

Structural Depth Study:

The following is a description of the main structural depth study proposed by the author for Penn State Architectural Engineering Senior Thesis, Spring 2010.

The Columbia University Northwest Science Building’s lateral system was determined to be governed by wind forces in Technical Report 3. This is due to the large 110 MPH wind design speed of New York City. It is also due to the fact that the building is rectangular shaped with the long side measuring 193 feet by 226 feet in height. These large East and West areas of the building act as a wind sail. This creates a large amount of wind force acting upon the East-West lateral system. The lateral design of the building provides large diagonal braced frames and wind girts at mezzanine levels. This lateral system design clearly indicates the large wind forces it resists.

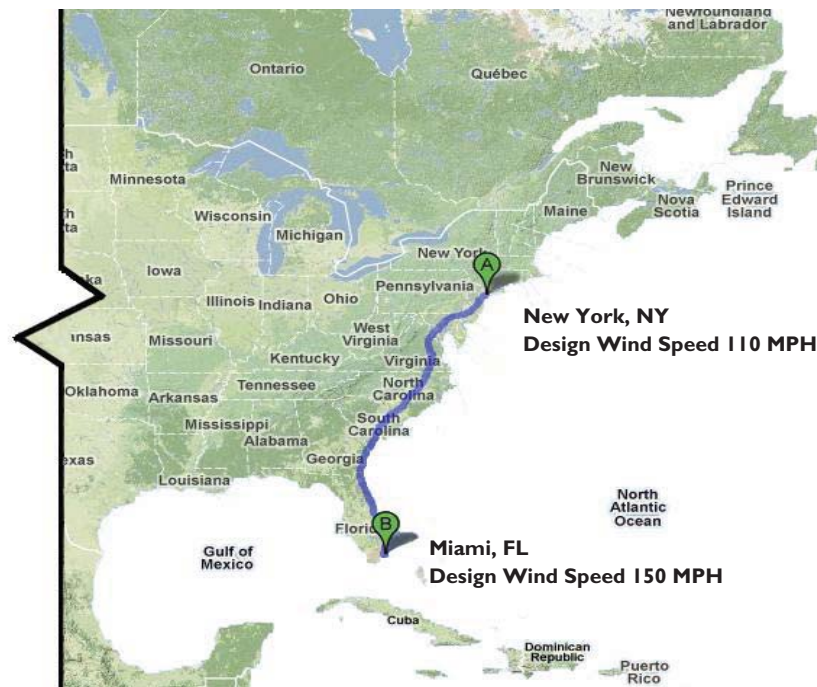
To further study wind effects upon the building and its lateral system, it is proposed by the author to move the building site from New York City, NY (110 MPH design wind speed) to Miami, FL where there is an increase in design wind speed to 150 MPH. This increase is due to Miami, FL being in a more hurricane prone area. It is also in the author’s interest to research different lateral bracing systems (chevron, eccentric, and k bracing) and propose one of them in the redesign.

The relocation of the building to Miami, FL will affect the lateral system design. This in turn should affect the diagonal brace member sizes and locations.

This structural breadth study will consist of the following three tasks.

- Calculation of Wind Forces for Miami, FL
- Analyze Existing Lateral System for Miami, FL
- Redesign and Analyze Lateral System

Figure 6: Relocation of Building to Miami, FL (Wind Force Study)



Structural Depth Study

Task One – Calculation of Wind Forces (Miami, FL)

Description:

Task one was completed to determine wind forces for the relocation of the Columbia University Northwest Science building to Miami, FL. These calculations will be used throughout this thesis for determining a lateral system redesign. A basic wind speed of 150 MPH was determined for Miami, FL. The following tables, graphs, figures, and conclusions provide a detailed description and documentation of these wind forces.

Tables, Graphs, and Figures:

Below is a bulleted list explaining the tables, graphs, and figures to follow, regarding wind calculations and diagrams.

- Table 1: Basic Wind Pressure Parameters
 - Provides basic wind factors based upon location of site, topography of site, and additional building properties.
- Table 2: Gust Factor Parameters
 - Provides factors needed in finding the gust effect on the structure.
- Table 3: C_p , Gust Factor, GC_{pi} Factors
 - Summarizes the gust factors found for the leeward and windward sides of the building. Also provides the external pressure coefficient (C_p), and internal pressure coefficient (GC_{pi}) values.
- Figure 7: Wind North-South Direction Diagram
 - Provides a visual of the wind forces (windward and leeward) on the structure in PSF.
- Figure 8: Wind East-West Direction Diagram
 - Provides a visual of the wind forces (windward and leeward) on the structure in PSF.
- Graph 1: Comparison of Base Shears (NYC vs. Miami)
 - Provides a numerical and visual comparison of the base shears of each city.
- Tables 4A & 4B: Wind North-South Direction (*found in Structural Depth Appendix A*)
 - Provides the excel spreadsheet wind analysis that was used in finding the wind forces acting on the structure. Also, provides the final base shear and overturning moment for the structure caused by wind.
- Tables 5A & 5B: Wind East-West Direction (*found in Structural Depth Appendix A*)
 - Provides the excel spreadsheet wind analysis that was used in finding the wind forces acting on the structure. Also, provides the final base shear and overturning moment for the structure caused by wind.
- Table 6: Unfactored Story Forces for ETABS Deflection Analysis (*found in Structural Depth Appendix A*)
 - Provides the story forces that will be entered into ETABS for lateral wind analysis.

Conclusions:

A 1400 kips base shear was calculated for the building in the North-South direction, while 5490 kips base shear was calculated for the East-West direction. These values were suspected to rise due to an increase in basic wind speed of 150 MPH compared to New York City's 110 MPH. The values did rise considerably. A 192% increase in base shear for both the North-South and East-West base shear took place.

Table 1: Basic Wind Pressure Parameters

Basic Wind Speed (V)	150 MPH
Wind Exposure Category	C
Building Category	III
Importance Factor	1.15
Wind Directionality Factor (K_d)	0.85
Topographic Factor (K_{zt})	1.0
Number of Stories	14
Building Height (Feet)	226'-0"
N-S Building Length (Feet)	196.75'
E-W Building Length (Feet)	60.5'
L/B in N-S Direction	3.252
L/B in E-W Direction	0.307

Table 2: Gust Factor Parameters

Variable	Gust Factor	
	Wind Direction	
	N-S	E-W
Stiffness	Flexible ($n_1 < 1$)	Flexible ($n_1 < 1$)
n_1	0.4425	0.4425
B (Feet)	60.5196	196.75
L (Feet)	196.75	60.5
h (Feet)	226	226
I_z	0.158	0.158
L_z (Feet)	663.31	663.31
Q	0.854	0.824
g_r	3.99	3.99
g_Q & g_v	3.4	3.4
V_z	177.73	177.73
α	1/6.5	1/6.5
b	0.65	0.65
N_1	1.651	1.651
R_n	0.0997	0.0997
R_h	0.312	0.312
R_B	0.662	0.346
R_L	0.124	0.339
R	0.660	0.517
G_f	0.992	0.935

Table 3: C_p , Gust Factor, GC_{pi} Factors

Wind Direction	C_p (Windward)	C_p (Leeward)	Gust Factor (Windward)	Gust Factor (Leeward)	GC_{pi}
N-S Direction	0.8	-0.225	0.992	0.935	± 0.18
E-W Direction	0.8	-0.5	0.992	0.935	± 0.18

Figure 7: Wind North-South Direction Diagram

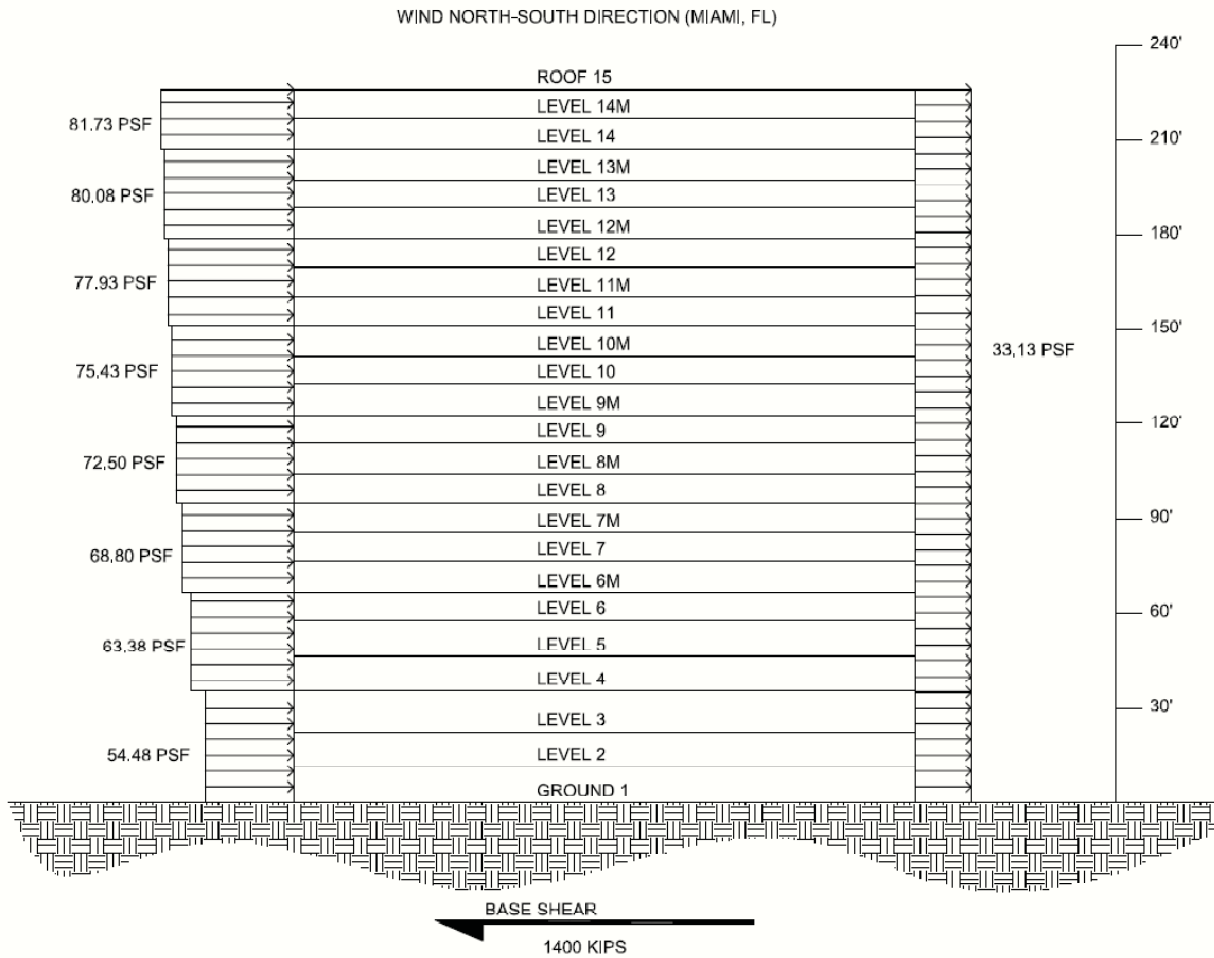
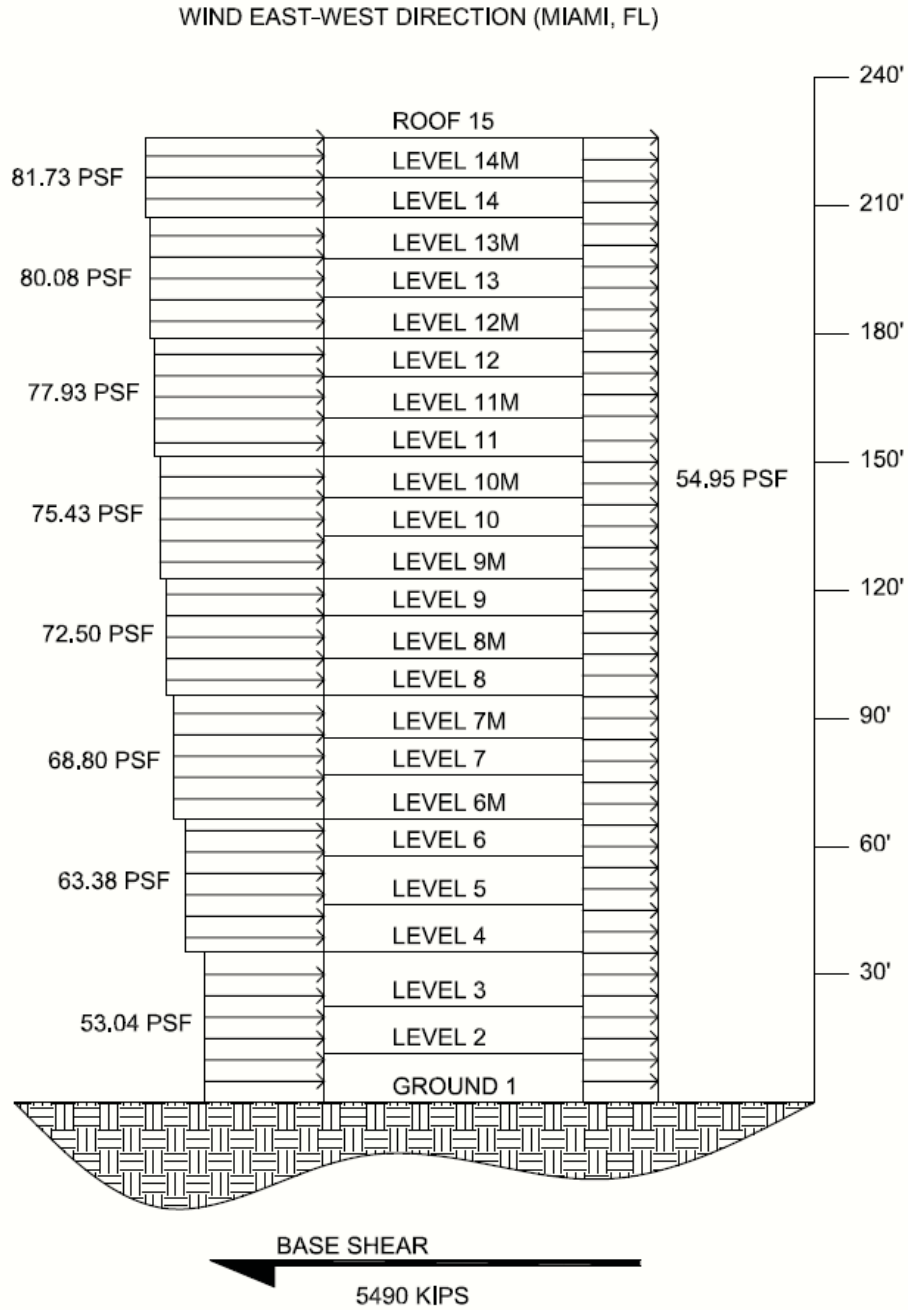
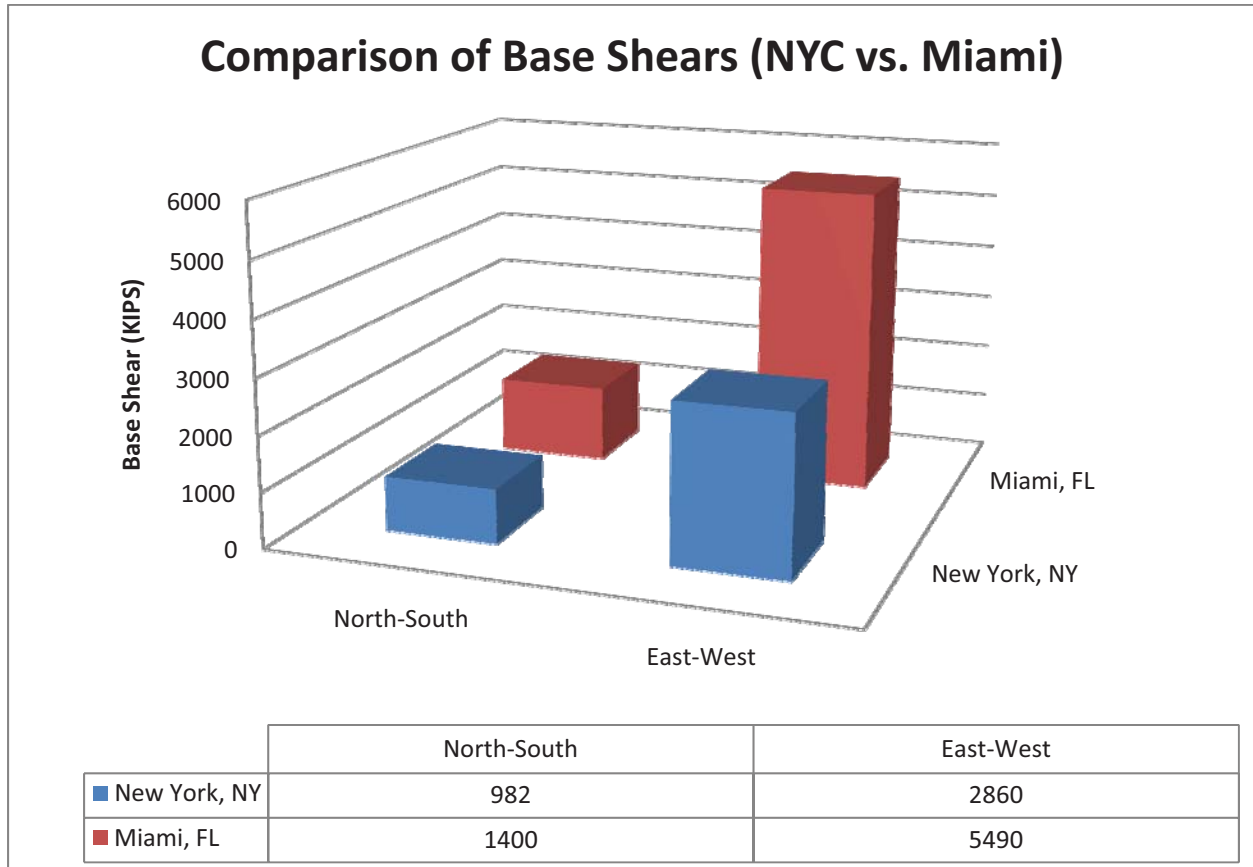


Figure 8: Wind East-West Direction Diagram



Graph I: Comparison of Base Shears (NYC vs. Miami)



Discussion of Graph I:

As you can see above in the graph, there is a substantial difference in base shear forces from New York, NY to Miami, FL. The relocation of the building to Miami, as shown above, will cause a great increase in wind forces in both the North-South and East-West directions. A substantial part of this thesis will be providing a redesign of the building’s lateral system to meet these new wind force requirements.

Structural Depth Study

Task Two – Analyze Existing Lateral System (Miami, FL)

Description:

Task two was completed to determine if the existing lateral system could withstand Miami, FL wind forces. Task one's wind calculations were used along with an ETABS model to determine if the existing lateral design is still satisfactory for Miami, FL.

The author suspects that the lateral system will be unsatisfactory due to the increase in wind load with the building's relocation. The following calculations and analysis will take place:

- Recording/checking wind drifts and story drifts.
- Comparing drifts and story drifts to Technical Report 3 results.
- Providing checks of overturning and strength.

Tables, Graphs, and Figures:

Below is a bulleted list explaining the tables, graphs, and figures to follow, regarding the existing lateral system's wind analysis for Miami, FL.

- Figures 9 & 10: ETABS Model Images 1 & 2
 - Images of ETABS model used.
- Table 7: Wind Case Summary
 - Provides the forces each grid must resist for Miami, FL wind forces.
- Graph 2: Maximum Grid Force Summary - Wind
 - Compares each grid's maximum shear resisting forces in bar graph format.
- Table 8: Overturning Moment Calculations
 - Provides a spreadsheet of all the calculations made for overturning moment checks.
- Table 9: East-West Direction – Wind Serviceability Checks (*found in Structural Depth Appendix A*)
 - Provides the drift and story drifts for each grid of the East-West lateral system.
- Table 10: North-South Direction – Wind Serviceability Checks (*found in Structural Depth Appendix A*)
 - Provides the drift and story drifts for each grid of the North-South lateral system.
- Table 11: Wind Serviceability Checks - Summary
 - Provides a summary of the met and unmet drift and story drifts of the existing lateral system.
- Graph 3: Wind Drift Comparison – NYC vs. Miami
 - Compares the max wind drifts of the building located in NYC vs. Miami.

Conclusions:

From this existing lateral system analysis for Miami, FL the author found that the East-West lateral system needed a substantial redesign. This system failed drift, story drift, and strength requirements. The North-South lateral system seems to meet most requirements. However, the author does suspect strength concerns in this direction as well. The following pages discuss the results of Structural Depth Study, Task 2.

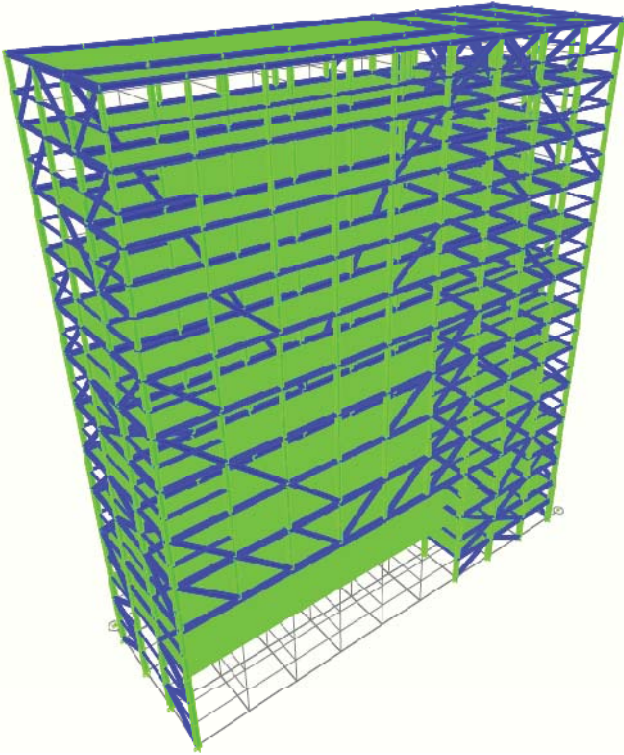


Figure 9: ETABS Model – Image 1

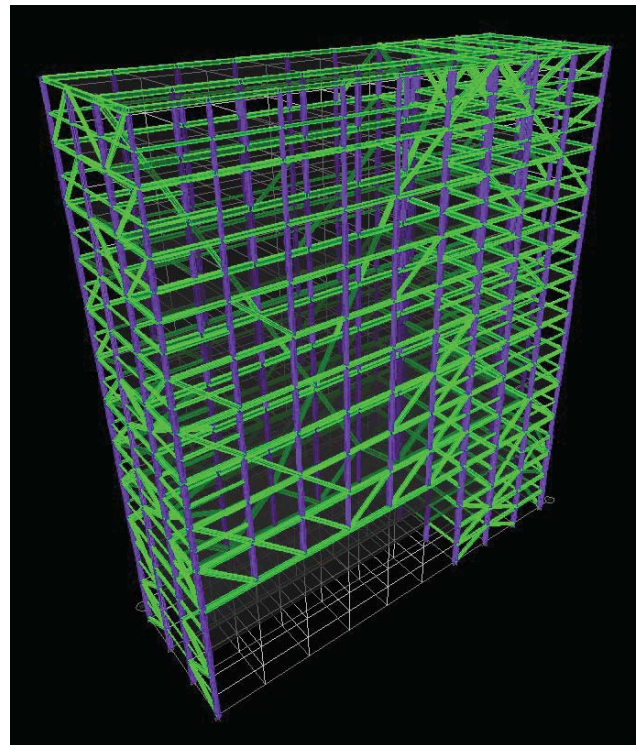


Figure 10: ETABS Model – Image 2

ETABS Model:

The ETABS model seen on the previous page was used in assisting the existing lateral system analysis for Miami, FL hurricane wind loads. This model was created to match, to the best ability, the structural drawings of ARUP (structural design engineering firm).

All members of the lateral system were inputted with their proper material properties and connection requirements. All of the beams within the structure were moment released on both ends. This is due to the fact that the entire lateral system contains only braced frames, and no moment frames.

Load Combinations Used:

The author is only focusing on a wind analysis of the existing lateral system for Miami, FL. The relocation of the building to a hurricane prone area causes the author to strongly believe wind will control the lateral design. Therefore the following load combinations will be used:

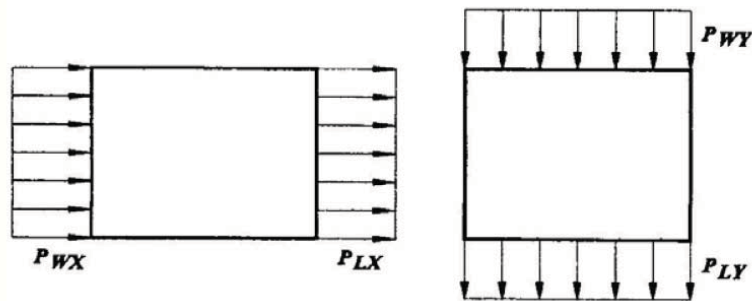
- $1.2(\text{Dead}) + 1.6(\text{Roof Live}) + 0.8(\text{Wind})$
- $1.2(\text{Dead}) + 1.6(\text{Wind}) + 1.0(\text{Live}) + 0.5(\text{Roof Live})$
- $0.9(\text{Dead}) + 1.6(\text{Wind})$

Wind Cases:

Following is a description of each wind case to be considered. Each wind case will provide an image of the wind forces and the tabulation of results.

Wind Case I:

Wind Case I considers the full wind pressures acting perpendicular to the building structure. The pressures are considered separately in each direction as shown below.

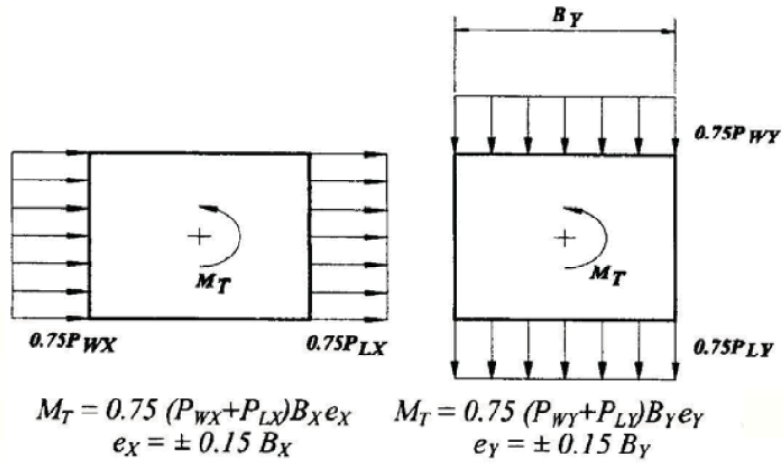


	Grid A	Grid C	Grid D	Grid I	Grid 2	Grid 3	Grid 4	Grid 10
Wind Case I	566	125	573	2180	298	412	156	2444

*All values shown above are in kips and un-factored.

Wind Case 2:

Wind Case 2 considers three quarters of the design wind pressure acting perpendicular to the building structure. Also a torsional moment is considered for each principal axis.

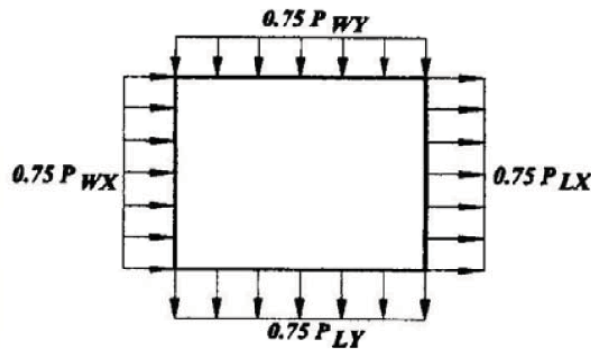


	Grid A	Grid C	Grid D	Grid I	Grid 2	Grid 3	Grid 4	Grid 10
Wind Case 2 (+M)	351	92	470	1400	194	280	434	1940
Wind Case 2 (-M)	461	86	351	1697	223	290	101	1617

*All values shown above are in kips and un-factored.

Wind Case 3:

Wind Case 3 considers three quarters of the design wind pressure acting perpendicular to the building structure in both directions simultaneously.

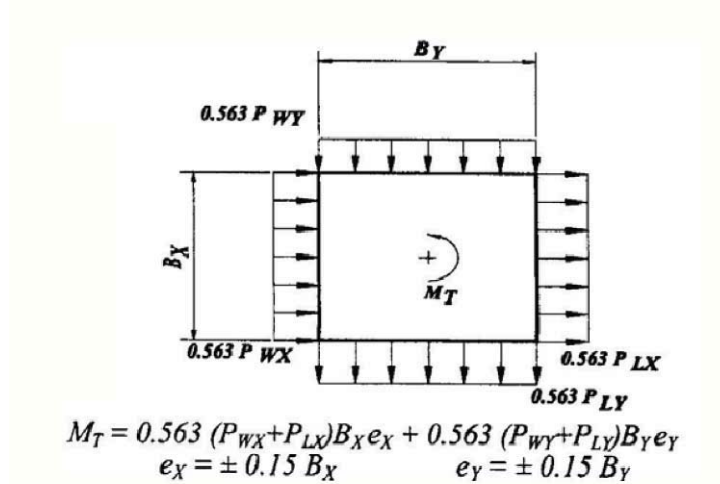


	Grid A	Grid C	Grid D	Grid I	Grid 2	Grid 3	Grid 4	Grid 10
Wind Case 3	485	80	315	1600	208	278	99	1783

*All values shown above are in kips and un-factored.

Wind Case 4:

Wind Case 4 considers loading similar to Wind Case 2, however the wind is acting simultaneously. Moment and wind forces are factored according to the image below.



	Grid A	Grid C	Grid D	Grid I	Grid 2	Grid 3	Grid 4	Grid 10
Wind Case 4 (+M)	85	82	566	617	109	212	112	2043
Wind Case 4 (-M)	672	45	66	1857	227	241	51	716

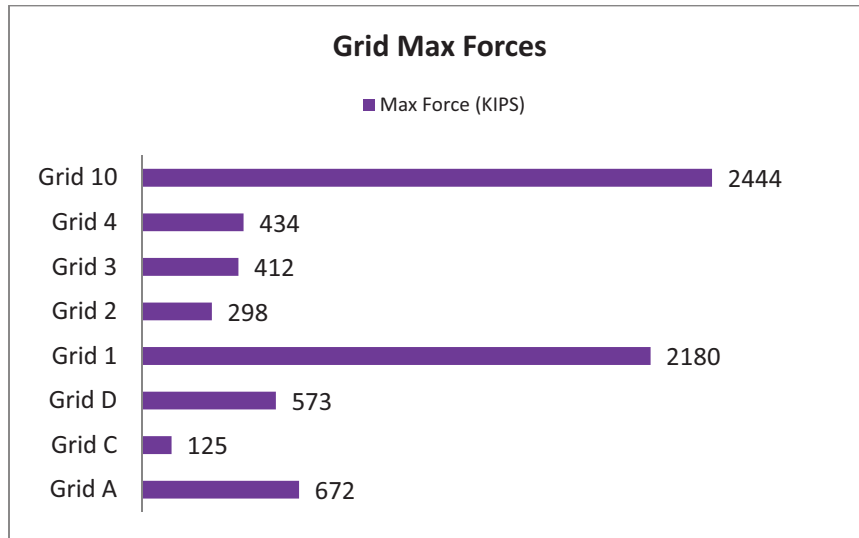
*All values shown above are in kips and un-factored.

Wind Cases 1-4 Summary:

Table 7: Wind Case Summary

	Grid A	Grid C	Grid D	Grid I	Grid 2	Grid 3	Grid 4	Grid 10
Wind Case 1	566	125	573	2180	298	412	156	2444
Wind Case 2 (+M)	351	92	470	1400	194	280	434	1940
Wind Case 2 (-M)	461	86	351	1697	223	290	101	1617
Wind Case 3	485	80	315	1600	208	278	99	1783
Wind Case 4 (+M)	85	82	566	617	109	212	112	2043
Wind Case 4 (-M)	672	45	66	1857	227	241	51	716
	Grid A	Grid C	Grid D	Grid I	Grid 2	Grid 3	Grid 4	Grid 10
Max Force (KIPS)	672	125	573	2180	298	412	434	2444

Graph 2: Maximum Grid Force Summary - Wind



As seen from the chart and graph comparison above, Grids 1 & 10 are required to withstand the largest wind forces from Wind Cases 1-4 analysis. Grids 1 & 10 are both resisting forces in the East-West Direction. The East-West direction is a large concern of the author and will be discussed in-depthly throughout this thesis report.

Overturing Checks:**Table 8: Overturing Moment Calculations**

Overturing Moment due to 1.6Wind										Overturing Moment (K-FT)	
N-S	PSF*1.6 (N-S)	Height of Level (FT)	Width	Force (K)	E-W	PSF*1.6 (E-W)	Height of Level (FT)	Width	Force (K)	N-S	E-W
14	183.28	18.67	80.66	276.00	14	218.19	18.67	193	786.21	59236	168739
13M	182.20	9.83	80.66	144.46	13M	217.11	9.83	193	411.91	28947	82536
13	181.19	8.83	80.66	129.05	13	216.10	8.83	193	368.28	24654	70359
12M	180.03	7.83	80.66	113.70	12M	214.95	7.83	193	324.82	20775	59350
12	178.94	8.83	80.66	127.45	12	213.85	8.83	193	364.45	22225	63554
11M	177.68	9.83	80.66	140.88	11M	212.59	9.83	193	403.33	23253	66572
11	176.48	8.83	80.66	125.70	11	211.40	8.83	193	360.26	19574	56102
10M	175.10	9.83	80.66	138.83	10M	210.01	9.83	193	398.43	20324	58329
10	173.78	8.83	80.66	123.77	10	208.69	8.83	193	355.65	16964	48747
9M	172.23	9.83	80.66	136.56	9M	207.15	9.83	193	393.00	17444	50199
9	170.75	8.83	80.66	121.61	9	205.66	8.83	193	350.49	14400	41500
8M	169.00	9.83	80.66	134.00	8M	203.91	9.83	193	386.87	14616	42197
8	167.30	8.83	80.66	119.16	8	202.22	8.83	193	344.61	11885	34374
7M	165.27	9.83	80.66	131.04	7M	200.19	9.83	193	379.79	11848	34339
7	163.27	8.83	80.66	116.29	7	198.19	8.83	193	337.75	9429	27386
6M	160.72	10.25	80.66	132.88	6M	195.64	10.25	193	387.02	9507	27690
6	158.31	8.67	80.66	110.71	6	193.22	8.67	193	323.32	6873	20073
5	154.62	11.5	80.66	143.42	5	189.53	11.5	193	420.66	7458	21874
4	150.33	11	80.66	133.38	4	185.24	11	193	393.27	5435	16026
3	143.75	12.75	80.66	147.84	3	178.67	12.75	193	439.66	4269	12695
2	138.33	11	80.66	122.73	2	169.93	11	193	360.77	2086	6133
1	138.41	11.5	80.66	128.39	1	169.74	11.5	193	376.73	738	2166
Totals										351941	1010941

Overturing Moment/0.5Length		Weight of Building	Weight of Building/2
N-S	E-W		
911.76	6266.68	21724	10862
Overturing Issue			
N-S	E-W		
No	No		

To check if an overturning issue is present in the existing lateral design for the relocation of the building to Miami, FL, an overturning moment was calculated for a wind factor of 1.6. This moment was then divided by 0.5 x Length. This length is the length of the building the overturning moment is acting upon. This value was compared to both the total building weight, and half the total building weight. The overturning moment for Miami, FL increased almost 2 times the overturning moment calculated for New York City wind forces. However, this increase as shown in the calculations is still not enough to cause in overturning moment issue. With no overturning moment issue for Miami, FL the author suspects minimal foundation design changes.

Strength Check:

A strength check has been performed by the author for the relocation of the building to Miami, FL. This strength check focuses on the lateral system wind analysis forces.

Strength Check – Grid 10 – Wind Case I

A strength check for Grid 10 – Wind Case I was performed by the author. The analysis of Wind Case I resulted in a maximum lateral force of 2444 kips resistance provided by Grid 10. This extreme case needed to be checked by the author for further analysis and conclusions.

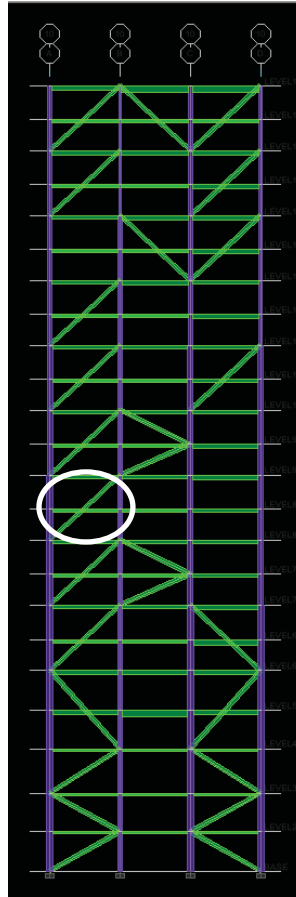


Figure 11: Grid 10 Elevation

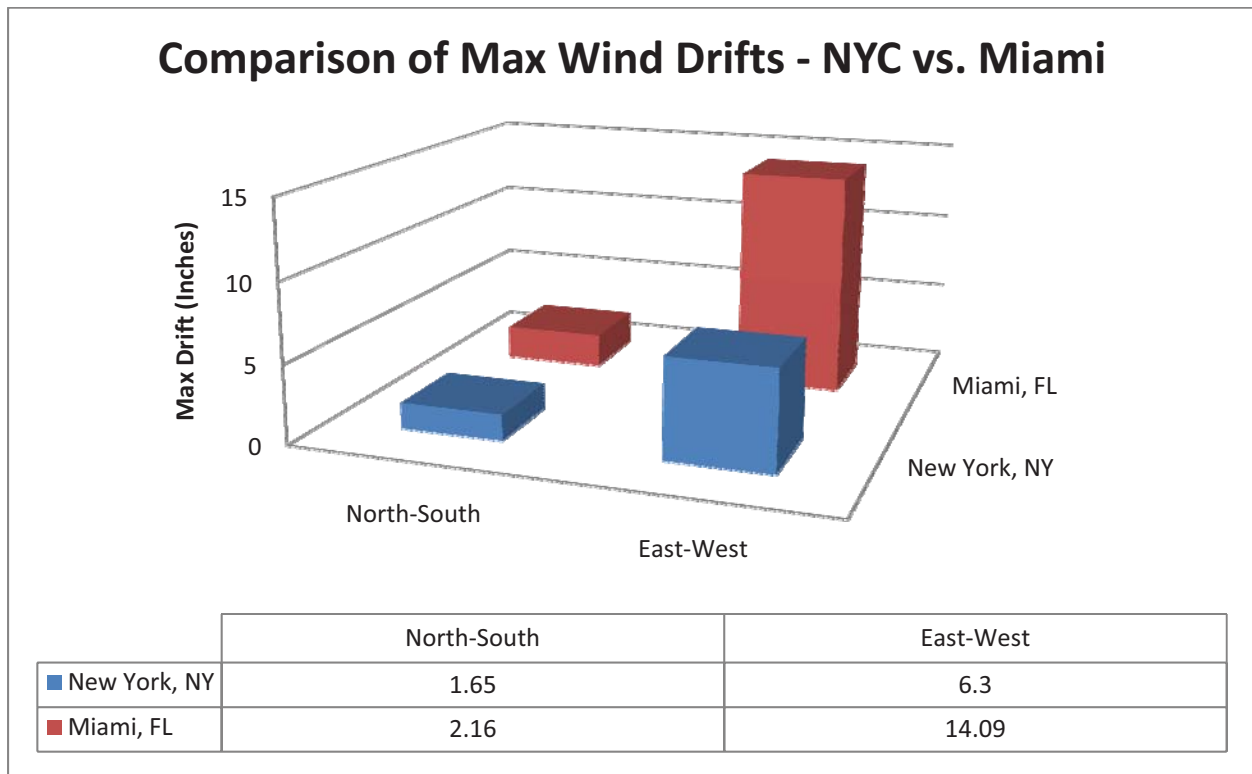
An axial capacity strength check was performed for the circled diagonal member above on Grid 10. This existing member is a W14x90. The strength check concluded that the member does not meet strength requirements. The author suspects many braced frames in the East-West lateral system to fail strength requirements. This issue will be considered during the redesign for Miami, FL. Please see Appendix Section A at the end of this report for supportive calculations.

Table 11: Wind Serviceability Checks - Summary

Wind – Serviceability Checks - Drift		Maximum Allowable Drift: 6.78 inches (H/400)
North-South – Max Drift	East-West – Max Drift	
2.16 Inches	14.09 Inches	
Okay	Not Okay	

Wind – Serviceability Checks – Story Drift		Maximum Allowable Story Drift: 0.32 inches (0.020h _{sx})
North-South – Max Story Drift	East-West – Max Story Drift	
0.18 Inches	0.96 Inches	
Okay	Not Okay	

Graph 3: Wind Drift Comparison – NYC vs. Miami



Discussion of Serviceability Checks:

As seen on the previous page the East-West direction is not fulfilling drift and story drift requirements. Therefore, the East-West direction will need to have an increase in overall stiffness upon redesign. The author will propose additional braced frames, and larger members to fulfill stiffness requirements to reduce drift and story drifts seen previously.

Structural Depth Study

Task Three – Redesign and Analyze Lateral System (Miami, FL)

Description:

The completion of task two concluded that a redesign of the Northwest Science Building's lateral system was necessary due to the increase wind forces of Miami, FL. The lateral system must be made stiffer in the East-West direction. Instead of just increasing the cross sectional sizes of the diagonal bracing members, it is proposed to do a complete lateral redesign of the structure. Chevron bracing has been researched and is seen as a viable system based on economical concerns. Using this bracing type, the lateral system has been redesigned. The redesign process and analysis can be found on the following pages.

Upon the selection of the chevron bracing system, the following steps have been completed in the following order for task three.

- Provide initial frame sketches and stiffness calculations believed to withstand Miami, FL wind forces.
- Create ETABS model of redesigned lateral system.
- Analyze model with obtained wind forces. (Miami, FL)
- Record drifts and story drifts.
- Compare drifts and story drifts to Task 2 results.
- Provide checks of overturning and strength.
- Note any impact on foundations and design accordingly.

Tables and Figures:

Below is a bulleted list explaining the tables and figures to follow, regarding the redesign of the lateral system for Miami, FL.

- Figure 13: Lateral Bracing Systems
 - Images of the four bracing systems to be considered as a redesign component.
- Table 12: Lateral Bracing Systems – Advantages/Disadvantages
 - Discusses the positives & negatives to be aware of for each system.
- Figure 15: Braced Frame Sketch (Grids 1 & 10)
 - Proposed additional braced framing by author.
- Figure 16: Preliminary Braced Frame Sizes (Grids 1 & 10)
 - Proposed section sizes of members based on axial and tension loads.
- Table 13: Wind Case Summary
 - Provides the maximum base shear forces on each grid. This information is used by the author to determine the governing wind force on each grid.
- Table 14: East-West Direction – Wind Serviceability Checks (*found in Structural Depth Appendix A*)
 - Story drift and drift checks of redesigned lateral system in East-West direction.
- Table 15: North-South Direction – Wind Serviceability Checks (*found in Structural Depth Appendix A*)
 - Story drift and drift checks of redesigned lateral system in North-South direction.
- Table 16: Wind Serviceability Checks – Summary
 - Provides conclusions on story drift and drift checks of redesigned lateral system in North-South direction.
- Graph 5: Wind Drift Comparison – Existing vs. Redesign

Types of Lateral Bracing Systems:

Below is an image of four lateral bracing systems to be considered for the Northwest Science Building's redesign in Miami, FL.

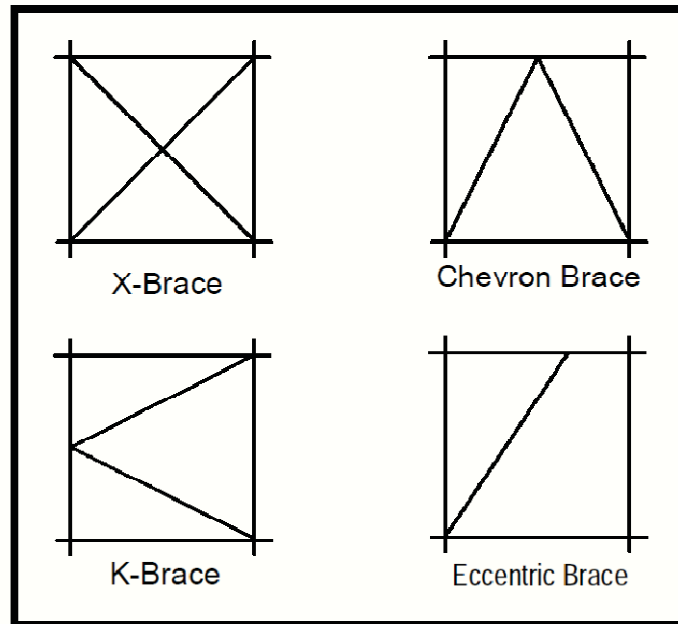
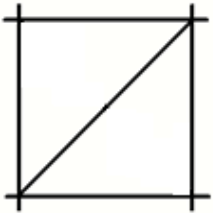
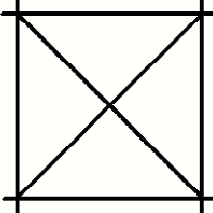
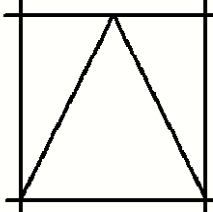
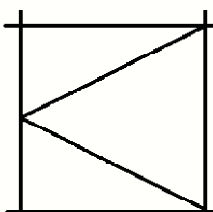
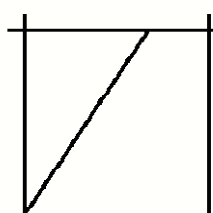


Figure 13: Lateral Bracing Systems

The advantages and disadvantages of each bracing system (along with the existing bracing system) are discussed on the following page.

Table 12: Lateral Bracing Systems – Advantages/Disadvantages

Lateral Bracing System	Advantages	Disadvantages
 <p>Diagonal Brace (Existing System)</p>	<ul style="list-style-type: none"> • Designed as both a compression and tension member • Less connection labor • Economical Design 	<ul style="list-style-type: none"> • Larger members/sections required • Blocks circulation within building, must be coordinated with architect
 <p>X-Brace</p>	<ul style="list-style-type: none"> • Smaller members/sections used • Geometrically stable/braced in all four corners 	<ul style="list-style-type: none"> • More connections required • Connection labor expensive • Blocks circulation within building, must be coordinated with architect
 <p>Chevron Brace</p>	<ul style="list-style-type: none"> • Smaller members/sections used • Allow circulation within building 	<ul style="list-style-type: none"> • Design must considered shear transfer at midpoint of beam
 <p>K-Brace</p>	<ul style="list-style-type: none"> • Smaller members/sections used 	<ul style="list-style-type: none"> • Blocks circulation within building, must be coordinated with architect • Design must considered shear transfer at midpoint of column
 <p>Eccentric Brace</p>	<ul style="list-style-type: none"> • Flexible design - can provide plenty coordination with architect's requests 	<ul style="list-style-type: none"> • Design must considered eccentric force effects

Discussion of Lateral Bracing Systems:

The previous page explains many advantages/disadvantages a designer should be aware of when choosing a lateral bracing frame system. After studying each system, the author believes implementing the Chevron Brace into this thesis redesign is the best alternative. The following paragraph describes the reasons why the chevron bracing system was chosen.

Task 2's Existing Lateral System Analysis confirmed that the lateral system needs a substantial increase in the stiffness of the East-West lateral system. A great amount of stiffness in this direction comes from the two exterior frames of the structure. The author believes more interior frame bracing will be needed for the East-West direction. Chevron bracing will allow for minimal circulation concerns with the addition of these braced interior frames. The design will require more connection design and labor than the existing system; however, the increase in connections is not substantial compared to the three other proposed systems.

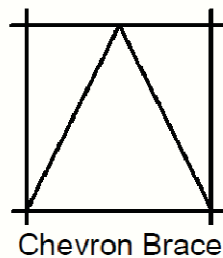


Figure 14: Chevron Brace – Chosen Lateral Bracing System

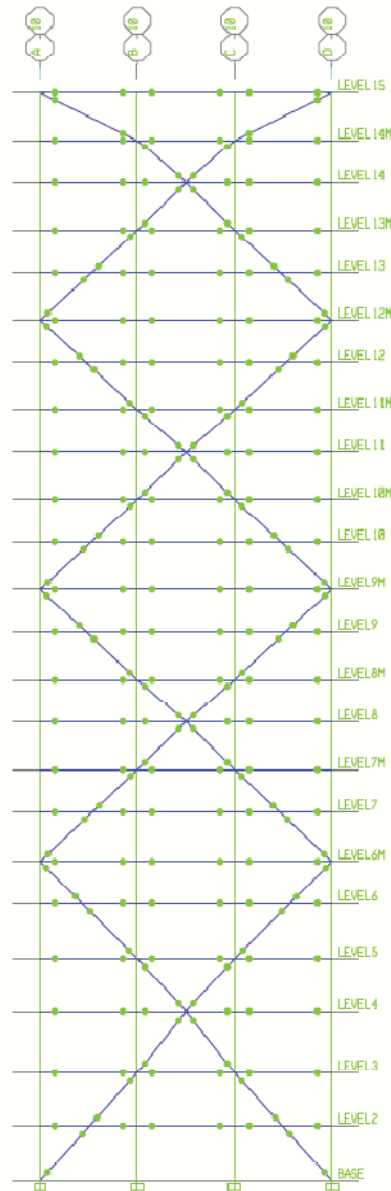
Preliminary Redesign:

The East-West lateral system as discussed in Task 2 needs to be redesigned to meet drift, story drift, and strength requirements. The redesign of the East-West lateral system is of more concern to the author and therefore will be redesigned, analyzed, and discussed more than the North-South system. The North-South redesign will be limited, due to the existing design fulfilling drift and story drift requirements and most strength requirements.

The preliminary design addressed the two exterior braced frames in the East-West direction. These frames currently provide most of the lateral resistance. The existing design, however, does not provide a continuous bracing path from the top to the bottom of the structure. This existing design was effective and cost efficient for New York City. With the relocation of the building to Miami, FL the author believes that these two braced frames will need to provide continuous bracing. Larger member sizes are also expected to be utilized.

The author chose the use of chevron bracing. After a few hand sketches, a schematic braced frame design was chosen. The following page provides the braced frame sketch.

Figure 15: Braced Frame Sketch (Grids I & 10)



This sketch provides continuous bracing from the top to bottom of the structure. This continuous bracing is expected to increase the stiffness of the East-West lateral system. This design is also seen to be more geometrically pleasing to the eye. These grids are exterior and will be seen. The use of architectural materials along with the brace framed system will be studied in the Architectural Breadth Study later in this report.

Once the braced frame geometry was chosen and sketched a design analysis was ready to take place. In order to get the members to reasonably accurate sizes, an ETABS model was used to find axial forces within the braced frame members. Braced frame sections were chosen based on the following two assumptions.

- The controlling wind cases for each grid were the same as the existing lateral system analysis. (See Task 2)
- Due to concentric connections the braced members were analyzed as axial members.

With these assumptions braced frame members could be chosen. Their unbraced length along with axial forces found will determine the member size. This process had to be reiterated several times until axial load forces remained fairly constant. The following preliminary design was determined.

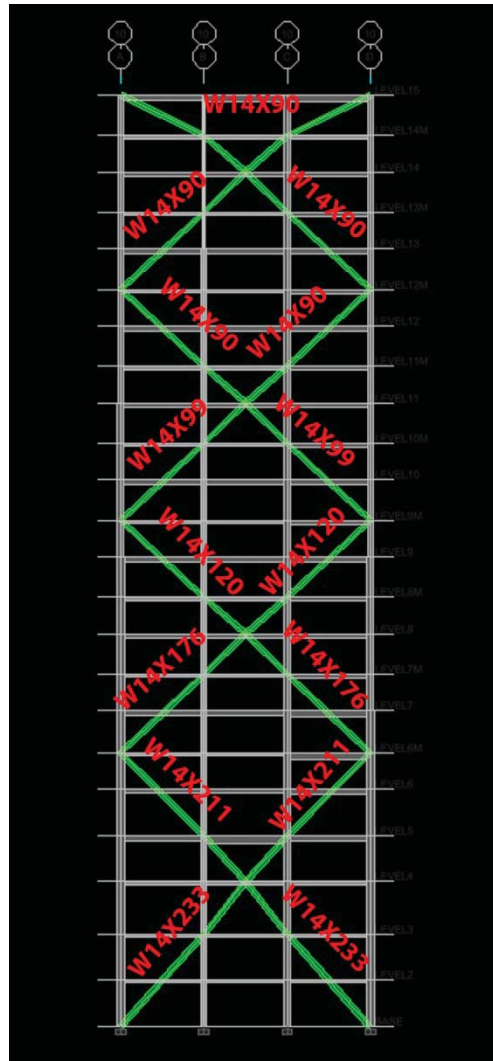


Figure 16: Preliminary Braced Frame Sizes (Grid I & 10)

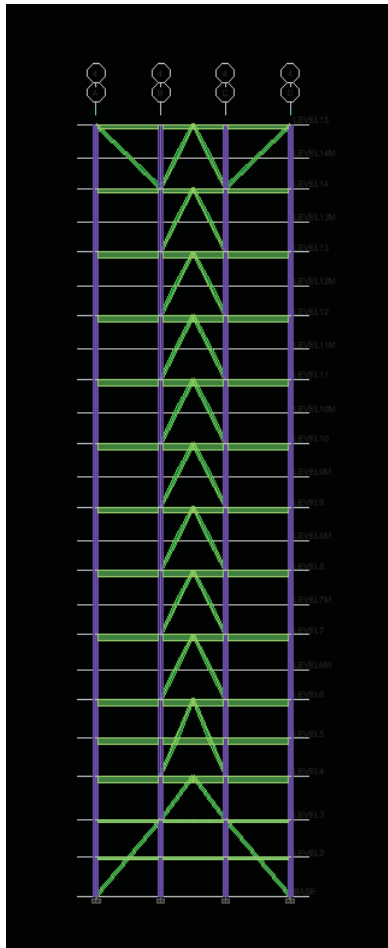
Finalized Redesign:

To finalize the redesign the following steps needed to be made:

- Provide additional stiffness to East-West lateral system to limit drift to an allowable drift of 6.78 inches. Currently preliminary design is drifting 7.62” at roof level.
- Once preliminary design is finalized, recheck strength requirements of braces.
- Check the strength requirements of the columns participating in the lateral system and redesign accordingly.
- Check the North-South lateral system for strength requirements.

Additional stiffness was provided within Grid 4 of the East-West lateral system. Chevron bracing was utilized throughout this grid because it is an interior frame. Chevron bracing allows for minimal interior space interference. The chevron bracing seen below is adjacent to an elevator shaft. This placement of bracing was seen by the author to be both architecturally and structurally acceptable.

Figure 17: Grid 4 – Chevron Bracing



The additional stiffness provided by Grid 4 reduced the overall deflection to 6.77 inches which meets serviceability requirements.

The braces strength requirements were checked based on pure axial and tension requirements. All of the braces provided are assumed to be concentric, therefore pure axial and tension will be governing design factors. LRFD compression and tension tables were used to check each member's capacity.

Summary of Strength Requirements Checked for Bracing:

- Available Compressive Strength ($\Phi_c P_n$)
- Local Buckling
- Effective Length and Column Slenderness
- Available Strength in Axial Tension ($\Phi_t P_n$)

All of the bracing for the East-West lateral system was checked and modified if needed for the above design checks. All concentric braces were assumed to transfer only wind loads. Therefore a 1.6 Wind Load factor and combination was used. For finalized member framing sizes see the Appendix Section A at the end of this report.

North-South direction design checks were focused upon the truss bracing at the 126 foot clear span level. These members are critical due to the fact that they support both gravity and lateral loads. Most of the members were acceptable with increased loading. The author believes the factor of safety these members were designed with was higher than first expected. A higher factor of safety could be due to the fact that this structure is very unique (has a 125 foot clear span) and therefore additional safety measures were implemented. A few of the members were not acceptable and were modified accordingly for the increase in loads.

Summary of Strength Requirements Checked for Columns:

- Available Compressive Strength ($\Phi_c P_n$)
- Local Buckling
- Effective Length and Column Slenderness
- Available Strength in Axial Tension ($\Phi_t P_n$)

Columns in the East-West direction were strength checked similarly to the brace members. The difference is that the columns will be carrying dead and live loads in addition to the wind loads. The following load combinations were assumed to control by inspection.

- $1.2(\text{Dead}) + 1.6(\text{Wind}) + 1.0(\text{Live})$
- $0.9(\text{Dead}) + 1.6(\text{Wind})$

Several columns needed to be redesigned due to increased wind loads and additional brace frame load transfer. These columns were modified appropriately. For finalized member framing sizes see Appendix Section A at the end of this report.

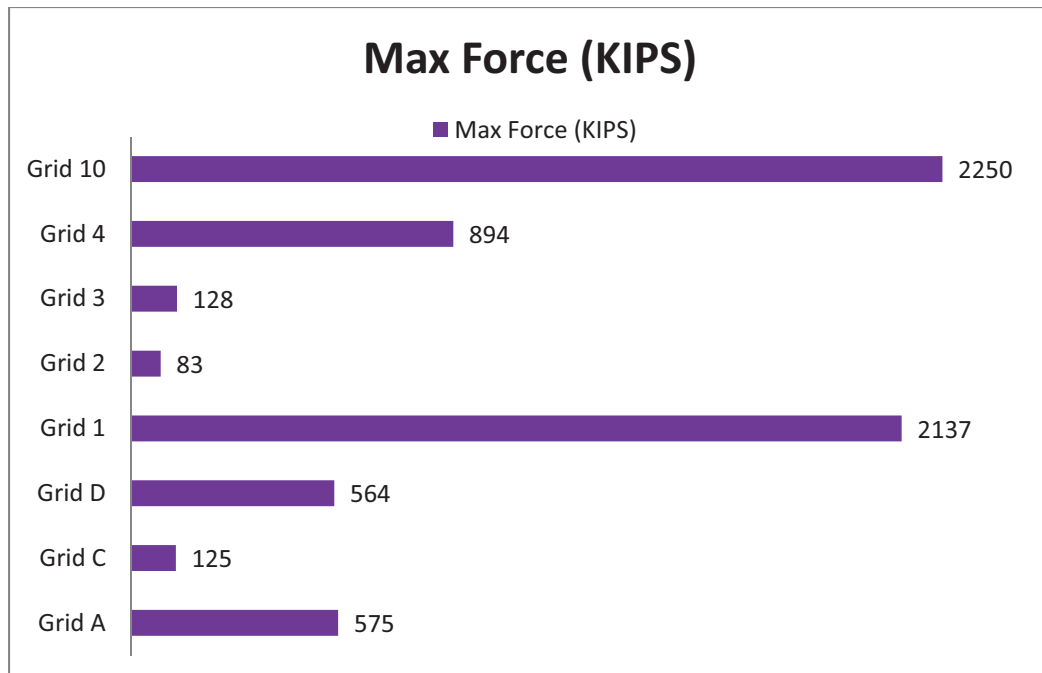
North-South direction columns were checked with the increase loads on the structure. Most columns met their strength criteria. This again is assumed by the author to be due to factor of safety in the initial design. W14x730 column members provide most of the column support towards the bottom of the structure. These members are massive in section and are sufficient for the increased loads.

Table 13 and Graph 4 on the following page summarize the participation of each lateral braced frame for the redesign of the structure. Grids 1 & 10, as seen, provide a great amount of stiffness in the East-West direction and therefore participate greatly in the lateral system.

Table 13: Wind Case Summary

	Grid A	Grid C	Grid D	Grid I	Grid 2	Grid 3	Grid 4	Grid I0
Wind Case 1	575	125	564	2137	83	128	894	2250
Wind Case 2 (+M)	386	90	432	1352	50	84	627	1814
Wind Case 2 (-M)	438	87	375	1686	57	78	640	1465
Wind Case 3	416	89	395	1523	56	75	630	1644
Wind Case 4 (+M)	181	80	470	507	31	81	485	1988
Wind Case 4 (-M)	470	62	155	1905	66	53	515	553
	Grid A	Grid C	Grid D	Grid I	Grid 2	Grid 3	Grid 4	Grid I0
Max Force (KIPS)	575	125	564	2137	83	128	894	2250

Graph 4: Maximum Grid Force Summary - Wind



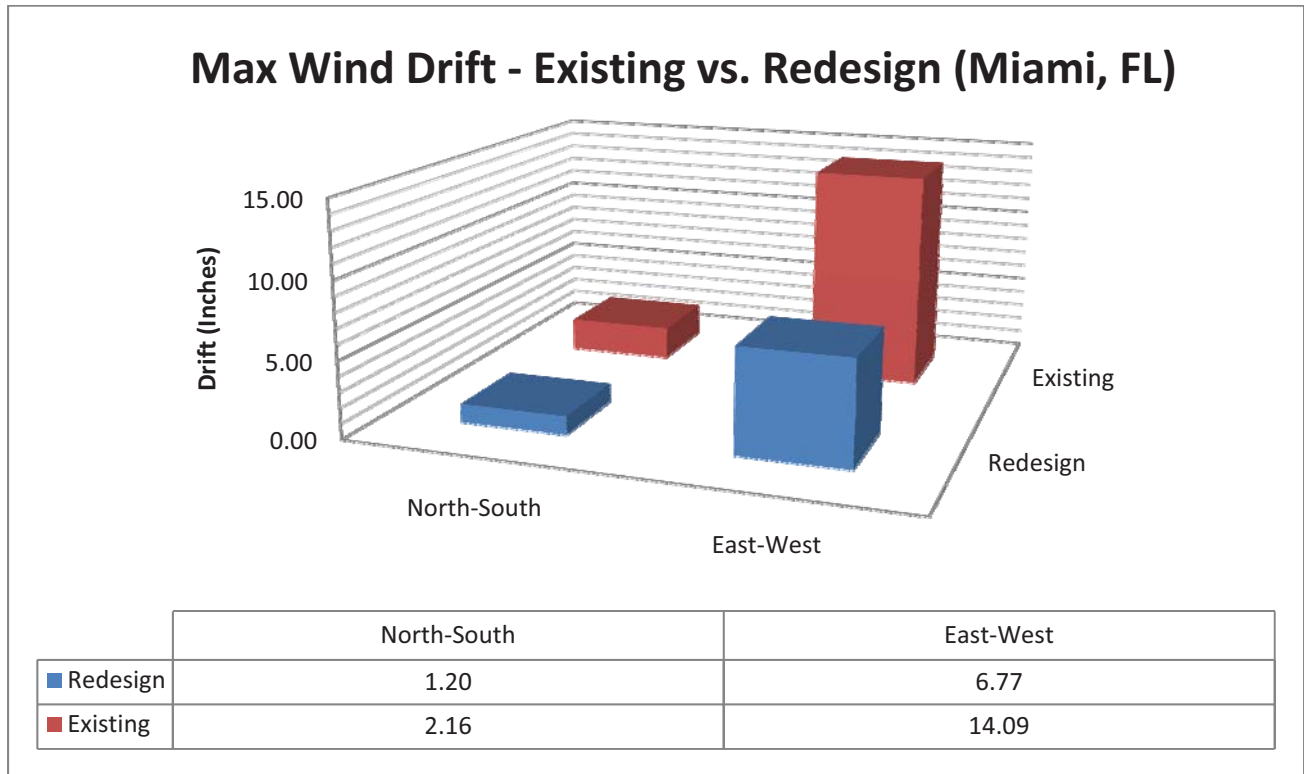
Redesigned Drifts & Story Drifts:

Table 16: Wind Serviceability Checks – Summary

Wind – Serviceability Checks - Drift		Maximum Allowable Drift: 6.78 inches (H/400)
North-South – Max Drift	East-West – Max Drift	
1.20	6.77 Inches	
Okay	Okay	

Wind – Serviceability Checks – Story Drift		Maximum Allowable Story Drift: 0.32 inches (0.020h _{sx})
North-South – Max Story Drift	East-West – Max Story Drift	
0.17 Inches	0.45 Inches	
Okay	Okay (Close Enough)	

Graph 5: Wind Drift Comparison – Existing vs. Redesign



Discussion of Serviceability Checks for Redesign:

The redesigned lateral system is acceptable for story drift and drift requirements as shown on the previous page. With added stiffness in the East-West direction (Grids 1, 4, & 10), the overall drift was reduced by 50% (from 14.09 to 6.77 inches). Serviceability requirements have been met by the author for the relocation of the building to Miami, FL.

Overturning and Strength Concerns of Redesign:

The existing lateral system was analyzed in Miami, FL for overturning acceptability. The existing system did not have any overturning concerns. This is based on the assumption that the site soils are fairly similar to those of the current site (NYC). The redesigned lateral system contains additional stiffness and therefore weighs more than the existing system. With increased weight there is even less of a concern of overturning issues. Therefore, it is assumed by the author that overturning is not a concern for the building. With no overturning concerns, the foundation of the building is seen to be acceptable for strength requirements. Strength checks of the foundation system are not included in the scope of this thesis project. The author suspects the foundation to increase in size slightly due to the increased weight of the redesigned structure.

As previously analyzed and discussed, strength requirements were checked for all lateral system members. After all checks and modifications have been made, strength requirements of the entire lateral system are now seen by the author to be acceptable.