TECHNICAL REPORT 3

The New York City Bus Depot

New York, NY

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Executive Summary:

The following technical report gives a summary of the existing lateral system of the New York City Bus Depot using the 2010 New York State Building Code for analysis as well as the 2006 International Building code and ASCE 7-05. RAM Structural system is the primary tool used in the analysis of the lateral system. SAP2000 is supplemented to this as well for the determination of stiffness of the lateral frames of the building.

RAM Structural system provides a quick and easy analysis of the lateral system through modeling of gravity members, lateral members, diaphragms, and load cases. The preprogrammed load cases from the IBC2006/ASCE7-05 make for a quick and easy analysis of the load cases analyzed to determine the controlling factor on the building.

To determine the controlling load cases, deflections were analyzed from the RAM model. These deflections were set to a ratio with the maximum permitted deflections. The maximum considered deflection for wind is H/400, and the maximum controlling seismic drift is H/240. This seismic drift is used instead of the 0.02H limit defined in the code to prevent nonstructural damage in the event of a quake.

From the controlling load case, shears were determined from the story forced applied to the diaphragms. Relative stiffnesses were also determined from SAP and used to distribute the forces to the frames in each of the three buildings.

In addition to the direct shear resulting from the seismic loads, torsional shear also needed to be taken into account for each building due to the offset of the center of rigidity from the center of mass. These shears combined with the direct shears give the total shear present in each level of the member. No defined numbers are given in the report for this, but a sample torsional shear calculation is shown.

Next, the overturning moments produced are analyzed. The overturning moments produced by the seismic loads that control the design of the building are significantly lower than the resisting moment that results as a function of the mass of the building.

A member check confirms that the analysis of the building from RAM Structural system is indeed accurate. The analyses presented in this report prove the adequacy of the New York City Bus Depot and its lateral system to resist the lateral loads imposed on the building.

Building Introduction (Existing Conditions):

The New York City Bus Depot is a new design-build project that broke ground in June of 2011. This $150 million project is slated for completion in January of 2012. The building site can be seen below in Figure 1 highlighted in red. It is in an area that is currently zoned to be commercial specifically for heavy automotive repair shops that are used for community purposes. The region where this building is to be located was once the place of a river that ran through this part of the city. For this reason, the water table on the site is high and the soil is liquefiable. There is also a portion of the site where there is no solid rock creating a need for piles to be driven down as deep as 150 feet.

Figure 1: Aerial view of the building site highlighted in red. (*Image courtesy of Google Maps).*

The New York City Bus Depot is on a plot of land that is being reused. It was once a former trolley barn in the 1800s and, prior to the most recent demolition, an out-of-date, undersized bus depot that needed expansion for use by the New York City Transit Authority. This new and more environmentally friendly 390,000 square foot bus station will contain facilities for a fleet of 150 busses. The depot will be three stories tall, with each story at an approximate height of 25 feet. On the first floor, facilities will be available for bus refueling, servicing, fare collection, bus washing, and maintenance. The second and third floors will house parking for each of the 150 busses stationed out of the depot. Included in the space will also be offices for employees stationed at the bus depot.

Figure 2: Rendering of the New York City Bus Depot showing its south face and both the corrugated metal and brick veneer facades. *(Image courtesy of STV Inc.)*

Externally, this new facility has a modern appearance with a corrugated metal and brick veneer anchored onto CMU walls as seen in Figure 2. Large, rectangular expanses of windows with aluminum frames help to provide well lit spaces while using minimal electric lighting. The brise soleil that line the tops of the windows on the East façade to control the sunlight entering the building, helping to achieve the most energy efficient performance possible. To pay homage to the vibrant culture of the neighborhood in which the depot is located, artwork will be placed at street level for any passer-by to see. All of these features will help give life to an area of the borough looking to be renewed and revitalized.

In order to be an environmentally friendly facility, the New York City Bus Depot plans to employ green technologies. Two major highlights for this are located on top of the building: a green roof and a white roof. This green roof will help to minimize carbon dioxide emissions (particularly important for such a crowded borough of the city), and the white roof will help to regulate heat gain for the building. Other technologies to be included in the building are a rain water collection system, low emission boilers, heat recovery units, water efficient fixtures, recycled materials, and day-light centered lighting design. In addition to a rain water collection system, a water reclamation system is planned to recycle the water used in bus washing facility. All of these features aim to lead the New York City Bus Depot to a LEED certification upon completion of construction.

Structurally, this building is one which is steel framed. It has unique floor framing due to the multitudes of point loads applied from busses and their towing counterparts. Floors on levels two and three are also ramped like an over-sized parking garage for this bus fleet. Unique loading patterns are also created due to the busses as well as the mixed use occupancy of the building. At the present time, the building is at a 65% submittal stage with its contract documents and more information will be provided as updates are received.

Structural Overview

The New York City Bus Depot is a three story, 80' tall building that rests on piles grouped together with caps scattered throughout the site. The piles are deep due to the site class E classification that indicates the chance for liquefaction of the soil. The building itself can be treated as three separate buildings, as shown in figure 3, due to the large expansion gaps that separate the framing systems of the building. The first floor consists of a heavily reinforced slab that is 14" to 18" thick for travel by heavy busses and towing vehicles. The framing system consists of heavy steel beams that are designed to resist the loads caused by the traveling busses. On top of each level of this steel framing sits a 6" reinforced concrete slab. This slab is supported by 2" 18 gage metal deck, however this deck is considered as sacrificial and all designs are calculated as though there is simply a concrete deck sitting upon the steel beams.

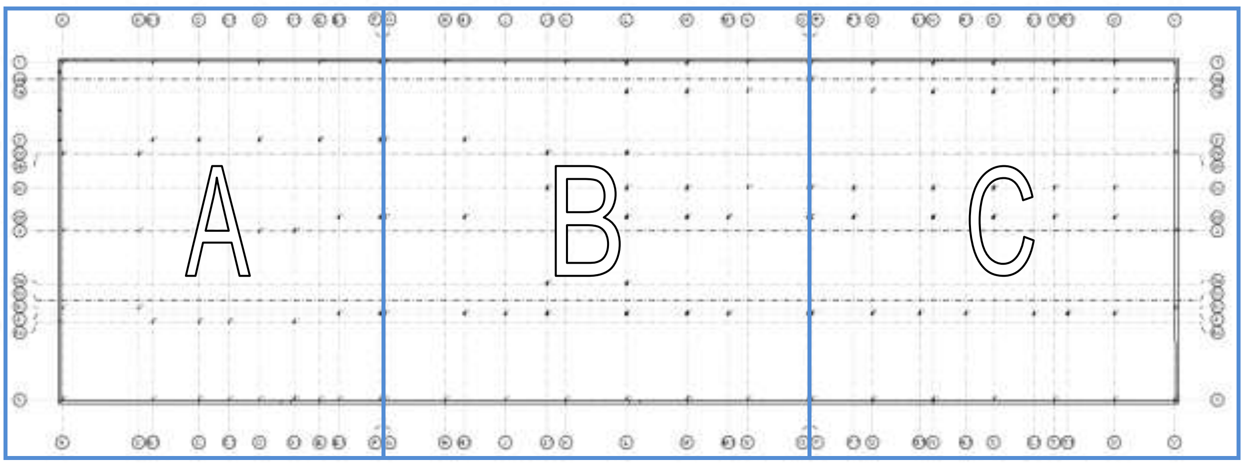


Figure 3: Depiction of the -6" Expansions joints that separate the structure into three distinct structural systems as denoted by the blue boxes.

Foundations:

The New York City bus depot requires the use of deep pile foundations due to the site's soil conditions. The site contains layers of organic material that compress under long-term loading, making the site unsuitable to maintain a shallow foundation. Another reason for the pile foundation lies in the liquefaction potential of the soils. Those below the water table, which is about 8' below the site surface, consist of a stratum of sand and a stratum of silt and clay all over weathered rock and bedrock. When tested, it was deemed that these would likely not liquefy during a strong earthquake, but there were some local areas that showed liquefaction potential if the 2500-year event were to occur in the city.

The piles recommended for the site are steel HP12x102 piles that possess the ability to maintain 220 tons (or a service load of 200 tons after subtracting 20 tons of downdrag). These piles are used to support the ground floor structural slabs, columns, and heavy equipment requiring extra reinforcing. They terminate at an elevation 107'-6" above sea level. These piles are required to be driven down to bedrock, which is between 35' and 100' below grade depending on the area of the site. The piles must be hammered into the ground and have a final driving resistance no less than 5 blows per quarter inch of penetration. Also, because of the low pH of the ground water, corrosion effects must be taken into consideration. Due to the effects of this, the piles are to be analyzed for strength at a size 1/8" thinner in the webs and flanges than prescribed. In addition to being able to maintain 200 tons of compression, the piles are to withstand a lateral load of 5.5kips for a single pile and 3.8kips for each pile when analyzed in groups in the pile caps.

Floor Systems:

Two flooring systems are considered in the New York City Bus Depot. On the first floor, there is a slab on grade with a thickness still to be determined. This thickness is to be between 14" and 18" due to the heavy, concentrated loads imposed by the various busses and maintenance vehicles utilizing the facility and the long spans of the slab between piles.

The typical framed flooring system on the second floor, third floor, and third floor mezzanine consists of steel beams and girders supporting a 6" one-way concrete slab on a 2" gage sacrificial composite form deck. This slab on deck is to be reinforced with a rebar layout that yet to be determined on the design drawings. Analysis presented later in this report yields a theoretical value for this reinforcing. The span of this deck is also yet to be determined since the reinforcement has also yet to be determined.

What controls the design of the thickness of the slab is not the distributed load, but instead the point loads induced by the buses. Worst case loadings of the tires of the busses are treated as 4.5"x4.5" squares with the applied point loads dictated in the dead load section of this report. This 4.5"x4.5" square is used in the evaluation of punching shear, which controls the thickness of the slab.

Various beam sizes are used in construction of this structure because of the varying spans, many of which are much longer than the conventional 30 feet bays. Smaller spans under 30'-0" are generally made up of inlay beams of W14s, W16s, and W18s. Larger spans are made of W 24s, W27s, and W30s. Examples of these spans include W27x84s that span 49'-10" and W30x99s that span 55'-6". Girders utilized on these floors include W30s, W33s, W40s, and W44s.

On the west end of the building, ramps are utilized to lead busses to the parking areas on the second and third floors. These are also steel framed with same metal decking described as typical on other areas of the floor. They utilize W24x76s that span the following: 45'-0" on the North and South ends of the ramp and 44'-2" on the West end.

Framing System

The rest of the framing system of the New York City Bus Depot consists of steel columns. They are all W14s with the exception of one W15x655 in a moment frame that supports 1001kips of service dead load and 573kips of service live load. The columns can be expected to support rather large axial loads due to the heavy imposed loads seen in appendix B and the heavy materials.

Lateral System

The lateral system for this building consists of two types of frames: braced and moment. Braced frames flank the interior runs of the ramps on the west side of the building and also run east to west on the exterior lines between column lines O and P as shown in blue on Figure 4. The moment frames are those which run north and south. They are located at column lines F, H.1, J.1, L, M, P.1, Q.1, S, T, U, and V respectively as shown in Figure 4 in orange.

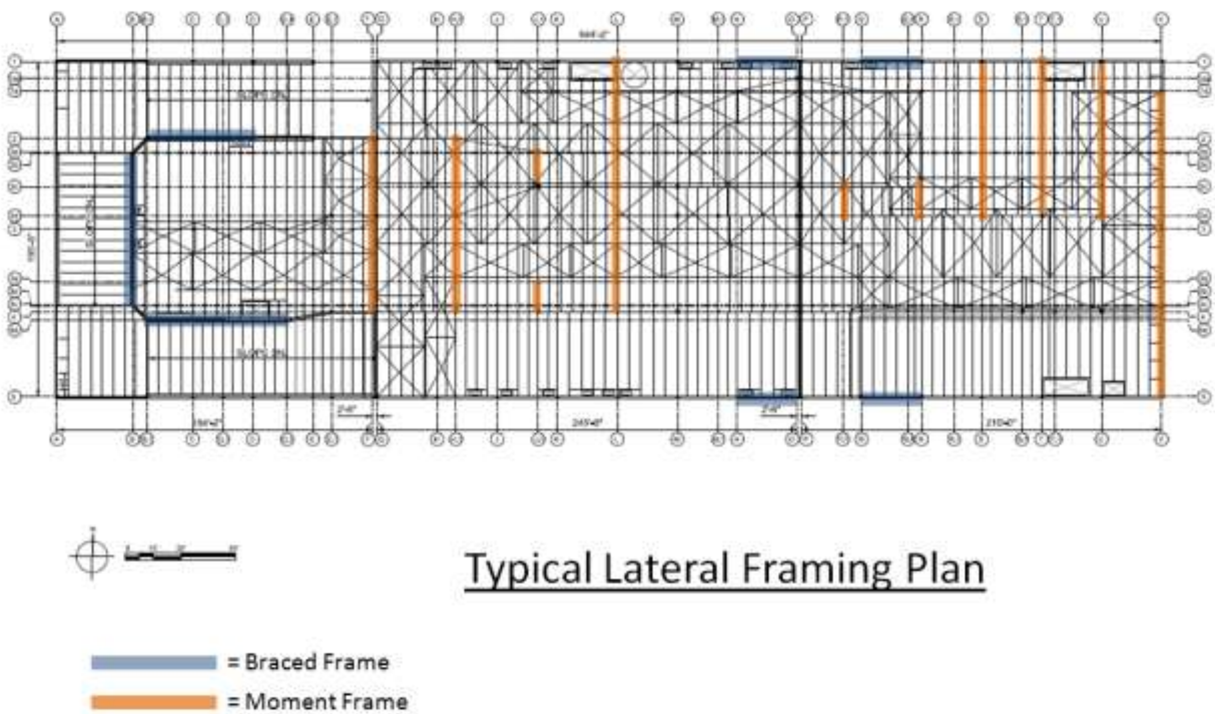


Figure 4: Locations of Moment and Braced Frames.

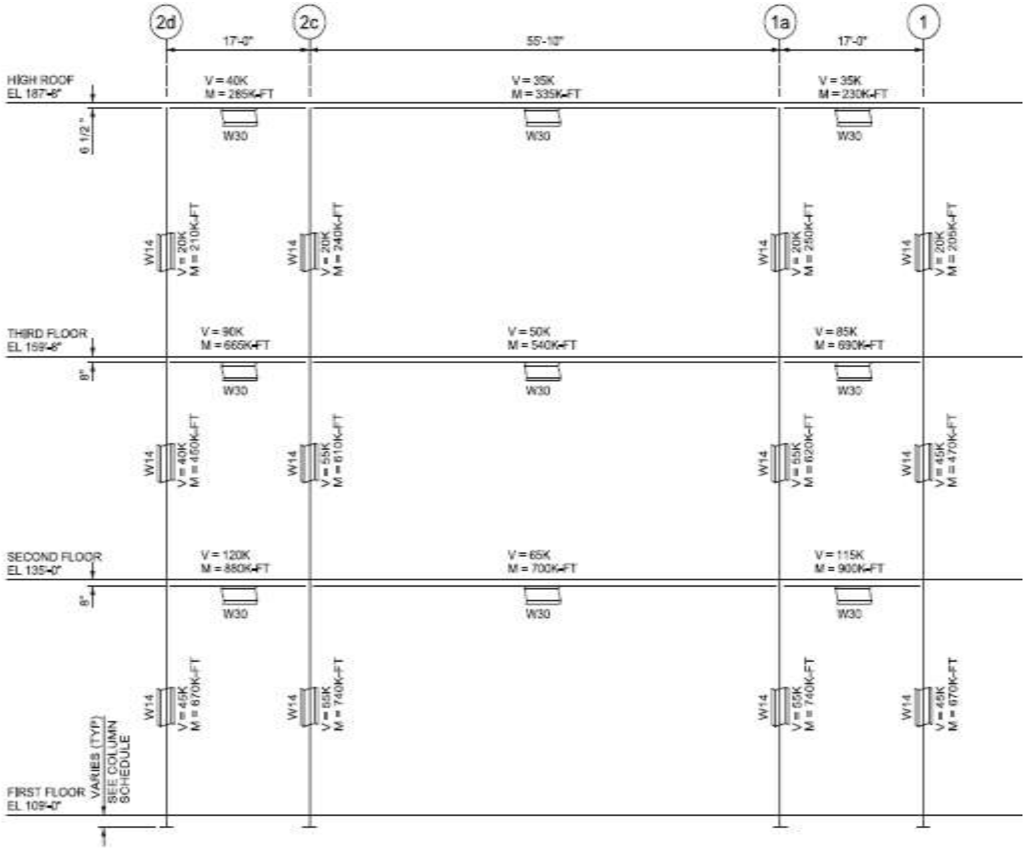


Figure 5: Typical moment frame construction

The moment frames are constructed of W14 columns and W30 beams assembled such that the controlling seismic loads may be resisted. The moment frames are required to resist service loads ranging from shears of 5kips along the first floor columns of the frame running along F, to 455kips on the second floor beam along column line V between columns 5 and 3c. These must also resist moments of 1895kip-ft along column line V to 65kip-ft in first-floor column 2F. A typical construction of a moment frame is shown in Figure 5.

The braced frames are constructed of W14 columns of significant weight with W12 members that act as bracing. The diagonal lines that can be seen in Figure 6 show the ramp in the garage. This location, on the west end of the bus depot, is most heavily reinforced with these braced frames due to the vibrations that the walls will have to handle from the traveling busses.

With the exception of one frame, all of the braced frames run from east to west. It is easy to use the braded frames on the west end of the building because there will be no interference with architectural features on the façade there. Windows are in place in the bus parking and office areas to the east, but not in the location of the ramp. Also, on the interior, where these are located will not interfere with bus travel lanes: a key component to the functionality of the bus depot.

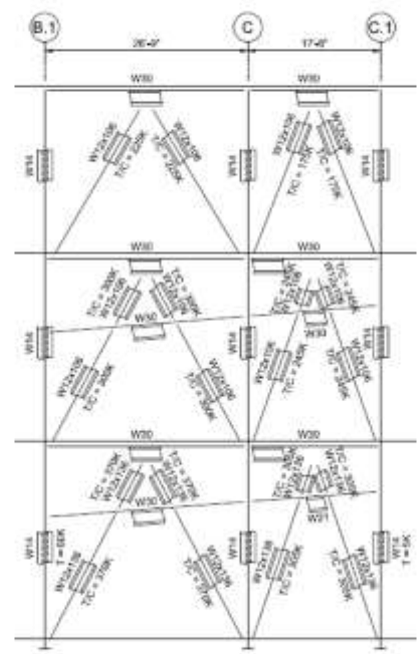


Figure 6: Typical braced frame construction.

Roof Systems

The roof of the building is framed similarly to the floors below with respect to size and bay spacing. Certain bays, particularly those above the ramp, utilize smaller W21s because they do not need to be concerned with carrying the weight of the busses. Overall, the roof maintains a similar beam sizing because significant weight is still expected to be carried by the system. The roof will be supporting a green roof as well as a series of air handlers stationed along the north and south edges of the roof.

The decking on the roof will consist of a 4 ½" concrete covering on a 2" 18 gage cold form metal deck. Reinforcement and span for the roof deck/slab system is yet to be determined at this stage of the project.

It should also be noted that the roof has two levels to it. The main roof consists of a diaphragm at 72' and a parapet extending up to 80". The 69' swath of the roof furthest east is actually a bulkhead above the 3rd floor mezzanine where the office space is located. This tops off at a level of 93.' This high level is used in computing wind loads so that the highest factor of safety is considered. See the Wind Load section for more details and Appendix B for calculations.

Design Codes

- 2010 Building code of New York State
    - Adopts 2006 Family of Codes (IBC, IRC, IFC, IMC, IPC, IFGC, IPMC, IEBC) and 2009 IECC
- North American Specifications for the Design of Cold Formed Structural Steel Members "AISI-NASPEC" (Metal Decking)
- 2008 New York City Building Code (Foundations)
- AISC Manual of Steel Construction – Allowable Stress Design, Thirteenth Edition
- Structural Welding Code – Steel (AWS D.1 – Modified by AISC Section J2)
- Details and Detailing of Concrete Reinforcement ACI 315
- Building Code Requirements for Structural Concrete ACI 318-08
- 2008 Building Code Requirements for Masonry Structures (ACI 530-08/ASCE 5-08/ TMS 402-08)
- Specifications for Masonry Structures (ACI 530.1-08/ASCE 6-08/TMS 602-08)

Materials Used (continued on next page)

Material Properties		
Material		Strength
Steel	Grade	fy = ksi
Wide Flange Shapes	A992	50
Hollow Structural Shapes	A500, GR. B	46
Plates	A572	50
Pipe Shapes	A53, GR. B	46
Anchor Rods	F1554	36
Sag Rods	A36	36

Welding Electrodes	E70XX	70
Welding Electrodes (Gr. 65)	E80XX	80
Steel Reinforcement	A615	60
Bolts (3/4”-1” dia.)	A325	N/A
Bolts (1-1/8” dia)	A490	N/A
Deck	Gage	
2” Form Galvanized Metal	18	
Concrete	Weight (pcf)	f’c = psi
Formed Slabs	150	5,000
Structural SOG	150	5,000
Slabs on Metal Deck	150	5,000
Foundations	150	5,000
Masonry	Grade	fy = ksi
Concrete Masonry Units	C90	1.9
Mortar	C270, Type M	N/A

Table 1: Material Properties

Gravity Loads:

Dead and Live Loads:

The dead and live load distributions on the floors and roof can be seen in the plans in Appendix B. The following charts compare the dead and live loads utilized in the design with those outlined in the New York State Building Code (2010 Edition):

Dead Loads:

Floor	Distributed Floor Dead Load (psf)	Area (ft^2)	Col. Wt (lb)	Exterior Façade (lb)	Weight per floor (k):
Floor 1	200	125902	502.5	1047696	25682.9
Floor 2	100	125902	922.3	1934208	13512.5
Floor 3	100	125902	622.2	1450656	13212.4
Floor 3 (Mezz)	100	13489.5	30	1128288	1378.95
Roof	100	112412.5	189.9	1128288	11431.15
High Roof	100	13489.5	18.4	564144	1367.35

Table 2: Dead Loads and Floor Weight

In the New York State Building Code, dead loads are dictated to be the actual weight of construction materials. No superimposed loads are suggested in the code, but in this project, they are included. The distributed floor dead load in the chart above does not include these superimposed values. This includes the slab weight and a 15psf beam allowance. Added to this, for total construction weight per floor, is the weight of the columns per floor, and the weight of the exterior façade, which is assumed to be 48psf. The additional superimposed dead loads are 10psf for the first floor; 35psf for the second floor, third floor, and third floor mezzanine; and 95psf for the roves for miscellaneous permanent and semi-permanent equipment such as the air handlers on the roof, maintenance equipment on the first floor, and office materials on the third floor mezzanine.

Live Loads:

Floor	Function	Assigned Live Load (psf)	NYS Code 2010 Perscribed LL (psf)	Notes
Floor 1	Maintenance	250	50	See Chart: Concentrated Loads
	Storage	300	250	
Floor 2	Bus Parking	175	50	See Chart: Concentrated Loads
	Future Shop	250	250	
	Office	150	50	Compact, Versitile
	Vault	600	250	Undisclosed Use
Floor 3	Bus Parking	100	50	See Chart: Concentrated Loads
	Office	150	50	Compact, Versitile
Floor 3 (Mezz)	Office	150	50	Compact, Versitile
Roof	Roof	30	100	Green Roof

Table 2: Live Loads analyzed vs perscriped

The live loads prescribed in the design documents (seen in appendix B) for the New York City Bus Depot are generally close to those dictated in the 2010 New York State Building Code. The reason for some of the larger discrepancies is due to the unique occupancy of the structure. Live loads for bus and truck parking garages are generally defined in linearly distributed loads along lanes and concentrated loads. Below are the New York State Building Code's minimums for bus and truck parking facilities as well as the concentrated loads expected for the facility by the design engineers. These values are show in tables 3, 4, and 5 respectively

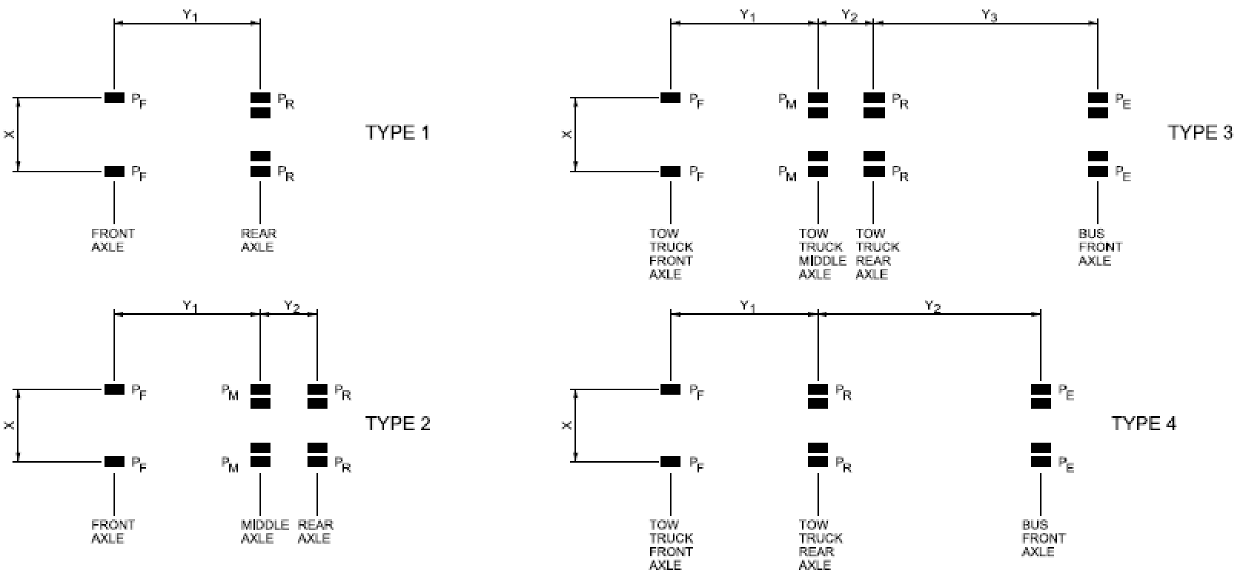
2010 New York State Building Code:
TABLE 1607.6 UNIFORM AND CONCENTRATED LOADS

LOADING CLASS[a]	UNIFORM LOAD (pounds/linear foot of lane)	CONCENTRATED LOAD (pounds)[b]	
		For moment design	For shear design
H20-44 and HS20-44	640	18,000	26,000
H15-44 and HS15-44	480	13,500	19,500

a. An H loading class designates a two-axle truck with a semitrailer. An HS loading class designates a tractor truck with a semitrailer. The numbers following the letter classification indicate the gross weight in tons of the standard truck and the year the loadings were instituted.

b. See Section 1607.6.1 for the loading of multiple spans.

Table 3



CONCENTRATED WHEEL LOAD DIAGRAMS

NOTE: THERE ARE SLIGHT VARIATIONS IN LOAD FOR P_F, P_M, P_R AND P_E, HOWEVER DESIGN IS BASED ON THE HIGHEST VALUE.

CONCENTRATED WHEEL LOAD TABLE										
VEHICLE	TYPE	LOCATION	X	Y_1 (DIMENSIONS IN FEET)	Y_2	Y_3	P_F	P_M (LOADS IN KIPS)	P_R	P_E
STANDARD HS20 TRUCK	2	1st, 2nd, 3rd	6.0	14.0	14.0	-	4.0	16.0	16.0	-
MCI 2915 BUS	2	1st, 2nd, 3rd	6.67	26.5	4.0	-	5.7	8.9	4.8	-
ORION HYBRID "NEW GEN" 3877 BUS	1	1st, 2nd, 3rd	6.17	23.83	-	-	6.0	-	11.35	-
VAN HOOL DOUBLE DECKER BUS TD 925	2	1st, 2nd, 3rd	7.17	16.58	4.25	-	5.72	8.91	5.72	-
TOW TRUCK E050-08	2	1st, 2nd, 3rd	7.0	21.67	4.0	-	9.75	8.5	6.6	-
TOW TRUCK E052-03	1	1st	7.0	23.0	-	-	9.9	-	9.1	-
TOW TRUCK E050-08 LIFTING MCI 2915 BUS	3	1st, 2nd, 3rd	7.0	21.67	4.0	45.33	5.57	15.44	15.07	10.08
TOW TRUCK E052-03 LIFTING MCI 2915 BUS	4	1st	7.0	23.0	45.33	-	5.88	-	23.94	10.08
TOW TRUCK E050-08 LIFTING ORION 3877 BUS	3	1st, 2nd, 3rd	7.0	21.67	4.0	39.67	4.31	15.59	15.65	7.77
TOW TRUCK E052-03 LIFTING ORION 3877 BUS	4	1st	7.0	23.0	39.67	-	4.73	-	26.57	7.77
TOW TRUCK E050-08 LIFTING DOUBLE DECKER BUS TD 925	3	1st, 2nd, 3rd	7.0	21.67	4.0	35.67	5.57	15.87	15.45	10.08
TOW TRUCK E052-03 LIFTING DOUBLE DECKER BUS TD 925	4	1st	7.0	23.0	35.67	-	5.88	-	24.69	10.08
OPEN TOP CONTAINER TRUCK	2	1st, 2nd	7.0	9.0	4.5	-	13.0	13.5	13.5	-

NOTE: WHEN TOWED BUS LOADS ARE APPLIED SIMULTANEOUSLY WITH OTHER WHEEL LOADS ON A COMMON MEMBER, TOWED BUS WHEEL LOADS ARE REDUCED BY 25%. SIMULTANEOUS VEHICLE LOADS HAVE BEEN ANALYZED PER THE STALL LAYOUT SHOWN ON THE ARCHITECTURAL DRAWINGS. COMBINATIONS OF VEHICLE TYPES WERE PLACED IN EACH STALL GROUP IN SUCH A WAY TO PRODUCE THE WORST CASE LOADING FOR THE MEMBER BEING STUDIED.

Table 4: Concentrated wheel loads and values

Snow Loads

Snow Loads for the New York City Bus Depot are minimal. It is assumed they are included in the distributed Live loads where applicable so no additional calculations were necessary for them. The chart on the right is a display of the design criteria for the snow loading.

SNOW DESIGN CRITERIA
SNOW IMPORTANCE FACTOR 1ST 1.0
OCCUPANCY CATEGORY: I
GROUND SNOW LOAD: 25 PSF
EXPOSURE FACTOR: CS=0.90
THERMAL FACTOR: C1=1.00
FLAT ROOF SNOW LOAD: 15, 75 PSF
SNOW DRIFT LAOD: INCLUDED WHERE APPLICABLE

Table 5: Snow design criteria

Lateral Loads:

Wind Loads:

Wind loads were calculated to be lower than those provided in the drawings. Not all values were given. Those assumed included topographic factor and GCpi (assumed +/- 0.18 for an enclosed system). To the left is a table of the design criteria used in the analysis. Charts proceeding in this section show the achieved values through calculations shown in Appendix A. The values received show that wind is not the controlling factor in the lateral system, but instead seismic forces are. The computer analysis discussed later in this report yields the same results.

Design Criteria	
Importance Factor (I):	1.0
Occupancy Category:	II
Exposure:	C
Basic Wind Speed (V):	100 mph
Directionality Factor (kd):	1
Topographic Factor (kzt):	1.0
Gust Factor (G):	0.85 (rigid)

Table 6: Wind Design Criteria

Wind Pressures N-S Direction										
Type	Floor	Elevation (ft)	k_z (interpolated)	Velocity Pressure (psf)	Cp	Wind Pressure (psf):	Internal Pressure		Net Pressure	
							$+GC_{pi}$	$-GC_{pi}$	$+GC_{pi}$	$-GC_{pi}$
Windward Walls	1st	0	0.85	21.76	0.8	14.80	5.76	-5.76	20.56	9.04
	2nd	26	0.91	23.30	0.8	15.84	5.76	-5.76	21.60	10.08
	3rd	51	1.10	28.16	0.8	19.15	5.76	-5.76	24.91	13.39
	3rd (Mezz)	65	1.15	29.44	0.8	20.02	5.76	-5.76	25.78	14.26
	Roof	79	1.21	30.98	0.8	21.06	5.76	-5.76	26.82	15.30
	Parapet	84	1.22	31.23	0.8	21.24	5.76	-5.76	27.00	15.48
	Bulkhead	93	1.25	32.00	0.8	21.76	5.76	-5.76	27.52	16.00
Leeward Walls	All	All	1.25	32.00	-0.5	-13.60	5.76	-5.76	-7.84	-19.36
Side Walls	All	All	1.25	32.00	-0.7	-19.04	5.76	-5.76	-13.28	-24.80
Roof	N/A	0 to 46.5	1.25	32.00	-0.9	-24.48	5.76	-5.76	-18.72	-30.24
	N/A	46.5 to 93	1.25	32.00	-0.9	-24.48	5.76	-5.76	-18.72	-30.24
	N/A	93 to 186	1.25	32.00	-0.5	-13.60	5.76	-5.76	-7.84	-19.36
	N/A	>186	1.25	32.00	-0.3	-8.16	5.76	-5.76	-2.40	-13.92

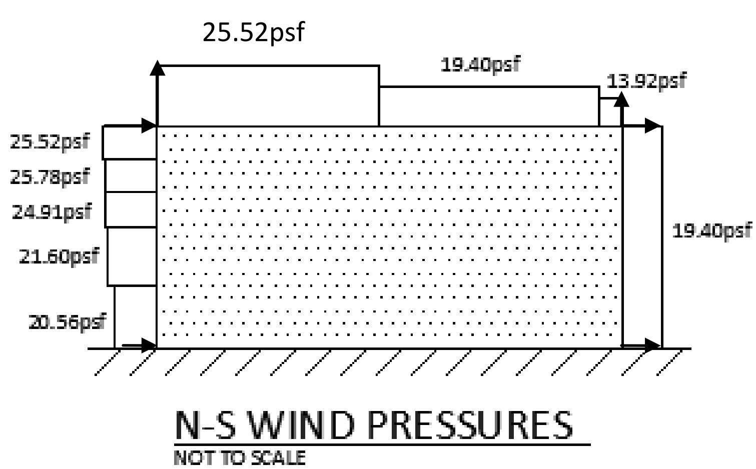


Figure 7: Table stating north-south wind pressures and diagram showing them applied.

Wind Forces N-S								
Floor	Elevation (ft)	Trib. Below		Trib. Above		Story Force (k)	Story Shear (K)	Overturning Moment (k.ft)
		Height (ft)	Area (ft2)	Height (ft)	Area (ft2)			
1st	0	0.0	0.0	13.0	8372.0	172.10	1437.63	0.00
2nd	26	13.0	8372.0	12.5	8050.0	354.74	1265.53	4611.57
3rd	51	12.5	8050.0	7.0	4508.0	312.80	910.80	3910.06
3rd (Mezz)	65	7.0	4508.0	7.0	4508.0	232.43	597.99	1626.98
Roof	79	7.0	4508.0	2.5	1610.0	164.11	365.57	1148.75
Parapet	84	2.5	1610.0	4.5	2898.0	121.71	201.46	304.26
Bulkhead	93	4.5	2898.0	0.0	0.0	79.75	79.75	358.89
							Total Base Shear:	1437.63
							Total Overturning Moment:	133699.95

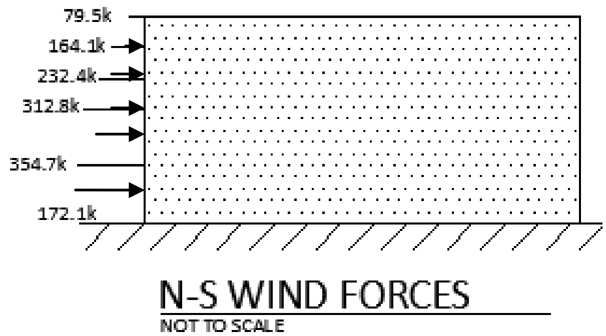


Figure 9: Table stating north-south wind forces and diagram showing them applied.

Wind Pressures E-W Direction										
Type	Floor	Elevation (ft)	k_z (interpolated)	Velocity Pressure (psf)	Cp	Wind Pressure (psf):	Internal Pressure		Net Pressure	
							$+GC_{pi}$	$-GC_{pi}$	$+GC_{pi}$	$-GC_{pi}$
Windward Walls	1st	0	0.85	21.76	0.8	14.80	5.76	-5.76	20.56	9.04
	2nd	26	0.91	23.30	0.8	15.84	5.76	-5.76	21.60	10.08
	3rd	51	1.10	28.16	0.8	19.15	5.76	-5.76	24.91	13.39
	3rd (Mezz)	65	1.15	29.44	0.8	20.02	5.76	-5.76	25.78	14.26
	Roof	79	1.21	30.98	0.8	21.06	5.76	-5.76	26.82	15.30
	Parapet	84	1.22	31.23	0.8	21.24	5.76	-5.76	27.00	15.48
	Bulkhead	93	1.25	32.00	0.8	21.76	5.76	-5.76	27.52	16.00
Leeward Walls	All	All	1.25	32.00	-0.3	-7.34	5.76	-5.76	-1.58	-13.10
Side Walls	All	All	1.25	32.00	-0.7	-19.04	5.76	-5.76	-13.28	-24.80
Roof	N/A	0 to 46.5	1.25	32.00	-0.9	-24.48	5.76	-5.76	-18.72	-30.24
	N/A	46.5 to 93	1.25	32.00	-0.9	-24.48	5.76	-5.76	-18.72	-30.24
	N/A	93 to 186	1.25	32.00	-0.5	-13.60	5.76	-5.76	-7.84	-19.36
	N/A	>186	1.25	32.00	-0.3	-8.16	5.76	-5.76	-2.40	-13.92

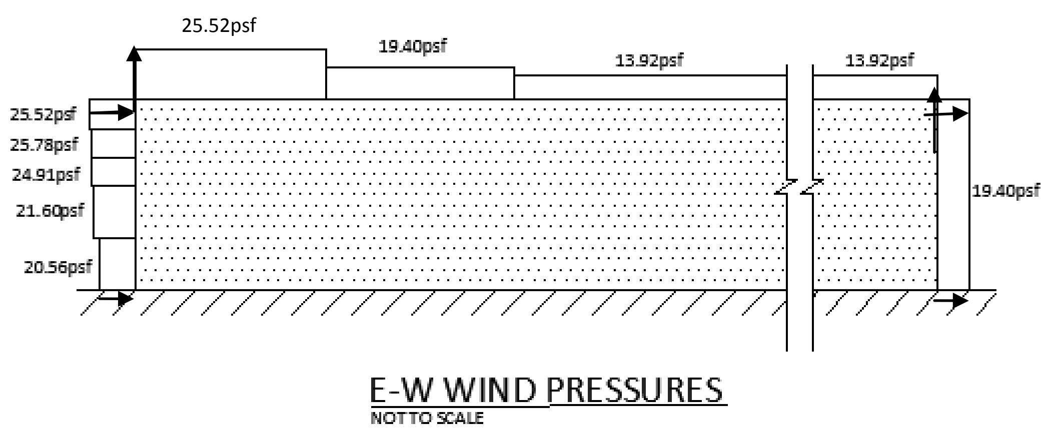


Figure 10: Table stating east-west wind pressures and diagram showing them applied.

Wind Forces E-W								
Floor	Elevation (ft)	Trib. Below		Trib. Above		Story Force (k)	Story Shear (K)	Overturning Moment (k.ft)
		Height (ft)	Area (ft2)	Height (ft)	Area (ft2)			
1st	0	0.0	0.0	13.0	2541.5	52.25	436.42	0.00
2nd	26	13.0	2541.5	12.5	2443.8	107.69	384.18	1399.94
3rd	51	12.5	2443.8	7.0	1368.5	94.96	276.49	1186.98
3rd (Mezz)	65	7.0	1368.5	7.0	1368.5	70.56	181.53	493.90
Roof	79	7.0	1368.5	2.5	488.8	49.82	110.98	348.73
Parapet	84	2.5	488.8	4.5	879.8	36.95	61.16	92.37
Bulkhead	93	4.5	879.8	0.0	0.0	24.21	24.21	108.95
							Total Base Shear:	436.42
							Total Overturning Moment:	40587.48

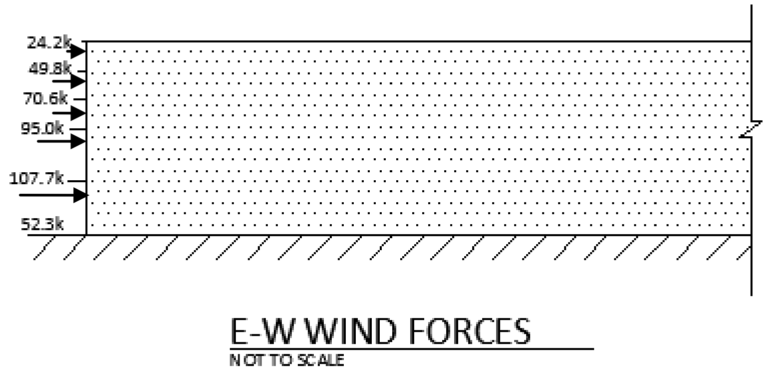


Figure 11: Table stating east-west wind forces and diagram showing them applied.

Seismic Loads:

The following series of charts presents a summary of the results of the seismic analysis of the New York City Bus Depot. There are three sets of results for the three buildings that were analyzed separately due to the 6” expansion joint separating them. For the 65% submittal drawings that have been the guide so far, the building was analyzed as one entity, but here, the building is further divided for greater accuracy in consideration of the expansion joints. There are discrepancies between the computer model and the hand calculation. This is likely due to simplifications made for hand calculations that were not made for the RAM Structural System model.

For further detail on the calculations, see Appendix B.

Building A:

Building Dimensions:		
N-S	195.5	ft
E-W:	184.167	ft
Mezz/High F	68	ft
Beam Allow	15	psf

Base Shears		
Direction	C_s	V (k)
(NS)	0.05	1130.33
(EW)	0.053	1198.14

N-S Seismic Analysis									
Floor	Distributed Floor Dead Load (psf)	Area (ft^2)	Elevation (ft):	Weight (k):	$w_x h_x^k$	C_{vx}	NS Story Force Fx(k)=CvxV	NS Story Shear (k)	NS Overturning Moment (k-ft)
Floor 1	200.00	36004.65	0.00	7703.43	0.00	0.00	0.00	1130.33	0.00
Floor 2	100.00	36004.65	26.00	4522.76	117591.89	0.22	252.04	1130.33	29388.45
Floor 3	100.00	36004.65	51.00	4222.66	215355.91	0.41	461.58	878.28	44792.52
Roof	100.00	22710.65	79.00	2460.96	194416.22	0.37	416.70	416.70	32919.44
								Total Overturning Moment:	237679.90

E-W Seismic Analysis									
Floor	Distributed Floor Dead Load (psf)	Area (ft^2)	Elevation (ft):	Weight (k):	$w_x h_x^k$	C_{vx}	EW Story Force	EW Story Shear (k)	EW Overturning
Floor 1	200	36004.65	0	7703.43	0.00	0.00	0.00	1198.14	0.00
Floor 2	100	36004.65	26	4522.76	210011.28	0.20	235.87	1198.14	6132.61
Floor 3	100	36004.65	51	4222.66	433614.98	0.41	487.01	962.27	24837.28
Roof	100	22710.65	79	2460.96	423165.37	0.40	475.27	475.27	37546.28
								Total Overturning Moment:	68516.17

Figure 12: Building A Seismic Analysis

Building B:

Building Dimensions:		
N-S	195.5	ft
E-W:	210	ft
Mezz/High Roof (EW):	68	ft
Beam Allowance:	15	psf

Base Shears		
Direction	C_s	V (k)
(NS)	0.05	1404.457377
(EW)	0.053	1488.724819

N-S Seismic Analysis									
Floor	Distributed Floor Dead Load (psf)	Area (ft^2)	Elevation (ft):	Weight (k):	$w_x h_x^k$	C_{vx}	NS Story Force	NS Story Shear (k)	NS Overturning Moment (k-ft)
Floor 1	200	41055	0	8713.5	0	0.00	0.00	1404.46	0.00
Floor 2	100	41055	26	5027.8	130722.8	0.16	223.94	1404.46	36515.89
Floor 3	100	41055	51	4727.7	241112.7	0.29	413.04	1180.52	60206.63
Floor 3 (Mezz)	100	13294	65	1359.4	88361	0.11	151.37	767.48	49886.40
Roof	100	27761	79	2966	234314	0.29	401.39	616.12	48673.16
High Roof	100	13294	93	1347.8	125345.4	0.15	214.72	214.72	19969.28
								Total Overturning Moment:	237679.9002

E-W Seismic Analysis									
Floor	Distributed Floor Dead Load (psf)	Area (ft^2)	Elevation (ft):	Weight (k):	$w_x h_x^k$	C_{vx}	EW Story Force	EW Story Shear (k)	EW Overturning
Floor 1	200	41055	0	8713.5	0.00	0.00	0.00	1488.72	0.00
Floor 2	100	41055	26	5027.8	233462.21	0.14	204.98	1488.72	5329.52
Floor 3	100	41055	51	4727.7	485475.79	0.29	426.25	1283.74	21738.80
Floor 3 (Mezz)	100	13294	65	1359.4	185762.99	0.11	163.10	857.49	10601.58
Roof	100	27761	79	2966	510006.68	0.30	447.79	694.39	35375.36
High Roof	100	13294	93	1347.8	280865.48	0.17	246.60	246.60	22933.97
								Total Overturning Moment:	95979.22462

Figure 13: Building B Seismic Analysis

Building C:

Building Dimensions:		
N-S	195.5	ft
E-W:	210	ft
Mezz/High Roof (EW):	68	ft
Beam Allowance:	15	psf

Base Shears		
Direction	C_s	V (k)
(NS)	0.05	1404.46
(EW)	0.053	1488.72

N-S Seismic Analysis

Floor	Distributed Floor Dead Load (psf)	Area (ft^2)	Elevation (ft):	Weight (k):	$w_x h_x^k$	C_{vx}	NS Story Force Fx(k)=CvxV	NS Story Shear (k)	NS Overturning Moment (k-ft)
Floor 1	200	41055	0	8713.5	0	0.00	0.00	1404.46	0.00
Floor 2	100	41055	26	5027.8	130722.8	0.16	223.94	1404.46	36515.89
Floor 3	100	41055	51	4727.7	241112.7	0.29	413.04	1180.52	60206.63
Floor 3 (Mezz)	100	13294	65	1359.4	88361	0.11	151.37	767.48	49886.40
Roof	100	27761	79	2966	234314	0.29	401.39	616.12	48673.16
High Roof	100	13294	93	1347.8	125345.4	0.15	214.72	214.72	19969.28
								Total Overturning Moment:	237679.90

E-W Seismic Analysis

Floor	Distributed Floor Dead Load (psf)	Area (ft^2)	levation (ft)	Weight (k):	$w_x h_x^k$	C_{vx}	EW Story Force	EW Story Shear (k)	EW Overturning
Floor 1	200	41055	0	8713.5	0.00	0.00	0.00	1488.72	0.00
Floor 2	100	41055	26	5027.8	233462.21	0.14	204.98	1488.72	5329.52
Floor 3	100	41055	51	4727.7	485475.79	0.29	426.25	1283.74	21738.80
Floor 3 (Mezz)	100	13294	65	1359.4	185762.99	0.11	163.10	857.49	10601.58
Roof	100	27761	79	2966	510006.68	0.30	447.79	694.39	35375.36
High Roof	100	13294	93	1347.8	280865.48	0.17	246.60	246.60	22933.97
								Total Overturning Moment:	95979.22

Figure 13: Building C Seismic Analysis

Lateral System:

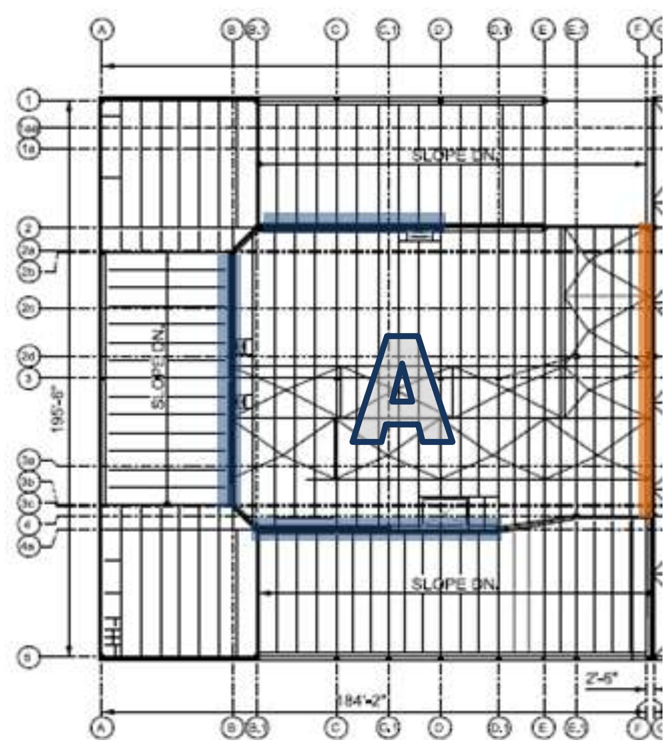
The lateral system for the New York City Bus Depot consists of 19 lateral force resisting frames: 6 braced frames in the East-West direction, 12 moment frames in the North-South direction, and an additional braced frame along column line B on the inside of the ramp in building A. These frames resist the lateral forces applied to the building according to their determined stiffness relative to the other frames. In order to determine frame stiffness, each frame is modeled in SAP2000 with a lateral point load of 1 kip applied to the top of the frame. A diaphragm constraint is also applied to each floor to ensure each vertical level is treated as a rigid diaphragm: an element with infinite inertia that forces the nodes of each story not to move with respect to one another. The frame's deflection is noted upon analysis with the 1 kip point load and is applied in the following equation:

$$K = \frac{P}{\delta}$$

From this equation, relative stiffness can be determined for each frame as a percentage of total stiffness acting in each direction per building. This is calculated by taking the stiffness of an individual frame and dividing it by the sum of the stiffness values of the frames in parallel planes. Relative stiffness is calculated using the equation:

$$\% = \left(\frac{K}{\Sigma K}\right) \text{ x } 100$$

Below, the separate structures are shown with a chart displaying the stiffness and relative stiffness of each frame. The relative stiffness states how much of the load applied to the corresponding side of the building will be taken on by the particular frame. This will be applied later in the direct shear portion of the report



Building A		
Column Line	K=P/δ	Relative Stiffness
B	2000.00	99.2%
F	15.22	0.8%
2	833.33	61.3%
4a	526.32	38.7%

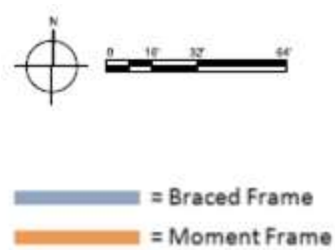
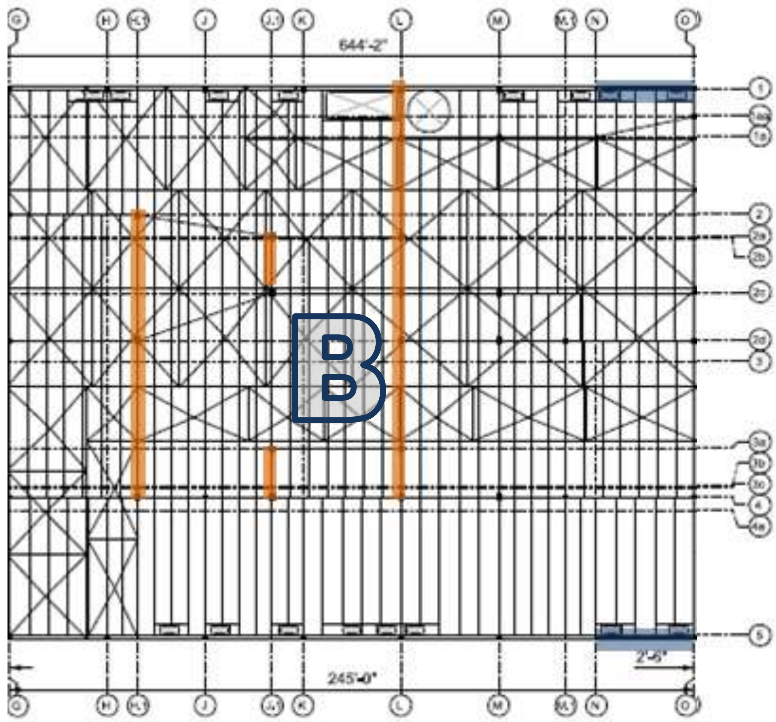


Figure 14: Building A Lateral System and Stiffness



Building B		
Column Line	K=P/δ	Relative Stiffness
H.1	42.74	12.4%
J.1 (N)	34.72	10.1%
J.1 (S)	35.34	10.2%
L	142.86	41.4%
M	89.29	25.9%
1	476.19	47.5%
5	526.32	52.5%

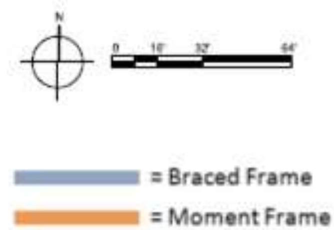
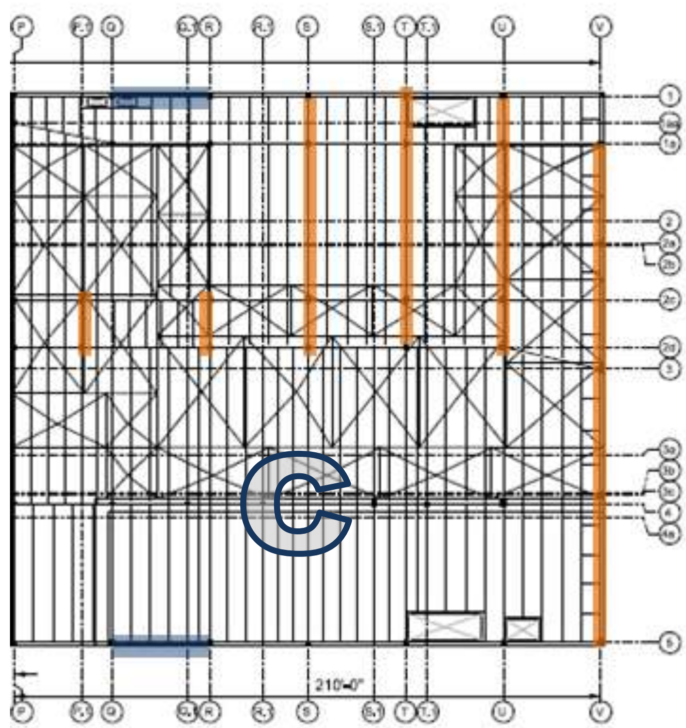


Figure 15: Building B Lateral System and Stiffness



Building C		
Column Line	K=P/δ	Relative Stiffness
P.1	26.32	9.4%
R	22.73	8.1%
S	48.31	17.3%
T	33.11	11.8%
U	33.11	11.8%
V	116.28	41.5%
1	833.33	42.8%
5	833.33	42.8%

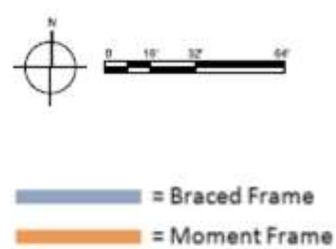


Figure 16: Building A Lateral System and Stiffness

RAM Structural System Model

RAM Structural System is the primary structural analysis program employed in this lateral system evaluation. This program allows for easy rendering of both lateral and gravity members of the structural system which creates a rather accurate representation of the structure and its reaction to the loads employed on it. Another particularly useful feature of the program is the ability to apply load combinations directly from the ASCE 7-05/IBC 2006 codes. This is useful for applying the various load combinations necessary for the inspection of wind and seismic forces on the building.

The New York City Bus Depot is divided into three separate structures for analysis due to a 6" expansion joint separating each structure. Models showing the structures are below. Blue members are gravity members, red members are lateral members, and purple members are braces.

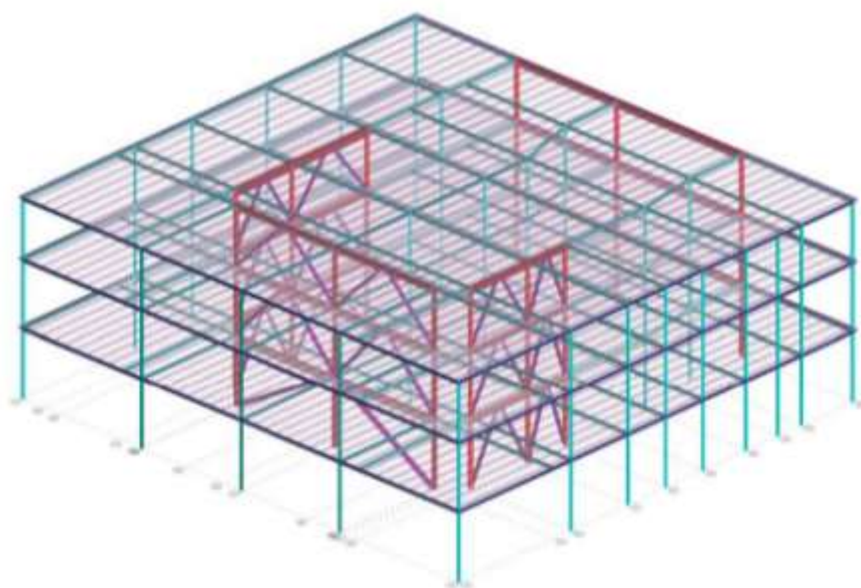


Figure 17: Building A

Building A is modeled with both lateral members and major gravity members. All diaphragms are shown as horizontal surfaces because RAM Structural System does not have the capacity to model a rigid diaphragm as a slanted surface for the ramps located in this section of the bus depot.

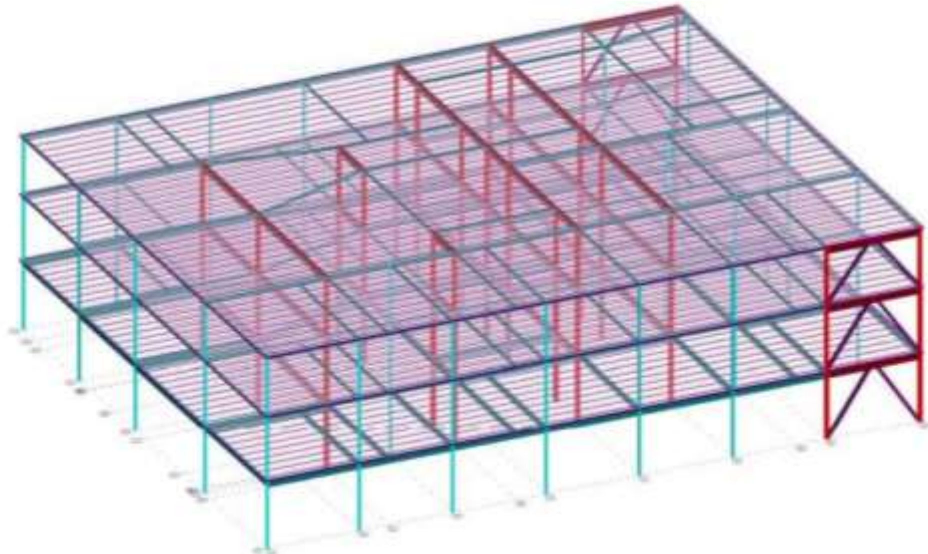


Figure 18: Building B

Building B is modeled with both lateral and major gravity members. A rigid diaphragm forms both floors and the roof. There were no unique circumstances to take into consideration with this model.

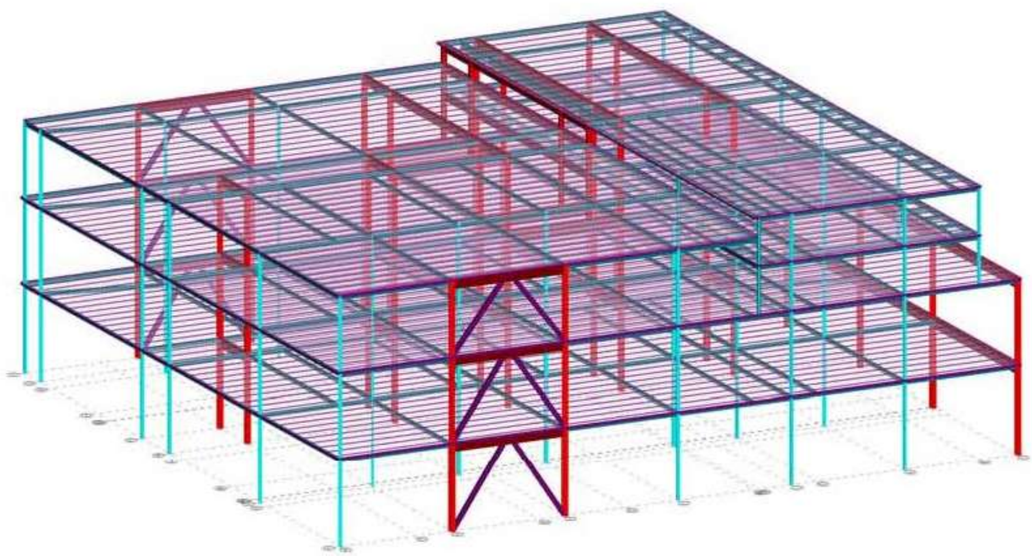


Figure 19: Building C

Building C's structures creates the most complicated model. Posts are included connecting the diaphragms of the third floor mezzanine, roof, and high roof together. These posts, particularly the ones on the north side of the building, must be modeled as lateral members continuous from the third floor to the high roof. These must be modeled as lateral members in the program to indicate that they are the load path for forces applied to the high roof and mezzanine. They are the only means of lateral force resistance in the x-direction for these levels. The remainder of the load path from these posts to moment frames at column lines L and M must also be modeled as lateral members, but with pinned major and minor axis connections and a fixed torsion connection.

Load Cases and Combinations:

This analysis utilizes load cases and combinations from ASCE 7-05 and IBC 2006. The controlling load case is determined by the largest ratio of actual to allowable deflection. Deflection and drift will be discussed further later in this report. Orange indicates the controlling case and combination.

Load Case Definitions: IBC 2006		
Variable	**Type**	**Definition**
D	Dead Load	User
Lp	Live Load	User
W1	Wind	X
W2	Wind	Y
W3	Wind	X + e
W4	Wind	X - e
W5	Wind	Y + e
W6	Wind	Y - e
W7	Wind	X + Y
W8	Wind	X - Y
W9	Wind	X + Y CW
W10	Wind	X+ Y CCW
W11	Wind	X - Y CW
W12	Wind	X - Y CCW
E1	Seismic	X + e
E2	Seismic	X - e
E3	Seismic	X + e
E4	Seismic	X - e

Allowable Stress Design Load Combinations: ASCE 7-05		
	Code Defined Loads	**Lateral Loads**
1.	**D** + **F**	--
2.	**D** + **H** + **F** + **L** + **T**	--
3.	**D** + **H** + **F** + (L_r or **S** or **R**)	--
4.	**D** + **H** + **F** + 0.75(**L** + **T**) + 0.75(L_r or **S** or **R**)	--
5.	**D** + **H** + **F** + (**W** or 0.7**E**)	(**W** or 0.7**E**)
6.	**D** + **H** + **F** + 0.75(**W** or 0.7**E**) + 0.75**L** + 0.75(L_r or **S** or **R**)	(**W** or 0.7**E**)
7.	0.6**D** + **W** + **H**	**W**
8.	0.6**D** + 0.7**E** + **H**	0.7**E**
D = Dead Load; **E** = Earthquake; **F** = Well-defined Fluids; **H** = Lateral Earth Pressure; **L** = Live Load; L_r = Roof Live Load; **R** = Rain Load; **S** = Snow Load; **T** = Self-straining Force; **W** = Wind Load		

Figure 20: Load cases and combinations. Highlighted indicates controlling.

Drift and Displacement

Upon analysis of the building lateral systems with the load cases applied, drift values were obtained for each load case. The drift values determine the controlling load case. Each deflection is set in a ratio to the maximum allowable deflection for the type of load. The maximum allowable load cases are as follows:

$$\frac{H}{400} \ (Wind\ per\ Code)$$

$$0.020h_{sx} \ (Seismic\ per\ Code)$$

$$\frac{H}{240} \ (Seismic\ for\ Nonstructural)$$

For the New York City Bus Depot, H/240 is used to control the seismic design because it is a good limit to prevent damage to other non structural elements of the building. This standard is frequently applied in the professional world according to Chris Cerino, a structural engineer at STV Incorporated. Below is a chart of the maximum wind and seismic deflections for each of the three buildings:

Structure	Load	Max (in)	Permitted (in)	Ratio
A	EQ	0.50053	3.634	0.14
	W	0.20579	2.180	0.09
B	EQ	1.45441	3.634	0.40
	W	0.62195	2.180	0.29
C	EQ	4.53502	3.934	1.15
	W	0.86859	2.557	0.34

Controlling Cases		
Structure	Load Case	Direction
A	EQ: Y ± E	E - W
B	EQ: Y ± E	E - W
C	EQ: Y ± E	E - W

Controlling Displacement and Story Drift Summary						
Height	Building A		Building B		Building C	
(ft)	Δ (in)	δ (in)	Δ (in)	δ (in)	Δ (in)	δ (in)
78.67	--	--	--	--	4.535	0.418
72.67	0.501	0.153	1.454	0.407	4.117	0.612
64.67	--	--	--	--	3.505	1.177
50.67	0.347	0.197	1.047	0.547	2.328	1.303
26.00	0.150	0.150	0.500	0.500	1.025	1.025
0.00	0.000	0.000	0.000	0.000	0.000	0.000

Figure 21: Tables containing information on drift and story displacement

Direct Shear

Direct shear is a result of the controlling lateral load acting on the structure. For this, the applied story values were obtained from RAM Structural System. They were distributed to the frames according to their relative stiffness. The sum of the story forces is equal to the base shear of the structure, which is shown on the lower line of each structure's chart.

Building A: Direct Shear Values						
Floor	Direct Shear - North South			Direct Shear - East West		
	Story Force (k)	Frame B	Frame F	Story Force (k)	Frame 2	Frame 4
Roof	481.37	477.52	3.85	481.37	295.08	186.29
Third	399.60	396.40	3.20	399.60	244.95	154.65
Second	185.70	184.21	1.49	185.70	113.83	71.87
Σ	1066.67	1058.14	8.53	1066.67	653.87	412.80

Building B: Direct Shear Values									
Floor	Direct Shear - North South						Direct Shear - East West		
	Story Force (k)	Frame H.1	Frame J.1 (N)	Frame J.1 (S)	Frame L	Frame M	Story Force (k)	Frame 1	Frame 5
Roof	674.86	83.68	68.16	68.84	279.39	174.79	643.66	305.74	337.92
Third	560.84	69.54	56.64	57.21	23.68	145.26	530.84	252.15	278.69
Second	263.54	32.68	26.62	26.88	11.13	68.26	245.94	116.82	129.12
Σ	1499.24	185.91	151.42	152.92	314.20	388.30	1420.44	674.71	745.73

Building C: Direct Shear Values									
Floor	Direct Shear - North South						Direct Shear - East West		
	Story Force (k)	Frame P.1	Frame R	Frame S	Frame T	Frame U	Frame V	Story Force (k)	Frame 1	Frame 5
High Roof	179.75	--	--	--	21.21	21.21	74.60	179.75	--	--
Roof	348.87	32.79	28.26	60.35	41.17	41.17	144.78	348.87	174.44	174.44
3rd Mezz	136.77	--	--	--	16.14	16.14	56.76	136.77	--	--
Third	415.96	39.10	33.69	71.96	49.08	49.08	172.62	415.96	207.98	207.98
Second	193.04	18.15	15.64	33.40	22.78	22.78	80.11	193.04	96.52	96.52
Σ	1094.64	90.04	77.59	165.71	129.17	150.38	454.28	1094.64	478.94	478.94

Figure 22: Tables containing information on direct shear values per story

Torsion:

Due to each building's lack of alignment between the center of rigidity and center of mass, the effects of torsion must be taken into account in the analysis of the building. First, the building's eccentricity must be calculated. This is the distance between the center of rigidity and the center of mass. Values for this were obtained using the outputs from Ram Structural System. The center of mass can be found with the building displacements, and the center of rigidity can be found through the application of a special load case specific to that purpose. Figure 23 below shows the results:

Building A : Mass and Rigidity						
Level	Centers of Rigidity		Centers of Mass		Eccentricity	
	Xr (ft)	Yr (ft)	Xm (ft)	Ym (ft)	X (ft)	Y (ft)
Roof	46	110	92	98	46	12
3rd Floor	45	109	92	98	47	11
2nd Floor	45	109	92	98	47	11

Building B : Mass and Rigidity						
Level	Centers of Rigidity		Centers of Mass		Eccentricity	
	Xr (ft)	Yr (ft)	Xm (ft)	Ym (ft)	X (ft)	Y (ft)
Roof	129	89	123	98	6	9
3rd Floor	129	95	123	98	6	3
2nd Floor	129	99	123	98	6	1

Building C : Mass and Rigidity						
Level	Centers of Rigidity		Centers of Mass		Eccentricity	
	Xr (ft)	Yr (ft)	Xm (ft)	Ym (ft)	X (ft)	Y (ft)
High Roof	148	147	163	100	15	47
Roof	126	98	65	98	61	0
3rd Mezz	150	144	164	99	14	46
3rd Floor	135	98	106	99	30	1
2nd Floor	130	99	106	98	24	1

Figure 23: Tables containing information on each structure's center of mass and center of rigidity locations

The story forces applied to each story are multiplied by the eccentricities above to obtain a moment as shown in Figures 24 below:

Building Torsion: N-S Forces due to Seismic Loads				
Structure	**Level**	**Story Force (k)**	**Eccentricity (ft)**	**Moment (k.ft)**
A	Roof	481.37	46	22143.02
	Third	399.60	47	18781.20
	Second	185.70	47	8727.90
			Total Moment:	49652.12
B	Roof	674.86	6	4049.16
	Third	560.84	6	3365.04
	Second	263.54	6	1581.24
			Total Moment:	8995.44
C	High Roof	179.75	15	2719.62
	Roof	348.87	61	21218.27
	3rd Mezz	136.77	14	1899.74
	Third	415.96	30	12403.93
	Second	193.04	24	4594.35
			Total Moment:	42835.91

Building Torsion: E-W Forces due to Seismic Loads				
Structure	**Level**	**Story Force (k)**	**Eccentricity (ft)**	**Moment (k.ft)**
A	Roof	481.37	12	5617.59
	Third	399.60	11	4395.60
	Second	185.70	11	1986.99
			Total Moment:	12000.18
B	Roof	643.66	9	5792.94
	Third	530.84	3	1592.52
	Second	245.94	1	245.94
			Total Moment:	7631.40
C	High Roof	179.75	47	8487.80
	Roof	348.87	0	73.26
	3rd Mezz	136.77	46	6281.85
	Third	415.96	1	316.13
	Second	193.04	1	210.41
			Total Moment:	15369.45

Figure 24: Tables containing information on the Forces exerted on each level of each structure

Torsional Shear:

Due to the torsion in the building structures, torsional shear on the lateral members must also be accounted for. The following is a sample calculation of torsional shear acting on the frames in building A at the roof level:

Building A: Frame Torsional Shear							
Level	Frame	V_{tot} (k)	R_i	e_x (ft)	d_i (ft)	$R_i d_i^2$	Torsional Shear (k)
Roof	B	481.37	0.99	46.00	1.83	3.33	258.01
	F	481.37	0.01	46.00	138.17	152.72	156.84
	2	481.37	0.61	11.67	40.00	980.80	52.66
	4a	481.37	0.39	11.67	65.00	1635.08	54.02

Figure 25: Table containing a sample torsional shear computation and distribution.

Torsional Shear is calculated as follows:

$$T = \frac{V_{tot} \cdot e_x \cdot d_i \cdot R_i}{\Sigma(R_i d_i^2)}$$

V_{tot} = Story Force
e_x = distance from center of mass to center of rigidity
d_i = distance from frame to center of rigidity
R_i = relative stiffness of frame

Overturning Moment:

Lateral forces on the building cause a moment to be induced. In this case, seismic loads again control the resistance to overturning moment. The story force acting at each level acts at a moment arm to the center of the bottom of the building. The charts below show the induced overturning moments for each building. Also, at the bottom of figure 26, the resisting moments are shown, all of which are much higher than the overturning moments.

Building A: Overturning Moments					
Floor	Height (ft)	North-South		East-West	
		Lateral Force (k)	Moment (k.ft)	Lateral Force (k)	Moment (k.ft)
Roof	72.67	481.37	34981.16	481.37	34981.16
Three	50.67	399.60	20247.73	399.60	20247.73
Second	26.00	185.70	4828.20	185.70	4828.20
Total Overturning Moment:			**60057.09**		**60057.09**

Building B: Overturning Moments					
Floor	Height (ft)	North-South		East-West	
		Lateral Force (k)	Moment (k.ft)	Lateral Force (k)	Moment (k.ft)
Roof	72.67	674.86	49042.08	643.66	46774.77
Three	50.67	560.84	28417.76	530.84	26897.66
Second	26.00	263.54	6852.04	245.94	6394.44
Total Overturning Moment:			**84311.88**		**80066.88**

Building B: Overturning Moments					
Floor	Height (ft)	North-South		East-West	
		Lateral Force (k)	Moment (k.ft)	Lateral Force (k)	Moment (k.ft)
High Roof	78.67	179.75	14140.93	179.75	14140.93
Roof	72.67	348.87	25352.38	348.87	25352.38
3rd Mezz	64.67	136.77	8844.92	136.77	8844.92
Three	50.67	415.96	21076.69	415.96	21076.69
Second	26.00	193.04	5019.04	193.04	5019.04
Total Overturning Moment:			**60293.03**		**60293.03**

Resisting Moments			
Structure	Property	N/S	E/W
A	Weight	12,272	12,272
	Width	196	184
	M_{Resist}	**1,199,588**	**1,130,067**
B	Weight	12,272	12,272
	Width	196	245
	M_{Resist}	**1,199,588**	**1,503,320**
C	Weight	12,272	12,272
	Width	196	210
	M_{Resist}	**1,199,588**	**1,288,560**

Figure 26: Tables containing information on each structure's overturning and resisting moments

Member Check:

To check the validity of the frame design, one member of the lateral force resisting frame along column line F was checked. This was inspected for wind resistance as well as seismic resistance. The frame is expected to carry 1% of the loads imposed on the entire façade of the building after calculating relative stiffness compared to the member along column line B. The pressures imposed by the wind and the forces imposed by the seismic loading were acceptable for a column designed as a W 14x176. Detailed calculations can be seen in appendix C of this report.

Conclusion:

Through the analysis of the building lateral systems, a better understanding of the structural systems is achieved. The analysis of the lateral systems though RAM Structural System shows that the lateral frames and diaphragms are sufficient for withstanding wind and seismic forces imposed on the structure according to IBC 2006 and ASCE7-05.

The New York City Bus Depot was analyzed in three parts according to divisions in the structure from expansion joints. According to deflection ratios, all three of these structures were controlled by earthquake forces acting in the Y direction. This was the same result yielded by the hand calculations.

Shear and stiffness analyses from the controlling load cases show the amount of shear that each individual frame was required to handle. Contributors to the shear in each frame included both direct and torsional shear. Torsional shear was induced as a result of the eccentricity resulting from the center of mass and the center of rigidity not aligning.

The structure’s overturning moment was also analyzed. All moments induced by the controlling seismic loads are countered by the resisting moment provided by the building’s weight.

In conclusion, analysis through RAM Structural System was able to confirm the New York City Bus Depot’s design is more than adequate to resist the lateral forces imposed on it.

Appendix A: Gravity Load Calculations

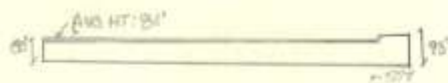
Wind Load Calcs | AE Senior Thesis | TRIEBL | 1

Location: New York City
Terrain: Urban
Framing: Steel, Enclosed

DESIGN CRITERIA: MWFRS

Importance Factor: 1.0
Occupancy Category: II
Exposure: C
Basic Wind Speed: 100 mph

PLAN



ELEVATION

Velocity Pressure:

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

$K_z = 1.24$
$K_{zt} = 1.0$
$K_d = 0.85$
$V = 100$ mph
$I = 1.0$

$q_z = 0.00256(1.24)(1.0)(0.85)(100^2)(1.0)$
$= 26.98$ psf

$q_h = 26.98$ psf @ $h = 93'$

Gust factor: (6.5.8)

Find Natural frequency first:

$T_a = C_t h_n^x$

*RIGID STRUCTURE
- SEE SEISMIC CALCS

$G = 0.85$ (6.5.8.1)

Internal Pressure Coefficient:
$GC_{pi} = \pm 0.18$

External Pressure Coefficient:
Wall C_p:
- Windward: 0.8
- Sidewall: -0.7

Leeward: L/B (644' wall): 0.304 $C_p = -0.5$
L/B (195'-6" wall): 3.29 $C_p = -0.27$ (interpol.)

*B: Normal to wind *L: Parallel to wind

WIND LOAD CALCS | AE SENIOR THESIS | TRIEBL | 2

•Roof C_p:
h/L: 0.48 to 0.14 : both ≤ 0.5

Horiz. Dist. from windward edge:	C_p
0 to h/2: (0 to 46'-6")	-0.9
h/2 to h: (46'-6" to 93')	-0.9
h to 2h: (93' to 186')	-0.5
>2h: (>186')	-0.3

* Second Value for Load Combos with Snow & Live Load

MWFRS Pressures: Rigid Structure

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

Parapet:

$p = q_p(GC_p - GC_{pn})$

Appendix B: Seismic Load Calculations

SEISMIC DESIGN | AE SENIOR THESIS | TRIEBL | 1

DESIGN CRITERIA:

Importance Factor: 1.0
Seismic Use Group: I
Seismic Design Category: C
Mapped Spectral Response: $S_s = 0.28g$, $S_1 = 0.06g$; $S_{DS} = 0.448$, $S_{D1} = 0.14$ } Confirmed w/ 2010 New York State Building Code
Fundamental Period: 0.48s

	N-S	E-W
LFRS	Moment Frames	Concentrically Braced Frames
C_s	0.048	0.060
R	3.5	3.25

• Checking Spectral Response Acceleration Parameters:

$S_s = 0.28g$ $F_a = 2.4$ (interpolated) $S_{MS} = F_a S_s = 0.672$ $S_{DS} = \frac{2}{3} S_{MS} = 0.448$ ✓

$S_1 = 0.06g$ $F_v = 3.5$ $S_{M1} = F_v S_1 = 0.21$ $S_{D1} = \frac{2}{3} S_{M1} = 0.14$ ✓

• Check Fundamental Period:

$T_a = C_t h_n^x$
$= 0.2(72.7')^{0.75}$ ← height to roof w/out parapet
$= 0.49$ sec ✓ ← defined on S-003 as 0.48s

$T = C_u T_a$
$T = 1.62(0.49) = .806s$
$T_L = 6$ sec
$T < T_L$ ✓

$C_s = \frac{S_{DS}}{R/I} = \frac{0.25}{3.5} = 0.071$ ← NS

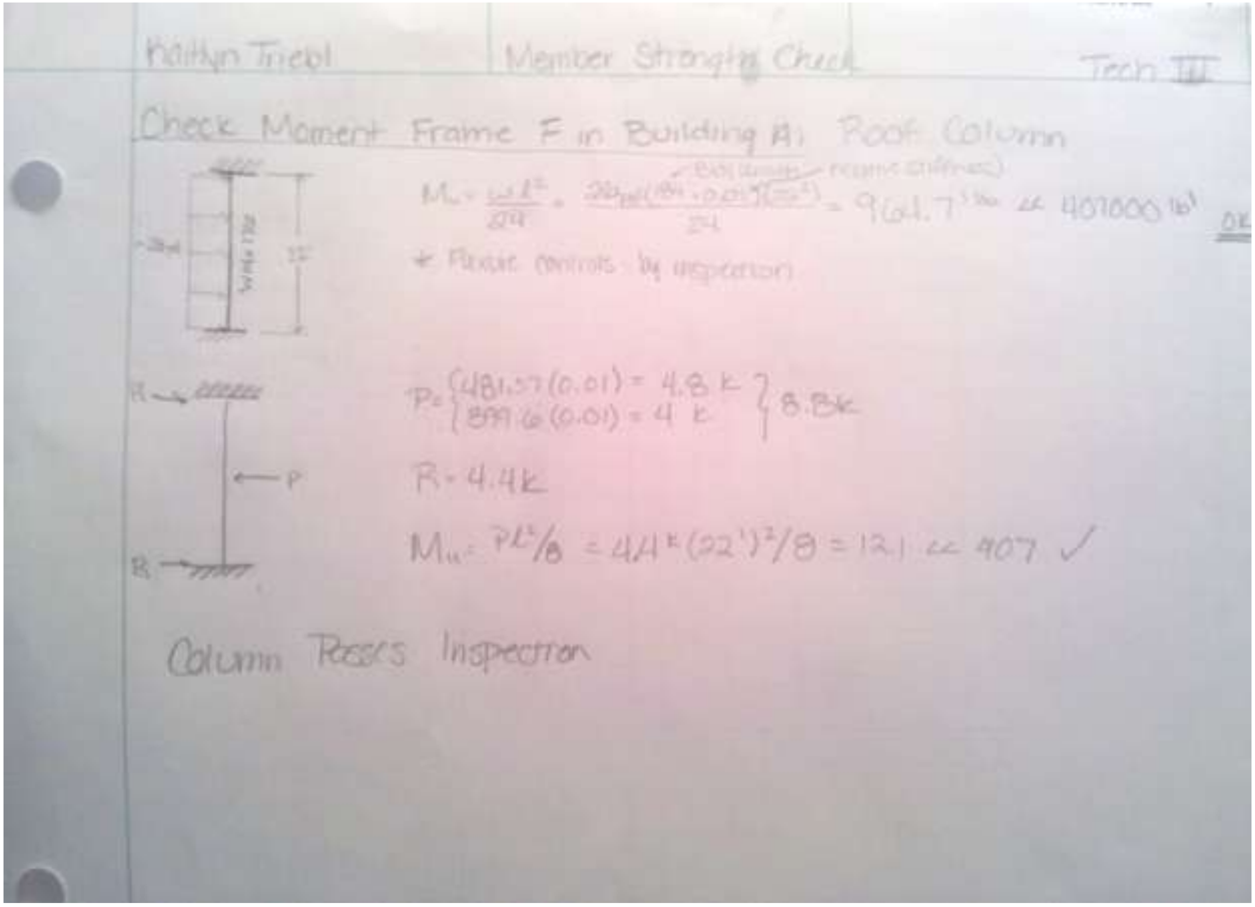
$C_s = \frac{S_{DS}}{R/I} = \frac{0.25}{3.25} = 0.077$ ← EW

$C_s < S_{D1}/(R/I)T = 0.14/[(3.5/1.0)(.806)] = 0.050$ ← NS } CONTROLS

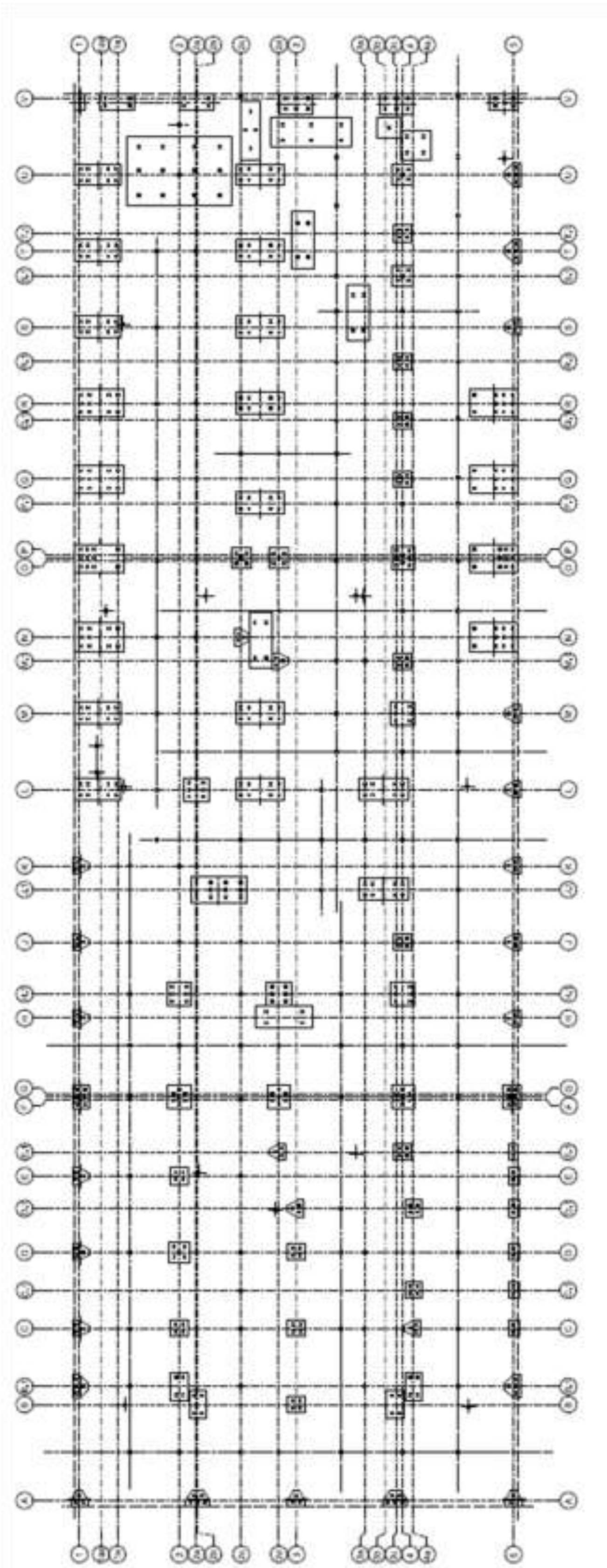
$C_s < S_{D1}/(R/I)T = 0.14/[(3.25/1.0)(0.806)] = 0.053$ ← EW } CONTROLS

$C_s > 0.01$ (NS & EW)

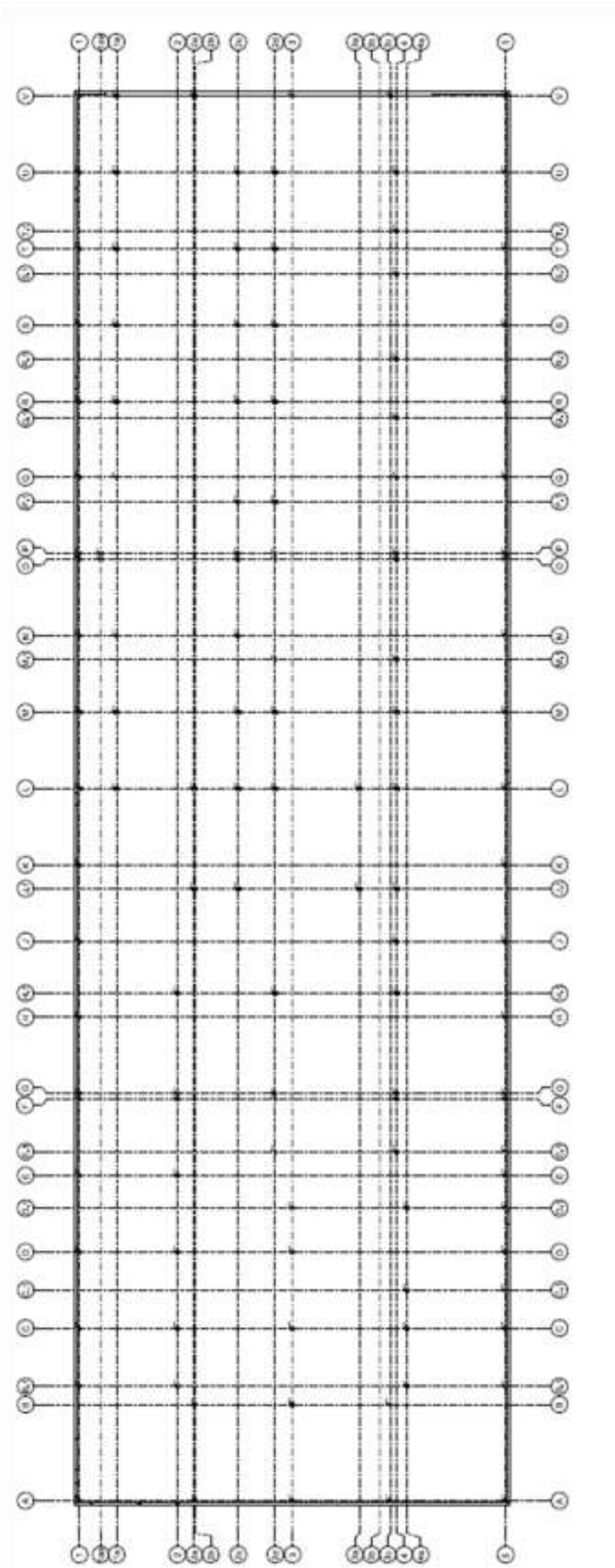
Appendix C: Member Check



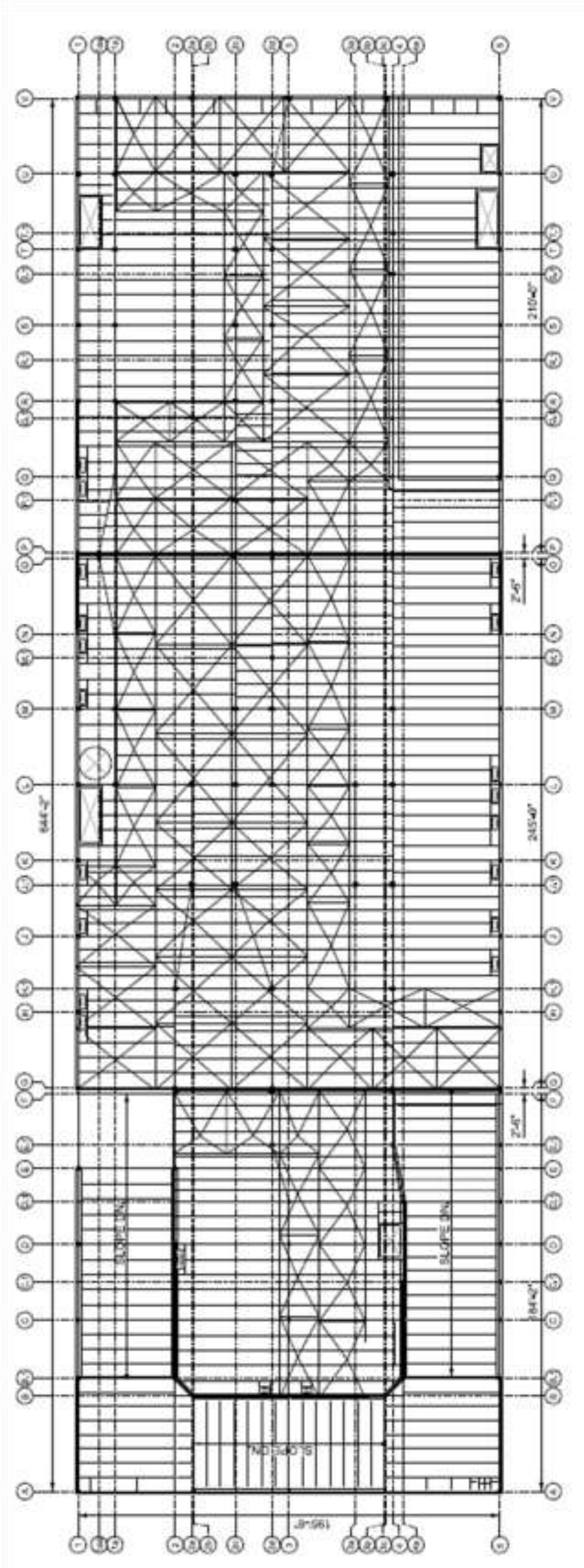
Appendix D: Framing Plans



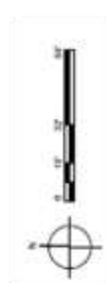
Foundation Plan

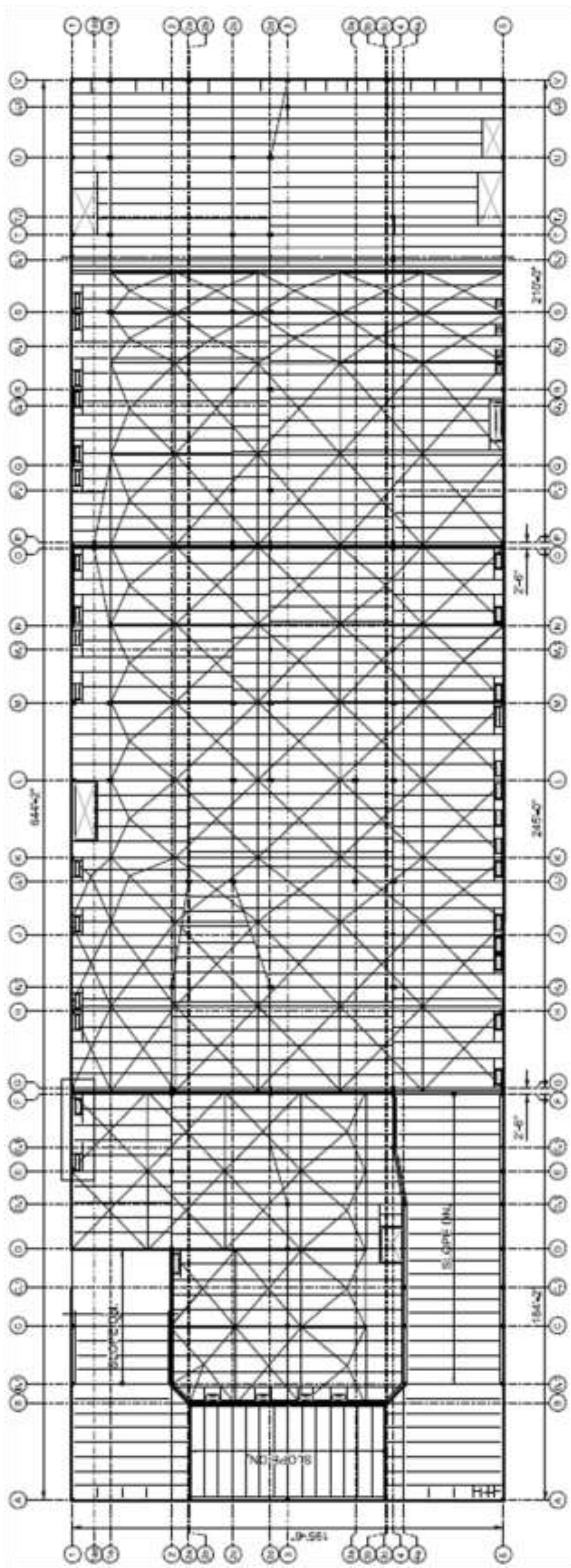


First Floor Plan

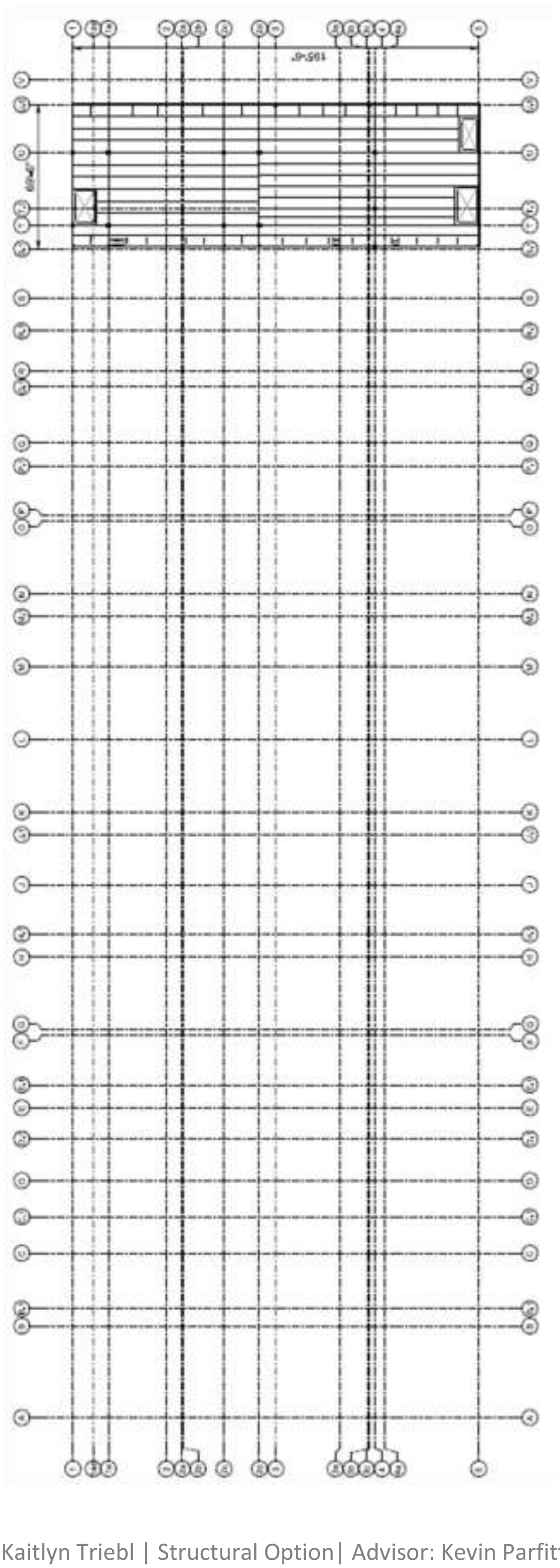


Second Floor Framing Plan

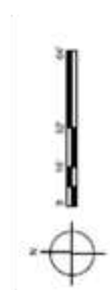


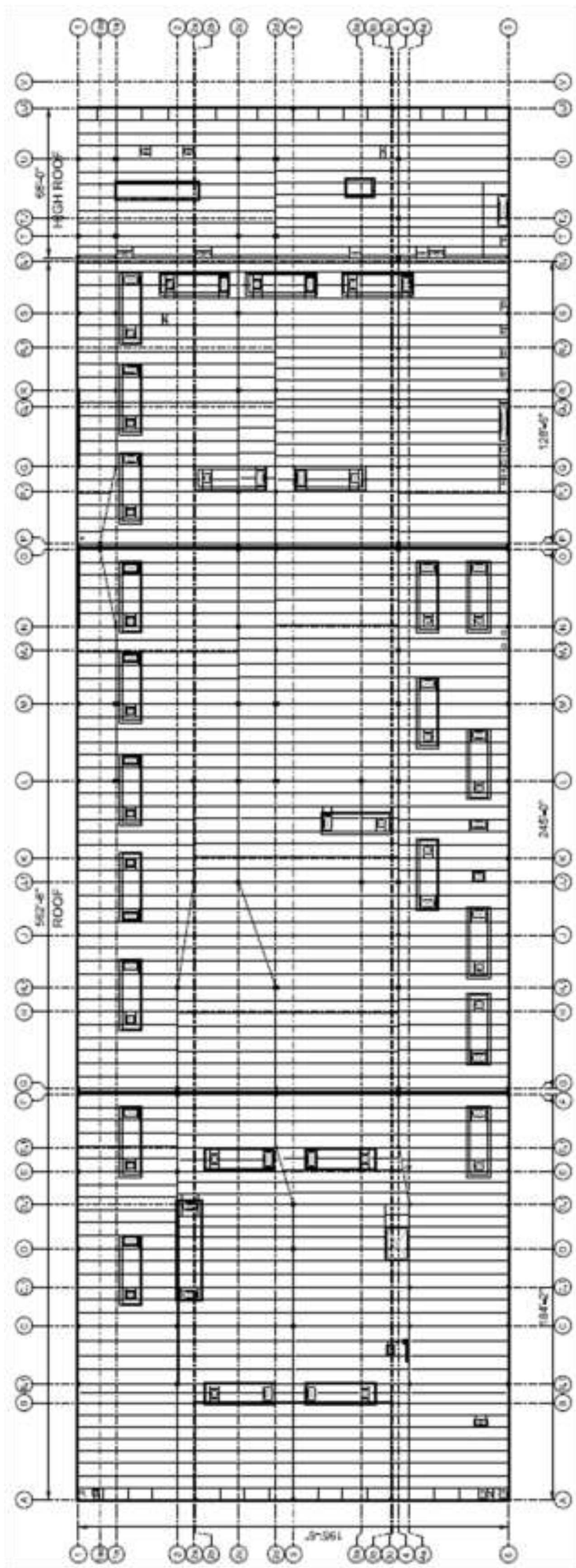


Third Floor Framing Plan



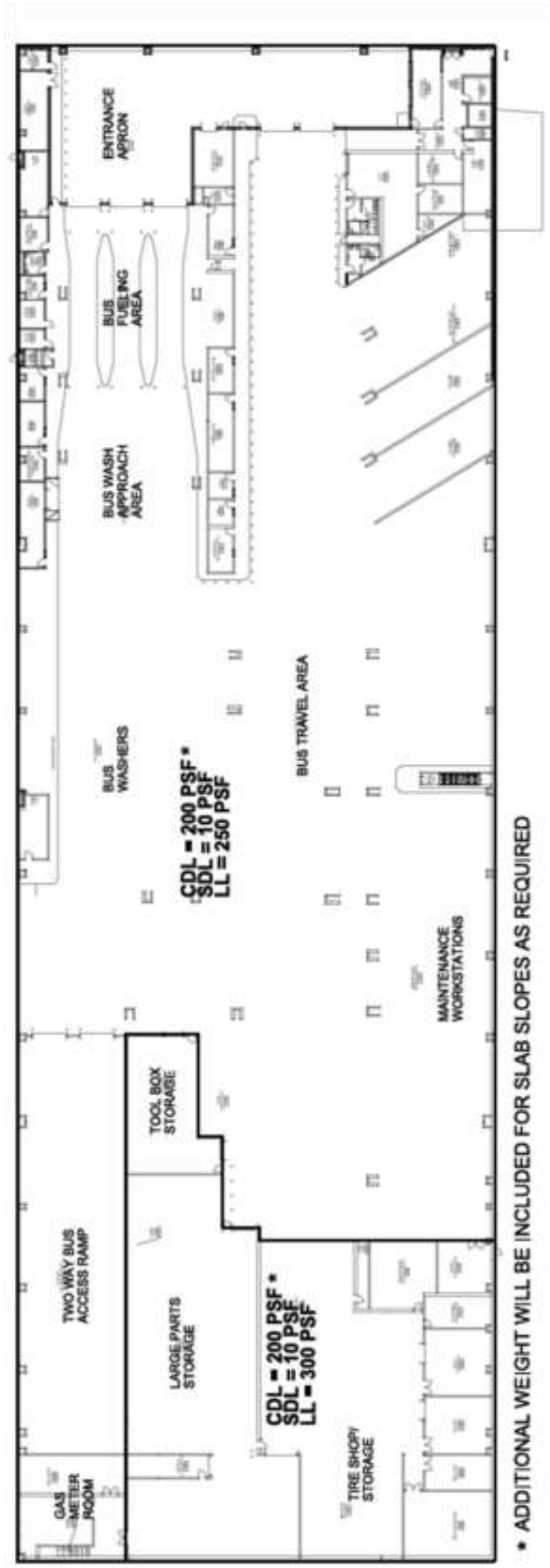
Third Floor Mezzanine Framing Plan



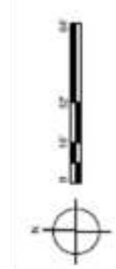


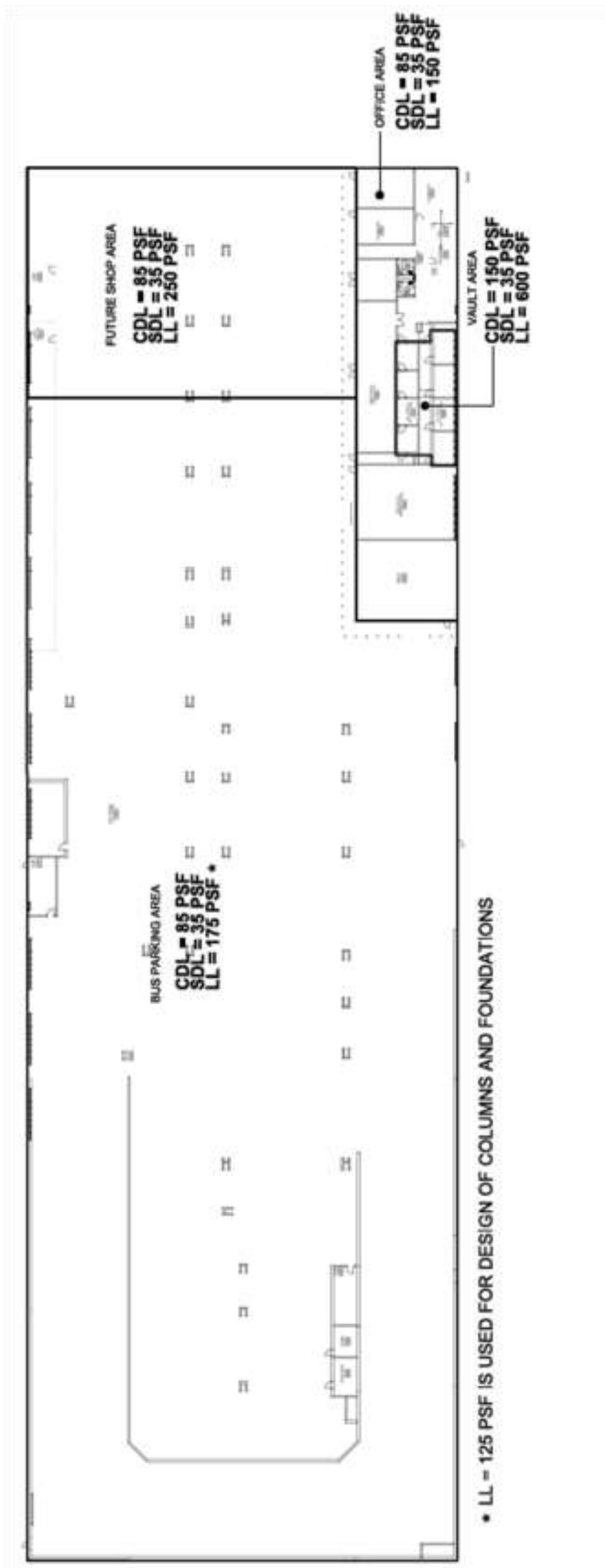
Composite Roof and High Roof Framing Plan

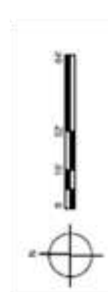
Appendix E: Distributed Loads



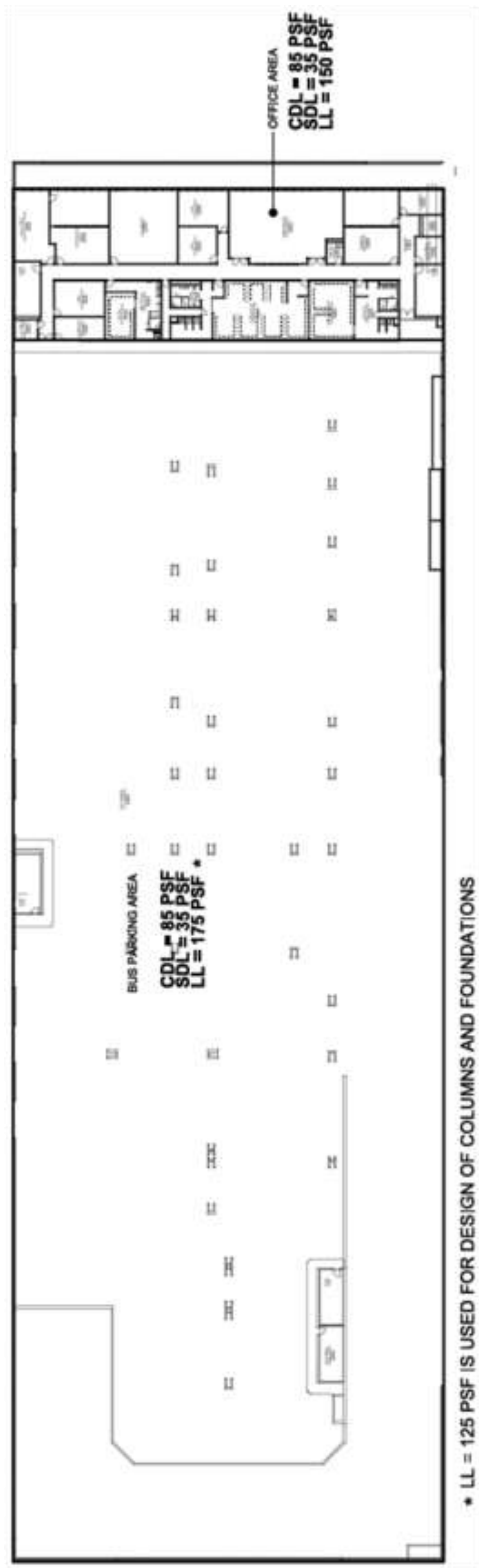
First Floor Load Map







Second Floor Load Map



Third Floor Load Map

Roof and Third Floor Mezzanine Load Map

High Roof Load Map