181 Fremont
San Francisco, CA

Tech Report 1

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Structural Option

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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).

Introduction

Purpose

The purpose of this report is to outline the structural design concept and seismic detailing behind 181 Fremont. Various systems of the San Francisco high-rise will be explained, including the gravity, lateral, and foundation systems, as well as the codes and analysis procedures guiding the system selections.

Building Summary

Figure 1 | Southwest Elevation View (Courtesy of Heller Manus)

181 Fremont, as seen in Figure 1, is a mixed-use high-rise that is located in the South of Market/Transbay neighborhood of San Francisco, California. It is composed of 54 stories above ground, which includes two penthouse levels, and 5 stories below grade. Rising to a total height of 700' (802' with the spire), 181 Fremont will be the second tallest building in the city upon completion.

Approximately 2,000 sq. ft. of retail space, over 400,000 sq. ft. of office space (Figure 2) and over 160,000 sq. ft. of residential space are provided in the layout. Offices comprise the first 36 stories of the tower, while the top 15 stories consist of 68 exclusive condominiums. Separating the two uses are an amenity floor on level 37 and a mechanical floor on level 38. Additional features include a 78-stall bike barn, valet parking in the underground garage, and a direct connection to the City Park rooftop of the neighboring Transbay Transit Center at the fifth floor.

Construction of 181 Fremont is a contributor to The San Francisco Transit Center District Plan – a redevelopment plan for the area surrounding the previous Transbay Terminal and the future Transbay Transit Center (Figure 3). As part of the plan, height increases will allow for the construction of multiple new skyscrapers. Originally, the height of 181 Fremont was set to be 900 feet tall and consist of 66 floors, but became reduced to 700 feet due to a maximum height limit imposed on the site. In the building's exterior, structural function merges with architectural design. The exposed primary lateral force-resisting system, composed of mega beams, columns, and braces, provides functional transparency and adds to 181 Fremont's unique imprint.

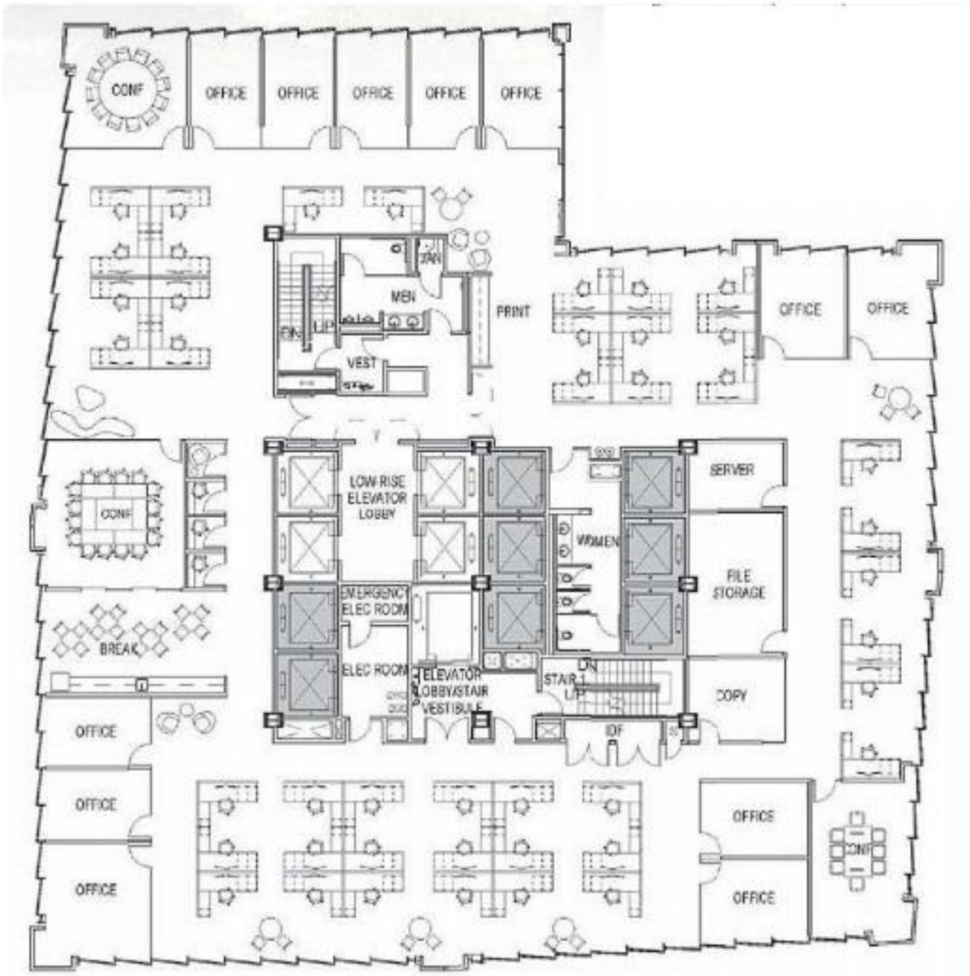

Figure 2 | Typical Office Layout (Courtesy of Heller Manus)

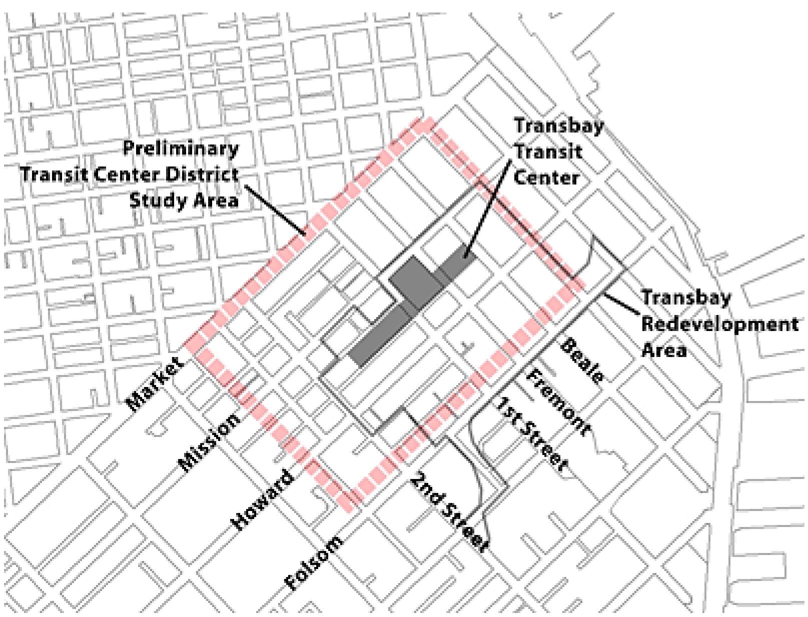

Figure 3 | San Francisco Transbay Redevelopment Area (Courtesy of Heller Manus)

Design Codes and Standards

Relevant design codes and standards used in the structural design are listed below, as well as the exceptions in code usage. The basis of analysis and design of 181 Fremont stems from these codes and standards, as well as from other testing methods in some cases.

Building Codes and Referenced Standards Utilized

- 2010 California Building Code (CBC, 2010)
- 2010 San Francisco Building Code (SFBC, 2010)
- ASCE 7-05
- ASCE 7-10

Seismic References

- SF AB-083, 2010
- PEER Tall Building Initiative
- ATC-72
- ASCE 41-06 for the acceptance criteria of moment frame beams
- Arup's REDi Rating System

Material References

- AISC 360-05
- AISC 341-10
- ACI 318-08

Exceptions

181 Fremont utilizes a mega-brace system, as described in the building summary, that is not in table 12.2-1 of ASCE 7-05. Equivalence to a system that is listed in the code is allowed through other analysis and testing means per ASCE 7-05. To accomplish this, 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) were utilized.

Design Approach

The following section is intended to outline the methods by which the building was designed. Various approaches guided system selection and the determination of an efficient design.

Dead and Live Loads

Due to the high seismic activity in San Francisco, different loads for the same occupancy or use were used depending on what was being investigated. For example, mechanical equipment is considered a live load for gravity design, but a superimposed dead load for seismic design. A summary of the loads used in the project are listed in table 1 below. Loads specific to earthquake design are designated with an "(E)" and loads designated with a "(G)" are specific to gravity design.

Occupancy/Use	Live Load (psf)	Superimposed Dead Load (psf)
Garage	40	10
Office	50	11
Residential	40	20
Mechanical Equipment	Actual Weight (G)	Actual Weight (E)
Stairs/Exits	100	n/a
Office corridors above 1st floor	80	n/a
Residential corridors	40	n/a
Mechanical	125	36
Partitions in Offices	15 (G)	10 (E)
Partitions in Residential	15 (G)	10 (E)
Roof		75
Storage	125 (G), 250 (E)	n/a

Table 1 | Summary of Building Loads

Wind

Although seismic is the controlling lateral force, the structural designers wanted to ensure occupant comfort on a daily basis due to wind loads as well. To achieve this, strength design based on wind tunnel testing was performed. This utilized a 100 mph wind for a 3 second gust at 10 meters and resulted in wind force equal to 138.2 kip at the 54th story. In order to meet the ISO 10137 residential acceleration criteria, a supplementary damping system was designed.

Seismic

The preliminary design is based on a response spectrum analysis and the final loads were determined by a non-linear response history analysis (NLRHA). To carry out the NLRHA, the software LS-DYNA was used and to carry out the response spectrum analysis, Arup's finite element analysis software, GSA, was used.

Structural Design

The following section is intended to explain the overall structural design by breaking it into components and looking at the specific structural systems.

Overview of Structural Framing

181 Fremont utilizes steel as the only framing material for the lateral systems. Due to the high seismic zone that 181 Fremont is located in, seismic design was the controlling lateral force for the structural design. Wind considerations too, however, were also considered to ensure occupant comfort. Additional measures to mitigate wind effects include an increased number of collector beams in the floor framing as story levels increase. Viscous dampers in exterior braced frames reduce the vibrations caused by wind as well.

A mega-frame exterior acts as the primary lateral seismic-resisting system. Large scale beams, columns, and diagonal bracing members provide most of the structure's stiffness, and are supplemented by exterior moment frames and some interior braced frames.

Depending on the floor level, the gravity system consists of either lightweight or normal weight slab on deck atop steel beams and girders. The foundations are composed of concrete walls and 8'-0" think drilled shaft caps that sit on 5' and 6' diameter caissons.

Floor Framing and Structural Slabs

As the building rises, the exterior inclines inward and the area of the floor plates decrease. A typical lower story floor is just over 12,000 sq. ft., whereas a typical upper story floor is just over 9,000 ft. To mitigate vibrations and for acoustical purposes, the top residential floor slabs are normal weight concrete on metal deck. The lower office floors, however, utilize lightweight concrete.

Figure 4 | Location of Composite Beams (S108)

A typical lower story floor framing plan consist of 5 ¼" light weight concrete on 18 gauge metal deck. The majority of deck is puddle welded to the supporting beams, with the exception of a few locations where studs are utilized (Figure 4). 24'-5" span W24 girders support 18'-9" long W14 beams at the core of the floor plan. The steel girders frame into six columns at the core and into the four mega columns at the corners of the building as well as standard exterior wide flange columns (Figure 5).

Level five framing is consistent with the typical lower floor framing except at the 33' wide connection to the Transbay Transit Center Roof. The connection is centered on the north elevation and is composed of cantilevered W21's spaced at just over 5'. Additional lateral-force collectors diagonal to the regular floor framing are added as well (figure 5).

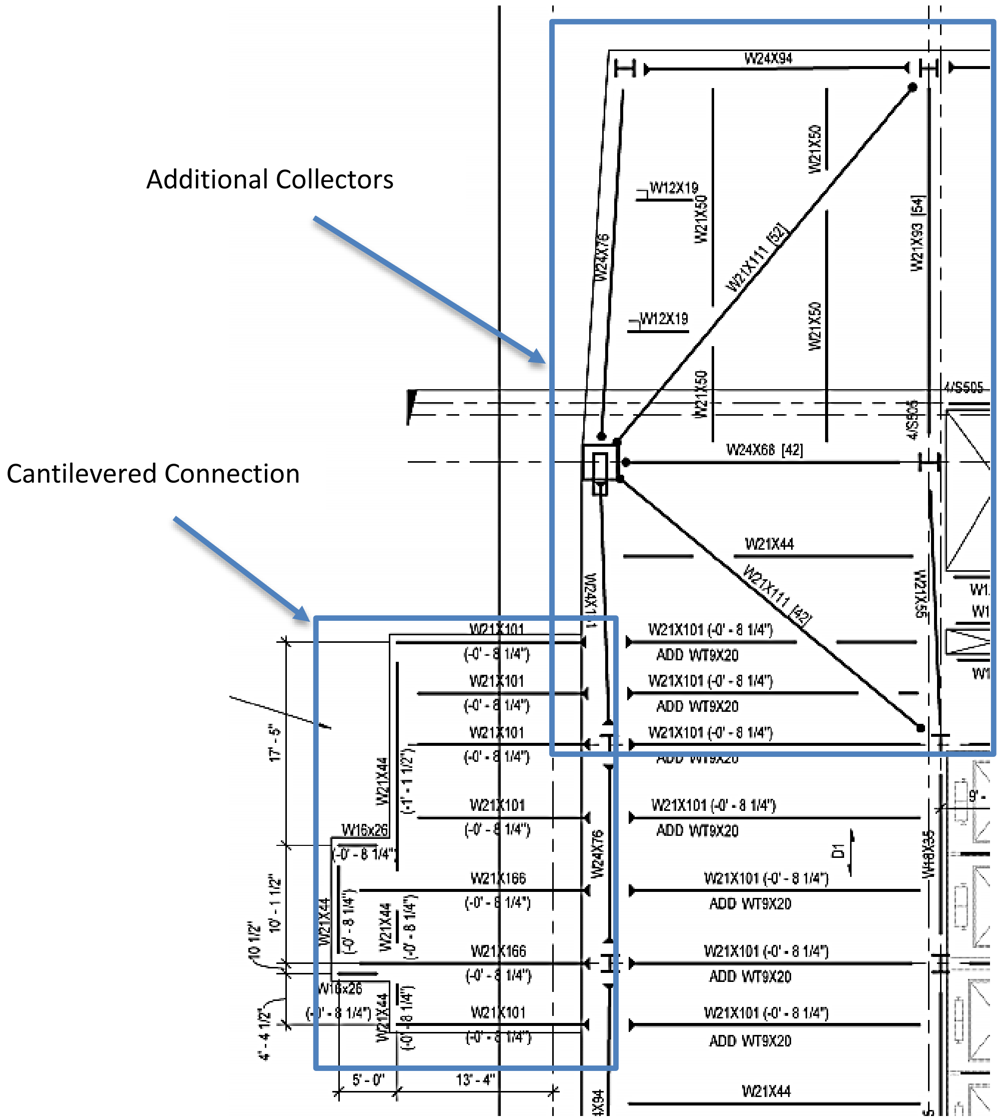

Figure 5 | Cantilevered Connection and Additional Collectors at 5th Floor (S105)

Typical upper story floors have 5 ¼" concrete on 18 gauge metal deck as well, but utilize normal weight concrete rather than lightweight. Other differences include the larger number of collectors to account for the greater seismic loads and a higher proportion of diagonally laid out beams (Figure 6).

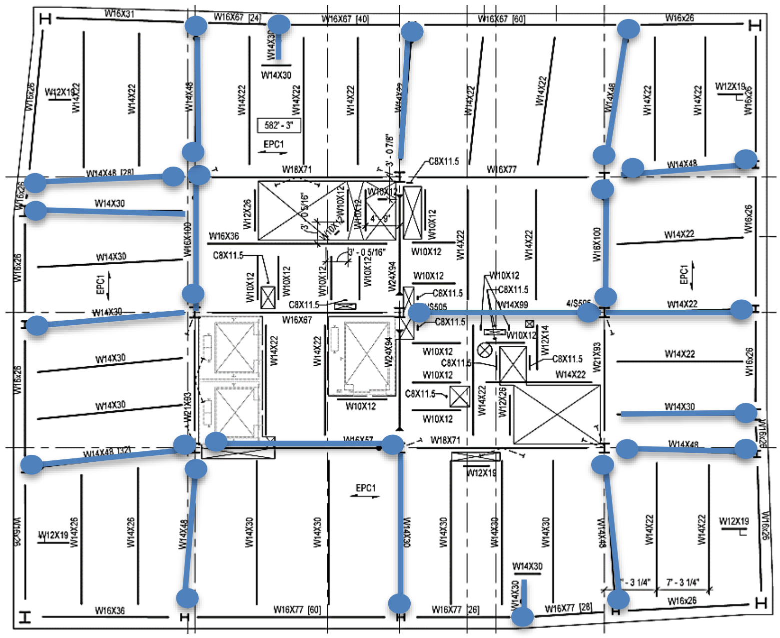

Figure 6 | Upper Story Collectors (S146)

Roof framing includes lightweight concrete over foam at the center of the plan and framing for the rooftop mechanical equipment. Diagonal members surround the gridded core, and each diagonal provides collectors (Figure 7).

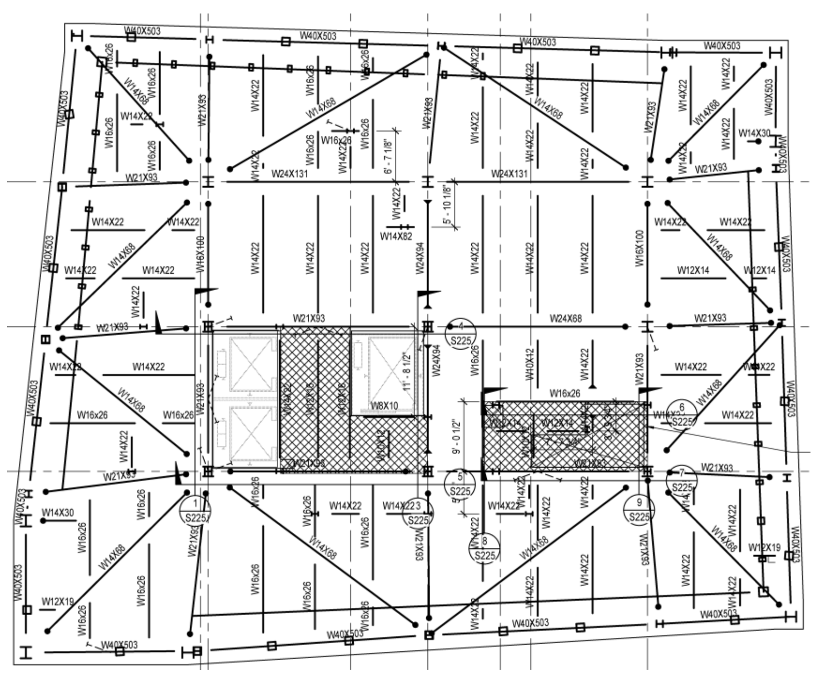

Figure 7 | Roof Framing With Diagonal Collector Members (S156)

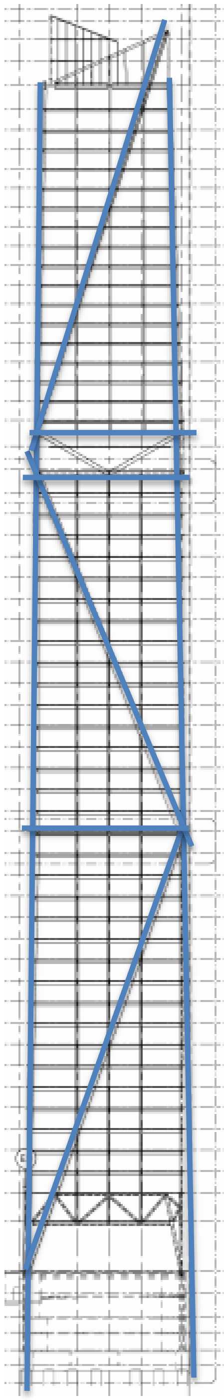

Figure 8 | South Elevation Of Primary Lateral System (1-S201)

Lateral System

A visible primary lateral system on the building's exterior is supplemented by an exterior secondary lateral system at the office levels and an interior secondary lateral system at the core of the residential levels.

Four mega-columns sit at the edges of the building, into which mega beams and steel braces frame. Together, the members form the primary lateral system (Figure 8). Various diagonal members contain viscous dampers as well to mitigate wind vibrations. This provides the additional benefit of decreasing seismic inertial forces.

Secondary Lateral Systems

At the office levels, exterior moment frames provide additional lateral force resistance while still maintaining the load path to the mega frame. At the residential levels, buckling restrained brace frames (BRBs) provide extra resistance at the core (Figure 9). The design of these BRBs is contracted out and provided by Star Seismic. The braces are encased by round HSS and pinned on each end.

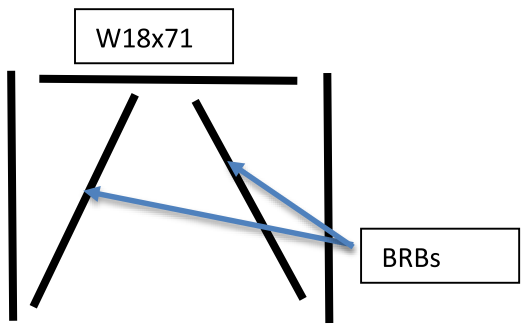

Figure 9 | Buckling Restrained Braces at Upper Levels

The exterior trusses, like the one seen in figure 8, transfer gravity loads over the open lobby and transfer seismic loads back to the mega frame as well. All secondary lateral systems are designed to bring loads to the mega frame, as is discussed later in the "Load Path" section.

Mega Columns

The mega-columns, as mentioned briefly in the Lateral System section above, consist of cruciform steel starter columns encased by a concrete column. Studs on the flanges of the steel cruciform help it act compositely with the concrete, and weld ties are made from the concrete to steel (Figure 10).

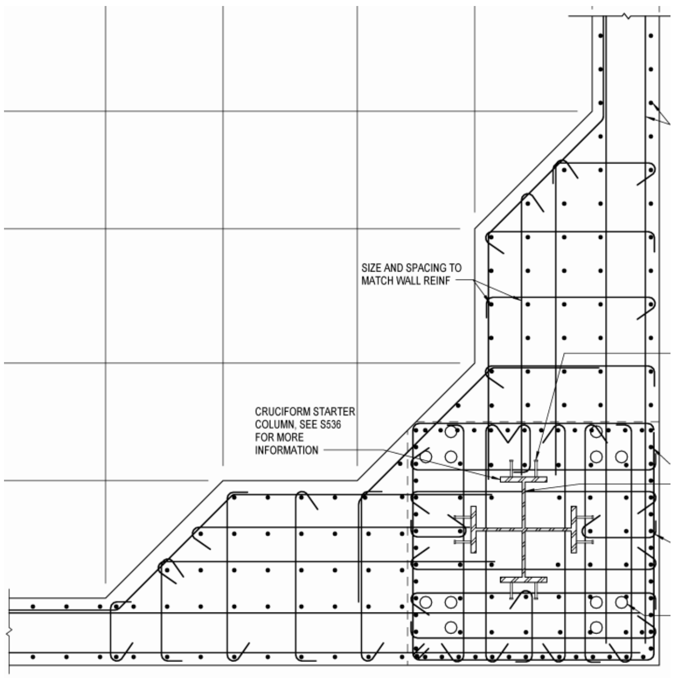

Figure 10 | Typical Mega Column (Detail 1-S332)

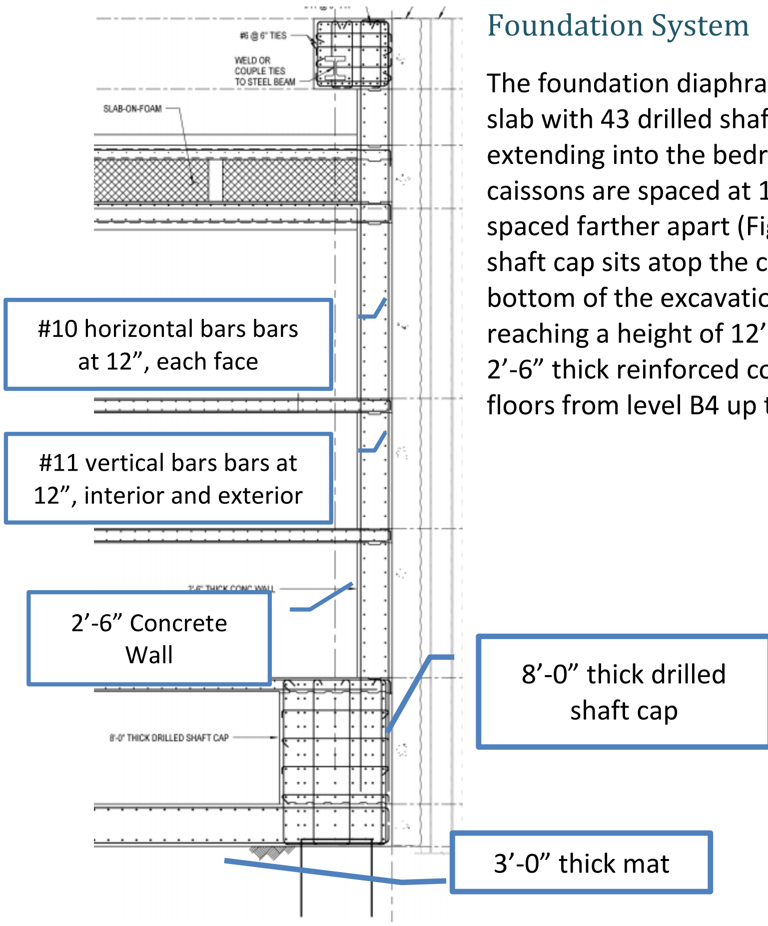

Figure 11 | Section Cut at Foundation (Detail 2-S320)

Foundation System

The foundation diaphragm consists of a reinforced mat slab with 43 drilled shafts that are 5’ and 6’ in diameter extending into the bedrock to support the tower. Exterior caissons are spaced at 13’-9” while interior caissons are spaced farther apart (Figure 12). An 8’-0” thick drilled shaft cap sits atop the caissons and extends from the bottom of the excavation up to basement level B4, reaching a height of 12’-0”. Enclosing the basement are 2’-6” thick reinforced concrete walls that span between floors from level B4 up to level 1 (Figure 11).

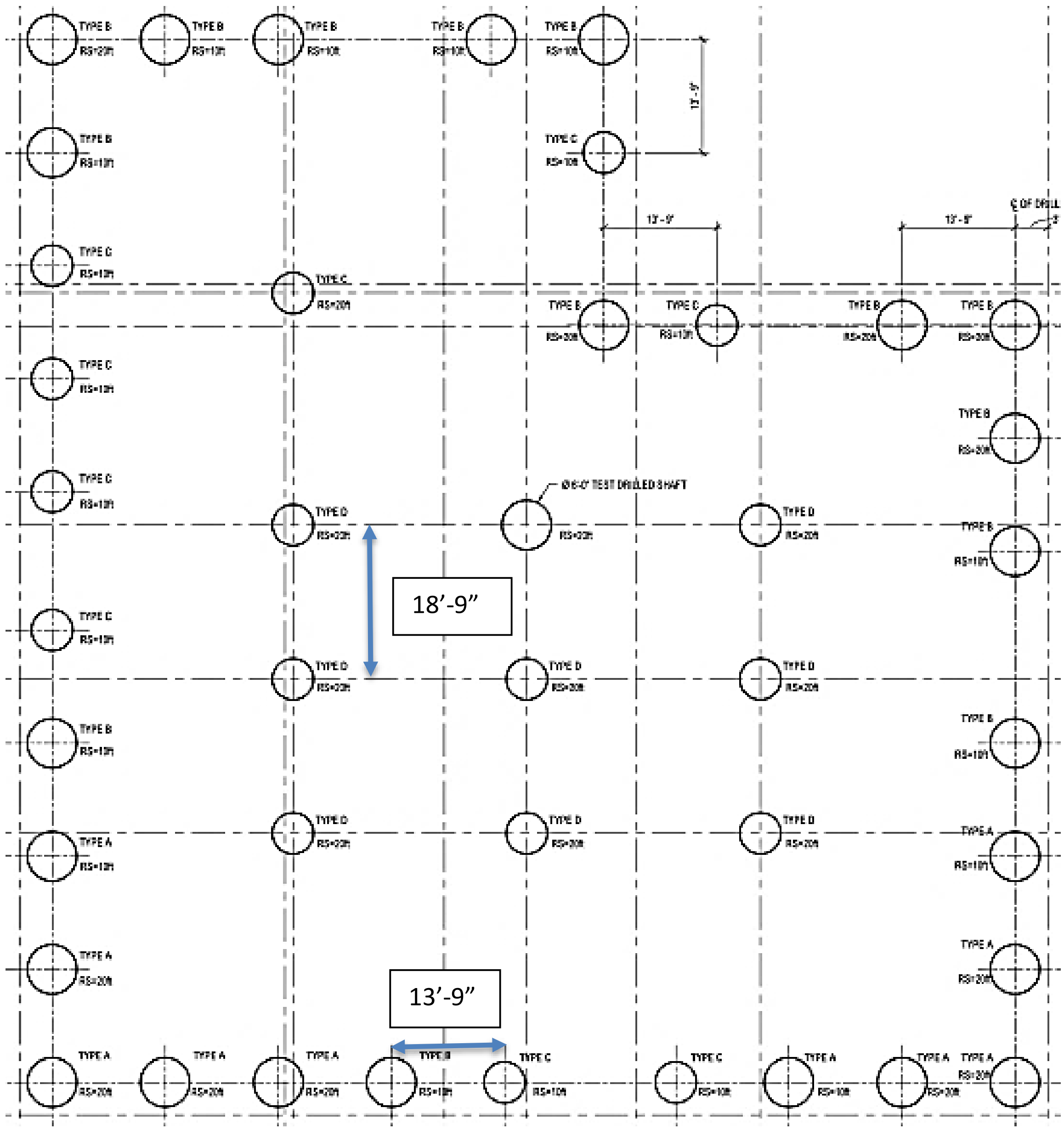

Figure 12 | Foundation Layout (S100F)

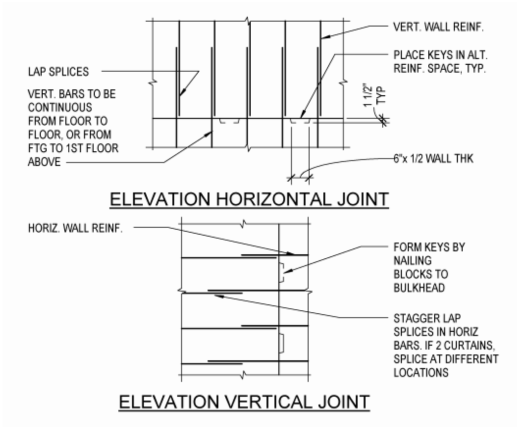

Figure 13 | Horizontal and Vertical Wall Joints (Detail 9-S304)

Joint Detailing

Joint details are critical both for successful construction and for adequate load transfer between members. This section outlines both concrete construction joints, as well as the various steel connections detailed.

Concrete Joints

For horizontal concrete wall joints, every other space between vertical rebar contains a key. Rebar must be continuous from floor to floor. Likewise, vertical joints require keys in every other rebar spacing, and in addition to having continuous rebar across the joint, the rebar laps must be staggered as well (Figure 13). Slab construction joints must be done at mid span and require additional #5 bar reinforcing spaced at 12”.

Steel Moment Connection

Moment Frame beam-to-column connections utilize bolted shear plates with the same thickness as the beams. The shear plates are factory welded to the column along their full height. Additional stiffness is provided by doubler plates on each side of the column web. Field welds around the beam flanges and welds that connect the shear tab to the beam wed complete the moment connection.

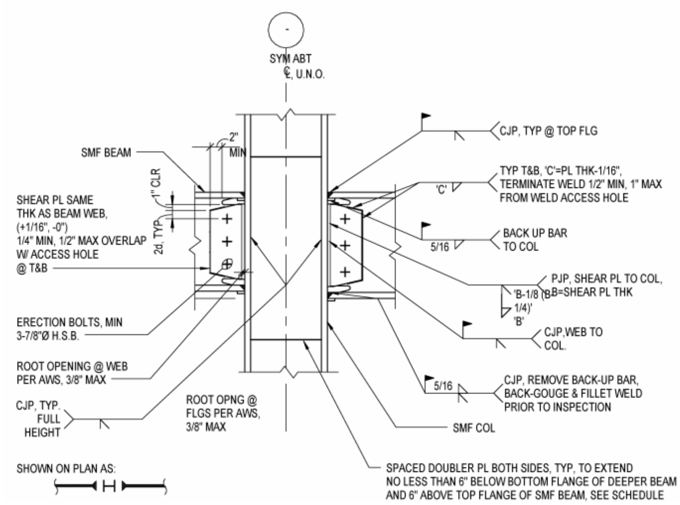

Figure 14 | Moment Frame Connection (Detail 1-S510)

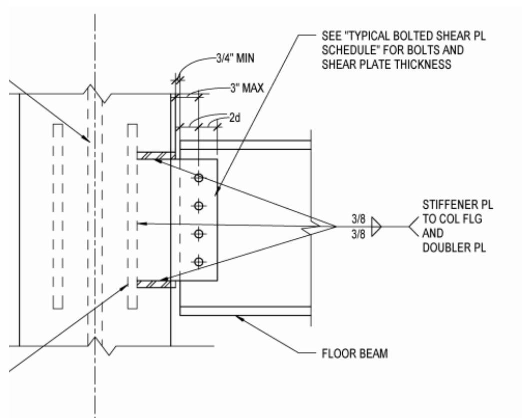

Figure 15| Floor Beam to Moment Frame Column (Detail 4-S510)

A typical floor beam framing into an exterior moment frame column has a bolted shear connection from the web of the beam to the web of the column. In addition to the shear plate, there are stiffener plates connecting the beam web to column flange (Figure 15).

Mega Column Connections

Continuity in load transfer to and within the mega-frame is critical. Continuity plates, as seen in figure 16, provide an uninterrupted load path from steel moment frames.

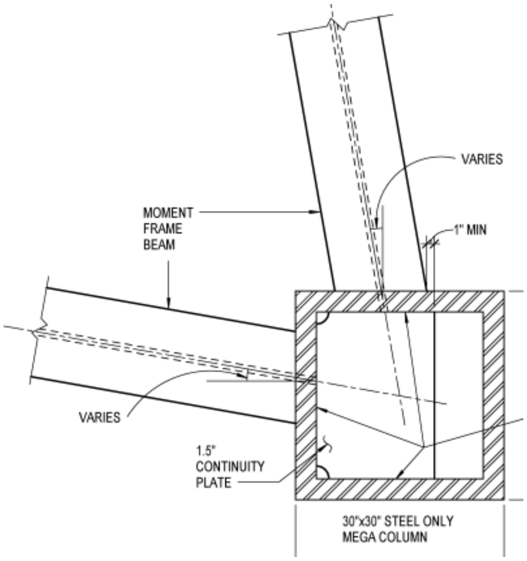

Figure 16 | Continuity Plate Through Mega Column (Detail 6-S511)

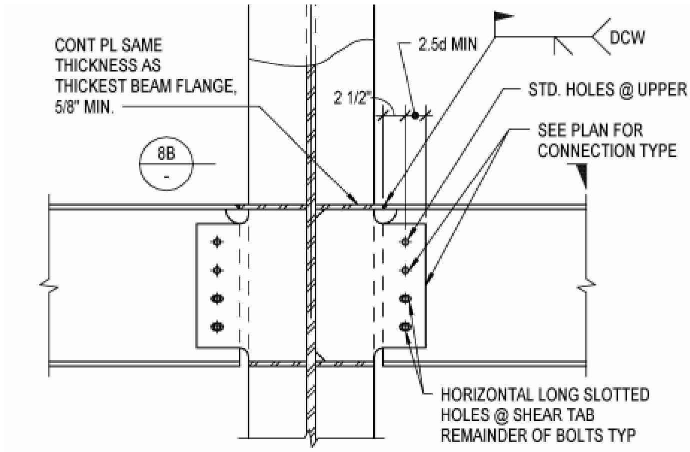

Figure 17 | Beam-to-Column Web Collector Connection (Detail 5-S512)

Collector Details

Collectors play a critical role in transferring lateral load from the floor diaphragms to the primary lateral system. Each level has at least one collector. Beam-to-column web collectors consist of continuous plates attached with demand critical welds and shear tabs consisting of two standard bolt holes at the top of the beam and two long slotted holes at the bottom (Figure 17). Beam-to-column flange connections are similar, but require continuity plates only at the top flange.

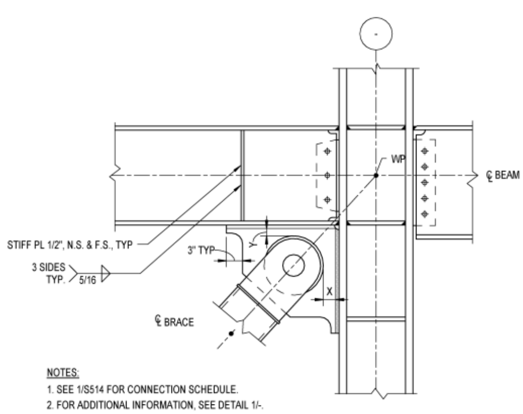

Figure 18 | Buckling Restrained Brace Pin Connection (Detail 2-S515)

Brace Frame Connections

All brace frames achieve pinned-end connections in the braces in a similar manner (Figure 18). The buckling restrained braces attach to the gusset plate through a pin hole. Circular reinforcing plates are shop welded onto each side of the gusset plate. Holes through the gusset and reinforcing plates align with a hole in the buckling restrained brace, through which a pin holds the mechanism together.

Load Path

The lateral load path, beginning from the diaphragm, consists of collectors that transfer load from each floor and the roof diaphragms to the mega-frame. Secondary lateral systems are designed to feed into the mega-frame, which then in turn carries the loads into the foundation. Because the mega-frame absorbs all lateral load eventually, that load is then distributed through the basement wall to the exterior caissons of level B5. For this reason, the perimeter caissons are spaced closer together than the interior caissons.

Unlike the lateral system, the gravity system does not transfer all loads directly to the mega-frame. Only exterior gravity loads eventually feed into the mega-frame when column loads are transferred into the exterior trusses, but interior gravity loads are carried straight down to the foundation through interior columns.

Conclusion

181 Fremont expresses a unique and complicated design solution in response to the high seismic demand brought about for a San Francisco high rise building. This demand was resolved using a mega-frame system which acts as the primary lateral system of the structure into which all other lateral forces are carried.

Because the mega-frame system is not defined in ASEC 7-05, an in depth seismic analysis conforming 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) was completed.

Some of the aspects that will be most challenging as I move forward relate to the seismic analysis. The majority of the analysis for this building utilized non-prescriptive methods. Not only does the analysis not always follow the codes I am familiar with, but it involves analyzing complex systems unlike the ones I have had experience with. The composite mega-columns, for example, are a new concept in the way of what assumptions to make and approach to use when modeling it.

Another big challenge is the enormity of the structure. There is so much intricacy in the design and detailing that I will have to be extra careful and particular in order to accurately portray the structural behavior in my analysis.