TECHNICAL ASSIGNMENT 3

LATERAL SYSTEM ANALYSIS AND CONFIRMATION DESIGN

Duquesne University Multipurpose/ Athletic Facility

Michael Szott
Structural Option
Advisor: M. Kevin Parfitt

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Technical Report 3

Executive Summary

The purpose of this report is to analyze the lateral forces at work on the Duquesne University Multipurpose Athletic Facility and determine the effectiveness of the existing system in resisting those forces. Load calculations, confirmations, and spot checks in a variety of areas were made to confirm the assumption that the existing lateral system is adequately and efficiently designed.

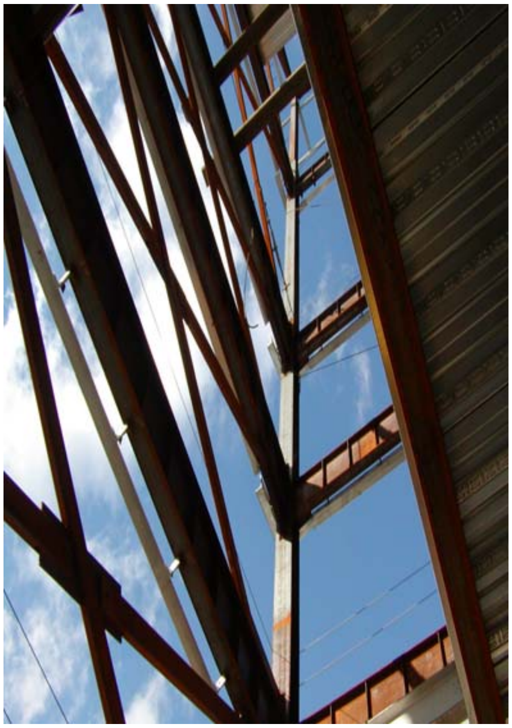
In Technical Assignment 1, wind and seismic forces were calculated (by hand) to establish a controlling load case. After determining that wind forces were indeed the controlling case, lateral spot checks were done to crudely verify this finding. In Technical Assignment 3, RAM Structural System and RAM Advanse were used to model the entire structure, and the individual frames to draw more accurate conclusions pertaining to the lateral resisting system. For distribution of forces, the method of relative stiffness was used to find the forces acting on each individual frame. After the forces were distributed, they were checked against the forces found in the RAM model and found to be accurate. For strength, another spot check was done, similar to the one performed in Tech 1. Also, RAM Advanse was used to model one of the individual frames and the bracing was again checked (and confirmed) for strength.

Drift calculations, as well as torsional analysis, were performed and checked using RAM. In the case of drift, total displacement of the structure was found to be within the limitation used, H/400. The upper High Roof level was found to be above this limit; however it is adequately designed for lateral strength and is not occupied. Therefore, the drift limitation is met. Torsion calculations seemed to contradict the RAM model findings. Hand calculations showed what appears to be significant torsion on the upper roof levels of the structure. When checking the RAM model, the rotation of each story is extremely minimal, leading to a question as to why the two checks yield different results. While no further analysis was performed for this report, I would like to further investigate the presence of torsion in a later proposal.

Overall, the lateral system of the Duquesne University Multipurpose Athletic Facility seems to do the job that it is intended to do. The resistance of lateral forces is adequate for strength and serviceability requirements. The RAM modeling confirmed the hand calculations done in Technical Assignment 1 and revised for Technical Assignment 3. Torsion seems to be an issue at present, and it will be further investigated in a future report.

Table of Contents

Introduction



Duquesne University, located in the city of Pittsburgh, is in the process of expanding its campus. The land being developed is situated along Forbes Avenue, adjacent to the A.J. Palumbo Center, and "will be used for commercial and educational purposes, improving both the entrance to campus and the Forbes Avenue corridor." The first phase of the project, a multipurpose athletic facility, is currently under construction, and should be ready for use in January 2008. The building itself will be home to a variety of spaces including retail outlets, fitness and recreation facilities, athletic offices, and a ballroom/conference center.

The Multipurpose Facility rises 7 stories above grade, housing 125,000 square feet of floor space. The structure itself is comprised of composite steel, clad in red brick, rock face CMU, and glass. A steel pedestrian bridge spans from the 7th floor ballroom to an adjoining parking garage on Duquesne's campus.

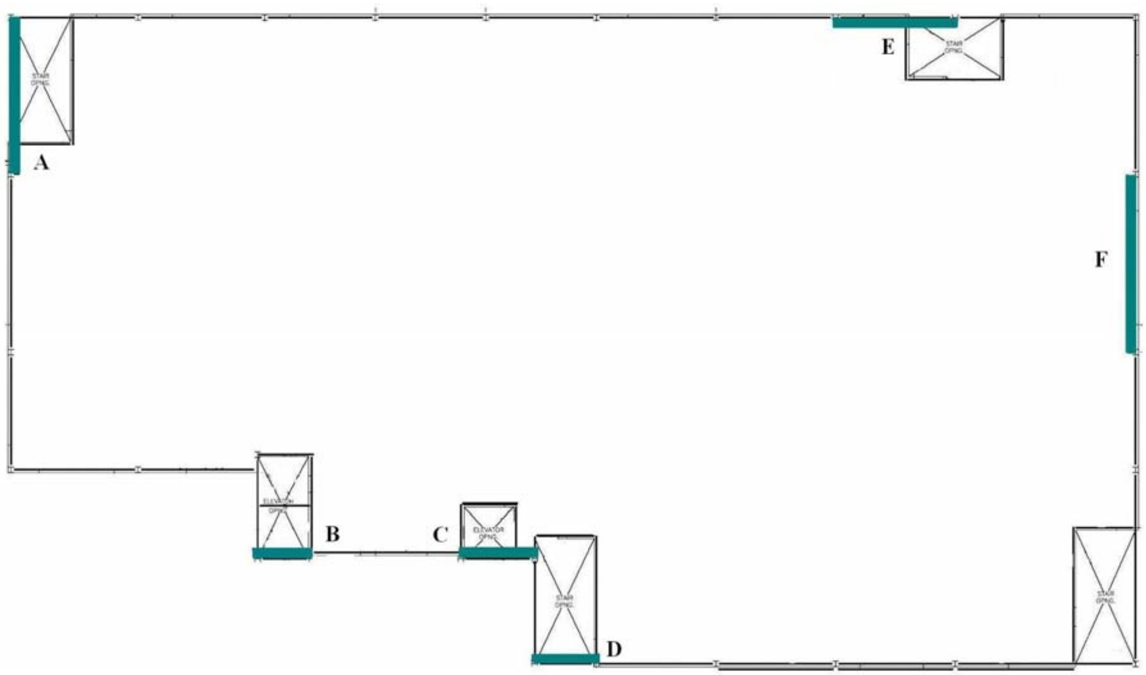
The building is supported by a steel superstructure, including a composite steel floor system. Each of the first three floors are framed in rectangular bays, ranging in size from 20'x20' to 21'x34'. The upper athletic and ballroom floors are also composite steel, but are framed with longer spans (79'6") due to the open plan of the gymnasiums below. The lateral system for the Multipurpose Facility is concentrically braced frames: All of which are located on the exterior faces of the structure.

Lateral System Description

Duquesne University Multipurpose Facility uses concentrically braced steel frames to resist lateral loads. Each lateral element or frame is located along the perimeter of the structure and is based at the Forbes Avenue level of the structure. The upper level interior spaces, gymnasiums and ballrooms, are not as favorable for lateral elements because they require so much open space. Exterior locations of stair wells and elevator cores lend themselves as unobstructed positions for the braced frames. These areas are devoid of windows and other openings allowing the frames to be well hidden from view. Where other frames are needed, exterior elevations without windows or openings were again chosen to hide these elements.

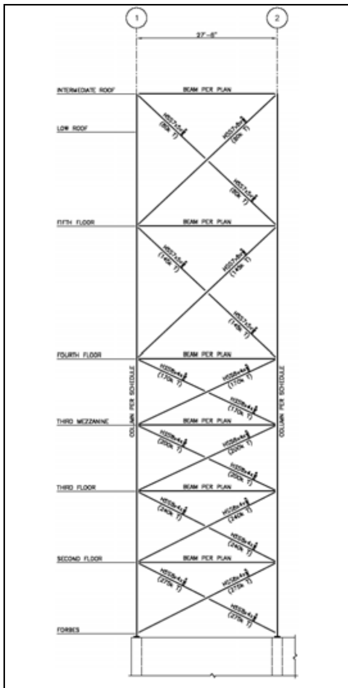
On the South face of the building, frames are constructed around both elevator shafts and a stair tower. The same is true on the North and West faces of the building where bracing is positioned at stair towers. The typical columns used in each of bracing elements are W14's ranging from W14x53 to W14x132. Each floor to floor section makes use of a series of cross braced HSS members ranging in size from HSS6x4's to HSS8x4's, 1/4" to 5/8" thick. The bracing members designed to see 30 – 275 kips in tension. (Figure 1.4)

Locations of Frames

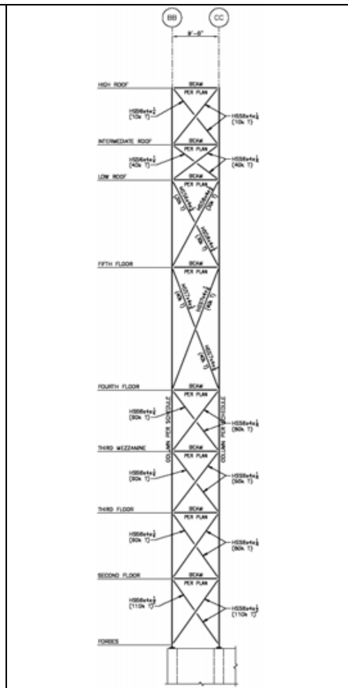


Letters correspond to the elevations on the following page

Braced Frame Elevations



A



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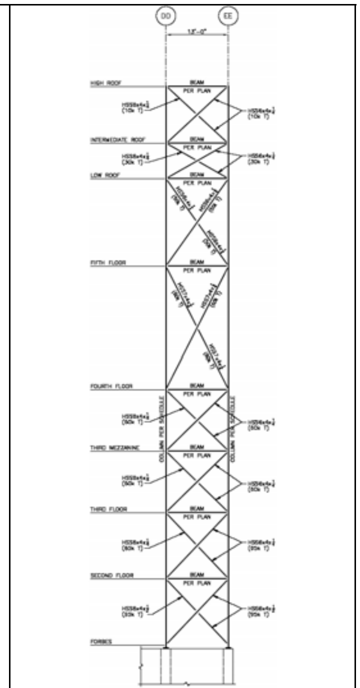

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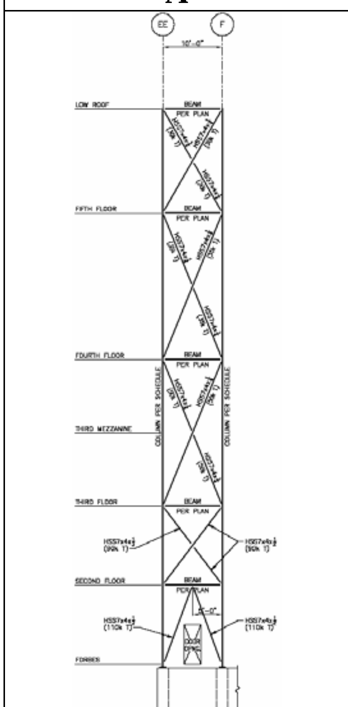

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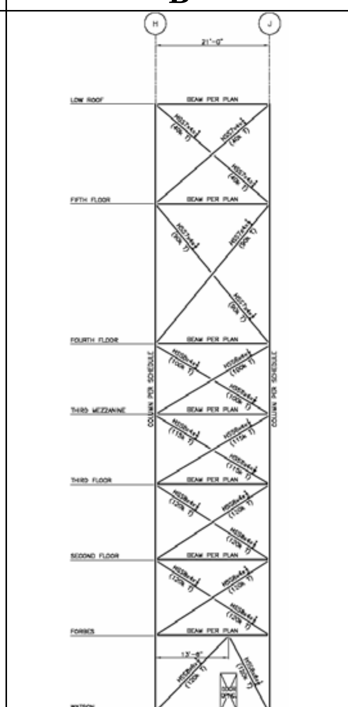

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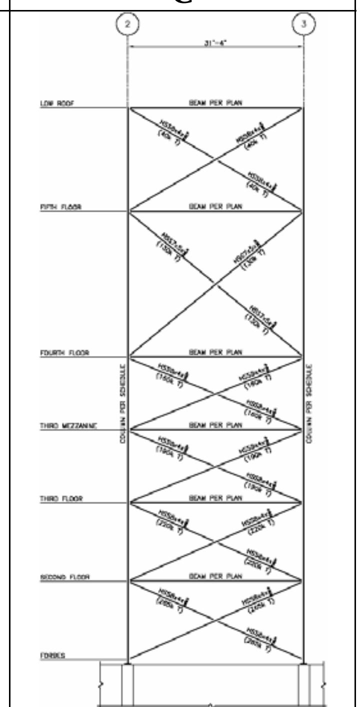

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Load Cases

In a previously submitted technical report, lateral load cases were considered to determine which case controlled the design. In *Technical Assignment 1*, ASCE 7-02 and IBC 2003 were consulted for both seismic and wind loading conditions and design methods. Calculations for wind and seismic loading were done using Excel spreadsheets and are available in the appendices of *Technical Assignment 1*. The lateral loading highlighted on the following pages is the result of those calculations. It was found that wind loading controlled the design of the lateral bracing system.

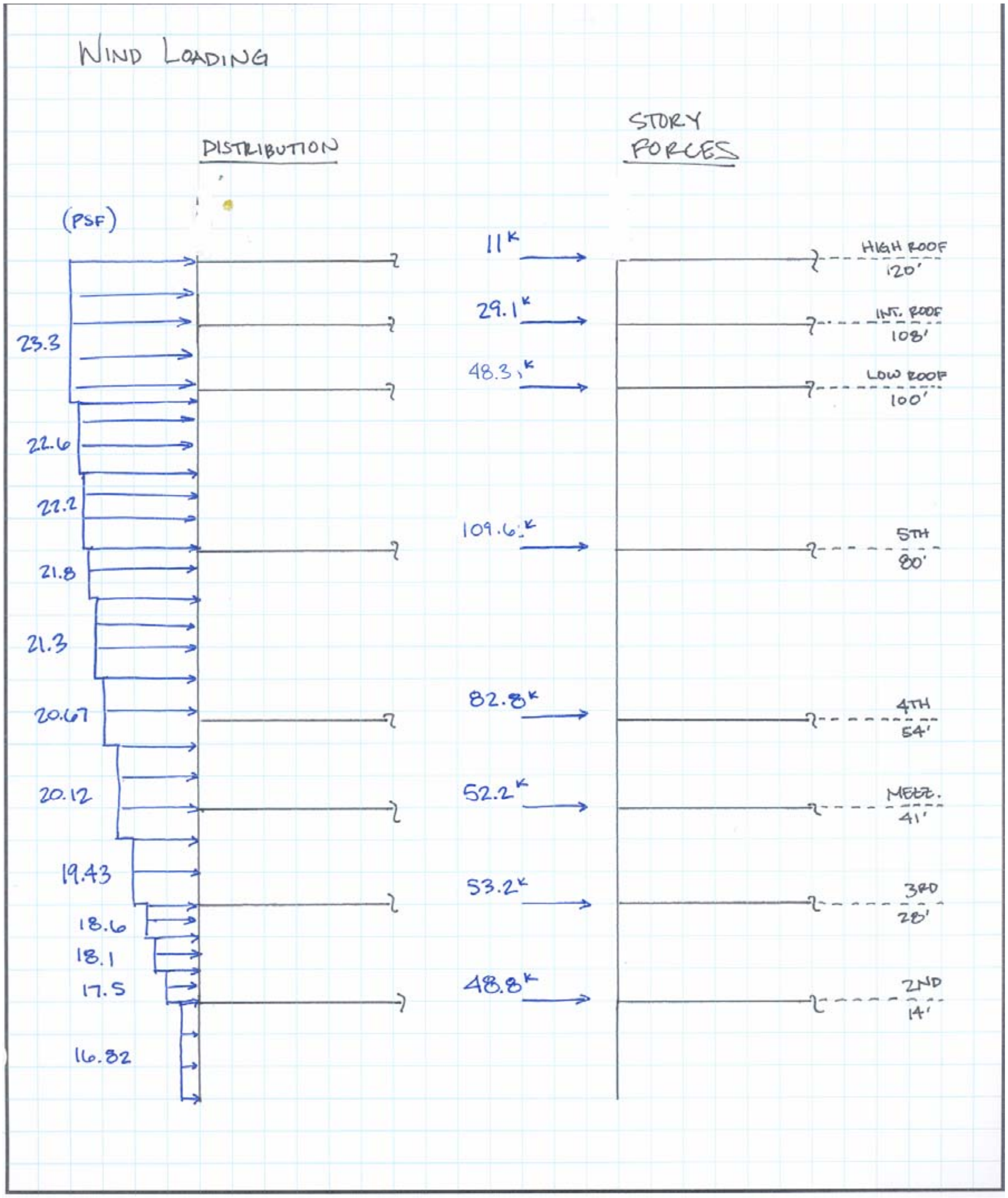
Wind Loading (ASCE 7-02)

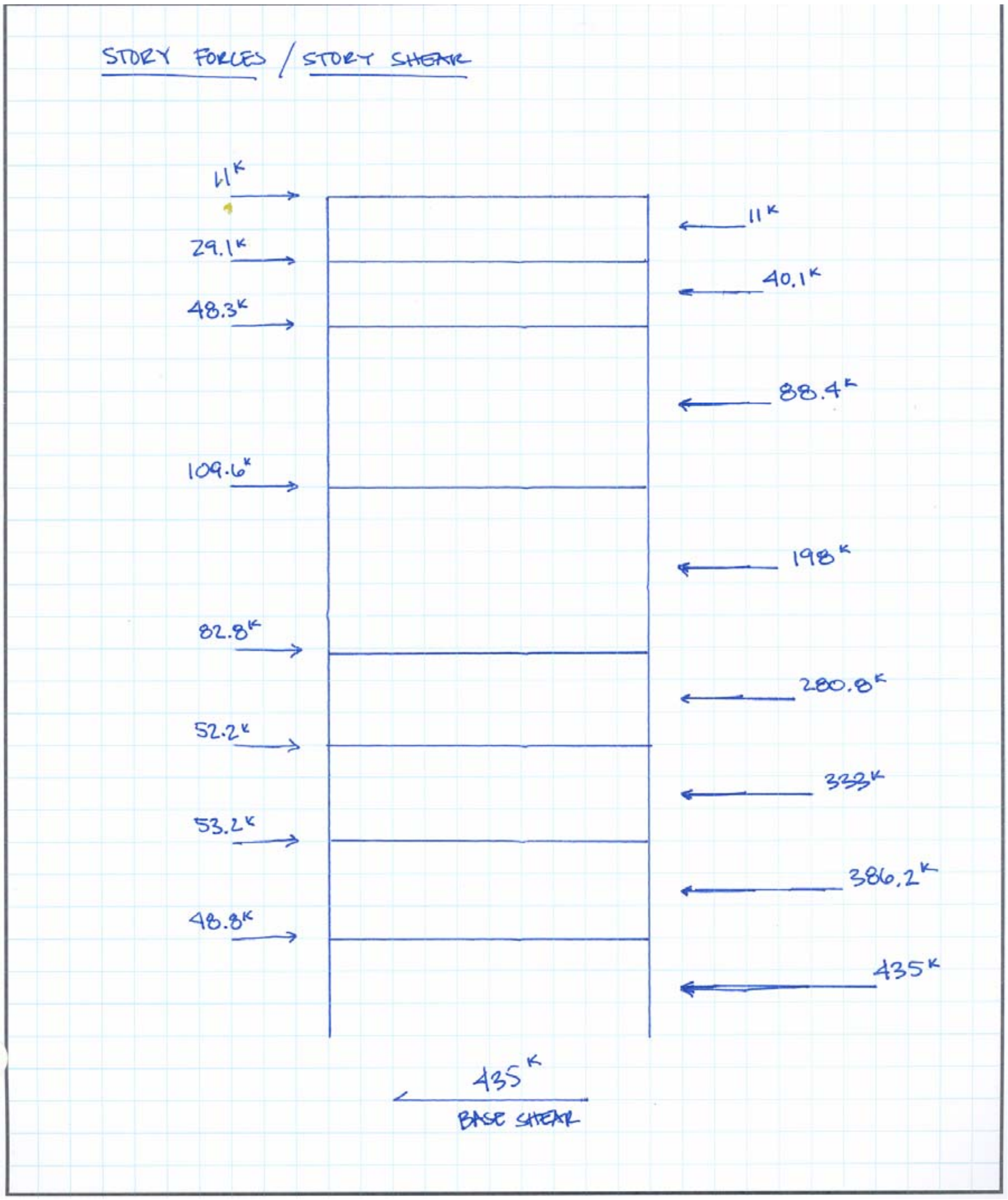
Basic Wind Speed…………………………..90 MPH
Exposure Category…………………………III
Enclosure Classification……………………Enclosed
Building Category…………………………..B
Importance Factor………………………….. 1.15
Internal Pressure Coefficient………………..0.18

NORTH/SOUTH RESULTS						
z(ft)	k_z(T6-3)	q_z	$P_{sidewall}$(psf)	$P_{leeward}$(psf)	$P_{windward}$(psf)	P_{total}(psf)
0-15	0.57	11.554	-6.874	-8.959	7.856	16.816
20	0.62	12.567	-7.477	-8.959	8.546	17.505
25	0.66	13.378	-7.960	-8.959	9.097	18.056
30	0.70	14.189	-8.442	-8.959	9.648	18.607
40	0.76	15.405	-9.166	-8.959	10.475	19.434
50	0.81	16.418	-9.769	-8.959	11.164	20.124
60	0.85	17.229	-10.251	-8.959	11.716	20.675
70	0.89	18.040	-10.734	-8.959	12.267	21.226
80	0.93	18.851	-11.216	-8.959	12.818	21.777
90	0.96	19.459	-11.578	-8.959	13.232	22.191
100	0.99	20.067	-11.940	-8.959	13.645	22.604
120	1.04	21.080	-12.543	-8.959	14.335	23.294

Base Shear (N/S): 435 kips
Overturning Moment: 26845 ft-kips ***Controls Wind v. Seismic Loading ***

Base Shear (E/W): 219.1 kips
Overturning Moment: 13640 ft-kips


WIND LOADING
DISTRIBUTION
STORY FORCES
(PSF)
23.3
22.6
22.2
21.8
21.3
20.67
20.12
19.43
18.6
18.1
17.5
16.82
11k
29.1k
48.3k
109.6k
82.8k
52.2k
53.2k
48.8k
HIGH ROOF
120'
INT. ROOF
108'
LOW ROOF
100'
5TH
80'
4TH
54'
MEZZ.
41'
3RD
28'
2ND
14'



STORY FORCES / STORY SHEAR
11K
29.1K
48.3K
109.6K
82.8K
52.2K
53.2K
48.8K
11K
40.1K
88.4K
198K
280.8K
333K
386.2K
435K
435K
BASE SHEAR

Duquesne Multipurpose Facility Story Forces (Kips)					
		Hand Calculations		RAM Output	
Level	Height	Wind (x-direction)	Wind (y-direction)	Wind (x-direction)	Wind (y-direction)
High Roof	120	2	11	2.07	7.46
Int. Roof	108	16.2	29.1	10.24	27.95
Low Roof	100	31.8	48.3	29.83	-3.37
5	80	50.7	109.6	51.31	138.45
4	54	41.4	82.8	44.04	80.82
Mezzanine	41	27.4	52.2	9.24	50.65
3	28	25.7	53.2	38.83	50.47
2	14	23.9	48.8	22.29	47.43
Forbes Avenue	0	0	0	33.7	7.27
Base Shear (k)		219.1	**435**	241.55	**407.13**
Overturn Moment (ft-k)		13,638.8	**26,845**	12,598.42	**23,170.91**

RAM Modeling

In Technical Assignment 1, hand calculations were used to get a fairly accurate idea of the forces acting on the structure. For this assignment, RAM Structural System is being used to more precisely determine controlling forces. The RAM model references the same codes as the performed hand calculations, ASCE 7-02 and IBC 2003, for wind and seismic loading.

In the case of the wind loading conditions, the RAM output and hand calculations seem to justify each other. The hand calculations are slightly higher in both the X and Y directions, and when comparing base shear and overturning moment. This is most likely due to conservative estimates such as rounded building dimensions and wind pressures. The only glaring miscalculation is seen at the low roof level of the RAM output. At this level, RAM calculates a negative pressure that seems extremely out of place. I have not been able to locate the cause of this error but, to my knowledge, this could only be caused by a glitch in the RAM model or its force calculation method.

Seismic Loading (ASCE7-02)

Seismic Design Category………………….. A
Seismic Use Group………………………… II
Importance Factor (I_E)…………………….. 1.25
S_S…………………………………………0.128
S_1…………………………………………0.057
S_{DS}………………………………………..0.102
S_{D1}………………………………………..0.065
Site Class……………………………………C
Response Coefficient
N-S…………………………0.0231
E-W…………………………0.0231
Response Modification Factor
N-S…………………………5
E-W…………………………5

Period (T) = 0.7
V = 352
K = 1.1

Level	Weight	Story Height h	h^k	Wx*hx^k	Cvx	Fx
2	2655	14	18.23	48396	0.04	13.1
3	2655	28	39.07	103738	0.08	28.1
Mezzanine	1800	41	59.44	106988	0.08	29.0
4	2655	54	80.47	213647	0.16	57.9
5	2655	80	123.99	329203	0.25	89.2
Low Roof	1460	98.5	155.88	227579	0.18	61.7
Inter. Roof	1460	108	172.49	251837	0.19	68.2
High Roof	92	120	193.69	17819	0.01	4.8
Sum	**15432**			**1299207**	**1**	**352.0**

Base Shear: **352 kips**
Overturning Moment: **26440 ft-kips**

*Seismic loading does not control the design of lateral elements

Lateral Load Distribution

The lateral loads imposed on the building are distributed into story forces and then further distributed to each frame on the basis of relative stiffness. It stands to reason that the wider, shorter frames would be the stiffest, and take the most amount of load once distributed. The taller, more slender frames take less load after distribution.

Due to the unresolved issue in the RAM output data, the forces derived through hand calculations are charted below. These forces have been checked against the overall RAM data and have been deemed to be an accurate representation of the overall force on the structure.

East-West Direction

Approximate Load on Each Frame Story, kips

Frame	1/Defl	2	3	Mezz	4	5	LR	IR	HR	Total Load
1 H-J	3.99	16	17	18	27	33	21	0	0	132
4.4 BB-CC	0.5836	2	2	3	4	5	3	4	5	28
4.4 DD-EE	0.6581	3	3	3	4	5	3	4	5	30
5 EE-F	0.8428	3	4	4	6	7	4	0	0	28
		0	0	0	0	0	0	0	0	0
	6.0745	24	26	28	41	51	31	8	10	219

North-South Direction

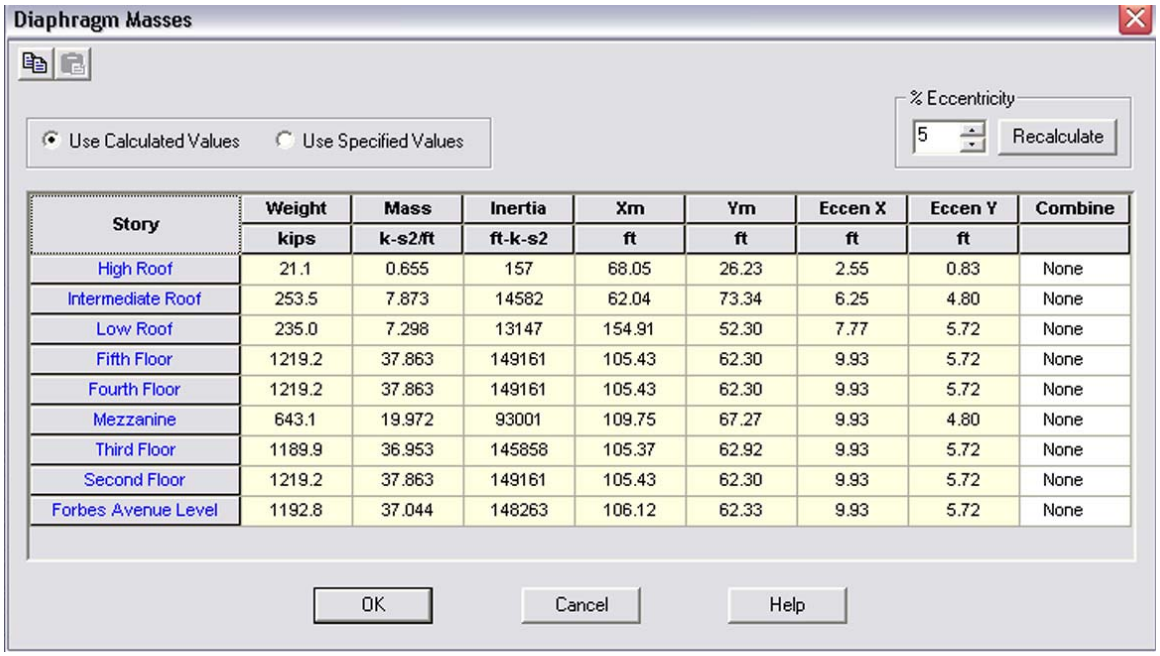
Approximate Load on Each Frame Story, kips

Frame	1/Defl	2	3	Mezz	4	5	LR	IR	HR	Total Load
A 1-2	6.395	22	24	23	37	48	21	13	0	188
K 2-3	8.07	27	30	29	46	61	27	0	0	220
		0	0	0	0	0	0	0	0	0
	14.465	49	53	52	83	110	48	13	0	408

Torsion

Center of Mass/Rigidity

The center of mass (Xm, Ym) for each floor in the Duquesne University Multipurpose Facility was found through the use of a RAM model. The results are shown in the chart below. The center of mass for the entire building is located at the point (105.9’, 62.8’).



Diaphragm Masses

Use Calculated Values   Use Specified Values

% Eccentricity 5   Recalculate

Story	Weight	Mass	Inertia	Xm	Ym	Eccen X	Eccen Y	Combine
	kips	k-s2/ft	ft-k-s2	ft	ft	ft	ft	
High Roof	21.1	0.655	157	68.05	26.23	2.55	0.83	None
Intermediate Roof	253.5	7.873	14582	62.04	73.34	6.25	4.80	None
Low Roof	235.0	7.298	13147	154.91	52.30	7.77	5.72	None
Fifth Floor	1219.2	37.863	149161	105.43	62.30	9.93	5.72	None
Fourth Floor	1219.2	37.863	149161	105.43	62.30	9.93	5.72	None
Mezzanine	643.1	19.972	93001	109.75	67.27	9.93	4.80	None
Third Floor	1189.9	36.953	145858	105.37	62.92	9.93	5.72	None
Second Floor	1219.2	37.863	149161	105.43	62.30	9.93	5.72	None
Forbes Avenue Level	1192.8	37.044	148263	106.12	62.33	9.93	5.72	None

OK   Cancel   Help

The center of rigidity (98’, 57.1’) is located at approximately (7.9’, 5.7’) from the center of mass, causing a torsional force to be introduced into the rigid diaphragm at each floor. As the floor levels rise, the building experiences more torsion due to the displacement or offset of the upper roof levels.

Torsion Effects

The forces related to torsion that act on the structure are largely negligible on the lower floor levels. In analyzing the upper levels of the building and the roof line, the effects of torsion seem to be large enough that they may affect the design of the structure. However, when looking at RAM's rotation output, the High Roof level only sees a rotation of 0.00191 radians. Because of these contradictory calculations at the upper levels, I will ignore torsion at this point, and focus on it in further study.

First, the actual eccentricity, measured from the geometrical center of the building, is much less than the 5% accidental eccentricity normally assumed. The eccentricity used is that of 5% of the total building dimension. This is a conservative measure and therefore the effects associated with torsion are somewhat negligible. The torsion calculations can be seen in the next section of this report

Torsion Calculations

As stated above, the difference in the center of mass and rigidity will introduce torsion into the structure. Torsion calculations can be seen below.

East-West Direction											
Frame	**1/Defl**	**2**	**2T**	**3**	**3T**	**Mezz**	**Mezz.T**	**4**	**4T**	**5**	**5T**
1 H-J	3.99	16	0.76555	17	0.80107	18	0.72270	27	-1.11460	33	-1.39799
4.4 BB-CC	0.5836	2	0.05599	2	0.06737	3	0.07758	4	-0.12903	5	-0.18589
4.4 DD-EE	0.6581	3	0.06313	3	0.07597	3	0.08749	4	-0.14550	5	-0.20962
5 EE-F	0.8428	3	0.12834	4	0.14947	4	0.16386	6	-0.26891	7	-0.37881
	6.0745	24	1.01301	26	1.09389	27	1.05163	41	-1.65804	51	-2.17231

North-South Direction											
Frame	**1/Defl**	**2**	**2T**	**3**	**3T**	**Mezz**	**Mezz.T**	**4**	**4T**	**5**	**5T**
A 1-2	6.395	22	1.87943	24	2.081033	23	2.093471	37	-3.369657	48	-4.662341
K 2-3	8.07	27	2.47001	30	2.693613	29	2.6418	46	-4.166777	61	-5.369424
	14.465	49	4	53	4.774645	52	4.735271	83	-7.536434	110	-10.03176

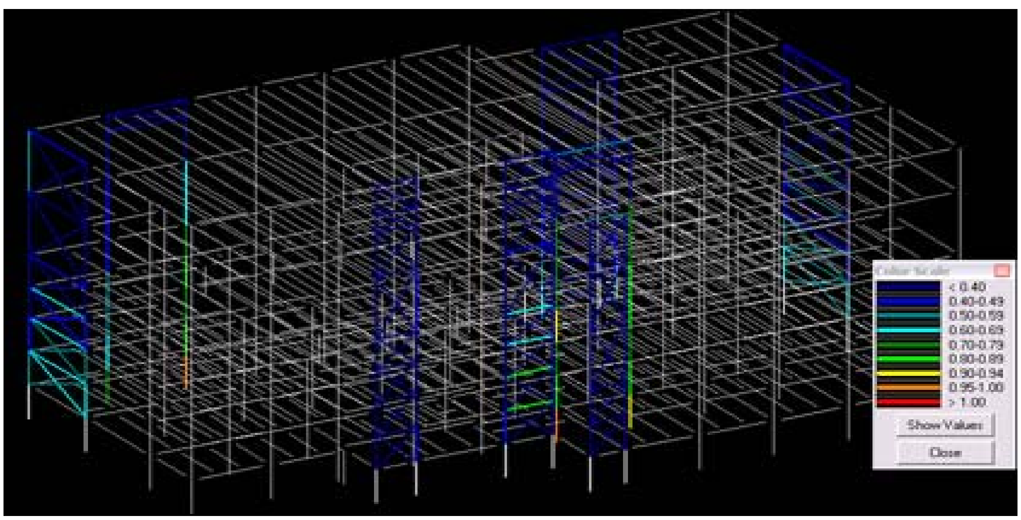
Lateral Stability Checks

Strength Check

A strength check of each lateral element and its structural members was performed by RAM's Standard Provisions Member Code Check. The code used for the standard provisions check is AISC's LRFD and ASCE 7-02. The load cases included in the check were a combination of dead, live, wind, and earthquake loading, including:

- 1.4D
- 1.2D + 1.6L
- **1.2D + 0.5L + 1.6W**
- 1.2D + 0.5L + 1.6E
- 1.2D + 1.0E

Among these combinations, the controlling case was 1.2D + 0.5L + 1.6W. This load case was used to generate the forces on each member of the structural frame. The results of the RAM analysis can be seen below.



Most all members in the braced frames are stressed to less than 50% of their capacity. The members are designed to meet strength requirements as well as drift requirements, which control in this structure. As was done in *Technical Assignment 1*, a strength check of the lateral bracing was done to assure that the axial design loads area accurate. A spot check of the braced frame A1-2, with lateral loads applied can be seen on the following page. The spot check of a particular bracing member takes into account the story shear on the isolated frame.

LATERAL ELEMENT AXIAL CHECK

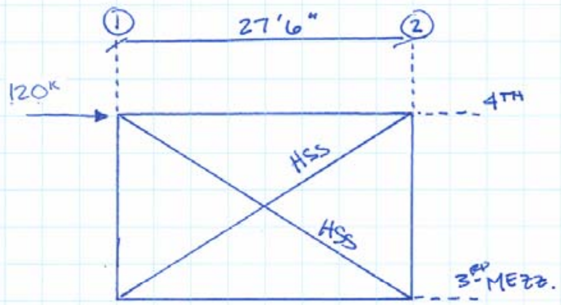
FRAMES BETWEEN $\begin{cases} A1\text{-}2 \\ K2\text{-}3 \end{cases}$ IN NORTH - SOUTH DIRECTION

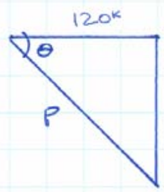
A1-2 : $1/\Delta = 6.395$ % DIST = 0.442
K2-3 : $1/\Delta = 8.07$ % DIST = 0.558

** 10^K UNIT LOAD @ TOP OF EACH FRAME

4TH FLOOR LOADING: Σ LOADS FROM ROOF = STORY SHEAR = 270^K

℄ A





$\theta = \tan^{-1}(13'/27.5')$
$= 25.3°$

$L = 27.5 / \cos 25.3° = 30.4'$

$\cos 25.3° = 120^K / P$

$\underline{P = 132^K}$

$\underline{P_{DESIGN} = 170^K}$

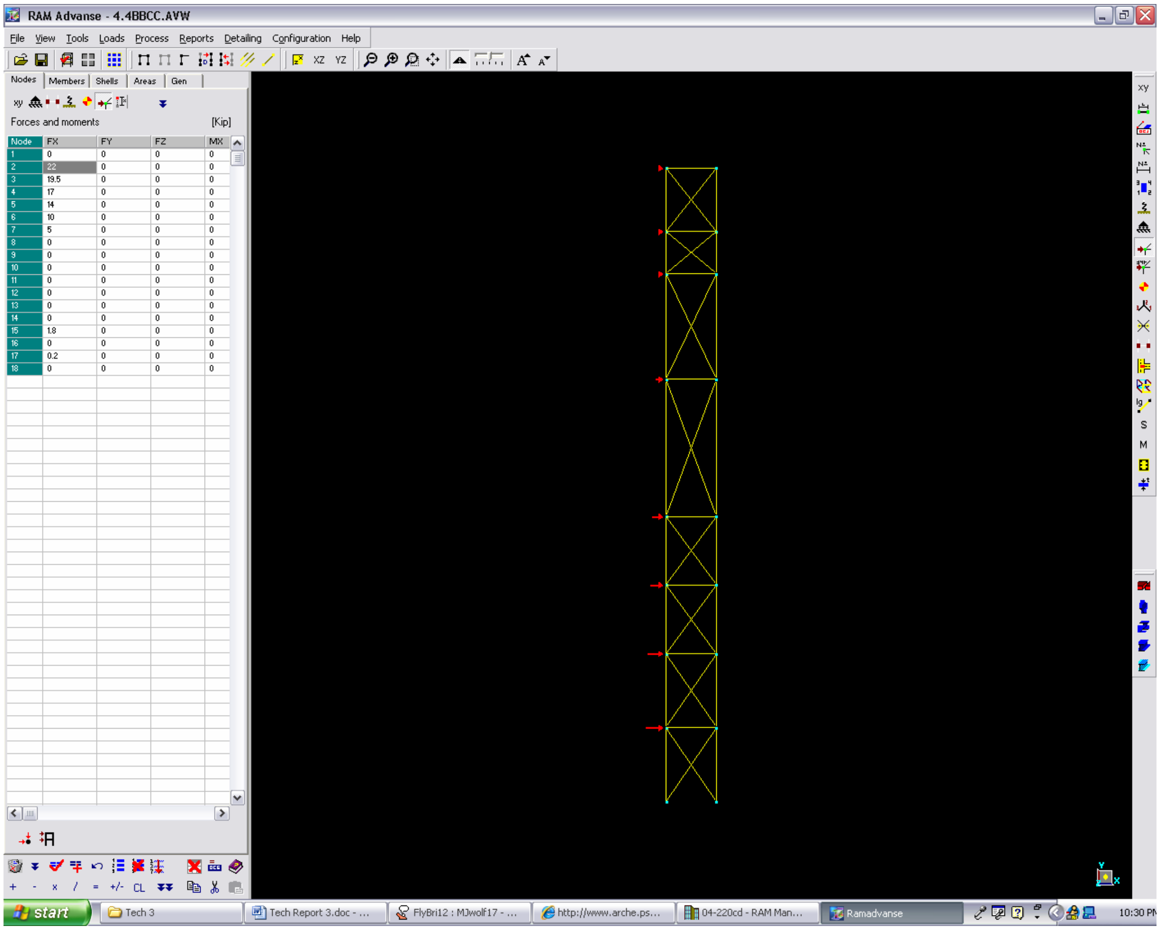
· DESIGN IS ADEQUATE WITH REGARDS TO LATERAL LOADS ONLY, IN THIS CASE.

RAM Advanse Frame Check

A further check of the capability of the existing bracing was done using RAM Advanse. This program models frames in a similar manner to that of STAAD software. The RAM Advanse output confirms that the members in frame 4.4BB-CC are well within the designed capacities listed on the bracing elevations. As in the RAM model, the members are stressed at less than 50%.

Maximum forces at members (4.4 BB-CC)

	RAM Advanse	DESIGN		RAM Advanse	DESIGN
	Axial [Kip] (+) Tension	Axial [Kip] (+) Tension		Axial [Kip] (+) Tension	Axial [Kip] (+) Tension
HR Brace			4th FL Brace		
Max	0.09	10	Max	24.66	60
Min	0.09	10	Min	24.66	60
HR Brace			4th FL Brace		
Max	-0.25	x	Max	-27.21	x
Min	-0.25	x	Min	-27.21	x
IR Brace			Mezz. Brace		
Max	1.24	40	Max	37.78	60
Min	1.24	40	Min	37.78	60
IR Brace			Mezz. Brace		
Max	-2.03	x	Max	-40.79	x
Min	-2.03	x	Min	-40.79	x
LR Brace			3rd FL Brace		
Max	6.84	30	Max	53.77	60
Min	6.84	30	Min	53.77	60
LR Brace			3rd FL Brace		
Max	-7.23	x	Max	-54.9	x
Min	-7.23	x	Min	-54.9	x
5th FL Brace			2nd FL Brace		
Max	21.87	40	Max	83.59	110
Min	21.87	40	Min	83.59	110
5th FL Brace			2nd FL Brace		
Max	-22.33	x	Max	-81.17	x
Min	-22.33	x	Min	-81.17	x

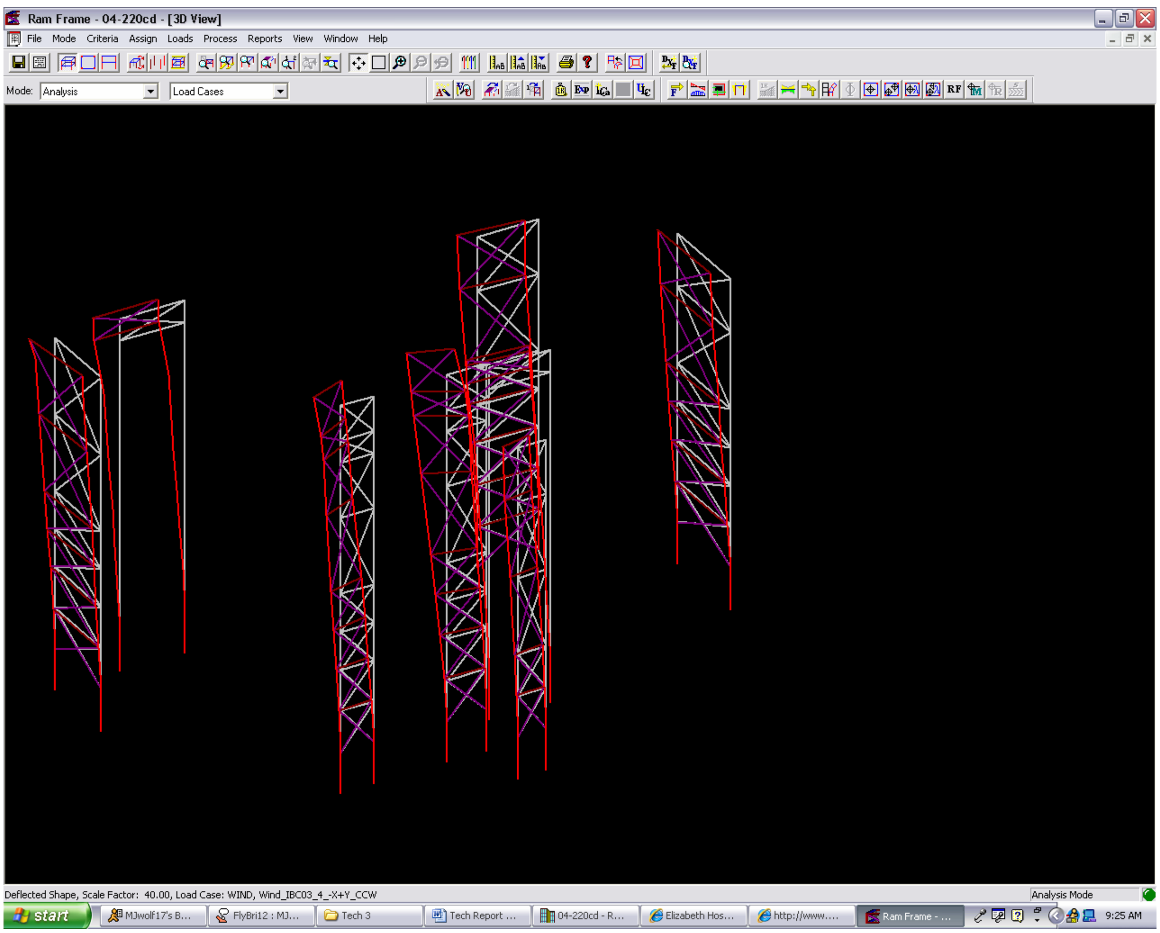


RAM Advanse Model of frame 4.4BB-CC

Drift Check

An industry accepted standard for the amount of drift a building is allowed to experience is H/400. For the Duquesne Multipurpose Facility, the total height from ground to roof is 132’, making H/400 = 3.96”. This drift limitation is purely based on serviceability, overall comfort for all who may be inside the structure. With that in mind, the High Roof penthouse level of this facility may be allowed to drift a larger amount. It is over designed for strength as is, and may not require drift limitations due to its lack of public access.

Floor	Height (ft)	Floor-Floor Height (ft)	N/S (critical) Disp. (in.)	H/400 (in.)	Inner Story Drift (in.)	H/400 (in.)
HR	132	12	5.62	3.96	0.0075	0.36
IR	120	14	3.3	3.96	0.0045	0.42
LR	106	12	2.36	3.96	0.0015	0.36
5th Floor	94	26	2.13	3.96	0.0029	0.78
4th Floor	68	13	1.54	3.96	0.0024	0.39
Mezz.	55	13	1.17	3.96	0.0025	0.39
3rd Floor	42	14	0.78	3.96	0.0025	0.42
2nd Floor	28	14	0.37	3.96	0.0022	0.42
Forbes	14	14	n/a	n/a	n/a	n/a
Watson	0	n/a	n/a	n/a	n/a	n/a
**Ground slopes upward, making Watson and Forbs both ground levels						



Deflected structure in RAM Structural System

Overturning of Lateral Frames

The overall overturning moment, found using hand calculated wind forces, resisted by the structure is 26,845 ft-kips. Each frame, when loaded with the distributed lateral loads will have an overturning moment as well. Because of the distribution to the resisting elements in the N/S and E/W direction, the overturning moments of the individual frames are expected to have a moment proportional to the distribution of forces. Below are the overturning moments calculated for each frame.

Braced Frame	Overturning Moment
A1-2	11,265 ft-k
K2-3	12,471 ft-k
1H-J	5,746 ft-k
4.4BB-CC	2,155 ft-k
4.4DD-EE	2,200 ft-k
5EE-F	1,600 ft-k

Foundations

The frames with the largest moments will exert the largest combined axial and overturning moment forces onto their foundations. The foundations themselves consist of 24" auger cast piles, which have a design capacity of 35 tons. At the locations of the lateral columns, more piles are drilled to resist the higher loads associated the forces exerted by said columns. With such a larch capacity per pile, the forces in the lateral columns should be accounted for by the addition of multiple piles to resist the compression forces.