Technical Report III

Army National Guard Readiness Center
Arlington, Virginia

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December 1, 2009

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EXECUTIVE SUMMARY

Technical Report III is an in depth study of lateral loads to gain a better understanding of how they are distributed as well as to verify a load path and confirm the adequacy of the lateral members that have been design for both strength and serviceability criteria. Reinforced concrete shear walls were utilized as the lateral load resisting system in the Army National Guard Readiness Center Addition. The lateral loads determined in Technical Report I were slightly modified and applied to the lateral system. A summary of both wind and seismic loads is presented in this technical report. Various load combinations from ASCE 7-05 were used to check the shear strength design. An ETABS model was generated of the building's lateral system. Output from this analysis was compared to hand calculations to verify the system's shear strength. An investigation into the torsion, overturning moment, and story and overall building drifts was also completed.

Hand calculations were completed to determine the relative stiffness of each of the shear walls. The center of mass and center of rigidity were also calculated to determine the shear forces caused by eccentricity. The torsional moments calculated were converted to shear values acting on the building's lateral system. The loads were appropriately distributed and a strength check was performed according to ACI 318-08 to verify the strength of the walls. From this, it was concluded that the walls were adequately designed.

Building drift requirements for lateral loads were considered in this technical report. The overall building drift values were taken from the ETABS output and compared to the limitation of H/400 set forth by code and industry standards. Hand calculations were also completed to find story displacements and were also check against the H/400 limit. The Army National Guard Readiness Center Addition passed the building drift and story displacement limit check. The hand calculations neglected any coupling action that would have been present where the walls are connected and would have reduced the displacement. The ETABS analysis took this into consideration and therefore the ETABS values could not be directly compared to the hand calculated values.

Overturning moment was also investigated in this report. Due to the presence of the lateral forces, it was evident that overturning moments would exist and could potentially effect the building's foundation. A stress check between the lateral loads and the dead loads from the buildings self-weight was performed. From this check, it was concluded that the self-weight of the building would sufficiently resist the overturning moments and there would be a minimal effect on the foundation. A slight increase around the perimeter of the foundation would be expected due to he uplift caused by the wind pressure.

From this technical report a better understanding of the distribution of lateral loads throughout the Army National Guard Readiness Center Addition has been gained. It can be concluded from the analysis in Technical Report III that the shear walls that comprise the building's lateral system have been satisfactorily designed.

INTRODUCTION

The Army National Guard Readiness Center headquarters addition is sited to the south of the existing facility, on the location where previous storm water retention pond was located. Due to the loss of the retention pond, the project also includes the installation of storm water detention tanks. The new building is 82 feet above grade and approximately 251,000 square feet. The contract value was $100 million and is a Design-Bid-Build project with Tompkins Builders, Inc., the general contractor, holding lump sum contracts with all subcontractors. The eight-story facility is comprised of 3 underground levels (Referred to as Levels 3P, 2P and 1P) and a 5 level tower component (Levels referred to as 1T – 5T) as well as a mechanical penthouse. The three underground levels account for the majority of the building's square footage, with a much larger footprint than the above ground floors. The underground levels encompass approximately 150,000 square feet and the five-story tower encompasses 100,000 square feet. This design was developed to increase the amount of green space since a large portion of the underground levels will be topped with an intensive green roof system.

The addition is designed to meet Department of Defense Anti-Terrorism and Force Protection Requirements. This required that physical security measures, such as internal bracing to prevent progressive collapse, blast walls, berms, bollards and heavy landscape, to have been integrated into the design of the building. The facility is also expected to achieve LEED Silver Certification. LEED points are anticipated through the green roof system, offering bicycle storage and changing rooms, low-emitting and fuel efficient vehicles, reduction of water usage, water efficient landscaping, use of low-emitting as well as recycled and regional materials, and creating office space that can be 75% daylight. The building will incorporate open office spaces, general office suites, conference rooms, specialized compartmented information facilities, a fitness center, small library, and an auditorium.

As a result of the location and the existing facilities that are on site, several other features have been incorporated into the project. This includes the installation of the storm water detention tanks, the relocation of an existing radio tower, relocation of existing gate, a one story bridge connecting the new facility with the existing headquarters, construction of a new mailroom, and a construction of a new multi-story parking facility. This report will focus on the new Army National Guard Readiness Center Addition and none of the other project features will be discussed or analyzed.

BACKGROUND

The Army National Guard (ArNG) Readiness Center is located at 111 South George Mason Drive in Arlington County, Virginia. The site is bordered on the east by the U.S. Department of State, National Foreign Affairs Training Center, on the north by Arlington Boulevard, on the west by George Mason Drive, and on the south by a residential community. The fifteen-acre site is comprised of a 248,000 square foot headquarters facility, two 3-story parking garages and several small out buildings.

The Army National Guard Readiness Center houses administrative and resource functions that provide support and liaison to the National Guard in all 50 states and requisite territories and to the Pentagon. Currently there is about 1,300 staff based at this facility. The 2005 Base Realignment and Closure Act (BRAC) actions required the realignment of Jefferson Plaza 1 in Crystal City by relocating National Guard Bureau Headquarters and Air Force Headquarters to the Army National Guard Readiness Center in Arlington and to Andrews Air Force Base, in Maryland. This means the relocation of more than 1,200 National Guard Bureau Joint Staff and Army National Guard Staff to relocate to the Readiness Center. This relocation has created a great need for a Readiness Center Addition. Due to the BRAC Requirements the 1,200 personnel must be relocated before 2011. This makes the construction schedule particularly crucial.

Figure 1: West Perspective

STRUCTURAL SYSTEMS

Foundation

The geotechnical report engineering survey was performed by CH2M Hill on April 21, 2008. In this study, it was found that a relatively high water level of approximately 6 feet to 10 feet below the existing surface was anticipated. As much as 35 feet of excavation was required to reach the building grades. Therefore, drilled in soldier piles with wood lagging and tied-back anchors was recommended for temporary excavation support as well as the installation of dewatering well points. CH2M Hill noted that, with proper ground water management and control, the existing subsurface is suitable for support of the building using a mat foundation system based on evaluation of allowable bearing capacity and anticipated settlement. The recommended allowable bearing capacity for the new building location was 4800 lbs/ft^2 for a mat footing. As a result, a 43-inch concrete mat foundation was designed.

Columns

A reasonably consistent column layout exists throughout the building even with the changes in the shape of the floors between level 3P and 1T. The typical interior gravity column is a 22-inch by 22-inch, reinforced normal weight concrete column. The strength of all columns is 4,000 pounds per square inch. While the size and shape of the column is the same on each floor, there are three changes in reinforcement. For levels 3P to 1P columns are reinforced with sixteen No. 10 vertical bars. These change after the 1P level where the tower component of the building begins. For levels 1T and 2T columns are reinforced with sixteen #8 vertical bars. The reinforcement changes again at the 3T level up to the 5T level; these columns are reinforced with eight #8 vertical bars. #3 ties are located 12 inches on center at every level.

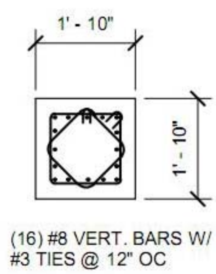


Figure 2: Typical Interior Column

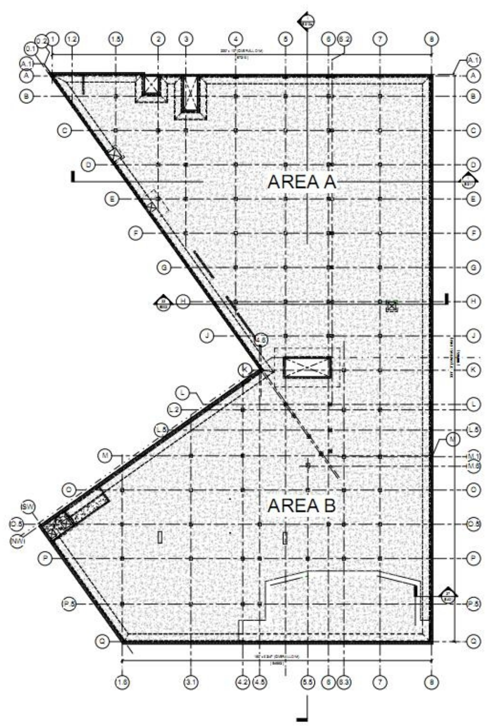


Figure 3: Typical Column Layout for Below Grade Levels

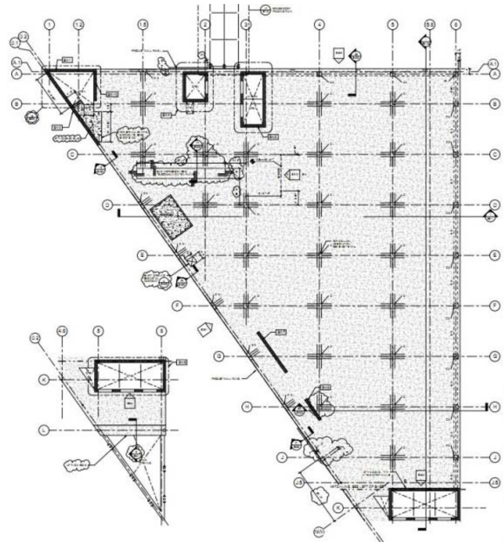


Figure 4: Typical Column Layout for Tower Levels

Floor Systems

The Army National Guard Readiness Center Addition utilizes a reinforced concrete structural system. All of the floors are two-way flat slab with column strips and edge beams along the eastern and northern walls of the Tower component. The typical concrete strength is 4,000 psi. The typical slab thickness is nine inches however; this changes in areas where the access flooring changes and for drainage areas in mechanical and electrical rooms. No. 6 and No. 8 bars are typically used for reinforcement in the floor systems.

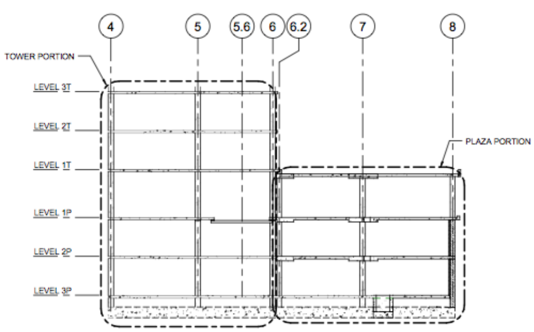


Figure 5: Elevation showing location of expansion joint and relationship between the Plaza portion and Tower Portion

Due to the irregular shape of the building and the change in shape from the underground portion of the building to the tower component, a two-inch expansion joint is located at the 3P to 1T levels along column line 6.2. This expansion joint makes the building act as almost two separate building, the tower portion and the plaza portion. The tower portion extends from level 3P to 5T while the plaza portion is comprised of the subgrade levels and topped of with an intensive green roof. This can be seen in figures 5 and 6.

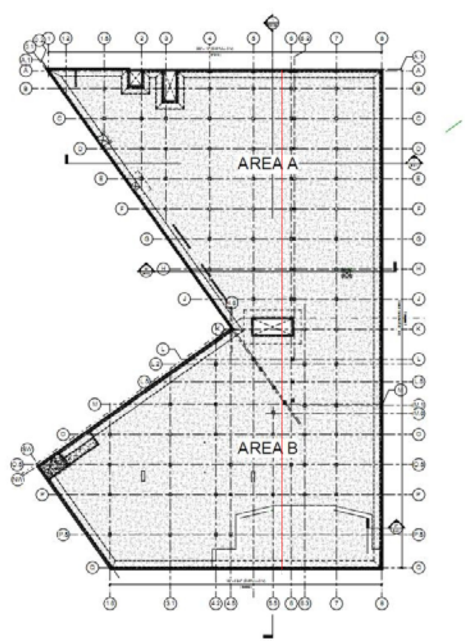


Figure 6: Location of Expansion Joint

Roof Systems

The penthouse roof of the tower is a two-way flat slab. The slab is 10" thick with a concrete strength of 4,000 pounds per square inch. This roof was designed to hold a 30 pounds per square foot snow load and is reinforced with #5 bars at 12 inches on center and 18 inches on center. A large skylight over the northern stairs required steel framing, which consists of beams ranging from W12x14 to W12x26.

The plaza roof is also a two-way slab with drop panels. The slab thickness ranges from eight inches to sixteen inches with a concrete strength of 4,000 pounds per square inch. This roof will act as an intensive green roof and therefore had to be designed to carry a 100-pound per square foot roof garden load. It is reinforced with #6 bars and includes a two-inch expansion joint where the roof abuts the floor of the first tower level (1T), as do the floors below.

Lateral System

The lateral system for the ArNG Readiness Center consists of reinforced concrete shear walls. These walls have a thickness of twelve inches and a concrete strength of 4,500 pounds per square inch. The numbers of shear walls varies between levels due to the building's change in footprint. Typical shear wall locations can be seen in figures 10 and 11 below. This system resists lateral loads in the north-south and east-west direction depending upon the orientation of the wall.

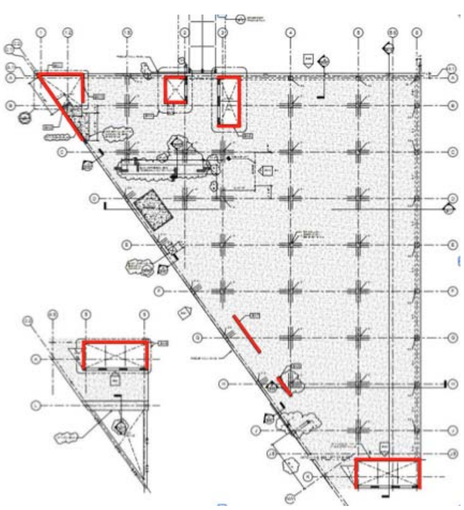


Figure 8: *Shear Wall Locations in Tower Levels*

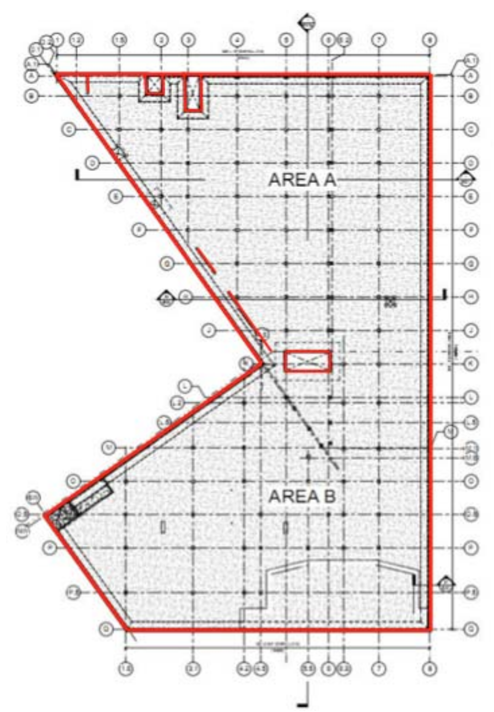


Figure 7: *Shear Wall Locations in Levels 3P to 1P*

DESIGN & CODE REVIEW

Codes and References

The following documents were either furnished for review or otherwise considered for this report:

- ACI 318-08 *Building Code Requirements for Structural Concrete* published in January 2008 by the American Concrete Institute
- AISC 13th Edition (LRFD) *Steel Construction Manual* Published in December 2005 by the American Institute of Steel Construction, Inc.
- ASCE/SEI 7-05 *Minimum Design Loads for Buildings and Other Structures* published in 2006 by the American Society of Civil Engineers
- IBC 2006 *International Building Code* published in January 2006 by the International Code Council, Inc.
- *Notes on ACI 318-08 Building Code Requirements for Structural Concrete* Published in 2005 by the Portland Cement Association
- Construction Documents originally dated August 25, 2008 by DMJM H&N, Inc.

Deflection Criteria

Floor Deflection Criteria

Typical Live Load Deflection limited to L/360

Typical Total Deflection limited to L/240

Maximum Deflection limited to ¾”

Lateral Deflection Criteria

Total Allowable Building Drift limited to H/400

Story Wind Drift limited to H/400 to H/600

Story Seismic Drift limited to $0.015h_{SX}$

Load Combinations

The following load combinations were considered for combining factored loads for gravity and lateral load analysis. All load combinations are based on LRFD design and come from ASCE 7-05 Section 2.3. By inspection, it was clear that the wind would control in the East/West direction and the earthquake controls in the North/South direction. Therefore, for all hand calculations, load case 4 was used for East/West and case 5 was used for North/South. All load cases were input into the ETABS model for further analysis and to check hand calculations.

1.4(D+L)

1.2(D+F+T)+1.6(L+H)+0.5(L_r or S or R)

1.2D+1.6(L_r or S or R)+(L or 0.8W)

1.2D+1.6W+L+0.5(L_r or S or R)

1.2D+1.0E+L+0.2S

0.9D+1.6W+1.6H

0.9D+1.0E+1.6H

LOADS

Live Loads

The live loads for the Army National Guard Readiness Center were calculated in accordance with IBC 2006, which references ASCE 7-05, Chapter 6. The loads that were determined from these references are noted in the table below.

Table 1: *Live Loads*		
Occupancy	**Design Load**	**ASCE 7-05 Load**
Office	50 psf + 15 for partitions	50 psf
Lobbies	100 psf	100 psf
First Floor Corridor	100 psf	100 psf
Corridors (Above First Floor)	80 psf	80 psf
Fitness Center	100 psf	100 psf
Roof	20 psf	20 psf
Roof Garden	100 psf	100 psf

Dead Loads

The dead loads used for the design of the Army National Guard Readiness Center were noted on the structural drawings for this project. These occupancy types and loading are summarized in Table 2 below.

Table 2: *Dead Loads*	
Typical Floor Dead Loads	
Occupancy	Design Loads
6" Raised Floor	43 psf
24" Raised Floor	20 psf
Normal Weight Concrete	150 pcf
MEP/Ceiling	15 psf
CMU Partitions	Actual Weight
Typical Roof Dead Loads	
Occupancy	Design Loads
Normal Weight Concrete	150 pcf
MEP/Ceiling	15 psf
Roofing Finish	4 psf

Wind Loads

In accordance with IBC 2006, the wind loads on the building were determined by the provisions of ASCE 7-05 Chapter 6. To examine the lateral wind loads in both the North/South and East/West direction, Method 2, the analytical method, was used. From Figure 6-1 in ASCE 7-05 it was found that the basic wind speed in Arlington, Virginia is 90 mph. This method does not take into account any apparent shielding afforded by other buildings to reduce wind velocity. This could be crucial due to the relative proximity of the new facility with the existing structures that surround the building. For this technical report, a few assumptions were made to simplify the procedure. The main assumption was the ArNG Readiness Center was considered a regular-shaped building.

Using the commentary within ASCE 7-05 the approximate fundamental frequency of the building was calculated. It was determined from this that the building is rigid in nature and therefore 0.85 could be used for the Gust factors. Figures below summarize the story forces and shear in both the North-South and East-West direction. Appendix C contains detailed spreadsheets, calculations, and criteria that were determined to ascertain the wind forces.

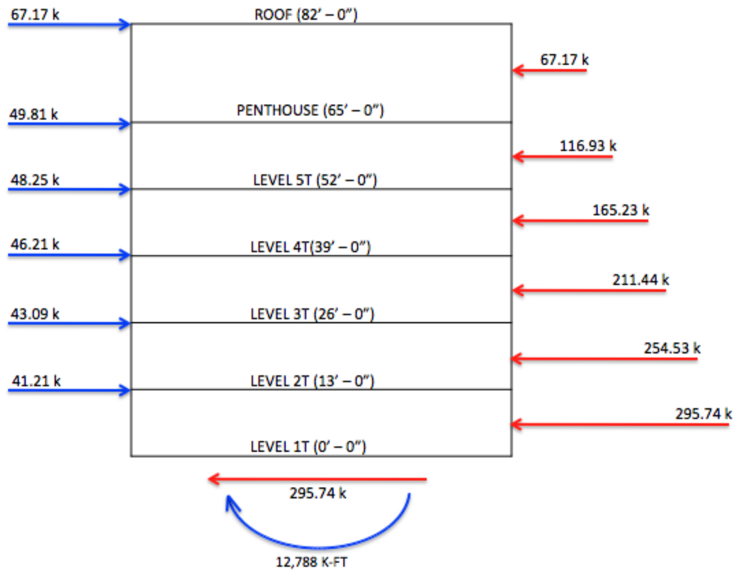


Figure 9: *Story Forces and Shear in the North-South Direction*

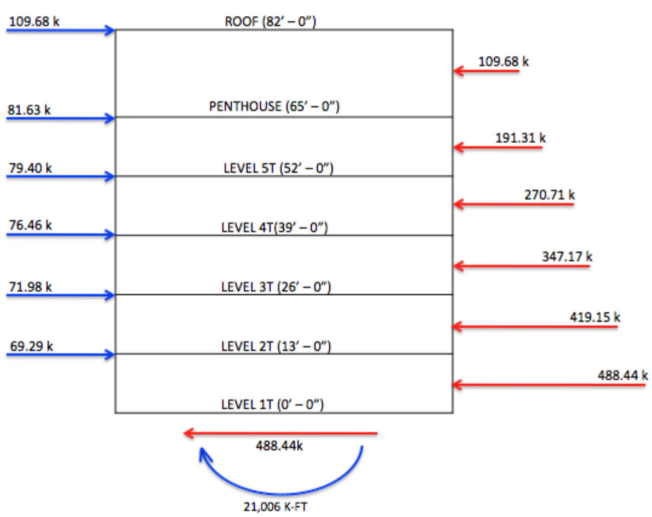


Figure 10: *Story Forces and Shear in the East-West Direction*

Seismic Loads

Chapters 11 and 12 of ASCE 7-05 were referenced in order to calculate the seismic forces on the Army National Guard Readiness Center. It was assumed that the ArNG Readiness Center employed a rigid diaphragm, which allowed for the use of the Equivalent Lateral Force Procedure (ELF) found in section 12.8 of ASCE 7-05 standards. Upon investigation of the geotechnical report provided by CH2M Hill, it was determined that the Army National Guard Readiness Center falls under Site Class D. S_S and S_1 were then determined using the United State's Geological Surveying (USGS) website. All design variables and site parameters that were used in determining the seismic loads can be found in Appendix C along with detailed calculations and spreadsheets that were utilized to obtain the building weight, base shear, and overturning moment. Figure 14 is a loading diagram that summarizes the story forces, base shear, and overturning moment acting on the ArNG Readiness Center due to seismic loads.

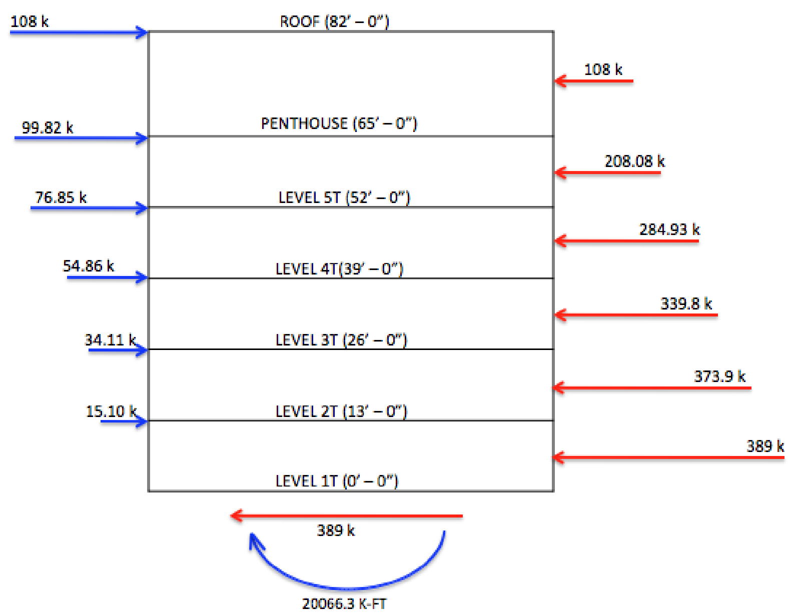


Figure 11: *Story Forces and Shear*

MODELED LATERAL SYSTEM ANALYSIS

ETABS is a computer modeling and analysis program developed by Computers & Structures, Inc. The goal of this analysis was to determine how the loads are distributed throughout the building's lateral system. For this technical report, only the lateral elements and diaphragm of the building were modeled for simplicity as well as to reduce possible errors. The mass of each of the shear walls was incorporated into membranes that define each portion of the wall. Walls were meshed into areas with a given maximum dimension allowing walls that were connected to act as one rigid unit. The diaphragms were modeled as to act completely rigid, which is accurate due to them being concrete. Results from this model were compared to hand calculated values for center of mass, center of rigidity, and story forces. Additional information was pulled from the model such as overall building drift and the controlling load cases.

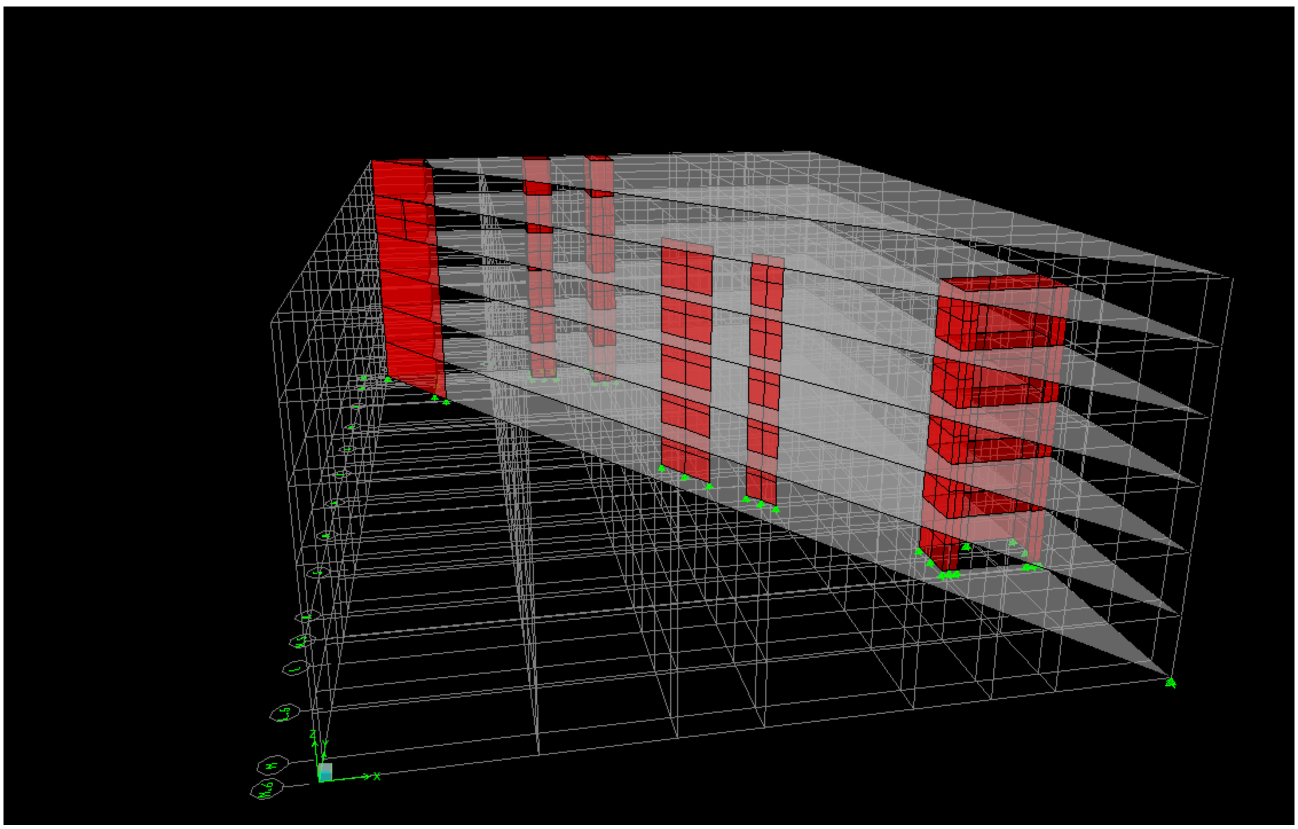


Figure 12: *ETABS Model*

DISTRIBUTION OF LATERAL LOADS

It is assumed that the distribution of the lateral loads throughout the Army National Guard Readiness Center is controlled by relative stiffness. The lateral forces caused primarily through the wind and seismic loading hit the building's façade. The concrete floor slabs act like beams to transfer the lateral loads to the shear walls and the shear walls act like cantilevered beams and carry the loads into the foundation. The relative stiffness of each shear wall is determined by the rigidity of the wall. The most rigid walls draw the forces to them.

The shear walls (seen in the figure below) are in the same location on each floor of the ArNG Readiness Center and maintain a 12" thickness everywhere with the exception of the penthouse level. Shear walls six; seven, and eight do not exist on the penthouse level. Due to the irregular shape of the building, not all of the shear walls are positioned in the direct North-South or East-West direction, but at a 35.5-degree angle from the horizontal. These walls were resolved into X and Y components to determine the relative stiffness of each wall with respect to the East-West lateral forces or the North-South lateral forces.

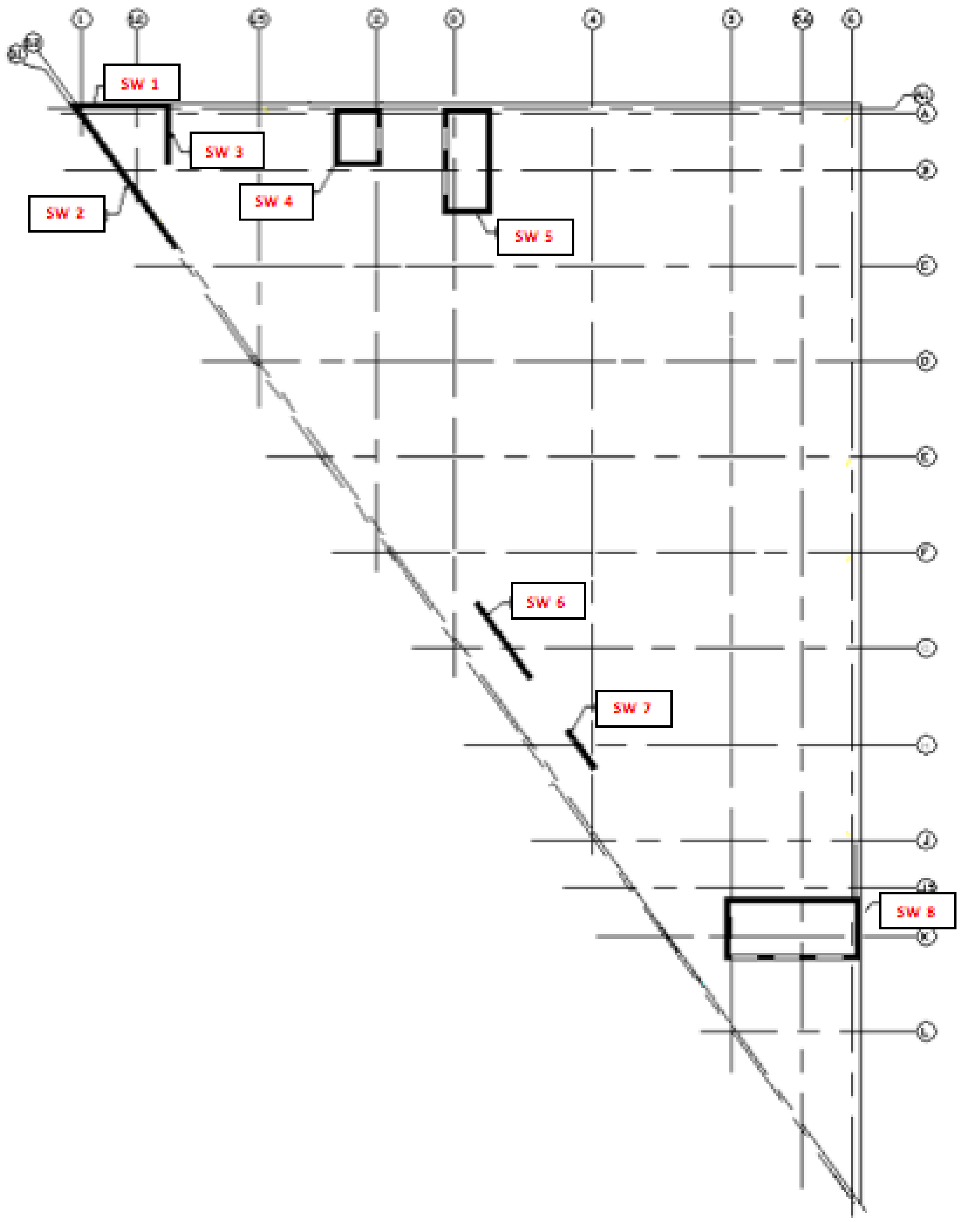


Figure 13: *Shear Wall Locations*

Shear Wall Stiffness

To determine the forces that go to each shear wall, the stiffness of each is critical due to the diaphragm acting rigidly. The torsion of each floor as well as the overall building torsion is also dependent on the stiffness since it affects the rigidity. The more rigid the shear wall the less deflection will be created.

The rigidity of each wall was determined using the equation:

$$R_i = \frac{Et}{4\left(\frac{h}{L}\right)^3 + 3\left(\frac{h}{L}\right)}$$

Table 4-a: *Wall Rigidity (N-S Span)*

Floor	Ht	Wall 2	Wall 3	Wall 4	Wall 5	Wall 6	Wall 7	Wall 8	Sum(Rigidities)	Center of Rigidity (x)
		Length=253.2"	Length=138"	Length=144"	Length=252"	Length=133"	Length=69.6"	Length=162"		
1T	162	15464	4592	5059	15339	4216	799	6555	52024	1203
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3T	486	1346	248	280	1331	223	33	392	3853	1239
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5T	810	326	56	63	322	50	7	89	913	1246
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]

Table 4-b: *Wall Rigidity (E-W Span)*

Floor	Ht	Wall 1	Wall 2	Wall 4	Wall 5	Wall 6	Wall 7	Wall 8	Sum(Rigidities)	Center of Rigidity (y)
		Length=216"	Length=356.4"	Length=96"	Length=96"	Length=186"	Length=97.2"	Length=300"		
1T	162	11653	26381	1890	1890	8730	1951	20394	72889	832
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3T	486	877	3224	86	86	579	53	2098	7003	802
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5T	810	207	853	19	19	134	20	528	1780	795
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]

The rigidity values for each shear wall can be seen in the following table and supporting calculations can be referenced in Appendix D. Once the rigidity values were known, the relative stiffness of each wall was determined. The relative stiffness dictates the percentage of lateral force that is distributed to each wall. Again, the values for each shear wall can be found in the following tables and calculations in Appendix D. The relative stiffness for each wall was established by:

$$Relative Stiffness = \frac{R_i}{\Sigma R} x100\%$$

Table 5-a: *Relative Stiffness (North-South Force)*

	Wall 2	Wall 3	Wall 4	Wall 5	Wall 6	Wall 7	Wall 8
Level 1T	29.7	8.8	9.7	29.5	8.1	1.5	12.6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Level 3T	34.9	6.4	7.3	34.5	5.8	0.9	10.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Level 5T	35.7	6.1	6.9	35.3	5.5	0.8	9.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 5-b: *Relative Stiffness (East-West Force)*

	Wall 1	Wall 2	Wall 4	Wall 5	Wall 6	Wall 7	Wall 8
Level 1T	16.0	36.2	2.6	2.6	12.0	2.7	28.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Level 3T	12.5	46.0	1.2	1.2	8.3	0.8	30.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Level 5T	11.6	47.9	1.0	1.0	7.5	1.1	29.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Center of Mass & Center of Rigidity

In order to find the location of the resultant story force the center of mass (COM) and center of rigidity (COR) for each diaphragm were calculated. These two points determine the eccentricity of each floor, which creates a torsional moment. The center of mass was calculated as the center of mass of a triangle to simplify the calculations. The center of rigidity was determined on each floor using the rigidity values that were found for each shear wall on the given floor.

$$CenterofRigidity = \frac{\Sigma(R \times DistanceBetweenElement \,\&\, Orgin)}{\Sigma R}$$

The hand calculated values for both the center of mass and the center of rigidity were compared to the ETABS output and can be seen in Table 6. From this table it can be seen that the hand calculated values are comparable to the ETABS output. The slight variation in the center of mass values is mostly caused by the assumption made in the hand calculation to use the center of mass of a triangle, which neglected and openings within the diaphragm as well as wall locations that were most likely considered in the ETABS analysis. There was also a small difference in the center of rigidity values, which suggests that the diaphragms were considered in the determination of rigidity, as opposed to the hand calculations where it was assumed that only the shear walls were to be considered. For this technical report, the values produced by the hand calculations for both the center of rigidity and the center of mass where used where required. Example hand calculations can be referenced in Appendix D.

Table 6: *Center of Rigidity & Center of Mass*

	Center of Rigidity				Center of Mass			
	ETABS		Hand Calculations		ETABS		Hand Calculations	
	X	Y	X	Y	X	Y	X	Y
2T	-	-	832	1203	695.8756	432.298	6648	652
3T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4T	757.32	1236.326	802	1239	695.8756	432.298	6648	652
5T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Penthouse	707.409	1252.839	795	1246	695.8756	432.298	6648	652
PH Roof	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TORSION

Torsion is present in the Army National Guard Readiness Center since the center of mass and the center of rigidity are not in the same location. The torsion must be considered along with the direct story force applied to each floor while calculating the lateral forces acting on the buildings lateral system. The eccentricity between the center of mass and center of rigidity produces a moment, which creates an additional torsional shear that must also be considered. The torsional shear will be discussed further when the direct shear component is analyzed.

For buildings with rigid diaphragms, like the Army National Guard Readiness Center, there are two separate moments that must be accounted for according to section 12.8 of ASCE 7-05. There is the inherent moment, M_t, and the accidental moment, M_{ta}. The inherent moment is the moment due to the eccentricity between the center of mass and center of rigidity. The accidental moment is caused by an assumed displacement of the center of mass and was determined according to ASCE 7-05 section 12.8.4. Table 7 shows the torsional moments that were produced by forces in both directions.

Table 7: *Overall Building Torsion*

	N/S Force				E/W Force			
	Factored Lateral Force (k)	M_t (ft-k)	M_{ta} (ft-k)	M_{total} (ft-k)	Factored Lateral Force (k)	M_t (ft-k)	M_{ta} (ft-k)	M_{total} (ft-k)
Level 2T	15.10	210.4	250.9	461.3	110.90	-5092.2	1807.7	-3284.5
Level 3T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Level 4T	54.86	627.2	911.8	1539	122.34	-5984.4	1992.3	-3992.1
Level 5T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Penthouse	99.82	1083.1	1659	2742.1	130.61	-6465.2	2128.9	-4336.3
PH Roof	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

SHEAR

Direct Shear

The lateral forces that act on a building cause direct shear and are distributed to the shear walls by relative stiffness. The direct shear for each wall was determined by multiplying the story shear by the relative stiffness of the given wall. The values for the direct shear can be seen in the following tables and example calculations can be found in Appendix E.

Table 8-a: *North/South Direct Shear*

Load Combination 0.9D+1.0E-1.6E	Force (k)	Factored Force (k)	Distributed Force (k)						
			Wall 2	Wall 3	Wall 4	Wall 5	Wall 6	Wall 7	Wall 8
Level 2T	15.10	15.10	4.48	1.31	1.47	4.45	1.22	0.24	1.90
Level 3T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Level 4T	54.86	54.86	15.15	3.51	4.00	18.91	3.18	0.49	5.60
Level 5T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Penthouse	99.82	99.82	35.64	6.09	6.89	35.24	5.49	0.80	9.68
PH Roof	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 8-b: *East/West Direct Shear*

Load Combination 1.2D+1.6W+0.5(L, or S or R)	Force (k)	Factored Force (k)	Distributed Forces (k)						
			Wall 1	Wall 2	Wall 4	Wall 5	Wall 6	Wall 7	Wall 18
Level 2T	69.29	110.90	17.74	40.13	2.88	2.88	13.30	3.00	31.04
Level 3T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Level 4T	76.46	122.34	15.29	56.28	1.47	1.47	10.15	0.98	36.70
Level 5T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Penthouse	81.63	130.61	15.15	62.56	1.31	1.31	9.80	1.44	38.79
PH Roof	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Torsional Shear

As mentioned previously, torsional shear is also present when torsion is produced by the building and must be considered with the direct shear. Torsional shear was calculated for the shear walls supporting Level 4T as an example. The shear was calculated using the equation:

$$T = \frac{V_{Total} e d_i R_i}{J}$$

Values found from the example calculation can be found in Table 9 and supporting calculations in Appendix E.

Table 9: *Torsional Shear in Shear Wall Supporting Level 4T*							
		V_{tot} (k)	R_i	e (in)	d_i (in)	$(R_i)(d_i^2)$	Torsional Shear (k)
Wall 1	N/S	555.47	0.000	134.2	-	0.00	-
	E/W	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wall 2	N/S	555.47	0.349	134.2	1681.8	987129.48	19.38
	E/W	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wall 3	N/S	555.47	0.064	134.2	1573.8	158518.17	3.32
	E/W	[illegible]	[illegible]	[illegible]	-	[illegible]	-
Wall 4	N/S	555.47	0.073	134.2	1151.8	96844.96	2.78
	E/W	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wall 5	N/S	555.47	0.345	134.2	777.8	208715.63	8.86
	E/W	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wall 6	N/S	555.47	0.058	134.2	729.8	30891.27	1.40
	E/W	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wall 7	N/S	555.47	0.009	134.2	527.8	2502.06	0.16
	E/W	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wall 8	N/S	555.47	0.102	134.2	171.8	3010.55	0.58
	E/W	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
					Torsional Moment of Inertia=	2258156.40	

Shear Strength Check

Shear strength checks were done on the lateral elements of the Army National Guard Readiness Center to confirm the strength of the shear walls is adequate to carry the loads determined previously in this report. For an example, the shear strength of the walls supporting Level 4T was checked. From section 21.9.4.1 from ACI 318-08 the equation for shear strength of reinforced shear walls is:

$$V_n = A_{cv}[(a_c \lambda \sqrt{f'_c}) + (\rho_t f_y)]$$

The values determined for the shear strength of each wall supporting level 4T can be found in Table 10 below. All of the were within the capacity that was determined using the equation from ACI 318-08 above. Detailed hand calculations can be referenced in Appendix E.

Table 10: *Shear Wall Strength Check*													
Level 4T	Direction	Direct Shear (k)	Torsional Shear (k)	Vu (k)	Vertical Reinforcement	Spacing (in)	Length (in)	Thickness (in)	ACV (in2)	αC	ρt	Vn (k)	Check
Wall 1	N/S	-	-	-	(2) #8	8	-	12	-	2	0.0165	-	-
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wall 2	N/S	11.60	19.38	30.98	(2) #8	8	253	12	3036.4	2	0.0165	5561.4	OK
	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wall 3	N/S	2.39	3.32	5.71	(2) #8	8	138	12	1656	2	0.0165	1396.2	OK
	[illegible]							[illegible]		[illegible]	[illegible]		
Wall 4	N/S	2.69	2.78	5.47	(2) #8	8	144	12	1728	2	0.0165	1459.9	OK
	[illegible]		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wall 5	N/S	11.36	8.86	20.22	(2) #8	8	252	12	3024	2	0.0165	2549.6	OK
	[illegible]		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wall 6	N/S	2.15	1.40	3.55	(2) #8	8	133	12	1596	2	0.0165	1349.6	OK
	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wall 7	N/S	0.34	0.16	0.50	(2) #8	8	70	12	835.2	2	0.0165	704.2	OK
	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]		[illegible]		[illegible]	[illegible]	[illegible]
Wall 8	N/S	3.68	0.58	4.26	(2) #8	8	162	12	1944	2	0.0165	1639	OK
	[illegible]	[illegible]	[illegible]	[illegible]					[illegible]		[illegible]	[illegible]	[illegible]

DRIFT AND DISPLACEMENT RESULTS

The drift of a building is a serviceability issue that must be considered in the building design. Drift is inversely proportional to the total stiffness of the building's lateral structure and should be limited as much as reasonably possible. The maximum building deflection due to lateral wind loads is limited to 1/400th of the total building height. For the Army National Guard Readiness Center the drift is limited to:

$$\Delta_{Limit} = \left(990''/400\right) = 2.475''$$

The building drift was taken from the ETABS analysis. From ETABS it was found that the building drifts 1.32" in the x-direction (due to the East/West forces) and 1.49" in the y-direction (due to the North/South forces). Both of these drifts were well below the deflection limit and therefore building drift is not and issue for the Army National Guard Readiness Center.

Each story was also examined independently to determine an approximate value for the story displacement and drifts of each level. Hand calculations were performed to find these values. The equation used was:

$$\Delta = \Delta_{Flexure} + \Delta_{Shear} = \frac{Ph^3}{3E_c I} + \frac{1.2Ph}{E_r A}$$

As an example, the story displacement was calculated for Shear Wall 2 in the North-South direction. All supporting calculations and tables can be found in Appendix F. These hand calculations were performed for a rough approximation and assumptions were made to simplify these calculations. Since these assumptions neglected some factors that were included in the ETABS analysis, it was a true approximation and the values calculated by hand cannot be compared to the ETABS values.

OVERTURNING MOMENT

Overturning moments are cause by lateral forces on a building and must be considered due to the effects it could have on the building's foundation. The moments were calculated by multiplying the story shear by the mid-height of each level. This was done with the seismic loads in the North-South direction and wind forces in the East-West direction. These values can be seen in the table below. A rough estimate showed that the overturning moment would not be an issue in the Army National Guard Readiness Center. This approximation was done by comparing the stresses due to the lateral loads on the building with the stresses caused by the dead loads (self weight) of the building. The dead load stresses of the building will counteract the stresses from the lateral load to eliminate overturning issues. Because the stresses produced by the lateral forces are only a small portion of the produced by the building's self weight, overturning moments would have only a minimal effect on the foundation. It is expected that there will be slight increases around the perimeter where a small uplift force will be present on the windward side and downward force on the leeward side.

Table 11: *Overturning Moments*

Floor	Height Above Ground (ft)	Story Height (ft)	N/S Seismic		E/W Wind	
			Lateral Force	Moment	Lateral Force	Moment
1T	0.00	0.00	0.00	0.00	0.00	0.00
2T	13.50	13.50	15.14	102.20	34.40	232.20
3T	27.00	13.50	34.11	690.73	37.10	751.28
4T	40.50	13.50	54.86	1851.53	41.63	1405.01
5T	54.00	13.50	76.85	3631.16	44.75	2114.44
Penthouse	67.50	13.50	99.82	6064.07	46.87	2847.35
PH Roof	82.00	14.50	108.22	8089.45	64.26	4803.44
		Totals:	389.00	20429.12	269.01	12153.71

CONCLUSION

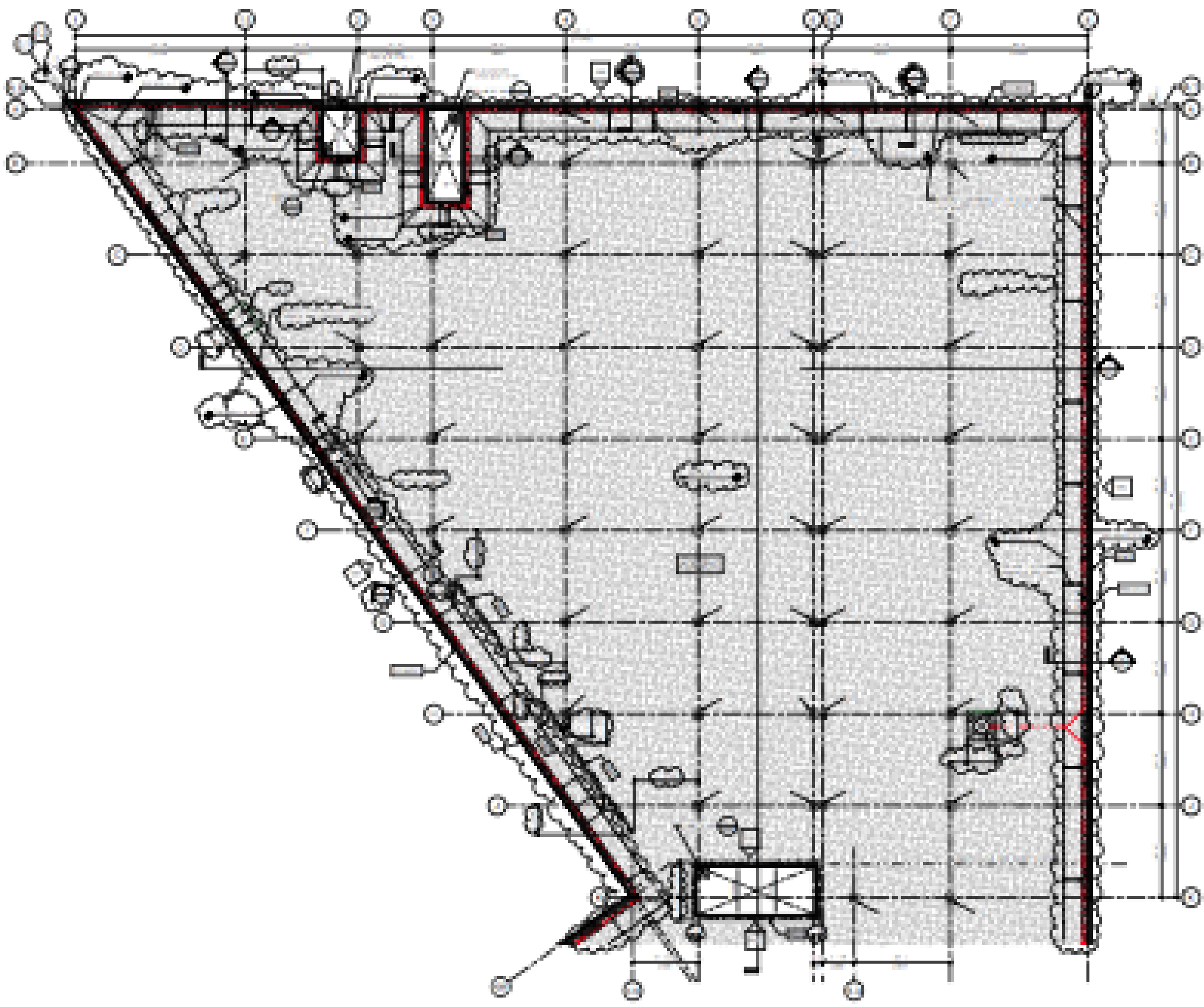
Throughout this technical report, the lateral system of the Army National Guard Readiness Center was analyzed. To perform the lateral analysis the loads that were initially determined in Technical Report I had to be adjusted and then factored according to the load combinations for strength design from ASCE 7-05. It was determined that the lateral forces were controlled by the seismic loads in the North-South direction and wind loads in the East-West direction. From this lateral analysis it can by concluded that the wind and seismic loads that create the lateral forces cause shear at each level which are resisted by the reinforced concrete shear walls located throughout the building. Since the floor diaphragms act rigidly, the lateral loads are distributed to the shear walls on the basis of relative stiffness. A computer model was generated of the building's diaphragms and lateral system using ETABS. From this modeled analysis, the overall building drift was found to be 1.32" in the x-direction and 1.49" in the y-direction. Hand calculations were also completed to check the story displacement and drift. All values were within the H/400 limit.

It was determined that torsion was present in the building due to the eccentricity between the center of mass and center of rigidity. This added torsional shear to the walls, which needed to be considered along with the direct shear, distributed to each of the shear walls. Shear strength checks were performed on the walls including both torsional and direct shear. It was concluded from this analysis that the walls were adequately designed to resist the anticipated shear loads. The presence lateral forces also create overturning moments that could effect the building's foundation. A stress check between the lateral loads and the dead loads caused by the self-weight of the building concluded that the building weight would sufficiently resist the overturning moment that exists.

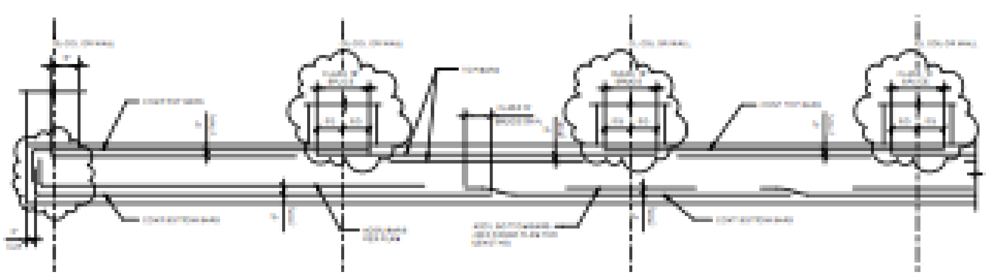
From Technical Report III, the distribution of the lateral loads throughout the Army National Guard Readiness Center can be better understood. A more complex model and further analysis into the lateral system would need to be performed in the future depending on what changes and concepts will be investigated in the second portion of senior thesis. From this analysis, it can be concluded that the shear walls in the Army National Guard Readiness Center are satisfactorily designed.

APPENDIX A: BUILDING LAYOUTS

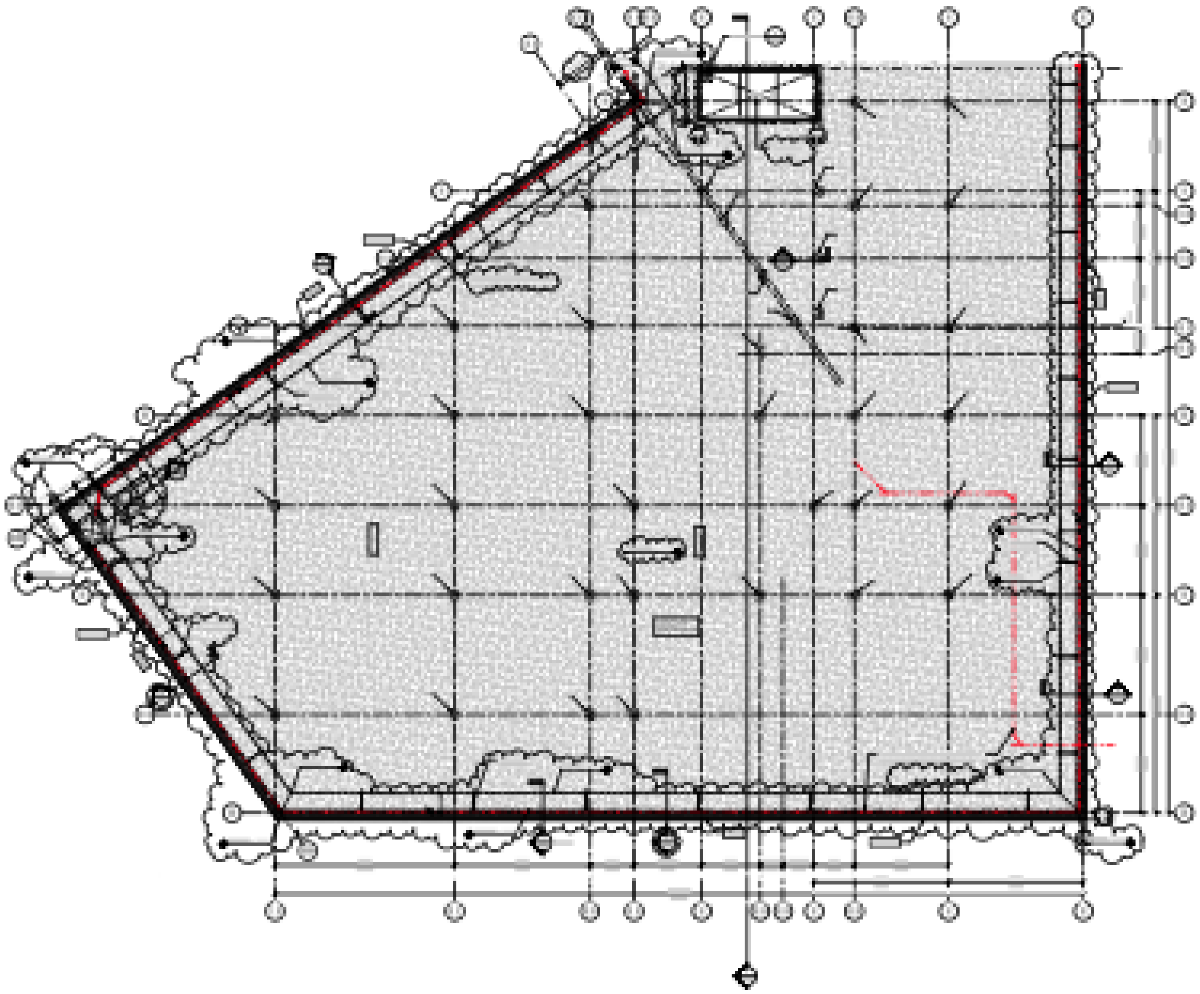
Presented in this appendix are some of the main drawings and details that were referenced during the investigation and research to complete this technical report.



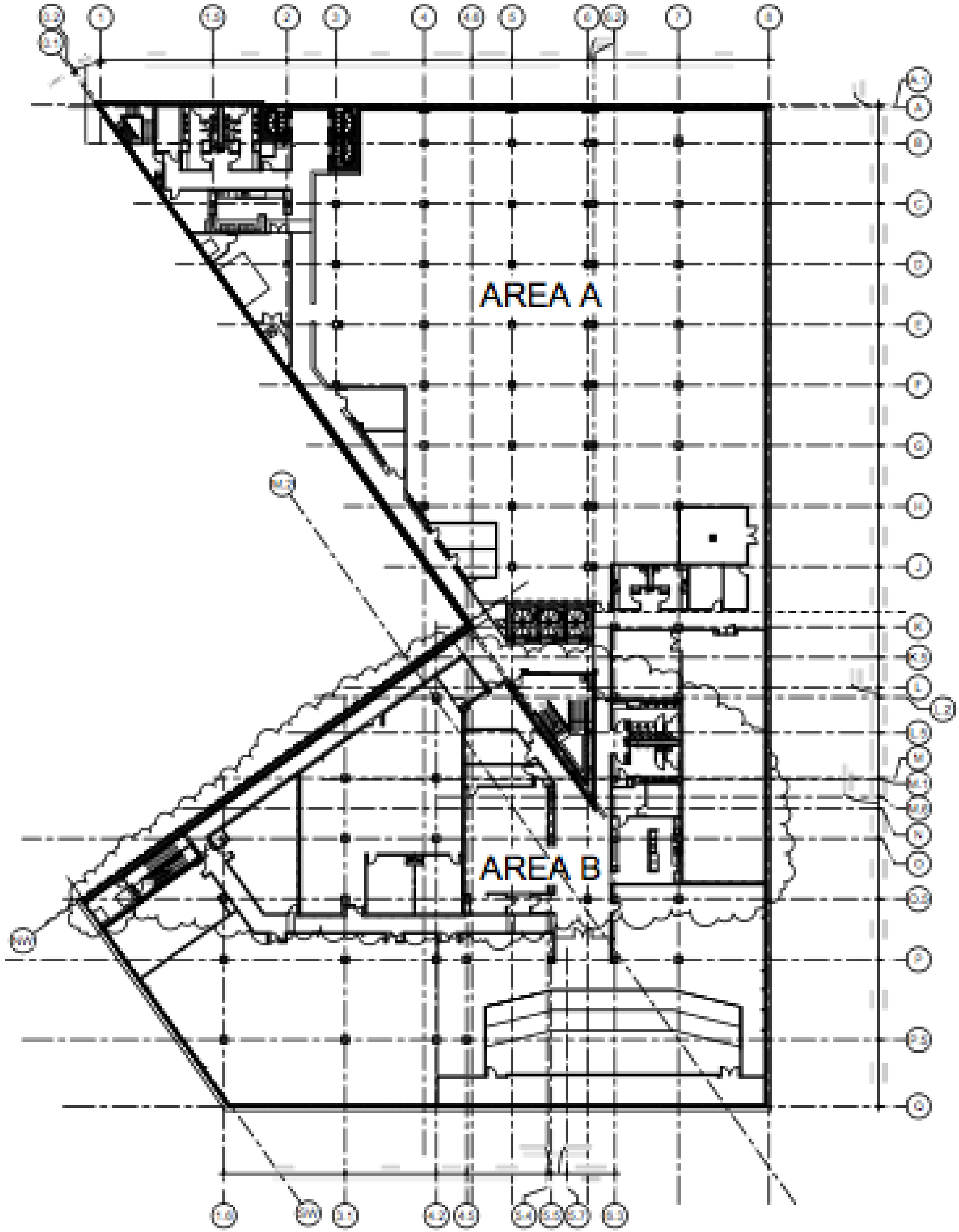
Partial Mat Foundation Plan



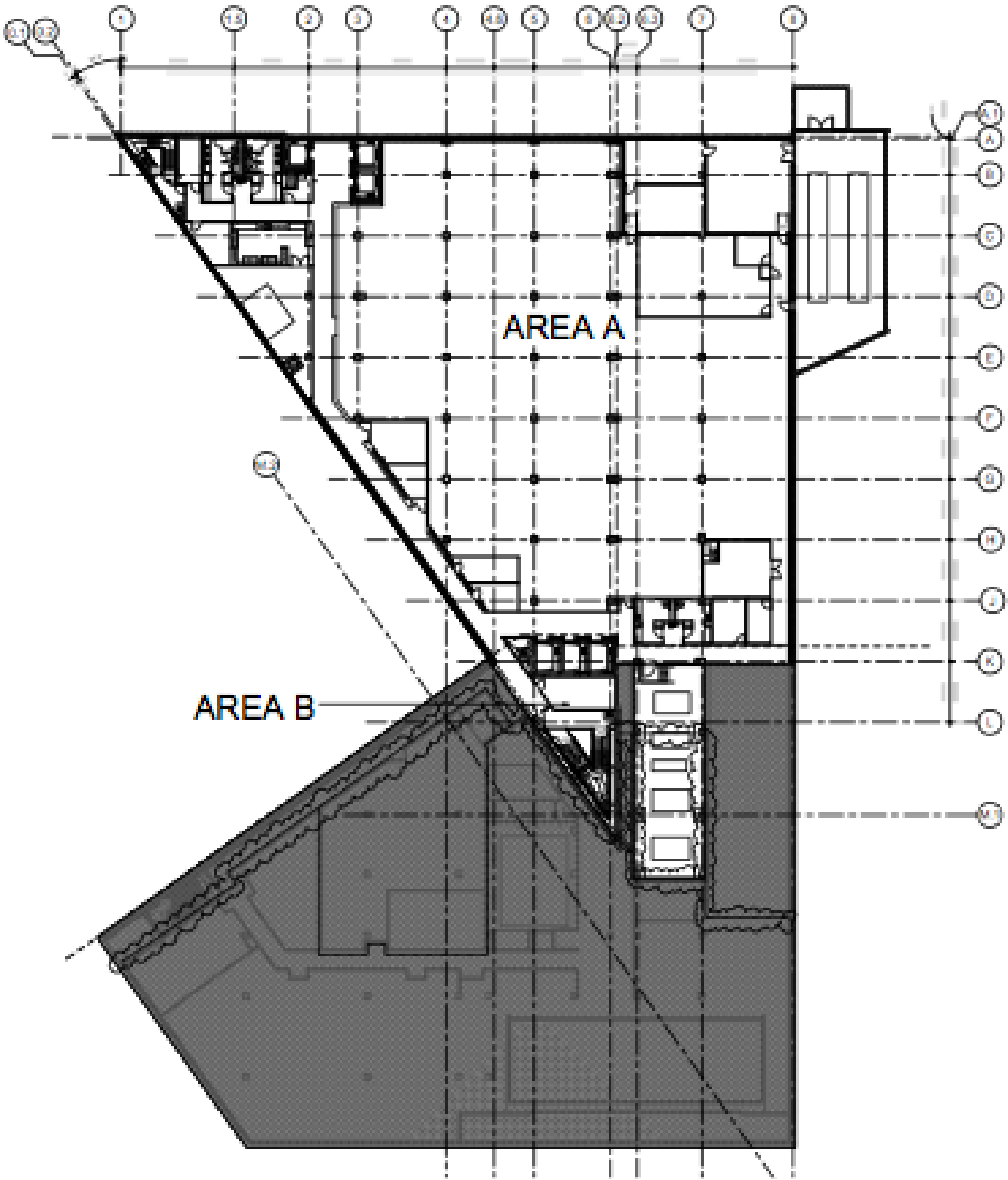
Typical Mat Foundation Detail



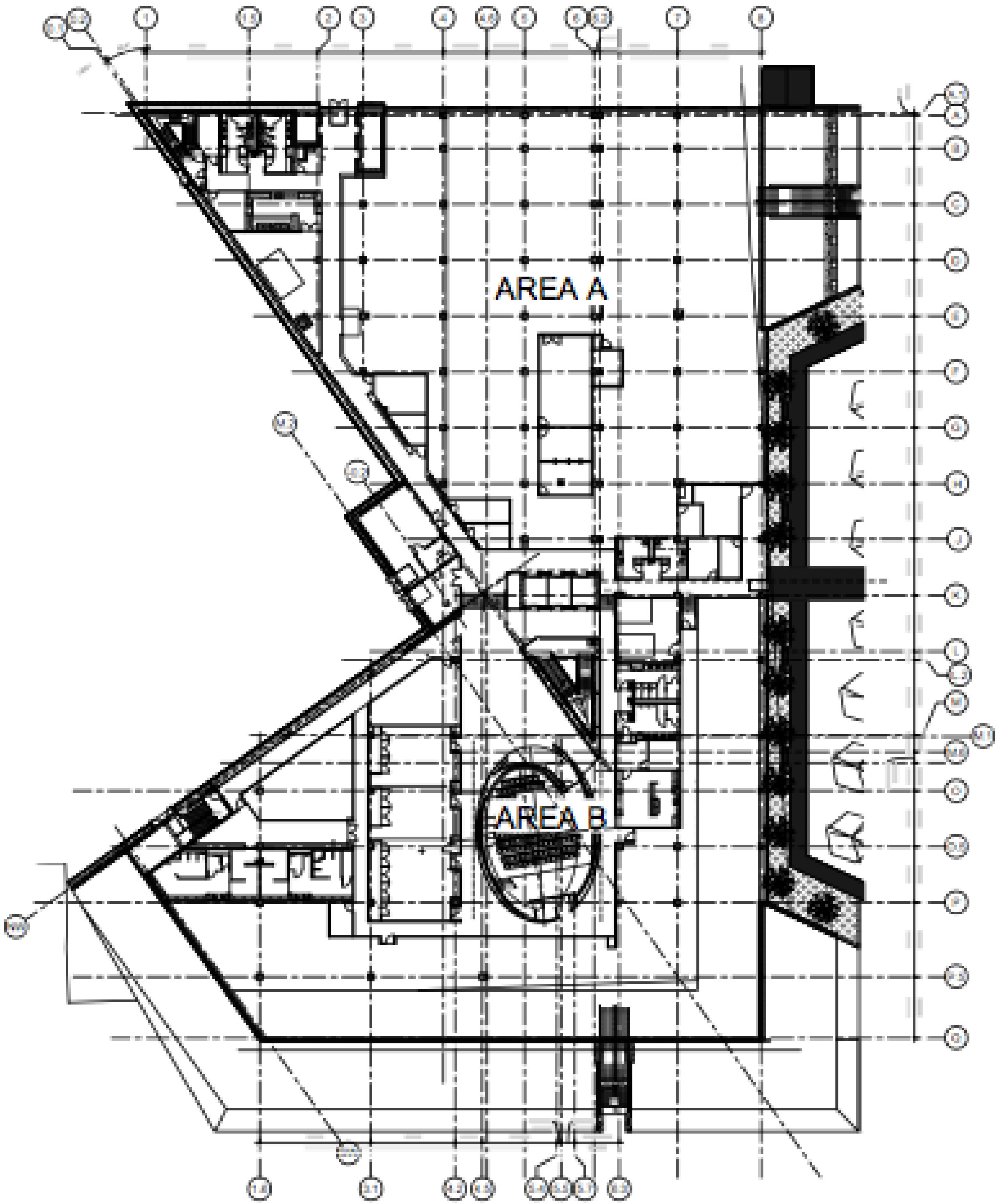
Partial Mat Foundation Plan



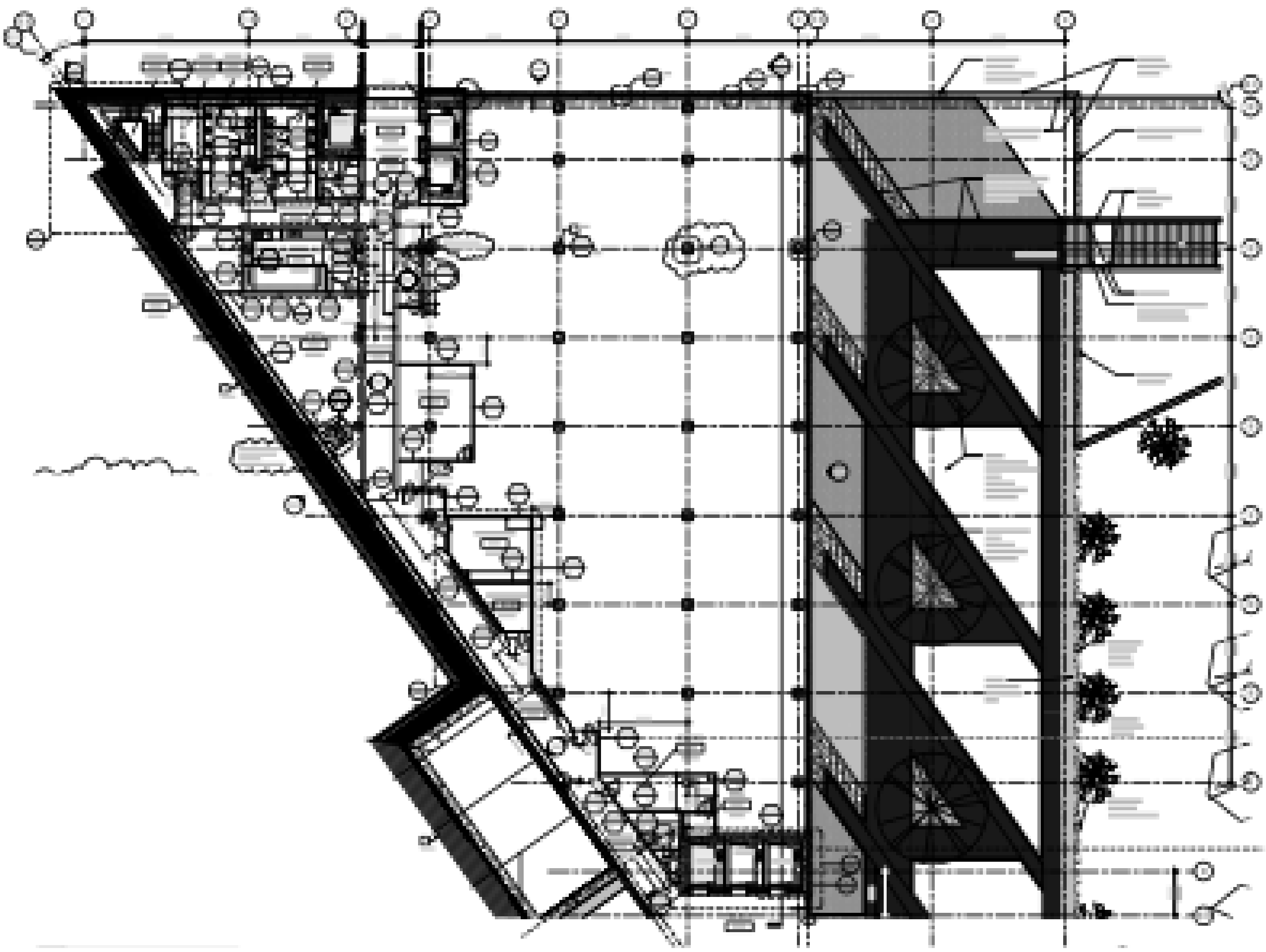
Level 3P Floor Plan



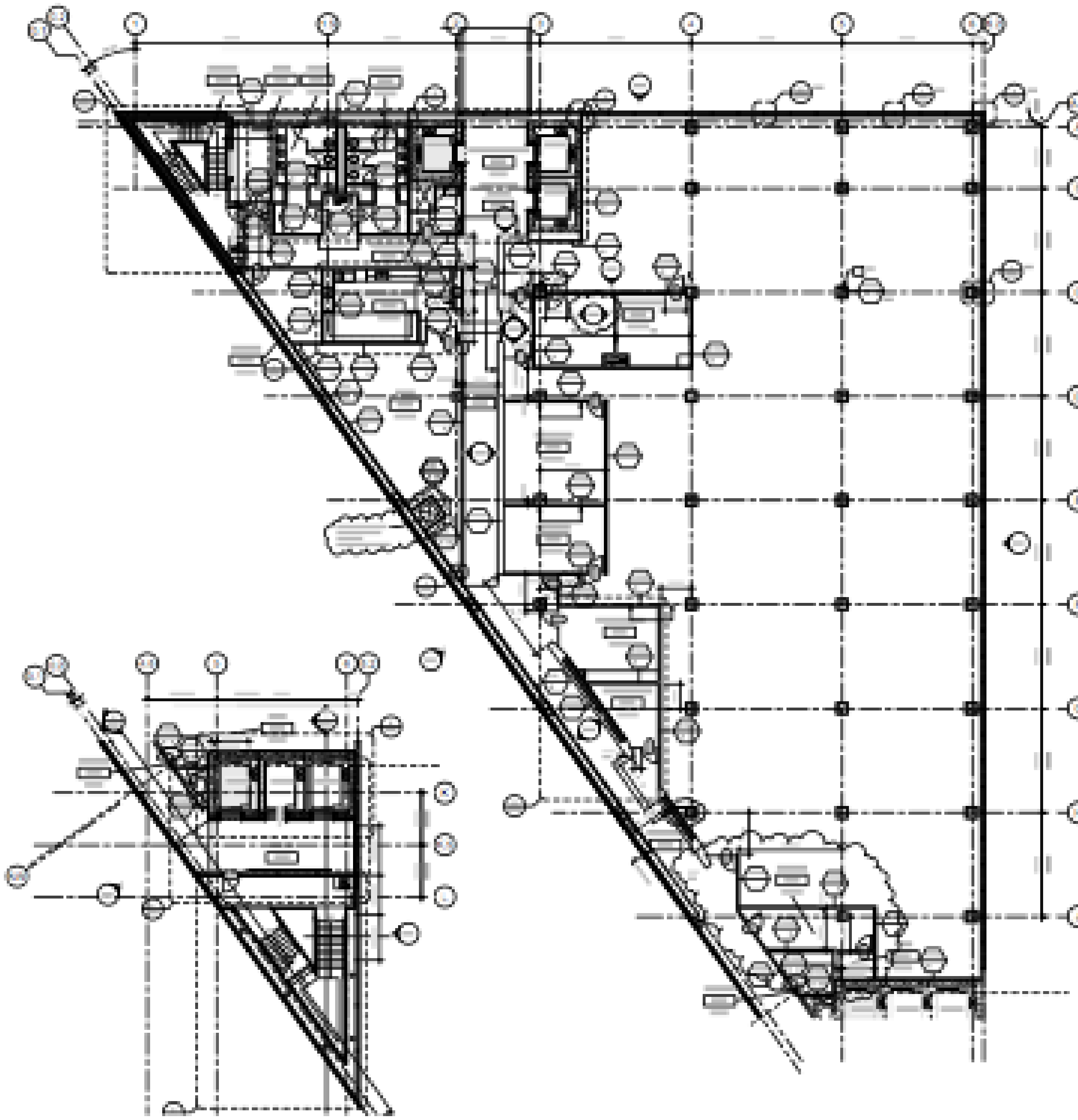
Level 2P Floor Plan



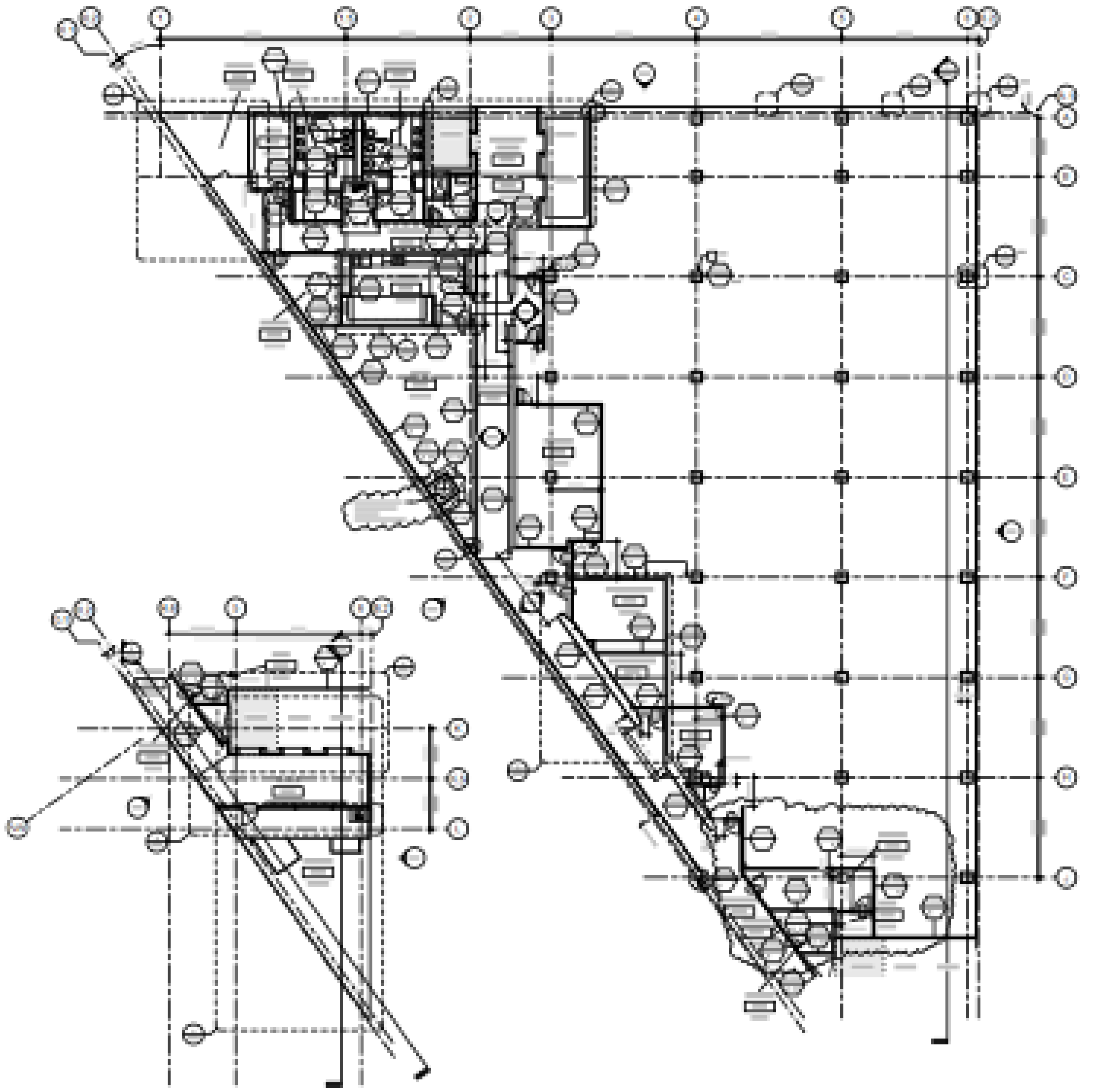
Level 1P Floor Plan



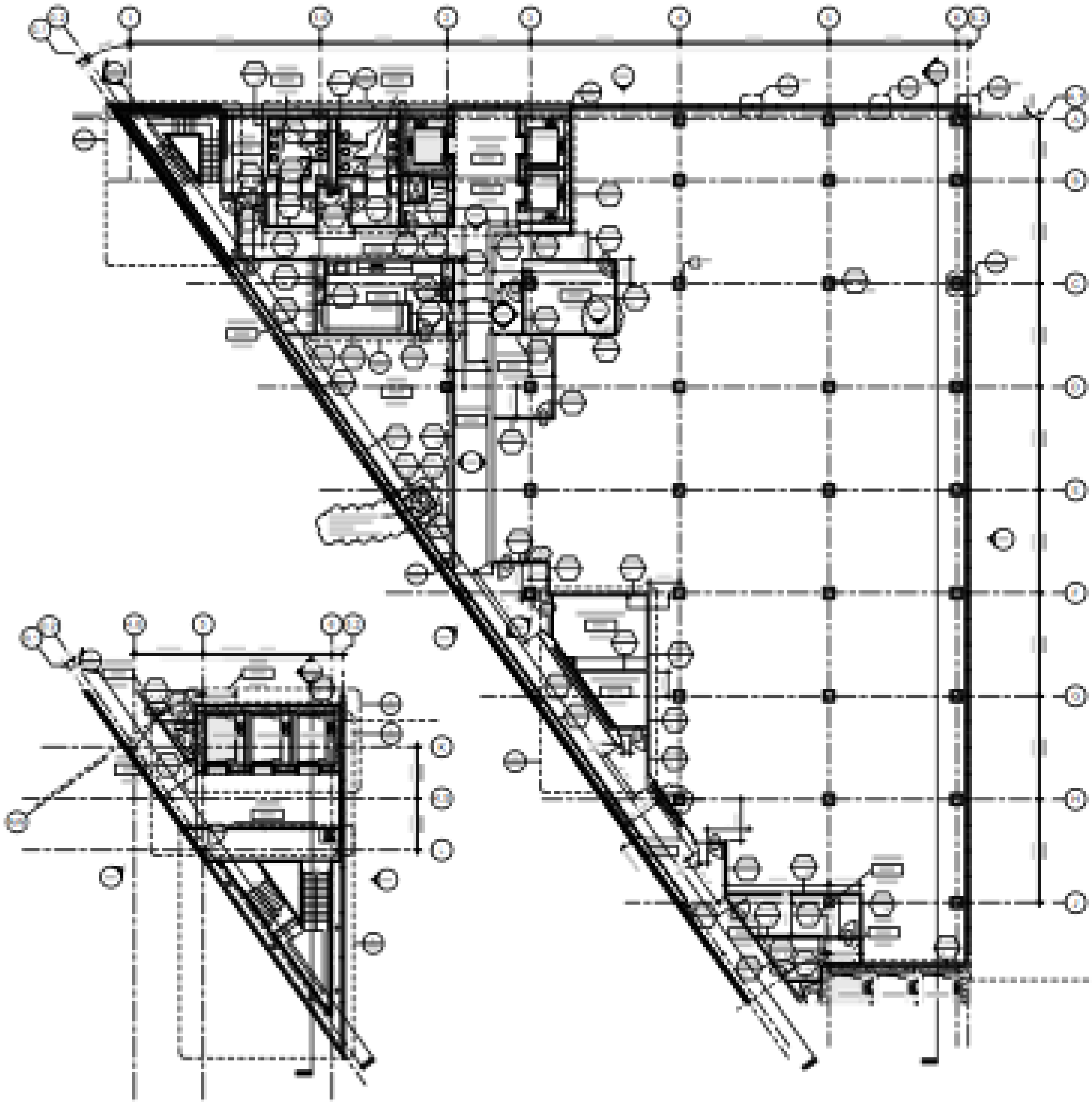
Partial Level 1T Floor Plan



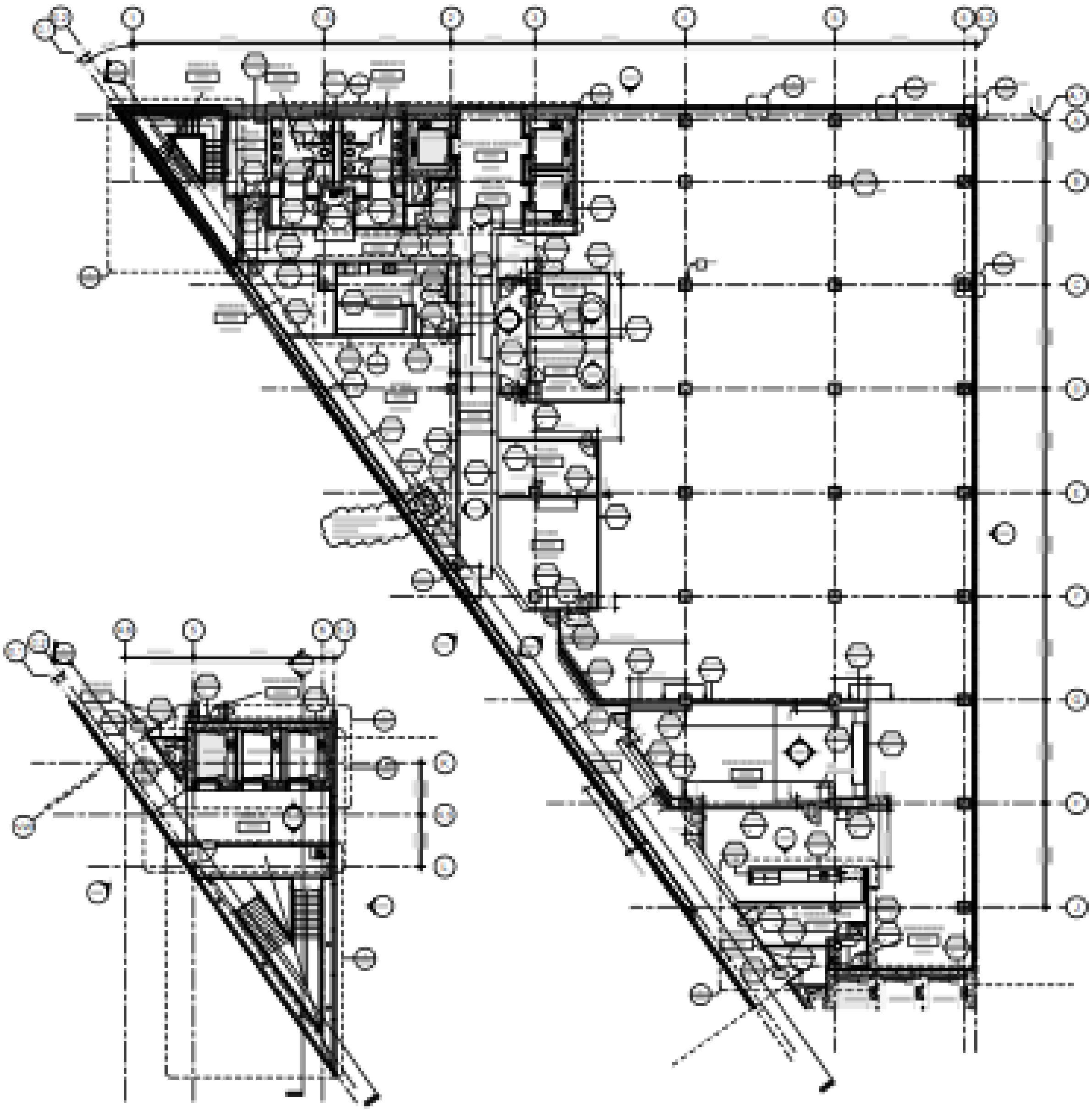
Level 2T Floor Plan



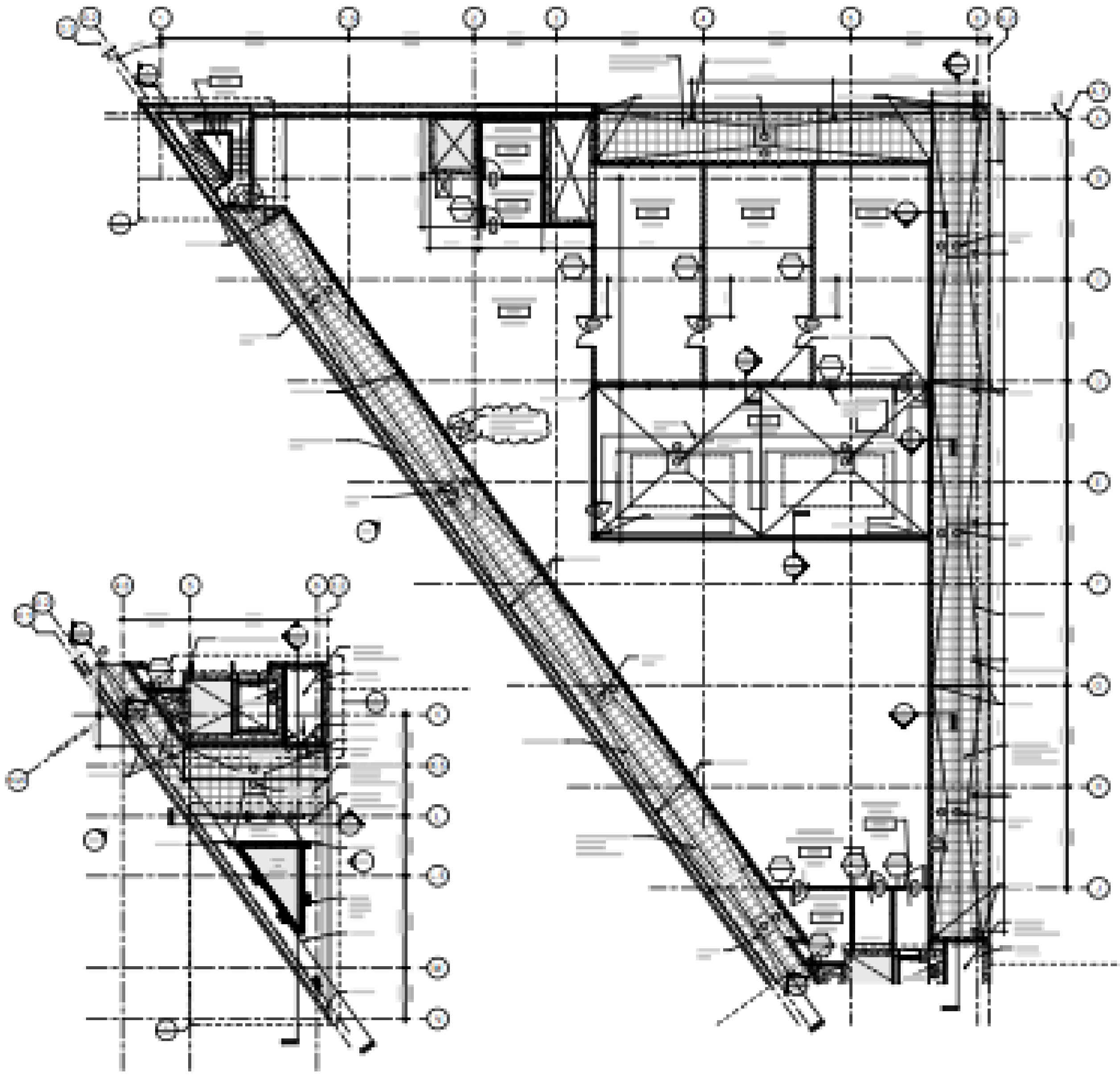
Level 3T Floor Plan



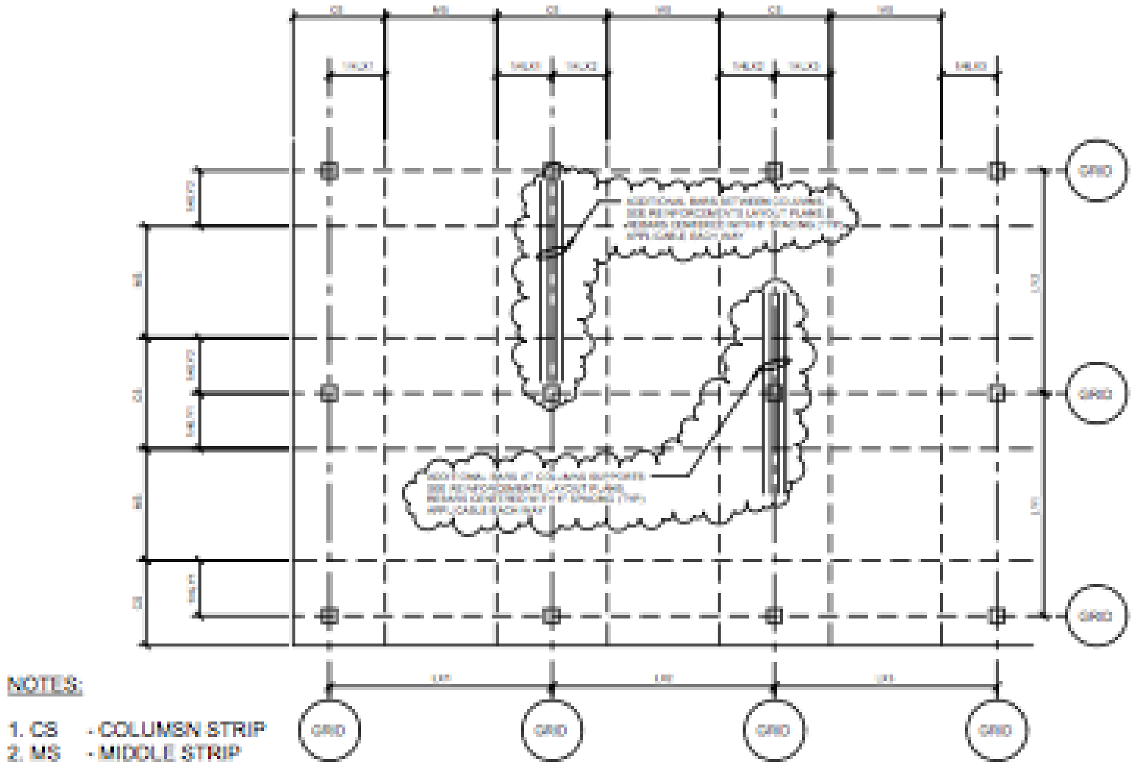
Level 4T Floor Plan



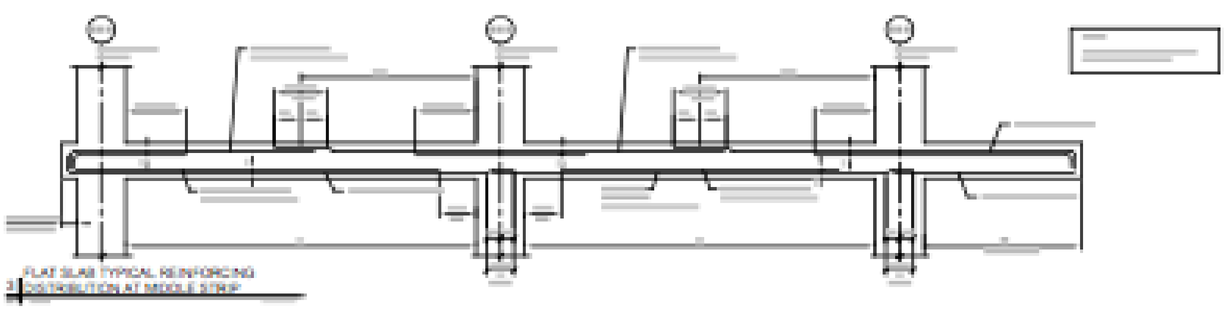
Level 5T Floor Plan



Level PH Floor Plan



Typical Column Strip and Middle Strip Detail



Typical Flat Slab Detail

APPENDIX B: WIND LOAD CALCULATIONS

Presented in this appendix are summaries of variables and building parameters required to determine wind loads in both the North-South and East-West directions. Hand calculations were performed and can be referenced here as well as force distribution tables and diagrams used to determine the base shear and overturning moments caused by wind forces.

Building Location Parameters	
Basic Wind Speed (V)	90 mph
Wind Enclosure Category	C
Importance Factor	1.15
Wind Directionality Factor (K_d)	0.85
Topographic Factor (K_{zt})	1

Building Information	
Number of Stories	5
Building Height (Feet)	82
N-S Building Length (Feet)	163
E-W Building Length (Feet)	232.75
L/B in N-S Direction	1.43
L/B in E-W Direction	0.7

Gust Factor		
Variable	Wind Direction	
	N-S	E-W
Stiffness	Rigid	
B (Feet)	162	232.75
L (Feet)	232.75	162
h (Feet)	82	82
[illegible]	0.5242	0.5242
c	0.20	0.20
z_{BAR}	49	49
$I_{Z(BAR)}$	0.281	0.281
g_Q & g_v	3.4	3.4
g_r	4.146	4.146
Q	0.791	0.785
V_{BAR}	65.4	65.4
N_1	3.83	3.83
R_n	0.063	0.063
R_h	0.[illegible]	0.[illegible]
N_h	4.75	4.75
R_B	0.099	0.031
N_B	9.58	13.67
R_L	0.022	0.031
N_L	45.78	32.06
R	0.0113	0.095
G	0.85	0.85

Gust Factors				
Wind Direction	C_p; Windward	C_p; Leeward	Gust Factor	GC_{pi}
N-S Direction	0.8	-0.3	0.85	0.18
E-W Direction	0.8	-0.5	0.85	0.18

Typical Wind Pressures in North-South Direction					
Height (Feet)	K_z	q_z	Wind Pressures (psf)		
			N-S Windward	N-S Leeward	N-S Total
82	0.94	19.05	16.38	-8.29	24.67
80	0.93	18.85	16.25	-8.29	24.54
70	0.89	18.04	15.7	-8.29	23.99
60	0.85	17.23	15.15	-8.29	23.44
50	0.81	16.42	14.59	-8.29	22.88
40	0.76	15.40	13.9	-8.29	22.19
30	0.7	14.19	13.08	-8.29	21.37
25	0.66	13.38	12.53	-8.29	20.82
20	0.62	12.57	11.98	-8.29	20.27
0-15	0.57	11.55	11.28	-8.29	19.57

Typical Wind Pressures in East-West Direction					
Height (Feet)	K_z	q_z	Wind Pressures (psf)		
			E-W Windward	E-W Leeward	E-W Total
82	0.94	19.05	16.38	-11.53	28
80	0.93	18.85	16.25	-11.53	27.87
70	0.89	18.04	15.7	-11.53	27.32
60	0.85	17.23	15.15	-11.53	26.77
50	0.81	16.42	14.59	-11.53	26.21
40	0.76	15.40	13.9	-11.53	25.52
30	0.7	14.19	13.08	-11.53	24.7
25	0.66	13.38	12.53	-11.53	24.15
20	0.62	12.57	11.98	-11.53	23.6
0-15	0.57	11.55	11.28	-11.53	22.9

Wind Load Distribution in North-South Direction								
Level	Height (Feet)	Tributary Height (Feet)	Windward (psf)	Leeward (psf)	Total (psf)	Story Force (Kips)	Story Shear (Kips)	Overturning Moment (Ft-Kips)
Roof	82	17	16.1	-8.29	24.39	67.17	0	443.11
Penthouse	[illegible]	13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5T	52	13	14.62	-8.29	22.91	48.25	116.98	3204.96
4T	[illegible]	13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3T	26	13	12.17	-8.29	20.46	43.09	211.44	8341.52
2T	[illegible]	13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1T	0	0	0	0	0	0	**295.74**	**11762.66**

Table 7B: Wind Load Distribution in East-West Direction								
Level	Height (Feet)	Tributary Area (Feet)	Windward (psf)	Leeward (psf)	Total (psf)	Story Force (Kips)	Story Shear (Kips)	Overturning Moment (Ft-Kips)
Roof	82	17	14.1	-11.62	27.72	105.68	0	546.21
Penthouse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5T	52	13	1462	-11.62	26.24	7940	191.31	560375
4T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3T	26	13	1217	-11.62	23.79	7198	347.17	19826.98
2T	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1T	0	0	0	0	0	0	**488.44**	**31675**

TECH REPORT III	WIND DESIGN	ArNG Readiness Center	1

- Determine lateral forces on the building caused by wind using the analytical procedure from ASCE 7-05 Chapter 6 (Method 2)

-BASIC WIND SPEED (From 6-1)

$V = 90$ mph (V<120 mph therefore not located in wind blown debris zone)

-LOCATION PARAMETERS

$K_d = 0.85$ (Table 6-4)
$I = 1.15$ (Table 6-5)
Exposure Category C
$K_{zt} = 1.0$ (Table 6-4)

-VELOCITY PRESSURE EXPOSURE COEFFICIENTS
USING TABLE 6-3

HEIGHT	K_z
82	0.94
80	0.93
70	0.89
60	0.85
50	0.81
40	0.76
30	0.7
25	0.66
20	0.62
0-15	0.57

-VELOCITY PRESSURE

$q_z = 0.00256 K_z K_{zt} K_d V^2 I = 0.00256 K_z (1.0)(0.85)(90)^2(1.15) = 20.269 K_z$
(K_z: VARIES BY HEIGHT REFERENCE CHART)

$\bar{z} = 0.6h = 66' > z_{min} = 30'$ ∴ OKAY

$I_{\bar{z}} = c\left(\frac{33}{\bar{z}}\right)^{1/6} = 0.60$

$L_{\bar{z}} = \ell\left(\bar{z}/33\right)^{1/3} = 403.2$

$Q = \sqrt{\frac{1}{\left(1+0.63\left(\frac{B+h}{L_{\bar{z}}}\right)^{0.63}\right)}}$

NORTH-SOUTH
$B = 162'$ $L = 232.75$
$Q_{N/S} = 0.828$

EAST-WEST
$B = 232.75'$ $L = 162'$
$Q_{EW} = 0.806$

ASSUMING RIGID STRUCTURE
$G_f = 0.85$

TECH REPORT III | WIND DESIGN | ArNG Readiness Center | 2

$q_n = 0.00256(0.94)(1.0)(0.85)(90)^2(1.15) = 19.05$

- PRESSURE COEFFICIENT (From Fig 6-6)
  - N-S Direction
    - Windward Walls : $C_p = 0.8$ (USE WITH q_z)
    - Leeward Walls : ($L/B = 0.7$) $C_p = -0.3$ (USE WITH q_n)
  - E-W Direction
    - Windward Walls : $C_p = 0.8$ (USE WITH q_z)
    - Leeward Walls : ($L/B = 1.43$) $C_p = -0.5$ (USE WITH q_N)

- PRESSURE (From Equation 6-17)
  - $P_z = q_z GC_p - q_n(GC_{pi})$ ← Windward
  - $P_n = q_n GC_p - q_n(GC_{pi})$ ← Leeward

$GC_{pi} = \pm 0.18$ For Enclosed Buildings (From 6-5)

NORTH/SOUTH

Windward → $P_z = q_z(0.85)(0.8) - (19.05)(-0.18)$
$= \boxed{0.68q_z + 3.429}$

Leeward → $P_n = (19.05)(0.85)(-0.3) - (19.05)(+0.18)$
$= \boxed{-8.29}$

SOUTH/WEST

Windward → $P_z = q_z(0.85)(0.8) - (19.05)(-0.18)$
$= \boxed{0.68q_z + 3.429}$

Leeward → $P_n = (19.05)(0.85)(-0.5) - (19.05)(+0.18)$
$= \boxed{-11.53}$

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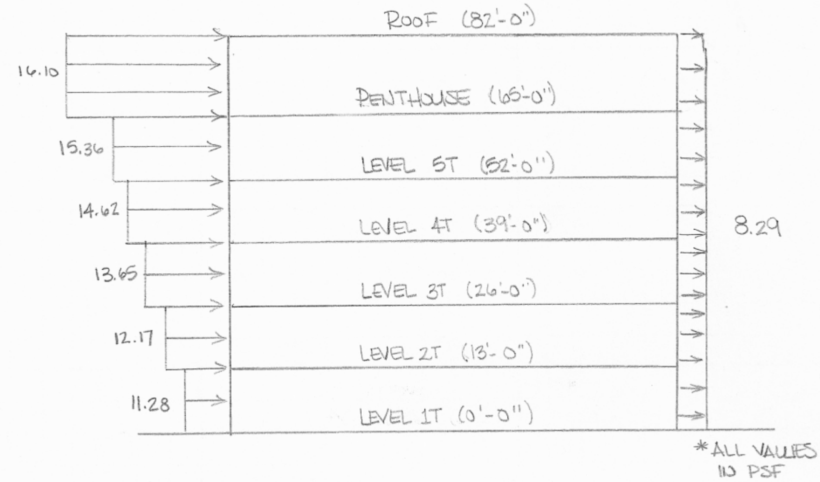
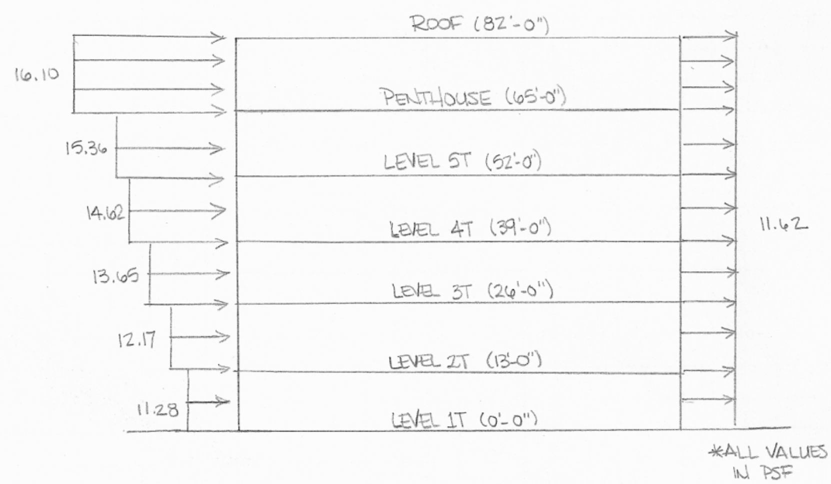
• WIND PRESSURE DIAGRAMS



PRESSURE DISTRIBUTION- N-S DIRECTION



PRESSURE DISTRIBUTION- E-W DIRECTION

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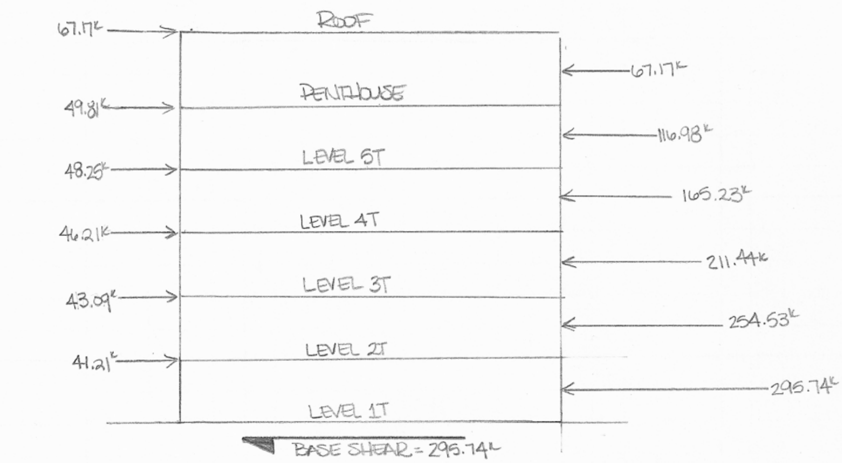
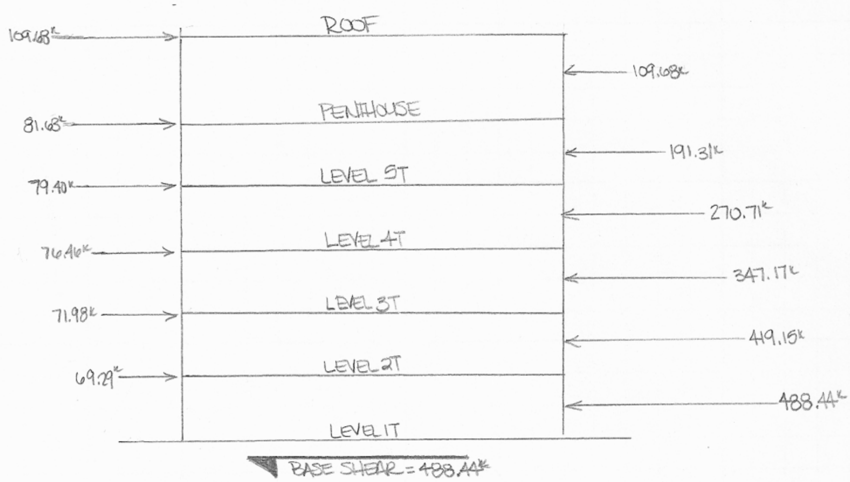
• WIND STORY LOAD DIAGRAMS



STORY FORCES & SHEAR – NS DIRECTION



STORY FORCES & SHEAR – EW DIRECTION

- **MOMENT CALCULATIONS**

N-S Direction

ROOF (@73.5'): M = 67.17k × 8.5' = 570.95'k
PH (@58.5'): M = (67.17×23.5') + (49.81×6.5') = 1902.26'k
5T (@ 45.5'): M = (67.17×36.5') + (49.81×19.5') + (48.25×6.5') = 3736.63'k
4T (@ 32.5'): M = (67.17×49.5') + (49.81×32.5) + (48.25×19.5) + (46.21×6.5) = 6184.98'k
3T (@ 19.5'): M = (67.17×62.5) + (49.81×45.5) + (48.25×32.5) + (46.12×19.5) + (43.09×6.5) = 9212.03'k
2T (@ 6.5'): M = (67.17×75.5') + (49.81×58.5) + (48.25×45.5) + (46.12×32.5) + (43.09×19.5) + (41.21×6.5') = 12787.6'k

OVERTURNING MOMENT = 12788'k

E-S Direction

ROOF (@73.5'): M = 109.68k × 8.5' = 932.28'k
PH (@58.5'): M = (109.68×23.5) + (81.63×6.5') = 3108.08'k
5T (@ 45.5): M = (109.68×36.5) + (81.63×19.5') + (79.40×6.5') = 6111.21'k
4T (@ 32.5'): M = (109.68×49.5) + (81.63×32.5) + (79.40×19.5') + (76.46×6.5') = 10127.43'k
3T (@ 19.5'): M = (109.68×62.5) + (81.63×45.5) + (79.40×32.5) + (76.46×19.5') + (71.98×6.5) = 15108.51'k
2T (@ 6.5'): M = (109.68×75.5) + (81.63×58.5) + (79.40×45.5) + (76.41×32.5) + (71.98×19.5) + (69.29×6.5') = 21006.22'k

OVERTURNING MOMENT = 21006'k

APPENDIX C: SEISMIC LOAD CALCULATIONS

Presented in this appendix are summaries of variables and building parameters required to determine the seismic loads on the Army National Guard Readiness Center Addition. Hand calculations were performed and can be referenced here as well as force distribution tables and diagrams used to determine the base shear and overturning moments caused by wind forces.

General Seismic Information		
Occupancy Category		III
Site Class		D
Seismic Design Category		B
Short Period Spectral Response	S_s	0.1799
Spectral Response (1Sec)	S_1	0.0639
Maximum Short Period Spectral Response	S_{MS}	[illegible]
Maximum Spectral Response (1 Sec)	S_{M1}	0.1534
Design Short Spectral Response	S_{DS}	0.192
Design Spectral Response (1 Sec)	S_{D1}	0.102
Response Modification Coefficient	R	5
Seismic Response Coefficient	C_S	0.026
Effective Period	T	[illegible]
Base Shear		**389 k**
Overturning Moment		**20066.34**

Seismic Loads									
Level	Height h_x (ft)	Tributary Height (Ft)	Story Weight w_x (Kips)	h_x^k	$w_x h_x^k$	C_{vx}	Lateral Force F_x (kips)	Story Shear V_x (kips)	Moments M_x (ft-kips)
Roof	82	8.5	2513.5	174.98	439813.67	0.28	108.22	0.00	0.00
Penthouse	65	[illegible]	3044	145.27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5T	52	13	3044	102.60	312320.55	0.20	76.85	208.04	3186.83
4T	[illegible]	[illegible]	3044	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3T	26	13	3044	45.54	138609.63	0.09	34.11	339.75	10445.32
2T	[illegible]	[illegible]	3044	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1T*	0	6.5	264.5	0.00	0.00	0.00	0.00	**389**	**20066.34**
$\Sigma(w_i h_i^k)$ = 1580867.38	**$\Sigma(F_x)$ = V = 389 Kips**				**ΣM = 20066.34 K-Ft**				
Total Building Weight(Above Grade) = 14,957 kips									
* The Level 1T story weight is only weight of the columns whose base is at the ground floor. Weights of slabs, beams, and superimposed deads loads are not considered at the ground floor because the base shear is related only to the levels above grade and the components mentioned are at grade level.									

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- SEISMIC GROUND MOTION VALUES

$S_1 = 0.0639$
$S_S = 0.1799$

SITE CLASS D

- SOIL MODIFIED ACCELERATIONS
  - SITE COEFFICIENTS

FOR SITE CLASS D AND $S_S \leq 2.5$

$F_a = 1.6$ (From Table 11.4-1)

FOR SITE CLASS D AND $S_1 \leq 0.1$

$F_v = 2.4$ (From Table 11.4-2)

$S_{MS} = F_a S_S = 1.6 \times 0.1799 = 0.288$

$S_{M1} = F_v S_1 = 2.4 \times 0.0639 = 0.1534$

- DESIGN ACCELERATIONS

$S_{DS} = \frac{2}{3} S_{MS} = \frac{2}{3}(0.288) = 0.192$

$S_{D1} = \frac{2}{3} S_{M1} = \frac{2}{3}(0.1534) = 0.102$

- SEISMIC DESIGN CATEGORY D WAS USED

- DESIGN COEFFICIENTS FOR SEISMIC FORCE RESISTING SYSTEM
  - Ordinary reinforced Concrete shear walls with steel elements

$R = 5.0$ $\Omega_0 = 2.5$ $C_d = 4.5$

$C_t = 0.016$
$x = 0.9$ (From Table 12.8-2)

$T_s = S_{D1}/S_{DS} = \frac{0.102}{0.192} = 0.53$ sec

$T_a = C_t h_n^x = 0.016(82')^{0.9} = 0.844$ sec
$> 0.8T_s = 0.8(0.53) = 0.424$ sec OK

$T_L = 12$ [From Figure 22-15]

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$$C_s = \min \begin{cases} \frac{S_{DS}}{R/I} = \frac{0.192}{5.0/1.5} = 0.0256 \leftarrow \text{CONTROLS} \\ \frac{S_{D1}}{T(R/I)} = \frac{0.102}{0.844(5.0/1.5)} = 0.0363 \\ \frac{S_{D1} \cdot T}{T^2(R/I)} = \frac{(0.102)(0.844)}{(0.844)^2(5.0/1.5)} = 0.515 \end{cases}$$

$C_s \simeq 0.026$

$f = 1/T = \frac{1}{0.844} = 1.185 > 1.0$ ∴ RIGID DIAPHRAGM

SEE EXCEL SPREAD SHEET FOR FLOOR WEIGHTS

LEVEL 1T : 18970 sq ft . . . . 13.95 psf
LEVEL 2T : 18970 sq ft . . . . 160.5 psf
LEVEL 3T : 18970 sq ft . . . . 160.5 psf
LEVEL 4T : 18970 sq ft . . . . 160.5 psf
LEVEL 5T : 18970 sq ft . . . . 160.5 psf
PH/ROOF : 18970 sq ft . . . . 132.5 psf

TOTAL BUILDING WEIGHT (w_T)

$w_T = 18970(13.95) + 18970(160.5) \times 4 \text{ floors} + 18970(132.5)$

$w_T = 14{,}956{,}896.5 \text{ lbs} \Rightarrow \underline{14{,}957^k}$

$V = C_s w_T = 0.026 \times 14957 = 389^k$ ← BASE SHEAR

$k = 0.75 + 0.5(0.844) = 1.172$

$w_x h_x^k$ → Varies with height (See Excel Spreadsheet)

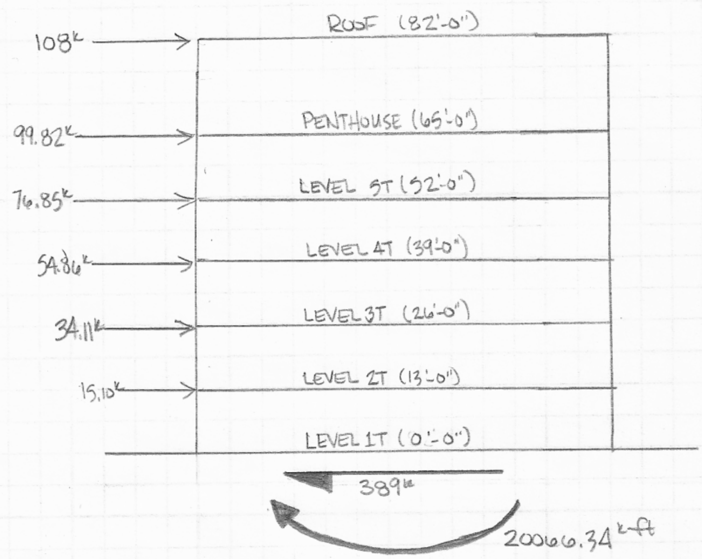
$\sum w_x h_x^k = 1580867.38$

$C_{vx} = \frac{w_x h_x^k}{\sum w_x h_x^k}$ → Varies at height (See Excel Spreadsheet)

$F_x = C_{vx} V$ → Varies (See Spreadsheet)

TECH REPORT III | SEISMIC DESIGN | ArNG Readiness Center | 3

OVERTURNING MOMENT



PH: OM@ 73.5' = (108)(8.5) = 918.0 k-ft

5T: OM@ 58.5' = (108)(23.5)+(99.82)(6.5) = 3186.83 k-ft

4T: OM@ 45.5' = (108)(49.5)+(99.82)(19.5)+(76.85)(6.5) = 6388.02 k-ft

3T: OM@ 32.5' = (108)(62.5)+(99.82)(32.5)+(76.85)(19.5)+(54.86)(6.5) = 10445.32 k-ft

2T: OM@ 19.5' = (108)(62.5)+(99.82)(45.5)+(76.85)(32.5)+(54.86)(19.5)+(34.11)(6.5) = 15080.92 k-ft

1T: OM@ 6.5' = (108)(75.5)+(99.82)(58.8)+(76.85)(45.5)+(54.86)(32.5)+(34.11)(19.5)+(15.10)(6.5) = 20066.34 k-ft

APPENDIX D: LOAD DISTRIBUTION

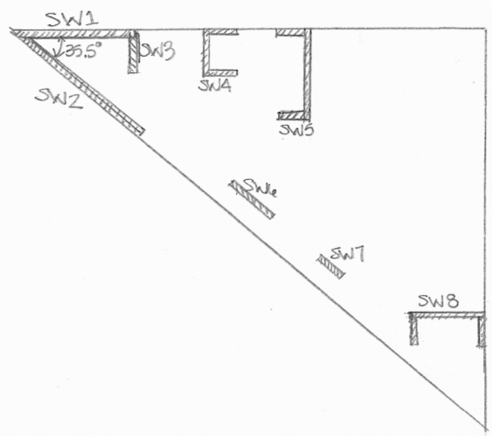
Presented in this appendix are summaries of variables and building parameters required to determine the load path and distribution for the lateral system of the Army National Guard Readiness Center Addition. Hand calculations were performed and can be referenced here as well as force distribution tables and diagrams used to determine the rigidity and relative stiffness of all the shear walls and the center of mass and center of rigidity.

Wall Rigidity (E W Span)										
Floor	Ht	Wall 1	Wall 2	Wall 4	Wall 5	Wall 6	Wall 7	Wall 8	Sum(Rigidities)	Center of Rigidity (y)
		Length=216"	Length=356.4"	Length=96"	Length=96"	Length=186"	Length=97.2"	Length=300"		
1T	162	11653	26301	1890	1890	8733	1951	20394	72889	832
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3T	486	877	3224	86	86	579	53	2098	7003	802
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5T	810	207	853	19	19	134	20	528	1780	795
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]

Wall Rigidity (N-S Span)										
Floor	Ht	Wall 2	Wall 3	Wall 4	Wall 5	Wall 6	Wall 7	Wall 8	Sum(Rigidities)	Center of Rigidity (x)
		Length=153.2"	Length=138"	Length=144"	Length=252"	Length=133"	Length=69.6"	Length=162"		
1T	162	15444	4592	5059	15339	4215	799	6555	52024	1203
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3T	486	1346	248	380	1331	223	33	392	3853	1239
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5T	810	326	56	63	322	50	7	89	913	1246
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]

Relative Stiffness (North-South Force)							
	Wall 2	Wall 3	Wall 4	Wall 5	Wall 6	Wall 7	Wall 8
Level 1T	29.7	8.8	9.7	29.5	8.1	1.5	12.6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Level 3T	34.9	6.4	7.3	34.5	5.8	0.9	10.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Level 5T	35.7	6.1	6.9	35.3	5.5	0.8	9.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Relative Stiffness (East-West Force)							
	Wall 1	Wall 2	Wall 4	Wall 5	Wall 6	Wall 7	Wall 8
Level 1T	16.0	36.2	2.6	2.6	12.0	2.7	28.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Level 3T	12.5	46.0	1.2	1.2	8.3	0.8	30.0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Level 5T	11.6	47.9	1.0	1.0	7.5	1.1	29.7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]



RIGIDITY:

$$R = \frac{Et}{4(h/L)^3 + 3(h/L)}$$

$E = 57000\sqrt{f'_c} = 57000\sqrt{4500} = 3823676$

t = THICKNESS = 12"

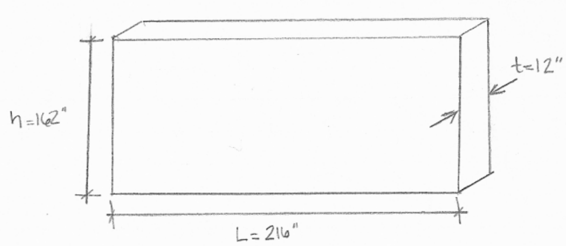
h = HEIGHT

L = LENGTH OF WALL

- Walls at a 35.5° angle from horizontal were broken down into an East-West component and North-South component

- EAST-WEST

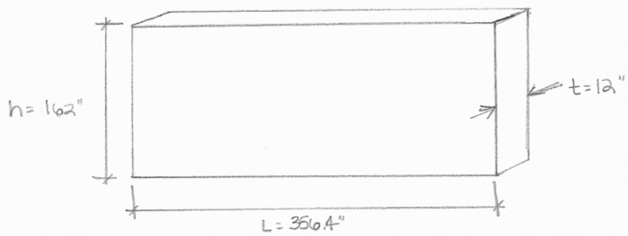
◦ SHEAR WALL 1



$$R = \frac{3823676 \times 12}{4(162/216)^3 + 3(162/216)} = \underline{11653}$$

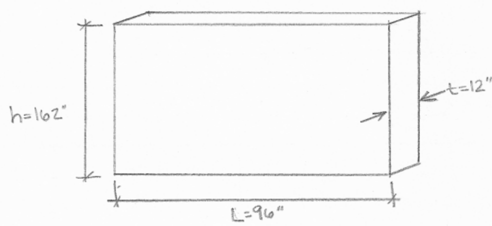
TECH REPORT III | RIGIDITY CALCULATIONS | ArNG Readiness Center | 2

- SHEAR WALL 2:



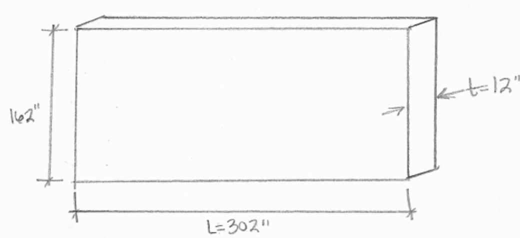
$$R = \frac{3823676 \times 12}{4(162/356.4)^3 + 3(162/356.4)} = \underline{23681}$$

- SHEAR WALL 4 & 5:



$$R = \frac{3823676 \times 12}{4(162/96)^3 + 3(162/96)} = \underline{1890}$$

- SHEAR WALL 8:



$$R = \frac{3823676 \times 12}{4(162/302)^3 + 3(162/302)} = \underline{20394}$$

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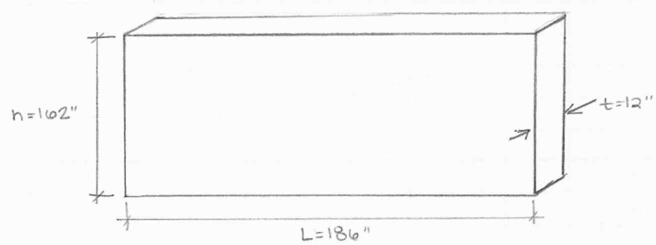
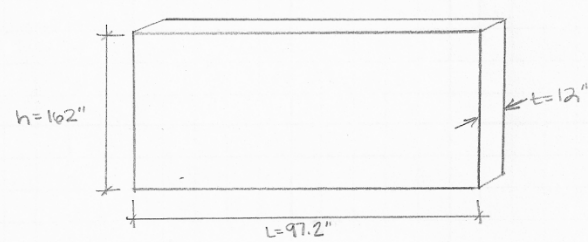
• SHEAR WALL 6:



$$R = \frac{3823676 \times 12}{4(162/186)^3 + 3(162/186)} = \underline{8730}$$

• SHEAR WALL 7:

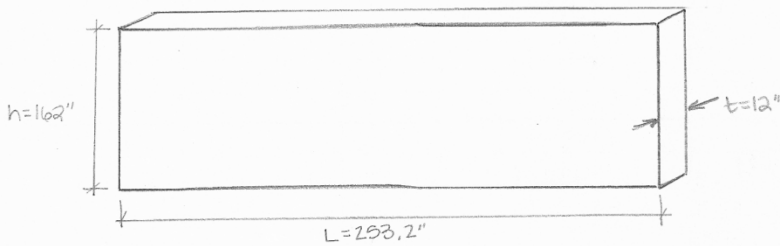


$$R = \frac{3823676 \times 12}{4(162/97.2)^3 + 3(162/97.2)} = \underline{1951}$$

TECH REPORT III | RIGIDITY CALCULATIONS | ArNG Readiness Center | 4

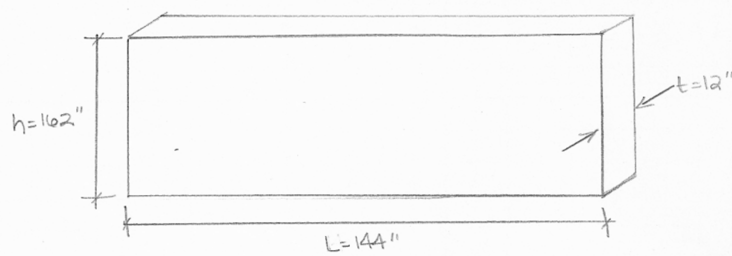
-NORTH-SOUTH

- SHEAR WALL 2



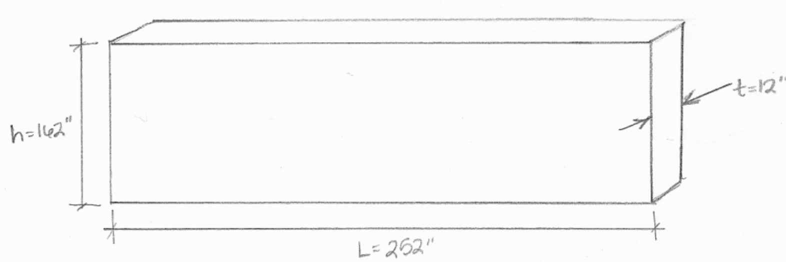
$$R = \frac{3823676 \times 12}{4(162/253.2)^3 + 3(162/253.2)} = \underline{15464}$$

- SHEAR WALL 4



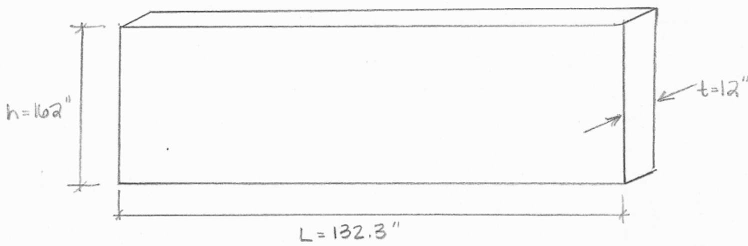
$$R = \frac{3823676 \times 12}{4(162/144)^3 + 3(162/144)} = \underline{5059}$$

- SHEAR WALL 5



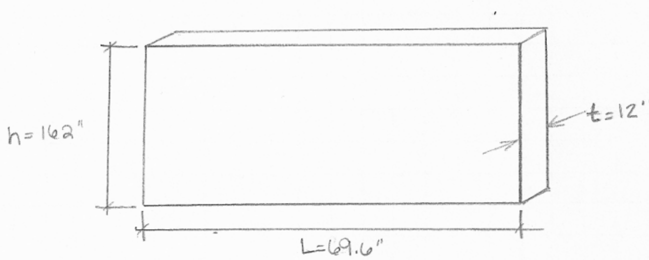
$$R = \frac{3823676 \times 12}{4(162/252)^3 + 3(162/252)} = \underline{15339}$$

• SHEAR WALL 6:



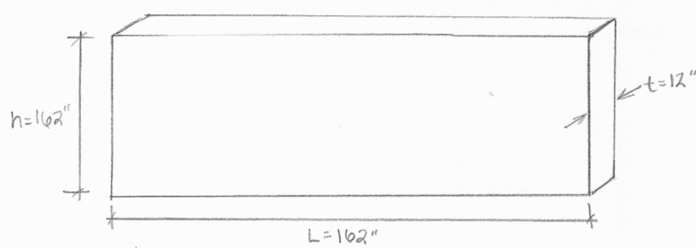
$$R = \frac{3823676 \times 12}{4\left(\frac{162}{132.3}\right)^3 + 3\left(\frac{162}{132.3}\right)} = \underline{4168}$$

• SHEAR WALL 7:



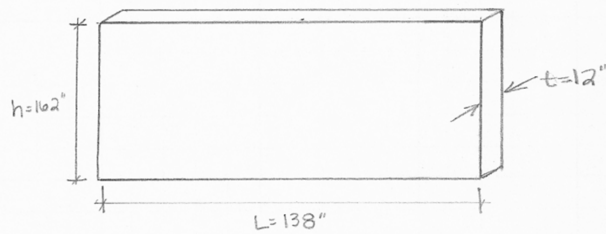
$$R = \frac{3823676 \times 12}{4\left(\frac{162}{69.6}\right)^3 + \left(\frac{162}{69.6}\right)} = \underline{799}$$

• SHEAR WALL 8:



$$R = \frac{3823676 \times 12}{4\left(\frac{162}{162}\right)^3 + 3\left(\frac{162}{162}\right)} = \underline{6555}$$

• SHEAR WALL 3



$$R = \frac{3823676 \times 12}{4(162/138)^3 + 3(162/138)} = \underline{4592}$$

TECH REPORT III	RELATIVE STIFFNESS	ArNG Readiness Center	7

- EAST-WEST

$$R\% = \frac{R}{\Sigma R} \times 100$$

$$\Sigma R = 11653 + 26381 + 1890 + 1890 + 8730 + 1951 = 72889$$

- SW1 → R = 11653

$$\% = \frac{11653}{72889} \times 100 = \underline{15.98\%}$$

- SW 2 → R = 26381

$$\% = \frac{26381}{72889} \times 100 = \underline{36.19\%}$$

- SW4 & 5 → R = 1890

$$\% = \frac{1890}{72889} \times 100 = \underline{2.59\%}$$

- SW 6 → R = 8730

$$\% = \frac{8730}{72889} \times 100 = \underline{11.98\%}$$

- SW 7 → R = 1951

$$\% = \frac{1951}{72889} \times 100 = \underline{2.68\%}$$

- SW 8 → R = 20394

$$\% = \frac{20394}{72889} \times 100 = \underline{27.98\%}$$

TECH REPORT III | RELATIVE STIFFNESS | ArNG Readiness Center | 8

- NORTH-SOUTH

$$R\% = \frac{R_i}{\Sigma R} \times 100$$

$$\Sigma R = 15464 + 5059 + 15339 + 6555 + 4168 + 799 + 6002 = 53386$$

- SW2 → R = 15464

$$\% = \frac{15464}{53386} \times 100 = \underline{28.9\%}$$

- SW3 → R = 6002

$$\% = \frac{6002}{53386} \times 100 = \underline{1.5\%}$$

- SW4 → R = 5059

$$\% = \frac{5059}{53386} \times 100 = \underline{9.5\%}$$

- SW5 → R = 15339

$$\% = \frac{15339}{53389} \times 100 = \underline{28.7\%}$$

- SW6 → R = 4168

$$\% = \frac{4168}{53389} \times 100 = \underline{7.8\%}$$

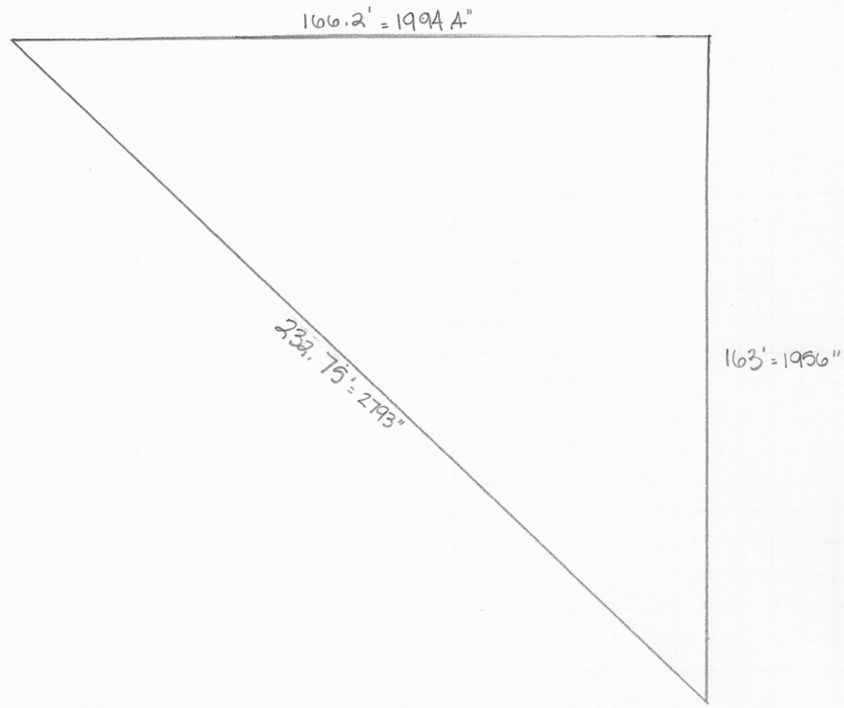
- SW7 → R = 799

$$\% = \frac{799}{53389} \times 100 = \underline{11.4\%}$$

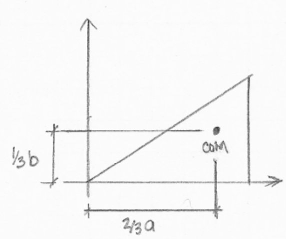
- SW8 → R = 6555

$$\% = \frac{6555}{53389} \times 100 = \underline{12.2\%}$$

TECH REPORT III | CENTER OF MASS | ArNG Readiness Center | 9



CENTER OF MASS OF A TRIANGLE:

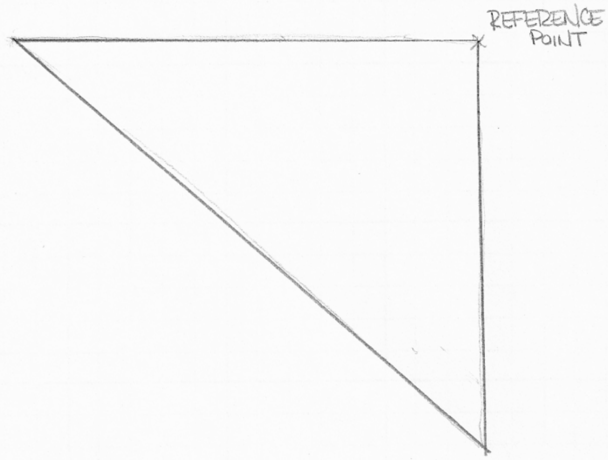


$$COM_x = 1994.4 - \frac{2}{3}(1994.4) = \boxed{664.8''}$$

$$COM_y = \frac{1}{3}(1956) = \boxed{652''}$$

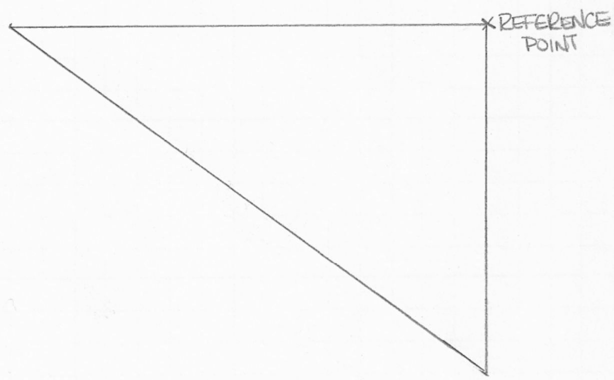
TECH REPORT III	CENTER OF RIGIDITY	ArNG Readiness Center	10

• X-Coordinate (LEVEL 1T)



$$COR_x = \frac{\Sigma(Rd)}{\Sigma R} = \frac{64223358}{53386} = \boxed{1203''}$$

• Y-Coordinate (LEVEL 1T)



$$COR_y = \frac{\Sigma Rd}{\Sigma R} = \frac{60638040}{72889} = \boxed{832''}$$

APPENDIX E: SHEAR CALCULATIONS

Presented in this appendix are summaries of variables and building parameters required to determine the shear forces and shear strength check for the lateral system of the Army National Guard Readiness Center Addition. Hand calculations were performed and can be referenced here as well as force distribution tables and diagrams used to determine the direct shear, torsional shear, and the shear strength of the shear walls.

Shear Wall Strength Check													
Level 4T	Direction	Direct Shear (k)	Torsional Shear (k)	VU (k)	Vertical Reinforcement	Spacing (in)	Length (in)	Thickness (in)	ACV (in2)	αC	ρt	Vn (k)	Check
Wall 1	N/S	-	-	-	(2) #8	8	-	12	-	2	0.0165	-	-
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]		[illegible]	[illegible]	[illegible]
Wall 2	N/S	11.60	19.38	30.98	(2) #8	8	253	12	[illegible]	2	0.0165	5561.4	OK
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]		[illegible]	[illegible]	[illegible]
Wall 3	N/S	[illegible]	[illegible]	[illegible]	(2) #8	8	[illegible]	12	[illegible]	2	0.0165	[illegible]	OK
	[illegible]				[illegible]						[illegible]		
Wall 4	N/S	2.69	2.78	5.47	(2) #8	8	144	12	1728	2	0.0165	1456.9	OK
	[illegible]	[illegible]	[illegible]		[illegible]				[illegible]		[illegible]	[illegible]	[illegible]
Wall 5	N/S	11.36	8.86	20.22	(2) #8	8	252	12	3024	2	0.0165	2549.6	OK
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]		[illegible]	[illegible]	[illegible]
Wall 6	N/S	2.15	1.40	3.55	(2) #8	8	133	12	1596	2	0.0165	1345.6	OK
	[illegible]		[illegible]	[illegible]	[illegible]				[illegible]		[illegible]	[illegible]	[illegible]
Wall 7	N/S	0.34	0.16	0.50	(2) #8	8	70	12	835.2	2	0.0161	704.2	OK
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]		[illegible]	[illegible]	[illegible]
Wall 8	N/S	3.68	0.58	4.26	(2) #8	8	162	12	1944	2	0.0161	1639	OK
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]		[illegible]	[illegible]	[illegible]

TECH REPORT III | DIRECT SHEAR | ArNG Readiness Center

- Direct shear forces are determined by multiplying the factored story forces for each level by the relative stiffness of each member

- NORTH/SOUTH
  Load Combination = 0.9D + 1.0E + 1.6H

FLOOR	FORCE (k)	FACTORED FORCE (k)	DISTRIBUTED FORCE (k)
2T	15.10	15.10	15.10 (Ri)
3T	34.11	34.11	34.11 (Ri)
4T	54.86	54.86	54.86 (Ri)
5T	76.85	76.85	76.85 (Ri)
PH	99.82	99.82	99.82 (Ri)
Roof	108.0	108.0	108.0 (Ri)

- EAST/WEST
  Load Combination = 1.2D + 1.6W + 0.5 [L, or S or R]

FLOOR	FORCES (k)	FACTORED FORCES (k)	DISTRIBUTED FORCES (k)
2T	69.29	110.86	110.86 (Ri)
3T	71.98	115.17	115.17 (Ri)
4T	76.46	122.34	122.34 (Ri)
5T	79.40	127.04	127.04 (Ri)
PH	81.63	130.61	130.61 (Ri)
Roof	109.68	175.5	175.5 (Ri)

~ Reference charts for the direct forces distributed to each shear wall.

TECH REPORT III | TORSIONAL SHEAR | ArNG Readiness Center

• EXAMPLE CALCULATION – Shear wall 1 supporting level 4T

TORSIONAL SHEAR:

$$V_t = \frac{V_{tot}\, e\, d_i R_i}{J}$$

V_{tot} = Story shear
e = Eccentricity (Distance from CoM to CoR)
d_i = Distance from wall to CoR
R_i = Relative Stiffness of Element
J = Torsional Moment of Inertia $(\Sigma R_i d_i^2)$

SW 1. (E/W Direction)

• Factored Story Shear = $1.0(339.75^k) = \underline{339.75^k}$

• $CoR_y = 1239''$, $CoM_y = 652''$ } HAND CALCULATION VALUES WERE USED

$$e = 1239 - 652 = \underline{584''}$$

• Location of Wall 1 & Y-Coordinate

$$d_i = 1239 - 6 = \underline{1233''}$$

• Torsional Moment of Inertia

$$J = \Sigma R_i d_i^2 = 2258156.4\ in^2$$

• Relative Stiffness of Wall 1:

$$R_i = 0.125$$

$$V_i = \frac{(339.75^k)(584'')(1233'')(0.125)}{2258156.4\ in^2} = \boxed{6.35^k}$$

TECH REPORT III	SHEAR WALL STRENGTH	ArNG Readiness Center

- According to ACI 318-08 §21.9.4.1
  - Shear strength of reinforced concrete shear walls:

$$\phi V_n = \phi A_{cv}\left[(\alpha_c \sqrt{f'_c} + (\rho_t f_y)\right]$$

$\phi = 0.75$
A_{cv} = Gross area of concrete
α_c = Coefficient = 2.0 (if $h_w/\ell_w \geq 2.0$)
$\rho_t = A_v/s \cdot h$
s = Spacing of shear reinforcement
h = thickness of shear wall (12")

- Example Calculation:
  - Wall 1 supporting level 4T

Direct Shear = 15.64^k
Torsional Shear = 6.36^k
$V_u = 15.64 + 6.35 = 21.99^k$

Vertical Reinforcement: (2) #8 @ 8" oc
$$\rho_t = \frac{(2)(0.79)}{(8")(12)} = 0.0165$$

A_{cv} = (LENGTH)(THICKNESS) = (216")(12") = 2592 in²

$$\phi V_n = 0.75(2592)\left[2.0(\sqrt{4000}/1000) + (0.0165)(60)\right] = 2185.4^k$$

$$\boxed{\phi V_n = 2185.4^k > V_u = 21.99^k} \quad \therefore \text{ OKAY}$$

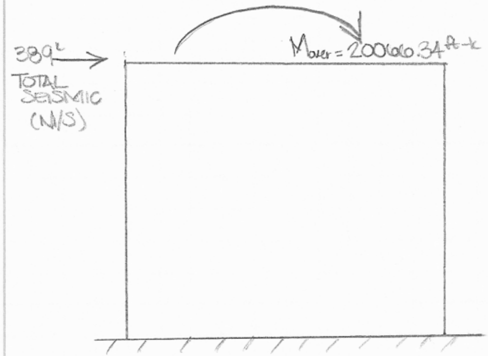
~ Shear strength checks for all walls can be found in excel spreadsheet.

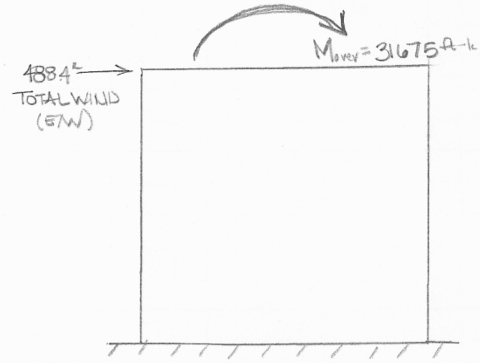
APPENDIX F: OVERTURNING MOMENT

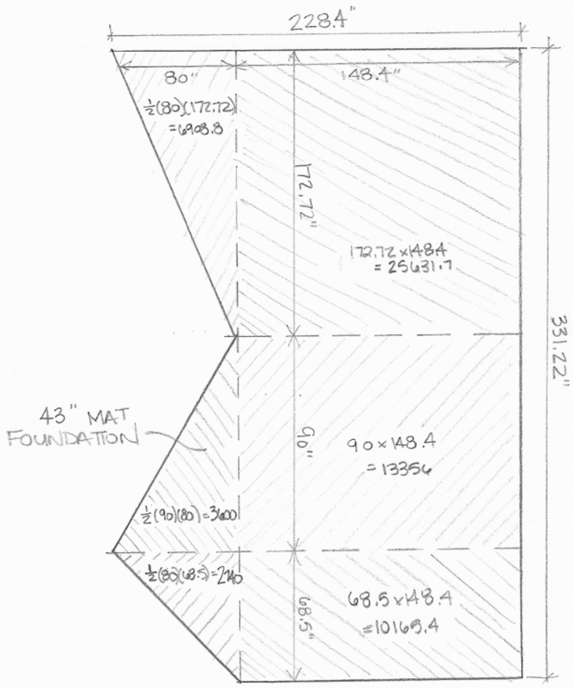
Presented in this appendix are summaries of variables and building parameters required to determine the overturning moments for the Army National Guard Readiness Center Addition. Hand calculations were performed and can be referenced here as well as tables and diagrams used to determine the stress check for overturning moment control.

Overturning Moments						
Floor	Height Above Ground (ft)	Story Height (ft)	N/S Seismic		E/W Wind	
			Lateral Force	Moment	Lateral Force	Moment
1T	0.00	0.00	0.00	0.00	0.00	0.00
2T	13.50	13.50	15.14	[illegible]	[illegible]	[illegible]
3T	27.00	13.50	34.11	690.73	37.10	751.28
4T	40.50	13.50	[illegible]	[illegible]	41.63	[illegible]
5T	54.00	13.50	76.85	3631.16	44.75	2114.44
Penthouse	67.50	13.50	[illegible]	[illegible]	[illegible]	[illegible]
PH Roof	82.00	14.50	108.22	8089.45	64.26	4803.44
		Totals:	389.00	20429.12	269.01	12153.71

TECH REPORT III | OVERTURNING MOMENT | ArNG Readiness Center







$SQ\ FT_{mat} = 5200.154$ sq. ft

- STRESS DUE TO DEAD LOAD:

$$\frac{BLDG\ WT}{SQ\ FT_{mat}} = \frac{14957^k}{5200.154\ sq\ ft} \times 1000\ lb.$$

$$= 2876\ PSF$$

- STRESS DUE TO N/S SEISMIC:

$$\frac{389^k}{5200.154\ ft^2} \times 1000^{lb} = 74.8\ PSF\ \ (2.6\%\ of\ DL)$$

- STRESS DUE TO E/W WIND:

$$\frac{488.4}{5200.154} \times 1000\ lb = 93.92\ PSF\ \ (3.3\%\ of\ DL)$$

~ Since the stresses that were determined for the lateral loads are such small percentages than the resisting gravity load, overturning is not a critical issue.

APPENDIX G: DRIFT & DISPLACEMENT

Presented in this appendix are summaries of variables and building parameters required to determine the overall building drift and story displacements for the Army National Guard Readiness Center Addition. Hand calculations were performed and can be referenced here as well as tables and diagrams used to determine the building drift and story displacement.

STORY DISPLACEMENT

~An approximate method of Δ_{CANT} was used to determine story shear of the building

$$\Delta_{CANT} = \Delta_{FLEX} + \Delta_{SHEAR} = \frac{Ph^3}{3E_cI_c} + \frac{1.2Ph}{E_r A}$$

$$E_c = 57000\sqrt{4500} = 3823676 \text{ psi}$$

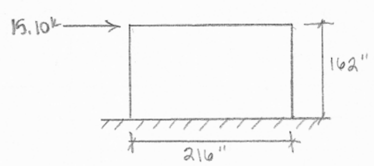
$$E_r = 0.4E_c = 0.4(3823676) = 1529470 \text{ psi}$$

$$A = \text{length} \times \text{Thickness}$$

$$I = \frac{(\text{Thickness})(\text{Length})^3}{12}$$

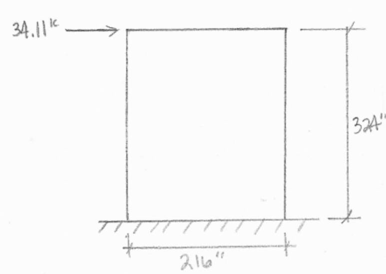
Example Calculation
Shear Wall 2 (N/S Direction)
Load Combination → 0.9D + 1.0E + 1.6H

- WALL 2 SUPPORTING LEVEL 2T



$$\Delta = \frac{(15100)(162^3)}{3(3823676)(10077696)} + \frac{1.2(15100)(162)}{(1529470)(2592)} = 5.5534\times10^{-4} + 7.4045\times10^{-4} = \underline{0.001269''}$$

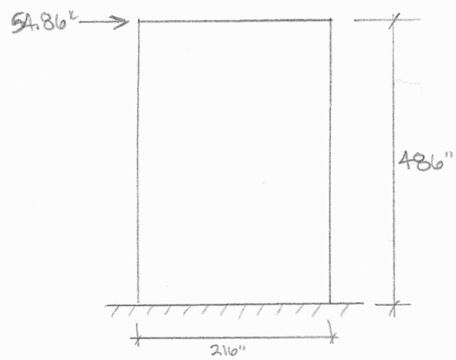
- WALL 2 SUPPORTING LEVEL 3T



$$\Delta = \frac{(34110)(324)^3}{3(3823676)(10077696)} + \frac{1.2(341100)(324)}{(1529470)(2592)} = 0.010036 + 0.003345 = \underline{0.01338''}$$

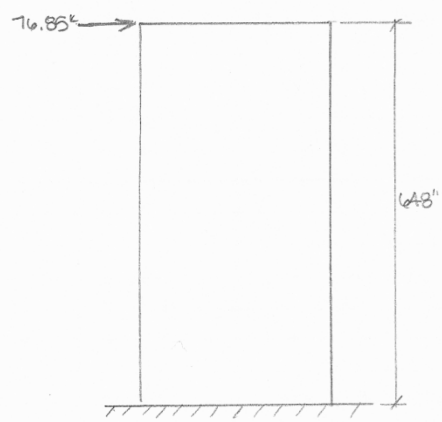
TECH REPORT III | DISPLACEMENT | ArNG Readiness Center | 2

- WALL 2 SUPPORTING LEVEL 4T



$$\Delta = \frac{(54860)(486)^3}{3(3823676)(10077696)} + \frac{1.2(54860)(486)}{(1529470)(2592)} = 0.054479'' + 0.00807'' = \underline{0.06255''}$$

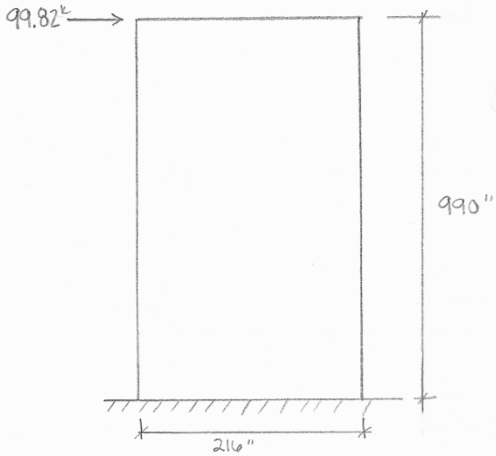
- WALL 2 SUPPORTING LEVEL 5T



$$\Delta = \frac{(76850)(648)^3}{3(3823676)(10077696)} + \frac{1.2(76850)(648)}{(1529470)(2592)} = 0.180886'' + 0.015074'' = \underline{0.19599''}$$

TECH REPORT III	DISPLACEMENT	ArNG Readiness Center	3

• WALL 2 SUPPORTING LEVEL PH



$$\Delta = \frac{(99820)(990)^3}{3(3823676)(10077696)} + \frac{1.2(99820)(990)}{(1529470)(2592)} = 0.83784" + 0.29913" = \underline{0.86776"}$$

OVERALL BUILDING DISPLACEMENT

$$\Sigma\Delta = 0.001269" + 0.01338" + 0.06255" + 0.19599" + 0.86775" = \boxed{1.14"}$$

$$\Delta_{limit} = H/400 = 990"/400 = \underline{2.475"}$$

$$\Delta_{limit} = 2.475" > 1.14" \quad \therefore \boxed{\text{OKAY!}}$$