TECHNICAL ASSIGNMENT 3

LATERAL SYSTEM ANALYSIS AND CONFIRMATION DESIGN

THE TOWERS AT THE CITY UNIVERSITY OF NEW YORK

NEW YORK CITY, NEW YORK

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EXECUTIVE SUMMARY

Technical Assignment 3 contains a detailed analysis and design check of the concrete shear walls used as the lateral force resisnting system. Using the wind and seismic loads calculated from Technical Assignment 1, the walls are analyzed for strength, drift, and torsion and are compared to the original design.

The resultant lateral load acts at the center or rigidity of the floor and is distributed to the shear walls based on relative stiffness of the walls. The building then rotates about the center of rigidity.

The forces on the walls are determined by loading in the y direction because it gives the largest eccentricity between the centers of mass and rigidity. Using the provisions in the Building Code of the City of New York, it was determined that the seismic loads will cause greater shear and torsional forces.

The foundations under the shear walls are 42" thick mat slabs. These slabs are required to be much larger than the typical spread footings to carry the large base shear and resist the overturning moment due to lateral loads.

The distribution of forces to the shearwalls was determined by the relative stiffness of each walls. Torsion was calculated by multiplying the resultant story force by the eccentricity between the center of mass and center of rigidity. Story drift was checked using ETABS.

Appendix A consists of calculations of relative stiffnesses of the shear walls and the lateral loads used in the design of The Towers. Appendix B consists of the design check of the shear wall thickness and reinforcement. Appendix C contains building plans showing the shear wall locations on each of the typical floors.

LATERAL SYSTEM

Lateral loads imposed on the building are resisted by concrete shear walls located throughout the building. One wall is located in the north wing of the building, and the other walls are around the stair towers and elevator core. The typical structural layouts in Figures 1, 2 and 3 below illustrate the locations of shear walls on each floor. The concrete floor slab acts as a rigid diaphragm to transfer the loads to the lateral force resisting system. The shear walls are 10" thick and are reinforced with two curtains of reinforcing.

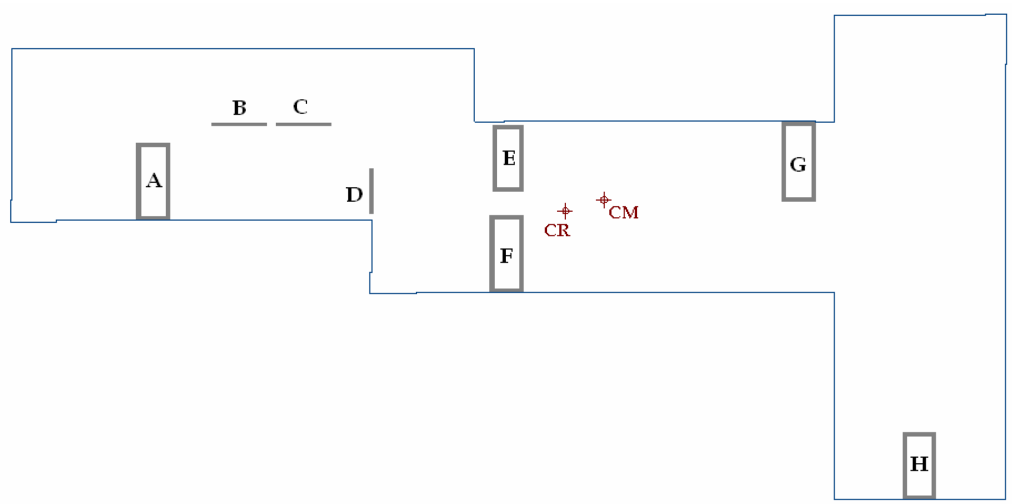


Figure 1: Shear wall plan for floors 1 - 5

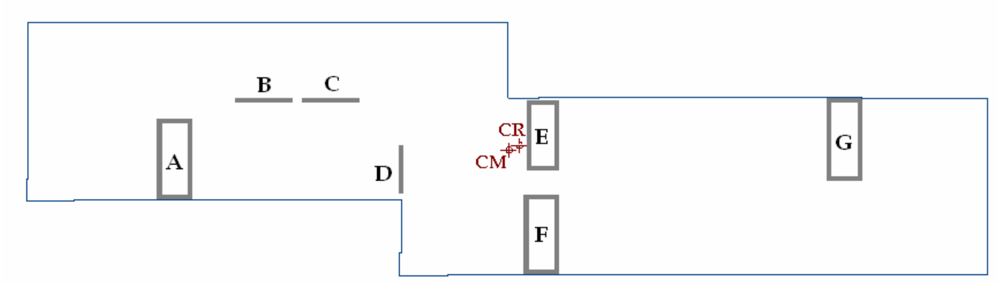


Figure 2: Shear wall plan for floors 6 - 8

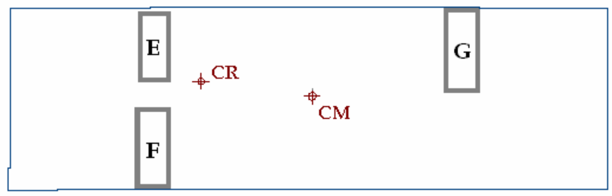


Figure 3: Shear wall plan for floors 9 - 10

LATERAL LOADS

Lateral loads imposed on The Towers are the result of wind and seismic forces. Per the City Building Code of the City of New York, the wind loads are calculated based on the methods provided in ASCE 7-98 and the seismic loads are calculated based on the UBC Section 2312-1990.

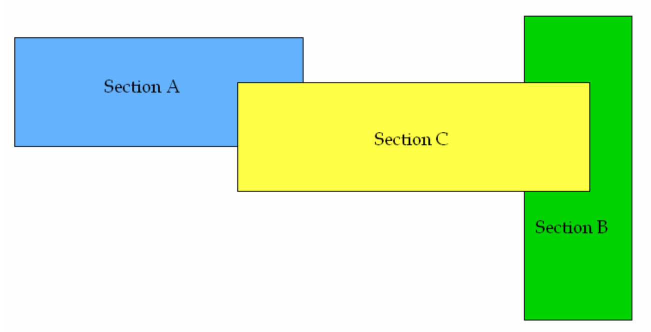


Figure 2: Building components used for lateral load calculations

To simplify the loading for wind and seismic, the building was broken up into three components as shown in Figure 2. Section A, B and C consist of 8, 6, and 11 stories consecutively. Wind loading was calculated for both the north-south and east-west directions. However, since the loading area of the east-west direction is significantly greater than the north-south direction, the loading diagrams are only shown for the east-west direction.

The following is a summary of the wind and seismic loads, as well as diagrams to illustrate the loading patterns on the building. See Appendix B for complete loading calculations.

WIND LOADS

- Basic Wind Speed	V = 95 mph	
- Importance Factor	I_w = 1.0	
	Category 4	
- Building Exposure	D	
- Mean Roof Height	110′-0″	
- Gust Factor (Rigid Structure)	G = 0.85	
- Topographic Factor	Kzt = 1.0	
- Wind Directionality Factor	Kd = 0.85	
- Velocity Pressure Coefficients	Kh = 1.455	
	Kz = 1.03	0 – 15′
	Kz = 1.08	15 – 20′
	Kz = 1.12	20 – 25′
	Kz = 1.16	25 – 30′
	Kz = 1.22	30 – 40′
	Kz = 1.27	40 – 50′
	Kz = 1.31	50 – 60′

	Kz = 1.34	60 – 70′
	Kz = 1.38	70 – 80′
	Kz = 1.40	80 – 90′
	Kz = 1.43	90 – 100′
	Kz = 1.455	100 – 110′
- Internal Pressure Coefficient	GCpi = +/- 0.18	
- Wall Pressure Coefficients	Cp = 0.8 (windward)	
	Cp = -0.5 (leeward ⊥ 294'-8")	
	Cp = -0.3 (leeward ⊥ 144'-4")	
	Cp = -0.7 (sidewall)	
- Roof Pressure Coefficients	Cp = -0.9 (0 – h)	
	Cp = -0.5 (h – 2h)	
	Cp = -0.3 (>2h)	

<u>East – West Wind</u>

Loading Diagrams

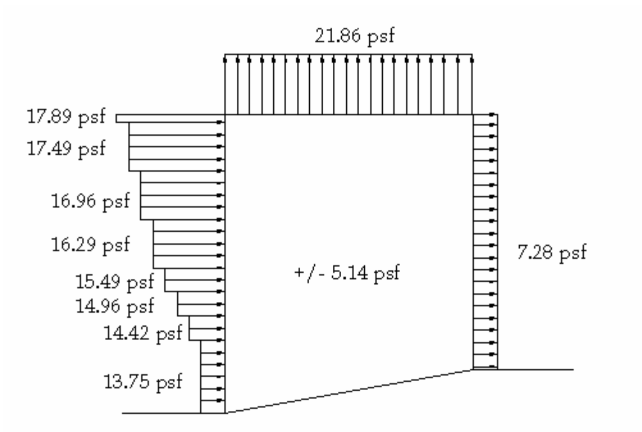


Figure 4: Wind pressure on Section A

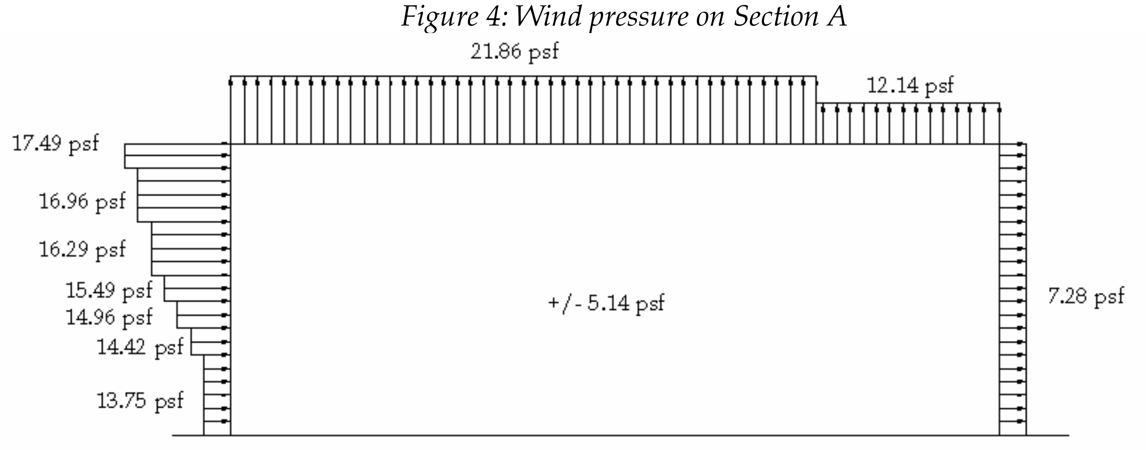


Figure 5: Wind pressure on Section B

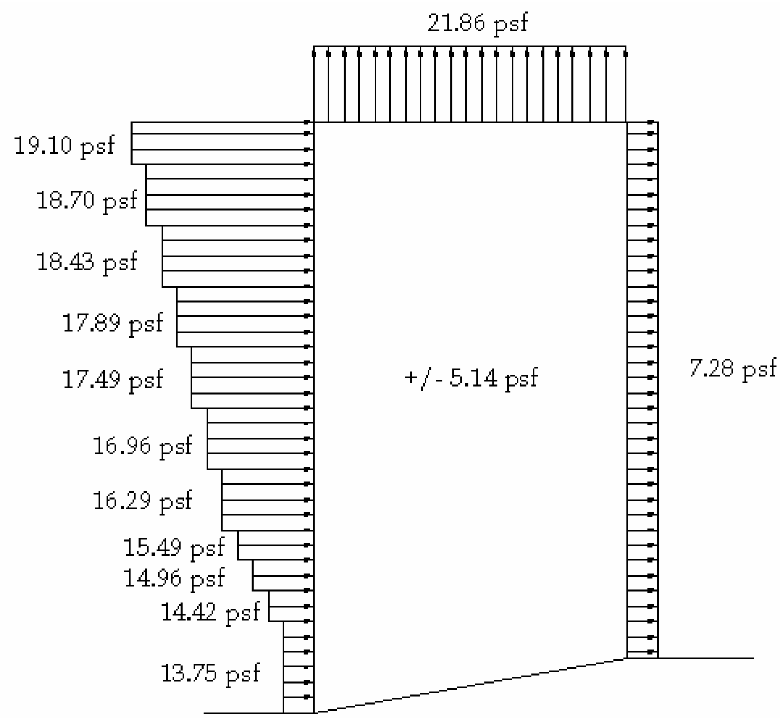


Figure 6: Wind pressure on Section C

Story Shears

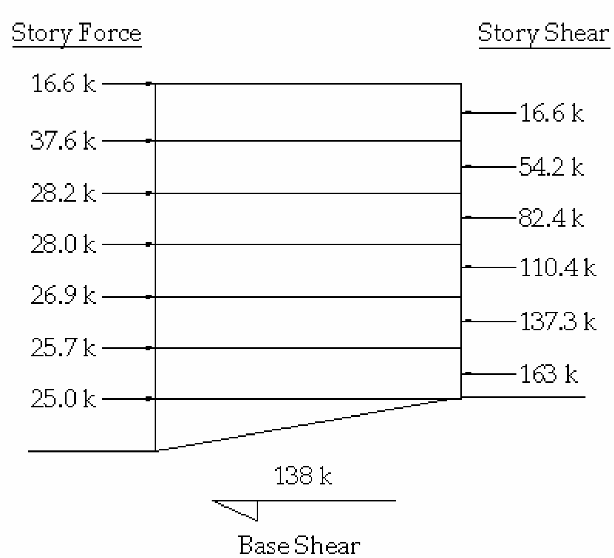


Figure 7: Story forces on Section A

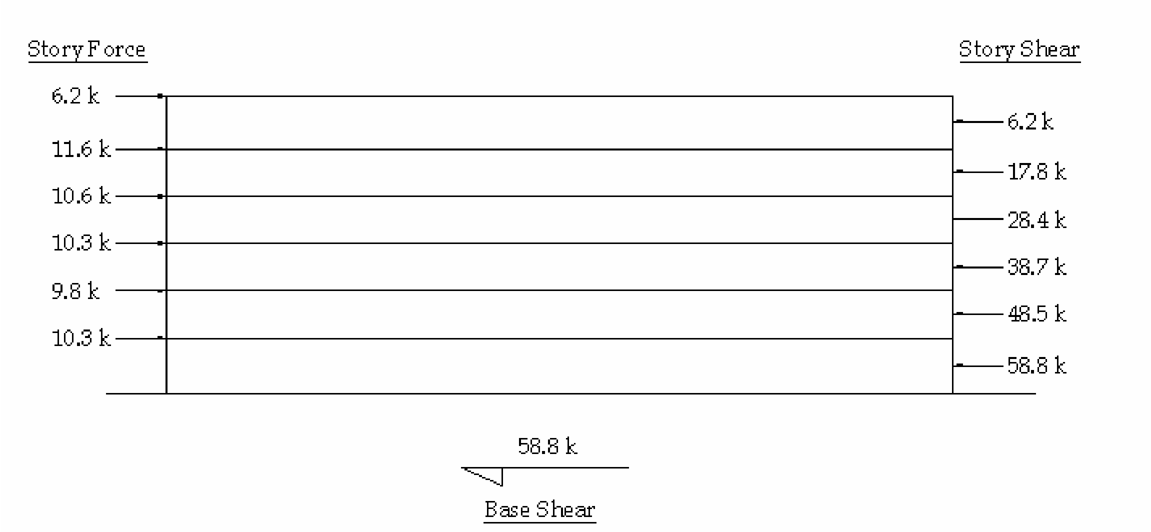


Figure 8: Story forces on section B

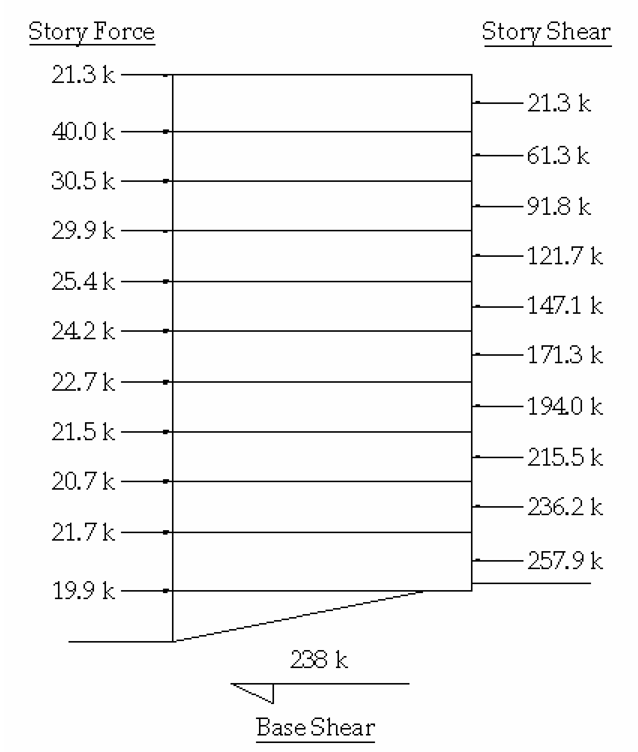


Figure 9: Story forces on section C

SEISMIC LOADS

- Seismic Zone Factor	Z = 0.15
- Site Coefficient	S_1 = 1.0
- Importance Factor	I = 1.0
	I_p = 1.0
- Analysis Procedure	Equivalent Lateral Force
- Plan Structural Irregularities	No
- Vertical Structural Irregularities	No
- Building Height	h_n = 110′
- Type of Lateral System	Typical Frame with Concrete Shear Walls R = 5 C_T = 0.020

In calculating the weight of the Towers for seismic forces, 100% of the dead load and 25% of the live load are considered. The resultant story force acts at the center of mass of the floor.

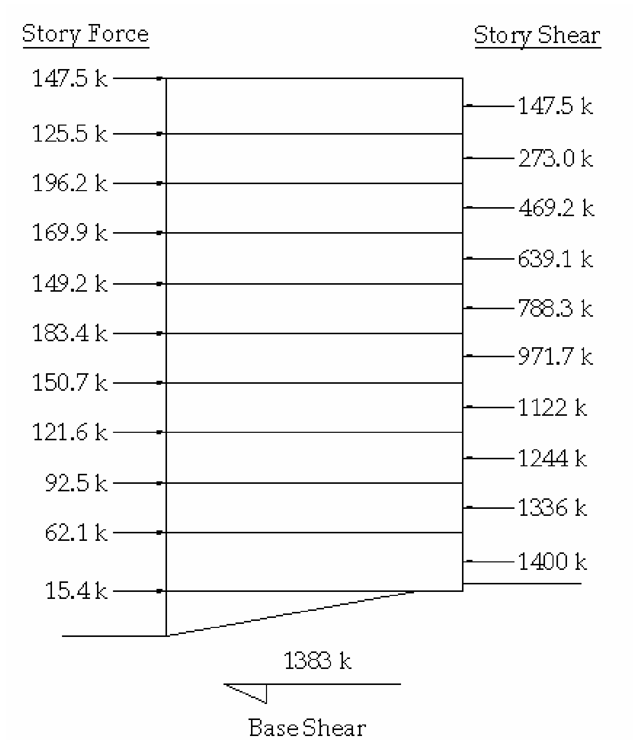


Figure 10: Seismic story forces

TORSION AND ROTATION CHECK

Torsion on each floor of the building is found by multiplying the resultant force acting on the center of mass of the floor by the eccentricity between the center of mass and center of rigidity of the lateral load resisting system. Due to the change in floor layouts, eccentricity varies on the three typical floor plans as follows:

Floor 1 – 5 : e = 11.41′
Floor 6 – 8 : e = 31.11′
Floor 9 – roof : e = 2.88′

Rotation is very small for both load cases and therefore shouldn't affect the stability of the building.

Torsional Forces			Rotation	
Floor	Wind (ft-k)	Seismic (ft-k)	Wind (rad)	Seismic(rad)
1	-629.3	-175.7	0.000396464	0.000110609
2	-652.7	-708.7	0.000410833	0.000446022
3	-660.7	-1055.6	0.000415855	0.000664369
4	-685.8	-1387.6	0.000431659	0.00087337
5	-713.2	-1719.7	0.000448898	0.001082377
6	-776.0	-2092.9	0.000488398	0.001317239
7	-187.2	-430.2	0.000214998	0.000494267
8	-150.8	-490.0	0.000173253	0.000562835
9	948.8	6103.8	0.003447831	0.021852203
10	1244.4	3904.3	0.004521769	0.014187034
roof	662.6	4588.7	0.016674007	0.016674007

DRIFT CHECK

Drift of the building was determined from an ETABS model of the building. The program applies code standard wind and seismic loads to the building and performs an analysis in the x and y directions. The load factors used in the program were determined from ASCE 7-05 and are:

- 0.9D + 1.6W
- 0.9D + 1.0E

From the calculated shears and deflections, it was determined that the earthquake forces produce the maximum deflection of the shear walls. See Figure 10 below for the deflected shapes.

These values may vary slightly from actual displacements because of other requirements provided by the Building Code of the City of New York. The following table provides shear wall heights and deflections in the y-direction for each shear wall.

Drift In Y-Direction							
Wall	Height				Deflection (in)	H/400 (in)	
A	79	ft	6	in	1.14	2.385	ok
D	79	ft	6	in	0.045	2.385	ok
E	106	ft	6	in	0.158	3.195	ok
F	106	ft	6	in	0.158	3.195	ok
G	106	ft	6	in	2.89	3.195	ok
H	59	ft	3	in	0.015	1.7775	ok

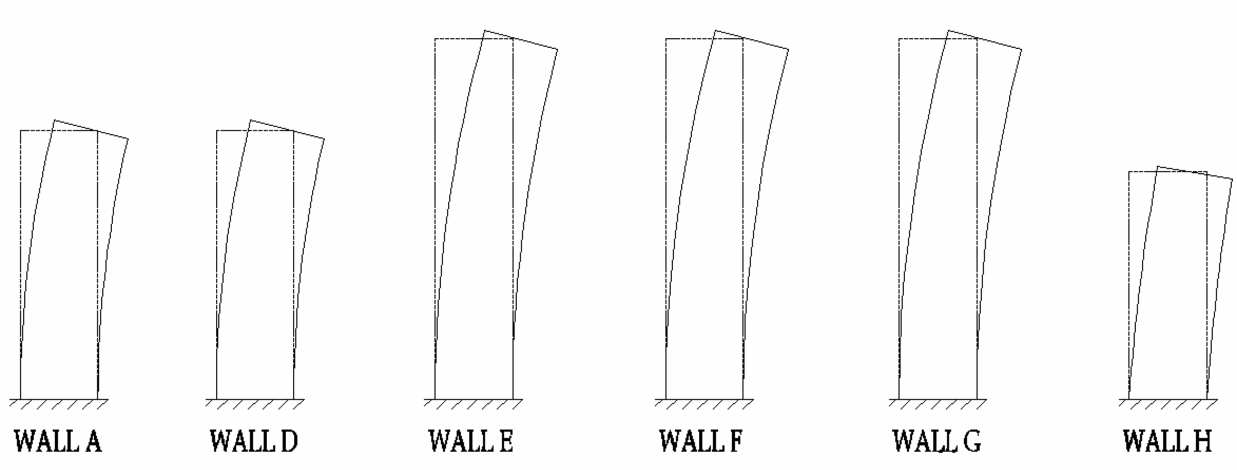


Figure 10: Deflected shapes of shear walls in y-direction

OVERTURNING CHECK AND FOUNDATION IMPACT

The total overturning force for the shear walls were determined for the y-direction of the shear walls using the seismic loads. Refer to Figure 11 below for overturning and base shear values.

The large moments and base shears must be resisted by a large foundation. Mat slab foundations are used under the shear walls of the building. These mats are 42″ thick and are heavily reinforced with #9 and #11 bars in the top and bottom of the slab.

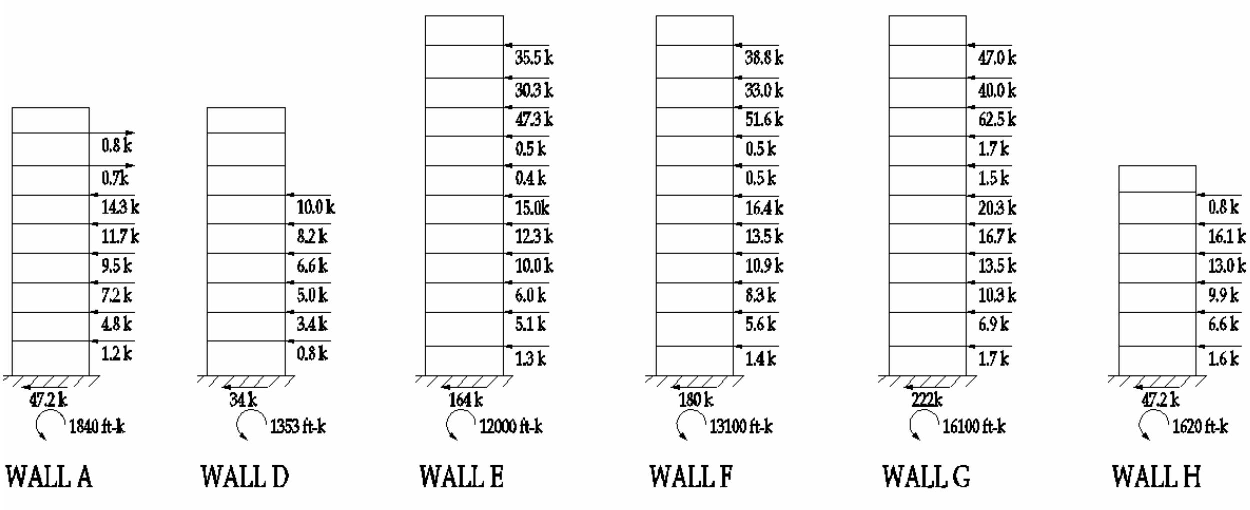


Figure 11: Base shear and overturning moments for shear walls due to seismic loads

STRENGTH CHECK

The lateral framing check of strength and story drift was performed on a shear wall in the stair tower. The shear wall was checked against seismic loading and the forces were distributed to the walls by the method of rigidity. For complete calculations of the design checks, see Appendix B.

The seismic loads analyzed at the base of the building and are distributed as shown in Figures 13 below. The loads are distributed by rigidity and all shear walls are assumed the have equal stiffness. The story force acts at the center of mass of the floor, and the floor rotates about the center of stiffness.

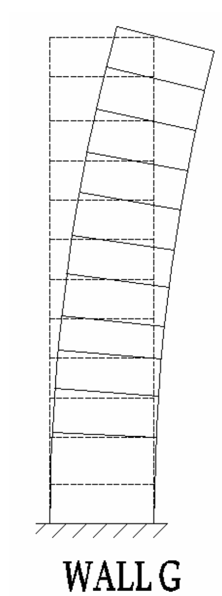


Figure 2: Deflected shape of shear wall G in the y-direction

Shear wall G was analyzed for seismic loads in the y-direction. It was determined that a 10″ wall with #6 bars in the transverse and longitudinal directions will suffice for the total base shear applied. See Appendix B for detailed calculations for required reinforcement.

The maximum drift encountered by the wall is 2.9″ which is less than the industry standard of H/400.

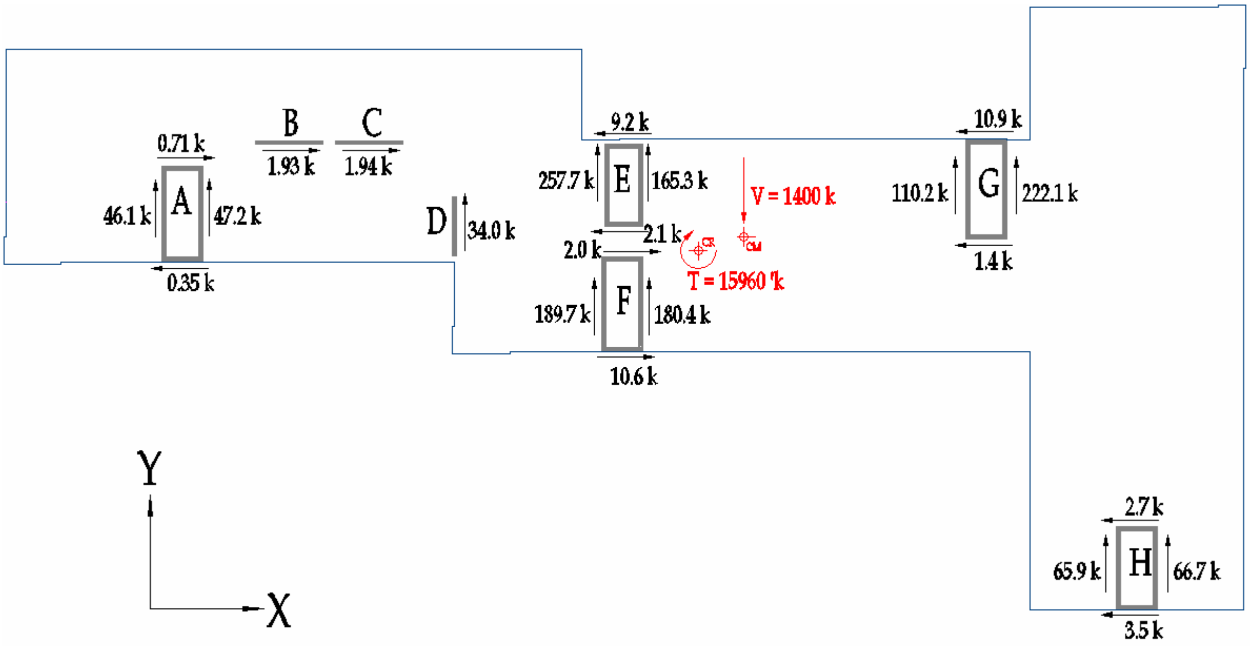


Figure 13: Load distribution to shear walls due to total seismic base shear

CONCLUSION

The lateral resisting system of The Towers is sufficient in transferring the wind and seismic loads to the shear walls and into the foundation. When calculating the size and reinforcement of the shear walls, it was determined that the walls are over-reinforced for the given loads. The drift of the all the shear walls in the building also fall within the H/400 industry standard, and the rotation of the building caused by the torsion will not be a concern.

APPENDIX A

LATERAL LOAD CALCULATIONS

A.1

CENTER OF RIGIDITY AND CENTER OF MASS

Floors 1 – 6

Center of Rigidity

X dimension				Y dimension			
	k	x	kx		k	y	ky
1	22.50	38.42	864.38	1	8.83	0.42	3.68
2	22.50	47.25	1063.13	2	8.83	20.58	181.82
3	14.00	107.00	1498.00	3	8.83	61.42	542.51
4	19.50	142.58	2780.37	4	8.83	81.92	723.59
5	19.50	150.58	2936.37	5	8.83	82.75	730.96
6	21.33	141.75	3024.00	6	8.83	104.42	922.34
7	21.33	151.00	3221.33	7	8.83	90.00	795.00
8	23.00	228.17	5247.83	8	8.83	112.58	994.48
9	23.00	237.42	5460.58	9	8.00	92.00	736.00
10	21.00	264.50	5554.50	10	8.00	110.67	885.33
11	21.00	273.25	5738.25	11	17.00	110.33	1875.67
SUM	228.67		37388.74	12	17.17	110.33	1894.06
				SUM	120.83		10285.44
	x =	kx = / Σk	163.51		y =	ky = / Σk	85.12

Center of Mass

X dimension			Y dimension		
Area	x	Ax	Area	y	Ay
5480	53.33	292248	5480	108.25	593210
644	122	78568	644	123.33	79424.5
9733	200.67	1953121	9733	86.92	845992
1640	268.67	440619	1640	128.5	210740
3152	268.83	847352	3152	30.5	96136
20649		3611908	20649		1825503
x =	ΣAx = / ΣA	174.919	y =	ΣAy = / ΣA	88.4064

Floors 7 – 9

Center of Rigidity

X dimension				Y dimension			
	k	x	kx		k	y	ky
1	22.50	38.42	864.38	3	8.83	61.42	542.51
2	22.50	47.25	1063.13	4	8.83	81.92	723.59
3	14.00	107.00	1498.00	5	8.83	82.75	730.96
4	19.50	142.58	2780.37	6	8.83	104.42	922.34
5	19.50	150.58	2936.37	7	8.83	90.00	795.00
6	21.33	141.75	3024.00	8	8.83	112.58	994.48
7	21.33	151.00	3221.33	9	8.00	92.00	736.00
8	23.00	228.17	5247.83	10	8.00	110.67	885.33
9	23.00	237.42	5460.58	11	17.00	110.33	1875.67
SUM	186.67		26095.99	12	17.17	110.33	1894.06
				SUM	103.17		10099.94
	x =	kx = / Σk	139.80		y =	ky = / Σk	97.90

Center of Mass

X dimension			Y dimension		
Area	x	Ax	Area	y	Ay
5480	53.33	292248	5480	108.25	593210
644	122	78568	644	123.33	79424.5
8700	190.67	1658829	8700	86.92	756204
14824		2029645	14824		1428839
x =	ΣAx = / ΣA	136.916	y =	ΣAy = / ΣA	96.3868

Floor 10 and roof

Center of Rigidity

X dimension				Y dimension			
	k	x	kx		k	y	ky
4	19.50	142.58	2780.37	3	8.83	61.42	542.51
5	19.50	150.58	2936.37	4	8.83	81.92	723.59
6	21.33	141.75	3024.00	7	8.83	90.00	795.00
7	21.33	151.00	3221.33	8	8.83	112.58	994.48
8	23.00	228.17	5247.83	9	8.00	92.00	736.00
9	23.00	137.42	3160.58	10	8.00	110.67	885.33
SUM	127.67		20370.49	SUM	51.33		4676.92
	x =	$\frac{kx}{\Sigma k}$ =	159.56		y =	$\frac{ky}{\Sigma k}$ =	91.11

Center of Mass

X dimension			Y dimension		
Area	x	Ax	Area	y	Ay
8700	190.67	1658829	8700	86.92	756204
8700		1658829	8700		756204
x =	$\frac{\Sigma Ax}{\Sigma A}$ =	190.67	y =	$\frac{\Sigma Ay}{\Sigma A}$ =	86.92

A.2

WIND PRESSURES

Velocity Wind Pressure

Windward pressure

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

$$q_z = (0.00256)(1.03)(0.085)(1.0)(95\text{mph})^2(1.0)$$

$$q_z = 20.23\text{psf}$$

Height	kz	qz	
0 - 15	1.03	20.23	psf
15 - 20	1.08	21.21	psf
20 - 25	1.12	22.00	psf
25 - 30	1.16	22.78	psf
30 - 40	1.22	23.96	psf
40 - 50	1.27	24.94	psf
50 - 60	1.31	25.73	psf
60 - 70	1.34	26.32	psf
70 - 80	1.38	27.10	psf
80 - 90	1.4	27.49	psf
90 - 100	1.43	28.08	psf
100 - 110	1.455	28.57	psf

Leeward pressure

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

$$q_h = (0.00256)(1.455)(0.085)(1.0)(95\text{mph})^2(1.0)$$

$$q_h = 28.57\text{psf}$$

Design Wind Pressure

Windward wall

$$p = q_z GCp - (GCpi) q_h$$

$$p = (20.23\text{psf})(0.85)(0.8) - (\pm 0.18)(28.57)$$

$$p = 13.75 \pm 5.14\text{psf}$$

Height	qz		p			
0 - 15	20.23	psf	13.75	+/-	5.14	psf
15 - 20	21.21	psf	14.42	+/-	5.14	psf
20 - 25	22.00	psf	14.96	+/-	5.14	psf
25 - 30	22.78	psf	15.49	+/-	5.14	psf
30 - 40	23.96	psf	16.29	+/-	5.14	psf
40 - 50	24.94	psf	16.96	+/-	5.14	psf
50 - 60	25.73	psf	17.49	+/-	5.14	psf
60 - 70	26.32	psf	17.89	+/-	5.14	psf
70 - 80	27.10	psf	18.43	+/-	5.14	psf
80 - 90	27.49	psf	18.70	+/-	5.14	psf
90 - 100	28.08	psf	19.10	+/-	5.14	psf
100 - 110	28.57	psf	19.43	+/-	5.14	psf

Leeward wall with north-south wind

$$p = q_h GCp - (GCpi) q_h$$
$$p = (28.57\,psf)(0.85)(-0.3) - (\pm 0.18)(28.57)$$
$$p = -7.28 \pm 5.14\,psf$$

Roof with north south wind

$$\frac{h}{L} = \frac{110'}{294'-8''} = 0.373$$

$$p = q_h GCp - (GCpi) q_h$$
$$p = (28.57\,psf)(0.85)(-0.9) - (\pm 0.18)(28.57) \qquad 0 - 110'$$
$$p = -21.86 \pm 5.14\,psf$$

$$p = q_h GCp - (GCpi) q_h$$
$$p = (28.57\,psf)(0.85)(-0.5) - (\pm 0.18)(28.57) \qquad 110' - 220'$$
$$p = -12.14 \pm 5.14\,psf$$

$$p = q_h GCp - (GCpi) q_h$$
$$p = (28.57\,psf)(0.85)(-0.3) - (\pm 0.18)(28.57) \qquad 220' - 294'\text{-}8''$$
$$p = -7.28 \pm 5.14\,psf$$

Leeward wall east-west wind

$$p = q_h GCp - (GCpi)q_h$$
$$p = (28.57psf)(0.85)(-0.5) - (\pm 0.18)(28.57)$$
$$p = 12.14 \pm 5.14psf$$

Roof with east-west wind

$$\frac{h}{L} = \frac{110'}{144'-4''} = 0.762$$

$$p = q_h GCp - (GCpi)q_h$$
$$p = (28.57psf)(0.85)(-0.9) - (\pm 0.18)(28.57) \qquad 0 – 110'$$
$$p = -21.86 \pm 5.14psf$$

$$p = q_h GCp - (GCpi)q_h$$
$$p = (28.57psf)(0.85)(-0.5) - (\pm 0.18)(28.57) \qquad 110' – 220'$$
$$p = -12.14 \pm 5.14psf$$

$$p = q_h GCp - (GCpi)q_h$$
$$p = (28.57psf)(0.85)(-0.3) - (\pm 0.18)(28.57) \qquad 220' – 294'\text{-}8''$$
$$p = -7.28 \pm 5.14psf$$

A.3

SEISMIC FORCES

Building Period

$$T = Ct(h_n)^{3/4}$$

$$T = (0.02)(110')^{3/4}$$

$$T = 0.679s$$

Design Base Shear

$$V = \frac{CvI}{RT} w = \frac{(0.12)(1.0)}{(5)(0.679)}(42700k)$$

$$V = 1510$$

$$Ft = 0.07VT = (0.07)(1510k)(0.679)$$

$$Ft = 71.7k$$

$$Fi = \frac{(V - Ft)w_i h_i}{\Sigma w_i h_i}$$

Level	h_i	w_i	$w_i h_i$	F_i
1	8.67	2600	22533	15.43
2	18.90	4800	90700	62.12
3	27.56	4900	135056	92.50
4	36.23	4900	177523	121.58
5	44.90	4900	219989	150.67
6	53.56	5000	267813	183.42
7	62.23	3500	217802	149.17
8	70.90	3500	248135	169.95
9	79.56	3600	286425	196.17
10	87.23	2100	183181	125.46
roof	97.90	2200	215371	147.51

$\Sigma w_i h_i$=	2064528

APPENDIX B

DESIGN CHECK CALCULATIONS

B.1

LATERAL SYSTEM CHECK

SEISMIC LOADS

Checking the shear wall for worst case, therefore earthquake load controls

Assuming the shear wall is s the same stiffness throughout the whole height:
Shearwall Base Shear = 223k

$f'c = 4000psi$
$\rho_l = 0.0025$
$\rho_t = 0.0020$
$A_c = (10")(23')(12"/1') = 2760in^2$

$A_{sl} = (0.0025)(10")(12")$
$A_{sl} = 0.30in^2 \Rightarrow$ **Try #6 longitudinal bars at 12" on center**

$A_{st} = (0.002)(10")(12")$
$A_{st} = 0.24in^2 \Rightarrow$ **Use #6 transverse bars at 12" on center**

$$\rho_t = \frac{(0.44in^2)}{(10")(12")} = 0.00367$$

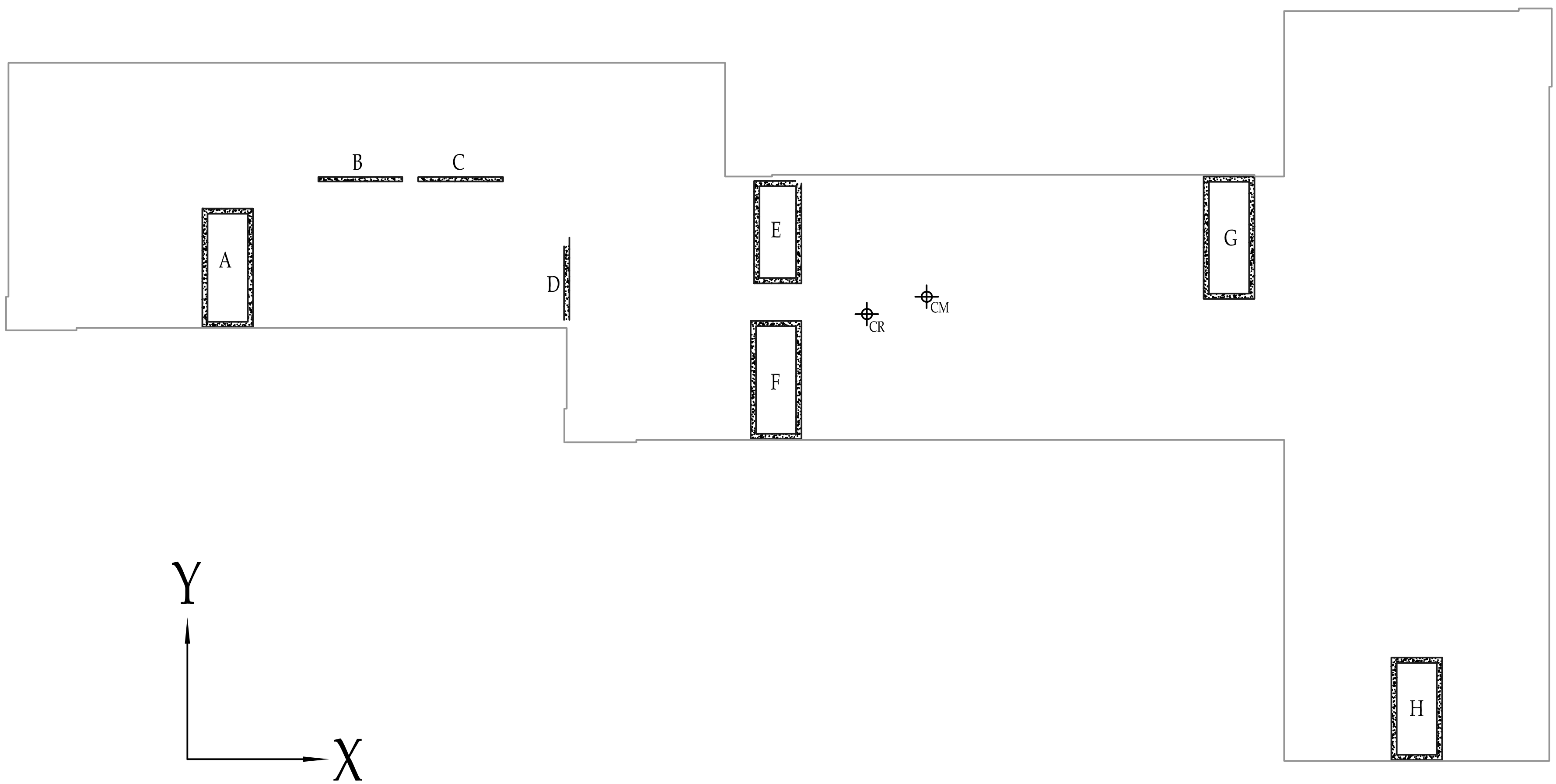
Nominal Shear Capacity:
$Vn = A_c(\alpha_c\sqrt{f'c} + \rho_t fy) = (2760in^2)[(3.0)(\sqrt{4000psi}) + (0.00367)(60000psi)]$
$Vn = 1130k$

Vn > Vu

Use 10" Shear wall with #6 longitudinal and transverse bars at 12" o.c.

APPENDIX C

LATERAL FORCE RESISTING SYSTEM

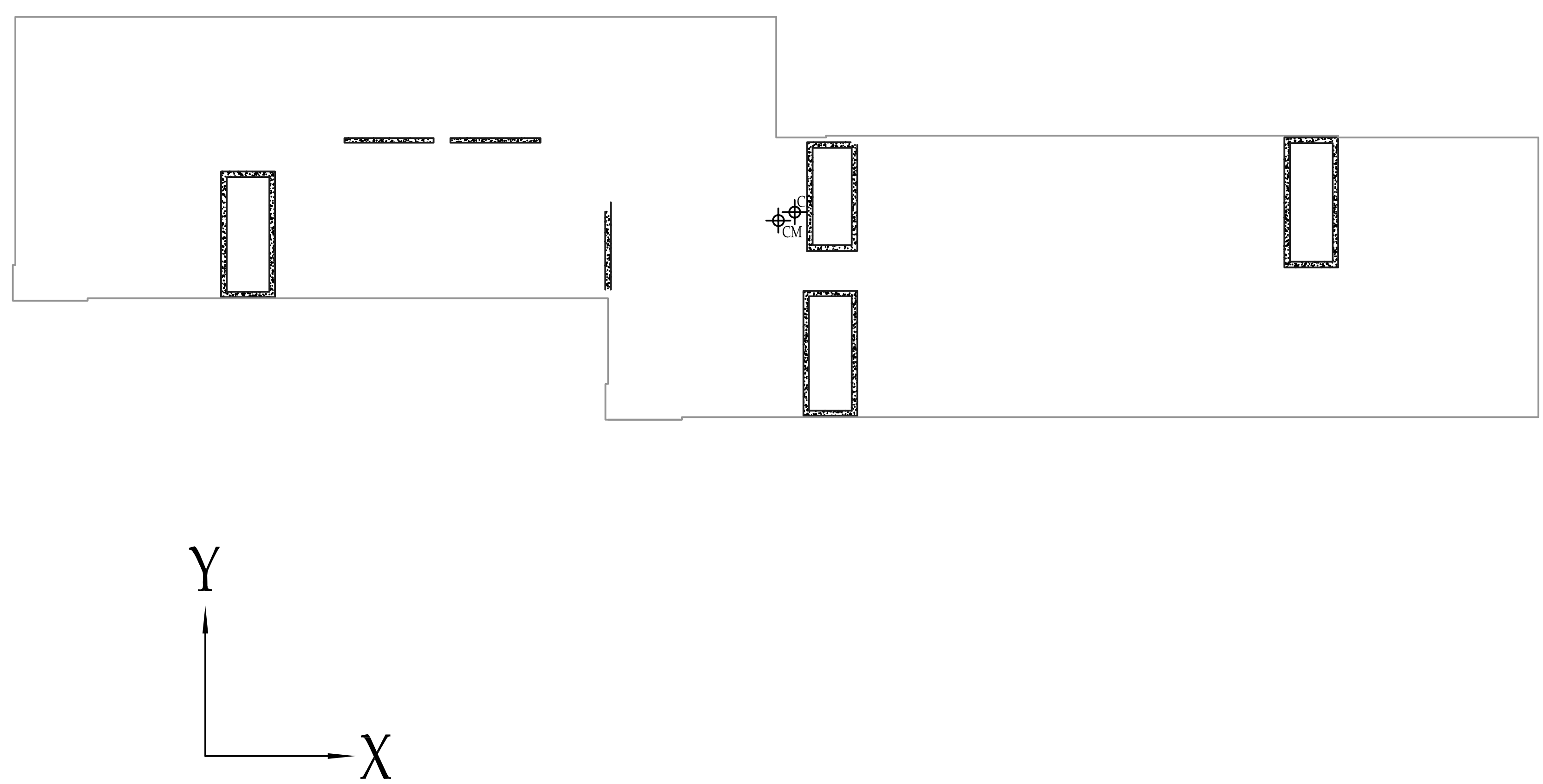


The Towers at The City College of New York

FLOOR 1 - FLOOR 5 SHEAR WALL PLAN

SCALE: 1" = 32'-0"

S1.1

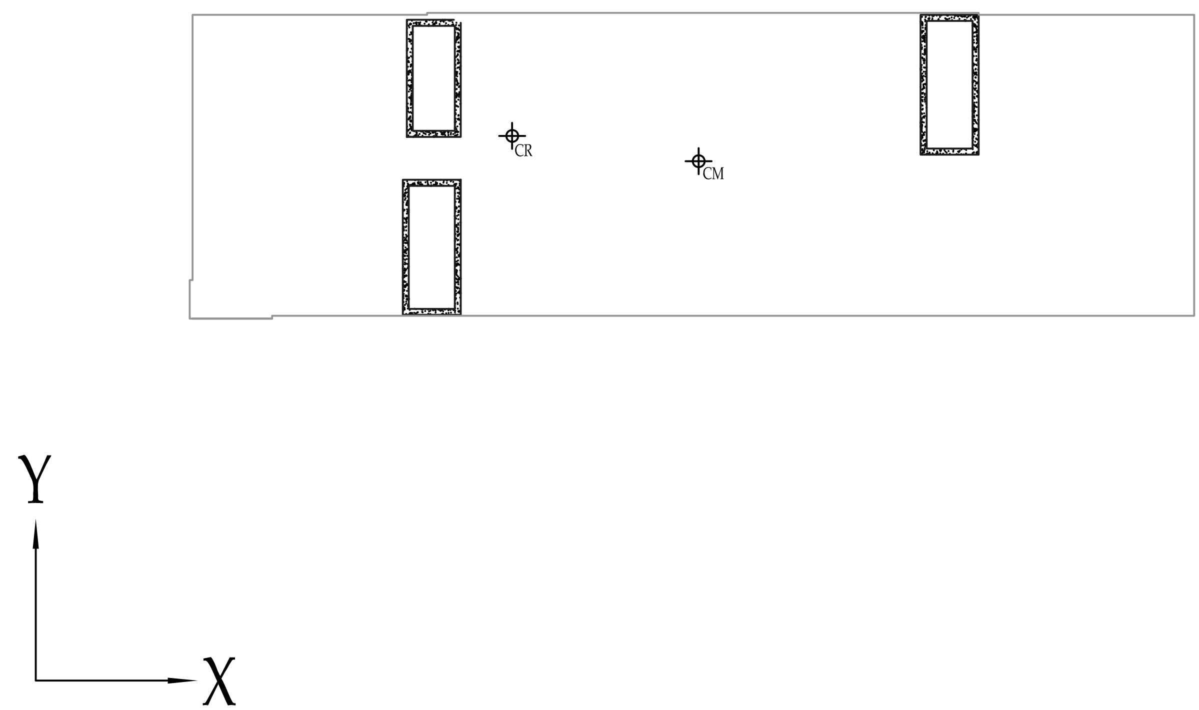


The Towers at The City College of New York

FLOOR 6 - FLOOR 8 SHEAR WALL PLAN

SCALE: 1" = 32'-0"

S1.2



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FLOOR 9 - ROOF SHEAR WALL PLAN

SCALE: 1" = 32'-0"

S1.3