The Residences of Sherman Plaza
Evanston, IL

Senior Thesis 2006

The Pennsylvania State University
Department of Architectural Engineering

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Structural Option

The Residences of Sherman Plaza
Evanston, IL

Presentation Outline

- Building Description
- Existing Structural System
- Problem Statement and Solution Overview
- Structural System Redesign
- Construction Management Breadth Study
- Acoustics Breadth Study
- Conclusion

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Building Description

- 25 story condominium
- Located in downtown Evanston, IL
- Rectangular base of building contains 152,000 sq. ft. of retail space and a 54,000 sq. ft. health club.
- Topped by a 23 story L-shaped condominium tower.
- Building steps back on 3rd, 6th and 7th floors and is covered by a ½ acre intensive roof garden.

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Existing Structural System: Overview

- Reinforced Cast-in-Place Concrete System
- Belled Caisson Foundations
- Lateral System: Combination of Concrete Shear Walls and Moment Frames

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Floor System

- Two-Way Flat Plate: 8” depth
  - Reinforcement: #6@12” column strip, #5@12” middle strip
- Typical bay size: 14’x14’ or 21’x21’
- Columns, typical sizes:
  - Floors 2-6: 36”x36”interior and 18”x54” on perimeter.
  - Floors 8-25: 24”x24” interior and 13”x36” on perimeter.
- Typical floor begins on Level 8.
- Large transfer girders on Level 22 for change in column grid on penthouse level.

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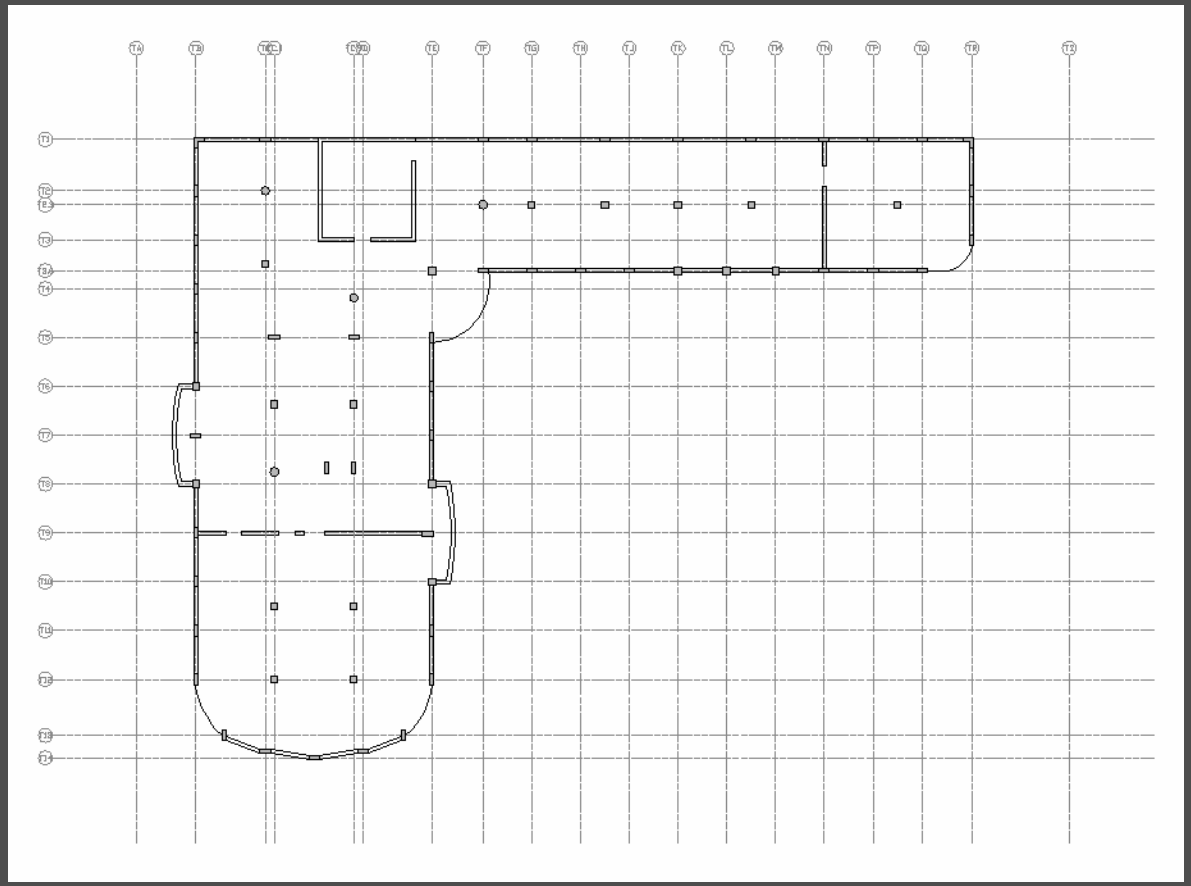
Floor Plan: Typical Floor



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Lateral System

- Combination of concrete shear walls and moment frames.
- Shear Wall Sizes:
  - Floors 2-6: 18” thick
  - Floors 7-12: 15” thick
  - Floors 12-25: 12” thick
- Reinforcement: #5@12” in general.
- Moment Frames:
  - Perimeter Edge Beams: 13”x34”, with 4#7 T&B bars
  - Columns: 13”x36”, with 8#7 bars.

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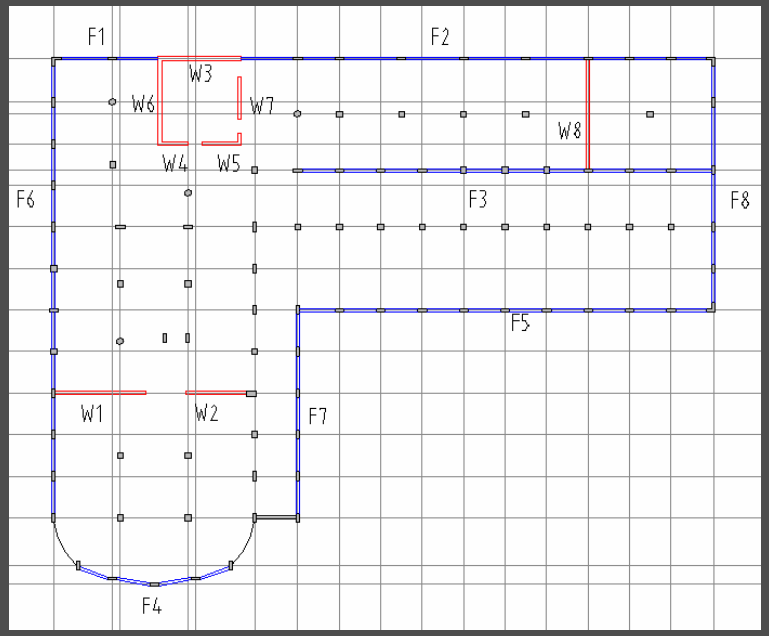
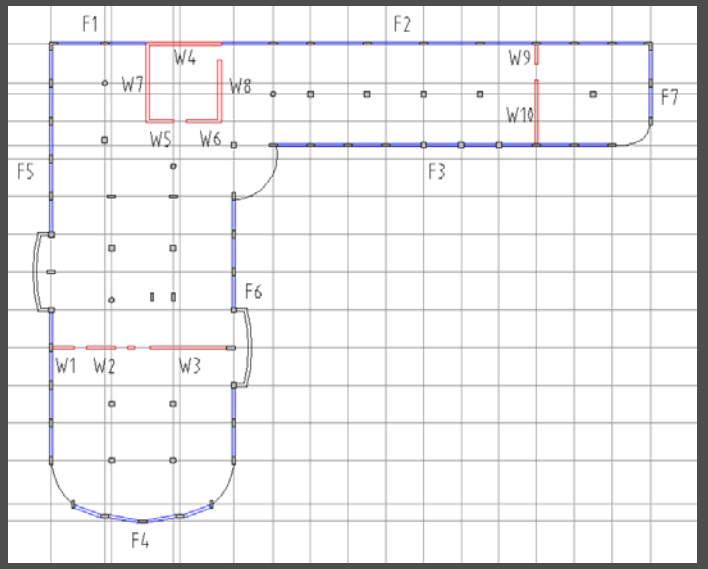
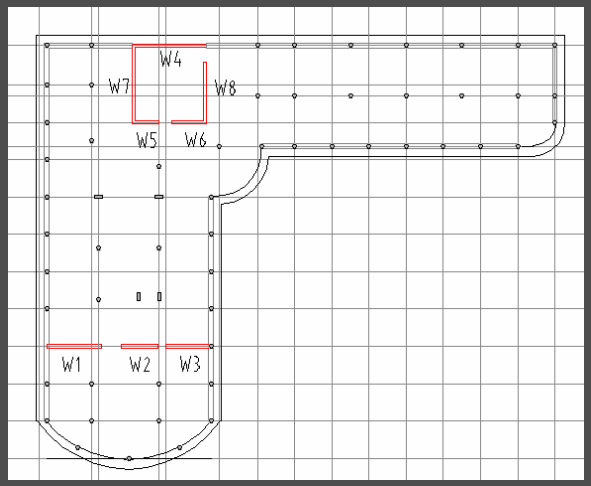
Floor Plans: Layout of Lateral Elements



Level 6



Level 8



Level 25

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Foundations

- Reinforced Concrete Belled Caissons
  - Sizes vary from 15'-6" bell diameter and 6'-0" shaft to a 6'-0" bell and 2'-6" shaft.
- Extend to hardpan 70' below grade
- Soil with minimum allowable bearing capacity of 30 ksf
- 5" slab on grade above caissons
- Grade beams located underneath shear walls

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Goals of Building Redesign

- To gain a greater understanding of designing a high-rise building's gravity and lateral systems.

- To produce an alternate structural system that will improve constructability, reduce the building weight and lower costs without decreasing the building's quality.

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Problem Statement

- Concrete System Drawbacks:
  - Placing formwork and shoring makes construction difficult and time-consuming
  - High building weight
  - Large foundations and grade beams
  - Inefficient use of material for large columns and beams in moment frames

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Solution Overview

- Change existing concrete system to a composite steel gravity and lateral system.

- Advantages:
  - Lower building weight
  - Reduce foundation sizes
  - Easier to construct
- Disadvantages:
  - Increase building height

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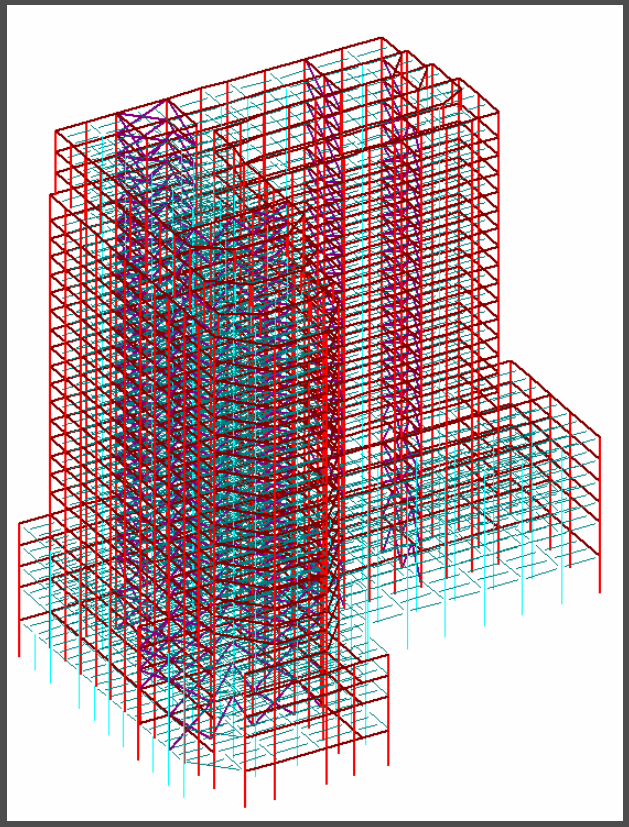
Gravity System Redesign

- Column grid remained the same due to architectural constraints.

- RAM Steel was used to design the new beam and column sizes.



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Gravity System Redesign

- Composite Floor Deck: 1.5” 18 gage
- Topped with 2” lightweight concrete
- Shear studs: 3” long, ¾” diameter
- Surface loads applied in RAM Steel:

Table 1: Surface Loads		
	Superimposed	
	Dead Load	Live Load
Retail	25 psf	100 psf
Residential	15 psf	80 psf
Storage	25 psf	125 psf
Roof Garden	15 psf	150 psf

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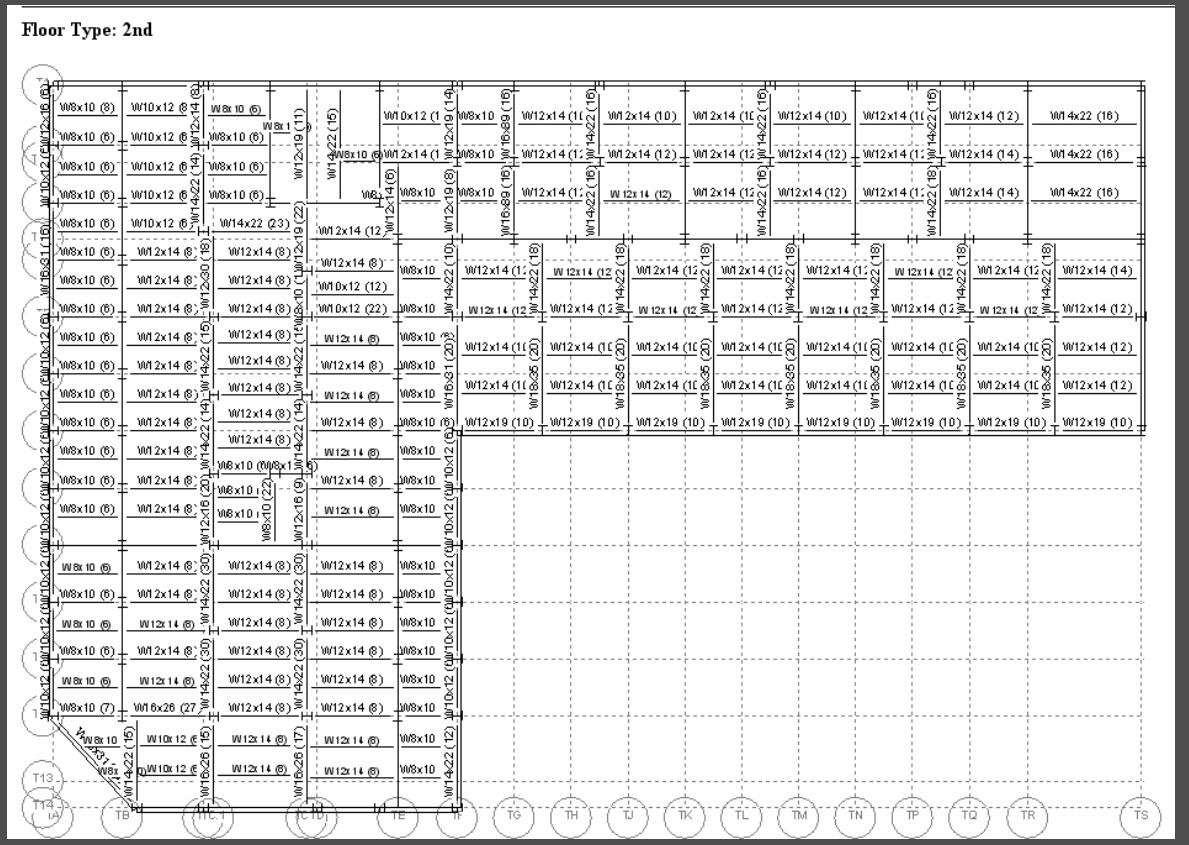
Floors 2-7:

- Beam sizes limited to W16s
- Sizes range from W8x10 to W16x31
- Typical Sizes:
  - Beam: W12x14 (8)
  - Girder: W16x26 (16)



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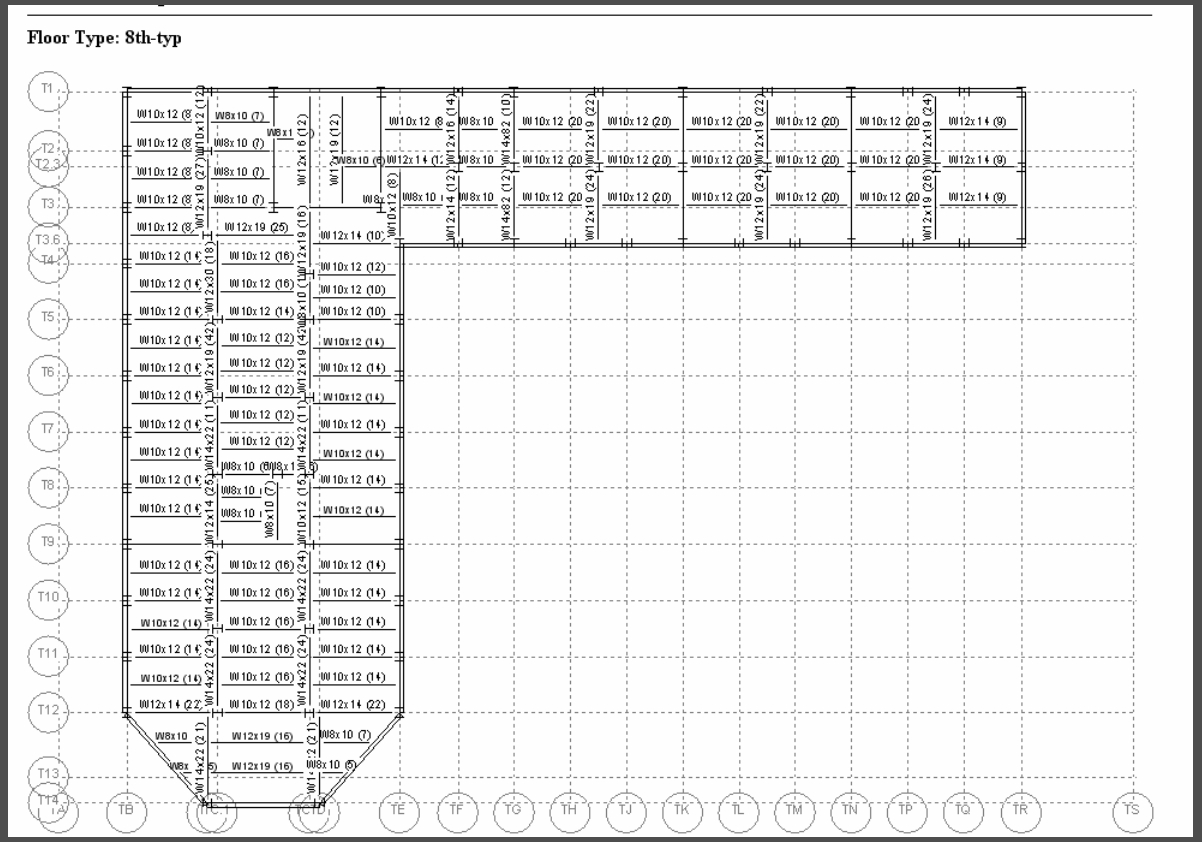
Floors 8-21:

- Beam sizes limited to W14s
- Sizes range from W8x10 to W14x22
- Typical Sizes:
  - Beam: W10x12 (16)
  - Girder: W14x22 (24)



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Gravity System Redesign

- Increase in depth of structural materials caused increase in building height.
  - New Building Height: 283.25 feet
  - Original Height: 260.5 feet
  - Increase of 22.75 feet
- Columns designed with new floor to floor height
  - Sizes range from W10x33 to W14x193
  - Ground Floor: Typical sizes W14x132 and W14x145
  - Floor 25: Typical size W14x43
  - Penthouse Levels: Typical size W10x33

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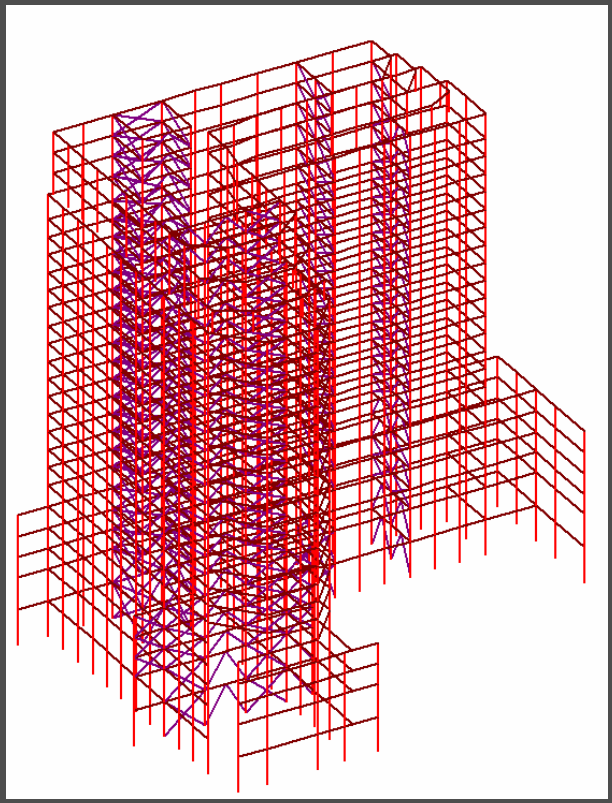
Lateral System Redesign

- New lateral system made up of steel moment and braced frames.
- RAM Steel was used to design the new lateral system.
- Allowable drift = H/600 which is 5.665”



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Lateral System Redesign

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

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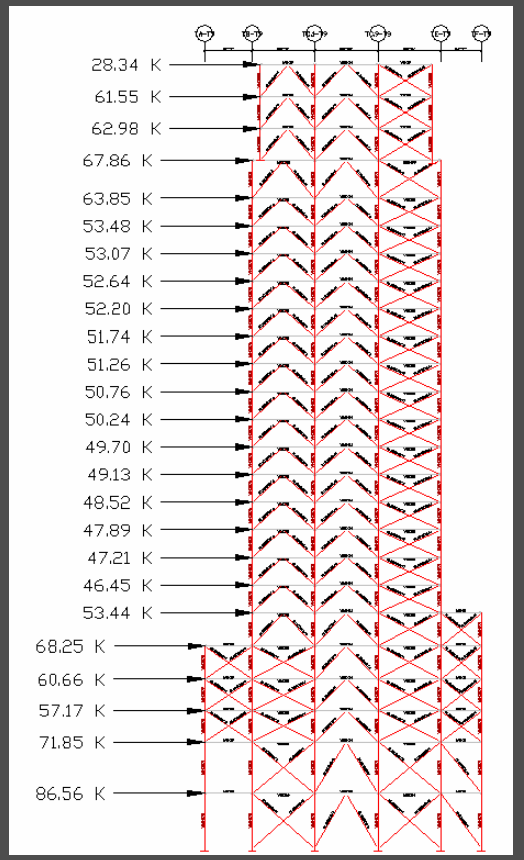
Lateral System Redesign

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



Controlling Load Case – Wind Y

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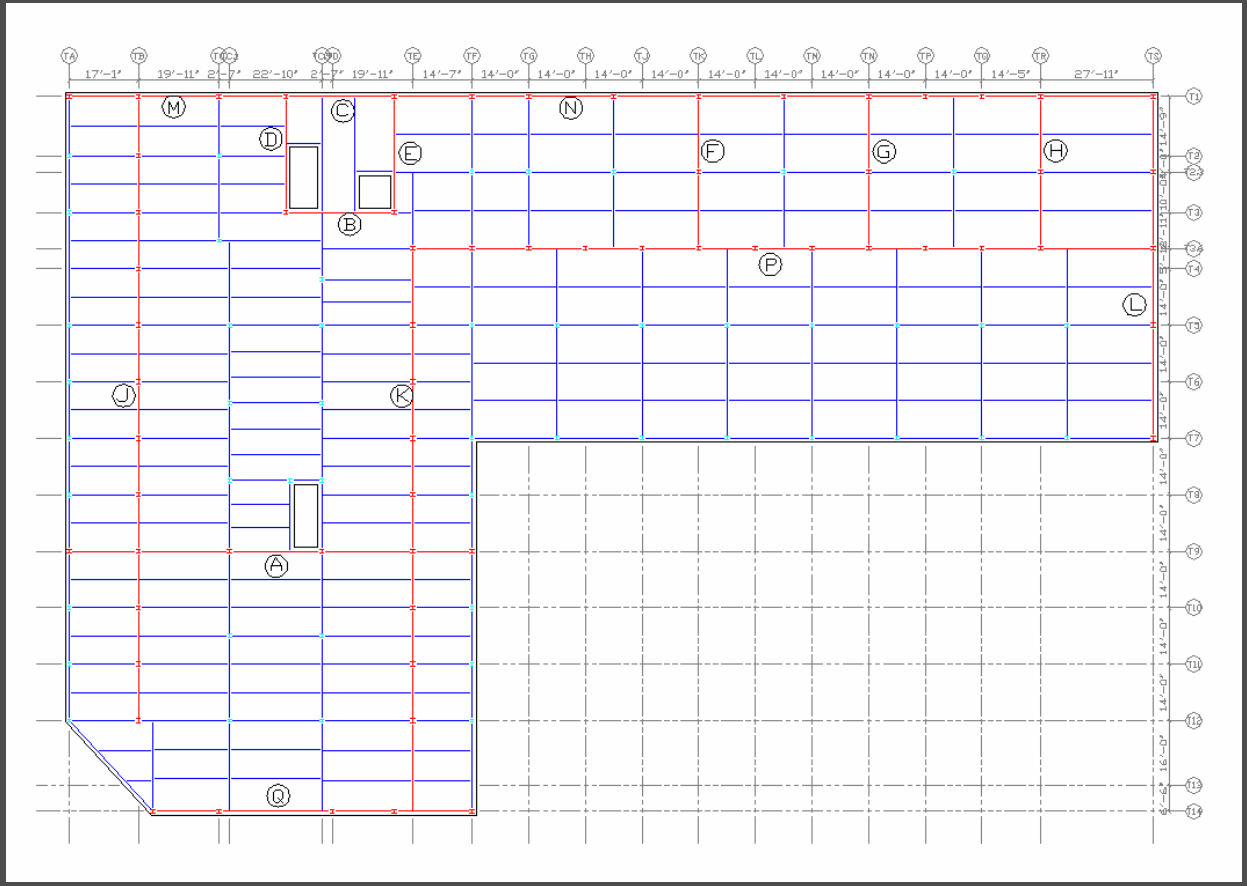
- Braced frames were placed in the locations of the existing shear walls.
- Additional braced frame needed to control drift in Y direction.
- Frames A-G are braced frames.
- Frames H-Q are moment frames.



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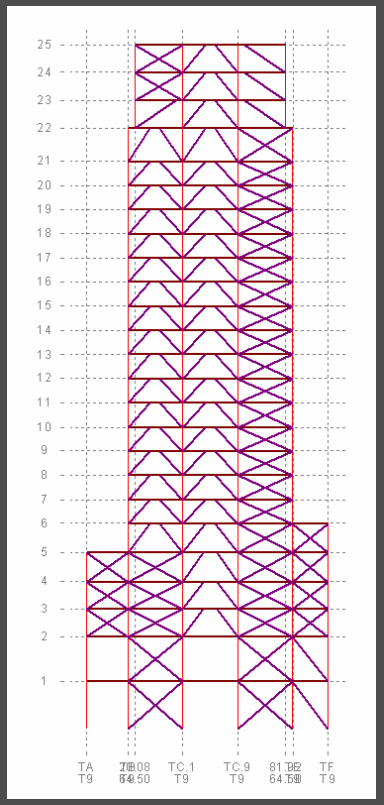
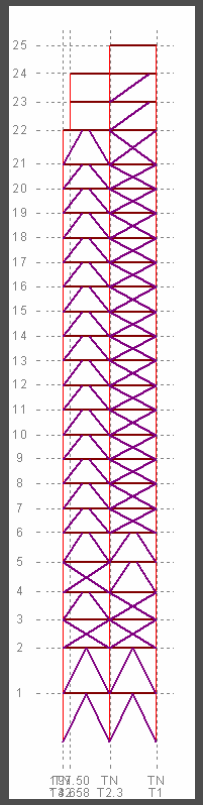
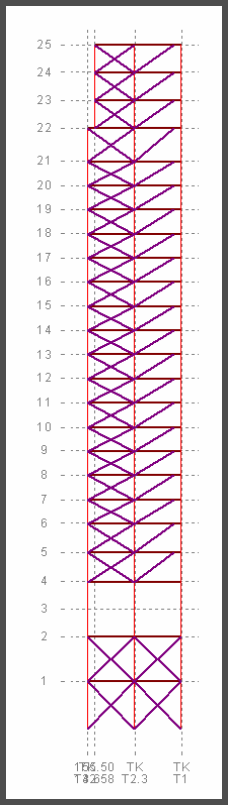
- Cross bracing used for bays with no openings.
- Chevron or diagonal braces were used for openings and doorways.
- After trial and error, the braces were made up of 2 L8x8x¾.







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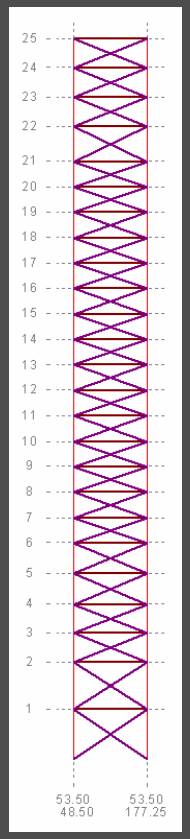
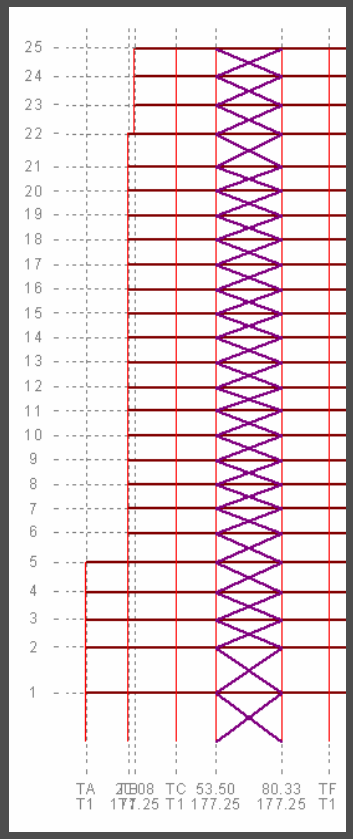
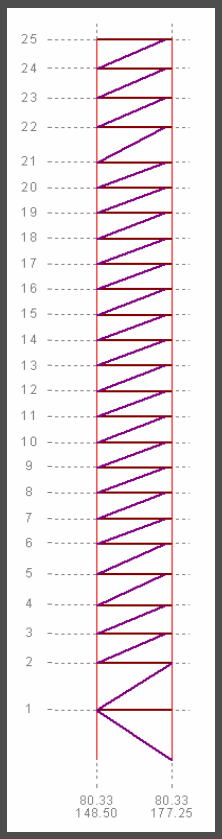
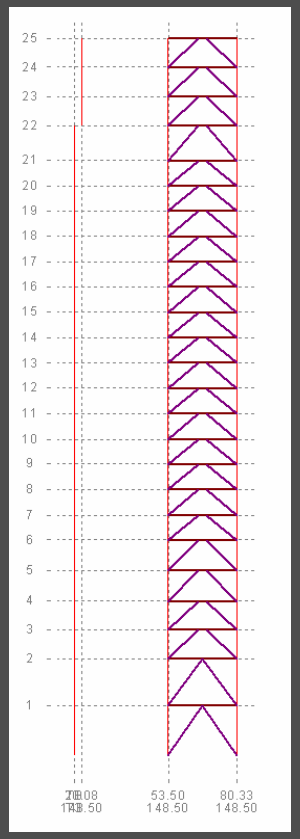
Elevator Core Braced Frames









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Lateral System Redesign

- Moment and Braced Frame Sizes:
  - Beams range between W16x89 on the lower floors to W14x82 on the upper floors
  - Columns in the frames along the Y axis were sized from W14x257 to W14x370.
  - Columns in frames along the X axis were sized W14x132 to W14x370.

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Design Controlled by Load Case: 1.2D+0.5Lp-1.3W2

Drift = -5.6254”

Allowable Drift = H/600 = 5.665”

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 - 1.3W1	-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 + 1.3W2	-0.695	5.1216
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 - 1.3W6	0.2231	-4.7742
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 - 1.3W6	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

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Foundation Redesign

- Allowable Soil Bearing Capacity = 30 ksf
- The new caisson area was estimated by dividing the column load by 30 ksf.
- Original Caisson Sizes: range between a 15'-6" bell diameter and a 6'-0" bell diameter.
- New Caisson Sizes: range between 3'-0" bell diameter and a 7'-0" bell diameter.

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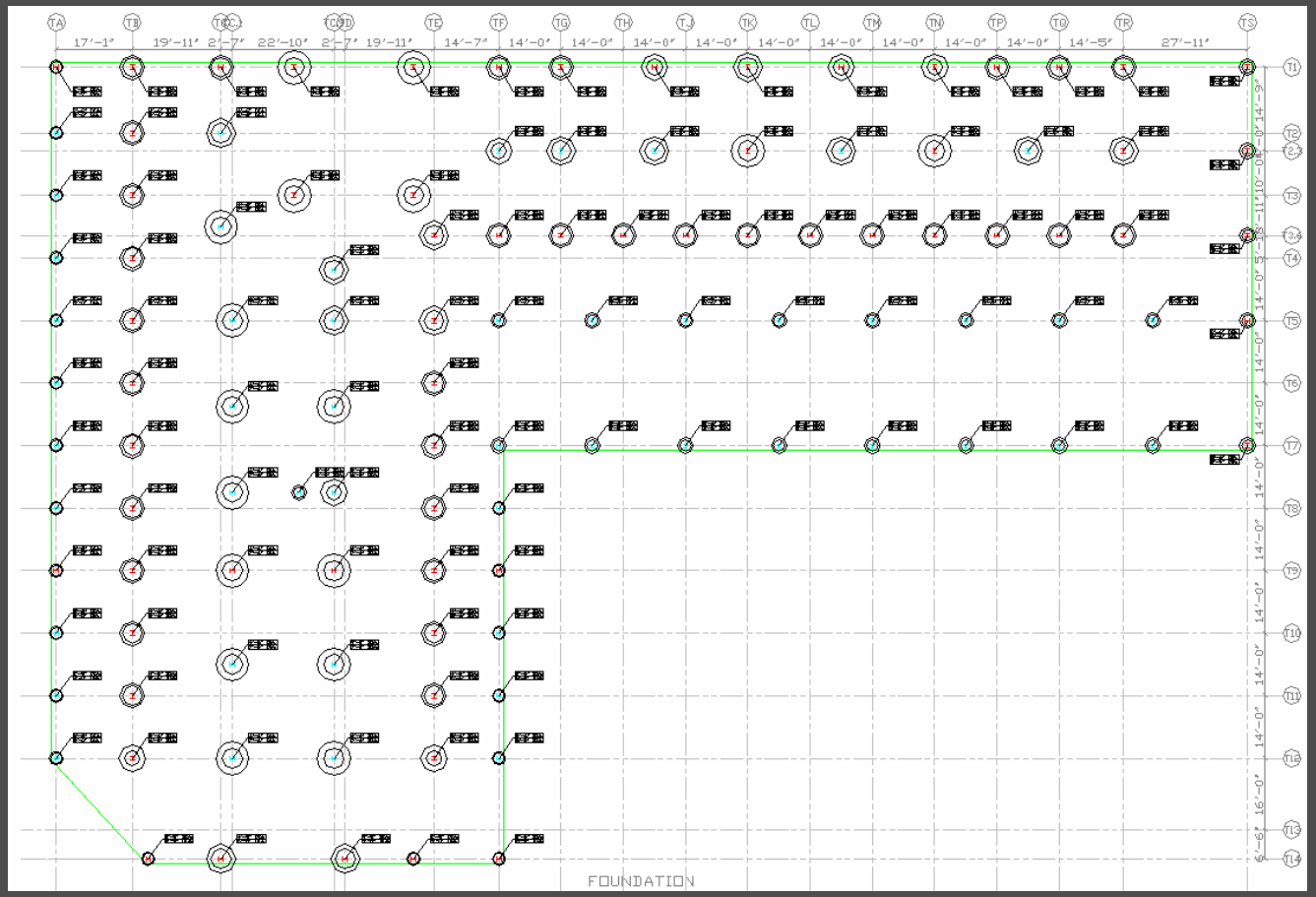
Foundation Plan



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Construction Management Study

- R.S. Means was used to estimate the costs and schedule of both the existing and the new structural systems.
- The structural materials of each system were considered.
- An estimate of the exterior cladding material was also included to account for the increase in height of the new building.

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Table 6: Steel System Cost Summary		
	Total Length (ft.)	Total Cost
Steel Beams	99845.69	3113651.45
Steel Columns	23015.2	3750311.38
Lateral Bracing	25884.8	694489.184
	Total No. Studs	Total Cost
Shear Studs	67681	92722.97
	Total Sq. Feet	Total Cost
Metal Deck	593800	1146034
	Total Sq. Feet	Total Cost
Concrete Slab	5500	569525
	Total Cu. Yards	Total Cost
Foundations	3837.03	3473184.2
	Total Sq. Feet	Total Cost
Ext. Cladding	220668.07	4614169.3
Total Cost Steel System:		17454087.5

Table 7: Concrete System Cost Summary		
	Total Cu. Yards	Total Cost
Concrete Columns	3316.452	3028635.148
	Total Cu. Yards	Total Cost
Concrete Slab	14662	7169718
	Total Cu. Yards	Total Cost
Shear Walls	2265.222	377100.3204
	Total Cu. Yards	Total Cost
Foundations	3509.74	10790575.1
	Total Sq. Feet	Total Cost
Ext. Cladding	203964.58	4264899.4
Total Cost Concrete System:		25630928.0

Concrete Cost = $25.6 million

Steel Cost = $17.5 million

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Table 8: Steel System Schedule Summary		
	Total Length (ft.)	Total Days
Steel Beams	99845.69	143.8260964
	Total Length (ft.)	Total Days
Steel Columns	23015.2	24.06033438
	Total Length (ft.)	Total Days
Lateral Bracing	25884.8	115.0435556
	Total No. Studs	Total Days
Shear Studs	67681	70.50104167
	Total Sq. Feet	Total Days
Metal Deck	593800	138.0930233
	Total Sq. Feet	Total Days
Concrete Slab	5500	34.375
	Total Cu. Yards	Total Days
Foundations	3837.04	619.3
Total Days Steel System:		1145.2

Table 9: Concrete System Schedule Summary		
	Total Cu. Yards	Total Days
Concrete Columns	3316.452	222.60
	Total Cu. Yards	Total Days
Concrete Slab	14662	484.85
	Total Cu. Yards	Total Days
Shear Walls	2265.222	29.810
	Total Cu. Yards	Total Days
Foundations	3509.74	1922.3
Total Days Concrete System:		2659.6

Concrete Time = 2660 days

Steel Time = 1146 days

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Acoustics Study

- By changing the structural material of the building, the transmission loss values of the floors and walls were also changed.
- This change will affect both the floor system and the area that contained the shear walls in the original design.
- The transmission loss of these areas will be analyzed to determine if they provide adequate sound isolation.

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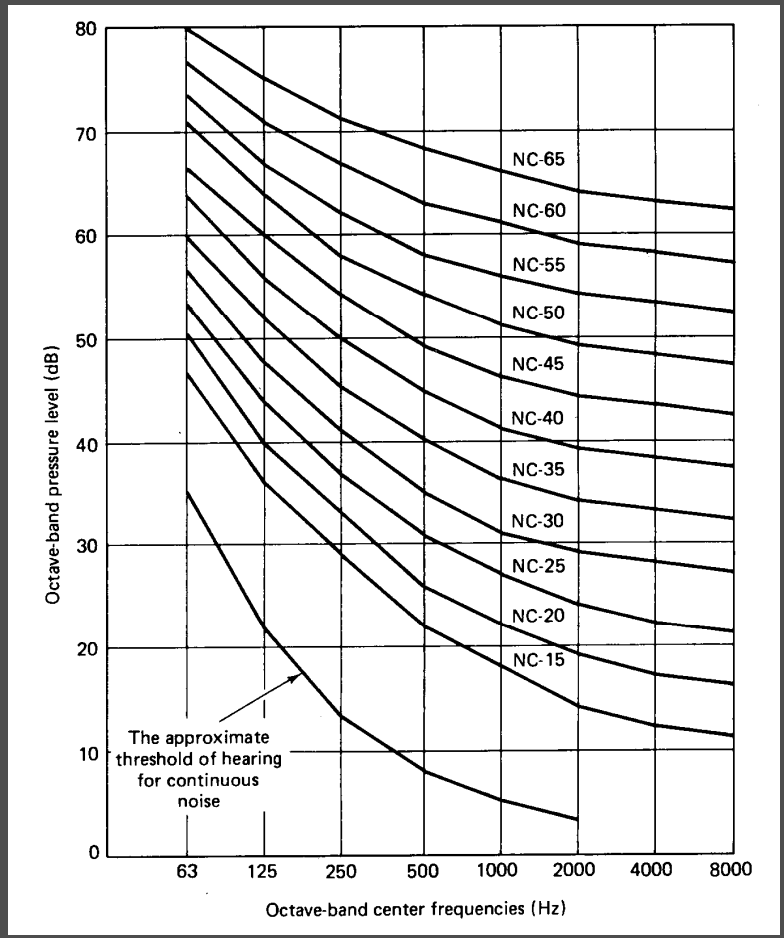
Acoustics Study

- Acceptable Range of Noise Criteria for Residential Space: NC-25 to NC-35
- Noise Reduction:

  $NR = TL + \log(a/S)$
- Receiving Room Sound Pressure Level:

  $L2 = L1 - NR$



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Transmission Loss of Floor System

Original Floor System: 8" Reinforced Concrete Floor

Source Room: Health Club
Receiving Room: Residential Area

	Surface Area:	Sound Absorption Coefficients					
Concrete Walls	490	0.1	0.05	0.06	0.07	0.09	0.08
Partition Walls	2170	0.55	0.14	0.08	0.04	0.12	0.11
Floor	1344	0.04	0.04	0.07	0.06	0.06	0.07
Ceiling	1344	0.01	0.01	0.02	0.02	0.02	0.02
Windows	0	0.35	0.25	0.18	0.12	0.07	0.04
a = S*alpha		1309.7	395.5	323.96	228.62	412.02	398.86
TL of Floor		38	48	56	60	67	72
10 log(a/S)		6	1	0	0	1	1
NR = TL + 10 log(a/S)		44	49	56	60	68	73
Sound Pressure Level		78	84	89	86	80	72
L2 = L1 - NR		34	35	33	26	12	0
NC-25		44	37	33	27	25	23

New Floor System: 3" Concrete Slab on Composite Metal Deck

Source Room: Health Club
Receiving Room: Residential Area

	Surface Area:	Sound Absorption Coefficients					
Concrete Walls	490	0.1	0.05	0.06	0.07	0.09	0.08
Partition Walls	2170	0.55	0.14	0.08	0.04	0.12	0.11
Floor	1344	0.04	0.04	0.07	0.06	0.06	0.07
Ceiling	1344	0.01	0.01	0.02	0.02	0.02	0.02
Windows	0	0.35	0.25	0.18	0.12	0.07	0.04
a = S*alpha		1309.7	395.5	323.96	228.62	412.02	398.86
TL of Floor		48	42	45	56	57	66
10 log(a/S)		6	1	0	0	1	1
NR = TL + 10 log(a/S)		54	43	45	56	58	67
Sound Pressure Level		78	84	89	86	80	72
L2 = L1 - NR		24	41	44	30	22	5
NC-25		44	37	33	27	25	23

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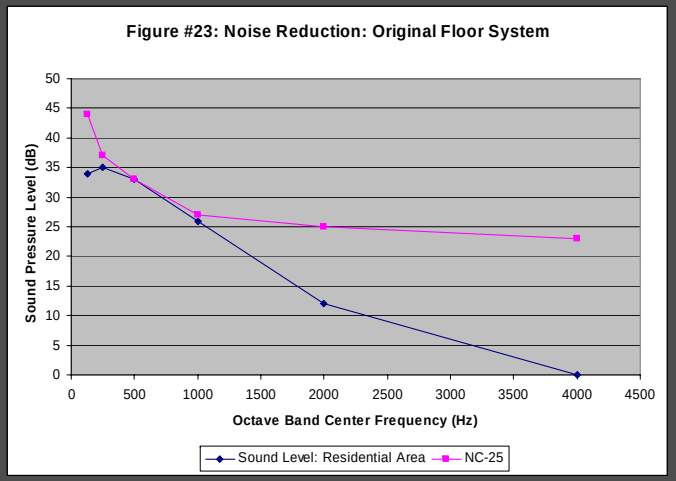
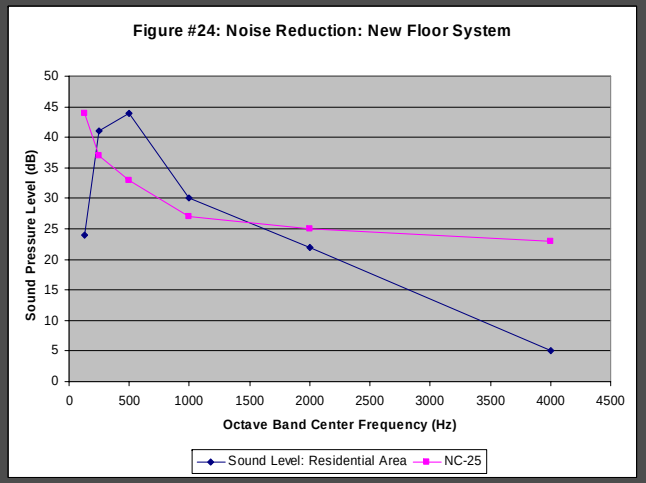
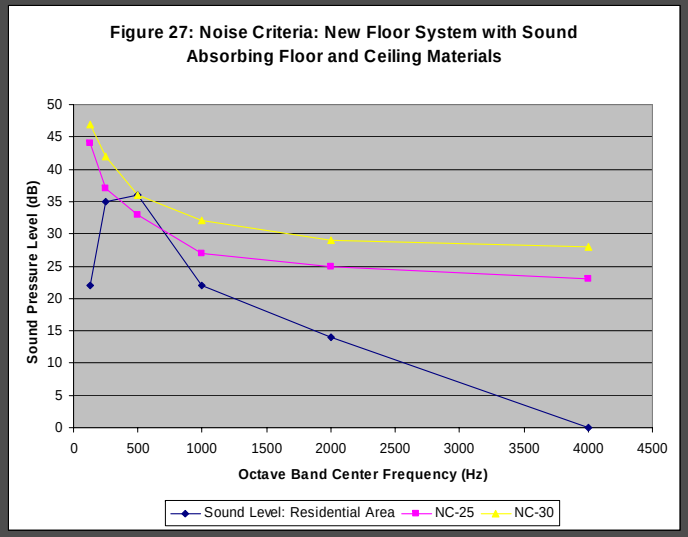




With the addition of sound absorbing floor and ceiling materials, the new floor system was acceptable for the NC-30 noise criteria curve.



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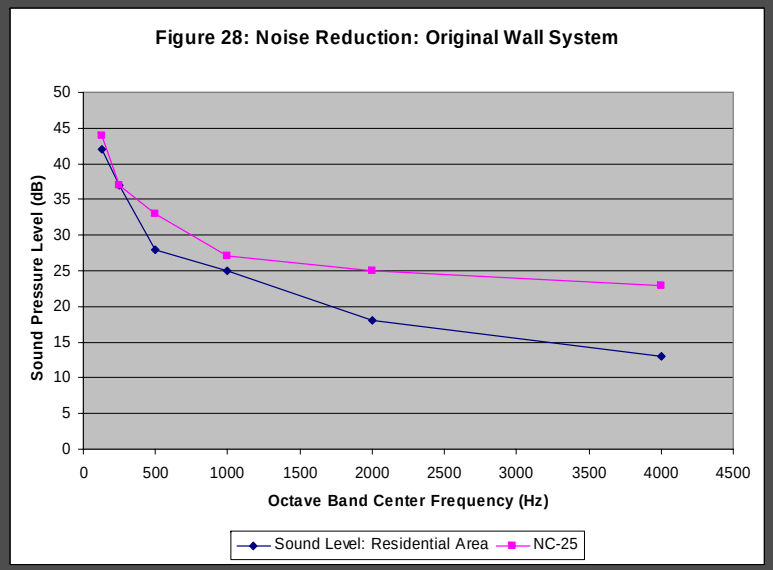
Transmission Loss of Partition Wall

- The existing concrete shear wall had adequate transmission loss.
- Three alternative walls were analyzed:
  - 2 ½" steel studs with 5/8" gypsum board both sides, with 2" insulation in cavity
  - 2 ½" steel studs with 2 layers 5/8" gypsum board one side, one layer other side, with 2" insulation in cavity
  - 3 5/8" steel studs with 2 layers 5/8" gypsum board both sides, with 3" insulation in cavity.



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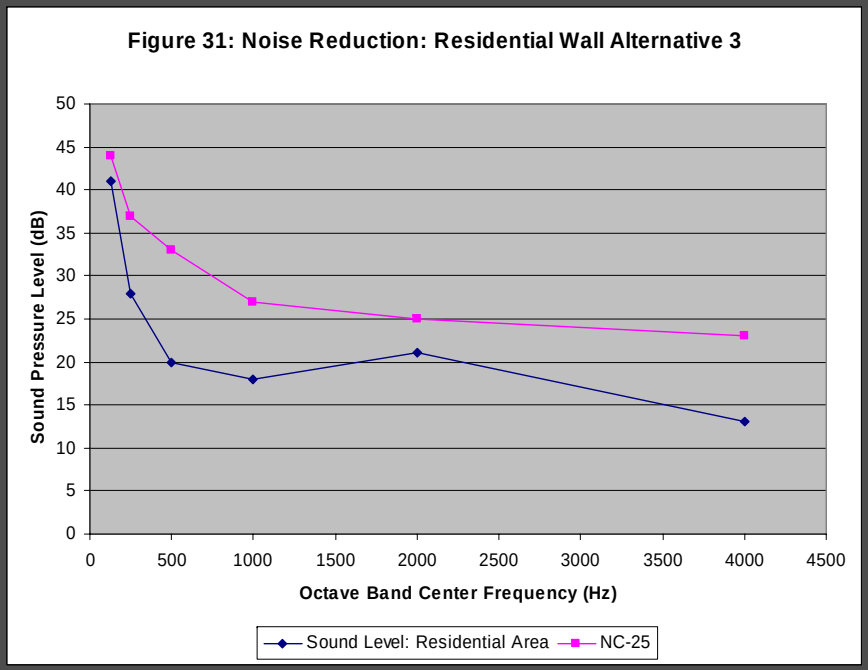
Transmission Loss of Partition Wall

- The first two alternatives did not provide sufficient transmission loss.
- The third alternative was acceptable according to the NC-25 noise criteria curve.



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Conclusions

- Gravity System:
  - Composite steel beams worked well with the given column layout.
  - Increase in depth of floor system increases overall building height by 22.75 feet.
- Lateral System:
  - Achieved a building drift of 5.625” which was less than the allowable drift of H/600.
  - Architectural constraints limited locations and configurations of braced frames.
- Foundations:
  - Foundations were sized down considerably due to the decrease in building weight.

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Conclusions

- Construction Management:
  - Steel system was $8.18 less expensive.
  - Steel system could be erected 1514 days faster.
- Acoustics:
  - Steel floor system was acceptable with the addition of sound absorbing floor and ceiling materials.

- The steel structural system is a feasible alternative to the existing reinforced concrete system.

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Questions or Comments?