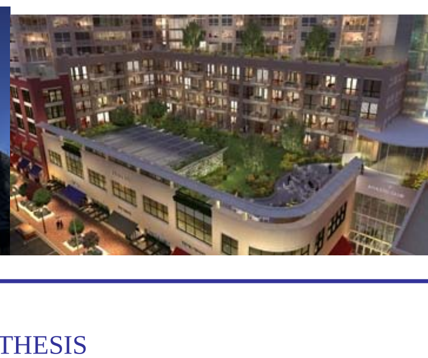
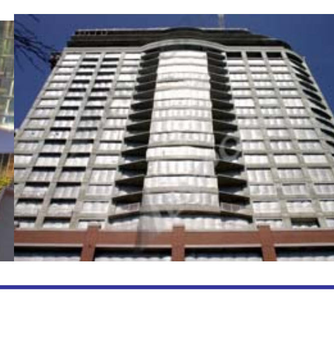




STRUCTURAL SYSTEM ANALYSIS AND REDESIGN



Structural System Analysis and Redesign

Gravity System:

The existing reinforced cast-in-place concrete system was replaced with a structural steel system in an effort to better understand the complexity of designing a high-rise building's gravity and lateral systems. Due to architectural constraints, it was determined that the column grid would remain the same as the existing system. The floor plans were then entered into RAM Structural System to design the new floor framing.

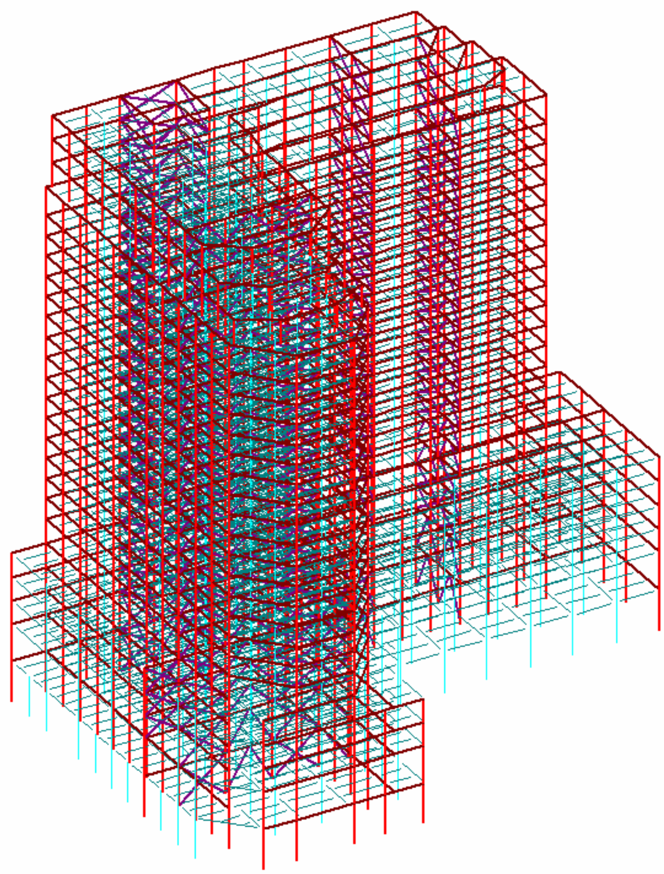


Figure 5: 3D Model of Building in RAM Steel

A 1.5" 18 gage composite Lok-Floor deck was chosen from the United Steel Deck catalogue. The deck can span 10.10 feet and will hold a maximum uniform live service load of 400 psf. The deck is topped by 2" lightweight concrete, and the shear studs are 3" long by ¾" diameter. Surface loads were applied to each floor, and a line load was applied to the perimeter of each floor to account for the weight of the cladding material. Table 1 contains the surface loads that were used in the RAM model.

Table 1: Surface Loads		
	Superimposed	
	Dead Load	Live Load
Retail	25 psf	100 psf
Residential	15 psf	80 psf
Storage	25 psf	100 psf
Roof Garden	15 psf	80 psf

The entire second level was applied with the retail area loads. The third, fourth and fifth floors contain both residential areas and storage areas. The sixth and seventh floors are residential floors but are also applied with a higher load where the building steps back to account for the extra load due to the intensive roof garden. The remaining floors are all residential levels and are applied with the typical residential load. On the top three penthouse levels, the slab projects several feet beyond the beam edge to account for the additional weight of the concrete eyebrow overhangs.

The gravity beams were designed by RAM Structural System. In an effort to limit the overall building height, the beams on floors 8-25 were restricted to W14s and beams on floors 2-7 were restricted to W16s. For level 8, the typical floor, the beam sizes range between W8x10 and W14x22. The normal size for an in-fill beam spanning 21’ is W10x12 with 16 shear studs. A typical girder size is W14x22 with 24 studs or a W12x19 with 24 shear studs, spanning 21’. See Figure 6 for the beam sizes on the typical floor.

For the lower levels, the beam sizes range between a W8x10 and a W16x31. The normal size for an in-fill beam spanning 21’ is W12x14 with 8 shear studs, and a typical girder size is W14x22 with 20 studs or a W16x26 with 16 studs. For the top three penthouse levels, the beam sizes range between W8x10 and W12x22. The typical in-fill beam size is W10x12 with 10 studs, and a normal girder size is W12x19 with 30 shear studs. Only the 22^{nd} floor differs from these typical sizes, because it contains large transfer girders which hold extra weight due to the different column grid of the penthouse levels. The beam sizes of the 22^{nd} floor range between W8x10 and W24x117. See Figures 6-9 for the beam sizes of the typical lower floor, penthouse level and the 22^{nd} floor.

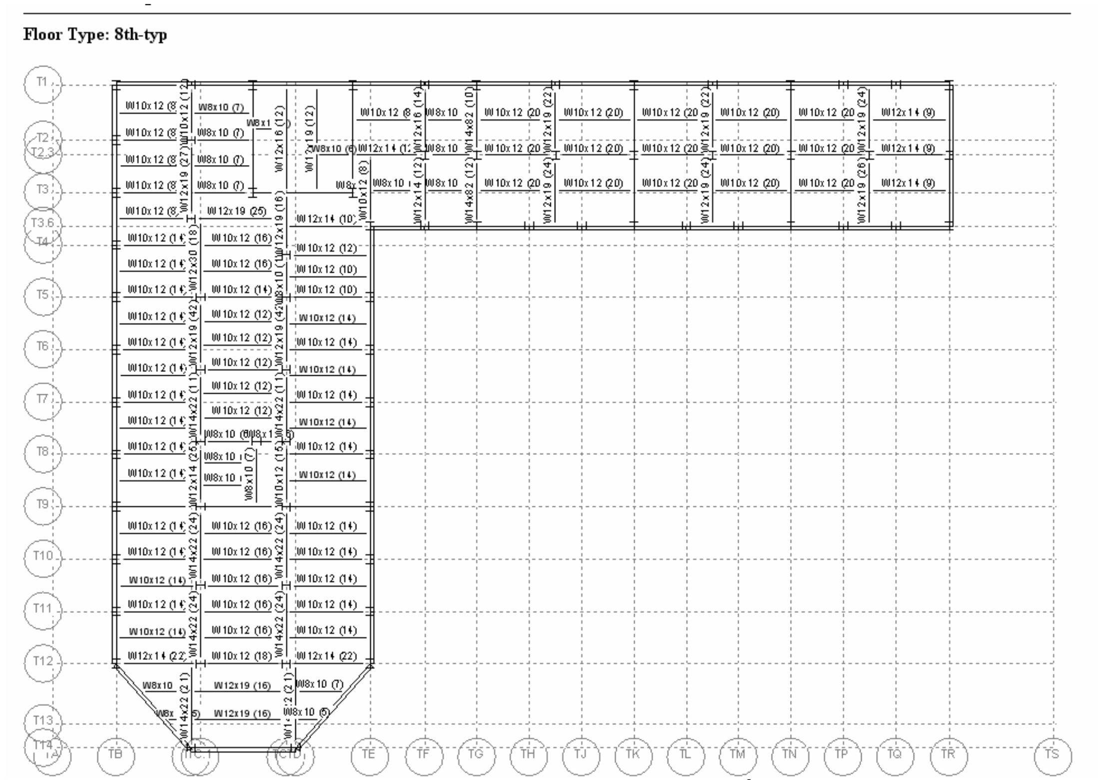


Figure 6: Beam Sizes for Typical Floor (8th Floor Plan)

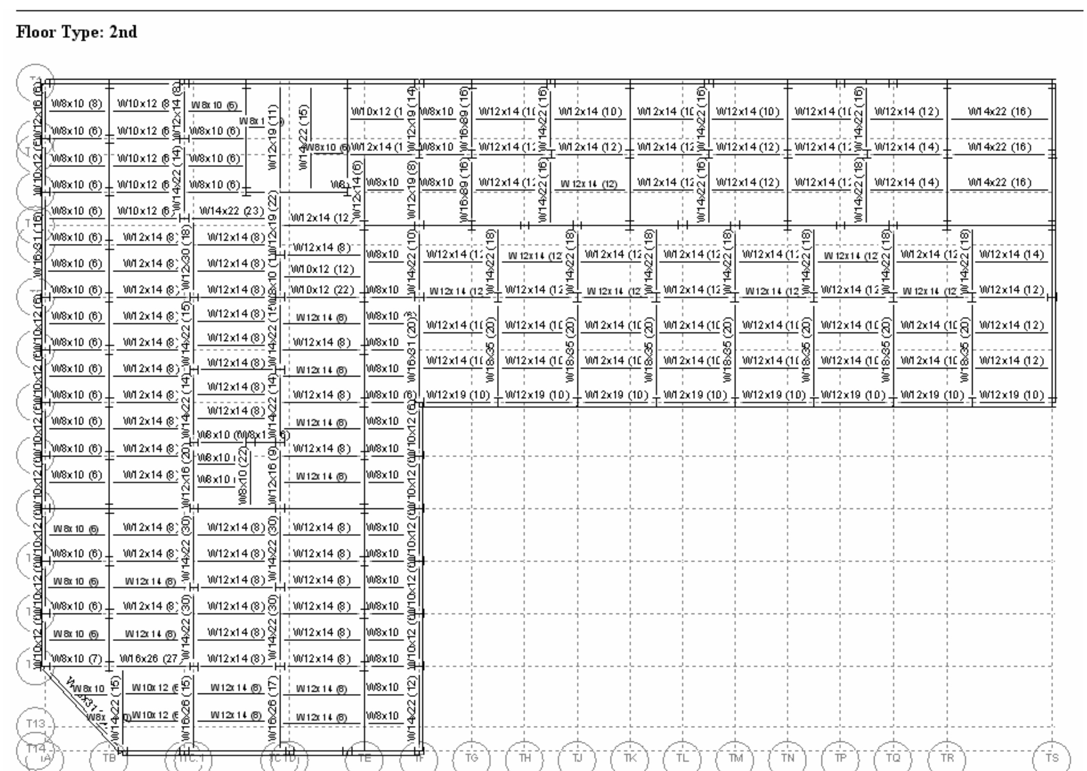


Figure 7: Beam Sizes for Typical Lower Floor (2nd Floor Plan)

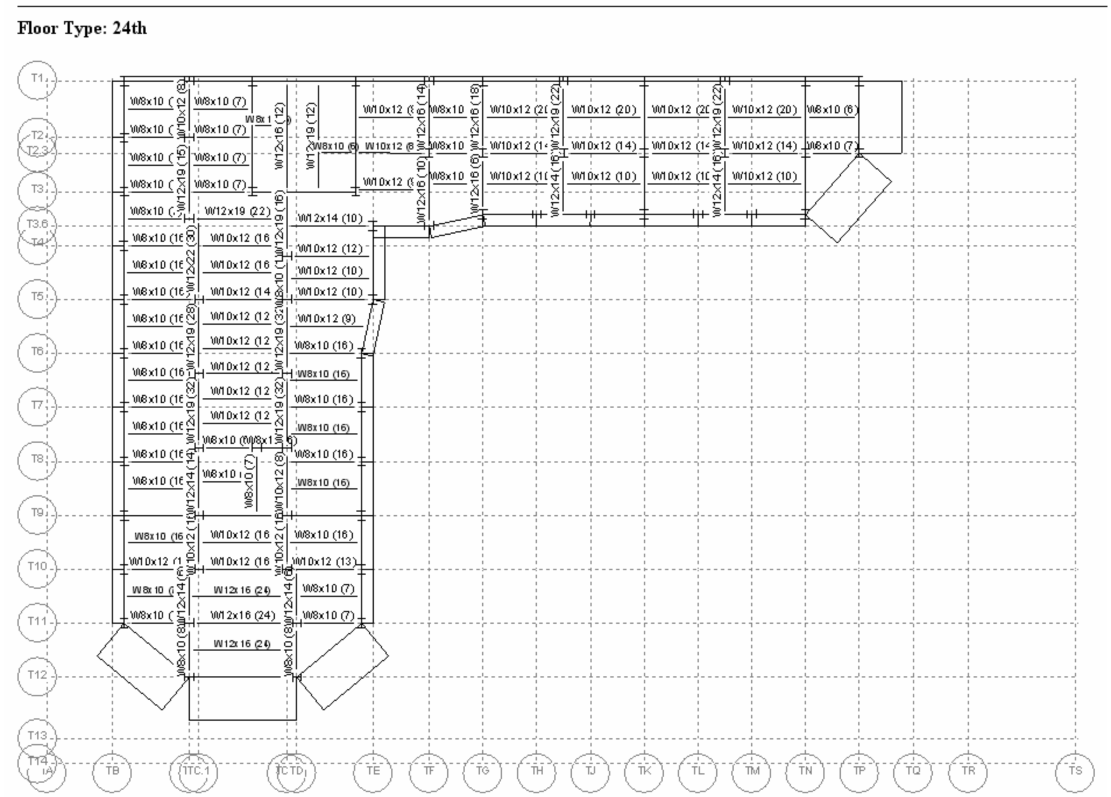


Figure 8: Beam Sizes for Typical Penthouse Level (24th Floor Plan)

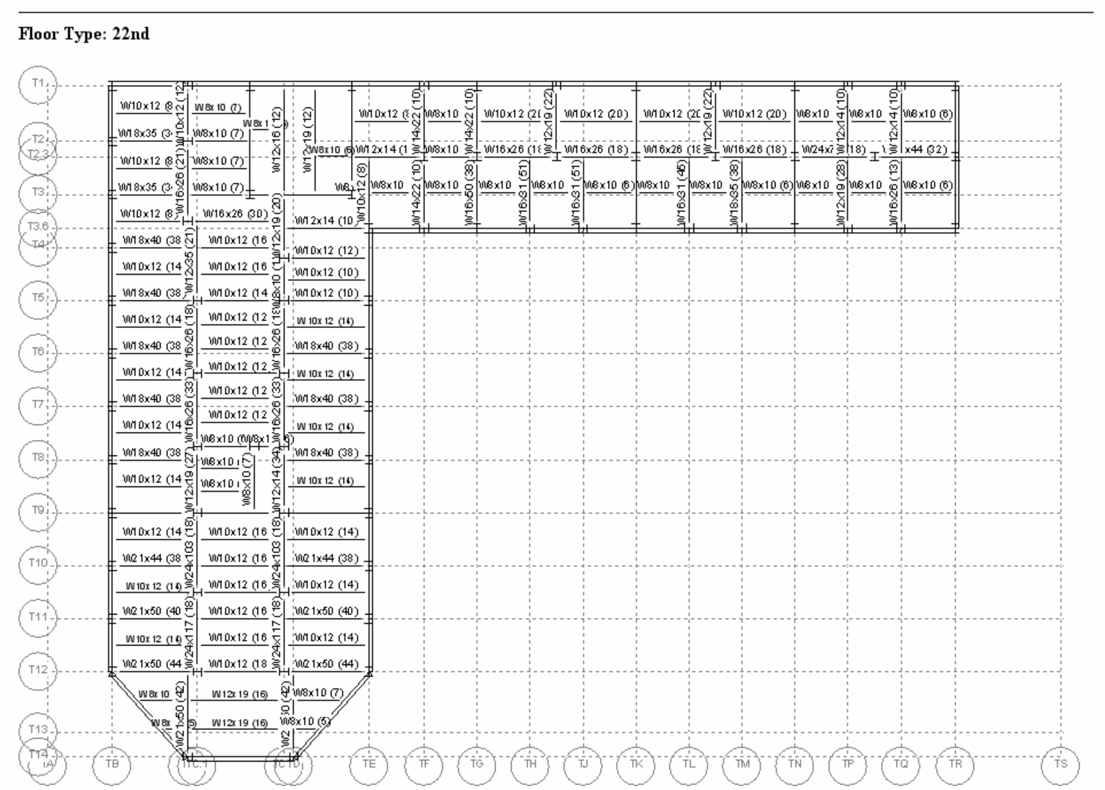


Figure 9: Beam Sizes for 22nd Floor

After designing the beams, the new building height was calculated in order to input the new floor to floor heights with which to design the columns. Each level retains the same floor to ceiling height as the existing system, but the structural materials of the steel system created a larger ceiling to floor section depth than the flat plate concrete system. The original building was 260.5 feet high and the redesigned building is 283.25 feet. Table 2 shows the new building height calculations.

Table 2: Overall Building Height Calculations

Floor #:	Beam Size	Depth (in.)	Deck (in.)	Total Depth (in.)	Original Story Height (ft.)	New Story Height (ft.)	Actual Story Height (ft.)
2	W16x31	15.9	5	20.9	18.6667	19.7417	19.75
3	W16x31	15.9	3.5	19.4	17.5	18.4500	18.5
4	W16x31	15.9	3.5	19.4	10.3333	11.2833	11.3333
5	W16x31	15.9	3.5	19.4	10.3333	11.2833	11.3333
6	W16x31	15.9	3.5	19.4	11	11.9500	12
7	W16x31	15.9	3.5	19.4	11	11.9500	12
8	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
9	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
10	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
11	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
12	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
13	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
14	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
15	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
16	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
17	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
18	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
19	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
20	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
21	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
22	W14x30	13.8	3.5	17.3	9.1667	9.9417	10
23	W24x68	23.7	3.5	27.2	12	13.6000	13.6667
24	W14x43	13.7	3.5	17.2	10.6667	11.4334	11.5
25	W14x38	14.1	3.5	17.6	10.6667	11.4667	11.5
ROOF	W14x38	14.1	3.5	17.6	10.8333	11.6333	11.6667
				TotalHeight =	260.5005	281.9172	283.25

After inputting the new floor to floor height, the columns were designed in RAM Steel. The column sizes range from W10x33 and W14x193. The typical column size on the ground floor is W14x145 to W14x132. On the column lines that extend from the ground floor to the roof, the typical column size at the 25^{th} floor is W14x43. On the three penthouse levels, the typical size is a W10x33 due to the fact that they extend up only three floors. See Figures 10-11 for the column layout and column schedule.

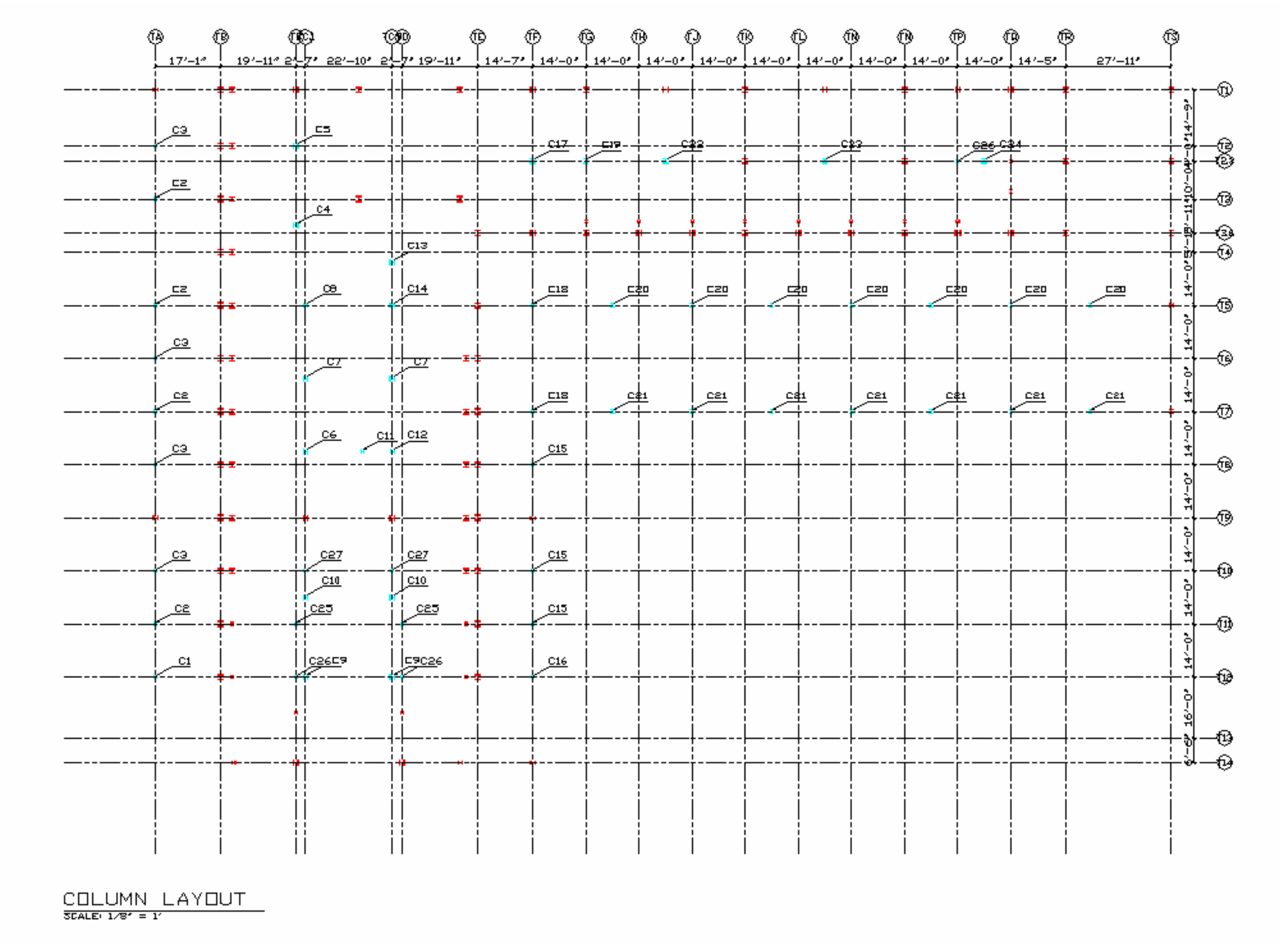


Figure 10: Column Layout from RAM Steel

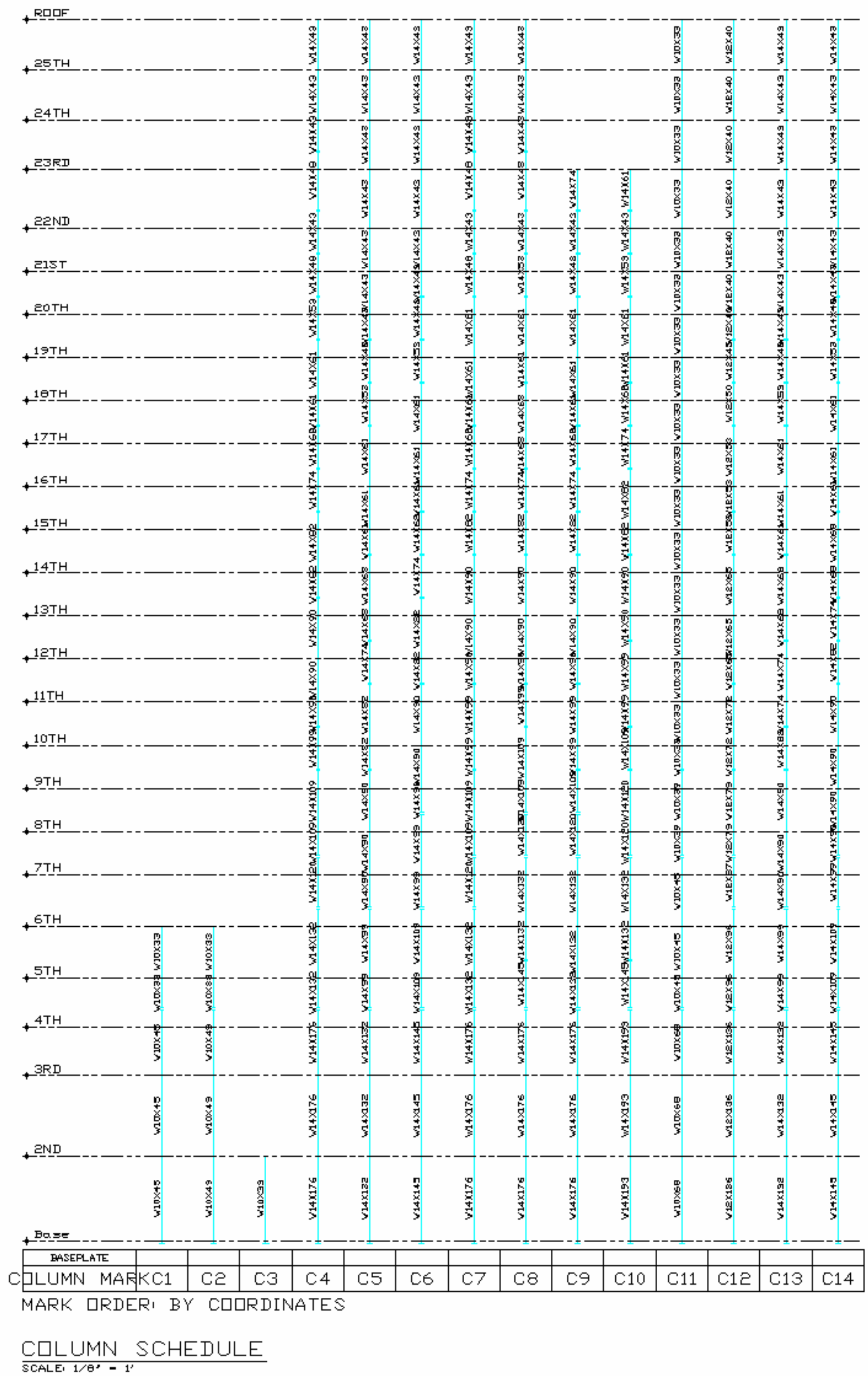


Figure 11a: Column Schedule

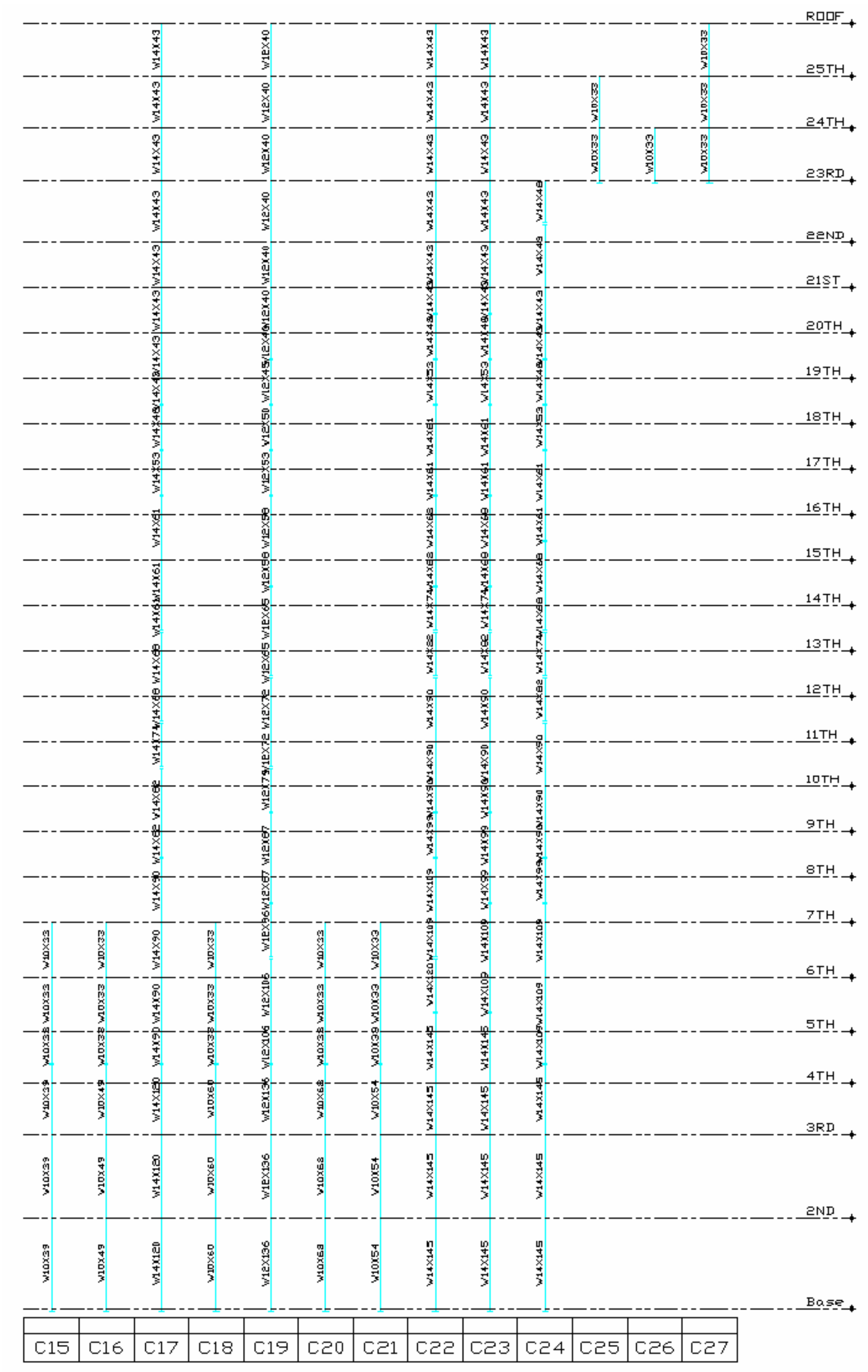


Figure 11b: Column Schedule

Lateral System:
After designing the building's structural steel gravity system, the existing lateral system, which is made up of both concrete shear walls and moment frames, was redesigned using a combination of steel moment and braced frames. While the concrete shear walls could have been used in the new design of the building, it was decided that they would be eliminated in an attempt to reduce the weight of the building and to shorten the construction time.

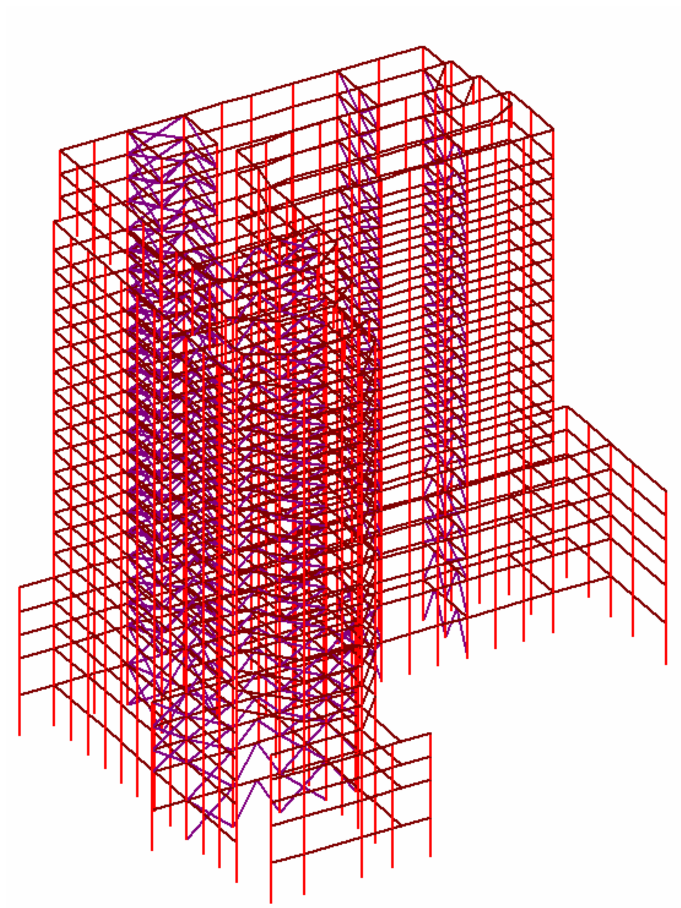


Figure 12: 3D Model of Lateral System

After a few lateral system designs were tested in the RAM Steel model, it was determined that the drift limit would control the design. The drift limit of Sherman Plaza was set at H/600 for other trades to use, such as windows and exterior cladding material. Since these materials will not be changed in the building redesign, the allowable drift for the structural steel building will be H/600. For a building of 283.25 feet, this drift value is 5.665 inches.

When choosing the locations of the lateral elements, it was important to lessen the impact on the architectural design as much as possible. The braced frames, therefore, were placed in the locations of the original shear walls. The moment frames, also, replaced the existing concrete moment frames around the building's perimeter. With this design, the building drift was too high in the Y direction, so another braced frame was added where there is a wall between two residential units. See Figure 13 for the location of the braced frames and shear walls. Frames A-G are braced frames, and Frames G-Q are moment frames.

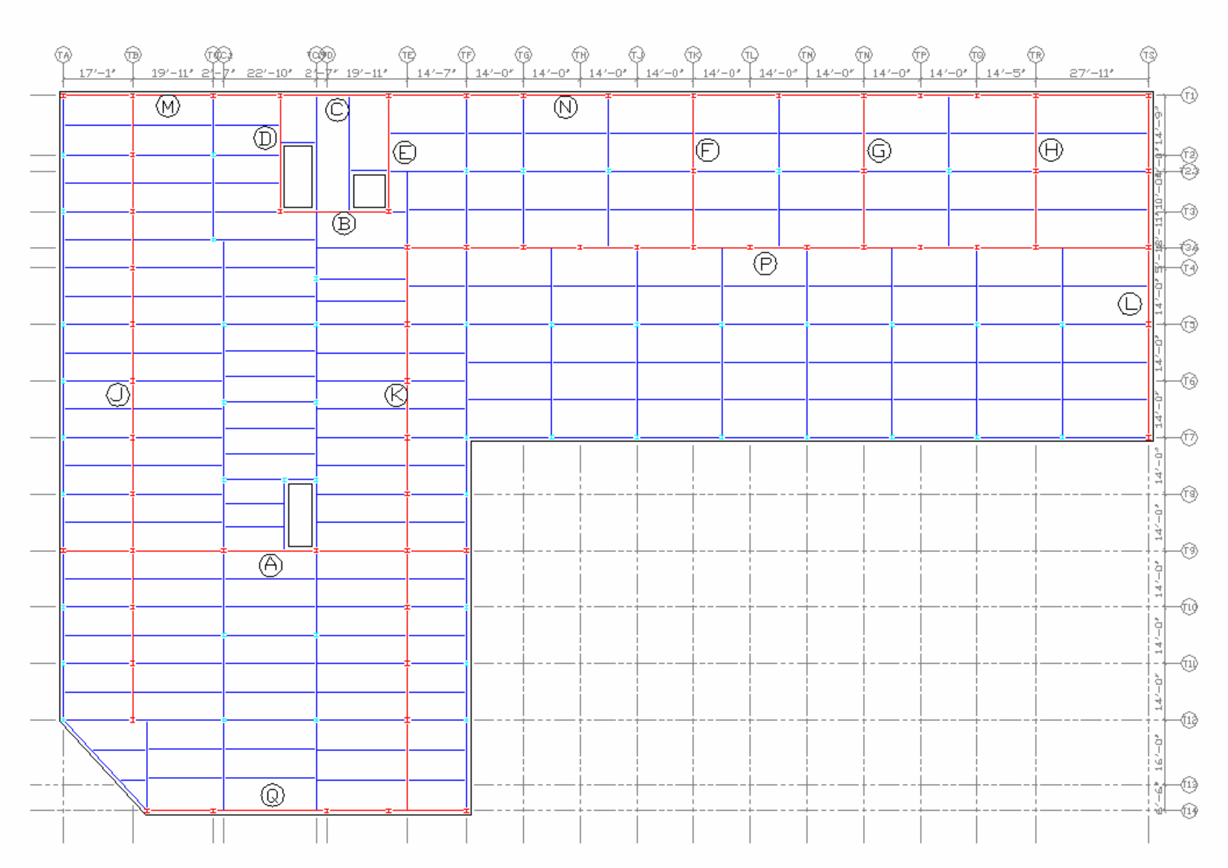


Figure 13: Moment and Braced Frame Locations

After determining the locations of the lateral elements, the architecture of each floor was analyzed to determine the shape of the bracing elements. Cross braces were used in bays with no openings. Several of the bays contained doorways, so these bays contain either chevron or diagonal braces. See Figures 14-20 for the braced frame designs.

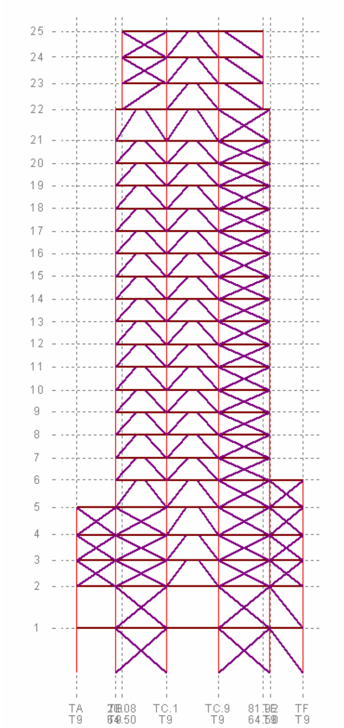


Figure 14: Braced Frame A

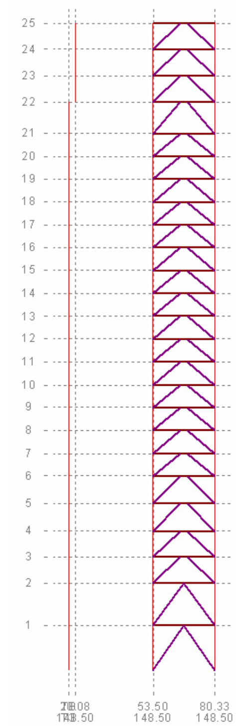


Figure 15: Braced Frame B

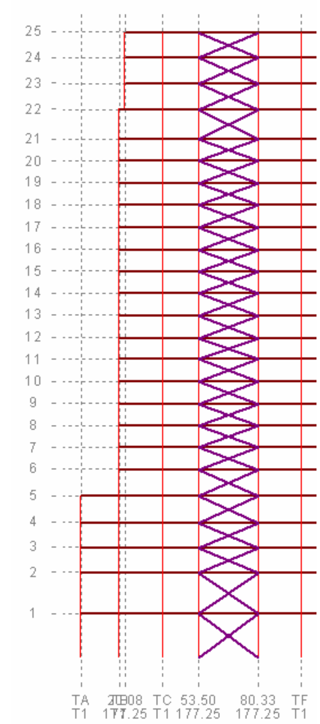


Figure 16: Braced Frame C

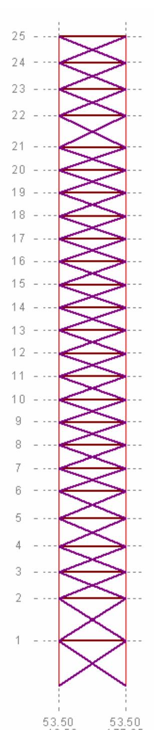


Figure 17: Braced Frame D

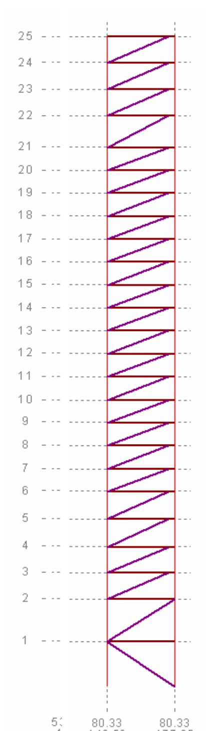


Figure 18: Braced Frame E

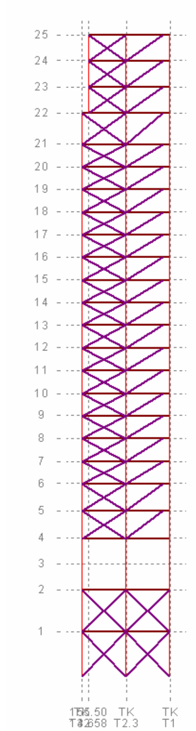


Figure 19: Braced Frame F

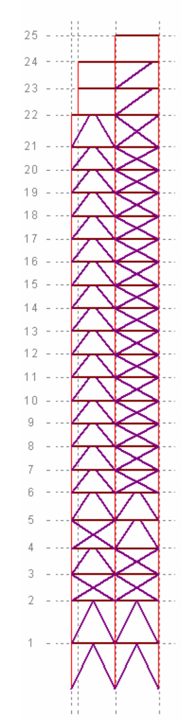


Figure 20: Braced Frame G

Next, the seismic calculations were updated with the new building height and weight. The full hand calculations can be found in Tables A.5-A.6 in the Appendix. The analysis of the building, however, was performed with loads generated by RAM Steel using the code provisions of ASCE 7-02. The computer generated loads have been compared to the hand calculations and both result in very similar values. The error in the hand calculations can be attributed to the estimate of the building weight on each floor. A summary of the computer loads which were used to design the lateral system are presented in Tables 3-4. The wind load cases are taken from the four load cases in ASCE 7-02, Figure 6-9.

Table 3: Wind Load Cases according to ASCE 7-02, Figure 6-9

	Wind1 X	Wind1 Y	Wind2 X+E	Wind2 X-E	Wind2 Y+E	Wind2 Y-E	Wind3 X+Y		Wind3 X-Y		Wind4 CW		Wind4 CCW	
Level	Fx (kips)	Fy(kips)	Fx (kips)	Fx (kips)	Fy(kips)	Fy (kips)	Fx (kips)	Fy (kips)	Fx (kips)	Fy (kips)	Fx (kips)	Fy(kips)	Fx (kips)	Fy (kips)
ROOF	21.25	28.34	18.6	18.6	24.8	24.8	15.94	21.25	15.94	-21.25	13.95	18.6	13.95	18.6
25	43.92	61.55	38.43	38.43	53.85	53.85	32.94	46.16	32.94	-46.16	28.82	40.39	28.82	40.39
24	46.33	62.98	40.54	40.54	55.11	55.11	34.75	47.23	34.75	-47.23	30.41	41.33	30.41	41.33
23	52.08	67.86	45.57	45.57	59.37	59.37	39.06	50.89	39.06	-50.89	34.18	44.53	34.18	44.53
22	48.95	63.85	42.83	42.83	55.87	55.87	36.72	47.89	36.72	-47.89	32.13	41.9	32.13	41.9
21	40.99	53.48	35.86	35.86	46.8	46.8	30.74	40.11	30.74	-40.11	26.9	35.1	26.9	35.1
20	40.66	53.07	35.58	35.58	46.43	46.43	30.49	39.8	30.49	-39.8	26.68	34.83	26.68	34.83
19	40.32	52.64	35.28	35.28	46.06	46.06	30.24	39.48	30.24	-39.48	26.46	34.55	26.46	34.55
18	39.96	52.2	34.97	34.97	45.67	45.67	29.97	39.15	29.97	-39.15	26.23	34.25	26.23	34.25
17	39.6	51.74	34.65	34.65	45.27	45.27	29.7	38.8	29.7	-38.8	25.98	33.95	25.98	33.95
16	39.21	51.26	34.31	34.31	44.85	44.85	29.41	38.45	29.41	-38.45	25.73	33.64	25.73	33.64
15	38.82	50.76	33.96	33.96	44.42	44.42	29.11	38.07	29.11	-38.07	25.47	33.31	25.47	33.31
14	38.4	50.24	33.6	33.6	43.96	43.96	28.8	37.68	28.8	-37.68	25.2	32.97	25.2	32.97
13	37.97	49.7	33.22	33.22	43.49	43.49	28.47	37.27	28.47	-37.27	24.92	32.61	24.92	32.61
12	37.51	49.13	32.82	32.82	42.99	42.99	28.13	36.85	28.13	-36.85	24.62	32.24	24.62	32.24
11	37.03	48.52	32.4	32.4	42.46	42.46	27.77	36.39	27.77	-36.39	24.3	31.84	24.3	31.84
10	36.52	47.89	31.95	31.95	41.9	41.9	27.39	35.91	27.39	-35.91	23.96	31.42	23.96	31.42
9	35.97	47.21	31.48	31.48	41.31	41.31	26.98	35.4	26.98	-35.4	23.61	30.98	23.61	30.98
8	35.22	46.45	30.81	30.81	40.64	40.64	26.41	34.84	26.41	-34.84	23.11	30.48	23.11	30.48
7	37.1	53.44	32.46	32.46	46.76	46.76	27.82	40.08	27.82	-40.08	24.35	35.07	24.35	35.07
6	38.85	68.25	34	34	59.72	59.72	29.14	51.19	29.14	-51.19	25.5	44.79	25.5	44.79
5	36.57	60.66	32	32	53.08	53.08	27.43	45.5	27.43	-45.5	24	39.81	24	39.81
4	34.35	57.17	30.06	30.06	50.02	50.02	25.76	42.88	25.76	-42.88	22.54	37.52	22.54	37.52
3	42.93	71.85	37.57	37.57	62.87	62.87	32.2	53.89	32.2	-53.89	28.17	47.15	28.17	47.15
2	51.31	86.56	44.9	44.9	75.74	75.74	38.48	64.92	38.48	-64.92	33.67	56.81	33.67	56.81

Table 4: Seismic Load Cases according to ASCE 7-02				
	EQ X+E	EQ X-E	EQ Y+E	EQ Y-E
Level	Fx (kips)	Fx (kips)	Fy (kips)	Fy (kips)
ROOF	17.65	17.65	13.89	13.89
25	18.44	18.44	14.4	14.4
24	18.69	18.69	14.47	14.47
23	18.24	18.24	14	14
22	17	17	12.91	12.91
21	16.11	16.11	12.13	12.13
20	15.23	15.23	11.37	11.37
19	14.36	14.36	10.62	10.62
18	13.5	13.5	9.89	9.89
17	12.64	12.64	9.17	9.17
16	11.8	11.8	8.47	8.47
15	10.98	10.98	7.79	7.79
14	10.16	10.16	7.13	7.13
13	9.35	9.35	6.48	6.48
12	8.56	8.56	5.85	5.85
11	7.78	7.78	5.24	5.24
10	7.02	7.02	4.65	4.65
9	6.27	6.27	4.09	4.09
8	5.54	5.54	3.54	3.54
7	7.72	7.72	4.83	4.83
6	7.08	7.08	4.3	4.3
5	5.77	5.77	3.39	3.39
4	4.07	4.07	2.3	2.3
3	3.25	3.25	1.74	1.74
2	1.79	1.79	0.85	0.85

After a trial and error of several shapes and sizes, including W shapes, double angles, and tube shapes, the double angles resulted in the least drift. The bracing members were sized at 2L8x8x¾. The columns and beams that were a part of the moment and braced frames also needed to be resized. The gravity columns and beams were relatively small sizes and therefore did not provide much lateral resistance. The lateral beam sizes range between W16x89 on the lower floors to W14x82 on the upper floors. The columns in the frames along the Y axis were sized as W14x370 to W14x257, in general, and the columns in frames along the X axis were sized from W14x132 to W14x370. This design produced an acceptable building drift. The drift values for each load case and for critical load combinations are listed in Table 5.

Table 5: Drift for Load Cases and Combinations		
Load Cases	Drift X (in.)	Drift Y (in.)
D	-0.0863	-0.0825
Lp	-0.928	-0.6116
W1	3.1386	0.0354
W2	-0.4549	4.0159
W3	2.8335	0.0794
W4	2.6591	-0.0175
W5	-0.5449	3.4314
W6	-0.2512	3.5963
W7	2.0128	3.0384
W8	2.6952	-2.9854
W9	1.9227	2.7485
W10	1.5997	2.5687
E1	0.8287	0.07
E2	0.7681	0.0379
E3	0.011	0.8237
E4	0.0986	0.8703
Load Combinations	Drift X (in.)	Drift Y (in.)
1.2D + 0.5Lp + 1.3W2	-0.7914	4.8158
1.2D + 0.5Lp + 1.3W5	-0.9083	4.0561
1.2D + 0.5Lp + 1.3W6	-0.5265	4.2704
1.2D + 0.5Lp + 1.3W8	3.3038	-4.2858
1.2D + 0.5Lp - 1.3W1	-4.2802	-0.4508
1.2D + 0.5Lp - 1.3W2	0.3915	-5.6254
1.2D + 0.5Lp - 1.3W5	0.5085	-4.8657
1.2D + 0.5Lp - 1.3W6	0.1267	-5.0799
1.2D + 0.5Lp - 1.3W7	-2.8165	-4.3547
1.2D + 1.3W2	-0.695	5.1216
1.2D + 1.3W5	-0.8119	4.3619
1.2D + 1.3W6	-0.4301	4.5762
1.2D - 1.3W1	-4.1838	-0.145
1.2D - 1.3W2	0.4879	-5.3196
1.2D - 1.3W5	0.6049	-4.5599
1.2D - 1.3W6	0.2231	-4.7742
1.2D - 1.3W7	-2.721	-4.0489
0.9D + 1.3W1	4.0026	-0.0283
0.9D + 1.3W2	-0.6691	5.1464
0.9D + 1.3W6	-0.4042	4.6009
0.9D - 1.3W1	-4.1579	-0.1202
0.9D - 1.3W2	0.5138	-5.2949
0.9D - 1.3W5	0.6308	-4.5351
0.9D - 1.3W6	0.2489	-4.7494
1.2D +0.5Lp -1.0E1	-1.0286	-0.4748
1.2D +0.5Lp -1.0E3	-0.2109	-1.2285
1.2D +0.5Lp -1.0E4	-0.2985	-1.2751

As can be seen in Table 5, the lateral system design was controlled by the load combination, 1.2D+0.5Lp-1.3W2. This combination produced a drift of 5.6254 inches, which is less than the allowable drift of H/600 = 5.665 inches.

Foundation:

The original foundation design called for large belled caissons due to the large building weight. The new foundation sizes were estimated according to the new column loads. The allowable soil bearing capacity for the building site's soil is 30 ksf. To get the area of the new caisson bell, the column load in units of kips was divided by the allowable soil bearing capacity. The area of the bell was then used to find the new bell diameter. See Table A.7 in the Appendix for the full calculations of each foundation. The layout of the new foundations is shown in Figure 21.

The original foundation sizes varied between a 15'-6" bell diameter and 6'-0" shaft diameter caisson to a 6'-0" bell and 2'-6" shaft. The new design results in caisson sizes that range between a 3'-0" bell and a 7'-0" bell.

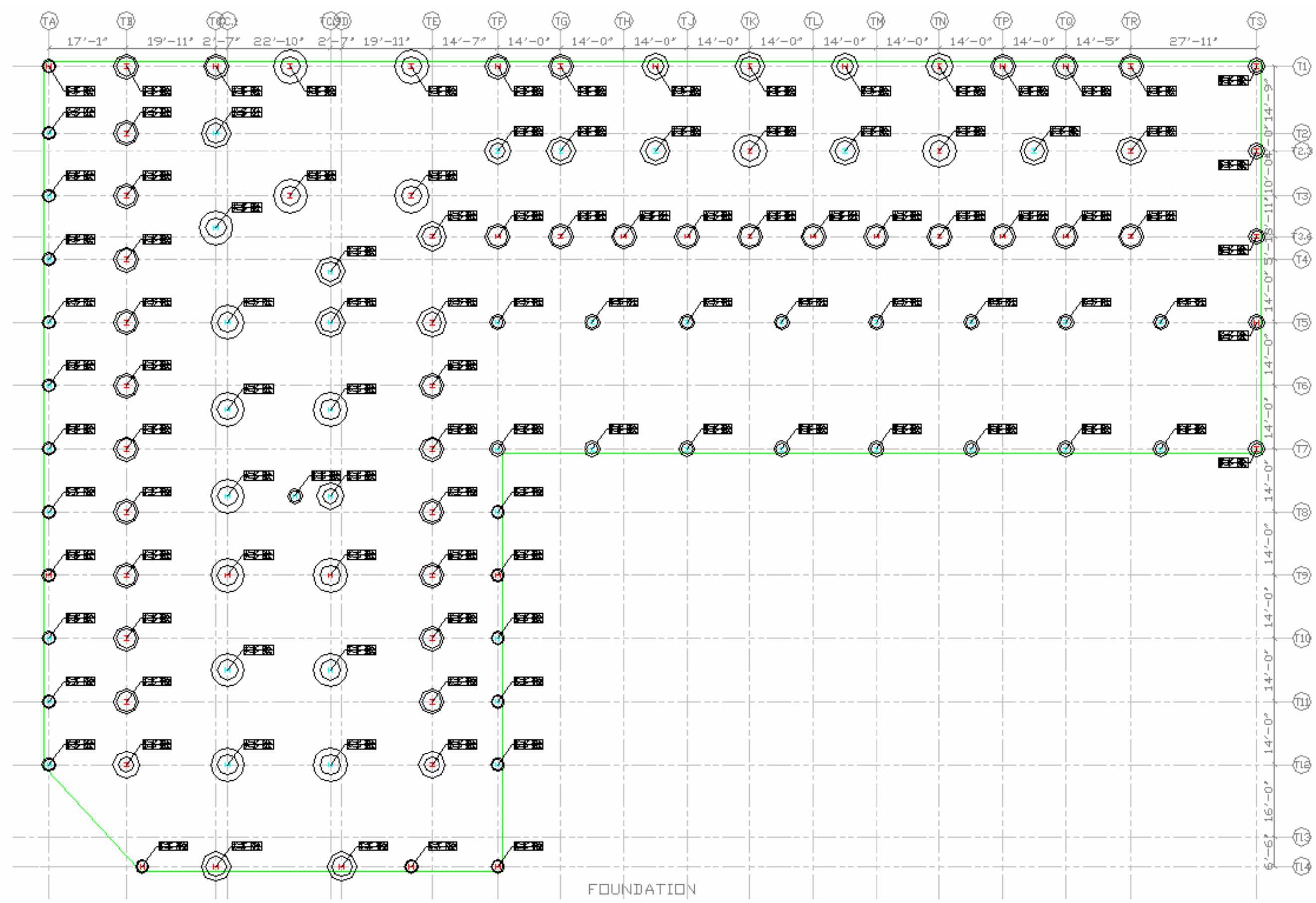


Figure 21: Foundation Plan

Summary:

The program, RAM Structural System, was used to design both the gravity and lateral system of Sherman Plaza. The column grid was not altered due to architectural restraints, and a layout of beams and girders was designed. The plans were entered into RAM, and a composite metal floor deck was chosen. The deck is a 1.5” 18 gage composite Lok-Floor and is topped by 2” lightweight concrete. The shear studs are 3” by ¾” diameter. The gravity system was designed and resulted in beam sizes that ranged between W8x10 and W16x31 on the lower floors and betweenW8x10 and W14x22 on the upper floors. From these beam sizes, the new building height was calculated to be 283.25 feet. The gravity columns were then designed, and it was found that the sizes varied between W14x193 and W10x33.

After designing the gravity system, the lateral system was designed using RAM Steel. The drift limit of the building was set to H/600, which results in a maximum allowable drift of 5.665 inches at the top story. To achieve an acceptable drift, it was determined that the building required braced frames in the locations of the original shear walls. Moment frames were also placed around the building’s perimeter. The lateral beam sizes were increased to W16x89 and W14x82, and the column sizes ranged between W14x257 and W14x370. The lateral bracing is made up of 2 L8x8x3/4. This design resulted in a drift of 5.6254 inches, which is below the allowable drift.

Using the new building design, new foundation sizes were estimated. The column load at the ground floor was found from RAM Steel. This value was used to find the caisson surface area, by dividing the column load by the allowable soil bearing pressure of 30 ksf. The surface area was then used to find the bell diameter for each of the caissons.

In all, the steel structural system was an effective design for this building. The composite steel produced an efficient gravity system that worked well with the given column layout. The drawback to this system, however, was that the structural system’s ceiling to floor section depth was greater than that of the existing concrete system. This increase in depth at each floor resulted in an increase of building height from 260.5 feet to 283.25 feet, which is an increase of 22.75 feet. The newly designed lateral system also produced acceptable results. The design, however, uses a large number of braced frames and moment connections that will increase construction time and costs.

The building weight was dramatically reduced, which allowed the foundation sizes to be decreased. Due to the fact that the caissons extend down 70 feet, this size reduction will result in large savings in concrete and in construction time. This savings will be investigated further in the construction management breadth study.