Technical Report 3

Lateral System Analysis and Confirmation Design

Columbia University Northwest Science Building

Broadway & 120th Street, New York, NY

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Addendum:

In Technical Report 1 an error was discovered by the author. A base shear wind calculation was done incorrectly for the North-South wind direction. The windward and leeward wind pressures were originally calculated correctly. However, upon analysis during this Technical Report 3, it was found that an incorrect base shear was determined. See *Figure 1* below displaying the corrected base shear (circled in purple).

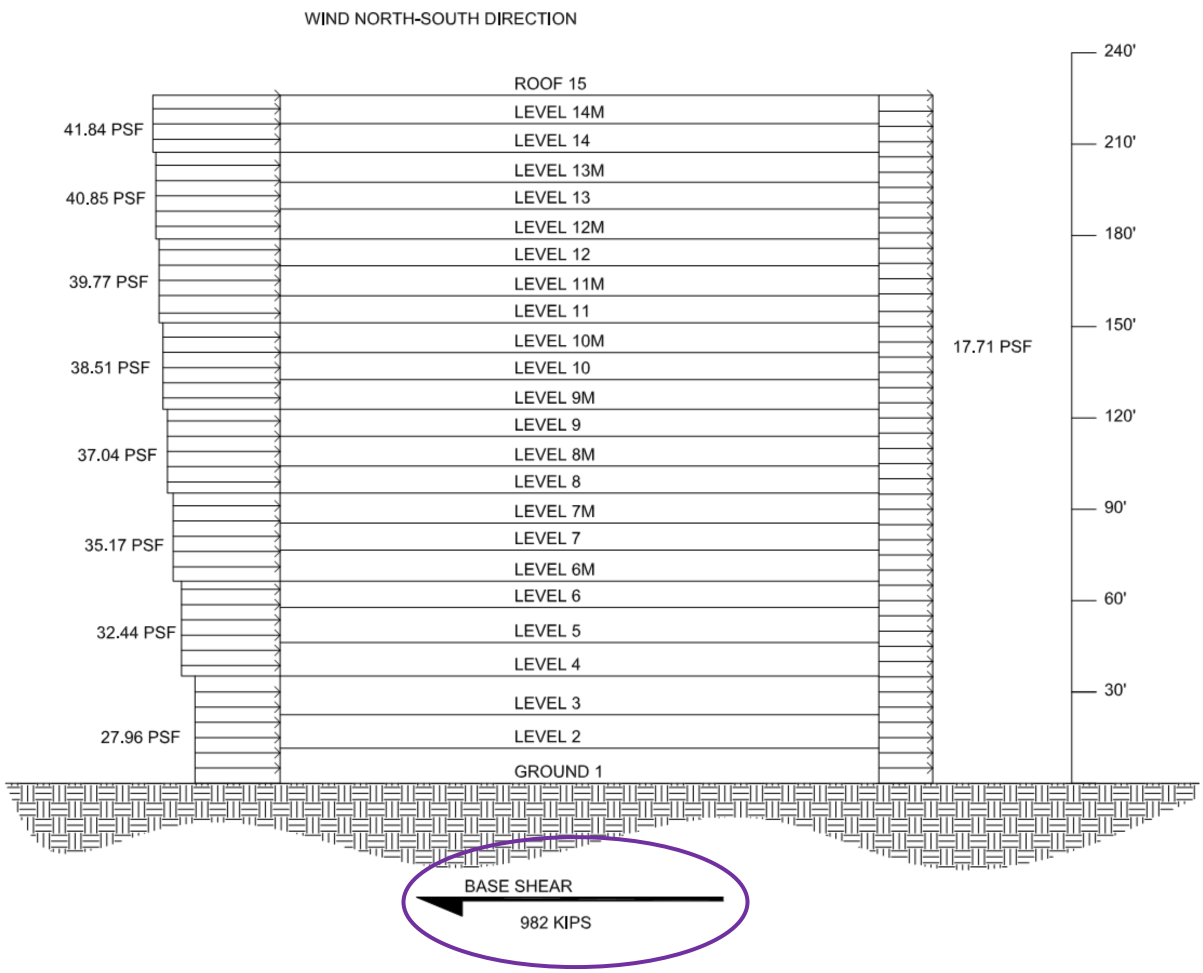


Figure 1: Corrected Wind North-South Direction Diagram

Executive Summary:

The overall objective of this technical report is to study the lateral system of the Columbia University Northwest Science Building located in New York City. This building provides scientific laboratory space for the university, is 226 feet high, and consists of steel framing for both its lateral and gravity systems. This study involves a lateral load analysis along with confirmation checks of strength, story drift, overturning, and building torsion.

Northwest Science Building lateral system contains braced frames in each direction. Below is a typical floor plan, with the North-South braced frames highlighted in purple and the East-West highlighted in green.

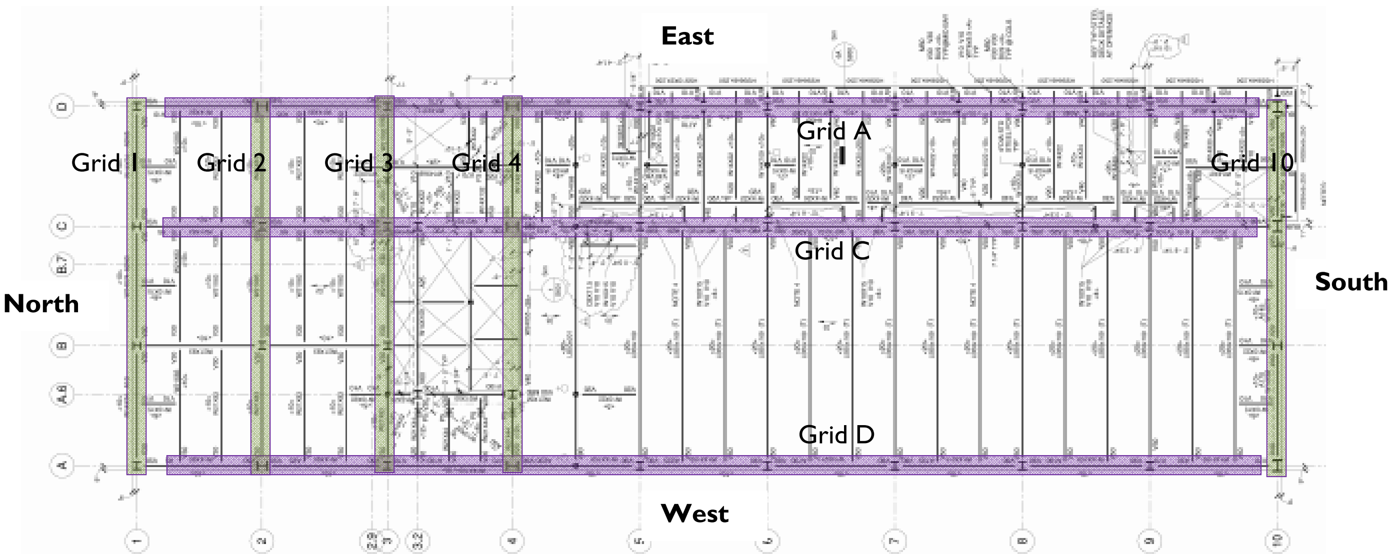


Figure 2: Typical Structural Floor Plan – Lateral System

Due to the complexity of this lateral system with its irregular bracing and large frames, a 2D lateral analysis of the frames was performed, instead of a more advanced 3D analysis. This 2D analysis allowed the author to take the relative stiffness values of each braced frame and use them to distribute the wind and seismic forces determined in Technical Report 1 accordingly.

From this analysis, it was determined that the wind will control the lateral system design. This is partly due to the fact that the Northwest Science Building is located on the east coast where wind forces are critical and the building is not in an active seismic region. The table on the following page contains the critical load values for each braced frame in red. Notice that more than one wind case controls the overall lateral design. Wind Case 1 will control the design of Grids A, C, & D. Wind Case 2 (Eccentric Case 2) controls the design of Grids 1, 2, 3, & 4, while Wind Case 3 (Eccentric Case 1) controls Grid 10. For a description of each load case see pages 17 & 18.

Table 1: Wind & Seismic Grid Load Values

Load Cases	Grid A	Grid C	Grid D	Grid 1	Grid 2	Grid 3	Grid 4	Grid 10
Wind Case 1	**451**	**117**	**413**	0	0	0	0	0
Wind Case 2 (Ecc. Case 1)	86	8	79	837	270	263	257	1234
Wind Case 2 (Ecc. Case 2)	227	20	208	**997**	**312**	**295**	**277**	980
Wind Case 3 (Ecc. Case 1)	228	45	57	790	254	248	242	**1461**
Wind Case 3 (Ecc. Case 2)	361	57	65	942	294	278	262	927
Seismic Case 1	100	26	91	0	0	0	0	0
Seismic Case 2	7	1	6	69	27	27	26	68

*All Values in KIPS (All Loads Currently Not Factored)

The following table summarizes the additional lateral analysis spot checking results. For more information on these checks see their corresponding listed pages.

Table 2: Lateral Analysis Results

Design Concern	Impact on Foundations	Drift & Story Drift	Strength Check	Building Torsion	Overturning
North-South Lateral Resisting System	**No Impact** (pg. 44)	**Okay** (pg. 41)	**Okay** (pg. 40)	**Okay** (pg. 44)	**Okay** (pg. 41-43)
East-West Lateral Resisting System	**No Impact** (pg. 44)	**Okay** (pg. 41)	**Okay** (pg. 40)	**Okay** (pg. 44)	**Okay** (pg. 41-43)

The wind and seismic analysis, along with the calculation checks on foundations, story drift, drift, strength, building torsion, and overturning all confirm the existing lateral system design to be satisfactory.

Introduction

Columbia University's Northwest Science Building is located at the intersection of Broadway and 120th Street in New York City. This building will provide Columbia University with science research facility space. It is approximately 188,000 square feet in size with 14 stories above grade. This building design had to overcome an existing spatial concern. In order to use the site to its full capacity, the building design called for a 126 foot clear span over an existing gymnasium structure. Diagonal bracing is utilized throughout the structure not only for lateral forces, but to transfer gravity loads for the 126 foot clear span. Also, the diagonal members serve as a key architectural feature. The diagonal members create braced frames in each direction of the building, which serve as the building's lateral system.

As part of the in-depth analysis of the building's lateral system, this report also includes the codes and design requirements used, the load cases and calculated loads, a distribution of lateral loads, a SAP model, member checks and supportive hand calculations.

Figure 3: Northwest Science Building Exterior Rendering

*Special thanks to Turner Construction Company for providing the necessary documents, information, and images necessary for this Architectural Engineering Senior Thesis, Technical Report 3.

Existing Structural Lateral System

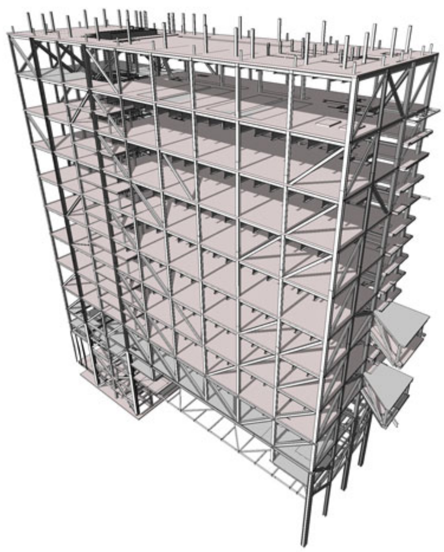


Figure 4: Structure Rendering

Note: For additional descriptions and images on the existing structural system, please see Technical Reports 1 & 2 on the Columbia University Northwest Science Building.

1. Lateral System

The lateral system utilizes diagonal bracing, wind girts, a composite floor system, moment connections, and wide flange beams and columns. The lateral load is first distributed into the building by beams, wind girt members, and the composite floor system. It is then distributed downwards into diagonal bracing, moment connections and columns until it reaches the foundation of the structure.

For a more detailed description of each lateral system element, see the following literature.

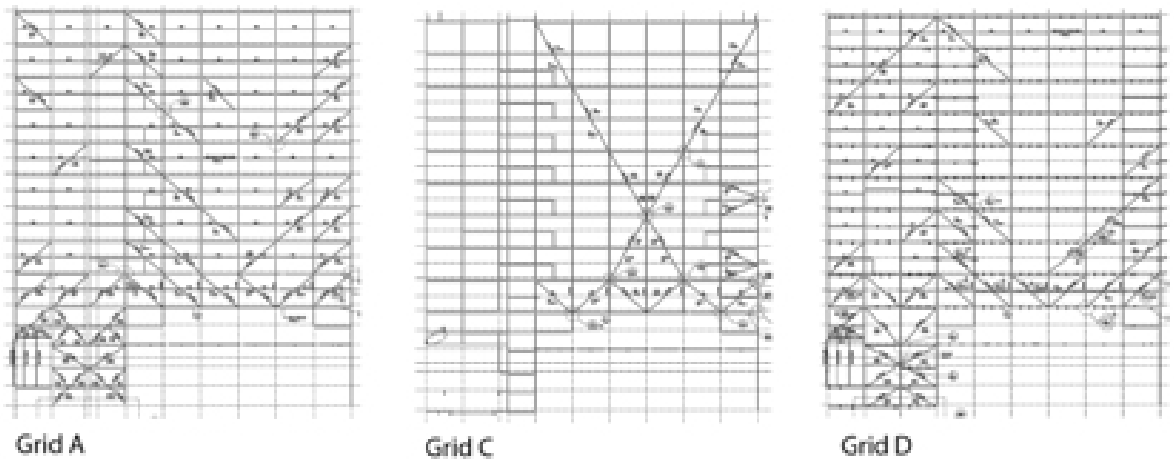
A. Diagonal Bracing

The diagonal bracing elements are made up of W14 members. These members vary in pounds per linear foot from W14x36 to W14x550. The W14x36 members can be found towards the top of the structure. They are utilized at the top because the story shear is less and there is less lateral force transfer. The W14x550 members are found at the truss level (126 foot span of the structure). These elements are used to support gravity tensile loads. However, they also participate in the lateral system.

The following page will discuss the diagonal bracing seen throughout the building.

The North-South direction of the building contains three frames with diagonal bracing. These frames are considered the main defense to lateral forces acting on the building in the North and South directions. See *Figure 5* below depicting these frames.

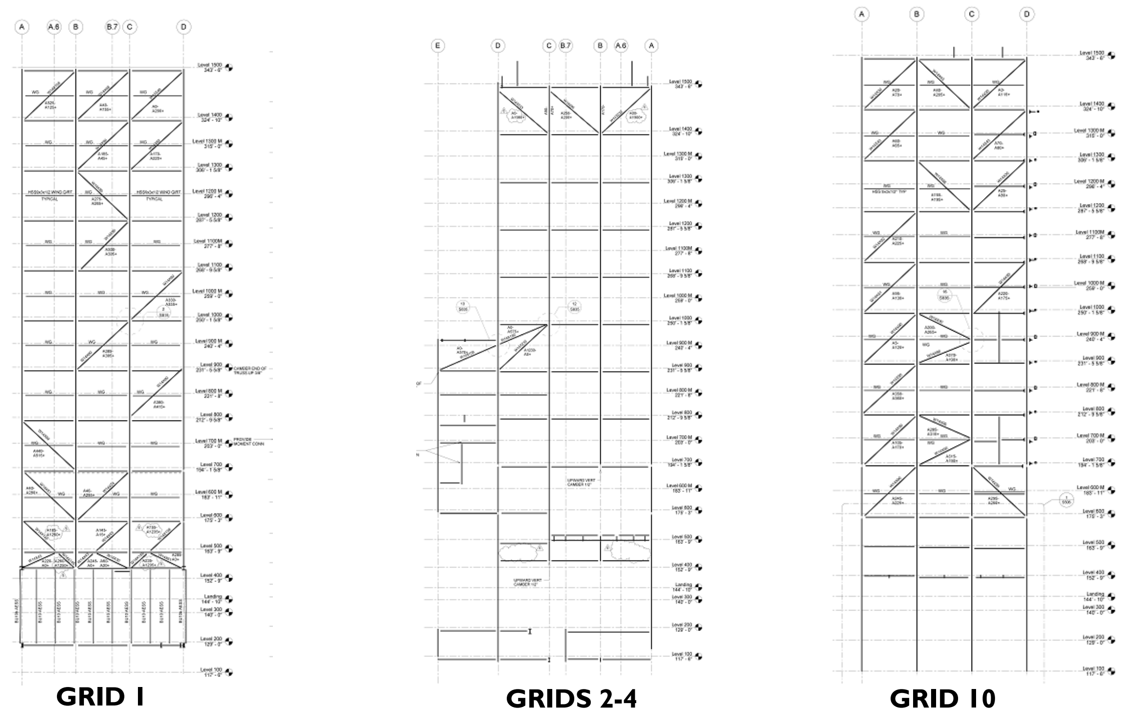
Figure 5: North-South Direction Frames



Grids A & D are the exterior frames of the building, while Grid C lies in between. The diagonal bracing in Grids A & D seems to be random, while, Grid C can be described as a large X-frame. All the grids shown above are approximately 192 feet wide and 226 foot in height. Grid C X-frame was designed to support a large amount of the dead and live loads of the 126 foot clear span of the building. This X-frame distributes the above forces to the 126 foot clear span edges. However, even though Grid C can be described as a gravity frame, it will still participate in the lateral system.

The East-West direction of the building contains five frames with diagonal bracing. These frames are considered the main defense to lateral forces acting on the building in the East and West directions. See *Figure 6* on the following page depicting these frames.

Figure 6: East-West Direction Frames



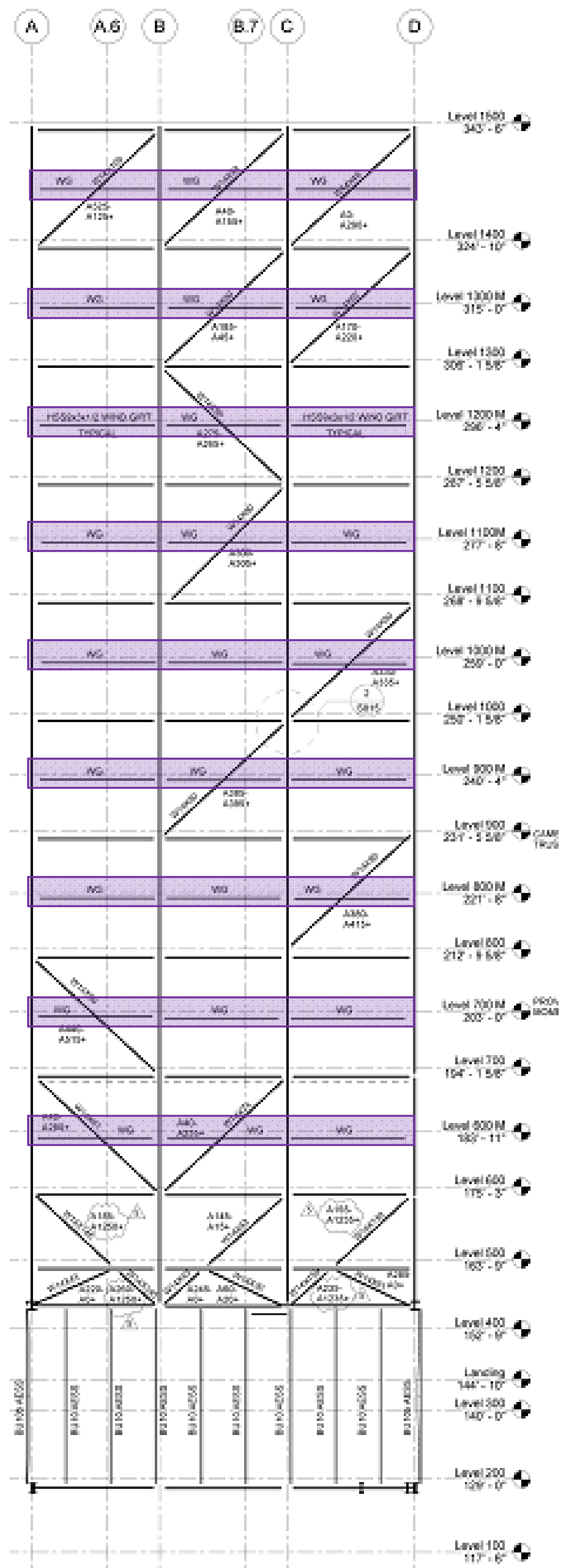
Grids 1 & 10 are the exterior frames and noticeably have more diagonal bracing than the middle grids (Grids 2-4). This means that they will have a greater participation in the lateral resisting system. Grids 2-4 provide some stiffness and will account for some participation. All the grids shown above are approximately 60 feet wide and 226 foot in height.

B. Wind Girts

The wind girts are HSS shaped members. A typical HSS member size used is a 9x3x1/2. The wind girts allow wind to be distributed into the structure at the mezzanine levels, which are in between each main level of the building. These HSS members provide additional stiffness and bracing at the midpoints of each level. They are only functional for the building's lateral system and do not participate in the gravity system.

Figure 7 on the following page provides a frame with wind girts. These girt members are highlighted in purple at each mezzanine level.

Figure 7: Wind-Girt Frame Elevation



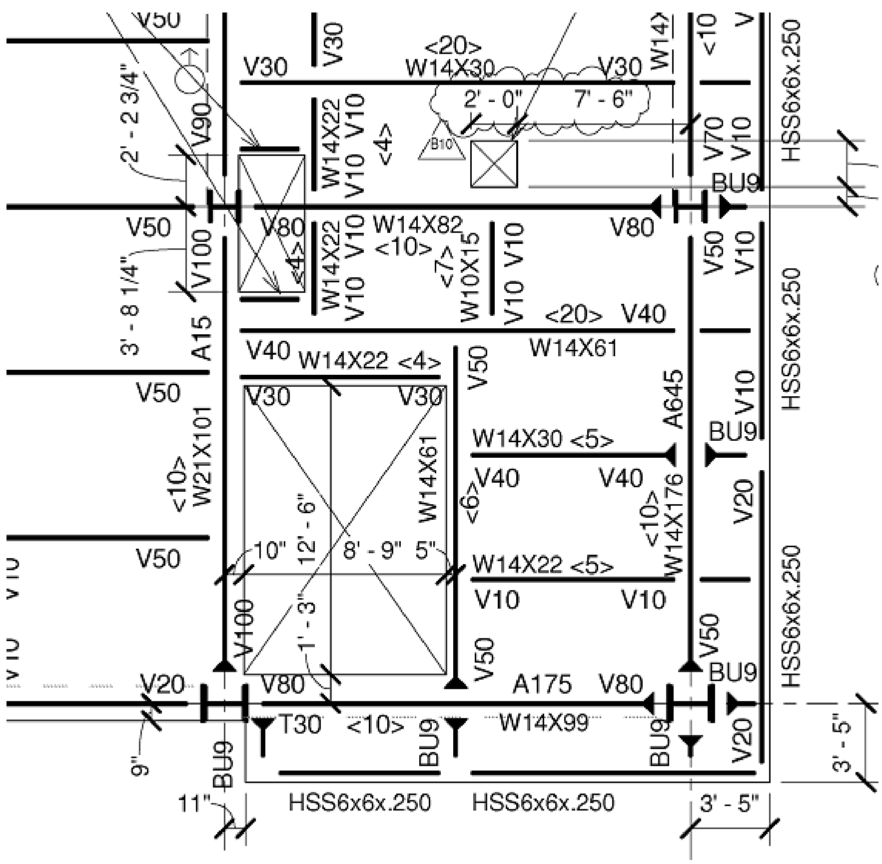
C. Composite Floor System

The floor system consists of composite decking that is shear studded to the steel W-shape spanning. This floor system due to its composite action is assumed to act as a rigid diaphragm. Due to this assumption of a rigid diaphragm at each level, it can also be assumed that the lateral forces will be distributed solely based on the stiffness of each lateral frame. Rigid diaphragms allow the lateral load to be fully distributed across each floor of the structure.

D. Moment Connections

Moment connections are utilized throughout the building structure. Moment connections are traditionally thought of as a lateral defense mechanism. However, the moment connections in the Northwest Science Building are assumed to solely be designed to control deflections. Moment connections are used for cantilever connections within the structure. These connections are used to control deflections of the cantilevers. Even though these connections will cause additional stiffness and participate in the lateral system to some extent; this technical report assumes that they are negligible to the lateral system analysis. *Figure 8* below represents a typical moment connection/cantilever occurrence.

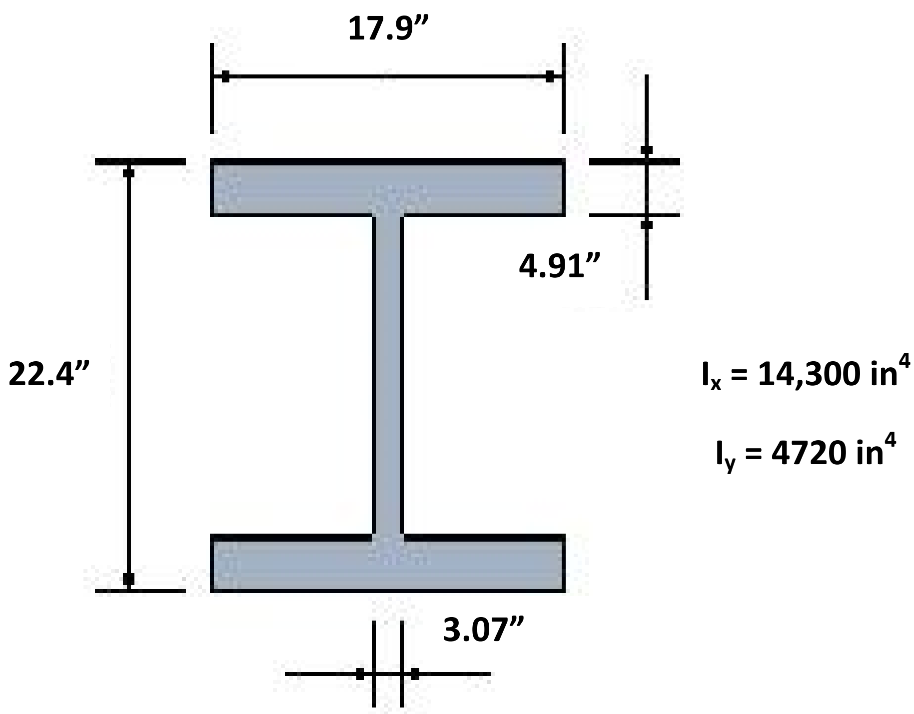
Figure 8: Moment Connected Cantilevers



E. Wide Flange Beams and Columns

A great amount of stiffness comes from the structure's wide flange beams and columns. Some of the columns and beams toward the lower part of the structure are very heavy and have large steel cross-sectional areas. These members were designed to take a large amount of shear, especially the accumulated lateral forces from the top to bottom of the structure. *Figure 9* below, gives the cross sectional dimensions and data of a W14x730 member. W14x730 members can be seen at the ground level of the building. *Figure 9* depicts the enormous size of these members.

Figure 9: W14x730 Cross-Sectional Properties



I. Codes & Design Requirements:

The following codes were used by the design team engineers of the Columbia University Northwest Science Building.

- "International Building Code 2006" – International Code Council
- "ACI 318-05 Manual of Concrete Practice" – American Concrete Institute
- "Manual of Steel Construction 9th Edition" – American Institute of Steel Construction, Inc.
- "ASCE 7-05 Minimum Design Loads for Buildings and Other Structures" – American Society of Civil Engineers
- "New York City Building Code & Regulations"
- "New York City Construction Code"
- Lateral Movements
    - Allowable Building Drift Δ_{Wind} = H/500
    - Allowable Seismic Drift $\Delta_{Seismic}$ = H/200

The following codes were used by the author of this technical report.

- "International Building Code 2006" – International Code Council
- "ACI 318-05 Manual of Concrete Practice" – American Concrete Institute
- "Manual of Steel Construction 9th Edition" – American Institute of Steel Construction, Inc.
- "ASCE 7-05 Minimum Design Loads for Buildings and Other Structures" – American Society of Civil Engineers
- Lateral Movements
    - Allowable Building Drift Δ_{Wind} = H/400
    - Allowable Story Drift $\Delta_{Seismic}$ = $0.020h_{sx}$

Since the Northwest Science Building was also designed with New York City Codes, design checks may vary slightly.

II. Loads and Load Combinations

The following diagrams represent the wind and seismic loads used for this technical report's lateral analysis. These values were determined in Technical Report #1. These values will be used in the wind and seismic analysis throughout this report.

Figure 10: Wind North-South Direction Diagram

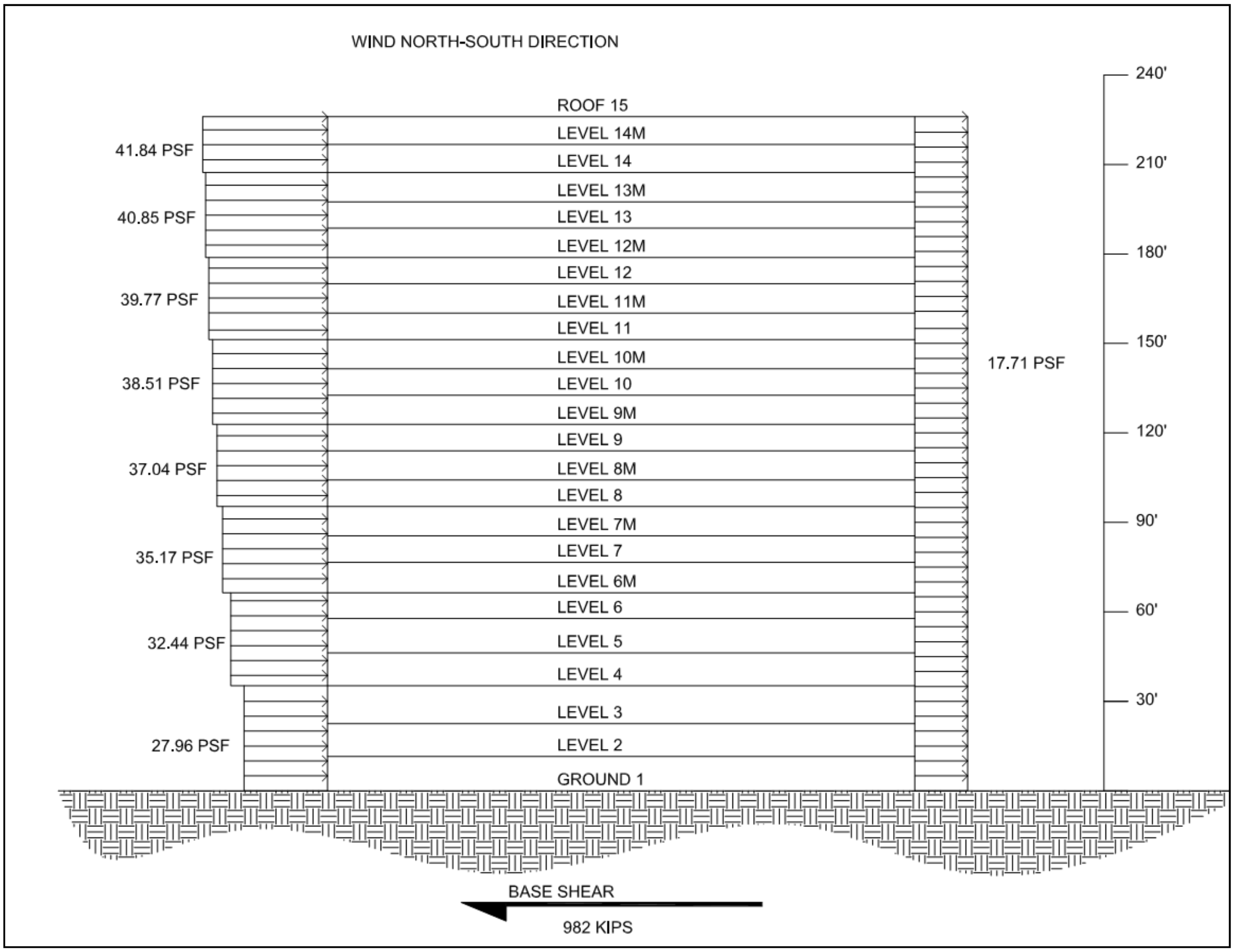


Figure 11: Wind East-West Direction Diagram

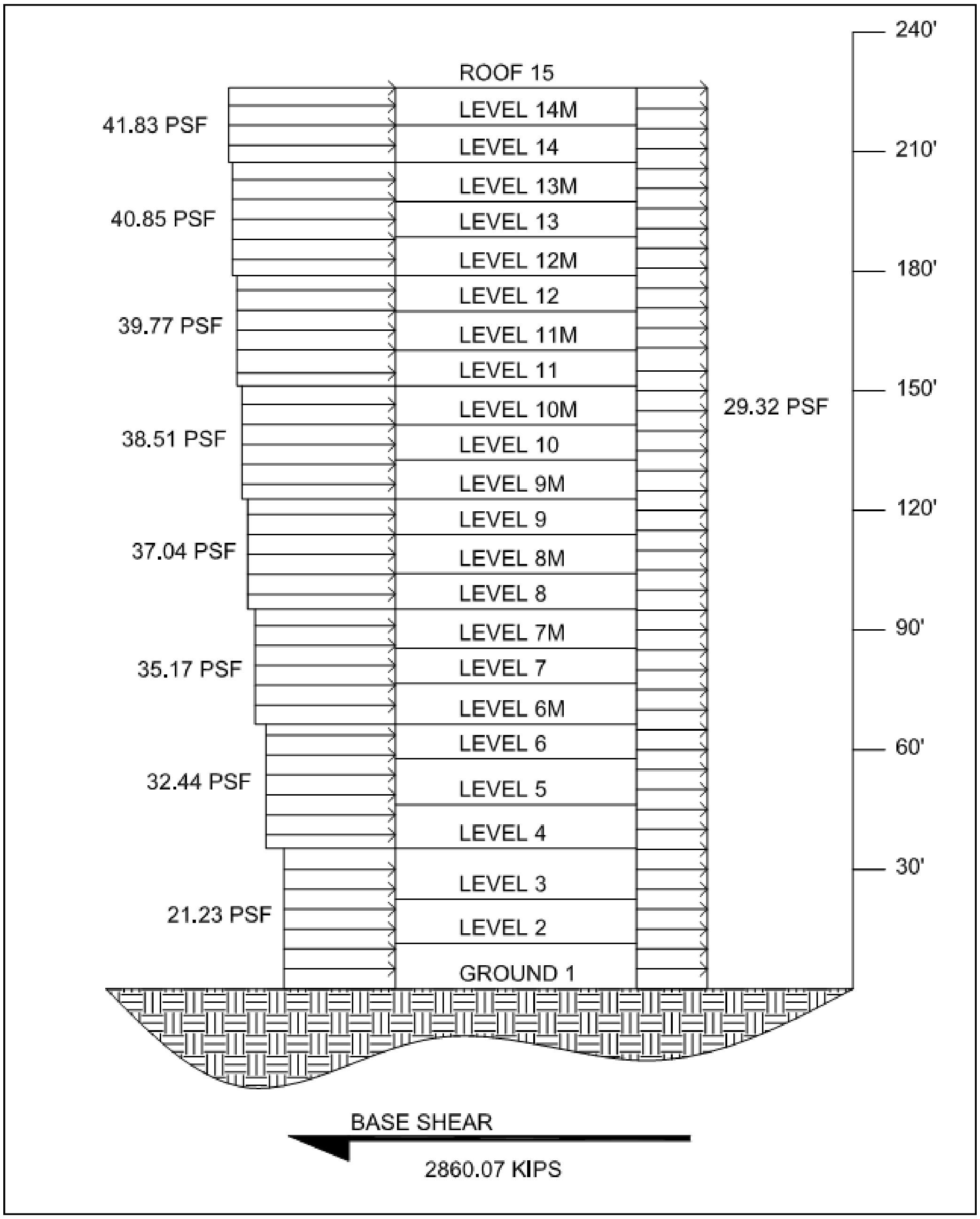
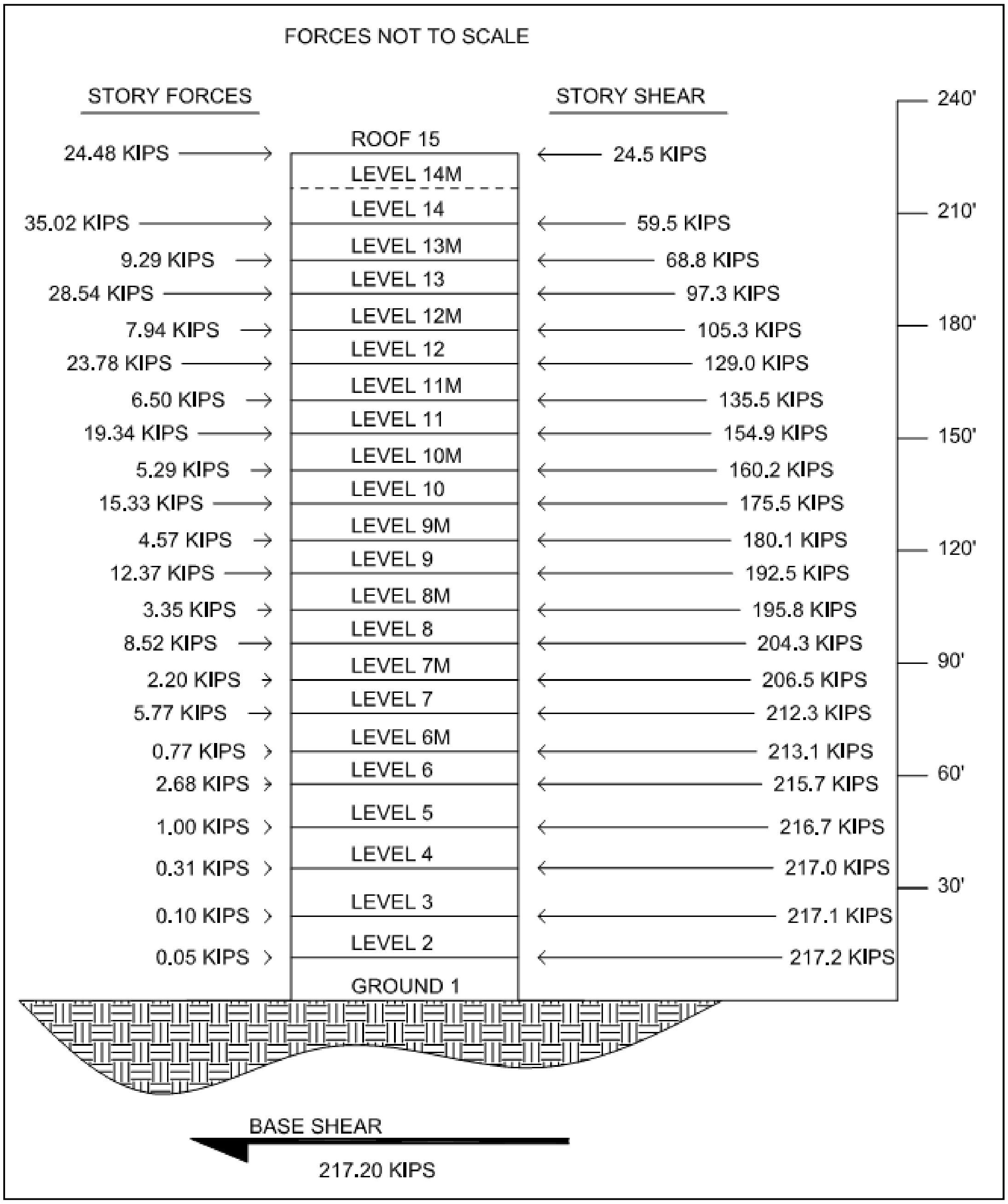


Figure 12: Seismic Load Diagram



The following load combinations were used for the wind and seismic analysis on the building's lateral system elements.

- **1.2(Dead) + 1.6(Roof Live) + 0.8(Wind)**
- **1.2(Dead) + 1.6(Wind) + 1.0(Live) + 0.5(Roof Live)**
- **1.2(Dead) + 1.0(Seismic) + 1.0(Live)**
- **0.9(Dead) + 1.6(Wind)**
- **0.9(Dead) + 1.0(Seismic)**

Only the load combinations pertaining to lateral design are listed above. These load combinations will be utilized for overturning and strength checks, as well as impact on foundation concerns.

Seismic/Wind Directional Load Cases:

The seismic/wind loads determined in Technical Report 1 must be analyzed on the building with three unique lateral load cases of different directions. They are as follows:

Seismic/Wind Load Case 1:

Seismic/Wind load case one considers lateral force acting on the building in the North-South direction. The force will be acting on the shorter dimension of the building as seen below. These cases consider both direct and torsion forces acting on the lateral system.

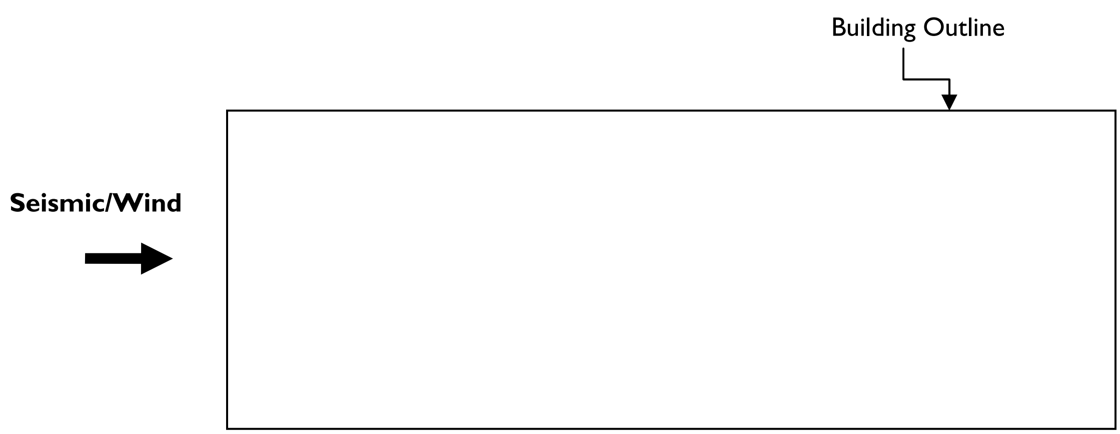


Figure 13: Seismic/Wind Load Case 1 Diagram

Seismic/Wind Load Case 2:

Seismic/Wind load case two considers lateral force acting on the building in the East-West direction. The lateral force will be acting on the larger dimension of the building as seen below. These load cases consider both direct and torsion forces acting on the lateral system.

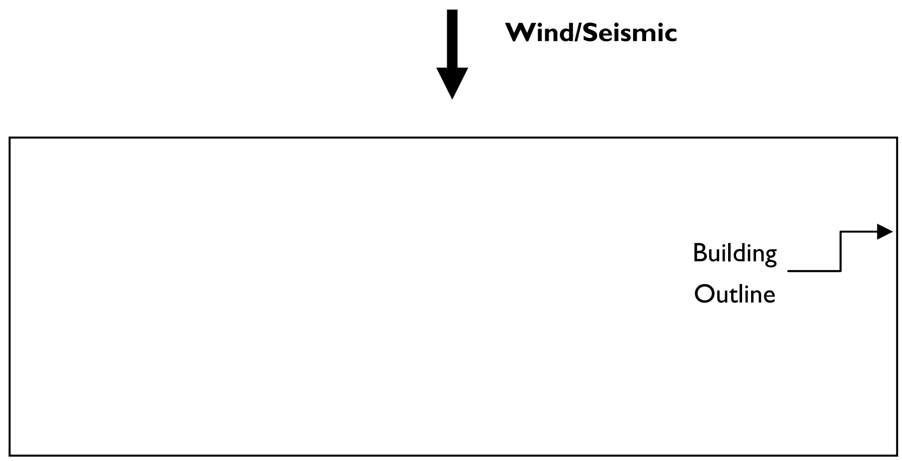


Figure 14: Seismic/Wind Load Case 2 Diagram

Wind Load Case 3:

Wind load case three considers wind acting on the building at an angle. This angle (θ) is determined by the building geometry and wind forces in each direction. This wind load case considers both direct and torsion forces acting on the lateral system.

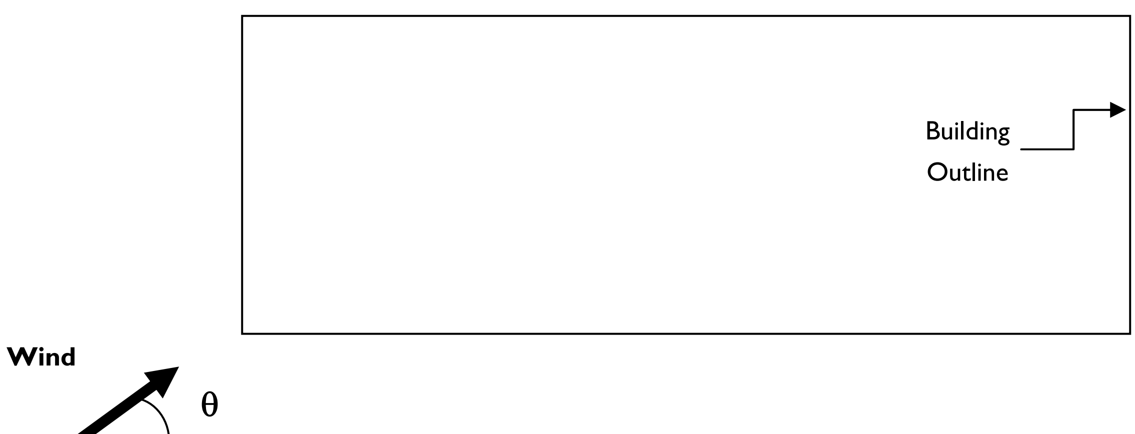


Figure 15: Wind Load Case 3 Diagram

III. Distribution of Lateral Loads

A. Relative Stiffness:

The relative stiffness was calculated for each lateral resisting frame in each direction. The relative stiffness was calculated by modeling each 2D frame in SAP. A 100 kip load was placed at the top level of each frame, and the corresponding top level displacement was recorded. The stiffness, k, was then calculated by taking the 100 kip load and dividing it by its corresponding displacement. Please note, that these stiffness values are relative. These stiffness values are not exact; however, they do relate each frame to one another and can be used for the distribution of lateral forces, which will take place later on during this technical report.

Below is a description of the figures and tables to follow regarding relative stiffness calculations and results.

- *Figure 16* of Grids A, C, & D is part of the North-South lateral resisting system. Notice the 100 kip load applied on each grid and the displacements shown.
- *Table 3* gives the relative stiffness calculations made and their corresponding percents for the North-South resisting lateral system.
- *Figure 17* of Grids 1, 2-4, & 10 are part of the East-West lateral resisting system. Notice the 100 kip load applied on each frame and the displacements shown.
- *Table 4* gives the relative stiffness calculations made and their corresponding percents for the East-West resisting lateral system.

North-South Lateral Resisting System:

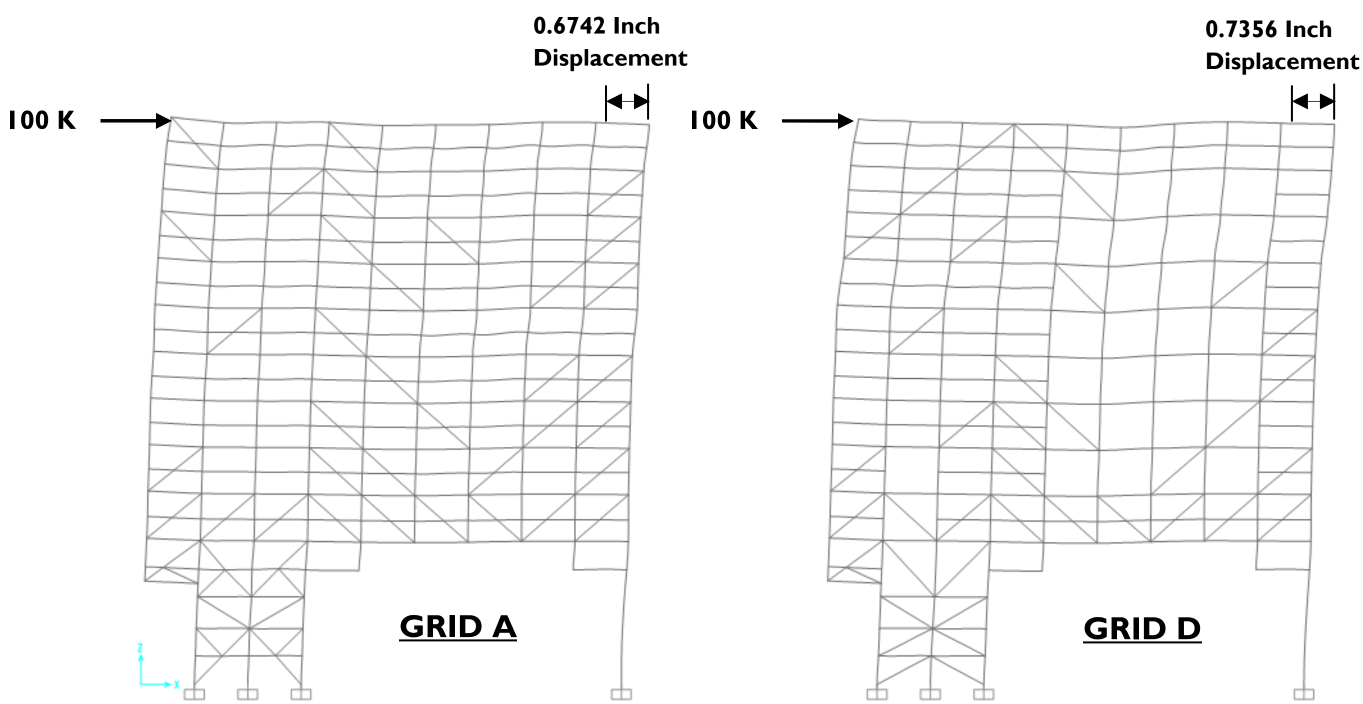


Figure 16: SAP Frames North-South

North-South Lateral Resisting System Continued:

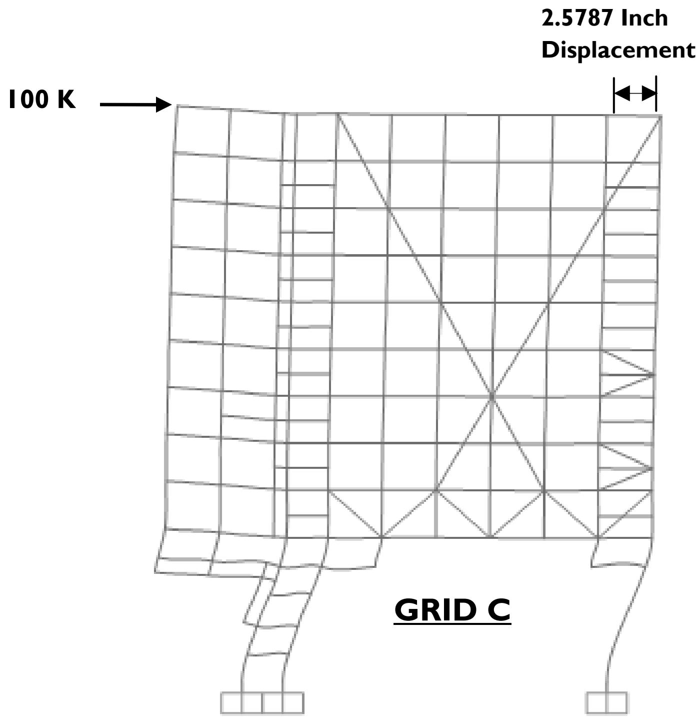


Figure 16 Continued: SAP Frames North-South

Relative Stiffness				
Grid	P (Kips)	Δ_p (IN)	k (K/IN)	Percent of Total Stiffness
A	100	0.6742	148.32	45.91%
C	100	2.5787	38.78	12.00%
D	100	0.7356	135.94	42.08%
Totals			323.05	100.00%

Table 3: Relative Stiffness North-South Calculations

East-West Lateral Resisting System:

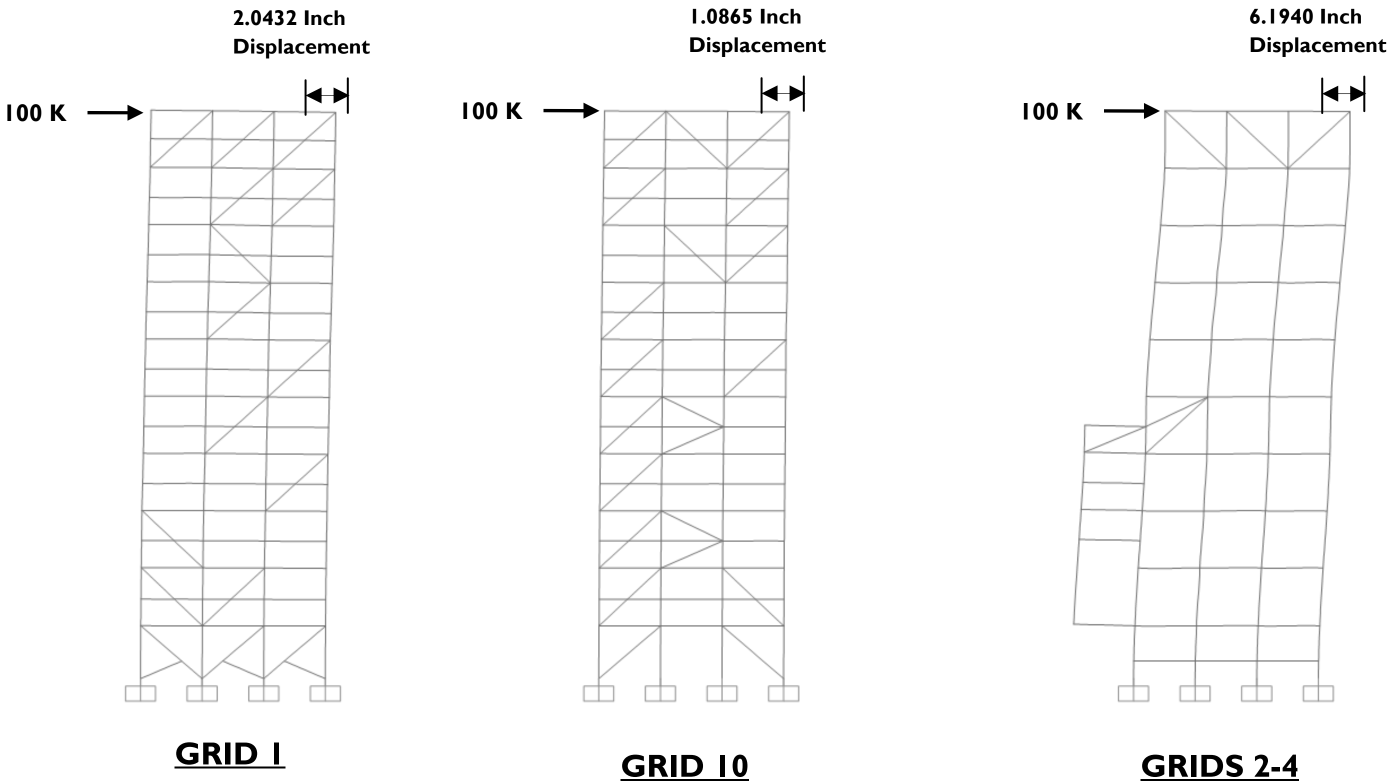


Figure 17: SAP Frames East-West

Relative Stiffness				
Grid	P (Kips)	Δ_p (IN)	k (K/IN)	Percent of Total Stiffness
1	100	2.0432	48.94	25.84%
2--4	100	6.1940	16.14	8.52%
10	100	1.0865	92.04	48.59%
Totals			189.42	100.00%

Table 4: Relative Stiffness East-West Calculations

B. Center of Rigidity:

The center of rigidity was calculated in each direction by taking the relative stiffness values and weighing them appropriately, depending on their distances from one another. *Figure 18* is an image of the center of rigidity for the lateral system. The purple shades are the lateral resisting frames in the North-South Direction, while the green shades are the lateral resisting frames in the East-West Direction. The center of rigidity can be seen as the black dot close to the center of the building footprint.

Note: For calculations on the center of rigidity, see the appendix section at the end of this technical report.

Figure 18: Center of Rigidity

C. Center of Mass:

The center of mass (COM) was calculated based on two assumptions. They are as follows:

- The COM will be located on the midpoint in the short direction of the buildings footprint. Research has been done on the building, giving the author confidence that the floor masses in this short direction are relatively similar.
- The floor masses in the long direction are relatively similar.

The 126 foot span of the structure is supported more by the North end of the structure. This North end contains more area on levels 1-5 and therefore more mass on these levels than the South end. This will cause the COM to shirt towards the North end of the building in the long direction. A calculation was performed to find the exact location of the COM. See the figure on the following page.

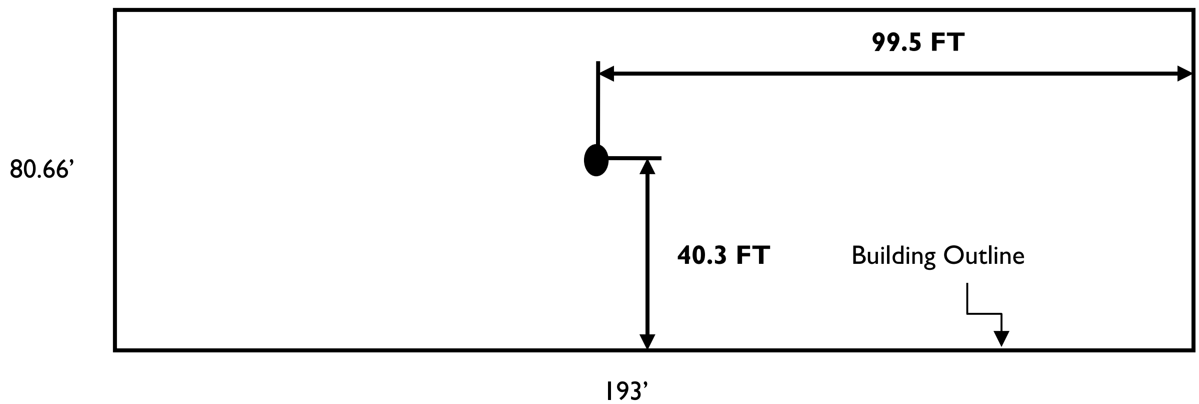


Figure 19: Center of Mass

For supporting calculations on the center of mass, see the appendix section at the end of this report.

D. Direct Forces:

From the stiffness values determined for each of the grids, wind lateral load distribution was able to be calculated. The following figures show the amount of direct wind load resistance each frame provides. Note that these values are currently not factored.

<u>Wind Case 1:</u>

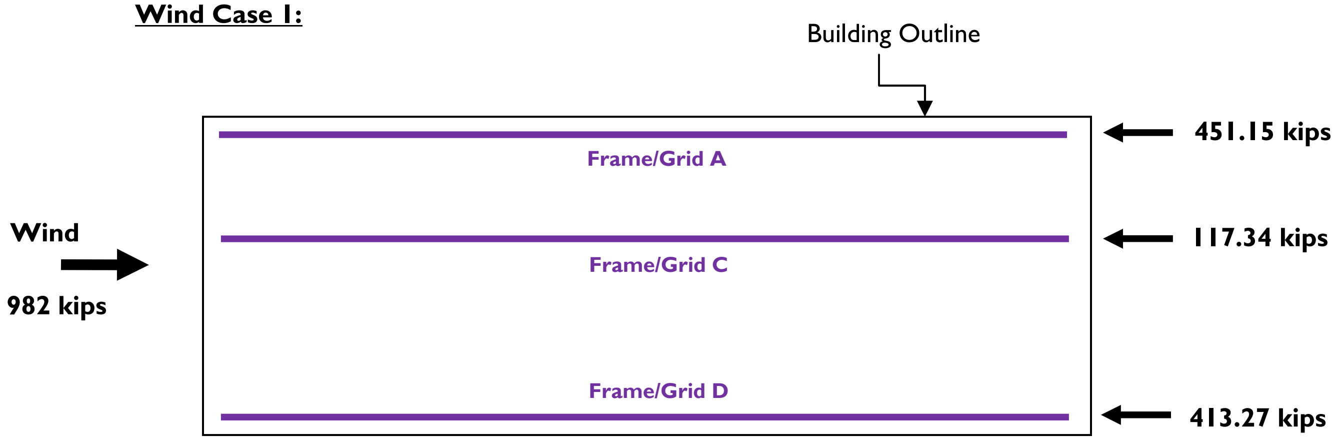


Figure 20: North-South Wind Resisting System & Forces
(Wind Case 1)

Wind Case 2:

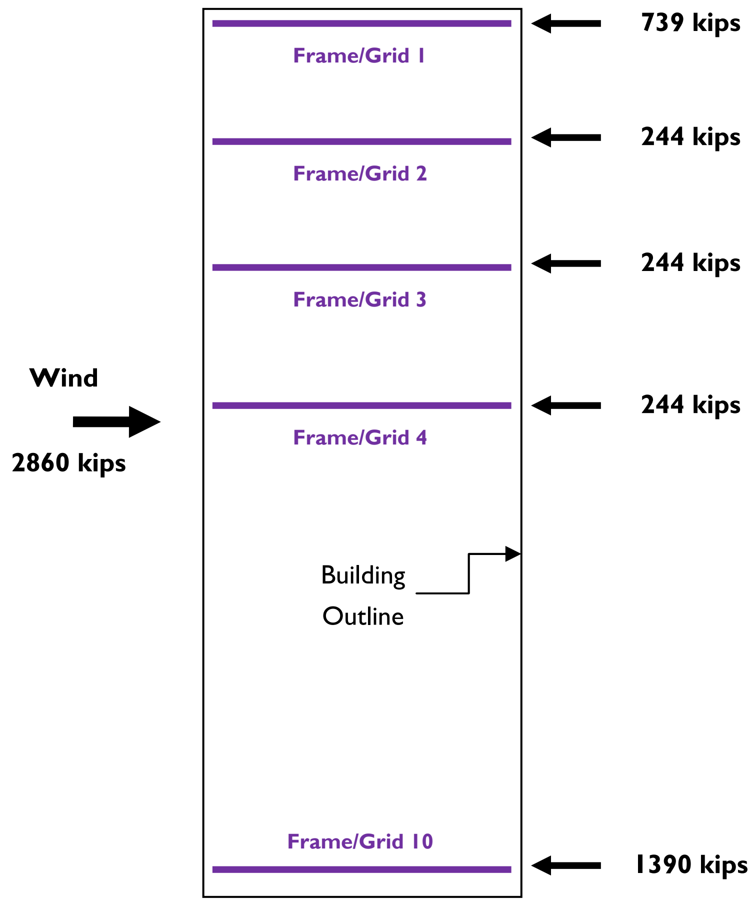


Figure 21: East-West Wind Resisting System & Forces
(Wind Case 2)

Wind Case 3:

Wind Case 3 has wind acting on the building at a certain angle. This angle was determined by taking the wind forces and in each direction and combining them with trigonometry to find the angle that provides the greatest force on the building. Once this angle and force was found it was broken down into components, so a North-South and East-West analysis could be performed. For further calculations on Wind Case 3, see the appendix section at the end of this report.

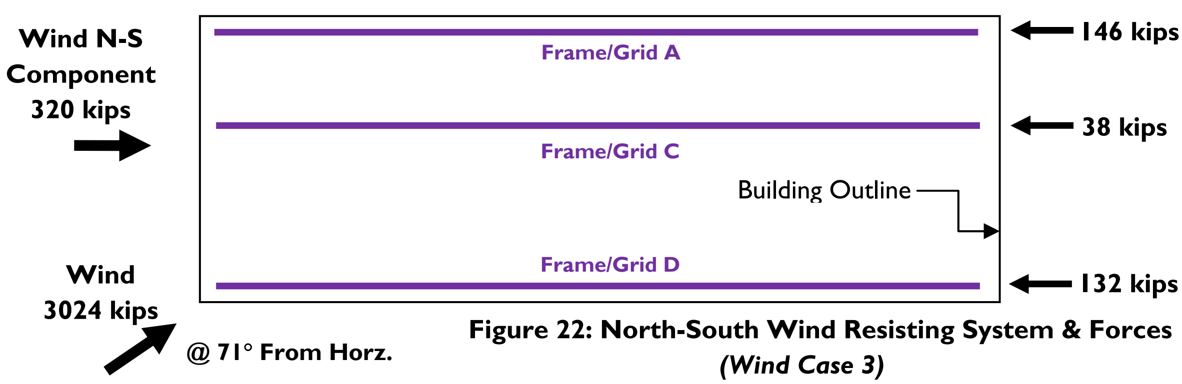
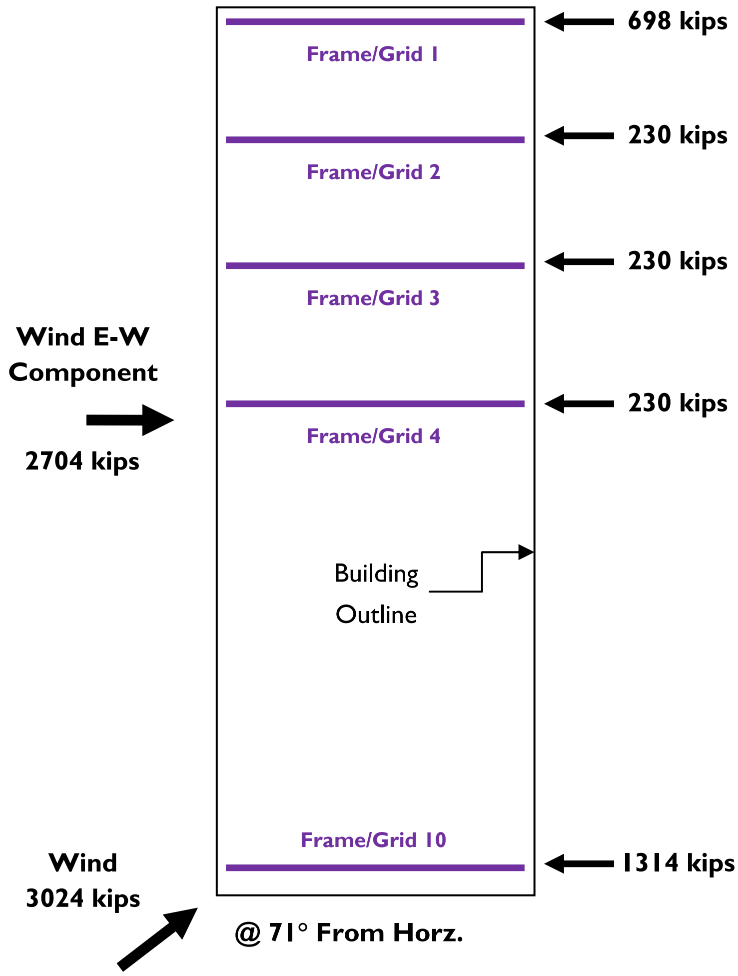


Figure 22: North-South Wind Resisting System & Forces
(Wind Case 3)

Figure 23: East-West Wind Resisting System & Forces
(Wind Case 3)



From the stiffness values determined for each of the grids, seismic lateral load distribution was able to be calculated. The following figures represent the amount of seismic load resistance each frame provides. Note that these values are currently not factored.

Seismic Case 1:

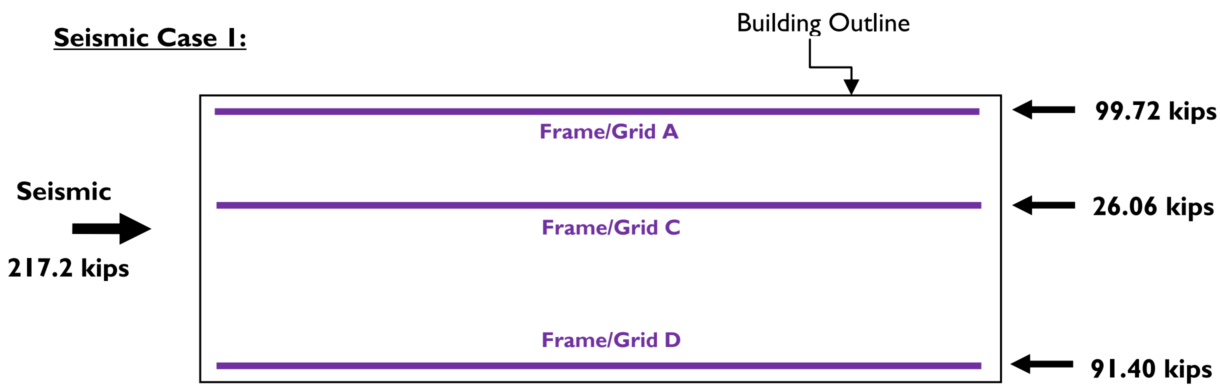


Figure 24: North-South Wind Resisting System & Forces
(Seismic Case 1)

Seismic Case 2:

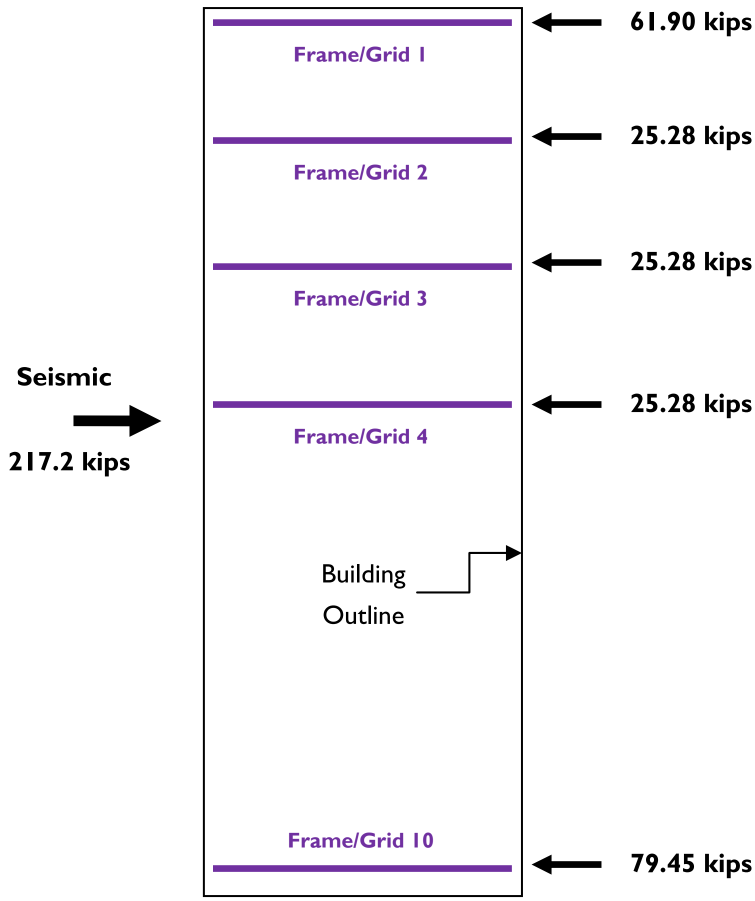


Figure 25: East-West Seismic Resisting System & Forces
(Seismic Case 2)

E. Torsion Forces:

From the center of mass and center of rigidity calculations, the torsion forces acting on the lateral resisting system could be determined. Below is a listing of each case along with its tabulated calculations and force diagram. For a detailed description of each load case, see the *Loads and Load Combinations* section on page 13.

Eccentric Wind Load Cases:

Wind Case 1:

There is no eccentricity in this direction. Therefore, no torsion forces present for Eccentric Load Cases 1 & 2.

Wind Case 2 (Eccentric Case 1):

Table 5: Torsion Force Calculation Spreadsheet – Wind Case 2 (Eccentric Case 1)

Wind Case 2/Eccentric Case 1					
Grid	k (K/IN)	k (K/FT)	d_i (FT)	$k*d_i^2$ (K-FT)	$F_{itorsion} = k_i d_i \theta_t$ (K)
A	148.32	1779.84	30.3	1634053.31	86.37
C	38.78	465.36	10.3	49370.04	7.68
D	135.94	1631.28	30.3	1497661.86	79.16
1	48.94	587.28	104.3	6388719.61	98.10
2	16.14	193.68	83.2	1340699.44	25.81
3	16.14	193.68	62.1	746909.49	19.26
4	16.14	193.68	41	325576.08	12.72
10	92.04	1104.48	88	8553093.12	155.66

$\Sigma k*d_i^2$ (K-FT)	20536082.94
M_r (K-FT)	32890.00
θ_t	0.00160

Figure 26: North-South Resisting System Torsion Forces
(Wind Case 2/Eccentric Case 1)

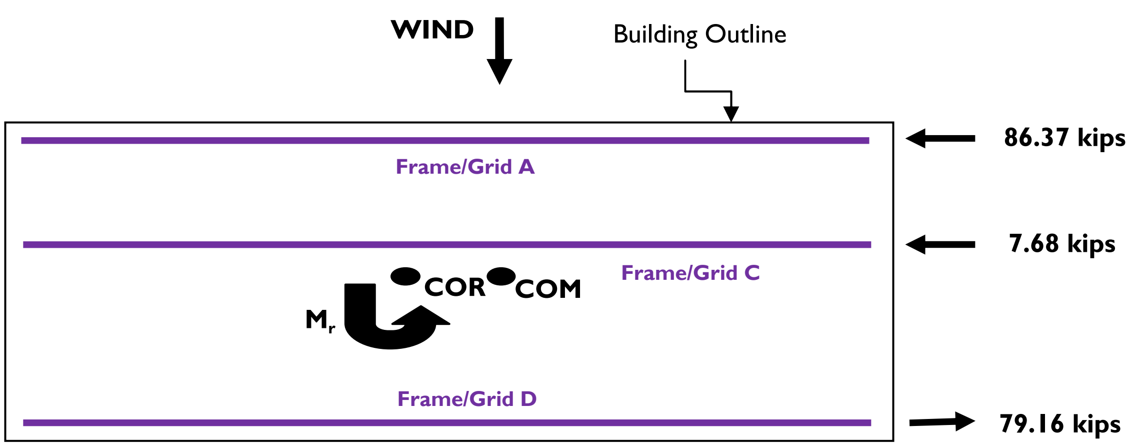
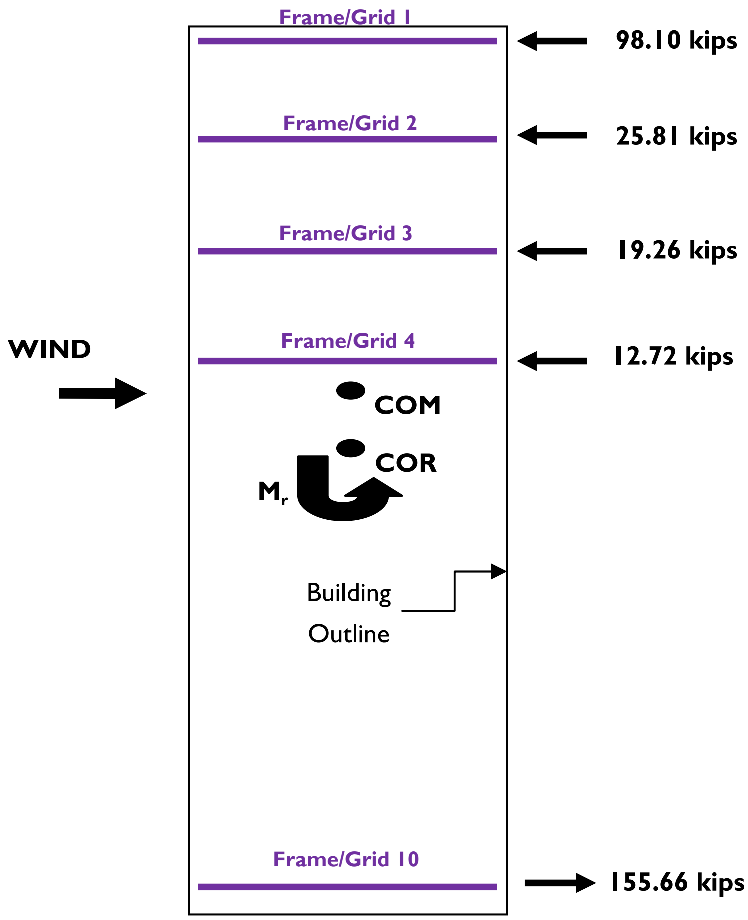


Figure 27: East-West Resisting System Torsion Forces
(Wind Case 2/Eccentric Case 1)



Wind Case 2 (Eccentric Load Case 2):

Table 6: Torsion Force Calculation Spreadsheet – Wind Case 2 (Eccentric Case 2)

Wind Case 2/Eccentric Case 2					
Grid	k (K/IN)	k (K/FT)	d_i (FT)	$k*d_i^2$ (K-FT)	$F_{itorsion} = k_i d_i \theta_t$ (K)
A	148.32	1779.84	30.3	1634053.31	227.29
C	38.78	465.36	10.3	49370.04	20.20
D	135.94	1631.28	30.3	1497661.86	208.32
1	48.94	587.28	104.3	6388719.61	258.16
2	16.14	193.68	83.2	1340699.44	67.91
3	16.14	193.68	62.1	746909.49	50.69
4	16.14	193.68	41	325576.08	33.47
10	92.04	1104.48	88	8553093.12	409.63
		$\Sigma k*d_i^2$ (K-FT)		20536082.94	
		M_r (K-FT)		86550.75	
		θ_t		0.00421	

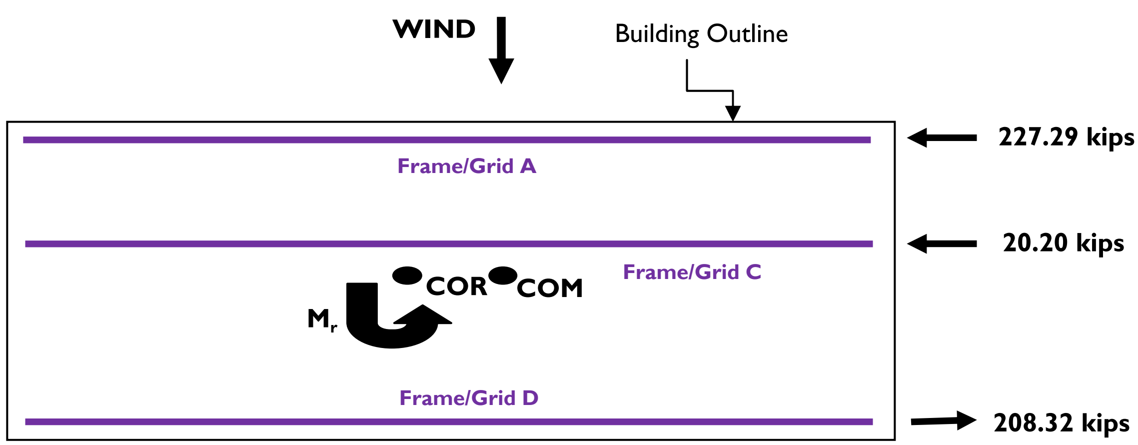


Figure 28: North-South Resisting System Torsion Forces
(Wind Case 2/Eccentric Case 2)

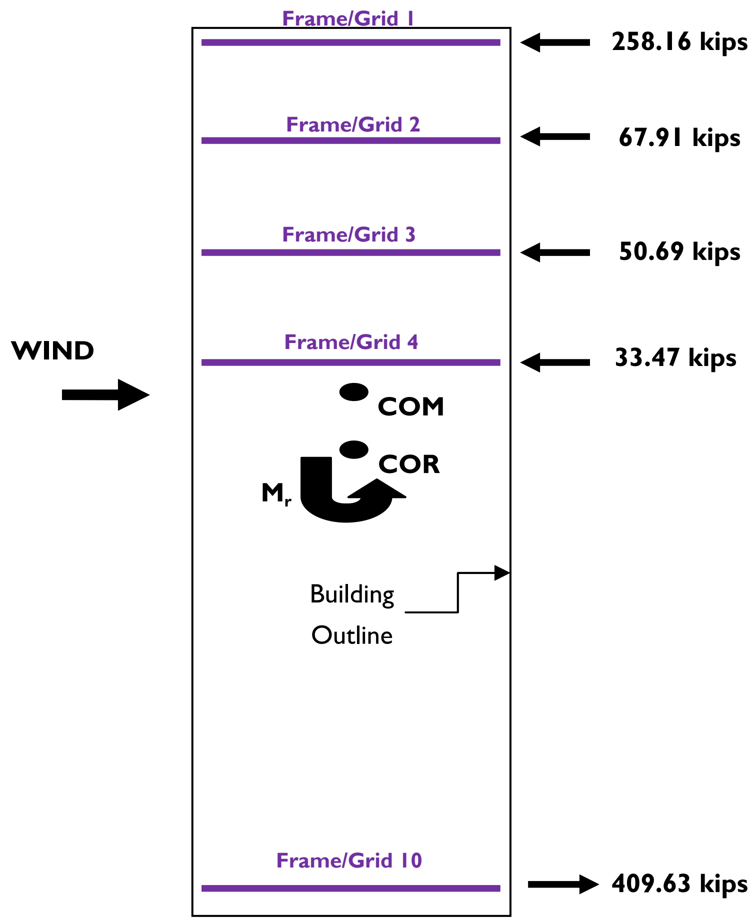


Figure 29: East-West Resisting System Torsion Forces
(Wind Case 2/Eccentric Case 2)

Wind Case 3 (Eccentric Load Case 1):

Table 7: Torsion Force Calculation Spreadsheet – Wind Case 3 (Eccentric Case 1)

Wind Case 3/Eccentric Case 1					
Grid	k (K/IN)	k (K/FT)	d_i (FT)	$k*d_i^2$ (K-FT)	$F_{itorsion} = k_i d_i \theta_t$ (K)
A	148.32	1779.84	30.3	1634053.31	81.66
C	38.78	465.36	10.3	49370.04	7.26
D	135.94	1631.28	30.3	1497661.86	74.84
1	48.94	587.28	104.3	6388719.61	92.75
2	16.14	193.68	83.2	1340699.44	24.40
3	16.14	193.68	62.1	746909.49	18.21
4	16.14	193.68	41	325576.08	12.02
10	92.04	1104.48	88	8553093.12	147.17

$\Sigma k*d_i^2$ (K-FT)	20536082.94
M_r (K-FT)	31096.00
θ_t	0.00151

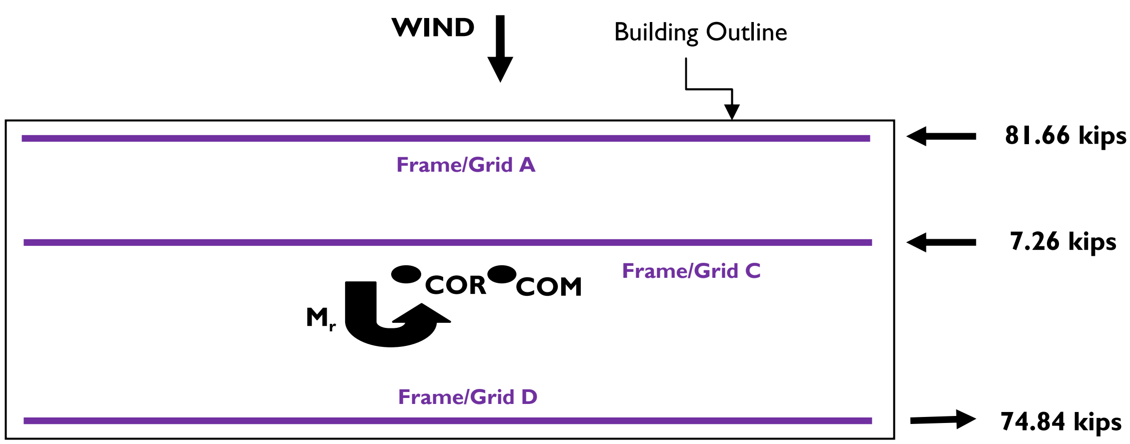
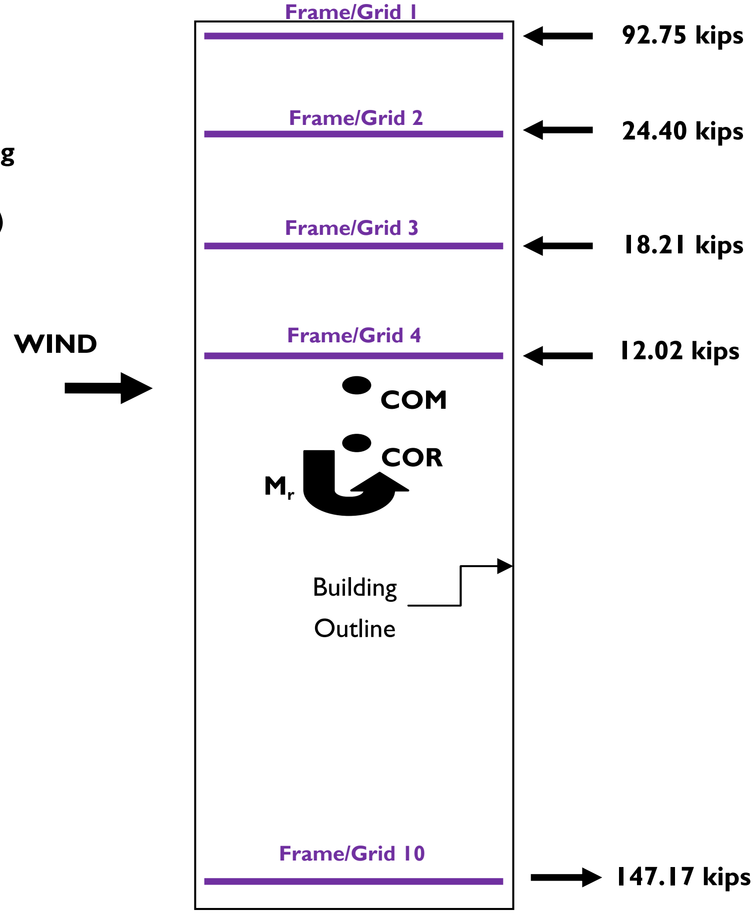


Figure 30: North-South Resisting System Torsion Forces
(Wind Case 3/Eccentric Case 1)

Figure 31: West-East Resisting System Torsion Forces
(Wind Case 3/Eccentric Case 1)



Wind Case 3 (Eccentric Load Case 2):

Table 8: Torsion Force Calculation Spreadsheet – Wind Case 3 (Eccentric Case 2)

Wind Case 3/Eccentric Case 2					
Grid	k (K/IN)	k (K/FT)	d_i (FT)	$k*d_i^2$ (K-FT)	$F_{itorsion} = k_i d_i \theta_t$ (K)
A	148.32	1779.84	30.3	1634053.31	214.89
C	38.78	465.36	10.3	49370.04	19.10
D	135.94	1631.28	30.3	1497661.86	196.95
1	48.94	587.28	104.3	6388719.61	244.08
2	16.14	193.68	83.2	1340699.44	64.21
3	16.14	193.68	62.1	746909.49	47.93
4	16.14	193.68	41	325576.08	31.64
10	92.04	1104.48	88	8553093.12	387.29

$\Sigma k*d_i^2$ (K-FT)	20536082.94
M_r (K-FT)	81830.00
θ_t	0.00398

Figure 32: North-South Resisting System Torsion Forces
(Wind Case 3/Eccentric Case 2)

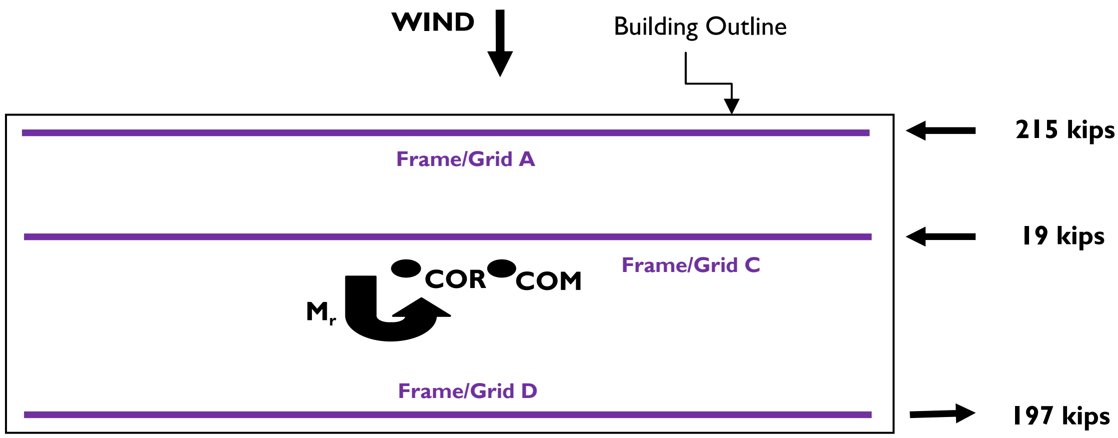
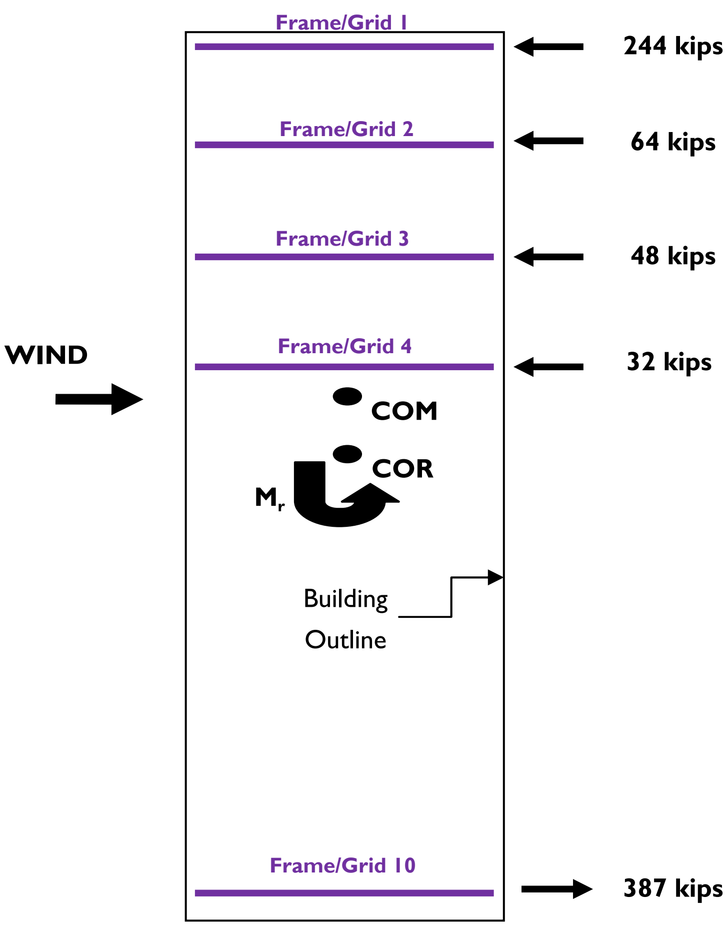


Figure 33: East-West Resisting System Torsion Forces
(Wind Case 3/Eccentric Case 2)



Eccentric Seismic Load Cases:

Seismic Case 1:

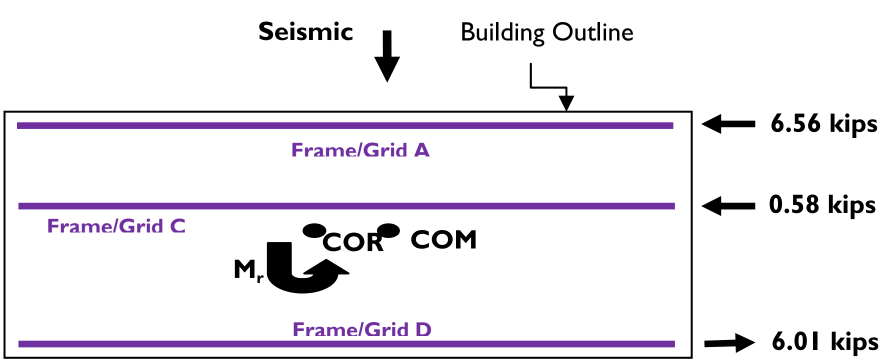
There is no eccentricity in this direction. Therefore, no torsion forces present for Seismic Case 1.

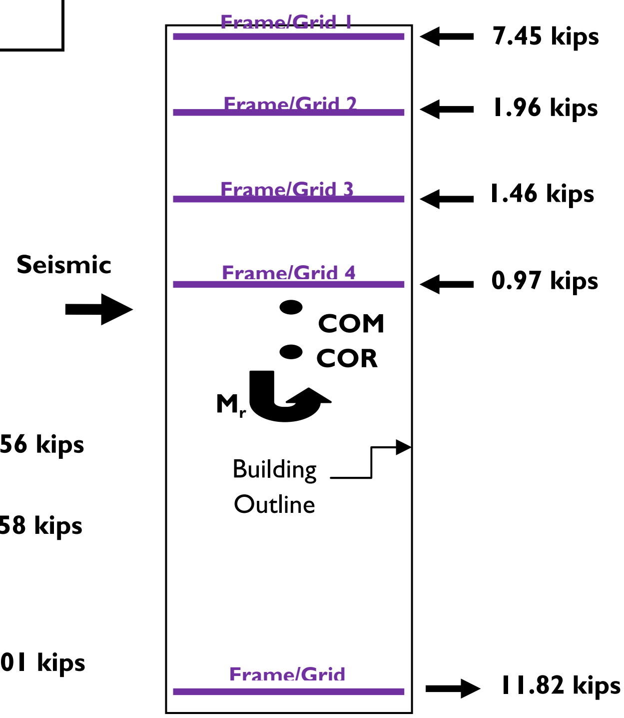
Seismic Case 2:

Table 9: Torsion Force Calculation Spreadsheet – Seismic Case 2

Seismic Case 2					
Grid	k (K/IN)	k (K/FT)	d_i (FT)	$k*d_i^2$ (K-FT)	$F_{itorsion} = k_i d_i \theta_t$ (K)
A	148.32	1779.84	30.3	1634053.31	6.56
C	38.78	465.36	10.3	49370.04	0.58
D	135.94	1631.28	30.3	1497661.86	6.01
1	48.94	587.28	104.3	6388719.61	7.45
2	16.14	193.68	83.2	1340699.44	1.96
3	16.14	193.68	62.1	746909.49	1.46
4	16.14	193.68	41	325576.08	0.97
10	92.04	1104.48	88	8553093.12	11.82
		$\Sigma k*d_i^2$ (K-FT)		20536082.94	
		M_r (K-FT)		2497.80	
		θ_t		0.00012	

Figure 34: Resisting System Torsion Forces
(Seismic Case 2)





F. Net Forces:

The direct and torsion forces for all the wind and seismic load cases were combined. Each load case is listed with its corresponding diagrams of the net forces in each direction.

Wind Case 1:

Since there is no eccentricity between the center of mass and rigidity for this wind case, the direct forces are also the net forces.

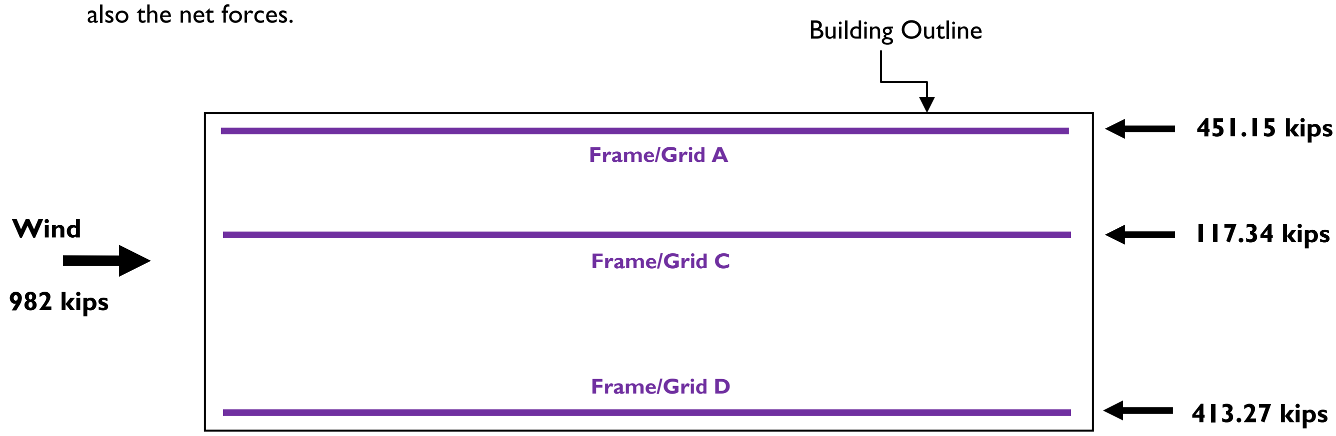


Figure 35: Wind Case 1 Net Forces

Wind Case 2 (Eccentric Case 1):

The direct and torsion values were summed for this load case and the results can be seen below.

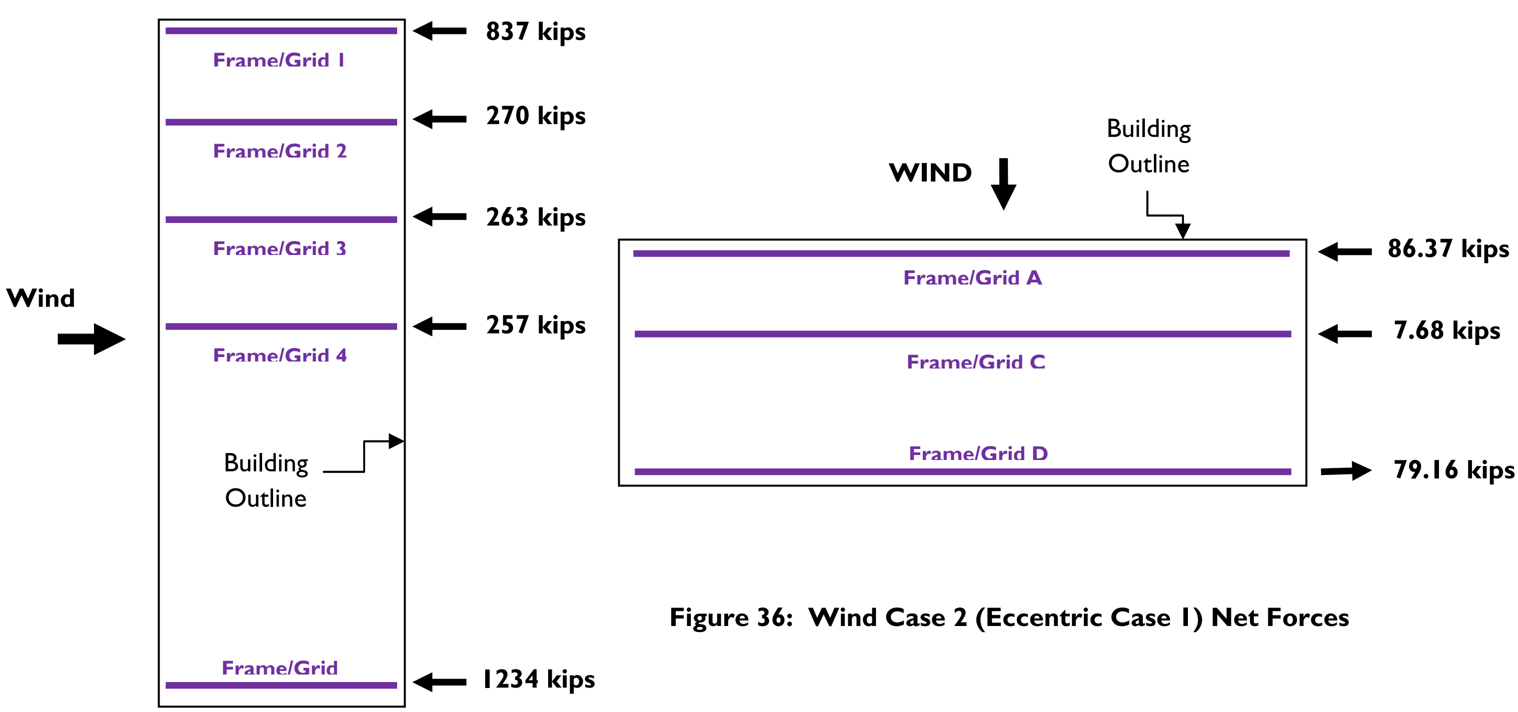
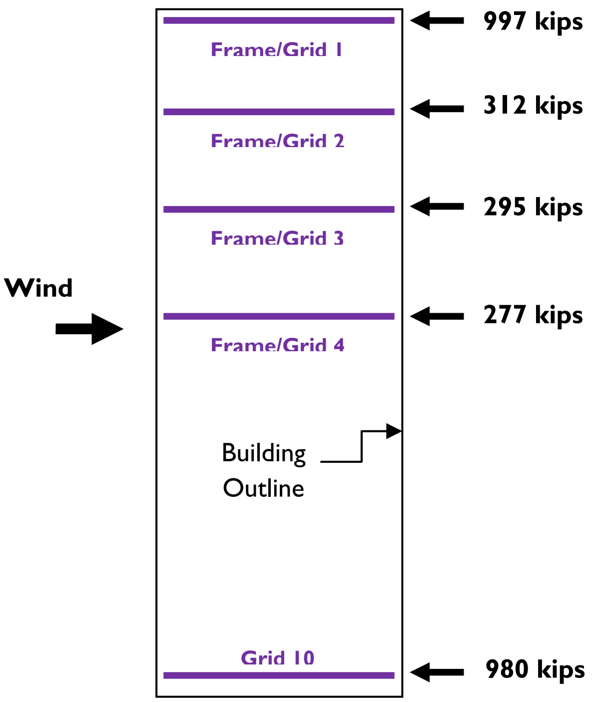


Figure 36: Wind Case 2 (Eccentric Case 1) Net Forces

Wind Case 2 (Eccentric Case 2):

The direct and torsion values were summed for this load case and the results can be seen below.



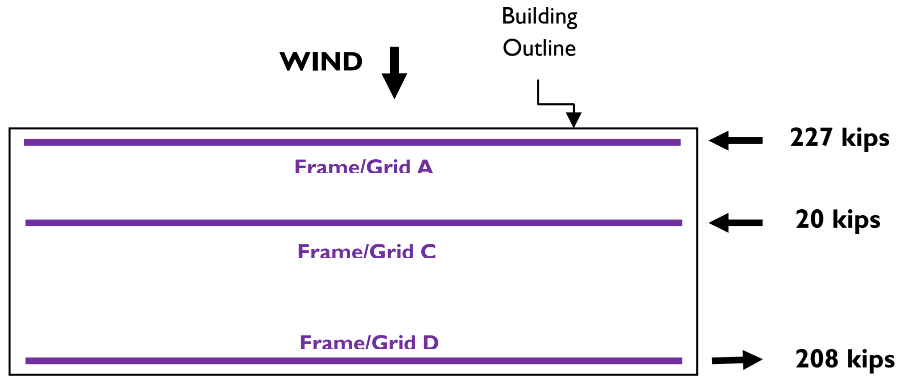
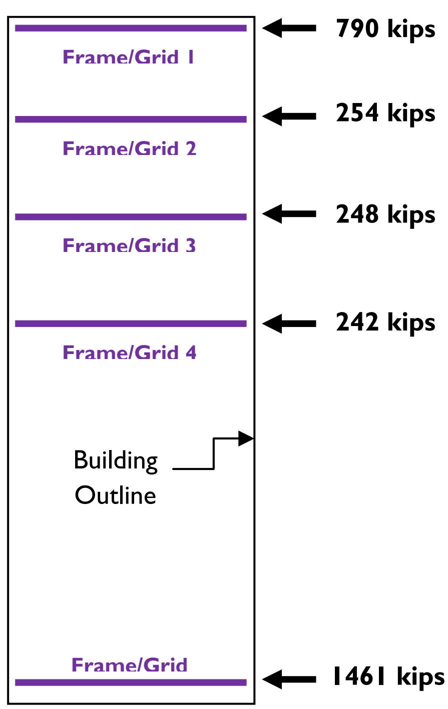


Figure 37: Wind Case 2 (Eccentric Case 2) Net Forces

Wind Case 3 (Eccentric Case 1):

The direct and torsion values were summed for this load case and the results can be seen below.



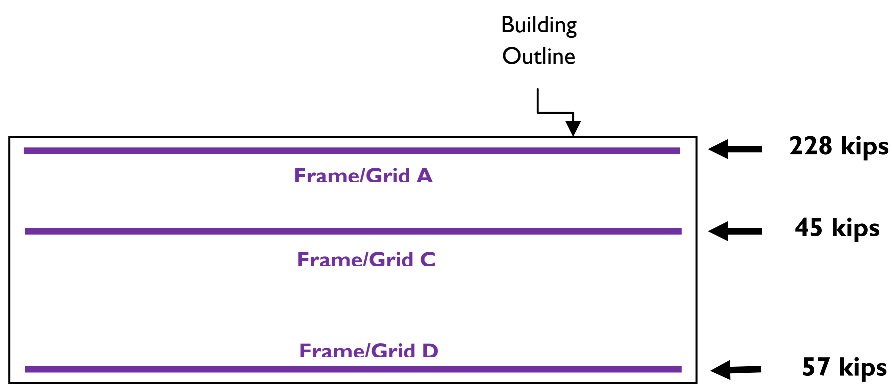


Figure 38: Wind Case 3 (Eccentric Case 1) Net Forces

Wind Case 3 (Eccentric Case 2):

The direct and torsion values were summed for this load case and the results can be seen below.

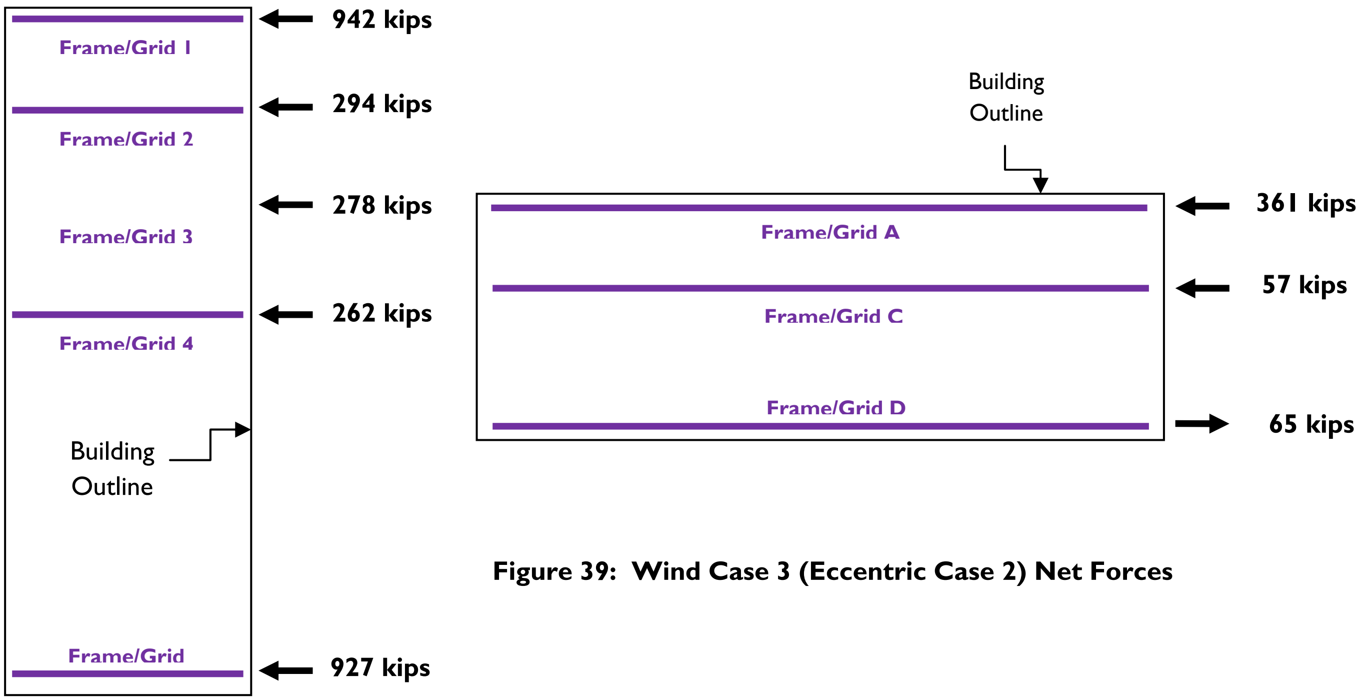


Figure 39: Wind Case 3 (Eccentric Case 2) Net Forces

Seismic Case 1:

Since there is no eccentricity between the center of mass and rigidity for this seismic case, the direct forces are also the net forces.

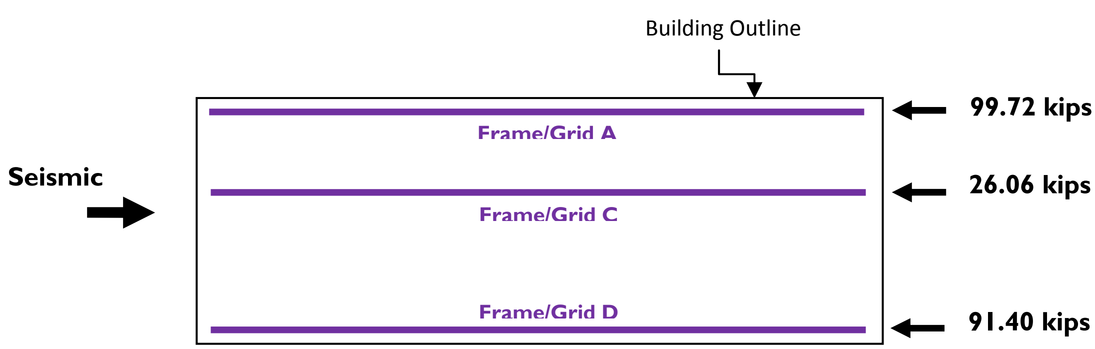
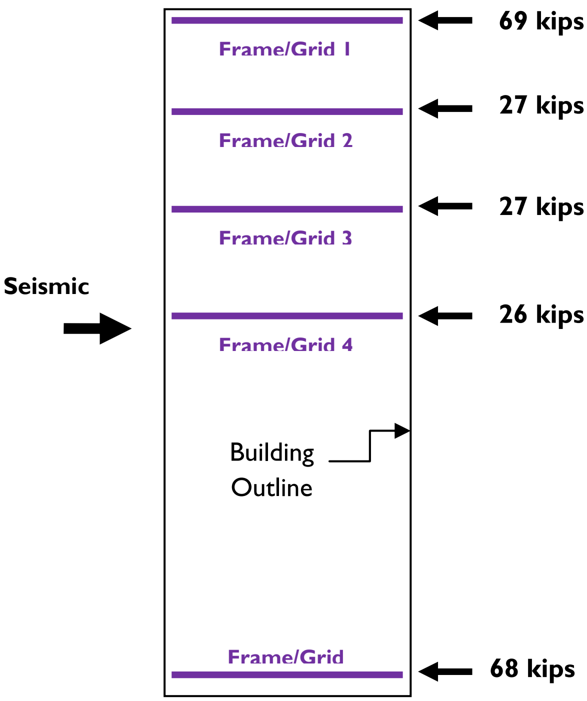


Figure 40: Seismic Case 1 Net Forces

Seismic Case 2:

The direct and torsion values were summed for this load case and the results can be seen below.



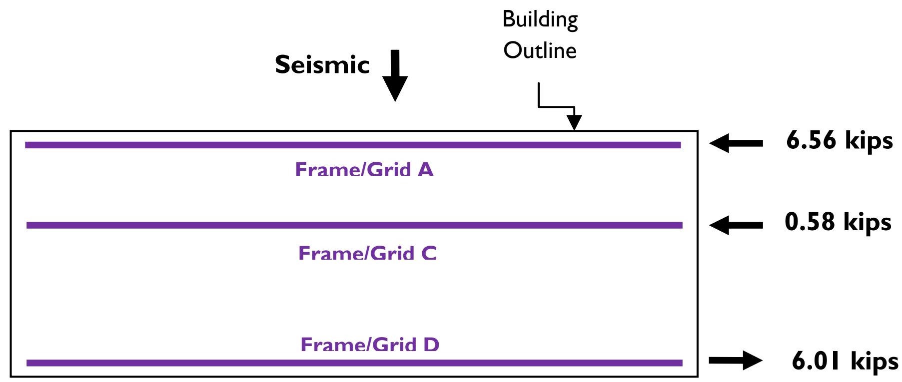


Figure 41: Seismic Case 2 Net Forces

IV. Lateral System Load Path Confirmations:

As shown through the lateral direct and torsion analysis, the forces were distributed solely by their relative stiffness values. This assumption was made because of the building's rigid diaphragm (composite steel floor system). The forces are to enter the structure through the beam and wind girt elements. From there, the forces enter the stiff floor system, which distribute the lateral forces according to each grids relative stiffness values.

Even though this analysis isn't 100% scientific, it is adequate enough to find the net forces acting upon each grid. The relative stiffness load distribution provides an effective and efficient way to laterally analyze the structure. This analysis can be confirmed by checking the building's drift, story drift, and strength. Checks can be found on pages 40-44. These checks all confirm the building's successful resistance to lateral loads, and therefore provide confidence in the lateral system's load path and Technical Report 3 analysis.

Note: Some of the provided structural drawings were missing lateral bracing information near the bottom levels of a few braced frames. Without this bracing, lateral loads were not able to reach the foundations of the structure and it was causing excessive deflections. This issue was solved by providing assumed bracing within the structure. (The thesis advisor of this technical report was aware of this decision.)

V. Lateral System Checks:

1. Strength:

A strength check of the bracing members towards the bottom of Grid D was performed. See *Figure 42* below. These members are critical for the North-South lateral resisting system. Due to the 126 foot clear span of the structure, the majority of the lateral force needs to make its way towards the left side of Grid D shown below. It is visually apparent that the lower left side of Grid D contributes greatly in the lateral system due to its excessive bracing. All of the diagonal bracing in question (at the bottom-left of the grid) are W14x90 shapes.

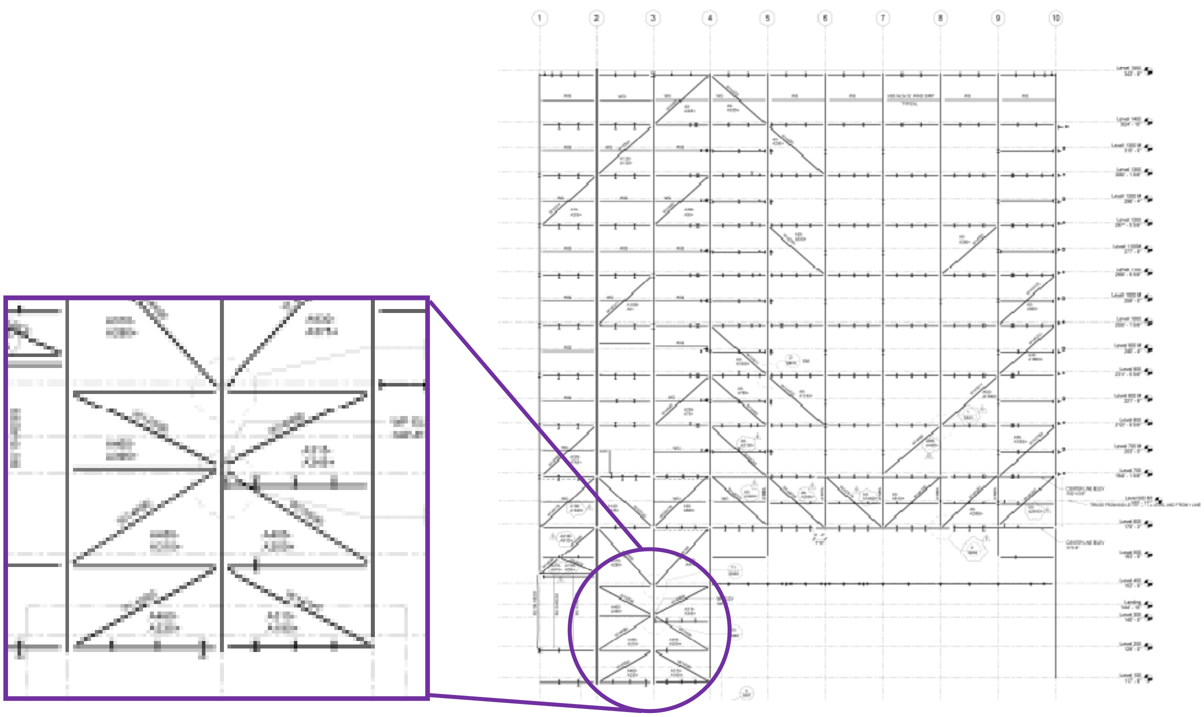


Figure 42: Grid D – Strength Check

A conservative approach was taken to check the axial strength of these W14x90 bracing members. Below is a list of conservative assumptions taken during the axial strength calculation.

- The lateral controlling load on Grid D (Wind Case 1) was factored appropriately and the entire load was placed on the bottom left braced frame (circled in purple).
- Each W14x90 diagonal brace is assumed to take the full lateral load (661 kips).
- Due to concentric connections the W14x90 members were analyzed as axial members.

These conservative assumptions led to an axial strength check that was acceptable for design. Please see the appendix section at the end of this report for further calculations.

2. Drift & Story Drift:

A. Drift:

Allowable overall building drift was chosen to be H/400. The building is 226 feet tall, therefore H/400 = 6.78 inches. This means that the building is allowed to move laterally at the roof level a total of 6.78 inches but no more. The majority of the calculations were done by SAP frame analysis, however additional hand calculations were performed. Below are the results for wind and seismic lateral forces at the roof level. For further calculations and spreadsheets, see the appendix section at the end of this report.

Table 10: Maximum Drift Values – Wind & Seismic

Wind		Seismic		Max Drift is 6.78 inches
N-S	E-W	N-S	E-W	
2.36	6.3	0.1	0.1	
Okay	Okay	Okay	Okay	

All drifts seen above are satisfactory.

B. Story Drift:

Allowable overall building drift was chosen to be $0.020h_{sx}$, where h_{sw} is each levels height. This means that the each story level is allowed to move laterally a distance of be $0.020h_{sx}$ inches. The majority of the calculations were done by SAP frame analysis, however additional hand calculations were performed. The spreadsheets which are very detailed can be found in the appendix section. Please note that the majority of the story drift calculations were found to meet the $0.020h_{sx}$ drift criteria, with a few exceptions. These exceptions are believed to be due to inadequate drawing information. Diagonal shear bracing is shown throughout most of the drawings; however bracing near the bottom of a few grids is not shown. For further discussion on this occurrence see page 39.

3. Overturning:

To check if overturning is an issue of concern, the overturning moment needed to be calculated for both the 1.6Wind and 1.0Seismic load cases. On the following pages are spreadsheet calculations for both overturning cases.

Table 11: Overturning Moment – 1.6 Wind

Overturning Moment due to 1.6Wind										Overturning Moment (K-FT)	
N-S	PSF*1.6	Height of Level (FT)	Width	Force (K)	E-W	PSF*1.6	Height of Level (FT)	Width	Force (K)	N-S	E-W
14	95.28	18.67	80.66	143.48	14	113.84	18.67	193	410.20	30795	88039
13M	93.70	9.83	80.66	74.29	13M	112.27	9.83	193	213.00	14886	42680
13	93.70	8.83	80.66	66.73	13	112.27	8.83	193	191.33	12749	36553
12M	93.70	7.83	80.66	59.18	12M	112.27	7.83	193	169.66	10812	31000
12	91.97	8.83	80.66	65.50	12	110.54	8.83	193	188.39	11423	32852
11M	91.97	9.83	80.66	72.92	11M	110.54	9.83	193	209.72	12036	34616
11	91.97	8.83	80.66	65.50	11	110.54	8.83	193	188.39	10200	29337
10M	89.95	9.83	80.66	71.32	10M	108.53	9.83	193	205.90	10441	30142
10	89.95	8.83	80.66	64.07	10	108.53	8.83	193	184.95	8781	25350
9M	89.95	9.83	80.66	71.32	9M	108.53	9.83	193	205.90	9110	26300
9	87.60	8.83	80.66	62.39	9	106.18	8.83	193	180.94	7387	21425
8M	87.60	9.83	80.66	69.46	8M	106.18	9.83	193	201.44	7576	21972
8	87.60	8.83	80.66	62.39	8	106.18	8.83	193	180.94	6223	18048
7M	84.61	9.83	80.66	67.08	7M	103.18	9.83	193	195.76	6065	17700
7	84.61	8.83	80.66	60.26	7	103.18	8.83	193	175.85	4886	14258
6M	84.61	10.25	80.66	69.95	6M	103.18	10.25	193	204.12	5005	14604
6	80.24	8.67	80.66	56.11	6	98.82	8.67	193	165.35	3484	10266
5	80.24	11.5	80.66	74.43	5	98.82	11.5	193	219.32	3870	11405
4	80.24	11	80.66	71.19	4	98.82	11	193	209.79	2901	8549
3	73.07	12.75	80.66	75.15	3	80.88	12.75	193	199.03	2170	5747
2	73.07	11	80.66	64.83	2	80.88	11	193	171.71	1102	2919
1	73.07	11.5	80.66	67.78	1	80.88	11.5	193	179.51	390	1032
									Totals	182294	524795

Overturning Moment/0.5Length		Weight of Building/2
N-S	E-W	
472.26	3253.13	10862

Overturning Issue	
N-S	E-W
No	No

To check if an overturning issue is present in the lateral design, an overturning moment was calculated for the 1.6Wind load case. This moment was then divided by 0.5Length. This length is the length of the building the overturning moment is acting upon. This value was compared to half the total building weight. Since half the total building weight is greater in both the N-S and E-W directions, there is no overturning issue for the 1.6Wind load case.

Table 12: Overturning Moment – 1.0 Seismic

Overturning Moment due to 1.0Quake				
N-S	**Force*1.0 (K)**	**Height hx (FT)**	**Overturning Moment (K-FT)**	**Overturning Moment/0.5Length**
14	35.02	214.63	7516	**195.93**
13M	9.29	200.38	1861	
13	28.54	191.05	5452	**Weight of Building/2**
12M	7.94	182.72	1451	
12	23.78	174.39	4147	**10862**
11M	6.50	165.06	1073	
11	19.34	155.73	3012	**Overturning Issue**
10M	5.29	146.40	774	
10	15.33	137.07	2101	**No**
9M	4.57	127.74	584	
9	12.37	118.41	1465	
8M	3.35	109.08	365	
8	8.52	99.75	850	
7M	2.20	90.42	199	
7	5.77	81.09	468	
6M	0.77	71.55	55	
6	2.68	62.09	166	
5	1.00	52.00	52	
4	0.31	40.75	13	
3	0.10	28.88	3	
2	0.05	17.00	1	
1	0.00	5.75	0	
		Total	**31608**	

The same check/comparison was made for the 1.0Seismic load case. As seen above there is not an overturning issue.

4. Impact on Foundations:

The calculations and research done on the overturning moment, drift checks, and story drift checks (all being acceptable), show that the foundations will not be changed from their existing design. The existing design of spread footings, piers, and strip footings will provide an efficient transfer of both the gravity and lateral loads of the structure. For more information and description on the existing foundation system please see Technical Report 1.

5. Building Torsion:

In the wind analysis, torsion forces were seen to have an impact on the East-West Lateral Resisting System. This is due to the fact that there is a substantial eccentricity of 11.5 feet between the center of mass and rigidity in this direction. This eccentricity allowed for torsion forces to have a greater impact on the overall net forces on the lateral system. The table below supports this concept.

Table 13: Wind & Seismic Grid Lateral Load Values

Load Cases	Grid A	Grid C	Grid D	Grid 1	Grid 2	Grid 3	Grid 4	Grid 10
Wind Case 1	**451**	**117**	**413**	0	0	0	0	0
Wind Case 2 (Ecc. Case 1)	86	8	79	837	270	263	257	1234
Wind Case 2 (Ecc. Case 2)	227	20	208	**997**	**312**	**295**	**277**	980
Wind Case 3 (Ecc. Case 1)	228	45	57	790	254	248	242	**1461**
Wind Case 3 (Ecc. Case 2)	361	57	65	942	294	278	262	927
Seismic Case 1	100	26	91	0	0	0	0	0
Seismic Case 2	7	1	6	69	27	27	26	68

*All Values in KIPS (All Loads Currently Not Factored)

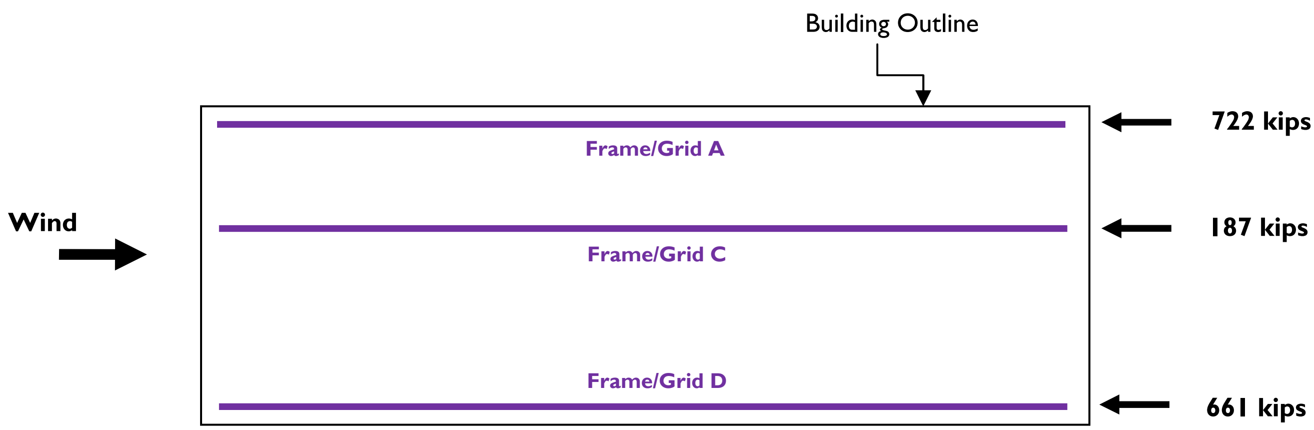
In the table above, notice Wind Case 2 (Eccentric Case 2) and Wind Case 3 (Eccentric Case 1) controlling force values for Grids 1, 2, 3, 4, & 10. This is partly due to the eccentricity in the East-West Lateral System direction.

Conclusions:

The analysis of the Northwest Science Building's lateral system has given the author a better understanding of the overall structure, and further confidence in its lateral design abilities. This system has been determined by the author to meet proper drift, story drift, overturning moment, and strength requirements.

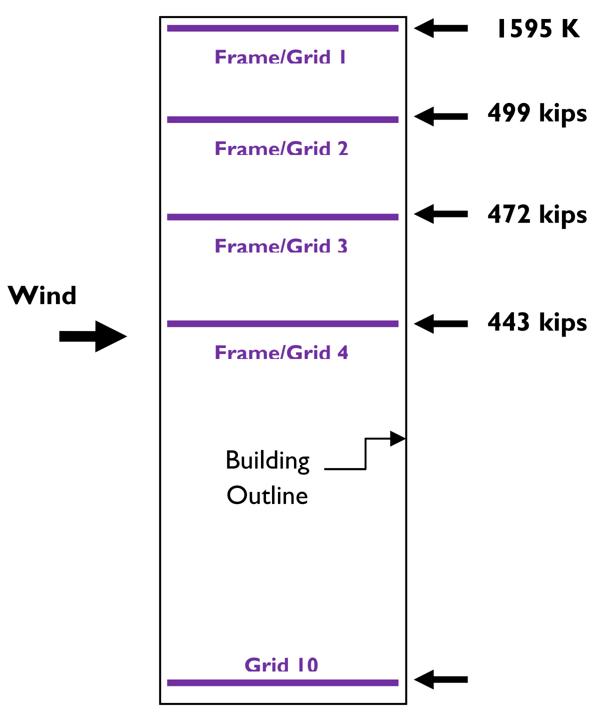
The governing lateral load cases are as follows:

- Wind Case 1 will control the design of Grids A, C, & D.



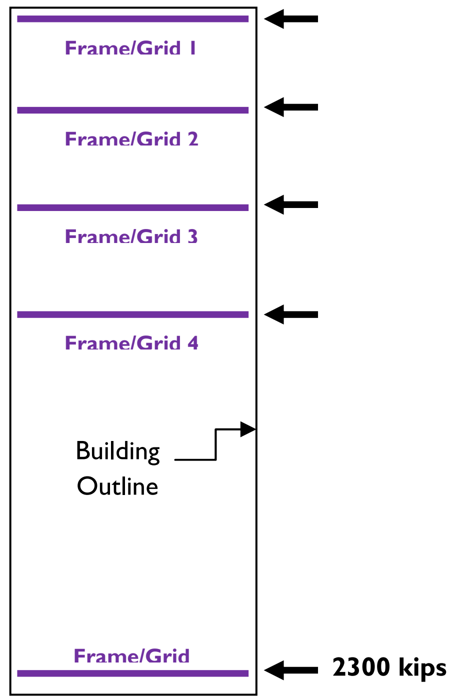
Controlling Load Combination: 1.2(Dead) + 1.6(Wind) + 1.0(Live) + 0.5(Roof Live)
Loads in figure above are factored.

- Wind Case 2 (Eccentric Case 2) controls the design of Grids 1, 2, 3, & 4.



Controlling Load Combination: 1.2(Dead) + 1.6(Wind) + 1.0(Live) + 0.5(Roof Live)
Loads in figure are factored.

- Wind Case 3 (Eccentric Case 1) controls Grid 10.



Controlling Load Combination: 1.2(Dead) + 1.6(Wind) + 1.0(Live) + 0.5(Roof Live)
Loads in figure above are factored.

Appendix:

(Hand Calculations & Spreadsheets)

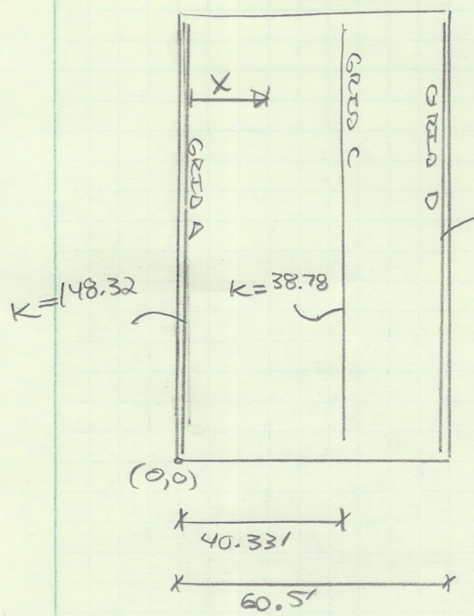
Appendix A: (Center of Mass and Rigidity)

1

CENTER OF RIGIDITY:

NORTH-SOUTH DIR:

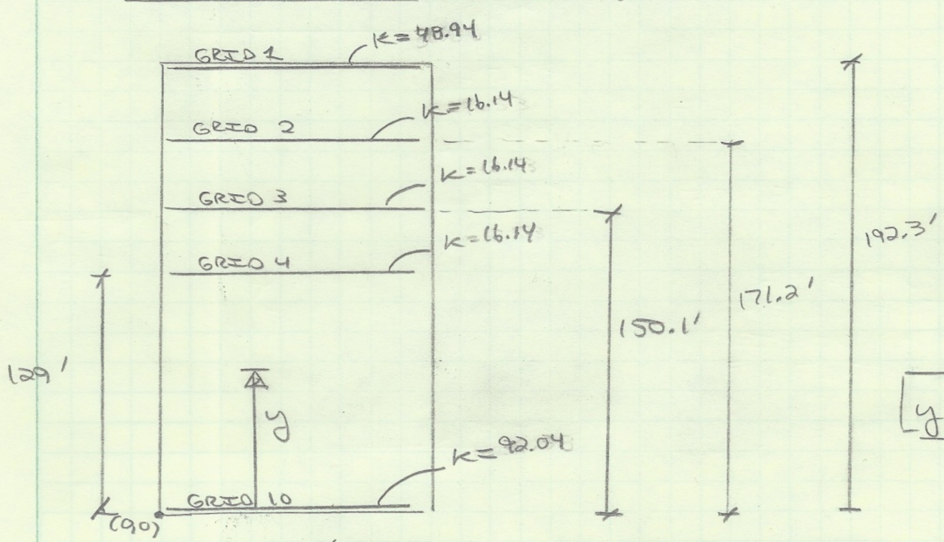
$\Sigma K = 323.05$



$$X = \frac{40.33(38.78)}{323.05} + \frac{60.5(135.94)}{323.05}$$

$$X = 30.3'$$

EAST-WEST DIR: $\Sigma K = 189.42$

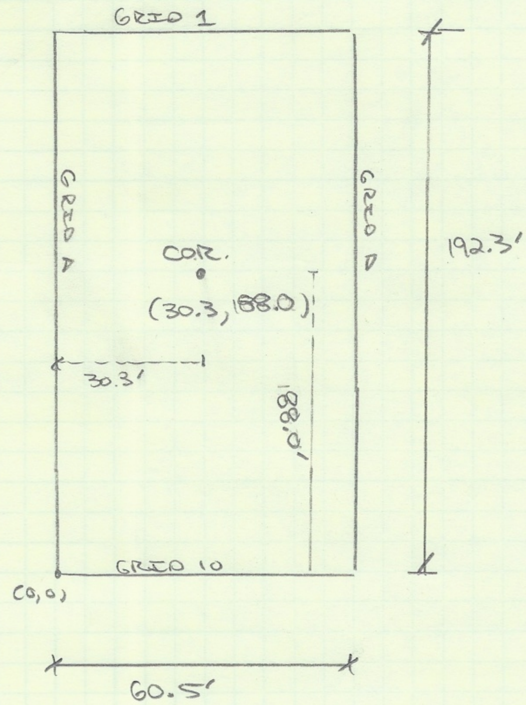


$$y = 88.0'$$

$$y = \frac{16.14(129')}{189.42} + \frac{16.14(150.1)}{189.42} + \frac{16.14(171.2)}{189.42} + \frac{48.94(192.3)}{189.42}$$

2

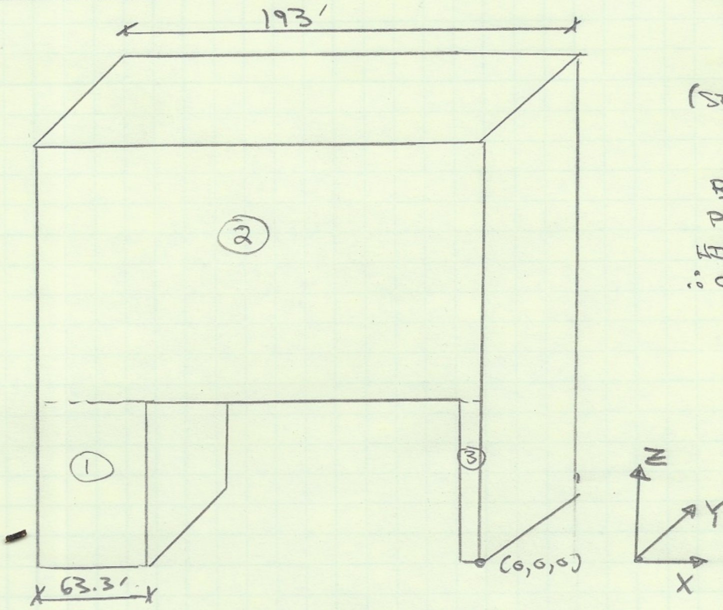
CENTER OF RIGIDITY:



1

CENTER OF MASS:

BASIC BLD MASS:



(SIMPLIFIED CALCULATION)
↓
Believed TO PRODUCED A HIGHER e
∴ CONSERVATIVE.

— NOTE:
- ALONG THE Y DIRECTION THE CENTER OF MASS IS TO OCCUR IN THE MIDDLE. IT IS ASSUMED THAT EACH FLOOR LOAD DOES NOT VARY MUCH IN THIS DIRECTION.
- THE X DIRECTION WILL NOT BE IN THE MIDDLE DUE TO THE MASS OF BLOCK 1 SHOWN ABOVE. THE COM IN THIS DIRECTION WILL BE PULLED MORE TOWARDS BLOCK 1. CALCULATION IS DONE BELOW.

BLOCK 1 WEIGHT:

LEVELS 1–5 → [FROM SEISMIC CALCS OF BLD WEIGHT FOR TECH 1]

LEVEL 1 (FLR WT) → 470^k
LEVEL 2 (FLR WT) → 461^k
LEVEL 3 (FLR WT) → 274^k
LEVEL 4 (FLR WT) → 380^k
LEVEL 5 (FLR WT) → 745^k

TOTAL = 2330

$$2330 \cdot \frac{63}{82} = 1790^k$$

↑ FACTOR TO TAKE AWAY MASS OF BLOCK 3 BASED ON DIMENSIONS

1790^k = BLOCK 1 WT.

2

CENTER OF MASS:

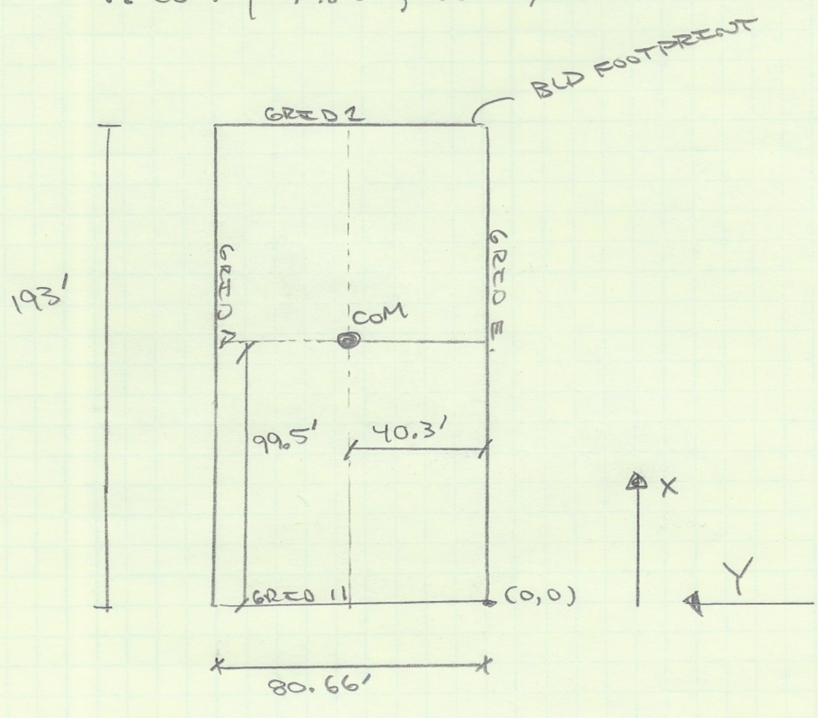
BLOCK 2 WT:

TOTAL BLD WT − BLOCK 1 + 2 WTS

$21724^k - 2330 = 19394^k$

$$COM_{X\,DIR} = \frac{19394(193')/2}{21724} + \frac{1790(161.35)}{21724} = 99.5'$$

∴ COM (99.5′, 40.3′) (X, Y)



Appendix B: (Wind & Seismic SAP Serviceability Checks)

Grid A Seismic (Serviceability Checks)

Level	Seismic Force (K)	Seismic Force Based on Stiffness (K)	Displacement (in)	Story Drift (in)	Total Shear Resistance
Roof	24.48	11.24	0.42	0.03	99.72
14M	0	0.00	0.40		
14	35.02	16.08	0.39	0.02	
13M	9.29	4.27	0.38		
13	28.54	13.10	0.37	0.02	
12M	7.94	3.65	0.36		
12	23.78	10.92	0.35	0.02	
11M	6.5	2.98	0.34		
11	19.34	8.88	0.33	0.06	
10M	5.29	2.43	0.32		
10	15.33	7.04	0.27	0.05	
9M	4.57	2.10	0.23		
9	12.37	5.68	0.22	0.03	
8M	3.35	1.54	0.20		
8	8.52	3.91	0.19	0.03	
7M	2.2	1.01	0.17		
7	5.77	2.65	0.16	0.01	
6M	0.77	0.35	0.15		
6	2.68	1.23	0.15	0.01	
5	1	0.46	0.14		
4	0.31	0.14	0.12	0.05	
3	0.1	0.05	0.07		
2	0.05	0.02	0.03	0.03	
1	0	0.00	0.00		
Totals	217.2	99.72			

Grid C Seismic (Serviceability Checks)

Level	Seismic Force (K)	Seismic Force Based on Stiffness (K)	Displacement (in)	Story Drift (in)	Total Shear Resistance
Roof	24.48	2.94	0.58	0.01	26.06
14M	0	0.00	0.58		
14	35.02	4.20	0.57	0.00	
13M	9.29	1.11	0.57		
13	28.54	3.42	0.57	0.02	
12M	7.94	0.95	0.56		
12	23.78	2.85	0.55	0.02	
11M	6.5	0.78	0.53		
11	19.34	2.32	0.53	0.00	
10M	5.29	0.63	0.53		
10	15.33	1.84	0.53	0.01	
9M	4.57	0.55	0.53		
9	12.37	1.48	0.52	0.00	
8M	3.35	0.40	0.52		
8	8.52	1.02	0.52	0.02	
7M	2.2	0.26	0.52		
7	5.77	0.69	0.50	0.08	
6M	0.77	0.09	0.48		
6	2.68	0.32	0.42	0.03	
5	1	0.12	0.39		
4	0.31	0.04	0.32	0.10	
3	0.1	0.01	0.22		
2	0.05	0.01	0.09	0.09	
1	0	0.00	0.00		
Totals	217.2	26.06			

Grid D Seismic (Serviceability Checks)

Level	Seismic Force (K)	Seismic Force Based on Stiffness (K)	Displacement (in)	Story Drift (in)	Total Shear Resistance
Roof	24.48	10.30	0.43	0.02	91.40
14M	0	0.00	0.42		
14	35.02	14.74	0.41	0.04	
13M	9.29	3.91	0.39		
13	28.54	12.01	0.37	0.07	
12M	7.94	3.34	0.34		
12	23.78	10.01	0.30	0.05	
11M	6.5	2.74	0.28		
11	19.34	8.14	0.25	0.04	
10M	5.29	2.23	0.23		
10	15.33	6.45	0.21	0.03	
9M	4.57	1.92	0.19		
9	12.37	5.21	0.18	0.02	
8M	3.35	1.41	0.17		
8	8.52	3.59	0.16	0.02	
7M	2.2	0.93	0.15		
7	5.77	2.43	0.14	0.01	
6M	0.77	0.32	0.14		
6	2.68	1.13	0.13	0.02	
5	1	0.42	0.11		
4	0.31	0.13	0.07	0.03	
3	0.1	0.04	0.04		
2	0.05	0.02	0.03	0.03	
1	0	0.00	0.00		
Totals	217.2	91.40			

Grid A Wind (Serviceability Checks)

Level	Tributary Area (ft) Based on Relative Stiffness Percentage	Windward Wind Force (PSF)	K/FT	Leeward Wind Force (PSF)	K/FT	Displacement (in)	Story Drift (in)
Roof	37.01	41.84	1.55	17.71	0.66	1.30	0.08
14M	37.01	41.84	1.55	17.71	0.66	1.27	
14	37.01	41.84	1.55	17.71	0.66	1.22	0.07
13M	37.01	40.85	1.51	17.71	0.66	1.20	
13	37.01	40.85	1.51	17.71	0.66	1.15	0.05
12M	37.01	40.85	1.51	17.71	0.66	1.13	
12	37.01	39.77	1.47	17.71	0.66	1.10	0.06
11M	37.01	39.77	1.47	17.71	0.66	1.08	
11	37.01	39.77	1.47	17.71	0.66	1.04	0.21
10M	37.01	38.51	1.43	17.71	0.66	0.93	
10	37.01	38.51	1.43	17.71	0.66	0.83	0.09
9M	37.01	38.51	1.43	17.71	0.66	0.78	
9	37.01	37.04	1.37	17.71	0.66	0.74	0.07
8M	37.01	37.04	1.37	17.71	0.66	0.71	
8	37.01	37.04	1.37	17.71	0.66	0.67	0.05
7M	37.01	35.17	1.30	17.71	0.66	0.64	
7	37.01	35.17	1.30	17.71	0.66	0.62	0.02
6M	37.01	35.17	1.30	17.71	0.66	0.61	
6	37.01	32.44	1.20	17.71	0.66	0.60	0.12
5	37.01	32.44	1.20	17.71	0.66	0.48	
4	37.01	32.44	1.20	17.71	0.66	0.30	0.15
3	37.01	27.96	1.03	17.71	0.66	0.15	
2	37.01	27.96	1.03	17.71	0.66	0.09	0.09
1	37.01	27.96	1.03	17.71	0.66	0.00	
Total Shear Resistance		451.15 KIPS					

Grid C Wind (Serviceability Checks)

Level	Tributary Area (ft) Based on Relative Stiffness Percentage	Windward Wind Force (PSF)	K/FT	Leeward Wind Force (PSF)	K/FT	Displacement (in)	Story Drift (in)
Roof	9.67	41.84	0.40	17.71	0.17	2.36	0.02
14M	9.67	41.84	0.40	17.71	0.17	2.35	
14	9.67	41.84	0.40	17.71	0.17	2.34	0.00
13M	9.67	40.85	0.40	17.71	0.17	2.34	
13	9.67	40.85	0.40	17.71	0.17	2.34	0.01
12M	9.67	40.85	0.40	17.71	0.17	2.33	
12	9.67	39.77	0.38	17.71	0.17	2.33	0.01
11M	9.67	39.77	0.38	17.71	0.17	2.32	
11	9.67	39.77	0.38	17.71	0.17	2.32	0.03
10M	9.67	38.51	0.37	17.71	0.17	2.32	
10	9.67	38.51	0.37	17.71	0.17	2.29	0.04
9M	9.67	38.51	0.37	17.71	0.17	2.27	
9	9.67	37.04	0.36	17.71	0.17	2.25	0.03
8M	9.67	37.04	0.36	17.71	0.17	2.24	
8	9.67	37.04	0.36	17.71	0.17	2.22	0.04
7M	9.67	35.17	0.34	17.71	0.17	2.19	
7	9.67	35.17	0.34	17.71	0.17	2.18	0.04
6M	9.67	35.17	0.34	17.71	0.17	2.16	
6	9.67	32.44	0.31	17.71	0.17	2.14	0.26
5	9.67	32.44	0.31	17.71	0.17	1.88	
4	9.67	32.44	0.31	17.71	0.17	1.38	0.65
3	9.67	27.96	0.27	17.71	0.17	0.73	
2	9.67	27.96	0.27	17.71	0.17	0.29	0.29
1	9.67	27.96	0.27	17.71	0.17	0.00	
Total Shear Resistance		117.34 KIPS					

Grid D Wind (Serviceability Checks)

Level	Tributary Area (ft) Based on Relative Stiffness Percentage	Windward Wind Force (PSF)	K/FT	Leeward Wind Force (PSF)	K/FT	Displacement (in)	Story Drift (in)
Roof	33.98	41.84	1.42	17.71	0.60	1.30	0.03
14M	33.98	41.84	1.42	17.71	0.60	1.29	
14	33.98	41.84	1.42	17.71	0.60	1.27	0.11
13M	33.98	40.85	1.39	17.71	0.60	1.26	
13	33.98	40.85	1.39	17.71	0.60	1.16	0.17
12M	33.98	40.85	1.39	17.71	0.60	1.08	
12	33.98	39.77	1.35	17.71	0.60	0.99	0.12
11M	33.98	39.77	1.35	17.71	0.60	0.94	
11	33.98	39.77	1.35	17.71	0.60	0.87	0.11
10M	33.98	38.51	1.31	17.71	0.60	0.82	
10	33.98	38.51	1.31	17.71	0.60	0.76	0.08
9M	33.98	38.51	1.31	17.71	0.60	0.72	
9	33.98	37.04	1.26	17.71	0.60	0.68	0.06
8M	33.98	37.04	1.26	17.71	0.60	0.65	
8	33.98	37.04	1.26	17.71	0.60	0.62	0.06
7M	33.98	35.17	1.20	17.71	0.60	0.59	
7	33.98	35.17	1.20	17.71	0.60	0.56	0.02
6M	33.98	35.17	1.20	17.71	0.60	0.55	
6	33.98	32.44	1.10	17.71	0.60	0.54	0.09
5	33.98	32.44	1.10	17.71	0.60	0.45	
4	33.98	32.44	1.10	17.71	0.60	0.32	0.10
3	33.98	27.96	0.95	17.71	0.60	0.22	
2	33.98	27.96	0.95	17.71	0.60	0.13	0.13
1	33.98	27.96	0.95	17.71	0.60	0.00	
Total Shear Resistance		413.27 KIPS					

Grid 1 Seismic (Serviceability Checks)

Level	Seismic Force (K)	Seismic Force Based on Stiffness (K)	Displacement (in)	Story Drift (in)	Total Shear Resistance
Roof	24.48	6.33	0.73	0.05	56.12
14M	0	0.00	0.71		
14	35.02	9.05	0.68	0.05	
13M	9.29	2.40	0.66		
13	28.54	7.37	0.63	0.10	
12M	7.94	2.05	0.58		
12	23.78	6.14	0.53	0.11	
11M	6.5	1.68	0.47		
11	19.34	5.00	0.42	0.07	
10M	5.29	1.37	0.38		
10	15.33	3.96	0.35	0.11	
9M	4.57	1.18	0.30		
9	12.37	3.20	0.24	0.07	
8M	3.35	0.87	0.20		
8	8.52	2.20	0.17	0.10	
7M	2.2	0.57	0.11		
7	5.77	1.49	0.07	0.05	
6M	0.77	0.20	0.04		
6	2.68	0.69	0.02		
5	1	0.26	FIXED AT THIS LEVEL DUE TO LACK OF DRAWING INFORMATION	FIXED AT THIS LEVEL DUE TO LACK OF DRAWING INFORMATION	
4	0.31	0.08			
3	0.1	0.03			
2	0.05	0.01			
1	0	0.00			
Totals	217.2	56.12			

Grids 2-4 Seismic (Serviceability Checks)

Level	Seismic Force (K)	Seismic Force Based on Stiffness (K)	Displacement (in)	Story Drift (in)	Total Shear Resistance
Roof	24.48	2.09	0.79	0.02	18.51
14M	0	0.00			
14	35.02	2.98	0.77	0.05	
13M	9.29	0.79			
13	28.54	2.43	0.72	0.09	
12M	7.94	0.68			
12	23.78	2.03	0.63	0.11	
11M	6.5	0.55			
11	19.34	1.65	0.52	0.08	
10M	5.29	0.45			
10	15.33	1.31	0.44	0.04	
9M	4.57	0.39			
9	12.37	1.05	0.40	0.09	
8M	3.35	0.29			
8	8.52	0.73	0.31	0.14	
7M	2.2	0.19			
7	5.77	0.49	0.17	0.12	
6M	0.77	0.07			
6	2.68	0.23	0.05		
5	1	0.09	FIXED AT THIS LEVEL DUE TO LACK OF DRAWING INFORMATION	FIXED AT THIS LEVEL DUE TO LACK OF DRAWING INFORMATION	
4	0.31	0.03			
3	0.1	0.01			
2	0.05	0.00			
1	0	0.00			
Totals	217.2	18.51			

Grid 10 Seismic (Serviceability Checks)

Level	Seismic Force (K)	Seismic Force Based on Stiffness (K)	Displacement (in)	Story Drift (in)	Total Shear Resistance
Roof	24.48	11.89	0.69	0.04	105.54
14M	0	0.00	0.67		
14	35.02	17.02	0.65	0.06	
13M	9.29	4.51	0.63		
13	28.54	13.87	0.59	0.05	
12M	7.94	3.86	0.57		
12	23.78	11.55	0.54	0.15	
11M	6.5	3.16	0.47		
11	19.34	9.40	0.39	0.05	
10M	5.29	2.57	0.36		
10	15.33	7.45	0.34	0.04	
9M	4.57	2.22	0.33		
9	12.37	6.01	0.30	0.08	
8M	3.35	1.63	0.26		
8	8.52	4.14	0.22	0.10	
7M	2.2	1.07	0.17		
7	5.77	2.80	0.12	0.06	
6M	0.77	0.37	0.09		
6	2.68	1.30	0.06		
5	1	0.49	FIXED AT THIS LEVEL DUE TO LACK OF DRAWING INFORMATION	FIXED AT THIS LEVEL DUE TO LACK OF DRAWING INFORMATION	
4	0.31	0.15			
3	0.1	0.05			
2	0.05	0.02			
1	0	0.00			
Totals	217.2	105.54			

Grid 1 Wind (Serviceability Checks)

Level	Tributary Area (ft) Based on Relative Stiffness Percentage	Windward Wind Force (PSF)	K/FT	Leeward Wind Force (PSF)	K/FT	Displacement (in)	Story Drift (in)
Roof	49.61	41.83	2.08	29.32	1.45	5.60	0.34
14M	49.61	41.83	2.08	29.32	1.45	5.49	
14	49.61	41.83	2.08	29.32	1.45	5.26	0.36
13M	49.61	40.85	2.03	29.32	1.45	5.12	
13	49.61	40.85	2.03	29.32	1.45	4.90	0.65
12M	49.61	40.85	2.03	29.32	1.45	4.59	
12	49.61	39.77	1.97	29.32	1.45	4.25	0.80
11M	49.61	39.77	1.97	29.32	1.45	3.86	
11	49.61	39.77	1.97	29.32	1.45	3.45	0.51
10M	49.61	38.51	1.91	29.32	1.45	3.21	
10	49.61	38.51	1.91	29.32	1.45	2.94	0.80
9M	49.61	38.51	1.91	29.32	1.45	2.58	
9	49.61	37.04	1.84	29.32	1.45	2.14	0.59
8M	49.61	37.04	1.84	29.32	1.45	1.86	
8	49.61	37.04	1.84	29.32	1.45	1.55	0.88
7M	49.61	35.17	1.74	29.32	1.45	1.07	
7	49.61	35.17	1.74	29.32	1.45	0.67	0.48
6M	49.61	35.17	1.74	29.32	1.45	0.39	
6	49.61	32.44	1.61	29.32	1.45	0.19	
5	49.61	32.44	1.61	29.32	1.45	FIXED AT THIS LEVEL DUE TO LACK OF DRAWING INFORMATION	FIXED AT THIS LEVEL DUE TO LACK OF DRAWING INFORMATION
4	49.61	32.44	1.61	29.32	1.45		
3	49.61	21.23	1.05	29.32	1.45		
2	49.61	21.23	1.05	29.32	1.45		
1	49.61	21.23	1.05	29.32	1.45		
Total Shear Resistance		622.00					

Grids 2-4 Wind (Serviceability Checks)

Level	Tributary Area (ft) Based on Relative Stiffness Percentage	Windward Wind Force (PSF)	K/FT	Leeward Wind Force (PSF)	K/FT	Displacement (in)	Story Drift (in)
Roof	16.36	41.83	0.68	29.32	0.48	6.30	0.03
14M	16.36	41.83	0.68	29.32	0.48		
14	16.36	41.83	0.68	29.32	0.48	6.27	0.35
13M	16.36	40.85	0.67	29.32	0.48		
13	16.36	40.85	0.67	29.32	0.48	5.92	0.60
12M	16.36	40.85	0.67	29.32	0.48		
12	16.36	39.77	0.65	29.32	0.48	5.32	0.75
11M	16.36	39.77	0.65	29.32	0.48		
11	16.36	39.77	0.65	29.32	0.48	4.57	0.59
10M	16.36	38.51	0.63	29.32	0.48		
10	16.36	38.51	0.63	29.32	0.48	3.98	0.31
9M	16.36	38.51	0.63	29.32	0.48		
9	16.36	37.04	0.61	29.32	0.48	3.67	0.84
8M	16.36	37.04	0.61	29.32	0.48		
8	16.36	37.04	0.61	29.32	0.48	2.83	1.22
7M	16.36	35.17	0.58	29.32	0.48		
7	16.36	35.17	0.58	29.32	0.48	1.61	1.14
6M	16.36	35.17	0.58	29.32	0.48		
6	16.36	32.44	0.53	29.32	0.48	0.47	
5	16.36	32.44	0.53	29.32	0.48	FIXED AT THIS LEVEL DUE TO LACK OF DRAWING INFORMATION	FIXED AT THIS LEVEL DUE TO LACK OF DRAWING INFORMATION
4	16.36	32.44	0.53	29.32	0.48		
3	16.36	21.23	0.35	29.32	0.48		
2	16.36	21.23	0.35	29.32	0.48		
1	16.36	21.23	0.35	29.32	0.48		
Total Shear Resistance		200.00					

Grid 10 Wind (Serviceability Checks)

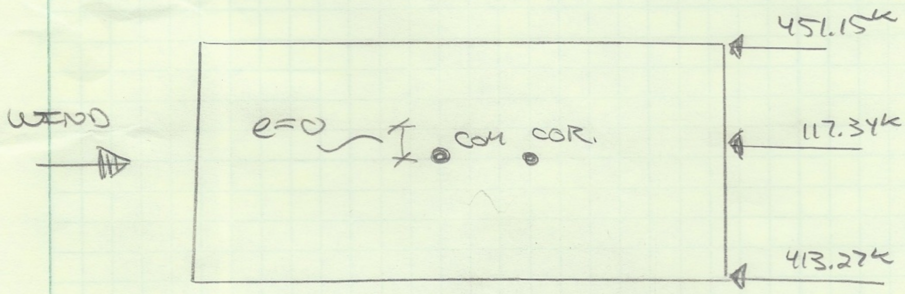
Level	Tributary Area (ft) Based on Relative Stiffness Percentage	Windward Wind Force (PSF)	K/FT	Leeward Wind Force (PSF)	K/FT	Displacement (in)	Story Drift (in)
Roof	93.29	41.83	3.90	29.32	2.74	5.37	0.24
14M	93.29	41.83	3.90	29.32	2.74	5.33	
14	93.29	41.83	3.90	29.32	2.74	5.13	0.39
13M	93.29	40.85	3.81	29.32	2.74	4.97	
13	93.29	40.85	3.81	29.32	2.74	4.74	0.31
12M	93.29	40.85	3.81	29.32	2.74	4.63	
12	93.29	39.77	3.71	29.32	2.74	4.43	1.07
11M	93.29	39.77	3.71	29.32	2.74	3.93	
11	93.29	39.77	3.71	29.32	2.74	3.36	0.39
10M	93.29	38.51	3.59	29.32	2.74	3.18	
10	93.29	38.51	3.59	29.32	2.74	2.97	0.56
9M	93.29	38.51	3.59	29.32	2.74	2.68	
9	93.29	37.04	3.46	29.32	2.74	2.41	0.80
8M	93.29	37.04	3.46	29.32	2.74	2.03	
8	93.29	37.04	3.46	29.32	2.74	1.61	0.70
7M	93.29	35.17	3.28	29.32	2.74	1.21	
7	93.29	35.17	3.28	29.32	2.74	0.91	0.49
6M	93.29	35.17	3.28	29.32	2.74	0.67	
6	93.29	32.44	3.03	29.32	2.74	0.42	
5	93.29	32.44	3.03	29.32	2.74	FIXED AT THIS LEVEL DUE TO LACK OF DRAWING INFORMATION	FIXED AT THIS LEVEL DUE TO LACK OF DRAWING INFORMATION
4	93.29	32.44	3.03	29.32	2.74		
3	93.29	21.23	1.98	29.32	2.74		
2	93.29	21.23	1.98	29.32	2.74		
1	93.29	21.23	1.98	29.32	2.74		
Total Shear Resistance		1774.00					

Appendix C: (Torsion Calculations)

TORSION FORCES 1

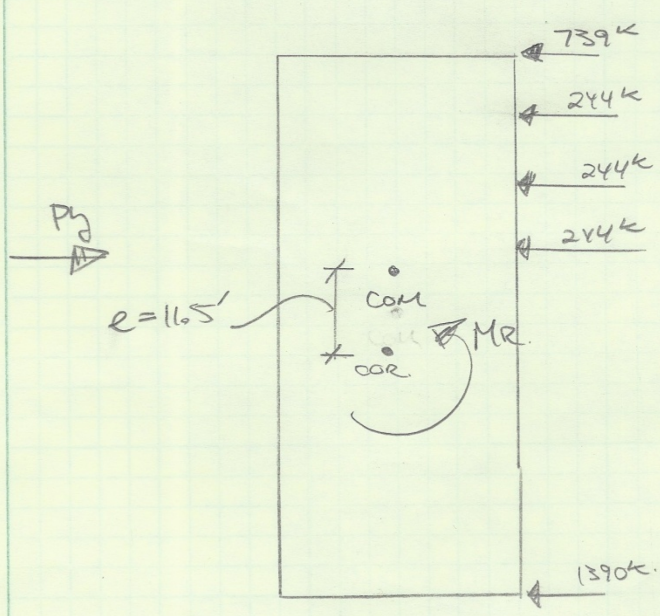
TORSION FORCES:

WIND CASE 1: (ECCENTRICITY CASE 1 + 2 AS WELL)



∴ NO TORSION FORCES FOR WIND CASE 1.

WIND CASE 2: (ECCENTRIC CASE 1 AS WELL)



$$11.5(\overset{Py}{2860^{k}}) = 32890^{k \cdot FT.} = M_R.$$

$$F_{(TORSION)} = k_i d_i \theta_t$$

• SEE EXCEL SPREAD ON WIND CASE 2/ ECCENT CASE 1 FOR FURTHER CALCS.

TORSION FORCES 2

WIND CASE 2: (ECCENTRIC CASE 2 AS WELL)

P_y NOW IS $0.75P_y$

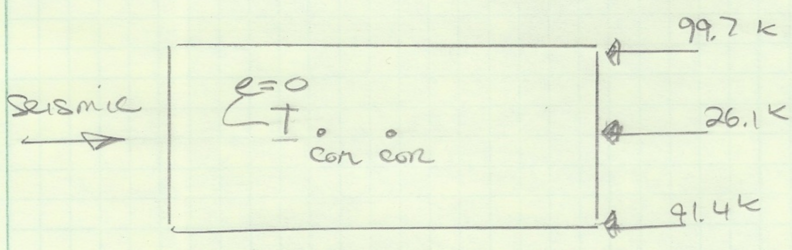
NOW $e_x = e_x + 0.15 B_x$

$11.5 + (0.15)(192.3) = 40.35$ FT.

$40.35(0.75)(2860) = 86{,}550.75$ K·FT

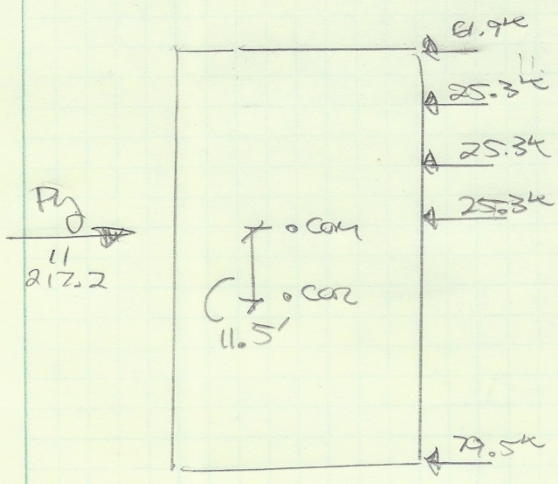
• SEE EXCEL SPREADSHEET ON WIND CASE 2/ ECCENT CASE 2 FOR FURTHER CALCS.

SEISMIC CASE 1: (E



∴ NO TORSION FORCES FOR SEISMIC CASE 1.

SEISMIC CASE 2:



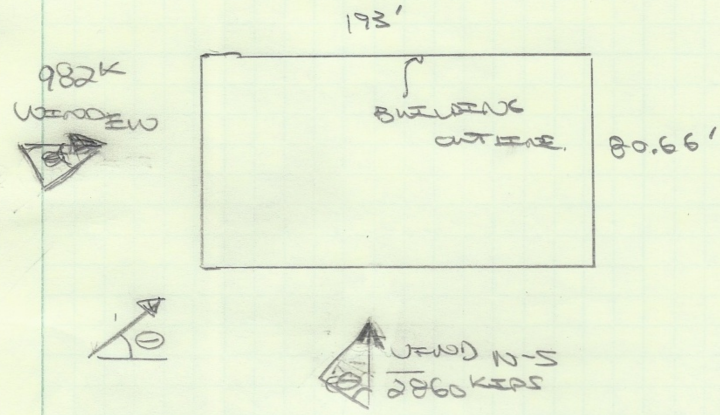
$11.5(217.2) = M_R = 2497.8$ FT·K

$F_{t\,TORSION} = K_i d_i \theta_t$

• SEE EXCEL SPREADSHEET ON SEISMIC CASE 2 FOR FURTHER CALCS.

TORSION FORCES 3

WIND CASE 3:



FIND θ FOR MAX WIND FORCE:

$\sin\theta = \frac{x}{2860} \Rightarrow 2860\sin\theta$

$\cos\theta = \frac{y}{982} \Rightarrow 982\cos\theta$

$2860\sin\theta + 982\cos\theta \quad \frac{d}{d\theta}$

$2860\cos\theta - 982\sin\theta$

SET = 0 TO FIND θ FOR MAX:

$2860\cos\theta - 980\sin\theta = 0$

$2860\cos\theta = 980\sin\theta$

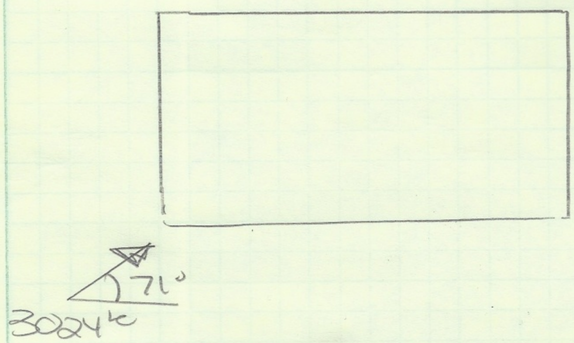
$\frac{2860}{980} = \frac{\sin\theta}{\cos\theta} \Rightarrow \tan^{-1}\left(\frac{2860}{980}\right) = \theta$

$\theta = 71^\circ$

MAX WIND FORCE:

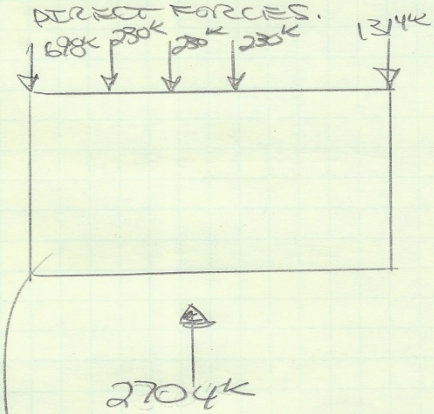
$2860\sin 71^\circ + 982\cos 71^\circ =$ **3024 KIPS @ 71°**

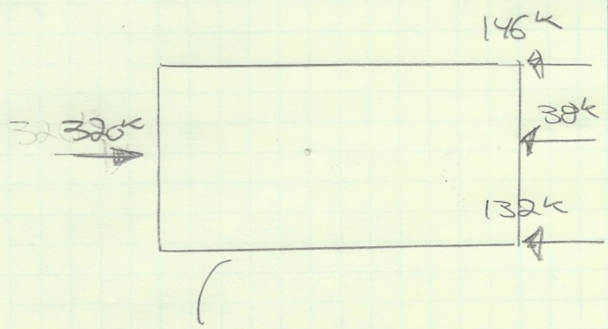
WIND CASE 3 CONT:



BREAK INTO COMPONENTS:

DIRECT FORCES.





NO TORSION FORCES CAUSE COR + COM ON SAME LINE

TORSION FORCES

$M_e = 11.5(2704)$ ECC. CASE 1. $\Rightarrow M_e = 31096^{k \cdot ft}$

$M_e = 40.35(0.75)(2704) = 81830^{k \cdot ft}$ $\Rightarrow$ ECC. CASE 2.

FOR FURTHER CALCS SEE WIND CASE 3 (ECC. CASES 1 + 2) SPREADSHEETS.

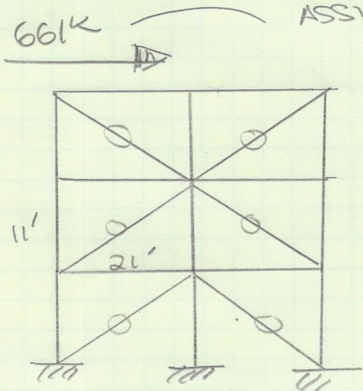
Appendix D: (Strength Check)

STRENGTH 1

STRENGTH CHECK:

CHECK PART OF GRID SHEAR FOR SHEAR CAPACITY:

– WIND CASE 1 CONTROLS FOR GRID D.
(→ LATERAL LOAD IS $413^k(1.6) = \boxed{660.8^k}$



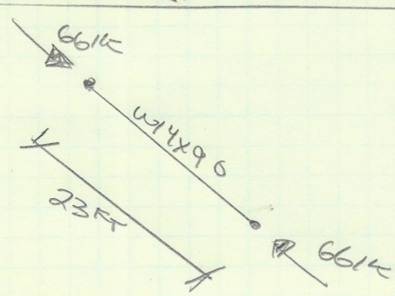
ASSUME ENTIRE LATERAL LOAD IS DISTRIBUTED TO THIS BRACED PART OF THE STRUCTURE.
→ CONSERVATIVE FOR THIS CHECK, BECAUSE SOME OF THE FORCE WILL BE TAKEN BY THE FAR GRID D COLUMN.

(FIGURE 1)

→ ALL O MEMBERS ARE W24X90'S.

(→ WHAT IS THE AXIAL CAPACITY OF THESE MEMBERS?

CONSERVATIVE CHECK:



$P_u = 661^k$

• TREAT AS PIN-PIN COLUMN.

$\phi P_n = 821^k$ (22FT)

$\phi P_n = 765^k$ (24FT)

STRENGTH 2

$\phi P_n = 793^k$ (23FT)

$P_u = 661^k$

$\phi P_n > P_u$

$793 > 661^k$ } OKAY

∴ ALL W14X90's (BRACES) IN FIGURE 1, MEET STRENGTH REQUIREMENTS.