of the existing lateral system, better and more informed decisions can be made in the design of an alternative system for future assignments.

INTRODUCTION: General Description

Located in the middle of New Haven, CT, the addition of the Smilow Cancer Center to the Yale-New Haven Hospital complex will feature a 16-story, 240-ft, state-of-the-art building with the latest equipment for the treatment of the disease. The structural system consists of a 7-1/2" concrete slab on metal deck floor system supported on a steel framing system (moment, lateral braced, and regular gravity frames) and four reinforced concrete (RC) shear walls. On the first level, concrete beams of varying sizes run along three edges of the building. The floor slab and steel beams act in composite action with each other, while the moment frames and shear walls share the lateral load. The whole structure rests on a 4-foot thick mat slab foundation (the slab is 8 feet thick at shear wall locations). A relatively simple structure, the footprint of the building through the first five levels is almost square (210 ft. x 176 ft.). At the beginning of the seventh floor, however, the northeast "corner" of the building ends in a rooftop garden, and the rest of the building rises to the roof as an L-shape.

The Lateral System Analysis and Confirmation Design Report (Tech Report 3) is a study of the lateral resisting system of Smilow Cancer Center, which is described in detail in the following section. Components of the building's structure which resist lateral loads such as wind and seismic are analyzed for strength and serviceability issues. These include concerns like strength of critical members, story drift and displacement, overturning moments, and impacts on the structure's foundation. This report refers to load values calculated for Tech Report 1 and determines their distribution to each lateral system element. Appropriate load cases and combinations are also considered. Note that Tech Report 3 does not consider gravity loads on any component of the lateral resisting system (with the exception of any computer models which may account for dead loads on elements).

BACKGROUND INFORMATION: Description of Lateral Resisting System

Smilow Cancer Center's lateral resisting system is a combination of six primary moment frames (MF), several smaller lateral braced frames on the roof, and four C-shaped reinforced concrete shear walls (SW). Four of the six main moment frames are located at the edges of the building, while the remaining two run along the east-west direction at approximately one-third points of the building's length. Beams ranging from W24 to W36 and columns ranging from W14 to W24 make up the moment frames. A custom "cruciform column" is used for several of the building's exterior columns. This column consists of a W27x281 with two WT12's welded to its web. The four shear walls are all located towards the southeast quadrant of the building, strategically placed around central elevator and mechanical openings. All four shear walls rise up to either the sixteenth or seventeenth floor, ending where the lateral braced frames of the roof begin. Concrete for the shear walls is rated at 5000 psi, and each shear wall is 18 inches thick.

Plans and elevations of various components of the building's lateral system are shown in the following figures. Cross sections of the four shear walls are hand-drawn and can be found in pages A1 through A2 of the Appendix.

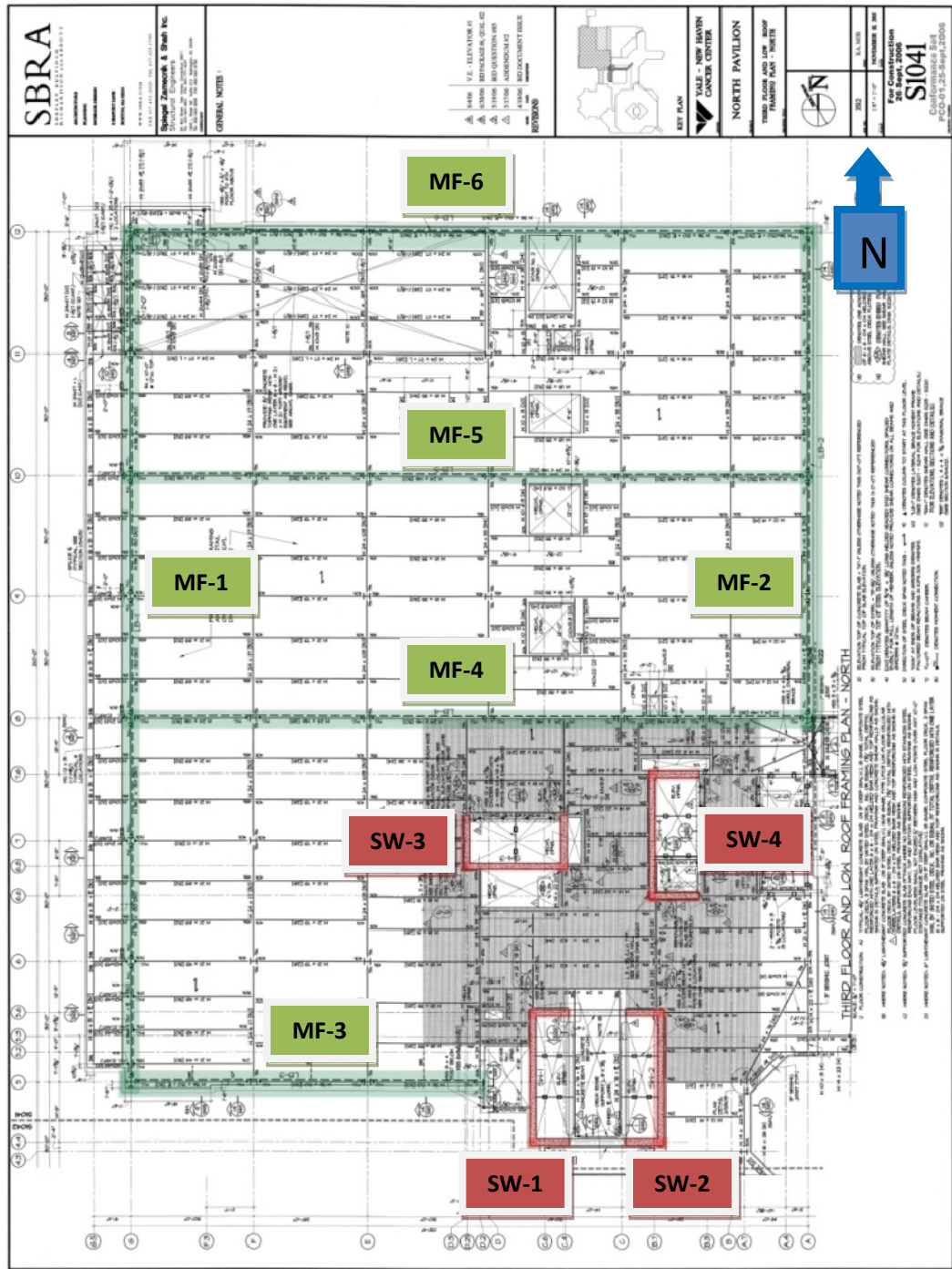


Figure 1a: Typical Framing Plan for Levels 1-5. Green denotes Moment Frames; Red denotes Shear Walls

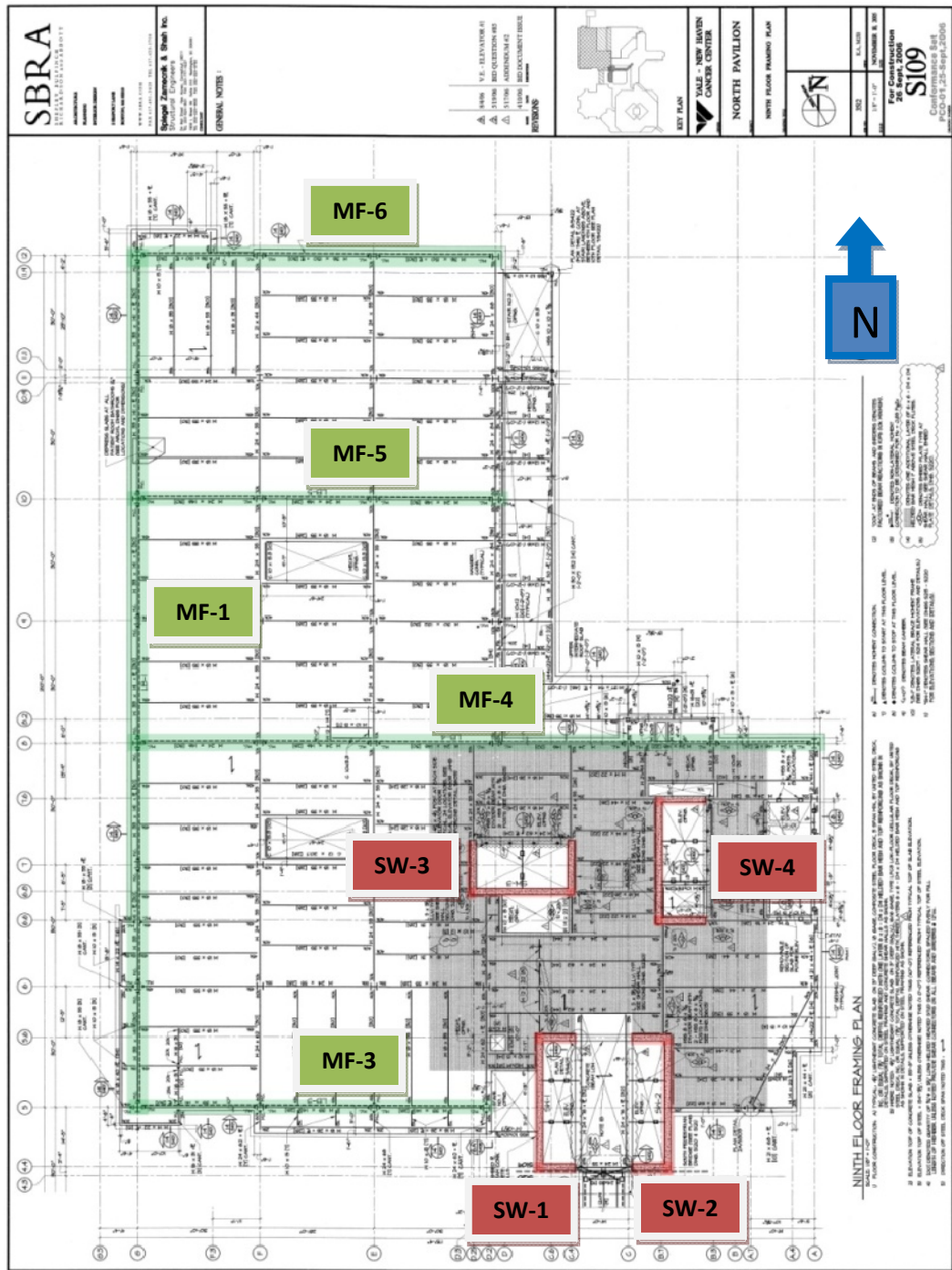


Figure 1b: Typical Framing Plan for Levels 7-17. Green denotes Moment Frames; Red denotes Shear Walls.

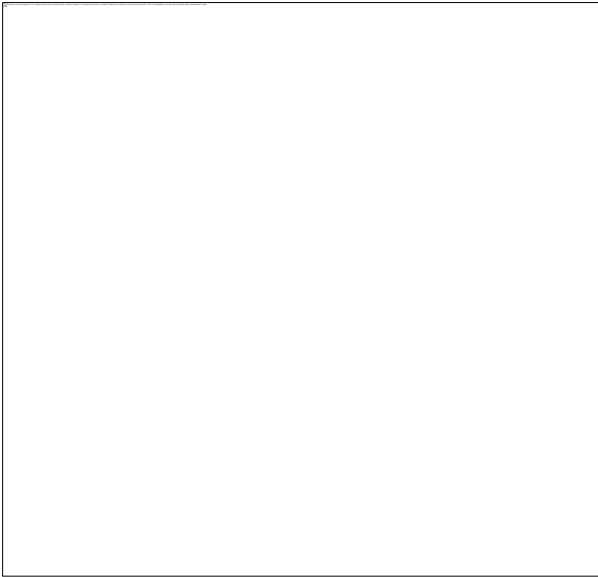


Figure 2a: Elevation of Moment Frame 1

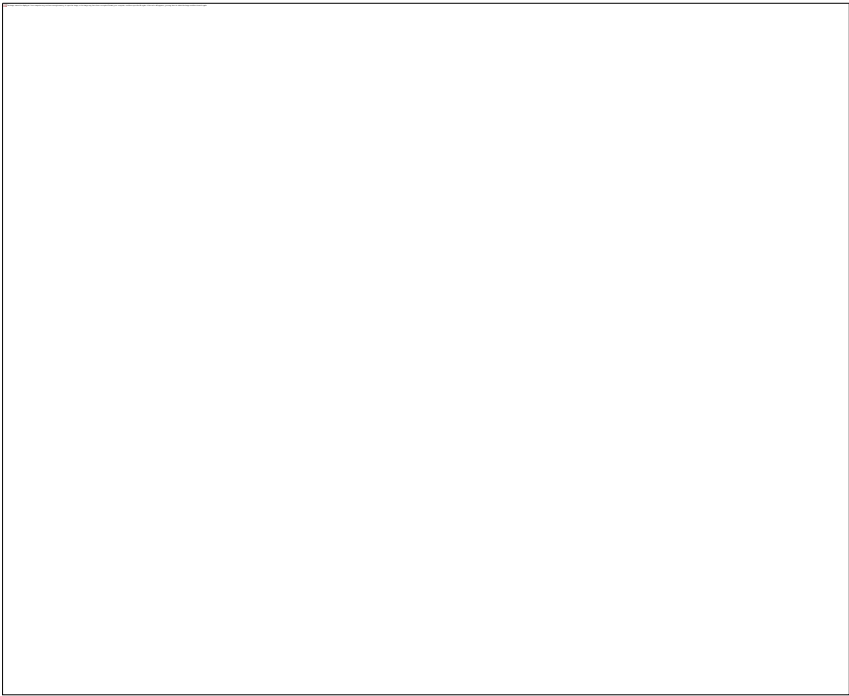


Figure 2b: Elevations of Moment Frames 2 & 3

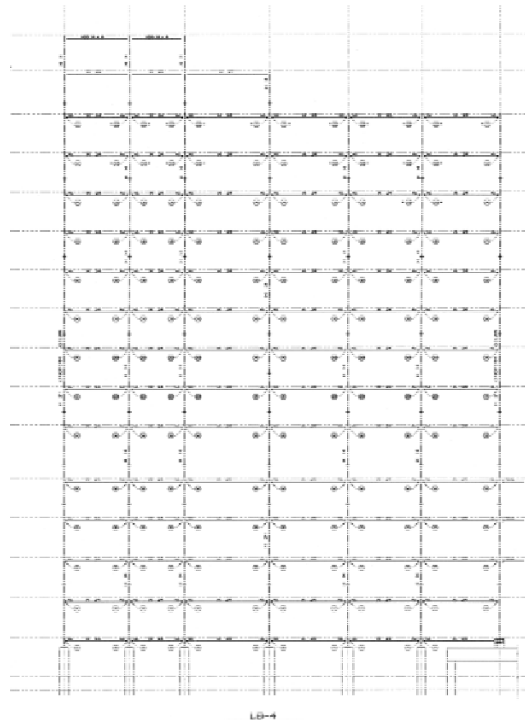


Figure 2c: Elevation of Moment Frame 4

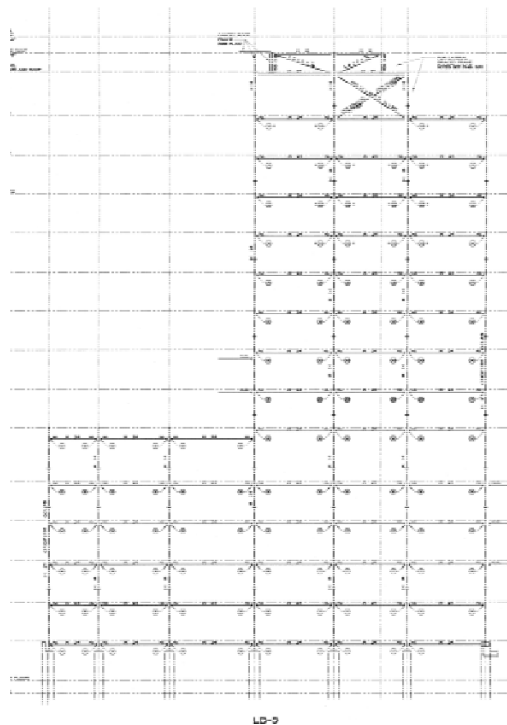


Figure 2d: Elevation of Moment Frame 5

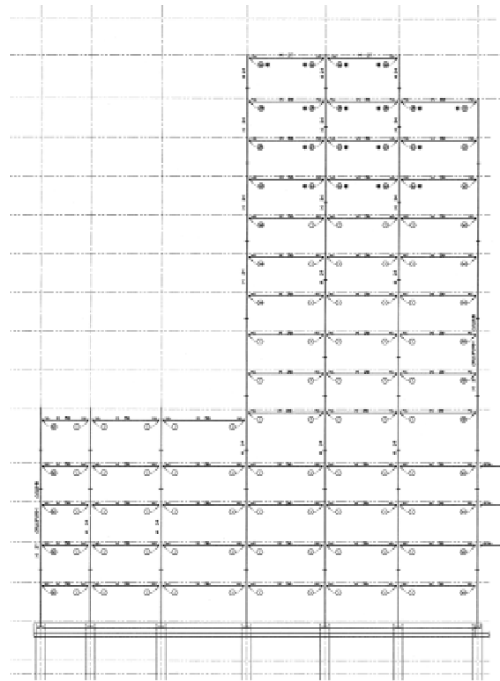


Figure 2e: Elevation of Moment Frame 6

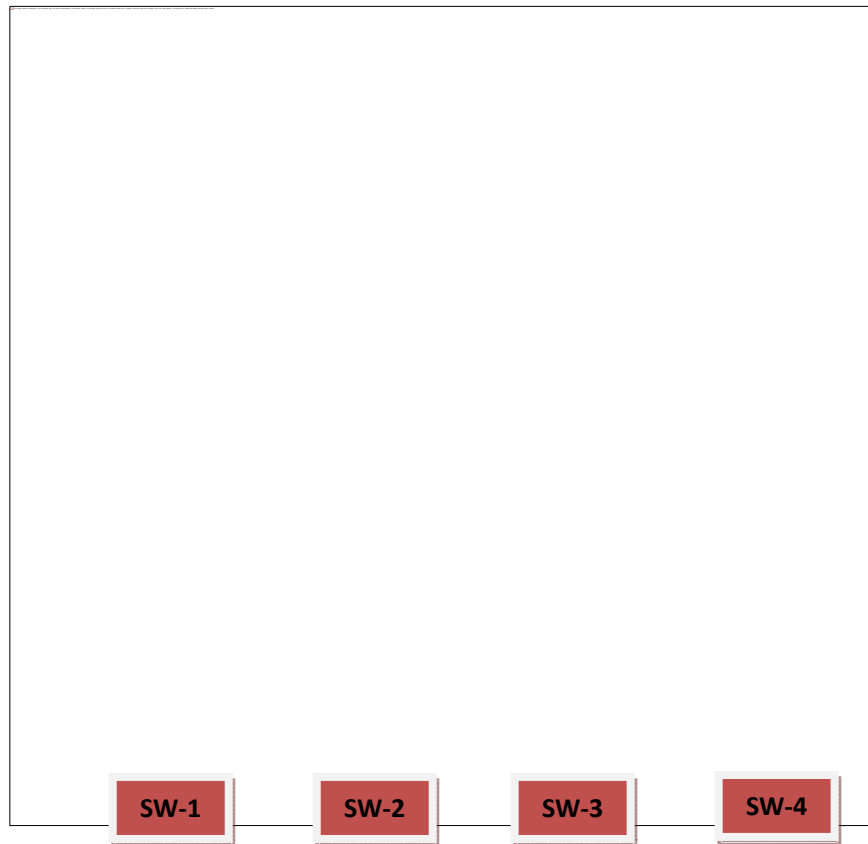


Figure 2f: Elevations of Shear Walls 1-4

ANALYSIS: Loads and Load Cases

As discussed in Tech Report 1, the more critical lateral loads on the structure are wind and seismic. These two loads were calculated using the Main Wind Force Resisting System (MWFRS) method and the Equivalent Lateral Force Procedure (ELFP), respectively. Other references include IBC 2006 and the United States Geological Service website, www.usgs.gov. Tables of calculated wind and seismic loads are included in pages A7 and A8 of the Appendix.

By comparing the magnitudes of wind and seismic loads, it is evident that seismic is the controlling load case for Smilow Cancer Center. Based on the list of load combinations outlined in ASCE 7-05, wind and earthquake loads are never combined into any one of the seven possible options. And since no other loads are considered in this report, seismic loads control in the analysis of the lateral system. This only reinforces the adage that the wind does not blow when there is an earthquake. A list of the seven basic ASCE 7-05 load combinations follows:

$$\begin{aligned} &1.4(D + F) \\ &1.2(D + F + T) + 1.6(L + H) + 0.5(Lr \text{ or } S \text{ or } R) \\ &1.2D + 1.6(Lr \text{ or } S \text{ or } R) + (L \text{ or } 0.8W) \\ &1.2D + 1.6W + L + 0.5(Lr \text{ or } S \text{ or } R) \\ &1.2D + 1.0E + L + 0.2S \\ &0.9D + 1.6W + 1.6H \\ &0.9D + 1.0E + 1.6H \end{aligned}$$

where W=wind load, and E=earthquake load.

ANALYSIS: Distribution of Lateral Loads

Note: Upon initial inspection of the structure's lateral system, the student and consultant decided to neglect the role of the six moment frames in resisting lateral loads. This was due to the assumption that the four shear walls would be much stiffer compared to the steel frames. Therefore, loads are distributed only to the shear walls.

In distributing the lateral loads calculated for Tech Report 1, this report uses the method of relative stiffness. This principle is based on the assumption that the stiffer, more rigid elements of the lateral resisting system will absorb a greater portion of the load. Thus, the first step in this method is calculating the stiffness or rigidity of each shear wall in both the N-S and E-W directions, labeled X and Y, respectively, in calculations. An ETABS model for each wall was created with a 1.0 kip load at the top of the structure. Each model was then analyzed for story drift and total displacement at the height of the applied load. To determine rigidity, the inverse relationship between displacement and stiffness was used (i.e. RIGIDITY = LOAD/DISPLACEMENT). With all rigidity values found, the distribution of lateral loads to each shear wall was calculated using the following equation:

$$\text{Element Load} = \text{Total Load} \times (\text{Element } i \text{ Rigidity} / \text{Total Rigidity})$$

Note: Total Load refers to lateral loads calculated for Tech Report 1.

The lateral load distribution process is summarized in the following tables.

Table 1a: Story Drift Tables for X-Direction Loading

	Story	Item	X	Y	Z	Drift X (in)	Drift Y (in)
	SW1&2	STORY16	Max Drift X	0	0	2424	0.000012
STORY16		Max Drift Y	0	105	2424		0.000019
STORY15		Max Drift X	0	0	2244	0.000015	
STORY15		Max Drift Y	0	105	2244		0.000018
STORY14		Max Drift X	0	0	2064	0.000015	
STORY14		Max Drift Y	0	105	2064		0.000018
STORY12		Max Drift X	0	0	1884	0.000015	
STORY12		Max Drift Y	0	105	1884		0.000018
STORY11		Max Drift X	0	0	1704	0.000014	
STORY11		Max Drift Y	0	105	1704		0.000017
STORY10		Max Drift X	0	0	1524	0.000014	
STORY10		Max Drift Y	0	105	1524		0.000016
STORY9		Max Drift X	0	0	1344	0.000013	
STORY9		Max Drift Y	0	105	1344		0.000015
STORY8		Max Drift X	0	0	1164	0.000011	
STORY8		Max Drift Y	0	105	1164		0.000013
STORY7		Max Drift X	0	0	984	0.000001	
STORY7		Max Drift Y	0	105	984		0.000012
STORY5		Max Drift X	0	0	736	0.000008	
STORY5		Max Drift Y	0	105	736		0.000001
STORY4		Max Drift X	0	0	556	0.000006	
STORY4		Max Drift Y	0	105	556		0.000008
STORY3		Max Drift X	384	0	370	0.000004	
STORY3		Max Drift Y	0	105	370		0.000004
STORY2		Max Drift X	384	105	182	0.000001	
STORY2		Max Drift Y	384	105	182		0.000006

DISPLACEMENT (in)	
X	Y
0.000147	0.000174

RIGIDITY (k/in)	
X	Y
6803	5747

	Story	Item	X	Y	Z	Drift X (in)	Drift Y (in)
	SW3	STORY16	Max Drift X	0	153	2424	0.000001
STORY16		Max Drift Y	0	153	2424		0.000029
STORY15		Max Drift X	0	0	2244	0.000001	
STORY15		Max Drift Y	0	153	2244		0.000028
STORY14		Max Drift X	0	0	2064	0.000001	
STORY14		Max Drift Y	0	153	2064		0.000028
STORY12		Max Drift X	0	0	1884	0.000001	
STORY12		Max Drift Y	0	153	1884		0.000027
STORY11		Max Drift X	0	0	1704	0.000001	
STORY11		Max Drift Y	0	153	1704		0.000026
STORY10		Max Drift X	0	0	1524	0.000001	
STORY10		Max Drift Y	0	153	1524		0.000024
STORY9		Max Drift X	0	0	1344	0.000001	
STORY9		Max Drift Y	0	153	1344		0.000022
STORY8		Max Drift X	0	0	1164	0.000001	
STORY8		Max Drift Y	0	153	1164		0.00002
STORY7		Max Drift X	0	153	984	0.000001	
STORY7		Max Drift Y	0	153	984		0.000017
STORY5		Max Drift X	0	153	736	0.000001	
STORY5		Max Drift Y	0	153	736		0.000014
STORY4		Max Drift X	0	153	556	0.000001	
STORY4		Max Drift Y	0	153	556		0.000011
STORY3		Max Drift X	288	0	370	0.000002	
STORY3		Max Drift Y	0	153	370		0.000007
STORY2		Max Drift X	288	153	182	0.000008	
STORY2		Max Drift Y	0	0	182		0.000006

DISPLACEMENT (in)	
X	Y
0.000021	0.000259

RIGIDITY (k/in)	
X	Y
47619	3861

	Story	Item	X	Y	Z	Drift X (in)	Drift Y (in)
SW4	STORY17	Max Drift X	0	0	2625	0.000015	
	STORY17	Max Drift Y	0	138	2625		0.000017
	STORY16	Max Drift X	0	0	2424	0.000018	
	STORY16	Max Drift Y	0	138	2424		0.000016
	STORY15	Max Drift X	0	0	2244	0.000019	
	STORY15	Max Drift Y	0	138	2244		0.000016
	STORY14	Max Drift X	0	0	2064	0.000019	
	STORY14	Max Drift Y	0	138	2064		0.000016
	STORY12	Max Drift X	0	0	1884	0.000018	
	STORY12	Max Drift Y	0	138	1884		0.000015
	STORY11	Max Drift X	0	0	1704	0.000017	
	STORY11	Max Drift Y	0	138	1704		0.000014
	STORY10	Max Drift X	0	0	1524	0.000016	
	STORY10	Max Drift Y	0	138	1524		0.000013
	STORY9	Max Drift X	0	0	1344	0.000015	
	STORY9	Max Drift Y	0	138	1344		0.000012
	STORY8	Max Drift X	0	0	1164	0.000013	
	STORY8	Max Drift Y	0	138	1164		0.000011
	STORY7	Max Drift X	0	0	984	0.000011	
	STORY7	Max Drift Y	0	138	984		0.00001
	STORY5	Max Drift X	0	0	736	0.000009	
	STORY5	Max Drift Y	0	138	736		0.000008
	STORY4	Max Drift X	0	0	556	0.000007	
	STORY4	Max Drift Y	0	138	556		0.000006
	STORY3	Max Drift X	361	0	370	0.000006	
	STORY3	Max Drift Y	0	138	370		0.000004
	STORY2	Max Drift X	361	138	182	0.000011	
	STORY2	Max Drift Y	361	138	182		0.000006

DISPLACEMENT (in)	
X	Y
0.000194	0.000164

RIGIDITY (k/in)	
X	Y
5155	6098

Table 1b: Relative Stiffness Table for X-Direction Loading

	X	Y
ΣR=	66379	21453

Shear Wall	Relative Stiffness	
	X	Y
1	0.10	0.27
2	0.10	0.27
3	0.72	0.18
4	0.08	0.28

Note: Neglect stiffness in Y-direction since no load in this direction.

Table 1c: Lateral Load Distribution Tables for X-Direction Loading

SW #	STORY	Total P (kips)		RELATIVE STIFFNESS	Element P (kips)	
		WIND	SEISMIC		WIND	SEISMIC
SW1&2	2	42	268	0.10	4	27
	3	46	212		5	21
	4	49	167		5	17
	5	52	138		5	14
	7	54	106		5	11
	8	56	95		6	9
	9	58	85		6	8
	10	60	77		6	8
	11	63	70		6	7
	12	66	64		7	6
	14	69	59		7	6
	15	71	55		7	6
	16	73	52		7	5

SW #	STORY	Total P (kips)		RELATIVE STIFFNESS	Element P (kips)	
		WIND	SEISMIC		WIND	SEISMIC
SW3	2	42	268	0.72	30	192
	3	46	212		33	152
	4	49	167		35	120
	5	52	138		37	99
	7	54	106		39	76
	8	56	95		40	68
	9	58	85		42	61
	10	60	77		43	55
	11	63	70		45	50
	12	66	64		47	46
	14	69	59		49	43
	15	71	55		51	40
	16	73	52		52	37

SW #	STORY	Total P (kips)		RELATIVE STIFFNESS	Element P (kips)	
		WIND	SEISMIC		WIND	SEISMIC
SW4	2	42	268	0.08	3	21
	3	46	212		4	17
	4	49	167		4	13
	5	52	138		4	11
	7	54	106		4	9
	8	56	95		5	8
	9	58	85		5	7
	10	60	77		5	6
	11	63	70		5	6
	12	66	64		5	5
	14	69	59		5	5
	15	71	55		6	4
	16	73	52		6	4
	17	76	49		6	4

Table 2a: Drift Story Tables for Y-Direction Loading

	Story	Item	X	Y	Z	Drift X (in)	Drift Y (in)
SW1&2	STORY16	Max Drift X	0	0	2424	0.000001	
	STORY16	Max Drift Y	0	105	2424		0.000074
	STORY15	Max Drift X	0	0	2244	0.000001	
	STORY15	Max Drift Y	0	105	2244		0.000073
	STORY14	Max Drift X	0	0	2064	0.000001	
	STORY14	Max Drift Y	0	105	2064		0.000072
	STORY12	Max Drift X	0	0	1884	0.000001	
	STORY12	Max Drift Y	0	105	1884		0.000069
	STORY11	Max Drift X	0	0	1704	0.000001	
	STORY11	Max Drift Y	0	105	1704		0.000066
	STORY10	Max Drift X	0	0	1524	0.000001	
	STORY10	Max Drift Y	0	105	1524		0.000062
	STORY9	Max Drift X	0	0	1344	0.000001	
	STORY9	Max Drift Y	0	105	1344		0.000057
	STORY8	Max Drift X	0	0	1164	0.000001	
	STORY8	Max Drift Y	0	105	1164		0.000052
	STORY7	Max Drift X	0	0	984	0.000001	
	STORY7	Max Drift Y	0	105	984		0.000044
	STORY5	Max Drift X	0	105	736	0.000001	
	STORY5	Max Drift Y	0	105	736		0.000035
	STORY4	Max Drift X	0	105	556	0.000001	
	STORY4	Max Drift Y	0	105	556		0.000027
	STORY3	Max Drift X	384	0	370	0.000001	
	STORY3	Max Drift Y	0	105	370		0.000016
	STORY2	Max Drift X	384	105	182	0.000001	
	STORY2	Max Drift Y	0	0	182		0.000007

DISPLACEMENT (in)	
X	Y
0.000022	0.000654

RIGIDITY (k/in)	
X	Y
45455	1529

	Story	Item	X	Y	Z	Drift X (in)	Drift Y (in)
SW3	STORY16	Max Drift X	0	0	2424	0.000021	
	STORY16	Max Drift Y	0	153	2424		0.000017
	STORY15	Max Drift X	0	0	2244	0.000025	
	STORY15	Max Drift Y	0	153	2244		0.000017
	STORY14	Max Drift X	0	0	2064	0.000027	
	STORY14	Max Drift Y	0	153	2064		0.000016
	STORY12	Max Drift X	0	0	1884	0.000027	
	STORY12	Max Drift Y	0	153	1884		0.000016
	STORY11	Max Drift X	0	0	1704	0.000026	
	STORY11	Max Drift Y	0	153	1704		0.000015
	STORY10	Max Drift X	0	0	1524	0.000024	
	STORY10	Max Drift Y	0	153	1524		0.000014
	STORY9	Max Drift X	0	0	1344	0.000022	
	STORY9	Max Drift Y	0	153	1344		0.000013
	STORY8	Max Drift X	0	0	1164	0.00002	
	STORY8	Max Drift Y	0	153	1164		0.000012
	STORY7	Max Drift X	0	0	984	0.000017	
	STORY7	Max Drift Y	0	153	984		0.00001
	STORY5	Max Drift X	0	0	736	0.000014	
	STORY5	Max Drift Y	0	153	736		0.000008
	STORY4	Max Drift X	0	0	556	0.00001	
	STORY4	Max Drift Y	0	153	556		0.000006
	STORY3	Max Drift X	288	0	370	0.000008	
	STORY3	Max Drift Y	0	153	370		0.000004
	STORY2	Max Drift X	288	153	182	0.000009	
	STORY2	Max Drift Y	288	153	182		0.000006

DISPLACEMENT (in)	
X	Y
0.00025	0.000154

RIGIDITY (k/in)	
X	Y
4000	6494

	Story	Item	X	Y	Z	Drift X (in)	Drift Y (in)
SW4	STORY17	Max Drift X	0	138	2625	0.000001	
	STORY17	Max Drift Y	0	138	2625		0.000042
	STORY16	Max Drift X	0	0	2424	0.000001	
	STORY16	Max Drift Y	0	138	2424		0.000041
	STORY15	Max Drift X	0	0	2244	0.000001	
	STORY15	Max Drift Y	0	138	2244		0.000041
	STORY14	Max Drift X	0	0	2064	0.000001	
	STORY14	Max Drift Y	0	138	2064		0.000039
	STORY12	Max Drift X	0	0	1884	0.000001	
	STORY12	Max Drift Y	0	138	1884		0.000038
	STORY11	Max Drift X	0	0	1704	0.000001	
	STORY11	Max Drift Y	0	138	1704		0.000036
	STORY10	Max Drift X	0	0	1524	0.000001	
	STORY10	Max Drift Y	0	138	1524		0.000034
	STORY9	Max Drift X	0	0	1344	0.000001	
	STORY9	Max Drift Y	0	138	1344		0.000031
	STORY8	Max Drift X	0	0	1164	0.000001	
	STORY8	Max Drift Y	0	138	1164		0.000028
	STORY7	Max Drift X	0	138	984	0.000001	
	STORY7	Max Drift Y	0	138	984		0.000024
	STORY5	Max Drift X	0	138	736	0.000001	
	STORY5	Max Drift Y	0	138	736		0.000019
	STORY4	Max Drift X	0	138	556	0.000001	
	STORY4	Max Drift Y	0	138	556		0.000014
STORY3	Max Drift X	361	0	370	0.000002		
STORY3	Max Drift Y	0	138	370		0.000009	
STORY2	Max Drift X	361	138	182	0.000001		
STORY2	Max Drift Y	0	0	182		0.000006	

DISPLACEMENT (in)	
X	Y
0.000024	0.000402

RIGIDITY (k/in)	
X	Y
41667	2488

Table 2b: Relative Stiffness Table for Y-Direction Loading

	X	Y
$\Sigma R =$	136576	12039

Shear Wall	Relative Stiffness	
	X	Y
1	0.33	0.13
2	0.33	0.13
3	0.03	0.54
4	0.31	0.21

*Note: Neglect stiffness in X-direction
since no load in this direction.*

Table 2c: Load Distribution Tables for Y-Direction Loading

SW #	STORY	Total P (kips)		RELATIVE STIFFNESS	Element P (kips)	
		WIND	SEISMIC		WIND	SEISMIC
SW1&2	2	53	268	0.13	7	35
	3	58	212		7	28
	4	61	167		8	22
	5	64	138		8	18
	7	67	106		9	14
	8	70	95		9	12
	9	73	85		9	11
	10	75	77		10	10
	11	79	70		10	9
	12	83	64		11	8
	14	86	59		11	8
	15	89	55		12	7
	16	91	52		12	7

SW #	STORY	Total P (kips)		RELATIVE STIFFNESS	Element P (kips)	
		WIND	SEISMIC		WIND	SEISMIC
SW3	2	53	268	0.54	29	145
	3	58	212		31	114
	4	61	167		33	90
	5	64	138		35	75
	7	67	106		36	57
	8	70	95		38	51
	9	73	85		39	46
	10	75	77		41	41
	11	79	70		43	38
	12	83	64		45	35
	14	86	59		46	32
	15	89	55		48	30
	16	91	52		49	28

SW #	STORY	Total P (kips)		RELATIVE STIFFNESS	Element P (kips)	
		WIND	SEISMIC		WIND	SEISMIC
SW4	2	53	268	0.21	11	56
	3	58	212		12	44
	4	61	167		13	35
	5	64	138		14	29
	7	67	106		14	22
	8	70	95		15	20
	9	73	85		15	18
	10	75	77		16	16
	11	79	70		17	15
	12	83	64		17	13
	14	86	59		18	12
	15	89	55		19	12
	16	91	52		19	11
	17	95	49		20	10

ANALYSIS: Distribution of Lateral Loads (*cont'd.*)

As for the real structure, the load path would begin at the curtain walls of the building (or at the base in the case of seismic) and flow into the concrete slab on metal deck floor diaphragms. In turn, these loads would travel to the shear walls and moment frames of the structure—mostly to the shear walls. And although they are not designed for lateral loads, the structure’s gravity frames may also transfer some of this load onto the lateral system. Possible weak links of the lateral structure are the significant floor openings around the shear walls (see Figure 3). These voids in the floor diaphragm for elevator shafts and mechanical equipment may affect the distribution of loads to the lateral resisting system. This may be one of the reasons for the additional mesh reinforcing in the floor slab in the area around the shear walls (highlighted gray in Figure 3).

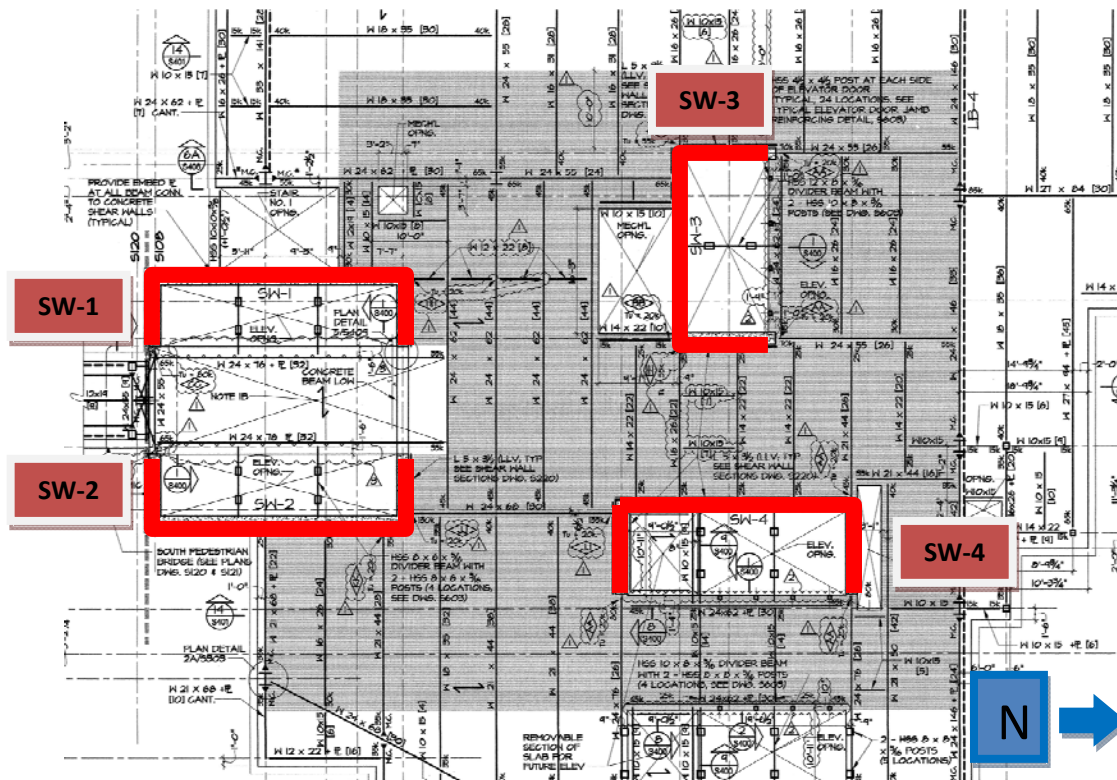


Figure 3: Detailed Plan of Shear Walls and Floor Openings

ANALYSIS: Strength and Serviceability Checks

Strength and serviceability checks were performed using a combination of hand calculations and computer modeling. For simplicity, only Shear Wall 3 was checked using manual calculations. Also note that SW-3 was checked only for loading in the in the E-W direction (parallel to the “web” of the shear wall). The “flanges” of the wall were neglected in hand calculations. These calculations followed requirements and recommendations of ACI 318-08. Values found were then compared with values from ETABS computer models. All calculations and results can be found in pages A3 through A6 of the Appendix.

Results of drift calculations are summarized in the following tables. Values are compared to the 1968 Structural Engineering Handbook standard of $1/400$ times the story height above ground level. It is easy to see that the actual story drift is well within the allowable limits.

Table 3: Story Drift versus Allowable Drift (X-Direction Loading)

SW #	STORY	Height (ft)	LOAD (kips)	Drift X (in)	Disp X (in)	Allowable Δ
SW1&2	2	15.17	27	0.00011	0.00115	0.0379
	3	30.83	21	0.00011	0.00104	0.0771
	4	46.33	17	0.00011	0.00093	0.1158
	5	61.33	14	0.00011	0.00082	0.1533
	7	82.00	11	0.00011	0.00071	0.2050
	8	97.00	9	0.00011	0.00060	0.2425
	9	112.00	8	0.00010	0.00050	0.2800
	10	127.00	8	0.00010	0.00040	0.3175
	11	142.00	7	0.00009	0.00030	0.3550
	12	157.00	6	0.00008	0.00021	0.3925
	14	172.00	6	0.00006	0.00014	0.4300
	15	187.00	6	0.00005	0.00008	0.4675
	16	202.00	5	0.00003	0.00003	0.5050

SW #	STORY	Height (ft)	LOAD (kips)	Drift X (in)	Disp X (in)	Allowable Δ
SW3	2	15.17	192	0.00998	0.09959	0.0379
	3	30.83	152	0.00997	0.08961	0.0771
	4	46.33	120	0.00992	0.07965	0.1158
	5	61.33	99	0.00981	0.06973	0.1533
	7	82.00	76	0.00964	0.05991	0.2050
	8	97.00	68	0.00936	0.05028	0.2425
	9	112.00	61	0.00896	0.04092	0.2800
	10	127.00	55	0.00842	0.03195	0.3175
	11	142.00	50	0.00750	0.02354	0.3550
	12	157.00	46	0.00633	0.01604	0.3925
	14	172.00	43	0.00502	0.00971	0.4300
	15	187.00	40	0.00336	0.00469	0.4675
	16	202.00	37	0.00133	0.00133	0.5050

SW #	STORY	Height (ft)	LOAD (kips)	Drift X (in)	Disp X (in)	Allowable Δ
SW4	2	15.17	21	0.00010	0.00111	0.0379
	3	30.83	17	0.00010	0.00102	0.0771
	4	46.33	13	0.00010	0.00092	0.1158
	5	61.33	11	0.00010	0.00082	0.1533
	7	82.00	9	0.00010	0.00072	0.2050
	8	97.00	8	0.00010	0.00062	0.2425
	9	112.00	7	0.00009	0.00053	0.2800
	10	127.00	6	0.00009	0.00044	0.3175
	11	142.00	6	0.00008	0.00035	0.3550
	12	157.00	5	0.00008	0.00026	0.3925
	14	172.00	5	0.00007	0.00019	0.4300
	15	187.00	4	0.00005	0.00012	0.4675
	16	202.00	4	0.00004	0.00007	0.5050
	17	218.75	4	0.00003	0.00003	0.5469

Table 4: Story Drift versus Allowable Drift (Y-Direction Loading)

SW #	STORY	Height (ft)	LOAD (kips)	Drift Y (in)	Disp Y (in)	Allowable Δ
SW1&2	2	15.17	35	0.00315	0.03144	0.0379
	3	30.83	28	0.00314	0.02829	0.0771
	4	46.33	22	0.00313	0.02515	0.1158
	5	61.33	18	0.00309	0.02203	0.1533
	7	82.00	14	0.00304	0.01893	0.2050
	8	97.00	12	0.00295	0.01589	0.2425
	9	112.00	11	0.00283	0.01294	0.2800
	10	127.00	10	0.00266	0.01012	0.3175
	11	142.00	9	0.00237	0.00746	0.3550
	12	157.00	8	0.00200	0.00509	0.3925
	14	172.00	8	0.00159	0.00309	0.4300
	15	187.00	7	0.00107	0.00149	0.4675
	16	202.00	7	0.00043	0.00043	0.5050

SW #	STORY	Height (ft)	LOAD (kips)	Drift Y (in)	Disp Y (in)	Allowable Δ
SW3	2	15.17	145	0.00131	0.01360	0.0379
	3	30.83	114	0.00131	0.01229	0.0771
	4	46.33	90	0.00131	0.01099	0.1158
	5	61.33	75	0.00130	0.00968	0.1533
	7	82.00	57	0.00128	0.00838	0.2050
	8	97.00	51	0.00125	0.00710	0.2425
	9	112.00	46	0.00121	0.00585	0.2800
	10	127.00	41	0.00114	0.00465	0.3175
	11	142.00	38	0.00103	0.00350	0.3550
	12	157.00	35	0.00089	0.00247	0.3925
	14	172.00	32	0.00074	0.00158	0.4300
	15	187.00	30	0.00055	0.00084	0.4675
	16	202.00	28	0.00029	0.00029	0.5050

SW #	STORY	Height (in)	LOAD (kips)	Drift Y (in)	Disp Y (in)	Allowable Δ
SW4	2	15.17	56	0.00283	0.03055	0.0379
	3	30.83	44	0.00283	0.02773	0.0771
	4	46.33	35	0.00282	0.02490	0.1158
	5	61.33	29	0.00279	0.02209	0.1533
	7	82.00	22	0.00275	0.01929	0.2050
	8	97.00	20	0.00269	0.01654	0.2425
	9	112.00	18	0.00260	0.01385	0.2800
	10	127.00	16	0.00248	0.01125	0.3175
	11	142.00	15	0.00232	0.00877	0.3550
	12	157.00	13	0.00206	0.00645	0.3925
	14	172.00	12	0.00173	0.00439	0.4300
	15	187.00	12	0.00137	0.00266	0.4675
	16	202.00	11	0.00092	0.00129	0.5050
	17	218.75	10	0.00038	0.00038	0.5469

DISCUSSION and CONCLUSION:

Reviewing the results of the different analyses shows that the lateral system of Smilow Cancer Center is more than adequate to resist the loads of wind and seismic. It should be apparent that the four shear walls were designed to carry loads other than the aforementioned ones. Even after neglecting the six moment frames in the lateral system, the capacity still greatly exceeds the calculated loads.

Overdesigning the shear walls may be due to the high profile nature and importance of the hospital. Or it could be that the structural engineers were under stricter guidelines concerning loads and other issues such as vibration or fireproofing.

The discrepancies in deflections calculated by hand and by computer modeling could be because of the assumptions and simplifications in the manual calculation. For instance, neglecting the “flanges” of the shear wall significantly reduces the stiffness of the wall, thereby producing a much larger deflection value. Also, the simplified equation for deflection used in hand calculation could give varying values than that of the computer model analysis.

In any case, Tech Report 3 is a valuable in-depth study of the lateral system of the structure. With a deeper understanding of the existing lateral system, better and more informed decisions can be made in the design of an alternative system for future assignments.

TECH REPORT 3

SMILOW CANCER HOSPITAL

SHEAR WALL SECTIONS

21 NOVEMBER 2008

□ SHEAR WALL PROPERTIES

$$f'_c = 5000 \text{ PSI}$$
$$E_c = 4000 \text{ KSI}$$

THICKNESS, $t = 18"$ (TYPICAL)

□ SHEAR WALLS 1 & 2

NOTE: WALLS 1 & 2 ARE MIRROR IMAGES OF EACH OTHER.

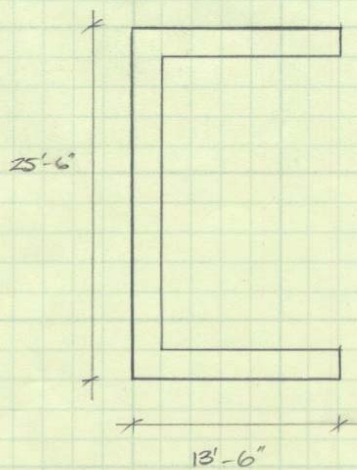


- NOT TO SCALE -
- REINFORCEMENT -
NOT SHOWN

SECTION

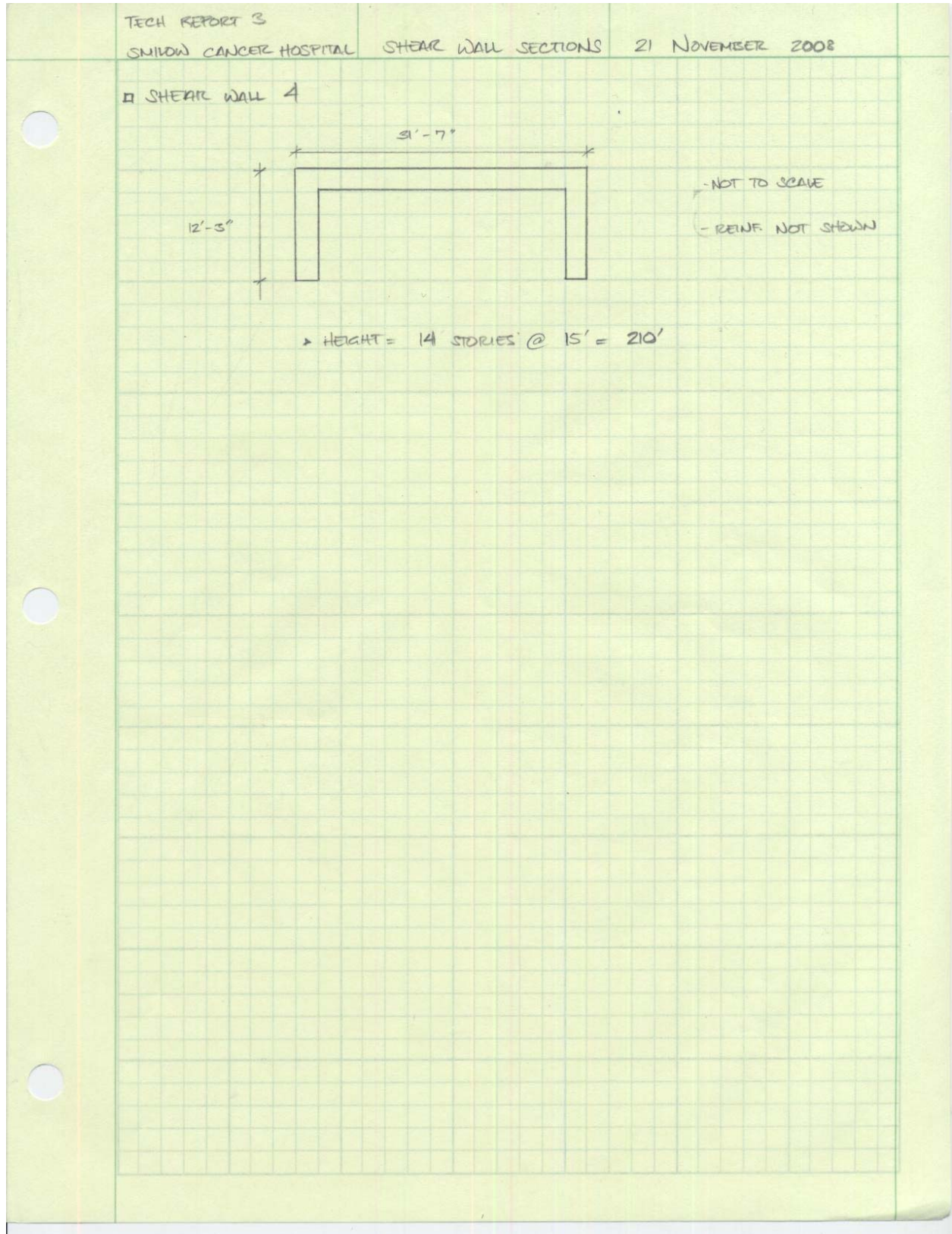
▷ HEIGHT = 13 STORIES @ $\sim 15'$ = 195'

□ SHEAR WALL 3



- NOT TO SCALE
- REINFORCEMENT NOT
SHOWN

▷ HEIGHT = 13 STORIES @ $15'$ = 195'



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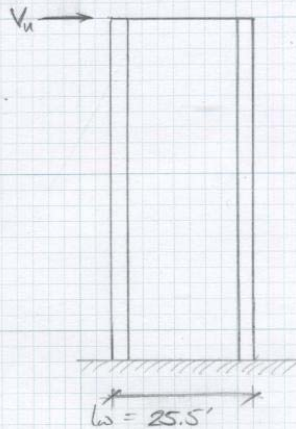
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Assignment TECH REPORT 3: SMILOW CANCER CENTER

Class _____

□ SHEAR WALL 3. STRENGTH CHECK

(LOADING IN Y-DIRECTION / PARALLEL TO "WEBS" OF SHEAR WALL)



$$f'_c = 5000 \text{ psi}$$

$$f_y = 60 \text{ ksi}$$

$$h_w = 19.5'$$

$$l_w = 25.5'$$

$$t = 18''$$

$$V_u = 780 \text{ k}$$

→ BASE SHEAR OBTAINED FROM COMPUTER MODEL

① CHECK MAX PERMITTED SHEAR STRENGTH:

$$\begin{aligned} V_u &\leq \phi V_n = \phi 10 \sqrt{f'_c} t \cdot d = \phi 10 \sqrt{f'_c} t (0.8 l_w) \\ &= 0.75 (10) \sqrt{5000} (18) (0.8) (25.5 \times 12) \left(\frac{1}{1000} \right) \\ &= 2337 \text{ k} \end{aligned}$$

$$\Rightarrow \phi V_{n, \text{max}} > V_u = 780 \text{ k} \quad \therefore \text{OK}$$

② SHEAR STRENGTH OF CONCRETE (V_c):

$$\begin{aligned} \text{CRITICAL SECTION: } a &\leq l_w/2 = 12.75' \\ &\leq h_w/2 = 9.75' \end{aligned} \quad \left. \vphantom{\begin{aligned} a &\leq l_w/2 \\ &\leq h_w/2 \end{aligned}} \right\} a = 12.75'$$

CONT'D.



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□ SHEAR WALL 3 STRENGTH CHECK (cont'd)

► USE DETAILED EQ:

$$V_c = \left[0.6 \sqrt{f'_c} + \frac{l_w (1.25 \sqrt{f'_c} + 0.2 \frac{V_u}{l_w h})}{\frac{M_u}{V_u} - \frac{l_w}{2}} \right] h d$$

$\frac{M_u}{V_u} - \frac{l_w}{2} \rightarrow V_u l_w$

$$V_c = \left[0.6 \sqrt{5000} + \frac{(25.5 \times 12)(1.25 \sqrt{5000} + 0)}{\frac{1}{2}(25.5 \times 12)} \right] \frac{(18)(0.8 \times 25.5 \times 12)}{1000}$$

$$V_c = 966 \text{ k}$$

③ HORIZ. SHEAR REINF. ?

$$V_u \stackrel{?}{>} \frac{1}{2} \phi V_c = \frac{1}{2} (0.75)(966)$$

$$V_u > 362 \text{ k} \quad \therefore \text{NEED } V_s \text{ ACCORDING TO 11.10.9}$$

$$\Rightarrow V_u \leq \phi V_n = \phi (V_c + V_s)$$

$$780 = 0.75(966 + V_s)$$

$$V_s = 74 \text{ k}$$

HORIZONTAL REINFORCING: #8 @ 12" OC

$$V_s = \frac{A_v f_y d}{s} = \frac{2(0.79)(60)(24.5)}{12} = 1936 \text{ k} \gg 74 \text{ k}$$

∴ OK FOR HORIZONTAL SHEAR.

CONT'D.



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□ SHEAR WALL 3 STRENGTH CHECK

④ CHECK FLEXURAL STRENGTH:

$$M_u = 780 \text{ k} (195') = 152,100 \text{ ft-k}$$

$$M_u \leq \phi M_n = \phi A_s f_y j d$$

$$\Rightarrow 152,100 (12) = 0.9 A_{sreq} (60)(0.9)(245)$$

$$A_{sreq} = 153 \text{ in}^2$$

$$\Rightarrow c = T$$

$$0.85(5000)(18)(a) = 153(60,000)$$

$$a = 120$$

$$\Rightarrow j d = d - \frac{a}{2} = 245 - \frac{120}{2} = \underline{185''}$$

$$\Rightarrow 152,100(12) = 0.9(A_{sreq})(60)(185)$$

$$\underline{A_{sreq} = 183 \text{ in}^2}$$

$$\Rightarrow A_{sprov.} : (2) \#10 @ 6'' \times 3.5 \text{ ft} = (14) \#10 \text{ BARS}$$

$$(2) \#9 @ 12'' \times 10 \text{ ft} = (20) \#9 \text{ BARS}$$

$$A_{sprov} = 14(1.27) + 20(1.00) = 38 \text{ in}^2$$

$$A_{sprov} < A_{sreq} \quad \therefore \underline{\text{NO GOOD.}}$$

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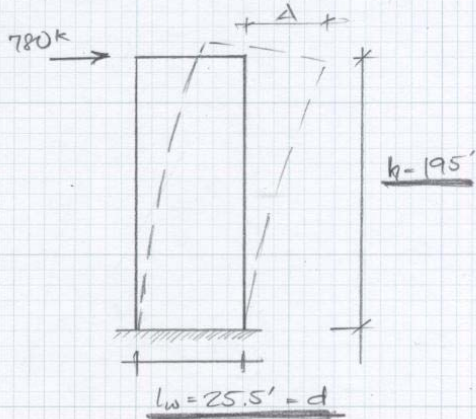
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Assignment TECH REPORT 3: SMILOW CANCER CENTER

Class _____

□ SHEAR WALL 3 DEFLECTION CALCULATION



$$\begin{aligned}\Delta_{\text{CANTILEVER}} &= \Delta_F + \Delta_S \\ &= \frac{Ph^3}{3EI} + \frac{1.2Ph}{E_r A}\end{aligned}$$

* OR USE SIMPLIFIED EQUATION:

$$\begin{aligned}\Delta_{\text{CANT}} &= 0.0926 \frac{h}{d^3} + 0.0694 \frac{h}{d} \\ &= 0.0926 \left(\frac{195 \times 12}{(25.5 \times 12)^3} \right) + 0.0694 \left(\frac{195 \times 12}{25.5 \times 12} \right) \\ \Delta &= 0.53''\end{aligned}$$

Table A1: Wind Load Values from Tech Report 1 (X-Direction Loading)

Location	Height (ft.)	K _z	q _z	p _z (psf)	P _z (kips)	Overturning Moment, M _o (ft-kips)
Windward	30	0.70	25.2	16.6	42.45	1273.59
	40	0.76	27.4	18.1	46.09	1843.68
	50	0.81	29.2	19.3	49.12	2456.22
	60	0.85	30.6	20.2	51.55	3093.01
	70	0.89	32.1	21.2	53.98	3778.33
	80	0.93	33.5	22.1	56.40	4512.16
	90	0.96	34.6	22.8	58.22	5239.93
	100	0.99	35.7	23.5	60.04	6004.08
	120	1.04	37.5	24.7	63.07	7568.78
	140	1.09	39.3	25.9	66.11	9254.78
	160	1.13	40.7	26.9	68.53	10965.03
	180	1.17	42.2	27.8	70.96	12772.32
	200	1.2	43.2	28.5	72.78	14555.35
	235	1.26	45.4	30.0	76.42	17957.67
Leeward	ALL	1.26	45.4	-16.9	-42.98	-5050.59

Table A2: Wind Load Values from Tech Report 1 (Y-Direction Loading)

Location	Height (ft.)	K _z	q _z	p _z (psf)	P _z (kips)	Overturning Moment, M _o (ft-kips)
Windward	30	0.70	25.2	16.6	53.05	1591.59
	40	0.76	27.4	18.0	57.60	2304.02
	50	0.81	29.2	19.2	61.39	3069.50
	60	0.85	30.6	20.2	64.42	3865.29
	70	0.89	32.1	21.1	67.45	4721.72
	80	0.93	33.5	22.1	70.48	5638.78
	90	0.96	34.6	22.8	72.76	6548.26
	100	0.99	35.7	23.5	75.03	7503.22
	120	1.04	37.5	24.7	78.82	9458.60
	140	1.09	39.3	25.9	82.61	11565.56
	160	1.13	40.7	26.8	85.64	13702.84
	180	1.17	42.2	27.8	88.67	15961.38
	200	1.2	43.2	28.5	90.95	18189.61
	235	1.26	45.4	29.9	95.50	22441.43
Leeward	ALL	1.26	45.4	-18.7	-59.68	-7012.95

Table A3: Seismic Load Values from Tech Report 1

Story Level	Height (ft)	F _x (kips)	Story Shear, V _x (kips)	M _o (ft-kips)
1	0	0.00	0.00	0.00
2	15	268.19	268.19	4022.81
3	30.5	211.65	479.84	6455.27
4	45.5	167.39	647.23	7616.24
5	60.5	138.02	785.25	8350.35
7	80.5	106.30	891.54	8556.75
8	95.5	94.56	986.10	9030.63
9	110.5	84.81	1070.92	9371.84
10	125.5	76.72	1147.64	9628.89
11	140.5	69.96	1217.60	9829.52
12	155.5	64.25	1281.85	9990.56
14	170.5	59.37	1341.22	10122.76
15	185.5	55.17	1396.39	10233.29
16	200.5	51.51	1447.89	10327.14
17	217.5	48.98	1496.87	10653.26
18	232	1.04	1497.92	241.36