181 Fremont
San Francisco, CA

Tech Report 4

11/17/2014

Caroline Klatman

Structural Option

Advisor: Dr. Thomas Boothby

Caroline Klatman
cjk5258@psu.edu

November 17, 2014

Dr. Thomas Boothby
The Pennsylvania State University
209 Engineering Unit A
University Park, PA 16802

Dear Dr. Boothby:

Enclosed is Technical Report 4, a technical report analyzing the existing lateral system of 181 Fremont. This report evaluates the strength and drift performance of the lateral force resisting system under the design wind and earthquake loads calculated in Technical Report 2.

Included in this report is an abstract describing primary building systems, a list of building codes and specifications used, and calculations including computer analysis results and member spot checks.

Thank you for taking the time to review this report.

Sincerely,

Caroline Klatman

Table of Contents

Executive Summary

181 Fremont is a 54 story high-rise in the South of Market neighborhood in San Francisco, California. Its construction is a part of the San Francisco Transit Center District Plan – a redevelopment plan that allows for greater building heights within that area of the city. As such, the building rises to 700 feet, the maximum height allowed per the limitations on the site.

In response to the high seismic loading brought about by the site location, the structure expresses a unique and complicated design solution. A mega-frame system, expressed on the exterior of the building, acts as the primary lateral system of the structure into which all other lateral forces are carried.

Buckling restrained brace frames in the interior of upper stories of the structure and moment frames at the lower story exteriors supplement the mega-frame in providing lateral-force-resistance. Other contributors to the lateral system include collectors at each floor and viscous dampers in the exterior braces of the structure.

Because the mega-frame system is not defined in ASEC 7-05, an in depth seismic analysis was completed that conforms to the San Francisco Department of Building Inspection Administrative Bulletin on the Seismic Design & Review of Tall Buildings Using Non-Prescriptive Procedures (SF AB-083, 2010) and the PEER Guidelines for Performance-based Seismic Design of Tall Buildings (PEER TBI, 2010).

181 Fremont
San Francisco, California

General Information
Dates of Construction | Nov 2013 - 2016
Project Delivery Method | Design-Bid-Build
Occupancy| Mixed-use Office and Residential
Cost | $375 Million
Number of Stories | 54 Stories
Height | 700 ft.
Size | 411,000 sq. ft.

Project Team
General Contractor | Level 10 Construction
Construction Manager | Jay Paul Company
Owner | Jay Paul Company
Architect | Heller Manus
Structural Engineer | Arup
MEP Engineer | Arup

Structural Systems
The structure rests atop a mat foundation, below which roughly 60 piles extend 150 feet down to reach bedrock. Various systems such as viscous dampers and steel moment frames provide lateral force resistance, but the primary lateral force resisting system is an exterior steel mega-frame.

Sustainability
In pursuit for LEED Platinum, multiple steps toward sustainability including a curtain wall system that favors natural lighting, a green roof, grey water system, and use of recycled materials are featured.

Architecture
The architectural design features transparency in the structural system by exposing the exterior steel mega-frame, which extends beyond the roofline. A curtain wall system with angular glass units and walls that taper in as the building rises also add to the building's exterior aesthetic expression.

Various amenities are provided for residents, including a two-story open air terrace that wraps around the 36th floor. Also features is a pedestrian bridge on the 5th floor that allows residents to access the Transit Tower's rooftop City Park, as shown in the photos at left and below.

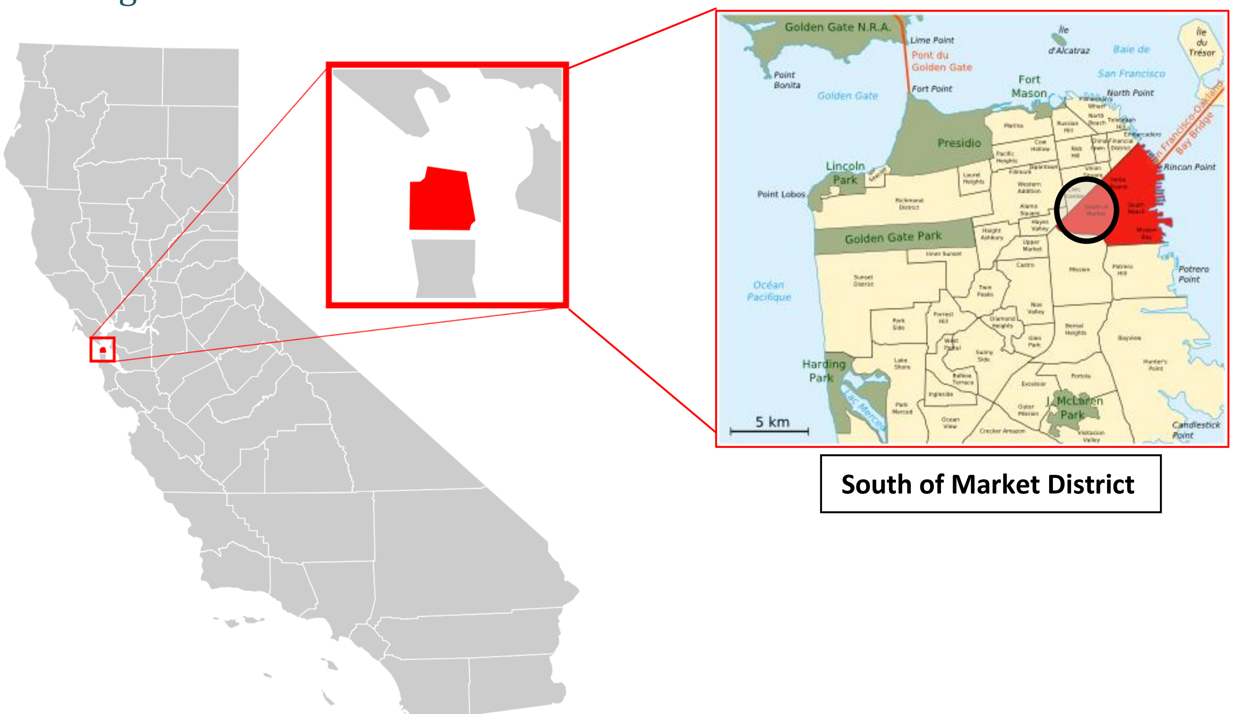
Mechanical Systems
181 Fremont's mechanical system is comprised of a forced-air ventilation system, with air intake and filtration occurring on the mechanical floor on level 37. Air is then transferred to each individual residential unit, where it is again filtered and either heated or cooled by a fan coil unit.

CAROLINE KLATMAN
STRUCTURAL OPTION
ADVISOR | DR. THOMAS BOOTHBY

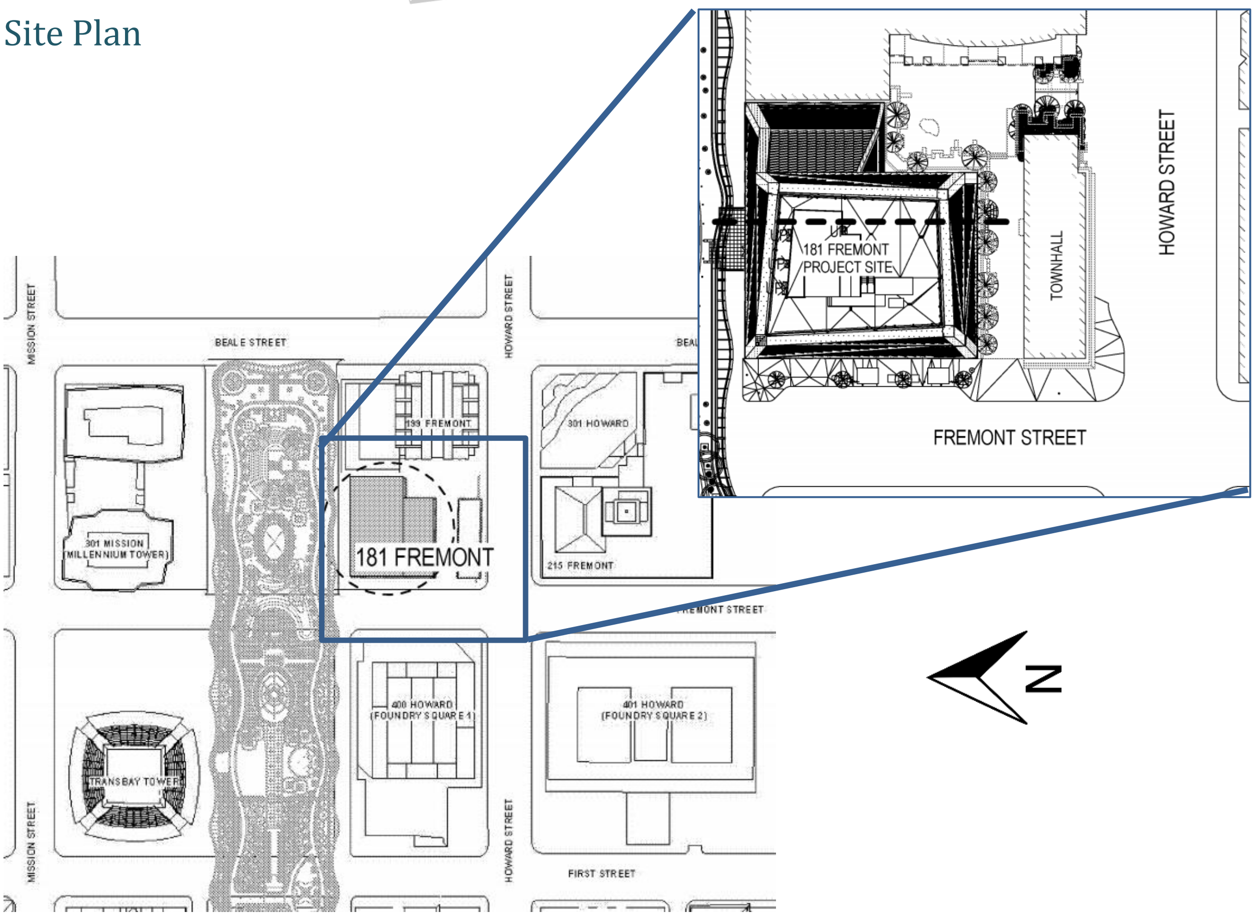
http://www.engr.psu.edu/ae/thesis/portfolios/2015/cjk5258/index.html

Building Location and Site Plan

Building Location



Site Plan



Documents Used in Preparation of This Report

- ASCE 7-05
- AISC Manual of Steel Construction

Modelling Approach and Assumptions

Approach

The Framing of 181 Fremont includes geometry that slopes in two dimensions at once. Because these slopes cause considerable change in floor areas and center of rigidity, SAP2000 was used to model the complex geometry.

In order to determine the rigidity contribution of the mega-frame and the secondary systems respectively, three models were created – one that represents just the mega-frame, one that represents just the secondary lateral systems, and one that contains both types of systems together.

Loads were applied at the center of rigidity for wind and center of mass, which is further described later.

Assumptions

- Pinned bases
- Rigid diaphragm constraints on nodes for each level
- Table of Assumptions
- E=29,000 ksi

Input

Due to the irregular floor plan of the lower office floors, the correct geometry of the mega-frame was modeled without simplification in order to account for torsion.

Buckling restrained braces are modeled without consideration of global buckling behavior. Instead, just the effective steel core area is modeled.

The structural design of the 181 Fremont mega columns includes a concrete fill for the box columns up to level 20. To account for this added stiffness, the columns were modeled as transformed square sections, with the concrete transformed into a steel area as shown in Equation 1.

$$A_{TR} = A_{steel} + nA_{concrete} \qquad \text{(Equation 1)}$$

$$n = E_{concrete}/E_{steel} = 3605/29000 = 0.1243 \qquad \text{(Equation 2)}$$

Mega frame braces are modeled as pinned at each end to represent the actual pin connection detailed, but column to column connections are modeled as fixed at the nodes where the braces intersect. The perimeter moment frames on the lower office floors have fixed connections. Residential levels, above level 39, have buckling restrained brace frames. No function exists in SAP to model their specific behavior, so brace section areas were modeled instead.

Wind Load Analysis

Center of Rigidity

To calculate the center of rigidity by hand, unit loads of 1 kip were applied where the mega-frame bracing and columns meet at levels 20, 37, 39, and 56. Loads were applied separately to the mega-frame (Figures 1-4) and moment frame (Figure 5) models in order to determine the stiffness contribution of each. The corresponding story displacements were then used to determine the in-plane stiffness of each frame type and subsequently calculate the center of rigidity by hand, as shown on the following pages.

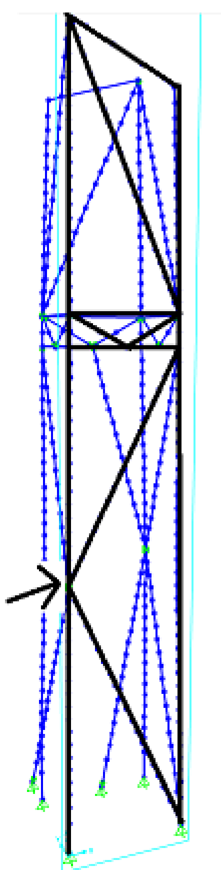


Figure 1| West Elevation Mega-Frame, Unit Load at Level 20

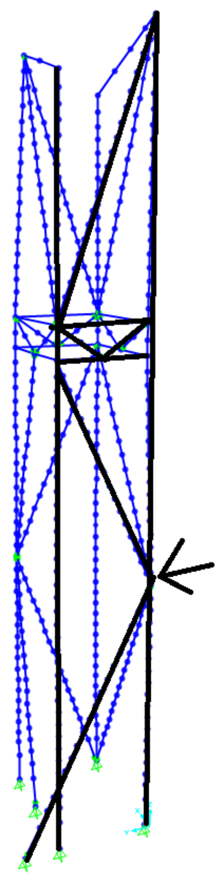


Figure 2| North Elevation Mega-Frame, Unit Load at Level 20

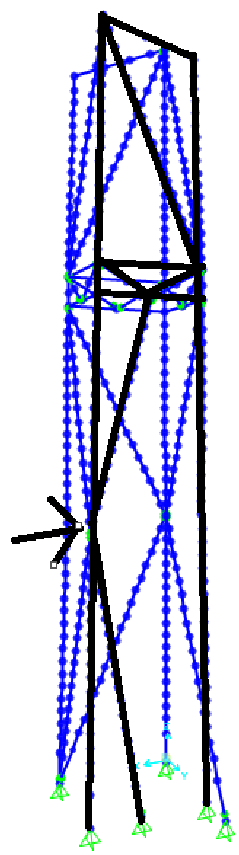


Figure 3| East Elevation Mega-Frame, Unit Load at Level 20

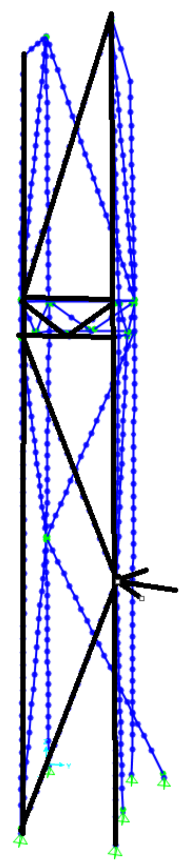


Figure 4| South Elevation Mega-Frame, Unit Load at Level 20

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

Center of Rigidity

Meg = Mega Frame
Mom = Moment Frame

West Elevation, Level 20

$\Delta_{meg} = 0.0017''$ → $K_{meg} = \frac{1}{0.0017} = 588$ k/in

$\Delta_{mom} = 0.0009''$ → $K_{mom} = \frac{1}{0.0009} = 1111$ k/in

North Elevation, Level 20

$\Delta_{meg} = 0.0016''$ → $K_{meg} = \frac{1}{0.0016} = 625$ k/in

$\Delta_{mom} = 0.0003''$ → $K_{mom} = \frac{1}{0.0003} = 3333$ k/in

East Elevation, Level 20

$\Delta_{meg} = 0.0018''$ → $K_{meg} = \frac{1}{0.0018} = 556$ k/in

$\Delta_{mom} = 0.0003''$ → $K_{mom} = \frac{1}{0.0003} = 3333$ k/in

South Elevation, Level 20

$\Delta_{meg} = 0.0022$ → $K_{meg} = \frac{1}{0.0022} = 455$ k/in

$\Delta_{mom} = 0.0012''$ → $K_{mom} = \frac{1}{0.0012} = 833$ k/in

West Elevation, Level 37

$\Delta_{meg} = 0.0016''$ → $K_{meg} = \frac{1}{0.0016} = 625$ k/in

$\Delta_{mom} = 0.0008''$ → $K_{mom} = \frac{1}{0.0008} = 1250$ k/in

North Elevation, Level 37

$\Delta_{meg} = 0.0014''$ → $K_{meg} = \frac{1}{0.0014} = 714$ k/in

$\Delta_{mom} = 0.0003''$ → $K_{mom} = \frac{1}{0.0003} = 3333$ k/in

East Elevation, level 37

$\Delta_{meg} = 0.0018'' \rightarrow K_{meg} = \frac{1}{0.0018} = 556 \text{ k/in}$

$\Delta_{mom} = 0.0003'' \rightarrow K_{meg} = \frac{1}{0.0003} = 3333 \text{ k/in}$

South Elevation Level 37

$\Delta_{meg} = 0.002 \rightarrow K_{meg} = \frac{1}{0.002} = 500 \text{ k/in}$

$\Delta_{mom} = 0.0011'' \rightarrow K_{mom} = \frac{1}{0.0011} = 909 \text{ k/in}$

Vest Elevation, Level 39

$\Delta_{meg} = 0.0016'' \rightarrow K_{meg} = \frac{1}{0.0016} = 625 \text{ k/in}$

$\Delta_{mom} = 0.0008'' \rightarrow K_{mom} = \frac{1}{0.0008} = 1250 \text{ k/in}$

North Elevation, Level 39

$\Delta_{meg} = 0.0014'' \rightarrow K_{meg} = \frac{1}{0.0014} = 714 \text{ k/in}$

$\Delta_{mom} = 0.0003'' \rightarrow K_{mom} = \frac{1}{0.0003} = 3333 \text{ k/in}$

East Elevation, Level 39

$\Delta_{meg} = 0.0018'' \rightarrow K_{meg} = \frac{1}{0.0018} = 556 \text{ k/in}$

$\Delta_{mom} = 0.0003'' \rightarrow K_{mom} = \frac{1}{0.0003} = 3333 \text{ k/in}$

South Elevation, Level 39

$\Delta_{meg} = 0.002'' \rightarrow K_{meg} = \frac{1}{0.002} = 500 \text{ k/in}$

$\Delta_{mom} = 0.0011'' \rightarrow K_{mom} = \frac{1}{0.0011} = 909 \text{ k/in}$

West Elevation, Level 56 BF = Braced Frame

$\Delta_{meg} = 0.0016'' \rightarrow K_{meg} = \frac{1}{0.0016} = 625$ k/in

$\Delta_{BF} = 0.0005'' \rightarrow K_{BF} = \frac{1}{0.0005} = 2000$ k/in

North Elevation, Level 56

$\Delta_{meg} = 0.0014'' \rightarrow K_{meg} = \frac{1}{0.0014} = 714$ k/in

$\Delta_{BF} = 0.0003'' \rightarrow K_{BF} = \frac{1}{0.0003} = 3333$ k/in

East Elevation Level 56

$\Delta_{meg} = 0.0016'' \rightarrow K_{meg} = \frac{1}{0.0016} = 625$ k/in

$\Delta_{BF} = 0.0005'' \rightarrow K_{BF} = \frac{1}{0.0005} = 2000$ k/in

South Elevation Level 56

$\Delta_{meg} = 0.0018'' \rightarrow K_{meg} = \frac{1}{0.0018''} = 556$ k/in

$\Delta_{BF} = 0.0007 \rightarrow K_{BF} = \frac{1}{0.0007} = 1429$ k/in

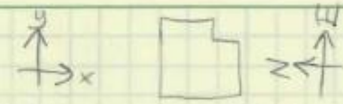
East Elevation Along Gridline A

Level 20:

$\Delta_{mom} = 0.0003'' \rightarrow K_{mom} = \frac{1}{0.0003} = 3333$ k/in

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

$$\bar{x}_R = \frac{\Sigma R_y x}{\Sigma R_y} \qquad \bar{y}_R = \frac{\Sigma R_x y}{R_x}$$



Level 20:

$$\bar{x}_R = \frac{625(4.042) + 3333(4.042) + 455(117.585) + 833(117.585)}{625 + 3333 + 455 + 833}$$

$$= 31.92'$$

$$\bar{y}_R = \frac{588(4.042) + 1111(4.042) + 556(95.958) + 3333(95.958) + 3333(119.612)}{588 + 1111 + 556 + 3333 + 3333}$$

$$= 87.29'$$

Level 37:

$$\bar{x}_R = \frac{714(9.667) + 3333(9.667) + 500(114.205) + 909(114.205)}{714 + 3333 + 500 + 909}$$

$$= 36.666'$$

$$\bar{y}_R = \frac{625(10.792) + 1250(10.792) + 556(95.958) + 3333(95.958)}{625 + 1250 + 556 + 3333}$$

$$= 81.27'$$

Level 39:

$$\bar{x}_R = \frac{714(9.667) + 3333(9.667) + 500(114.205) + 909(114.205)}{714 + 3333 + 500 + 909}$$

$$= 36.666'$$

$$\bar{y}_R = \frac{625(10.792) + 1250(10.792) + 556(95.958) + 3333(95.958)}{625 + 1250 + 556 + 3333}$$

$$= 81.27'$$

Level 56:

$$\bar{x}_R = \frac{714(9.667) + 3333(9.667) + 556(108.651) + 1429(108.651)}{714 + 3333 + 556 + 1429}$$

$$= 42.24'$$

$$\bar{y}_R = \frac{625(10.792) + 2000(10.792) + 625(90.667) + 2000(90.667)}{625(2) + 2000(2)}$$

$$= 50.73'$$

Center of Mass

Level 20:

$$\bar{x}_{com} = \frac{(110.922)(89.945)(55.3675) + (58.69)(23.679)(29.345)}{(110.922)(89.945) + (58.69)(23.679)}$$

$$= 52.19'$$

$$\bar{y}_{com} = \frac{(110.922)(89.945)(44.973) + (58.69)(23.679)(100.107)}{(110.922)(89.945) + (58.69)(23.679)}$$

$$= 51.714'$$

Level 37 & 39:

$$\bar{x}_{com} = \frac{(104.541)(85.166)(52.2705)}{(104.541)(85.166)}$$

$$= 52.27'$$

$$\bar{y}_{com} = \frac{(104.541)(85.166)(42.583)}{(104.541)(85.166)}$$

$$= 42.58'$$

Level 56:

$$\bar{x}_{com} = \frac{(99.377)(78.541)(49.689)}{(99.377)(78.541)}$$

$$= 49.689'$$

$$\bar{y}_{com} = \frac{(99.377)(78.541)(39.271)}{(99.377)(78.541)}$$

$$= 39.27'$$

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

Wind Load Distribution Checks

Level 20: COM: (52.19, 51.714) COR: (31.92, 87.29)

Torsional Rigidity,

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

$$= 588(79.599')^2 + 1111(79.599')^2 + 3333(24.631')^2$$
$$+ 556(0.952')^2 + 3333(0.952')^2 + 625(25.07')^2$$
$$+ 3333(25.07')^2 + 455(78.815')^2 + 833(78.815')^2$$
$$= 23{,}278{,}900 \ k/in \cdot ft^2$$

Direct Shear,

$$V_d = \frac{R_i}{\Sigma R_i} V \qquad V_{N\text{-}S} = 58.8^k \qquad V_{E\text{-}W} = 53.5^k$$

$$M_t = Ve \qquad e_x = 20.27' \qquad e_y = 35.576'$$

$$= 58.8(35.576) = 2092 \ 'k/in \ (N\text{-}S)$$
$$= 53.5(20.27) = 1084 \ 'k/in \ (E\text{-}W)$$

$$V_t = \frac{M_t}{J}(R_i d_i)$$

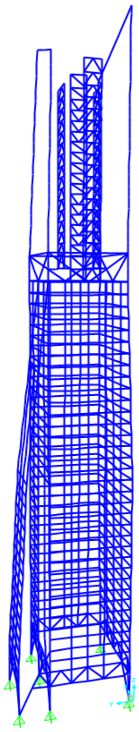


Figure 5| Brace Frames and Moment Frames Model

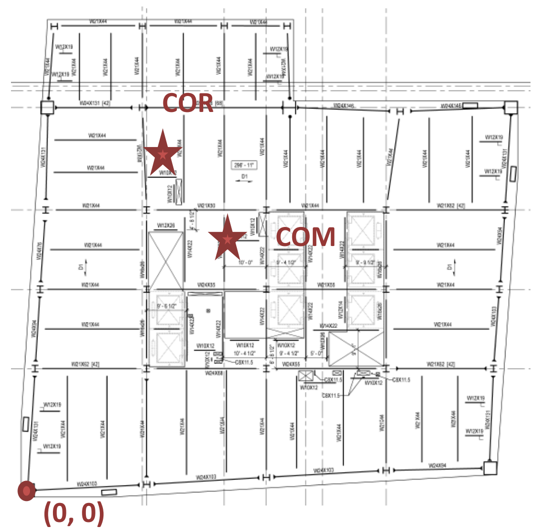


Figure 6| Level 20 center of rigidity at x = 31.92', y =87.29'. Center of mass at (52.19', 51.714')

Elevation	Frame	Rigidity (k/in)	Vd, N-S	Vd, E-W	di	Vt, N-S	Vt, E-W	V, N-S	V, E-W
West	Mega	588	44.41025	40.38427	79.599	4.206144	2.179474	48.61639	42.56375
	Moment	1111	83.9112	76.3043	79.599	7.947324	4.11802	91.85853	80.42232
North	Mega	625	47.20477	42.92546	25.07	1.4081	0.729627	48.61287	43.65509
	Moment	3333	251.7336	228.9129	25.07	7.509117	3.890957	259.2427	232.8039
East	Mega	556	41.99336	38.18649	0.952	0.047568	0.024648	42.04093	38.21114
	Moment	3333	251.7336	228.9129	0.952	0.285149	0.147754	252.0188	229.0607
East at Grid A	Moment	3333	251.7336	228.9129	24.631	7.377625	3.822823	259.1112	232.7357
South	Mega	455	34.36507	31.24974	78.815	3.222697	1.669887	37.58777	32.91962
	Moment	833	62.91452	57.21105	78.815	5.900015	3.057178	68.81453	60.26823
	SUM:	14167							

Table 1| ASCE 7-05 Case 1 Wind Load Distribution to Lateral Systems

As a way to verify the computer output, shear distribution to the various frames, with inclusion of torsional shear, was calculated at level 20 (See output in Table 1). To ensure the model accounted for torsion as well, nodes with diaphragm constraints were placed at each level's center of rigidity and wind story forces were applied to the node. Initially wind loads were modeled at the exterior of the frame, however sufficient load distribution to the mega frame was not occurring as a result.

The shear due to lateral loads absorbed by the mega-braces, compared to the shear in the moment frames, is significantly lower in the SAP model (Figure 7). The hand-check demonstrates lower shear within the mega-frames, but not to the same extent. This is likely due to the behavior of the pinned ends in the model. Axial load, however, is significantly larger in the mega frame under the applied lateral loads than in the moment frames (Figure 8).

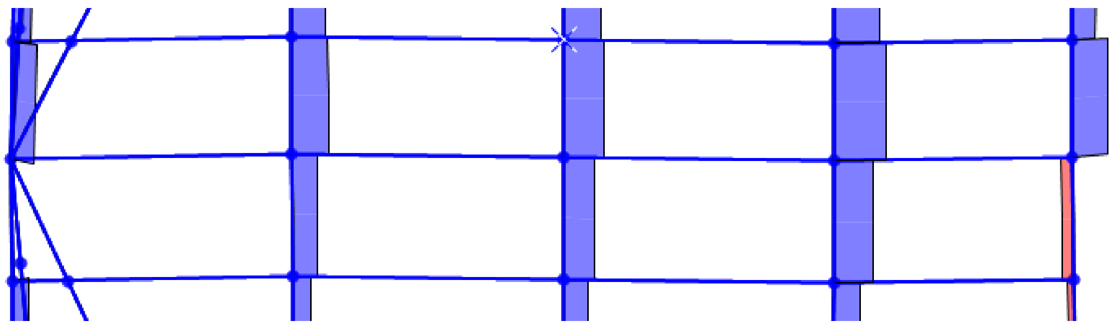


Figure 7| Little Shear in Mega-Brace Compared to Braced Frame (about 40 kips at top center column pictured).

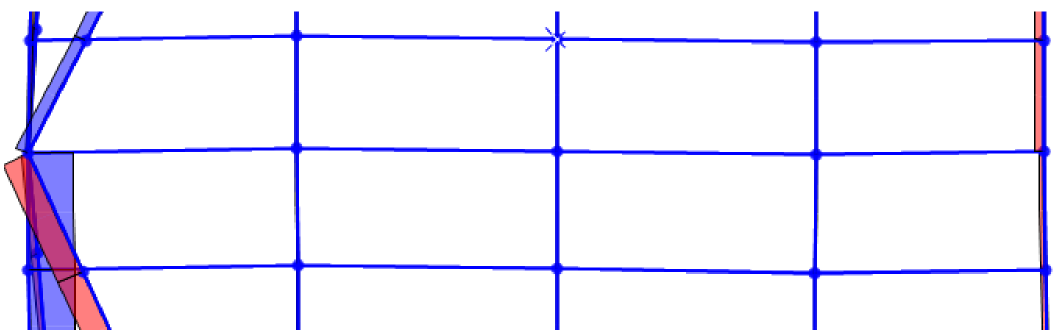


Figure 8| 4000 kip Axial Load in Mega-Brace in the Lower Left of the Image.

Adding up the sum of the west elevation moment frame shears at level 20 results in a total shear load experienced of about 125 kips. This is conservative compared to the 92 kip value in the table above, however, and is therefore acceptable.

Strength and Overturning

The largest overturning moment due to wind was equal to 301,926 ft-kips. This is larger than the hand calculated value of 224,018 ft-kips. Reduction in this value may come from an improved modeling of buckling restrained brace frame behavior, but overall it suggests the high effect the eccentricity between the center of mass and center of rigidity has.

The torsional moment was found to be over 292,000 kips, indicating significant issues with the center of rigidity eccentricity and subsequent torsion produced. This large eccentricity is caused by the partial extrusion of the floor on the office levels, up to level 37.

Drift and Story Drift

Under wind loads, upper stories experienced between 20 and 30 inches of drift. At it's greatest, this is significantly larger than the drift required for serviceability of h/600 = 700*12/600 = 21”. Since a linear analysis was used, however, many simplifications were made in the model. The effect of the dampers located on some of the mega-braces, for example, were not modeled, nor was the effect of a slosh damper located on one of the upper stories. The actual drift 181 Fremont is likely to experience, therefore, will not be of concern.

Seismic Load Analysis

Frame Performance

Seismic in the mega-braces and corresponding moment frames or braced frame, depending on the level, were close in value (Figure 9). Additionally, axial loads at the base of the mega-columns (about 14,000 kips) are significantly larger than those at the base of the moment-frames (about 4,000 kips). This demonstrates the load transfer of all secondary systems to the mega-frame.

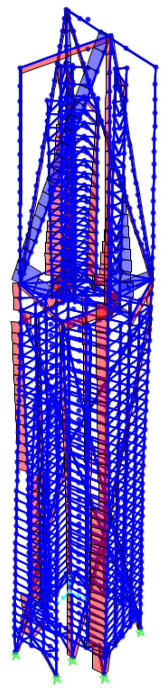


Figure 9

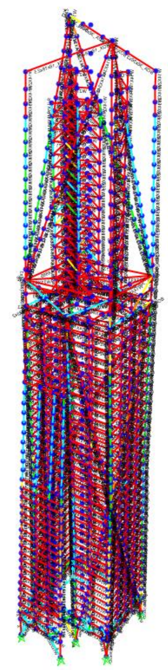


Figure 10

Upon doing a steel design check, the majority of the members failed under the seismic loading in SAP. For the mega-frames, this may be do to inaccurate representation of the stiffness. Upon further inspection of the moment frame members, failure was experienced in flexure for many member columns.

Strength, Overturning, and Torsion

The overturning moment due to seismic at the base of the building was 213,000 kips. This is significantly lower than the overturning due to wind, demonstrating the need to further investigate the computer model's validity, especially since the seismic base shear is about 1,200 kips greater than wind base shear. Because the wind load was applied at the center of rigidity, however, this overturning moment still demonstrates the poor torsional

Drift and Story Drift

Displacements at the upper floors of the building due to seismic loads were 133 inches in the worst case (about 11’). This is much greater than the wind drift value, which is to be expected.

Areas for Improvement

Although the majority of the geometry was represented correctly, some simplifications were made with modeling the upper story braced frames at the core as well as with modeling the center of rigidity and center of masses. Moving forward, to improve the models ability to approximate the structural behavior, more precise center of rigidities and center of masses may be modeled.

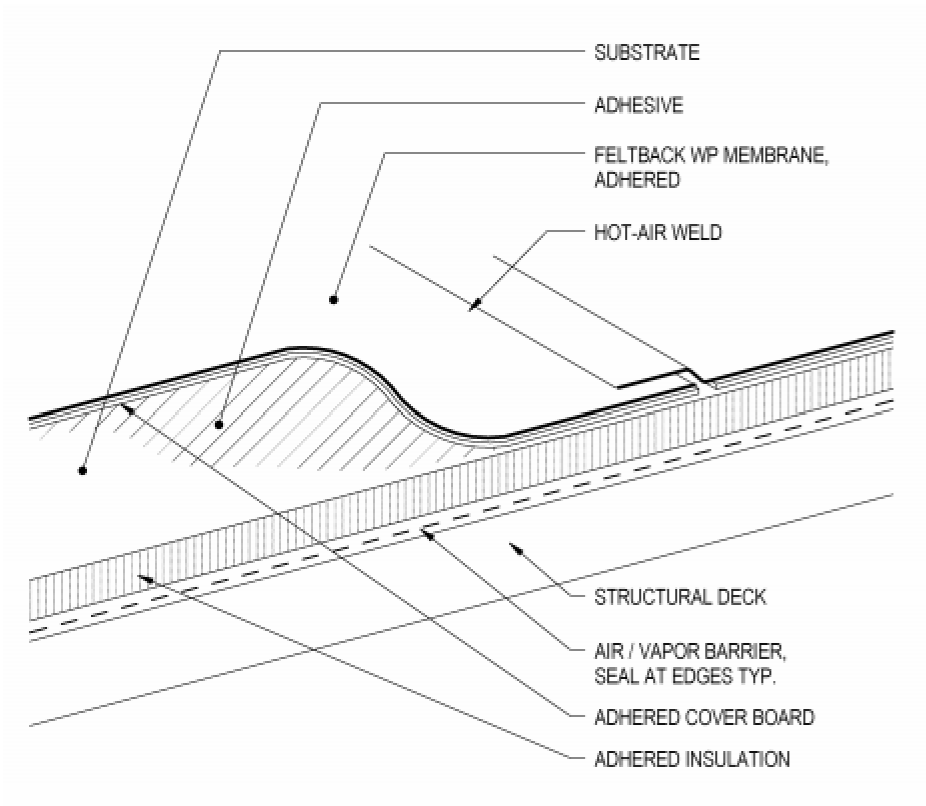
Stiffness assumptions and member modeling may also be refined. Using a more representative approach to modeling the buckling restrained brace frames in the upper stories would likely improve the seismic performance and drift greatly. Additionally, more precise representation of the stiffened floor framing on level 37, rather than the simplified framing put in place for the braced frames to sit on, would also improve the stiffness behavior of the braced frames.

The inaccurate representation of failure members in SAP is likely due to a modeling error which must be further inspected. Taking the steps above, as well as verifying all member orientations may improve the SAP output.

Appendix A

Gravity Loads

Typical Roof Bay Cross Section



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3-0235 — 50 SHEETS — 5 SQUARES
3-0206 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

Typical Roof Bay

Dead Load:

6" NW conc. on 2" metal deck	- 91 psf	→ use for entire roof to be conservative
Membrane + Air/Vapor barrier + cover board	- 5 psf	
Rigid Insulation	- 1.5psf (4") = 6 psf	
Steel Framing	- 10 psf	
MEP	- 3 psf	
Ceilings	- 5 psf	
Sprinklers	- 3 psf	
	123 psf	

This is higher than the 107 psf load on S-019

Live Load:

20 psf per ASCE 7-05 table 4-1

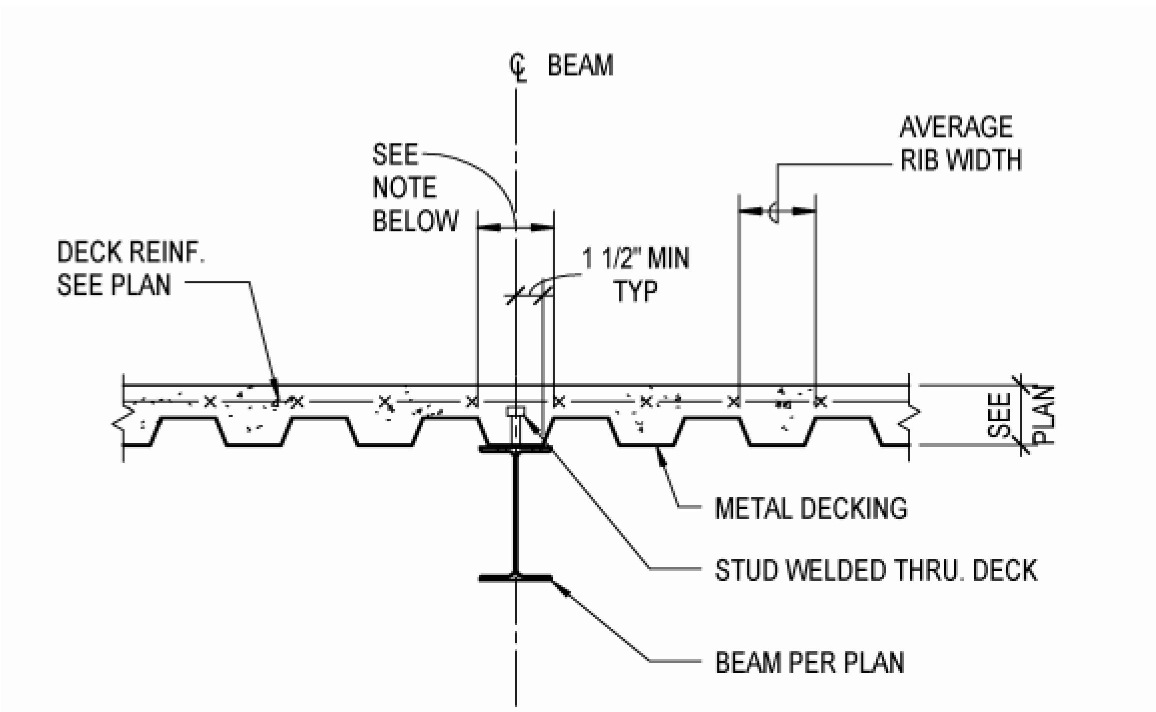
Snow Load: (ASCE 7-05)

$p_f = 0.7 C_e C_t I p_g$ (eqn 7-1)

$p_g = 0$ (Fig 7-1)

$\therefore \; p_f = 0$

Typical Floor Cross Section, Deck Parallel to Beam



Gravity Loads

10

Typical Residential Floor

Dead:

3¼" NW conc. on 2" Epicore Metal Deck	-	65 psf
MEP	-	15 psf
Ceilings	-	5 psf
Sprinklers	-	3 psf
Additional concrete	-	5 psf
Steel Framing	-	10 psf
		103 psf

103 psf = typical residential load on S-019, but different allowances used

Live:

(ASCE 7-05) (table 4-1)

Residential, Private Rooms and areas serving them	-	40 psf
Partitions	-	15 psf
		55 psf

Typical Office Floor

Dead:

3¼" LWC on 2" metal deck	-	44 psf
MEP	-	15 psf
Ceilings	-	5 psf
sprinklers	-	3 psf
additional concrete	-	5 psf
steel framing	-	10 psf
		82 psf

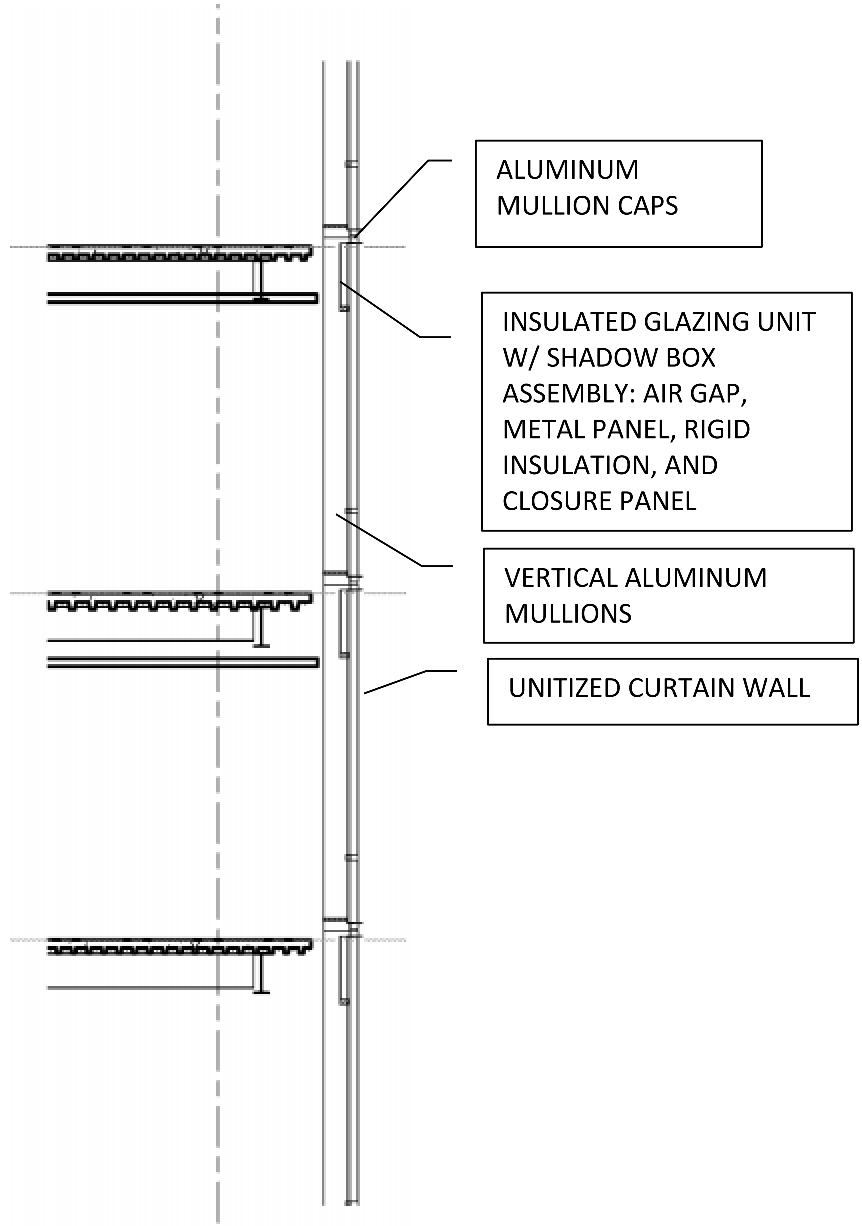
82 psf > typical office load of 60 psf on S-019

Live:

(ASCE 7-05)

Offices	-	50 psf
Partitions	-	15 psf
		65 psf = design load on S-019
corridors	-	80 psf = design load on S-019

Typical Exterior Wall Detail Cross-Section



Gravity Loads

12

Typical Exterior Wall

Dead Load:

Curtain Wall System - 13 psf

Load Path:

The curtain wall anchors into the concrete slabs at each level using angles embedded in the slab edges. Through these connections, the lateral loads experienced by the curtain wall and the wall's self-weight are transferred to the structure's diaphragm.

Non-typical Dead Loads:

Roof Mechanical Equipment - actual weight (2 chillers, waiting on size)

Mechanical Floors - 100 psf (deck) + typical allowances
Levels 2, 38 + 25 psf allowance for concrete curbs and housekeeping

Retail Space - extra 16 psf for ceramic floors
Level 5

Lobby - 150 psf (12" slab) + typical allowances = 163 psf

Non-Typical Live Loads:

Roof Mechanical Room - 150 psf (ASCE Armories & Drill Rooms)

Mechanical Floors - 125 psf (ASCE light manufacturing)
Level 2, 38

Storage - 125 psf (ASCE light storage)
Level 2

Retail - 100 psf (ASCE Store retail)
Level 5

Lobby - 100 psf

Wind Loads

*Note: 181 Fremont was analyzed using wind tunnel testing and selective use of ASCE 7-10. This report however, will instead only use ASCE 7-05 per the California Building Code requirements (CBC 2010).

ASCE 7-05:

Analysis Method

high-rise building greater than 60 ft → Method 2 used (§6.5)

Assumption:

This report assumes items in condition 2 of §6.5.1 are not present. In reality, the building is likely to be susceptible to one or more of these items, such as across wind loading, and a wind tunnel procedure would be the necessary analysis method.

Basic wind speed, V

$V = 85$ mph (Fig. 6-1)

Importance Factor

Occupancy Category II (table 1-1)

$I = 1.00$ (table 6-1)

Exposure

Surface Roughness B (§ 6.5.6.2)

Exposure C, case 2 in table 6-3

$K_z = 2.01 (z/z_g)^{2/\alpha}$

where $z_g = 900$ ft $\alpha = 9.5$ (table 6-2)

*see table on page 15 for values of K_z

$K_{zt} = 1.0$ $K_d = 0.85$ (table 6-4)

Gust Effect Factor

Use $G = 0.85$ (§ 6.5.8.1)

Enclosed Building

Wind Loads

14

Internal Pressure Coefficient

$GC_{pi} = +/- 0.18$ (Fig. 6-5)

External Pressure Coefficients

roof slope = 1/4"/1' = 1.2°

$h/L = 700/137.5 = 5.1$ $L/B = 137.5/125 = 1$

Windward Roof:
0 to $\frac{h}{2}$, $C_p = -1.3(0.8) = -1.04, -0.18$
$\geq \frac{h}{2}$, $C_p = -0.7, -0.18$

Leeward Roof:
$C_p = -0.7 + \frac{(14-10)(-.6 - -0.7)}{(15-10)}$
$= -0.62$

(Fig. 6-6)

Windward Wall: $C_p = 0.8$ Leeward Wall: $C_p = -0.5$ Side Wall: $C_p = -0.7$ (Fig. 6-6)

Velocity Pressure

$q_h = 0.00256 K_h K_{zt} K_d V^2 I$

$= 0.00256(1.7)(1.0)(0.85)(85^2)(1.0) = 26.7$ psf

$q_z = 0.00256 K_z K_{zt} K_d V^2 I$ (eqn. 6-15)

* see table table on page 15 for q_z values

Design Wind Pressure

$p = qGC_p - q_i(GC_{pi})$ (eqn. 6-17)

* see table on page 15 for p values

Wind Loads in N-S and E-W directions

* see table on page 17 for wind loads

Building Level	Height above ground level, z (ft)	Kz	qz (psf)	qzGCp	Leeward qhGCp	+qhGCpi	-qhGCpi	p (psf)
1	0	0.57	8.961312	6.09369216	-11.3475	4.806	-4.806	22.24719
1A	7.5	0.57	8.961312	6.09369216	-11.3475	4.806	-4.806	22.24719
1B	17.91666667	0.881239367	13.85449283	9.42105513	-11.3475	4.806	-4.806	25.57456
2	29.83333333	0.981101182	15.42448034	10.4886466	-11.3475	4.806	-4.806	26.64215
3	46.33333333	1.076377712	16.92237984	11.5072183	-11.3475	4.806	-4.806	27.66072
4	58.83333333	1.131885698	17.79505418	12.1006368	-11.3475	4.806	-4.806	28.25414
5	71.33333333	1.178737532	18.53163998	12.6015152	-11.3475	4.806	-4.806	28.75502
6	83.83333333	1.219495227	19.17241616	13.037243	-11.3475	4.806	-4.806	29.19074
7	96.33333333	1.255704476	19.74168349	13.4243448	-11.3475	4.806	-4.806	29.57784
8	108.8333333	1.288374888	20.25531464	13.773614	-11.3475	4.806	-4.806	29.92711
9	121.3333333	1.318204909	20.7242903	14.0925174	-11.3475	4.806	-4.806	30.24602
10	133.8333333	1.345699256	21.15654542	14.3864509	-11.3475	4.806	-4.806	30.53995
11	146.3333333	1.371235367	21.55801395	14.6594495	-11.3475	4.806	-4.806	30.81295
12	158.8333333	1.395103418	21.9332579	14.9146154	-11.3475	4.806	-4.806	31.06812
13	171.3333333	1.417531648	22.28586555	15.1543886	-11.3475	4.806	-4.806	31.30789
14	183.8333333	1.438703046	22.61871382	15.3807254	-11.3475	4.806	-4.806	31.53423
15	196.3333333	1.458766742	22.93414721	15.5952201	-11.3475	4.806	-4.806	31.74872
16	208.8333333	1.477845983	23.23410341	15.7991903	-11.3475	4.806	-4.806	31.95269
17	221.3333333	1.496043888	23.5202036	15.9937384	-11.3475	4.806	-4.806	32.14724
18	233.8333333	1.513447663	23.79381878	16.1797968	-11.3475	4.806	-4.806	32.3333
19	246.3333333	1.530131765	24.05611955	16.3581613	-11.3475	4.806	-4.806	32.51166
20	259.4166667	1.546893252	24.31963694	16.5373531	-11.3475	4.806	-4.806	32.69085
21	271.9166667	1.562295104	24.56177871	16.7020095	-11.3475	4.806	-4.806	32.85551
22	284.4166667	1.577147748	24.79528603	16.8607945	-11.3475	4.806	-4.806	33.01429
23	296.9166667	1.591493663	25.02082677	17.0141622	-11.3475	4.806	-4.806	33.16766
24	309.4166667	1.605370418	25.23899157	17.1625143	-11.3475	4.806	-4.806	33.31601
25	321.9166667	1.618811414	25.45030553	17.3062078	-11.3475	4.806	-4.806	33.45971
26	334.4166667	1.631846485	25.6552377	17.4455616	-11.3475	4.806	-4.806	33.59906
27	346.9166667	1.644502398	25.85420891	17.5808621	-11.3475	4.806	-4.806	33.73436
28	359.4166667	1.656803267	26.04759824	17.7123668	-11.3475	4.806	-4.806	33.86587
29	371.9166667	1.668770895	26.2357485	17.840309	-11.3475	4.806	-4.806	33.99381
30	384.4166667	1.68042507	26.41897077	17.9649001	-11.3475	4.806	-4.806	34.1184
31	396.9166667	1.691783804	26.59754825	18.0863328	-11.3475	4.806	-4.806	34.23983
32	409.4166667	1.702863547	26.77173954	18.2047829	-11.3475	4.806	-4.806	34.35828
33	421.9166667	1.713679365	26.94178151	18.3204114	-11.3475	4.806	-4.806	34.47391
34	434.4166667	1.724245092	27.10789163	18.4333663	-11.3475	4.806	-4.806	34.58687
35	446.9166667	1.734573462	27.27027015	18.5437837	-11.3475	4.806	-4.806	34.69728
36	459.4166667	1.74467623	27.42910182	18.6517892	-11.3475	4.806	-4.806	34.80529
37	473.0833333	1.755476556	27.59890023	18.7672522	-11.3475	4.806	-4.806	34.92075
38	486.8333333	1.766096952	27.76586984	18.8807915	-11.3475	4.806	-4.806	35.03429
39	502.3333333	1.777788777	27.94968403	19.0057851	-11.3475	4.806	-4.806	35.15929
40	513.75	1.78621965	28.08223086	19.095917	-11.3475	4.806	-4.806	35.24942
41	525.1666667	1.794503887	28.21247231	19.1844812	-11.3475	4.806	-4.806	35.33798
42	536.5833333	1.802647143	28.34049733	19.2715382	-11.3475	4.806	-4.806	35.42504
43	548	1.810654743	28.46638961	19.3571449	-11.3475	4.806	-4.806	35.51064
44	559.4166667	1.818531703	28.59022803	19.4413551	-11.3475	4.806	-4.806	35.59486

Building Level	Height above ground level, z (ft)	Kz	qz (psf)	qzGCp	Leeward qhGCp	+qhGCpi	-qhGCpi	p (psf)
45	570.8333333	1.826282757	28.71208699	19.5242192	-11.3475	4.806	-4.806	35.67772
46	582.25	1.833912375	28.8320368	19.605785	-11.3475	4.806	-4.806	35.75929
47	593.6666667	1.841424787	28.95014394	19.6860979	-11.3475	4.806	-4.806	35.8396
48	605.0833333	1.848823996	29.06647134	19.7652005	-11.3475	4.806	-4.806	35.9187
49	616.5	1.856113796	29.18107866	19.8431335	-11.3475	4.806	-4.806	35.99663
50	627.9166667	1.863297787	29.29402249	19.9199353	-11.3475	4.806	-4.806	36.07344
51	639.3333333	1.870379387	29.40535658	19.9956425	-11.3475	4.806	-4.806	36.14914
52	650.75	1.877361846	29.515132	20.0702898	-11.3475	4.806	-4.806	36.22379
53	662.1666667	1.884248255	29.62339736	20.1439102	-11.3475	4.806	-4.806	36.29741
54	673.5833333	1.891041557	29.73019894	20.2165353	-11.3475	4.806	-4.806	36.37004
55	686	1.898327471	29.84474516	20.2944267	-11.3475	4.806	-4.806	36.44793
56	700	1.906418634	29.9719512	20.3809268	-11.3475	4.806	-4.806	36.53443

Design Wind Loads

Building Level	N-S Story Force (kip)	E-W Story Force (kip
1		
1A	22.94241692	20.85674265
1B	36.63022219	33.30020199
2	43.65426734	39.68569758
3	62.75525463	57.05023148
4	48.5617977	44.14708882
5	49.42268235	44.92971123
6	50.17158951	45.61053592
7	50.83692071	46.21538246
8	51.43722712	46.76111556
9	51.98534241	47.25940219
10	52.49054059	47.71867326
11	52.95975692	48.14523357
12	53.3983233	48.54393027
13	53.81043349	48.9185759
14	54.1994499	49.27222718
15	54.56811267	49.60737516
16	54.91868649	49.92607863
17	55.25306608	50.23006007
18	55.57285383	50.52077621
19	55.87941785	50.79947077
20	58.80948265	53.46316604
21	56.47040699	51.33673363
22	56.74331868	51.58483516
23	57.00691941	51.82447219
24	57.26189952	52.05627229
25	57.50887272	52.28079338
26	57.74838719	52.49853381
27	57.98093478	52.70994071
28	58.20695857	52.91541688
29	58.42685919	53.11532654
30	58.64100022	53.3100002
31	58.84971264	53.49973876
32	59.05329871	53.68481701
33	59.25203526	53.8654866
34	59.44617647	54.04197861
35	59.63595636	54.21450578
36	59.82159087	54.38326443
37	65.62191342	59.65628493
38	66.23670735	60.2151885
39	74.93322646	68.12111497
40	55.33424103	50.30385548
41	55.47326836	50.43024396
42	55.60992973	50.55448158
43	55.7443145	50.67664955
44	55.87650685	50.79682441
45	56.00658621	50.91507838
46	56.13462764	51.03147967
47	56.26070208	51.1460928
48	56.38487674	51.25897885
49	56.50721528	51.37019571
50	56.62777811	51.47979828
51	56.74662261	51.58783874
52	56.8638033	51.69436664
53	56.97937206	51.79942915
54	57.0933783	51.90307118
55	62.22724154	56.57021958
56	70.32877162	63.93524693
Base Shear	3185.303255	2895.730232

Overturning Moment = 224,018 ft-kips

Seismic Loads

Seismic Loads

22

Floor area = 125'(137.5') − (37.5')(50')
= 15,312.5 ft²

Effective Seismic Weight

Level 1a & 1b have 50% of floor open to below, so total weight = 1 floor

Floor:	dead load:	partitions:	floor area:	# of floors:	weight:
1a & 1b	163 psf	0	15,312.5	1	2,496^k
2-4	82 psf	0	15,312.5	3	3,767^k
5	98 psf	0	15,312.5	1	1,501^k
6-37	82 psf	15 psf	15,312.5	32	47,530^k
38	138 psf	0	15,312.5	1	2,113^k
39-56	103 psf	0	15,312.5	18	28,389^k
					85,796,000^k

(Steel framing allowance included in above values)

Curtain wall:

$13\text{ psf}\,(700')\,[2(137.5) + 2(125)] = 3675^k$

Total Seismic Weight = 86,164^k

Parameters: (ASCE 7-05)

$S_s = 1.5$ $S_1 = 0.6$ (Fig 22-1, 22-2)

Site Class D

$S_{MS} = F_a S_s = 1.0(1.5) = 1.5$ (eqn 11.4-1)

$S_{M1} = F_v S_1 = 1.5(0.6) = 0.9$ (eqn 11.4-2)

$S_{DS} = 2/3\, S_{MS} = 1.0$ (eqn 11.4-3)

$S_{D1} = 2/3\, S_{M1} = 0.6$ (eqn 11.4-4)

Seismic Design Category

$I = 1$ (table 11.5-1)

$S_{DS} > 0.5$ → Seismic Design Category D (table 11.6-1)

Seismic Loads

23

Equivalent Lateral Force Procedure (§ 12.8)

$V = C_s W$ (eqn. 12.8-1)

$C_s = \frac{S_{DS}}{\left(\frac{R}{I}\right)}$ (eqn 12.8-2)

$R = 3.5$

* actual structural system not in code, so equivalency to C4 assumed

$= 1.0/3.5$

$= 0.286$

$0.286 > \frac{0.5 S_1}{\frac{R}{I}}$? (eqn 12.8-6)

$> 0.5(0.6)/4.5 = 0.067$ ✓ ∴ ok

$T_a = C_t h_n^x$ (12.8-7)

$= 0.02(700)^{0.75} = 2.72$

$T_L = 12\,s$ (fig 22-15)

$T < T_L \rightarrow C_s \leq \frac{S_{D1}}{T(R/I)} = \frac{0.6}{(2.72)(4.5)} = 0.05$

$\therefore C_s = 0.05$

$V = 0.05(86{,}164) = 4308^k$

Distribution of Seismic Forces

$F_x = C_{vx} V$ (12.8-11)

$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$ (12.8-12)

$k = 2$

* see table on next page for story forces

Building Level	Height above ground level (ft)	hi (ft)	w (kip)	wxhx	Cvx	Story Forces (kips)
1	0.00					
1A	7.50	7.50	1248.00	5656.01	0.0008	3.51
1B	17.92	10.42	1248.00	10868.20	0.0016	6.74
2	29.83	11.92	1256.00	16033.04	0.0023	9.94
3	46.33	16.50	1256.00	22305.39	0.0032	13.82
4	58.83	12.50	1256.00	26681.32	0.0038	16.54
5	71.33	12.50	1501.00	36842.58	0.0053	22.83
6	83.83	12.50	1485.00	41142.34	0.0059	25.50
7	96.33	12.50	1485.00	45662.42	0.0066	28.30
8	108.83	12.50	1485.00	50037.76	0.0072	31.01
9	121.33	12.50	1485.00	54288.96	0.0078	33.64
10	133.83	12.50	1485.00	58431.86	0.0084	36.21
11	146.33	12.50	1485.00	62478.98	0.0090	38.72
12	158.83	12.50	1485.00	66440.47	0.0096	41.18
13	171.33	12.50	1485.00	70324.69	0.0101	43.58
14	183.83	12.50	1485.00	74138.65	0.0107	45.95
15	196.33	12.50	1485.00	77888.26	0.0112	48.27
16	208.83	12.50	1485.00	81578.61	0.0117	50.56
17	221.33	12.50	1485.00	85214.12	0.0123	52.81
18	233.83	12.50	1485.00	88798.63	0.0128	55.03
19	246.33	12.50	1485.00	92335.53	0.0133	57.22
20	259.42	13.08	1485.00	95989.75	0.0138	59.49
21	271.92	12.50	1485.00	99438.22	0.0143	61.63
22	284.42	12.50	1485.00	102847.26	0.0148	63.74
23	296.92	12.50	1485.00	106219.04	0.0153	65.83
24	309.42	12.50	1485.00	109555.51	0.0158	67.90
25	321.92	12.50	1485.00	112858.44	0.0162	69.94
26	334.42	12.50	1485.00	116129.46	0.0167	71.97
27	346.92	12.50	1485.00	119370.04	0.0172	73.98
28	359.42	12.50	1485.00	122581.55	0.0176	75.97
29	371.92	12.50	1485.00	125765.26	0.0181	77.94
30	384.42	12.50	1485.00	128922.32	0.0185	79.90
31	396.92	12.50	1485.00	132053.82	0.0190	81.84
32	409.42	12.50	1485.00	135160.75	0.0194	83.76
33	421.92	12.50	1485.00	138244.06	0.0199	85.67
34	434.42	12.50	1485.00	141304.60	0.0203	87.57
35	446.92	12.50	1485.00	144343.21	0.0208	89.45

36	459.42	12.50	1485.00	147360.64	0.0212	91.32
37	473.08	13.67	1485.00	150636.32	0.0217	93.35
38	486.83	13.75	2113.00	218995.27	0.0315	135.72
39	502.33	15.50	1577.00	167330.72	0.0241	103.70
40	513.75	11.42	1577.00	170174.93	0.0245	105.46
41	525.17	11.42	1577.00	173003.37	0.0249	107.22
42	536.58	11.42	1577.00	175816.48	0.0253	108.96
43	548.00	11.42	1577.00	178614.66	0.0257	110.69
44	559.42	11.42	1577.00	181398.31	0.0261	112.42
45	570.83	11.42	1577.00	184167.79	0.0265	114.13
46	582.25	11.42	1577.00	186923.46	0.0269	115.84
47	593.67	11.42	1577.00	189665.65	0.0273	117.54
48	605.08	11.42	1577.00	192394.69	0.0277	119.23
49	616.50	11.42	1577.00	195110.89	0.0281	120.92
50	627.92	11.42	1577.00	197814.54	0.0285	122.59
51	639.33	11.42	1577.00	200505.92	0.0288	124.26
52	650.75	11.42	1577.00	203185.32	0.0292	125.92
53	662.17	11.42	1577.00	205852.99	0.0296	127.57
54	673.58	11.42	1577.00	208509.19	0.0300	129.22
55	686.00	12.42	1577.00	211385.30	0.0304	131.00
56	700.00	14.00	1577.00	214612.60	0.0309	133.00
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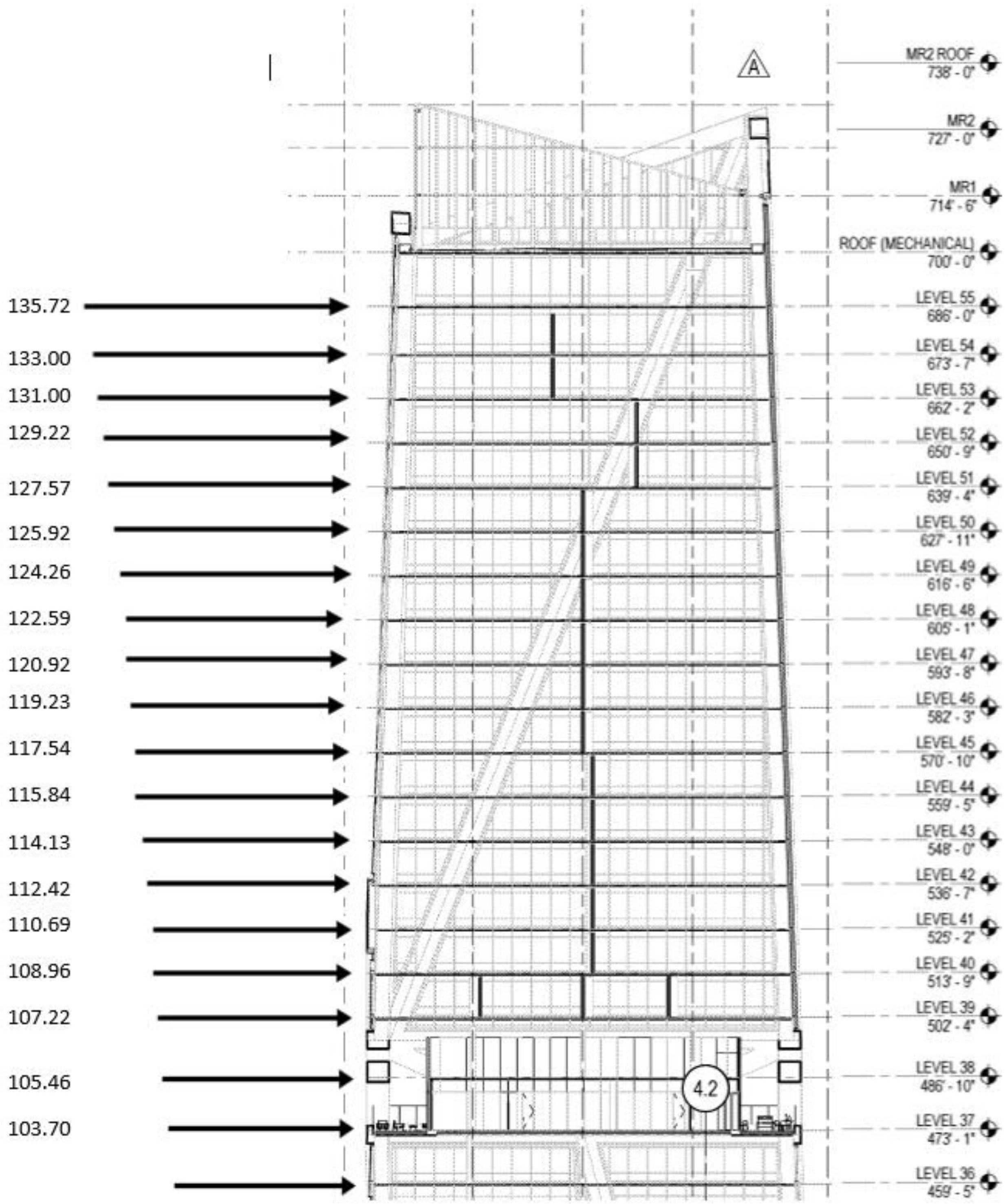
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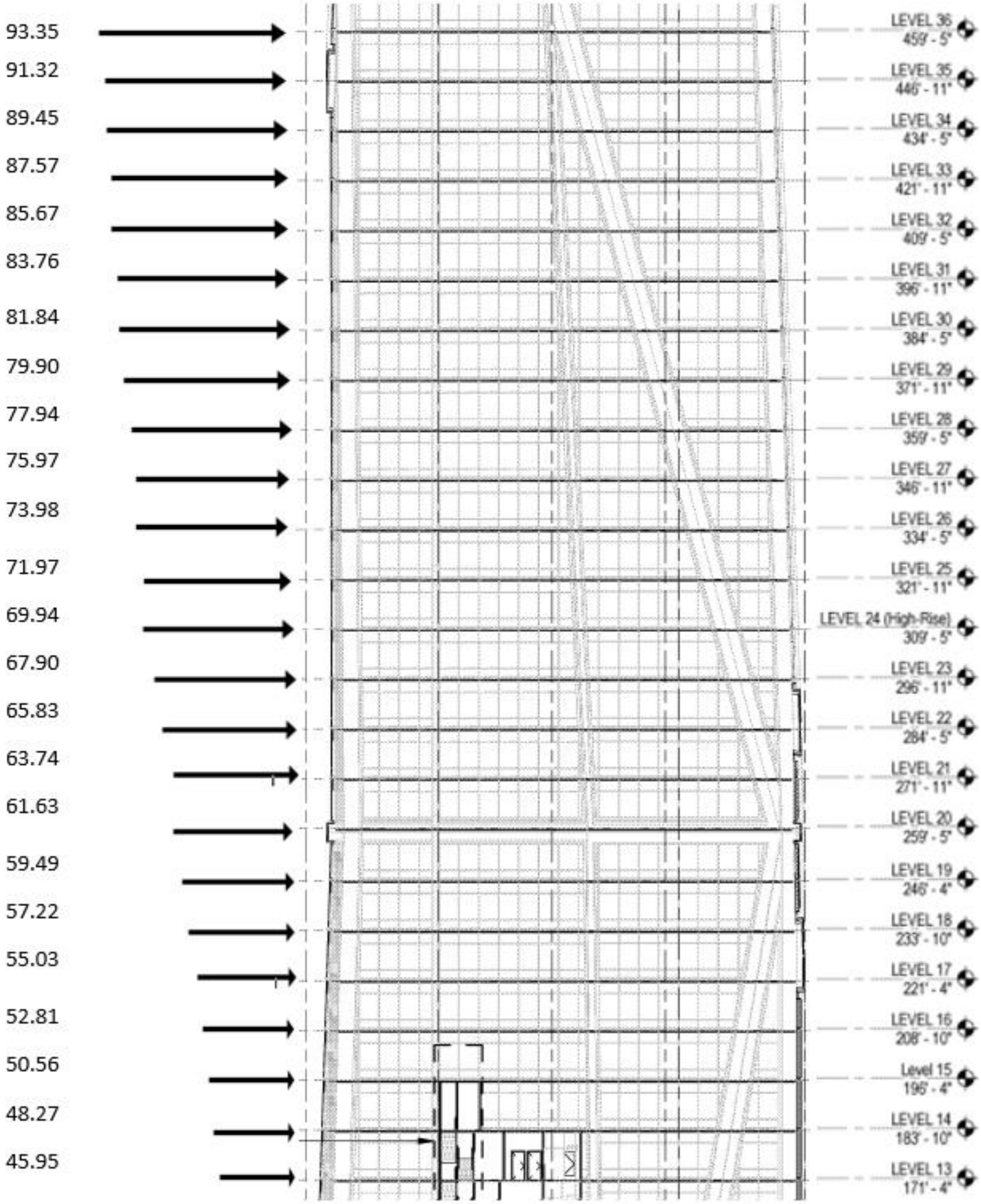
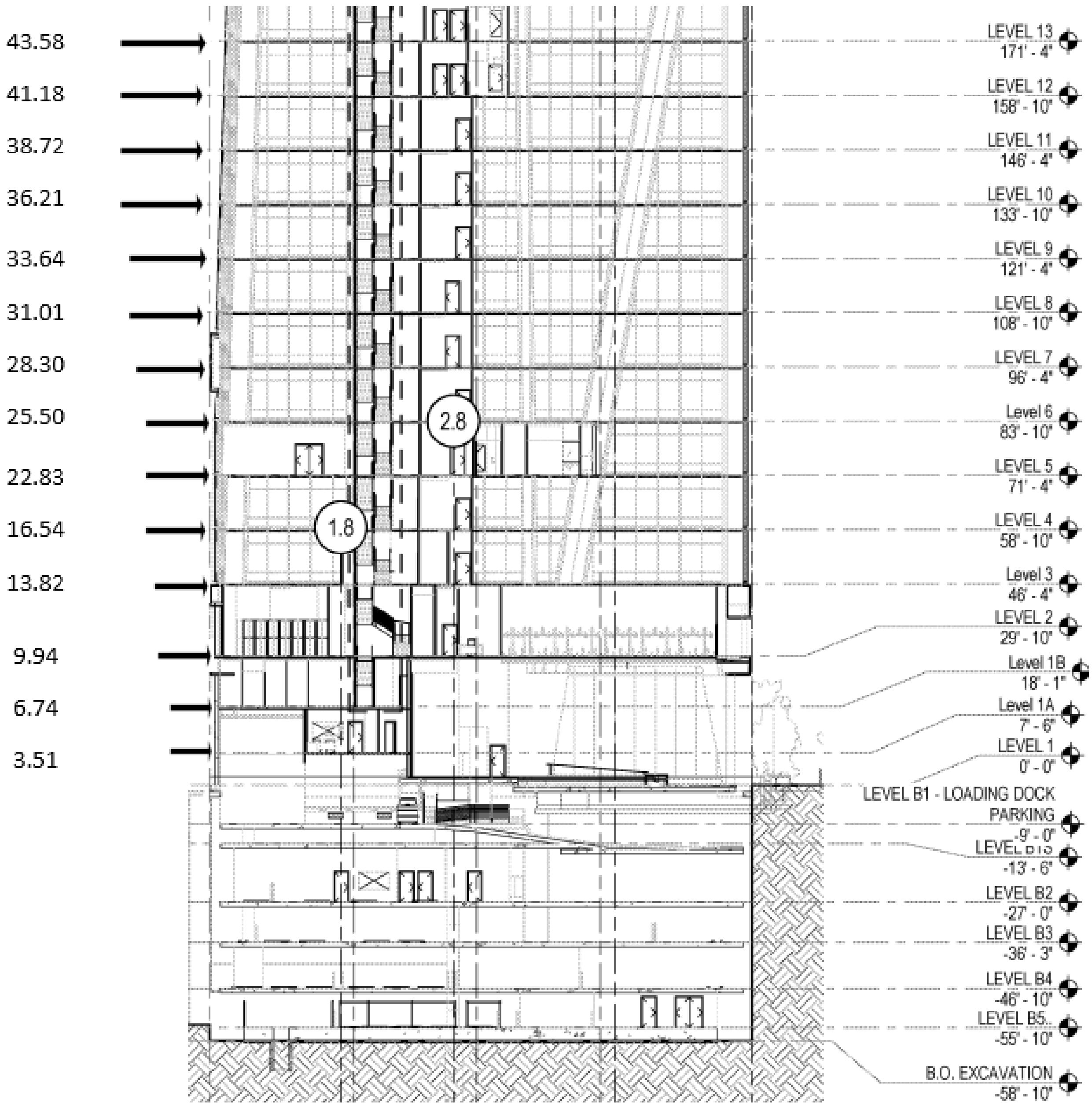
133.00
131.00
129.22
127.57
125.92
124.26
122.59
120.92
119.23
117.54
115.84
114.13
112.42
110.69
108.96
107.22
105.46
103.70
MR2 ROOF 738' - 0"
MR2 727' - 0"
MR1 714' - 6"
ROOF (MECHANICAL) 700' - 0"
LEVEL 55 686' - 0"
LEVEL 54 673' - 7"
LEVEL 53 662' - 2"
LEVEL 52 650' - 9"
LEVEL 51 639' - 4"
LEVEL 50 627' - 11"
LEVEL 49 616' - 6"
LEVEL 48 605' - 1"
LEVEL 47 593' - 8"
LEVEL 46 582' - 3"
LEVEL 45 570' - 10"
LEVEL 44 559' - 5"
LEVEL 43 548' - 0"
LEVEL 42 536' - 7"
LEVEL 41 525' - 2"
LEVEL 40 513' - 9"
LEVEL 39 502' - 4"
LEVEL 38 486' - 10"
LEVEL 37 473' - 1"
LEVEL 36 459' - 5"
4.2
A


93.35
91.32
89.45
87.57
85.67
83.76
81.84
79.90
77.94
75.97
73.98
71.97
69.94
67.90
65.83
63.74
61.63
59.49
57.22
55.03
52.81
50.56
48.27
45.95
LEVEL 36 459' - 5"
LEVEL 35 446' - 11"
LEVEL 34 434' - 5"
LEVEL 33 421' - 11"
LEVEL 32 409' - 5"
LEVEL 31 396' - 11"
LEVEL 30 384' - 5"
LEVEL 29 371' - 11"
LEVEL 28 359' - 5"
LEVEL 27 346' - 11"
LEVEL 26 334' - 5"
LEVEL 25 321' - 11"
LEVEL 24 (High-Rise) 309' - 5"
LEVEL 23 296' - 11"
LEVEL 22 284' - 5"
LEVEL 21 271' - 11"
LEVEL 20 259' - 5"
LEVEL 19 246' - 4"
LEVEL 18 233' - 10"
LEVEL 17 221' - 4"
LEVEL 16 208' - 10"
Level 15 196' - 4"
LEVEL 14 183' - 10"
LEVEL 13 171' - 4"


43.58
41.18
38.72
36.21
33.64
31.01
28.30
25.50
22.83
16.54
13.82
9.94
6.74
3.51
2.8
1.8
LEVEL 13
171' - 4"
LEVEL 12
158' - 10"
LEVEL 11
146' - 4"
LEVEL 10
133' - 10"
LEVEL 9
121' - 4"
LEVEL 8
108' - 10"
LEVEL 7
96' - 4"
Level 6
83' - 10"
LEVEL 5
71' - 4"
LEVEL 4
58' - 10"
Level 3
46' - 4"
LEVEL 2
29' - 10"
Level 1B
18' - 1"
Level 1A
7' - 6"
LEVEL 1
0' - 0"
LEVEL B1 - LOADING DOCK
PARKING
-9' - 0"
-13' - 6"
LEVEL B2
-27' - 0"
LEVEL B3
-36' - 3"
LEVEL B4
-46' - 10"
LEVEL B5
-55' - 10"
B.O. EXCAVATION
-58' - 10"