# TECHNICAL REPORT 3

November 16, 2011


## CityFlatsHotel – Holland, Michigan

Hunter Woron – Structural
Professor M. Kevin Parfitt
The Pennsylvania State University

# Table of Contents

# Executive Summary

The following technical report provides an analysis of the existing design of the lateral force resisting system of the CityFlatsHotel. The loads that were calculated in the existing structural conditions report were applied to the lateral force resisting system, which was analyzed for this report. The lateral force resisting system is comprised of reinforced concrete masonry shear walls. A detailed description of the structural system of the building and how all loads are transferred to the foundation is given in this report.

To verify the strength of the building, an ETABS model was created to compare the analysis results to the hand calculations performed for the CityFlatsHotel. Note that this model represents an analysis of the existing lateral members only; shear walls and rigid diaphragms. Gravity columns and transfer beams were excluded in order to simplify the model of the CityFlatsHotel. In accordance, all hand calculations also only accounted for the shear walls as the lateral resisting system. Lateral loads were applied to the model to determine center of rigidity, center of mass, torsion, overturning moment, story drift, and story shear. These results were compared to the hand calculations and checked against allowable code requirements. Diaphragms were modeled as rigid area elements with applied area masses that were determined in the existing structural conditions report. Finally, the ETABS model was used to determine the Fundamental Period of the building.

After comparing the ETABS model with the hand calculations, a few differences were noticeable in the location of the center of rigidity. The differences are most likely a result of the hand calculations only accounting for the shear walls, whereas the ETABS model includes the rigid diaphragms. As a result, the center of rigidity values calculated by the ETABS model will be used in determining relative stiffness, torsion, shear, and overturning moment. Based on the hand calculations, the shear walls are properly reinforced and provide the majority of the lateral resistance. This verifies that it is only necessary to include the shear walls for this analysis.

The result of the overturning moment calculations show that the gravity system of the building will resist any uplift or torsion on the building from lateral loads due to the fact that the lateral loads are only a small fraction compared to the gravity loads. Other results such as displacements and story drifts were found to be within the allowable code limits, and are verified by hand calculations, as well as the ETABS model. Detailed calculations for each analysis performed can be found in the Appendixes at the end of the report.

# Introduction: CityFlatsHotel

CityFlatsHotel is the latest eco-boutique hotel located at 61 East 7th Street in Holland Michigan. This environmentally friendly hotel has been awarded LEED Gold and is only the third eco-boutique hotel to achieve such status in the United States and is the first of its kind to earn such recognition in the Midwest. Located on the outskirts of downtown Holland, which was named the second happiest place in America in 2009, the 56-guest room hotel is a unique place to stay. Not only are the hotel rooms decorated in a variety of ways, so that no two rooms are alike, this 5-story hotel offers many additional features to keep visitors satisfied. Accommodations include guest rooms, junior suites, master suites and more. Coupled with being located close to top of the line shopping, fine dining and extravagant art venues CityFlatsHotel is the place to stay when visiting Holland and its surrounding unique attractions.

The ground floor houses the main lobby for the hotel, a fitness suite and the CitySen Lounge. Also available is office space, high-tech conference rooms, and a digital theater for those who may want to conduct business meetings or private get-togethers. The remaining floors of the building are occupied by the various hotel rooms, with the top floor mostly reserved for CityVu Bistro restaurant and City Bru bar. The views from the restaurant of downtown Holland and Lake Macatawa are spectacular, which go well with the diverse fresh entrees served at CityVu Bistro.

The exterior of CityFlatsHotel consists of multiple materials. Mainly covered in glass, other features including brick accents, metal panels, and terra cotta finishing make up the building seen at the intersection of College Ave and 7th Street. The contrast in simple materials leaves an appealing building image and gives it a sense of modernity, which is continued throughout the entire hotel. Accompanying the exterior image and fascinating interior design, efficient features can be found in every room. Such features include but are not limited to cork flooring, occupancy sensors, low flow toilets and faucets, fluorescent lighting, Cradle-to-Cradle countertops, and low VOC products.

CityFlatsHotel’s lateral system will be analyzed throughout this report by taking a closer look at the structural features that resist the lateral loads that act on the building. An ETABS model of the building was designed to compare the results of the hand calculations with the lateral analysis of the building model.

# Structural Systems

## *Foundation*

Soils & Structures Inc. completed the geotechnical engineering study for the CityFlatsHotel on July 16, 1998. A series of five test borings were drilled in the locations shown in the proposed plan (Figure 1.1). Each test boring was drilled to a depth of 25 feet in order to reveal the types of soil consistent with the location of the site. The results showed that the soil profile consisted of compact light brown fine sand to a depth of 13.0 to 18.0 feet over very compact coarse sand and compact fine silt. In test boring two a small seam of very stiff clay was discovered at 20.0 feet. Groundwater was encountered at a depth of 14.0 feet. From these findings it was recommended that a bearing value of 4000 psf be used for design of rectangular or square spread foundations and a value of 3000 psf be used for strip foundations. Since the test boring was performed in a relatively dry period, it was noted that the water table might rise by as much as 2.0 to 3.0 feet during excessive wet periods.

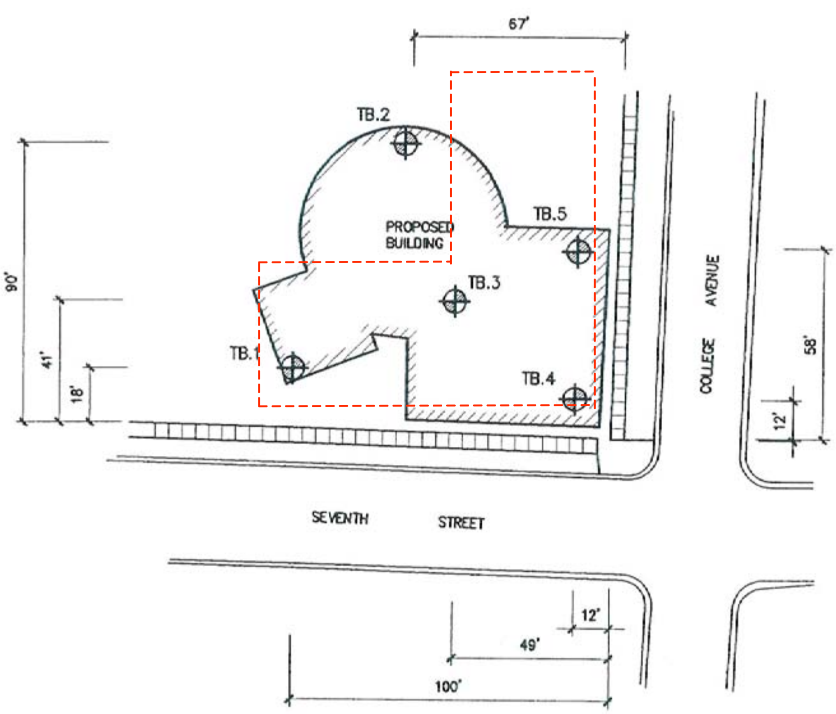



**FIGURE 1.1:** This is a plan view of the Five Test Boring Locations
Note: The layout of the building here was the proposed shape. The actual building takes on an L-shape as can be seen later in Figure 1.8

Based on the conclusion from the geotechnical report it was decided to have all sand and/or sand fill be compacted to a density of 95 percent of its maximum density as determined by ASTM D1557. By compacting the soil through methods of vibration allowed the soil bearing capacity to be set at 8000 psf for footings. The basement floor consists of 4" concrete slab on grade that has a concrete compressive strength of 3000 psi and is reinforced with 6x6 W2.9xW2.9 welded wire fabric. Examples of the foundation and footings can be seen in Figures 1.2 and 1.3 respectively. This typical layout is consistent throughout the entire foundation system.

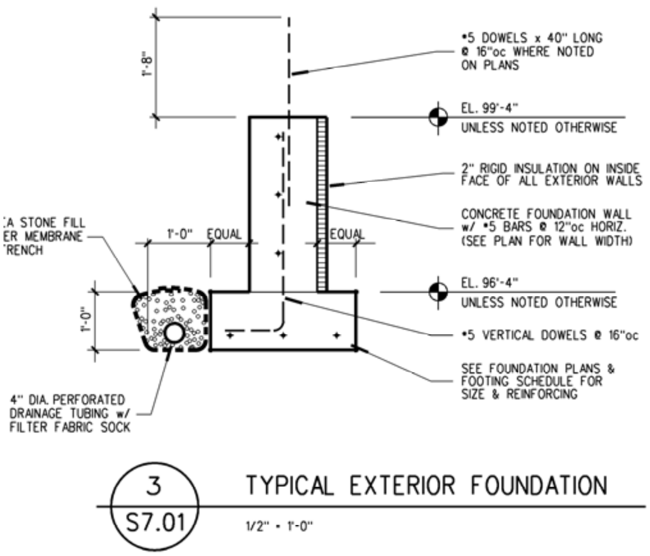



**Figure 1.2:** Typical Exterior Foundation

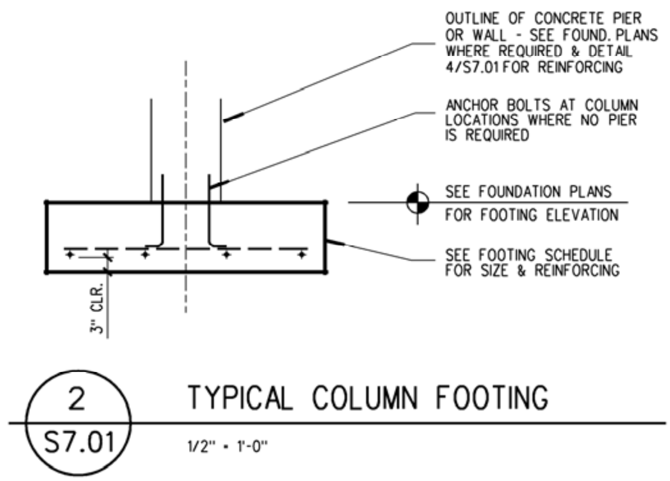



**Figure 1.3:** Typical Column Footing

## *Superstructure*

Due to the relatively "L" shape of CityFlatsHotel, the buildings framing system is able to follow a simple grid pattern. The overall building is split into two rectangular shapes that consist of 6 and 7 bays. The typical grid size is between 18'-0" to 18'-8" wide and 22'-6" to 30'-2" long. The main floor system used is an 8" precast planking deck with 2" non-composite concrete topping. The concrete topping is normal weight concrete and has a compressive strength of 4000 psi. The floor system is then supported by steel beams, which range in size and include W30x173's for exterior bays and W8x24's for interior corridors. Details for these two beam connections can be seen in Figure 1.4 below.

The precast plank allows for quicker erection, longer spans, and open interior spaces. The use of precast plank is typical for all floors other than the basement floor and specific areas of the ground floor, which utilizes slab on grade. All floor slabs on grade are 4” thick except for radiant heat areas, which require the slab to be 5” thick. Both of these slabs are reinforced with 6x6 W2.9x2.9 welded wire fabric.

Masonry walls are also used throughout the building layout to hold up the precast concrete plank floors. Refer to Appendix A for wall locations. These walls simply consist of concrete masonry units that are reinforced with #5 bars vertically spaced at 16” o.c. and extend the full height of the wall (Figure 1.5). In order to connect the precast planks with the masonry block, 4” dowels, typically 3’-0” long spaced at 48” o.c., are grouted into keyways and used to connect the two members together (Figure 1.6).

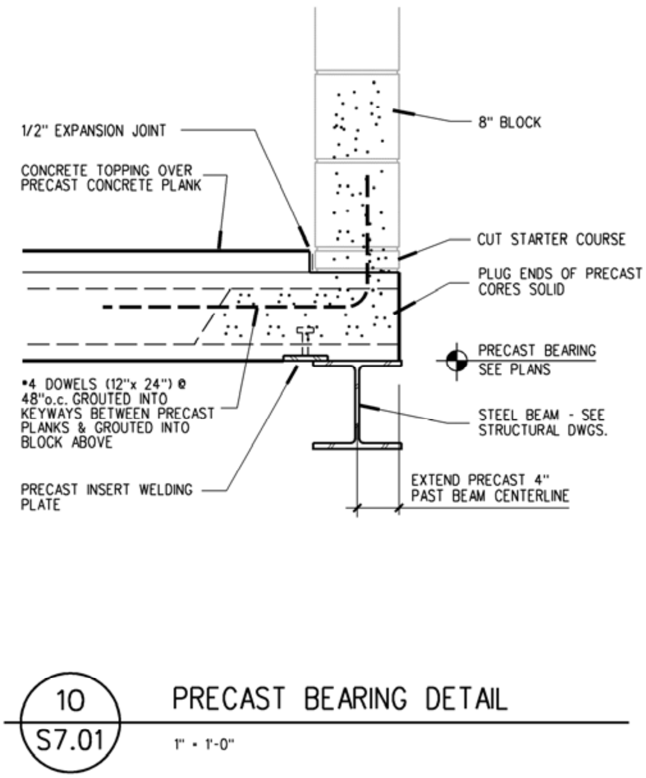



**Figure 1.4:** Typical Steel Beam Support Detail

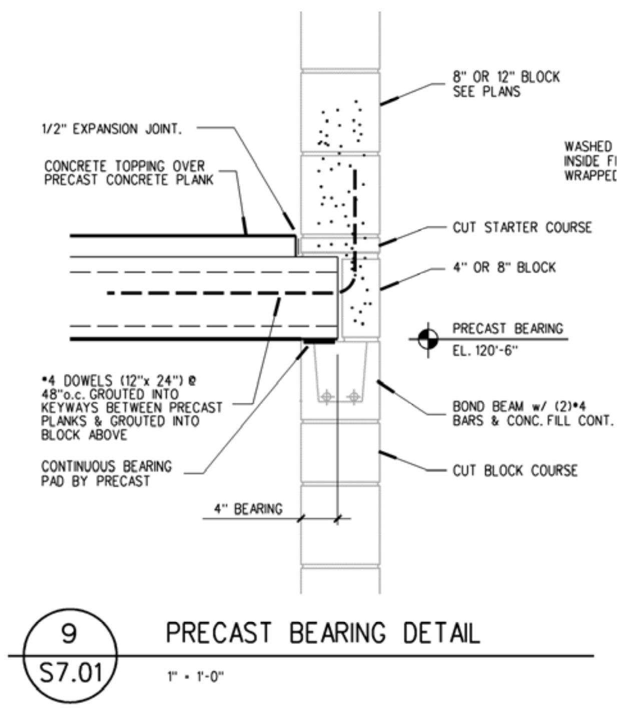



**Figure 1.5:** Typical Masonry Wall Reinforcing

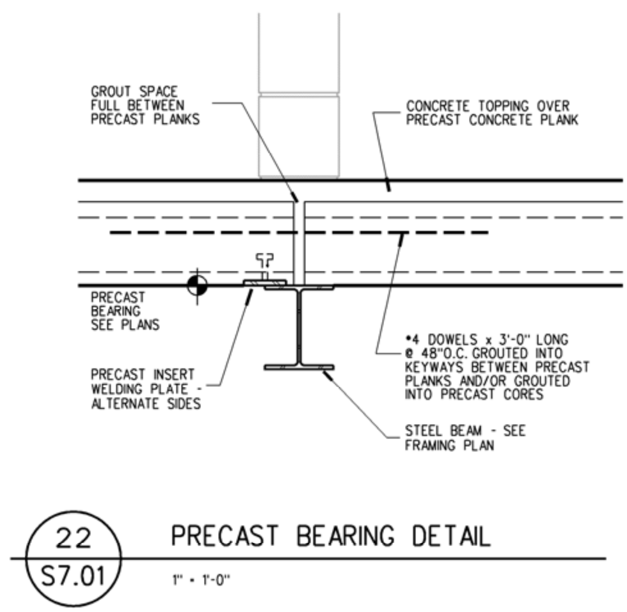



**Figure 1.6:** Typical Member Connection Detail

Columns add the final support and are typically HSS columns located around the perimeter of the building as well as along the corridors of the hotel. Refer to Appendix A for plans with column locations. HSS 8x8x3/8" columns were typically used on the exterior and HSS 8x8x1/2" columns were used in the interior. HSS 12x12x5/8" were used in order to support the larger beams and greater tributary areas. All load bearing masonry walls and steel beams will take the reaction load from the precast concrete plank flooring, as well as any additional loads from upper levels, and transfer the loads thru the columns and exterior walls thru to the foundation system.

## *Lateral System*

The main lateral system for the CityFlatsHotel consists of the concrete masonry shear walls. The exterior as well as the interior walls are constructed with 8" concrete masonry, which extend the entire height of the building. The core shear walls are located around the staircases and elevator shafts. The average spacing between these walls are 18'-6" and they extend between 22'-6" to 25'-6" in length. In addition to the masonry walls there are steel moment connections in the southeast corner of the building similar to (Figure 1.7), which allows for additional lateral support of the two-story entrance atrium. Moment connections are also utilized on the top floor again similar to (Figure 1.7). This is in order to support the large amounts of glazing that is present, as an architectural feature for the restaurant located there. On floors three to five there are lateral braces used again in the southeast corner of the building that help with resisting the lateral load, which is prominent in the North/South direction. This will be expressed later when calculating wind loads.

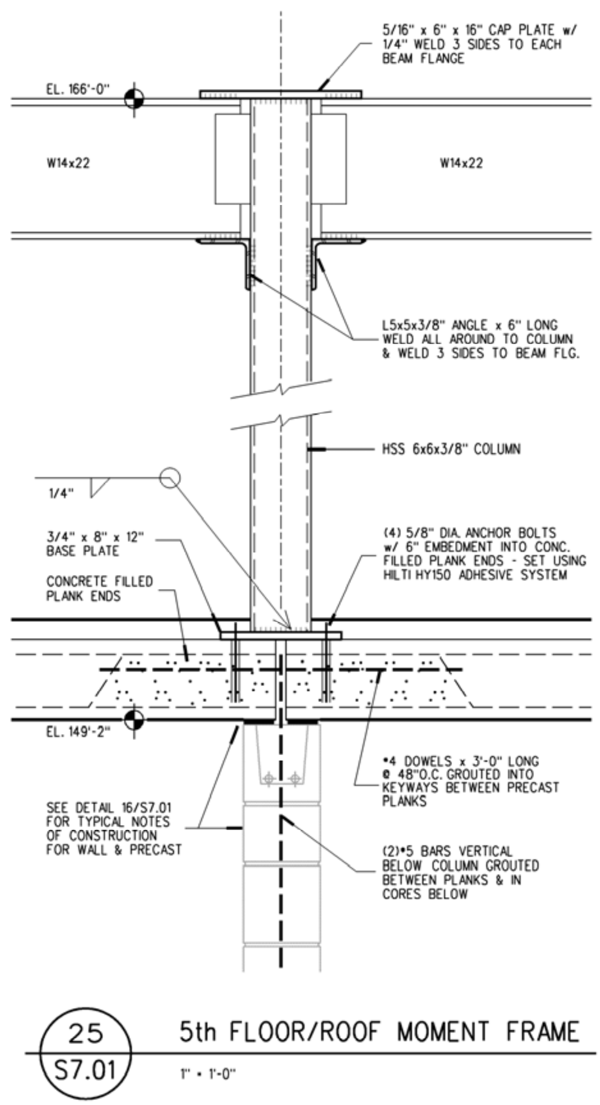



**Figure 1.7:** Typical Moment Frame Connection

### *Roof System*

The roof framing system like the floor framing system is laid out in a rectangular grid. It consists of 1.5B 20-gauge metal decking supported by K-series joists. The typical joists that are used range between 12K1 an 20K5, which have depths of 12” and 20” respectively. These K-series joists span between 16’-6” to 30’-8”. The roof deck spans longitudinally, which is perpendicular to the K-series joists. The joists are spaced no further than 5’-0” apart and typically no shorter than 4’-0”.

# ETABS Model

ETABS is a recognized industry leader for building analysis and design software developed by Computers and Structures, Inc. One of the advantages of this program is the ability to look at each floor of the building strictly as a rigid diaphragm against lateral loading. Therefore, for the analysis of this technical assignment, the building's later system and diaphragms were the only building components modeled as shown in Figures 1.8 and 1.9. Material properties were inputted for the shear walls, and a rigid diaphragm was assigned for the floor. Gravity loads were then applied as additional area masses to the floor diaphragms. Wind and seismic loads were applied about the centers of rigidity of the building. In addition to comparing the results of hand calculations, an ETABS model effectively determines the following: center of mass, center of rigidity, controlling ASCE 7-05 load combinations, story displacements, story drifts, story shears, and the effects of torsion.

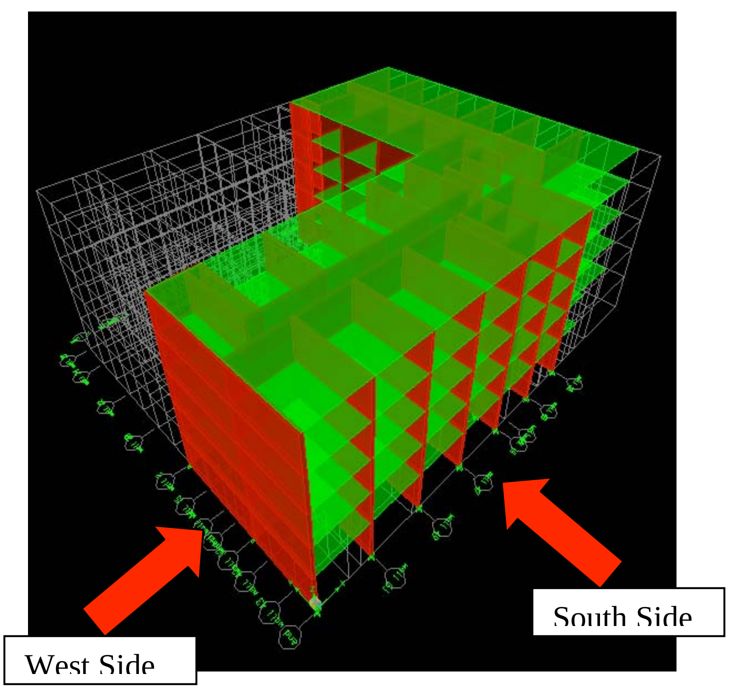



**Figure 1.8:** ETABS Model

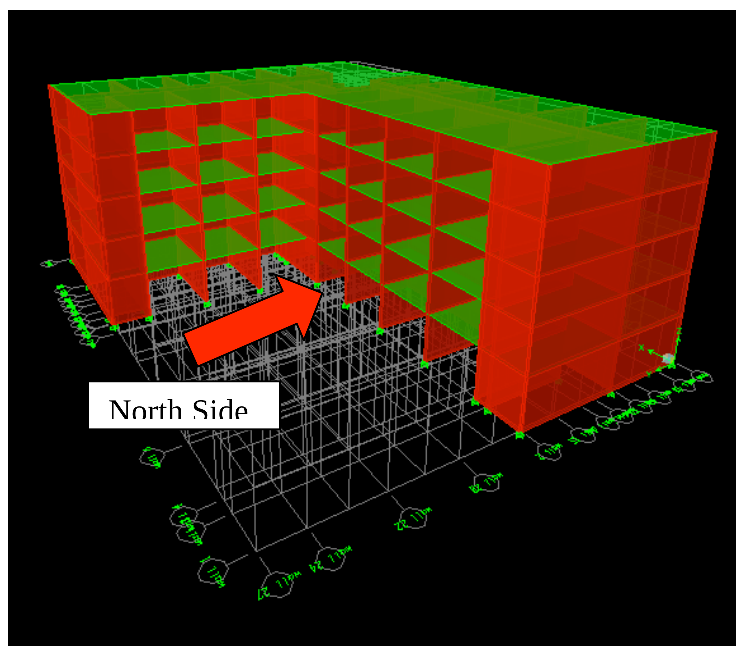



**Figure 1.9:** ETABS Model

# Codes and References

## *Codes Used in the Original Design*

- 2003 Michigan Building Code
- ASCE 7-05, Minimum Design Loads for Buildings
- ACI 318-05, Building Code Requirements for Structural Concrete
- Specifications for Structural Steel Buildings (AISC)
- International Building Code (IBC), 2006

## *Codes Used in Analysis*

- ASCE 7-05, Minimum Design Loads for Buildings
- ACI 318-05, Building Code Requirements for Structural Concrete
- Specifications for Structural Steel Buildings (AISC), 13th Edition
- International Building Code (IBC), 2009
- PCI Design Handbook, 7th Edition
- ETABS Building Analysis and Design Software – Computers and Structures, Inc.

DRIFT CRITERIA

The following allowable drift criteria used to check deflection of CityFlatsHotel is in accordance with the International Building Code, 2006 edition.

Allowable Building Drift: $\Delta_{wind} = H/400$

Allowable Story Drift: $\Delta_{seismic} = 0.02H_{sx}$

## LOAD COMBINATIONS

The following list shows the various load combinations according to ASCE 7-05 for factored loads using strength design and from the International Building Code, 2006 edition. These load combinations are used in the analysis of the lateral system for this report.

$1.4D$

$1.2D + 1.6L + 0.5L_r$

$1.2D + 1.6L_r + 1.0(L \text{ or } W)$

$1.2D + 1.6W + 1.0L + 0.5L_r$

$1.2D + 1.0E + 1.0L$

$0.9D + 1.6W$

$0.9D + 1.0E$

All load combinations were considered in the analysis of the ETABS model. After evaluating the story displacement, shears, and drifts computed by ETABS for each of the above load combinations, it was concluded that the controlling load combination for the North/South direction was $1.2D + 1.6W + 1.0L + 0.5L_r$ due to its large surface area. The controlling load combination for the East/West direction was $0.9D + 1.0E$.

# Gravity Loads

The gravity load conditions determined by ASCE 7-05 are provided for reference in Table 1.1 below and are compared to the Design Loads used by GMB.

| Live Loads (LL) | | |
|---|---|---|
| **Area** | **GMB Design Loads (PSF)** | **ASCE 7-05 Load (PSF)** |
| Private Guest Rooms | 40 | 40 |
| Public Spaces | 100 | 100 |
| Corridors | 100 | 40 (Private Corridor) / 100 (Public Corridor) |
| Lobbies | 100 | 100 |
| Stairs | 100 | 100 |
| Storage/Mechanical | 125 | 125 (Light) |
| Theater (Fixed) | 60 | 60 |
| Restaurant/Bar | 100 | 100 |
| Patio (Exterior) | 100 | 100 |

| Dead Loads (DL) | | |
|---|---|---|
| **Material** | **GMB Design Loads (PSF)** | **ASCE 7-05 Load (PSF)** |
| 8" Precast w/2" Topping | 80 | Section 3.1 |
| 10" Precast w/2" Topping | 92 | |
| 8" Masonry Wall, Full Grout w/Rein. @ 16" o.c. | - | |
| MEP | 10 | |
| Partition | 25 | |
| Finishes/Miscellaneous | - | |
| Roof | 15 | |

| Snow Load (SL) | | |
|---|---|---|
| **Area** | **GMB Design Loads (PSF)** | **ASCE 7-05 (PSF)** |
| Flat Roof | 35 | 35 |
| Ground | 50 | 50 |

**Table 1.1:** Summary of Design Loads

# Lateral Loads

## *Wind Analysis*

The following wind analysis was conducted in accordance with ASCE 7-05, chapter 6. Since the overall building height exceeds 60’-0” and reaches a height of 67’-2”, it is required, as it is stated in Section 6.5, to use Method 2 – Analytical Procedure, as apposed to Method 1 – Simplified Procedure. All of the wind variables used in determining the wind pressures can be found in Table 1.2. For complete analysis calculations refer to Appendix C. The North/South and East/West wind directions are labeled on the typical floor plan in Figure 1.10.

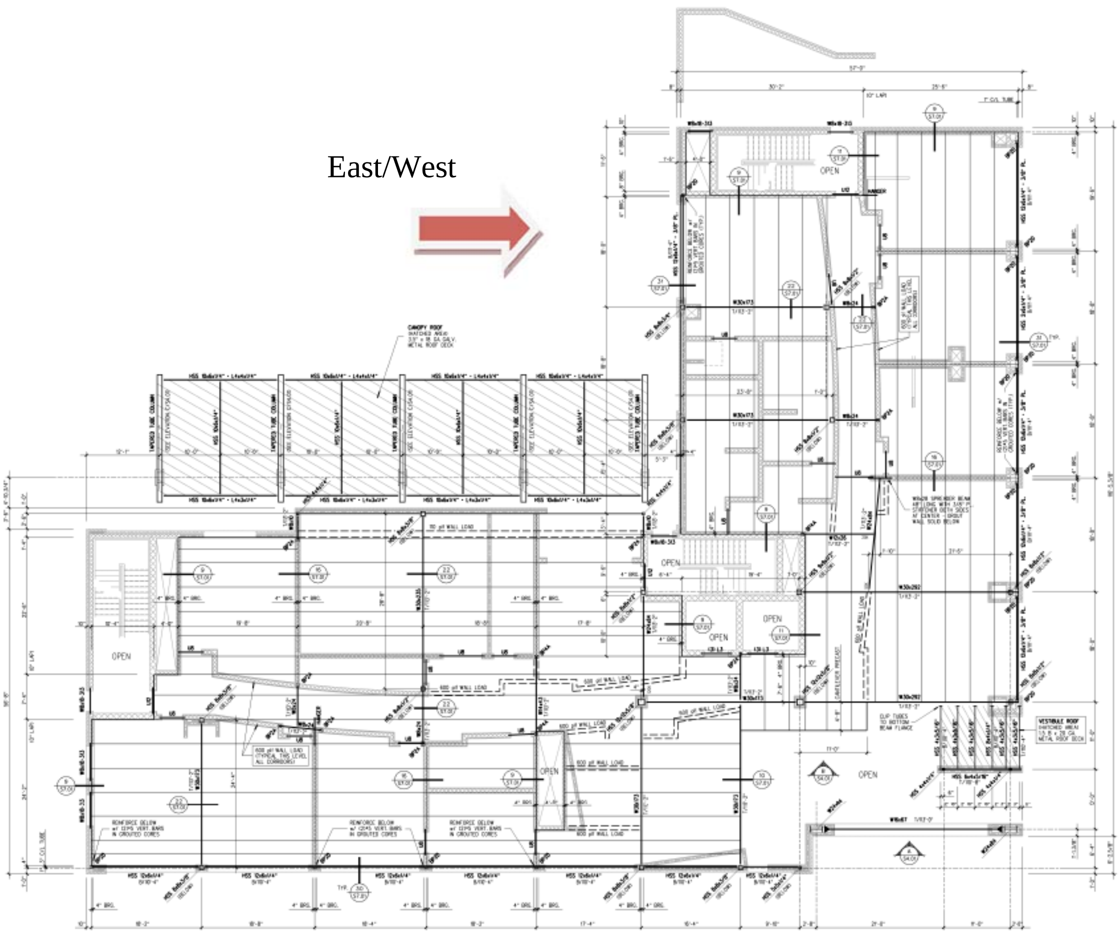



**Figure 1.10:** Wind Directions on Typical Plan

| **Wind Variables** | | | **ASCE Reference** |
|---|---|---|---|
| Name | Symbol | Value | |
| Basic Speed | V | 90 mph | Figure 1 |
| Directional Factor | $K_d$ | 0.85 | Table 6-4 |
| Importance Factor | I | 1.0 | Table 6-1 |
| Occupancy Category | | II | Table 1-1 |
| Exposure Category | | B | Section 6.5.6.3 |
| Enclosure Classification | | Enclosed | Section 6.5.9 |
| Building Natural Frequency | $n_1$ | 2.31 (Rigid) | See Below |
| Topographic Factor | $K_{zt}$ | 1.0 | Section 6.5.7.2 |
| Velocity Pressure Exposure Coefficient Evaluated @ Height Z | $K_z$ | Varies | Table 6-3 |
| Velocity Pressure @ Height Z | $q_z$ | Varies | Equation 6-15 |
| Velocity Pressure @ Mean Roof Height | $q_h$ | 0.87 | Equation 6-15 |
| Gust Effect Factor | G | 0.85 | Section 6.5.8.1 |
| Product of Internal Pressure Coefficient & Gust Effect Factor | $GC_{pi}$ | +/- 0.18 | Figure 6-5 |
| External Pressure Coefficient (Windward) | $C_p$ | 0.8 (All Values) | Figure 6-5 |
| External Pressure Coefficient (Leeward) | $C_p$ | -0.5 (North/South)<br>-0.2 (East/West) | Figure 6-5 |

**Table 1.2:** Wind Variables and Reference Sections

Building Natural Frequency Equation:

fn1 = (150/H) where H = Building Height (ft.)

fn1 = (150/67.167) = 2.23 ≥ 1 Hz ∴ the building is considered to be rigid.

The wind pressures in the North/South direction that were determined in the analysis are in Table 1.3 located below. Wind traveling in the North/South direction is the dominate direction since it has contact with the building through a wall of length 154’-4” as compared to the East/West direction which only has contact with a wall of length 116’-5 3/8”. Obstruction from the front and back of the hotel will not cause a significant wind load blockage, so any surrounding hindrances have been ignored during the analysis. In Figure 1.11 the windward and leeward pressures at all levels of CityFlatsHotel as well as the base shear can be seen on the building elevation. A basic loading diagram is also provided in Figure 1.12, which shows wind loads and story shears produced from wind coming from the North/South direction.

| Wind Loads - North / South Direction | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Level | Height Above Ground, z (ft.) | Story Height (ft.) | $K_z$ | $q_z$ | Wind Pressure (PSF) | | Total Pressure (PSF) | Force of Total Pressure (k) | Force of Windward Pressure Only (k) | Total Story Shear (k) | Windward Story Shear (k) | Total Moment (ft-k) | Windward Moment (ft-k) |
| | | | | | Windward | Leeward | | | | | | | |
| Top of Roof | 67.17 | 2.25 | 0.88 | 15.5 | 13.24 | -9.06 | 22.3 | 3.87 | 2.30 | 3.87 | 2.30 | 0.00 | 0.00 |
| Roof | 64.92 | 14.92 | 0.87 | 15.3 | 13.12 | -9.06 | 22.2 | 29.42 | 17.41 | 33.29 | 19.71 | 66.19 | 39.17 |
| Fifth | 50.00 | 12.00 | 0.81 | 14.3 | 12.40 | -9.06 | 21.5 | 45.42 | 26.60 | 78.71 | 46.30 | 743.90 | 435.99 |
| Fourth | 38.00 | 12.00 | 0.75 | 13.2 | 11.69 | -9.06 | 20.7 | 39.09 | 22.31 | 117.80 | 68.61 | 1213.00 | 703.68 |
| Third | 26.00 | 12.00 | 0.67 | 11.8 | 10.73 | -9.06 | 19.8 | 37.54 | 20.75 | 155.34 | 89.37 | 1663.46 | 952.72 |
| Second | 14.00 | 12.00 | 0.57 | 10.0 | 9.53 | -9.06 | 18.6 | 35.54 | 18.76 | 190.88 | 108.12 | 2089.94 | 1177.79 |
| First | 0.00 | 14.00 | 0.00 | 0.0 | 0.00 | 0.00 | 0.0 | 17.22 | 8.82 | 208.10 | 116.94 | 2296.52 | 1283.67 |
| | | | | | | | | | **Sum** | **208.10** | **116.94** | **2296.52** | **1283.67** |

**Table 1.3:** North/South Wind Loads

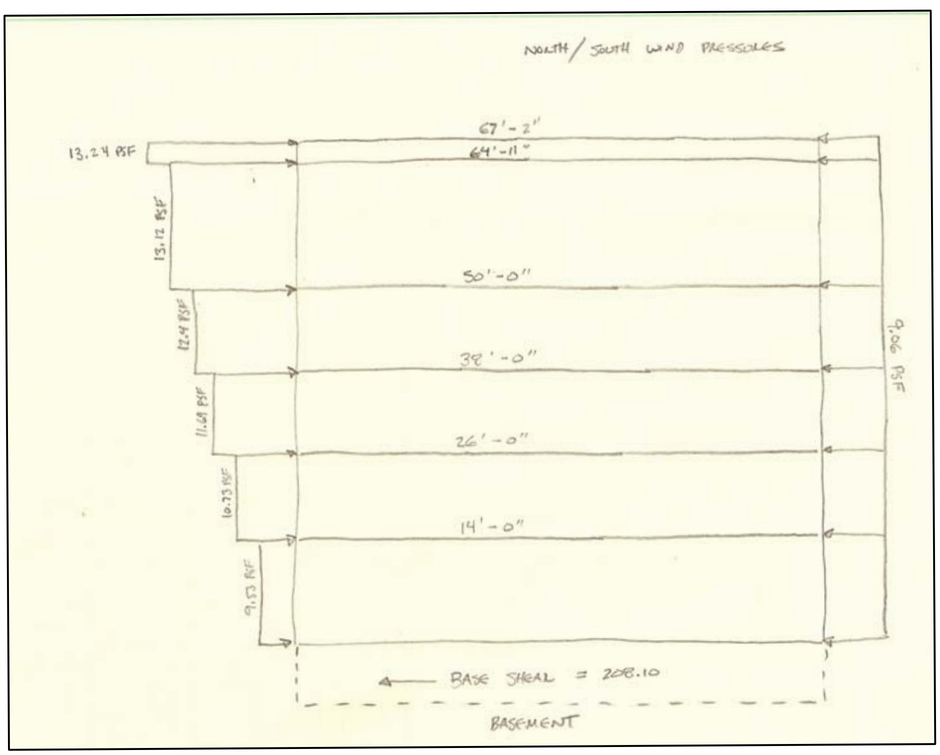



**Figure 1.11:** North/South Wind Pressures

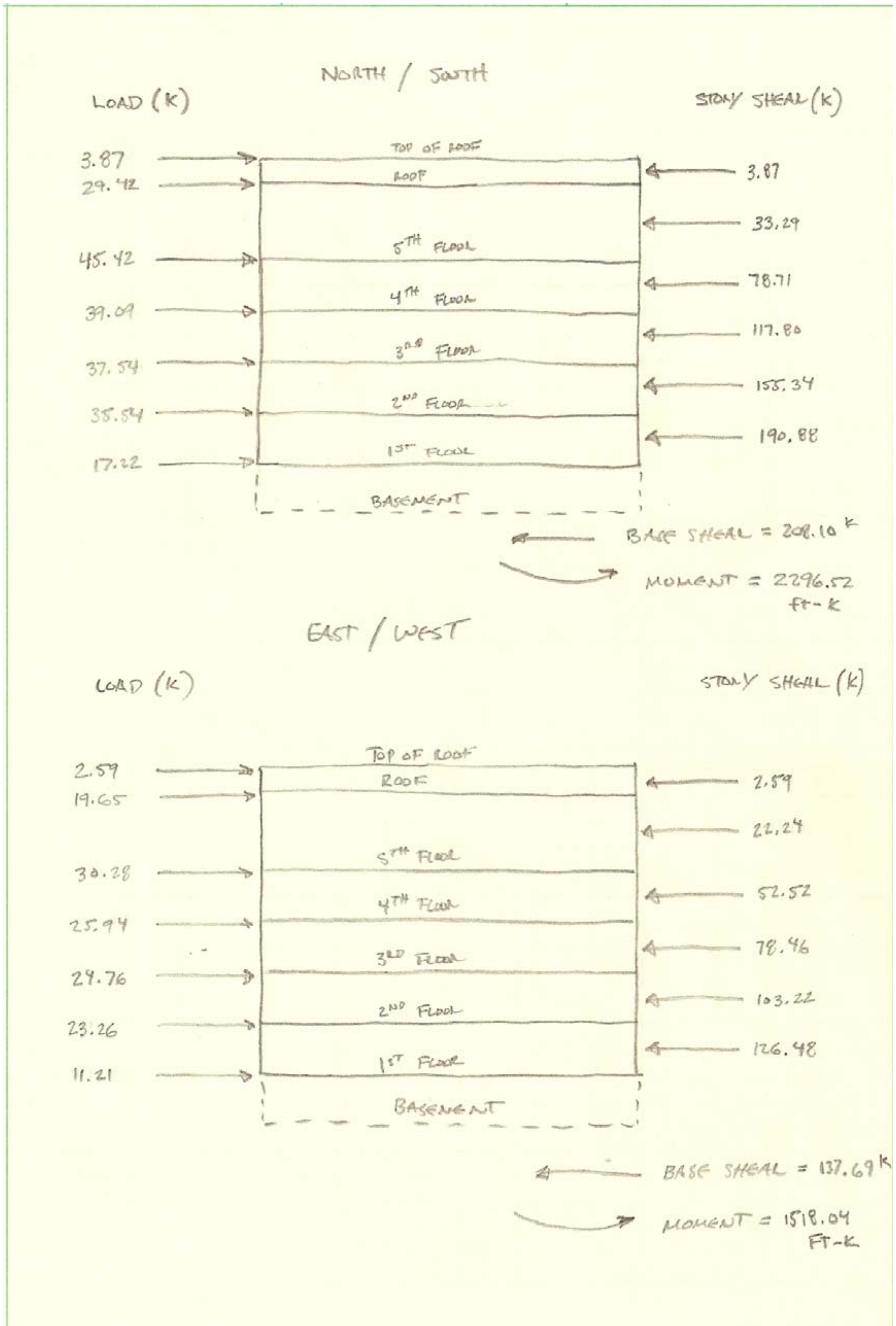



**Figure 1.12:** Shear and Moment Loading Diagrams

The wind pressures in the East/West direction that were determined in the analysis are in Table 1.4 located below. Any buildings that may be surrounding CityFlatsHotel can have effects on the full wind loading, however the wind loading must be examined as if buildings were not present. In Figure 1.13 the windward and leeward pressures at all levels of CityFlatsHotel as well as the base shear can be seen on the building elevation. A basic loading diagram is also provided in Figure 1.12, which shows wind loads and story shears produced from wind coming from the East/West direction.

| Wind Loads - East / West Direction | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Level | Height Above Ground, z (ft.) | Story Height (ft.) | $K_z$ | $q_z$ | Wind Pressure (PSF) | | Total Pressure (PSF) | Force of Total Pressure (k) | Force of Windward Pressure Only (k) | Total Story Shear (k) | Windward Story Shear (k) | Total Moment (ft-k) | Windward Moment (ft-k) |
| | | | | | Windward | Leeward | | | | | | | |
| Top of Roof | 67.17 | 2.25 | 0.88 | 15.5 | 13.24 | -6.52 | 19.8 | 2.59 | 2.30 | 2.59 | 2.30 | 0.00 | 0.00 |
| Roof | 64.92 | 14.92 | 0.87 | 15.3 | 13.12 | -6.52 | 19.6 | 19.65 | 13.14 | 22.24 | 15.44 | 44.21 | 29.55 |
| Fifth | 50.00 | 12.00 | 0.81 | 14.3 | 12.40 | -6.52 | 18.9 | 30.28 | 20.07 | 52.52 | 35.50 | 496.01 | 328.96 |
| Fourth | 38.00 | 12.00 | 0.75 | 13.2 | 11.7 | -6.52 | 18.2 | 25.94 | 16.83 | 78.46 | 52.34 | 807.25 | 530.94 |
| Third | 26.00 | 12.00 | 0.67 | 11.8 | 10.7 | -6.52 | 17.2 | 24.76 | 15.66 | 103.22 | 67.99 | 1104.43 | 718.85 |
| Second | 14.00 | 12.00 | 0.57 | 10.0 | 9.5 | -6.52 | 16.0 | 23.26 | 14.15 | 126.48 | 82.15 | 1383.52 | 888.67 |
| First | 0.00 | 14.00 | 0.00 | 0.0 | 0.0 | 0.00 | 0.0 | 11.21 | 6.66 | 137.69 | 88.80 | 1518.04 | 968.55 |
| | | | | | | | | | Sum | 137.69 | 88.80 | 1518.04 | 968.55 |

**Table 1.4:** East/West Wind Loads

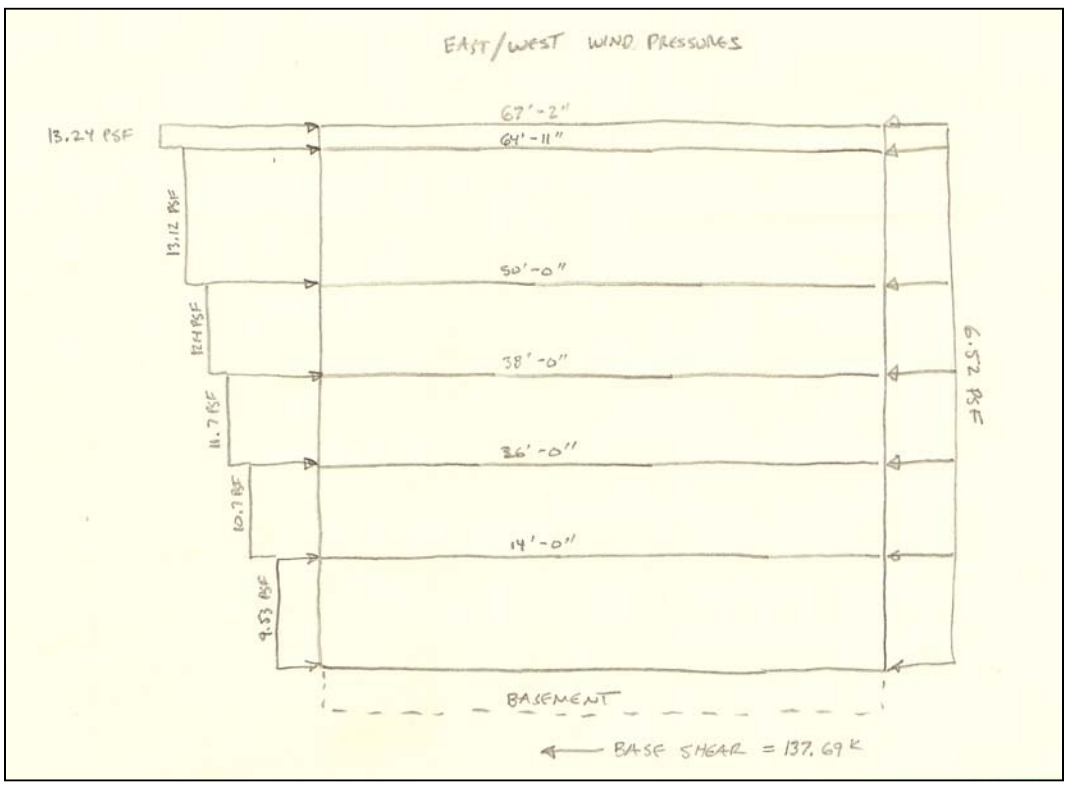



**Figure 1.13:** East/West Wind

## *Seismic Analysis*

The seismic analysis of CityFlatsHotel was conducted in accordance with ASCE 7-05 chapters 11 and 12. The building was designed to resist the effects of earthquakes using a Site Class for Seismic Design of "D". This is in accordance with the IBC. All variables that were used while conducting this analysis are listed in Table 1.5 It is important to note that seismic loads in the North/South direction is the same as loads in the East/West direction due to the structural type being the same throughout. However, it is important to note that the impact may be different due to the geometry, center or rigidity, framing layout, ect.

| Seismic Design Variables | | | |
|---|---|---|---|
| Site Class | | D | Table 20.3-1 |
| Occupancy Factor | | II | Table 1-1 |
| Importance Factor | | 1.0 | Table 11.5-1 |
| Structural System | | Ordinary Reinforced Masonry Wall | Table 12.2-1 |
| | | | |
| Spectral Response Acceleration, Short | $S_s$ | 0.098 | Figure 22-1 thru 22-14 |
| Spectral Response Acceleration, 1s | $S_1$ | 0.045 | Figure 22-1 thru 22-15 |
| Site Coefficient | $F_a$ | 1.6 | Table 11.4-1 |
| Site Coefficient | $F_v$ | 2.4 | Table 11.4-2 |
| MCE Spectral Response Acceleration, Short | $S_{ms}$ | 0.1568 | Equation 11.4-1 |
| MCE Spectral Response Acceleration, 1s | $S_{m1}$ | 0.1080 | Equation 11.4-2 |
| Design Spectral Accerleration, Short | $S_{ds}$ | 0.1045 | Equation 11.4-3 |
| Design Spectral Accerleration, 1s | $S_{d1}$ | 0.0720 | Eqaution 11.4-4 |
| Seismic Design Category | $S_{dc}$ | B | Table 11.6-2 |
| Response Modification Coefficient | R | 2.0 | Table 12.2-1 |
| Building Height (Above Grade) [ft.] | $h_n$ | 67.167 | From Design |
| | | | |
| Calculated Perod Upper Limit Coefficient | $C_t$ | 0.02 | Table 12.8-1 |
| Approximate Period Parameter | X | 0.75 | Table 12.8-2 |
| Approximate Period Parameter | $C_u$ | 1.7 | Table 12.8-2 |
| Approximate Fundamental Period | $T_a$ | 0.469 | Equation 12.8-7 |
| Fundamental Period | T | 0.797 | Section 12.8.2 |
| Long Period Transition Period | $T_L$ | 12 | Figure 22-12 |
| Seismic Response Coefficient | $C_s$ | 0.0452 | Equation 12.8-2 |
| Structural Period Exponent | k | 1.1485 | Section 12.8.3 |

**Table 1.5:** Seismic Deign Variables

In order to effectively calculate the overturning moments and base shear due to seismic loads, it was necessary to calculate the buildings total weight, which was done by determining each individual floors weight. Refer to Appendix D for the detailed calculations of each floors weight. In Table 1.6 the base shear and overturning moments due to seismic loading for each story level can be found. In Figure 1.14 a seismic loading diagram can be seen which shows the story forces and story shears at each floor level.

| Base Shear and Overturning Moment Distribution | | | | | | | | | k = 1.1485<br>V = 463.7 |
|---|---|---|---|---|---|---|---|---|---|
| Story | Floor Area | $h_x$ (ft.) | Story Weight (PSF) | Story Weight (k) | $w_x h_x^k$ | $C_{vx}$ | Lateral Force $F_x$ (k) | Story Shear $V_x$ (k) | $M_x$ (ft-k) |
| First | 12235 | 0.0 | 177.26 | 2168.78 | 0 | 0.00 | 0.00 | 463.70 | 0.0 |
| Second | 12200 | 14.0 | 160.42 | 1957.12 | 40546 | 0.09 | 41.12 | 463.70 | 287.8 |
| Third | 12200 | 26.0 | 160.39 | 1956.76 | 82534 | 0.18 | 83.70 | 422.58 | 1674.0 |
| Fourth | 12200 | 38.0 | 160.56 | 1958.83 | 127755 | 0.28 | 129.56 | 338.88 | 4146.0 |
| Fifth | 12200 | 50.0 | 162.79 | 1986.04 | 177523 | 0.39 | 180.04 | 209.31 | 7921.6 |
| Roof | 11500 | 67.2 | 20.00 | 230.00 | 28871 | 0.06 | 29.28 | 29.28 | 1715.8 |
| | | | Total | 10258 | 457229 | | | | |

**Table 1.6:** Base Shear and Overturning Moment

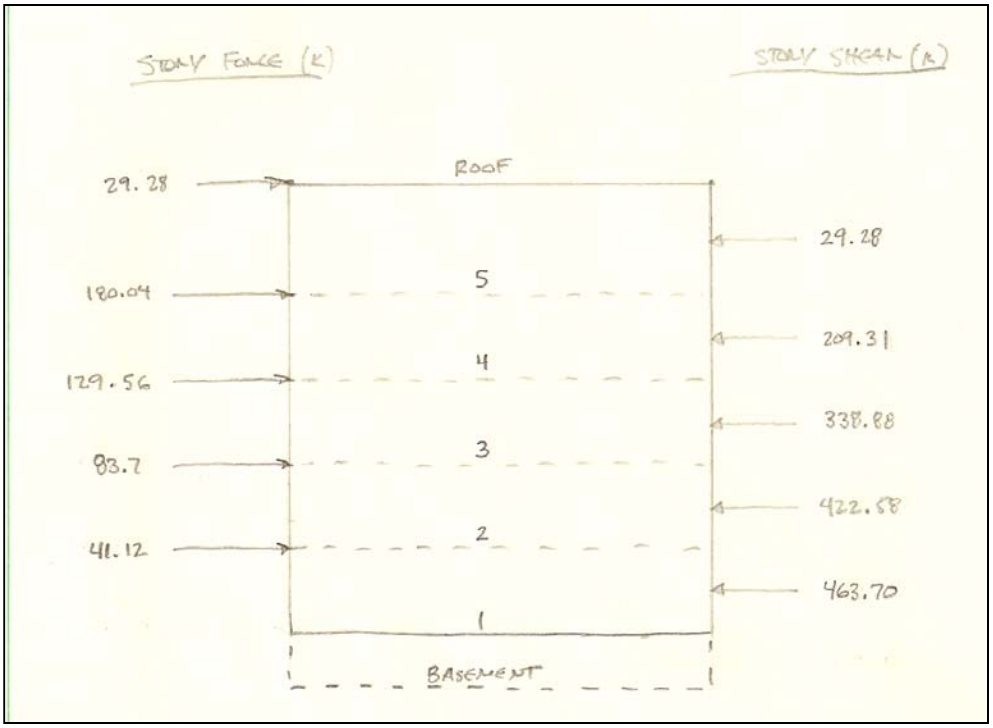



**Figure 1.14:** Story Force and Story Shear

# Load Distribution

**Load Path**

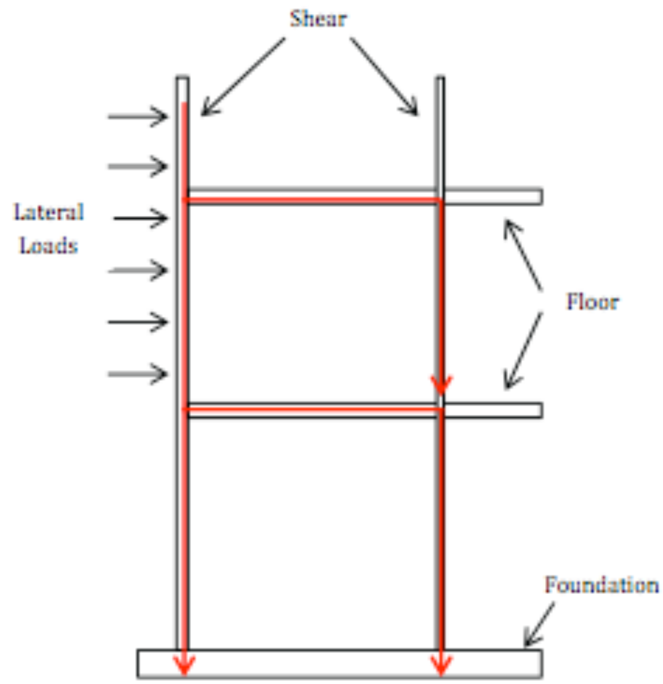



**Figure 1.15:** Load Path Diagram

In order to get the lateral loads that are applied to the building, either wind or seismic loads, through the building and into the ground there needs to be a clear path. This load path is governed by the concept of relative stiffness, which states that the most rigid members in a building draw the most forces to them. In the case of CityFlatsHotel, lateral forces come in contact with the exterior of the building, are then transmitted through the rigid diaphragms, to the masonry shear walls, and down into the foundation in order to disperse into the ground. This load path is shown in Figure 1.15. The exterior shear walls with longer spans resist the majority of the lateral forces due to the minimal resistance the slab provides. The steel columns that are scattered throughout the building only transfers gravity loads from the transfer beams to the foundation.

**Center of Rigidity and Center of Mass**

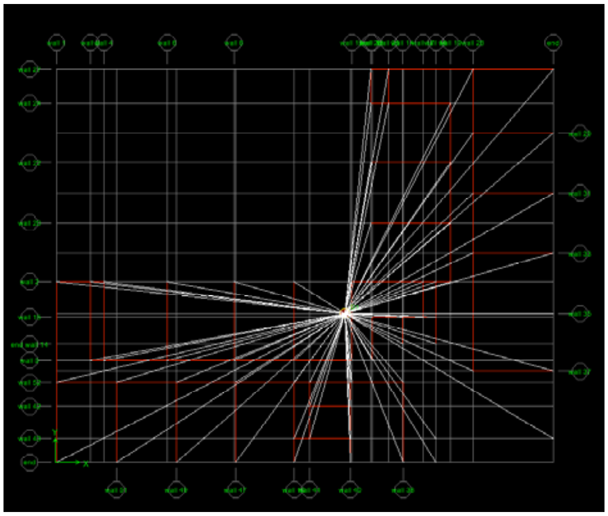


**Figure 1.16:** Center of Mass

Every concrete masonry wall in the CityFlatsHotel is essentially a shear wall because they are all reinforced and grouted. For this assignment, the shear walls analyzed consisted of walls with minimal or no openings for windows. Figure 1.17 has the shear wall number assignments for each shear wall as reference to what shear walls are being discussed throughout the analysis. Exterior and core shear walls are 12" thick while the interior shear walls are 8" thick. These walls vary in length and are located at different distances from the center of rigidity, which is based on the thickness, height of wall from base, and length of wall. Figure 1.16 shows the center of mass of CityFlatsHotel that was calculated using ETABS.

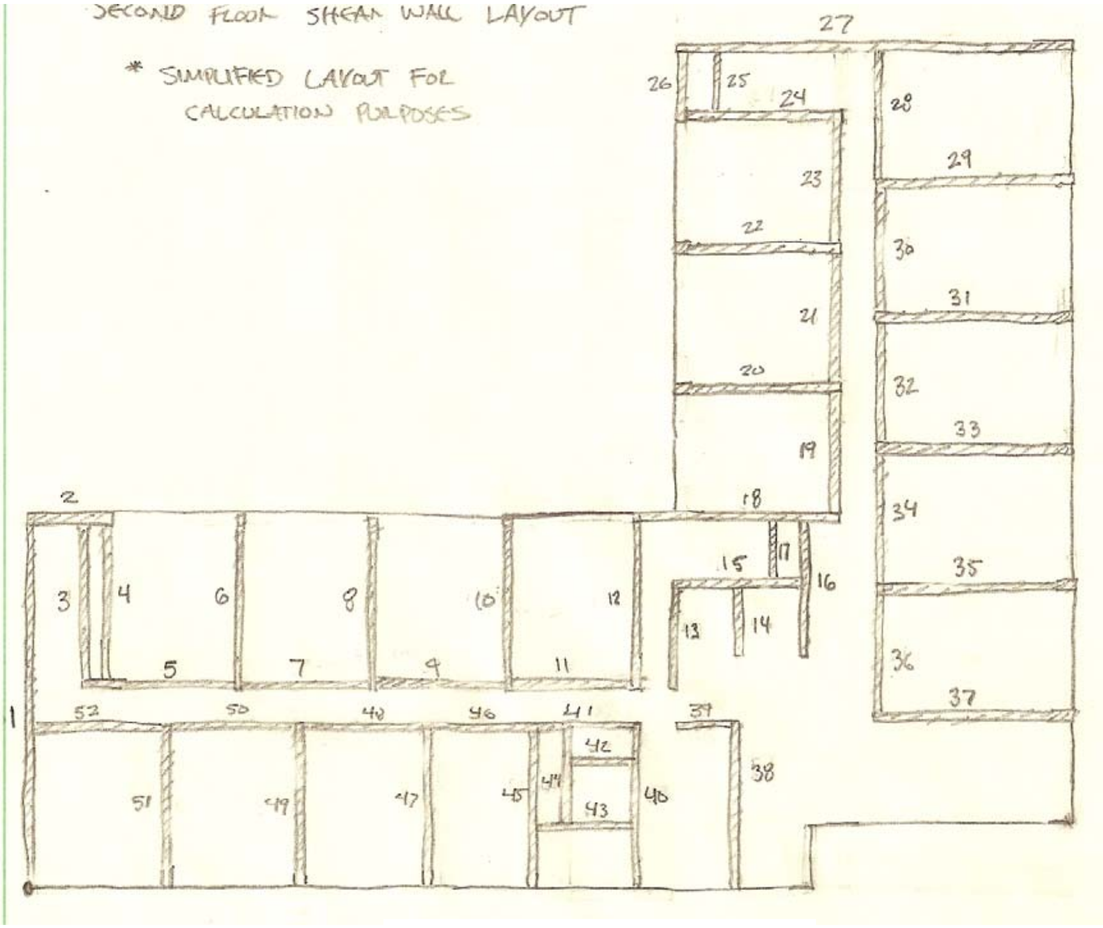



**Figure 1.17:** Number Shear Walls

Individual wall rigidities are shown in Tables in Appendix C. The rigidities of each wall were calculated using the following equation:

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

Using the rigidities it is possible to determine the center of rigidity of each floor using the following equation:

$$Center\ of\ Rigidity = \frac{\Sigma[(R)(Distance\ between\ origin\ and\ element)]}{\Sigma R}$$

Since the building is made up of two rectangles, it becomes simpler to determine the center of mass of the building. The center of mass does not vary from floor to floor and is consistent throughout the building. Along with the center of mass, the center of rigidity values can be found in Table 1.7, which is a comparison of the ETABS results and hand calculations. The values differ because of the assumptions made for each calculation. The hand calculations for rigidity only account for the shear walls, whereas the ETABS model takes into account the floor diaphragms as well. The ETABS results will be used whenever the center of mass or center of rigidity is needed to complete remaining calculations. Detailed calculations can be found in Appendix C.

| ETABS vs. Hand Calculation Comparison | | | | | | |
|---|---|---|---|---|---|---|
| | Center of Rigidity | | | | Center of Mass | |
| | ETABS Calculation | | Hand Calculation | | ETABS Calculation | |
| | X | Y | X | Y | X | Y |
| Floor 5 | 1116.173 | 559.323 | - | - | 1093.144 | 569.535 |
| Floor 4 | 1075.520 | 583.098 | 992.7 | 548.2 | 1093.144 | 569.535 |
| Floor 3 | 1023.977 | 613.906 | 951.6 | 595.9 | 1093.144 | 569.535 |
| Floor 2 | 978.062 | 642.275 | 890.8 | 672.9 | 1093.144 | 569.535 |
| Floor 1 | 957.468 | 658.475 | - | - | 1093.144 | 569.535 |

**Table 1.7:** ETABS vs. Hand Calculations

**Relative Stiffness**

With the rigidity of the walls determined, the relative stiffness, which is the percentage of lateral force being distributed into each shear wall, can be determined. The relative stiffness will not be consistent throughout the entire height of the building, so each wall on every floor can be found using the following equation:

$$Relative\ Stiffness = \frac{R}{\Sigma R}$$

The values for the North/South walls at every floor can be found in Table 1.8, and the values for the East/West walls at every floor can be found in Table 1.9 below. By determining the relative stiffness of each wall, these values can be directly applied to the loads at each floor to determine how much of the load each wall will have to resist. Appendix C shows detailed calculations for the relative stiffness of the individual walls.

| Relative Stiffness (%) | | | | | |
|---|---|---|---|---|---|
| North - South Force | | | | | |
| | Floor 1 | Floor 2 | Floor 3 | Floor 4 | Floor 5 |
| Wall 1 | - | 27.96 | 35.37 | 39.31 | - |
| Wall 3 | - | 5.42 | 5.00 | 4.50 | - |
| Wall 4 | - | 3.61 | 3.33 | 3.00 | - |
| Wall 6 | - | 3.61 | 3.33 | 3.00 | - |
| Wall 8 | - | 3.61 | 3.33 | 6.21 | - |
| Wall 10 | - | 3.61 | 3.33 | 3.00 | - |
| Wall 12 | - | 5.42 | 5.00 | 4.50 | - |
| Wall 13 | - | 1.51 | 1.23 | 1.04 | - |
| Wall 14 | - | 0.34 | 0.26 | 0.21 | - |
| Wall 16 | - | 3.15 | 2.72 | 2.37 | - |
| Wall 17 | - | 0.52 | 0.40 | 0.34 | - |
| Wall 19 | - | 1.96 | 1.68 | 1.46 | - |
| Wall 21 | - | 2.00 | 1.73 | 1.50 | - |
| Wall 23 | - | 1.91 | 1.64 | 1.43 | - |
| Wall 25 | - | 0.52 | 0.40 | 0.34 | - |
| Wall 26 | - | 0.52 | 0.40 | 0.34 | - |
| Wall 28 | - | 3.15 | 2.72 | 2.37 | - |
| Wall 30 | - | 2.00 | 1.73 | 1.50 | - |
| Wall 32 | - | 2.00 | 1.73 | 1.50 | - |
| Wall 34 | - | 2.00 | 1.73 | 1.50 | - |
| Wall 36 | - | 1.83 | 1.56 | 1.35 | - |
| Wall 38 | - | 3.61 | 3.33 | 3.00 | - |
| Wall 40 | - | 3.61 | 3.33 | 3.00 | - |
| Wall 44 | - | 1.67 | 1.42 | 1.23 | - |
| Wall 45 | - | 3.61 | 3.33 | 3.00 | - |
| Wall 47 | - | 3.61 | 3.33 | 3.00 | - |
| Wall 49 | - | 3.61 | 3.33 | 3.00 | - |
| Wall 51 | - | 3.61 | 3.33 | 3.00 | - |

**Table 1.8:** Relative Stiffness in North-South Direction

| Relative Stiffness (%) | | | | | |
|---|---|---|---|---|---|
| East - West Force | | | | | |
| | Floor 1 | Floor 2 | Floor 3 | Floor 4 | Floor 5 |
| Wall 2 | - | 1.99 | 1.64 | 1.44 | - |
| Wall 5 | - | 3.46 | 3.14 | 2.91 | - |
| Wall 7 | - | 2.50 | 2.18 | 1.98 | - |
| Wall 9 | - | 1.94 | 1.64 | 1.47 | - |
| Wall 11 | - | 1.68 | 1.41 | 1.25 | - |
| Wall 15 | - | 4.05 | 3.57 | 3.25 | - |
| Wall 18 | - | 8.89 | 8.79 | 8.51 | - |
| Wall 20 | - | 4.07 | 3.79 | 3.54 | - |
| Wall 22 | - | 4.07 | 3.79 | 3.54 | - |
| Wall 24 | - | 6.11 | 5.68 | 5.32 | - |
| Wall 27 | - | 27.23 | 34.03 | 38.92 | - |
| Wall 29 | - | 4.07 | 3.79 | 3.54 | - |
| Wall 31 | - | 4.07 | 3.79 | 3.54 | - |
| Wall 33 | - | 4.07 | 3.79 | 3.54 | - |
| Wall 35 | - | 4.07 | 3.79 | 3.54 | - |
| Wall 37 | - | 4.07 | 3.79 | 3.54 | - |
| Wall 39 | - | 1.36 | 1.12 | 0.99 | - |
| Wall 41 | - | 1.60 | 1.33 | 1.18 | - |
| Wall 42 | - | 0.78 | 0.62 | 0.54 | - |
| Wall 43 | - | 1.60 | 1.33 | 1.18 | - |
| Wall 46 | - | 1.81 | 1.52 | 1.36 | - |
| Wall 48 | - | 1.85 | 1.56 | 1.40 | - |
| Wall 50 | - | 1.94 | 1.64 | 1.47 | - |
| Wall 52 | - | 2.71 | 2.28 | 2.04 | - |

**Table 1.9:** Relative Stiffness in East-West Direction

*Floor 1 and Floor 5 were not calculated by hand since the layout differs from the other floors.

## Torsion

Torsion occurs when the center of rigidity and the center of mass locations do not coincide. Eccentricity, which is the distance between the center of rigidity and center of mass, induces a moment that creates additional forces on the building. The resulting force is the torsional shear. When determining the torsional effects on the CityFlatsHotel, two different types of torsional moments need to be taken into account. According to ASCE 7-05, torsion for rigid diaphragms is the sum of the inherent torsional moment and the accidental torsional moment. The inherent torsional moment, $M_t$, is the caused by the eccentricity between the center of rigidity and center of mass. The lateral force exerted on the building at a specified floor level, times the eccentricity, will give the inherent torsional moment. The accidental torsional moment, $M_{ta}$, is caused by an assumed displacement of the center of mass, due to the rigidity of the slab. This displacement is equal to 5% of the center of mass dimension each way from the actual location perpendicular to the direction of the applied force. Torsional moments produced can be seen in Tables 1.10 and 1.11. Detailed calculations can be found in Appendix D.

| Overall Building Torsion | | | | | |
|---|---|---|---|---|---|
| North/South Direction | | | | | |
| Story Level | Factored Lateral Force (k) | COR-COM (ft.) | $M_t$ (ft-k) | $M_{ta}$ (ft-k) | $M_{t,tot}$ (ft-k) |
| Story 5 | 72.7 | 1.92 | 139.6 | 662.3 | 801.9 |
| Story 4 | 62.5 | -1.47 | -91.9 | 569.4 | 477.5 |
| Story 3 | 60.1 | -5.76 | -346.2 | 547.5 | 201.3 |
| Story 2 | 56.9 | -9.59 | -545.7 | 518.4 | -27.3 |
| Story 1 | 27.6 | -11.31 | -312.2 | 251.4 | -60.7 |
| | | | | Total: | 1392.7 |

**Table 1.10:** Torsion in North/South Direction

| Overall Building Torsion | | | | | |
|---|---|---|---|---|---|
| East/West Direction | | | | | |
| Story Level | Factored Lateral Force (k) | COR-COM (ft.) | $M_t$ (ft-k) | $M_{ta}$ (ft-k) | $M_{t,tot}$ (ft-k) |
| Story 5 | 48.4 | -0.84 | -40.7 | 229.9 | 189.2 |
| Story 4 | 41.5 | 1.13 | 46.9 | 197.1 | 244.0 |
| Story 3 | 39.6 | 3.7 | 146.5 | 188.1 | 334.6 |
| Story 2 | 37.2 | 6.06 | 225.4 | 176.7 | 402.1 |
| Story 1 | 17.9 | 7.41 | 132.6 | 85.0 | 217.7 |
| | | | | Total | 1387.7 |

**Table 1.11:** Torsion in East/West Direction

# Shear

The overall shear force at each level is the combination of direct and torsional shear. Direct shear forces relate to the relative stiffness of the shear walls, whereas the torsional shear forces relate to the torsional moments produced on each floor as a result of the wind or seismic loads.

### Direct Shear

The distribution of the lateral forces among the shear walls at each level is considered the direct shear. These lateral forces are directed through the load path where, the wall with larger shear wall stiffness resists the larger load. Tables 1.12 and 1.13 show the direct shears applied to each wall for each floor level. Detailed calculations for obtaining the direct shear for the North/South and East/West direction may be found in Appendix E.

| North/South Direct Shear | | | | | | |
|---|---|---|---|---|---|---|
| 1.2D+1.6W+1.0L+0.5L$_r$ | | Roof | Floor 5 | Floor 4 | Floor 3 | Floor 2 |
| Force (k) | | 29.42 | 45.42 | 39.09 | 37.54 | 35.54 |
| Factored | | 47.07 | 72.67 | 62.54 | 60.06 | 56.86 |
| Distributed Force (k) | Wall 1 | 21.11 | 29.52 | 22.12 | 16.79 | 10.99 |
| | Wall 3 | 2.05 | 3.38 | 3.12 | 3.25 | 3.25 |
| | Wall 4 | 1.37 | 2.25 | 2.08 | 2.17 | 2.17 |
| | Wall 6 | 1.37 | 2.25 | 2.08 | 2.17 | 2.17 |
| | Wall 8 | 1.37 | 2.25 | 2.08 | 2.17 | 2.17 |
| | Wall 10 | 1.37 | 2.25 | 2.08 | 2.17 | 2.17 |
| | Wall 12 | 2.05 | 3.38 | 3.12 | 3.25 | 3.25 |
| | Wall 13 | 0.46 | 0.78 | 0.77 | 0.90 | 1.21 |
| | Wall 14 | 0.09 | 0.16 | 0.16 | 0.20 | 0.33 |
| | Wall 16 | 1.06 | 1.78 | 1.70 | 1.89 | 2.16 |
| | Wall 17 | 0.15 | 0.25 | 0.25 | 0.31 | 0.09 |
| | Wall 19 | 0.65 | 1.10 | 1.05 | 1.18 | 1.37 |
| | Wall 21 | 0.67 | 1.13 | 1.08 | 1.20 | 1.39 |
| | Wall 23 | 0.63 | 1.07 | 1.03 | 1.15 | 1.34 |
| | Wall 25 | 0.15 | 0.25 | 0.25 | 0.31 | 0.49 |
| | Wall 26 | 0.15 | 0.25 | 0.25 | 0.31 | 0.49 |
| | Wall 28 | 1.06 | 1.78 | 1.70 | 1.89 | 2.16 |
| | Wall 30 | 0.67 | 1.13 | 1.08 | 1.20 | 1.39 |
| | Wall 32 | 0.67 | 1.13 | 1.08 | 1.20 | 1.39 |
| | Wall 34 | 0.67 | 1.13 | 1.08 | 1.20 | 1.39 |
| | Wall 36 | 0.60 | 1.01 | 0.97 | 1.10 | 1.30 |
| | Wall 38 | 1.37 | 2.25 | 2.08 | 2.17 | 2.17 |
| | Wall 40 | 1.37 | 2.25 | 2.08 | 2.17 | 2.17 |
| | Wall 44 | 0.54 | 0.92 | 0.89 | 1.01 | 1.21 |
| | Wall 45 | 1.37 | 2.25 | 2.08 | 2.17 | 2.17 |
| | Wall 47 | 1.37 | 2.25 | 2.08 | 2.17 | 2.17 |
| | Wall 49 | 1.37 | 2.25 | 2.08 | 2.17 | 2.17 |
| | Wall 51 | 1.37 | 2.25 | 2.08 | 2.17 | 2.17 |

**Table 1.12:** North/South Direct Shear

| East/West Direct Shear | | | | | | |
|---|---|---|---|---|---|---|
| 0.9D+1.0E | | Roof | Floor 5 | Floor 4 | Floor 3 | Floor 2 |
| Force (k) | | 19.65 | 30.28 | 25.94 | 24.76 | 23.26 |
| Factored | | 31.44 | 48.45 | 41.50 | 39.62 | 37.22 |
| Distributed Force (k) | Wall 2 | 0.41 | 0.70 | 0.68 | 0.79 | 1.01 |
| | Wall 5 | 0.85 | 1.41 | 1.30 | 1.37 | 1.40 |
| | Wall 7 | 0.57 | 0.96 | 0.91 | 0.99 | 1.10 |
| | Wall 9 | 0.42 | 0.71 | 0.68 | 0.77 | 0.90 |
| | Wall 11 | 0.36 | 0.61 | 0.58 | 0.67 | 0.81 |
| | Wall 15 | 0.94 | 1.57 | 1.48 | 1.61 | 1.74 |
| | Wall 18 | 2.58 | 4.12 | 3.65 | 3.52 | 3.10 |
| | Wall 20 | 1.05 | 1.72 | 1.57 | 1.61 | 1.57 |
| | Wall 22 | 1.05 | 1.72 | 1.57 | 1.61 | 1.57 |
| | Wall 24 | 1.57 | 2.58 | 2.36 | 2.42 | 2.36 |
| | Wall 27 | 13.49 | 18.86 | 14.12 | 10.79 | 7.18 |
| | Wall 29 | 1.05 | 1.72 | 1.57 | 1.61 | 1.57 |
| | Wall 31 | 1.05 | 1.72 | 1.57 | 1.61 | 1.57 |
| | Wall 33 | 1.05 | 1.72 | 1.57 | 1.61 | 1.57 |
| | Wall 35 | 1.05 | 1.72 | 1.57 | 1.61 | 1.57 |
| | Wall 37 | 1.05 | 1.72 | 1.57 | 1.61 | 1.57 |
| | Wall 39 | 0.28 | 0.48 | 0.47 | 0.54 | 0.69 |
| | Wall 41 | 0.34 | 0.57 | 0.55 | 0.63 | 0.78 |
| | Wall 42 | 0.15 | 0.26 | 0.26 | 0.31 | 0.44 |
| | Wall 43 | 0.34 | 0.57 | 0.55 | 0.63 | 0.78 |
| | Wall 46 | 0.39 | 0.66 | 0.63 | 0.72 | 0.86 |
| | Wall 48 | 0.40 | 0.68 | 0.65 | 0.73 | 0.87 |
| | Wall 50 | 0.42 | 0.71 | 0.68 | 0.77 | 0.90 |
| | Wall 52 | 0.58 | 0.99 | 0.95 | 1.07 | 1.28 |

**Table 1.13:** East/West Direct Shear

**Torsional Shear**

Since torsion is present in the CityFlatsHotel structure, each shear wall has to resist torsional shear, due to the torsional moments caused on each floor by the eccentricity. The total torsional shear at each wall is dependant on the relative stiffness of each shear wall, where once again, the greater the relative stiffness, the greater the shear force on that wall. To determine the torsional shear, the following equation is used:

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

Where:

$V_{tot}$ = Total Story Shear

e = eccentricity

$d_i$ = distance from center of rigidity to shear wall

$R_i$ = relative stiffness of shear wall

J = torsional moment of inertia

The torsional shear forces were determined for the shear walls supporting floor 2 and can be found in Table 1.14. Additional detailed calculations for obtaining the torsional shear can be found in Appendix E.

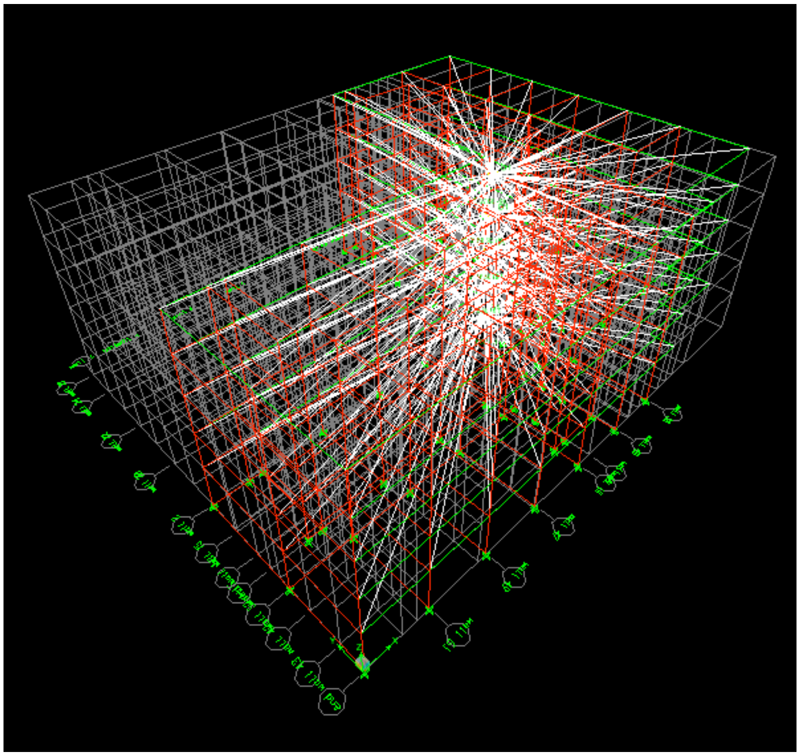


**Figure 1.18:** Center of Masses

| Torsional Shear in Shear Walls Supporting Floor 3 | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Factored Story Shear $V_{tot}$ (k) | Relative Stiffness $R_i$ | Distance from COM to COR e (in) | Distance from $Wall_i$ to COR $d_i$ (in) | $(R_i)(d_i^2)$ | Torsional Shear (k) |
| Wall 1 | N/S | 188.48 | 0.280 | 69.167 | 1017.977 | 289695 | 4.877 |
| Wall 3 | N/S | 188.48 | 0.054 | 69.167 | 891.977 | 43111 | 0.828 |
| Wall 4 | N/S | 188.48 | 0.036 | 69.167 | 841.977 | 25609 | 0.521 |
| Wall 6 | N/S | 188.48 | 0.036 | 69.167 | 605.977 | 13265 | 0.375 |
| Wall 8 | N/S | 188.48 | 0.036 | 69.167 | 357.977 | 4629 | 0.222 |
| Wall 10 | N/S | 188.48 | 0.036 | 69.167 | 133.977 | 648 | 0.083 |
| Wall 12 | N/S | 188.48 | 0.054 | 69.167 | 80.023 | 347 | 0.074 |
| Wall 13 | N/S | 188.48 | 0.015 | 69.167 | 156.023 | 367 | 0.040 |
| Wall 14 | N/S | 188.48 | 0.003 | 69.167 | 268.023 | 241 | 0.015 |
| Wall 16 | N/S | 188.48 | 0.031 | 69.167 | 392.023 | 4835 | 0.211 |
| Wall 17 | N/S | 188.48 | 0.005 | 69.167 | 344.023 | 615 | 0.031 |
| Wall 19 | N/S | 188.48 | 0.020 | 69.167 | 445.023 | 3880 | 0.149 |
| Wall 21 | N/S | 188.48 | 0.020 | 69.167 | 445.023 | 3970 | 0.153 |
| Wall 23 | N/S | 188.48 | 0.019 | 69.167 | 445.023 | 3791 | 0.146 |
| Wall 25 | N/S | 188.48 | 0.005 | 69.167 | 216.023 | 243 | 0.019 |
| Wall 26 | N/S | 188.48 | 0.005 | 69.167 | 150.023 | 117 | 0.013 |
| Wall 28 | N/S | 188.48 | 0.031 | 69.167 | 529.023 | 8805 | 0.285 |
| Wall 30 | N/S | 188.48 | 0.020 | 69.167 | 527.023 | 5568 | 0.181 |
| Wall 32 | N/S | 188.48 | 0.020 | 69.167 | 527.023 | 5568 | 0.181 |
| Wall 34 | N/S | 188.48 | 0.020 | 69.167 | 527.023 | 5568 | 0.181 |
| Wall 36 | N/S | 188.48 | 0.018 | 69.167 | 527.023 | 5070 | 0.165 |
| Wall 38 | N/S | 188.48 | 0.036 | 69.167 | 270.023 | 2634 | 0.167 |
| Wall 40 | N/S | 188.48 | 0.036 | 69.167 | 74.023 | 198 | 0.046 |
| Wall 44 | N/S | 188.48 | 0.017 | 69.167 | 77.977 | 102 | 0.022 |
| Wall 45 | N/S | 188.48 | 0.036 | 69.167 | 133.977 | 648 | 0.083 |
| Wall 47 | N/S | 188.48 | 0.036 | 69.167 | 351.977 | 4475 | 0.218 |
| Wall 49 | N/S | 188.48 | 0.036 | 69.167 | 571.977 | 11818 | 0.354 |
| Wall 51 | N/S | 188.48 | 0.036 | 69.167 | 795.977 | 22887 | 0.493 |
| Wall 2 | E/W | 125.536 | 0.020 | 44.371 | 60.094 | 72 | 0.009 |
| Wall 5 | E/W | 125.536 | 0.035 | 44.371 | 232.906 | 1877 | 0.059 |
| Wall 7 | E/W | 125.536 | 0.025 | 44.371 | 232.906 | 1356 | 0.043 |
| Wall 9 | E/W | 125.536 | 0.019 | 44.371 | 232.906 | 1050 | 0.033 |
| Wall 11 | E/W | 125.536 | 0.017 | 44.371 | 232.906 | 911 | 0.029 |
| Wall 15 | E/W | 125.536 | 0.041 | 44.371 | 69.906 | 198 | 0.021 |
| Wall 18 | E/W | 125.536 | 0.089 | 44.371 | 60.094 | 321 | 0.039 |
| Wall 20 | E/W | 125.536 | 0.041 | 44.371 | 280.094 | 3196 | 0.084 |
| Wall 22 | E/W | 125.536 | 0.041 | 44.371 | 504.094 | 10352 | 0.150 |
| Wall 24 | E/W | 125.536 | 0.061 | 44.371 | 726.094 | 32215 | 0.325 |
| Wall 27 | E/W | 125.536 | 0.272 | 44.371 | 852.094 | 197680 | 1.699 |
| Wall 29 | E/W | 125.536 | 0.041 | 44.371 | 614.094 | 15362 | 0.183 |
| Wall 31 | E/W | 125.536 | 0.041 | 44.371 | 390.094 | 6199 | 0.116 |
| Wall 33 | E/W | 125.536 | 0.041 | 44.371 | 166.094 | 1124 | 0.050 |
| Wall 35 | E/W | 125.536 | 0.041 | 44.371 | 57.906 | 137 | 0.017 |
| Wall 37 | E/W | 125.536 | 0.041 | 44.371 | 273.906 | 3056 | 0.082 |
| Wall 39 | E/W | 125.536 | 0.014 | 44.371 | 314.906 | 1353 | 0.031 |
| Wall 41 | E/W | 125.536 | 0.016 | 44.371 | 314.906 | 1584 | 0.037 |
| Wall 42 | E/W | 125.536 | 0.008 | 44.371 | 403.906 | 1270 | 0.023 |
| Wall 43 | E/W | 125.536 | 0.016 | 44.371 | 523.906 | 4384 | 0.061 |
| Wall 46 | E/W | 125.536 | 0.018 | 44.371 | 314.906 | 1790 | 0.042 |
| Wall 48 | E/W | 125.536 | 0.018 | 44.371 | 314.906 | 1833 | 0.043 |
| Wall 50 | E/W | 125.536 | 0.019 | 44.371 | 314.906 | 1920 | 0.045 |
| Wall 52 | E/W | 125.536 | 0.027 | 44.371 | 314.906 | 2685 | 0.062 |
| Torsional Moment on Inertia J = J = $\Sigma(R_i)(d_i^2)$ = | | | | | | 760627 | |

**Table 1.14:** Torsional Shear

**Shear Strength Check**

In order to verify if there is sufficient reinforcement in the shear walls, a shear strength check must be performed. According to ACI 318-08, the shear strength of a reinforced concrete masonry shear wall can be obtained by the following equation:

$$\boxed{V_n = A_{cv}[\alpha_c \lambda \sqrt{f'c} + \rho_t f_y]}$$

The shear wall strength checks performed for walls supporting floor 2 can be found in Table 1.15. Each shear wall was within the capacity determined by the shear strength, which verifies that the masonry reinforcement is adequately designed. Detailed calculations for shear strength can be found in Appendix E.

| Shear Wall Strength Check | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Supporting Floor 3 | | | | | | | | | | | |
| Floor | Direct Shear (k) | Torsional Shear (k) | Vu (k) | Vertical Reinforcement | Spacing (in) | Length (in) | Thickness (in) | $A_{cv}$ ($in^2$) | $\alpha_c$ | $\rho_t$ | $\Phi V_n$ (k) |
| Wall 1 | 72.74 | 4.88 | 77.62 | (2) #5 | 24 | 680 | 12 | 8160 | 2 | 0.00215 | 1337.9 |
| Wall 3 | 8.55 | 0.83 | 9.38 | (2) #5 | 24 | 277 | 12 | 3324 | 2 | 0.00215 | 544.99 |
| Wall 4 | 5.70 | 0.52 | 6.22 | (2) #5 | 24 | 277 | 12 | 3324 | 2 | 0.00215 | 544.99 |
| Wall 6 | 5.70 | 0.38 | 6.07 | (2) #5 | 24 | 277 | 8 | 2216 | 2 | 0.00323 | 470.67 |
| Wall 8 | 5.70 | 0.22 | 5.92 | (2) #5 | 24 | 277 | 8 | 2216 | 2 | 0.00323 | 470.67 |
| Wall 10 | 5.70 | 0.08 | 5.78 | (2) #5 | 24 | 277 | 8 | 2216 | 2 | 0.00323 | 470.67 |
| Wall 12 | 8.55 | 0.07 | 8.62 | (2) #5 | 24 | 277 | 12 | 3324 | 2 | 0.00215 | 544.99 |
| Wall 13 | 2.01 | 0.04 | 2.05 | (2) #5 | 24 | 165 | 12 | 1980 | 2 | 0.00215 | 324.63 |
| Wall 14 | 0.41 | 0.02 | 0.43 | (2) #5 | 24 | 96 | 12 | 1152 | 2 | 0.00215 | 188.88 |
| Wall 16 | 4.54 | 0.21 | 4.76 | (2) #5 | 24 | 220 | 12 | 2640 | 2 | 0.00215 | 432.85 |
| Wall 17 | 0.65 | 0.03 | 0.68 | (2) #5 | 24 | 112 | 12 | 1344 | 2 | 0.00215 | 220.36 |
| Wall 19 | 2.80 | 0.15 | 2.95 | (2) #5 | 24 | 214 | 8 | 1712 | 2 | 0.00323 | 363.62 |
| Wall 21 | 2.88 | 0.15 | 3.03 | (2) #5 | 24 | 216 | 8 | 1728 | 2 | 0.00323 | 367.02 |
| Wall 23 | 2.73 | 0.15 | 2.88 | (2) #5 | 24 | 212 | 8 | 1696 | 2 | 0.00323 | 360.22 |
| Wall 25 | 0.65 | 0.02 | 0.67 | (2) #5 | 24 | 112 | 12 | 1344 | 2 | 0.00215 | 220.36 |
| Wall 26 | 0.65 | 0.01 | 0.66 | (2) #5 | 24 | 112 | 12 | 1344 | 2 | 0.00215 | 220.36 |
| Wall 28 | 4.54 | 0.29 | 4.83 | (2) #5 | 24 | 226 | 8 | 1808 | 2 | 0.00323 | 384.01 |
| Wall 30 | 2.88 | 0.18 | 3.06 | (2) #5 | 24 | 216 | 8 | 1728 | 2 | 0.00323 | 367.02 |
| Wall 32 | 2.88 | 0.18 | 3.06 | (2) #5 | 24 | 216 | 8 | 1728 | 2 | 0.00323 | 367.02 |
| Wall 34 | 2.88 | 0.18 | 3.06 | (2) #5 | 24 | 216 | 8 | 1728 | 2 | 0.00323 | 367.02 |
| Wall 36 | 2.59 | 0.16 | 2.75 | (2) #5 | 24 | 208 | 8 | 1664 | 2 | 0.00323 | 353.42 |
| Wall 38 | 5.70 | 0.17 | 5.87 | (2) #5 | 24 | 277 | 8 | 2216 | 2 | 0.00323 | 470.67 |
| Wall 40 | 5.70 | 0.05 | 5.75 | (2) #5 | 24 | 277 | 8 | 2216 | 2 | 0.00323 | 470.67 |
| Wall 44 | 2.35 | 0.02 | 2.37 | (2) #5 | 24 | 201 | 8 | 1608 | 2 | 0.00323 | 341.53 |
| Wall 45 | 5.70 | 0.08 | 5.78 | (2) #5 | 24 | 277 | 8 | 2216 | 2 | 0.00323 | 470.67 |
| Wall 47 | 5.70 | 0.22 | 5.92 | (2) #5 | 24 | 277 | 8 | 2216 | 2 | 0.00323 | 470.67 |
| Wall 49 | 5.70 | 0.35 | 6.05 | (2) #5 | 24 | 277 | 8 | 2216 | 2 | 0.00323 | 470.67 |
| Wall 51 | 5.70 | 0.49 | 6.19 | (2) #5 | 24 | 277 | 8 | 2216 | 2 | 0.00323 | 470.67 |
| Wall 2 | 1.79 | 0.01 | 1.80 | (2) #5 | 24 | 186 | 12 | 2232 | 2 | 0.00215 | 365.95 |
| Wall 5 | 3.56 | 0.06 | 3.62 | (2) #5 | 24 | 276 | 8 | 2208 | 2 | 0.00323 | 468.97 |
| Wall 7 | 2.44 | 0.04 | 2.48 | (2) #5 | 24 | 240 | 8 | 1920 | 2 | 0.00323 | 407.8 |
| Wall 9 | 1.82 | 0.03 | 1.85 | (2) #5 | 24 | 216 | 8 | 1728 | 2 | 0.00323 | 367.02 |
| Wall 11 | 1.55 | 0.03 | 1.58 | (2) #5 | 24 | 204 | 8 | 1632 | 2 | 0.00323 | 346.63 |
| Wall 15 | 4.00 | 0.02 | 4.02 | (2) #5 | 24 | 248 | 12 | 2976 | 2 | 0.00215 | 487.94 |
| Wall 18 | 10.35 | 0.04 | 10.39 | (2) #5 | 24 | 355 | 12 | 4260 | 2 | 0.00215 | 698.46 |
| Wall 20 | 4.34 | 0.08 | 4.42 | (2) #5 | 24 | 297 | 8 | 2376 | 2 | 0.00323 | 504.65 |
| Wall 22 | 4.34 | 0.15 | 4.49 | (2) #5 | 24 | 297 | 8 | 2376 | 2 | 0.00323 | 504.65 |
| Wall 24 | 6.50 | 0.32 | 6.83 | (2) #5 | 24 | 297 | 12 | 3564 | 2 | 0.00215 | 584.34 |
| Wall 27 | 46.47 | 1.70 | 48.17 | (2) #5 | 24 | 684 | 12 | 8208 | 2 | 0.00215 | 1345.8 |
| Wall 29 | 4.34 | 0.18 | 4.52 | (2) #5 | 24 | 297 | 8 | 2376 | 2 | 0.00323 | 504.65 |
| Wall 31 | 4.34 | 0.12 | 4.45 | (2) #5 | 24 | 297 | 8 | 2376 | 2 | 0.00323 | 504.65 |
| Wall 33 | 4.34 | 0.05 | 4.39 | (2) #5 | 24 | 297 | 8 | 2376 | 2 | 0.00323 | 504.65 |
| Wall 35 | 4.34 | 0.02 | 4.35 | (2) #5 | 24 | 297 | 8 | 2376 | 2 | 0.00323 | 504.65 |
| Wall 37 | 4.34 | 0.08 | 4.42 | (2) #5 | 24 | 297 | 8 | 2376 | 2 | 0.00323 | 504.65 |
| Wall 39 | 1.23 | 0.03 | 1.26 | (2) #5 | 24 | 188 | 8 | 1504 | 2 | 0.00323 | 319.44 |
| Wall 41 | 1.46 | 0.04 | 1.50 | (2) #5 | 24 | 200 | 8 | 1600 | 2 | 0.00323 | 339.83 |
| Wall 42 | 0.67 | 0.02 | 0.69 | (2) #5 | 24 | 152 | 8 | 1216 | 2 | 0.00323 | 258.27 |
| Wall 43 | 1.46 | 0.06 | 1.53 | (2) #5 | 24 | 200 | 8 | 1600 | 2 | 0.00323 | 339.83 |
| Wall 46 | 1.68 | 0.04 | 1.72 | (2) #5 | 24 | 210 | 8 | 1680 | 2 | 0.00323 | 356.82 |
| Wall 48 | 1.72 | 0.04 | 1.77 | (2) #5 | 24 | 212 | 8 | 1696 | 2 | 0.00323 | 360.22 |
| Wall 50 | 1.82 | 0.04 | 1.86 | (2) #5 | 24 | 216 | 8 | 1728 | 2 | 0.00323 | 367.02 |
| Wall 52 | 2.52 | 0.06 | 2.58 | (2) #5 | 24 | 210 | 12 | 2520 | 2 | 0.00215 | 413.17 |

**Table 1.15:** Shear Strength Check

# Drift and Displacement

Overall drift of nonstructural members is a concern and should be limited as much as possible. The drift is a serviceability consideration that relates the rigidity of each of the shear walls. As the height of the building increases building drift and deformation become larger factors. According to IBC 2006, wind load drift is limited to an allowable drift of Δ = l/400, whereas seismic drift is limited to an allowable drift of $\Delta = 0.02h_{sx}$. Wind controls the drift in the North/South direction of the CityFlatsHotel, while seismic forces control the drift in the East/West direction. The allowable building drift limit for CityFlatsHotel is:

$$\Delta\text{limit} = 1852\text{”} / 400 = 4.63\text{”}$$

Each floor is examined independently to determine an approximate story displacement and story drift. In order to determine the overall building drift, the displacement and story drift of each individual floor is summed. The following equation was used to determine the overall building drift:

$$\Delta\text{cantilever} = \Delta\text{flexural} + \Delta\text{shear}$$

Detailed hand calculations used to determine the drift and displacement can be found in Appendix F. Table 1.16 is a summary of story displacement for wall 10.

| Wall 10 Story Displacement | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Floor Supported | Lateral Force (k) | $E_c$ (ksi) | $E_r$ (ksi) | I (in$^4$) | Thickness (in) | Length (in) | Height (in) | $\Delta_{flex}$ | $\Delta_{shear}$ | Story Dissplacement (in) | Story Drift (in) | Allowable Story Drift (in) |
| Roof | 1.37 | 2577 | 1031 | 14169289 | 8 | 277 | 779 | 0.005891 | 0.000559 | 0.006450 | 0.0000083 | 1.9475 |
| Floor 5 | 2.25 | 2577 | 1031 | 14169289 | 8 | 277 | 600 | 0.004440 | 0.000710 | 0.005149 | 0.0000086 | 1.5 |
| Floor 4 | 2.08 | 2577 | 1031 | 14169289 | 8 | 277 | 456 | 0.001803 | 0.000499 | 0.002302 | 0.0000050 | 1.14 |
| Floor 3 | 2.17 | 2577 | 1031 | 14169289 | 8 | 277 | 312 | 0.000602 | 0.000356 | 0.000957 | 0.0000031 | 0.78 |
| Floor 2 | 2.17 | 2577 | 1031 | 14169289 | 8 | 277 | 168 | 0.000094 | 0.000191 | 0.000285 | 0.0000017 | 0.42 |
| Total Wall Displacement (in) | | | | | | | | | | 0.015143 | | |

**Table 1.16:** Example Story Displacement

# Overturning Moments

Due to the lateral forces and moments that are exerted on the building, overturning affects must be taken into consideration. These overturning moments are a concern because of the impact they potentially have on the foundation system. A calculation must be conducted to determine if the building dead load is sufficient to resist any impact of the overturning moments. As shown in Table 1.17, total overturning moments are provided due to wind and seismic loads. In order to verify that the dead load is adequate to resist overturning moments due to wind and seismic loads, the stresses due to the lateral loads are compared to the stresses due to the building self-weight. The analysis results of the CityFlatsHotel conclude that stresses due to lateral loads are minimal compared to the dead load stresses, therefore the foundation experiences minimal overturning effects. However, a force will be present along the perimeter of the building due to the moment exerted on the structure. Detailed calculations for overturning moments are in Appendix G.

| Overturning Moments | | | | | | |
|---|---|---|---|---|---|---|
| Floor | Height Above Ground Z (ft) | Story Height (ft) | N/S Wind Forces | | E/W Seismic Forces | |
| | | | Lateral Force $F_x$ (k) | Total Moment $M_x$ (ft-k) | Lateral Force $F_x$ (k) | Total Moment $M_x$ (ft-k) |
| Roof | 64.92 | 14.92 | 29.42 | 39.17 | 29.28 | 1715.8 |
| Floor 5 | 50 | 12 | 45.42 | 435.99 | 180.04 | 7921.6 |
| Floor 4 | 38 | 12 | 39.09 | 703.68 | 129.56 | 4146 |
| Floor 3 | 26 | 12 | 37.54 | 952.72 | 83.7 | 1674 |
| Floor 2 | 14 | 14 | 35.54 | 1177.79 | 41.12 | 287.8 |
| Floor 1 | 0 | 0 | 17.22 | 1283.67 | 0 | 0 |
| | | Total = | 204.23 | 4593.02 | 463.7 | 15745.2 |

**Table 1.17:** Overturning Moments

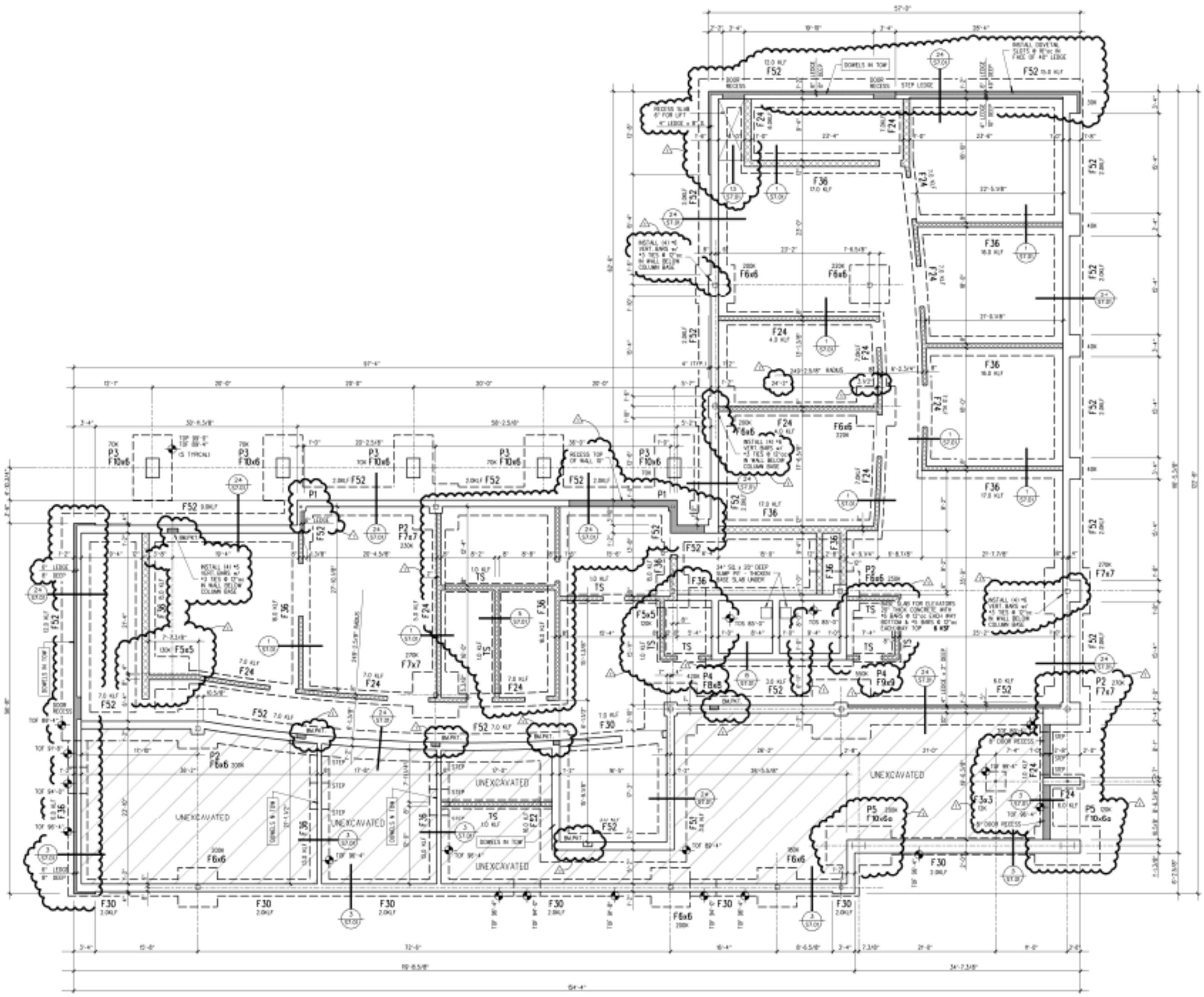
# Conclusion

Creating a model in ETABS and completing a thorough investigation of the lateral resisting system, by applying wind and seismic loads, provided a basic analysis of the CityFlatsHotel's existing lateral system. By evaluating the basic load combinations as defined by ASCE 7-05, it was determined through ETABS that the load case 1.2D+1.6W+1.0L+0.5$L_r$ controls in the North/South direction, and 0.9D+1.0E controls in the East/West direction. These results are due to the overall shape, size, and layout of CityFlatsHotel.

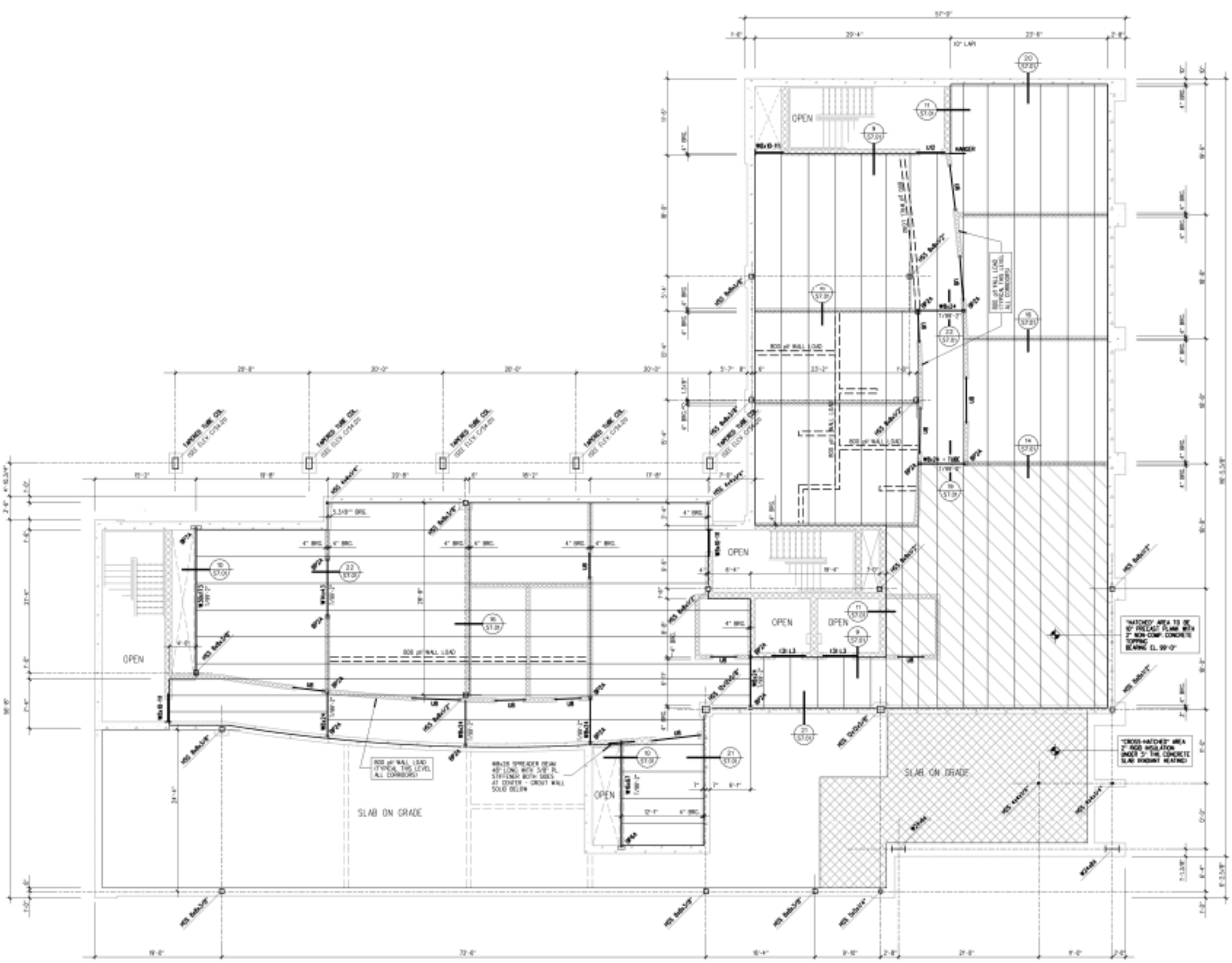
In order to apply the proper lateral loads to the structure it was necessary to revise the wind and seismic analysis performed in Technical Report 1. These corrected loads were applied to the ETABS model, which was used as a reference to verify that the model and hand calculations were providing similar and reasonable results. It was found that the center of rigidity values differed between the ETABS model and hand calculations. This is because the hand calculations only take into account the shear walls, and ignoring the floor diaphragm, which is included in the computer model analysis. As a result the values from the computer model for center of rigidity and center of mass were used in the remaining calculations.

Torsion was present in the building due to the eccentricity between the center of mass and rigidity. This created a torsional shear in addition to the direct shear, which was already acting on the shear walls. A shear strength check was performed to determine if the reinforcement and thickness of the shear walls was designed adequately to resist the total shear. The overall building drift was determined by ETABS and by hand calculations to be within the allowable code limitations. However, because the calculations neglect that the fact that the interior core shear walls act as a unit, the drifts and displacements can only be considered an approximation. Overturning moments were present due to the lateral loads on the building, but a stress check determined that the self-weight of the building resists the overturning moments and the impact on the foundations due to overturning is minimal. These checks conclude that the shear walls designed are adequate to resist the load combinations applied to the CityFlatsHotel.

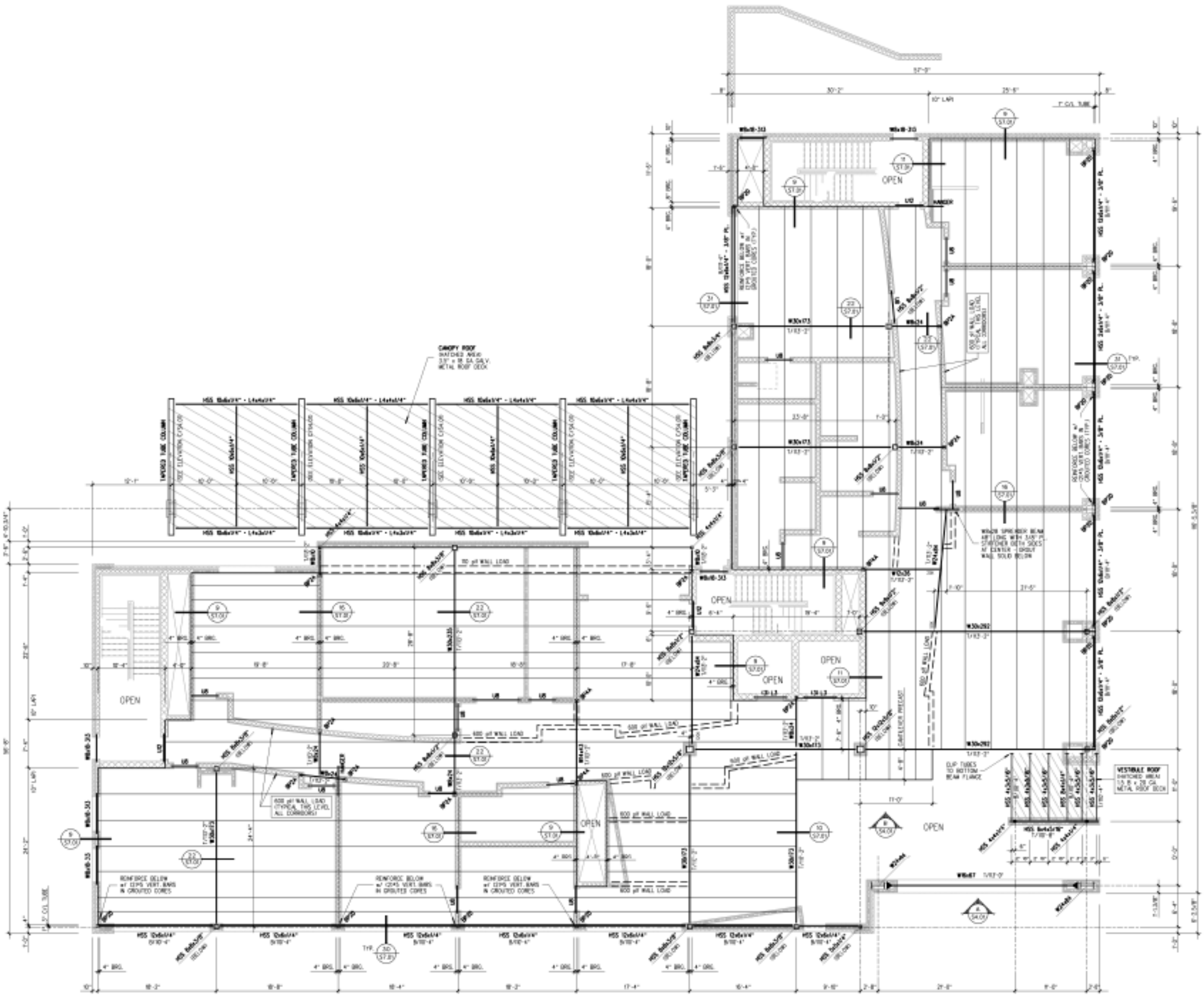
# Appendix A: Plans



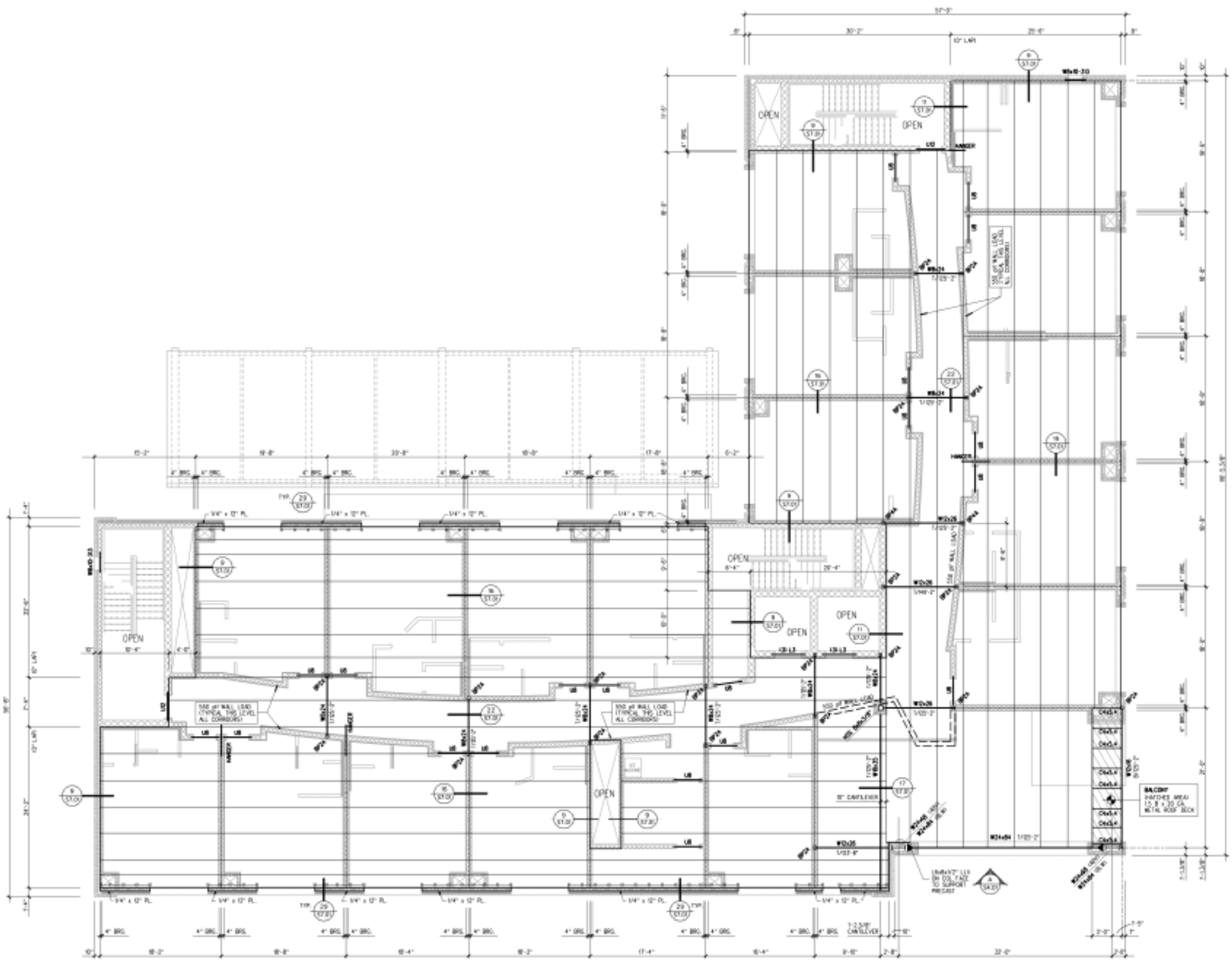
Foundation Plan



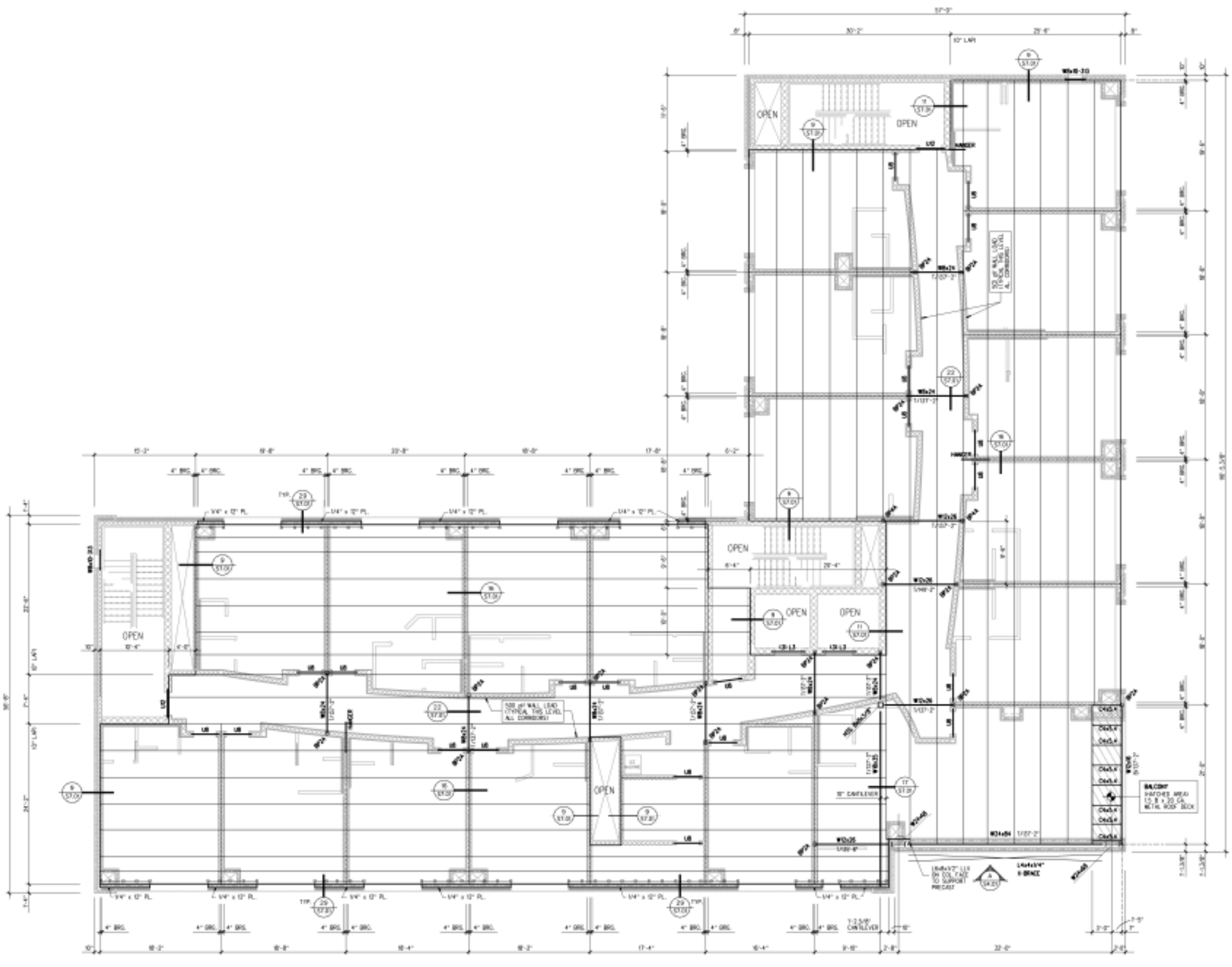

First Level Framing Plan



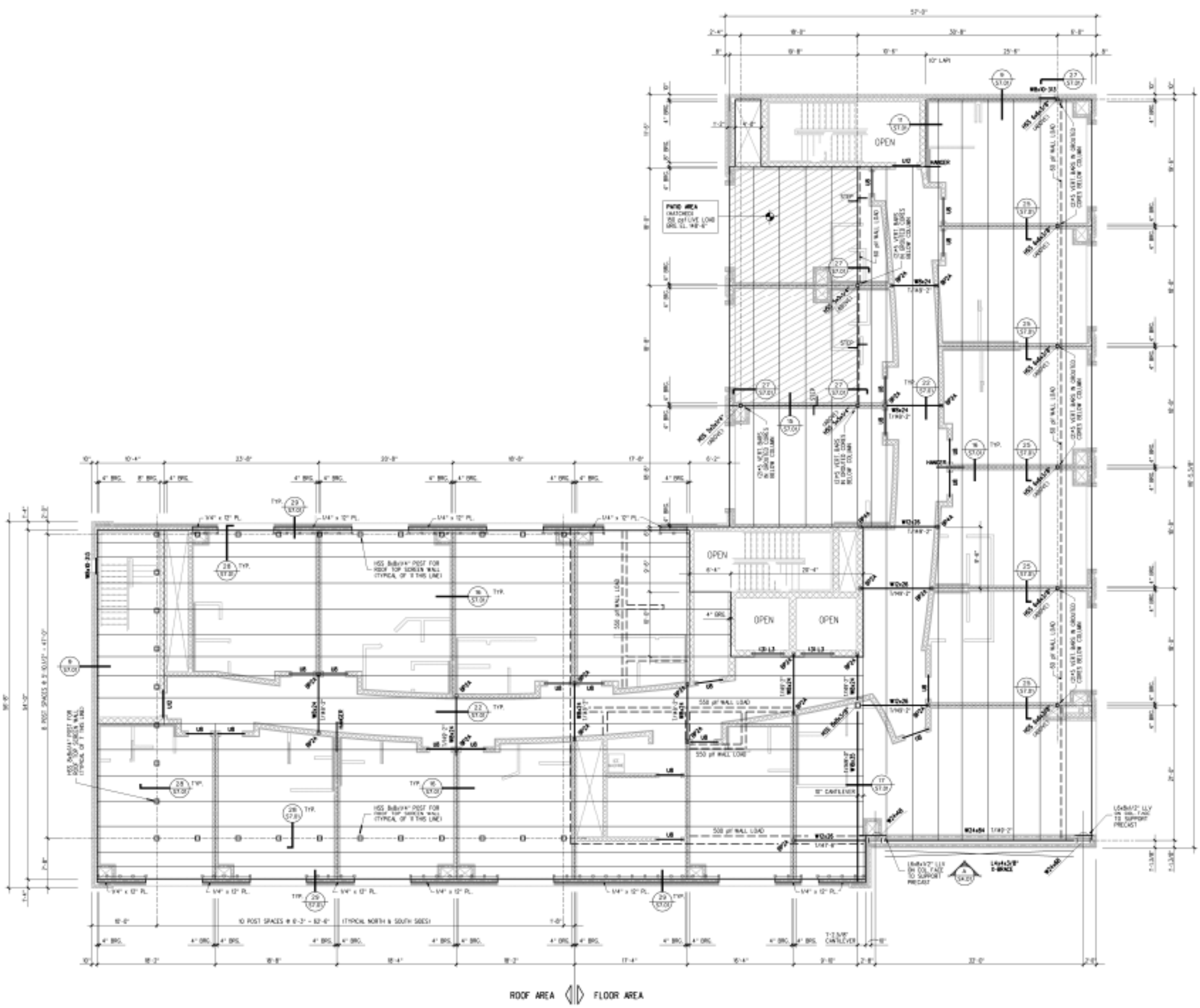
Second Level Framing Plan



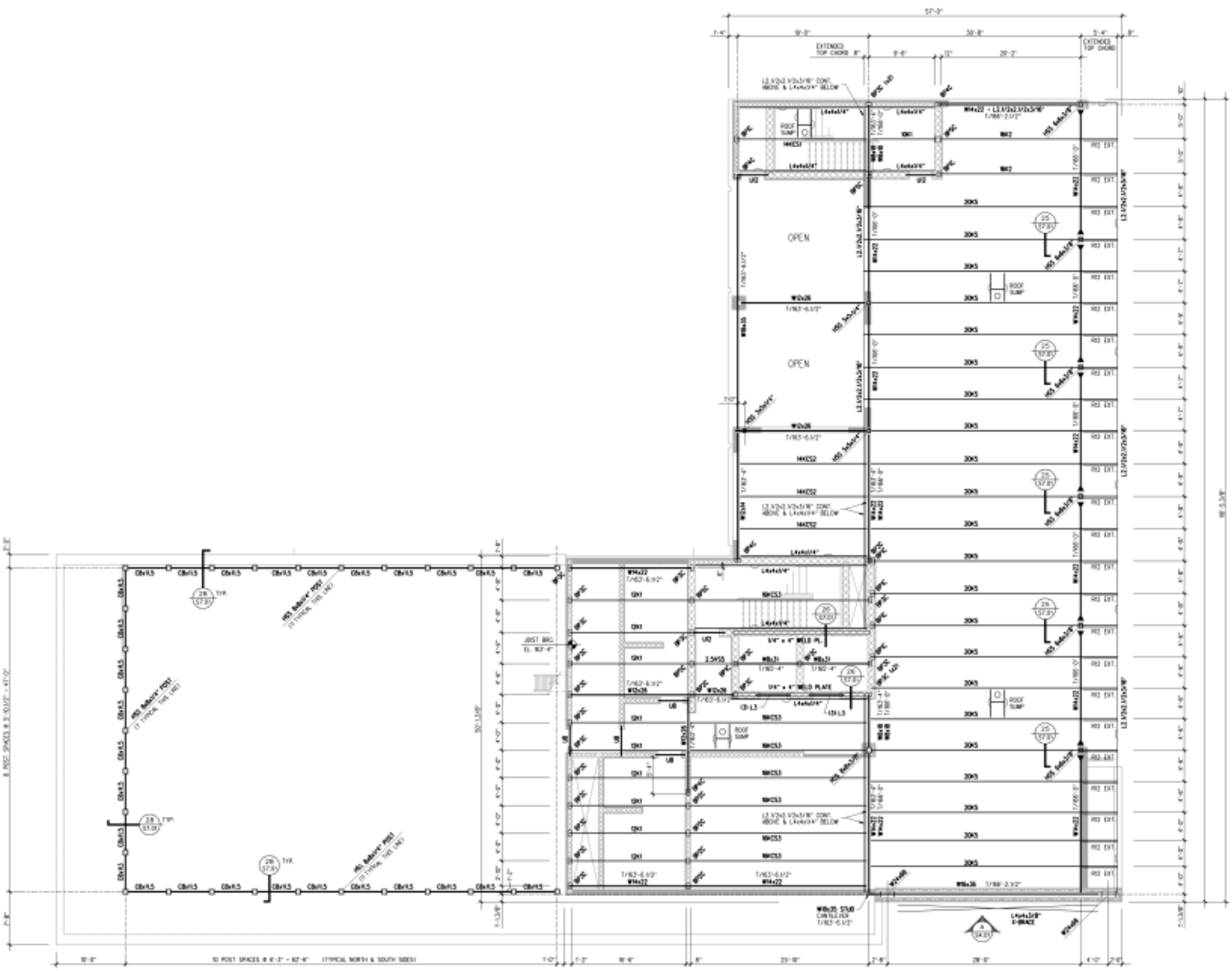
Third Level Framing Plan



Fourth Level Framing Plan




Fifth Level Framing Plan



Sixth Level (Upper Roof) Framing Plan

# Appendix B: Loads

### Wind Loads

WIND LOADS

METHOD 2 - ANALYTICAL PROCEDURE

WIND VARIABLES: $V = 90$ MPH $K_d = 0.85$ $I = 1.0$ $K_{zt} = 1.0$ EXPOSURE B

$K_z$ VALUES AT DIFFERENT FLOOR HEIGHTS
FROM TABLE 6-3
CASE II

* MUST INTERPOLATE FOR PROPER $K_z$ VALUES

| LEVEL | HEIGHT ABOVE GRADE | $K_z$ FACTOR |
|---|---|---|
| FIRST FLOOR | 0' - 0" | 0 |
| SECOND FLOOR | 14' - 0" | 0.57 |
| THIRD FLOOR | 26' - 0" | 0.668 * |
| FOURTH FLOOR | 38' - 0" | 0.748 * |
| FIFTH FLOOR | 50' - 0" | 0.81 * |
| ROOF | 64' - 11" | 0.87 * |
| TOP OF ROOF | 67' - 2" | 0.879 * |

* INTERPOLATION FORMULA: $y_2 = \dfrac{(x_2 - x_1)(y_3 - y_1)}{(x_3 - x_1)} + y_1$

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

$= 0.00256\, K_z (1.0)(0.85)(90)^2(1.0) = 17.6256\, K_z$

PLUG $K_z$ VALUE INTO EQUATION TO GET $q_z$ VALUE AT PROPER HEIGHT
THESE VALUES ARE FOUND IN THE TABLE

$q_h = 0.00256\, K_z K_{zt} K_d V^2 I$ WHERE $\bar{z} = \dfrac{67'\text{-}2'' + 52'\text{-}8''}{2} = 59'\text{-}11''$

$= 0.00256(0.85)(1.0)(0.85)(90)^2(1.0)$ $\Rightarrow K_z = 0.85$

$= 14.98$ PSF

CHECK $\bar{z} = 0.6h > \bar{z}_{MIN}$

$0.6(59.917) = 35.95 > 30'$

* $z_{MIN}$ FROM TABLE 6-2

WIND LOADS (CONTINUED)

- EXTERNAL PRESSURE COEFFICIENTS ($C_p$)

NORTH / SOUTH

LEEWARD = −0.5
WINDWARD = 0.8

$L/B = 0.75$

$L = 116'\text{-}5\frac{3}{8}''$ $B = 154'\text{-}4''$

EAST/WEST

LEEWARD = −0.3
WINDWARD = 0.8

$L/B = 1.33$

$L = 154'4''$ $B = 116'\text{-}5\frac{3}{8}''$

- WIND PRESSURE

$P_z = q_z G C_p - q_h G C_{pi}$ (WINDWARD)

$P_h = q_h G C_p - q_h G C_{pi}$ (LEEWARD)

EQUATION 6-17 FROM SECTION 6.5.12.2

NORTH / SOUTH @ SECOND LEVEL

$P_z = (10.05)(0.85)(0.8) - (14.98)(-0.18)$

$= 9.53$ PSF

$P_h = (14.98)(.85)(-.5) - (14.98)(0.18)$

$= -9.06$ PSF

EAST/WEST @ SECOND LEVEL

$P_z = (10.05)(.85)(0.8) - (14.98)(-0.18)$

$= 9.53$ PSF

$P_h = (14.98)(.85)(-0.3) - (14.98)(0.18)$

$= -6.52$ PSF

WIND PRESSURES CALCULATED FOR EACH LEVEL AND PUT IN TABLE

WIND LOADS (CONTINUED)

- FORCE OF TOTAL PRESSURE: $F_T = B(\text{STORY HEIGHT})\, P_{TOTAL}$

NORTH/SOUTH @ SECOND LEVEL

$$F_T = [(19.8\text{ PSF})(6) + (18.6)(6)](154.33) = 35.6^{K}$$

EAST/WEST @ SECOND LEVEL

$$F_T = [(17.2\text{ PSF})(6) + (16.0)(6)](116.45^{k}) = 23.2^{k}$$

- FORCE OF WINDWARD ONLY: $F_W = B(\text{STORY HEIGHT})\, P_z$

NORTH/SOUTH @ SECOND LEVEL

$$F_W = [(10.73)(6) + (9.53)(6)](154.33) = 18.8^{k}$$

EAST/WEST @ SECOND LEVEL

$$F_W = [(10.73)(6) + (9.53)(6)](116.45) = 14.2^{k}$$

- TOTAL STORY SHEAR: $F = F_T\, e\,(\text{TOP OF ROOF} + \text{ROOF} + \text{FIFTH})$

NORTH/SOUTH @ FIFTH LEVEL

$$F = (3.87 + 29.42 + 45.42) = 78.21^{k}$$

EAST/WEST @ FIFTH LEVEL

$$F = (2.59 + 19.65 + 30.28) = 52.52^{k}$$

- WINDWARD STORY SHEAR: $F = F_W\, e\,(\text{TOP OF ROOF} + \text{ROOF} + \text{FIFTH})$

NORTH/SOUTH @ FIFTH LEVEL

$$F = (2.30 + 17.41 + 26.60) = 46.30^{k}$$

EAST/WEST @ FIFTH LEVEL

$$F = (2.30 + 13.14 + 20.07) = 35.50^{k}$$

**Seismic Loads**

**Example of Floor Weights Found**

| Seismic Force Resisting System: Second Floor | |
|---|---|
| Approximate Area (SF) | 12200 |
| Floor to Floor Height (ft.) | 12 |
| **Walls** | |
| Perimeter (ft.) | 555 |
| Height (ft.) | 12 |
| Unit Weight (PSF) | 91 |
| Weight (k) | **606.06** |
| **Superimposed** | |
| Partitions (PSF) | 15 |
| MEP (PSF) | 10 |
| Finishes (PSF) | 5 |
| Weight (k) | **366** |
| **Slab** | |
| Thickness (in.) | 8 |
| Unit Weight (PSF) | 80 |
| Weight (k) | **976** |

| Columns | | | | |
|---|---|---|---|---|
| Shape | Quantity | Weight (PLF) | Column Height (ft.) | Weight (k) |
| HSS 8x8x3/8" | 1 | 37.61 | 12 | 0.45 |
| W24x84 | 2 | 84 | 12 | 2.02 |
| Totals | 3 | 121.61 | | **2.47** |

| Beams | | | | |
|---|---|---|---|---|
| Shape | Quantity | Weight (PLF) | Beam Length (ft.) | Weight (k) |
| W8x10 | 2 | 10 | 4 | 0.08 |
| W8x24 | 8 | 24 | 6.5 | 1.25 |
| W12x16 | 1 | 16 | 21 | 0.34 |
| W12x26 | 4 | 26 | 11 | 1.14 |
| W18x35 | 1 | 35 | 27 | 0.95 |
| W24x84 | 1 | 84 | 32 | 2.69 |
| C 4x5.4 | 8 | 5.4 | 4.5 | 0.19 |
| Totals | 25 | 195 | | **6.64** |

| | |
|---|---|
| Total Weight of Floor (k) | 1957.16 |
| Total Weight of Floor (PSF) | 160.42 |

SEISMIC LOADS

- SITE CLASS D — SOFT SOIL PROFILE
- OCCUPANCY II
- IMPORTANT FACTOR 1.0
- SPECTRAL RESPONSE ACCELERATION, SHORT — $S_s = 0.098$

  SPECTRAL RESPONSE ACCELERATION, 1s — $S_1 = 0.045$
- SITE COEFFICIENTS: $F_a = 1.6$ AND $F_v = 2.4$
- $S_{ms} = F_a S_s = (1.6)(0.098) = 0.1568$
- $S_{m1} = F_v S_1 = (2.4)(0.045) = 0.1080$
- $S_{ds} = 2/3\, S_{ms} = 2/3\,(0.1568) = 0.1045$
- $S_{d1} = 2/3\, S_{m1} = 2/3\,(0.1080) = 0.0720$
- $T_a = C_t h_n^x = 0.02\,(67.167)^{0.75} = 0.469\ s$
- $C_u = 1.7$
- $T = T_a C_u = 0.469\,(1.7) = 0.797\ s$
- $C_s = \text{MIN}\begin{cases} \dfrac{S_{d1}}{T(R/I)} = \dfrac{0.072}{(0.797)(2/1)} = 0.0452 \geq 0.01 \Rightarrow \text{USE THIS VALUE} \\ \dfrac{S_{ds}}{(R/I)} = \dfrac{0.1045}{(2/1)} = 0.05225 \geq 0.01 \\ \dfrac{S_{d1} T_L}{T^2 (R/I)} = \dfrac{(.072)(12)}{(.797)^2(2/1)} = 0.680 \geq 0.01 \end{cases}$
- $k = \dfrac{(0.797-0.5)(2-1)}{(2.5-0.5)} + (1) = 1.1485$

  [LINEAR INTERPOLATION SINCE THE PERIOD IS BETWEEN 0.5 AND 2.5]

SEISMIC LOADS CONTINUED

| FLOOR | FLOOR AREA | PERIMETER | TOTAL WEIGHT |
|---|---|---|---|
| FIRST | 12,235 | 570 | 177.26 PSF |
| SECOND | 12,200 | 555 | 160.42 PSF |
| THIRD | 12,200 | 555 | 160.39 PSF |
| FOURTH | 12,200 | 555 | 160.56 PSF |
| FIFTH | 12,200 | 389 | 162.79 PSF |
| ROOF | 11,500 | 389 | 20 PSF |

- TOTAL BUILDING WEIGHT

$$\text{WEIGHT} = (12,235)(177.26) + (12,200)(160.42) + (12,200)(160.39) + (12,200)(160.56) + (12,200)(162.79) + (11500)(20)$$

$$\text{WEIGHT} = \boxed{10258^k}$$

- BASE SHEAR

$$V = C_s(\text{WEIGHT}) = 0.0452\,(10258) = \boxed{463.7^k}$$

- $w_x h_x^k$ => VARIES DEPENDING ON LEVEL

@ LEVEL 3 : $w_3 = 1956.8$, $h_3 = 26'$, $k = 1.1485$

$$w_3 h_3^k = (1956.8)(26)^{1.1485} = \boxed{82534 \text{ ft-k}}$$

- $$\Sigma w_x h_x^k = 40546 + 82534 + 127755 + 177523 + 28871$$

$$= \boxed{457229 \text{ ft-k}}$$

- $C_{vx} = \dfrac{w_x h_x^k}{\Sigma w_x h_x}$ => VARIES DEPENDING ON LEVEL

@ LEVEL 3 ; $C_{vx} = 82534 / 457229 = \boxed{0.18}$

- $F_x = C_{vx}(V)$

@ LEVEL 3 : $F_x = (0.18)(463.7) = \boxed{83.7^k}$

- STORY SHEAR : $V_x = F_x(\text{@ LEVEL}) + F_x(\text{@ ALL LEVELS ABOVE})$

@ LEVEL 5 : $V_x = F_x(\text{LEVEL 5}) + F_x(\text{ROOF})$

$$= 180.04 + 29.28 = \boxed{209.31^k}$$

SEISMIC LOADS (CONTINUED)

MOMENTS:

$$M_x = (\text{TRIBUTARY FLOOR AREA HEIGHT})(F_x)$$

@ LEVEL 5: $\left[\dfrac{(50+38)}{2}\right](180.04) = \boxed{7921.7 \text{ ft-k}}$

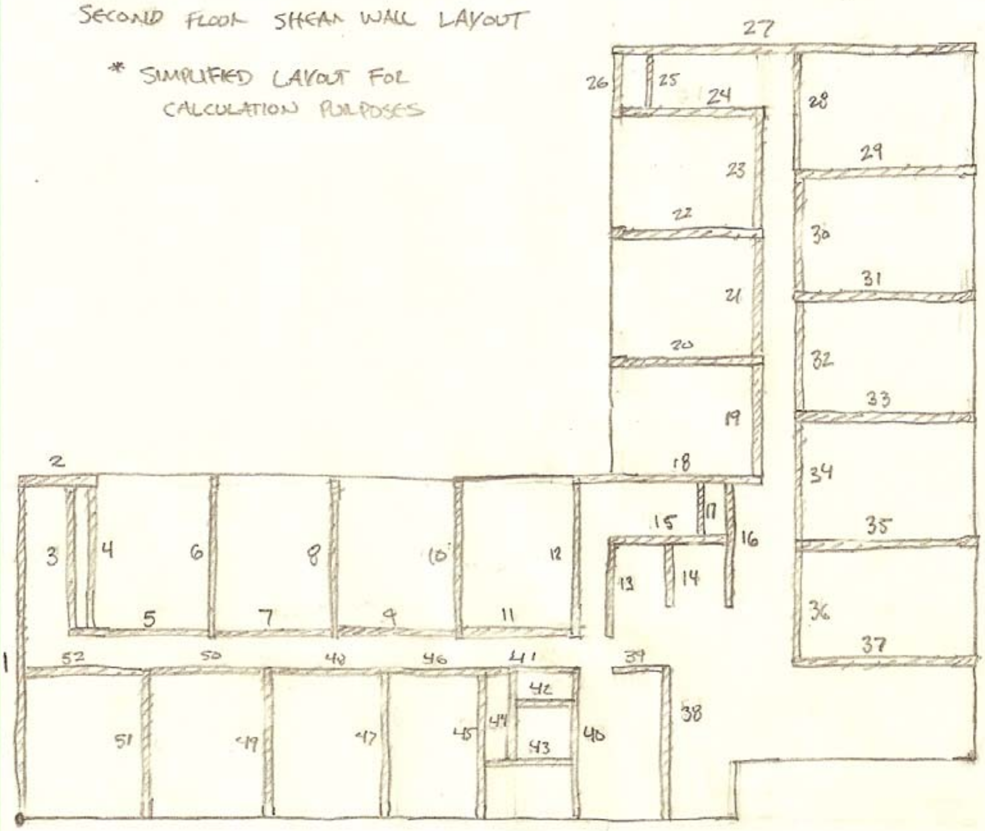
# Appendix C: Load Distribution

**Rigidity and Relative Stiffness**

RIGIDITY

SECOND FLOOR SHEAR WALL LAYOUT

* SIMPLIFIED LAYOUT FOR CALCULATION PURPOSES




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

WHERE: $E = 33 w^{1.5} \sqrt{f'_c}$

$= 33 (145 \text{ PCF})^{1.5} \sqrt{2000}$

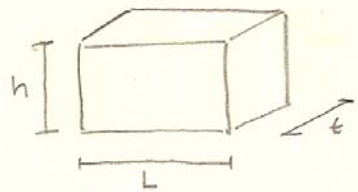
$= 2.577 \times 10^6$ PSI

$= 2577$ KSI

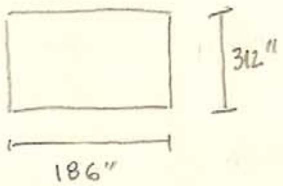
$t = 12''$ (EXTERIOR/CORE) $8''$ (INTERIOR)

$h$ = HEIGHT FROM BASE TO EACH LEVEL (SO VARIES)

$L$ = LENGTH OF WALL ELEMENT

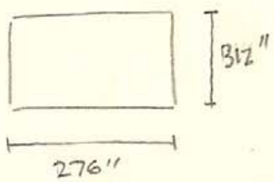


WALL 2 (Y-COORD)



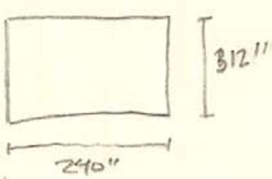

$$R_1 = \frac{(2577\ ksi)(12'')}{4\left(\frac{312}{186}\right)^3 + 3\left(\frac{312}{186}\right)} = 1293$$

WALL 5



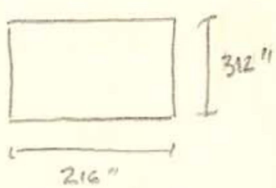

$$R_1 = \frac{(2577\ ksi)(8'')}{4\left(\frac{312}{276}\right)^3 + 3\left(\frac{312}{276}\right)} = 2248$$

WALL 7



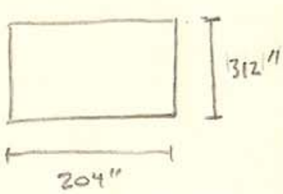

$$R_1 = \frac{(2577\ ksi)(8'')}{4\left(\frac{312}{240}\right)^3 + 3\left(\frac{312}{240}\right)} = 1625$$

WALL 9, 50



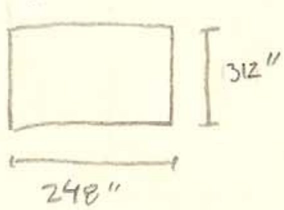

$$R_1 = \frac{(2577\ ksi)(8'')}{4\left(\frac{312}{216}\right)^3 + 3\left(\frac{312}{216}\right)} = 1258$$

WALL 11



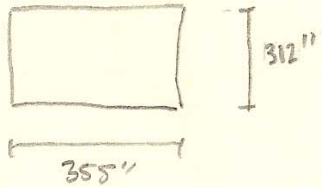

$$R_1 = \frac{(2577\ ksi)(8'')}{4\left(\frac{312}{204}\right)^3 + 3\left(\frac{312}{204}\right)} = 1091$$

WALL 15



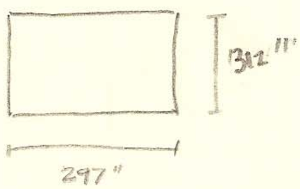

$$R_1 = \frac{(2577\ ksi)(12'')}{4\left(\frac{312}{248}\right)^3 + 3\left(\frac{312}{248}\right)} = 2634$$

WALL 18 (Y-COORD)



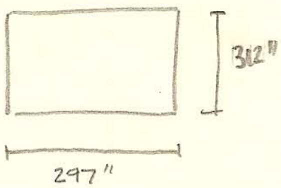

$$R_1 = \frac{(2577 \text{ ksi})(12'')}{4\left(\frac{312}{355}\right)^3 + 3\left(\frac{312}{355}\right)} = 5778$$

WALLS 20, 22, 29, 31
33, 35, 37



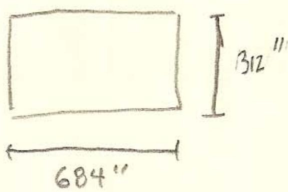

$$R_1 = \frac{(2577 \text{ ksi})(8'')}{4\left(\frac{312}{297}\right)^3 + 3\left(\frac{312}{297}\right)} = 2647$$

WALL 24



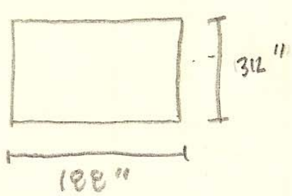

$$R_1 = \frac{(2577 \text{ ksi})(12'')}{4\left(\frac{312}{297}\right)^3 + 3\left(\frac{312}{297}\right)} = 3970$$

WALL 27



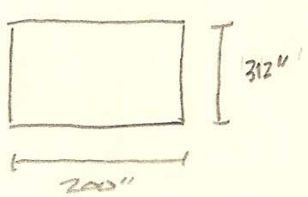

$$R_1 = \frac{(2577 \text{ ksi})(12'')}{4\left(\frac{312}{684}\right)^3 + 3\left(\frac{312}{684}\right)} = 17691$$

WALL 39




$$R_1 = \frac{(2577 \text{ ksi})(8'')}{4\left(\frac{312}{188}\right)^3 + 3\left(\frac{312}{188}\right)} = 886$$

WALLS 41, 43




$$R_1 = \frac{(2577 \text{ ksi})(8'')}{4\left(\frac{312}{200}\right)^3 + 3\left(\frac{312}{200}\right)} = 1038$$

(Y-COORD)

WALL 42

152''

$$R_1 = \frac{(2577\ \text{ksi})(8'')}{4\left(\frac{312}{152}\right)^3 + 3\left(\frac{312}{152}\right)} = 506$$

WALL 46

210''

$$R_1 = \frac{(2577\ \text{ksi})(8'')}{4\left(\frac{312}{210}\right)^3 + 3\left(\frac{312}{210}\right)} = 1173$$

WALL 48

212''

$$R_1 = \frac{(2577\ \text{ksi})(8'')}{4\left(\frac{312}{212}\right)^3 + 3\left(\frac{312}{212}\right)} = 1201$$

WALL 52

210''

$$R_1 = \frac{(2577\ \text{ksi})(12'')}{4\left(\frac{312}{210}\right)^3 + 3\left(\frac{312}{210}\right)} = 1760$$

$\Sigma R = 64976$

• RELATIVE STIFFNESS $\Rightarrow \% = R/\Sigma R \times 100$

WALL 2 = 1.99%

WALL 5 = 3.46%

WALL 7 = 2.80%

WALLS 9 & 50 = 1.94%

WALL 11 = 1.68%

WALL 15 = 4.05%

WALL 18 = 8.89%

WALLS 20, 22, 29, 31, 33, 35, 37 = 4.07%

WALL 24 = 6.11%

WALL 27 = 27.23%

WALL 39 = 1.36%

WALLS 41, 43 = 1.60%

WALL 42 = 0.78%

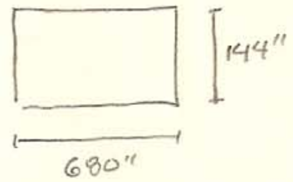
WALL 46 = 1.81%

WALL 48 = 1.85%

WALL 52 = 2.71%

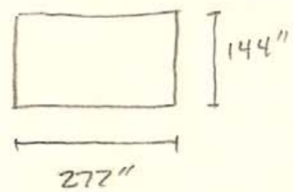
= 100%

WALL 1 (X-COORD)



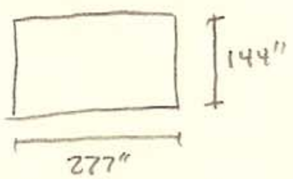

$$R_1 = \frac{(2577\text{ ksi})(12")}{4\left(\frac{312'}{680}\right)^3 + 3\left(\frac{312'}{680}\right)} = 17542$$

WALLS 3, 12



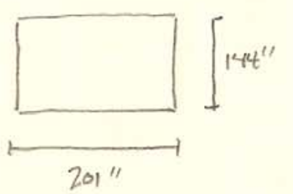

$$R_1 = \frac{(2577\text{ ksi})(12")}{4\left(\frac{312'}{277}\right)^3 + 3\left(\frac{312'}{277}\right)} = 3400$$

WALLS 4, 6, 8, 10
51, 49, 47, 45, 40, 38



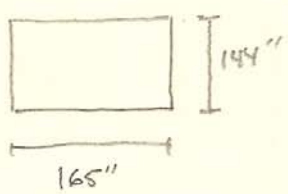

$$R_1 = \frac{(2577\text{ ksi})(8")}{4\left(\frac{312'}{277}\right)^3 + 3\left(\frac{312'}{277}\right)} = 2267$$

WALL 44



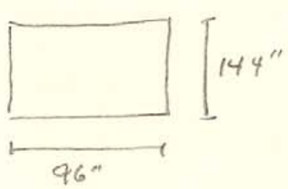

$$R_1 = \frac{(2577\text{ ksi})(8")}{4\left(\frac{312'}{201}\right)^3 + 3\left(\frac{312'}{201}\right)} = 1051$$

WALL 13




$$R_1 = \frac{(2577\text{ ksi})(12")}{4\left(\frac{312'}{165}\right)^3 + 3\left(\frac{312'}{165}\right)} = 945$$

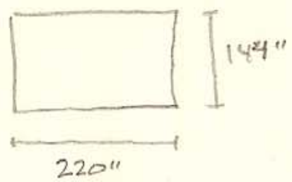
WALL 14




$$R_1 = \frac{(2577\text{ ksi})(12")}{4\left(\frac{312'}{96}\right)^3 + 3\left(\frac{312'}{96}\right)} = 210$$

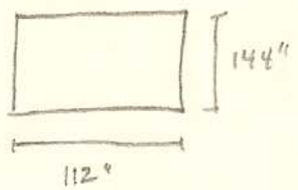
(X-COORD)

WALL 16



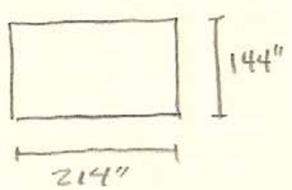

$$R_1 = \frac{(2577\text{ ksi})(12'')}{4\left(\frac{312}{220}\right)^3 + 3\left(\frac{312}{220}\right)} = 1974$$

WALL 17



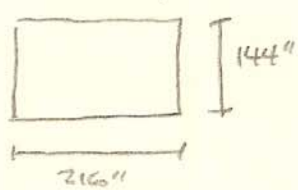

$$R_1 = \frac{(2577\text{ ksi})(12'')}{4\left(\frac{312}{112}\right)^3 + 3\left(\frac{312}{112}\right)} = 326$$

WALL 19



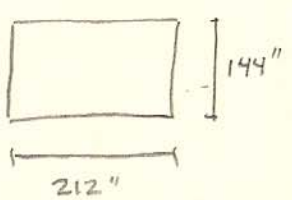

$$R_1 = \frac{(2577\text{ ksi})(8'')}{4\left(\frac{312}{214}\right)^3 + 3\left(\frac{312}{214}\right)} = 1229$$

WALLS 21, 30, 32, 34



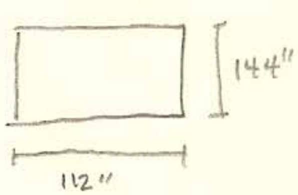

$$R_1 = \frac{(2577\text{ ksi})(8'')}{4\left(\frac{312}{216}\right)^3 + 3\left(\frac{312}{216}\right)} = 1258$$

WALL 23



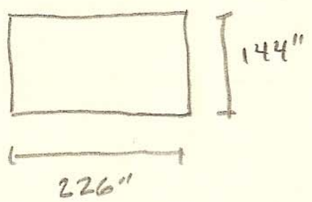

$$R_1 = \frac{(2577\text{ ksi})(8'')}{4\left(\frac{312}{212}\right)^3 + 3\left(\frac{312}{212}\right)} = 1201$$

WALLS 25, 26



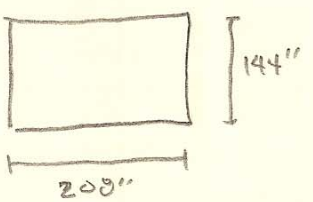

$$R_1 = \frac{(2577\text{ ksi})(12'')}{4\left(\frac{312}{112}\right)^3 + 3\left(\frac{312}{112}\right)} = 326$$

WALL 28 (X-COORD)




$$R_1 = \frac{(2577\ \text{KSI})(12'')}{4\left(\frac{312}{226}\right)^3 + 3\left(\frac{312}{226}\right)} = 2109$$

WALL 36




$$R_1 = \frac{(2577\ \text{KSI})(8'')}{4\left(\frac{312}{208}\right)^3 + 3\left(\frac{312}{208}\right)} = 1145$$

$\Sigma R = 62886$

- RELATIVE STIFFNESS => $\% = R/\Sigma R \times 100$

WALL 1 = 27.89 %

WALLS 3, 12 = 5.41 %

WALLS 4, 6, 8, 10, 51, 49, 47, 45, 40, 38 = 3.60 %

WALL 44 = 1.67 %

WALL 13 = 1.50 %

WALL 14 = 0.33 %

WALL 16 = 3.14 %

WALL 17 = 0.52 %

WALL 19 = 1.95 %

WALLS 21, 30, 32, 34 = 2.00 %

WALL 23 = 1.91 %

WALLS 25, 26 = 0.52 %

WALL 28 = 3.35 %

WALL 36 = 1.82 %

= 100 %

# Appendix D: Torsion

OVERALL BUILDING TORSION

$M_{t,TOT} = M_t + M_{ta}$

FACTORED LATERAL FORCE $= 1.6\,W$
$= 1.6$ (TOTAL WIND PRESSURE FORCE @ STORY)
* FOUND IN WIND TABLES FOR EACH DIRECTION

$M_t =$ (FACTORED LATERAL FORCE)(ECCENTRICITY)

WHERE ECCENTRICITY = CENTER OF RIGIDITY − CENTER OF MASS

EXAMPLE @ FLOOR 2 IN X DIRECTION

$e = 978.062 - 1093.144 = -115.082 = -9.59'$

FACTORED LATERAL FORCE $= 1.6\,(35.54) = 56.9^K$

$M_t = 56.9^k(-9.59') = -545.7$ ft-K

$M_{ta} =$ (FACTORED LATERAL FORCE)(5% ASSUMED DISPLACEMENT EACH WAY OF COM)

→ ASCE 7-05, SEC 12.8.4.2

EXAMPLE @ FLOOR 2 IN X DIRECTION

COM = 1093.144
5% DISPLACEMENT IN EACH DIRECTION = 109.31'' = 9.11'

FACTORED LATERAL FORCE $= 1.6\,(35.54) = 56.9^K$

$M_{ta} = 56.9^k(9.11') = 518.3$ ft-K

$M_{t,TOT} = M_t + M_{ta} = -545.7 + 518.1 = -27.4$ ft-k

OVERALL BUILDING TORSION FOR EACH FLOOR IN EACH DIRECTION IS IN TABLES.

# Appendix E: Shear

SHEAR

- CONTROLLING LOAD COMBINATIONS

  NORTH / SOUTH : $1.2D + 1.6W + 1.0L + 0.5L_R$

  EAST / WEST : $0.9D + 1.0E$

- DIRECT SHEAR

  DIRECT SHEAR = (FACTORED STORY FORCE) $\left(\frac{\text{RELATIVE STIFFNESS \%}}{100}\right)$

  - EXAMPLE FOR FLOOR 2 IN N/S DIRECTION @ WALL 1

    DIRECT SHEAR = $(1.6 \times 35.54)(0.1932) = 10.99^K$

- TORSIONAL SHEAR

  $T = \frac{V_{TOT} \cdot e d_i R_i}{J}$ WHERE
  $V_{TOT}$ = STORY SHEAR
  $e$ = DISTANCE FROM CENTER OF MASS TO CENTER OF RIGIDITY
  $d_i$ = DISTANCE FROM ELEMENT TO CENTER OF RIGIDITY
  $R_i$ = RELATIVE STIFFNESS OF ELEMENT
  $J$ = TORSIONAL MOMENT OF INERTIA

  - EXAMPLE FOR WALL 10 SUPPORTING FLOOR 3

    - FACTORED STORY SHEAR = $1.6(117.80) = 188.480$ ft-k
    - COR (X-COORD) = 1023.977
    - COM (X-COORD) = 1093.144"
    - $e = |COR - COM| = 69.167$"
    - $R_i = 0.036$

    - LOCATION OF WALL 10 = 890" (X-COORD)
    - $d_i = WALL_i - COR_i = |890" - 1023.977"| = 133.977$
    - $R_i \times d_i^2 = 0.036(133.977)^2 = 648$

    $J = 760627$

    $$T = \frac{(188.48)(69.167)(133.977)(0.036)}{760627} = 0.083$$

SHEAR STRENGTH

- ACI 318.08 (SECTION 21.9.4) => STRUCTURAL WALLS SHALL NOT EXCEED $V_N$

$$\phi V_N = \phi A_{cv}(\alpha_c \lambda \sqrt{f'_c} + \rho_t f_y)$$

WHERE: $\phi = 0.75$
$A_{cv}$ = GROSS AREA OF CONCRETE
$\alpha_c$ = COEFFICIENT
= 2 IF $h_w/l_w \geq 2.0$
$\rho_t = A_v/sh$
WHERE:
$s$ = SHEAR REINFORCEMENT SPACING
$h$ = THICKNESS OF WALL

- EXAMPLE FOR WALL 10 SUPPORTING FLOOR 3

- DIRECT SHEAR = DISTRIBUTED DIRECT FORCE ON ALL FLOORS ABOVE FLOOR 3 OF WALL 10

FROM TABLE 1.12 = $1.37 + 2.25 + 2.08 = 5.70^K$

- TORSIONAL SHEAR (FROM TABLE 1.14 => 0.083)

$V_u = 5.70^K + 0.083 = 5.783^K$

- VERTICAL REINFORCEMENT: (2) #5 @ 24" O.C

$$\rho_t = \frac{(2)(0.31)}{(24)(8)} = 0.00323$$

$A_{cv} = (277)(8) = 2216\ in^2$

$$\phi V_N = 0.75(2216)\left[2.0\left(\frac{\sqrt{2000}}{1000}\right) + (0.00323)(60)\right]$$

$\phi V_N = 471^K >> 5.593^K$

- REMAINING SHEAR STRENGTH CALCULATIONS ARE LOCATED IN TABLE 1.15

# Appendix F: Drift and Displacement

STORY DISPLACEMENT

- APPROXIMATE THE STORY SHEAR BY $\Sigma\Delta$ CANTILEVER OF EACH STORY
- STORY DRIFT

$$\Delta = 0.020 h_{sx}$$

WHERE $h_{sx}$ = STORY HEIGHT BELOW STORY $x$ (ASCE 7-05, TABLE 12.12-1)

$$\Delta_{CANT} = \Delta_{FLEXURAL} + \Delta_{SHEAR}$$

WHERE: $\Delta_{FLEXURAL} = \dfrac{Ph^3}{3E_cI}$

$$\Delta_{SHEAR} = \frac{1.2Ph}{E_rA}$$

$$\Delta_{CANT} = \frac{Ph^3}{3E_cI} + \frac{1.2Ph}{E_rA}$$

WHERE

$E_c = 33\,(145\text{ PCF})^{1.5}\sqrt{2000\text{ PSI}} = 2577$ KSI (ALL STORIES)

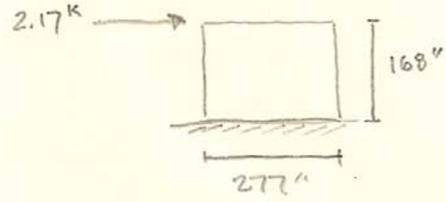
$E_r = 0.4E_c = 0.4(2577) = 1031$ KSI (ALL STORIES)

$A = (\text{LENGTH}) \times (\text{THICKNESS})$

$I = \dfrac{(\text{THICKNESS}) \times (\text{LENGTH})^3}{12}$

• EXAMPLE FOR WALL 10 IN N/S DIRECTION

FLOOR 2 SUPPORTED:



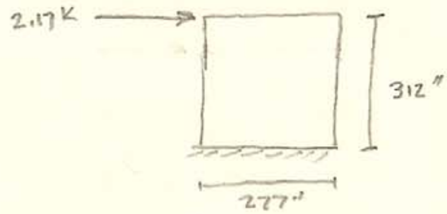

$A = (8)(277) = 2216 \text{ IN}^2$

$I = 8(277)^3/12 = 14169289 \text{ IN}^4$

$\Delta_2 = \dfrac{(2.17^K)(168)^3}{3(2577)I} + \dfrac{1.2(2.17)(168)}{1031(2216)}$

$\Delta_2 = 9.39E{-5} + 1.91E{-4}$
$= 2.85E{-4} \text{ IN.}$

FLOOR 3 SUPPORTED:



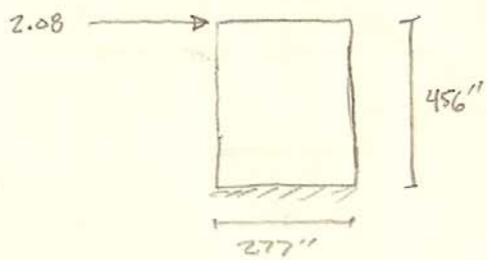

$A = 2216 \text{ IN}^2$
$I = 14169289 \text{ IN}^4$

$\Delta_3 = \dfrac{(2.17)(312)^3}{3(2577)I} + \dfrac{1.2(2.17)(312)}{1031(2216)}$

$\Delta_3 = 6.02E{-4} + 3.56E{-4}$

$= 9.58E{-4} \text{ IN}$

FLOOR 4 SUPPORTED:



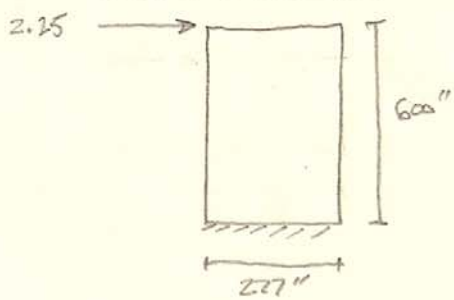

$A = 2216 \text{ IN}^2$
$I = 14169289 \text{ IN}^4$

$\Delta_4 = \dfrac{(2.08)(456)^3}{3(2577)I} + \dfrac{1.2(2.08)(456)}{1031(2216)}$

$\Delta_4 = 1.80E{-3} + 4.98E{-4}$

$= 0.002298 \text{ IN}$

FLOOR 5 SUPPORTED:



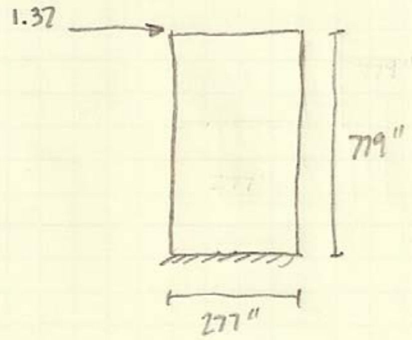

$A = 2216 \text{ IN}^2$
$I = 14169289 \text{ IN}^4$

$\Delta_5 = \dfrac{(2.25)(600)^3}{3(2577)I} + \dfrac{1.2(2.25)(600)}{1031(2216)}$

$\Delta_5 = 0.00444 + 7.09E{-4}$

$= 0.00515 \text{ IN}$

ROOF SUPPORTED:




$A = 2216 \text{ IN}^2$

$I = 14169289$

$$\Delta_R = \frac{(1.37)(779)^3}{3(2577)I} + \frac{1.2(1.37)(779)}{1031(2216)}$$

$$\Delta_R = 0.00591 + 5.61\text{E-}4$$

$$= 0.006471$$

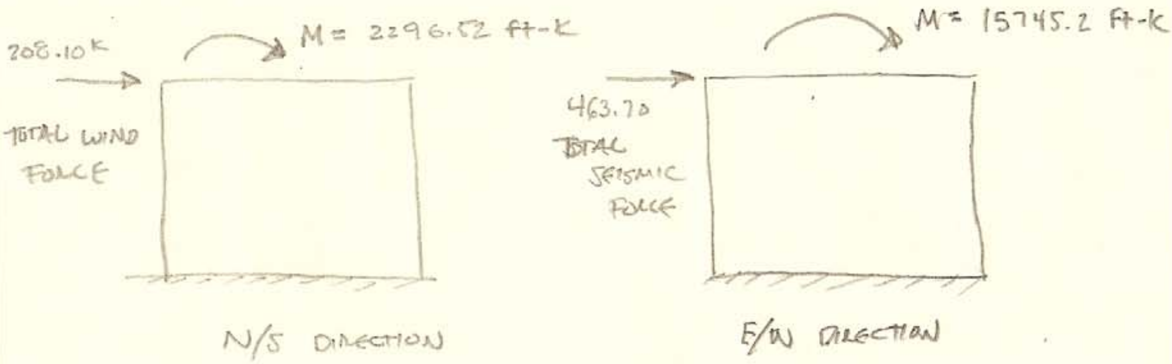
• OVERALL DISPLACEMENT OF WALL 10

$$\Sigma\Delta = 2.95\text{E-}4 + 9.58\text{E-}4 + 0.002298 + 0.00515 + 0.006471 = 0.015162$$

$$\Delta_{LIMIT} = H/400 = 779/400 = 1.95'' > 0.015162'' \therefore OK$$

# Appendix G: Overturning Moments

OVERTURNING MOMENT




- LATERAL LOADS WILL CREATE OVERTURNING MOMENT, WHILE THE GRAVITY LOADS WILL TRY TO RESIST THE OVERTURNING MOMENT

- TO DETERMINE IF THE GRAVITY LOADS WILL EXCEED THE LATERAL LOADS, THE STRESS DUE TO SEISMIC AND LATERAL LOADS WILL BE CALCULATED.

STRESS DUE TO DEAD LOADS

$$\frac{\text{WEIGHT OF BUILDING}}{\text{SQUARE FOOTAGE OF FOUNDATION}} = \frac{10258^k}{8911\ SF} \times 1000\ lbs = 1151.2\ PSF$$

STRESS DUE TO E/W SEISMIC LOADS

$$\frac{463.70^k}{8911\ SF} \times 1000\ lb = 52.04 \Rightarrow \frac{52.04}{1151.2} \times 100\% = 4.52\% \text{ OF DEAD LOAD}$$

STRESS DUE TO N/S LATERAL LOADS

$$\frac{208.10^k}{8911\ SF} \times 1000 = 23.35 \Rightarrow \frac{23.35}{1151.2} \times 100\% = 2.03\% \text{ OF DEAD LOAD}$$

- SINCE THE STRESSES OF THE LATERAL AND SEISMIC LOADS ARE A MUCH SMALLER PERCENTAGE OF THE GRAVITY LOADS, OVERTURNING IS NOT A CONCERN FOR THE DESIGN OF THE CITYFLATS HOTEL.