# technical report 3:

# lateral system analysis and confirmation design

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## executive summary

This Lateral System and Confirmation Design Report focused on the integration of manual calculations and computer analysis results from an ETABS model for Granby Tower. Hand calculations were used to determine accurate wind and seismic lateral loads that would be input into ETABS as user defined lateral loads. This approach ensures that the program will solve a specific set of equations instead of acting as a "black box."

An analysis of the lateral force resisting system for Granby Tower was conducted using ETABS. ETABS is a structural modeling program developed by Computers & Structures, Inc. that is a very powerful tool for analyzing the lateral effects on a structure. Because ETABS specializes in lateral analysis, I only input the lateral resisting elements (shear walls). This allowed me to minimize the number of unknown variables so that accurate lateral distribution could be expected.

The distribution of wind and seismic forces to shear walls allowed spot checks for the strength of critical shear wall sections. I found that the shear walls at the 7$^{th}$ level were under designed for the wind loads [1.2(dead) + 1.6(wind) + 0.5(live)] calculated for the x and y directions. I have concluded that this is a result of several factors. At level 7 the parking garage terminates, so the compressive strength drops from f'c = 8000 psi (level 6) to f'c = 6000 psi and wall thickness decreases from 24" to 14". While I believe the structural engineer designed the shears walls adequately for the wind and seismic loads they analyzed, my results show that the under designed shear walls effect the overall building displacement. The acceptable drift ($\Delta$ = H/400) for Granby tower is 11.00 inches, and the x-direction and y-direction drifts are 12.33 inches (H/357) and 9.92 inches (H/444), respectively. Drift analysis reinforces my belief that increased material strength at level 7 would help to reduce overall displacement. While displacements due to wind were slightly higher than the acceptable limit, the story drifts from seismic loading were acceptable in both x and y directions.

The existing foundation proved adequate for resisting overturning moments since the pile cap directly under the central shear wall cores is tied to 255 tension designed square, precast, pre-stressed concrete piles. Overturning moments were also analyzed with respect to the building weight, at the center of mass to the nearest shear wall and found to be adequate.

Torsion has very little effect on Granby Tower since the floor plan is relatively symmetric around both axes. The eccentricity caused from the location of the center of mass and center of rigidity is fairly minimal. It has been assumed that the geometric center and center of rigidity create minimal eccentricity as well since deflection animations in ETABS show no rotation. Drift calculations show very little perpendicular displacement (displacement perpendicular to lateral load due to torsion) due to wind or seismic forces.

## introduction

The Granby Tower (*fig 1*) is a proposed mixed-use, luxury, high rise located in the downtown historic district of Norfolk, Virginia. Historically Granby Street was the premier shopping, dining, gathering and theatre corridor, and these luxuries were supplemented by the direct connection to the Elizabeth River waterfront. The conveniences of Granby Street fell out of favor in the 1960's as suburban development between Norfolk and Virginia Beach promised bargain shopping malls. Due to the decline in popularity of a very important landmark and cultural center, city officials began reviving the city center in the 1970's and are still working to regain the prestige that Granby Street held in the early 1900's.

Granby Tower will be the tallest building in Norfolk upon completion and will provide roughly 300 luxury apartments with views of downtown Norfolk and the Elizabeth River, 6 stories of parking, a roof top fitness center and pool, leasable office space. It is becoming increasingly popular in the Norfolk and Virginia Beach areas to build above parking structures for a number of reasons. One of the most obvious reasons is that you must provide parking space, and since the site has little open space for a free standing garage, the best way to maximize your profit is to utilize the lower floors for parking. The second main reason for an above ground parking structure housed within the buildings structure is due to the sandy soil conditions and high ground water table that do not allow for deep foundations. Most designs, especially heavy concrete structures, require slab on grade with deep piles to penetrate the deep Yorktown Strata layer that is buried beneath layers of unstable sand and clay.

The lateral force resisting system at Granby Tower is designed as a concrete shear wall core which helps to maximize leasable space while keeping most views unobstructed. The floor framing system is a two-way flat-plate post-tensioned slab with minimal drop panels to capitalize on floor to ceiling height. The longest span seen by the slab is 30 feet with typical bays at 26' x 30'. These design features will allow spaces to feel spacious and elegant and with a design focused on luxury, it is easy to see that Granby Tower will stand as a landmark for the city to celebrate a vibrant history and a promising future.

This report will focus on the analysis of the lateral load resisting system of Granby Tower through a combination of hand calculations and computer analysis to determine if the shear wall core is adequate for resisting the wind and seismic forces calculated in technical report one. An analysis of the ETABS results for lateral distribution, building drift, story drift, overturning moments, and torsion will determine if Granby Tower has been adequately designed to resist the strength and service loads previously calculated.

*fig 1 – rendering of Granby Tower*

## structural overview

### foundation

To determine the soil bearing capacity, sixteen (16) 100 to 110-foot deep Standard Penetration Test borings were drilled within the proposed Granby Tower site. Borings were conducted in accordance with ASTM D 1586 standards and performed with rotary wash drilling procedures to analyze the soil types at 5 foot integrals. Soil tests determined that the first 20 feet of most samples consisted of silty fine sand (SM) or poorly graded fine sand (SP-SM). The next 25 feet of bore was composed of clay (CL) followed by 55 feet of poorly graded fine to coarse sand (SP-SM) and/or silty fine sand (SM). Due to the composition of the soil and location of the groundwater table (6 to 7 feet below grade), the geotechnical engineer recommended a deep pile foundation system with driven, precast, pre-stressed, concrete piles since shallow foundations would result in excessive settlements due to the extreme building weight.

To determine the feasibility and required depths of the piles, fifteen test piles were driven and evaluated with a Pile Driving Analyzer. The analysis dictated the use of 12" square, precast, pre-stressed concrete piles (SPPC) at 80 feet deep with 100 ton capacity and 14" SPPC at 90 feet with 140 ton capacity. Roughly 1000 piles support Granby Tower, with 255-14" SPPC piles supporting the ordinary shear wall core (*fig 2*). Due to the lateral forces seen by the shear walls, the outer 156 piles are designed for tension. The pile cap supporting the shear wall is 10 feet thick with a 28-day compressive strength (f'c) of 5000 psi and #10 and #11 reinforcing on top and bottom, while all other pile caps will be designed with an f'c of 4000 psi and # 7 and #8 reinforcing.

The slab on grade is 5" thick, reinforced with 6x6-W2.9xW2.9 welded wire fabric over a 10 mil polyethylene vapor barrier. The geotechnical engineer specified the slab to be placed over 4" porous fill with less than 5% passing the No. 200 sieve to act as a capillary barrier. The slab should also be "floating" in the sense that it is not rigidly connected to columns or foundations to reduce cracking.

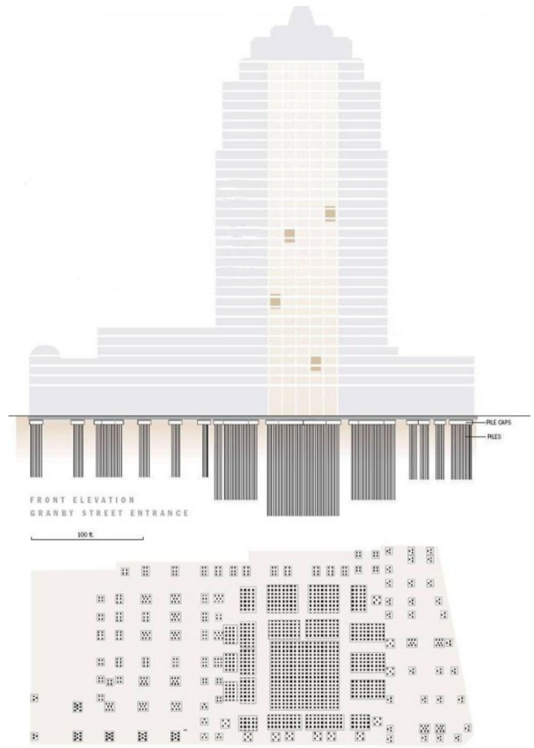



*fig 2 – front elevation and plan of piles for Granby Tower. source: Abiouness, Cross and Bradshaw, Inc.*

### floor system

The floor system for the Granby Tower consists of a two-way flat plate post tensioned slab (*fig 3*) designed in accordance with the Post-Tensioning Manual 6th Edition by the Post-Tensioning Institute and ACI 318-02. All slabs are designed with a 28-day compressive strength (f'c) of 5000 psi, and the first 7 levels of the tower require a 9" slab while the remaining levels are designed as an 8" slab. Tendons for post-tensioning will be ½" diameter (ø), 7-wire, low relaxation strand, fully encased in grease with a minimum sheathing thickness of 50mm. Maximum sag for tendons will be 5 ½" and supported by chairs or bolsters. Post-tensioning will occur when the concrete has reached 75% of its designed f'c, and all of the uniform tendons shall be stressed before banded tendons. Uniform tendons are even distributed through the north-south (long) direction with a maximum span of 26' while banded tendons run east-west (short direction) along column lines with a maximum span of 30'.

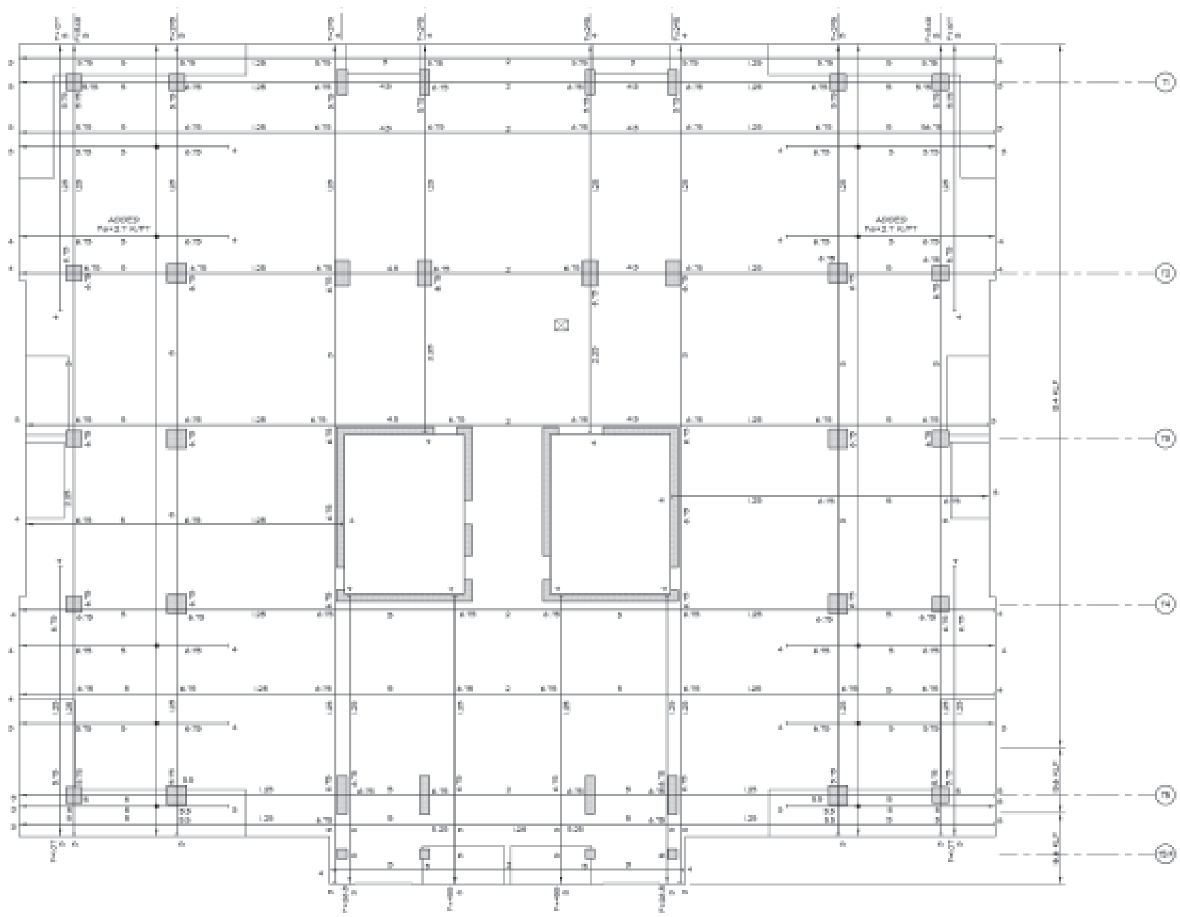


*fig 3 – typical post-tensioning plan for levels 8 through 12. Plan and True North* **→N (x-direction)**

## columns

Gravity columns are laid out on a fairly regular grid with the largest bay at 26'x30' (refer again to *fig 3* for column layout). Roughly 32 columns run the full building height with some of the exterior columns terminating at the buildings first significant set-back on the $29^{th}$ floor. Most columns are square reinforced columns with rebar ranging from #7 to #10, but rectangular columns with the strong axis in the short building direction (east-west) are architecturally situated in central east and west apartments. Columns above the parking garage (Level 7) are designed with f'c = 5000 psi, and columns between Level 6 and the foundation are designed with f'c = 6500 psi. Banded tendons running through columns should be within 1.5 x T (thickness slab) of the column face and placed above other uniform tendons or rebar. Some drop panels are required on upper floors as column sizes decrease and slab edges become flush with exterior columns.

## lateral system

The lateral load resisting system of Granby Tower consists of ordinary reinforced concrete shear walls (*fig 4*) that were designed in accordance to ACI 318-02. These two shear wall cores house the elevators, stairs, electrical and gas lines, and fire dampers. The first 6 levels consist of 24" thick reinforced shear walls with f'c = 8000 psi, while the remaining levels consist of 14" shear walls with 28-day compressive strengths of 6000 (Levels 7 through 23) and 5000 psi (Levels 24 through 34). Typical vertical reinforcement ranges in size and spacing from #10 @ 6" o.c. to #8 @ 12" o.c. while horizontal reinforcement ranges from #6 @ 6" o.c. to #5 @ 12" o.c. Typical end reinforcement consists of ten vertical rebar within a square section determined by the wall width and #4 ties @ 8" o.c vertical spacing from the foundation to Level 7 and #3 ties @ 8" o.c. vertical spacing from Level 7 to 34.

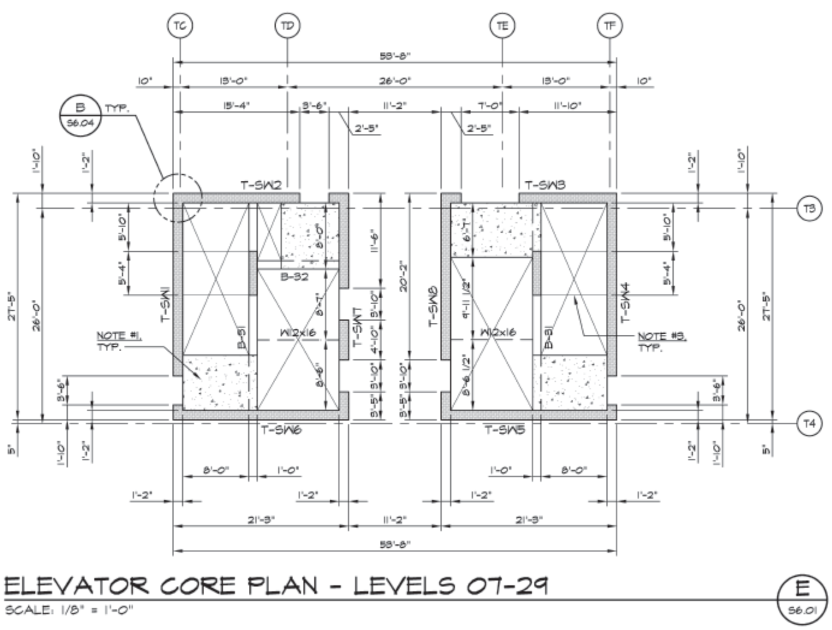



*fig 4 – typical plan of shear wall core.*

# codes and material properties

## codes and standards

At the time in which the Abiouness, Cross and Bradshaw began structural design of Granby Tower, the overarching permissible codes for design were the 2000 International Building Code (IBC), which references American Society of Civil Engineers (ASCE) 7-98, and Virginia Uniform Statewide Building Code 2000. Concrete was designed in accordance with American Concrete Institute (ACI) 318-99 and all masonry in accordance with ACI 530-99. Post-tensioning design references the Post-Tensioned Manual by the Post-Tensioned Institute, ACI 318-02, and IBC 2000. All steel design references the American Institute of Steel Construction (AISC) ASD 9$^{th}$ Edition, and cold-formed metal design references the 1996 American Iron and Steel Institute (AISI) Specification.

For my analysis of Granby Tower I utilized more recent building codes such as IBC 2006 and ASCE 7-05. All concrete design was based on ACI 318-05, and I will utilize the Load and Resistance Factor Design information from AISC Thirteenth Edition Steel Manual.

## materials

*Concrete: Normal Weight Concrete*

| | |
|---|---|
| Foundations | f’c = 4000 psi / 5000 psi |
| Shear Walls | f’c = 8000 psi / 6000psi / 5000 psi |
| Slab on Grade | f’c = 4000 psi |
| Elevated Slabs | f’c = 5000 psi |
| Columns | f’c = 6500 psi / 5000 psi |

*Reinforcing Steel*

| | |
|---|---|
| Reinforcing Bar | ASTM A615, Grade 60 |
| Welded Wire Fabric | ASTM A185 |

*Structural Steel*

| | |
|---|---|
| Structural Tubing (HSS) | ASTM A500, Grade B, Fy = 46ksi |
| W-shapes | ASTM A992, Grade 50, Fy = 50 ksi |
| Other rolled plates and shapes | ASTM A36, Fy = 36 ksi |

# loads

## dead loads

The dead loads used for design (as shown below) include all structural elements and permanent equipment at its full operating weight as required by ASCE 7-05 § 12.7.2 for effective seismic weight. Normal weight concrete was used for concrete calculations.

| Level | Slab | Shear Walls | Columns | Curtain Wall | Beams | Drop Panels | Mech Eq | Total |
|---|---|---|---|---|---|---|---|---|
| Spire | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 83.0 |
| 34 | 250.8 | 32.0 | 3.8 | 11.0 | 282.8 | 0.0 | 2.3 | 582.7 |
| 33 | 613.6 | 280.8 | 16.5 | 22.0 | 155.5 | 0.0 | 0.0 | 1088.4 |
| 32 | 1027.6 | 303.3 | 76.1 | 29.0 | 361.2 | 0.0 | 84.8 | 1882.0 |
| 31 | 886.0 | 360.6 | 98.4 | 94.0 | 124.3 | 0.0 | 0.0 | 1563.3 |
| 30 | 1509.8 | 312.9 | 76.1 | 72.7 | 71.8 | 7.6 | 0.0 | 2050.9 |
| 29 | 1556.5 | 312.9 | 110.7 | 82.0 | 23.5 | 25.6 | 0.0 | 2111.2 |
| 28 | 1556.5 | 312.9 | 164.5 | 82.0 | 14.5 | 18.1 | 0.0 | 2148.5 |
| 27 | 1556.5 | 312.9 | 182.2 | 82.0 | 14.5 | 18.1 | 0.0 | 2166.2 |
| 26 | 1556.5 | 312.9 | 182.2 | 82.0 | 14.5 | 18.1 | 0.0 | 2166.2 |
| 25 | 1587.3 | 312.9 | 182.2 | 82.0 | 14.5 | 18.1 | 0.0 | 2197.0 |
| 24 | 1911.9 | 312.9 | 189.1 | 82.0 | 37.0 | 7.5 | 0.0 | 2540.4 |
| 23 | 1883.0 | 312.9 | 223.7 | 88.4 | 10.0 | 0.0 | 0.0 | 2518.0 |
| 22 | 1883.0 | 312.9 | 223.7 | 88.4 | 10.0 | 0.0 | 0.0 | 2518.0 |
| 21 | 1883.0 | 312.9 | 223.7 | 88.4 | 10.0 | 0.0 | 0.0 | 2518.0 |
| 20 | 1883.0 | 312.9 | 223.7 | 88.4 | 10.0 | 0.0 | 0.0 | 2518.0 |
| 19 | 1883.0 | 312.9 | 223.7 | 88.4 | 10.0 | 0.0 | 0.0 | 2518.0 |
| 18 | 1883.0 | 312.9 | 223.7 | 88.4 | 10.0 | 0.0 | 0.0 | 2518.0 |
| 17 | 1883.0 | 312.9 | 223.7 | 88.4 | 10.0 | 0.0 | 0.0 | 2518.0 |
| 16 | 1883.0 | 312.9 | 223.7 | 88.4 | 10.0 | 0.0 | 0.0 | 2518.0 |
| 15 | 1883.0 | 312.9 | 223.7 | 88.4 | 10.0 | 0.0 | 0.0 | 2518.0 |
| 14 | 1883.0 | 312.9 | 223.7 | 88.4 | 10.0 | 0.0 | 0.0 | 2518.0 |
| 13 | 1892.2 | 312.9 | 223.7 | 88.4 | 10.0 | 0.0 | 0.0 | 2527.2 |
| 12 | 1892.2 | 312.9 | 223.7 | 88.4 | 10.0 | 0.0 | 0.0 | 2527.2 |
| 11 | 1892.2 | 312.9 | 387.5 | 88.4 | 10.0 | 0.0 | 0.0 | 2691.0 |
| 10 | 1892.2 | 312.9 | 387.5 | 88.4 | 10.0 | 0.0 | 0.0 | 2691.0 |
| 9 | 1892.2 | 312.9 | 387.5 | 88.4 | 10.0 | 0.0 | 0.0 | 2691.0 |
| 8 | 1892.2 | 312.9 | 387.5 | 88.4 | 10.0 | 0.0 | 0.0 | 2691.0 |
| 7 | 1889.3 | 372.8 | 453.6 | 103.6 | 10.0 | 0.0 | 0.0 | 2829.3 |
| 6 | 2125.5 | 541.5 | 404.7 | 30.8 | 16.1 | 0.0 | 0.0 | 3118.6 |
| 5 | 2125.5 | 541.5 | 404.7 | 30.8 | 16.1 | 0.0 | 0.0 | 3118.6 |
| 4 | 2125.5 | 541.5 | 404.7 | 30.8 | 16.1 | 0.0 | 0.0 | 3118.6 |
| 3 | 2125.5 | 541.5 | 404.7 | 30.8 | 16.1 | 0.0 | 0.0 | 3118.6 |
| 2 | 2125.5 | 541.5 | 404.7 | 30.8 | 16.1 | 0.0 | 0.0 | 3118.6 |
| 1 | 1944.4 | 596.9 | 434.3 | 33.0 | 42.2 | 0.0 | 0.0 | 3050.8 |
| SOG | 0.0 | 841.2 | 612.0 | 23.3 | 0.0 | 0.0 | 0.0 | 1476.5 |
| | | | | | | **Total Dead** | **Load (k)** | **84528.0** |

## live loads

An extensive list of the live loads used in design of Granby Tower was provided with the structural general notes, but since this analysis was carried out with current codes, all assumed live loads were validated with ASCE 7-05.

*Live Loads*

| | |
|---|---|
| Roofs | 30 psf |
| Residential Floors | 40 psf |
| Garage | 50 psf |
| Balconies | 100 psf |
| Public Rooms and Corridors | 100 psf |
| Stairs | 100 psf |
| Roof Garden | 100 psf |
| Mechanical and Electrical Rooms | 125 psf |

## snow loads

Norfolk, Virginia experiences mild winters with an expected ground snow load, $P_g = 10$ psf. There are very few flat or low sloped areas for snow to collect on the tower due to the slope of the spire. The exposed portion of the parking structure would be susceptible to some drift possibilities so the flat roof snow load ($P_f$) was calculated to be 6.3 psf. The calculations below were performed in accordance with ASCE 7-05 § 7.3.

*Snow Load Calculations*

| | |
|---|---|
| Ground Snow Load, $P_g$ | 10 psf |
| Importance Factor, I | 1.0 |
| Snow Exposure Factor, $C_e$ | 0.9 |
| Thermal Factor, $C_t$ | 1.0 |
| Flat Roof Snow Load, $Pf = 0.7 * P_g * I * C_e * C_t =$ | 6.3 psf |

## wind loads

Wind analysis was completed using ASCE 7-05 § 6.5 Method 2 – Analytical Procedure. This Method was necessary over § 6.4 Method 1 – Simplified Procedure because the building height was greater than 60 feet and deemed partially enclosed by the designers. To maintain consistency with the proposed design, I elected to share many assumptions that the designer chose for their wind analysis.

| General Information | Value | Source |
|---|---|---|
| Occupancy Category | II | General Structural Notes |
| Importance Factor | 1.0 | General Structural Notes |
| Basic Wind Speed, V | 110 mph | General Structural Notes |
| Exposure Category | C | General Structural Notes |
| Enclosure Classification | Partially Enclosed | General Structural Notes |
| Internal Pressure, $GC_{pi}$ | ± 0.55 | General Structural Notes |

Detailed calculations implementing these assumptions are provided in appendix b. External Pressure Coefficients ($C_p$) and Gust Factors ($G_f$) were calculated using the Analytical Procedure § 6.5.11.2 which references Fig 6-6 and § 6.5.8 respectively. Pressures vary depending on the directionality of the wind, based on the effective length and width of the building that the wind contacts. A summary of the values needed to derive lateral wind pressures are listed below.

| Factor | N-S | E-W | Source |
|---|---|---|---|
| $C_p$ | | | |
| Windward | 0.8 | 0.8 | ASCE 7-05 § 6.5.11.2, Fig 6-6 |
| Leeward | -0.465 | -0.5 | ASCE 7-05 § 6.5.11.2, Fig 6-6 |
| Sidewall | -0.7 | -0.7 | ASCE 7-05 § 6.5.11.2, Fig 6-6 |
| $G_f$ | 1.015 | 1.006 | ASCE 7-05 § 6.5.8 |

As the next page of calculations displays, wind pressures in the east-west direction are the controlling lateral load. East-West wind produces a Base Shear ($V_b$) of 2596.9 kips while base shear in the north-south direction is 2247.4 kips. This outcome is expected since the east-west faces have a larger surface area and could accrue more wind shear, which results in a higher base shear force.

*Wind Pressures (psf)*

| Story | $h_x$ (ft) | $K_z$ | $q_z$ | N-S Windward | N-S Leeward | N-S Side Wall | E-W Windward | E-W Leeward | E-W Side Wall | $GC_{pi}$ (±) |
|---|---|---|---|---|---|---|---|---|---|---|
| Spire btm. | 366.90 | 1.66 | 43.81 | 35.576 | -22.235 | -31.129 | 35.295 | -22.060 | -30.884 | 24.10 |
| 34 | 358.75 | 1.66 | 43.61 | 35.408 | -22.235 | -31.129 | 35.129 | -22.060 | -30.884 | 24.10 |
| 33 | 348.50 | 1.65 | 43.34 | 35.193 | -22.235 | -31.129 | 34.915 | -22.060 | -30.884 | 24.10 |
| 32 | 338.25 | 1.64 | 43.07 | 34.972 | -22.235 | -31.129 | 34.696 | -22.060 | -30.884 | 24.10 |
| 31 | 325.00 | 1.62 | 42.71 | 34.679 | -22.235 | -31.129 | 34.406 | -21.001 | -30.884 | 24.10 |
| 30 | 314.75 | 1.61 | 42.42 | 34.446 | -22.235 | -31.129 | 34.174 | -21.001 | -30.884 | 24.10 |
| 29 | 304.50 | 1.60 | 42.13 | 34.207 | -21.034 | -31.129 | 33.937 | -22.060 | -30.884 | 24.10 |
| 28 | 294.25 | 1.59 | 41.82 | 33.961 | -21.034 | -31.129 | 33.693 | -22.060 | -30.884 | 24.10 |
| 27 | 284.00 | 1.58 | 41.51 | 33.708 | -21.034 | -31.129 | 33.443 | -22.060 | -30.884 | 24.10 |
| 26 | 273.75 | 1.57 | 41.19 | 33.449 | -21.034 | -31.129 | 33.185 | -22.060 | -30.884 | 24.10 |
| 25 | 263.50 | 1.55 | 40.86 | 33.181 | -21.034 | -31.129 | 32.919 | -22.060 | -30.884 | 24.10 |
| 24 | 253.25 | 1.54 | 40.52 | 32.905 | -21.568 | -31.129 | 32.646 | -22.060 | -30.884 | 24.10 |
| 23 | 243.00 | 1.53 | 40.17 | 32.620 | -20.678 | -31.129 | 32.363 | -22.060 | -30.884 | 24.10 |
| 22 | 232.75 | 1.51 | 39.81 | 32.325 | -20.678 | -31.129 | 32.071 | -22.060 | -30.884 | 24.10 |
| 21 | 222.50 | 1.50 | 39.43 | 32.020 | -20.678 | -31.129 | 31.768 | -22.060 | -30.884 | 24.10 |
| 20 | 212.25 | 1.48 | 39.04 | 31.704 | -20.678 | -31.129 | 31.454 | -22.060 | -30.884 | 24.10 |
| 19 | 202.00 | 1.47 | 38.64 | 31.375 | -20.678 | -31.129 | 31.128 | -22.060 | -30.884 | 24.10 |
| 18 | 191.75 | 1.45 | 38.22 | 31.033 | -20.678 | -31.129 | 30.789 | -22.060 | -30.884 | 24.10 |
| 17 | 181.50 | 1.44 | 37.78 | 30.676 | -20.678 | -31.129 | 30.435 | -22.060 | -30.884 | 24.10 |
| 16 | 171.25 | 1.42 | 37.32 | 30.303 | -20.678 | -31.129 | 30.064 | -22.060 | -30.884 | 24.10 |
| 15 | 161.00 | 1.40 | 36.84 | 29.912 | -20.678 | -31.129 | 29.676 | -22.060 | -30.884 | 24.10 |
| 14 | 150.75 | 1.38 | 36.33 | 29.501 | -20.678 | -31.129 | 29.268 | -22.060 | -30.884 | 24.10 |
| 13 | 140.50 | 1.36 | 35.80 | 29.067 | -20.678 | -31.129 | 28.837 | -22.060 | -30.884 | 24.10 |
| 12 | 130.25 | 1.34 | 35.23 | 28.607 | -20.678 | -31.129 | 28.381 | -22.060 | -30.884 | 24.10 |
| 11 | 120.00 | 1.32 | 34.63 | 28.117 | -20.678 | -31.129 | 27.896 | -22.060 | -30.884 | 24.10 |
| 10 | 109.75 | 1.29 | 33.98 | 27.594 | -20.678 | -31.129 | 27.376 | -22.060 | -30.884 | 24.10 |
| 9 | 99.50 | 1.27 | 33.29 | 27.030 | -20.678 | -31.129 | 26.817 | -22.060 | -30.884 | 24.10 |
| 8 | 89.25 | 1.24 | 32.53 | 26.418 | -20.678 | -31.129 | 26.210 | -22.060 | -30.884 | 24.10 |
| 7 | 77.25 | 1.20 | 31.56 | 25.627 | -20.678 | -31.129 | 25.425 | -22.060 | -30.884 | 24.10 |
| 6 | 67.00 | 1.17 | 30.63 | 24.871 | -20.678 | -31.129 | 24.675 | -22.060 | -30.884 | 24.10 |
| 5 | 56.75 | 1.13 | 29.58 | 24.016 | -20.678 | -31.129 | 23.827 | -22.060 | -30.884 | 24.10 |
| 4 | 46.50 | 1.08 | 28.36 | 23.030 | -20.678 | -31.129 | 22.848 | -22.060 | -30.884 | 24.10 |
| 3 | 36.25 | 1.03 | 26.91 | 21.854 | -20.678 | -31.129 | 21.682 | -22.060 | -30.884 | 24.10 |
| 2 | 26.00 | 0.96 | 25.09 | 20.377 | -20.678 | -31.129 | 20.216 | -22.060 | -30.884 | 24.10 |
| 1 | 15.00 | 0.85 | 22.35 | 18.149 | -20.678 | -31.129 | 18.006 | -22.060 | -30.884 | 24.10 |
| SOG | 0.00 | 0.00 | 22.38 | 18.173 | -20.678 | -31.129 | 18.029 | -22.060 | -30.884 | 0.000 |

## seismic loads

To calculate the seismic forces as seen by the Granby Tower I refrenced ASCE 7-05, §11 & §12 and IBC 2006. A very helpful tool for determing some seismic values was provided by the United States Government Seismic Design Value for Buildings (http://earthquake.usgs.gov/research/hazmaps/design). The USGS web site uses the latitude and longitude of the speific site to determine the mapped and adjusted spectral response accelerations depending on site class. The design engineer also provided some insight as to some of the values that were used in their seismic calcuation, so I made sure to check those values with some more current references. As the table shows below the siesmic base shear, $V_b$, was 845 kips. This was much lower than the base shear related to wind for the following reasons: the favorable site class, the ordinary reinforced shear walls (represent a response modification factor of 5), and building's location along the mid-Atlantic which results in a higher wind speed. Seismic calculations are provided in appendix c.

| Input | Value | Source |
|---|---|---|
| Occupancy Category | II | ASCE 7-05 |
| Importance Factor | 1.0 | ASCE 7-05 |
| Soil Site Class | D | Geotech Report |
| Seismic Design Category | B | ASCE 7-05 |
| $S_S$ | 0.118 | USGS.gov |
| $S_1$ | 0.048 | USGS.gov |
| Fa | 1.6 | ASCE 7-05, Tbl 11.4-1 |
| Fv | 2.4 | ASCE 7-05, Tbl 11.4-2 |
| $S_{DS}$ | 0.126 | ASCE 7-05 |
| $S_{D1}$ | 0.077 | ASCE 7-05 |
| R | 5 | ASCE 7-05, Tbl 12.2-1 |
| $h_n$ | 361.25 | |
| $C_t$ | 0.02 | ASCE 7-05, Tbl 12.8-2 |
| x | 0.75 | ASCE 7-05, Tbl 12.8-2 |
| $T_a$ | 1.66 | |
| $C_u$ | 1.7 | ASCE 7-05, Tbl 12.8-1 |
| T | 2.82 | |
| $T_L$ | 8 | ASCE 7-05, Fig 22-15 |
| $C_S$ | 0.01 | ASCE 7-05, Eq 12.8-5 |
| k | 2 | ASCE 7-05, Sec 12.8.3 |
| Effective Seismic Weight (W) | 84528 k | |
| **$V_b$** | **845.3 k** | appendix c |

## loads combinations

The following load cases from ASCE 7-05, Chapter 2 were used for member spot checks.

1 • 1.4(dead)

2 • 1.2(dead) + 1.6(live) + 0.5(roof live)

3 • 1.2(dead) + 1.6(roof live) + 1.0(live)

4 • 1.2(dead) + 1.6(wind) + 1.0(live) + 0.5(roof live)

5 • 1.2(dead) + 1.0(earthquake) + 1.0(live) + 0.2(snow)

6 • 0.9(dead) + 1.6(wind)

7 • 0.9(dead) + 1.0(earthquake)

# lateral analysis

## etabs model

An analysis of the lateral force resisting system for Granby Tower was conducted using ETABS. ETABS is a structural modeling program developed by Computers & Structures, Inc. that is a very powerful tool for analyzing the lateral effects on a structure. Because ETABS specializes in lateral analysis, I only included the lateral resisting elements (shear walls) as seen in *fig 5*. The material properties of the shear wall cores vary throughout the height of the building so three separate shear wall properties were made for each of the various compressive strengths. I modeled the shear walls with membrane properties since this assumes those shear walls take no-out-of plane forces. A conservative assumption, even though in reality walls will take some out-of-plane shears and moments. Consideration was taken to the size of the mesh quadrilaterals generated so that door openings could be created as accurately as possible (appendix d). While it may have been more conservative to model the shear walls with coupling beams spanning between the main wall sections, instead of voids representing door openings, I chose to delete segments of meshed areas for simplicity. Another reason that I decided not to model coupling beams is that cracked section properties were not taken into consideration. To effectively model coupling beams, cracked section properties may need to be considered since beam sections should be designed to crack.

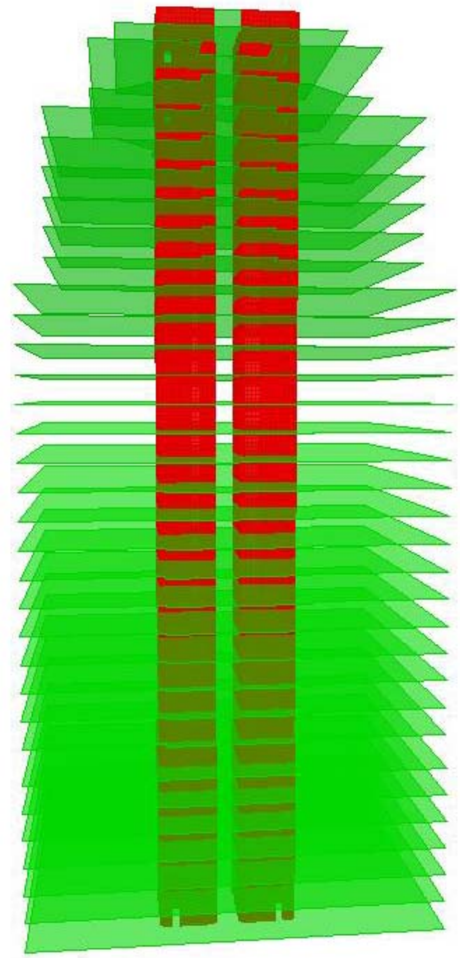


*fig 5 – ETABS model representing shear walls and null floor plate.*

To transfer lateral forces to shear walls, I assigned rigid diaphragms to each floor. By creating null floor areas, I could omit the material properties of the floor and assume that the floor plate would effectively transfer all of the lateral loads to the shear walls. Since these rigid diaphragms had no mass or weight, I assigned addition area masses (slug/ft$^2$) to each floor depending on the effective seismic weight per floor.

The lateral loads found from wind and seismic analysis conducted in technical report one were input as user defined loads to each floor diaphragm. Wind forces in the north-south and east-west directions act at the story's geometric center while seismic forces are assigned to the story's center of mass. Load combinations as discussed earlier impacted shear wall strength calculations while service loads were used to determine story drift and building drift.

## results

*Lateral Distribution*

Due to the number and variety of shear walls, manually calculating the rigidity of each shear wall to determine the amount of load distributed would have been a nightmare. ETABS is a valuable tool for determining lateral load distribution; I was able to quickly analyze shear wall forces using section cuts and pier labels. All shear walls were inspected at the base, level 7, and level 24 since the compressive strengths changed at these locations. I determined the worst case shear walls due to a combination of the amount of load seen and the size of opening existing, and then spot checked the critical shear walls for the 1.2(dead) + 1.6(wind) + 1.0(live) load case.

| Story | Pier | Load | Loc | P | V2 | V3 | T | M2 | M3 |
|---|---|---|---|---|---|---|---|---|---|
| STORY1 | BASE SW2 | WINDX | Top | -2401.08 | 955.8 | 0 | 0 | 0 | 38270.26 |
| STORY1 | BASE SW2 | WINDX | Bottom | -2498.6 | 955.8 | 0 | 0 | 0 | 32758.66 |
| STORY8 | STORY7 SW3 | WINDX | Top | -1236.37 | 1013.31 | 0 | 0 | 0 | 18604.02 |
| STORY8 | STORY7 SW3 | WINDX | Bottom | -1294.31 | 1013.31 | 0 | 0 | 0 | 19852.03 |
| STORY25 | STORY 24 SW3 | WINDX | Top | -507.11 | 362.96 | 0 | 0 | 0 | 2918.278 |
| STORY25 | STORY 24 SW3 | WINDX | Bottom | -571.11 | 362.96 | 0 | 0 | 0 | 2824.34 |
| STORY1 | BASE SW4 | WINDY | Top | -2771.29 | 1411.16 | 0 | 0 | 0 | 56371.22 |
| STORY1 | BASE SW4 | WINDY | Bottom | -2404.68 | 1411.16 | 0 | 0 | 0 | 72501.31 |
| STORY8 | STORY7 SW7 | WINDY | Top | -1386.49 | 880.14 | 0 | 0 | 0 | 30462.42 |
| STORY8 | STORY7 SW7 | WINDY | Bottom | -1198.03 | 880.14 | 0 | 0 | 0 | 31721.14 |
| STORY25 | STORY24 SW1 | WINDY | Top | -570.14 | 304.27 | 0 | 0 | 0 | 3377.494 |
| STORY25 | STORY24 SW1 | WINDY | Bottom | -641.53 | 304.27 | 0 | 0 | 0 | 3785.591 |

Spot checks (provided in appendix e) proved that the shear walls at the base and at level 24 were adequately designed for the loads found in my wind analysis. However, the shear walls at level 7 could not develop enough capacity in the boundary elements. Once the shear walls were modeled as membrane elements, the section cuts represented the most conservative case in which all the loads and moments were taken by shear walls parallel to the loading. To recheck the capacity of the shear walls at level 7, I analyzed a model in which the walls were designed as shell elements. Areas assigned as shell elements make for a more realistic model since walls will take some out-of-plane forces. While the resulting shear and moments from a shell model were less than a membrane model, the boundary elements still did not have adequate capacity for the previously calculated wind loads. Although the shear walls at level 7 were not adequate for either model (membrane or shell) in wind strength loading, I expect this to result in greater displacements and story drifts as will be discussed.

*Drift*

To analyze the total building drift I analyzed the wind induced deflections and compared these to the serviceability standard $\Delta = H/400$. The base shears calculated from wind in the north-south (x-direction) and east-west (y-direction) were 2247.41 kips and 2596.91 kips, respectively, but the x-direction wind resulted in the largest total building drift. I believe this to be the case because the shear walls in the x-direction are shorter in total length than the y-direction shear walls. For the reason that there is less effective area to resist shear, it results in more drift. The acceptable drift for Granby tower is 11.00 inches, and the x-direction and y-direction drifts are 12.33 inches (H/357) and 9.92 inches (H/444), respectively.

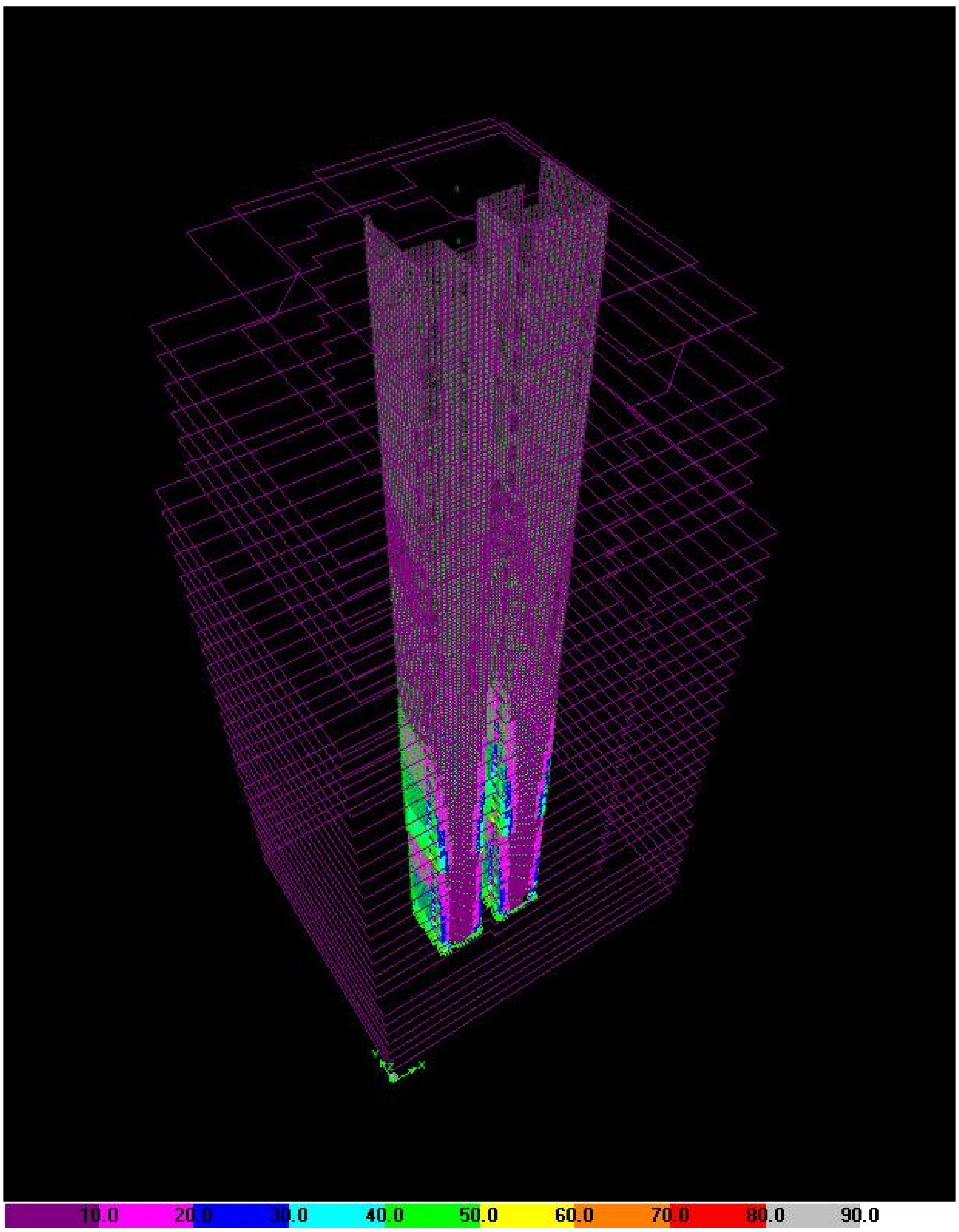



*fig 6 – ETABS Energy/Virtual Work Diagram for X-Direction Wind*

The ETABS image on the previous page (Energy/Virtual Work Diagram) represents the elements that should be stiffened to control lateral displacements (*fig 6*). This Energy/Virtual Work Diagram for X-Direction Wind indicates that best places to reduce drift are the shear walls at the base and at level 7. The walls at level 7 could benefit the most from increased stiffness since at this point the shear walls reduce in width from 24 inches (level 6) to 14 inches (level 7) and from a 28-day compressive strength ( f'c) of 8000psi to f'c = 6000psi. The stiffness demand could be addressed by simply increasing the compressive strength, and since the total building drift for x-direction wind is less than 1 ½" outside the acceptable serviceability limit, the higher strength concrete would most likely only be needed between levels 7 and 14.

*Story Drift*

The story drifts due to service seismic loading were computed through ETABS and then compared to the allowable story drift, $\Delta = 0.007h_{sx}$ (masonry shear wall structures), as discussed in ASCE 7-05 Table 12.12-1. The allowable story drift, $\Delta = 0.072$ inches so all story drifts associated with seismic loading are acceptable. To see all displacements and story drifts refer to appendix f.

*Overturning Moment*

Overturning moments due to wind and seismic loads were examined and provided in appendix g. Wind in the y-direction (east-west) produced the largest overturning moment since the east/west facades are 155ft long and thus have more potential to collect wind pressures. The overturning moment ($M_o$) was found to be 470729.6 ft-k, and this number was compared to the product of the base shear and ½ of the building height is ($M_u$ =) 476533f ft-k. The second overturning moment check compared $M_o$ to the product of the effective seismic weight and the shortest moment arm, from the center of mass to the nearest parallel shear wall. Both moment checks were adequate for wind in the y-direction and also a similar procedure proved the overturning moments adequate for the seismic forces in the y-direction. A quick check of the resisting moment available from the tension piles supporting the shear wall core proved that the piles in tension were adequate to resist the overturning forces due to y-direction wind.

*Torsion*

Torsion is created in buildings due to the location at which the resultant load is applied in reference the center of rigidity. Wind forces act at the geometric center while seismic forces act at the center of mass. Due to the centrally located concrete shear wall cores, torsion has very little effect on Granby Tower. This conclusion is evident for a number of reasons. The eccentricity created between the center of mass and center or rigidity in the seismic case is about 1 foot in the x-direction and 15 feet in the y-direction (appendix g). While this may be a substantial difference in the y-direction, the total building displacement is less than ½" from torsion. Another means of checking the effect of torsion involved analyzing the displacement animation to see if the shear walls rotated. Since there is very little perpendicular displacement (in direction perpendicular to applied load) observed in the animations or displacement tables, torsion should have little effect on shear wall design.

## conclusion

This report focused on the integration of computer analysis results from an ETABS model for Granby Tower along with manual calculations. Hand calculations were used to verify accurate wind and seismic lateral loads that were inserted into ETABS, as user defined lateral loads, so that the program would solve a specific set of equations instead of acting as a "black box."

The results of the lateral load distribution provided through the created model were used to research the critical sections of shear walls (base, level 7, and level 24). Each of these sections represents an area of wall at which the material stiffness properties vary. Shear walls investigated at the base and level 24 were adequate for the wind loads previously calculated, but the walls at level 7 could not develop enough capacity in the boundary elements to be considered adequately designed. I assume that these walls are adequately designed by the structural engineer and the discrepancy in my calculations may be due to the following explanation. The shear walls were modeled as membrane elements that take no-out-of plane forces, but take more axial loads and moments. This is a more conservative approach than modeling shell areas but it is less realistic to assume that the walls will not take any out-of-plane forces.

Since some of the shear walls were under designed according to my load calculations, the total building drift is slightly larger than the acceptable building drift, $\Delta = H/400$. An ETABS Energy/Virtual Work Diagram for X-Direction Wind suggests that the lateral displacements (x-direction) could be minimized with additional stiffness (higher strength concrete) in the shear walls at level 7. While displacements due to wind were slightly higher than the acceptable limit, the story drifts from seismic loading were acceptable in both x and y directions.

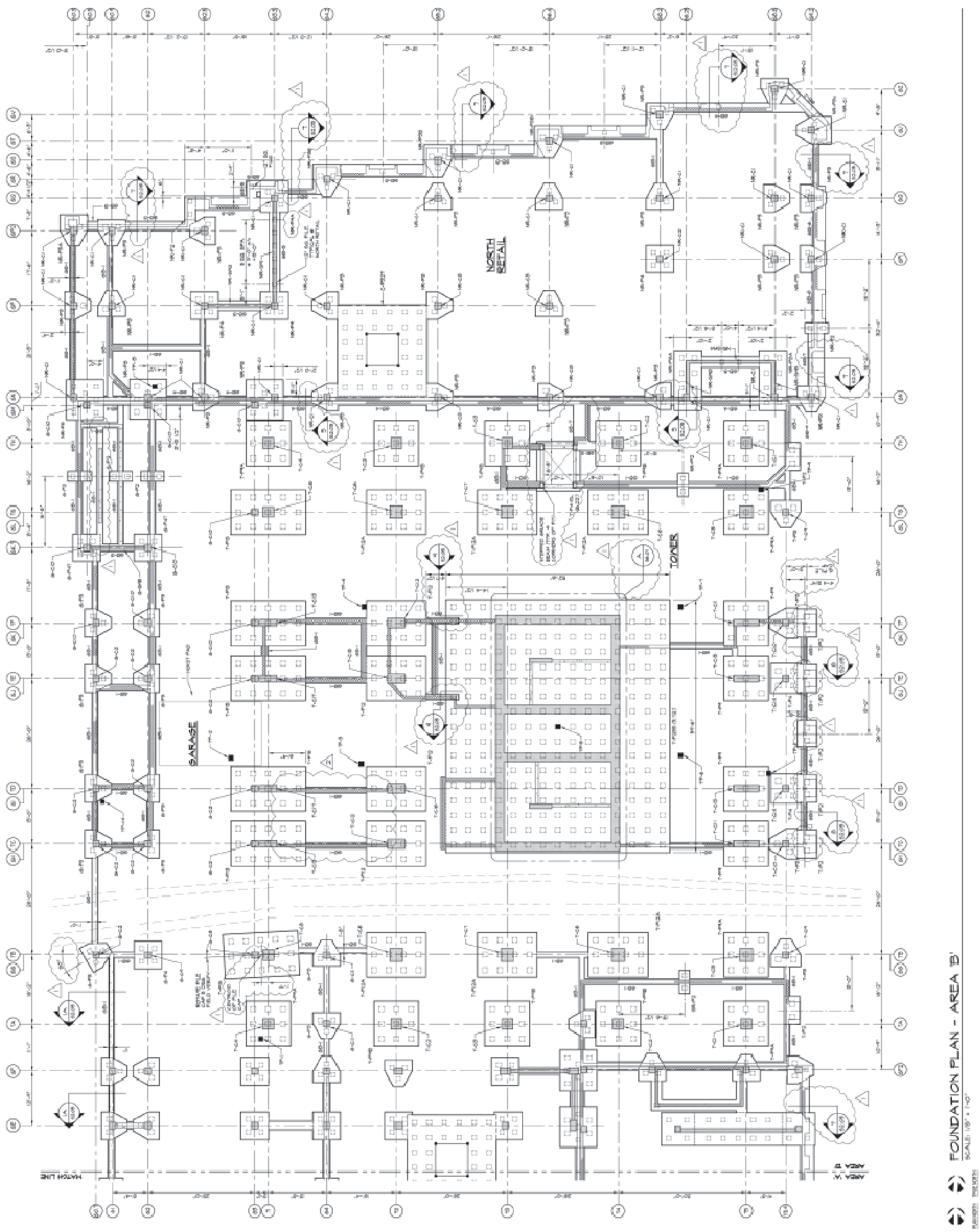
The existing foundation proved adequate for resisting overturning moments, since the pile cap directly under the central shear wall cores is tied to 255 tension designed square, precast, pre-stressed concrete piles. Overturning moments were also inspected with respect to the building weight at the center of mass and the nearest shear wall and found to be adequate.

Torsion has very little effect on Granby Tower due to the floor plan being relatively symmetric around both axes. The eccentricity caused from the location of the center of mass and center of rigidity is fairly minimal. It is assumed that minimal eccentricity exists between the geometric center and the center of rigidity, since deflection animations in ETABS show no rotation, and drift calculations show very little perpendicular displacement due to wind or seismic forces.

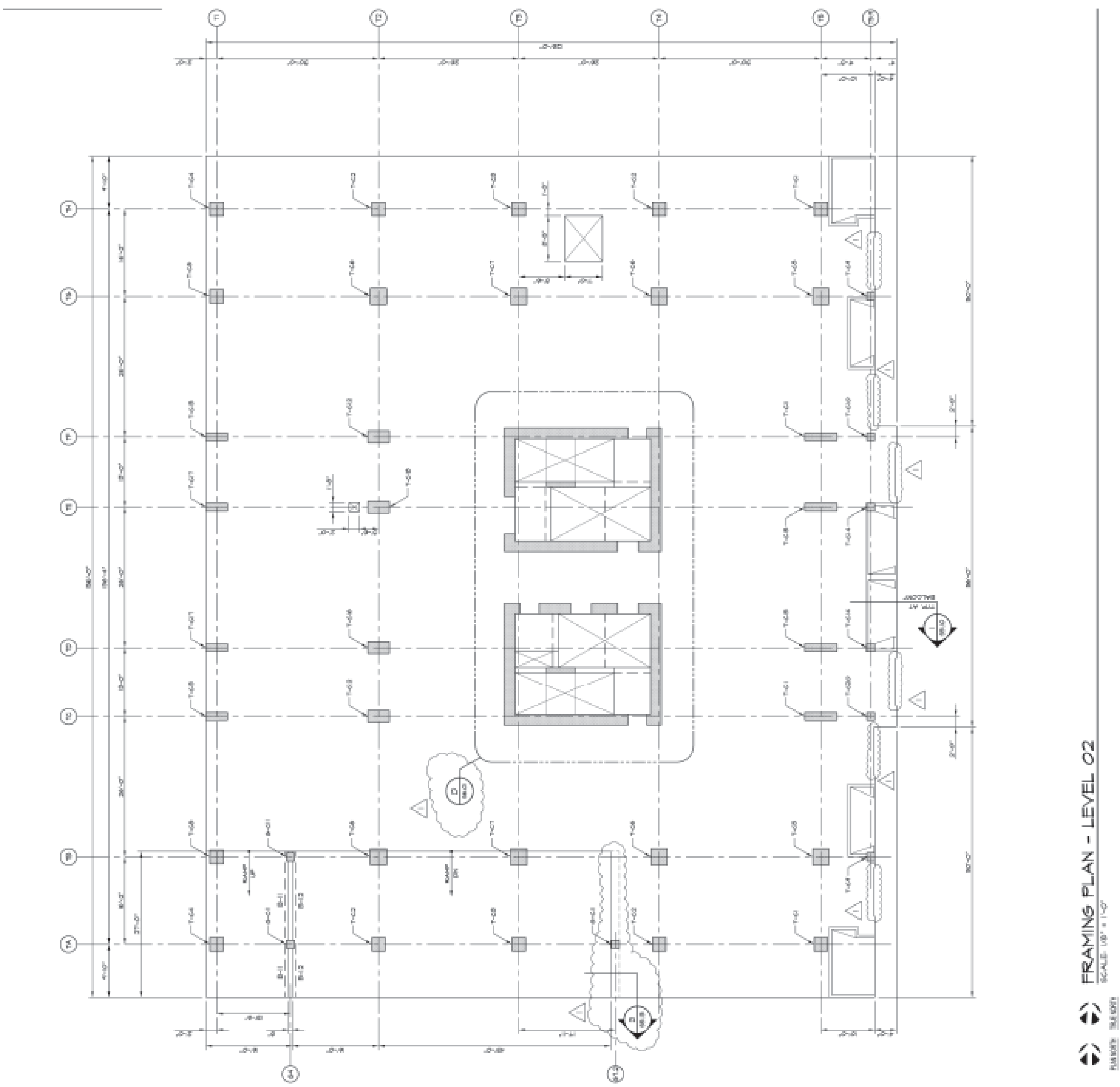
## appendix a • framing plans

The following images were provided by Turner Construction Company for use in Thesis Research. Included are several typical layouts of framing plans and shear wall layouts for reference. The plans that represent the largest number of floors were included as typical plans.

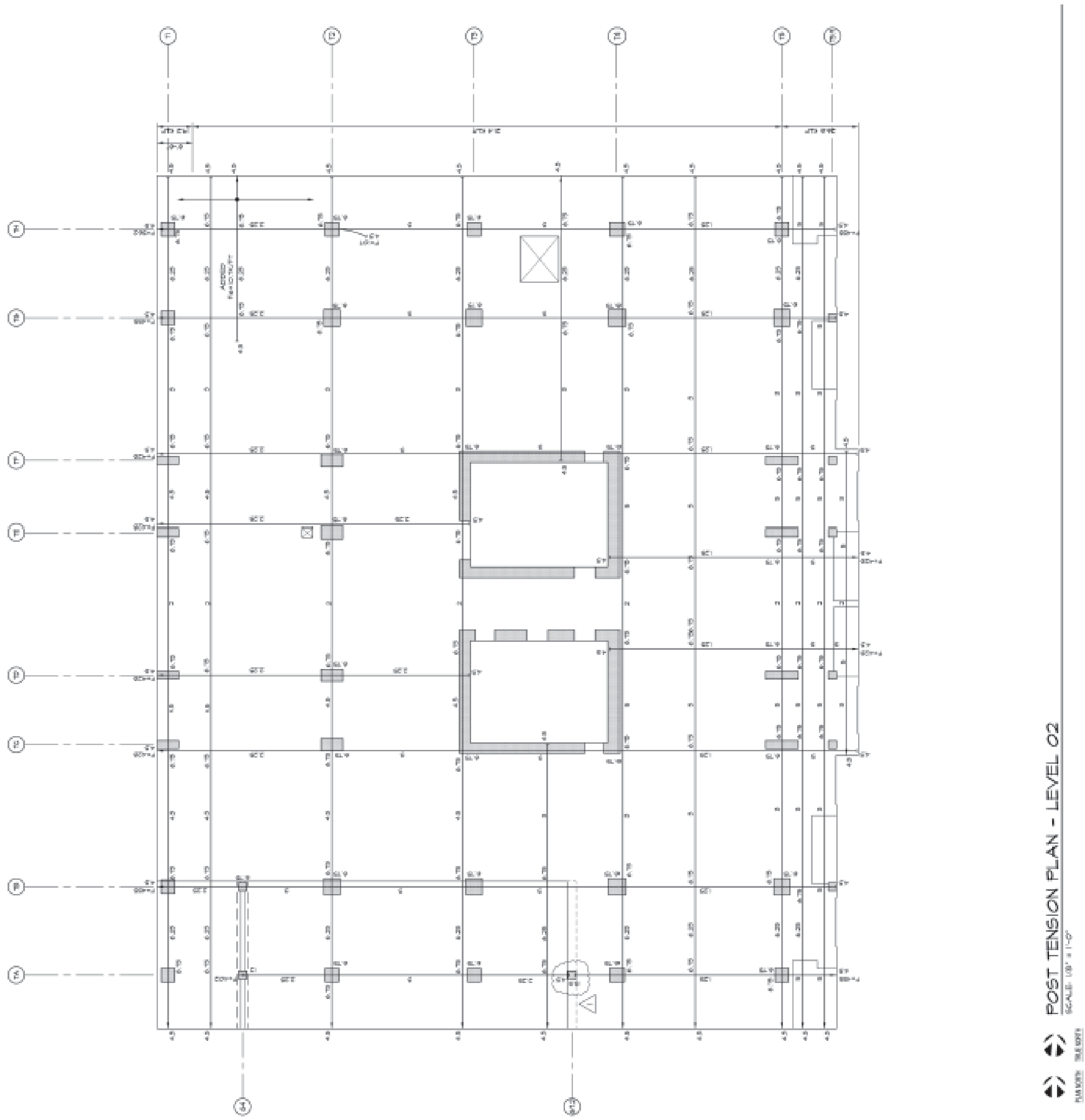
*Tower Foundation Plan*



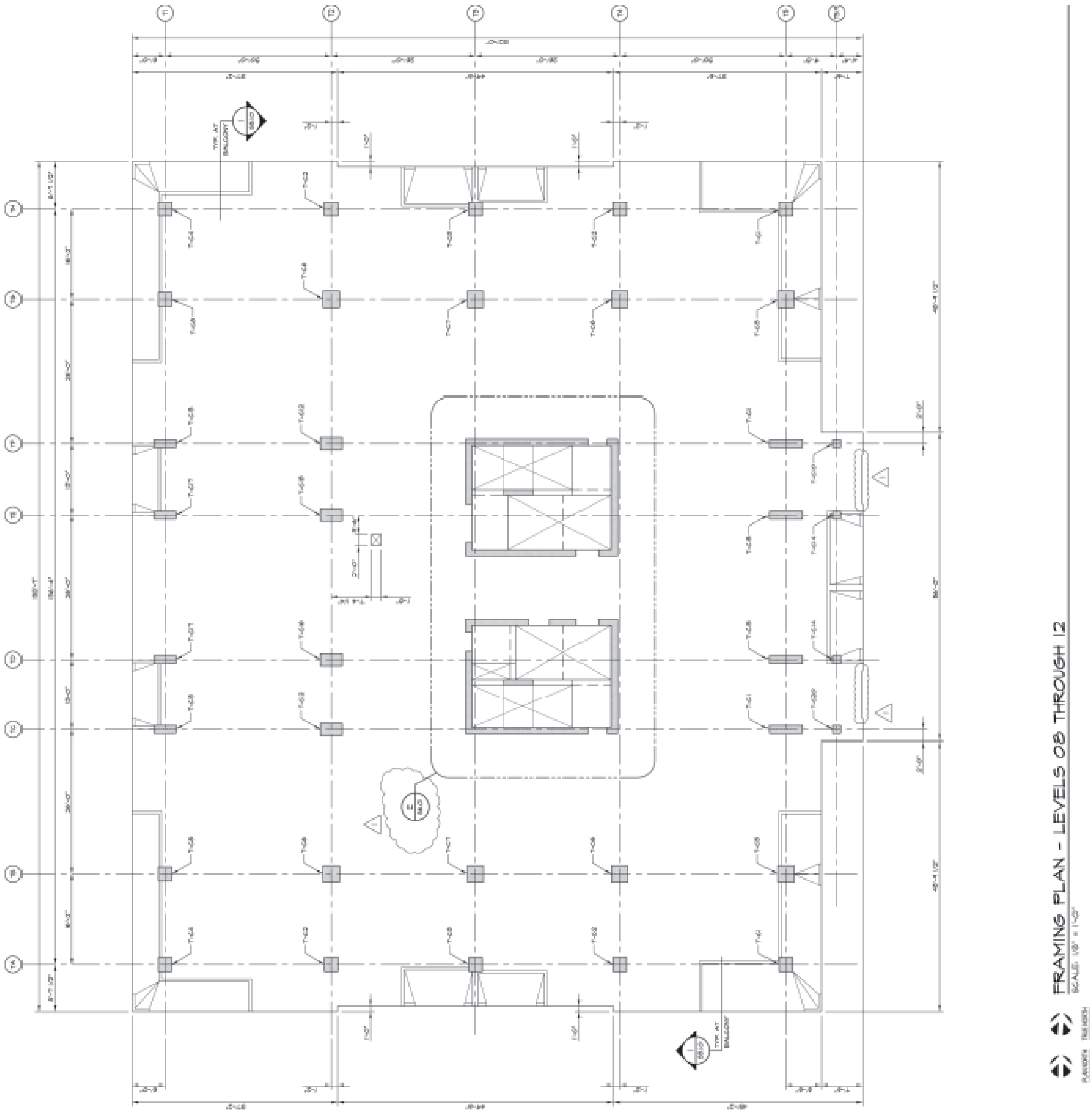
*Typical Framing Plan – Level 2 - 7*



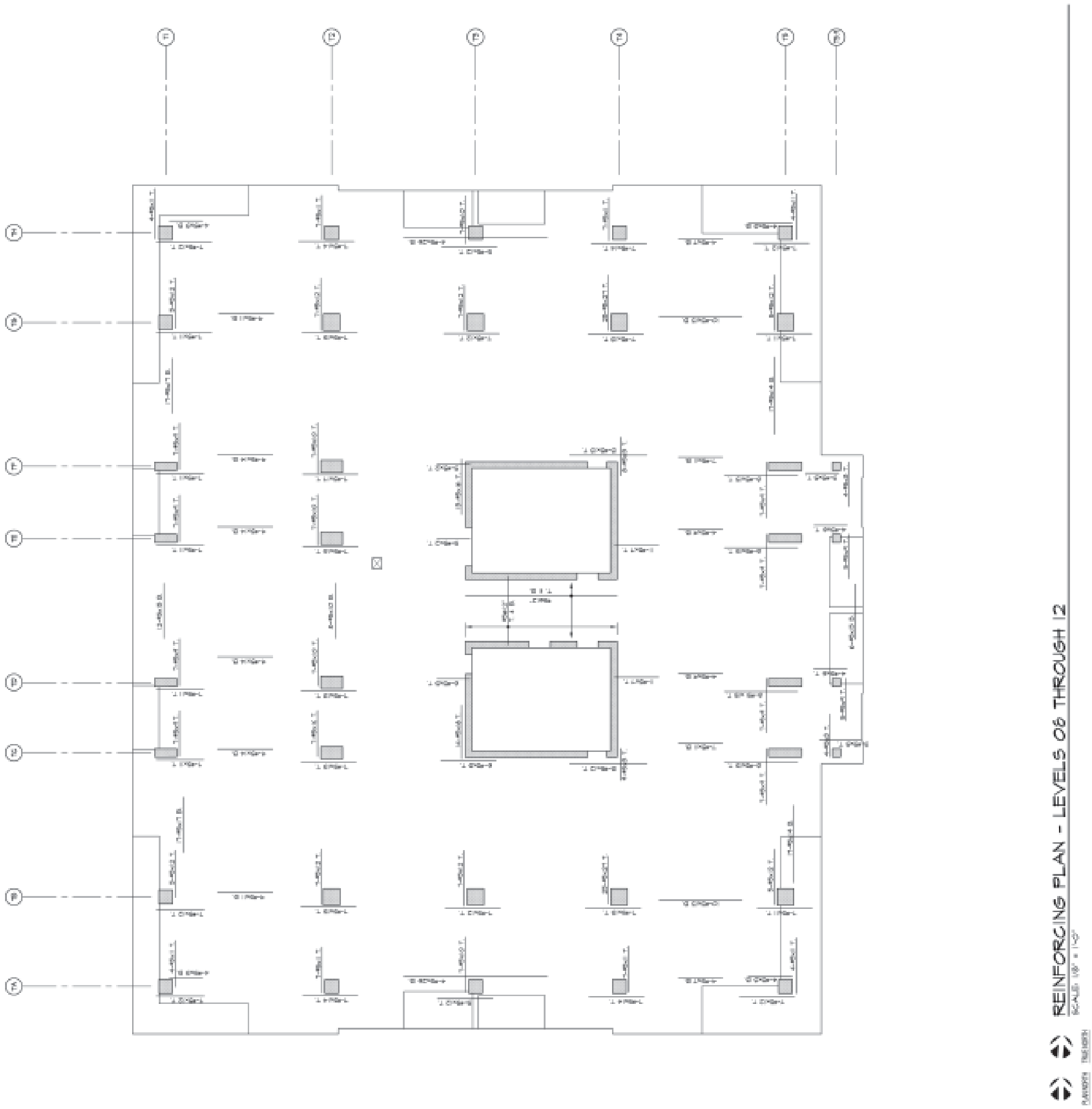
*Typical Post Tensioning Plan – Level 2-7*



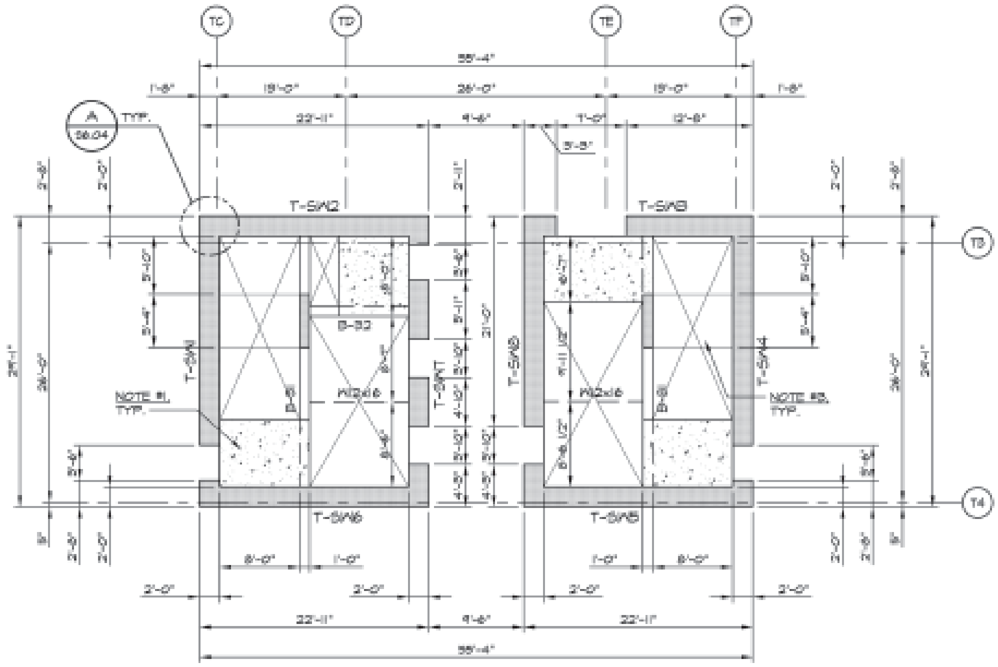
*Framing Plan – Level 8 - 12*



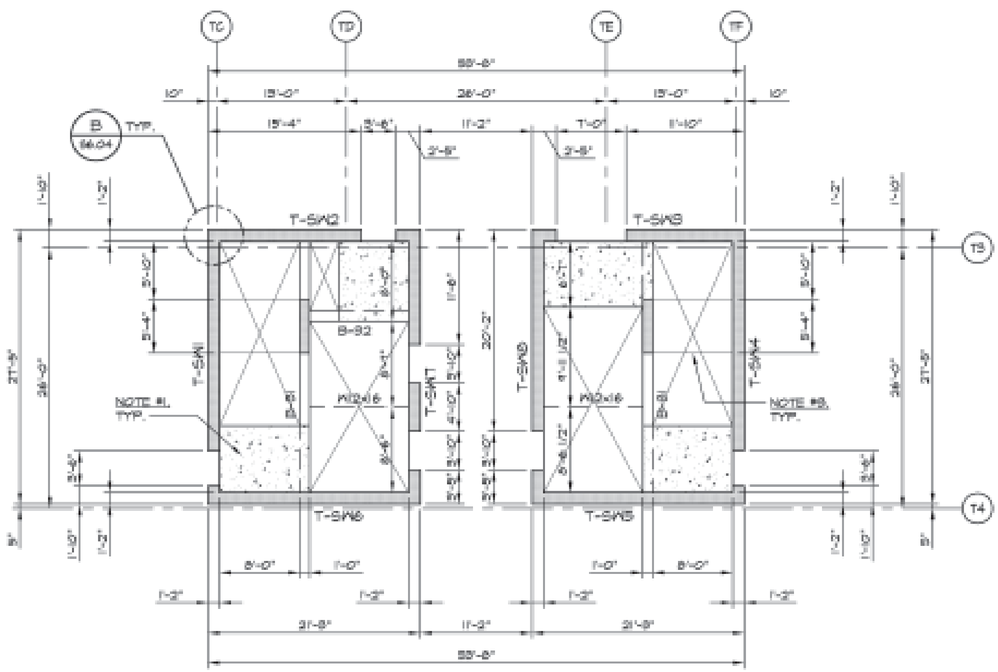
*Typical Reinforcing Plan – Levels 8 - 12*



*Shear Wall Plans*

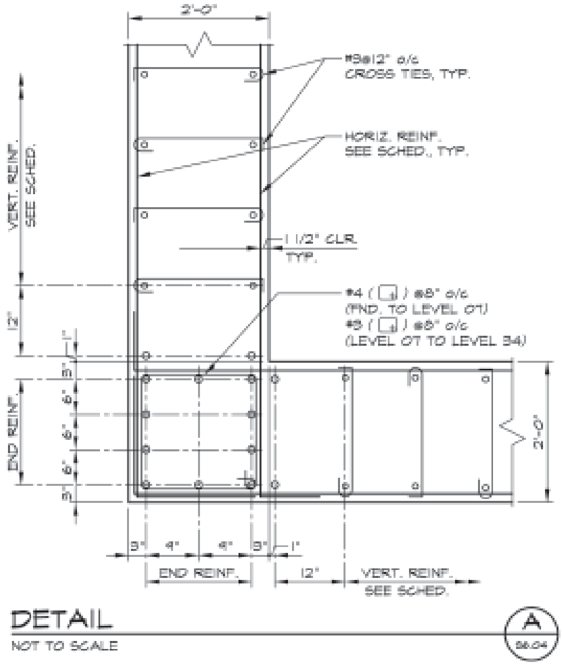


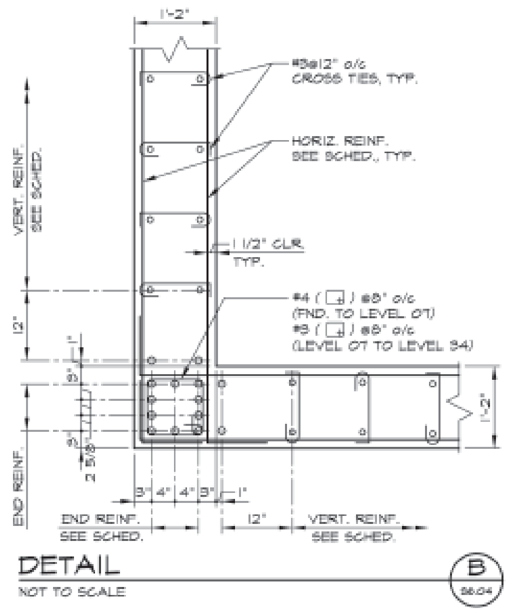

ELEVATOR CORE PLAN - LEVELS 02-06
SCALE: 1/8" = 1'-0"
D
S6.01




ELEVATOR CORE PLAN - LEVELS 07-29
SCALE: 1/8" = 1'-0"
E
S6.01

*Typical Shear Wall Corner Detail*



## appendix b • wind

| General Information | Value | Source |
|---|---|---|
| Occupancy Category | II | General Structural Notes |
| Importance Factor | 1.0 | General Structural Notes |
| Basic Wind Speed, V | 110 mph | General Structural Notes |
| Exposure Category | C | General Structural Notes |
| Directionality Factor, $k_d$ | 0.85 | ASCE 7-05 § 6.5.4.4 |
| h | 367 ft | Design |
| $k_h$ | 1.657 | ASCE 7-05 § 6.5.6.6 |
| $k_z$ | $2.01(z/z_g)^{2/\alpha}$ | ASCE 7-05 § 6.5.6.7 |
| α | 9.5 | ASCE 7-05 Table 6-2 |
| $z_g$ | 900 ft | ASCE 7-05 Table 6-2 |
| $k_{zt}$ | 1.0 | ASCE 7-05 § 6.5.7 |
| T | 4.38 sec | IBC 2006 |
| $n_1$ | 0.23 Hz | 1/T |
| Building Rigidity | Flexible | Frequency |

**Tower Gust Factor**

| Item | N-S | E-W |
|---|---|---|
| L | 155.25 | 132.08 |
| B | 132.08 | 155.25 |
| h | 367 | 367 |
| $n_1$ | 0.355 | 0.355 |
| Rigidity | Flexible | Flexible |
| $\bar{z}$ (ft) | 220.45 | 220.45 |
| c | 0.2 | 0.2 |
| $I_{\bar{z}}$ | 0.146 | 0.146 |
| ϵ | 0.2 | 0.2 |
| ℓ (ft) | 500 | 500 |
| $L_{\bar{z}}$ | 731.02 | 731.02 |
| **Q** | 0.818 | 0.814 |
| $g_Q$ | 3.4 | 3.4 |
| $g_v$ | 3.4 | 3.4 |
| $g_R$ | 3.82 | 3.82 |
| $\bar{\alpha}$ | 0.153 | 0.153 |
| $\bar{b}$ | 0.65 | 0.65 |
| $\bar{V}_{\bar{z}}$ | 140.23 | 140.23 |
| $N_1$ | 1.85 | 1.85 |
| $R_h$ | 0.296 | 0.296 |
| $R_B$ | 0.569 | 0.525 |
| $R_L$ | 0.223 | 0.253 |
| $R_n$ | 0.119 | 0.119 |
| β | 0.02 | 0.02 |
| R | 0.79759 | 0.77460 |
| $G_f$ | 1.015 | 1.006 |

| Factor | N-S | E-W | Source |
|---|---|---|---|
| $C_p$ | | | |
| Windward | 0.8 | 0.8 | ASCE 7-05 § 6.5.11.2, Fig 6-6 |
| Leeward | -0.465 | -0.5 | ASCE 7-05 § 6.5.11.2, Fig 6-6 |
| Sidewall | -0.7 | -0.7 | ASCE 7-05 § 6.5.11.2, Fig 6-6 |
| $G_f$ | 1.015 | 1.066 | ASCE 7-05 § 6.5.8 |

*North – South Results*

| Story | $h_x$ (ft) | Floor Height | Peri - meter | $K_z$ | $q_z$ | N-S Wind ward | N-S Lee ward | N-S Side Wall | Load (kip) | Shear (kip) | Moment (kip-ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Spire | 366.9 | 0.00 | 56.00 | 1.66 | 43.81 | 35.576 | -22.235 | -31.129 | 13.19 | 13.19 | 4840.30 |
| 34 | 358.8 | 8.15 | 56.00 | 1.66 | 43.61 | 35.408 | -22.235 | -31.129 | 29.70 | 42.89 | 10654.02 |
| 33 | 348.5 | 10.25 | 56.00 | 1.65 | 43.34 | 35.193 | -22.235 | -31.129 | 32.96 | 75.85 | 11487.74 |
| 32 | 338.3 | 10.25 | 88.50 | 1.64 | 43.07 | 34.972 | -22.235 | -31.129 | 59.49 | 135.34 | 20121.86 |
| 31 | 325.0 | 13.25 | 124.83 | 1.62 | 42.71 | 34.679 | -22.235 | -31.129 | 83.48 | 218.82 | 27130.61 |
| 30 | 314.8 | 10.25 | 124.83 | 1.61 | 42.42 | 34.446 | -22.235 | -31.129 | 72.52 | 291.34 | 22826.80 |
| 29 | 304.5 | 10.25 | 124.83 | 1.60 | 42.13 | 34.207 | -21.034 | -31.129 | 70.68 | 362.03 | 21522.41 |
| 28 | 294.3 | 10.25 | 124.83 | 1.59 | 41.82 | 33.961 | -21.034 | -31.129 | 70.37 | 432.39 | 20705.43 |
| 27 | 284.0 | 10.25 | 124.83 | 1.58 | 41.51 | 33.708 | -21.034 | -31.129 | 70.04 | 502.44 | 19892.40 |
| 26 | 273.8 | 10.25 | 124.83 | 1.57 | 41.19 | 33.449 | -21.034 | -31.129 | 69.71 | 572.15 | 19083.43 |
| 25 | 263.5 | 10.25 | 124.83 | 1.55 | 40.86 | 33.181 | -21.034 | -31.129 | 69.37 | 641.52 | 18278.65 |
| 24 | 253.3 | 10.25 | 132.08 | 1.54 | 40.52 | 32.905 | -21.568 | -31.129 | 73.75 | 715.26 | 18676.26 |
| 23 | 243.0 | 10.25 | 132.08 | 1.53 | 40.17 | 32.620 | -20.678 | -31.129 | 72.16 | 787.42 | 17534.02 |
| 22 | 232.8 | 10.25 | 132.08 | 1.51 | 39.81 | 32.325 | -20.678 | -31.129 | 71.76 | 859.18 | 16701.58 |
| 21 | 222.5 | 10.25 | 132.08 | 1.50 | 39.43 | 32.020 | -20.678 | -31.129 | 71.34 | 930.52 | 15874.18 |
| 20 | 212.3 | 10.25 | 132.08 | 1.48 | 39.04 | 31.704 | -20.678 | -31.129 | 70.92 | 1001.44 | 15051.99 |
| 19 | 202.0 | 10.25 | 132.08 | 1.47 | 38.64 | 31.375 | -20.678 | -31.129 | 70.47 | 1071.91 | 14235.22 |
| 18 | 191.8 | 10.25 | 132.08 | 1.45 | 38.22 | 31.033 | -20.678 | -31.129 | 70.01 | 1141.92 | 13424.09 |
| 17 | 181.5 | 10.25 | 132.08 | 1.44 | 37.78 | 30.676 | -20.678 | -31.129 | 69.53 | 1211.44 | 12618.82 |
| 16 | 171.3 | 10.25 | 132.08 | 1.42 | 37.32 | 30.303 | -20.678 | -31.129 | 69.02 | 1280.46 | 11819.68 |
| 15 | 161.0 | 10.25 | 132.08 | 1.40 | 36.84 | 29.912 | -20.678 | -31.129 | 68.49 | 1348.95 | 11026.95 |
| 14 | 150.8 | 10.25 | 132.08 | 1.38 | 36.33 | 29.501 | -20.678 | -31.129 | 67.93 | 1416.89 | 10240.97 |
| 13 | 140.5 | 10.25 | 132.08 | 1.36 | 35.80 | 29.067 | -20.678 | -31.129 | 67.35 | 1484.23 | 9462.08 |
| 12 | 130.3 | 10.25 | 132.08 | 1.34 | 35.23 | 28.607 | -20.678 | -31.129 | 66.72 | 1550.95 | 8690.69 |
| 11 | 120.0 | 10.25 | 132.08 | 1.32 | 34.63 | 28.117 | -20.678 | -31.129 | 66.06 | 1617.02 | 7927.27 |
| 10 | 109.8 | 10.25 | 132.08 | 1.29 | 33.98 | 27.594 | -20.678 | -31.129 | 65.35 | 1682.37 | 7172.36 |
| 9 | 99.5 | 10.25 | 132.08 | 1.27 | 33.29 | 27.030 | -20.678 | -31.129 | 64.59 | 1746.96 | 6426.56 |
| 8 | 89.3 | 10.25 | 132.08 | 1.24 | 32.53 | 26.418 | -20.678 | -31.129 | 69.20 | 1816.16 | 6176.41 |
| 7 | 77.3 | 12.00 | 132.08 | 1.20 | 31.56 | 25.627 | -20.678 | -31.129 | 68.04 | 1884.20 | 5256.19 |
| 6 | 67.0 | 10.25 | 132.08 | 1.17 | 30.63 | 24.871 | -20.678 | -31.129 | 61.67 | 1945.87 | 4131.58 |
| 5 | 56.8 | 10.25 | 132.08 | 1.13 | 29.58 | 24.016 | -20.678 | -31.129 | 60.51 | 2006.37 | 3433.87 |
| 4 | 46.5 | 10.25 | 132.08 | 1.08 | 28.36 | 23.030 | -20.678 | -31.129 | 59.17 | 2065.55 | 2751.56 |
| 3 | 36.3 | 10.25 | 132.08 | 1.03 | 26.91 | 21.854 | -20.678 | -31.129 | 57.58 | 2123.13 | 2087.31 |
| 2 | 26.0 | 10.25 | 132.08 | 0.96 | 25.09 | 20.377 | -20.678 | -31.129 | 57.62 | 2180.74 | 1497.99 |
| 1 | 15.0 | 11.00 | 132.08 | 0.85 | 22.35 | 18.149 | -20.678 | -31.129 | 66.67 | 2247.41 | 1000.02 |
| SOG | 0.0 | 15.00 | 132.08 | 0.00 | 22.38 | 18.173 | -20.678 | -31.129 | 0 | 2247.41 | 0.00 |
| **TOTAL** | **366.9** | | | | | | | | **2247.41** | | **419761.3** |

*East – West Results*

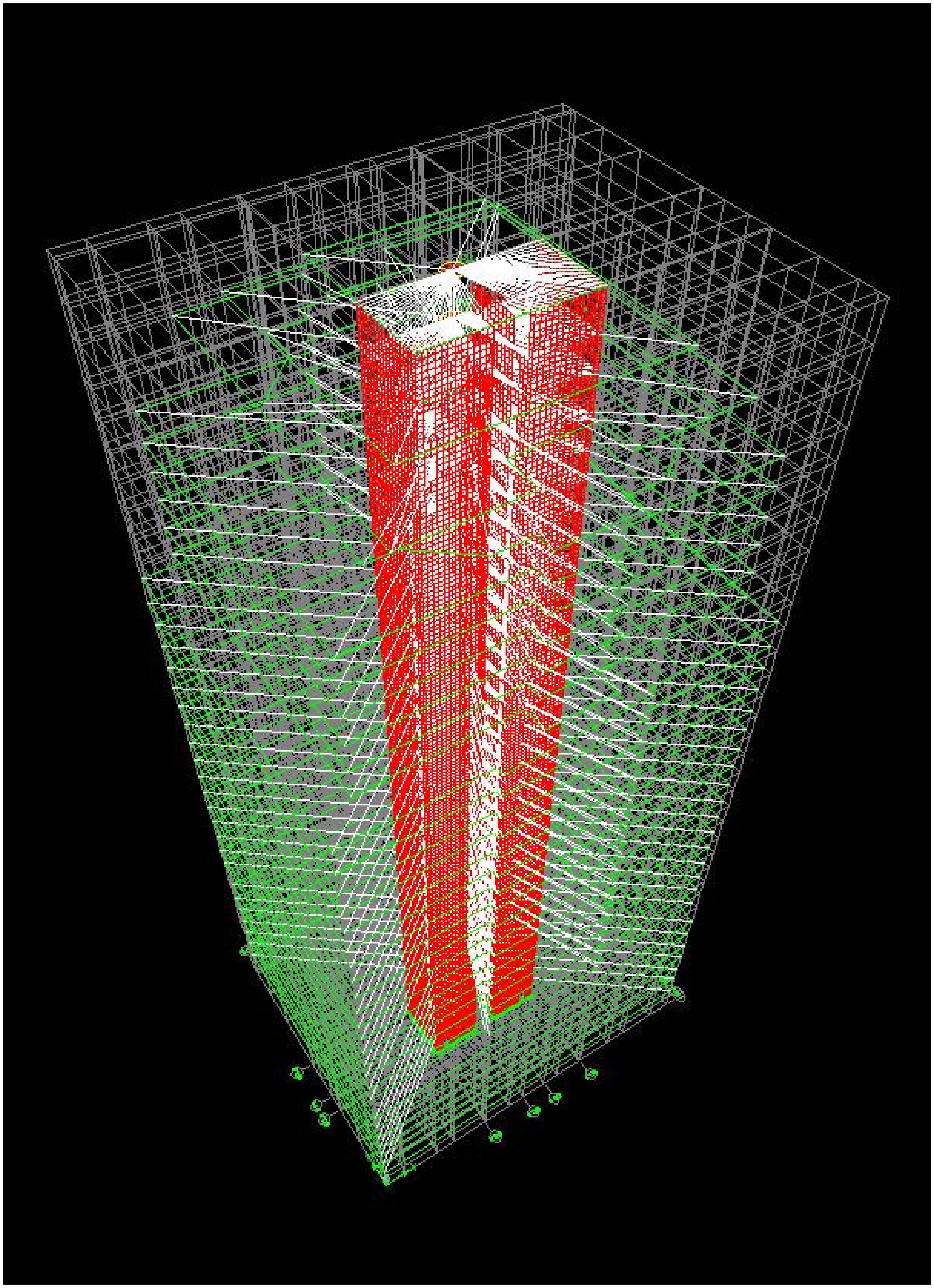
| Story | $h_x$ (ft) | Floor Height | Perimeter (ft) | $K_z$ | $q_z$ | E-W Windward | E-W Leeward | E-W Side Wall | Load (kip) | Shear (kip) | Moment (kip-ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Spire | 366.90 | 0.00 | 56.00 | 1.66 | 43.81 | 35.295 | -22.060 | -30.884 | 13.09 | 13.09 | 4802.15 |
| 34 | 358.75 | 8.15 | 56.00 | 1.66 | 43.61 | 35.129 | -22.060 | -30.884 | 29.46 | 42.55 | 10570.05 |
| 33 | 348.50 | 10.25 | 56.00 | 1.65 | 43.34 | 34.915 | -22.060 | -30.884 | 32.70 | 75.26 | 11397.19 |
| 32 | 338.25 | 10.25 | 88.50 | 1.64 | 43.07 | 34.696 | -22.060 | -30.884 | 59.02 | 134.27 | 19963.27 |
| 31 | 325.00 | 13.25 | 111.67 | 1.62 | 42.71 | 34.406 | -21.001 | -30.884 | 72.70 | 206.98 | 23627.57 |
| 30 | 314.75 | 10.25 | 111.67 | 1.61 | 42.42 | 34.174 | -21.001 | -30.884 | 63.15 | 270.13 | 19877.89 |
| 29 | 304.50 | 10.25 | 141.67 | 1.60 | 42.13 | 33.937 | -22.060 | -30.884 | 81.31 | 351.44 | 24760.07 |
| 28 | 294.25 | 10.25 | 141.67 | 1.59 | 41.82 | 33.693 | -22.060 | -30.884 | 80.96 | 432.40 | 23822.44 |
| 27 | 284.00 | 10.25 | 141.67 | 1.58 | 41.51 | 33.443 | -22.060 | -30.884 | 80.60 | 513.00 | 22889.27 |
| 26 | 273.75 | 10.25 | 141.67 | 1.56 | 41.19 | 33.185 | -22.060 | -30.884 | 80.22 | 593.22 | 21960.68 |
| 25 | 263.50 | 10.25 | 141.67 | 1.55 | 40.86 | 32.919 | -22.060 | -30.884 | 79.84 | 673.06 | 21036.80 |
| 24 | 253.25 | 10.25 | 141.67 | 1.54 | 40.52 | 32.646 | -22.060 | -30.884 | 79.44 | 752.50 | 20117.78 |
| 23 | 243.00 | 10.25 | 155.25 | 1.53 | 40.17 | 32.363 | -22.060 | -30.884 | 86.60 | 839.10 | 21044.59 |
| 22 | 232.75 | 10.25 | 155.25 | 1.51 | 39.81 | 32.071 | -22.060 | -30.884 | 86.14 | 925.24 | 20048.64 |
| 21 | 222.50 | 10.25 | 155.25 | 1.50 | 39.43 | 31.768 | -22.060 | -30.884 | 85.66 | 1010.89 | 19058.57 |
| 20 | 212.25 | 10.25 | 155.25 | 1.48 | 39.04 | 31.454 | -22.060 | -30.884 | 85.16 | 1096.05 | 18074.58 |
| 19 | 202.00 | 10.25 | 155.25 | 1.47 | 38.64 | 31.128 | -22.060 | -30.884 | 84.64 | 1180.69 | 17096.91 |
| 18 | 191.75 | 10.25 | 155.25 | 1.45 | 38.22 | 30.789 | -22.060 | -30.884 | 84.10 | 1264.79 | 16125.81 |
| 17 | 181.50 | 10.25 | 155.25 | 1.43 | 37.78 | 30.435 | -22.060 | -30.884 | 83.53 | 1348.32 | 15161.55 |
| 16 | 171.25 | 10.25 | 155.25 | 1.42 | 37.32 | 30.064 | -22.060 | -30.884 | 82.95 | 1431.27 | 14204.44 |
| 15 | 161.00 | 10.25 | 155.25 | 1.40 | 36.84 | 29.676 | -22.060 | -30.884 | 82.33 | 1513.59 | 13254.81 |
| 14 | 150.75 | 10.25 | 155.25 | 1.38 | 36.33 | 29.268 | -22.060 | -30.884 | 81.68 | 1595.27 | 12313.03 |
| 13 | 140.50 | 10.25 | 155.25 | 1.36 | 35.80 | 28.837 | -22.060 | -30.884 | 80.99 | 1676.27 | 11379.54 |
| 12 | 130.25 | 10.25 | 155.25 | 1.34 | 35.23 | 28.381 | -22.060 | -30.884 | 80.27 | 1756.53 | 10454.79 |
| 11 | 120.00 | 10.25 | 155.25 | 1.32 | 34.63 | 27.896 | -22.060 | -30.884 | 79.49 | 1836.03 | 9539.34 |
| 10 | 109.75 | 10.25 | 155.25 | 1.29 | 33.98 | 27.376 | -22.060 | -30.884 | 78.67 | 1914.70 | 8633.80 |
| 9 | 99.50 | 10.25 | 155.25 | 1.26 | 33.29 | 26.817 | -22.060 | -30.884 | 77.78 | 1992.47 | 7738.90 |
| 8 | 89.25 | 10.25 | 155.25 | 1.24 | 32.53 | 26.210 | -22.060 | -30.884 | 83.37 | 2075.84 | 7440.72 |
| 7 | 77.25 | 12.00 | 155.25 | 1.20 | 31.56 | 25.425 | -22.060 | -30.884 | 82.01 | 2157.86 | 6335.58 |
| 6 | 67.00 | 10.25 | 155.25 | 1.16 | 30.63 | 24.675 | -22.060 | -30.884 | 74.37 | 2232.23 | 4982.71 |
| 5 | 56.75 | 10.25 | 155.25 | 1.12 | 29.58 | 23.827 | -22.060 | -30.884 | 73.02 | 2305.25 | 4143.89 |
| 4 | 46.50 | 10.25 | 155.25 | 1.08 | 28.36 | 22.848 | -22.060 | -30.884 | 71.46 | 2376.71 | 3323.02 |
| 3 | 36.25 | 10.25 | 155.25 | 1.02 | 26.91 | 21.682 | -22.060 | -30.884 | 69.61 | 2446.31 | 2523.21 |
| 2 | 26.00 | 10.25 | 155.25 | 0.95 | 25.09 | 20.216 | -22.060 | -30.884 | 69.74 | 2516.05 | 1813.13 |
| 1 | 15.00 | 11.00 | 155.25 | 0.85 | 22.35 | 18.006 | -22.060 | -30.884 | 80.86 | 2596.91 | 1212.93 |
| SOG | 0.00 | 15.00 | 155.25 | 0.85 | 22.38 | 18.029 | -22.060 | -30.884 | 0 | 2596.91 | 0.00 |
| **TOTAL** | **366.90** | | | | | | | | **2596.91** | | **470729.6** |

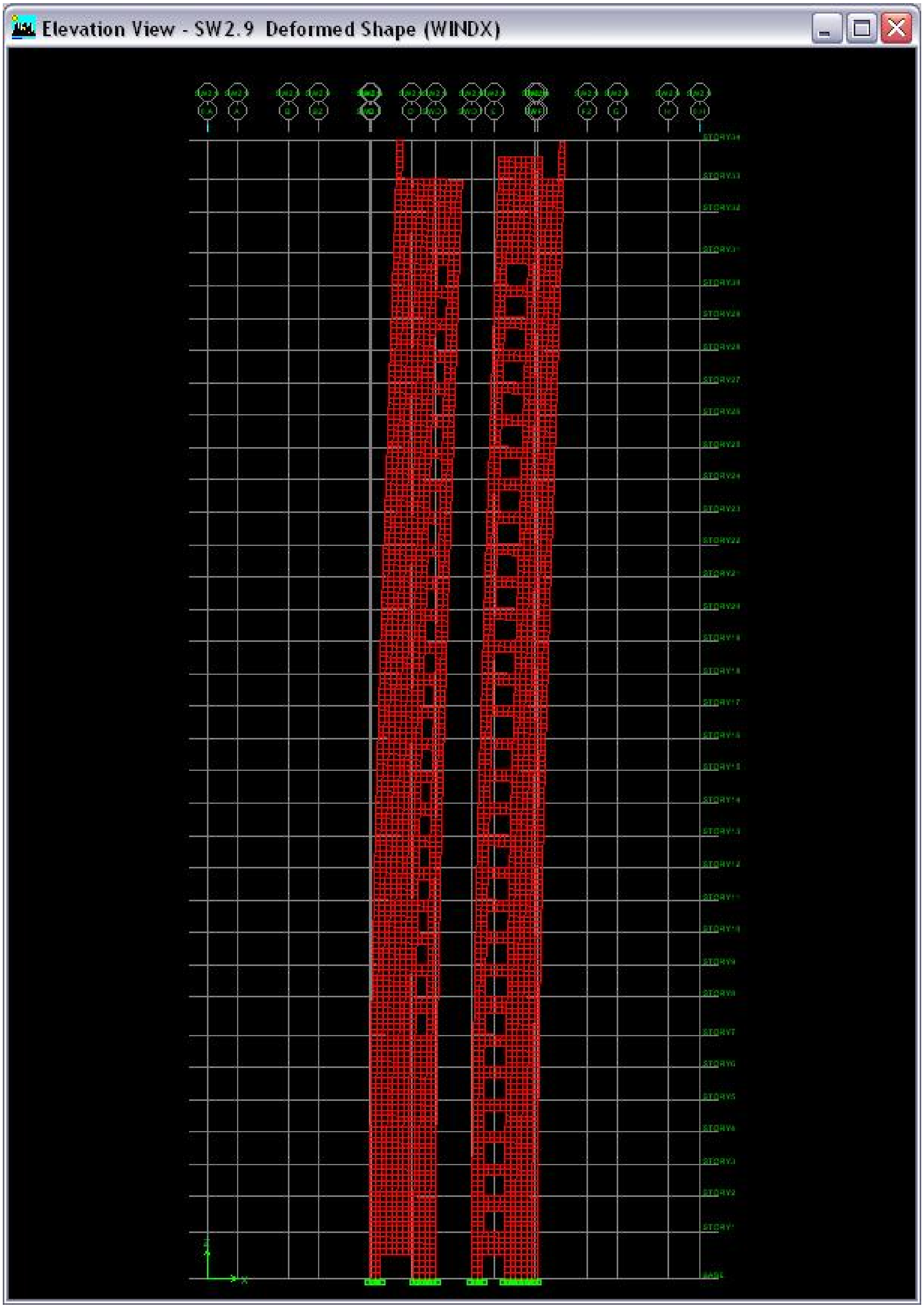
## appendix c • seismic

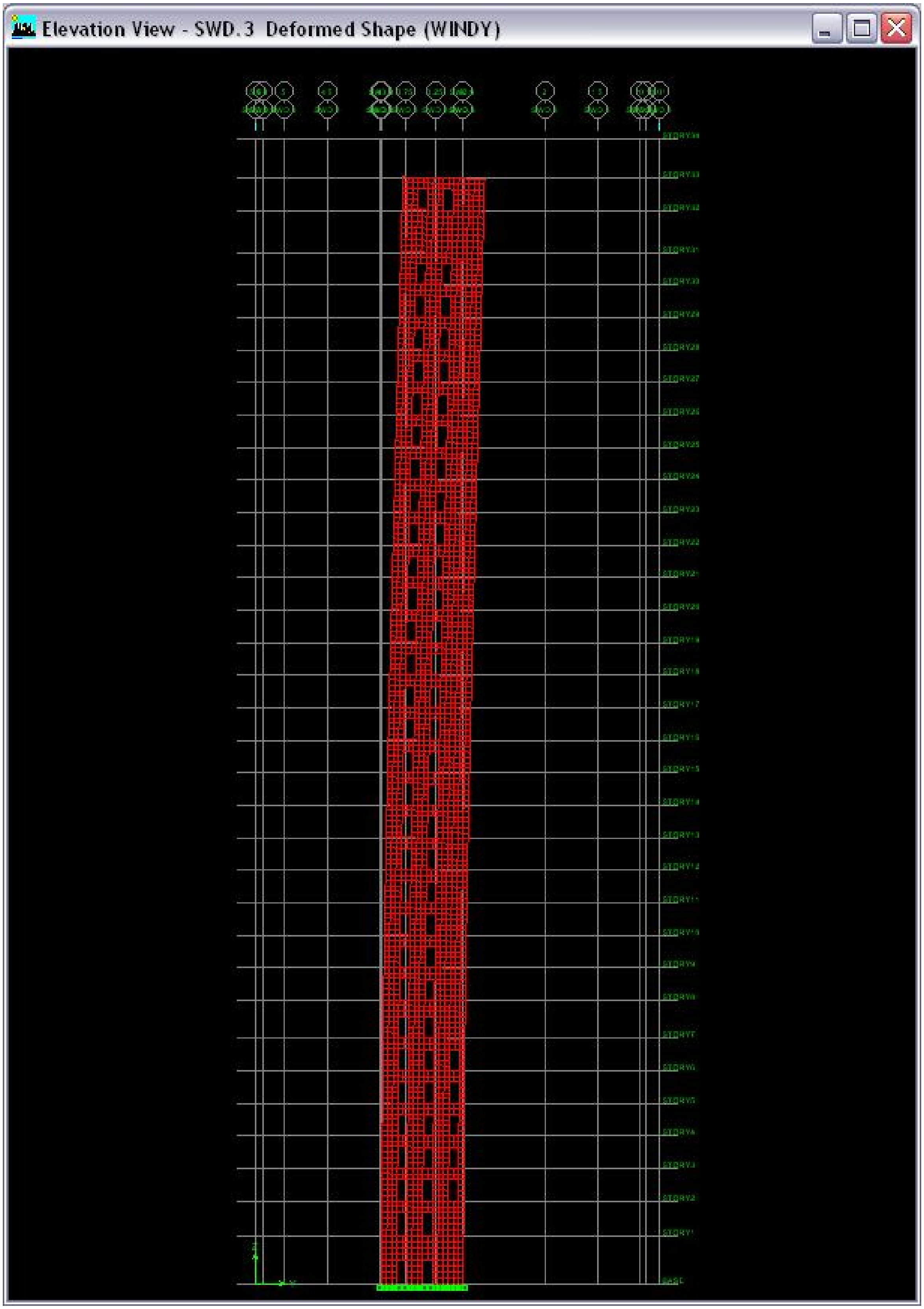
| Input | Value | Source |
|---|---|---|
| Occupancy Category | II | ASCE 7-05 |
| Importance Factor | 1.0 | ASCE 7-05 |
| Soil Site Class | D | Geotech Report |
| Seismic Design Category | B | ASCE 7-05 |
| $S_S$ | 0.118 | USGS.gov |
| $S_1$ | 0.048 | USGS.gov |
| Fa | 1.6 | ASCE 7-05, Tbl 11.4-1 |
| Fv | 2.4 | ASCE 7-05, Tbl 11.4-2 |
| $S_{DS}$ | 0.126 | ASCE 7-05 |
| $S_{D1}$ | 0.077 | ASCE 7-05 |
| R | 5 | ASCE 7-05, Tbl 12.2-1 |
| $h_n$ | 361.25 | |
| $C_t$ | 0.02 | ASCE 7-05, Tbl 12.8-2 |
| x | 0.75 | ASCE 7-05, Tbl 12.8-2 |
| $T_a$ | 1.66 | |
| $C_u$ | 1.7 | ASCE 7-05, Tbl 12.8-1 |
| T | 2.82 | |
| $T_L$ | 8 | ASCE 7-05, Fig 22-15 |
| $C_S$ | 0.01 | ASCE 7-05, Eq 12.8-5 |
| k | 2 | ASCE 7-05, Sec 12.8.3 |
| $V_b$ | **845.1 k** | |

| Story | $h_x$ (ft) | Floor Height | Floor Load $W_x$ (kip) | $h_x^kW_x$ | $C_{vx}$ | $F_x = C_{vx}V$ | $V_x$ (kips) | Mx (ft.-k) |
|---|---|---|---|---|---|---|---|---|
| Spire (btm) | 367.41 | 0.00 | 83.0 | 1.1204E+07 | 0.00360 | 3.04 | 3.04 | 1116.92 |
| 34 | 361.25 | 6.16 | 582.7 | 7.6045E+07 | 0.02441 | 20.63 | 23.67 | 7453.62 |
| 33 | 349.00 | 12.25 | 1088.4 | 1.3257E+08 | 0.04255 | 35.97 | 59.64 | 12553.25 |
| 32 | 338.75 | 10.25 | 1882.0 | 2.1596E+08 | 0.06932 | 58.59 | 118.24 | 19849.05 |
| 31 | 325.50 | 13.25 | 1563.3 | 1.6563E+08 | 0.05317 | 44.94 | 163.18 | 14628.06 |
| 30 | 315.25 | 10.25 | 2050.8 | 2.0381E+08 | 0.06542 | 55.30 | 218.48 | 17433.31 |
| 29 | 305.00 | 10.25 | 2111.2 | 1.9640E+08 | 0.06304 | 53.29 | 271.76 | 16252.73 |
| 28 | 294.75 | 10.25 | 2148.5 | 1.8666E+08 | 0.05992 | 50.65 | 322.41 | 14927.82 |
| 27 | 284.50 | 10.25 | 2166.2 | 1.7533E+08 | 0.05628 | 47.57 | 369.98 | 13534.33 |
| 26 | 274.25 | 10.25 | 2166.2 | 1.6293E+08 | 0.05230 | 44.21 | 414.19 | 12123.55 |
| 25 | 264.00 | 10.25 | 2197.0 | 1.5312E+08 | 0.04915 | 41.55 | 455.74 | 10968.15 |
| 24 | 253.75 | 10.25 | 2540.4 | 1.6357E+08 | 0.05251 | 44.38 | 500.12 | 11261.90 |
| 23 | 243.50 | 10.25 | 2518.0 | 1.4930E+08 | 0.04792 | 40.51 | 540.63 | 9863.79 |
| 22 | 233.25 | 10.25 | 2518.0 | 1.3699E+08 | 0.04397 | 37.17 | 577.80 | 8669.86 |
| 21 | 223.00 | 10.25 | 2518.0 | 1.2522E+08 | 0.04019 | 33.97 | 611.77 | 7576.38 |
| 20 | 212.75 | 10.25 | 2518.0 | 1.1397E+08 | 0.03658 | 30.92 | 642.69 | 6578.94 |
| 19 | 202.50 | 10.25 | 2518.0 | 1.0325E+08 | 0.03314 | 28.02 | 670.71 | 5673.12 |
| 18 | 192.25 | 10.25 | 2518.0 | 9.3065E+07 | 0.02987 | 25.25 | 695.96 | 4854.52 |
| 17 | 182.00 | 10.25 | 2518.0 | 8.3406E+07 | 0.02677 | 22.63 | 718.59 | 4118.71 |
| 16 | 171.75 | 10.25 | 2518.0 | 7.4276E+07 | 0.02384 | 20.15 | 738.74 | 3461.28 |
| 15 | 161.50 | 10.25 | 2518.0 | 6.5675E+07 | 0.02108 | 17.82 | 756.56 | 2877.83 |
| 14 | 151.25 | 10.25 | 2518.0 | 5.7603E+07 | 0.01849 | 15.63 | 772.19 | 2363.92 |
| 13 | 141.00 | 10.25 | 2527.2 | 5.0243E+07 | 0.01613 | 13.63 | 785.82 | 1922.15 |
| 12 | 130.75 | 10.25 | 2527.2 | 4.3204E+07 | 0.01387 | 11.72 | 797.55 | 1532.70 |
| 11 | 120.50 | 10.25 | 2691.0 | 3.9074E+07 | 0.01254 | 10.60 | 808.15 | 1277.52 |
| 10 | 110.25 | 10.25 | 2691.0 | 3.2709E+07 | 0.01050 | 8.87 | 817.02 | 978.46 |
| 9 | 100.00 | 10.25 | 2691.0 | 2.6910E+07 | 0.00864 | 7.30 | 824.32 | 730.14 |
| 8 | 89.75 | 10.25 | 2691.0 | 2.1676E+07 | 0.00696 | 5.88 | 830.21 | 527.85 |
| 7 | 77.75 | 12.00 | 2829.1 | 1.7102E+07 | 0.00549 | 4.64 | 834.85 | 360.78 |
| 6 | 67.50 | 10.25 | 3118.7 | 1.4210E+07 | 0.00456 | 3.86 | 838.70 | 260.24 |
| 5 | 57.25 | 10.25 | 3118.7 | 1.0222E+07 | 0.00328 | 2.77 | 841.47 | 158.78 |
| 4 | 47.00 | 10.25 | 3118.7 | 6.8892E+06 | 0.00221 | 1.87 | 843.34 | 87.85 |
| 3 | 36.75 | 10.25 | 3118.7 | 4.2120E+06 | 0.00135 | 1.14 | 844.49 | 42.00 |
| 2 | 26.50 | 10.25 | 3118.7 | 2.1901E+06 | 0.00070 | 0.59 | 845.08 | 15.75 |
| 1 | 15.50 | 11.00 | 3050.8 | 7.3295E+05 | 0.00024 | 0.20 | 845.28 | 3.08 |
| SOG | 0.00 | 15.50 | 1476.5 | 0.0000E+00 | 0.00000 | 0.00 | 845.28 | 0.00 |
| **TOTAL** | **367.41** | | **84528.0** | **3.1154E+09** | **1.00000** | **845.28** | | **216038.3** |

## appendix d • etabs model



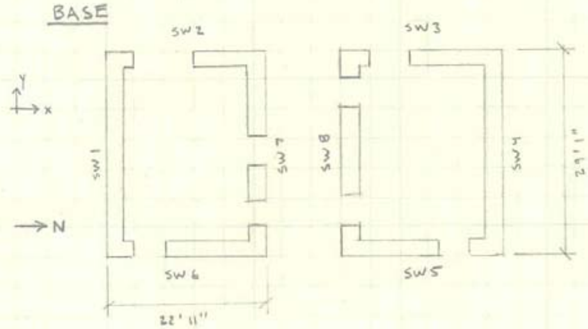

Elevation View - SW2.9 Deformed Shape (WINDX)


Elevation View - SWD.3 Deformed Shape (WINDY)

## appendix e • spot checks

SPOT CHECK | GRANBY TOWER | SHEAR WALL | 1

BASE




$f'_c = 8000$ psi
$f_y = 60000$ psi

$w = 24"$
$h = 15$ ft

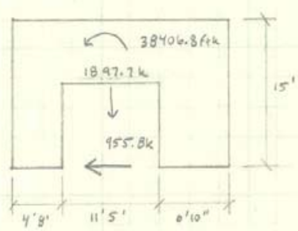
VERT REINF = #10 @ 6" o.c.
HORIZ REINF = #6 @ 6" o.c.
END REINF = 10 - #10

CHECK SHEAR WALL CAPACITIES

- USE LOADS DETERMINED THROUGH SECTION CUTS IN ETABS

  * NOTE: SINCE MODELED SHEAR WALLS AS MEMBRANE ELEMENTS, ASSUME NO OUT OF PLANE FORCES (CONSERVATIVE)

- SW 2 [WORST CASE FOR WIND X $(1.2D + 1.6W + 1L)$]




NOMINAL SHEAR CAPACITY

$V_n \le 8A_{cv}\sqrt{f'_c} = 8(24")(4'8" + 6'10")(12"/')\sqrt{8000}\left(\frac{1}{1000}\right) = 2369.87\text{ k}$

$\phi V_n = 0.6(2369.87\text{ k}) = 1421.82\text{ k} > V_u = 955\text{ k}$ OK

LONGITUDINAL AND TRANSVERSE REINFORCEMENT

$V_n \ge 2A_{cv}\sqrt{f'_c} = \frac{1}{4}(2369.87) = 592.5\text{ k}$

$V_u = 955\text{k} > V_n = 592.5\text{k}$ $\boxed{\therefore \text{ 2 CURTAINS NEEDED}}$

REQUIRED $\rho_\ell = 0.0015$, $\rho_n = 0.0025$

SPOT CHECK | GRANBY TOWER | SHEAR WALL | 2

$A_{SV} = 0.0015\,(24)(12) = 0.43\ in^2/ft \rightarrow$ NEED #6 @ 18" SPACING $(A_S = 0.58\ in^2/ft)$

$A_{SH} = 0.0025\,(24)(12) = 0.72\ in^2/ft^2 \rightarrow$ NEED #6 @ 12" SPACING $(A_S = 0.88^2/ft)$

$\boxed{\text{DESIGN REINFORCEMENT ADEQUATE}}$

CHECK NEED FOR BOUNDARY ELEMENT

$P_{u\,BE} = \frac{1}{2}P + M_u\left(\frac{1}{l_w - b/2}\right) = \frac{1}{2}(1847.7\,k) + 38406.8\,ft\,k\left(\frac{1}{23' - 2'}\right) = 2777.75\ k$

$A_g = 2(4'8" + 6'10") = 23\ ft^2$

$I_g = \frac{1}{12}(2)\left[(4'8")^3 + (6'10")^3\right] = 70.1\ ft^4$

$f_c = P_u/A_g + M_u(h_w/2)/I_g = \left(\left(2777.8\,k/23\,ft^2\right) + \left(38406.8\,ft\,k\,(21/2)/70.1\right)\right)\left(\frac{1}{144}\right) = 44.4\ ksi$

$f_c = 44.4\ ksi > 0.2\,f'_c = 1.6\ ksi$ $\boxed{\therefore \text{ BOUNDARY ELEMENT NEEDED}}$

BOUNDARY ELEMENT CAPACITY

CHECK DESIGN [10 - #10 IN LAST 2' OF SW]

$A_s = 10\,(1.27) = 12.7\ in^2$

$\rho_s = 12.7\ in^2/(24)(24) = 0.022 > \rho_{min} = 0.01$ ; $< \rho_{max} = 0.06$

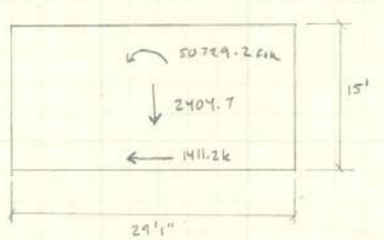
$\phi P_n = 0.8\,\phi\left[0.85\,f'_c\,(A_g - A_{st}) + f_y\,A_{st}\right]$

$= 0.8(0.9)\left[0.85(8\,ksi)(563.3) + 60\,ksi\,(12.7)\right] = 3306.6\ k$

$\phi P_n = 3306.6\ k > P_{u\,BE} = 2777.75\ k$ OK ✓

$\boxed{\text{SHEAR WALL 2 ADEQUATE FOR DESIGN LOADS AT BASE}}$

• SW 4 [WORST CASE FOR WIND Y (1.2D + 1.6W + 1L)]



CHECK NEED FOR BOUNDARY ELEMENT

$P_{uBE} = \frac{1}{2}P + M_u\left(\frac{1}{l_w - b/2}\right) = \frac{1}{2}(2409.7\text{ k}) + 50729.2\text{ ft k}\left(\frac{1}{29-2}\right) = 3081.2\text{ k}$

$A_g = 2(29') = 58\text{ ft}^2$

$I_g = \frac{1}{12}(2)(29)^3 = 4064.8\text{ ft}^4$

$f_c = P_u/A_g + M_u(h_w/2)/I_g = \left(\left(3081.2/58\right) + \frac{50729.2(14.5)}{4064.8\text{ ft}^2}\right)\left(\frac{1}{144}\right) = 1.63\text{ ksi}$

$f_c = 1.63\text{ ksi} > 0.2f'_c = 1.6\text{ ksi}$ $\boxed{\therefore \text{ BOUNDARY ELEMENT NEEDED}}$

LONGITUDINAL AND TRANSVERSE REINFORCEMENT

$V_n \geq 2A_{cv}\sqrt{f'_c} = 2(24")(29')(12"/') \sqrt{8000} = 1494.1\text{ k}$

$V_u = 1411.2\text{ k} \not> V_n = 1494.1\text{ k}$ $\boxed{\therefore \text{ ONLY 1 CURTAIN NEEDED, USE 2 FOR CONSISTENCY}}$

REQUIRED $\rho_\ell = 0.0015$, $\rho_h = 0.0025$

$\boxed{\therefore \text{ DESIGN REINFORCEMENT ADEQUATE}}$ (SEE PREVIOUS)

NOMINAL SHEAR CAPACITY

$V_n = A_{cv}(\alpha_c\sqrt{f'_c} + \rho f_y)$

$\alpha_c = h_w/l_w = (367')\left(\frac{1}{29'}\right) = 12.7 > 2 \rightarrow \alpha_c = 2$

$A_{cv} = 24(29)(12"/') = 8352\text{ in}^2$

$V_n = 8352\text{ in}^2\left(2\sqrt{8000} + \frac{0.88}{(24)(12)}(60000)\right) = 3025.25\text{ k}$

$\phi V_n = 0.6(3025.25\text{ k}) = 1815.5\text{ k} > V_u = 1411.2\text{ k}$

BOUNDARY ELEMENT CAPACITY

CHECK DESIGN [10 - #10 IN LAST 2' OF SW]

$A_s = 10(1.27\text{ in}^2) = 12.7\text{ in}^2 \rightarrow \rho_s = 0.022 > \rho_{min} = 0.01$ ; $< \rho_{max} = 0.06$

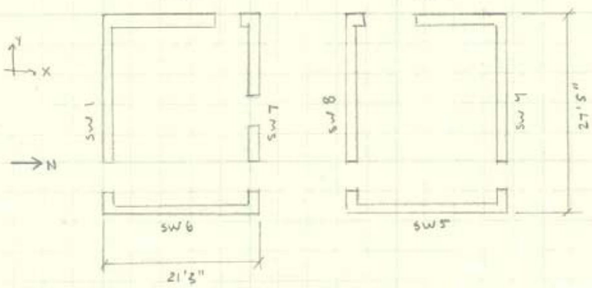
$\phi P_n = 0.8(0.9)\left[0.85(8\text{ ksi})(563.5) + 60\text{ ksi}(12.7)\right] = 3306.6\text{ k}$

$\phi P_n = 3306.6\text{ k} > P_{uBE} = 3081.2\text{ k}$ OK

$\boxed{\text{SHEAR WALL 4 (BASE) ADEQUATE FOR DESIGN LOADS}}$

SPOT CHECK | GRANBY TOWER | SHEAR WALL | 4

LEVEL 7

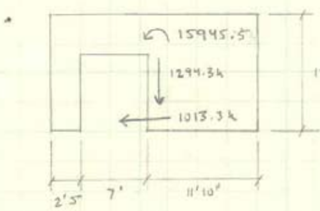



$f'_c = 6000$ psi
$f_y = 60000$ psi

$w = 14"$
$h = 12'$

VERT REINF = #9 @ 6"
HORIZ REINF = #5 @ 6"
END REINF = 10-#9

• SW 3 [WORST CASE FOR WIND X (1.2D + 1.6W + 1L)]




NOMINAL SHEAR CAPACITY

$V_n \le 8 A_{cv}\sqrt{f'_c} = 8(14")(2'5" + 11'10")(12"/') \sqrt{6000} = 1483.5$ k

$\phi V_n = 0.6(1483.5\text{ k}) = 890.1\text{ k} \not> V_u = 1013.3$ k    NO GOOD [CONTINUE CHECK]

LONGITUDINAL AND TRANSVERSE REINFORCEMENT

$V_n \ge 2 A_{cv}\sqrt{f'_c} = \frac{1}{4}(1483.5\text{ k}) = 222.5$ k

$V_u = 1013.3\text{ k} > V_n = 222.5$ k    $\boxed{\therefore \text{ 2 CURTAINS NEEDED}}$

REQUIRED $\rho_L = 0.0015$, $\rho_n = 0.0025$

$A_{sv} = 0.0015(14)(12) = 0.25\text{ in}^2/\text{ft}$ → NEED #5 @ 18" SPACING ($A_s = 0.41\text{ in}^2/\text{ft}$)

$A_{sh} = 0.0025(14)(12) = 0.42\text{ in}^2/\text{ft}$ → NEED #5 @ 12" SPACING ($A_s = 0.62\text{ in}^2/\text{ft}$)

$\boxed{\text{DESIGN REINFORCEMENT IS ADEQUATE}}$

SPOT CHECK | GRANBY TOWER | SHEAR WALL | 5

CHECK NEED FOR BOUNDARY ELEMENTS.

$P_{UBE} = \frac{1}{2}(1294.3k) + 15945.5\ ft\ k\left(\frac{1}{21.25-2}\right) = 1476k$

$A_g = \frac{14}{12}(2'5" + 11'10") = 16.6\ ft^2$

$I_g = \frac{1}{12}\left(\frac{14}{12}\right)\left((2'5")^3 + (11'10")^3\right) = 162.5\ ft^4$

$f_c = \left(1476k/16.6\ ft^2 + \frac{15845.5(21.25/2)}{162.5}\right)\left(\frac{1}{144}\right) = 7.86\ ksi$

$f_c = 7.86\ ksi > 0.2 f'_c = 1.2\ ksi$ $\boxed{\therefore \text{ BOUNDARY ELEMENT NEEDED}}$

BOUNDARY ELEMENT CAPACITY

CHECK DESIGN [10 - #9 IN LAST 14" OF SW]

$A_s = 10(1.0) = 10\ in^2$

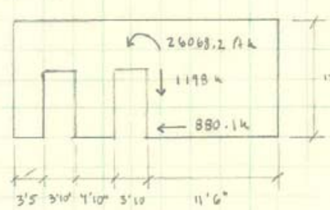
$\rho_s = 10\ in^2/(14)(14) = 0.051 > \rho_{min} = 0.01\ ; < \rho_{max} = 0.06$

$\phi P_n = 0.8(0.9)\left[0.85(6000)(186\ in^2) + 60000(10\ in^2)\right] = 1115\ k$

$\phi P_n = 1115\ k \not> P_{UBE} = 1476\ k$ NO GOOD

$\boxed{\text{MUST INCREASE BOUNDARY ELEMENT TO BECOME ADEQUATE}}$

- SW 7 [WORST CASE FOR WIND Y (1.2D + 1.6W + L)]




NOMINAL SHEAR CAPACITY

$V_n \leq 8A_{cv}\sqrt{f'_c} = 8(14")(3'5" + 4'10" + 11'6")(12"/')\sqrt{6000} = 2056.1\ k$

$\phi V_n = 0.6(2056.1\ k) = 1233.7\ k$

$\phi V_n = 1233.7\ k > V_u = 880.1\ k$ ok

SPOT CHECK | GRANBY TOWER | SHEAR WALL | 6

LONGITUDINAL AND TRANSVERSE REINFORCEMENT

$V_n \geq 2 A_{cv} \sqrt{f'_c} = \frac{1}{4}(2056.1k) = 514\ k$

$V_u = 880.1\ k > V_n = 514\ k$ $\boxed{\therefore \text{ 2 CURTAINS NEEDED}}$

$A_{sv} = 0.25\ in^2/ft \rightarrow$ NEED #5 @ 18" SPACING $(A_s = 0.41\ in^2/ft)$

$A_{sh} = 0.42\ in^2/ft \rightarrow$ NEED #5 @ 12" SPACING $(A_s = 0.62\ in^2/ft)$

$\boxed{\text{DESIGN REINFORCEMENT IS ADEQUATE}}$

CHECK NEED FOR BOUNDARY ELEMENTS

$P_{u_{BE}} = \frac{1}{2}(1198k) + 26068.2\ ft\,k \left(\frac{1}{27'5'' - 2'}\right) = 1624.6\ k$

$A_g = \frac{14}{12}(3'5'' + 4'10'' + 11'6'') = 23\ ft^2$

$I_g = \frac{1}{12}\left(\frac{14}{12}\right)\left((3'5'')^3 + (4'10'')^3 + (11'6'')^3\right) = 162.7\ ft^4$

$f_c = \left(1624.6\ k / 23\ ft^2 + 26068.2(27'5''/2) / 162.7\ ft^4\right)\left(\frac{1}{144}\right) = 15.7\ ksi$

$f_c = 15.7\ ksi > 0.2 f'_c = 1.2\ ksi$ $\boxed{\therefore \text{ BOUNDARY ELEMENT NEEDED}}$

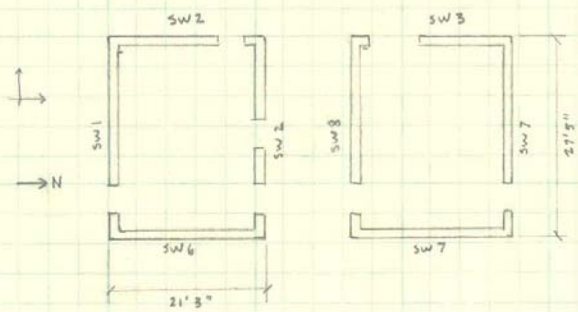
BOUNDARY ELEMENT CAPACITY

$\phi P_n = 1115\ k \not> P_{u_{BE}} = 1624.6\ k$ NO GOOD

$\boxed{\text{MUST INCREASE BOUNDARY ELEMENT CAPACITY TO BECOME ADEQUATE}}$

SPOT CHECK | GRANBY TOWER | SHEAR WALL | 7

LEVEL 24

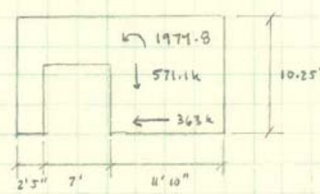



$f'_c = 5000$ psi
$f_y = 60000$ psi

$w = 14"$
$h = 10.25'$

VERT REINF = #9 @ 6" o.c
HORIZ REINF = #5 @ 6" o.c
END REINF = 10 - #9

• SW 3 [WORST CASE FOR WIND X (1.2D + 1.6W + 1L)]




NOMINAL SHEAR CAPACITY

$V_n \leq 8A_{cv}\sqrt{f'_c} = 8(14")(2'5"+4'10")(12"/')\sqrt{5000} = 1354.3\text{ k}$

$\phi V_n = 0.6(1354.3\text{ k}) = 812.6\text{ k} > V_u = 363\text{ k}$ ok✓

LONGITUDINAL AND TRANSVERSE REINFORCEMENT

$V_n \geq 2A_{cv}\sqrt{f'_c} = \frac{1}{4}(1354.3\text{ k}) = 338.6\text{ k}$

$V_u = 363.3\text{ k} > V_n = 338\text{ k}$ $\boxed{\therefore \text{ 2 CURTAINS NEEDED}}$

REQUIRED $\rho l = 0.0015$, $\rho_n = 0.0025$

$A_{sv} = 0.25\text{ in}^2/\text{ft}$ → NEED #5 @ 18" SPACING ($A_s = 0.41\text{ in}^2/\text{ft}$)

$A_{sh} = 0.42\text{ in}^2/\text{ft}$ → NEED #5 @ 12" SPACING ($A_s = 0.62\text{ in}^2/\text{ft}$)

$\boxed{\text{DESIGN REINFORCEMENT IS ADEQUATE}}$

CHECK NEED FOR BOUNDARY ELEMENT

$P_{uBE} = \frac{1}{2}(571.1k) + 1974.8\left(\frac{1}{21.25 - 2}\right) = 388.1\ K$

$A_g = \frac{14}{12}(2'5'' + 11'10'') = 16.6\ ft^2$

$I_g = \frac{1}{12}\left(\frac{14}{12}\right)\left((2'5'')^3 + (11'10'')^3\right) = 162.5$

$f_c = \left(388.1k/16.6ft^2 + \frac{1974.8\,(21.25/2)}{162.5}\right)\left(\frac{1}{144}\right) = 1.06\ ksi$

$f_c = 1.06\ ksi > 0.2 f'_c = 1\ ksi$ $\boxed{\therefore \text{ BOUNDARY ELEMENT NEEDED}}$

BOUNDARY ELEMENT CAPACITY

CHECK DESIGN [10-#9 IN LAST 14" OF SW]

$A_s = 10(1in^2) = 10in^2$

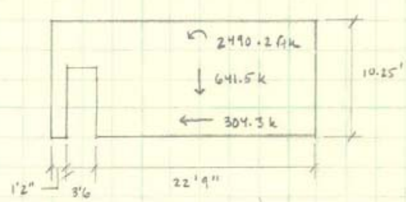
$\rho_s = 10in^2/(14)(14) = 0.051 > \rho_{min} = 0.01\ ; \ < \rho_{max} = 0.06$

$\phi P_n = 0.8(0.9)[0.85(5000)(186in^2) + 60000(10in^2)] = 1001.2\ k$

$\phi P_n = 1001.2k > P_{uBE} = 338.1\ k$ ok ✓

$\boxed{\text{SHEAR WALL 3 (LEVEL 24) ADEQUATE FOR DESIGN LOADS}}$

• SW 1 [WORST CASE FOR WIND Y (1.2 + 1.6W + 1L)]




NOMINAL SHEAR CAPACITY

$V_n = 8A_{cv}\sqrt{f'_c} = 8(14'')(1'2'' + 22'9'')(12''/1)\sqrt{5000} = 2272.9\ k$

$\phi V_n = (0.6)(2272.9k) = 1363.75\ k$

$\phi V_n = 1363.75k > V_u = 304.3\ k$ ok

SPOT CHECK | GRANBY TOWER | SHEAR WALL | 9

LONGITUDINAL AND TRANSVERSE REINFORCEMENT

$V_n \geq 2 A_{cv} \sqrt{f'_c} = \frac{1}{4}(2272.9k) = 568.2\ k$

$V_n = 568.2k > V_u = 304.2k$ $\boxed{\therefore \text{ 1 CURTAIN NEEDED, USE 2 FOR CONSISTENCY}}$

$A_{sv} = 0.25\ in^2/ft \rightarrow$ NEED #5 @ 18" SPACING $(A_s = 0.41\ in^2/ft)$

$A_{sh} = 0.42\ in^2/ft \rightarrow$ NEED #5 @ 12" SPACING $(A_s = 0.62\ in^2/ft)$

$\boxed{\text{DESIGN REINFORCEMENT ADEQUATE}}$

CHECK NEED FOR BOUNDARY ELEMENT

$P_{u\,DE} = \frac{1}{2}(641.5) + 2490.2\ ft\,k \left(\frac{1}{27'5" - 2'}\right) = 418.7\ k$

$A_g = \frac{14}{12}(1'2" + 22'9") = 27.9\ ft^2$

$I_g = \frac{1}{12}\left(\frac{14}{12}\right)\left((1'2)^3 + (22'9)^3\right) = 1144.9\ ft^4$

$f_c = \left(\frac{418.7k}{27.9\ ft^2} + \frac{2490.2\ ftk(27'5"/2)}{1144.9\ ft^4}\right)\left(\frac{1}{144}\right) = 7.59\ ksi$

$f_c = 0.31\ ksi < 0.2f'_c = 1.0\ ksi$ $\boxed{\therefore \text{NO BOUNDARY ELEMENT NEEDED}}$

$\boxed{\text{SHEAR WALL 1 (LEVEL 24) ADEQUATE FOR DESIGN LOADS}}$

## appendix f • drift

MEMBRANE 77 WINDXHI

ETABS v9.1.1 File:GRANBY TOWER MEMBRANE Units:Kip-in December 16, 2007 20:30
PAGE 1

D I S P L A C E M E N T S A N D D R I F T S AT P O I N T O B J E C T 77

| STORY | DISP-X | DISP-Y | DRIFT-X | DRIFT-Y |
|---|---|---|---|---|
| STORY34 | 12.331685 | -0.441138 | 0.003997 | 0.000048 |
| STORY33 | 11.744068 | -0.434015 | 0.003985 | 0.000041 |
| STORY32 | 11.253935 | -0.428994 | 0.003985 | 0.000040 |
| STORY31 | 10.620380 | -0.422594 | 0.003992 | 0.000053 |
| STORY30 | 10.129335 | -0.416039 | 0.003991 | 0.000060 |
| STORY29 | 9.638493 | -0.408673 | 0.003985 | 0.000066 |
| STORY28 | 9.148324 | -0.400512 | 0.003975 | 0.000073 |
| STORY27 | 8.659413 | -0.391527 | 0.003959 | 0.000080 |
| STORY26 | 8.172436 | -0.381707 | 0.003937 | 0.000087 |
| STORY25 | 7.688172 | -0.371053 | 0.003908 | 0.000093 |
| STORY24 | 7.207518 | -0.359615 | 0.003870 | 0.000097 |
| STORY23 | 6.731495 | -0.347642 | 0.003828 | 0.000103 |
| STORY22 | 6.260604 | -0.334928 | 0.003778 | 0.000109 |
| STORY21 | 5.795919 | -0.321471 | 0.003718 | 0.000115 |
| STORY20 | 5.338626 | -0.307275 | 0.003647 | 0.000121 |
| STORY19 | 4.890008 | -0.292353 | 0.003566 | 0.000127 |
| STORY18 | 4.451448 | -0.276723 | 0.003472 | 0.000133 |
| STORY17 | 4.024426 | -0.260414 | 0.003365 | 0.000138 |
| STORY16 | 3.610519 | -0.243463 | 0.003245 | 0.000143 |
| STORY15 | 3.211398 | -0.225918 | 0.003110 | 0.000147 |
| STORY14 | 2.828830 | -0.207843 | 0.002961 | 0.000151 |
| STORY13 | 2.464679 | -0.189316 | 0.002795 | 0.000153 |
| STORY12 | 2.120907 | -0.170439 | 0.002612 | 0.000155 |
| STORY11 | 1.799586 | -0.151340 | 0.002412 | 0.000156 |
| STORY10 | 1.502905 | -0.132184 | 0.002193 | 0.000154 |
| STORY9 | 1.233222 | -0.113188 | 0.001951 | 0.000150 |
| STORY8 | 0.993242 | -0.094731 | 0.001661 | 0.000137 |
| STORY7 | 0.754067 | -0.075010 | 0.001391 | 0.000107 |
| STORY6 | 0.582955 | -0.061794 | 0.001235 | 0.000103 |
| STORY5 | 0.431075 | -0.049111 | 0.001068 | 0.000097 |
| STORY4 | 0.299761 | -0.037137 | 0.000888 | 0.000090 |
| STORY3 | 0.190523 | -0.026086 | 0.000695 | 0.000080 |
| STORY2 | 0.105027 | -0.016302 | 0.000482 | 0.000063 |
| STORY1 | 0.041369 | -0.007990 | 0.000230 | 0.000044 |

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MEMBRANE 77 WINDYHI

ETABS v9.1.1 File:GRANBY TOWER MEMBRANE Units:Kip-in December 16, 2007 20:31
PAGE 1

D I S P L A C E M E N T S A N D D R I F T S AT P O I N T O B J E C T 77

| STORY | DISP-X | DISP-Y | DRIFT-X | DRIFT-Y |
|---|---|---|---|---|
| STORY34 | -0.067435 | 9.919556 | 0.000020 | 0.003136 |
| STORY33 | -0.064436 | 9.458612 | 0.000019 | 0.003135 |
| STORY32 | -0.062037 | 9.073027 | 0.000019 | 0.003135 |
| STORY31 | -0.058975 | 8.574506 | 0.000020 | 0.003138 |
| STORY30 | -0.056573 | 8.188542 | 0.000019 | 0.003140 |
| STORY29 | -0.054188 | 7.802262 | 0.000019 | 0.003140 |
| STORY28 | -0.051848 | 7.416050 | 0.000019 | 0.003136 |
| STORY27 | -0.049552 | 7.030306 | 0.000018 | 0.003128 |
| STORY26 | -0.047301 | 6.645508 | 0.000018 | 0.003116 |
| STORY25 | -0.045096 | 6.262226 | 0.000018 | 0.003098 |
| STORY24 | -0.042940 | 5.881145 | 0.000017 | 0.003073 |
| STORY23 | -0.040834 | 5.503199 | 0.000017 | 0.003045 |
| STORY22 | -0.038777 | 5.128610 | 0.000016 | 0.003012 |
| STORY21 | -0.036770 | 4.758195 | 0.000016 | 0.002970 |
| STORY20 | -0.034818 | 4.392871 | 0.000015 | 0.002921 |
| STORY19 | -0.032923 | 4.033643 | 0.000015 | 0.002862 |
| STORY18 | -0.031089 | 3.681604 | 0.000014 | 0.002794 |
| STORY17 | -0.029319 | 3.337935 | 0.000014 | 0.002716 |
| STORY16 | -0.027614 | 3.003900 | 0.000013 | 0.002626 |
| STORY15 | -0.025977 | 2.680851 | 0.000013 | 0.002525 |
| STORY14 | -0.024409 | 2.370224 | 0.000012 | 0.002412 |
| STORY13 | -0.022912 | 2.073540 | 0.000012 | 0.002286 |
| STORY12 | -0.021482 | 1.792412 | 0.000011 | 0.002145 |
| STORY11 | -0.020117 | 1.528542 | 0.000011 | 0.001990 |
| STORY10 | -0.018808 | 1.283741 | 0.000010 | 0.001819 |
| STORY9 | -0.017540 | 1.059966 | 0.000010 | 0.001630 |
| STORY8 | -0.016290 | 0.859480 | 0.000010 | 0.001398 |
| STORY7 | -0.014800 | 0.658151 | 0.000012 | 0.001178 |
| STORY6 | -0.013265 | 0.513196 | 0.000014 | 0.001057 |
| STORY5 | -0.011488 | 0.383229 | 0.000016 | 0.000925 |
| STORY4 | -0.009548 | 0.269445 | 0.000017 | 0.000783 |
| STORY3 | -0.007443 | 0.173172 | 0.000019 | 0.000628 |
| STORY2 | -0.005156 | 0.095982 | 0.000019 | 0.000448 |
| STORY1 | -0.002658 | 0.036849 | 0.000015 | 0.000205 |

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MEMBRANE 77 SEISMICX

ETABS v9.1.1 File:GRANBY TOWER MEMBRANE Units:Kip-in December 20, 2007 12:55
PAGE 1

D I S P L A C E M E N T S A N D D R I F T S AT P O I N T O B J E C T 77

| STORY | DISP-X | DISP-Y | DRIFT-X | DRIFT-Y |
|---|---|---|---|---|
| STORY34 | 7.264000 | -0.326992 | 0.002437 | 0.000035 |
| STORY33 | 6.905798 | -0.321904 | 0.002428 | 0.000030 |
| STORY32 | 6.607189 | -0.318217 | 0.002428 | 0.000030 |
| STORY31 | 6.221213 | -0.313389 | 0.002433 | 0.000042 |
| STORY30 | 5.922013 | -0.308273 | 0.002431 | 0.000048 |
| STORY29 | 5.623001 | -0.302341 | 0.002426 | 0.000055 |
| STORY28 | 5.324594 | -0.295621 | 0.002417 | 0.000061 |
| STORY27 | 5.027242 | -0.288119 | 0.002405 | 0.000067 |
| STORY26 | 4.731464 | -0.279854 | 0.002387 | 0.000073 |
| STORY25 | 4.437851 | -0.270864 | 0.002364 | 0.000079 |
| STORY24 | 4.147073 | -0.261203 | 0.002335 | 0.000082 |
| STORY23 | 3.859820 | -0.251132 | 0.002304 | 0.000087 |
| STORY22 | 3.576466 | -0.240479 | 0.002266 | 0.000091 |
| STORY21 | 3.297769 | -0.229277 | 0.002221 | 0.000095 |
| STORY20 | 3.024542 | -0.217565 | 0.002170 | 0.000099 |
| STORY19 | 2.757642 | -0.205388 | 0.002111 | 0.000102 |
| STORY18 | 2.497971 | -0.192798 | 0.002045 | 0.000105 |
| STORY17 | 2.246468 | -0.179846 | 0.001970 | 0.000108 |
| STORY16 | 2.004106 | -0.166594 | 0.001888 | 0.000110 |
| STORY15 | 1.771884 | -0.153103 | 0.001797 | 0.000111 |
| STORY14 | 1.550833 | -0.139445 | 0.001698 | 0.000112 |
| STORY13 | 1.342004 | -0.125696 | 0.001590 | 0.000112 |
| STORY12 | 1.146472 | -0.111945 | 0.001473 | 0.000111 |
| STORY11 | 0.965334 | -0.098295 | 0.001347 | 0.000109 |
| STORY10 | 0.799713 | -0.084864 | 0.001211 | 0.000106 |
| STORY9 | 0.650778 | -0.071807 | 0.001065 | 0.000101 |
| STORY8 | 0.519828 | -0.059378 | 0.000893 | 0.000090 |
| STORY7 | 0.391226 | -0.046380 | 0.000742 | 0.000069 |
| STORY6 | 0.299906 | -0.037902 | 0.000653 | 0.000065 |
| STORY5 | 0.219610 | -0.029893 | 0.000558 | 0.000061 |
| STORY4 | 0.150927 | -0.022435 | 0.000459 | 0.000055 |
| STORY3 | 0.094490 | -0.015635 | 0.000354 | 0.000048 |
| STORY2 | 0.050971 | -0.009677 | 0.000241 | 0.000038 |
| STORY1 | 0.019216 | -0.004625 | 0.000107 | 0.000026 |

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MEMBRANE 77 SEISMICY

ETABS v9.1.1 File:GRANBY TOWER MEMBRANE Units:Kip-in December 20, 2007 12:56
PAGE 1

D I S P L A C E M E N T S   A N D   D R I F T S   AT   P O I N T   O B J E C T   77

| STORY | DISP-X | DISP-Y | DRIFT-X | DRIFT-Y |
|---|---|---|---|---|
| STORY34 | -0.007941 | 5.420698 | 0.000011 | 0.001762 |
| STORY33 | -0.006322 | 5.161680 | 0.000008 | 0.001762 |
| STORY32 | -0.005282 | 4.944938 | 0.000008 | 0.001764 |
| STORY31 | -0.004076 | 4.664532 | 0.000008 | 0.001767 |
| STORY30 | -0.003087 | 4.447146 | 0.000008 | 0.001771 |
| STORY29 | -0.002117 | 4.229262 | 0.000007 | 0.001772 |
| STORY28 | -0.001264 | 4.011294 | 0.000006 | 0.001770 |
| STORY27 | -0.000522 | 3.793584 | 0.000005 | 0.001765 |
| STORY26 | 0.000114 | 3.576521 | 0.000004 | 0.001756 |
| STORY25 | 0.000649 | 3.360555 | 0.000004 | 0.001743 |
| STORY24 | 0.001085 | 3.146196 | 0.000003 | 0.001724 |
| STORY23 | 0.001449 | 2.934114 | 0.000002 | 0.001705 |
| STORY22 | 0.001723 | 2.724445 | 0.000001 | 0.001680 |
| STORY21 | 0.001906 | 2.517750 | 0.000001 | 0.001651 |
| STORY20 | 0.002001 | 2.314638 | 0.000000 | 0.001617 |
| STORY19 | 0.002012 | 2.115756 | 0.000001 | 0.001577 |
| STORY18 | 0.001942 | 1.921782 | 0.000001 | 0.001531 |
| STORY17 | 0.001796 | 1.733423 | 0.000002 | 0.001480 |
| STORY16 | 0.001579 | 1.551413 | 0.000002 | 0.001422 |
| STORY15 | 0.001294 | 1.376509 | 0.000003 | 0.001358 |
| STORY14 | 0.000948 | 1.209489 | 0.000003 | 0.001287 |
| STORY13 | 0.000546 | 1.051150 | 0.000004 | 0.001210 |
| STORY12 | 0.000096 | 0.902312 | 0.000004 | 0.001126 |
| STORY11 | -0.000393 | 0.763812 | 0.000004 | 0.001035 |
| STORY10 | -0.000910 | 0.636511 | 0.000004 | 0.000936 |
| STORY9 | -0.001433 | 0.521324 | 0.000004 | 0.000830 |
| STORY8 | -0.001942 | 0.419289 | 0.000004 | 0.000701 |
| STORY7 | -0.002490 | 0.318290 | 0.000000 | 0.000583 |
| STORY6 | -0.002494 | 0.246640 | 0.000001 | 0.000518 |
| STORY5 | -0.002343 | 0.182971 | 0.000002 | 0.000449 |
| STORY4 | -0.002093 | 0.127751 | 0.000003 | 0.000376 |
| STORY3 | -0.001739 | 0.081492 | 0.000004 | 0.000298 |
| STORY2 | -0.001265 | 0.044794 | 0.000004 | 0.000211 |
| STORY1 | -0.000674 | 0.017000 | 0.000004 | 0.000094 |

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## appendix g • overturning moments

SPOT CHECK — GRANBY TOWER — OVERTURNING MOMENT — 1

OVERTURNING MOMENTS

• WIND

EAST - WEST (Y-DIRECTION)

$V_b = 2596.91$ k

$M_o = 470729.6$ ft k

$M_u = \frac{1}{2} V_b \cdot h = \frac{1}{2}(2596.91\text{k})(367\text{ft}) = 476533$ ft k

$M_u = 476533$ ft k $> M_o = 470729.6$ ft k    ok ✓

• OVERTURNING MOMENT FROM BUILDING WEIGHT

$y_{cm} = 770$ in (FROM TOP)

$W = 84528$ k

$M_u = 84528\text{ k}\,(770\text{ in} - 663\text{ in})/12 = 753708$ ft k

$M_u = 753708$ ft k $> M_o = 470729.6$ ft k    ok ✓

• SEISMIC

$V_b = 845.28$ k

$M_o = 216038.3$ ft k

$M_u = \frac{2}{3} V_b h = \frac{2}{3}(845.28)(367') = 206812$ ft k

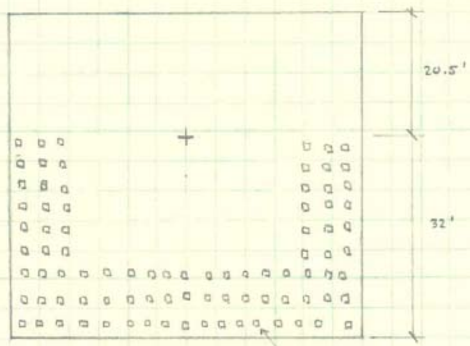
$M_u = 206812$ ft k $\approx M_o = 216038.3$ ft k    ok ✓

OVERTURNING MOMENT FROM BUILDING WEIGHT

$M_u = 753708$ ft k $> M_o = 216038.3$ ft k    ok ✓

SPOT CHECK | GRANBY TOWER | OVERTURNING MOMENT | 2

• TENSION PILES



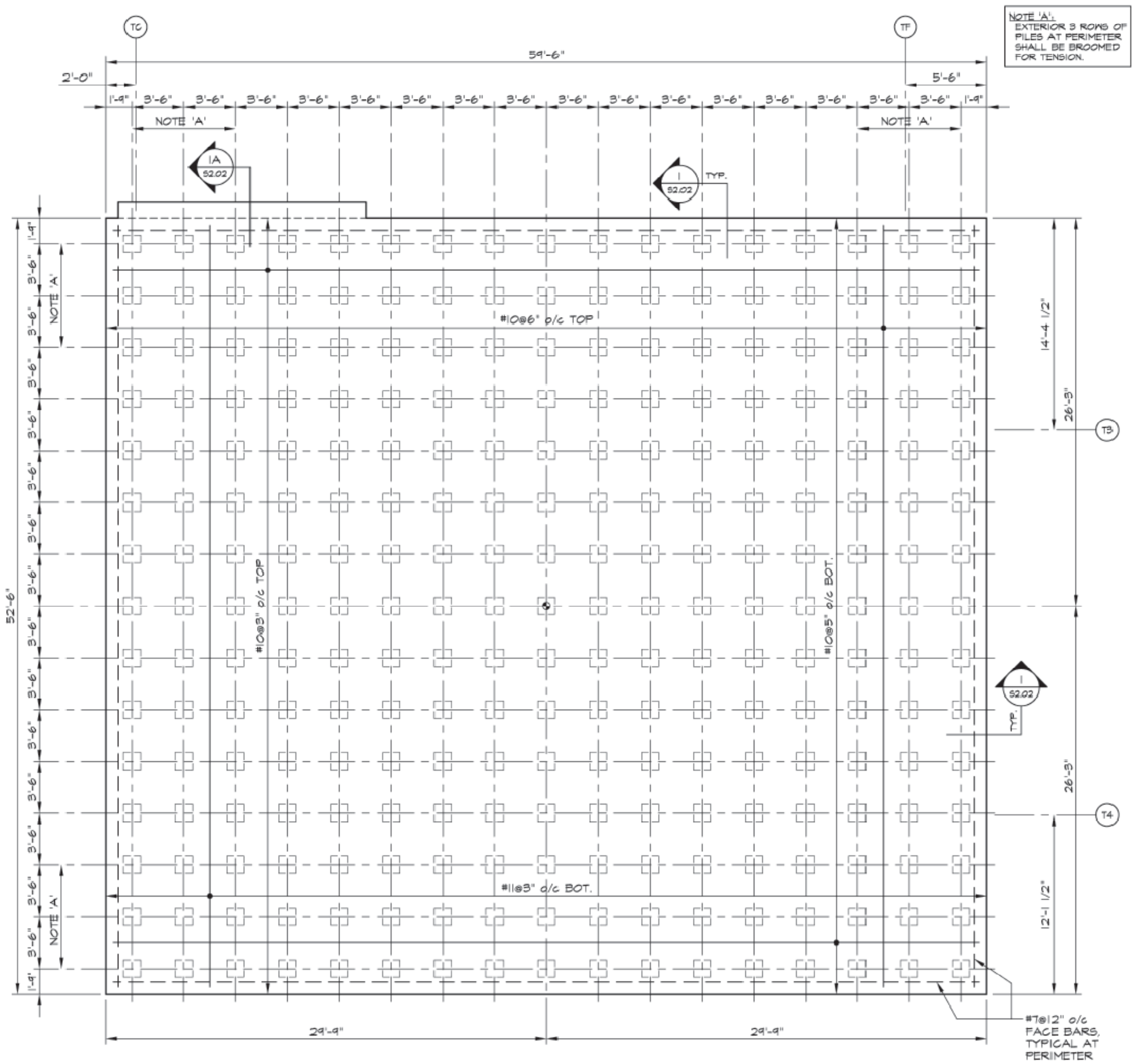

— 14" SPPC PILES, $f'_c$ = 5000 psi - TENSION CAPACITY = 140 TON.

MOMENT RESISTED BY TENSION PILES

$$M_R = \left[52(26.7\,ft) + 36(10.96\,ft)\right](140\,TON)(2\,k/TON) = 499374\ ft\,k$$

$$M_R = 499374\ ft\,k > M_x = 470729.6\ ft\,k$$ <u>ok</u>

*Shear Wall Pile Cap with Tension Piles*




PILE CAP TYPE 14P255 DETAIL (14" ⊕ PILES)
SCALE: 1/4" = 1'-0"

## appendix h • torsion

| Story | Diaph | Mass | XCM | YCM | XCCM | YCCM | XCR | YCR | XECC | YECC | XECC ft | YECC ft |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34 | D1 | 1.9819 | 937 | 788 | 937.0 | 787.5 | 921.3 | 575.3 | 15.7 | 212.2 | 1.31 | 17.68 |
| 33 | D1 | 3.6409 | 936 | 784 | 936.4 | 785.2 | 920.6 | 584.2 | 15.4 | 199.8 | 1.29 | 16.65 |
| 32 | D1 | 5.386 | 936 | 784 | 936.2 | 784.6 | 920.1 | 582.5 | 15.9 | 201.5 | 1.33 | 16.80 |
| 31 | D1 | 3.748 | 936 | 746 | 936.1 | 774.8 | 918.9 | 580.3 | 17.1 | 165.7 | 1.43 | 13.81 |
| 30 | D1 | 5.7187 | 936 | 783 | 936.1 | 777.2 | 919.0 | 580.4 | 17.0 | 202.9 | 1.41 | 16.91 |
| 29 | D1 | 5.8487 | 936 | 783 | 936.1 | 778.5 | 919.1 | 580.9 | 16.9 | 202.4 | 1.41 | 16.87 |
| 28 | D1 | 5.9787 | 936 | 783 | 936.1 | 779.4 | 919.2 | 581.4 | 16.8 | 201.9 | 1.40 | 16.82 |
| 27 | D1 | 5.9787 | 936 | 783 | 936.1 | 780.0 | 919.3 | 581.9 | 16.7 | 201.4 | 1.39 | 16.78 |
| 26 | D1 | 5.9787 | 936 | 783 | 936.0 | 780.5 | 919.4 | 582.4 | 16.6 | 200.9 | 1.38 | 16.74 |
| 25 | D1 | 6.1366 | 936 | 780 | 936.0 | 780.4 | 919.5 | 583.0 | 16.5 | 196.8 | 1.37 | 16.40 |
| 24 | D1 | 7.0166 | 936 | 775 | 936.0 | 779.7 | 919.6 | 583.5 | 16.4 | 191.3 | 1.37 | 15.94 |
| 23 | D1 | 6.8534 | 936 | 775 | 936.0 | 779.2 | 919.8 | 584.2 | 16.2 | 190.6 | 1.35 | 15.88 |
| 22 | D1 | 6.8534 | 936 | 775 | 936.0 | 778.7 | 919.9 | 584.9 | 16.1 | 189.9 | 1.34 | 15.82 |
| 21 | D1 | 6.8534 | 936 | 775 | 936.0 | 778.4 | 920.1 | 585.6 | 15.9 | 189.1 | 1.33 | 15.76 |
| 20 | D1 | 6.8534 | 936 | 775 | 936.0 | 778.1 | 920.3 | 586.4 | 15.7 | 188.4 | 1.31 | 15.70 |
| 19 | D1 | 6.8534 | 936 | 775 | 936.0 | 777.9 | 920.5 | 587.3 | 15.5 | 187.5 | 1.29 | 15.63 |
| 18 | D1 | 6.8534 | 936 | 775 | 936.0 | 777.6 | 920.7 | 588.2 | 15.3 | 186.6 | 1.27 | 15.55 |
| 17 | D1 | 6.8534 | 936 | 775 | 936.0 | 777.5 | 921.0 | 589.2 | 15.0 | 185.6 | 1.25 | 15.46 |
| 16 | D1 | 6.8534 | 936 | 775 | 936.0 | 777.3 | 921.3 | 590.3 | 14.7 | 184.5 | 1.22 | 15.37 |
| 15 | D1 | 6.8534 | 936 | 775 | 936.0 | 777.2 | 921.7 | 591.5 | 14.3 | 183.3 | 1.19 | 15.27 |
| 14 | D1 | 6.8534 | 936 | 775 | 936.0 | 777.0 | 922.1 | 592.8 | 13.9 | 182.0 | 1.16 | 15.16 |
| 13 | D1 | 6.8534 | 936 | 775 | 936.0 | 776.9 | 922.6 | 594.3 | 13.4 | 180.5 | 1.12 | 15.04 |
| 12 | D1 | 6.8534 | 936 | 775 | 936.0 | 776.8 | 923.1 | 595.9 | 12.9 | 178.9 | 1.08 | 14.91 |
| 11 | D1 | 7.343 | 936 | 775 | 936.0 | 776.7 | 923.7 | 597.7 | 12.3 | 177.1 | 1.03 | 14.76 |
| 10 | D1 | 7.343 | 936 | 775 | 936.0 | 776.6 | 924.3 | 599.6 | 11.7 | 175.2 | 0.97 | 14.60 |
| 9 | D1 | 7.343 | 936 | 775 | 936.0 | 776.5 | 925.1 | 601.8 | 11.0 | 173.0 | 0.91 | 14.41 |
| 8 | D1 | 7.343 | 936 | 775 | 936.0 | 776.5 | 925.9 | 604.2 | 10.1 | 170.6 | 0.84 | 14.22 |
| 7 | D1 | 7.696 | 936 | 740 | 936.0 | 774.9 | 926.9 | 606.6 | 9.1 | 133.4 | 0.76 | 11.12 |
| 6 | D1 | 8.4977 | 936 | 740 | 936.0 | 773.3 | 930.7 | 608.8 | 5.3 | 131.2 | 0.44 | 10.93 |
| 5 | D1 | 8.4977 | 936 | 740 | 936.0 | 771.8 | 935.1 | 611.3 | 0.9 | 128.7 | 0.08 | 10.72 |
| 4 | D1 | 8.4977 | 936 | 740 | 936.0 | 770.5 | 940.1 | 613.4 | -4.1 | 126.6 | -0.34 | 10.55 |
| 3 | D1 | 8.4977 | 936 | 740 | 936.0 | 769.2 | 945.8 | 614.2 | -9.8 | 125.8 | -0.81 | 10.49 |
| 2 | D1 | 8.4977 | 936 | 740 | 936.0 | 768.1 | 952.0 | 611.9 | -16.0 | 128.1 | -1.33 | 10.67 |
| 1 | D1 | 8.3373 | 936 | 740 | 936.0 | 767.1 | 957.3 | 603.4 | -21.3 | 136.6 | -1.78 | 11.38 |