University of North Carolina's

Imaging Research Building

Technical Report 3

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Structural Option

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Executive Summary

The third technical assignment includes an analysis and confirmation of the original lateral system designed by Mulkey Engineers and Consultants. The loads calculated in the first technical report were applied to the main lateral force resisting system composed of ordinary reinforced concrete shear walls. Necessary revisions were made to the initial wind and seismic loads. A RAM computer model was also created and its output was compared to hand calculations to verify the shear strength of the walls. Torsion and overturning and its impact on foundations were also examined this way. Overall building and story drifts from the RAM model were also compared to the allowable limits set forth by code and industry.

The computer model used was a complete model of the building including gravity members. When analyzing the model RAM Frame was used to isolate the lateral force resisting system and its effect. Hand calculations were also performed since this was a first attempt at using RAM Frame.

After reviewing the model's results and completing hand calculations, these values were compared. It was determined that the model was taken the slab's rigidity into account and shifted the center of rigidity, while calculations treated the shear walls as the only lateral force resisting elements. Therefore, the subsequent calculations including relative stiffness, torsion, direct shear, torsional shear, and overturning used the hand calculated results. In doing so, it was found that there is no serious concerns regarding torsion, shear, or overturning, which suggests that the shear walls are providing the majority of lateral resistance with minimal resistance from the slabs. Also, the drifts and displacements were found to be within the acceptable industry limits. Finally, a shear strength check was done of a north/south and east/west wall, with both walls being determined as being more than adequate.

Introduction

The Imaging Research Building, also known as IRB, is located on the University of North Carolina's Chapel Hill campus on Mason Farm road. It has an "L" shaped floor plan containing a re-entrant corner, with the long face dimensions of 282'-4" by 247'-3". It has an overall height of 180'-0" from Basement 2 (second floor subgrade) to the roof, with a setback at the mechanical mezzanine level. The building's usage will be a combination of research space, laboratories, and office space for the UNC.

Architectural Design Concepts

The Imaging Research Building at UNC Chapel Hill was designed by the architecture firm Perkins + Will. Its primary usage is the driving force behind many of the structural decisions for the project. Once it is open, it will contain the most advanced imaging equipment in any one spot in the world. First, the two subgrade floors house several heavy pieces of imaging research equipment that have large Gaussian fields. Because of this, foundations, walls, and slabs were made thicker than usual, which will result in the use of mass concrete pouring techniques to be required when constructed. For example, the foundation where a 1.5GHZ NMR machine will sit required a 6' thick mat footing.

Above grade you will find typical bays sizes of 21'-4" by 21'-4", and 21'-4" by 31'-4" driven by the laboratory space requirements on every floor. A bridge also connects the new imaging research facility to existing Lineberger Cancer Center on the second floor. At the eighth floor, a large area houses all of the mechanical equipment with a partial mezzanine at the floor above, which services all of the imaging and laboratory equipment below. These architectural and usage restraints have a generous effect on the structural system as noted below, and hopefully in future technical reports.

Structural System

Foundation

The geotechnical engineering study was performed by Tai and Associates on November 12, 2008. The study indicates that the subsurface materials on the site consist of pavement and topsoil, fill, residual soil, weathered rock, and rock and boulders. Based on this composition, Tai and Associates were confident in giving Mulkey a net allowable bearing pressure of 6000 pounds per square foot to use in their foundation calculations.

Because of this allowable bearing pressure, Mulkey had to be creative with their foundation design. The result is a mixture of spread footings under the columns, and a combination of spread and mat footings under the large imaging research equipment and shear walls. The walls below grade range from 18" to 36" in thickness, and in one location a 36" wall spans both subgrade floors to the first floor unbraced. An example of a typical mat footing can be seen in Figure 1.1. As with the other mat footings, this one is combined and sits under two pieces of large imaging equipment. It is 6'-0" thick and also services a shear wall that steps 6' in elevation. Another area of note in the foundation design is a 6'-0" thick concrete footing which will service a cyclotron, another heavy piece of imaging equipment.

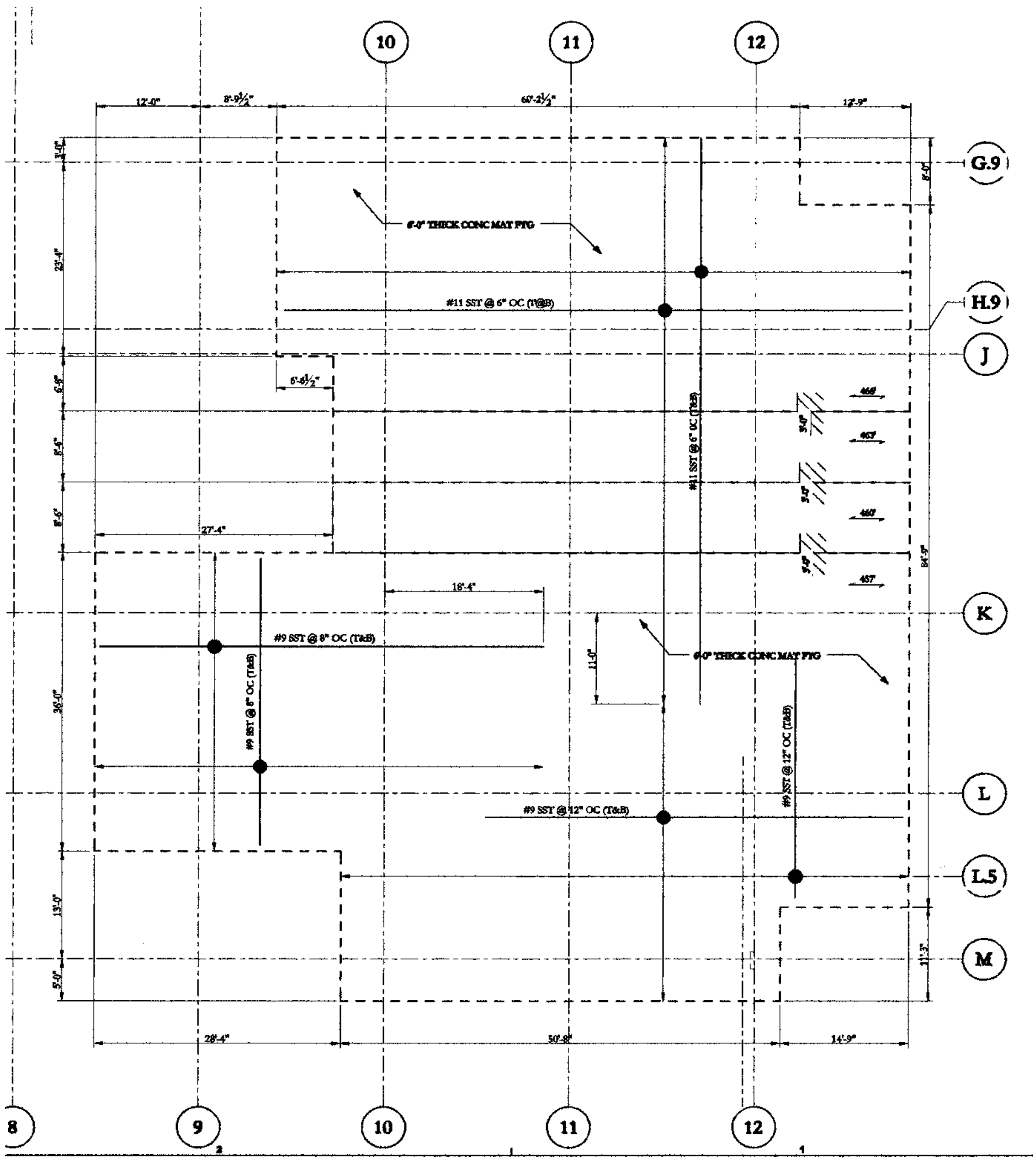

Figure 1.1 – Typical Mat Foundation under Imaging Equipment

Superstructure

The first floor and the floors above to the eighth floor is a 6" one-way cast-in-place slab (NWC) with a compressive strength (f'c) of 5 ksi. The beams on these levels are mostly 18"x20" T-Beams, which change directions at the re-entrant corner where the building changes directions. The girder dimensions vary, but are typically 28"x30".

Most of the columns in the Imaging Research Building are 20"x20" square columns with #3 ties above the first floor, and 24"x24" below grade, with all them having a compressive strength of 7 ksi. The typical frame consists of four bays with three of them being approximately twenty feet in width and the other being thirty feet in width to accommodate the laboratories that occupy these spaces on almost every floor of the building.

For more detail on the superstructure a section of the third floor framing is provided in figure 2.1 for reference.

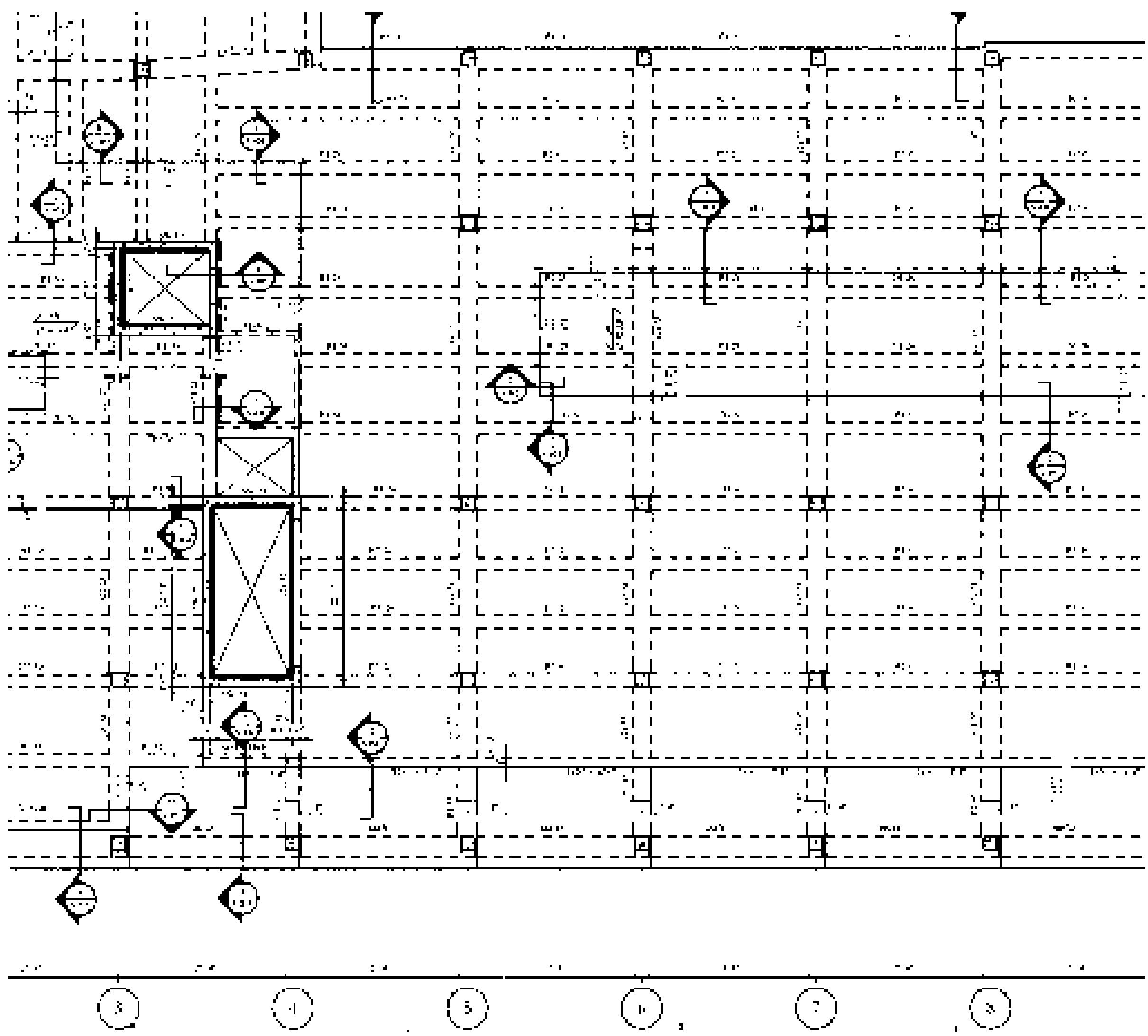

Figure 1.2 - Third Floor Framing

Lateral System

Ordinary reinforced concrete shearwalls are used as the main lateral force resisting system in the UNC Imaging Research Building. The largest shearwalls wrap around the main elevator and stairwell cores while the other ones encase mechanical closets. Most of the shearwalls run from the foundation to the mechanical mezzanine with only half of them continuing to the roof level. There are thirty-three shearwalls either 12" or 16" thick. Figure 1.3 shows an example of the shearwalls around the main stair and elevator core.

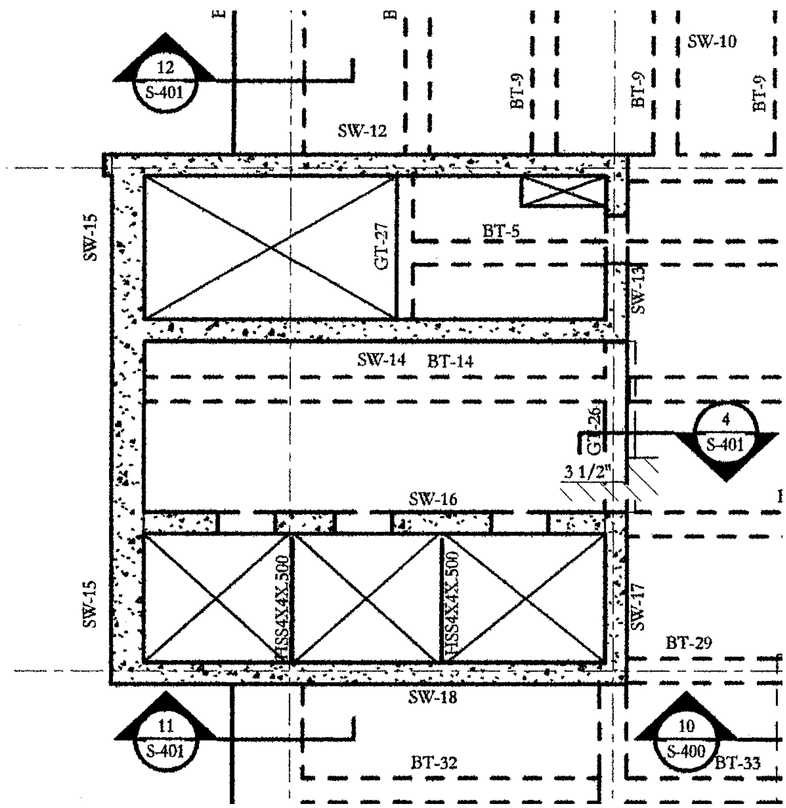

Figure 1.3 - Shearwalls around Elevator Core

The rest of the third technical report will discuss the lateral system in more detail. The lateral load paths, load distribution, torsion, drift, overturning, and several shearwall strength checks will be covered. An analysis from a RAM structural model that was created will also be compared to hand calculations for verification.

RAM Structural System Model

A model of the gravity and lateral framing was created using RAM Structural Suite software, and the lateral system was analyzed using RAM Frame. From RAM Frame, I was able to obtain the building's center of rigidity and center of mass. These numbers were compared to hand calculations which can be found in Appendix D. Also, the relative story drifts were able to be obtained from the RAM model. These numbers can be Appendix F. The RAM output is compared to the accepted allowable drift later in the report.

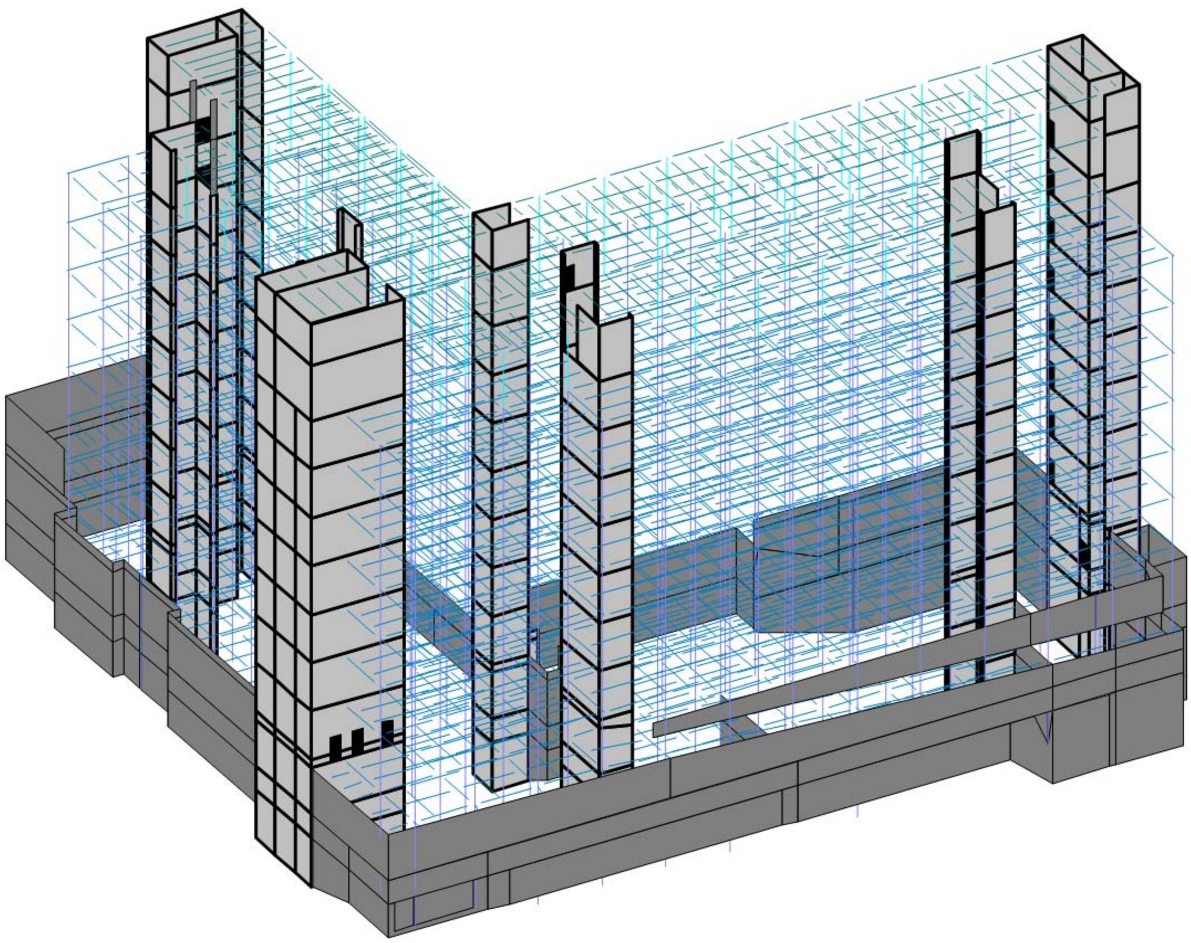

Figure 2 - RAM Model

Loads & Load Cases

Since the focus of this report is on lateral force resisting systems, wind and seismic loads will be discussed in detail. Gravity loads have also been included as a reference, but they were omitted in this analysis for simplicity. Once a complete three-dimensional model is constructed, all loads will be considered simultaneously.

Gravity Loads

As stated in Technical Report 1, the determination of gravity loads by Mulkey Engineers and Consultants was done using the 2009 North Carolina State Building Code (2006 International Building Code with Revisions), which adopts ASCE 7-05 for its minimum design loads for buildings. This report also uses ASCE 7-05 as the main reference in accordance with the requirements of AE Senior Thesis. In several places, Mulkey chose to use higher design loads than what was stipulated by the building code. These differences along with the rest of the design loads are noted in the Mulkey column of Table 1, while the code loads are in the ASCE 7-05 column. Calculations of the snow load are provided in Appendix A.

Table 1 -Gravity Loads

Description	Mulkey	ASCE 7-05
DEAD (DL)		
Reinforced Normal Weight Concrete	150 pcf	150 pcf
LIVE (LL)		
Roof	30 psf	20 psf
Offices	50 psf	50 psf
Public Areas, Lobbies	100 psf	100 psf
Laboratories	100 psf	60 psf
Corridors, 2nd & Above	100 psf	100 psf
Corridors Ground	100 psf	100 psf
Stairs	100 psf	100 psf
Catwalk	40 psf	40 psf
Storage	125 psf	125 psf
Heavy File Storage	200 psf	250 psf
Mechanical Rooms	150 psf	150 psf
Level B1	150 psf	N/A
SNOW (S)		
Snow	16.5 psf	16.5 psf
SUPERIMPOSED (SDL)		
Finishes, MEP, Partitions	20-25 psf	20-25 psf
Bathroom Terrazo	40 psf	N/A
Lobby Terrazo	60 psf	N/A
Mechanical Courtyard	300 psf	N/A
3T MRI Room	250 psf	N/A
7T Sheilding	75 psf	N/A
Hot Cells	350 psf	N/A
Water Tank	350 psf	N/A

Wind Loads

Wind loads were also previously determined in Technical Report 1 using ASCE 7-05 Section 6.5, which describes Method 2 – Analytical Procedure. The variables used in this analysis are located in Table 2a and the calculations that support these values can be found in Appendix B.

Table 2a - Wind Variables			ASCE 7-05 References
Basic Wind Speed	V	95 mph	(Fig. 6-1)
Directionality Factor	k_d	0.85	(Table 6-4)
Importance Factor	I	1.15	(Table 6-1)
Exposure Category		B	(Sec. 6.5.6.3)
Topographic Factor	K_{zt}	1	(Sec. 6.5.7.1)
Velocity Pressure Exposure Coefficient evaluated at Height z	K_z	Varies	(Table 6-3)
Velocity Pressure at Height z	q_z	Varies	(Eq. 6-15)
Velocity Pressure at Mean Roof Height (North/South)	q_h	25.29 psf	(Eq. 6-15)
Velocity Pressure at Mean Roof Height (East/West)	q_h	24.62 psf	(Eq. 6-15)
Equivalent Height of Struture	>	94.6'	(Table 6-2)
Intensity of Turbulence	$I_{>}$	0.252	(Eq. 6-5)
Integral Length Scale of Turbulence	$L_{>}$	454.6'	(Eq. 6-7)
Background Response Factor (East/West)	Q	0.794	(Eq. 6-6)
Background Response Factor (North/South)	Q	0.786	(Eq. 6-6)
Gust Effect Factor (East/West)	G	0.878	(Eq. 6-4)
Gust Effect Factor (North/South)	G	0.873	(Eq. 6-4)
External Pressure Coefficient (Windward)	C_p	0.8	(Fig. 6-6)
External Pressure Coefficient (E/W Leeward)	C_p	-0.47	(Fig. 6-6)
External Pressure Coefficient (N/S Leeward)	C_p	-0.5	(Fig. 6-6)

For technical report 1, summary tables 2b and 2c were developed to determine the wind pressures in the north/south and east/west direction, respectively. In the north/south direction the building is exposed at the first basement level, therefore the wind pressure is higher than in the east/west direction. For Technical Report 3, an additional column has been added of the factored story forces (1.6 multiplier for the most critical case).

Table 2b-Wind Loads (North/South) B=282'-4" L-247'-3"

Floor	Height Above Ground- z (ft)	Story Height (ft)	Kz	qz	Wind Pressure (psf)		Total Pressure (psf)	Force (k) of Windward only	Force (k) of Total Pressure	Story Shear Windward (k)	Story Shear Total (k)	Factored Story Force (k)	Factored Story Force (k)
					Windward	Leeward							
Roof	162	14.33	1.13	25.52	22.38	-15.59	37.97	73.00	123.86	73.00	123.86	198.17	198.17
Mech Mez.	148.66	18.66	1.11	25.07	22.06	-15.59	37.65	98.11	167.44	171.10	291.30	267.90	466.07
8	130	16	1.07	24.17	21.43	-15.59	37.02	96.80	167.22	267.90	458.52	267.56	733.63
7	114	16	1.03	23.26	20.80	-15.59	36.39	93.95	164.37	361.85	622.90	263.00	996.63
6	98	16	0.98	22.13	20.01	-15.59	35.60	90.39	160.81	452.24	783.71	257.30	1253.93
5	82	16	0.94	21.23	19.38	-15.59	34.97	87.54	157.96	539.78	941.67	252.74	1506.67
4	66	16	0.87	19.65	18.27	-15.59	33.86	82.55	152.97	622.33	1094.65	244.76	1751.43
3	50	16	0.81	18.29	17.33	-15.59	32.92	78.28	148.70	700.60	1243.35	237.92	1989.35
2	34	16	0.72	16.26	15.91	-15.59	31.50	71.86	142.29	772.47	1385.63	227.66	2217.01
1	18	18	0.6	13.55	14.02	-15.59	29.61	71.23	150.45	843.69	1536.09	240.73	2457.73
B1	0	0	0	0.00	0.00	0	0.00	0.00	0.00	843.69	1536.09	0.00	2457.73
∑Story Shear (Windward) = 843.69 k					**∑Story Shear (Total) = 1536.09 k**					**Factored Story Force = 2259.56**			

Table 2c-Wind Loads (East/West) B=247'-3" L=282'-4"

Floor	Height Above Ground- z (ft)	Story Height (ft)	Kz	qz	Wind Pressure (psf)		Total Pressure (psf)	Force (k) of Windward only	Force (k) of Total Pressure	Story Shear Windward (k)	Story Shear Total (k)	Factored Story Force (k)	Factored Story Shear (k)
					Windward	Leeward							
Roof	144	13.33	1.10	24.84	21.90	-14.59	36.49	46.52	77.50	46.52	77.50	124.01	124.01
Mech Mez.	130.66	18.66	1.06	23.94	21.27	-14.59	35.86	63.37	106.84	109.89	184.34	170.94	294.95
8	112	16	1.02	23.04	20.64	-14.59	35.23	81.65	139.37	191.54	323.71	222.99	517.94
7	96	16	0.98	22.13	20.01	-14.59	34.60	79.16	136.87	270.70	460.59	219.00	736.94
6	80	16	0.93	21.00	19.22	-14.59	33.81	76.04	133.76	346.74	594.34	214.01	950.95
5	64	16	0.87	19.65	18.27	-14.59	32.86	72.29	130.01	419.03	724.36	208.02	1158.97
4	48	16	0.80	18.07	17.17	-14.59	31.76	67.93	125.64	486.95	850.00	201.03	1360.00
3	32	16	0.71	16.03	15.75	-14.59	30.34	62.31	120.03	549.26	970.03	192.04	1552.04
2	16	16	0.58	13.10	13.70	-14.59	28.29	54.20	111.92	603.46	1081.94	179.07	1731.11
1	0	0	0.00	0.00	0.00	0	0.00	0.00	0.00	603.46	1081.94	0.00	1731.11
∑Story Shear (Windward) = 603.46 k					**∑Story Shear (Total) = 1081.94 k**					**Factored Story Force = 1731.11**			

Seismic Loads

Seismic loads were also previously calculated in Technical Report 1 using chapters 11 and 12 of ASCE 7-05. One possible reason as that for this is that for this analysis the Equivalent Lateral Force Method was used, despite the fact that IRB contains type two horizontal irregularities. This method was chosen for this report as a base method to approximate the seismic forces because type two horizontal irregularities require a more advanced modal response analysis which utilizes computer software which was not required for this technical report.

These calculations along with a sample calculation of the building weight for one floor, and a diagram of the story shear and base shear as a result of the seismic loads, can be found in Appendix C. Table 3a provides a list of variables used where Table 3b shows the calculations of story shear and overturning moments via excel.

Table 3a - Seismic Design Variables			ASCE 7-05 References
Site Class		C	(Table 20.3-1)
Occupancy		III	(Table 1-1)
Importance Factor		1.25	(Table 11.5-1)
Structural System		Building Frame Sytem: Ordinary Reinforced Concrete Shear Wall	(Table 12.2-1)
Spectral Response Acceleration, short	S_s	0.209 g	(USGS)
Spectral Response Acceleration, 1 s	S_1	0.081g	(USGS)
Site Coefficient	F_a	1.2	(Table 11.4-1)
Site Coefficient	F_v	1.7	(Table 11.4-2)
MCE Spectral Response Acceleration, short	S_{MS}	0.251	(Eq. 11.4-1)
MCE Spectral Response Acceleration, 1 s	S_{M1}	0.092	(Eq.11.4-2)
Design Spectral Acceleration, short	S_{DS}	0.167	(Eq. 11.4-3)
Design Spectral Acceleration, 1s	S_{D1}	0.092	(Eq. 11.4-4
Seismic Design Category	SDC	B	(Eq. 11.6-2)
Response Modification Coefficient	R	5	(Table 12.2-1)
Approximate Period Parameter	C_t	0.02	(Table 12.8-2)
Building Height (above grade)	h_n	162	
Approximate Period Parameter	x	0.75	(Table 12.8-2)
Calculated Period Upper Limit Coefficient	C_u	1.7	(Table 12.8-1)
Approximate Fundamental Period	T_a	0.92 s	(Eq. 12.8-7)
Fundamental Period Max	T_{max}	1.56	(Sec. 12.8.2)
Long Period Transition Period	T_L	8 g	(Fig. 22-15)
Seismic Response Coefficient	C_s	0.025	(Eq. 12.8-2)
Structural Period Exponent	k	1.21	(Sec. 12.8.3)

Table 3b- Seismic Loads								
Level	Story Weight W_x (k)	Height h_x (ft)	h_x^k	$w_x h_x^k$	C_{vx}	Lateral Force F_x (k)	Story Shear V_x (k)	Moments M_x (ft-k)
Roof	800	162	471.53	377227.33	0.03	55.45	0.00	8983.67
Mech Mez.	1200	148.66	424.97	509960.03	0.04	74.97	55.45	11144.64
8.00	7625	130	361.30	2754934.67	0.22	404.99	130.42	52649.02
7.00	7625	114	308.22	2350145.32	0.19	345.49	535.41	39385.39
6.00	7625	98	256.67	1957146.79	0.16	287.71	880.90	28195.84
5.00	7625	82	206.88	1577446.39	0.13	231.89	1168.61	19015.34
4.00	7625	66	159.09	1213076.00	0.10	178.33	1400.51	11769.76
3.00	7625	50	113.70	866949.01	0.07	127.45	1578.84	6372.34
2.00	7490.35	34	71.30	534061.91	0.04	78.51	1706.28	2669.35
1.00	7865.25	18	33.03	259771.95	0.02	38.19	1784.79	687.39
B1	9805.68	0	0.00	0.00	0.00	0.00	1822.98	0.00
$\sum w_i h_i^k$ = 12400719.41	**$**\sum F_x = V_x$ = 1822.98 k**				**$\sum$Moments M_x = 180872.73 ft-k**			
Total Building Weight (Above Grade) = 72911.28 k								

Load Combinations

The following factored load combinations from Chapter 2 of ASCE 7-05 are applicable to this lateral load analysis:

(Note: D_i, F, F_a, H, R, T, & W_i are assumed to be zero)

1. 1.4D
2. 1.2D + 1.6L +0.5(Lr or S)
3. 1.2D + 1.6(Lr or S) + (L or 0.8W)
4. 1.2D + 1.6W + L + 0.5(Lr or S)
5. 1.2D + 1.0E + L + 0.2S
6. 0.9D + 1.6W
7. 0.9D + 1.0E

After examining the load combinations, it is apparent that regardless of the impact of gravity loads, the critical factored lateral load will be either 1.6W of 1.0E. Therefore, it makes sense to assess the controlling load in each direction based on the application of these factors.

Load Path and Distribution

When lateral forces come in contact with a building, the loads need a way to travel through the structure and into the ground. The path that the load takes is assumed to be determined by the concept of relative stiffness. The members that are the most rigid draw the forces to them. Therefore, the loads are transmitted through the diaphragms, to the shear walls, and down to the foundation.

The Imaging Research building has thirty-three shear walls throughout the building encasing stairwell and elevator cores as well as mechanical shafts. Figure ___ shows the numbered system assigned to each wall to better reference which shear walls are being discussed throughout this report.

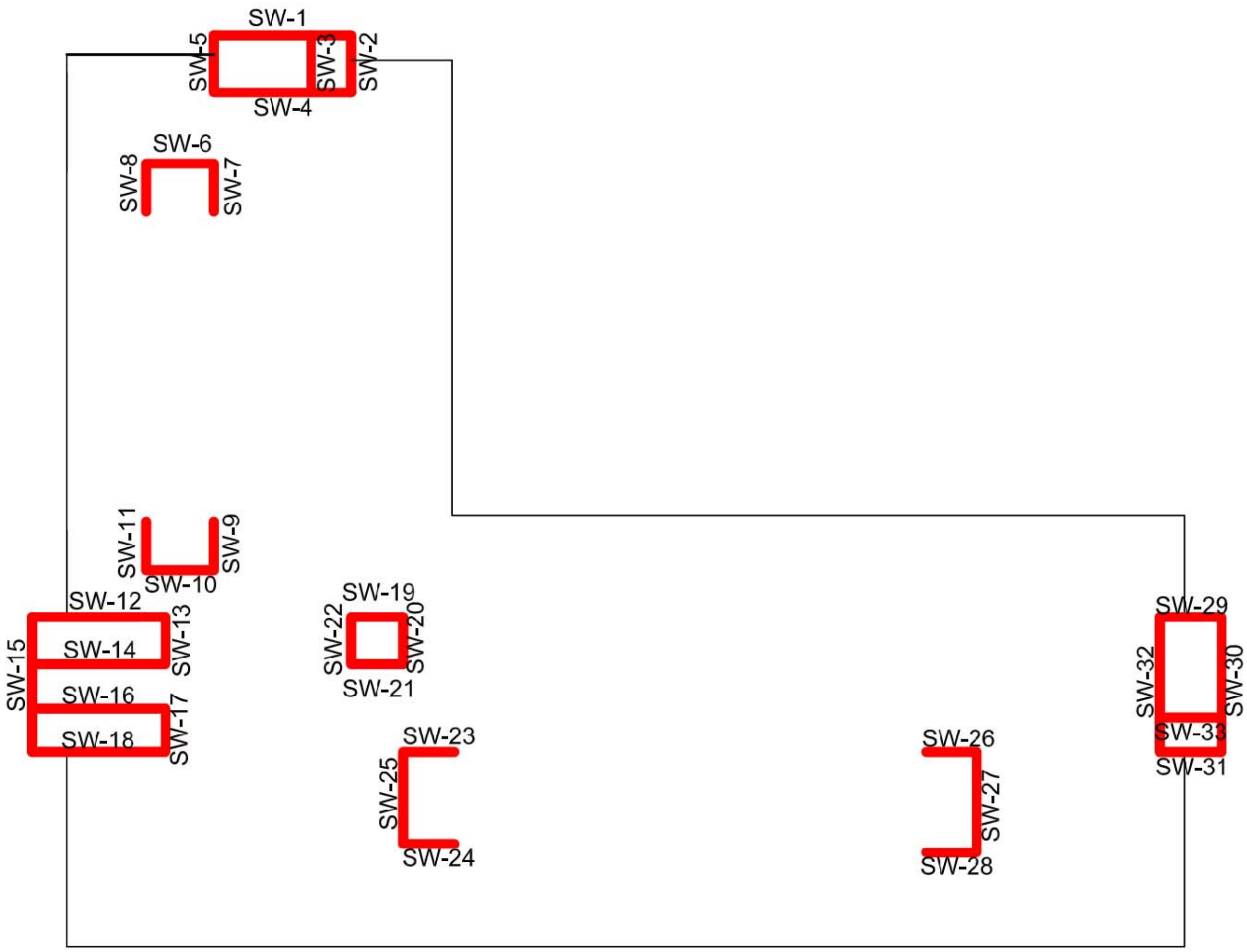

Figure 3 - Shearwall Plan

The shear walls vary in thickness, most being 16" or 12", and in length. They also vary in height as well depending on the floor. These variables all affect the rigidity of the walls which in turn affects the relative stiffness of each element. The tables located in Appendix D define the rigidities of the walls in both the north/south and east/west directions. These rigidities were found using the following equations:

$$R = \frac{Et}{4\left(\frac{h}{L}\right)^3 + 3\left(\frac{h}{L}\right)}$$

The rigidity values were then used to determine the center of rigidity on each floor with the equation:

$$Center\ of\ Rigidity = \frac{\sum(R)(distance\ between\ element\ and\ the\ origin)}{\sum R}$$

The values of both the center of mass (COM) and center of rigidity (COR) are located in Table 4. The coordinates found by hand and the RAM output are arranged in this table to show that the results are comparable. The COR values taken from the RAM model suggest that diaphragms are being considered in the determination of rigidity, as opposed to the hand calculations which are only assuming that the shear walls are being taken into account. For this report, the hand calculated values will be those used whenever COM and COR are needed.

Table 4								
Level	Center of Rigidity				Center of Mass			
	Ram Output		Hand Calculations		Ram Output		Hand Calculations	
	x	y	x	y	x	y	x	y
Sub-Basement	-	-	136.61	104.46	-	-	-	-
Basement	89.37	84.20	136.61	104.46	89.37	84.20	89.37	84.20
Level 1	101.47	93.00	134.24	103.65	104.10	100.07	104.10	100.07
Level 2	102.88	98.46	134.24	103.65	100.79	80.77	100.79	80.77
Level 3	100.74	99.33	134.24	103.65	100.74	78.62	100.74	78.62
Level 4	97.94	99.98	134.24	103.65	100.71	78.67	100.71	78.67
Level 5	95.25	100.50	134.24	103.65	100.69	78.71	100.69	78.71
Level 6	92.87	100.92	134.24	103.65	100.65	78.71	100.65	78.71
Level 7	90.85	101.24	134.24	103.65	100.65	78.71	100.65	78.71
Level 8	89.22	101.49	134.24	103.65	100.45	78.96	100.45	78.96
Mech Mezz	87.06	101.69	134.24	110.70	86.48	84.00	86.48	84.00
Roof	86.73	101.87	137.37	112.05	95.78	90.48	95.78	90.48

The rigidity of the walls is also used to determine the relative stiffness. The relative stiffness of each element dictates what percentage of the lateral force is distributed to it. This is calculated by the equation:

$$Relative\ Stiffness = \frac{R}{\sum R}$$

Table 5 lists the relative stiffness values obtained for all thirty-three shear walls at each level. These values can then be applied to the loads at each floor to determine how much load each wall will receive. Also, it important to note that as the length of the wall changes the relative stiffness varies as well.

Table 5 - Relative Stiffness (%) East-West Force									
	SW- 1	SW-4	SW-6	SW-10	SW-12	SW-14	SW-16	SW-18	
SubBasement	14.33	14.01	2.80	2.80	12.93	12.93	12.93	12.93	
Basement	14.33	14.01	2.80	2.80	12.93	12.93	12.93	12.93	
Floor 1	14.00	13.70	2.96	2.96	12.70	12.70	12.70	12.70	
Floor 2	14.00	13.70	2.96	2.96	12.70	12.70	12.70	12.70	
Floor 3	14.00	13.70	2.96	2.96	12.70	12.70	12.70	12.70	
Floor 4	14.00	13.70	2.96	2.96	12.70	12.70	12.70	12.70	
Floor 5	14.00	13.70	2.96	2.96	12.70	12.70	12.70	12.70	
Floor 6	14.00	13.70	2.96	2.96	12.70	12.70	12.70	12.70	
Floor 7	14.00	13.70	2.96	2.96	12.70	12.70	12.70	12.70	
Floor 8	14.00	13.70	2.96	2.96	12.70	12.70	12.70	12.70	
Mech Mezz.	16.03	15.69	3.39	3.39	14.55	14.55	-	14.55	
Roof	17.74	17.38	-	-	16.19	16.19	-	16.19	
	SW-19	SW-21	SW-23	SW-24	SW-26	SW-28	SW-29	SW-31	SW-33
SubBasement	1.51	1.51	1.30	1.30	1.23	1.23	2.05	2.68	1.54
Basement	1.51	1.51	1.30	1.30	1.23	1.23	2.05	2.68	1.54
Floor 1	1.65	1.65	1.42	1.42	1.42	1.34	2.23	2.87	1.67
Floor 2	1.65	1.65	1.42	1.42	1.42	1.34	2.23	2.87	1.67
Floor 3	1.65	1.65	1.42	1.42	1.42	1.34	2.23	2.87	1.67
Floor 4	1.65	1.65	1.42	1.42	1.42	1.34	2.23	2.87	1.67
Floor 5	1.65	1.65	1.42	1.42	1.42	1.34	2.23	2.87	1.67
Floor 6	1.65	1.65	1.42	1.42	1.42	1.34	2.23	2.87	1.67
Floor 7	1.65	1.65	1.42	1.42	1.42	1.34	2.23	2.87	1.67
Floor 8	1.65	1.65	1.42	1.42	1.42	1.34	2.23	2.87	1.67
Mech Mezz.	1.88	1.88	1.63	1.63	1.54	1.54	2.55	3.29	1.91
Roof	2.35	2.35	-	-	-	-	3.17	4.03	2.38
North-South Force									
	SW-2	SW-3	SW-5	SW-7	SW-8	SW-9	SW-11	SW-13	
SubBasement	3.22	1.21	3.22	1.89	1.89	1.89	1.89	2.35	
Basement	3.22	1.21	3.22	1.89	1.89	1.89	1.89	2.35	
Floor 1	3.45	1.29	3.45	2.05	2.05	2.05	2.05	2.55	
Floor 2	3.45	1.29	3.45	2.05	2.05	2.05	2.05	2.55	
Floor 3	3.45	1.29	3.45	2.05	2.05	2.05	2.05	2.55	
Floor 4	3.45	1.29	3.45	2.05	2.05	2.05	2.05	2.55	
Floor 5	3.45	1.29	3.45	2.05	2.05	2.05	2.05	2.55	
Floor 6	3.45	1.29	3.45	2.05	2.05	2.05	2.05	2.55	
Floor 7	3.45	1.29	3.45	2.05	2.05	2.05	2.05	2.55	
Floor 8	3.45	1.29	3.45	2.05	2.05	2.05	2.05	2.55	
Mech Mezz.	3.45	1.29	3.45	2.05	2.05	2.05	2.05	2.55	
Roof	4.90	1.84	4.90	-	-	-	2.95	3.68	
	SW-15	SW-17	SW-20	SW-22	SW-25	SW-27	SW-30	SW-32	
SubBasement	19.87	1.89	1.76	1.76	8.87	8.87	19.87	19.55	
Basement	19.87	1.89	1.76	1.76	8.87	8.87	19.87	19.55	
Floor 1	19.25	2.06	1.91	1.91	8.87	8.87	19.25	18.96	
Floor 2	19.25	2.06	1.91	1.91	8.87	8.87	19.25	18.96	
Floor 3	19.25	2.06	1.91	1.91	8.87	8.87	19.25	18.96	
Floor 4	19.25	2.06	1.91	1.91	8.87	8.87	19.25	18.96	
Floor 5	19.25	2.06	1.91	1.91	8.87	8.87	19.25	18.96	
Floor 6	19.25	2.06	1.91	1.91	8.87	8.87	19.25	18.96	
Floor 7	19.25	2.06	1.91	1.91	8.87	8.87	19.25	18.96	
Floor 8	19.25	2.06	1.91	1.91	8.87	8.87	19.25	18.96	
Mech Mezz.	19.25	2.06	1.91	1.91	8.87	8.87	19.25	18.96	
Roof	24.51	3.01	2.76	2.76	-	-	24.51	24.17	

Torsion

Torsion is present when the center of mass and the center rigidity are not in the same location. This results in an eccentricity and moments and torsional shear are produced. Torsional shear can be determined from the following equation:

$$T = \frac{V_{tot} e d_i R_i}{J}$$

- V_{tot} = story shear
- e = distance from the center of mass to the center of rigidity
- d_i = distance from element to the center of rigidity
- R_i = relative stiffness of the element
- J = torsional moment of inertia = $\sum(R \times d_i^2)$

As an example, the torsional shear was computed for the shear walls supporting Floor 6 and can be found in table 6.

Table 6 - Torsional Shear in Shear Wall Supporting Floor 6							
		Factored Story Shear V_{tot} (k)	Relative Stiffness R_i	Distance from COM to COR e (inches)	Distance from Wall X to COR di (inches)	$(R_i)(d_i^2)$	Torsional Shear (k)
SW-2	N/S	1253.93	0.03	403.08	816.88	23021.61	5.59
SW-3	N/S	1253.93	0.01	403.08	929.88	11154.33	2.38
SW-5	N/S	1253.93	0.03	403.08	1200.88	49752.89	8.22
SW-7	N/S	1253.93	0.02	403.08	1200.88	29563.31	4.88
SW-8	N/S	1253.93	0.02	403.08	1389.88	39601.21	5.65
SW-9	N/S	1253.93	0.02	403.08	1200.88	29563.31	4.88
SW-11	N/S	1253.93	0.02	403.08	1389.88	39601.21	5.65
SW-13	N/S	1253.93	0.03	403.08	1335.38	45472.61	6.75
SW-15	N/S	1253.93	0.19	403.08	1707.38	561165.69	65.17
SW-17	N/S	1253.93	0.02	403.08	1335.38	36734.74	5.45
SW-20	N/S	1253.93	0.02	403.08	672.88	8647.86	2.55
SW-22	N/S	1253.93	0.02	403.08	816.88	12745.30	3.09
SW-25	N/S	1253.93	0.09	403.08	672.88	40160.48	11.83
SW-27	N/S	1253.93	0.09	403.08	928.62	76489.12	16.33
SW-30	N/S	1253.93	0.19	403.08	1612.62	500604.58	61.55
SW-32	N/S	1253.93	0.19	403.08	1440.62	393493.18	54.16
SW-1	E/W	950.95	0.14	299.30	1294.68	234666.03	20.24
SW-4	E/W	950.95	0.14	299.30	1135.68	176697.12	17.37
SW-6	E/W	950.95	0.03	299.30	937.68	26025.39	3.10
SW-10	E/W	950.95	0.03	299.30	194.82	1123.51	0.64
SW-12	E/W	950.95	0.13	299.30	325.82	13482.48	4.62
SW-14	E/W	950.95	0.13	299.30	457.82	26619.56	6.49
SW-16	E/W	950.95	0.13	299.30	581.32	42918.07	8.24
SW-18	E/W	950.95	0.13	299.30	701.82	62554.73	9.95
SW-19	E/W	950.95	0.02	299.30	325.82	1751.66	0.60
SW-21	E/W	950.95	0.02	299.30	457.82	3458.45	0.84
SW-23	E/W	950.95	0.01	299.30	701.82	6994.31	1.11
SW-24	E/W	950.95	0.01	299.30	957.82	13027.46	1.52
SW-26	E/W	950.95	0.01	299.30	701.82	6994.31	1.11
SW-28	E/W	950.95	0.01	299.30	957.82	12293.52	1.43
SW-29	E/W	950.95	0.02	299.30	325.82	2367.40	0.81
SW-31	E/W	950.95	0.03	299.30	701.82	14136.38	2.25
SW-33	E/W	950.95	0.02	299.30	605.82	6129.28	1.13
Torsional Moment of Inertia $J = \sum(R_i)(d_i^2) =$						2549011.1	

Direct Shear

Direct shear is that which is caused by the lateral forces acting on a building that are distributed to the shear walls. These values are determined by multiplying the story shear by the relative stiffness of each member. The direct shears that are applied to each wall can be found in table 7.

Table 7 - Direct Shear											
East/West											
Load Combination 0.9d + 1.0E + 1.6H	Force (k)	Factored Force (k)	Distributed Forces (k)								
			SW- 1	SW-4	SW-6	SW-10	SW-12	SW-14	SW-16	SW-18	
SubBasement	0.00	0.00	-	-	-	-	-	-	-	-	
Basement	0.00	0.00	-	-	-	-	-	-	-	-	
Floor 1	38.19	38.19	5.47	5.35	1.07	1.07	4.94	4.94	4.94	4.94	
Floor 2	78.51	78.51	10.99	10.76	2.32	2.32	9.97	9.97	9.97	9.97	
Floor 3	127.45	127.45	17.84	17.46	3.77	3.77	16.19	16.19	16.19	16.19	
Floor 4	178.33	178.33	24.97	24.43	5.28	5.28	22.65	22.65	22.65	22.65	
Floor 5	231.89	231.89	32.46	31.77	6.86	6.86	29.45	29.45	29.45	29.45	
Floor 6	287.71	287.71	40.28	39.42	8.52	8.52	36.54	36.54	36.54	36.54	
Floor 7	345.49	345.49	48.37	47.33	10.23	10.23	43.88	43.88	43.88	43.88	
Floor 8	404.99	404.99	56.70	55.48	11.99	11.99	51.43	51.43	51.43	51.43	
Mech Mezz.	74.97	74.97	10.50	10.27	2.22	2.22	9.52	9.52	9.52	9.52	
Roof	55.45	55.45	8.89	8.70	1.88	1.88	8.07	8.07	-	8.07	
	Force (k)	Factored Force (k)	Distributed Forces (k)								
			SW-19	SW-21	SW-23	SW-24	SW-26	SW-28	SW-29	SW-31	SW-33
SubBasement	0.00	0.00	-	-	-	-	-	-	-	-	
Basement	0.00	0.00	-	-	-	-	-	-	-	-	
Floor 1	38.19	38.19	0.58	0.58	0.50	0.50	0.47	0.47	0.78	1.02	0.59
Floor 2	78.51	78.51	1.30	1.30	1.11	1.11	1.11	1.05	1.75	2.25	1.31
Floor 3	127.45	127.45	2.10	2.10	1.81	1.81	1.81	1.71	2.84	3.66	2.13
Floor 4	178.33	178.33	2.94	2.94	2.53	2.53	2.53	2.39	3.98	5.12	2.98
Floor 5	231.89	231.89	3.83	3.83	3.29	3.29	3.29	3.11	5.17	6.66	3.87
Floor 6	287.71	287.71	4.75	4.75	4.09	4.09	4.09	3.86	6.42	8.26	4.80
Floor 7	345.49	345.49	5.70	5.70	4.91	4.91	4.91	4.63	7.70	9.92	5.77
Floor 8	404.99	404.99	6.68	6.68	5.75	5.75	5.75	5.43	9.03	11.62	6.76
Mech Mezz.	74.97	74.97	1.24	1.24	1.06	1.06	1.06	1.00	1.67	2.15	1.25
Roof	55.45	55.45	1.04	1.04	0.90	0.90	0.85	0.85	1.41	1.82	1.06
North/South											
Load Combination 1.2D + 1.6W + L + 0.5Lr	Force (k)	Factored Force (k)	Distributed Forces (k)								
			SW-2	SW-3	SW-5	SW-7	SW-8	SW-9	SW-11	SW-13	
SubBasement	0.00	0.00	-	-	-	-	-	-	-	-	
Basement	0.00	0.00	-	-	-	-	-	-	-	-	
Floor 1	150.45	240.72	7.75	2.91	7.75	4.55	4.55	4.55	4.55	5.66	
Floor 2	142.29	227.66	7.85	2.94	7.85	4.67	4.67	4.67	4.67	5.81	
Floor 3	148.70	237.92	8.21	3.07	8.21	4.88	4.88	4.88	4.88	6.07	
Floor 4	152.97	244.75	8.44	3.16	8.44	5.02	5.02	5.02	5.02	6.24	
Floor 5	157.96	252.74	8.72	3.26	8.72	5.18	5.18	5.18	5.18	6.44	
Floor 6	160.81	257.30	8.88	3.32	8.88	5.27	5.27	5.27	5.27	6.56	
Floor 7	164.37	262.99	9.07	3.39	9.07	5.39	5.39	5.39	5.39	6.71	
Floor 8	167.22	267.55	9.23	3.45	9.23	5.48	5.48	5.48	5.48	6.82	
Mech Mezz.	167.44	267.90	9.24	3.46	9.24	5.49	5.49	5.49	5.49	6.83	
Roof	123.86	198.18	6.84	2.56	6.84	4.06	4.06	4.06	4.06	5.05	
	Force (k)	Factored Force (k)	Distributed Forces (k)								
			SW-15	SW-17	SW-20	SW-22	SW-25	SW-27	SW-30	SW-32	
SubBasement	0.00	0.00	-	-	-	-	-	-	-	-	
Basement	0.00	0.00	-	-	-	-	-	-	-	-	
Floor 1	150.45	240.72	47.83	4.55	4.24	4.24	21.35	21.35	47.83	47.06	
Floor 2	142.29	227.66	43.82	4.69	4.35	4.35	20.19	20.19	43.82	43.16	
Floor 3	148.70	237.92	45.80	4.90	4.54	4.54	21.10	21.10	45.80	45.11	
Floor 4	152.97	244.75	47.11	5.04	4.67	4.67	21.71	21.71	47.11	46.40	
Floor 5	157.96	252.74	48.65	5.21	4.83	4.83	22.42	22.42	48.65	47.92	
Floor 6	160.81	257.30	49.53	5.30	4.91	4.91	22.82	22.82	49.53	48.78	
Floor 7	164.37	262.99	50.63	5.42	5.02	5.02	23.33	23.33	50.63	49.86	
Floor 8	167.22	267.55	51.50	5.51	5.11	5.11	23.73	23.73	51.50	50.73	
Mech Mezz.	167.44	267.90	51.57	5.52	5.12	5.12	23.76	23.76	51.57	50.79	
Roof	123.86	198.18	38.15	4.08	3.79	3.79	17.58	17.58	38.15	37.57	

Shear Strength Check

In order to confirm the shear strength of the shear walls, a check must be done that takes into account both the torsional and direct shears being applied. According to ACI 318-08 Section 21.9.4.1 the shear strength of a reinforced concrete shear walls is defined as:

$$Vn = A_{cv}\ [\left(\propto_c \lambda \sqrt{f'_c}\right) + \left(\rho_t f_y\right)]$$

Since there are thirty-three shear walls, a sample of two walls, one in the north/south direction and one in the east/west direction was taken to spot check shear strength. The hand calculations of the strength check done at these two walls supporting Floor 6 can be found in Appendix E. Both walls were well within the capacity determined with the above equations which can be seen in Table 8.

Table 8 - Shear Wall Strength Check
(Supporting Floor 6)

Floor 6	Direct Shear (k)	Torsional Shear (k)	V_u (k)	Vert. Reinf.	Spacing (in)	Length (in)	Thickness (in)	Acv (in^2)	α_c	ρ_t	ϕV_n(k)
Wall 2	34.38	5.59	39.97	(2) #7	18"	159.00	16.00	2544.00	2.00	0.004167	796.30
Wall 10	112.90	0.64	11354.00	(2) #7	12.00	199.00	12.00	2388.00	2.00	0.008333	1195.20

Drift and Displacement

Drift is serviceability consideration in building design that in inversely proportionate to rigidity. The drift has been limited to 1/400th of the overall building height which originated from the *Structural Engineering Handbook* (1968) by Gaylord and Gaylord. In the case of the Imaging Research Building, the drift limit is:

$$\Delta_{limit} = \left(\frac{1728"}{400}\right) = 4.32"$$

The story displacements taken from the RAM model are located in Appendix F. All of the load cases are presented but only the controlling wind and controlling seismic values are highlighted. The RAM output verified are previous assumption that the controlling load cases were 1.6W and 1.0E.

Once totaled, the overall building drift in the x-direction (due to east/west forces) = 3.43” which is below 4.32” Similarly, the drift in the y-direction (due to north/south forces) = 2.82” is within the limits enforced.

Overturning

Overturning moments are due to the presence of the lateral forces and can be found by multiplying the story forces by their mid-heights. This was done with the north/south wind forces and the east west seismic forces with values shown in Table 12. These moments are transformed into axial loads as they are transmitted through the lateral elements and into the foundation. To do a rough estimate of whether or not overturning would be an issue in the Imaging Research Building, the stresses due to these lateral loads were examined and compared to the stresses due to the dead load (self weight) of the building which serves to counteract the overturning. Calculations supporting this estimate can be found in Appendix G. Because the stresses produced by the lateral forces are only a small fraction of that produced by the self weight of the structure, the overturning will have a minimal effect on the foundation. Due to the presence of the moments, however, it is expected that there will be a slight increase of force around the perimeter with a small uplift force on the windward side and a slight downward force on the leeward sides.

Table 9 - Overturning

			N/S Wind Forces		E/W Seismic Forces	
Floor	Height Above Ground-z (ft)	Story Height	Factored Lateral Force Fx (k)	Moment Total (ft-k)	Lateral Force Fx (k)	Moments Mx (ft-k)
Roof	162.00	13.33	123.86	20065.39	55.45	8982.93
Mech Mezz	148.67	18.67	267.90	39827.78	74.97	11145.54
8.00	130.00	16.00	267.56	34782.80	404.99	52648.70
7.00	114.00	16.00	263.00	29982.00	345.49	39385.86
6.00	98.00	16.00	257.30	25215.40	287.71	28195.58
5.00	82.00	16.00	252.74	20724.68	231.89	19014.98
4.00	66.00	16.00	244.76	16154.16	178.33	11769.78
3.00	50.00	16.00	237.92	11896.00	127.45	6372.50
2.00	34.00	16.00	227.66	7740.44	78.51	2669.34
1.00	18.00	18.00	240.73	4333.14	38.19	687.42
Basement	0.00	0.00	0.00	0.00	0.00	0.00
			2383.43	210721.80	1822.98	180872.63

Conclusion

Once adjusting the values found in the first technical assignment, the lateral forces were applied to the Imaging Research Building. These loads were then factored according to ASCE 7-05 load combinations for strength design. It was determined that the combination of 1.2D + 1.6W + L + 0.5(Lr or S or R) controlled in the north/south direction, while 0.9D + 1.0E + 1.6H controlled in the east/west direction. The reason for the wind controlling in one direction and the seismic in the other is that the building is exposed one full story more in the north/south direction and it is also has slightly larger façade in that direction then in the east/west direction.

Although the RAM model was used as reference and in some comparisons to verify that the model and hand calculations were providing similar and reasonable results, the values computed by hand were those used in all subsequent calculations. The reason behind this was because although fairly familiar with RAM, this was the first attempt at modeling the lateral system in the program and using RAM Frame to analyze it, and there was some uncertainty as to whether or not everything was input with all the proper assumptions. Therefore, to ensure consistency and to verify that only the shear walls were acting to resist lateral forces, hand calculations were done.

This report confirms that looking to the shear walls alone was a reasonable assumption. There was torsion due to the eccentricity between the center of mass and the center of rigidity that added torsional shear to the walls. Shear strength checks were done including both the direct and torsional shear and it was deduced that the thickness, length and reinforcement were designed to adequately resist the total shear. Overall building drift, as determined by RAM output, was within the limit of H/400. Overturning is present due to the lateral loads, but a stress check concluded that the self weight of the building can do most of the work to resist this. A more complex model and additional calculations will follow when the second portion of senior thesis begins. At this stage of analysis, however, it was determined that the shear walls were satisfactorily designed to resist various combinations of loading.

Appendix A- Shear Wall Elevations

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Appendix B- Wind Calculations

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PROJECT NAME UNC Imaging Research Building
PROJECT NO. SHEET 1 OF 8
SUBJECT Wind Calcs
PREPARED BY DRH DATE 9/30/09 CHECKED BY DATE

Wind Calculations

ASCE 7-05 Method 2 - Analytical Procedure

V = 95 mph Occupancy Classification: Cat III

$I_w = 1.15$ Exposure Category: B

K_z

Level	Height (ft)	K_z (Interpolated)
B1	0	0
1	18	0.6
2	34	0.72
3	50	0.81
4	66	0.87
5	82	0.94
6	98	0.98
7	114	1.03
8	130	1.07
Mech Mez.	148.66	1.11
Roof	162	1.13

$q_z = 0.00256 K_z K_{zt} K_d V^2 I$

$q_z = 0.00256 (K_z)(1.0)(0.85)(95)^2(1.15)$ — K_z varies at levels

$q_h = 0.00256 K_h K_{zt} K_d V^2 I$

N/S: $q_h = 0.00256 (1.12)(1.0)(0.85)(95)^2(1.15) = \boxed{25.29 \text{ psf}}$
→ h = 157.66 (N/S)

E/W: $q_h = 0.00256 (1.09)(1.0)(0.85)(95)^2(1.15) = \boxed{24.62 \text{ psf}}$
→ h = 139.66 (E/W)

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PROJECT NAME UNC - IRB
PROJECT NO. SHEET 2 OF 8
SUBJECT Wind Calcs
PREPARED BY DRH DATE 9/30/09 CHECKED BY DATE

Gust Effect Factors, G & G_f

$n_1 = 100/H = 100/157.66 = 0.63 < 1\,Hz$ ∴ **Flexible**

$g_Q = g_v = 3.4$

$g_R = \sqrt{2\ln(3600 n_1)} + \frac{0.577}{\sqrt{2\ln(3600 n_1)}}$

$g_R = \sqrt{2\ln(3600(0.63))} + 0.577/\sqrt{2\ln(3600(0.63))} = 4.08$

$\bar{z} = 0.6h = 0.6(157.66) = 94.6' > z_{min} = 30'$

$I_{\bar{z}} = c\left(\frac{33}{\bar{z}}\right)^{1/6} = 0.30\left(\frac{33}{94.6}\right)^{1/6} = 0.252$

$L_{\bar{z}} = \ell\left(\frac{\bar{z}}{33}\right)^{\bar{\epsilon}} = 320\left(\frac{94.6}{33}\right)^{1/3.0} = 454.6'$

$Q = \sqrt{\frac{1}{1 + 0.63\left(\frac{B+h}{L_{\bar{z}}}\right)^{0.63}}}$

N/S: B = 282.33' L = 247.25' E/W: B = 247.25' L = 282.33'

$Q_{N/S} = 0.786$ $Q_{E/W} = 0.794$

$\bar{V}_{\bar{z}} = \bar{b}\left(\frac{\bar{z}}{33}\right)^{\bar{\alpha}} V\left(\frac{88}{60}\right) = 0.45\left(\frac{94.6}{33}\right)^{1/4}(95)\left(\frac{88}{60}\right) = 81.59$

$N_1 = \frac{n_1 L_{\bar{z}}}{V_{\bar{z}}} = \frac{0.63\,(454.6)}{81.59} = 3.51$

$R_n = \frac{7.47 N_1}{(1 + 10.3 N_1)^{5/3}} = \frac{7.47(3.51)}{(1 + 10.3(3.51))^{5/3}} = 0.0634$

$R_B = \frac{1}{n} - \frac{1}{2n^2}\left(1 - e^{-2n}\right)$ for $n > 0$

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PROJECT NO. ____ SHEET 3 OF 8
SUBJECT Wind Calcs
PREPARED BY DRH DATE 9/30/09 CHECKED BY ____ DATE ____

$\eta = 4.6 n_1 B / \bar{V}_{\bar{z}}$

N/S: $\eta = 4.6(0.63)(282.33)/81.59 = 10.03$

E/W: $\eta = 4.6(0.63)(247.25)/81.59 = 8.78$

R_B N/S: $\frac{1}{10.03} - \frac{1}{2(10.03)^2}\left(1 - e^{-2(10.03)}\right) = 0.0947$

R_B E/W: $\frac{1}{8.78} - \frac{1}{2(8.78)}\left(1 - e^{-2(8.78)}\right) = 0.0569$

$R_h = \frac{1}{\eta} - \frac{1}{2\eta^2}\left(1 - e^{-2\eta}\right)$ for $\eta > 0$

$\eta = 4.6 n_1 h / \bar{V}_{\bar{z}} = 4.6(0.63)(157.66)/81.59 = 5.6$

$R_h = \frac{1}{5.6} - \frac{1}{2(5.6)^2}\left(1 - e^{-2(5.6)}\right) = 0.163$

$R_L = \frac{1}{\eta} - \frac{1}{2\eta^2}\left(1 - e^{-2\eta}\right)$ for $\eta > 0$

$\eta = 15.4 n_1 L / \bar{V}_{z}$

N/S: $\eta = 15.4(0.63)(247.25)/81.59 = 29.4$

E/W: $\eta = 15.4(0.63)(282.33)/81.59 = 33.57$

R_L N/S $= \frac{1}{29.4} - \frac{1}{2(29.4)^2}\left(1 - e^{-2(29.4)}\right) = 0.0334$

R_L E/W $= \frac{1}{33.57} - \frac{1}{2(33.57)^2}\left(1 - e^{-2(33.57)}\right) = 0.0293$

$\beta = 2\%$ (concrete)

$R = \sqrt{\frac{1}{\beta} R_n R_h R_B (0.53 + 0.47 R_L)}$

$R_{N/S} = 0.0163$ $R_{E/W} = 0.0126$

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$$G_f = 0.925\left(\frac{1+1.7 I_{\bar{z}}\sqrt{g_Q^2 Q^2 + g_R^2 R^2}}{1+1.7 g_v I_{\bar{z}}}\right)$$

$$G_f\ N/S = 0.925\left(\frac{1+1.7(0.252)\sqrt{3.4^2(0.786)^2 + 4.08^2(0.063)^2}}{1+1.7(3.4)(0.252)}\right)$$

$$\boxed{G_f\ N/S = 0.873}$$

$$G_f\ E/W = 0.925\left(\frac{1+1.7(0.252)\sqrt{3.4^2(0.794)^2 + 4.08^2(0.1012)^2}}{1+1.7(3.4)(0.252)}\right)$$

$$\boxed{G_f\ E/W = 0.878}$$

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PROJECT NO. SHEET 5 OF 8
SUBJECT Wind Calcs
PREPARED BY DRH DATE 9/30/09 CHECKED BY DATE

Wind Calculations Cont. – MWFRS

Enclosed Building

Parapet Pressure

$q_p = 0.00256 K_z K_{zt} K_d V^2 I$ K_z @ 164.33 = 1.14 (N/S)
↳ Parapet ht N/S

$q_p = 0.00256 (1.14)(1.0)(0.85)(95^2)(1.15)$

$q_p = 25.75$ psf (N/S)

$q_p = 0.00256 (1.10)(1.0)(0.85)(95^2)(1.15)$ K_z @ 146.33 = 1.10
↳ Parapet ht E/W

$q_p = 24.90$ psf

$GC_{pn} = +1.5$ (windward) $GC_{pn} = -1.0$ (leeward)

$P_p = q_p GC_{pn}$

N/S:

Windward: $P_p = 25.75(1.5) = 38.63$ psf

Leeward: $P_p = 25.75(-1.0) = -25.75$ psf

E/W:

Windward: $P_p = 24.90(1.5) = 37.35$ psf

Leeward: $P_p = 24.90(-1.0) = -24.90$ psf

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PROJECT NO. SHEET 6 OF 8
SUBJECT Wind Calcs
PREPARED BY DRH DATE 9/30/09 CHECKED BY DATE

Wind Calculations Cont.

Pressure Coefficient C_p (Fig 6-6)

N/S:

Windward: $C_p = 0.8$

Leeward: $L/B = 247.25/282.33 = 0.876$

$C_p = -0.5$

E/W:

Windward: $C_p = 0.8$

Leeward: $L/B = 282.33/247.25 = 1.14$

$C_p = -0.47$

Pressure

$p_z = q_z G_f C_p - q_h(GC_{pi})$ (Windward)

$p_h = q_h G_f C_p - q_h(GC_{pi})$ (Leeward)

w/ $GC_{pi} = +0.18, -0.18$ for enclosed bldgs (Fig 6-5)

N/S:

Windward $p_z = (q_z)(0.873)(0.8) - 25.29(-0.18)$

$$p_z = (q_z)(0.6984) + 4.552$$

Leeward $p_h = (25.29)(0.873)(-0.5) - 4.552 = \boxed{-15.59 \text{ psf}}$

E/W:

Windward $p_z = (q_z)(0.878)(0.8) - 24.62(-0.18)$

$$p_z = (q_z)(0.7024) + 4.43$$

Leeward $p_h = (24.62)(0.878)(-0.47) - 4.43 = \boxed{-14.59 \text{ psf}}$

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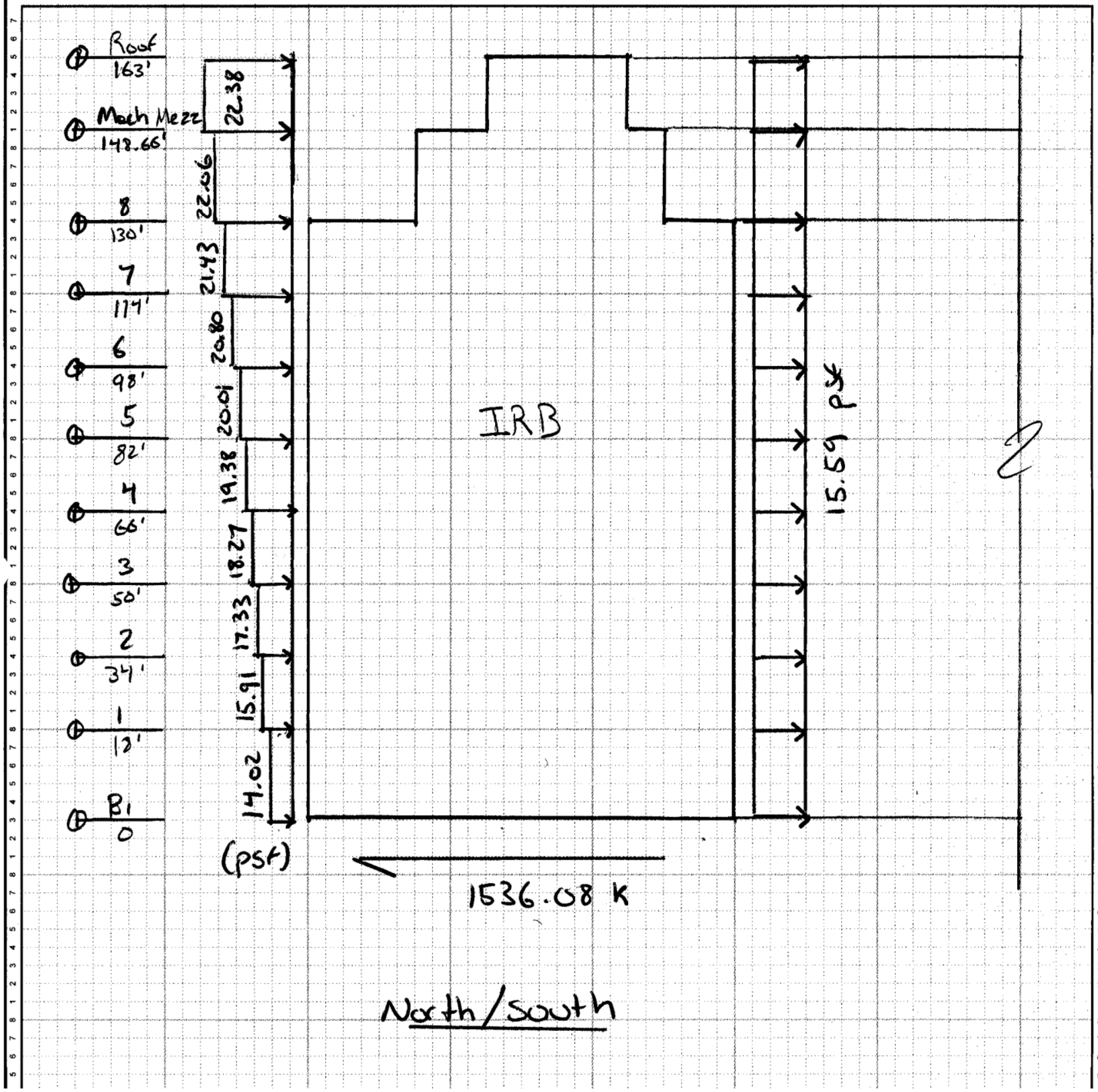
PROJECT NO. SHEET 7 OF 8
SUBJECT Wind Calcs
PREPARED BY DRH DATE 9/30/09 CHECKED BY DATE



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SUBJECT Wind Calcs

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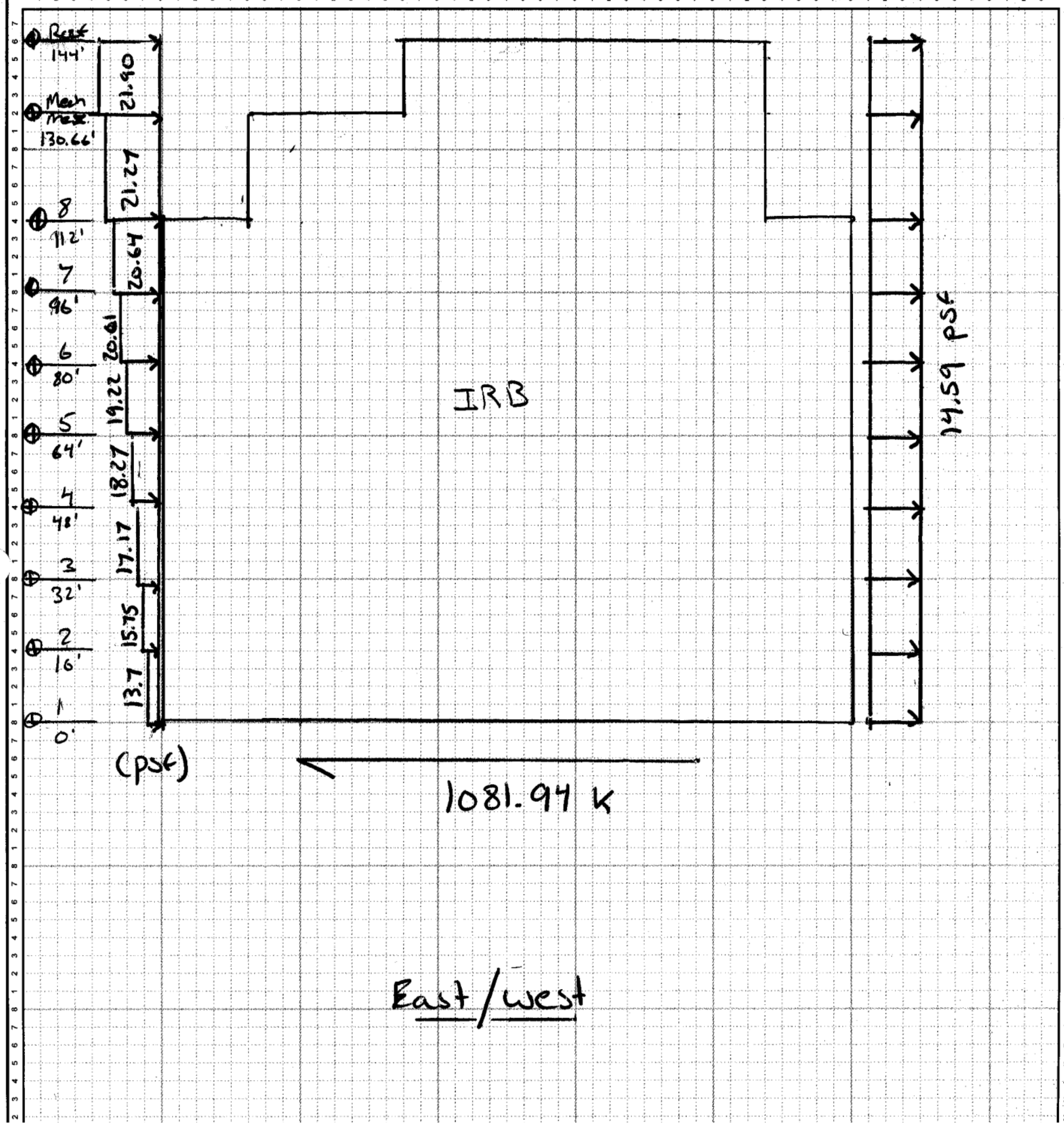

Appendix C - Seismic Calculations

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PROJECT NAME: UNC Imaging Research Building
PROJECT NO. ____ SHEET 1 OF 2
SUBJECT: Seismic Calculations
PREPARED BY: DRH DATE: 10/1/09 CHECKED BY ____ DATE ____

Seismic Calculations (Assuming rigid diapragm for Tech 1 analysis)

$S_S = 0.209\,g$; $S_1 = 0.081\,g$ (From USGS.gov)

$F_a = 1.2$; $F_v = 1.7$ Site Class C

$I_S = 1.25$

$S_{MS} = F_a S_S = 1.2(0.209) = 0.251$

$S_{M1} = F_v S_1 = 1.7(0.081) = 0.138$

Occupancy Cat.: III

$S_{DS} = 2/3\, S_{MS} = 2/3(0.251) = 0.167\,g$

$S_{D1} = 2/3\, S_{M1} = 2/3(0.138) = 0.092\,g$

Seismic Design Category based on Short Period Response Acceleration Parameter

SDC = B

Seismic Design Category based on 1-S period Response Acceleration Parameter

SDC = B

∴ Seismic Design Category → B

Determine Structure fundamental period, T

$T_S = S_{D1}/S_{DS} = 0.092/0.167 = 0.551$

$T_a = C_t h_n^x = 0.02(162)^{0.75} = 0.92\,s$

↳ ordinary Reinforced Concrete Shear Walls

$T_L = 8\,s$

$T = T_a = \underline{0.92} < T_{max} = C_u T_a = 1.7(0.92) = 1.56$

$T = 0.92 < 3.5 T_s = 3.5(0.551) = 1.93$

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PROJECT NO. SHEET 2 OF 2
SUBJECT Seismic Calcs
PREPARED BY DRH DATE 10/1/09 CHECKED BY DATE

Seismic Calculations Cont.

Determination of Type 2 Horizontal Irregularity - Re-Entrant Corners

West elevation: $\frac{247.25-114.25}{247.25} = 0.54(100) = 54\%$

North elevation: $\frac{179.75}{282.33} = 0.64(100) = 64\%$

∴ Type 2 Horizontal Irregularity - Reentrant Corners

- ASCE 7-05 requires Modal Response Spectrum Analysis or seismic response history procedure.
- For Tech 1 - Using Equivalent Lateral Force Procedure, differences will be noted in report

$$C_s = \min \begin{cases} \frac{S_{DS}}{\left(\frac{R}{I}\right)} = \frac{0.167}{\left(\frac{5}{1.25}\right)} = 0.04175 \\ \frac{S_{D1}}{T(R/I)} = \frac{0.092}{0.92(5/1.25)} = \boxed{0.025} \geq 0.01 \\ \frac{S_{D1}T_L}{T^2(R/I)} = \frac{0.092(8)}{(0.92)^2(5/1.25)} = 0.217 \end{cases}$$

$V = C_s W = 0.025(72{,}705.68) = 1817.6^k$

$k = 1.21$ (From interpolation)

$W_x h_x^k$ = Varies $\sum w_i h_i^k =$

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PROJECT NAME UNC - IRB

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SUBJECT Seismic Calcs

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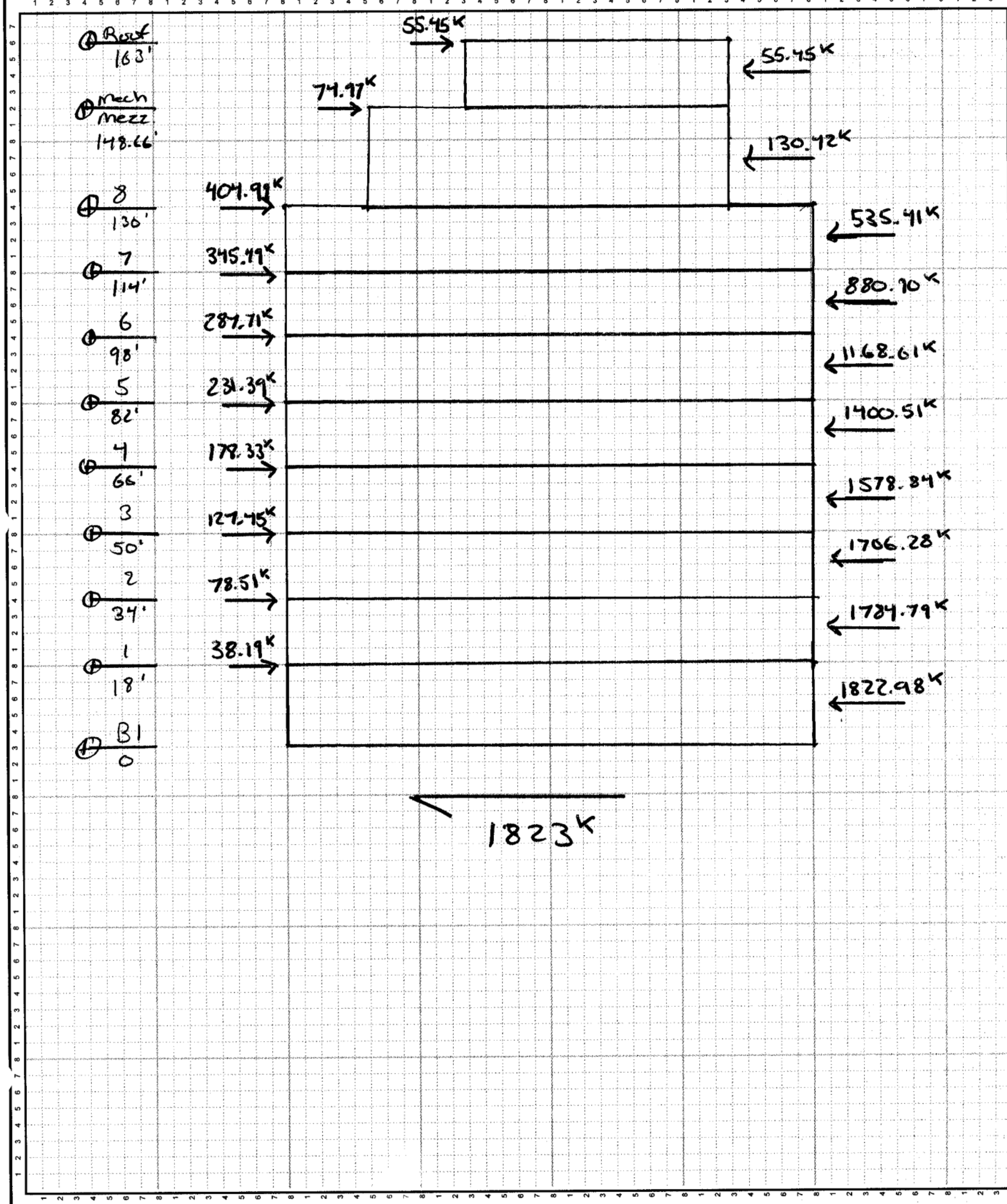

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Appendix D-Rigidity, Relative Stiffness, COR Calculations

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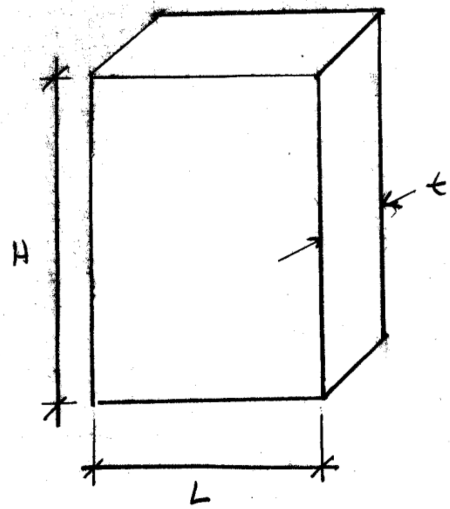
Tech 3 | UNC - IRB | Rigidity



Rigidity R

$$R = \frac{Et}{4\left(\frac{h}{L}\right)^3 + 3\left(\frac{h}{L}\right)}$$

$E = 57{,}000\sqrt{f'c}$

$= 57{,}000\sqrt{7000} = 4.769 \times 10^6$

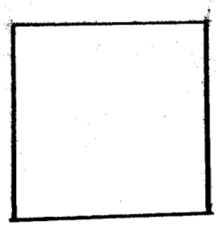
$t = 6'', 12''$ or $16''$

h = height from base to top of each level

L = length of wall element

Example Calculations

SW-1 $t = 16''$ $L = 408''$ $H = 216''$



Basement (2)

Found/sub basement (1)

$$R_{1-1} = \frac{(4.769 \times 10^3)(16'')}{4\left(\frac{216}{408}\right)^3 + 3\left(\frac{216}{408}\right)} = 34{,}973.6$$

From Excel → Total Rigidity = 233,971

$$\text{Relative Stiffness } \% = \frac{R}{\Sigma R} = \frac{34{,}973.6}{233{,}971} = 14.95\%$$

Center of Rigidity

Sample Calculation: (second Floor X coord)

$$\frac{\Sigma (Rd)}{\Sigma R} = \frac{39,940.24(-96.5") + [4244.93(2)(221")] + (5287.17 + 4280.61)\,275.5" + [7154.03 + (2)(4244.93)] \cdot (410") + 2682.76(681") + [7154.03 + 3695.38] \cdot (794") + [3965.38 + 18,402.79](938") + (18402.79)(2539.5") + 39,344.21(3051.5") + 39,940.24(3223.5")}{207,499.35}$$

↑ From Excel

$$X\text{-coord} = 1610.884"$$

$$= 134.24'$$

The rest of the Center of Rigidity Calculations were done using excel and can be found in spreadsheet below.

Note: Distances to the shear walls were found using AutoCAD.

Tech 3 | UNC - IRB | Shear Distribution

Controlling Load Cases

- North/South: $1.2D + 1.6W + L + 0.5L_r$
- East/West: $0.9D + 1.0E$

· Direct shear = (factored story force) × $\frac{\text{(relative stiff \%)}}{100}$

Torsional Shear:

$$V_i = \frac{V_{tot}\, e\, d_i R_i}{J}$$

V_{tot} = story shear
e = distance from COM to COR
d_i = distance from element i to COR
R_i = relative stiffness of element
J = torsional moment of inertia = $\Sigma (R \cdot d_i^2)$

Sample Calculation

Ex. SW-2 Supporting Floor 7 (N/S)

Factored Story Shear = 1253.93^k

· COR x: $(134.24')(12) = 1610.88''$

COM x: $(100.65)(12) = 1207.8''$

$e = 1610.88 - 1207.8 = 403.08''$

Location of SW-2: X-coordinate = 794"

$d_i = 1610.88 - 794 = 816.88''$

$J = \Sigma(R \cdot d_i)^2 = 2549011.1$ (From Excel)

$R_i = 0.03$

$$V_i = \frac{(1253.93)(403.08)(816.98)(0.03)}{2549011.1} = 5.59^K$$

East-West Walls (Sub Basement to Basement, Basement to First Floor)									
Wall	Thickness, t (inches)	Height, H (inches)	Length, L (inches)	Modulus of Elasticity, E (ksi)	Rigidity, R	Relative Stiffness %	Distance from Reference Point	R*d	COR (Y-Coord.) (inches)
SW-1	16.00	216.00	408.00	4769.00	34973.56	14.33	2538.50	88780373.15	
SW-4	16.00	216.00	402.00	4769.00	34179.61	14.01	2379.50	81330379.63	
SW-6	12.00	216.00	199.00	4769.00	6836.07	2.80	2181.50	14912890.79	
SW-10	12.00	216.00	199.00	4769.00	6836.07	2.80	1049.00	7171039.39	
SW-12	16.00	216.00	382.00	4769.00	31537.23	12.93	918.00	28951176.14	
SW-14	16.00	216.00	382.00	4769.00	31537.23	12.93	786.00	24788261.93	
SW-16	16.00	216.00	382.00	4769.00	31537.23	12.93	662.50	20893414.16	
SW-18	16.00	216.00	382.00	4769.00	31537.23	12.93	542.00	17093178.07	
SW-19	12.00	216.00	153.00	4769.00	3694.43	1.51	918.00	3391489.92	
SW-21	12.00	216.00	153.00	4769.00	3694.43	1.51	786.00	2903824.70	
SW-23	12.00	216.00	144.00	4769.00	3179.33	1.30	542.00	1723198.67	
SW-24	12.00	216.00	144.00	4769.00	3179.33	1.30	286.00	909289.33	
SW-26	12.00	216.00	140.50	4769.00	2988.98	1.23	542.00	1620026.57	
SW-28	12.00	216.00	140.50	4769.00	2988.98	1.23	286.00	854847.97	
SW-29	16.00	216.00	154.00	4769.00	5005.18	2.05	918.00	4594758.15	
SW-31	16.00	216.00	172.00	4769.00	6527.59	2.68	542.00	3537953.28	
SW-33	12.00	216.00	154.00	4769.00	3753.89	1.54	638.00	2394980.15	
					243986.38	100.00	∑R*d =	305851081.99	1253.56

East-West Walls (Floors 1-2,2-3,3-4,4-5,5-6,6-7,7-8)									
Wall	Thickness, t (inches)	Height, H (inches)	Length, L (inches)	Modulus of Elasticity, E (ksi)	Rigidity, R	Relative Stiffness %	Distance from Reference Point (inches)	R*d	COR (Y-Coord.) (inches)
SW-1	16.00	192.00	408.00	4769.00	41727.69	14.00	2538.50	105925736.84	
SW-4	16.00	192.00	402.00	4769.00	40834.10	13.70	2379.50	97164751.14	
SW-6	12.00	192.00	199.00	4769.00	8821.90	2.96	2181.50	19244981.14	
SW-10	12.00	192.00	199.00	4769.00	8821.90	2.96	1049.00	9254176.12	
SW-12	16.00	192.00	382.00	4769.00	37853.94	12.70	918.00	34749915.25	
SW-14	16.00	192.00	382.00	4769.00	37853.94	12.70	786.00	29753195.41	
SW-16	16.00	192.00	382.00	4769.00	37853.94	12.70	662.50	25078234.04	
SW-18	16.00	192.00	382.00	4769.00	37853.94	12.70	542.00	20516834.49	
SW-19	12.00	192.00	153.00	4769.00	4904.08	1.65	918.00	4501941.00	
SW-21	12.00	192.00	153.00	4769.00	4904.08	1.65	786.00	3854603.08	
SW-23	12.00	192.00	144.00	4769.00	4244.93	1.42	542.00	2300754.26	
SW-24	12.00	192.00	144.00	4769.00	4244.93	1.42	286.00	1214051.14	
SW-26	12.00	192.00	140.50	4769.00	3999.86	1.34	542.00	2167923.61	
SW-28	12.00	192.00	140.50	4769.00	3999.86	1.34	286.00	1143959.69	
SW-29	16.00	192.00	154.00	4769.00	6639.73	2.23	918.00	6095268.14	
SW-31	16.00	192.00	172.00	4769.00	8561.24	2.87	542.00	4640193.61	
SW-33	12.00	192.00	154.00	4769.00	4979.79	1.67	638.00	3177108.72	
					298099.85	100.00	∑R*d =	370783627.69	1243.82

East-West Walls (8-Mech. Mezz)									
Wall	Thickness, t (inches)	Height, H (inches)	Length, L (inches)	Modulus of Elasticity, E (ksi)	Rigidity, R	Relative Stiffness %	Distance from Reference Point (inches)	R*d	COR (Y-Coord.) (inches)
SW-1	16.00	192.00	408.00	4769.00	41727.69	16.03	2538.50	105925736.84	
SW-4	16.00	192.00	402.00	4769.00	40834.10	15.69	2379.50	97164751.14	
SW-6	12.00	192.00	199.00	4769.00	8821.90	3.39	2181.50	19244981.14	
SW-10	12.00	192.00	199.00	4769.00	8821.90	3.39	1049.00	9254176.12	
SW-12	16.00	192.00	382.00	4769.00	37853.94	14.55	918.00	34749915.25	
SW-14	16.00	192.00	382.00	4769.00	37853.94	14.55	786.00	29753195.41	
SW-18	16.00	192.00	382.00	4769.00	37853.94	14.55	542.00	20516834.49	
SW-19	12.00	192.00	153.00	4769.00	4904.08	1.88	918.00	4501941.00	
SW-21	12.00	192.00	153.00	4769.00	4904.08	1.88	786.00	3854603.08	
SW-23	12.00	192.00	144.00	4769.00	4244.93	1.63	542.00	2300754.26	
SW-24	12.00	192.00	144.00	4769.00	4244.93	1.63	286.00	1214051.14	
SW-26	12.00	192.00	140.50	4769.00	3999.86	1.54	542.00	2167923.61	
SW-28	12.00	192.00	140.50	4769.00	3999.86	1.54	286.00	1143959.69	
SW-29	16.00	192.00	154.00	4769.00	6639.73	2.55	918.00	6095268.14	
SW-31	16.00	192.00	172.00	4769.00	8561.24	3.29	542.00	4640193.61	
SW-33	12.00	192.00	154.00	4769.00	4979.79	1.91	638.00	3177108.72	
					260245.91	100.00	∑R*d =	345705393.65	1328.38

East-West Walls (Mech Mezz to Roof)									
Wall	Thickness, t (inches)	Height, H (inches)	Length, L (inches)	Modulus of Elasticity, E (ksi)	Rigidity, R	Relative Stiffness %	Distance from Reference Point (inches)	R*d	COR (Y-Coord.) (inches)
SW-1	16.00	168.00	408.00	4769.00	50380.53	17.74	2538.50	127890985.05	
SW-4	16.00	168.00	402.00	4769.00	49365.91	17.38	2379.50	117466173.88	
SW-12	16.00	168.00	382.00	4769.00	45976.75	16.19	918.00	42206656.85	
SW-14	16.00	168.00	382.00	4769.00	45976.75	16.19	786.00	36137725.80	
SW-18	16.00	168.00	382.00	4769.00	45976.75	16.19	542.00	24919398.71	
SW-19	12.00	168.00	153.00	4769.00	6662.40	2.35	918.00	6116082.94	
SW-21	12.00	168.00	153.00	4769.00	6662.40	2.35	786.00	5236646.17	
SW-23	12.00	168.00	144.00	4769.00	5808.86	2.05	542.00	3148400.57	
SW-29	16.00	168.00	154.00	4769.00	9013.19	3.17	918.00	8274108.35	
SW-31	16.00	168.00	172.00	4769.00	11461.18	4.03	542.00	6211961.16	
SW-33	12.00	168.00	154.00	4769.00	6759.89	2.38	638.00	4312811.38	
					284044.61	100.00	∑R*d =	381920950.85	1344.58

North-South Walls (Sub Basement to Basement, Basement to First Floor)									
Wall	Thickness, t (inches)	Height, H (inches)	Length, L (inches)	Modulus of Elasticity, E (ksi)	Rigidity, R	Relative Stiffness %	Distance from Reference Point (inches)	R*d	COR (X-Coord.) (inches)
SW-2	16.00	216.00	159.00	4769.00	5410.16	3.22	794.00	4295668.13	
SW-3	6.00	216.00	159.00	4769.00	2028.81	1.21	681.00	1381619.96	
SW-5	16.00	216.00	159.00	4769.00	5410.16	3.22	410.00	2218166.16	
SW-7	12.00	216.00	144.00	4769.00	3179.33	1.89	410.00	1303526.67	
SW-8	12.00	216.00	144.00	4769.00	3179.33	1.89	221.00	702632.67	
SW-9	12.00	216.00	144.00	4769.00	3179.33	1.89	410.00	1303526.67	
SW-11	12.00	216.00	144.00	4769.00	3179.33	1.89	221.00	702632.67	
SW-13	16.00	216.00	140.00	4769.00	3949.67	2.35	275.50	1088133.63	
SW-15	16.00	216.00	396.00	4769.00	33386.14	19.87	-96.50	-3221762.07	
SW-17	16.00	216.00	128.50	4769.00	3173.91	1.89	275.50	874413.43	
SW-20	12.00	216.00	140.00	4769.00	2962.25	1.76	938.00	2778591.69	
SW-22	12.00	216.00	140.00	4769.00	2962.25	1.76	794.00	2352027.51	
SW-25	12.00	216.00	292.00	4769.00	14909.83	8.87	938.00	13985415.87	
SW-27	12.00	216.00	292.00	4769.00	14909.83	8.87	2539.50	37863500.65	
SW-30	16.00	216.00	396.00	4769.00	33386.14	19.87	3223.50	107620207.58	
SW-32	16.00	216.00	392.00	4769.00	32857.47	19.55	3051.50	100264584.73	
					168063.95	100.00	∑R*d =	275512885.95	1639.33

North-South Walls (Floors 1-2,2-3,3-4,4-5,5-6,6-7,7-8)									
Wall	Thickness, t (inches)	Height, H (inches)	Length, L (inches)	Modulus of Elasticity, E (ksi)	Rigidity, R	Relative Stiffness %	Distance from Reference Point (inches)	R*d	COR (X-Coord.) (inches)
SW-2	16.00	192.00	159.00	4769.00	7154.03	3.45	794.00	5680298.70	
SW-3	6.00	192.00	159.00	4769.00	2682.76	1.29	681.00	1826960.05	
SW-5	16.00	192.00	159.00	4769.00	7154.03	3.45	410.00	2933151.72	
SW-7	12.00	192.00	144.00	4769.00	4244.93	2.05	410.00	1740422.97	
SW-8	12.00	192.00	144.00	4769.00	4244.93	2.05	221.00	938130.43	
SW-9	12.00	192.00	144.00	4769.00	4244.93	2.05	410.00	1740422.97	
SW-11	12.00	192.00	144.00	4769.00	4244.93	2.05	221.00	938130.43	
SW-13	16.00	192.00	140.00	4769.00	5287.17	2.55	275.50	1456616.40	
SW-15	16.00	192.00	396.00	4769.00	39940.24	19.25	-96.50	-3854232.78	
SW-17	16.00	192.00	128.50	4769.00	4280.61	2.06	275.50	1179306.85	
SW-20	12.00	192.00	140.00	4769.00	3965.38	1.91	938.00	3719526.82	
SW-22	12.00	192.00	140.00	4769.00	3965.38	1.91	794.00	3148512.04	
SW-25	12.00	192.00	292.00	4769.00	18402.79	8.87	938.00	17261817.09	
SW-27	12.00	192.00	292.00	4769.00	18402.79	8.87	2539.50	46733885.39	
SW-30	16.00	192.00	396.00	4769.00	39940.24	19.25	3223.50	128747350.99	
SW-32	16.00	192.00	392.00	4769.00	39344.21	18.96	3051.50	120058851.31	
					207499.35	100.00	∑R*d =	334249151.37	1610.84

North-South Walls (8-Mech Mezz.)									
Wall	Thickness, t (inches)	Height, H (inches)	Length, L (inches)	Modulus of Elasticity, E (ksi)	Rigidity, R	Relative Stiffness %	Distance from Reference Point (inches)	R*d	COR (X-Coord.) (inches)
SW-2	16.00	192.00	159.00	4769.00	7154.03	3.45	794.00	5680298.70	
SW-3	6.00	192.00	159.00	4769.00	2682.76	1.29	681.00	1826960.05	
SW-5	16.00	192.00	159.00	4769.00	7154.03	3.45	410.00	2933151.72	
SW-7	12.00	192.00	144.00	4769.00	4244.93	2.05	410.00	1740422.97	
SW-8	12.00	192.00	144.00	4769.00	4244.93	2.05	221.00	938130.43	
SW-9	12.00	192.00	144.00	4769.00	4244.93	2.05	410.00	1740422.97	
SW-11	12.00	192.00	144.00	4769.00	4244.93	2.05	221.00	938130.43	
SW-13	16.00	192.00	140.00	4769.00	5287.17	2.55	275.50	1456616.40	
SW-15	16.00	192.00	396.00	4769.00	39940.24	19.25	-96.50	-3854232.78	
SW-17	16.00	192.00	128.50	4769.00	4280.61	2.06	275.50	1179306.85	
SW-20	12.00	192.00	140.00	4769.00	3965.38	1.91	938.00	3719526.82	
SW-22	12.00	192.00	140.00	4769.00	3965.38	1.91	794.00	3148512.04	
SW-25	12.00	192.00	292.00	4769.00	18402.79	8.87	938.00	17261817.09	
SW-27	12.00	192.00	292.00	4769.00	18402.79	8.87	2539.50	46733885.39	
SW-30	16.00	192.00	396.00	4769.00	39940.24	19.25	3223.50	128747350.99	
SW-32	16.00	192.00	392.00	4769.00	39344.21	18.96	3051.50	120058851.31	
					207499.35	100.00	∑R*d =	334249151.37	1610.84

North-South Walls (Mech Mezz to Roof)									
Wall	Thickness, t (inches)	Height, H (inches)	Length, L (inches)	Modulus of Elasticity, E (ksi)	Rigidity, R	Relative Stiffness %	Distance from Reference Point (inches)	R*d	COR (X-Coord.) (inches)
SW-2	16.00	168.00	159.00	4769.00	9673.15	4.90	794.00	7680477.99	
SW-3	6.00	168.00	159.00	4769.00	3627.43	1.84	681.00	2470279.68	
SW-5	16.00	168.00	159.00	4769.00	9673.15	4.90	410.00	3965989.90	
SW-11	12.00	168.00	144.00	4769.00	5808.86	2.95	221.00	1283757.43	
SW-13	16.00	168.00	140.00	4769.00	7258.75	3.68	275.50	1999786.15	
SW-15	16.00	168.00	396.00	4769.00	48350.26	24.51	-96.50	-4665800.43	
SW-17	16.00	168.00	128.50	4769.00	5932.99	3.01	275.50	1634539.47	
SW-20	12.00	168.00	140.00	4769.00	5444.06	2.76	938.00	5106531.96	
SW-22	12.00	168.00	140.00	4769.00	5444.06	2.76	794.00	4322586.76	
SW-30	16.00	168.00	396.00	4769.00	48350.26	24.51	3223.50	155857074.61	
SW-32	16.00	168.00	392.00	4769.00	47672.63	24.17	3051.50	145473020.05	
					197235.61	100.00	∑R*d =	325128243.57	1648.43

Appendix E- Shear Wall Strength Check Calculations

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Tech 3 | UNC-IRB | Strength Check

Shear Strength

ACI 318-08 § 21.9.4

"structural walls shall not exceed Vn:"

$\phi V_n = \phi A_{cv}(\alpha_c \lambda \sqrt{f'c} + \rho_t f_y)$

$\phi = 0.75$

A_{cv} = gross area of concrete

α_c = coefficient = 2.0 if $h_w/\ell_w \geq 2.0$

$\rho_t = \frac{A_v}{s \cdot h}$

s = spacing of shear reinf

h = thickness of wall

Sample Calculation

Ex. SW-2 (N/S) supporting Floor 6 (Table 7)

Direct Shear = 9.07 + 9.23 + 9.24 + 6.84 = 34.38

Torsional Shear = 5.59^k (from Table 6)

$V_u = 34.38 + 5.59 = 39.97^k$

Vert Reinf: (2)#7 @ 18"

$\rho_t = \frac{(2)(0.60)}{(18)(16)} = 0.004167$

A_{cv} = (159" in length)(16") = 2544 in²

$\phi V_n = 0.75(2544)[(2)\sqrt{7000}) + 0.004167(60{,}000)]$

$\phi V_n = 796.3^k$

$V_u < \phi V_n$ ∴ OK

Ex. SW-10 (E/W) Supporting Floor 6

Direct Shear = 43.88 + 51.43 + 9.52 + 8.07 = 112.9

Torsional Shear = 0.64^k

$V_u = 113.54^k$

Vert Reinf: (2) #7 @ 12"

$$\rho_t = \frac{(2)(0.6)}{(12)(12)} = 0.008333$$

$A_{cv} = (199")(12") = 2388"$

$\phi V_n = 0.75(2388)\left[(2)\sqrt{7000} + 0.008333(60000)\right]$

$\phi V_n = 1195.2^k$

$V_u < \phi V_n \therefore$ ok

Appendix F- Drift and Story Displacements

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Story Displacements

RAM Frame v13.0
DataBase: UNCIRB
Building Code: IBC

CRITERIA:

Rigid End Zones:		Ignore Effects	
Member Force Output:		At Face of Joint	
P-Delta:	Yes	Scale Factor:	1.00
Ground Level:	BASEMENT 1		

Wall Mesh Criteria :

Max. Allowed Distance between Nodes (ft) : 8.00

LOAD CASE DEFINITIONS:

D	DeadLoad	RAMUSER
Lp	PosLiveLoad	RAMUSER
Ln	NegLiveLoad	RAMUSER
Rfp	PosRoofLiveLoad	RAMUSER
Rfn	NegRoofLiveLoad	RAMUSER
W1	Wind	Wind_IBC06_1_X
W2	Wind	Wind_IBC06_1_Y
W3	Wind	Wind_IBC06_2_X+E
W4	Wind	Wind_IBC06_2_X-E
W5	Wind	Wind_IBC06_2_Y+E
W6	Wind	Wind_IBC06_2_Y-E
W7	Wind	Wind_IBC06_3_X+Y
W8	Wind	Wind_IBC06_3_X-Y
W9	Wind	Wind_IBC06_4_X+Y_CW
W10	Wind	Wind_IBC06_4_X+Y_CCW
W11	Wind	Wind_IBC06_4_X-Y_CW
W12	Wind	Wind_IBC06_4_X-Y_CCW
E1	Seismic Force	EQ_IBC06_X_+E_F
E2	Seismic Force	EQ_IBC06_X_-E_F
E3	Seismic Force	EQ_IBC06_Y_+E_F
E4	Seismic Force	EQ_IBC06_Y_-E_F
E5	Seismic Drift	EQ_IBC06_X_+E_Drft
E6	Seismic Drift	EQ_IBC06_X_-E_Drft
E7	Seismic Drift	EQ_IBC06_Y_+E_Drft
E8	Seismic Drift	EQ_IBC06_Y_-E_Drft

Level: Penthouse Roof, Diaph: 1

Center of Mass (ft): (95.50, 90.57)

LdC	Disp X in	Disp Y in	Theta Z rad
D	0.25156	0.14269	0.00010
Lp	0.16809	0.08504	0.00005
Ln	0.00019	0.00048	0.00000
Rfp	0.00731	0.00572	0.00000
Rfn	0.00001	0.00003	0.00000
W1	0.64504	-0.00221	-0.00002
W2	0.01793	0.93141	0.00014
W3	0.47678	-0.00697	-0.00007
W4	0.49077	0.00365	0.00004

Story Displacements

RAM Frame v13.0
DataBase: UNCIRB
Building Code: IBC

W3	0.42441	0.00102	-0.00006
W4	0.44485	-0.00133	0.00004
W5	0.03953	0.61827	0.00019
W6	-0.00077	0.62266	-0.00000
W7	0.45401	0.62031	0.00008
W8	0.41525	-0.62062	-0.00011
W9	0.31773	0.46776	-0.00005
W10	0.36329	0.46271	0.00017
W11	0.28866	-0.46294	-0.00019
W12	0.33422	-0.46799	0.00003
E1	1.12327	-0.00141	0.00005
E2	1.14142	-0.00336	0.00013
E3	0.02049	1.08564	0.00010
E4	-0.00401	1.08823	-0.00002
E5	0.97954	-0.00118	0.00004
E6	0.99535	-0.00286	0.00012
E7	0.01823	0.96594	0.00009
E8	-0.00358	0.96822	-0.00002

Level: PENT/ROOF, Diaph: 1

Center of Mass (ft): (100.45, 78.96)

LdC	**Disp X** **in**	**Disp Y** **in**	**Theta Z** **rad**
D	0.19685	0.10897	0.00007
Lp	0.12981	0.06480	0.00004
Ln	0.00016	0.00036	0.00000
Rfp	0.00502	0.00391	0.00000
Rfn	0.00001	0.00002	0.00000
W1	0.48823	-0.00274	-0.00001
W2	0.02783	0.71958	0.00011
W3	0.35485	-0.00756	-0.00005
W4	0.37750	0.00345	0.00003
W5	0.04311	0.55062	0.00016
W6	-0.00136	0.52876	-0.00000
W7	0.38705	0.53763	0.00007
W8	0.34530	-0.54174	-0.00009
W9	0.26511	0.39090	-0.00004
W10	0.31546	0.41555	0.00015
W11	0.23380	-0.41863	-0.00016
W12	0.28415	-0.39398	0.00003
E1	0.94915	0.00431	0.00004
E2	0.96918	0.01409	0.00011
E3	0.02171	0.93618	0.00008
E4	-0.00530	0.92295	-0.00002
E5	0.82725	0.00379	0.00003
E6	0.84470	0.01232	0.00010
E7	0.01931	0.83254	0.00007
E8	-0.00472	0.82075	-0.00002

Story Displacements

RAM Frame v13.0
DataBase: UNCIRB
Building Code: IBC

E6	0.70853	0.00934	0.00008
E7	0.01545	0.70275	0.00006
E8	-0.00507	0.69334	-0.00002

Level: FLOOR 6, Diaph: 1

Center of Mass (ft): (100.65, 78.71)

LdC	Disp X in	Disp Y in	Theta Z rad
D	0.12964	0.06975	0.00005
Lp	0.08468	0.04145	0.00003
Ln	0.00011	0.00024	0.00000
Rfp	0.00294	0.00230	0.00000
Rfn	0.00000	0.00001	0.00000
W1	0.33495	-0.00227	-0.00001
W2	0.01781	0.49887	0.00007
W3	0.24321	-0.00498	-0.00004
W4	0.25921	0.00156	0.00002
W5	0.02896	0.38068	0.00011
W6	-0.00224	0.36763	-0.00001
W7	0.26457	0.37245	0.00005
W8	0.23785	-0.37586	-0.00006
W9	0.18073	0.27199	-0.00003
W10	0.21613	0.28668	0.00010
W11	0.16069	-0.28924	-0.00011
W12	0.19609	-0.27455	0.00002
E1	0.64489	0.00154	0.00003
E2	0.65886	0.00741	0.00008
E3	0.01309	0.64486	0.00005
E4	-0.00572	0.63691	-0.00002
E5	0.56129	0.00138	0.00002
E6	0.57343	0.00651	0.00007
E7	0.01164	0.57273	0.00005
E8	-0.00507	0.56564	-0.00001

Level: FLOOR 5, Diaph: 1

Center of Mass (ft): (100.69, 78.71)

LdC	Disp X in	Disp Y in	Theta Z rad
D	0.09879	0.05198	0.00004
Lp	0.06397	0.03104	0.00002
Ln	0.00008	0.00018	0.00000
Rfp	0.00212	0.00166	0.00000
Rfn	0.00000	0.00001	0.00000
W1	0.26109	-0.00198	-0.00001
W2	0.01313	0.39131	0.00005
W3	0.18953	-0.00381	-0.00003
W4	0.20210	0.00083	0.00002
W5	[illegible]	[illegible]	[illegible]

Story Displacements

RAM Frame v13.0
DataBase: UNCIRB
Building Code: IBC

W3	0.13890	-0.00278	-0.00002
W4	0.14820	0.00029	0.00001
W5	0.01574	0.21970	0.00006
W6	-0.00227	0.21353	-0.00000
W7	0.15029	0.21537	0.00003
W8	0.13681	-0.21786	-0.00003
W9	0.10248	0.15807	-0.00002
W10	0.12296	0.16499	0.00006
W11	0.09237	-0.16686	-0.00006
W12	0.11285	-0.15993	0.00001
E1	0.36143	-0.00016	0.00001
E2	0.36935	0.00269	0.00004
E3	0.00597	0.36721	0.00003
E4	-0.00469	0.36335	-0.00001
E5	0.31396	-0.00010	0.00001
E6	0.32084	0.00239	0.00004
E7	0.00531	0.32555	0.00003
E8	-0.00413	0.32210	-0.00001

Level: FLOOR 3, Diaph: 1

Center of Mass (ft): (100.74, 78.62)

LdC	Disp X in	Disp Y in	Theta Z rad
D	0.04594	0.02264	0.00002
Lp	0.02900	0.01384	0.00001
Ln	0.00004	0.00008	0.00000
Rfp	0.00087	0.00068	0.00000
Rfn	0.00000	0.00000	0.00000
W1	0.12810	-0.00130	-0.00000
W2	0.00548	0.19463	0.00003
W3	0.09294	-0.00191	-0.00002
W4	0.09921	-0.00004	0.00001
W5	0.01016	0.14787	0.00004
W6	-0.00194	0.14408	-0.00000
W7	0.10018	0.14500	0.00002
W8	0.09197	-0.14695	-0.00002
W9	0.06825	0.10663	-0.00001
W10	0.08203	0.11087	0.00004
W11	0.06209	-0.11233	-0.00004
W12	0.07587	-0.10809	0.00001
E1	0.23867	-0.00053	0.00001
E2	0.24393	0.00125	0.00003
E3	0.00333	0.24445	0.00002
E4	-0.00373	0.24203	-0.00001
E5	0.20709	-0.00044	0.00001
E6	0.21164	0.00113	0.00003
E7	0.00297	0.21649	0.00002
E8	-0.00329	0.21432	-0.00001

Story Displacements

RAM Frame v13.0
DataBase: UNCIRB
Building Code: IBC

E6	0.11964	0.00047	0.00001
E7	0.00099	0.12354	0.00001
E8	-0.00220	0.12226	-0.00000

Level: FLOOR 1, Diaph: 1

Center of Mass (ft): (98.24, 110.88)

LdC	Disp X in	Disp Y in	Theta Z rad
D	0.00881	0.00472	0.00000
Lp	0.00572	0.00310	0.00000
Ln	0.00001	0.00002	0.00000
Rfp	0.00016	0.00014	0.00000
Rfn	0.00000	0.00000	0.00000
W1	0.03162	-0.00051	-0.00000
W2	-0.00090	0.04835	0.00001
W3	0.02380	-0.00079	-0.00000
W4	0.02363	0.00002	0.00000
W5	-0.00084	0.03706	0.00001
W6	-0.00051	0.03546	-0.00000
W7	0.02304	0.03588	0.00000
W8	0.02439	-0.03664	-0.00001
W9	0.01747	0.02601	-0.00000
W10	0.01709	0.02781	0.00001
W11	0.01848	-0.02838	-0.00001
W12	0.01811	-0.02658	0.00000
E1	0.05589	-0.00021	0.00000
E2	0.05577	0.00051	0.00001
E3	0.00099	0.05878	0.00001
E4	-0.00082	0.05780	-0.00000
E5	0.04838	-0.00018	0.00000
E6	0.04827	0.00045	0.00001
E7	-0.00087	0.05194	0.00000
E8	-0.00072	0.05107	-0.00000

Level: LANDING/RAMP, Diaph: 1

Center of Mass (ft): (86.16, 12.20)

LdC	Disp X in	Disp Y in	Theta Z rad
D	0.00976	0.00322	0.00000
Lp	0.00629	0.00207	0.00000
Ln	0.00001	0.00001	0.00000
Rfp	0.00013	0.00011	0.00000
Rfn	0.00000	0.00000	0.00000
W1	0.02360	-0.00058	-0.00000
W2	0.00483	0.03759	0.00001
W3	0.01517	-0.00018	-0.00000
W4	0.02023	-0.00069	0.00000
W5	0.00846	0.03772	0.00001

Story Displacements

RAM Frame v13.0
DataBase: UNCIRB
Building Code: IBC

W3	0.00000	0.00000	0.00000
W4	0.00000	0.00000	0.00000
W5	0.00000	0.00000	0.00000
W6	0.00000	0.00000	0.00000
W7	0.00000	0.00000	0.00000
W8	0.00000	0.00000	0.00000
W9	0.00000	0.00000	0.00000
W10	0.00000	0.00000	0.00000
W11	0.00000	0.00000	0.00000
W12	0.00000	0.00000	0.00000
E1	0.00000	0.00000	0.00000
E2	0.00000	0.00000	0.00000
E3	0.00000	0.00000	0.00000
E4	0.00000	0.00000	0.00000
E5	0.00000	0.00000	0.00000
E6	0.00000	0.00000	0.00000
E7	0.00000	0.00000	0.00000
E8	0.00000	0.00000	0.00000

Appendix G-Overturning Calculations

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Tech 3	UNC - IRB	Overturning	

N/S : M_{OT} = 210,721.8 'k (wind) } see
E/W : M_{OT} = 180,872.6 'k (seismic) } Table 9

Lateral loads create overturning moment while gravity loads resist that moment.

Seismic wt (From tech 1) = 72,911.28^k/2 = 36,456^k

N/S: $\frac{210,721.8'k}{247.25} = 852^k$

$\frac{36,456^k}{852^k} = 42.8^x$ greater ∴ uplift not an issue

E/W: $\frac{180,872.6'k}{282.33} = 640.6^k$

$\frac{36,456^k}{640.6^k} = 56.9^x$ greater ∴ no concern