Hershey Research Park Building One

Technical Report 3

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Executive Summary

The following is the third technical report for the Hershey Research Park Building One. The report is detailed analysis of the lateral system of the building. The drawings, specifications, and pictures have all been provided by Brinjac Engineering with permission given be Wexford Equities, LLC. The building was constructed by Whiting – Turner Construction and all the architectural design work was performed by Ayers/Saint/Gross, Inc.

Located outside Hershey, Pa HRPBO is a pretty standard office/research building. It is the first building of a planned twelve to be part of a research park. The building has over 80,000 square feet of available tenant space, with access to the facilities of the Penn State Milton S. Hershey Medical Center.

The engineers for this project used ASCE 7-02 along with IBC 2003 to determine the design loads, and both were used as a starting point when performing the wind analysis, earthquake analysis, and spot checks. RAM Structure Systems was used as the modeling program to help make the analysis fast and easy. RAM uses both ASCE 7-05 and IBC 2006 when performing its analysis, and they were used to find the controlling load cases and combinations.

Story displacements and drifts were found using RAM and compared to the allow values of H/400 of wind loading and 0.02h for seismic loading. These displacements were then used to determine the stiffness of each lateral frame in the building.

The torsion, direct shear, and torsional shear values were also found using RAM. Due to the fact that the center of mass and center of rigidity are not in the same location, the effects of the torsion and torsional shear on the building were studied. The overturning moment was another emphasis, but the weight of the building is able to resist the overturning movement induced by both wind and seismic loads.

From all the analysis performed all aspects of the building's lateral structural system came out to be adequate. The spot checks confirmed that the beams and columns used are sufficient to carry the combination of gravity and lateral loads of the building.

Building Introduction

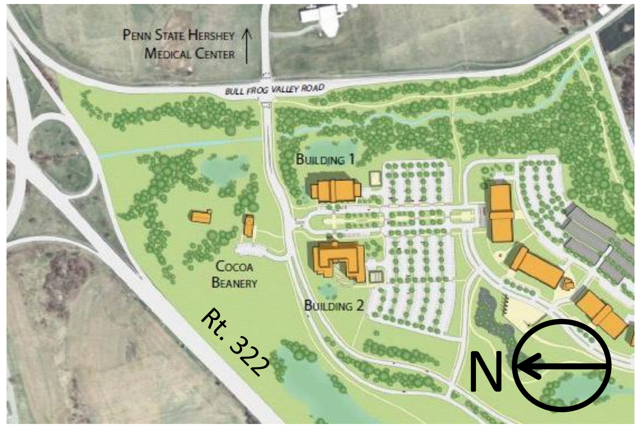


Figure 1: Site Master Plan

The Hershey Research Park Building One (HRPBO) is a research facility located in Hershey, Pa., directly across the street from the Penn State Milton S. Hershey Medical Center. It was designed by Ayers/Saint/Gross Inc. with the engineering done by Brinjac Engineering and the construction by Whiting – Turner Constructuion. Building One is the first building to be finished of a twelve building research park known as the Hershey Center for Applied Research or HCAR for short. Completed in Spring 2007, HRPBO is a state of the art research lab home to various medical and chemical research companies. They include Apeliotus Vision Science, Apogee Biotechnology, and vivoPharm along with some departments of Penn State Hershey's College of Medicine. The building has 80,867 square feet of rentable space and cost approximately $10.7 million dollars total to build. It was designed using the 2003 edition of the International Building Code and its supplements along with ASCE 7-02. Building One consists of a steel moment frame with brick, glass, curtain wall and metal panel façade.

The foundation is drilled steel piles system with concrete pile caps. The main superstructure is composite steel floor deck supported by steel beams, girders and columns. Also some parts of the first floor and basement levels are just slab on grade. The roof system is galvanized roof deck with insulation and water proofing placed on top of the beams. The Hershey Research Park Building One is designed to with stand wind gusts up to 90 mph and is seismic use group II along with a seismic site class of "D". The lateral resisting system is an ordinary steel moment frame which resists both the seismic and wind loads on the building. Even though Building One is not LEED certified there are still multiple forms of sustainability integrated into the building. Regional recycled steel was used in the building which reduces cost as well as waste by reuse. The roof system incorporates an efficient thermoplastic that helps reduce the energy used by the HVAC system, leading to overall reduced costs and emissions. Stones for the excavation of the site were reused for landscaping purposes. Also there is a storm management system integrated with green roof technology. The research center developers, Wexford Science and Technology, are planning on achieving a silver LEED certification on building two of the research park.

Structural Overview

Hershey Research Park Building One sits on a combination of footings and piers. Due to problems with the soil, footings are not enough to support the building. Other than a small portion of the basement, the building is composite steel deck spanning between steel beams. The lateral system utilizes a flexible steel moment frame throughout the entire building.

Foundation

Testing Service, Inc. performed geotechnical testing of the soil before the construction of Building One. The test consisted of nine different borings located throughout the footprint of the building with depths ranging from 25 feet to 38 feet. The results of their tests found three types of layers: residual soil with few rock fragments, residual soil with significant rock fragments, and decomposed limestone. In addition, groundwater was observed in seven of the nine borings after drilling was completed.

TSI recommended certain types of foundations to be used for Building One based on the results of their tests. Their recommendation was to use a shallow spread footing to support the building. In the report TSI also found that the proposed area of Building One was prone to sink holes. Keeping this in mind the engineers decide to use piers with concrete caps. Using a deep foundation like this added more support just in case sinkholes began to develop.

Floor System

The main superstructure is composite steel floor deck which is comprised of 4 ½ inch concrete slab on top of 3 inch deep 18 gage, galvanized composite steel floor deck reinforced with welded wire frame mesh. In addition, ¾ inch diameter, 6 inch steel studs are placed evenly across the beams. Also some parts of the first floor and basement levels are just 4 inch thick slab on grade. The concrete is 4000 psi with the reinforcement being grade 60 steel (Fy = 60ksi). On the structural steel side of things, the wide flange steel is A992 steel. Figure 2 is a typical floor section showing the composite metal deck sitting on top of the steel beam.

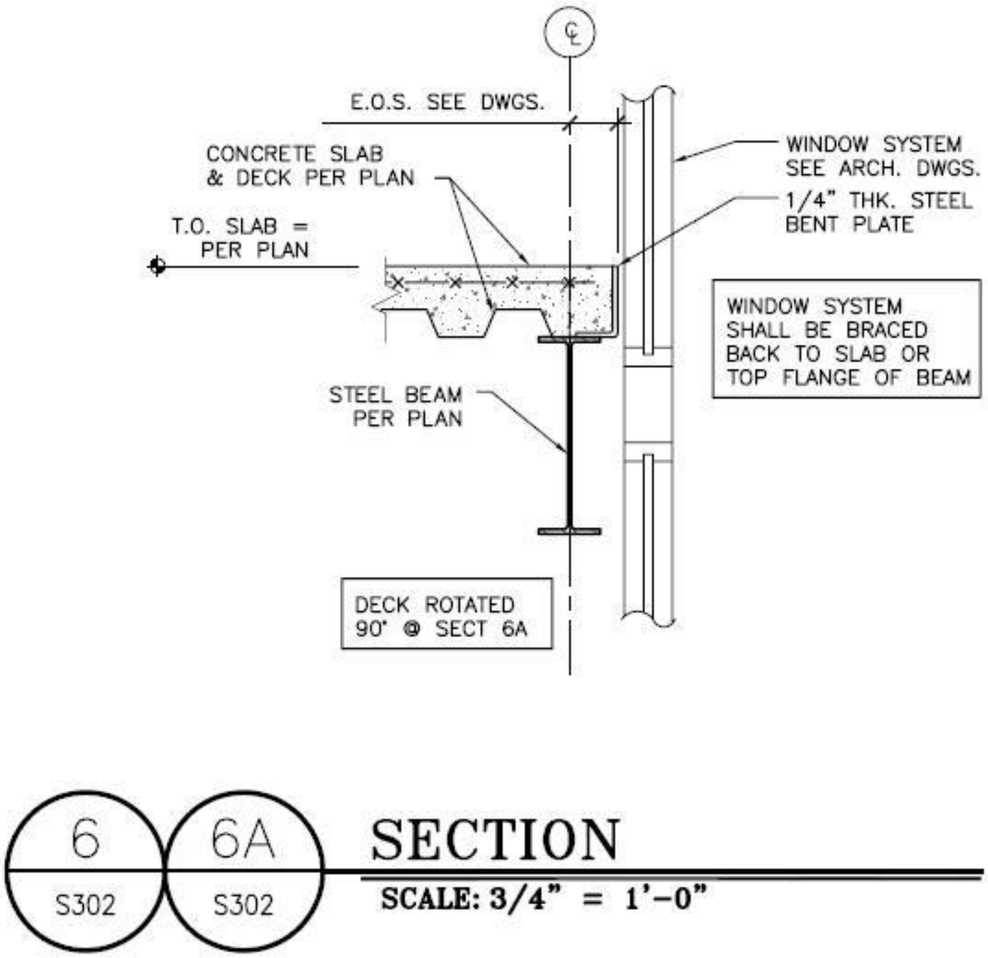


Figure 2: Typical Floor System

Framing System

The framing system of Hershey Research Park Building One is a basic one. It has a steel frame with composite metal deck on top. Beams frame into girders while the girders then frame into the columns which then transfer the forces to the foundation, the basic load path for any building. Figure three shows a basic floor framing plan with a zoomed in view of a typical bay. The numbers within the brackets next to the beam sizes refers to the number of evenly spaces steel studs. The area surrounded by the red box shows where the moment connections are within the frame. The small black arrows are the designator to show which connections are the moment connections. It is also important to note that the 2nd and 3rd floor framing plans are the same. The roof is slightly different.

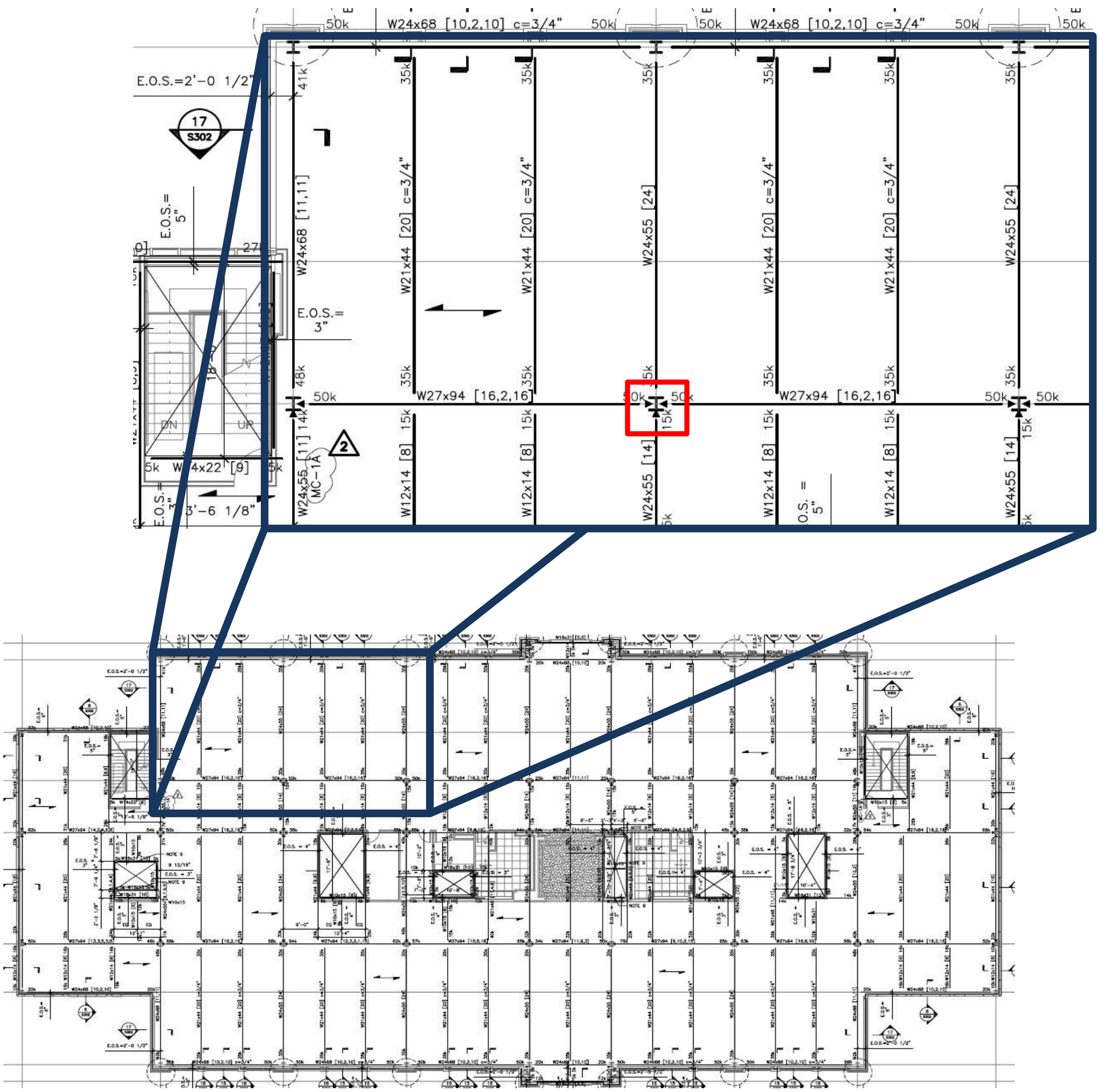


Figure 3: Second Floor Structural Plan with Spot Check Area

Structural Materials Used

Here is a list of all the structural materials as noted in the general notes section of the structural specifications.

Structural Steel Properties	
Material Shape	**ASTM Standard**
Wide Flange	ASTM A992
Tubes	ASTM A500, Grade B
Pipes	ASTM A53
M/S/Channel	ASTM A572, Grade 50
Angles and Plates	ASTM A36
High Strength Bolts	ASTM A325
Reinforcing Steel	ASTM A615, Grade 60
Welded Wire Fabric	ASTM A185
Embedded and Misc.	ASTM A36

Table 1

Structural Concrete Properties	
Type	**f ' c (psi)**
Caissons	3000
Slab on Grade	4000
Elevated Slabs	4000
Stairs	4000
Foundations	4000
Piers	4000
Walls	4000

Table 2 - Note: All exterior exposed concrete is air entrained.

Metal Deck Properties		
Deck Type	**Gage**	**Depth**
Roof	22	1 ½ in
Floors (Composite)	18	3 in

Table 3 - Note: Both types are galvanized steel deck.

Design Codes and Standards

The Hershey Research Park Building One was designed to the following codes.

Design Codes	
Name	**Description**
IBC 2003	International Business Code – Minimum Design Loads
ASCE 7-02	American Society of Civil Engineers – Minimum Design Loads
ACI 318/301	American Concrete Institution – Reinforced Concrete Construction (318) / Structural Concrete for Buildings (301)
ASTM	American Society for Testing and Materials - Various standard use throughout the building
AISC	American Institute for Steel Construction – Specifications for Steel Buildings
NEC	National Electric Code – Specifications of Electrical Components
IMC 2003	International Mechanical Code – Specifications of HVAC Requirements

Table 4

Design Loads

Dead Loads

All the dead loads for the building were designed using IBC 2003 Section 1606. The superimposed dead loads are as shown in the table below. The floor framing dead load is based on the floor deck used and also super imposed dead load. The floor deck used has a weight of 75 psf, and the super imposed load was determined to be 10 psf.

Dead Loads	
Slab on Grade	50 psf
Floor Framing	85 psf
Stair Framing	85 psf
Roof Framing	15 psf

Table 5

Live Loads

Live loads determined through IBC 2003 section 1607, which was the version that was used by the engineers on this project. Compared to the values in the IBC, the design live load numbers were more conservative.

Live Loads	
Slab on Grade	100 psf
Lab	100 psf
Office	100 psf
Mechanical	150 psf
Roof Framing	30 psf

Table 6

Wind Loads

The wind analysis was performed once using ASCE 7-02, since that was used by the original engineers. The hand calculations for the wind design loads can be found in Appendix A. The Hershey Research Park Building One is located in the 90 mph wind velocity section of figure 6-1 of the code, and also the fundamental frequency for the building is greater than one. Since the fundamental frequency is greater than one that means the building is rigid. Being rigid that leads to a gust factor of 0.85.

In plan view, the building geometry is not exactly a rectangle, but a simplifying assumption was made to change the geometry to a rectangle with the dimensions of 256.66 ft by 95.2 ft. A pressure distribution diagram is also present in the hand calculations to show how the wind load increases as the height increases. The figure below shows the distribution of forces throughout the different levels of the building.

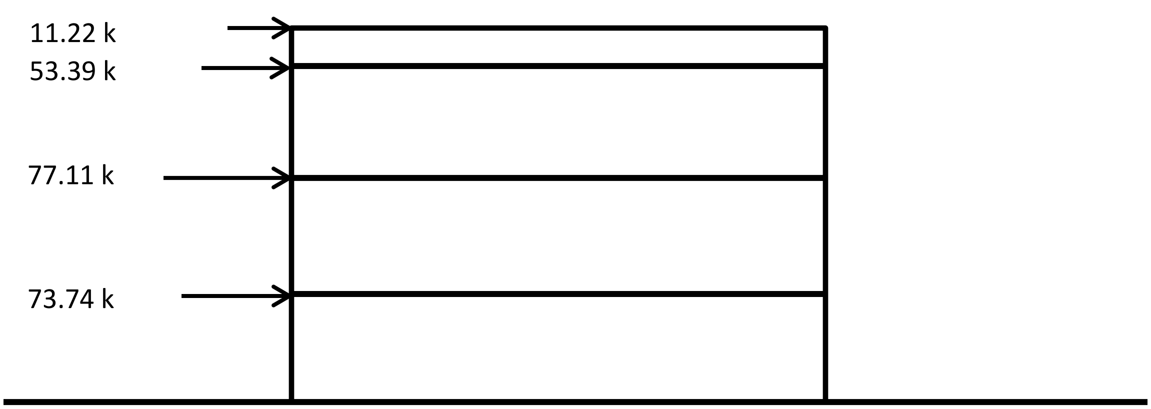


Figure 4 – Wind Force Distribution E-W

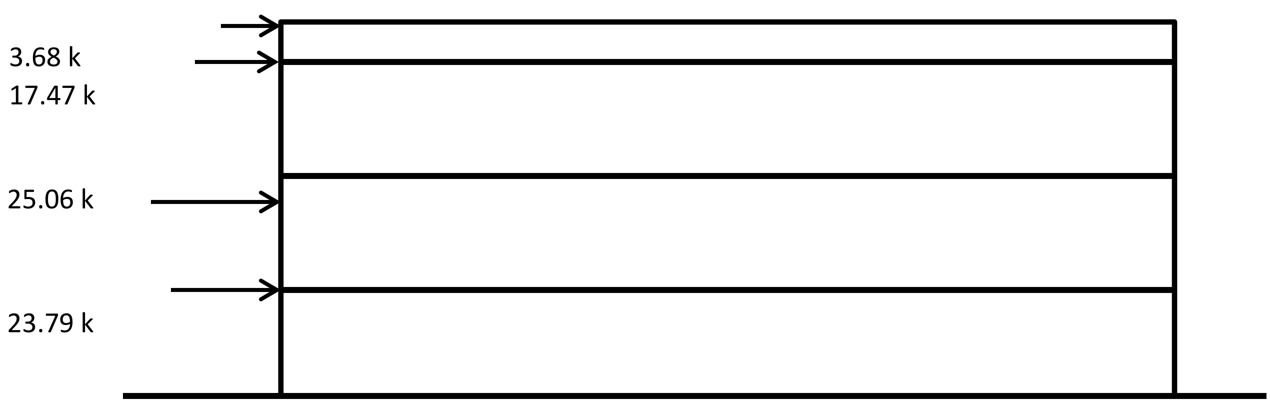


Figure 5 – Wind Force Distribution N-S

Wind Pressure Diagrams

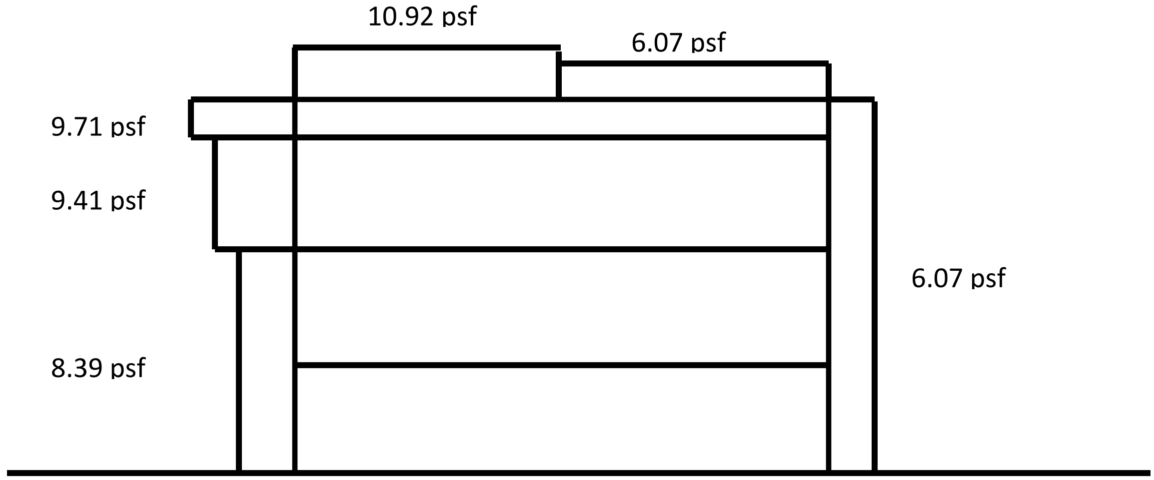


Figure 6: Wind Pressure E-W

Figure 7: Wind Pressure N-S

East-West Wind Hand Calculations									
Floor	Elevation (ft)	z	kz	qz	qh	Windward (psf)	Leeward (psf)	Trib. Area (ft^2)	Force (kip)
1	409.25	0	0.7	12.34	14.28	8.39	-6.07	1881.30	27.20
2	423.916	14.666	0.7	12.34	14.28	8.39	-6.07	3762.60	54.40
3	438.58	29.33	0.7	12.34	14.28	8.39	-6.07	3934.6	56.88
Roof	454.6	45.35	0.785	13.84	14.28	9.41	-6.07	2589.7	40.08
High Roof Framing	458.6	49.35	0.81	14.28	14.28	9.71	-6.07	536.4	8.46
								Total	187.02
								Overturn Moment	9229.48

Table 7

North-South Wind Hand Calculations									
Floor	Elevation (ft)	z	kz	qz	qh	Windward (psf)	Leeward (psf)	Trib. Area (ft^2)	Force (kip)
1	409.25	0	0.7	12.34	14.28	8.39	-3.64	697.8	8.39
2	423.916	14.666	0.7	12.34	14.28	8.39	-3.64	1385.6	16.67
3	438.58	29.33	0.7	12.34	14.28	8.39	-3.64	1459.4	17.56
Roof	454.6	45.35	0.785	13.84	14.28	9.41	-3.64	960.6	12.53
High Roof Framing	458.6	49.35	0.81	14.28	14.28	9.71	-3.64	199	2.66
								Total	57.81
								Overturn Moment	2853.05

Table 8

Earthquake Loads

The lateral system of the Hershey Research Park Building One was designed using ASCE 7-02 using the simplified method. The equivalent lateral force method from ASCE 7-10 is the more common method used. Both ways of calculating the earthquake forces were analysis in the calculations. The geotechnical report by TSI, was used to help determine the site classification which came out to be “D”. The resulting base shear from using the simplified method gave an answer closer to that actual value compared to using the equivalent lateral frame method. Using the table below and comparing it to the wind tables, the seismic load cases will be the controlling factor. The overturning moment due to seismic is slightly more than that caused by wind.

Seismic Hand Calculations							
Floor	**Height (ft)**	**Total Weight (kip)**	**w*h^K**	**Cvx**	**Fx (k)**	**V (k)**	**M (ft-K)**
2	14.66	4351.31	76465.9	0.272	88.5	88.5	1297
3	29.32	4351.31	160257.2	0.571	185.4	273.9	5436
Roof	49.35	684	43917.8	0.156	50.8	324.7	2508
Totals		**9386.62**	**280640.9**		**324.7**		**9241**

Table 9

Lateral System

The lateral force resisting system consists of moment frame construction. This type of resisting system transfer the moments in the beams and girders to the columns which then transfer them to the foundation. The moment frame is not the entire framing system. Only certain connections are moment connection. The interior core of the building is what makes up the laterals system. Figure 3 shows which beams and girders are part of the lateral system. Building One uses two different types of moment connections between the columns and beams. These two types are shown in figures four and five.

The lateral system has been broken down into 12 separate frames. There are nine frames spanning in the "Y" direction and three in the "X" direction. Using a 1 kip applied load at the top of the frame, the stiffness of each frame was determined. Using the data found from this analysis the relative stiffness of each frame was also determined. Also the "X" direction is equivalent to the N-S direction and the "Y" direction is E-W.

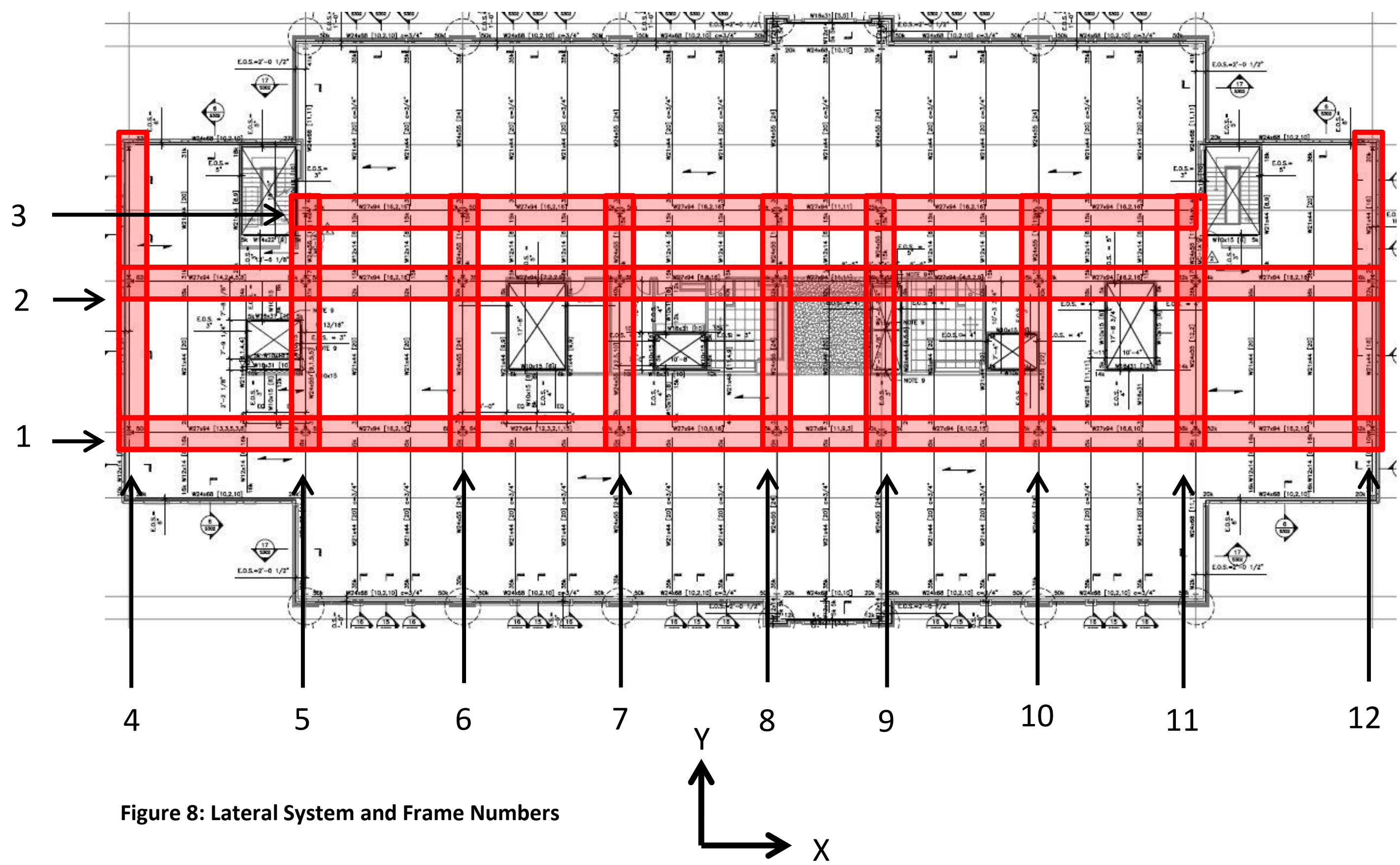


Figure 8: Lateral System and Frame Numbers

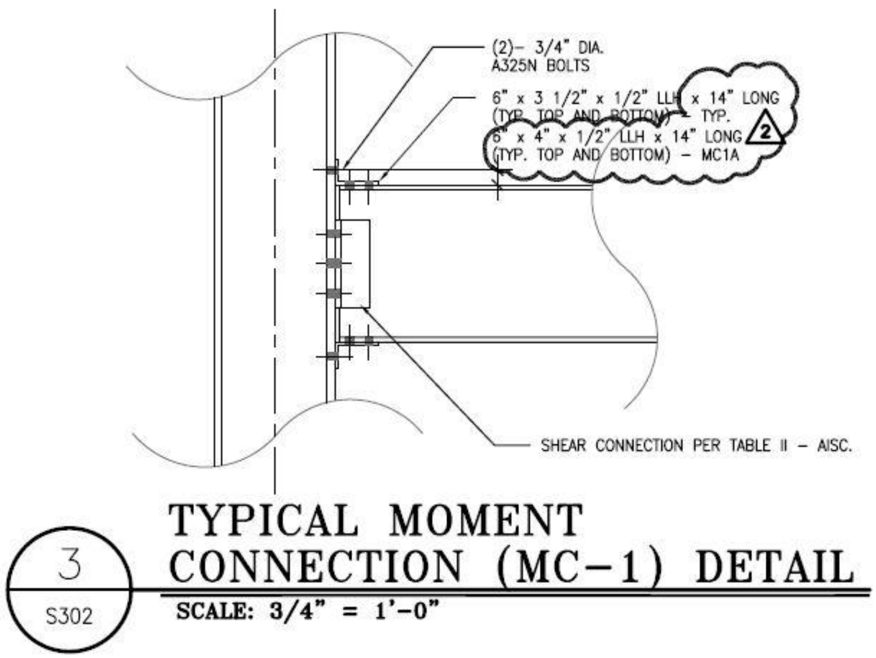


Figure 9: Connection Detail

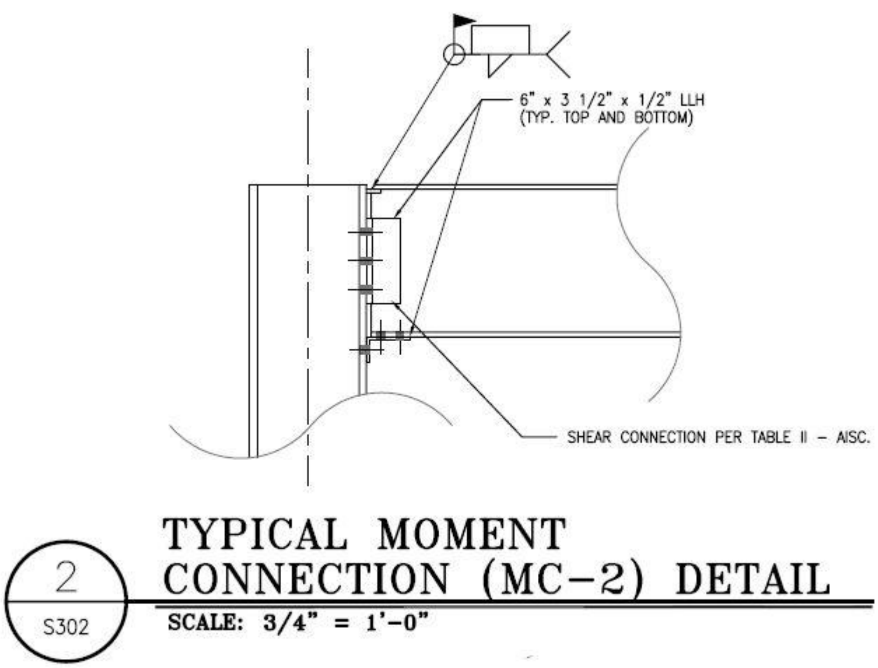


Figure 10: Connection Detail

Frame Stiffness's

Frame #	Displacement (in)	Load (k)	Stiffness	Relative Stiffness
X-Direction				
1	0.00968	1	103.3	0.338
2	0.00985	1	101.5	0.332
3	0.00992	1	100.8	0.330
			305.6	1
Y-Direction				
4	0.00603	1	165.8	0.105
5	0.00593	1	168.6	0.106
6	0.00584	1	171.2	0.108
7	0.00575	1	173.9	0.110
8	0.00567	1	176.4	0.111
9	0.00561	1	178.3	0.113
10	0.00552	1	181.2	0.114
11	0.00543	1	184.2	0.116
12	0.00543	1	184.2	0.116
			1583.7	1

Table 10

Load Cases and Combinations

When performing the analysis the following load cases and combinations were used to determine the controlling case. As determined earlier the seismic cases should be the controlling case.

Load Cases ASCE 7-05/IBC 2006		
Symbol	**Type**	**Description**
D	Dead	User Defined
Lp	Live	User Defined
Sp	Roof Live	User Defined
W1.A	Wind	X
W1.B	Wind	Y
W2.A	Wind	X + e
W2.B	Wind	X – e
W2.C	Wind	Y + e
W2.D	Wind	Y – e
W3.A	Wind	X + Y
W3.B	Wind	X – Y
W4.A	Wind	X + Y CW
W4.B	Wind	X + Y CCW
W4.C	Wind	X –Y CW
W4.D	Wind	X – Y CCW
E1	Seismic	X + e
E2	Seismic	X – e
E3	Seismic	Y + e
E4	Seismic	Y - e

Table 11

Combinations	
1.4 D	1.2 D + 1.6 Lp + 0.5 Sp
1.2 D + 1.6 Lp + 0.5 W1.A	1.2 D + 1.6 Lp + 0.5 W2
1.2 D + 1.0 E1 + 0.5 Sp	1.2 D + 1.0 W1.A + 1.0 Lp
0.9 D + E1	0.9 D + W1.A

Table 12

Computer Model

RAM Structural System was the primary analysis program used for testing the lateral system of the building. Through RAM, a complete 3-D model of the structural system can be made, which can then be used to analysis the different forces acting on the system. This forces will be gravity, wind, or seismic for this report. RAM also contains another feature where the load combinations from ASCE 7-05 and IBC 2006 can directly be applied to the frame using loads specified through the program.

Below are different views of the model from RAM Structural System. The blue members are the gravity members and the red members are the lateral system members. Figures 11 and 12 shows basic isometric views of the whole framing system while 13 and 14 shows the lateral system only. Figures 15 – 17 show plan views of the structural system with the lateral system highlighted in red. Also Figure 17 shows the location of the center of mass and center of rigidity.

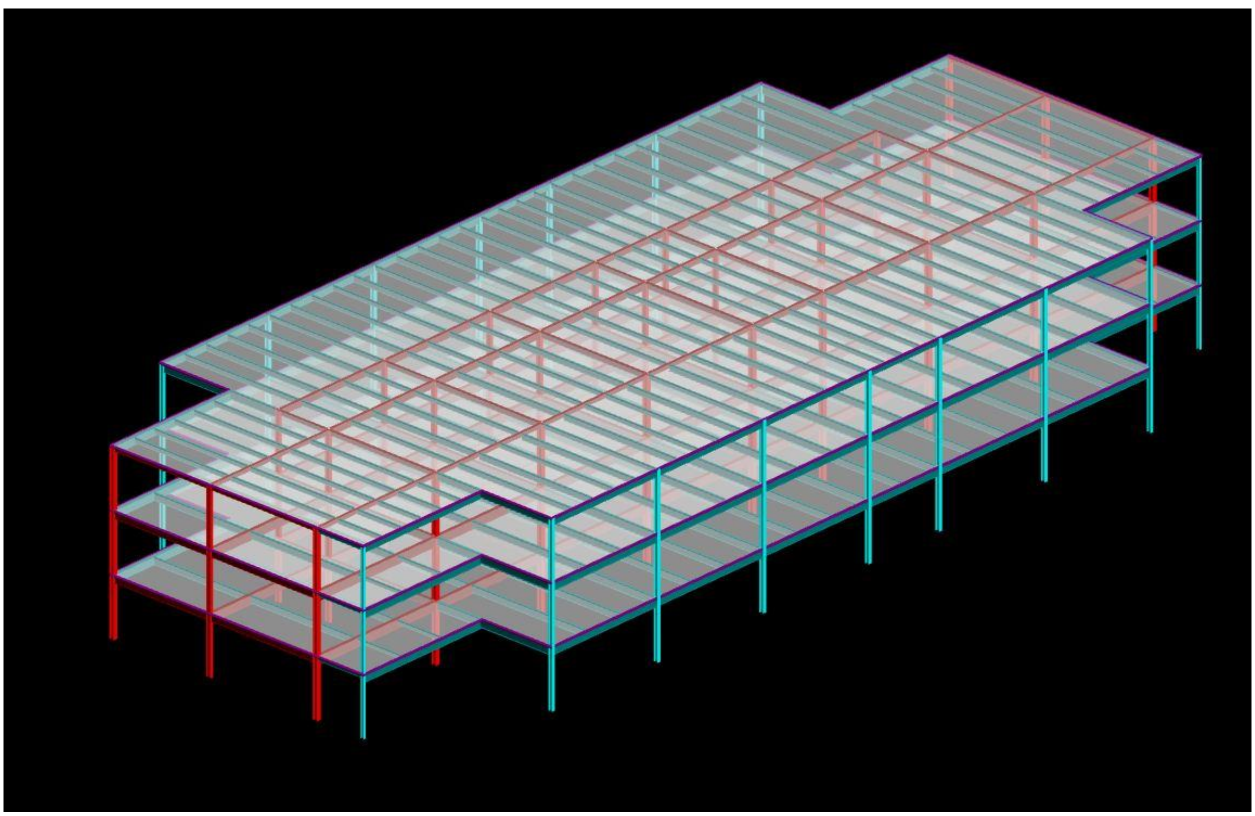


Figure 11: Isometric RAM Model Frame

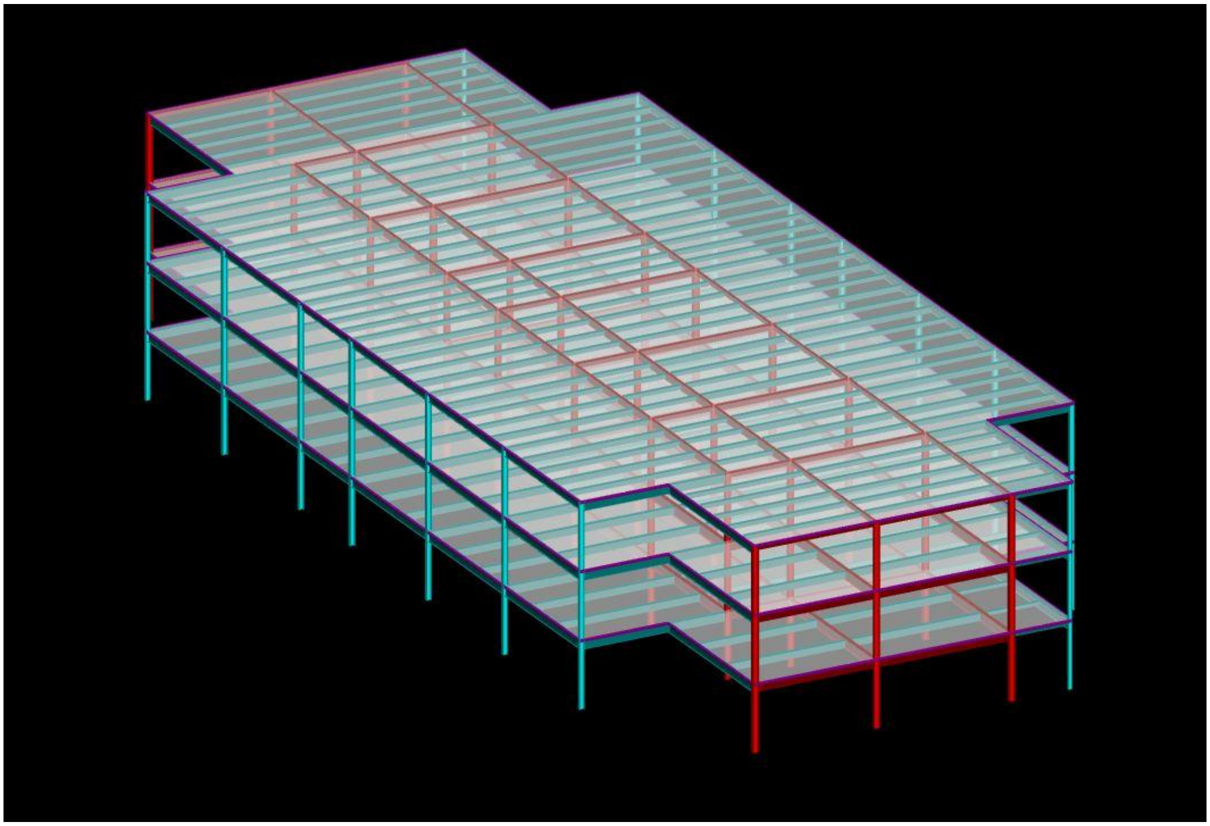


Figure 12: Isometric RAM Model Frame

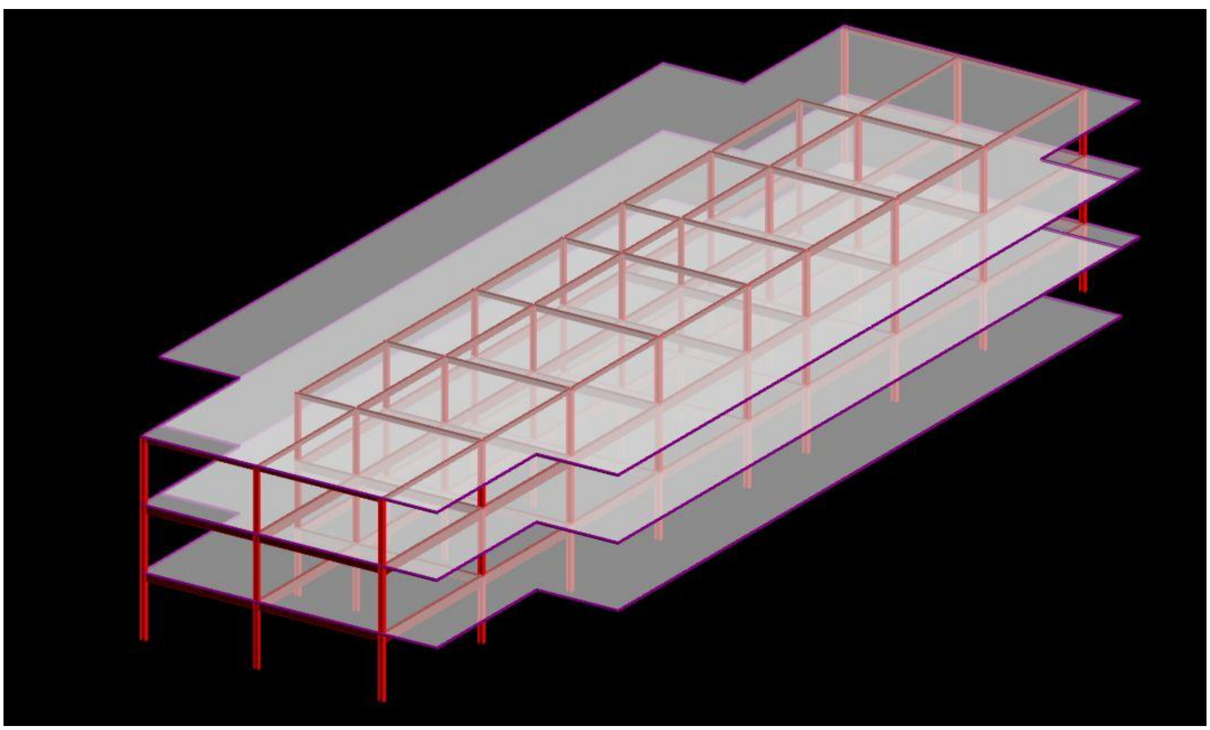


Figure 13: Isometric RAM Model Lateral System

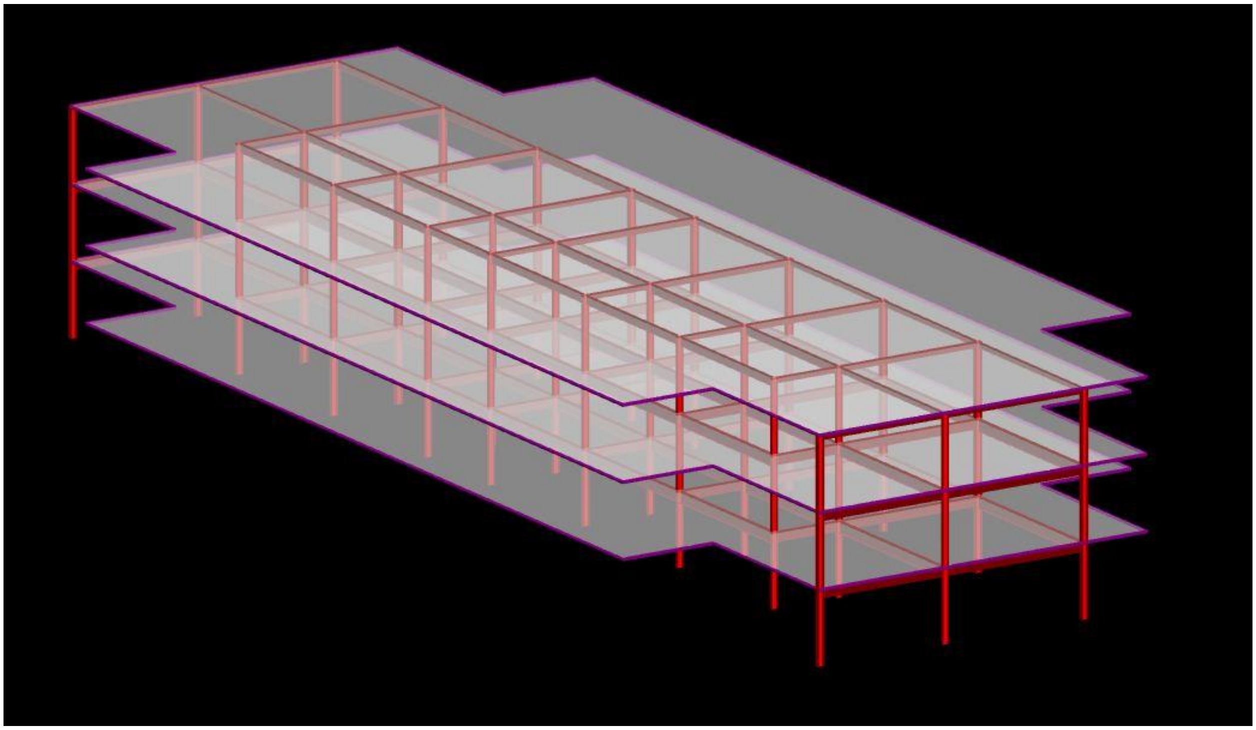


Figure 14: Isometric RAM Model Lateral System

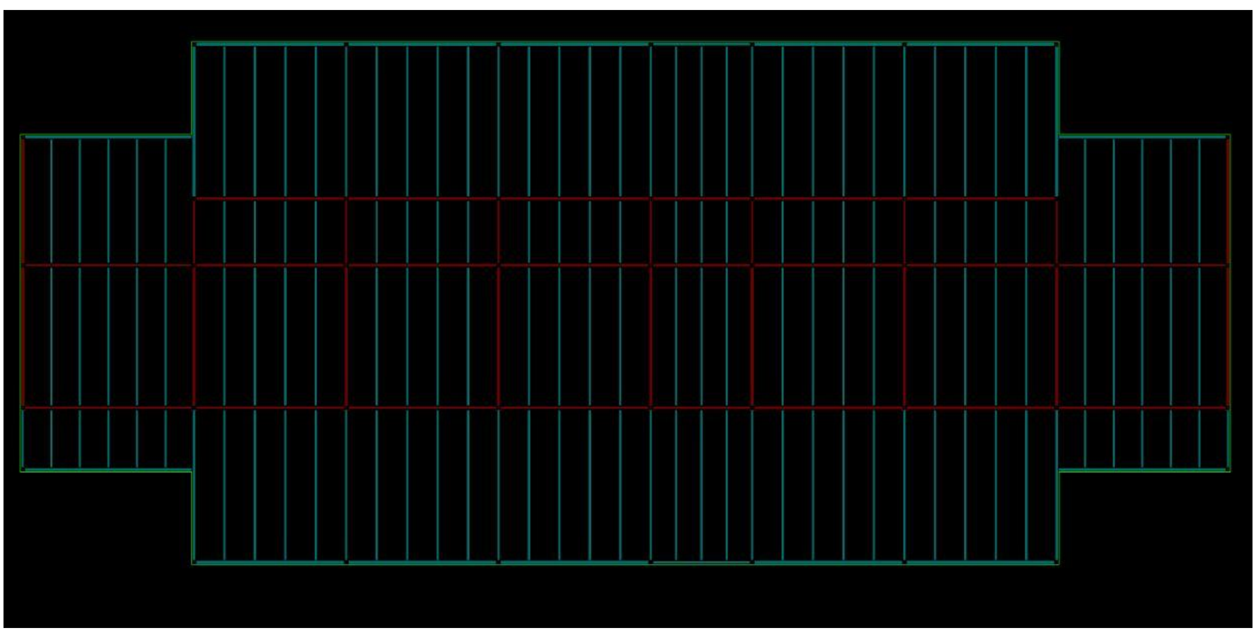


Figure 15: RAM Roof Framing Plan View

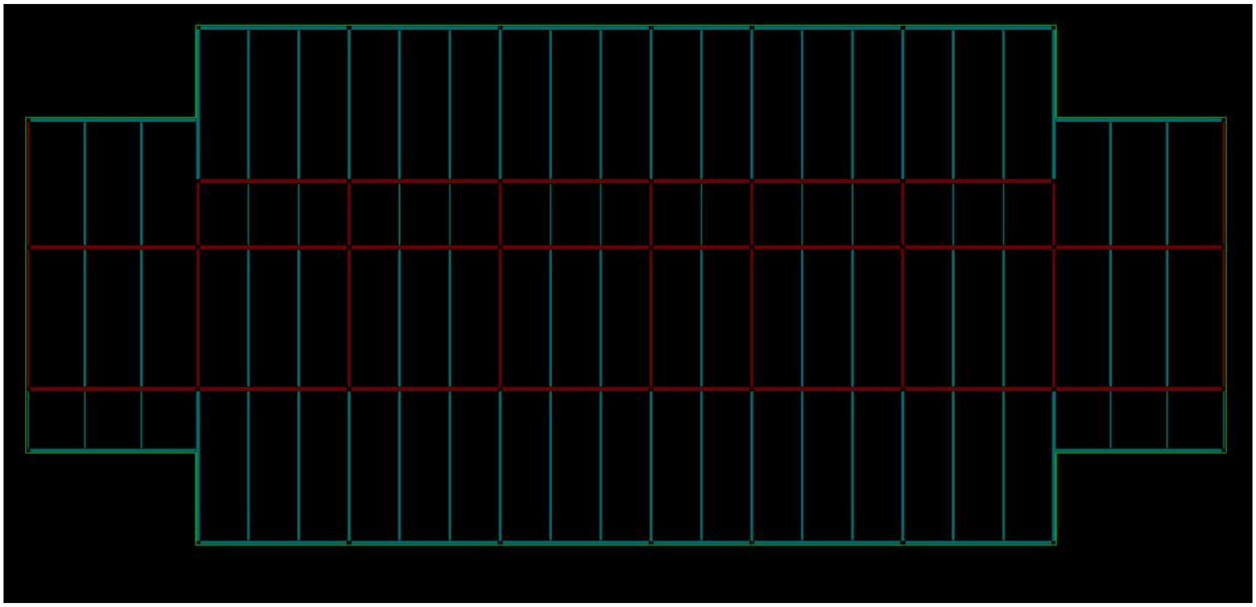


Figure 16: RAM 2nd / 3rd Floor Framing Plan View

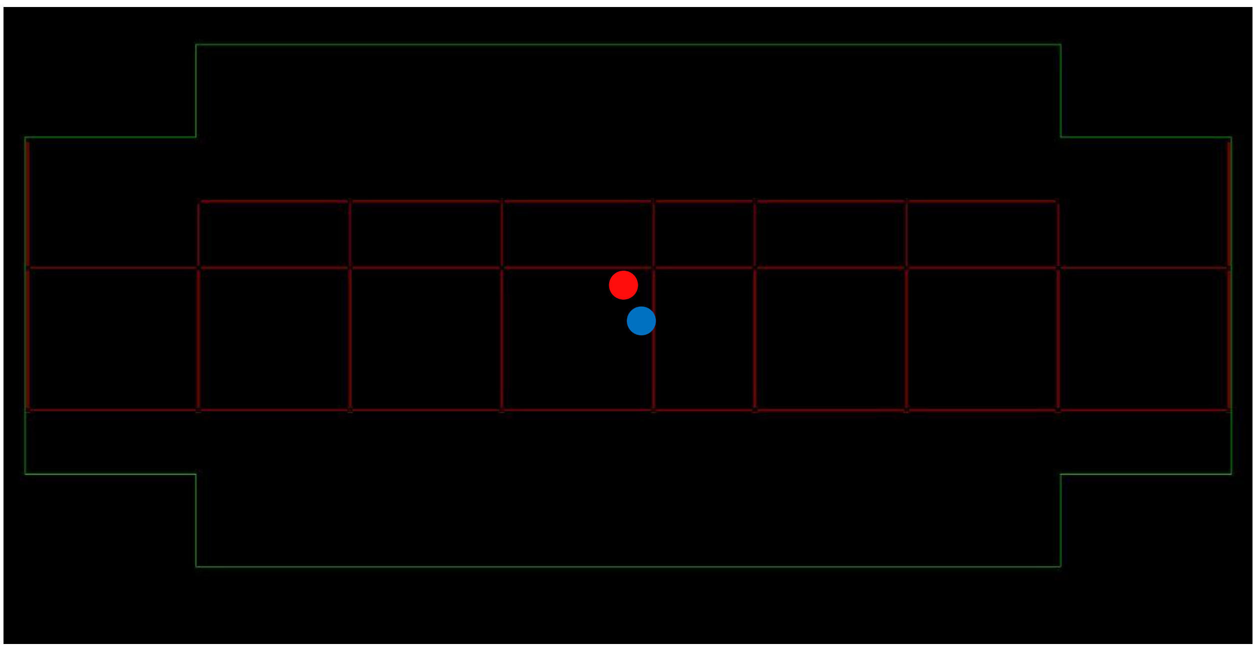


Figure 17: RAM Lateral Framing Plan View with Center of Mass (Red) and Center of Rigidity (Blue)

Drift and Displacement

After applying the load cases and combinations set forth, the drift and displacement was determined for the controlling wind and seismic cases. The controlling cases for wind were W1.A and W1.B which is just wind in the X direction and wind in the Y direction. For seismic it was E1 and E3 which are seismic forces in the X and Y directions respectively. The actual drift and deflection numbers are then compared to the allowable values in the code; for wind allowable equals H/400 and 0.02h for seismic.

Load Case W1.A					
Floor	X Delfection (in)	Y Delfection (in)	X Drift (in)	Y Drift (in)	Allowable Drift (in)
Roof	0.3044	0.0005	0.0467	0.0001	1.5
3rd	0.2577	0.0004	0.103	0.0002	1.5
2nd	0.1548	0.0002	0.1548	0.0002	1.5
			0.3045	0.0005	1.5

Table 12

Load Case W1.B					
Floor	X Delfection (in)	Y Delfection (in)	X Drift (in)	Y Drift (in)	Allowable Drift (in)
Roof	0.0013	0.3936	0.0002	0.0899	1.5
3rd	0.0011	0.3037	0.0006	0.1487	1.5
2nd	0.0006	0.155	0.0006	0.155	1.5
			0.0014	0.3936	1.5

Table 13

Load Case E1					
Floor	X Delfection (in)	Y Delfection (in)	X Drift (in)	Y Drift (in)	Allowable Drift (in)
Roof	1.513	0.005	0.1766	0.0007	12
3rd	1.3366	0.0043	0.5716	0.0021	12
2nd	0.7649	0.0021	0.7649	0.0021	12
			1.5131	0.0049	12

Table 14

Load Case E3					
Floor	X Delfection (in)	Y Delfection (in)	X Drift (in)	Y Drift (in)	Allowable Drift (in)
Roof	0.0077	0.806	0.0015	0.161	12
3rd	0.0062	0.645	0.0034	0.3272	12
2nd	0.0028	0.3178	0.0028	0.3178	12
			0.0077	0.806	12

Table 15

Torsion

Using the story shears found using the RAM model, the torsional forces were found. The center of mass and the center of rigidity are slightly different. The center of mass is at 126.7 ft in the x direction and 54.5 ft in the y direction. The center of rigidity is at 130 ft in the x direction and 48.5 ft in the y direction. Those distances are in reference to the plan view of the structural system with the point (0 ft, 0 ft) being the bottom left corner. As you can see, due to the one irregular bay the center of mass is not the direct center of the building.

X Direction Wind (W1.A)					
Floor	**Story Force**	**Center of Rigidity**	**Center of Mass**	**e**	**Torsional Moment (k-ft)**
Roof	11.62	130	126.7	-3.3	-38.35
3rd	35.86	130	126.7	-3.3	-118.34
2nd	60.53	130	126.7	-3.3	-199.75
Table 16				Total	**-356.43**

Y Direction Wind (W1.B)					
Floor	**Story Force**	**Center of Rigidity**	**Center of Mass**	**e**	**Torsional Moment (k-ft)**
Roof	27.62	48.5	54.5	6	165.7
3rd	83.3	48.5	54.5	6	499.8
2nd	134.9	48.5	54.5	6	809.4
Table 17				Total	**1474.9**

X Direction Seismic (E1)					
Floor	**Story Force**	**Center of Rigidity**	**Center of Mass**	**e**	**Torsional Moment (k-ft)**
Roof	38.83	130	126.7	-3.3	-128.14
3rd	204.9	130	126.7	-3.3	-676.17
2nd	295.75	130	126.7	-3.3	-975.97
Table 18				Total	**-1780.28**

Y Direction Seismic (E3)					
Floor	**Story Force**	**Center of Rigidity**	**Center of Mass**	**e**	**Torsional Moment (k-ft)**
Roof	38.77	48.5	54.5	6	232.62
3rd	197.91	48.5	54.5	6	1187.46
2nd	295.75	48.5	54.5	6	1774.50
Table 19				Total	**3194.58**

Direct Shear

The tables below show the direct of the controlling load cases acting on the lateral system per frame. The applied story forces were found from the RAM Structural System model.

X Direction Wind (W1.A)				
Floor	Story Force (k)	Frame 1	Frame 2	Frame 3
Roof	11.62	3.93	3.86	3.83
3rd	35.86	12.12	11.91	11.83
2nd	60.53	20.46	20.10	19.97
	Total = 108.01			

Table 20

Y Direction Wind (W1.B)										
Floor	Story Force (k)	Frame 4	Frame 5	Frame 6	Frame 7	Frame 8	Frame 9	Frame 10	Frame 11	Frame 12
Roof	27.62	2.90	2.94	2.99	3.03	3.08	3.11	3.16	3.21	3.21
3rd	83.3	8.75	8.87	9.01	9.15	9.28	9.38	9.53	9.69	9.69
2nd	134.9	14.16	14.36	14.59	14.81	15.02	15.18	15.43	15.69	15.69
	Total = 245.82									

Table 21

X Direction Seismic (E1)				
Floor	Story Force (k)	Frame 1	Frame 2	Frame 3
Roof	38.83	13.12	12.89	12.81
3rd	204.9	69.26	68.03	67.62
2nd	295.75	99.96	98.19	97.60
	Total = 539.48			

Table 22

Y Direction Seismic (E3)										
Floor	Story Force (k)	Frame 4	Frame 5	Frame 6	Frame 7	Frame 8	Frame 9	Frame 10	Frame 11	Frame 12
Roof	38.77	4.07	4.13	4.19	4.26	4.32	4.36	4.43	4.51	4.51
3rd	197.91	20.78	21.07	21.40	21.73	22.04	22.28	22.64	23.01	23.01
2nd	295.75	31.05	31.49	31.98	32.48	32.94	33.29	33.83	34.39	34.39
	Total = 532.43									

Table 23

Torsional Shear

Torsional shear, in addition to direct shear, must also be analyzed because of the difference between the center of mass and center of rigidity. The tables below show the torsion shear calculation in an excel spreadsheet. The direct shear is also taken into account. The tables show that the effects of the torsional shear on the building are not that great.

X Direction Wind (W1.A)										
Frame Direction	Frame	Vtot (k)	Ri	ex	ey	di	Ri*di^2	Torsional Shear	Direct Shear	Total Shear
X	1	108.01	0.338	3.3	-6	27.20	250.1	-0.89	36.508	35.616
	2	108.01	0.332	3.3	-6	13.23	58.1	-0.43	35.878	35.451
	3	108.01	0.330	3.3	-6	-16.69	91.9	0.53	35.625	36.159
Y	4	108.01	0.105	3.3	-6	130.00	1769.7	0.73	0.000	0.726
	5	108.01	0.106	3.3	-6	94.63	953.5	0.54	0.000	0.538
	6	108.01	0.108	3.3	-6	62.63	424.1	0.36	0.000	0.361
	7	108.01	0.110	3.3	-6	30.63	103.0	0.18	0.000	0.179
	8	108.01	0.111	3.3	-6	-1.37	0.2	-0.01	0.000	-0.008
	9	108.01	0.113	3.3	-6	-22.75	58.2	-0.14	0.000	-0.137
	10	108.01	0.114	3.3	-6	-54.69	342.1	-0.33	0.000	-0.334
	11	108.01	0.116	3.3	-6	-86.81	876.3	-0.54	0.000	-0.539
	12	108.01	0.116	3.3	-6	-122.79	1753.3	-0.76	0.000	-0.762
							6680.5			107.252

Table 24

Y Direction Wind (W1.A)										
Frame Direction	Frame	Vtot (k)	Ri	ex	ey	di	Ri*di^2	Torsional Shear	Direct Shear	Total Shear
X	1	245.82	0.338	3.3	-6	27.20	250.1	-2.03	0.000	-2.030
	2	245.82	0.332	3.3	-6	13.23	58.1	-0.97	0.000	-0.970
	3	245.82	0.330	3.3	-6	-16.69	91.9	1.22	0.000	1.215
Y	4	245.82	0.105	3.3	-6	130.00	1769.7	1.65	25.741	27.394
	5	245.82	0.106	3.3	-6	94.63	953.5	1.22	26.175	27.398
	6	245.82	0.108	3.3	-6	62.63	424.1	0.82	26.578	27.400
	7	245.82	0.110	3.3	-6	30.63	103.0	0.41	26.994	27.403
	8	245.82	0.111	3.3	-6	-1.37	0.2	-0.02	27.375	27.357
	9	245.82	0.113	3.3	-6	-22.75	58.2	-0.31	27.668	27.357
	10	245.82	0.114	3.3	-6	-54.69	342.1	-0.76	28.119	27.359
	11	245.82	0.116	3.3	-6	-86.81	876.3	-1.23	28.585	27.359
	12	245.82	0.116	3.3	-6	-122.79	1753.3	-1.73	28.585	26.851
							6680.5			244.094

Table 25

X Direction Seismic (E1)										
Frame Direction	Frame	Vtot (k)	Ri	ex	ey	di	Ri*di^2	Torsional Shear	Direct Shear	Total Shear
X	1	539.48	0.338	3.3	-6	27.20	250.1	-4.45	182.346	177.892
	2	539.48	0.332	3.3	-6	13.23	58.1	-2.13	179.199	177.070
	3	539.48	0.330	3.3	-6	-16.69	91.9	2.67	177.935	180.602
Y	4	539.48	0.105	3.3	-6	130.00	1769.7	3.63	0.000	3.628
	5	539.48	0.106	3.3	-6	94.63	953.5	2.69	0.000	2.685
	6	539.48	0.108	3.3	-6	62.63	424.1	1.80	0.000	1.805
	7	539.48	0.110	3.3	-6	30.63	103.0	0.90	0.000	0.896
	8	539.48	0.111	3.3	-6	-1.37	0.2	-0.04	0.000	-0.041
	9	539.48	0.113	3.3	-6	-22.75	58.2	-0.68	0.000	-0.682
	10	539.48	0.114	3.3	-6	-54.69	342.1	-1.67	0.000	-1.667
	11	539.48	0.116	3.3	-6	-86.81	876.3	-2.69	0.000	-2.690
	12	539.48	0.116	3.3	-6	-122.79	1753.3	-3.81	0.000	-3.805
							6680.5			535.692

Table 26

Y Direction Wind (E3)										
Frame Direction	Frame	Vtot (k)	Ri	ex	ey	di	Ri*di^2	Torsional Shear	Direct Shear	Total Shear
X	1	532.43	0.338	3.3	-6	27.20	250.1	-4.40	0.00	-4.396
	2	532.43	0.332	3.3	-6	13.23	58.1	-2.10	0.00	-2.101
	3	532.43	0.330	3.3	-6	-16.69	91.9	2.63	0.00	2.632
Y	4	532.43	0.105	3.3	-6	130.00	1769.7	3.58	55.75	59.333
	5	532.43	0.106	3.3	-6	94.63	953.5	2.65	56.69	59.343
	6	532.43	0.108	3.3	-6	62.63	424.1	1.78	57.57	59.348
	7	532.43	0.110	3.3	-6	30.63	103.0	0.88	58.47	59.352
	8	532.43	0.111	3.3	-6	-1.37	0.2	-0.04	59.29	59.253
	9	532.43	0.113	3.3	-6	-22.75	58.2	-0.67	59.93	59.253
	10	532.43	0.114	3.3	-6	-54.69	342.1	-1.65	60.90	59.259
	11	532.43	0.116	3.3	-6	-86.81	876.3	-2.65	61.91	59.258
	12	532.43	0.116	3.3	-6	-122.79	1753.3	-3.76	61.91	58.158
							6680.5			528.691

Table 27

Overturning Moment

When the lateral forces due to wind and seismic act on the building an overturning moment is induced. The shear at each floor creates a moment in the base that must be resisted by the foundation. The same controlling cases were used for this analysis; the controlling wind case for each direction and the controlling seismic case for each direction. The resisting moment was found by multiplying half the total weight of the building by the length of the building in the direction of interest.

X Direction Wind (W1.A)			
Floor	**Height (ft)**	**Lateral Force (k)**	**Moment (k-ft)**
Roof	45.00	11.62	522.90
3rd	29.34	35.86	1052.13
2nd	14.67	60.53	887.98
		Total	**2463.01**

Table 28

Y Direction Wind (W1.B)			
Floor	**Height (ft)**	**Lateral Force (k)**	**Moment (k-ft)**
Roof	45.00	27.62	1242.90
3rd	29.34	83.3	2444.02
2nd	14.67	134.9	1978.98
		Total	**5665.91**

Table 29

X Direction Seismic (E1)			
Floor	**Height (ft)**	**Lateral Force (k)**	**Moment (k-ft)**
Roof	45.00	38.83	1747.35
3rd	29.34	204.9	6011.77
2nd	14.67	295.75	4338.65
		Total	**12097.77**

Table 30

Y Direction Seismic (E3)			
Floor	**Height (ft)**	**Lateral Force (k)**	**Moment (k-ft)**
Roof	45.00	38.77	1744.65
3rd	29.34	197.91	5806.68
2nd	14.67	295.75	4338.65
		Total	**11889.98**

Table 31

Total Resisting Moment	X-Direction	**1204567 k-ft**
	Y-Driection	**570206 k-ft**

Member Check

A spot check was performed on one beam and one column with the lateral system of the building. The beam and column are located within frame 6. The spot check is to ensure the members can withstand the applied gravity and lateral loads that were specified in RAM. The loads used to verify the member's adequacy are obtained from the RAM output. Both the column and the beam were found to hold the applied load combination. The controlling load combination of 1.2 D + 1.0 E + 1.0 L was used to make sure the members would be adequate even in the most extreme case. The details of the spot check can be found in Appendix B.

Conclusion

By performing an analysis of the building lateral systems, a better understanding of the structural systems is achieved. Using RAM Structural System as an analyzing tool helps to show that the lateral moment frame is adequate for resisting the seismic and wind loads imposed on the structure, in accordance to IBC 2006 and ASCE7-05. Hershey Research Park Building One was analyzed by using the controlling load cases and combinations to ensure it can perform even in the worst possible conditions. The controlling wind cases in the “X” and “Y” direction as well as the controlling seismic in the “X” and “Y” direction were used in the analysis.

The RAM model was also used for to find shear, story displacement and story drifts in each of the twelve frames. Other information found using RAM was used to determine stiffness’s of frames, torsion, and for spot checking critical members. The overturning moment created from the wind and seismic lateral loads were found to be easily resisted by the building’s weight. In conclusion, the lateral system of Hershey Research Park Building One is adequate to resist the lateral loads that may be imposed on it.

Appendices

Appendix A: Structural Plans

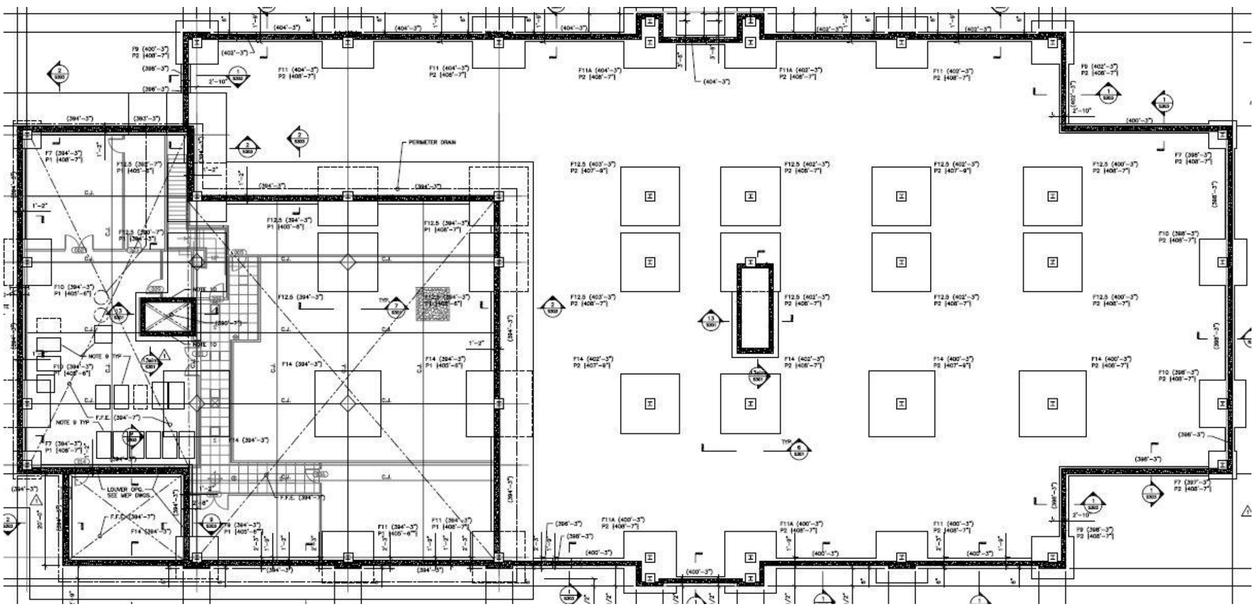


Figure 18 – Basement/Foundation Structural Plan

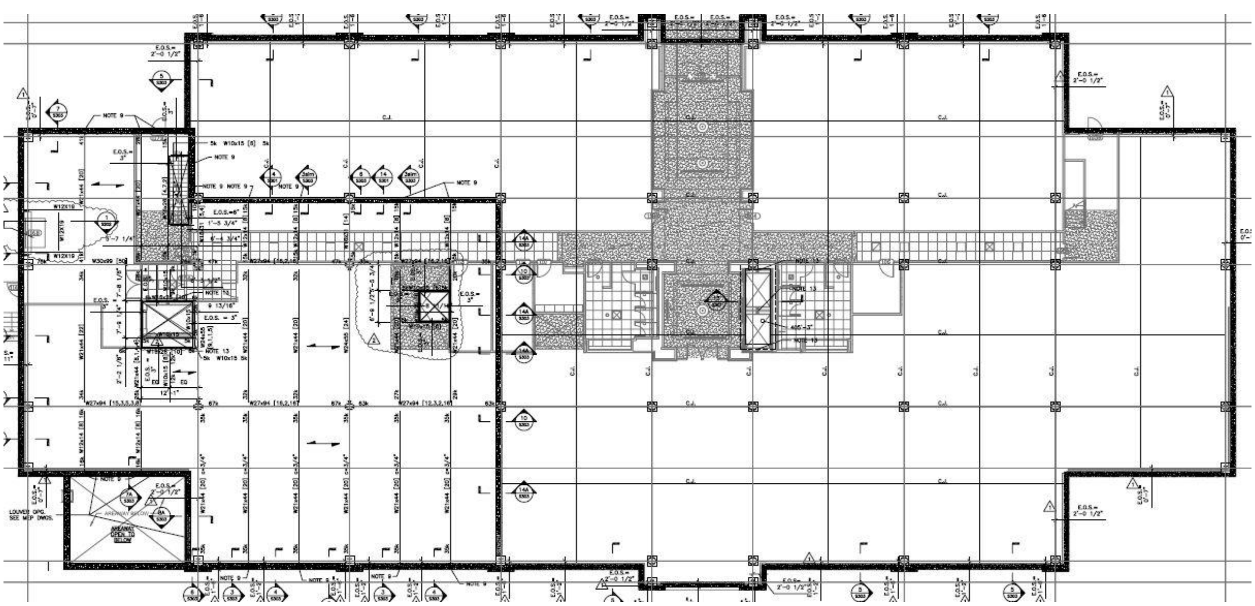


Figure 19 – First Floor Structural Plan

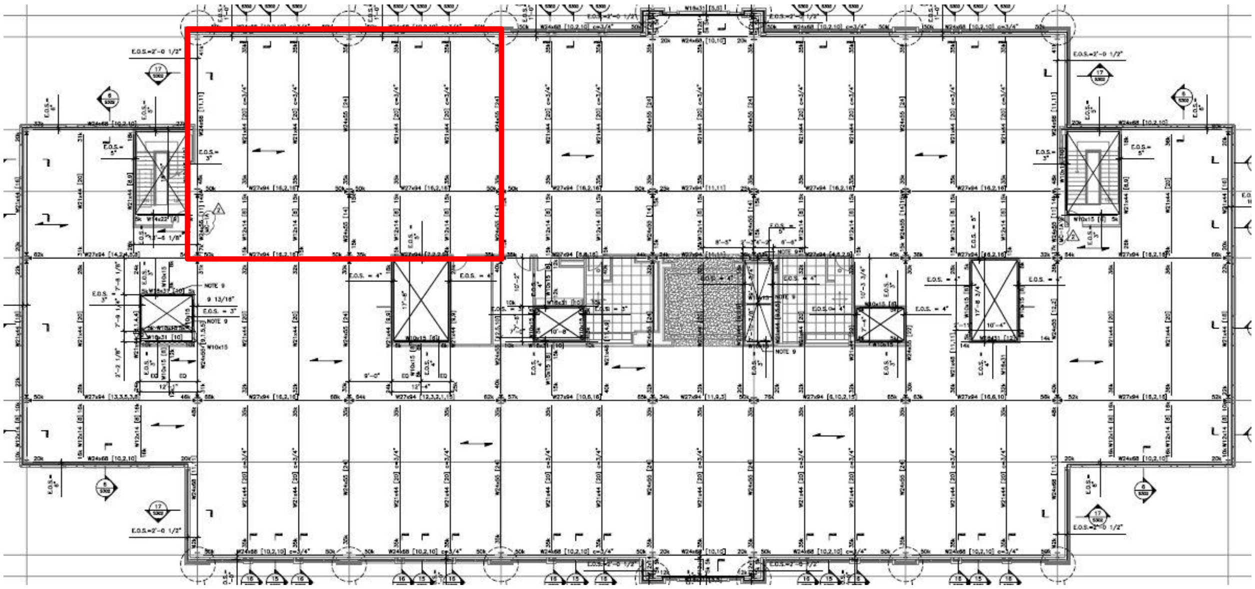


Figure 20 – Second Floor Structural Plan

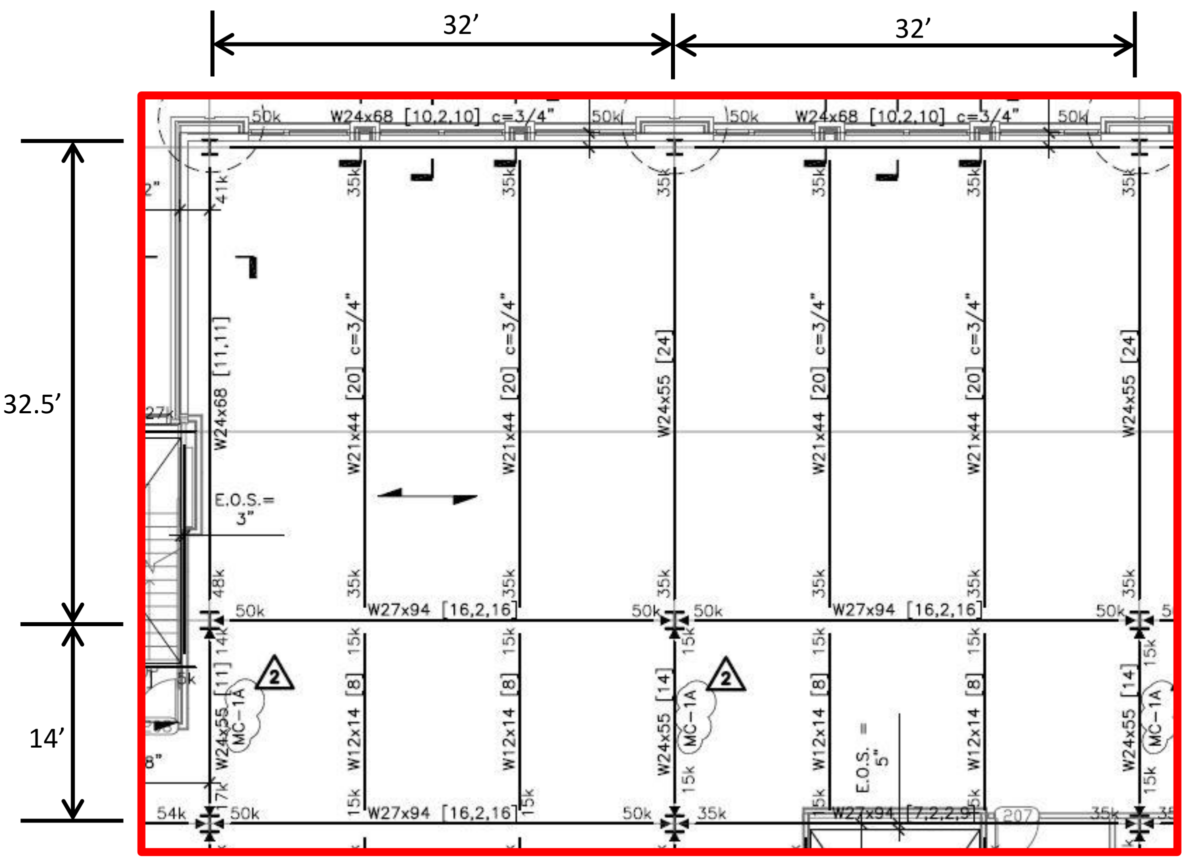


Figure 21 – Spot Check Area

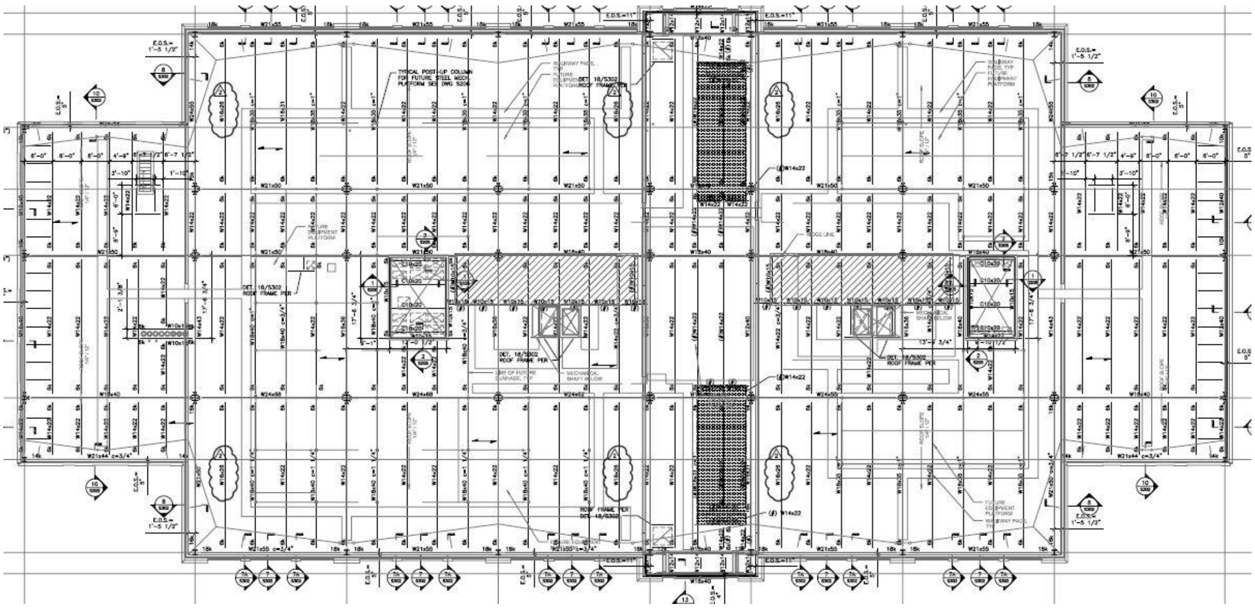


Figure 22 – Roof Structural Plan

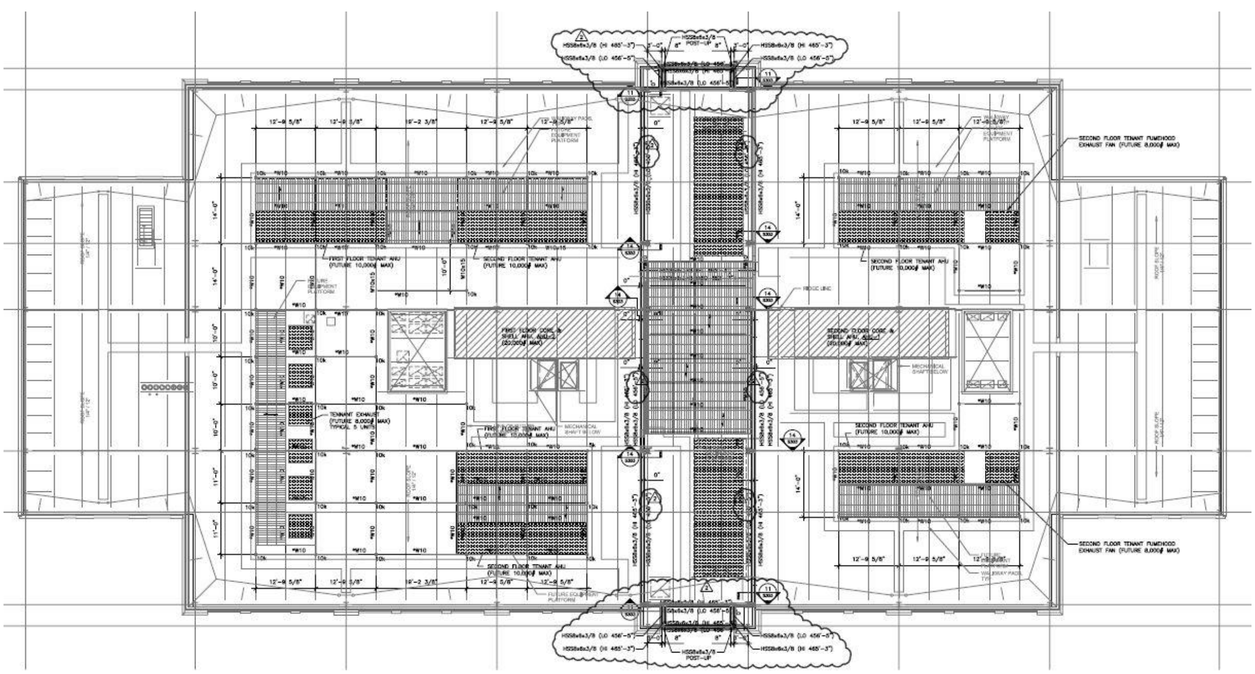


Figure 23 – High Roof Structural Plan

Appendix B: Hand Calculations

Jon Krepps AE Senior Thesis Wind Calcs - pg 1

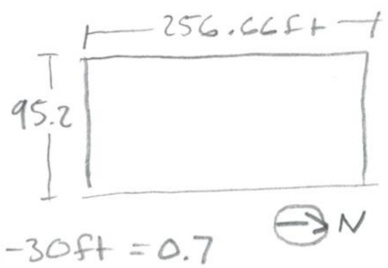
Basic wind Speed = 90mph = V. (Figur 6-1)

Occupancy Type II (Table 1-1)

Importance Factor $I_w = 1.0$ (Table 6-1)

Wind Exposure Factor B

PLAN VIEW



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

K_z = varies with height

↳ Table 6-3 Exposure B Case 1 = 0-30ft = 0.7, 45ft = 0.785, 50ft = 0.81

$K_{zt} = 1.0$

$K_d = 0.85$

$V = 90$ mph

$I = 1.0$

$q_z = 0.00256(K_z)(1.0)(0.85)(90)^2(1.0)$

$q_z = 12.34$ psf → 0-30ft

$q_z = 13.84$ psf → 45ft

$q_z = 14.28$ psf → 50ft

Structure is Rigid so $G = 0.85$

↳ $f > 1$

Internal Pressure Coefficient

$GC_{pi} = \pm 0.18$

Design Pressures for MWFRS Wind - pg 2

$P = qGC_p - q_i(GC_{pi})$

$q = q_z$ = Windwart walls
↳ variable

$q = q_h$ = leeward walls = 14.28psf
↳ constant

$G = 0.85$

C_p = External Pressure coefficient

$q_i = q_h = 14.28$psf, for enclosed building

$GC_{pi} = \pm 0.18$

$C_p = 0.8$ windward wall Pressure

$= -0.7$ side wall pressure

$= -0.5 \rightarrow L/B = 0.37$, leeward pressure normal to 256.66ft

$= -0.3 \rightarrow L/B = 2.7$, Leeward pressure normal to 95.2ft

Wind ward Pressure

$P = 12.34(0.85)(0.8)$

$= 8.39$

$P = 13.84(0.85)(0.8)$

$= 11.98$ psf → Roof

$P = 14.28(0.85)(0.8)$

$= 12.28$ psf → High Roof

Leeward Pressure East-West Wind – pg 3

$P = 14.28(0.85)(-0.5)$

$= -6.07$

Leeward Pressure North-South

$P = 14.28(0.85)(-0.3)$

$P = -6.21$ psf → constant

Roof Pressure

$C_p = -0.9$ 0 to h

$= -0.5$ h to 2h

$= -0.3$ >2h

$P = 14.28(0.85)(C_p)$

$= -10.92$ → 0-50ft

$= -6.07$ → 50-100ft

$= -3.64$ → >100ft

Jon Krepps AE Senior Thesis Seismic – pg 1

Seismic Site Class "D"
↳ Firm Soil

Seismic USE Group
II → $I = 1.25$

$S_s = 0.23$

$S_1 = 0.07$

Ordinary Steel Moment Frame
↳ $R = 3.5$

$F_a = 1.6$ => Site Class D, $S_s \leq 0.25$

$F_v = 2.4$ => Site Class D, $S_1 \leq 0.1$

$S_{ms} = F_a S_s$

$= 1.6(0.23) = 0.368$

$S_{m1} = F_v S_1$

$= 2.4(0.07) = 0.168$

$S_{DS} = 2/3\, S_{ms}$

$= (2/3)(0.368) = 0.245$

$S_{D1} = 2/3\, S_{m1}$

$= (2/3)(0.168) = 0.112$

Seismic – pg 2

$T_0 = 0.2(S_{D1}/S_{DS})$

$= 0.2(0.112/0.245) = 0.091$

$T_s = S_{D1}/S_{DS} = \frac{0.112}{0.245} = 0.457$

$T_L = 6s$

Simplified Analysis Method ⇒ used by designers
ASCE 7-02

$$V = \frac{1.2\,S_{DS}}{R}W$$

Total Dead Load

$W = DL + 20\%$ Roof Snow load

Roof DL = 15psf

Floor DL = 85psf + 10psf for partitions

Snow Load = 0.2(30) = 6psf

Roof Load

$(256.66)(95.2)(15+6) = 513^k$

Floor Load

$(256.66)(95.2)(95) = 2321^k$

Total DL

$= 513^k + (2,321^k)(2\text{ Floors}) = 5155^k$

Seismic pg 3

$V = \frac{1.2 S_{DS}}{R} W$

$V = \frac{1.2(0.245)}{3.5}(5155^k)$

$V = 433^k$

↳ Base shear using ASCE 7-02

Equivalent Lateral Force Procedure ⇒ ASCE 7-10

$V = C_s W$

$W = 5155^k$ → From last method

$C_s = \frac{S_{DS}}{(R/I_e)}$

$S_{DS} = 0.245$

$R = 3.5$ → Ordinary Steel Moment Frame

$I = 1.25$

$C_s = \frac{0.245}{3.5/1.25} = 0.0875$

$T = C_T h_n^x$ $C_T = 0.28$ $x = 0.8$

$T = 0.028(49.5)^{0.8}$ $h_n = 49.5^{ft}$

$T = 0.635 < T_L$

$C_s < \frac{S_{D1}}{(R/I)(T)} = \frac{0.112}{\left(\frac{3.5}{1.25}\right)(0.635)} = 0.063 < 0.0875$

↳ use for C_s

$V = 0.063(5155^k) = 324.7^k$

Jon Krepps AE Senior Thesis Snow load - pg 1

$P_f = 0.7 C_e C_t I P_g$ $P_g = 30psf$

$C_e = 1.0$

$P_f = 0.7(30)$ $C_t = 1.0$

$P_f = 21psf$ $I = 1.0$

Drift $\gamma = 0.13 p_g + 14 = 0.13(30) + 14 = 17.9 < 30$ ✓

Find drift height → Roof Projection, use figure 7-9 ASCE 7-02

$P_g = 30psf$

Chart value $h_d = 1.7ft$

$l_u = 27ft$

From §7.8 $h_d = 0.75 h_d$ ⇒ From Figure 7-9

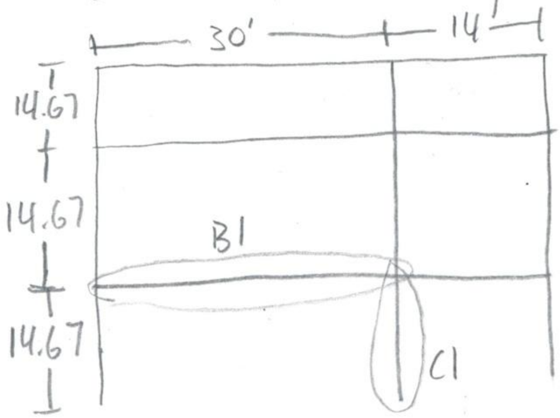
$h_d = 0.75(1.7) = 1.275ft$

$P_d = (1.275)(17.9) = 22.8psf$ → Roof snow load w/drift

$22.8psf > 21psf$ ✓

Critical Member Spot Check

Frame #6, Lateral System Members



Check Beam B1
= W24x55

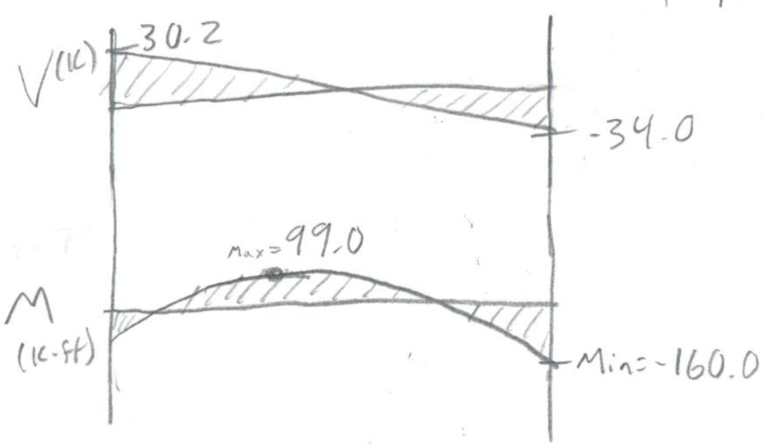
Check Column C1
= W14x68

* Controlling Case Lateral Used (1.2D+1.0E1+1.0L)

Beam B1, W24x55

$\phi V_{nx} = 252^{k}$

$\phi M_{px} = 503^{k\cdot ft}$



$V_{max} = 34^{k} < 252^{k}$ ✓

$M_{max} = 160^{k\cdot ft} < 503^{k\cdot ft}$ ✓

Column C1, W14x68

$p = 1.64 \times 10^{3}\ (\text{kips})^{-1}$

$b_x = 2.11 \times 10^{3}\ (\text{kips})^{-1}$

$b_y = 6.42 \times 10^{3}\ (\text{kips})^{-1}$

From RAM $\longrightarrow$ $M_{x1} = 37.83^{\text{k-ft}}$

$M_{x2} = 30.25^{\text{k-ft}}$

$P_r = 330.6^{\text{k}}$

$pP_r = 0.201 \geq 2.0$

$$pP_r + (b_x M_{rx} + \cancel{b_y M_{ry}}^{\,0}) \leq 1.0$$

$$0.201 + \frac{37.83}{2.11 \times 10^3} = 0.23 \leq 1.0$$

Both Beam and Column ok for combination of gravity and lateral Loads.