350 MISSION

AEI Charles Pankow Design Competition

WRITTEN BY:

Elizabeth Audet

Benjamin Bruso

Courtnae-Symone Currie

Irene Yeung

350 Mission

AEI Charles Pankow Design Competition

A Major Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the degree of Bachelor of Science in Architectural Engineering by:

Elizabeth Audet ______________________________

Benjamin Bruso ______________________________

Courtnae-Symone Currie ______________________________

Irene Yeung ______________________________

Approved by:

Professor Leffi C. Malloy, Advisor ______________________________

Professor Leonard D. Albano, Advisor ______________________________

Professor Kenneth M. Elovitz, Co-Advisor ______________________________

Professor Umberto Berardi, Co-Advisor ______________________________

Abstract

This project is based on the 2014 Charles Pankow Foundation Annual Architectural Engineering Student Design Competition. It proposes a new design for 350 Mission Street, San Francisco based on the original design from Skidmore, Owings & Merrill LLP. The team focused their efforts on designing the architectural, structural, mechanical, and integrated systems of a building with a near net zero output of energy, emissions, water, and waste. This project addresses the engineering challenges involved in high-rise design, specifically in the seismic, sustainable, and integrated design.

Authorship

The majority of the labor for this project was broken down into four concentrations: architectural, structural, mechanical, and building integration. Benjamin Bruso, an Architectural Engineering major with a concentration in structural systems, dealt with the overall building design and modeling in both AutoCAD and Revit, including all of the Revit renderings. Irene Yeung, an Architectural Engineering major with a concentration in structural systems, headed the structural section with help from Elizabeth Audet and Benjamin Bruso. All three contributed to the written section and edited their respective parts. Courtnae-Symone Currie, an Architectural Engineering major with a concentration in mechanical systems, headed the mechanical section with help from Elizabeth Audet and Benjamin Bruso. All three contributed to the written section and edits on their respective parts. Elizabeth Audet, an Architectural Engineering major with a concentration in structural systems, and Benjamin Bruso headed the Building Integration section with help from Irene Yeung and Courtnae-Symone Currie. Elizabeth Audet worked on the introduction of the written section, the fire protection and life safety plans, the core plumbing plan, and the beginning stages of the building design in Revit and AutoCAD. The group wrote the background, methodology, and results sections pertaining to each member's specific area of expertise on the project. The edits were done mainly by Benjamin Bruso, with help from the rest of the team.

Elizabeth Audet	______________________________
Benjamin Bruso	______________________________
Courtnae-Symone Currie	______________________________
Irene Yeung	______________________________

Acknowledgments

We would like to thank the ASCE Charles Pankow Foundation for hosting this competition and fostering sustainable design ideals for students in the engineering field. We would also like to thank the Skidmore, Owings & Merrill San Francisco Office for allowing us to access the building designs into which they have put so much time and effort. Thank you to Jeffery Faucon, Rand Refrigeri, and Gil Martin of RDK Engineers for taking the time out of your busy days to answer our questions about buildings systems, fire protection, and sustainable designs, as well as taking us on a tour of a sustainable building. We would like to thank Professor Brian Meacham for his help and guidance in fire protection as well as overall building systems. Finally, we would like to thank our advisors Professor Leffi Cewe-Malloy, Professor Leonard Albano, Professor Kenneth Elovitz, and Professor Umberto Berardi for all of your guidance, advice, encouragement, and commitment to this project.

Capstone Design

The Major Qualifying Project (MQP) is a showcase of engineering theory and practice. The capstone requirement for the MQP was met through an alternate design of 350 Mission Street, based on the original design of a thirty-story high performance building. The new design focuses on the architectural, structural, mechanical, and building integration systems of the building. The main goal for the new design of 350 Mission Street was to design a building with near net zero energy, emissions, waste, and water usage. Along with the high emphasis on sustainability throughout the design of the building, there was an emphasis on the site because the building is located in a highly active seismic zone. There were also certain aspects of the design that were mandated either by the competition guidelines or by the building codes. These include a decreased time from a design earthquake to building occupation and half of the building drift allowed by the building code. Throughout the building design process, the team had to consider the environment and sustainability, health and safety, manufacturability, social impact, and economics of the building. These considerations are described in detail below.

Environment and Sustainability

The new design of 350 Mission Street has many sustainable elements. There is a green wall in the lobby that helps reduce the carbon load of the building by purifying the air and naturally cooling the space. The green wall in the lobby is supplied by purified water from a water reclamation system that collects greywater from rainwater and sinks throughout the building. The use of greywater reduces waste from the building and lowers overall water usage. The HVAC units in the office spaces are zone controlled and let the occupants change the temperature in different zones, creating a more efficient system that leads to lower mechanical emissions and energy use. LED lamps are used in the lighting design of the office, lobby, and garage levels because of their efficiency, low energy consumption, and low emissions output. 350 Mission can qualify for a LEED Gold, or higher, rating due to all of the sustainable systems and practices used in the building life cycle.

Health and Safety

Health and safety during construction is important due to the high risk involved in construction. The building site is located at a busy intersection with heavy vehicular and pedestrian traffic. Construction precautions that were based on the height of building and specific types of protection adjacent to the construction site were used to ensure the safety of pedestrians during the construction process. In addition, the waste was contained in allotted trash bins and sanitary facilities were present on site.[1] For the safety of both the structure and the construction workers, fire extinguishers and at least one standpipe were installed for use during construction.[2]

Economics and Constructability

Payback period relates to the economy of the building. The payback period is the period of time that it takes for the revenue generated by the rentable space in the building to become profit for the owner. Every component of a building contributes to its payback period and, the shorter the payback period, the more profit the owner makes. Because of this, it is important to reduce the cost of the building components wherever possible.

The site for 350 Mission Street has limited space for extra building materials and equipment. The existing high-rise buildings and the busy intersection made the construction

---

[1] *California Building Code 2013*, Chapter 33 section 3305, http://www.ecodes.biz/ecodes_support/free_resources/2013California/13Building/PDFs/Chapter%2033%20-%20Safeguards%20During%20Construction.pdf (accessed 4 Nov. 2013)

[2] *California Building Code 2013*, Chapter 33 section 3309, 3311

schedule and material selection an important part of the project design. Constructability and construction management of the site were also important aspects of the design of the building. The scheduling for the construction of the high-rise determined whether the structural elements would be produced and constructed on site or be produced off-site and assembled on site.

Social Impact

The lobby for 350 Mission Street is a public space that has two retail shops, an art exhibition space, a public gathering space, and a restaurant. This space is a social space where the occupants of the building, as well as the general public, can gather and relax. New buildings in San Francisco are mandated to have one percent of the building budget devoted to a public art display area. The lobby has one large exhibit space on the second floor of the lobby.

Executive Summary

The Charles Pankow Foundation Annual Architectural Engineering Student Design Competition is a national student competition focusing on the innovative and integrated design of different types of buildings. This year's competition was in the spring of 2014 and was focused on the innovative design of a thirty-story high-rise at 350 Mission Street, San Francisco. The competition focuses on five main areas: building integration, structural systems, mechanical systems, electrical systems, and construction management. For this project, the team chose to focus on developing innovative structural and mechanical systems in addition to a new architectural layout.

The team developed specific goals to meet the competition requirements and enrich the project experience. These goals were:

1. To develop sustainable and energy efficient system designs that positively impact the environment and community.

2. To learn how to integrate structural and mechanical systems to complement each other and optimize the entire building system.

3. To use this experience as a learning tool to advance each member's knowledge in innovative and sustainable designs.

Architectural Design

The architectural design of a building is important because it dictates how the structural and mechanical systems of the building are designed by determining the shape, size, and height of all of the spaces. The design of 350 Mission was governed by the needs and desires of the owner and certain requirements imposed by the City of San Francisco and the Student Competition.

Lobby Design

The owner desired that the lobby of the building serve as a place where the public could gather and spend time, and the city required that the building allot a certain amount of space for the displaying of public art. In order to meet these requirements, the team created a lobby with a fifty-four foot atrium, three floors, and multiple amenities. The centerpiece of the lobby is a massive green wall that extends from the first floor to the third floor. In addition, multiple planters with trees and plants were placed throughout the interior of the lobby. This was done in order to improve the air quality of the space and to create an urban oasis in the middle of downtown San Francisco. Figure 1 below shows the view from the main entrance of the lobby with the green wall, the front desk, a retail space, and a grand staircase going to the second level.

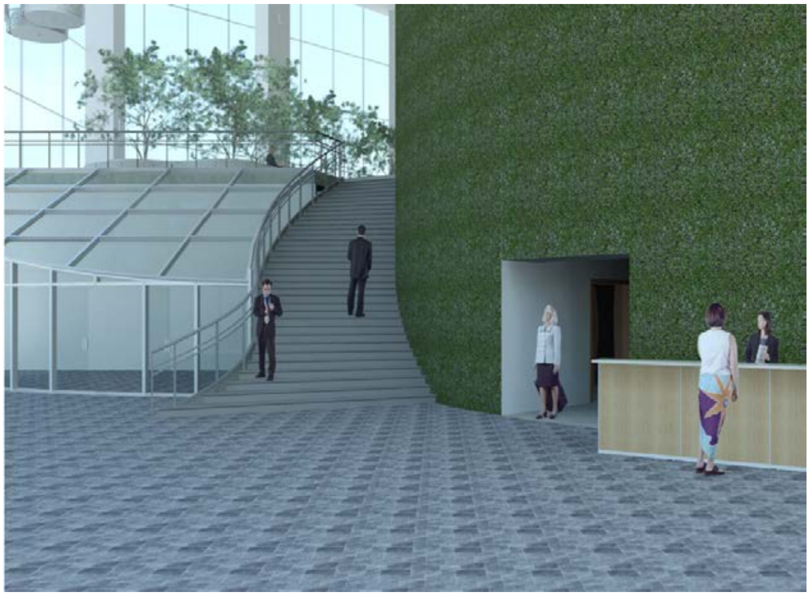


Figure 1: Main Entrance to the Lobby

The other side of the lobby consists of a café where the building occupants and the public can gather to relax. Located above the café is a large space dedicated to displaying art from local artists around San Francisco. As shown in Figure 2 below, it has a large balcony where people can look over the expansive atrium in the lobby that makes the space feel open and welcoming.

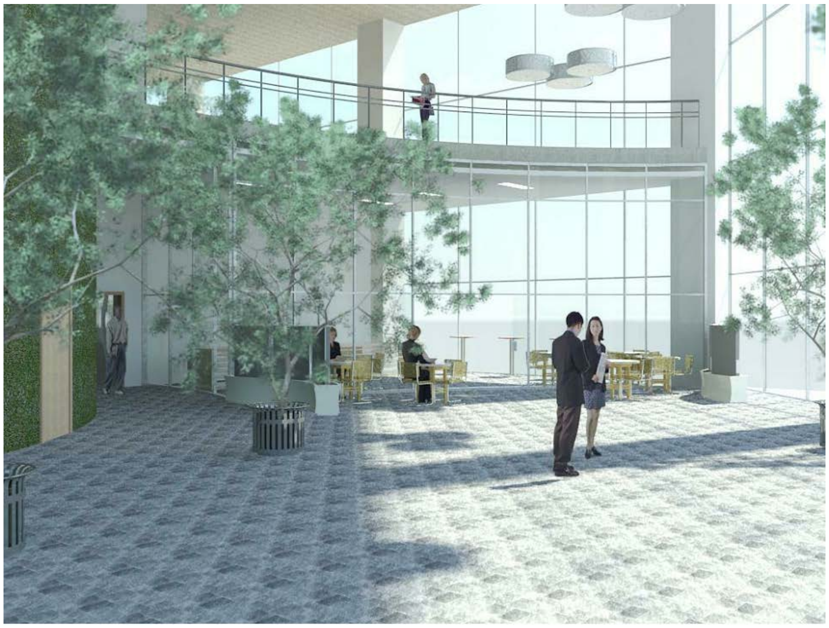


Figure 2: Café on the Main Floor of the Lobby

On the second level, there is also a large assembly area for the public and for the tenants of the building. There is a large amount of seating facing multiple directions and more planters with trees. This is shown in Figure 3 below.

Figure 3: Second Floor Public Assembly Area

The third floor of the lobby houses a restaurant. The restaurant space looks out onto the lower lobby levels and creates a casual atmosphere for the occupants in the space. The design of the lobby and its amenities meets and exceeds the needs of the owner, creating a welcoming, peaceful space in the center of downtown San Francisco.

Office Layout

The office floors are the most profitable areas of the building, so the team increased the maximum workspace area of each floor by six percent. The team then decided to encircle the core with the main offices, conference rooms, and break rooms in order to accentuate its curve. Workstations were placed on each side of the building, creating an open office space with large aisles. Placing the majority of the offices at the interior of the space dramatically increased the daylighting throughout the whole space, providing the entire floor with improved light quality and decreasing the need for the high use of artificial lighting. Figure 4 below shows the office interior.

Figure 4: Office Interior

The main utilities for each floor are located in the core to provide a centralized mechanical system that reduces maintenance and eliminates the amount of utilities going through and weakening the core wall.

Structural Design

In addition to creating an aesthetically pleasing and environmentally friendly building, the team was challenged to design a highly innovative structural system. Since the building is located in a highly active seismic zone, the building is required to be serviceable during and after any earthquake event.

A high-rise building is highly susceptible to wind and earthquake loads, and will deflect due to the building's height and flexibility. One of the competition's many challenges was to design a building with controlled deflections that are half of the allowable code-prescribed story drift. In order to meet the requirements, the team split the structural system into five design systems: lateral load resisting system, vertical load resisting system, floor system, foundation system, and roof system.

Lateral Load Resisting System

The lateral load resisting system is a crucial aspect of the structural design. The team chose to design a concrete building with a tube-in-tube structural system, which consists of an exterior octagonal tube and an interior circular core. The tube-in-tube structural system increases the overall stiffness of the building and reduces the story drift. In order to achieve half the drift permitted by the building code, the team designed exterior diagonal steel bracings for additional stiffness. These bracings are connected at the most vital deflection locations, which were computed and simulated using STAAD, a structural analysis program. Figure 5 below shows the general lateral load resisting system.

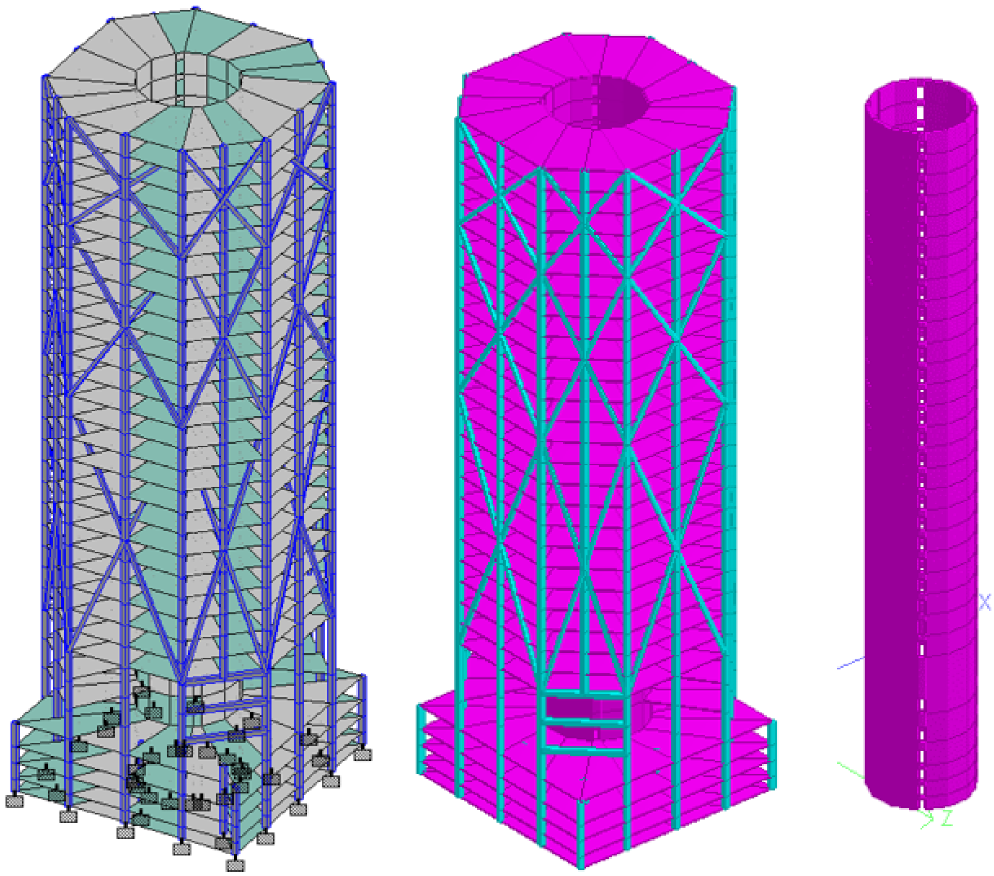


Figure 5: General Lateral Load Resisting System

Vertical Load Resisting System

After designing the lateral load resisting system, the team designed the central core walls and the perimeter columns as the main vertical load resisting system. Both the central core walls and the perimeter columns become progressively thicker in size from the roof to the basement in order to accommodate the accumulated loads from the previous floors. The team designed a uniformly distributed load path throughout all thirty floors, except for a particular side in the lobby. In order to place the parking garage entrance, a column was removed. To solve this issue, the team designed three Vierendeel trusses to redistribute the loads from the upper floors and to control the deflection. Figure 6 below displays the column placements and the Vierendeel trusses.

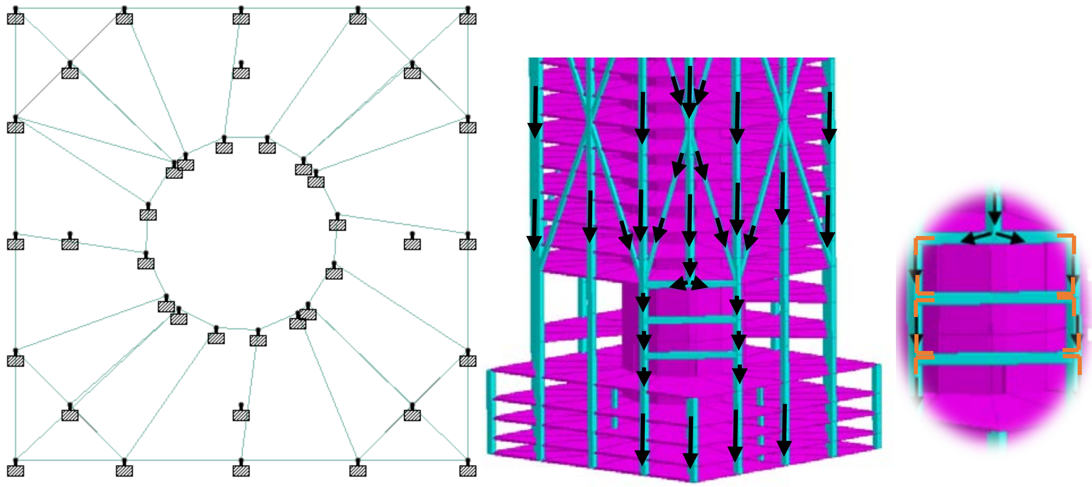


Figure 6: Lobby Column Load Transfer Path

Floor System

Next, the team investigated structural floor systems. The floor plates of the building are meant not only to provide a working surface for the occupants, but also to deliver loads from the exterior of the building to the concrete core wall. The plates act as outstretched arms attached to the main body, the core wall, of the building. Slab thickness is important because it affects the efficiency of the tube-in-tube system, with the goal of having the two tubes work simultaneously as one true cantilever beam. The team determined that a fourteen inch post-tensioned, one-way concrete slab was the most effective solution to maximize the open floor column-to-column spacing.

Foundation System

After the floor slabs were designed, the soil and foundation system were analyzed. Soil conditions are important when designing a high-rise. The structure causes the soil to become stressed and the soil can deform, settle, and lose its bearing capacity if it cannot withstand the induced loads from the building. The team designed a ten-foot thick reinforced concrete mat for the building to rest upon. The mat has two main purposes. First, it acts as a cushion on the dense soil when the building moves during a seismic event. Second, the mat ties all the columns together and redistributes the loads accordingly in the soil. Figure 7 shows the soil characteristics at the project site and the approximate mat location.

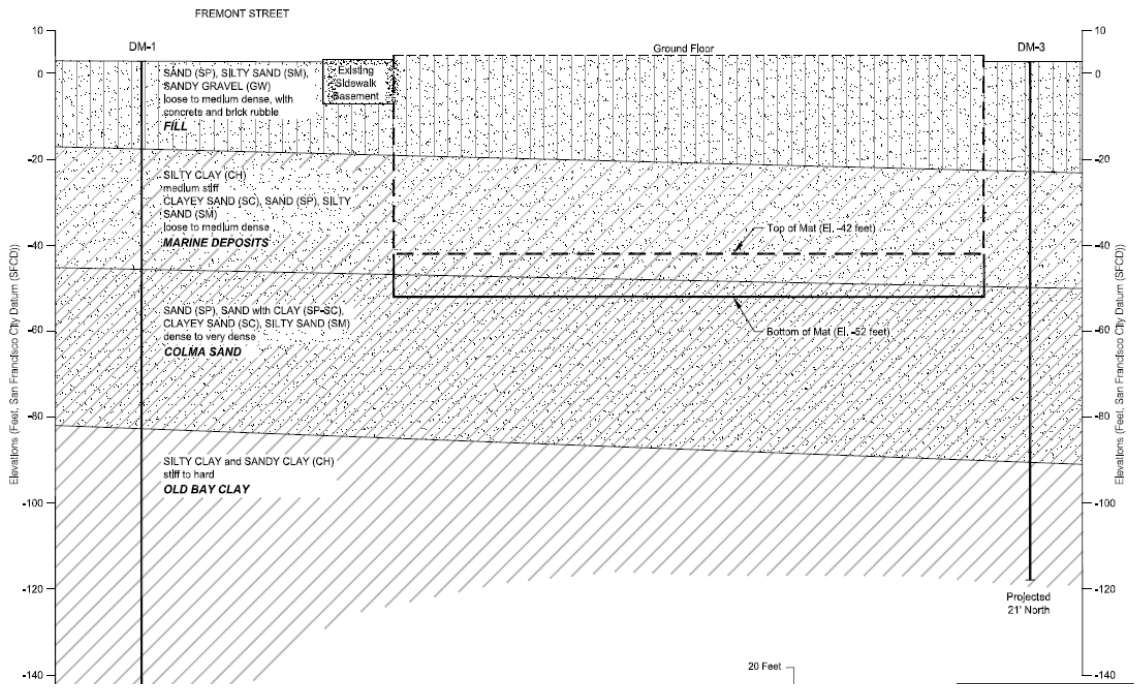


Figure 7: Idealized Subsurface Profile A-A’
(Taken from Treadwell & Rollo)

Roof System

Lastly, the team designed the roof system. The roof system is a protective covering for the building and a supporting level for the heavy-duty mechanical equipment. Because of this, both the roof slab and the columns were increased in size and strengthened.

Mechanical Design

The design of the mechanical systems of the new building encompasses three different areas: the design of the heating, ventilation, and air conditioning (HVAC) system, the design of the building envelope system, and the design of the fire protection systems. Each system plays an important role in the efficiency, comfort, and safety of the building.

HVAC Design

The HVAC system in a building regulates the interior environment by controlling the temperature and humidity of the different spaces. For the new design of the system, the team sought to design an HVAC system that would be able to handle the heating and cooling loads in an energy efficient manner and allow for increased occupant control. To achieve this goal, the team analyzed the performance of the system design in the existing building and reviewed alternatives. The existing design for 350 Mission uses an under-floor air distribution system (UFAD) with 100 percent intake air. This ventilation technology delivers space-conditioning to the building via an under-floor plenum between the structural concrete slab and the underside of a raised access floor system. Through research, the team learned that the main problem associated with UFAD systems is that occupants sometimes feel over-cooled and close the diffusers, creating an imbalance in the system and causing over-cooling in other areas of the room. Another issue associated with UFAD systems are plenum air leakages, limited occupant control, and thermal decay at the perimeter of the buildings.

In order to design a new system, the team created design criteria based on the objectives of the competition and the goals of the team members. The criteria are:

1.) Flexible individual control options

2.) Large floor-to-ceiling height (reduced plenum space)

3.) Limited Duct work

4.) Energy Efficiency

Based on these criteria, the team chose a hybrid HVAC system that uses an under-floor air distribution system in the interior and in-floor active chilled beams around the perimeter to handle the heating and cooling loads in those areas (shown in Figure 8 below). As a secondary mechanical system, the team selected an overhead mechanical system to exhaust air from the restrooms. In order to maximize occupant comfort and control, the team also redeveloped the HVAC zones.

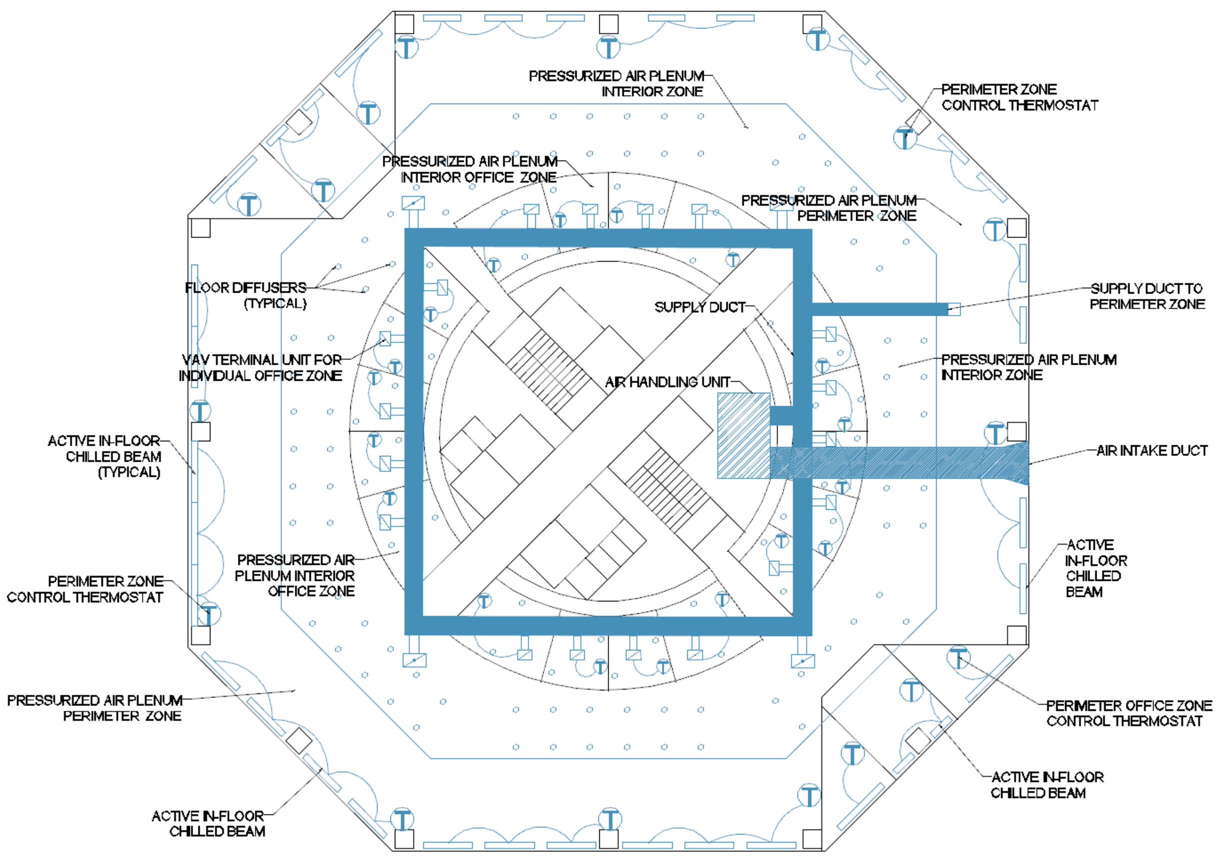


Figure 8: New Design of Mechanical System

The redesign of the building features the relocation of both the restrooms and the mechanical room to the core of the building. Moving the mechanical room from the exterior to the interior of the core reduces the travel distance of the air from the air intake vent to the air handling unit. This makes the whole system more efficient by reducing the duct material needed and by allowing the fan size to be reduced due to a lower volume of air intake. Moving the restroom to the core reduces the need for additional plumbing on the floor plan because all of the plumbing runs in the core and connects directly to the restrooms.

Façade Design

The building envelope of a building controls the flow of air, moisture, heat, and vapor between the interior and exterior, transfers wind and seismic loads to the structure, and serves a very important architectural and aesthetic role, giving the building a unique identity and personality. For the new design of the envelope, the team sought to create a high performance façade that would specifically reduce loading on the mechanical system and be highly aesthetically pleasing. Criteria were developed along these goals and are:

1) Reduced loading for mechanical system
2) High visible transmittance for high levels of daylighting
3) Strong framing for increased spans
4) Highly aesthetically pleasing

The team designed an innovative façade that uses a steel-framed curtain wall instead of the conventional aluminum frame. Steel was chosen because of its high strength, decreased thickness, increased spans, and low maintenance. Because of its increased spans, there are fewer breaks in the view from the interior of the building, creating a more open feeling in the space. The team also selected turquoise glazing with a high visible transmittance to let daylight into the space and a low U-value to decrease the heat transfer between the interior and exterior. The façade is not only beautiful, but also greatly increases the energy efficiency and environmental friendliness of the building. Figure 9 below shows the façade on the exterior of the building.

Figure 9: Exterior Façade of the Building

Conclusion

For the 2014 Student Competition, the team designed a high-rise that can achieve LEED Gold certification and includes innovative and environmentally friendly architectural, structural, and mechanical systems. This project gave the team members a fundamental understanding of the building design process, combining all of the knowledge gained in engineering courses to create building systems that integrate and work with each other. It also expanded each member's knowledge of different green technologies available on the market and how high-rise buildings can effectively incorporate sustainable technology.

Table of Contents

List of Figures

List of Tables

1.0 Introduction

The Charles Pankow Foundation Annual Architectural Engineering Student Design Competition is an annual student competition focusing on the innovative and integrated design of different types of buildings. The competition emphasizes the use of innovative engineering systems, construction management planning, and peer review in order to create the most innovative and high performance building possible. The participating students compete in interdisciplinary teams within the field of architectural engineering and demonstrate their knowledge and skills in categories such as structural engineering, mechanical engineering, electrical engineering, construction management, and integrated design. The competition is designed to reflect two of Pankow's goals, which are:

1. To improve the quality, efficiency and value of large buildings by advancing innovations in structural components and systems that can be codified.
2. To improve the performance of building design and construction teams by advancing integration, collaboration, communication, and efficiency through innovative new tools and technologies, and by advancing new means and methods for project team practices.[3]

1.1 The Challenge

The challenge for the 2014 Student Competition was to design a high performance thirty-story high-rise on the site of 350 Mission Street, San Francisco. The competition focused on five major design components: structural design, mechanical design, electrical design, construction

[3] ASCE Charles Pankow Foundation Annual Architectural Engineering Student Competition.2013.*2014 Project Guidelines*, http://content.asce.org/studentcompetition/competition.html (accessed 2 Sept. 2013)

management, and integrated design for the building. This project covers three of the components of the competition: structural design, mechanical design, and integration. In addition to these three components, the project also covers the development and design of a new architectural layout and design of the building for the competition.

There are many design considerations and challenges that must be taken into account when designing a high performance building. A high performance building is defined as "a building that integrates and optimizes on a life cycle basis all major high performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations."[4] The goal of this project was to design a high performance thirty-story office building with near net zero emissions, water, energy, and waste. In order to achieve this goal, the team addressed many possible alternatives for creating a sustainable, environmentally friendly high-rise, using the existing building design as a baseline.

In addition to creating a sustainable, environmentally friendly building, the team was also challenged to create a highly innovative structural system. Due to the project's being located in a seismically active area, the building was required to withstand and have enhanced performance in a major design earthquake. According to the competition guidelines, a building with enhanced performance is defined as a building with drift limited to approximately half of what is currently allowed by the building code and that limits the amount of damage done to the building by a design earthquake event. This competition requirement called for tight seismic restrictions and design considerations in the structural, mechanical, and building systems so that the building recovery

---

[4] ASCE Charles Pankow Foundation Annual Architectural Engineering Student Competition.2013.*2014 Project Guidelines*, http://content.asce.org/studentcompetition/competition.html (accessed 2 Sept. 2013)

time would be limited. The competition required that the building recovery time be limited in order to save money on repairs and to allow the tenants to return to work as soon as possible. In addition to these requirements, any building solution that increased the expected life cycle or minimized the carbon footprint of the building was considered when designing the building and its systems. The design of the building was greatly influenced by these seismic and sustainability requirements.

These are the main challenges and requirements that were addressed in the design of the high performance high-rise building for the Student Competition. Every step of the design process required collaboration between the members of the design team, innovative solutions to problems, and environmentally friendly decisions that would benefit the building and the surrounding environment.

1.2 Team Goals

In addition to the goals of the competition, the members of the team had specific goals that were addressed as they designed the building. These goals were:

1) To develop sustainable and energy efficient system designs that positively impact the environment and community.

2) To learn how to integrate structural and mechanical systems to complement each other and optimize the entire building system.

3) To use this experience as a learning tool to advance each member’s knowledge in innovative and sustainable designs.

The team worked together on the design of the different structural and mechanical systems with these goals in view. The team goals complemented the competition goals and helped the team focus to create the most innovative building possible. This project gave the team members a fundamental understanding of the building design process, combining all of the knowledge gained in engineering courses to create building systems that integrate and work with each other.

2.0 Background

This chapter is intended to provide insight into the various topics necessary to understand the development and design of a high performance building. Topics covered in this section include the main concepts, issues, and strategies involved in the design of integrated, structural, and mechanical building systems.

2.1 Architectural Design

The architectural design of a building must meet the needs and desires of the building owner and should be aesthetically pleasing. In addition, all of the rentable space must remain flexible to accommodate changes in the tenants and the use of the space. Sustainability should also be incorporated into the design in order to create a high performance building that is cost-effective, environmentally friendly, and has a low carbon footprint.

2.1.1 Typical Building Design

When starting the initial design of a high-rise office building, there are two main matters that need to be taken into account: the use of the building and the specific design elements that the owner desires and needs. These two matters give the design purpose and practicality. For example, the building would not be designed to meet the specific needs of one large company if the owner does not have a specific tenant moving into the space. Most of the time, building designs must be flexible in order to provide the building owner with different options for potential clients. The layouts for each floor could be job specific or be flexible to change with the tenants in the space.

The use of the building also decides the features and amenities that are included in the design. The building layout needs to account for employee areas, administrative office areas, and meeting areas. The building also needs to have parking options for the employees as well as allotted spaces for administrative staff. In addition, the building needs to have storage space for both tenants and the owner. The security of the building is important and should be adjusted to the level of security each tenant in the building requires. In order to attract tenants, the building may have dining options located either within or in close proximity to the building. The building may also have facilities within or in close proximity to childcare services, gyms, and art displays. All of these items are important considerations in building layout and design.

Once the features and amenities of the building are addressed, the economics of the building investment need to be considered. The building must be smart investment for the owner. While certain elements such as solar panels may help lower the overall carbon footprint of the building, they may be expensive and have a long payback period. The life cycle costs of each system should be low enough so that the owner will be able to break even quickly and profit from the investment. In order to maximize revenue, the building must be cost-effective, have flexible tenant space, be located in a safe and secure area, and be sustainable. High performance buildings must be sustainable, but also have to provide profit for the owner to make the business venture worthwhile.

2.1.2 Sustainable High-Rise Design Options

Designing a sustainable high performance high-rise building has many factors. One of the factors is aesthetics, and how the structure interacts in a positive way with both the tenants and the environment. The second factor is the usage of materials and the elimination of negative environmental impacts on the surrounding area. Third is a structural system that can perform well under the building load while also reducing the use of the building materials. Fourth is the life-cycle analysis of the building and materials to determine the useful life of the building and the payback period for the building elements. All these factors come under consideration when designing a high-rise building that is cost-effective, sustainable, aesthetically pleasing, and functional in both short and long term.

The current boom in the construction of sustainable buildings is the result of a more environmentally conscious community. As populations have increased, pollution has increased and the amount of available natural resources has decreased. Using materials sustainably to limit the negative environmental impact on the surrounding community is becoming more important in building owners and design teams. Companies are finding more sustainable ways of designing and building steel and concrete structures, sourcing components from local, sustainable manufacturers. In order to encourage the design of environmentally friendly buildings, the US Green Building Council created the Leadership in Energy & Environmental Design (LEED) rating system. The system has four levels of certification (certified, silver, gold, and platinum) based on a point system that reflect the sustainable practices incorporated in the project. As shown in Figure 10 below, LEED points can be obtained through effective energy use, water efficiency, indoor environmental quality, use of different materials and resources, and other categories.

LEED for New Construction and Major Renovations (v2009)

SUSTAINABLE SITES		**POSSIBLE: 26**
SSp1	Construction activity pollution prevention	REQUIRED
SSc1	Site selection	1
SSc2	Development density and community connectivity	5
SSc3	Brownfield redevelopment	1
SSc4.1	Alternative transportation - public transportation access	6
SSc4.2	Alternative transportation - bicycle storage and changing rooms	1
SSc4.3	Alternative transportation - low-emitting and fuel-efficient vehicles	3
SSc4.4	Alternative transportation - parking capacity	2
SSc5.1	Site development - protect or restore habitat	1
SSc5.2	Site development - maximize open space	1
SSc6.1	Stormwater design - quantity control	1
SSc6.2	Stormwater design - quality control	1
SSc7.1	Heat island effect - nonroof	1
SSc7.2	Heat island effect - roof	1
SSc8	Light pollution reduction	1
WATER EFFICIENCY		**POSSIBLE: 10**
WEp1	Water use reduction	REQUIRED
WEc1	Water efficient landscaping	4
WEc2	Innovative wastewater technologies	2
WEc3	Water use reduction	4
ENERGY & ATMOSPHERE		**POSSIBLE: 35**
EAp1	Fundamental commissioning of building energy systems	REQUIRED
EAp2	Minimum energy performance	REQUIRED
EAp3	Fundamental refrigerant Mgmt	REQUIRED
EAc1	Optimize energy performance	19
EAc2	On-site renewable energy	7
EAc3	Enhanced commissioning	2
EAc4	Enhanced refrigerant Mgmt	2
EAc5	Measurement and verification	3
EAc6	Green power	2
MATERIAL & RESOURCES		**POSSIBLE: 14**
MRp1	Storage and collection of recyclables	REQUIRED
MRc1.1	Building reuse - maintain existing walls, floors and roof	3
MRc1.2	Building reuse - maintain interior nonstructural elements	1
MRc2	Construction waste Mgmt	2
MRc3	Materials reuse	2
MRc4	Recycled content	2
MATERIAL & RESOURCES		**CONTINUED**
MRc5	Regional materials	2
MRc6	Rapidly renewable materials	1
MRc7	Certified wood	1
INDOOR ENVIRONMENTAL QUALITY		**POSSIBLE: 15**
EQp1	Minimum IAQ performance	REQUIRED
EQp2	Environmental Tobacco Smoke (ETS) control	REQUIRED
EQc1	Outdoor air delivery monitoring	1
EQc2	Increased ventilation	1
EQc3.1	Construction IAQ Mgmt plan - during construction	1
EQc3.2	Construction IAQ Mgmt plan - before occupancy	1
EQc4.1	Low-emitting materials - adhesives and sealants	1
EQc4.2	Low-emitting materials - paints and coatings	1
EQc4.3	Low-emitting materials - flooring systems	1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	1
EQc5	Indoor chemical and pollutant source control	1
EQc6.1	Controllability of systems - lighting	1
EQc6.2	Controllability of systems - thermal comfort	1
EQc7.1	Thermal comfort - design	1
EQc7.2	Thermal comfort - verification	1
EQc8.1	Daylight and views - daylight	1
EQc8.2	Daylight and views - views	1
INNOVATION		**POSSIBLE: 6**
IDc1	Innovation in design	5
IDc2	LEED Accredited Professional	1
REGIONAL PRIORITY		**POSSIBLE: 4**
RPc1	Regional priority	4
TOTAL		**110**

40-49 Points CERTIFIED	50-59 Points SILVER	60-79 Points GOLD	80+ Points PLATINUM

Figure 10: LEED New Construction Points

2.2 Structural Design

High-rise buildings are tall structures usually composed of steel, concrete, or composite materials that are above ten stories in height. High-rises are composed of many different systems, with each system working together to form a structure that provides functionality, stability, and positive performance for its spaces. The main considerations that must be taken into account for the structural design of high-rise buildings are based on wind and seismic loads. High performance high-rises take the conventional design of tall buildings to the next level by not only addressing these major structural design considerations, but also the economic and environmental impact. Many new structures are now being designed to meet the higher standards of high performance buildings while also increasing the structural strength and sustainability of their systems.

2.2.1 Structural Systems

The structural design of high-rise buildings has different design considerations than the design of low-rise buildings. Unlike the design of low-rise structures, in the design of high-rise structures, wind loads and seismic loads are more significant than any of the other loads. The wind loads are given this priority because the building's sway affects not only the structure, but also the occupants inside. The seismic loads on the building are important because the seismic design of the structure must work against inter-story drift caused by tectonic plate shifts in a seismic event and its impact on structural and non-structural systems. In order to prevent the systems from being damaged by these forces, high-rise buildings rely greatly on lateral load resisting systems.

2.2.1.1 Steel

Steel has been used in high-rise structures since the beginning of high-rise building design, starting with the Rand McNally Building by Burnham and Root in Chicago. The structural designs have evolved to provide resisting systems for a range of different building requirements, depending on the area of the building. A table that describes many different systems that are typically used in building designs is provided below.[5]

Table 1: Typical Steel Structural Systems Used in High-Rise Design

System	Description	Number of Stories favoring each system	Potential option	Notes:
Rigid Frame	Strength resisting lateral loads from moment interactoin between columns and beams. "The moment restraint at the ends leads to reduced positive bending moments for beams and reduced effective lengths for columns under gravity load" (Chapter 1.1 Lateral Load Resisting Systems for Steel Buildings)	25 Stories	NO	
Frames and Fully Restrained Connections	A rigid frame consists of parallel or orthogolan connections of columns and girders with moment resisting connections. "Resistance to horizontal loading is provided by the bending resistance of the columns and beams. The rigidity of the joint also assists in resisting gravity loading more efficiently by reducing the positive moments in the center span of beams. (Chapter 1.2 Lateral Load Resisting Systems for Steel Buildings)	10-15 stories	NO	
Concentric Braced Frames	"A braced frame improves upon the efficiency of a rigid frame by virtually eliminating the bending of columns and girders. This is because by adding web members such as diagonals or chevron braces, the horizontal shear is resisted by the web. The webs carry the lateral shear predominantly by axial forces in the braces thus minimizing bending of beams and columns. CBFs are quite efficient from strength and stiffness considerations" (Chapter 1.3 Lateral Load Resisting Systems for Steel Buildings)	Low Rise	NO	The brace in the frame allow for the structure to be controlled in both the bending at the top and bottom of the building.
Eccentric Braced Frames*	"Eccentrically braced frames can be configured in various forms as long as the brace is connected to at least one link. The underlying principle is to prevent buckling of the brace from large overloads that may occur during major earthquakes. This is achieved by designing the link to yield either in shear or in bending."(Chapter 1.4 Lateral Load Resisting Systems for Steel Buildings)	25-30 Stories	YES	The connections in this system allow the structure to perform well in a design earthquake.
Buckling Resisting Braced Frame*	"Buckling-restrained brace frames (BRBFs), have a high degree of ductility (energy absorbing capability) and good lateral stiffness, and are relatively simple to repair if need be, after a major earthquake. Unbonded brace frames, which may be considered a special class of BRBFs, consist of a steel core installed within an outer shell with mortar infill between the plate and the shell." (Chapter 1.5 Lateral Load Resisting Systems for Steel Buildings)	25-30 Stories	YES	Provides a strong seismic lateral system for design earthquakes
Steel Plate Shear Wall	"Steel plate shear walls consist of columns, beams, and steel plate elements. The plate infills the boundaries created by the columns and beams. The behavior of special steel plate shear wall is analogous to a vertically cantilevered steel plate girder with the columns acting as the plate girder flanges, the beams acting as the intermediate stiffeners, and the steel plate acting as the web of the plate girder." (Chapter 1.6 Lateral Load Resisting Systems for Steell Buildings)	Seismic - lateral system	YES	Works in a dual system. The steel plate shear wall creates the primary sheer resistance

[5] Taranath, Bungale S. *Wind and Earthquake Resistant Buildings Structural Analysis and Design* (New York: Marcel Dekker, 2005) Chapters 4 & 5.

Braced and Rigid Frames	"An economical structural solution can be configured by using rigid frames in conjunction with braced frames.Although deep girders are required for rigid frames they are perhaps less objectionable than additional columns from space planning considerations." (Chapter 1.8 Lateral Load Resisting Systems for Steel Buildings)	40-50 Stories	YES	There are 3 different configurations to this system. There is thecore braces and perimeter rigid frames, the braced core and exterior/interior rigid frames , and the moment-connect the girders between the braced core and the exterior columns.
Core and Outrigger Systems	"In high-rise buildings, the core can be related to the mast of the ship, the outrigger to the spreader, and the exterior columns to the stays or shrouds. Just as in sailing ships, these outriggers serve to reduce the overtuming moment in the core. In high-rise buildings, this same benefit is realized by a reduction of the base core overturning moments and the associated reduction in potential core uplift forces. The overturning moment resisted through a couple between the windward stay and the mast is similar to the moment transferred to gravity-loaded exterior columns in high-rise buildings." (Chapter 1.9 Lateral Load Resisting Systems for Steel Buildings)	40-50 Stories	YES	The system has disconneted structural elements, core and exterior.
Frame Tube System	"The idea here is to develop a fully three-dimensional structural system that engages the entire building inertia to resist lateral loads. The goal is to achieve a higher degree of efficiency toward lateral load resistance for taller buildings. The resulting organization for a framed tube system is generally one of closely spaced exterior columns and deep spandrel beams rigidly connected together, with the entire assemblage continuous along each façade and around the building corners. " (Chapter 1.10 Lateral Load Resisting Systems for Steel Buildings)	50-60 Stories	YES	This system only needs one lateral system. The structural system is designed where the wind loads prevelant on one wall are resisted with steel webs in the structure.
Irregular Tube	"Non-compact plans, and plans with reentrant corners, reduce the efficiency of the system. For framed tubes, a compact plan may be defined as one with an aspect ratio of not greater than 2.0. Elongated plans with higher aspect ratios impose a cost premium because (1) for wind design, the elongated building elevation acts like a sail collecting large wind loads; (2) the resulting shear forces most usually require closer spacing andor larger size columns and spandrels parallel to the wind; (3) shear lag effects are more pronounced particularly for columns oriented perpendicular to the direction of wind." (Chapter 1.11 Lateral Load Resisting Systems for Steel Buildings)		YES	One of the framed tube systems, Not as efficient as others.
Truss Tube	"A trussed tube however opens up the façade and is uniquely suited to the qualities and character of structural steel. This is achieved by introducing a minimum number of diagonals on each façade and making the diagonals intersect at the same point at the corner column. The system is tubular in that the fascia diagonals not only form a truss in the plane but also interact with the trusses on the perpendicular faces to affect the tubular behavior." (Chapter 1.12 Lateral Load Resisting Systems for Steel Buildings)	60-70 Stories	YES	One of the framed tube systems. This system allows for less steel columns or diagonals blocking out the daylight for the tenants of each floor
Bundled Tube	"A bundled tube that can be configured with multiple cells, on the other hand, provides for vertical offsets without much loss in efficiency. Additionally, it allows for wider column spacings that would be possible with a single cell tube. In principle, many building shapes can be configured using bundled tubes" (Chapter 1.13 Lateral Load Resisting Systems for Steel Buildings)	80-100 Stories	YES	One of the framed tube systems

Different steel structural systems allow the structure to act in different ways. The two most conventional methods of structural steel design are the tube-in-tube system and the braced and rigid frame system. The tube-in-tube system is a system where the building acts like a box, with all of the floors working together to resist the movement and torque created from the different loads acting on the structure. This system is similar to using a central core. The central core is a shear wall that resists the shear in the building by using the floor slabs to balance and transfer loads. The core also transfers the load from the floor slab to the foundation and to the ground. The other main steel system is the rigid frame and braced frame system, in which both frames work together to support the other's weaknesses. The rigid frame resists rotation and the braced frame resists lateral loads on the building. These systems can be used together and provide a flexible, strong design.

2.2.1.2 Concrete

Concrete is an important material when designing high-rise buildings due to the fact that it can function as the main structural system as well the foundation. Similar to steel design, one of the most common methods of structural concrete design is the tube-in-tube design. The tube-in-tube structure consists of a perimeter moment frame and an interior core wall. This structural system is commonly used in high-rise buildings, in which lateral load-resisting systems are crucial.

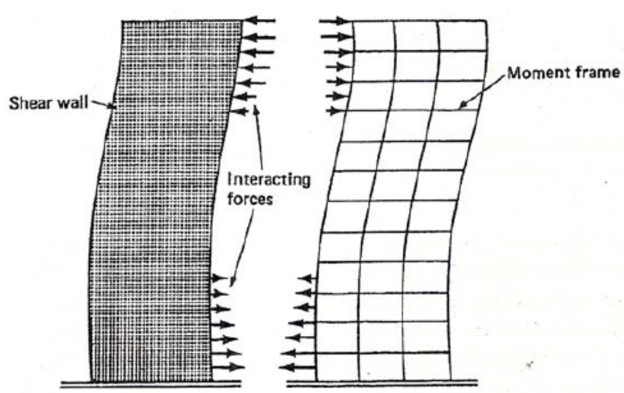


Figure 11: Wall-frame Interaction
(Taken from Lateral Load Design of Tall Buildings)

There are two main concrete lateral load-resisting systems: the shear wall and the pre-stressed slab. The concrete inner tube shear wall is the backbone of the building structure, providing both lateral stiffness and strength. Since a high-rise building is similar to a cantilever beam, it is a bending-dominated displacement structure where the bottom of the structure is fixed to the ground while the top is displaced by lateral loads. This behavior is shown in Figure 12.

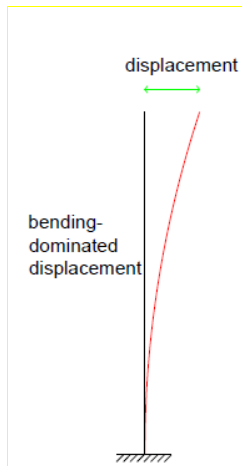


Figure 12: Bending-Dominated Displacement
(Taken from Lateral Load Design of Tall Buildings)

Pre-stressed concrete slabs are another major component of the lateral load-resisting structural system. These slabs are created when compression is induced in the concrete to counteract tensile stresses. The rebar in the slabs is put in tension before the concrete is placed over it at the factory. This method is used because the tensile strength of the steel combined with the compressive strength of the concrete creates a structural system that performs well under both tensile and compressive forces.

Another common concrete structural system uses post-tensioned slabs. In the post-tension system, the pre-stressing tendon is pulled into tension at the building site after the concrete is placed and cured. This requires specialized labor at the site to install the slabs correctly and safely. After the concrete cures and the tendons are released, the tendons induce compression on the concrete, increasing its capacity to withstand tension. Post-tensioning allows for larger spans between columns and a more ambitious span design. All of these design systems can be supported by the conventional or unconventional external column and inner core.

2.2.1.3 Comparison of Steel and Concrete

Concrete and steel systems can both be used in a range of project sizes and provide stable structural systems. The downside of steel systems is that they are limited by the space available for storage on the site. In some cases, however, when steel is the better material option, sections of the steel structure can be put together offsite and transported to the site. This process improves the efficiency of the assembly and construction of the building, but it can lead to logistical and transportation challenges. Unlike steel, prefabricated concrete is not limited by site storage space because the sections are assembled the day they arrive from the factory. This too, however, can lead to challenges with regards to transportation and logistics. The size of the construction site is not the only factor that influences the selection of structural systems; the size of the building, local labor capabilities, the availability of materials, and climate are also significant factors. When the project is large, it can be more economical to use steel, because the formwork for the concrete is too expensive. In addition, the skill and price of labor may vary in different locations, depending on the availability of workers who are familiar with the structural material being used.

2.2.1.4 Current Design

For the structural design of the existing building, SOM proposed a concrete structure. The existing structural design consists of a concrete core wall in the middle of the building functioning as the lateral load resisting system with concrete columns along the perimeter that serve as the gravity load resisting system. In addition, the concrete slabs at each level above ground are post-tensioned in order to minimize the thickness of the slabs. The use of the concrete core wall design and the post-tensioned slabs suggests that there was a concern to limit the overall building height while maximizing the number of floors in order to increase useable space.

2.2.2 Earthquakes

The west coast is one of the most seismically active areas in North America due to the juxtaposition of two large tectonic plates: the Pacific Plate and the North American Plate. Due to the earth's constant movement, different plate boundaries slide pass one another, creating faults. Three main faults, the San Andreas Fault, San Gregorio Fault, and Hayward Faults, are located near the project site. When the plates move, energy is stored within or near the fault lines, and this energy continues to build up until it surpasses the frictional forces containing it. When the elastic forces overcome the frictional forces, the fault slips and releases all of the built-up energy in waves and ground shaking events.

Seismic activity is a crucial consideration for this project because the project site is located in San Francisco's South of Market District. This site has a history of extensive damage from earthquakes, especially from the earthquake in 1906. The earthquake in 1906 registered an 8.3 on the Richter Scale and destroyed more than eighty percent of the city, engulfed the city in fire for days, and claimed more than three thousand lives.[6] The data record showing all the major earthquakes in the San Francisco Bay Area with their corresponding magnitude and distance from the fault responsible is given in Table 2.

[6] Ellsworth, W.L., *The Great 1906 San Francisco Earthquake*, U.S. Geological Survey, http://earthquake.usgs.gov/regional/nca/1906/18april/index.php (accessed 22 Sept. 2013)

Table 2: Regional Faults and Seismicity
(Taken from Treadwell & Rollo)

Fault Segment	Approx. Distance from fault (km)	Direction from Site	Mean Characteristic Moment Magnitude
N. San Andreas – Peninsula	13	West	7.23
N. San Andreas (1906 event)	13	West	8.05
N. San Andreas – North Coast	16	West	7.51
Total Hayward	16	East	7.00
Total Hayward-Rodgers Creek	16	East	7.33
San Gregorio Connected	19	West	7.50
Mount Diablo Thrust	33	East	6.70
Rodgers Creek	33	North	7.07
Total Calaveras	34	East	7.03
Green Valley Connected	38	East	6.80
Monte Vista-Shannon	41	Southeast	6.50
Point Reyes	42	West	6.90
West Napa	44	Northeast	6.70
Greenville Connected	51	East	7.00
Great Valley 5, Pittsburg Kirby Hills	55	East	6.70
Great Valley 4b, Gordon Valley	68	Northeast	6.80
Hunting Creek-Berryessa	76	North	7.10
N. San Andreas - Santa Cruz	77	Southeast	7.12
Great Valley 7	77	East	6.90
Zayante-Vergeles	87	Southeast	7.00
Great Valley 4a, Trout Creek	90	Northeast	6.60
Maacama-Garberville	91	North	7.40
Monterey Bay-Tularcitos	100	Southeast	7.30

With more investigation and advanced technology, scientists have started to see a trend in all of the seismic data collected. From 1836-1911, earthquake magnitudes in California ranged from 6.0 to 8.0 on the Richter scale. As shown in Figure 13, after the enormous earthquake in 1906, a new phenomenon occurred—San Francisco did not have any major earthquakes for a long period of time. Scientists have hypothesized that the rupture in 1906 initiated a sixty-eight year quiet period by releasing all of the seismic energy that had been building up. After this period of inactivity, however, the balance became offset once again. Scientists predict that the energy that has been built up during the quiet period will be released more violently than ever before.[7]

[7] U.S. Geological Survey *When will it happen again?*, http://earthquake.usgs.gov/regional/nca/1906/18april/whenagain.php (accessed 22 Sept. 2013)

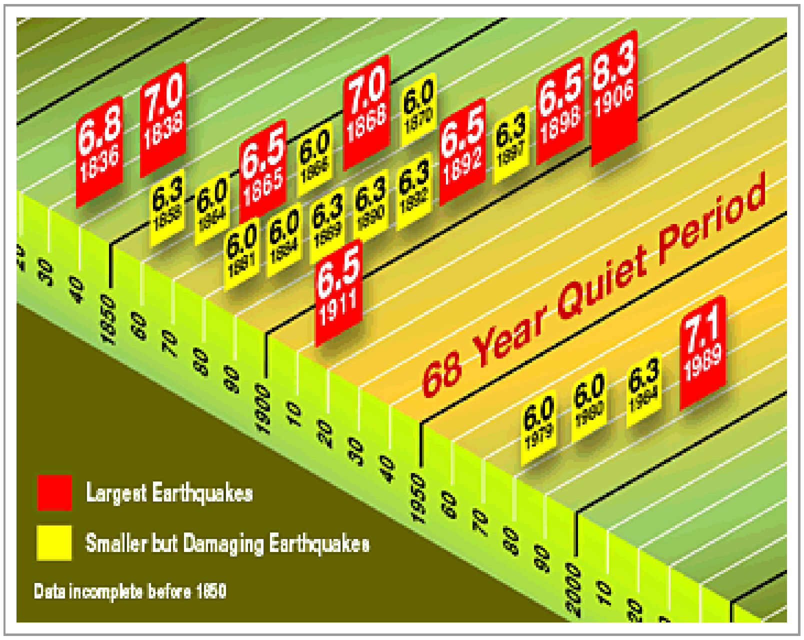


Figure 13: History of Earthquake in the San Francisco Bay
(Taken from Bancroft Library)

In 2008, the United States Geological Survey (USGS) published an earthquake forecast that predicts that the San Francisco Bay area has a sixty-three percent probability of experiencing one or more earthquakes with a magnitude of 6.7 or higher within the next twenty years. The same report indicates that the San Andreas Fault, which is thirteen kilometers west of the project site, has a twenty-one percent probability of causing a major earthquake event.[8] Other seismic faults to consider are the Hayward, San Gregorio, and Calaveras Faults, shown in Figure 14 below.

[8] Earthquake Safety.com "Earthquake History of the Bay Area" USGS http://www.earthquakesafety.com/earthquake-history.html (accessed 15 Sept. 2013)

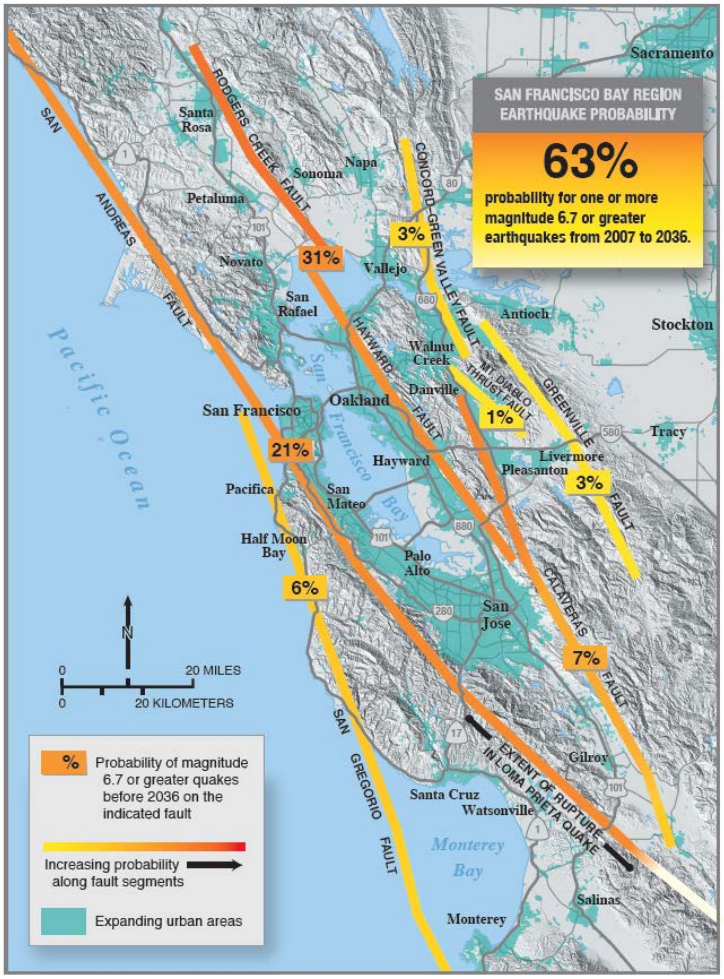


Figure 14: San Francisco Bay Region Earthquake Probability
(Taken from USGS San Francisco Bay Region Earthquake Probability)

2.2.2.1 Design Approach

Designing buildings to withstand earthquakes requires designing for the direction of motion, the displacement of the building from its neutral position, the acceleration of the ground motion, the general cyclic motion duration, and the frequency content of the earthquake. Since there are many different types of possible earthquake events, the proposed project can either be evaluated by a code-based approach or a performance-based approach. For a code-based approach, *ASCE/SEI 7-10* and *ACI 318* would be used to determine the allowable and target story drift. For a performance-based approach, the codes and regulations for the building would be adapted with city approval for that particular site. The reference data can be found in the Appendix A.

2.2.2.2 Design Considerations

According to Newton's Second Law, the force applied to an object is equal to the object's mass multiplied by its acceleration. When seismic waves act on a building, the building's response will depend on its major characteristics like the weight, height, stiffness, size, supports, joints, etc. Building structure, foundations, materials, and connections are major characteristics that must be taken into account. In addition, as shown in Figure 15, important attributes of performance for this project are safety, drift, post-earthquake occupancy, and cost.

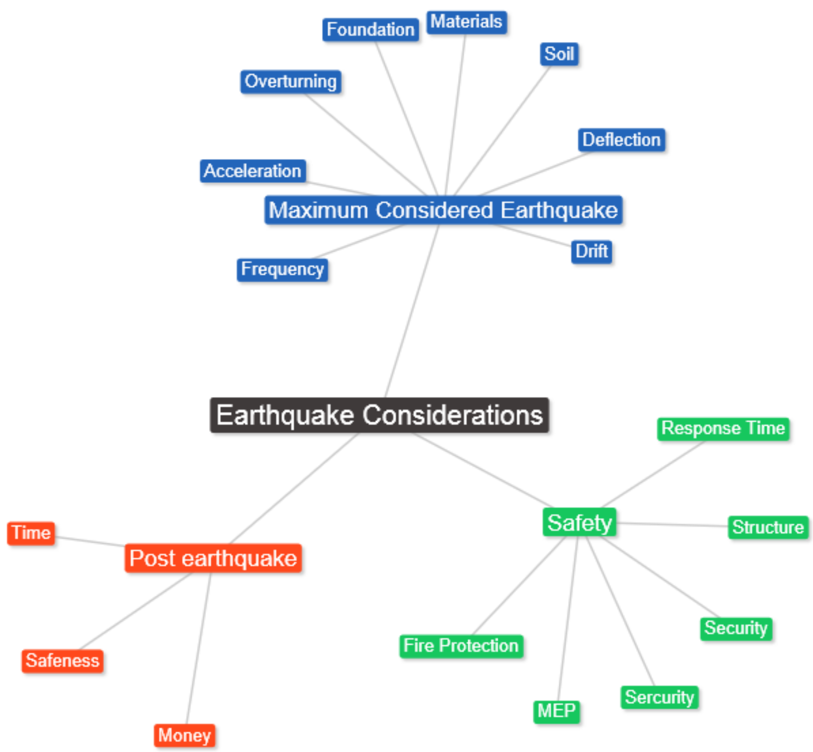


Figure 15: Earthquake Considerations

Safety is always the first priority when designing a building for an earthquake event. At the very least, the building must not collapse and must maintain its structural integrity until the last person has evacuated the building. In order to make the building safe, the structural design must minimize the Maximum Considered Earthquake (MCE) effects like drift and deformation. The design should include the lowest deformability possible and include a minimal story drift (the lateral deflection at the top of the story relative to the story beneath it) where the stability coefficient does not exceed the maximum value for overturning. In high-rise buildings, it is especially important to consider the whiplash effect of the whole building as the ground shakes violently back and forth.

It is also important to design the building for a low post-earthquake occupancy time, meaning that the building is still safe and functional after a major design event. After a seismic event, a post-event recovery evaluation must be conducted. This evaluation is meant to determine the time it will take for the building to be restored to operating order, as well as any associated costs from damage. For this project, it is important that the recovery time and any damages are minimized.

2.2.2.2.1 Site

The site condition is another important aspect of the seismic design considerations. The project site was previously known as Yerba Buena Mud Cove. This portion of land was originally a shallow bay used for warehouse storage, lumber company development, and the city dump. Historical maps of 1849 reveal that the shoreline was approximately due west of the building. Due to the growing demand for property in San Francisco, this barren area was filled in the late 1900s.[9]

The current developed area of San Francisco consists of four different layers of soil—fill, marine deposits, colma sand, and old bay clay—with each layer revealing the history of the area. Table 3 and Figure 16 below both provide a detailed description of the San Francisco's soil profile. The topography of San Francisco rests on bedrock that dates back to the Jurassic and Cretaceous ages. The first soil layer is a layer of old bay clay that is a mixture of broken sedimentary rocks

[9] Treadwell & Rollo, *Geotechnical Investigation 350 Mission Street San Francisco, California*. 28 Jun 2012, Project 730466502, 6.

that can be highly deformed.[10] The second layer of soil was formed roughly 125,000 years ago when the sea level dropped, exposing the underlying mud and depositing a layer of colma sand. The layer of colma sand molded with sediments carried by the wind, forming a strong, dense, and barely compressible layer. Next, a layer of marine sediment lying above the colma sand was deposited when the sea level rose again and formed an estuary from an uneven sediment distribution. The estuary, a place where the fresh water from rivers blends together with the salt water from the ocean, created a new marine habitat and deposited marine sediments forty-eight to fifty-three feet below the current ground level. Marine sediment deposits are generally soft, weak, and easily compressible, and can greatly amplify ground shaking caused by an earthquake. The final layer of soil, a layer of artificial fill materials, was constructed to permit the continued expansion of San Francisco during the early 1920s. The artificial fill is supposed to contain only loose to medium dense sand, slay, and gravel. Upon drilling in the area, however, bricks, decomposed sandstone and shale fragments, and rubble were discovered.[11] This unexpected discovery led geotechnical engineers to reevaluate the soil conditions and building designs of the area. It is also important to note that San Francisco's ground water also exists in this soil layer, approximately six to ten feet below ground level. This factor also weakens the soil, making it prone to consolidate under its own weight.

---

[10] Simpson, Lori A. *Case Studies in Mission Bay, San Francisco: Deep Foundations in Challenging Soil Conditions*, http://www.treadwellrollo.com/files/FileUpload/70/Case%20Studies%20in%20Mission%20Bay%20Paper.pdf (accessed 15 Sept. 2013)

[11] Treadwell & Rollo, 8-10

Table 3: Soil Layers in Yerba Buena Mud Area
(Taken from Treadwell & Rollo)

Soil	Mixture of	Characteristics	Depth	History	Notes
Fill	Sand, silty sand, sandy gravel	Loose to medium dense, with concrete and brick rubble	0 → -20’	Early 1920s	-ground water exists in this layer -discovered unexpected other types of soil
Marine Deposits	Silty clay, clayey sand, sand, silty sand	Loose to medium dense/ stiff	-20’ → -45’	Unknown	-soft, weak, and easily compressible, -can greatly amplify ground shaking caused by earthquake
Colma Sand	Sand, sand with clay, clayey sand, silty sand	Dense to very dense	-45’ → -85’	125,000 years ago	-dense, strong, hardly compressible -foundation for concrete mat -uneven distribution
Old Bay Clay	Silty clay, sandy clay	Stiff to hard	-85’→ -120’	600,000 years ago	-highly deformed and fractured Franciscan Formation” -weathered sandstone, shale, serpentine, and chert -estimated to settle 4-5” over the next 30 years

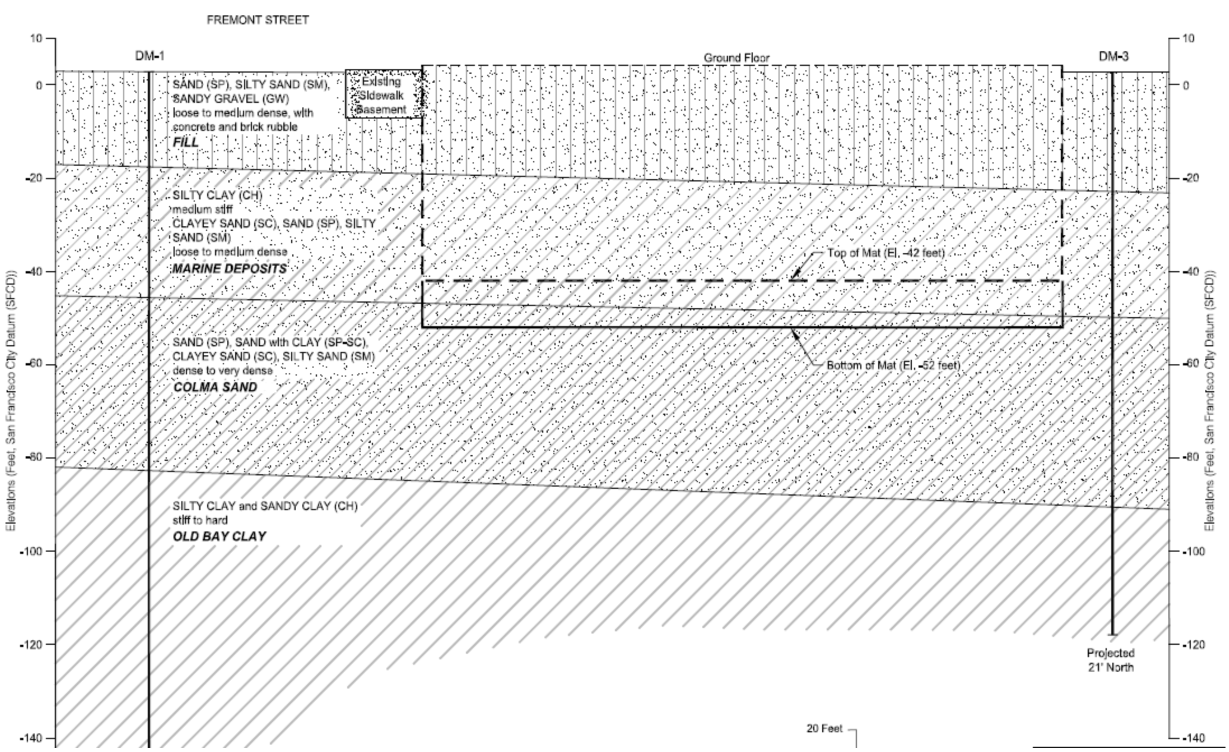


Figure 16: Idealized Subsurface Profile A-A’
(Taken from Treadwell & Rollo)

2.2.2.2.1.1 Soil Liquefaction

Soil liquefaction occurs when the soil loses its strength and stability due to saturation and sudden changes in the environment. Soil particles are typically packed together and hold their formation because of the irregularity of each particle. Between the particles are many voids that can store water and influence how the particles interact with one another. When a seismic event occurs, the rapid shaking exerts pressure between the voids and disrupts the soil formation. If the soil is saturated when a seismic event occurs, the soil particles tend to consolidate and become denser, which forces the water out of the pores. If the water cannot drain quickly, the soil movement increases the pore water pressure, resulting in decreased soil strength and stiffness. When this occurs, the soil loses it strength and flows as a liquid.[12] Soil liquefaction can cause extensive damage to the ground surface. Several properties associated with soil liquefaction areas include decreased soil strength and structural foundation instability.

According to a map published by the California Division of Mines and Geology, the current project site is susceptible to soil liquefaction. 350 Mission Street, circled in red in Figure 17, is located in a green colored area which identifies the areas that have "historical occurrence of liquefaction or local geological, geotechnical and ground water considerations [which] indicate a potential for permanent ground displacement such that mitigation as defined in the Public Resources Code Section 2593 would be required."[13] Because the project site is located near the bay, the process of saturation and soil liquefaction occurs rapidly. The first two layers of soil, sandy gravel and marine deposits, can cause the ground to settle 1-1/2 to 3 inches.[14]

---

[12] Johansson, Jorgen. *Welcome to the Soil Liquefaction*, Department of Civil Engineering, University of Washington. http://www.ce.washington.edu/~liquefaction/html/main.html (accessed 15 Sept. 2013)

[13] California: California Division of Mines and Geology, *Seismic Hazard Evaluation of the City and Country of San Francisco*, Open- File Report 2000- 009. http://www.sfgsa.org/modules/showdocument.aspx?documentid=10438 (accessed 12 Sept. 2013)

[14] Treadwell & Rollo, 8-10.

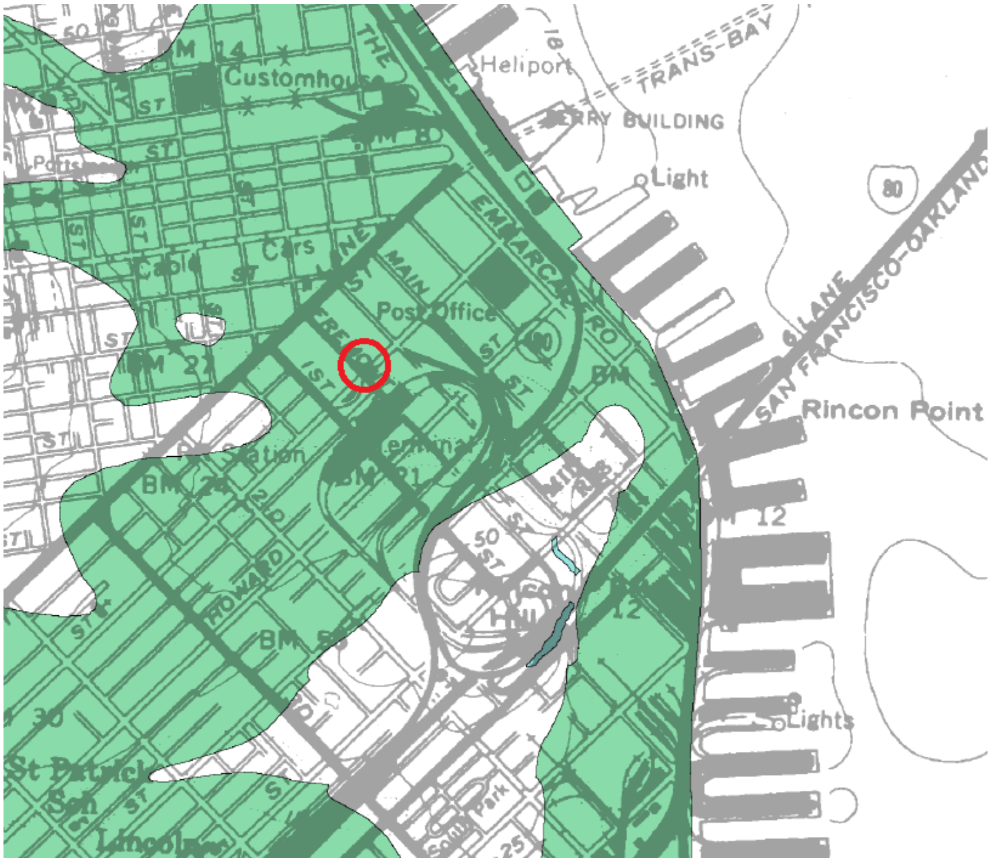


Figure 17: Soil Liquefaction Area
(Taken from California Division of Mines and Geology)

2.2.2.3 Earthquake Resisting Design Strategies

Many different damping systems are used to mitigate the effects of a seismic event. Table 4 below lists several earthquake-resistant construction methods with their corresponding advantages and disadvantages. For this project, the research focused on four different methods: the current method proposed by SOM and three different alternatives. SOM proposed a combination of a ten-foot seismic mat at the base of the building, a tube-in-tube shear wall structure, and moment resisting frames. The three alternatives the team considered for this design are liquid tuned dampers, oil dampers, and possible changes to the building's structural design.

Table 4: Earthquake-resistant Construction Methods

Strategy	Explanation	Advantages	Disadvantages
Base Isolation	-Foundation is not attached to building -Uses rollers/ rubber cylinders/ bearings	-Allows up to 4' horizontal movement, 2' vertical movement -Can be replace	-Expensive -Not recommended for tall buildings due to massive shear strength
Oil Dampers	-Absorbs seismic loads	-Cushions up to 50% of building sway	-Depending on the attachment to the building, may not be easy to replace/ updated
Core Columns	-Heavy interior core that resists/ carries loads -Uses staircase & elevators -Core column is surrounded by steel reinforcement	-Podium stability	-Main core of the damping system
Liquid Tuned Damper	-Counterweight water tank on roof of building	-Can potentially be integrated into HVAC -helps with fire protection	-Expensive -Pump water to the top of building daily (energy)
Shock absorbers	-Passive system	-Quick way to dissipate energy & loads	-Cannot be technologically updated if embedded in structure

2.2.2.4 Current Design

A four-story reinforced concrete structure with a basement has existed on the 350 Mission Street site since the early 1920s. According to a plan titled "Foundation Plan, Structural Design, Fremont and Mission Building, San Francisco," this building was supported by seven hundred timber piles driven into the ground.[15] Site work for the current project began with the demolition and removal of the existing structure. SOM designed a ten-foot concrete mat resting on top of the dense Colma sand layer at forty-two feet below elevation. The colma sand layer "can support

[15] Treadwell & Rollo, 15.

moderate to heavy foundation loads without excessive settlement."[16] The mat's purpose is to distribute loads equally, reduce differential settlement, and resist hydrostatic uplift forces. SOM anticipated dense sand at the foundation level. If something unexpected had been found at that level, they planned to replace it with engineered fill or control density fill. For the building of the foundation, "the main construction considerations are removal of existing piles, shoring requirements, dewatering for basement excavations, [and] differential settlement at building/ sidewalk interface. Additional concerns are the presence of concrete rubble debris, abandoned shoring, and underpinning elements in the near-surface fill."[17]

---

[16] Treadwell & Rollo, 8-10.
[17] Treadwell & Rollo, 8-10

2.3 Mechanical Systems

The coordination of the Mechanical, Electrical, Plumbing and Fire Protection (MEP/FP) systems in buildings is crucial for the development of integrated, high performance systems. Mechanical systems in high-rise buildings must be responsive to environmental requirements, energy consumption, and smoke and fire management. These systems influence the architectural design and various other aspects of the building design.

2.3.1 Heating, Ventilation, and Air Conditioning (HVAC) Systems

The heating, ventilation, and air conditioning (HVAC) systems implemented in a building play a vital role in how efficiently the building performs. The HVAC systems are responsible for maintaining thermal comfort within a building, regardless of varying temperatures and humidity on the exterior. Selecting the right HVAC system is crucial for reducing overall building costs and the floor to ceiling space. According to ASHRAE 2011, the overall cost of mechanical and electrical systems is typically 30% to 35% in a fully developed building and is usually over 25% of the overall cost for a high-rise commercial building. Additionally, mechanical and electrical equipment can consume 7% to 10% of the gross building area.

There are three main approaches used in HVAC system design: passive design strategy, active design strategy, and hybrid systems combining active and passive strategies. Passive design strategies use ambient energy sources to maximize the efficiency of a building envelope, while also having a low environmental impact. These strategies include the use of solar energy, natural ventilation, and daylighting. Unlike passive design, active design strategies incorporate systems such as radiant floor panels, electric lighting, and heat pumps that require purchased or generated energy to operate. Finally, hybrid systems incorporate active systems within passive systems to enhance the use of ambient energy sources. Examples of hybrid systems are heat recovery ventilation systems, solar thermal systems, and radiant facades.

2.3.1.1 Passive Design Strategies

Passive mechanical system design refers to the use of ambient energy sources such as wind or sunlight to aid in the operation of a building's HVAC systems. The use of passive design reduces the building's need for active HVAC systems and requires little maintenance over the life of the building. As a result, these systems can drastically reduce a building's energy use.

2.3.1.1.1 Passive Cooling

Ventilation is a key aspect of passive cooling systems. Natural ventilation relies on wind speed and thermal buoyancy to draw air into a building. The cooling of indoor areas occurs when the outside air drawn into the building displaces the hot air. The shape and location of a building's ventilation openings dictate the manner of ventilation. There are three main operations of ventilation within a building: Cross Ventilation, Single-Sided Ventilation, and Stack Ventilation.

During cross ventilation, wind-induced pressure differentials force air movement across two sides of a building envelope. Generally, the air moves from the windward side (positive pressure) to the leeward side. In single-sided ventilation, inlets and outlets are placed on the same wall. Thermal buoyancy allows cooler air to enter through the lower inlets and exhaust warmer polluted air through the upper outlets. The greater the vertical distance between the openings and the greater the temperature difference between the inside and the outside, the stronger the effect of the buoyancy is. In cases where there is one opening for ventilation, wind turbulence is the main driving force in cooling an area. A diagram displaying single-sided ventilation and cross ventilation is shown below.

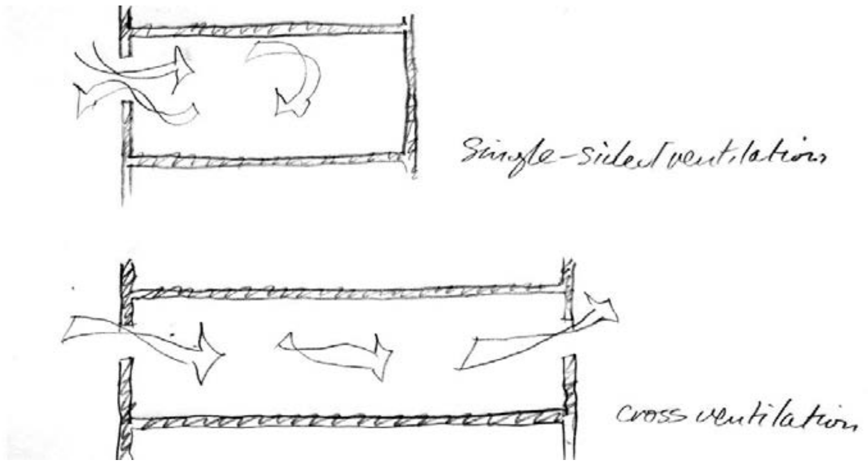


Figure 18: Diagram of Single-Sided Ventilation & Cross Ventilation
(Taken from Royal Institute of British Architects, Sustainability Hub)

In stacked ventilation, thermal buoyancy is a key factor in promoting the path of airflow. In this scenario, fresh air enters through the lower level and is exhausted through higher-level ventilation. Designing the outlet to be in an area of wind-induced under-pressure can enhance the effectiveness of stacked ventilation. In order for stacked ventilation to be effective, a certain height must exist between the inlet and outlet. This height can be achieved by numerous methods, such as increasing the height of the solar chimney, tilting the profile of the roof, or by increasing the floor to ceiling height. The stacked height is effective across a width that is five times the floor to ceiling height from an inlet to where the air is exhausted. Figure 19 illustrates how stacked ventilation functions. For additional passive design strategies, refer to Appendix B.

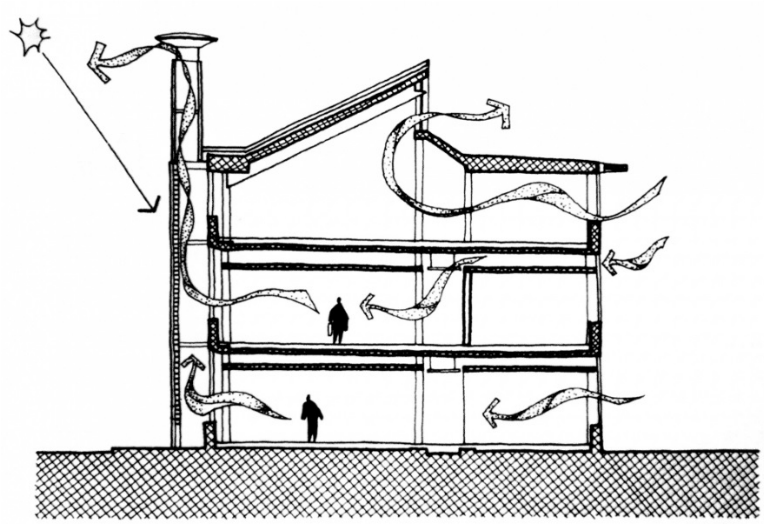


Figure 19: Illustration of Stack Ventilation
(Taken from Royal Institute of British Architects, Sustainability Hub)

2.3.1.2 Active Design Strategies

Active mechanical design refers to the use of purchased or generated energy to operate HVAC systems. For active design strategies, a central HVAC system may serve one or more thermal zones. In larger buildings, not all spaces can be evenly controlled and it is common for thermal variation to exist in different locations within the building. As a result, different HVAC zones are implemented to maintain air quality and thermal comfort. There are two main types of zone systems, single zone and multi-zone, which utilize constant-air volume and variable-air volume units.

2.3.1.2.1 Single Zone

As shown in Figure 20, single zone systems deliver air from the central air-handling unit at constant volume and varying temperatures, treating the entire space as a single zone. This system is commonly used in residences and small commercial buildings.

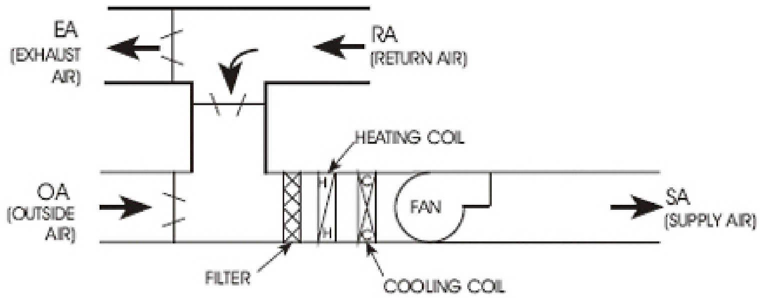


Figure 20: A single zone system
(Taken from Royal Institute of British Architects, Sustainability Hub)

2.3.1.2.2 Multi-Zone

Multi-zone systems deliver air to different zones at constant volume and varying temperatures. The air-handling unit has both a heating coil and a cooling coil in parallel. Supply air can be diverted to pass through the heating coil, cooling coil, or a combination of the two. This allows the supply air temperature to be varied to meet the requirements of the zone.[18] A multi-zone system is shown in Figure 21.

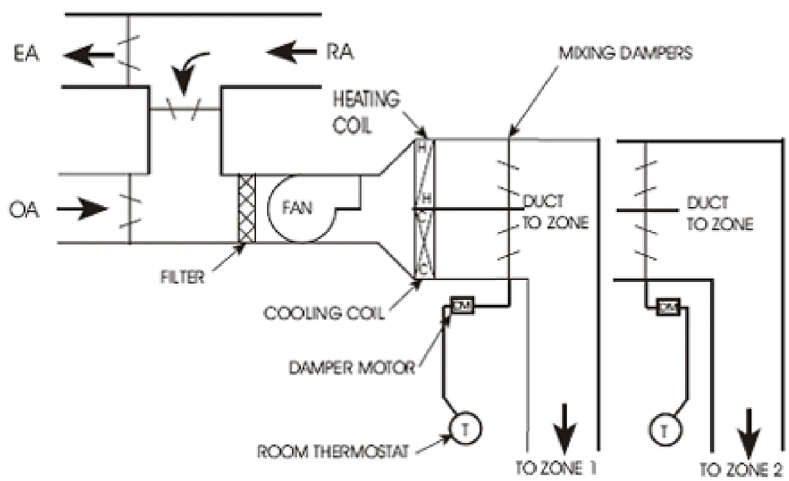


Figure 21: Multi-Zone System
(Taken from Royal Institute of British Architects, Sustainability Hub)

[18] McQuay International, "Multi-Zone Systems" *HVAC Sytems,* http://www.scribd.com/doc/19023899/Multi-Zone-Systems, (accessed 14 Oct. 2013)

2.3.1.2.3 Constant-Air Volume and Variable-Air Volume

Constant-air volume systems supply each zone with a fixed airflow rate, based on the cooling and heating loads of the zone. Air temperature can be varied in the air-handling unit to meet the sensible heating or cooling requirement of the zone. One air handling system is required for each zone because there can be only one supply air temperature at any given time.[19] Instead of varying the temperature of the supplied air, variable-air volume systems continuously adjust the volume of constant-temperature air that is supplied. By doing this, VAV systems meet the varying load conditions of each zone.

2.3.1.3 Common Systems Used in Buildings

Various active and passive HVAC systems have been designed and are commonly used to regulate building environments. In this section the following systems commonly used in buildings are discussed:

1) Under-Floor Air Distribution System
2) Dedicated Outdoor Air System
3) Chilled Beam System
4) Radiant Heating Systems
5) Radiant Cooling Systems
6) Cooling Towers

2.3.1.3.1 Under-Floor Air Distribution System (UFADS)

Under-floor air distribution systems deliver space conditioning within a building via an under-floor plenum between the structural concrete slab and the underside of a raised access floor

[19] McQuay International, "Multi-Zone Systems," *HVAC Systems*, http://www.scribd.com/doc/19023899/Multi-Zone-Systems, (accessed 14 Oct. 2013).

system. Using this under-floor space, conditioned air can be delivered at floor level through multiple diffusers, with return grilles located in the ceiling. When using an under-floor air distribution system, "the space is divided into two zones, an occupied zone extending from the floor to head level, and an unoccupied zone extending from the top of the occupied zone to the ceiling. The systems are designed to condition the lower occupied zone only; temperature conditions in the upper zone are allowed to float above normal comfort ranges, to avoid occupant discomfort, air is introduced into the space between 65°F and 68°F."[20] There are two general categories for under-floor air distribution systems: displacement ventilation systems and hybrid under-floor systems.

2.3.1.3.1.1 Displacement Ventilation System

In displacement ventilation systems, air is distributed into a space at a very low velocity (approximately fifty feet per minute). Due to this slow distribution velocity, the air released into a space is hardly felt by occupants. This system produces two distinct zones of air: cool and fresh air at the lower level and hot and stale air at higher levels. When a heat source is present in the space, the displacement effect is enhanced, as the "thermal plume created by a heat source has the effect of enhancing the airflow around the source, thereby improving overall heat removal."[21]

This system is most effective when applied to spaces that require cooling, not to spaces that require heating. In spaces with higher cooling loads, radiant cooling systems are used in combination with displacement ventilation. Recent research suggests that displacement ventilation

---

[20] Energy Design Resources, "Brief Design Underfloor Air Distribution and Access Floors," *Energy Design Resources*, 3, http://energydesignresources.com/media/1792/EDR_DesignBriefs_underfloordistro.pdf?tracked=true, (accessed 14 Oct. 2013).

[21] Energy Design Resources, "Brief Design Underfloor Air Distribution and Access Floors," *Energy Design Resources*, 3, http://energydesignresources.com/media/1792/EDR_DesignBriefs_underfloordistro.pdf?tracked=true, (accessed 14 Oct. 2013).

systems can be applied to spaces with cooling loads up to 38 Btu/hr-ft^2. Due to this limitation, radiant cooling systems are used in conjunction with this system in order to meet the demand of areas with higher cooling loads.[22]

2.3.1.3.1.2 Hybrid Under-Floor System

Hybrid under-floor systems feature a combination of a convectional mixing system and displacement ventilation. The hybrid under-floor system distributes air in the same manner as the displacement ventilation system; however, it supplies air at a higher velocity. In this system, the air is distributed through a smaller-size outlet at a velocity varying from 200 feet per minute to 400 feet per minute. While hybrid under-floor systems can lower the comfort problems "associated with an excessive temperature gradient, they usually create small subzones of excessive draft called 'clear areas' that occupants need to avoid".[23] Hybrid under-floor systems can handle higher cooling loads than displacement ventilation systems.

2.3.1.3.2 Dedicated Outdoor Air System (DOAS)

Dedicated outdoor air systems consist of two parallel systems: one that handles latent loads and another that handles sensible loads. Sensible heat is heat in an environment that is exchanged by a thermodynamic process and directly affects the temperature of the atmosphere. Latent heat is primarily associated with changes of state, specifically with phase changes of atmosphere, water vapor, and condensation. Sensible cooling loads refer to the dry bulb temperature of the building and latent cooling loads refer to the wet bulb temperature of the building. This separation of cooling loads in the DOAS system allows for the air to be conditioned efficiently.

---

[22] Energy Design Resources, "Brief Design Underfloor Air Distribution and Access Floors," *Energy Design Resources*, 3, http://energydesignresources.com/media/1792/EDR_DesignBriefs_underfloordistro.pdf?tracked=true, (accessed 14 Oct. 2013).
[23] Energy Design Resources, "Brief Design Underfloor Air Distribution and Access Floors," *Energy Design Resources*, 3, http://energydesignresources.com/media/1792/EDR_DesignBriefs_underfloordistro.pdf?tracked=true, (accessed 14 Oct. 2013).

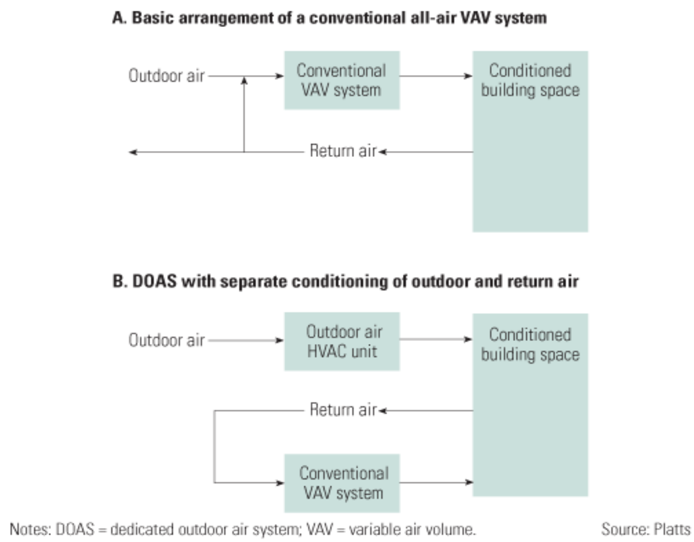


Figure 22: Comparison of VAV and DOAS Systems (Taken from Platts)

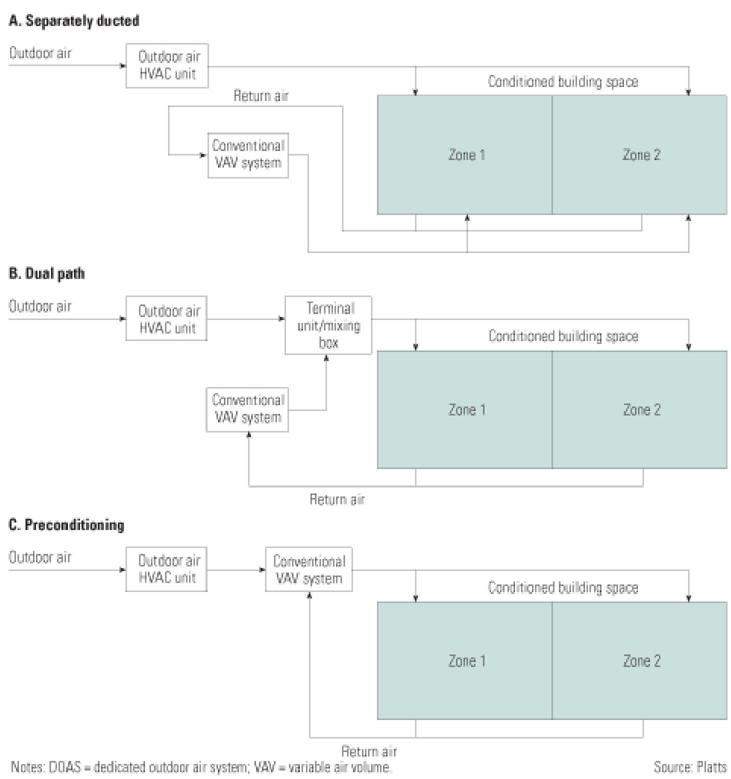


Figure 23: Configurations of Direct Outdoor Air System (Taken from Platts)

2.3.1.3.3 Chilled Beam System

Chilled beam systems cool a room by circulating interior and/or exterior air through ceiling-mounted chilled water coils and redistributing the air back into the room. Chilled beams provide a room with sensible cooling only, relying on other systems like a dedicated outdoor air system for dehumidification. A chilled beam includes a water-to-air heat exchanger, or cooling coil, which consists of rows of tubes that pass through sheets of formed fins. Chilled beam units enhance thermal and air comfort and can either be recessed or mounted to the ceiling.

There are two types of chilled beam systems: the passive chilled beam system and the active chilled beam system. Passive chilled beam systems rely on the natural buoyancy of air to operate. The hot upper layer of air surrounding the chilled beam is cooled by chilled water (typically 55°F to 63°F) circulating through the cooling coil. As a result of this process, the air is cooled and descends to floor level. Active chilled beam systems include the basic components of passive chilled beam systems in addition to an air supply designed to meet the minimum outdoor air requirements. The supply air passes through nozzles, inducing additional airflow from the conditioned space through the cooling coil and back down to the conditioned space. Due to this forced convection, active chilled beams achieve cooling densities about twice those of passive chilled beams.[24]

2.3.1.3.4 Radiant Heating Systems

Radiant heating systems involve electric heating coils or water-heated tubes positioned under the floor or in the ceiling. Radiant floor heating depends on convection to transfer heat. The advantages of using radiant heating include the reduction of dust and allergens, elimination of duct losses, and, for the hydronic systems, energy efficiency.[25] The electric radiant heating system uses zigzagging loops of resistance wire and generally serves a single room. This system is usually controlled by its own thermostat. The floor level does not need to be raised much, since the

[24]Roth, Dieckmann, Zogg, Brodrick, " Chilled Beam Cooling", *ASHRAE Journal*, 1, Sept. 2007
[25] U.S Department of Energy, "Radiant Heating," *U.S Department of Energy*, *http://energy.gov/energysaver/articles/radiant-heating*, (accessed 14 Oct. 2013

resistance wires are thin. Hydronic radiant heating systems circulate water from a water-heater through half-inch loops of polyethylene tubing. The flexible tubes can be installed in a variety of ways, like on top of the subfloor in grooved panels, clipped into aluminum strips on the underside of the floor, or embedded in placed concrete.[26]

2.3.1.3.5 Radiant Cooling Systems

Radiant cooling systems operate similarly to the radiant heating hydronic system and are installed in the same fashion. Instead of releasing heat into a space, however, chilled water is used to remove the sensible heat by radiant heat exchange.

2.3.1.3.6 Cooling Towers

A cooling tower is a heat exchanger that circulates condenser water to refrigerate or cool a space. In this processes, the condenser water absorbs heat from an air conditioning, refrigeration, or industrial process and enters the top of the tower. Due to heat exchange, as the warm water falls through the tower, fresh air is forced through it and cools it down. The cooled water then falls into a storage basin and is recirculated through the system repeatedly.[27] Through this process, a small amount of circulating water is lost due to drift and blowdown. While the amount of water lost is minimal, it still increases the amount of water consumed by the building systems.

2.3.2 Building Enclosures

Building enclosures perform several important functions. First, because the enclosure is the barrier between the exterior and interior environments, it acts as the skin of a building, allowing

---

[26] Joseph D'Agenese, "Radiant Floor Heating," *This Old House Magazine*, http://www.thisoldhouse.com/toh/article/0,,1548320,00.html (accessed 13 Oct. 2013).

[27] State Government Victoria, "Radiant Floor Heating," *Public Health Division*, http://docs.health.vic.gov.au/docs/doc/EB065358055413F3CA257ACA00137D4E/$FILE/whatisacoolingtower.pdf (accessed 13 Oct. 2013).

or preventing the free flow of air, moisture, heat, and vapor. Also, because the enclosure is incorporated into the main structure of the building, it resists and transfers wind and seismic loads. Finally, because the enclosure makes up the majority of the exterior surface area of the structure, it serves an important architectural and aesthetic role, giving the building a unique identity and personality. The best building enclosures fulfill all of these requirements in the most economic, efficient, and sustainable way.

For the past several decades, much research has been done on designing more efficient enclosures and creating high performance building enclosures. The difference between conventional and high performance building enclosures is that high performance building enclosures reduce the energy consumed by the building by creating more efficient designs and increasing overall building performance. Various areas for improvement include increasing wall and roof insulation levels, increasing glazing performance, creating more efficient ventilation systems, and taking full advantage of daylighting and natural energy. While renewable energy sources can also be included in the design, reducing the energy loads of the building is a much more practical and economical approach. Harvesting renewable energy such as solar power and wind power can be expensive and is more practical when the energy demands of the building have been significantly reduced through an efficient building enclosure design.

2.3.2.1 Controlling the Interior Environment

One of the main functions of a building enclosure is controlling the interior environment and the movement of air, moisture, and heat. Because buildings are created to provide areas for people to live and work in year round, they cannot be greatly affected by the fluctuations in weather and temperature.

Insulation plays a large role in making spaces habitable and comfortable throughout the year. Building insulation's main function is to reduce the amount of heat that is lost or gained in the building by creating a barrier that discourages heat transfer. Each type of insulation is given an R-value, which is the standard that indicates the insulator's efficiency. For example, traditional insulators like fiberglass batt have an R-value of 3.14 per inch while polyurethane has an R-value of 7.20 per inch, meaning that polyurethane is a much more efficient thermal insulator than fiberglass batt. R-values are used alongside building codes to determine the required insulation in the roof and walls of the building. Building codes are used when determining proper insulation levels because the codes reflect the local climate and environment. Since climates vary widely over different areas of the world, each location requires a specific level of insulation for its buildings. When building envelopes are composed mainly of curtain wall systems, the glass and systems used are assigned a U-value. The U-value is simply the inverse of the R-value and provides a measure of an insulator's efficiency. The lower the U-value is, the more thermally efficient it is.

Ventilation is also an important consideration when designing habitable and comfortable spaces. While a large stream of air flowing from the exterior to the interior of the building is undesirable (especially during the winter), having fresh outside air enter the building is important to maintain comfort and to remove any pollutants from the air in the interior spaces. In the past, designing for ventilation was not much of a concern because most buildings had many leaks in the enclosure that allowed air to circulate between the inside and the outside of the building. Because of recent advances in enclosure technology, it is possible to create an enclosure that is almost completely airtight and free of leaks and holes. There are several problems that arise with airtight enclosures, however. First, because the traditional way of passive air circulation is removed, new ventilation systems, whether active or passive, need to be created and included in the building to provide fresh air and to remove any pollutants or odors from the atmosphere. Without the new ventilation systems, the air within the enclosure can quickly become stale, since it has no outside air replacing it. Along the same lines, because there is no means for water vapor and moisture to leak out of the building enclosure, there can be a buildup of moisture and condensation. Condensation and moisture buildup can be a big problem because it can lead to mold and structural damage. Preventing moisture from building up requires HVAC systems that remove the moisture from the air and exhaust it to the exterior. Often times, the same systems are used to circulate air and remove moisture from the air. In order to create the best environment, these systems need to be designed in coordination with the building enclosure designers.

In addition to controlling the movement of air, moisture, and heat, building enclosures also have a great effect on daylighting in the interior environment. Depending on the type of material used, the tint of the glass, the way light is reflected, and other factors, the enclosure changes the amount of daylighting available in the space. Although the changes may seem small, productivity and mood can be greatly affected by them.

2.3.2.2 Transferring Loads

In addition to controlling the interior environment, the building enclosure also transfers loads from the exterior of the building to the building structure. These loads include gravity loads and lateral loads.

High-rise enclosure systems must be taken into account when designing the entire structure of a building. The reason for this is that the enclosure systems do not carry their own dead load, instead transferring their weight to the structural elements to which they are attached. Because the enclosure is a substantial portion of the building and has a substantial gravity load, the design of the structural system design must consider the enclosure. This can affect the size of the beams, girders, and columns along the building's perimeter, and is important when considering economic costs. When estimating the total cost of the project, not only does the cost of the enclosure materials and installation have to be calculated, but also the cost of the extra structural material necessary to support the building enclosure.

In addition to transferring their gravity loads to the building structure, building enclosures also transfer lateral wind loads. In windy regions and dense urban areas with many tall buildings, lateral wind loads can be very high. These wind loads must be transferred to the structure efficiently and without any damage to the building enclosure. In addition, enclosures must resist the pressure difference in areas with high-speed winds, such as areas that are subject to hurricanes. Pressure differences can cause parts of the enclosure to be pulled off the building and can cause damage. Every enclosure must be designed with these wind loads and pressure differences in mind.

2.3.3 Fire Protection

Fire protection and life safety play a large role in the architectural design of floor plans as well as the overall building. The fire protection and life safety designs are based on local or state fire and building codes. San Francisco and the state of California use the *International Building Code* (*IBC*) and *National Fire Protection Association (NFPA)* for their building codes and fire protection, respectively. The *IBC* codes relate to the egress codes for the building design, while *NFPA 92*, *72*, *13*, and *101* relate to the different fire protection life safety devices.

2.3.3.1 Egress Requirements

A building's design is affected by the egress requirements, addressed in Chapter 10 of the *IBC*, and the occupant loads for each area of the building. One of the most important egress requirements is the design of the exit route. The three steps in the exit route are the exit access, the exit, and the exit discharge. The exit access is the path occupants take to get from their location to the exit. The exit access dictates the aisle, corridor, and door width, as well as the maximum travel distances. The exit is the area that provides a protected path for the occupants to get from their floor or area to the exterior of the building. These can include fire-rated corridors and staircases. The exit discharge is the part of the exit route that gives the occupants direct access to the exterior of the building or an area of refuge. These three components of the exit route dictate the widths and distances from one area to another, affecting the placement and dimensions of stairways, rooms, and corridors.

For the safe and timely exit of all occupants on the floor, the occupant load must be considered. The occupant load is the factor that sets the specific widths of each part of the exit route. It also dictates the maximum travel distance from any area of the floor to the closest exit and where the stairways or exits need to be. The stairways are considered exits in high-rise buildings because the stairways (which have a two hour fire rating) give the occupants a direct exit from the building at ground level. The widths of the stairway and landings are based on the occupant load for each individual floor.

2.3.3.2 Fire Alarms and Sprinkler Systems

Every building has its own fire protection and life safety systems in place to protect the building as well as for the safety of the occupants. There are two main ways that buildings and its occupants are protected from fires. Smoke alarms and other various types of fire alarms alert the occupants about the fire while sprinkler systems suppress the fire. All building types do not need to have sprinkler systems in place, although it is a useful precautionary practice. The requirements for sprinkler design can be found in *NFPA 13*, the standard for installation of sprinkler systems. Fire alarm design requirements can be found in *NFPA 72*, the national fire alarm and signaling code. These two codes along with *NFPA 92*, the standard for smoke control systems, can affect the design of the building and mechanical spaces.

2.3.3.2.1 Fire Alarms

The most common type of fire protection systems is the fire alarm. Fire alarms can detect either smoke or heat. The smoke detectors test the air quality and, when a certain percentage of the air has smoke particles, the sensor makes the alarm go off. Heat detectors go off when the temperature in the room reaches a certain level in order to give the occupants of the space time before the room is consumed in fire. Fire alarms are usually connected to a building fire control panel that can be accessed by the fire department at a local area. Once a single alarm goes off, neighboring alarms also sound off and send alarm signals to the central fire control panel.

2.3.3.2.2 Sprinkler Systems

Sprinkler systems not only help to suppress fires for occupant safety, but also for the protection of the building from any damage. The sprinkler system is connected to the water main and, depending on the linear feet of sprinkler piping, a fire pump might need to be added to the system to provide the correct amount of pressure in the system. Depending on the combustibility of the materials in the space as well as the value of the space, there are different sprinkler systems that can be selected. In highly sensitive areas, dry sprinkler systems are generally used. This system does not hold water in the pipes until an individual sprinkler head is activated and releases water to the whole system. In normal areas, wet sprinkler piping is generally used. This system has water in the piping at all times and is ready to suppress the fire when the sprinkler heads are activated.

2.3.3.3 High-Rise Fire Protection Design

Fire protection systems in high-rise buildings are very collaborative. The fire alarm and the sprinkler systems are both connected to a main fire command center at the main floor of the building. The fire command center allows for the firefighters to communicate with the occupants of the fire floor as well as safely have the occupants of the existing floors exit the building. Stairways are the major egress path for occupants of a high-rise building. Smoke control in these areas is essential for the safety of the occupants and therefore the stairwells are pressurized. This provides a positive pressure in the stairwells and keeps the smoke from entering the space from the fire floor. To provide enough water pressure to all floors of a high-rise building, a fire pump must be connected to the system. The pump is located at the connection point from the water main to the building sprinkler system. These are important aspects of high-rise fire protection design and keep the occupants of the building safe from any fire in the building.

3.0 Methodology

In order to create the most innovative and sustainable high performance building possible, the team worked on the project in three design phases. In the first phase, the team analyzed the architectural, structural, and mechanical elements of the existing building. In the second phase, the team used the information in the previous step to develop design criteria for the three design components: architectural design, structural design, and mechanical design. Lastly, in the third phase, the team compared different alternatives based on the criteria developed in Phase II and chose specific systems for the building that were developed in detail. The team's approach for meeting the goals of this project was to develop multiple systems that were compared to the existing building system and each another. The basis for the comparison was the minimum requirements for optimal building performance in each area.

During B-Term, the team analyzed different alternatives in order to find the best systems that meet the architectural, structural, and mechanical requirements. For the architectural design, various building designs were modeled and various floor plans were created in order to design an attractive building with an efficient use of space. For the structural design, different structural materials such as steel and concrete were analyzed in order to find the material that met all of the structural requirements of the building in the most cost-effective way. In addition, earthquake resistance strategies including different trusses, liquid tuned dampers, oil dampers, and shock absorbing technologies were investigated. For the mechanical design, different HVAC systems and façade systems were analyzed in order to find a design that conditioned the space in an energy-efficient and cost-effective way. Once all of these various designs and components were created and analyzed, the team selected the most appropriate options and developed them during C-Term.

During C-Term, all of the options that had been selected in B-term were analyzed in detail and modeled in various software programs. Once the basic architectural design of the building was selected, the building was modeled in Revit Architecture with various levels of detail. After the design of the building was finalized and concrete was chosen as the main structural material, the structural design and analysis was done using STAAD. At the same time, the various calculations for the HVAC and fire protection systems were being completed and the systems were drawn in AutoCAD. Several other programs, including Visual Lighting, were used for other aspects of the design. At the end of C-Term, all of the designs of the final project building were finalized and compiled. Topics that were evaluated in B-Term and C-Term can be found in Appendix C.

During D-Term, final edits to the report and Revit model were made. Several presentations were created and given for Project Presentation Day and for the Architectural Engineering department. The poster created for Project Presentation Day can be found in Appendix O.

3.1 Architectural Design

The architectural design of a building is important because it sets the precedent for the rest of the system designs by determining the size, shape, and configuration of the building and its spaces. The architectural design of the 350 Mission office building and its floor plans was guided by two factors: the guidelines for the competition and the most effective use of space. The competition allowed modifications to the architecture, façade, and floor plans, but the gross square footage had to be maintained. In addition, the most effective use of space on the site was a factor that greatly affected the architectural design of the building. With these two factors in mind, the team created the overall building design, the office floor plan, and the lobby design in three separate phases.

3.1.1 Overall Building Architecture

The first major architectural decision that was made was the general shape and design of the new building. In order to make this decision, three phases of design were developed and followed. In the first phase of the architectural design of the building, the team reviewed the various features of the existing building design. Features that were reviewed include the height of the building, the number of floors, and the configuration of the core interior. In the second phase, two different building shapes were designed and modeled in Revit. Although these two designs have the same general features, the shape and geometry of the buildings varied drastically. Finally, in the third phase, one of the two building designs was selected and detailed.

3.1.1.1 Phase I – Review of Existing Design

The existing design of the 350 Mission consists of a thirty-story building that is around 414' tall and has a rectangular footprint. The upper floors of the building (Floors 5-30) are 122'10" by 130'4" while the lower floors (Garage and Lobby levels) are around 137' by 137'. One major design feature of the building is a cantilevered floor that runs from the lowest level of the basement to the roof. The cantilever was created by removing the column at the south corner of the building. The reason the column was removed is that the designers of the building wanted to create a large entryway into the lobby space of the building. Because that corner of the building is located on the intersection of Fremont Street and Mission Street and is right across from the future Transbay Transit Center, it will experience heavy pedestrian traffic. In order to make the building more attractive to pedestrians and possible tenants, the owner of the building wanted to create the most inviting entry possible. The existing design of the building is shown in Figure 24.

Figure 24: Existing Architectural Design
(Taken from Kilroy Realty Corporation)

3.1.1.2 Phase II – Design Criteria and New Layouts

The competition required that the new building design had to be able to contain the same number of occupants as the existing design. Because of this requirement, the team decided that there would not be any drastic changes to some features of the existing building such as the building height and number of floors. Instead of focusing on those features, the team chose instead to focus on criteria that would improve the overall environment inside of the building. The criteria are listed below.

Important Design Criteria:

1) Increased area per floor
2) Increased views around office floor
3) Similar building height and floor to existing design

The team created two different building designs based on the criteria above. The first building is thirty stories, like the existing design, but with a 136' by 136' square footprint. Unlike the existing design, the square dimensions of the building continue from the basement all the way to the top of the building. The reason for keeping the dimensions consistent was to increase the total square footage of each office floor, which increases potential revenue for the owner of the building by giving the owner more rentable space. Starting after the fifth story of the building, each floor was designed to rotate counterclockwise by 1.7 degrees, resulting in a 45-degree rotation at the top floor of the building. This rotation not only gives the building a unique architectural feature for the area, but also gives each floor a different view of the city. In addition, the team changed the core from a rectangular core to a circular one, believing that a circular core would resist lateral loads better than a rectangular one.

The second design that the team created was a thirty-story octagonal building with a circular core and with four sides 70' in length and the other four 46'8" in length. Although this building design has less square footage than the first option because it lacks the original four corners of the square, it still has a greater area per floor than the existing design. Like the first option, the increase in square footage means more rentable space and higher income for the owner. In addition to increased area, the octagonal shape of the building increases the view of the surrounding city from four major angles to eight, doubling the workers' views to the exterior. The two building design options are shown in Figure 25.

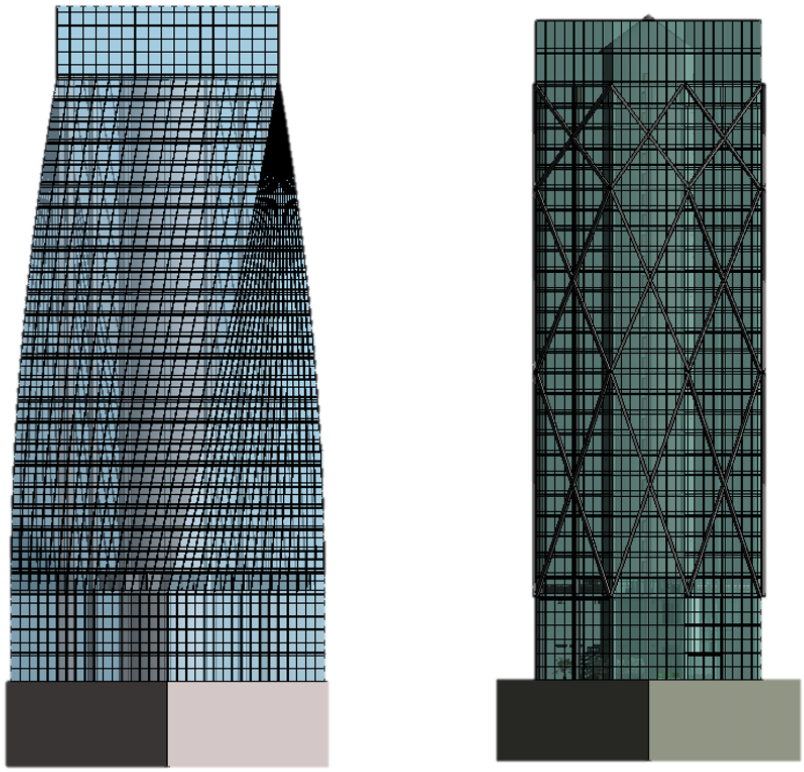


Figure 25: Building Design Options

3.1.1.3 Phase III – Comparing and Choosing the Final Design

Although the two architectural design options both have the same footprint on the site, each floor of the first option with the 45 degree rotation has 2,000 square feet more than each floor of the second option. In addition, the first option is more of a challenge structurally and has a more unique and interesting geometry, especially for a concrete building. Because of these two advantages over the octagonal building, the rotating building was originally selected. Structural, mechanical, and architectural designs were developed for approximately a month before the team realized that, because of the rotation, the building would not fit in the building site. Because the first building did not fit in the site, the second option was selected. Even though the octagonal building was the second choice, it still has several architectural advantages over the existing design of 350 Mission.

3.1.2 Office Floor Plan

Because 350 Mission is located in one of the business districts of San Francisco, the building is designated for use by a technology firm, a law firm, or a financial firm. For the competition, the team was required to design the office layout for one of these firms. In the first phase of the architectural design, the team decided to design a financial office layout and reviewed the existing financial office layout to determine how the space was being used. Second, the team developed criteria for the main necessities of the space, including the number of offices, desks, and conference rooms. Finally, several designs for the office were created and one was selected according to the previously developed criteria.

3.1.2.1 Phase I – Review of Existing Design

The existing office layout of 350 Mission consists of offices and conference rooms lining three of the four sides of the office floor with individual desks and workspaces occupying the fourth side and the center of the floor. There are bathrooms located on the northeast side of the core, and the mechanical room is located between the bathrooms and the façade. The existing office layout is shown in Figure 26.

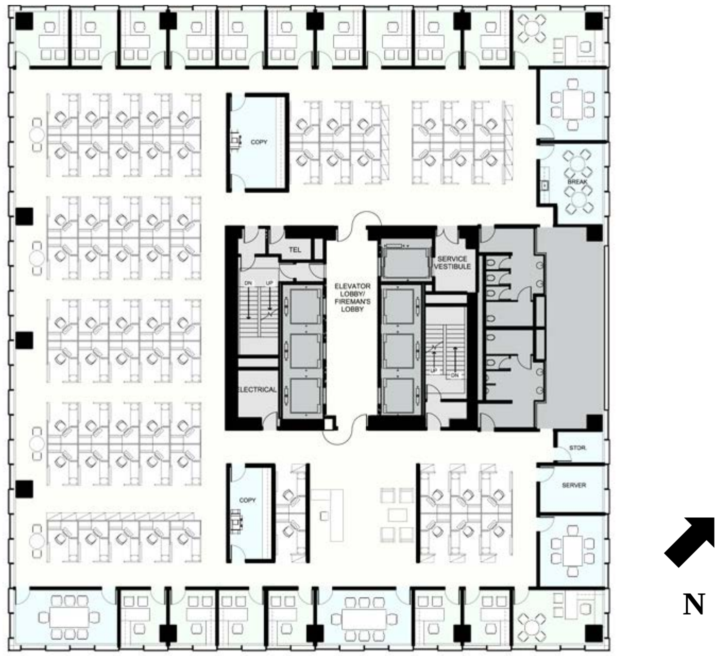


Figure 26: Existing Office Layout
(Taken from Kilroy Realty Corporation)

With the current design, about 11,900 square feet of the floor is dedicated to office workspace and about 4,100 square feet is dedicated to the bathrooms, service areas, and core. There are sixty-five workspaces that are grouped together on the southwest side of the building, with several more scattered throughout the floor. In addition, there are eighteen offices: sixteen small offices and two large executive offices. Four conference rooms are placed throughout the space, with three on the southeast side and one on the northeast side. The layout has seven elevators (six for normal use and one for service and firemen) and two stairs on opposite sides of the core. There are various smaller rooms throughout the office for servers, copying, and supplies.

3.1.2.2 Phase II – Design Criteria and New Layouts

The competition guidelines for the architectural design of the space were minimal. The main requirement was that none of the functions and capacities of the existing design were to be reduced or limited. Since sustainability and energy efficiency were key themes for this project, these aspects played a role in the design of the office layouts. Factors like daylighting in the office spaces also contributed to the overall design of the office layouts. With these in mind, the team developed criteria that also incorporate the competition guidelines and the most effective use of space.

Important Design Criteria:

1) 65 workspaces and 18 offices
2) 4 conference rooms
3) 7 elevators (6 normal and 1 service)
4) Maximized daylighting
5) Optimized for a circular core
6) More rentable space

Using these criteria, a couple of designs were developed for the rotating building design and the octagonal building design. The first major difference between the new layouts and the existing is that, in the new designs, there is a circular core instead of a rectangular one. Because the team made the core circular, it was no longer efficient to use a layout similar to the existing building. In order to maximize space, as well as daylighting, the majority of offices and conference rooms were moved from the perimeter of the space to the center, encircling the core. Not only did this remove the majority of barriers preventing daylight from entering the space, but it also maximized the area for other workspaces along the perimeter. Another major change was that the restrooms and mechanical room were moved to the interior of the core. This change prevented these rooms from occupying any space that could have been used for workspaces and offices, and also made the restrooms much more accessible to workers throughout the floor. In addition to these changes, the elevator lobby was positioned diagonally along the building in order to make the space seem larger and more open when entering the office. The two new layouts are shown in Figure 27 below.

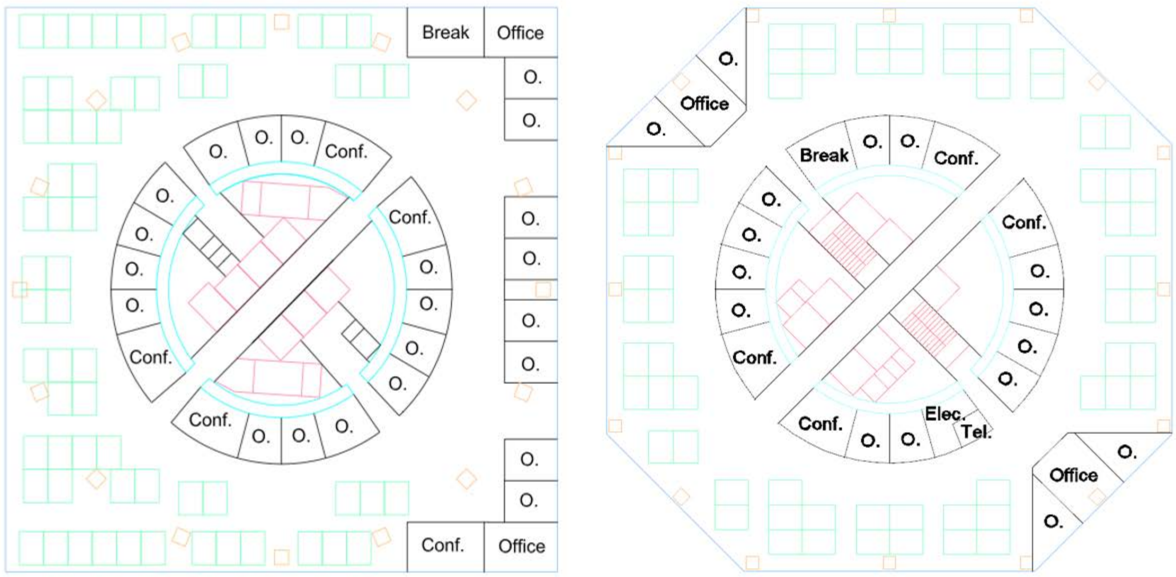


Figure 27: Office Layout Options

3.1.2.3 Phase III – Comparing and Choosing the Final Design

Besides the geometry of the floor plate, the main difference between the two proposed layouts is the number of offices and conference rooms. The square layout contains six more offices and one more conference room than the octagonal layout. The principle reason for this difference is that the octagonal layout has around 2,000 less square feet than the square design. Also, in the square office layout, all of the rooms that are not surrounding the circular core are located on the northeast side of the floor. In the octagonal layout, it was not possible to isolate all of the offices on one side because the space would have become too cramped. Instead, three offices are located at the east and west edges of the space. The choice of the final design, however, did not rely on these differences. Because the rectangular building did not fit on the project site, the rectangular floor plans were no longer an option and the octagonal layout was chosen to be the office layout.

3.1.3 Lobby Design

350 Mission is located in an area with a high density of pedestrians from the nearby Transbay Transit Center and Market Street. The owner wanted the lobby to serve as a public assembly space to attract people walking by the building. In the first phase of the lobby design, the team examined all of the features and amenities of the lobby in the existing building. In the second phase, the team created criteria for the requirements and amenities of the lobby. Because the lobby was not designed until after the building design was determined, the team designed the lobby for the octagonal building.

3.1.3.1 Phase I – Review of Existing Design

Based on the owner's desire to have the lobby serve as a public space, the lobby of the existing design of 350 Mission has many features and amenities that appeal to the public. The lobby consists of a fifty-four foot atrium with two levels. The first level of the space contains two retail spaces: the first being a bistro and coffee bar and the second being a small store. In addition to the retail spaces, there is also seating inside the bistro and scattered throughout the first floor of the lobby.

Figure 28: First Lobby Level of Existing Design
(Taken from Kilroy Realty Corporation)

The second level of the lobby consists of a small assembly and waiting area and a large restaurant. Running along the staircase going from the first level to the second level is more seating that is open to the general public.

Figure 29: Second Lobby Level of Existing Design
(Taken from Kilroy Realty Corporation)

In addition to the spaces for the general public, there is a giant media wall that occupies the majority of the core wall. The media wall serves as a stunning centerpiece of the lobby and can also be utilized to display public art. All of the features of the two levels of the lobby are clearly designed to be appealing to pedestrians walking near 350 Mission.

3.1.3.2 Phase II – Design Criteria and New Layout

Because it was so important for the owner to attract the public, having amenities and retail space was one of the most important of all the design criteria. Also, according to the San Francisco building code, every building like 350 Mission is required to dedicate space to display public art. Like other aspects of this project, environmental friendliness was a key aspect of the design of the lobby spaces. Because of this, sustainability and indoor environmental quality were important criteria. Another important criterion was the maximization of usable space on the site. In every aspect of the architectural design of the project, the team tried to increase the amount of usable and rentable space.

Important Design Criteria:

1) Public access and ease of use
2) Environmental friendliness
3) Increasing usable space
4) Public art space

A new design of the lobby was created in order to meet all of the criteria outlined above. Because the team wanted to maximize the usable space in the lobby, a third level was added above the second level. The reason it was placed above the second level was so that there could be more space without taking away any area from the atrium. In order to meet the owner's request, the two retail spaces from the existing building were enlarged and even more seating was placed throughout the different levels of the lobby, with seating located outside the café and along the assembly area of the second level. In order to meet San Francisco's requirement for public art, a large public art space was added to the second level where the restaurant was located in the original design. Finally, a dedicated restaurant space was added to the new third level of the lobby to continue to attract pedestrians and passersby.

In order to meet the team's goal for environmental friendliness, the media wall from the existing design was replaced with a large green wall stretching from the base of the core wall to the top of the atrium. The green wall accents the core wall and serves as the focal point of the space, with all of the floors and levels flowing around it. The green wall, along with trees and planters placed throughout the lobby, functions to turn the lobby of 350 Mission into an urban oasis where office workers and pedestrians can stop, rest, and relax. Figure 30 shows the design of the three levels of the lobby.

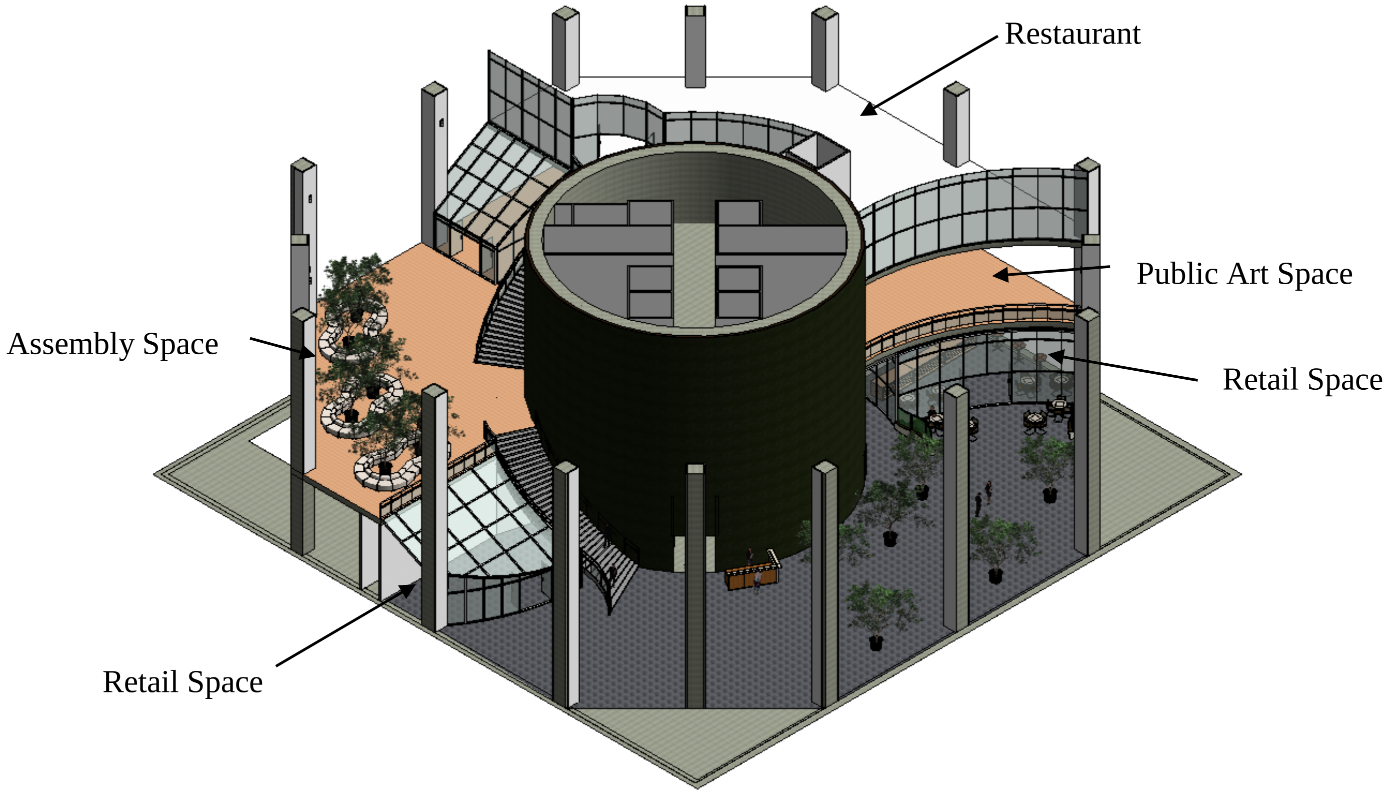


Figure 30: New Lobby Design

3.1.3.3 Phase III – Final Design

The lobby was designed after the octagonal building was selected to be the project building. Because of this timing, the lobby presented in this section was the only lobby design created.

3.2 Structural Design

The structural design of a system must integrate all of the building's architectural features while also providing the required strength and serviceability at an optimal cost. Strength design includes sustaining applied loads such as dead, live, wind, and seismic, whereas serviceability design includes human comfort, deflections, and story drift. Both aspects of design were considered in this building.

The structural challenge of this competition was to design innovative systems that could integrate and function with other building systems. In order to achieve this, the team first used Skidmore Owens & Merrill's existing structural design as a baseline for the new design. Once the strength and serviceability of their system were carefully studied and analyzed, the team began to develop new ideas and goals for the new design.

The structural design of the new system was guided by the design criteria for the competition, as well as by the team's goals. The building was required to be structurally sustainable, not only mechanically and functionally sustainable. Because building materials produce more carbon emissions than the other parts of the building, materials with low carbon emissions were chosen. This lowered the building's carbon footprint over its entire life cycle. The constraints on seismic performance were a major structural requirement that also affected the overall design of the building. In Phase I, the analysis of the existing structural design for the two most prominent high-rise building loads, wind load and seismic story drift, was completed. In Phase II, the criteria for the new design were compiled based on the results from Phase I and the design and sustainability requirements. In Phase III, the team tested the designs based on the two architectural models and chose a new design that was in line with the design criteria.

3.2.1 Phase I – Structural Analysis of the Current Design

During the first phase of the structural design, the team used two different methods to analyze the existing structure. First, the design loads, including the dead, live, wind, and seismic loads, necessary for the analysis and design of structural elements and the assessment of structural systems were calculated. Then, the total applied loads on the whole building for each specific load were hand-calculated. Next, the team used STAAD Pro V8.i to continue the structural analysis. The team created a model, compared hand-calculated load results with the results from the STAAD model, and obtained new structural data.

The team referenced *ASCE 7-10* to help hand-calculate the design loads on the existing structure. The loads were broken down into four different categories—dead, live, wind, and seismic—as shown in Table 5 below. The heaviest load is the dead load, which includes the total weight from all of the design materials. The live load was the next load calculated and consists of the variable loads acting on the building. Both the dead and a minimum of twenty-five percent of the floor live load contribute to the overall mass of the building and also respond to the applied wind and seismic forces.[28] The two most prominent loads for the high-rise are the wind load and the seismic load. The reason the wind load is one of the more prominent loads on the building is that the force exerted by the wind on a building increases with higher elevations. Because the building is more than 400' tall, the building's movement is controlled by the wind. Also, because the building is located in a highly active seismic zone, the base shear of the building and the lateral forces from each floor level were considered. Below is a quick summary of the calculated results, with the full results included in Appendix D.

[28] Minimum Design Loads for Buildings and Other Structures *ASCE* Standard/ *SEI 7-10*. Chapter 12.7.2 Effective Seismic Weight.

Table 5: Loads on Existing Building

Element	**Calculation Result**
Dead Load Weight	1.04×10^{8} lbs.
Live Load	3.9×10^{7} lbs.
Wind Pressure (Max)	22 psf
Base Shear	1.01×10^{8} lbs.
Seismic Lateral Force Distribution	1.31×10^{7} lbs.

3.2.1.1 Creating the STAAD Model

After completing the hand-calculations, the team built a model of the existing building in STAAD.

There are seven steps to creating a STAAD model:

1) Sketch the model design, as shown in the figure below. Divide each floor plan into four-node plates or slabs. Plates are connected to one another at their corners by nodes or joints. Only certain nodes will have columns. The figure below outlines how a sample floor plan was split up. The light blue boxes represent plates, the orange squares represent columns, and the white box represents the core.

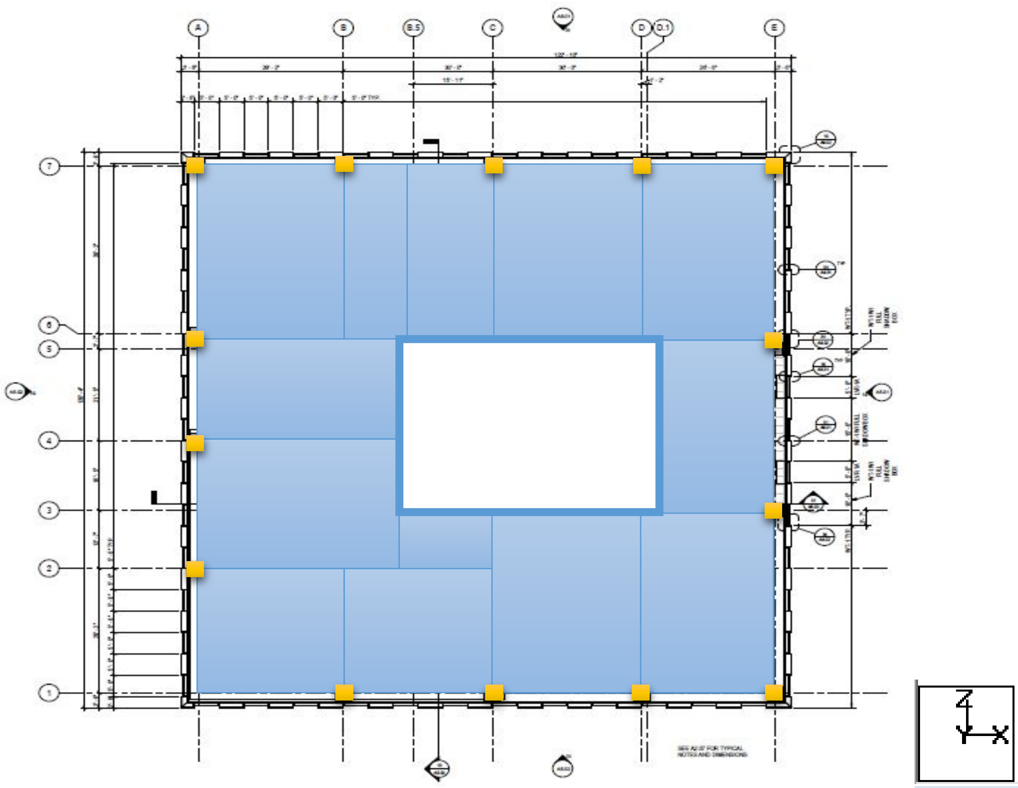


Figure 31: STAAD Model Layout

2) When a basic layer of a floor plan is complete, translate it to the remaining corresponding floors.
3) View a cut section of the building and connect two floors to form the core walls and columns.
4) Define element properties such as plate thickness, column thickness, and material properties.
5) Apply desired loads to design. The dead load and live load were applied uniformly throughout the building. Since the wind load is not a uniform distribution of forces across the exterior of the building envelope, the wind load was separated into three different sections: the bottom section, the middle section, and the top section. Each section has an east-west wind in the X direction and a north-south wind in the Z direction. The seismic

loads were applied according to the *IBC 2009* earthquake definition simulation, which is already programmed within STAAD. Table 6 below shows the different loads acting on the existing structure.

Table 6: Loads Acting on Existing Building

Load	Direction	Force
Dead	Y	-1
Live	Y	-80 lb./ft.^{2}
Wind	X (30th floor)	22 psf.
Wind	Z (30th floor)	22 psf.
Wind	X (18th floor)	18 psf.
Wind	Z (18th floor)	18 psf.
Wind	X (5th floor)	11 psf.
Wind	Z (5th floor)	11 psf.
Seismic	Y	*IBC 2009*

6) Include print results of forces, reactions, deflections, and story drift.

7) Run analysis.

3.2.1.2 Analyzing Existing Design

After the first STAAD simulation, the team compared the computed results with the hand-calculations to make sure that the model was in the correct range of loads. After close results were obtained, several simulations were run to understand more about the response of the existing structure, including axial forces, stress, strain, moment, bending, torsion, and deflection. Both deflection and story drift were major factors in the design challenge. Table 7 below shows the maximum allowable deflection referenced by *ACI-08*. According to *ASCE 7-10*, the building's maximum allowable story drift is 0.10*(story height).[29] The most restrictive values provided by *ACI-08* or *ASCE 7-10* governed the structural design.

[29] Minimum Design Loads for Buildings and Other Structures *ASCE* Standard/ *SEI 7-10*. Maximum Allowable Story Drift.

Table 7: Maximum Displacement According to ACI-08

Element	**Deflection**
Floors not supporting or attached to nonstructural elements likely to be damaged by large deflection	4.5 in
Roof or floor construction supporting or attached to nonstructural elements likely to be damaged by large deflection	3.4 in

In STAAD, the "X" and "Z" directions are the lateral deflections moving right to left and front to back respectively. The "Y" direction is the vertical deflection of the building. Table 8 below shows the building's maximum displacement in the three different directions in response to each applied load. The greatest vertical deflection is located at the top of the structure, near the cantilevered beam. Since the post-tensioning of the slab was not included in the STAAD model, the deflection results are slightly higher than in reality.

Table 8: Maximum Displacement of SOM Design Simulated by STAAD

Load	**X (in)**	**Y (in)**	**Z (in)**
Dead	2.3	-7.88	-2.0
Live	1.3	-6.8	-1.1
Wind	0.011	-0.0015	-0.013

Table 9 below shows the maximum seismic inter-story drift according to *ASCE 7-10*. These values are crucial and governed the seismic design because they ensure life safety and building serviceability. The final results can be found in Appendix E.

Table 9: Maximum Seismic Inter-story Drift

Level	**Height (ft.)**	**in**	**ft.-in**	**Factor**	**Max drift (in)**	**1/2 Drift (in)**
B4	7.67	12.00	92.04	0.01	0.92	0.46
B3-B1	10.00	12.00	120.00	0.01	1.20	0.60
B1-L1	14.33	12.00	171.96	0.01	1.72	0.86
L1-L2	18.00	12.00	216.00	0.01	2.16	1.08
L2-5	36.00	12.00	432.00	0.01	4.32	2.16
5-30	13.17	12.00	158.00	0.01	1.58	0.79

The models created in STAAD are shown in the figure below.

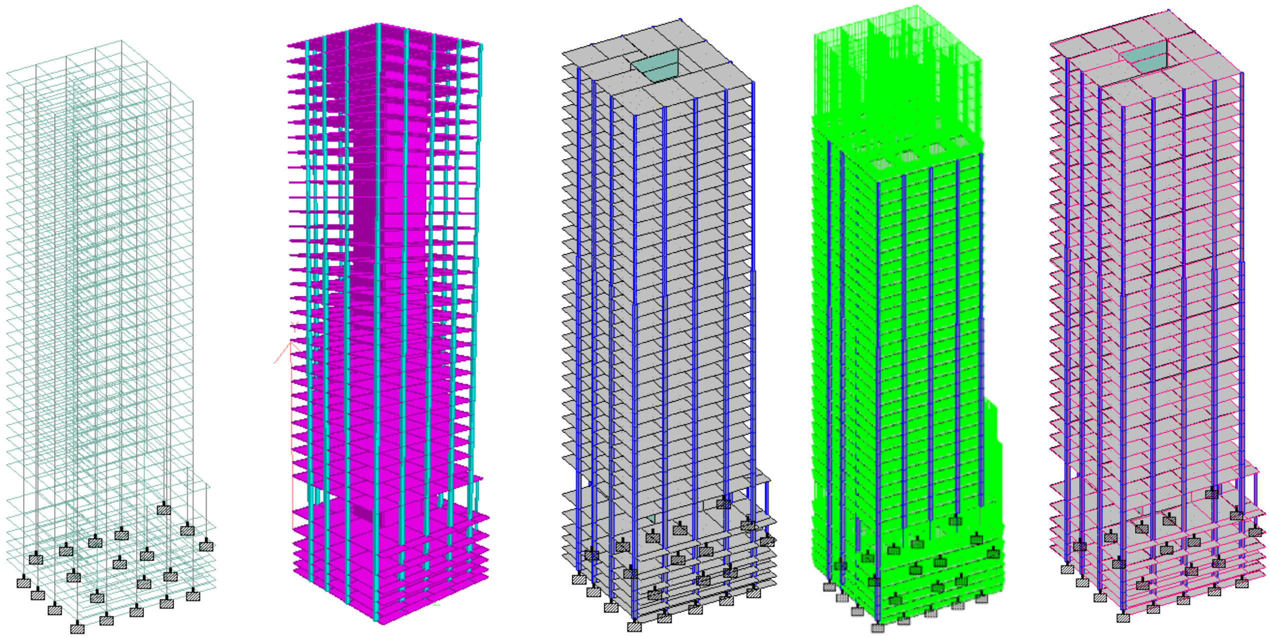


Figure 32: STAAD Models

3.2.2 Phase II – Structural Design Criteria

One of the competition goals challenged the team to design a building with half the code-allowed story drift. According to *ASCE 7-10*, the story drift is governed by the height of the story. This code requirement was set forth to serve as a measure to protect the owner, tenants, employees, building, structure, equipment, etc. Story drift accounted for some of the expected movement of the structure relative to each story, and heavily governed the lateral force resisting system design.

Safety was a very important factor in the new design because safety had to be guaranteed to all occupants of the building. The structure needs to be able to sustain itself at the very least until all occupants inside safely evacuate the building. Imposing a stringent story drift limit, limiting the inelastic deformations of both the structural and non-structural components, and minimizing the damages to the building allow for a quicker post-occupancy recovery time.

Lastly, cost was considered. Although the design cost was not one of the main driving forces of the team's design, the team still wanted to present the most cost-effective solution to the owner. This cost is not only a one-time cost for the structure, but also the cost of the building life cycle, which includes the maintenance and repair over the building's useful life. By reducing the allowable story drift, the building design is more elastic and can resist earthquakes better by controlling the inelastic deformation and impact on non-structural systems. The safety design may cost the owner extra money at first, but the owner will not have to do constant repairs and maintenance, which can both skyrocket if not considered during the design phase.

Important Design Criteria:

1) Half the allowable story drift
2) Safety (occupants, structural elements, and non-structural elements)
3) Increased post-occupancy time
4) Reduced earthquake damage/maintenance costs

Several options were considered when creating the structural system design. The first decision that was made was which material (steel or concrete) to use to construct the building. Concrete has more compressive strength than tensile strength and, per ton, produces less carbon emissions than steel. Steel, on the other hand, has more tensile strength and has other benefits that concrete does not. The table below shows the carbon emissions of building materials commonly used in construction.

Table 10: Carbon Emission of Materials
(Taken from Building Construction)

Material	Total Process Emissions (tons CE/ton of product)[1/2/]	Total Process Emissions Including Carbon Storage Within Material (tons CE/ton)[3/]
Framing lumber	0.033	-0.457
Concrete	0.034*	0.034
Concrete block	0.038*	0.038
Medium density fiberboard (virgin fiber)	0.088	-0.402
Brick	0.088	0.088
Glass	0.154	0.154
Recycled steel (100% from scrap)	0.220	0.220
Cement (Portland, masonry)	0.265	0.265
Recycled aluminum (100% recycled content)	0.309	0.309
Steel (virgin)	0.694	0.694
Molded Plastic	2.502	1.500
Aluminum (virgin)	4.529	4.529

Another decision that had to be made was the type of foundation system for the building. There were four different methods that were considered: the current method proposed by SOM and three different alternatives. The three alternatives considered for this design were two damping systems, liquid tuned dampers and oil dampers, as well as possible changes of the building's structural design. Other foundation solutions include the loads traveling to piles, caissons, pedestals, or footings to exert a concentrated pressure in the soil. Since, the soil is already soft, it will not be able to sustain the applied loads.

Other decisions that had to be made include the orientation of the columns, the number of floors, the post-tensioning of the slabs, and the shape of the shear wall.

3.2.3 Phase III – Structural Analysis of New Design

A new design for the whole structural system was created in order to meet all the criteria listed above. The building is an octagonal concrete high-rise with a circular core and an earthquake mat. The design of the fifty-four foot tall lobby was a challenge because it did not comply with the allowable story drift, which is solely dependent on story height. To reduce the story drift, another level in the lobby was introduced between the second floor lobby and the fifth floor office.

3.3 Mechanical Design

The mechanical systems of a building create a comfortable interior environment within the building and provide its occupants with life-safety systems. To achieve these key targets, the new mechanical system design includes heating, ventilation, and air conditioning (HVAC) design integrated with a high performance façade in order to promote indoor air quality and thermal comfort. It also includes fire protection design in order to promote occupant safety.

The mechanical design was guided by the design criteria for the competition as well as the team's goals. This section features three main mechanical system designs: HVAC design, façade design, and fire protection system design. These systems were designed in three phases. In the first phase, the existing mechanical systems were analyzed. In the second phase, the design criteria for the new systems were created and different options were investigated. Lastly, in the third phase, the new mechanical designs were selected and then developed in detail.

3.3.1 HVAC System Design

The team sought to design a heating, ventilation, and air conditioning system (HVAC) that would handle the heating and cooling loads for the building in an energy efficient manner and allow for increased individual occupant control. To achieve this goal, the performance of the existing HVAC system in 350 Mission was analyzed and other options were researched and reviewed.

3.3.1.1 Phase I – Review of Existing HVAC Systems

In SOM's HVAC design for 350 Mission, an under-floor air distribution system (UFAD) with one hundred percent intake air is used. This ventilation technology delivers space conditioning to the building via an under-floor plenum between the structural concrete slab and the underside of a raised access floor system. Through this under-floor space, conditioned air can be delivered to the floor level through multiple diffusers with return grilles located in the ceiling. When using an under-floor air distribution system, "the space is divided into two zones, an occupied zone extending from the floor to head level, and an unoccupied zone extending from the top of the occupied zone to the ceiling. The systems are designed to condition the lower occupied zone only; temperature conditions in the upper zone are allowed to float above normal comfort ranges and, to avoid occupant discomfort, air is introduced into the space between 65°F and 68°F."[30] In order to analyze the system, the office was divided into different zones (red zone, green, purple, and orange) and alphabetically labeled. The red area represents the corner zones. The purple area represents the copy rooms, a zone that generates a lot of heat. The orange area represents interior zones. The green zone represents both central and interior zones.

---

[30] Energy Design Resources, "Brief Design Underfloor Air Distribution and Access Floors," *Energy Design Resources*, 3, http://energydesignresources.com/media/1792/EDR_DesignBriefs_underfloordistro.pdf?tracked=true, (accessed 14 Oct. 2013).

Figure 33: Mechanical Zones

In order to analyze the existing floor plan, the team created an Excel sheet to calculate the heat gain in the existing building. The sheet included recorded weather data for different latitudes, data for the glass solar heat gain factor (SHGF), the cooling load factor (CLF) of the exterior glass for different orientations, data for the cooling load temperature difference (CLTD) for the different wall thicknesses and orientation, and data on the weather for the different peak month and hour. Using the architectural layouts, the team calculated the room, wall, and spandrel area for the rooms with exterior walls. In addition, the orientation, solar coefficient U-value, and a wall group type (where ‘A’ is the thickest wall type like a brick face masonary wall and ‘G’ is the thinnest wall type like a glass façade) were assigned for each room.

To calculate the heat gain from the building envelope, the team used the formulas:

Heat Gain through Exterior

$Q = U \times A \times CLTD_C$

Where,

Q= cooling load for roof, wall, or glass, BTU/hr

U =overall heat transfer coefficient for roof, wall, or glass, BTU/hr-ft^2-F

A =area of roof, wall, or glass, ft^2

CLTDc =corrected cooling load temperature difference, F

Solar Radiation through Glass

Q= SHGF x A x SC x CLF

Where,

Q = solar radiation cooling load for glass. BTU/hr

SHGF = maximum solar heat gain factor, BTU/hr-ft^2

A =area of glass, ft^2

SC = shading coefficient

CLF = cooling load factor for glass

The total heat gain for the entire floor was then tallied from the heat gains from each individual space. Then, the largest heat gain for the floor was calculated by adjusting the information for the peak month and peak hour.

3.3.1.1.1 Internal Heat Gain Calculation

All heat gain calculations were based on the formulas presented in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

3.3.1.1.1.1 People

To calculate the number of occupants per floor, the total number of rooms and work stations was multiplied by a factor of 1.5 to compensate for visiting persons in addition to the person assigned to the office space. Using the formula below, the sensible and latent heat gain was calculated.

$Q_s = q_s * n * CLF$

$Q_t = q_t * n$

$Total\ Q = Q_s + Q_t$

Where,

Q_s, Q_t = *sensible and latent heat gains loads*

Q_s, q_t = *sensible and latent heat gains per person*

n = number of people

CLF = cooling load factor for people

3.3.1.1.1.2 Lighting

To calculate the lighting loads, the team used a power desity of 3.0 W/ft^2. Using the formula below, the cooling load from lighting was determined.

$Q = 3.4 * (3.0 * A) * BF * CLF$

Where,

Q= cooling load from lighting, BTU/hr

A= room area

BF= ballast factor (1.25 for florouscent lights)

CLF = cooling load factor lighting (1.0)

3.3.1.1.1.3 Equipment

To calulate the equipment loads the team used the rated power (in watts) from the table below.

Table 11: Equipment Loads

Equipment	Recommended Rate of Heat Gain (Btu/Hr)
Desktop Computer	800
Printer (line, high-speed)	1000
Large Copier	1000

3.3.1.1.1.4 Heat Loss Due to Ventilation/Inflitration

To calculate the heat loss due to infiltration and ventilation for the floor, the team used the formula:

*V= ACH * A * (H/60)*

Where,

V = Ventilation of air in CFM

ACH = Air change per hour

A= Area of room

H= Height of room

3.1.1.1.2 Existing Typical Floor Performance

In the analysis of the existing building, the team used the standard U-value of 0.20 for the existing windows and walls, with a shading coefficient of 0.81. The analysis used an assumed glass height of two-thirds the overall wall height. Based on the existing floor plan, approximately 125 persons were estimated to occupy a typical floor. The analysis was perfomed for the month of September at 3pm, the hottest month of the year at the hottest time of the day, in San Francisio, CA. Using the previously mentioned methods of calculation, the following graphs were generated.

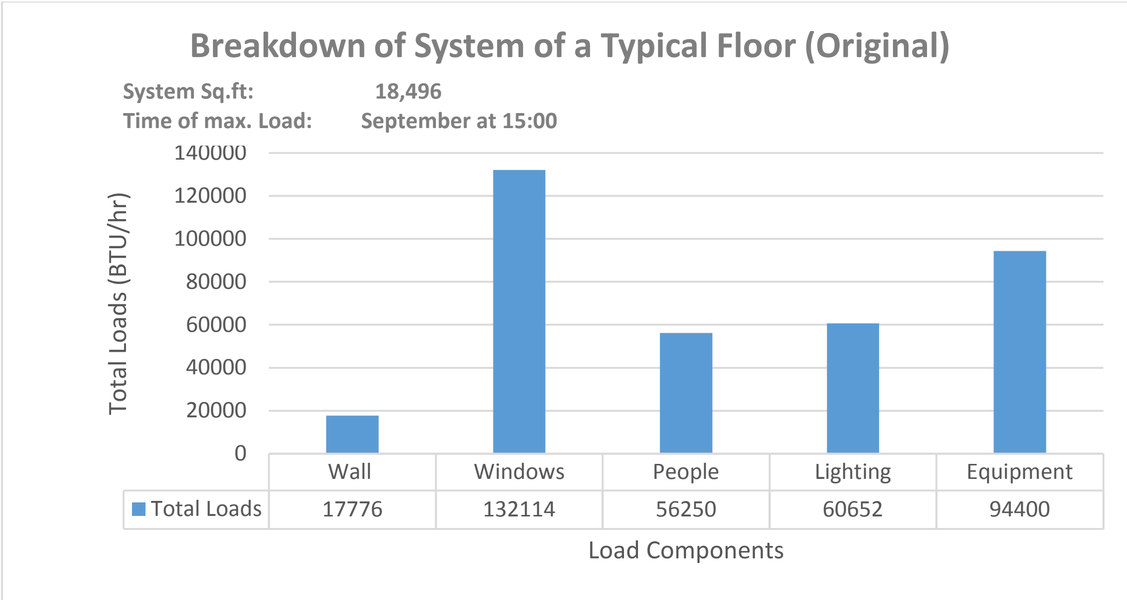


Figure 34: Total Loads on Typical Floor

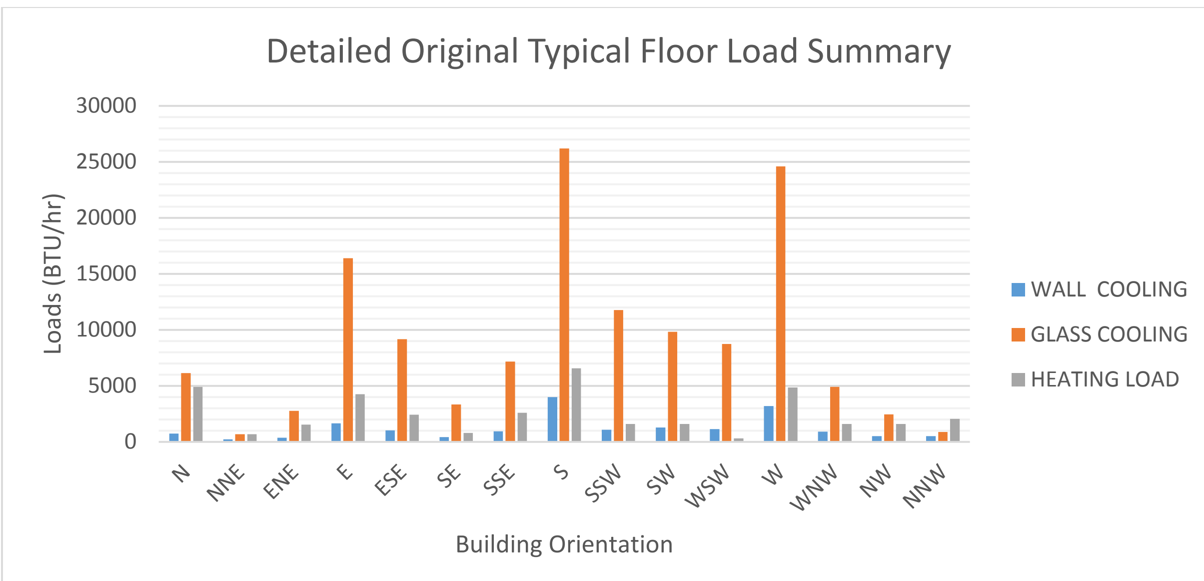


Figure 35: Floor Loads Based on Building Orientation

Based on the analysis, the team observed that the glazing (specifically the south-facing glazing) generated the most heat-gain and, as a result, required the highest amount of cooling. Additionally, the floor area along the perimeter of the building lost a large amount of heat. In comparison to a typical over-head HVAC systems, however, the under-floor air distribution system operated more efficiently, as less energy was required to cool the stale, hot upper layer of air.

3.3.1.2 Phase II – Design Criteria and New Systems

There were several key considerations for choosing the HVAC systems. The considerations are as follows:

Important Design Criteria:

1) Flexible individual control options
2) Large floor-to-ceiling height (reduced plenum space)
3) Limited duct work
4) Energy efficiency

For the selection of the new HVAC system, the team used a table to compare different system performances. As shown in Table 12, the considered systems were an under-floor air distribution system, an active chilled beam system, a passive chilled beam system, and a variable air volume system.

Table 12: Performance of Different Mechanical Systems

	UFAD	Active Chilled Beam	Passive Chilled Beam	VAV
Central Equipment	Cooling Tower on Rooftop/ Pumps in floor	Cooling Tower on Rooftop/ Pumps in floor	Cooling Tower	Cooling Tower/ Pumps in floor
DOAS	No	Yes	Yes	No
Ductwork	Limited	Yes	None	Yes
Control Options	Flexible	Limited	Limited	Highly Flexible
Zoning	No	Some	Restricted	Flexible
Supply Air Temperature	63°F	-	-	55°F
Threat of Water Damage	No	Yes	Yes	No

3.3.1.3 Phase III – Comparing and Choosing a Final Design

Based on the criteria developed in Phase II, the team chose a hybrid HVAC system that uses an under-floor air distribution system in the interior and in-floor active chilled beams around the perimeter.

3.3.2 Façade Design

The design of the façade was important because the facade affects and integrates with the structural, mechanical, and architectural systems of the whole building. For the first phase of the façade design, the existing façade was reviewed. For the second phase, the most important criteria, including the span, the daylighting, and the properties, were determined. Finally, the appropriate façade system was chosen using the criteria.

3.3.2.1 Phase I – Review of Existing Façade

There was not much information given about the existing façade. The main architectural feature of the façade is the basket weave pattern that extends from the lobby to the top of the building. This feature creates an interesting architectural effect, with the reflections of light on the façade differing at each location. The glass panel sizes of the curtain wall are about 5’ by 10.5’ stretching from the raised floor to the ceiling with a 5’ by 2.5’ section for the under-floor section of the building. These values were scaled from the plans provided by SOM.

Figure 36: Facade of Existing Building

3.3.2.2 Phase II – Design Criteria

The façade for 350 Mission performs three major functions: creates the building envelope that separates the interior and exterior environments, transfers loads to the structure, and gives the building a main part of its architectural identity. The criteria for the building façade were designed to meet these requirements in the most effective way.

Important Design Criteria:

1) Reduced loading for mechanical system
2) High visible transmittance for high levels of daylighting
3) Strong framing for increased spans
4) Highly aesthetically pleasing
5) Cost

For the framing of the curtain wall, two main types of material were reviewed: aluminum and steel. Aluminum mullions are typically used in most curtain wall systems. The reason they are used is that aluminum is lightweight (meaning it does not add much gravity load to the structure), does not corrode, and is less expensive than other materials that could potentially be used in curtain wall systems. Also, aluminum is easily extruded into many different shapes. Steel is not commonly used in curtain wall applications anymore because it corrodes when exposed to the elements. Recently, however, new developments in steel production have created a coating that prevents the steel from rusting. Steel curtain wall systems were considered for this project because steel systems support a much larger load and can have much larger spans of glass without requiring any additional reinforcement. In addition, the steel frames have a profile that is about one-third thinner than the aluminum frame. A table comparing the features of aluminum-framed and steel-framed curtain walls is shown below.

Table 13: Different Features of Curtain Wall Systems (Taken from TGP America)

	Steel Curtainwall Systems	Aluminum Curtainwall Systems
WIND LOAD CAPACITY	3x stronger	-
GLASS SIZE	Significantly larger	-
HEAT TRANSFER COEFFICIENT	Low	High
PROFILE SWEATING	Rare	Common
THERMAL EXPANSION	Minimal	High

Another major feature of the facade that was considered was the type of glazing to be used. Glazing plays a crucial role in the design of the façade and the HVAC system because its characteristics determine the loads on the HVAC system. Because the building is supposed to be high performance, the glazing of the façade needs to have low U-values, high visible transmittance values, a low solar heat gain coefficient, and still be aesthetically pleasing. What is convenient about glazing is that manufacturers are able to create virtually any glazing with the specifications dictated by clients. Because of this, the selection of the glazing was driven by the values that were most beneficial to the HVAC system.

3.3.2.3 Phase III – Comparing and Choosing Final Design

For this project, the steel-framed curtain wall was selected for the façade. The steel curtain wall system has several advantages over the aluminum system. Because the steel mullions are much thinner than the aluminum mullions and can support higher gravity loads, the glass span can be much larger than those in aluminum curtain walls, making the office feel more connected with the exterior environment and reducing the barriers that reduce visibility to the outside. Because the glass spans can be larger, less of them are needed and less work is required to install them.

Steel is also much more durable than aluminum, requiring much less maintenance over its longer lifetime. Because it is now possible to prevent steel from corroding, it is a much more efficient system for using large glazing sections. The steel mullions are 45 mm (1.78 in.) thick with concealed fastener joinery in order to create a smooth, consistent appearance. Specifications for the mullions can be found in Appendix F.

For the glazing, in order to reduce the loading on the HVAC system, a 1” double-paned glass with an argon gas airspace was selected. The reason argon was selected to fill the space between the two panes of glass is that it has better insulation properties than ordinary air. The selected glazing has a visible transmittance value of 70%, a summer U-value of 0.21, and a solar heat gain coefficient of 0.37. These glazing properties were selected in conjunction with the development of the HVAC system in order to optimize the system’s efficiency. In addition to selecting the properties of the glazing, the team also sized the glazing panels. The panels that run from the floor to the ceiling are 10’ tall and 8’9” wide. There are also opaque panels that run from the bottom of the slab to the raised floor called spandrels that are 3’2” tall and 8’9” wide. The spandrels’ function is to conceal the concrete slab and the raised floor system from the exterior of the building.

3.3.3 Fire Protection Design

Life safety is an important aspect of high-rise building design. In order to keep occupants safe in the case of a fire event, the different regulations from the building code must be met. The California building code references the *IBC* and the *NFPA* for all life safety codes relating to buildings. 350 Mission consists of three main occupancy zones: parking garage, assembly, and business. The exit routes in these zones are all tailored to the specific occupancy of the space. The egress pathway for the exit route and the fire safety systems are some of the most important areas for the fire protection design for high-rise buildings, as well as the design of the stairways and the access for firefighters. These codes and regulations have been based on previous building fires that have endangered the life of the occupants or resulted in a total building failure.

3.3.3.1 Occupancy Loads

Occupancy loads for each floor determine the range of widths for the exit routes and for fire rating of the space as well. There are 4 floors of parking garages below grade, which have an occupancy load that excludes the calculation of the core and exit routes. The lobby area is a public space that consists of retail, art, and restaurant zones. The first floor of the lobby has two retail areas and entrances to the core for access to the office space. The first floor was zoned as a standing assembly, mercantile, and mercantile storage/shipping. The second floor of the lobby has a public assembly and public art area that was zoned as unconcentrated assembly and exhibit assembly. The third floor is a restaurant and was zoned as assembly seating and kitchen. The office space was designated a business zone, with one subzone for the conference rooms that fall under the unconcentrated assembly. The occupancy loads for each zone were used to calculate the required egress widths for the exit routes. To view how the occupancy loads were calculated, go to Appendix J.

3.3.3.2 Egress

Based on the values from the occupancy loads, the egress requirements for the exit routes were determined. For high-rise buildings, the exit access, exit, and exit discharge are all highly engineered areas because, unlike smaller buildings, it takes occupants longer to leave the building due to the travel distance to the exit and higher flow of occupants traveling through the exit route.

For the office space, the exit access consists of the occupants leaving their desks or offices and traveling through aisles and corridors. According to *IBC Chapter 10, Section 1014.3*, the common path of egress travel for business occupancy is one hundred feet from the farthest route to the exit. The table below shows the required widths of each section of the exit access according to the *IBC*.

Table 14: Required Exit Access Widths

Section of Exit Access	**Minimum Required Width**	***IBC* Section Reference**
Aisle	36 inches	Chapter 10, Section 1017.2
Corridor	44 inches	Chapter 10, Section 1018.2
Doorway	32 inches	Chapter 10, Section 1008.1.1

Once the occupants reach the emergency staircase, they have entered the exit portion of the exit route. This area has to be protected with two-hour rated protective materials. There are two exit routes that occupants can take to evacuate the floor. The two emergency staircases that act as exits for the occupants were spaced at one third the diagonal distance of the floor, according to the requirements in *IBC Chapter 10, Section 1015.2*. The separation of exits and staircases divides the floor so that there is a safe path for all occupants to follow, rather than all following the same route. The minimum required width for a stairway is forty-four inches according to *IBC Chapter 10, Section 1009.1*. The third section of the exit route is the exit discharge. The emergency staircases lead into the exterior of the core on ground floor. The building requires four main exits that lead to the outside of the building. These requirements are put in place and work with the fire safety systems to help occupants safely exit the building through an easily accessed exit route.

High-rise buildings tend to have large atrium spaces in their lobby areas. Atriums are an area of concern with fires because of the difficulty of controlling the smoke. According to *NFPA 92*, in order to prevent smoke from the ground floor of an atrium space from getting into the open area of the top floor of an atrium space, there must be a barrier in the form of a one to one and a half foot partition along the top boundary of the two spaces. The smoke in these areas needs to be highly controlled because, in most instances, the lobby is designed as an exit discharge and should provide the occupants with a safe and easy access to the exterior of the building. To help with early fire detection, the placement of fire alarms in all floors and atriums is important. The smoke or fire alarms should not be placed in an area where they cannot sense the smoke or heat from a fire. The same rule applies to sprinkler placement. The sprinklers must be seven feet away from the closest wall, no more than fifteen feet away from one another, and no more than six feet close to one another, depending on the throw of the water from the specific sprinkler head used. The sprinklers and fire alarms increase the amount of time that occupants have to exit the building and play an important role in keeping the occupants, public, and building safe.

4.0 Results

After creating the criteria for the designs of the architectural, structural, and mechanical systems and choosing the new systems for the building, each design was developed in depth. This section presents the detailed designs of all of the systems of the new building.

4.1 Architectural Design

Three main components of the architectural design were developed and modeled in depth for this project: the exterior form, the office floor plan, and the lobby plans. Each component went through various design stages in order to make sure that they met the requirements and desires of the competition and owner.

4.1.1 Exterior Form

The new 350 Mission building is a thirty-story octagonal building with a circular core and three different levels of cross bracing. The building gives four more dynamic views of downtown San Francisco than the existing project and has innovative structural systems that enhance the aesthetics of the building. A rendering of the finished model is shown in the figure below.

Figure 37: Exterior View of New Design

4.1.2 Office Floor Plan

The new office floor plan is a column-free interior with large floor-to-ceiling heights, better daylighting, and increased workspace area. The office floor plan was designed for use by a financial firm and was designed to enhance the circular core by making it the focal point of the space. Moving all of the offices, conference rooms, and break rooms from the perimeter of the space, like in the existing office floor plan, to the center accentuates the circular core and also increases daylighting throughout the entire floor. Having all of the workstations positioned symmetrically around the core enhances the space by creating one major corridor and flow around the floor. In addition, centralizing the mechanical rooms, the service rooms, and the bathrooms in the core increases the amount of floor space that can be used as workspace. The new office floor plan is not only bigger than the existing one, but also has 6.2% more square footage dedicated to workspace on each floor. The figures below show a rendering and floor plan of the new office design.

Figure 38: Rendering of Office Floor

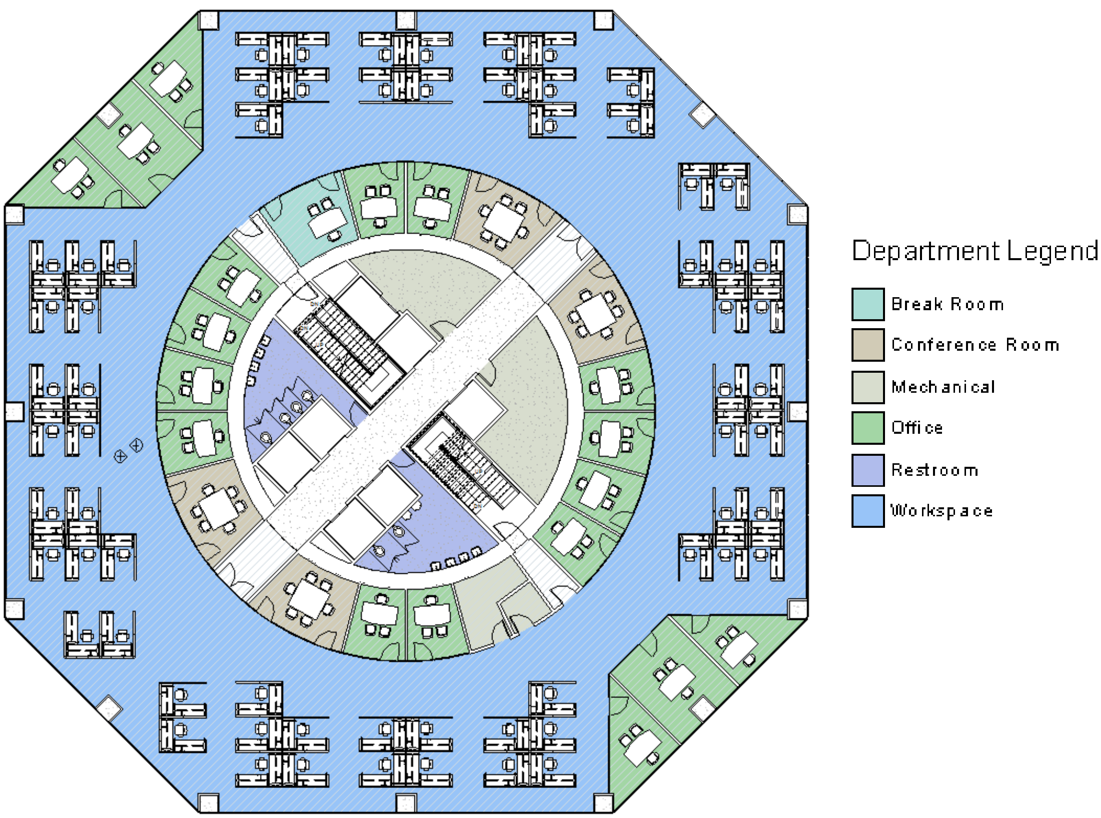


Figure 39: Plan View of Office Floor

4.1.3 Lobby Design

The lobby was designed in order to increase the appeal of the space to the general public and to create an urban oasis in downtown San Francisco that improves the quality of the workers' environment. The main entrance of the building is on the south corner, directly across from the future Transbay Transit Center. The focal point of the lobby is the circular core wall that is enveloped by a fifty-four foot green wall extending from the bottom of the lobby floor to the top of the lobby atrium. The green wall enhances the interior environment of the lobby by improving the air quality and maintaining a cooler temperature throughout the space. The main entrance is shown in Figure 40 below.

Figure 40: Main Entrance of the Lobby

There are two retail spaces on either side of the core wall. One is designated as a small store that could possibly serve as a gift shop, and the other is designated as a café with seating that extends into the lobby floor. The café was placed inside the lobby with extra seating in order to foster conversation and interaction. It is surrounded by plants and trees in planters that continue the oasis theme. Figure 41 below shows a rendering of the lobby and Figure 42 shows a plan design of the first level of the lobby.

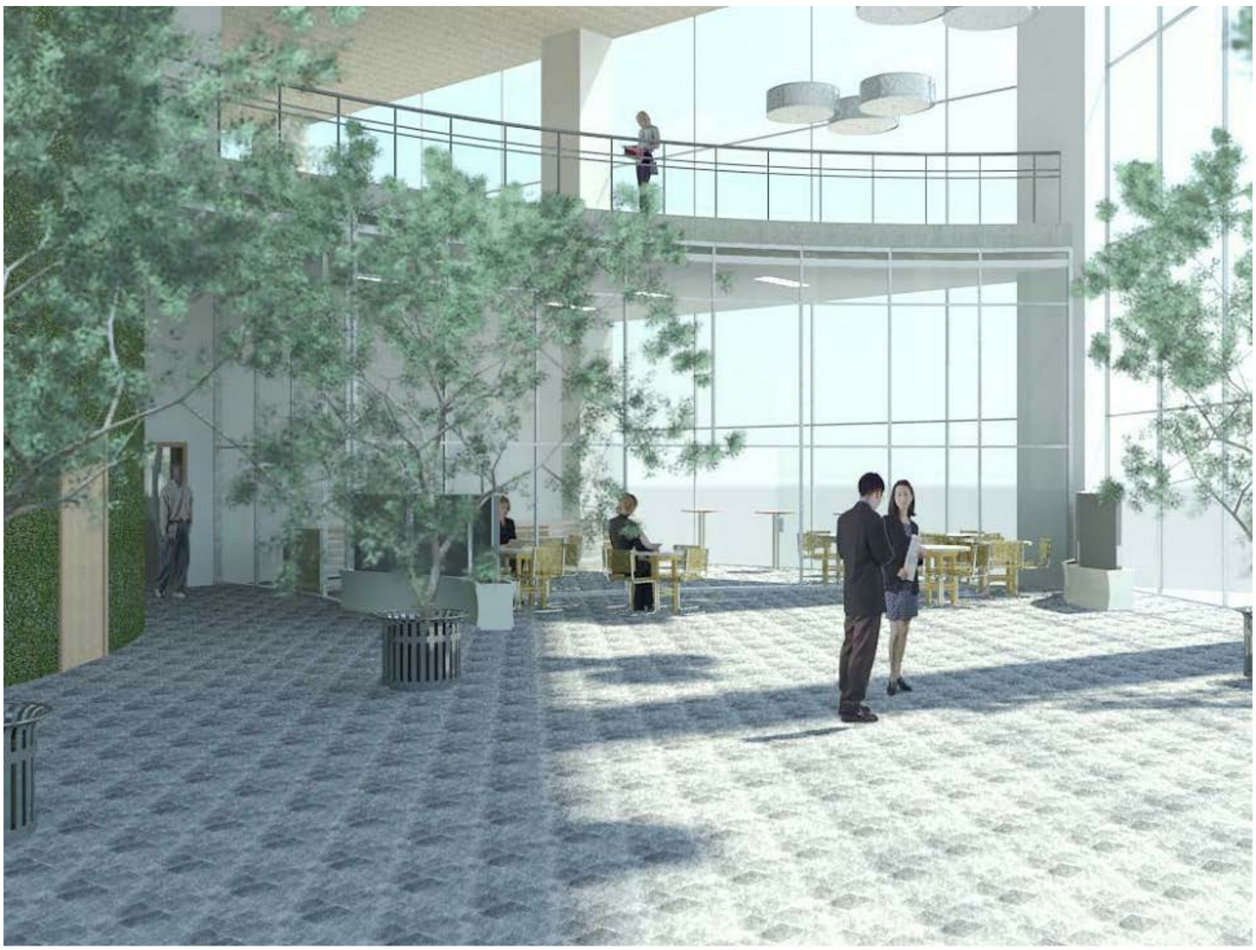


Figure 41: Cafe Space in Main Lobby Floor

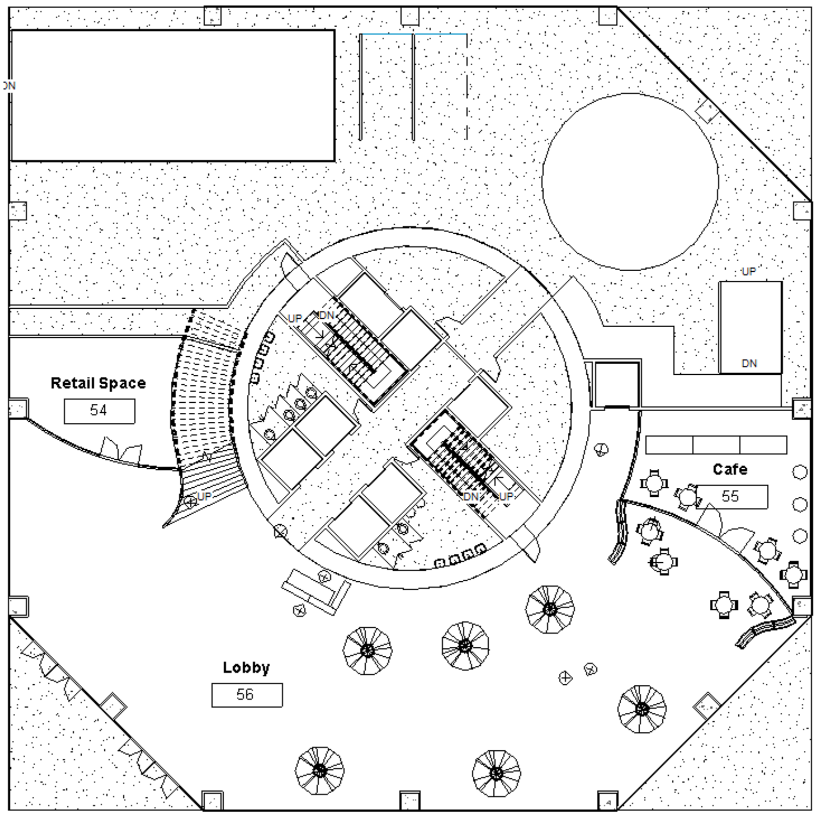


Figure 42: Lobby Level 1

There is a grand staircase on the right side of the lobby that follows the curve of the core wall up to the second and third floors of the lobby. The second floor of the lobby was created to serve two purposes: to function as a public assembly space and to display public art. The first half of the second floor is a public assembly space with seating and trees located throughout the area. The second half of the floor is an enclosed space that can be used for public art displays and events throughout the year. The public art space has a balcony above the café that overlooks the lobby and atrium. The public assembly space is shown in the figure below along with the floor plan design of the second level of the lobby.

Figure 43: Assembly Space on Second Floor of Lobby

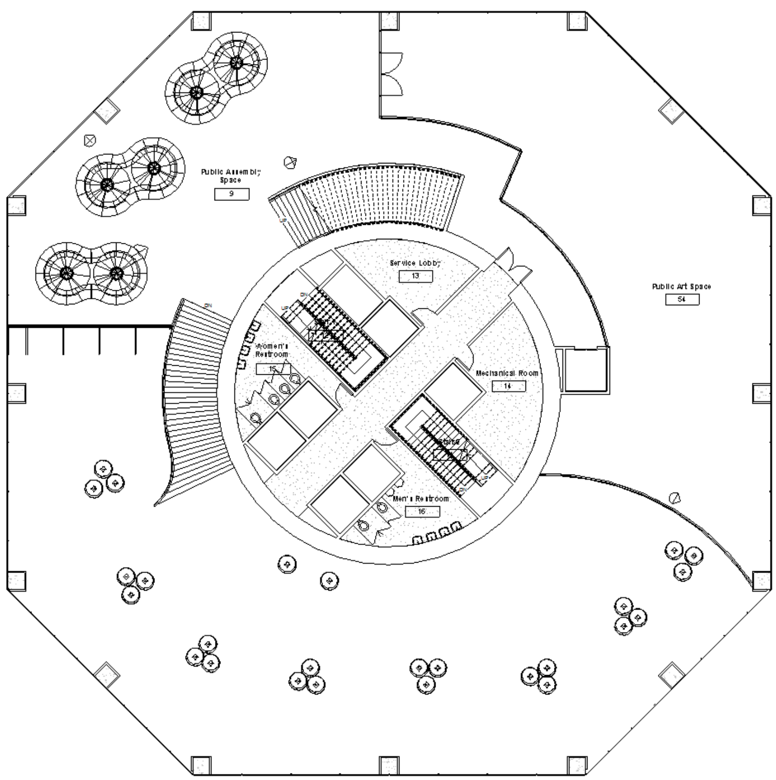


Figure 44: Lobby Level 2

The grand staircase continues from the second floor to the third floor, where it leads to a restaurant overlooking the lobby atrium. The restaurant is also intended to encourage the public to use the lobby as a place to relax and enjoy themselves in Downtown San Francisco. The floor plan of the third level of the lobby is shown in Figure 45 below. All of the major design features in the lobby were made to meet the owner's desire for an attractive public space and a high quality environment in which to work.

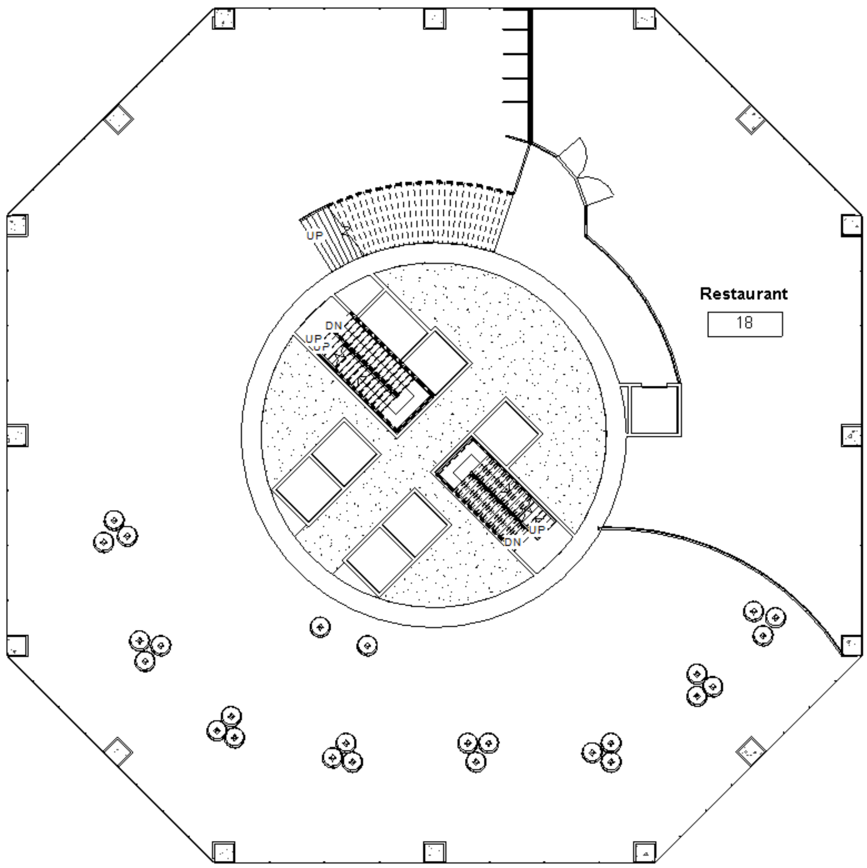


Figure 45: Lobby Level 3

4.2 Structural Design

The final structural system is a concrete octagonal building that uses a tube-in-tube structural system. The system is composed of a high performance inner concrete core wall and outer steel diagonal bracing. It has a column-free interior with sixteen high performance concrete columns along the perimeter that are tied together by uniquely distributed multistory cross-shaped steel bracings at four different floor levels. The floor slabs act as outriggers or levers to engage the perimeter columns and the exterior bracing as the interior core deflects under lateral forces. Both the core wall and columns then transfer the forces into the ten-foot-thick mat foundation, which distributes the loads into the soil.

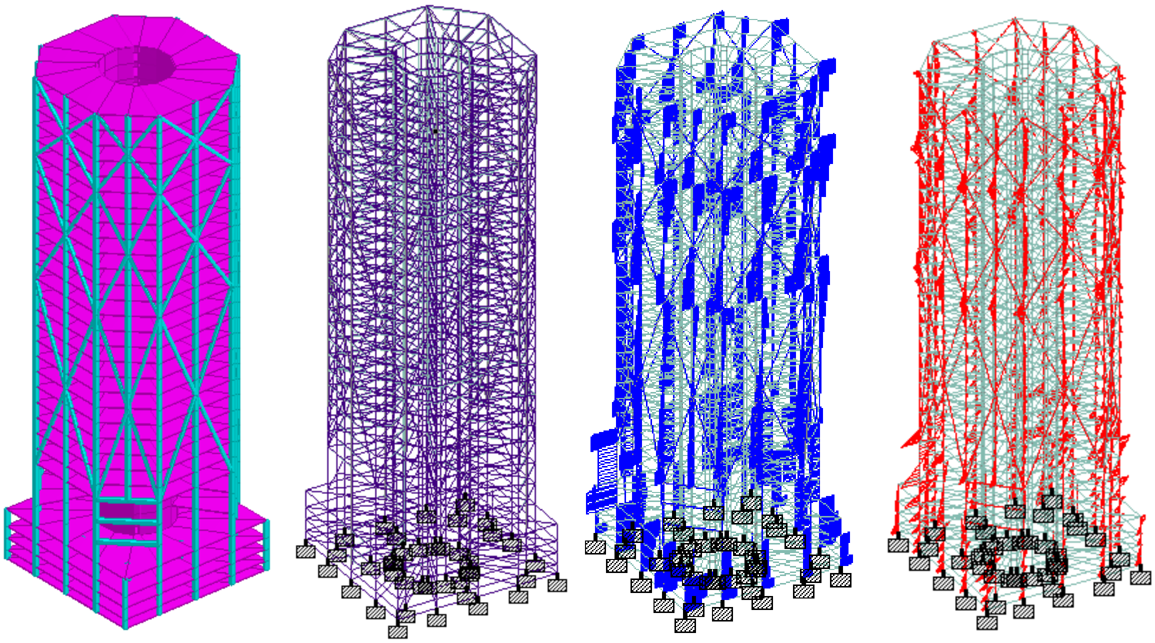
The building system is categorized into five structural subsystems:

1) Vertical load resisting system
2) Lateral load resisting system
3) Floor framing system
4) Foundation system
5) Roof framing system

Calculated loads for the strength design, deflection values, and supporting documents from codes and references are included in Appendix H.

4.2.1 Lateral Load Resisting System

A major idea that was implemented in the structural design of the building was the tube-in-tube system. It is a mixture of exterior diagonal bracing and interior shear walls in the core that resists not only the demanding vertical gravity loads, but also the lateral wind and earthquake loads. The designed steel bracings also provide for the adequate deflection, shear, stiffness, and bending resistance.



3-D Model Deflection Shear (Y Axis) Bending (Z Axis)

Figure 46: General Forces in STAAD

According to the simulated STAAD analysis of the existing design, the tube-in-tube structural system was sufficient to withstand wind loads and to satisfy the allowable story drift limit. However, one of the challenges of the project was to design a building with half of the allowable story drift limit. Because of this, exterior diagonal bracings were introduced to stiffen the structure and meet the requirement. The team chose tapered steel bracings that are 2' x 2' with an interior hollow of 1' x 1' to reduce the dead weight of the braces.

There are three exterior cross-diagonal bracings at four different floor levels, as shown in Figure 43. The bracings were placed at the fifth, seventeenth, twenty-fourth, and thirtieth floors, which are the floors with the top ten percent of story drift, as shown in Table 15. Table 15 compares a non-braced structure's story drift with a braced structure's story drift. Figure 47 shows the code limit deflections, one half of the code limit deflections, and floor story drift performances when a seismic load is applied in the east to west direction. More details can be found in Appendix H.

Table 15: Non-Bracing vs. Bracing Story Drift

Floor Levels	Non-Bracing Story Drift (in.)	Bracing Story Drift (in.)
5	1.065	1.346
17	0.804	0.173
24	1.031	0.108
30	1.317	0.017

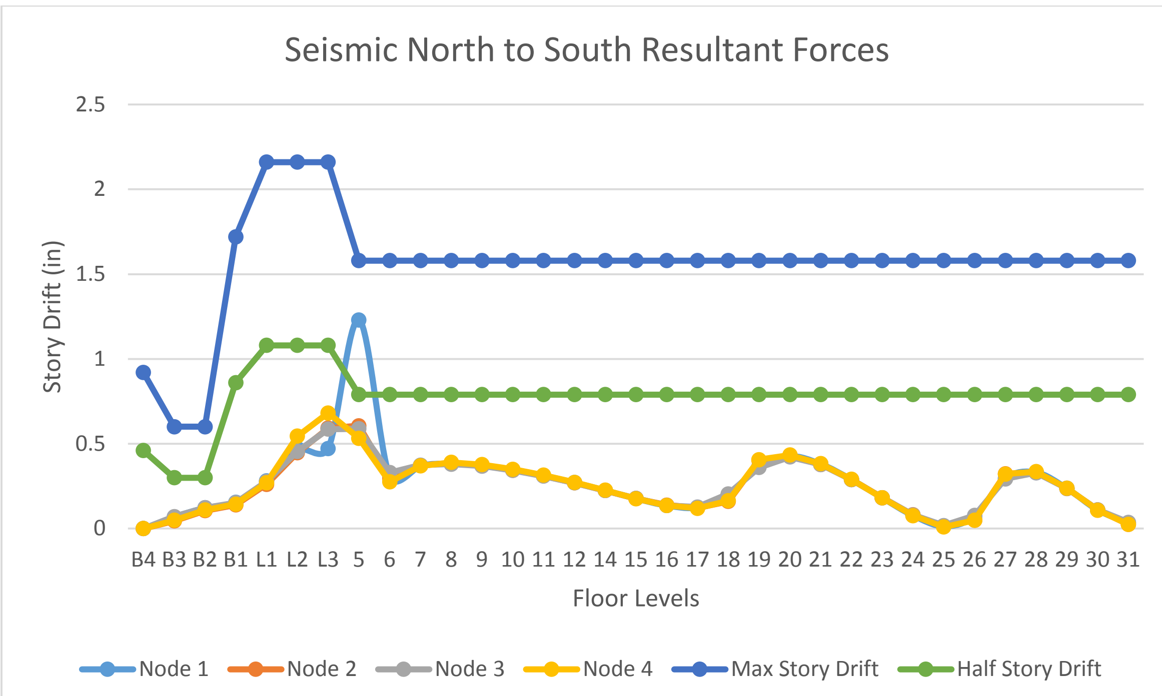


Figure 47: Seismic Load North to South Story Drift Resultant Forces

Another major feature of the new design is the circular shear core wall, which replaced the square shear core wall of the existing design. Figure 48 shows both the square and circular thirtieth floor core walls and the deflection of each when a seismic load is applied in the positive “X” direction. The blue outline is the static location of the building and the purple outline is the predicted displacement of the building after the load.

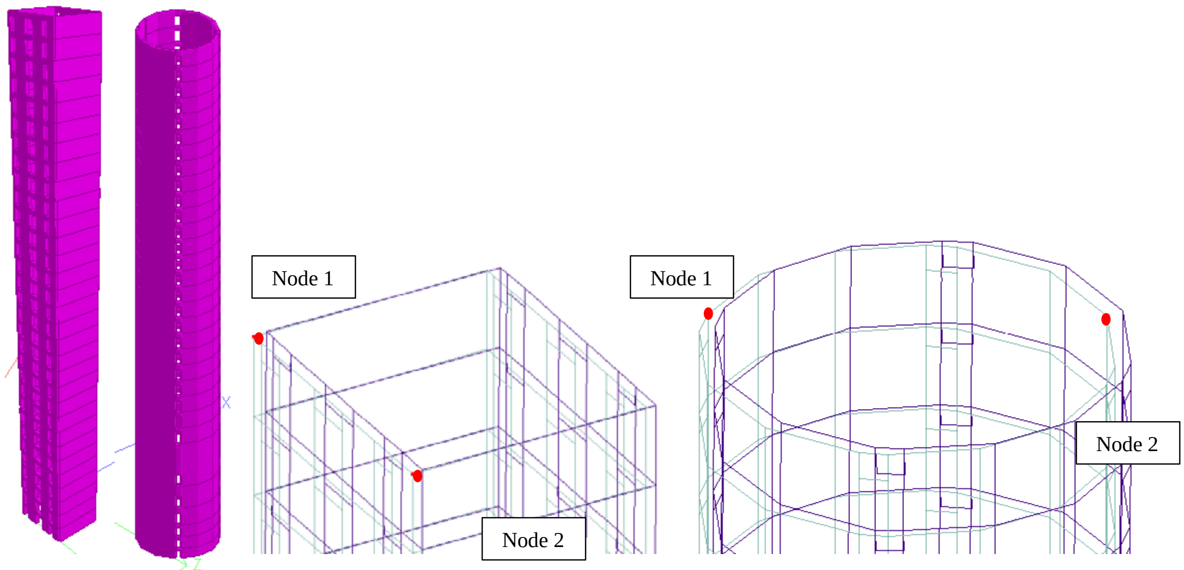


Figure 48: Square Core and Circular Core STAAD Model Comparison

The circular core wall has four openings and four equally distributed shear walls. The shear walls provide lateral stiffness and control the axial, shear, and bending in both north-south and east-west directions, as well as the lateral forces acting along the diagonals. In a tube-in-tube design, the circular core performs better in lateral load resistance than the square core. The circular core's geometric shape was also integrated with the architectural design. The core now contains the mechanical room, electrical room, and bathrooms in the office floor plan.

4.2.2 Vertical Load Resisting System

Along with the geometric change of the core wall, the structural system has different wall thicknesses as well. SOM split the core walls into three sections: basement to lobby, fifth floor to twenty-first floor, and twenty-second floor to roof. The bottom half of the structure must be able to sustain more loads as the load travels down to the base of the building. Because of this, the central core walls are progressively thicker to accommodate for the accumulated increase of loads transmitted from the floors above. Unlike SOM's structural core wall design, the team designed the core wall in two sections. To resist the rotational moment at the bottom of the structure, the core walls have a uniform thickness of two and a half feet. The core wall thickness was then decreased to two feet at the twenty-second floor. The thickness was decreased at the twenty-second floor because that floor is where the second set of exterior diagonal bracings meet, as shown in Figure 46 below. Because of this, it provides a good transition point between the core walls of differing thicknesses. Refer to Figure 49 for the core thickness.

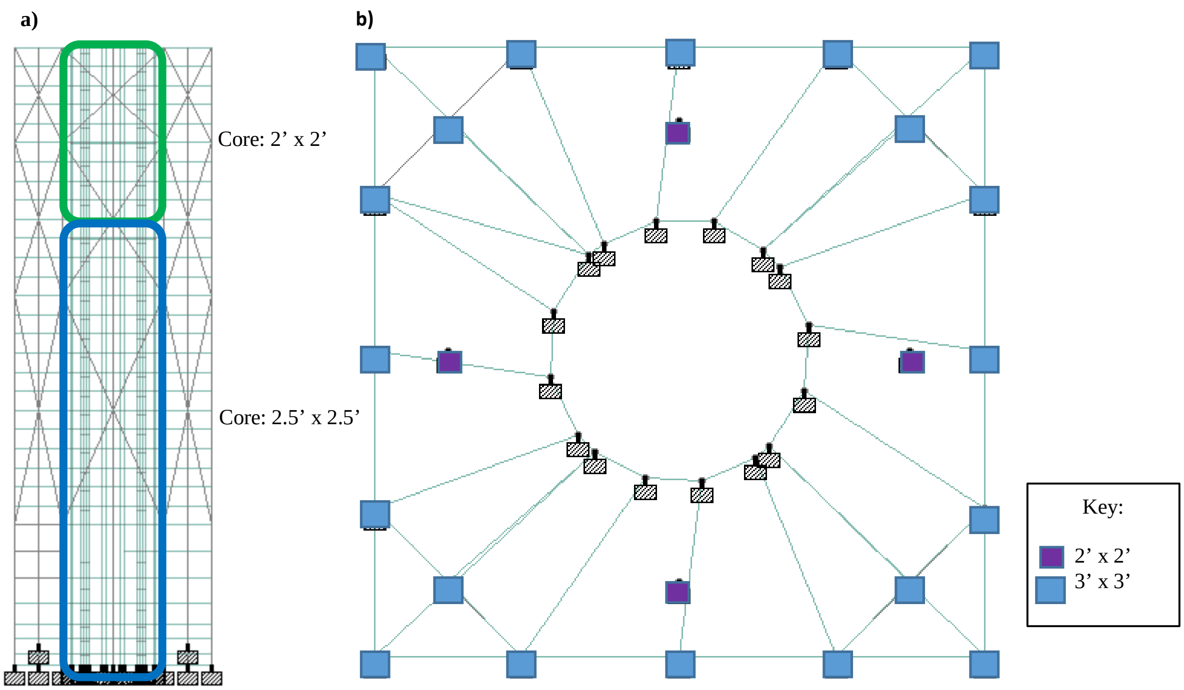


Figure 49: South Elevation and Building Floor Plan

Next, all of the perimeter columns were placed at each corner and halfway between the corners of the octagonal building. Sixteen 3'x 3' concrete columns span the entire perimeter of building. The basement includes eight more columns on each level, with four 3' x 3' columns at the square corners and four 2' x 2' columns in between the diagonals of the octagon.

There is a break in one of the main columns on the first floor lobby, circled in red in Figure 50 below, because of a garage entrance going into the basement levels.

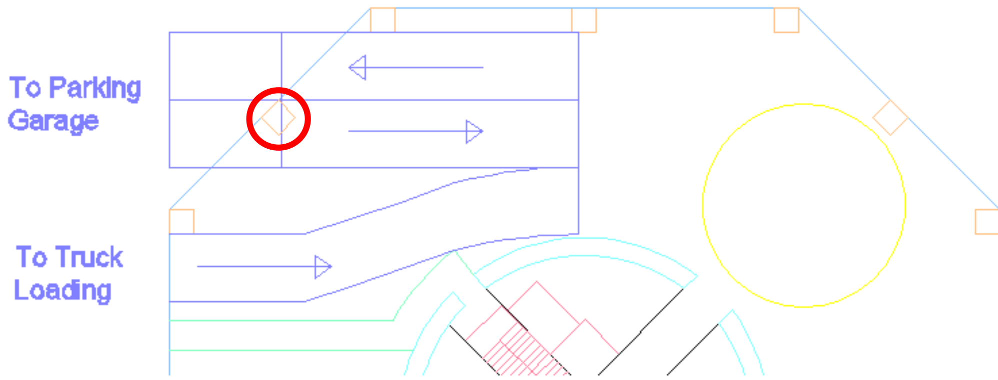


Figure 50: Missing Column in Lobby 1

A particular challenge was to find another method to redistribute the load in the absence of the missing column. Two possible solutions were investigated: one was to increase size of the neighboring columns, while the other was to create a Vierendeel system composed of spandrel beams and the neighboring columns. The first solution would have required massive columns and would have ruined the architectural aesthetics of the building. Because of this, the team chose the second solution, which was to place a 3’ x 3’ concrete spandrel beam tying the two neighboring columns together and forcing the section to act as a Vierendeel truss, as shown in Figure 37. Using this method, deflection and column sizing are both under control because it will keep the box from deforming from a rectangle to a parallelogram when the beams are connected by various ties in the three lobby levels, represented in orange in the Figure 51. Three Vierendeel trusses were erected in the lobby floors for aesthetic reasons.

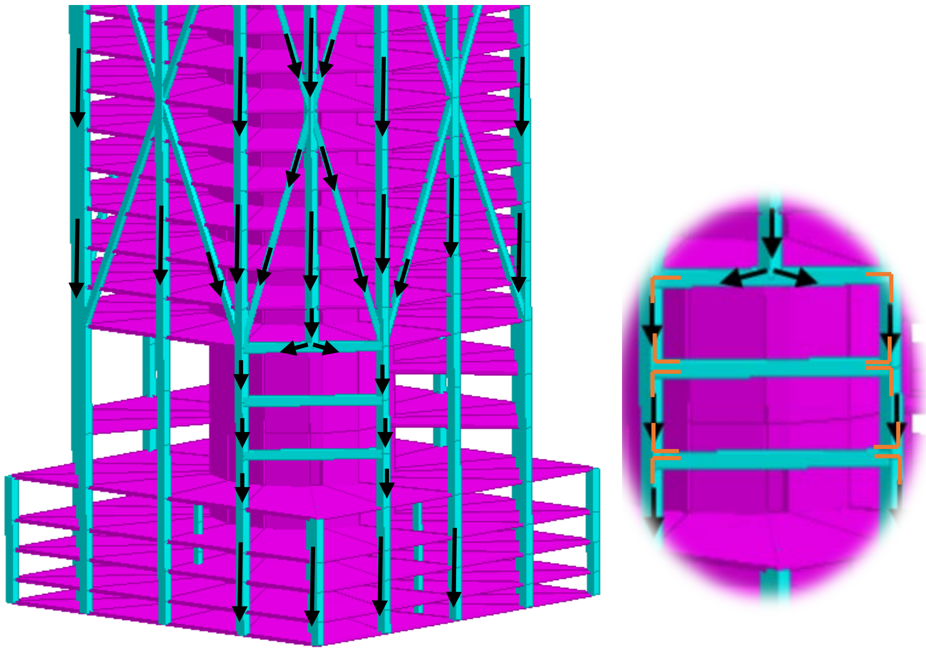


Figure 51: Lobby Column Load Transferring Path

4.2.3 Floor System

The floor plates of the building are meant not only to provide a working surface for occupants, but also to deliver the loads from the exterior of the building to the concrete core wall. The plates act as outstretched arms attached to the main body, the core wall, of the building. Slab thickness affects the efficiency of the tube-in-tube system, the goal of which is to have the two tubes work simultaneously as true cantilever beams. Consequently, the floor slabs, which connect the two tubes, must remain in plan during lateral deflection of the building. If the floor slab is too thin, it will be flexible and the exterior tube will not be able to fully engage in the cantilever beam effect. Likewise, the slab cannot be too thick, because it will decrease the floor-to-ceiling height of the space and also add more weight to the dead load. The thickness of the floor slab is also affected by the fire rating codes and fire resistance ratings for the construction type. At first, the floor slabs were kept at eleven inches thick. However, the team found that, with increased floor slab thickness, the total deflection value decreases, as shown in Appendix H. With fourteen inches of post-tensioned, one-way concrete slab, the column-to-column spacing can be lengthened since post-tensioned slabs start out convex and are flattened out when the loads are applied.

4.2.4 Foundation System

The team decided to use SOM's current foundation design of a ten-foot mat for the new design as well. The mat rests on the layer of dense colma sand and provides leverage for the building when it moves during a seismic event. The mat ties all the columns together so that they act as a single unit, rather than individual columns, and redistributes the loads absorbed from the building, distributing them accordingly in the soil. The dense mat resting in the middle of the loose soil can also make the seismic waves travel faster and decrease the wave forces before they propagate into the building.

4.2.5 Roof System

The roof supports heavy-duty mechanical equipment such as chillers, elevator machine rooms, generators, and boiler rooms, so the slab has to be thicker. The roof slab is eighteen inches thick and is supported by 3' x 3' reinforced concrete-encased steel columns from the top of the thirtieth floor.

4.3 Mechanical Design

After choosing the specific designs of the HVAC, façade, and fire protection systems, the mechanical systems were developed in detail according to the requirements of the competition. This section presents the designs of all of the new mechanical systems in the building.

4.3.1 HVAC System

Based on the criteria developed in Phase II, the team chose a hybrid HVAC system that uses an under-floor air distribution system in the interior and in-floor active chilled beams around the perimeter to handle the heating and cooling loads in those areas. Additionally, as a secondary mechanical system, the team chose an overhead mechanical system to exhaust air from the bathrooms. The redesign of the building features both the restrooms and the mechanical room located within the core of the building. By positioning the bathroom in the core the team reduced the need for additional plumbing on the floor plan. The team redeveloped the HVAC zones to maximize occupant comfort and control. As shown in Figure 52, there are three zones per floor: the perimeter zone, the interior zone, and the interior office zones. The division of the under-floor plenum space was achieved by using a plenum divider.

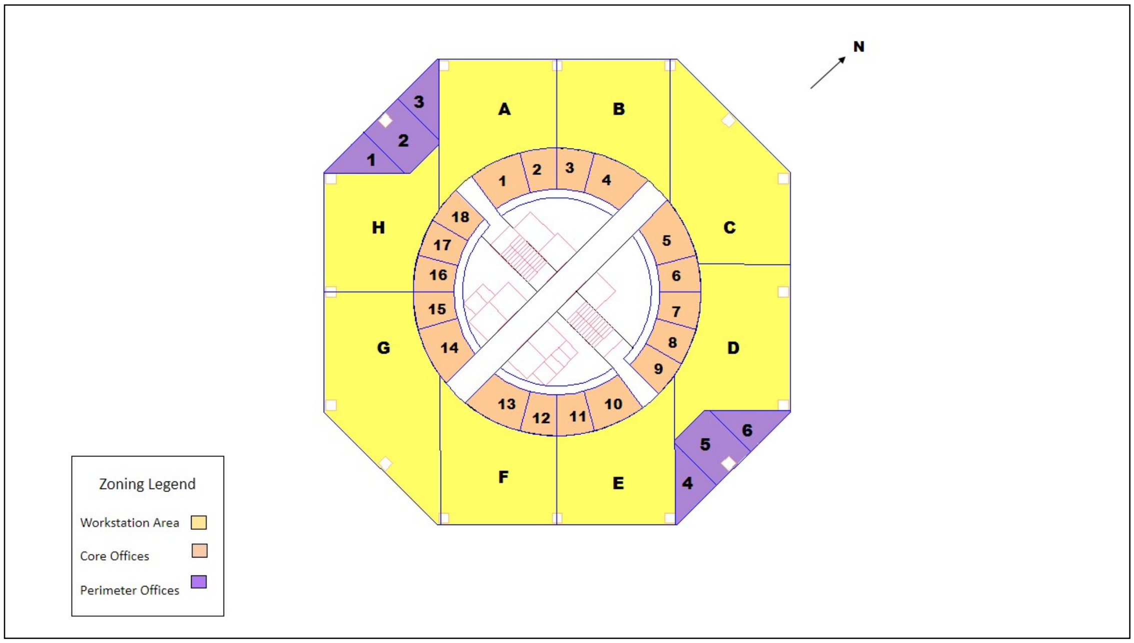


Figure 52: Mechanical Zones

The team analyzed the loads by using the aforementioned Excel sheet (see Appendix I) to calculate heat gain on the office floor and aid in the analysis and design of the mechanical system.

4.4.1.1 Redesign of Typical Floor Performance

To improve the building performance, the team increased the U-value of the windows from 0.24 to 0.21. Additionally, to minimize the solar heat gain from the windows the shading co-efficient was decreased from 0.81 to 0.37. Based on the new floor plan, approximately 96 persons were estimated to occupy a typical floor. The analysis of the building was performed for the month of September at 3pm, the hottest part of a day of the hottest part of the year. Using the aformentioned methods of calculation, the following graphs were generated.

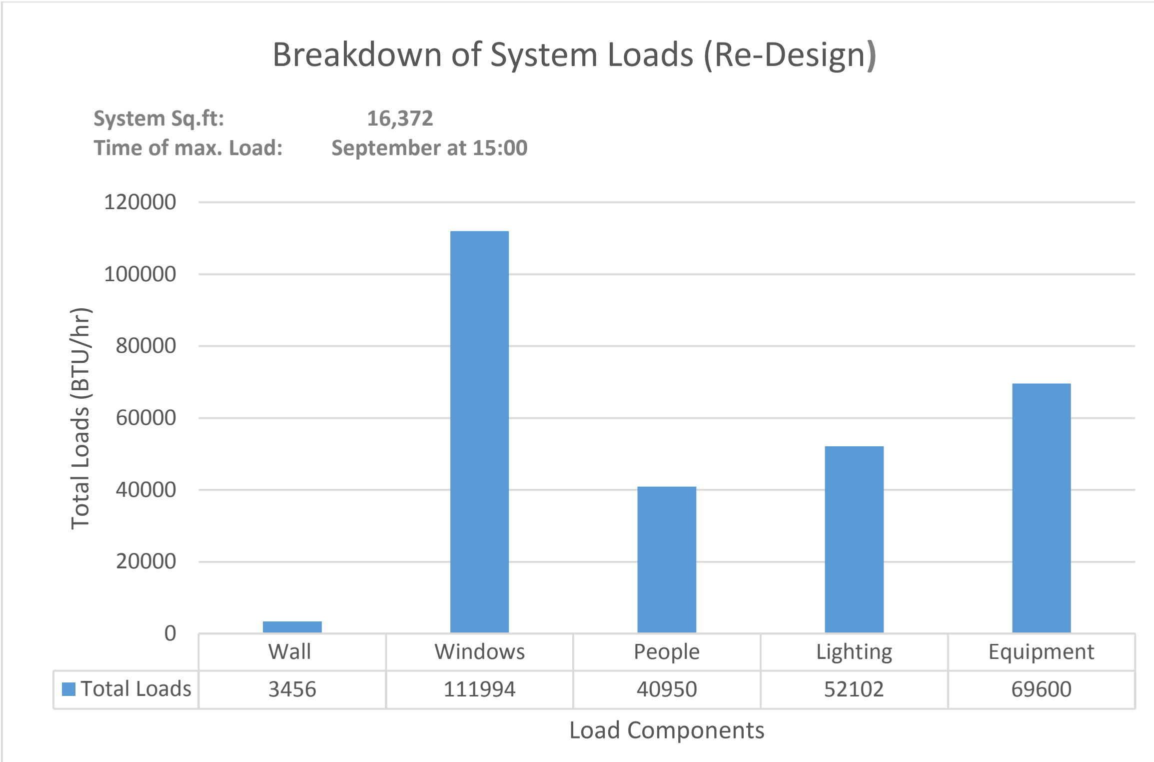


Figure 53: Breakdown of System Loads per Floor

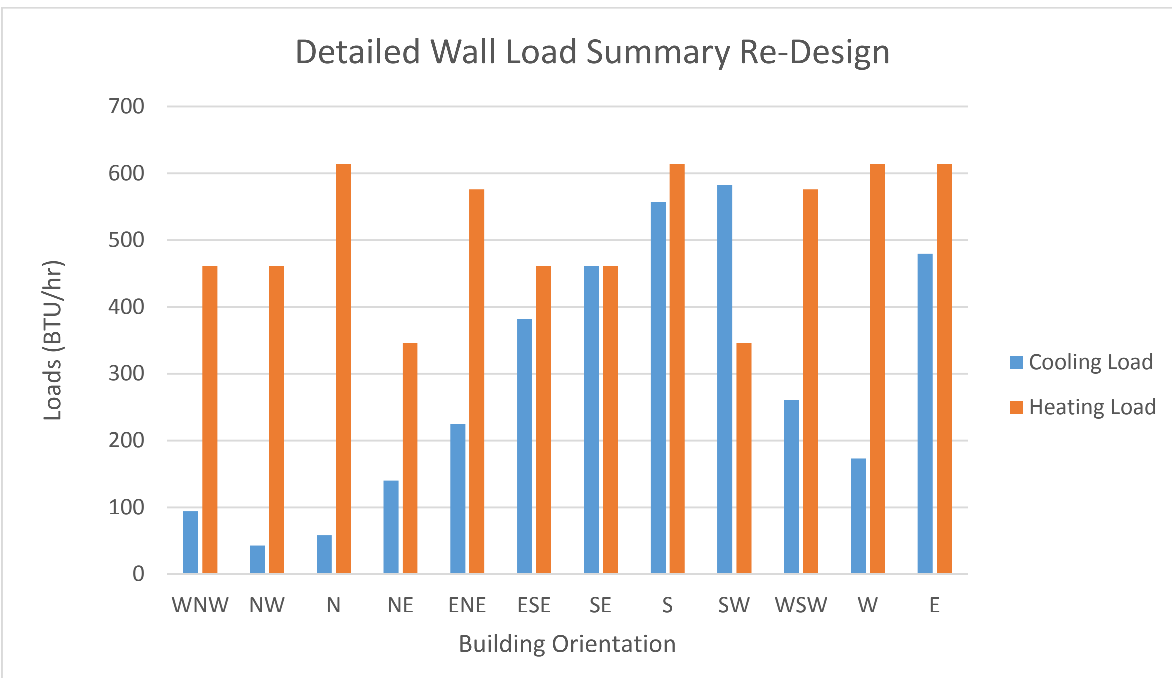


Figure 54: Summary of Loads Based on Orientation

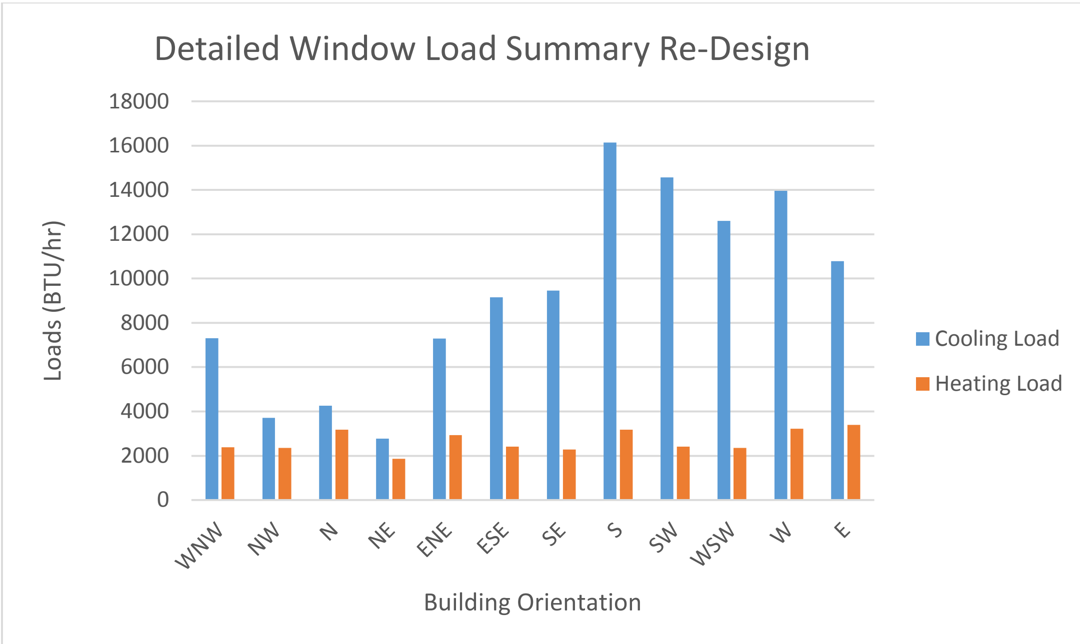


Figure 55: Window Load Summary

The redesigned load trend is similar to the existing building, where the south facing windows require the most amount of cooling. In comparison with the existing building, the windows in the new office design have a lower cooling and heating load.

4.4.1.2 Schematic Mechanical Design and Operation

For the mechanical layout in the new design, the supply and return ducts were looped around the core with VAV terminal units placed intermittently around the loop, providing air to the respective core offices and floor areas. There are louvers located on the lower plenum and upper plenum, with the lower louver providing fresh air to the system through an intake duct and the upper louver exhausting stale air. Additionally, the team positioned the under-floor active chilled beams in the each of the offices located at the perimeter and along the perimeter of the work floor.

In the design, there is a variable air volume pressurized plenum space with a supply air volume of approximately 11,000 CFM (see Appendix I for CFM required calculation). The team selected a variable air volume pressure to maintain flexibility within the office space, as well as reduce energy costs. Since there is limited ductwork, the pressure required to supply air to the occupied zone is reduced, also reducing the energy cost in the building. The typical pressure under the plenum ranges from 0.02 to 0.1 in inches of water (w.g.).

The schematic mechanical zone layout features a perimeter zone boundary fifteen feet away from the façade. To create an airtight zone, the plenum dividers were used along the perimeter boundary. A common issue faced with under-floor air distribution systems is thermal decay from the supply duct to the perimeter zone of buildings. As a solution to this problem, the team used in-floor active chilled beams to handle the building skin loads, as shown in Figure 56.

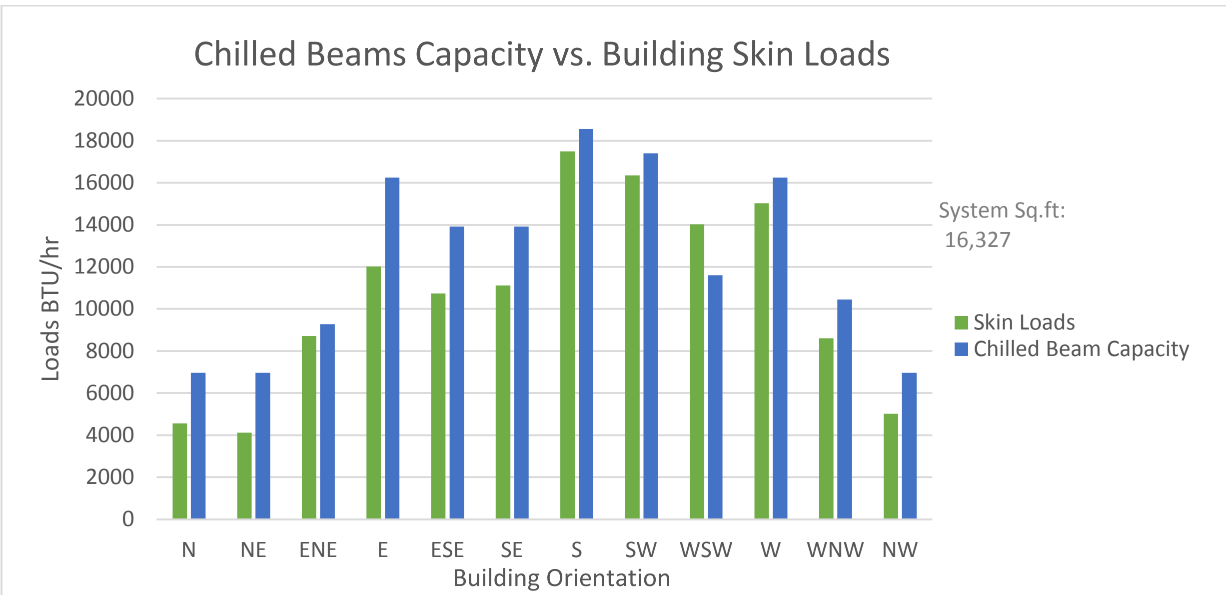


Figure 56: Chilled Beams vs. Building Skin Loads

A benefit of using in-floor active chilled beams is that they require little to no ductwork and there is no damage from condensation due to latent heat loads and/or leaking water lines. The active chilled beam can be individually controlled by a thermostat, but, in this design, one thermostat is assigned to a group of chilled beams, depending on the building orientation.

Using the results from the building load calculation and using the specification for in-floor active chilled beams from Tate Inc., the team selected the four-pipe High Density (HD) design with a cold water supply of 50°F and a hot water supply of 110°F. The four-pipe HD pipe has two supply and return pipe connections that allow for the simultaneous delivery of hot and cold water. By implementing this strategy in the new design, the team has optimized occupant comfort as well as significantly reduced the effect of thermal decay. To avoid occupant overcooling and improve the comfort levels of the space, the minimum supply outlet temperatures will be maintained between the temperatures 60^{o}F to 65^{o}F.

The under-floor air distribution system in the design is directly ducted to the outside, bringing 100% outside air into the air-handling unit and distributing it through the supply ducts. Every floor has its own mechanical room with an air-handling unit. Although the system will run on 100% outside air for improved ventilation and an exhaust fan is positioned in the upper plenum space to exhaust the stale air out, there is also a return duct with a damper that will supply some hot air to an economizer in order to reduce cooling loads in the air-handling unit. Figure 57 below shows the schematic design of the mechanical system for each office floor and Figure 58 shows a cross section of a typical office floor.

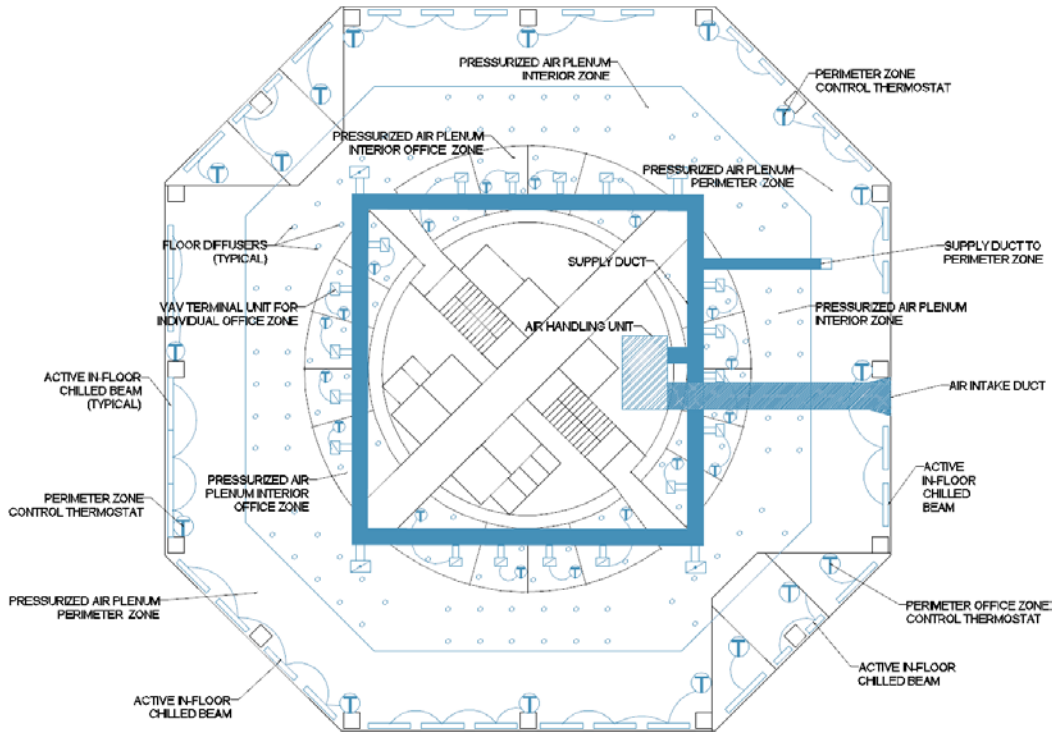


Figure 57: Mechanical Design

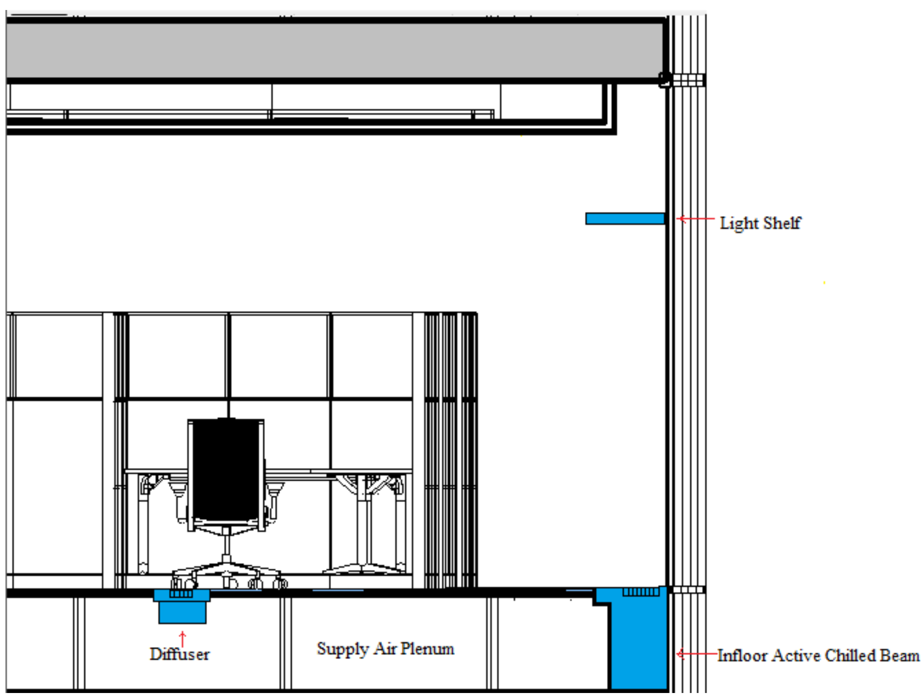


Figure 58: Cross Section of Office Ceiling and Plenum Space

4.3.2 Façade System

As stated in the Methodology, the curtain wall of the façade is constructed of steel mullions that are 45mm deep. The curtain wall lies behind the structural cross-bracing of the new design of the building in order to emphasize the bracing's aesthetic design.

The glazing is double-paned glass that has a turquoise tint and a visible transmittance value of 70%, a summer U-value of 0.21, and a solar heat gain coefficient of 0.37. The glazing panels are 10' tall and 8'9" wide and the spandrel panels that hide the under-floor plenum space are 3'2" tall and 8'9" wide.

4.3.3 Fire Safety Systems

The fire safety system in the high-rise building consists of sprinklers, a fire pump, and a fire tank that keeps stored water when there is a shortage from the city main entering the building. There are three main 6" standpipes in the building that are located in the two emergency staircases and the service elevator lobby. There is a fire department connection at each of these three points on every floor so that the firefighters can choose the safest route for fighting and controlling the fire in the building. All the standpipes are wet systems and lead to feed the sprinklers on every floor. The sprinklers are concealed pendants with a normal rating. Most of the occupancy groups for the building do not require a special sprinkler system. The restaurant has the required sprinkler rating to correctly service the floor in an event of a fire.

The fire pump room is located on the lowest basement level and has direct access to the exit, as required by *NFPA 20*. The fire pump services the whole building with the help of the reserve tank. When a single sprinkler is activated, the fire pump will start working and rely on the city water to provide consistent water pressure in the standpipes to feed the sprinklers. There is a connection for the fire department in the fire tank room as well if they need to use that as a water source to help contain and fight the fire. The fire protection sprinkler layout and locations of the fire risers are in Appendix J.

4.4 Construction Management

Construction in a city comes with many considerations that include safety, constructability, and city codes. The main problem with the 350 Mission site is the limited amount of space. The site is on the corner of two main streets that not only see a lot of vehicular traffic, but also foot traffic. The streets cannot be affected by the construction and the sidewalks cannot be blocked for long periods of time. Safety of pedestrians and vehicles during construction is an important aspect of building in close quarters to other high-rises and busy streets. The building site is shown in Figure 59. There is minimal space between the two adjoining buildings on Mission Street and Fremont Street. The problematic buildings are outlined in green while the building site 350 Mission Street is outlined in red.

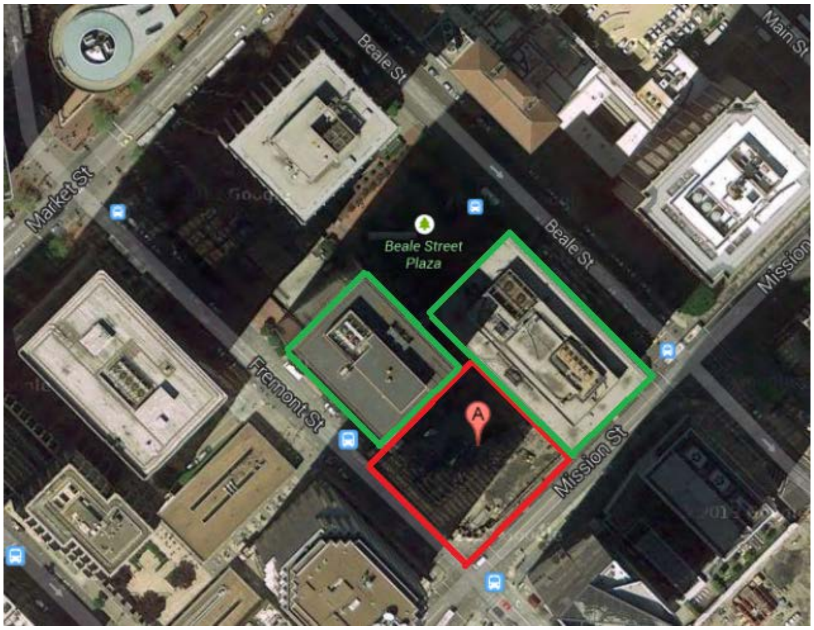


Figure 59: 350 Mission Street Building Site

Further down Fremont Street, construction for the new Transbay Transit Center is also underway. This construction might cause the area to be congested with traffic during the main rush hours. Other construction in the area can delay some of the scheduled deliveries for materials and, consequently, push back the completion of the project. Since materials can only have a limited space for storage on the site, they have to be stored offsite. These issues are incorporated into the construction management schedule.

4.4.1 Construction Management Schedule

Due to tight space and limited storage, the construction of the building has to be completed in layers. The construction is broken up into eight phases, as shown in Figure 60. A more detailed schedule is in Appendix L.

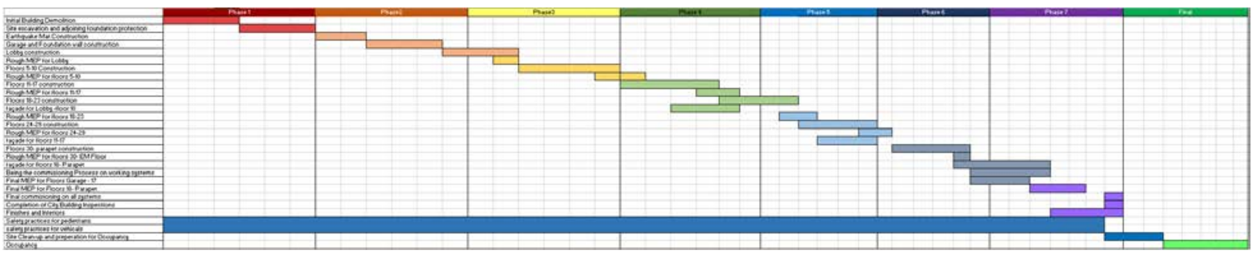


Figure 60: Brief Construction Schedule

The first phase of the construction process is to demolish the existing structure at the site and start excavating to reach the base layer of the building where the earthquake mat is constructed. When excavating, the sides of the site must be reinforced with a bracing wall to protect the neighboring high-rise foundations. Once the earthquake mat is constructed, the formwork for the garage foundation walls can be placed. The concrete will be cast-in-place reinforced concrete. All of the concrete slabs will be cast-in-place, while the core walls and the interior columns will be precast. This will allow for more space on site and the concrete trucks will not have to be on site placing concrete every day. Once the garage levels are completed up to the ground level lobby entrance, Phase 1 is complete and Phase 2 begins. The floors will be constructed in steps of five floors at a time. The floor slabs will be post-tension slabs and will be cast on site, and then tensioned by skilled workers. The first floor of the set of 5 will be cast in place and then the core wall and columns will be delivered and assembled on site. Each individual floor will be constructed this way. As the building rises higher, the walkways for the pedestrians will be covered to protect from the potential of falling materials. Special cranes and construction equipment will be either stored on site and reinforced in case of earthquakes, or brought into the site every day, depending on the machine.

The curtain walls will start to be attached to the building in Phase 6 as the final structural components are finished. Once the curtain walls are attached, the utilities will start to be brought into the building. While the utilities are brought on site and installed in the building, interior finishing on the spaces will be installed for a faster occupation time. Before occupation, there is an inspection period in which the contractor has to have all aspects of the building tested and looked at by the city building inspectors. There will also be a commissioning stage in which the building systems are placed into operation, tested, and then passed into the owner's control. Site security is a main concern not only for the pedestrians outside the site, but also in the site itself. Machines that stay on the site will be turned off and locked in a secure spot on the site to protect the area from a potential earthquake. Construction management for a high-rise building not only incorporates the construction materials and storage of the products, but also traffic, pedestrian and worker safety.

4.5 Lighting and Electrical Design

The electrical system in the design is connected to the main city power grid. The electricity in the building is used for general use, lighting systems, and emergency lighting systems. The layout for the typical office floor is shown in Figure 58 below. Each desk has task lighting not shown in the layout. There are 2 types of ambient lighting in the open desk areas. The main fixtures are 1' x 4' recessed with lamps that are all LED. The secondary ambient lighting is above each of the desk groups and is directed to the desks. These secondary ambient lighting fixtures are 2' x 2' recessed with LED lamps. As shown in Figure 61, the core corridor uses the same lamps as the main ambient lighting design of the 1' x 4' recessed with LED luminaires. A more detailed layout can be found in Appendix M.

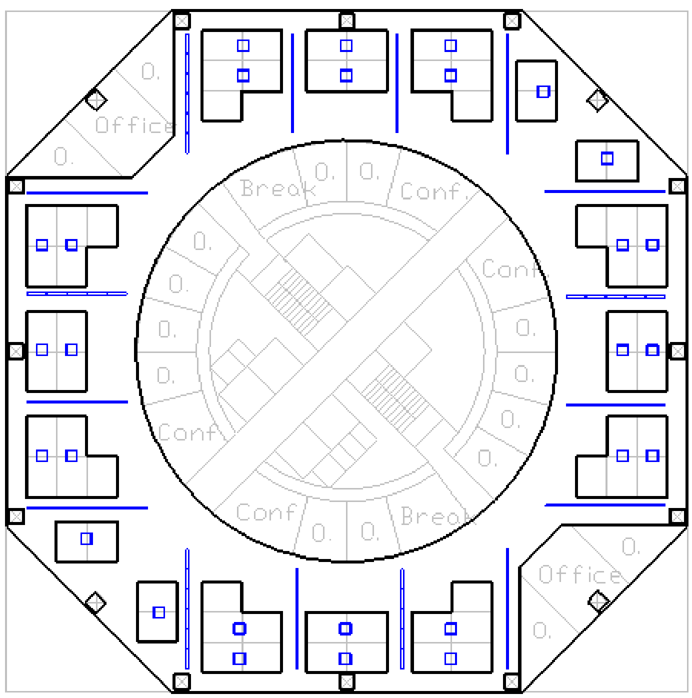


Figure 61: Lighting Layout for a Typical Office layout

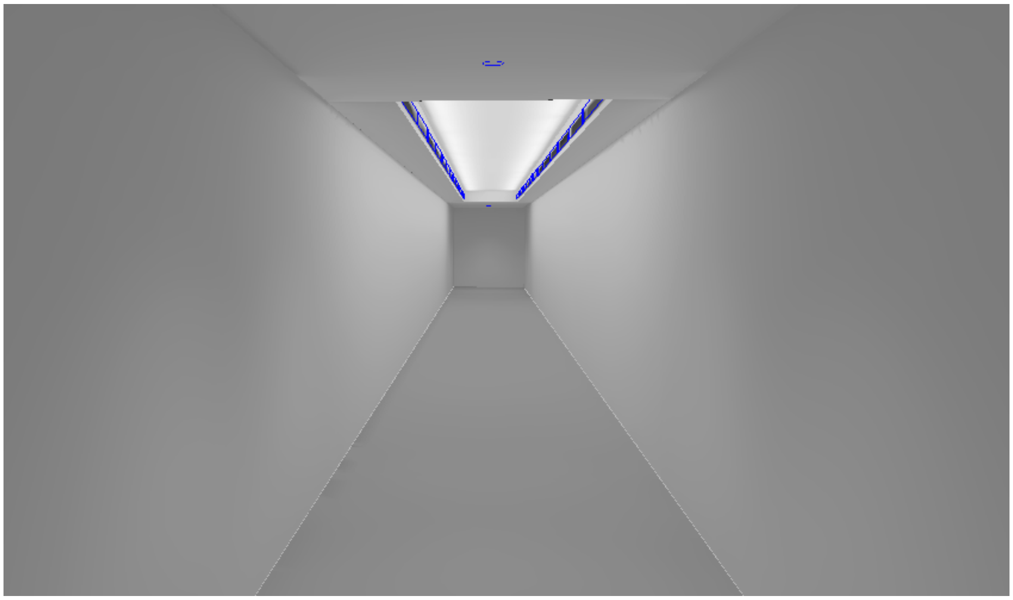


Figure 62: Core Lighting Plan

The offices all have 1’ x 4’ suspended LED ambient lighting. The fixtures are directly suspended over the desks and 6’ above the floor. The lighting rendering can be referenced in Figure 60 below. The offices also have task lighting that was not rendered in this figure.

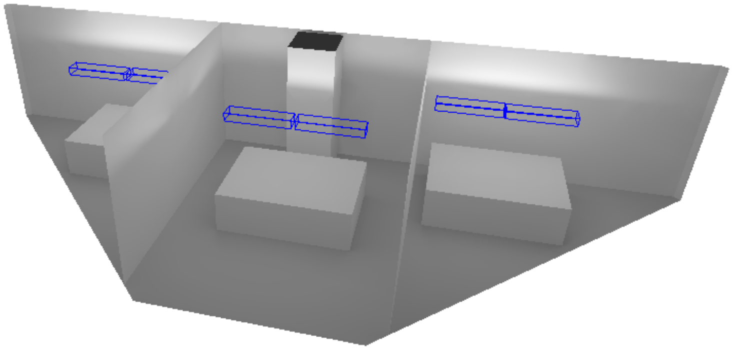


Figure 63: Ambient Typical Office Rendering

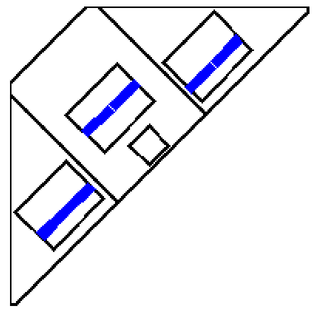


Figure 64: Ambient Typical Office Layout

As shown in Figure 65, the conference room has 1’ x 4’ LED lamps suspended 6’ from the floor with down lights around the perimeter of the room for presentation purposes. Figure 66 shows a full floor rendering of the ambient lighting for a typical office layout. To further promote sustainability in the building there are photometric sensors at the exterior facing each of the aisles in the open office space. The photometric sensors dim and turn the exterior lights off when the daylight is bright enough. The floors also have a motion sensor system for non-office hours. This will allow for the lighting system to light only the areas of need on the floor, rather than wasting energy to light the whole floor.

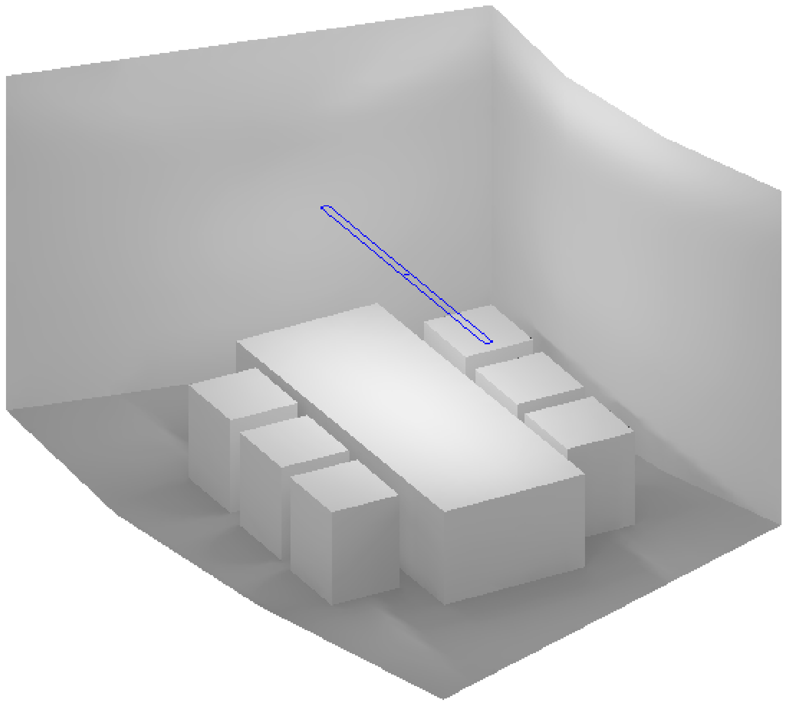


Figure 65: Conference Room Lighting

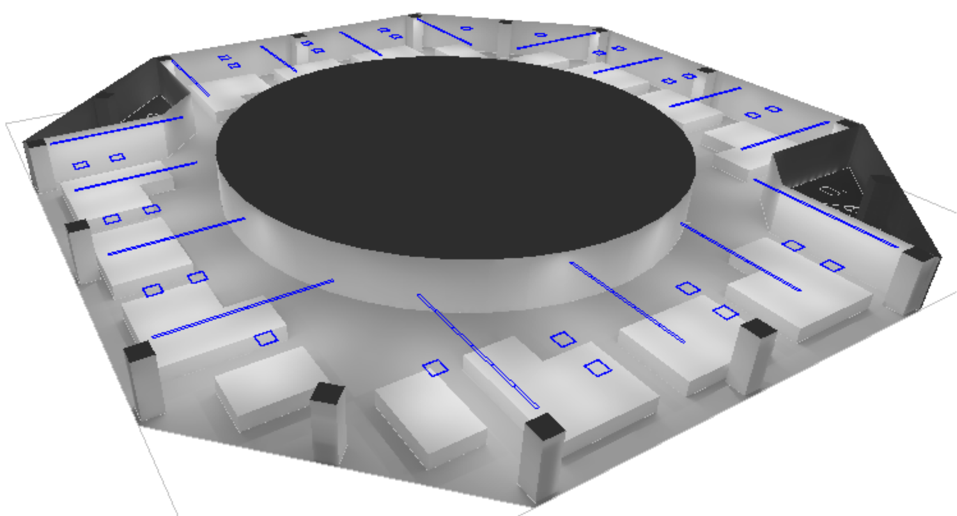


Figure 66: Ambient Typical Floor Rendering

Along with the lighting systems, the use of daylighting is accentuated with an interior light shelf. The ceiling is a cloud ceiling that ends 3’ off the curtain wall and allows for more sunlight to hit the light shelf and reflect deeper into the interior space. The reflectance on the interior surfaces is higher to heighten the use of daylighting in the space. The lighting system in 350 Mission accentuates the use of sustainability practices in the building and encourages sustainable living to the occupants of the space.

4.6 LEED

The new design of 350 Mission can qualify for LEED Gold accreditation due to the sustainable practices used in the construction and building occupancy phases. LEED for New Construction (Version 2009) addresses seven topics: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design, and regional priority.

One of the challenges of the competition required the team to optimize the building's energy performance and reduce its environmental and economic impacts. For the new building, the team increased the building energy performance by thirty-two percent by designing an efficient mechanical system that includes one-hundred percent natural air ventilation, in-floor active chilled beams, and zone-controlled diffusers to provide a comfortable interior environment. The new design also includes a rainwater collection system that collects rainwater and uses it to water the green wall in the lobby.

The team's new design also increases the community development and connectivity in Downtown San Francisco, with the lobby areas specifically allocated for public assembly. The project site is located in a prime location because tenants are able to use various transportation systems such as the subway, buses, ferries, and bike routes. The team has also included parking spaces for electric vehicles and storage spaces for bicycles. Appendix N contains a detailed breakdown of all the LEED points that can be achieved by the new building.

5.0 Conclusion

For the 2014 Student Competition, the team designed a high-rise that can achieve LEED Gold certification and includes innovative and environmentally friendly architectural, structural, and mechanical systems. The architectural design features a unique octagonal footprint with a central circular core wall and diagonal cross-bracing on the exterior. This design increased the floor space on each floor and increased the usable workspace. The lobby features a three-story public atrium with various amenities and a massive central green wall. The team then created the structural design based on the architectural design. In addition to maintaining the building's structural integrity, the design minimized the building's drift to half the allowable code prescribed story drift value. Lastly, the mechanical design features a hybrid under-air floor distribution system with in-floor active chilled beams along the perimeter of the office floor. Located in the office sub-floor, the mechanical design maximizes the floor-to-ceiling window height, enhancing the architectural design.

The team learned many lessons throughout the design process of 350 Mission that future teams can benefit from. Firstly, future teams should not completely redesign the architecture of the building, instead using the design provided in order to save time. By doing this, the teams can focus on developing and analyzing the systems judged in the competition. Secondly, much more analysis should be done by the team members in order to have a more competitive submission. Thirdly, all of the systems, including the structural, mechanical, and electrical systems, should be modeled in Revit and integrated together. Teams should focus more on integration and sustainability than on architecture.

This project gave the team members a fundamental understanding of the building design process, combining all of the knowledge gained in engineering courses to create building systems that integrate and work with each other. It also expanded each member's knowledge of different green technologies available on the market and how high-rise buildings can effectively incorporate sustainable technology.

Works Cited

American Institute of Steel Construction Inc. 2005. *Specification for Structural Steel Buildings ANSI/AISC 360-05.* Chicago, Illinois: American Institute of Steel Construction Inc.

American Institute of Steel Construction Inc. . 2005. *Seismic Provisions for Structural Steel Buildings.* Chicago, Illinois: American Institute of Steel Construction, Inc.

American Society of Civil Engineers and Structural Engineering Institute. 2010. *Minimum Design Loads for Buildings and Other Structures ASCE/SEI 7-10.* Reston, Virginia: American Society of Civil Engineers.

ASCE Charles Pankow Foundation Annual Architectural Engineering Student Competition. 2013. *2014 Project Guidelines.* Accessed September 2, 2013. http://content.asce.org/studentcompetition/index.html.

2013. "Chapter 33." In *California Building Code*, Section 3309, 3311.

2013. "Chapter 33." In *California Building Code 2013*, Section 3305.

D'Agenese, Joseph. n.d. *This Old House Magazine: Radiane Floor Heating.* Accessed October 13, 2013. http://www.thisoldhouse.com/toh/article/0,,1548320,00.html .

D'Agense, Joseph. n.d. *This Old House Magazine.* Accessed 10 13, 2013. http://www.thisoldhouse.com/toh/article/0,,1548320,00.html.

n.d. *Earthquake History of the Bay Area.* Accessed September 15, 2013. http://www.earthquakesafety.com/earthquake-history.html.

Earthquake Safety.com. n.d. http://www.earthquakesafety.com/earthquake-history.html.

Ellsworth, W.L. n.d. *The Great 1906 San Francisco Earhtquake.* Accessed September 22, 2013. http://earthquake.usgs.gov/regional/nca/1906/18april/index.php.

Energy Design Resources. n.d. *Energy Design Resources: Brief Design Underfloor Air Distribution and Access Floors.* Accessed October 14, 2013. http://energydesignresources.com/media/1792/EDR_DesignBriefs_underfloordistro.pdf?tracked=true.

Geology, California Division of Mines and. 2000-2009. *Seismic Hazard Evaluation of City and County of San Francisco.* Accessed September 12, 2013. http://www.sfgsa.org/modules/showdocument.aspx?documentid=10438.

International Code Concil. 2009. "Internation Building Code 2009." Chapters 3,5,6,7,9,10,16. International Code Concil .

Johansson, Jorgen, and Department of Civil Engineering University of Washington. n.d. *Welcome to the Soil Liquefactaion,.* Accessed September 15, 2013. http://www.ce.washington.edu/~liquefaction/html/main.html.

McQuay International. 2001. Accessed 10 14, 2013. http://www.yalemech.com/pdfs/multi_zone_systems.pdf.

—. n.d. *HVAC Systems : Multi-Zone Systems.* Accessed October 14, 2013. http://www.scribd.com/doc/19023899/Multi-Zone-Systems,.

Rollo, Treadwell &. 2012. *Geotechnical Investigation 350 Mission Street San Francisco, California.* Project 730466502, San Francisco: Treadwell & Rollo.

Roth, Kurth, John Dieckmann, Robert Zogg, and James Brodrick. 2007. "Chilled Beam Cooling." *ASHRAE Journal* 1.

Simpson, Lori A. n.d. *Case Studies in Mission Bay, San Francisco: Deep Foundations in Challengine Soil Conditions.* Accessed September 15, 2013. http://www.treadwellrollo.com/files/FileUpload/70/Case%20Studies%20in%20Mission%20Bay%20Paper.pdf .

State Government Victoria. n.d. "Public Health Division: Radiant Floor Heating." http://docs.health.vic.gov.au/docs/doc/EB065358055413F3CA257ACA00137D4E/$FILE/whatisacoolingtower.pdf . Accessed October 13, 2013.

U.S Department of Energy. 2012. *Radiant Heating.* 06 24. Accessed 10 13, 2013. http://energy.gov/energysaver/articles/radiant-heating.

—. n.d. *U.S Department of Energy: Radiant Heating.* Accessed October 14, 2013. http://energy.gov/energysaver/articles/radiant-heating.

United States Geological Survey. n.d. *When will it happen again?* Accessed September 22, 2013. http://earthquake.usgs.gov/regional/nca/1906/18april/whenagain.php.

Victoria, State Government. n.d. *Public Health Division.* Accessed 10 13, 2013. http://docs.health.vic.gov.au/docs/doc/EB065358055413F3CA257ACA00137D4E/$FILE/whatisacoolingtower.pdf.

Image Citations

350 Mission Street Building Site. Courtesy of Google Maps.

A Multi-Zone System. Courtesy of Royal Institute of British Architects, Sustainability Hub.

A Single Zone System. Courtesy of Royal Institute of British Architects, Sustainability Hub.

Bending-Dominated Displacement. Courtesy of Lateral Load Design of Tall Buildings.

Carbon Emission of Materials. Courtesy of Building Construction.

Comparison of VAV and DOAS Systems. Courtesy of Platts.

Configurations of Direct Outdoor Air System. Courtesy of Platts.

Different Features of Curtain Wall Systems. Courtesy of TGP America.

Existing Architectural Design. Courtesy of Kilroy Realty Corporation, 350 Mission Street.

Existing Office Layout. Courtesy of Kilroy Realty Corporation, 350 Mission Street.

Facade of Existing Building. Courtesy of Kilroy Realty Corporation, 350 Mission Street.

First Lobby Level of Existing Design. Courtesy of Kilroy Realty Corporation, 350 Mission Street.

History of Earthquake in the San Francisco Bay. Courtesy of Bancroft Library.

Idealized Subsurface Profile A-A'. Courtesy of Treadwell & Rollo.

Illustration of Stack Ventilation. Courtesy of Royal Institute of British Architects, Sustainability Hub.

LEED New Construction Points. Courtesy of United States Green Building Council.

Mechanical Zones. Courtesy of Kilroy Realty Corporation, 350 Mission Street.

Regional Faults and Seismicity. Courtesy of Treadwell & Rollo.

San Francisco Bay Region Earthquake Probability. Courtesy of USGS San Francisco Bay Region Earthquake Probability.

Second Lobby Level of Existing Design. Courtesy of Kilroy Realty Corporation, 350 Mission Street.

Single-sided Ventilation & Cross Ventilation. Courtesy of Royal Institute of British Architects, Sustainability Hub.

Soil Layers in Yerba Buena Mud Area. Courtesy of Treadwell & Rollo.

Soil Liquefaction Area. Courtesy of California Division of Mines and Geology.

STAAD Model Layout. Courtesy of Skidmore Owens & Merrill.

Typical Structural Concrete. Courtesy of Taranath, Bungale S. 2005. Wind and Earthquake Resistant Buildings Structural Analysis and Design.
Wall-frame Interaction. Courtesy of Lateral Load Design of Tall Buildings.

Appendix A: Seismic Loads

ASCE 7-10 Provisions for Seismic Design

1. Determine mapped acceleration parameters S_S and S_1 *(Web Application from the USGS website)*:

    S_S – mapped Maximum Considered Earthquake (MCE_R), 5% damped, spectral response acceleration parameter at short periods
    S_1 - mapped Maximum Considered Earthquake (MCE_R), 5% damped, spectral response acceleration parameter at a period of 1 second
    S_{DS} - design, 5% damped, spectral response acceleration parameter at short periods
    S_{D1} - design, 5% damped, spectral response acceleration parameter at a period of 1 second
    S_{MS} - mapped MCE_R, 5% damped, spectral response acceleration parameter at short periods adjusted for site class effects
    S_{M1} - mapped MCE_R, 5% damped, spectral response acceleration parameter at 1 second adjusted for site class effects
    Risk Category- III (building structures that have high occupancy levels ex. High-rise office buildings)

    S_S – 2.439 g
    S_1 – 1.172 g

2. Determine Site Class *(ASCE 7, 11.4.2):*

    Site Class D- as classified by the Rockwell Geotechnical Report
    It is also the default site class.

3. Determine MCE $S_{MS,}$ $S_{M1,}$ $F_{A,}$ F_V *(ASCE 7, 11.4.3):*

$$S_{MS}=F_A S_S$$
$$S_{M1}=F_A S_1$$

    S_{MS} = 2.439 g

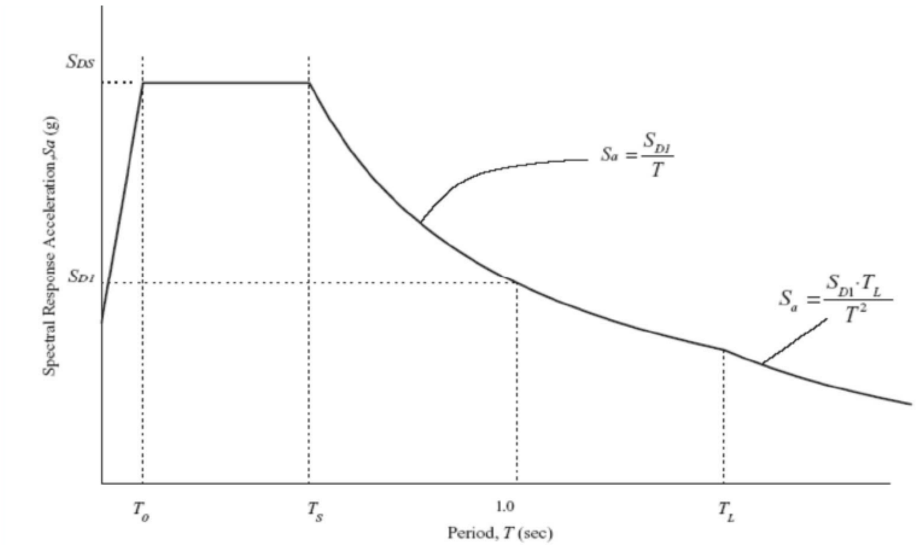
    S_{M1} = 1.759 g

4. Determine Design $S_{DS,}$ S_{D1} *(ASCE 7, 11.4.4):*

$$S_{DS} = \frac{2}{3} S_{MS}$$

$$S_{D1} = \frac{2}{3} S_{M1}$$

S_{DS} = 1.626 g
S_{D1} = 1.172 g



(ASCE 7-10, Figure 11.4-1 Design Response Spectrum)

a. For periods less than T_o:

$$S_a = S_{DS}\left(0.4 + 0.6\,\frac{T}{T_0}\right)$$

$$T_0 = 0.2\,\frac{S_{D1}}{S_{DS}}$$

$$T = C_u * T_a$$
$$T_a = C_t h_n^x$$

C_u (coefficient for upper limit on calculated period):

$S_{D1} \geq 0.4$ then C_u = 1.4 *(ASCE 7-10, Figure 12.8-1 Coefficient for Upper Limit on Calculated Period)*

C_t & x (Coefficient for approximate period parameters):

All other structural system then:

C_t = 0.02 ft. or 0.0488 m

X= 0.75 *(ASCE 7-10, Figure 12.8-2 Values of Approximate Period Parameters)*

h_n (Structural height of building):

Structural height of building = 413.79 ft.

$T_a = 0.02\ (413.79)^{(0.75)}$ = 1.835 s – Approximate building period

$T = 1.4 * 1.835 = 2.569$ s – Fundamental building period

$T_L = 12$ s *(Refer to ASCE 7-10, Figure 22-12 Mapped Long-Period Transition Period for the Conterminous United States)*

$S_a = 1.626\ (0.4 + 0.6\ (2.569/0.144)) = 2.391$ g

b. For periods in between T_o and T_S:
   i. The design spectral response S_a shall be equal to S_{DS}

c. For period greater than T_S and less than or equal to T_L:

$$S_a = \frac{S_{D1}}{T}$$

$$T_S = \frac{S_{D1}}{S_{DS}}$$

$T_S = 1.172/\ 1.626 = 0.721$ s
$S_a = 1.172/\ 2.569 = 0.4562$ g

d. For periods more than T_L:

$$S_a = \frac{S_{D1}T_L}{T^2}$$

$S_a = 1.172 * 12 / (2.569)^2 = 2.131$ g

5. Assign Importance Factor I_E *(ASCE 7, 11.5.1):*

   Seismic Importance Factor- 1.25

   (Refer to *ASCE 7-10, Table 1.5-2 Importance Factors)*

6. Assign Seismic Design Category *(ASCE 7, 11.5.1):*

   Seismic Design Category- **E** (when S_1 is greater than or equal to 0.75g, the Seismic Design Category is E for buildings in Risk Categories I, II, and **III**)

7. Select seismic-force resisting structural system *(ASCE 7, Table 12.2-1):*

   R= 6 (*ASCE 7-10 Table 12.2-1 Design Coefficients and Factors for Seismic Force-Resisting Systems, Building Frame System, Special reinforced concrete shear walls)*

8. Define seismic load effects and combinations for analysis *(ASCE 7, 12.4):*

Section	#	Equation	Seismic Load Effect
2.3.2	5	1.2 D + 1.0 E + L + 0.2 S	$E = E_h + E_v$
2.3.2	7	0.9 D + 1.0 E	$E = E_h - E_v$
2.4.1	5	D + (0.6 W or 0.7 E)	$E = E_h + E_v$
2.4.1	6b	D + 0.7 L + 0.75 (0.7 E) + 0.75 S	$E = E_h + E_v$
2.4.1	8	0.6 D + 0.7 E	$E = E_h - E_v$

E_h – Horizontal Seismic Load Effect

$$E_h = \rho Q_E$$

ρ – Redundancy factor = 1.3

Q_E – Effects of horizontal seismic forces from V or F_p

$$E_h = \rho Q_E = 1.3 * 1.01 \text{ x } 10^7 = 1.31 \text{ x } 10^7 \text{ lbs.}$$

E_v - Vertical Seismic Load Effect

$$E_v = 0.2\ S_{DS} D$$

D – Effect of dead load

$$E_v = 0.2\ (1.626)(1.04 \text{ x } 10^8) = 3.38 \text{ x } 10^7 \text{ lbs.}$$

Level	Weight	i	Height (ft)	H (in)	$H_x K$	$W_x H_x k$	C_{vx}	Vertical-F_x	Horizontal- V_x
B4	5.25E+06	1	7.67	92.04	8.47E+03	4.4E+10	0.000	5.00E+02	1.01E+07
B3	4.72E+06	2	17.67	212.04	4.50E+04	2.1E+11	0.000	2.38E+03	1.01E+07
B2	4.57E+06	3	27.67	332.04	1.10E+05	5E+11	0.001	5.67E+03	1.01E+07
B1	5.88E+06	4	42.00	504.00	2.54E+05	1.5E+12	0.002	1.68E+04	1.01E+07
Lobby	8.63E+06	5	96.00	1,152.00	1.33E+06	1.1E+13	0.013	1.29E+05	1.01E+07
5	2.75E+06	6	109.17	1,310.00	1.72E+06	4.7E+12	0.005	5.30E+04	9.95E+06
6	2.75E+06	7	122.33	1,468.01	2.16E+06	5.9E+12	0.007	6.66E+04	9.89E+06
7	2.75E+06	8	135.50	1,626.01	2.64E+06	7.3E+12	0.008	8.17E+04	9.83E+06
8	2.75E+06	9	148.67	1,784.02	3.18E+06	8.7E+12	0.010	9.83E+04	9.74E+06
9	2.75E+06	10	161.84	1,942.02	3.77E+06	1E+13	0.012	1.16E+05	9.65E+06
10	2.75E+06	11	175.00	2,100.02	4.41E+06	1.2E+13	0.013	1.36E+05	9.53E+06
11	2.75E+06	12	188.17	2,258.03	5.10E+06	1.4E+13	0.016	1.57E+05	9.39E+06
12	2.75E+06	13	201.34	2,416.03	5.84E+06	1.6E+13	0.018	1.80E+05	9.24E+06
14	2.75E+06	14	214.50	2,574.04	6.63E+06	1.8E+13	0.020	2.05E+05	9.06E+06
15	2.75E+06	15	227.67	2,732.04	7.46E+06	2.1E+13	0.023	2.31E+05	8.85E+06
16	2.75E+06	16	240.84	2,890.04	8.35E+06	2.3E+13	0.026	2.58E+05	8.62E+06
17	2.75E+06	17	254.00	3,048.05	9.29E+06	2.6E+13	0.028	2.87E+05	8.36E+06
18	2.75E+06	18	267.17	3,206.05	1.03E+07	2.8E+13	0.031	3.17E+05	8.08E+06
19	2.75E+06	19	280.34	3,364.06	1.13E+07	3.1E+13	0.035	3.50E+05	7.76E+06
20	2.75E+06	20	293.51	3,522.06	1.24E+07	3.4E+13	0.038	3.83E+05	7.41E+06
21	2.75E+06	21	306.67	3,680.06	1.35E+07	3.7E+13	0.041	4.18E+05	7.03E+06
22	2.75E+06	22	319.84	3,838.07	1.47E+07	4E+13	0.045	4.55E+05	6.61E+06
23	2.82E+06	23	333.01	3,996.07	1.60E+07	4.5E+13	0.050	5.06E+05	6.15E+06
24	2.82E+06	24	346.17	4,154.08	1.73E+07	4.9E+13	0.054	5.46E+05	5.65E+06
25	2.82E+06	25	359.34	4,312.08	1.86E+07	5.2E+13	0.058	5.89E+05	5.10E+06
26	2.82E+06	26	372.51	4,470.08	2.00E+07	5.6E+13	0.063	6.33E+05	4.51E+06
27	2.82E+06	27	385.67	4,628.09	2.14E+07	6E+13	0.067	6.78E+05	3.88E+06
28	2.82E+06	28	398.84	4,786.09	2.29E+07	6.5E+13	0.072	7.25E+05	3.20E+06
29	2.82E+06	29	412.01	4,944.10	2.44E+07	6.9E+13	0.077	7.74E+05	2.47E+06
30	2.82E+06	30	425.18	5,102.10	2.60E+07	7.3E+13	0.082	8.24E+05	1.70E+06
Roof	2.82E+06	31	438.34	5,260.10	2.77E+07	7.8E+13	0.087	8.76E+05	8.76E+05
otal Weight	1.01E+08								
K=	2								
um of Vihik	8.99E+14								
V	1.01E+07								

Basic Combinations for Strength Design
$(1.2 + 0.2\, S_{DS})D + \rho Q_E + L + 0.2\, S$
$(0.9 - 0.2\, S_{DS})D + \rho Q_E + 1.6\, H$

Basic Combinations for Allowable Stress Design
$(1.0 + 0.14\, S_{DS})D + H + F + 0.7\rho Q_E$
$(1.0 + 0.1\, S_{DS})D + H + F + 0.525\rho Q_E + 0.75L + 0.75\, (l_R$, S or R)
$(0.6 - 0.14\, S_{DS})D + 0.7\rho Q_E + H$

9. Apply seismic loads in those directions that produce the maximum effects *(ASCE 7, 12.5):*

Direction of Loading Seismic Category D (must meet Cat. B and C as well):

Category	**Requirements**
B	Design seismic forces are permitted to be applied independently in each of two orthogonal directions
B	Orthogonal interaction effects are permitted to be neglected
C	(a) Orthogonal combination procedure: 12.8, 12.9, or 16.1. Deemed satisfied if members and their foundations are designed for 100 % of the forces for one direction plus 30 % of the forces for the perpendicular direction.
C	(b) Simultaneous Application of Orthogonal Ground Motion: 16.1 or 16.2
D-F	Any column or wall that forms part of two or more intersecting seismic force-resisting systems and is subjected to axial load due to seismic forces acting along either principal plan axis equaling or exceeding 2-% of the axial design strength of the column or wall shall be designed for the most critical load effect. 12.5.3 (a or b)

10. Perform structural analysis for seismic forces *(ASCE 7, 12.6):*

(Refer to ASCE 7-10, Table 12.6-1 Permitted Analytical Procedures)

Structural Characteristics	Equivalent Lateral Force Analysis *(12.8)*	Modal Response Spectrum Analysis *(12.9)*	Seismic Response History Procedures *(16)*
Structures of light frame construction	X	X	X

Equivalent Lateral Force Analysis:

Seismic Base Shear:

$$V = C_s W$$

$$C_s = \frac{S_{D1}}{T\left(\frac{R}{I_e}\right)}$$

Requirements and check to use the equation above:

- $For\ T \le T_L$
- $C_s = 0.044\ S_{DS}\ I_e \geq 0.01$
    - $C_s = 0.044\ (1.626)\ (1.25) \geq 0.01 \rightarrow 0.08943 \geq 0.01$ (Check)
- For structures located where $S_1 \geq 0.6$ g, C_s should not be less than the C_s calculated in this formula: $C_s = 0.5\ S_1 / (R/\ I_e)$
    - $C_s = 0.5\ (1.172) / (6 / 1.25) = 0.1221$
    - R= 6 (*ASCE 7-10 Table 12.2-1 Design Coefficients and Factors for Seismic Force-Resisting Systems, Building Frame System, Special reinforced concrete shear walls)*

$C_s = \frac{1.172}{2.569\left(\frac{6}{1.25}\right)}$ = 0.0950 (Seismic response coefficient)

Effective Seismic Weight *(ASCE 7, 12.7.2):*

The weight includes dead load above the base and other loads above the base:

1. Areas used for storage- include a minimum of 25% floor live load
2. Provision for partitions- 10 psf (0.48 KN/ m^2) of floor area
3. Total operating weight of permanent equipment
4. No snow load is considered in this case
5. Weight of landscaping and other materials on roof:

W= 1.04×10^8 + 0.25(25,000) + 10*(6601) + 500,000+ (2,149,378) = 1.06×10^8 lbs.

$V = C_s W$ = 0.0950 * 1.06×10^8 = 1.01×10^7 lbs.

Vertical Distribution of Seismic Forces:

$$F_x = C_{vx} V$$

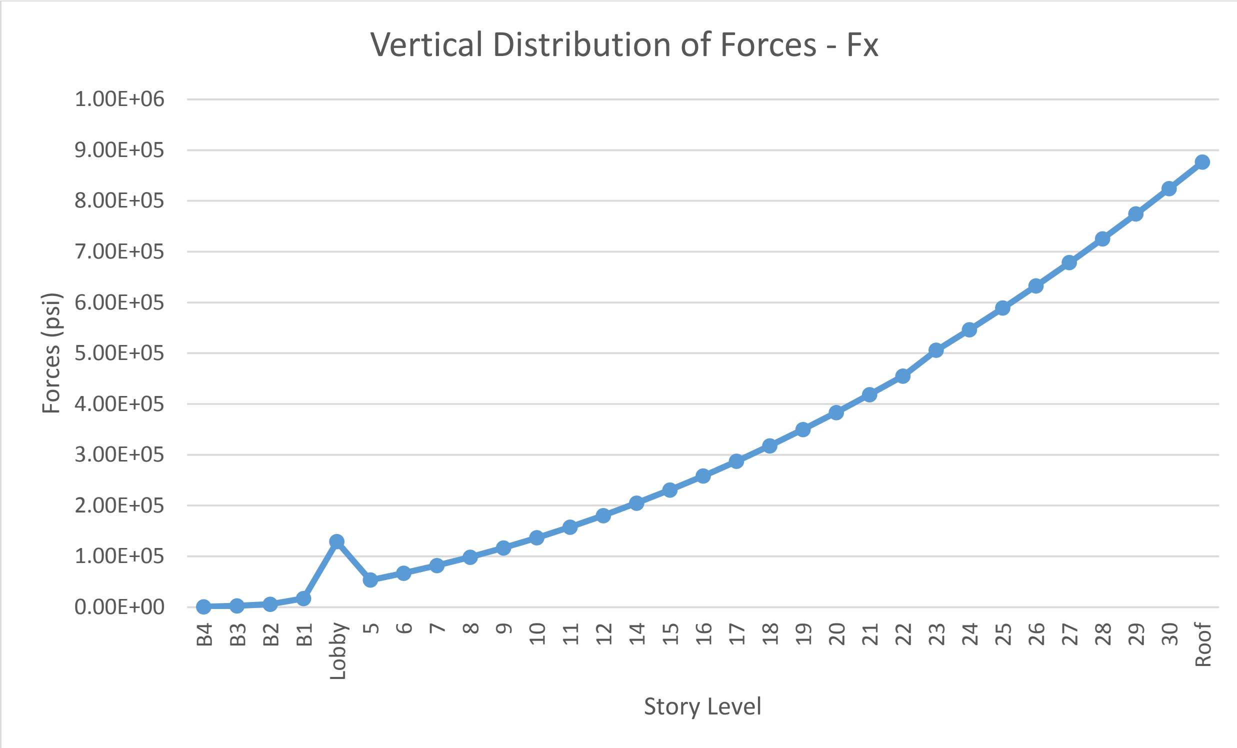
$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$$

W_x = total effective seismic weight

h_x = 413.79 ft.

k = 2 , for structures having a period of 2.5 s or more

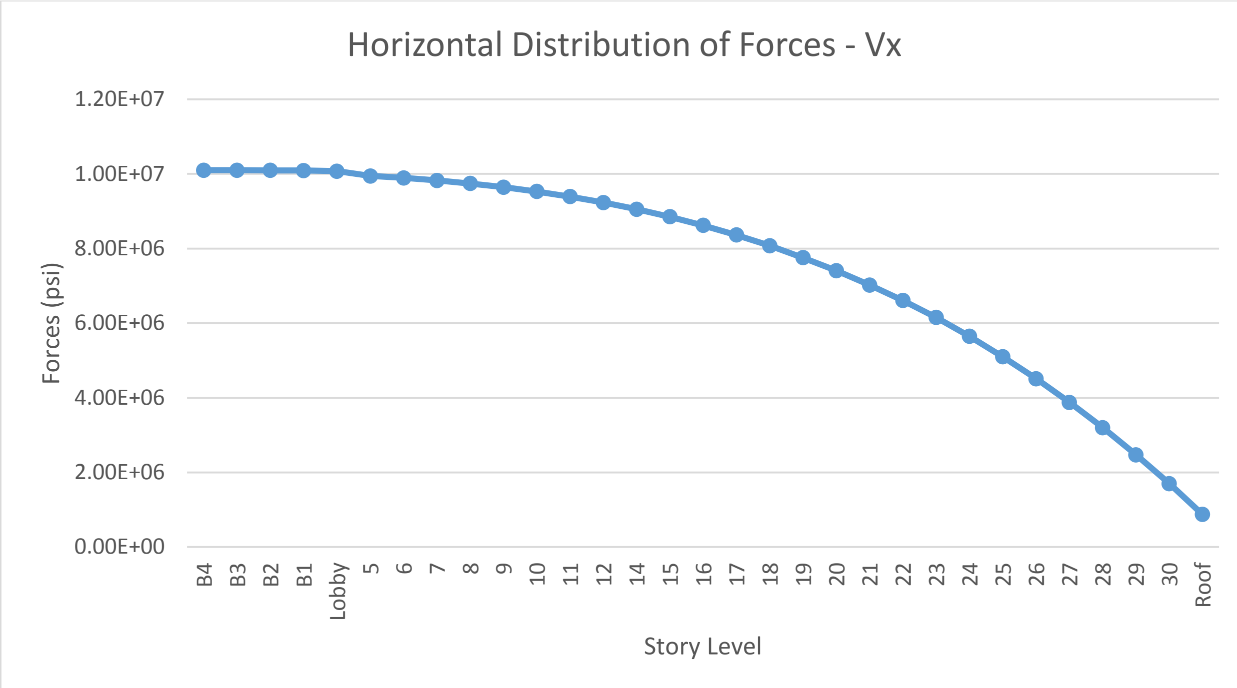
n = 30



Horizontal Distribution of Seismic Forces:

$$V_x = \sum_{i=x}^{n} F_i$$

F_i – the portion of the seismic base shear induced at level I



Torion & deflection will be based off of STAAD model stimulations:

Inherent Torsion – for flexible diaphragms, the distribution of forces to the vertical elements shall account for the position and distribution of the masses supported.

Accidental Torsion – for flexible diaphragms, the distribution of forces to the vertical elements shall account for the position and distribution of the masses supported.

Amplification of Accidental Torsional Moment:

$$A_x = \left(\frac{\delta_{max}}{1.2\delta_{avg}}\right)^2$$

$$\delta_x = \frac{C_d \delta_{xe}}{I_e}$$

C_d = 5 (*ASCE 7-10 Table 12.2-1 Design Coefficients and Factors for Seismic Force-Resisting Systems, Building Frame System, Special reinforced concrete shear walls)*

$\delta_{xe} = C_u * T_a =$

P-Delta Effects:

$$\theta = \frac{P_x \Delta I_e}{V_x h_{sx} C_d}$$

Δ - 0.010 h_{sx} (story height below level x) (*ASCE 7-10 Table 12.12-1 Allowable Story Drift)*

$\theta = \frac{P_x \Delta I_e}{V_x h_{sx} C_d}$

Stability Coefficient θ < θ_{max}

$$\theta_{max} = \frac{0.5}{\beta C_d} \leq 0.25$$

β – ratio of shear demand to shear capacity for story between levels x and x-1. This ratio is permitted to be conservatively taken as 1.0.

$\theta_{max} = \frac{0.5}{(1)(5)} \leq 0.25$ Check

Wall Anchorage of Structural Walls and Transfer of Design Forces into Diaphragms (12.11.2)

$$F_p = 0.4\, S_{DS}\, k_a I_e W_p$$

$$k_a = 1.0 + \frac{L_f}{100}$$

$k_a = 1.0 + \frac{123}{100}$ = 2.23

$F_p = 0.4\ (1.626)(2.23)(1.25)$(25315957.3) = 45.9 x 10 ^{7}

Modal Response Spectrum Analysis:

Seismic Response History Procedures:

Capacity Design:

1. Select a desirable mechanism of non-linear lateral deformation for the structure, which identifies those structural elements and actions that are intended to undergo nonlinear response. The mechanism should not lead to concentrated nonlinear deformations such as occurs, for example, with a story mechanism.
2. Ensure that the detailing of the designated nonlinear elements provides adequate ductility capacity, i.e., allows the elements to deform well beyond yield without significant strength degradation.
3. Design all other elements and actions of the structure for elastic, or nearly elastic, response.

(Maffei & Yuen, Seismic Performance and Design Requirements for High-Rise Concrete Buildings)

Flexure-Governed Design:

Two stage design process:

1. Design the building to comply with all code provisions (except for identified exceptions such as the height limit). For tall buildings with long periods, this code-level demand is typically governed by minimum base shear requirements.
2. Analyze the structure using an NLRH analysis at the Maximum Considered Earthquake Level of ground motion. It is currently defined in building codes to correspond to a 975-year return period in California.

(Maffei & Yuen, Seismic Performance and Design Requirements for High-Rise Concrete Buildings)

Deflection Calculations

CA Building Codes, Table 1604.3 Deflection Limits

Floor Members- Live and Dead Load – l/ 240

X axis- 137 ft. * 12 inches / 240 = 6.85 inches

Y axis- 135 ft. * 12 inches / 240 = 6.75 inches

ACI 318, Table 9.5b Table Maximum Permissible Computed Deflections

Floors not supporting or attached to nonstructural elements likely to be damaged by large deflection, immediate deflection due to live load L- l/ 360 ☐

137 ft. * 12 in/ 360 = 4.6 inches

135 ft. * 12 in/ 360 = 4.5 inches

Roof or floor construction supporting or attached to nonstructural elements likely to be damaged by large deflection, total deflection - l/ 480 ☐

137 ft. * 12 in/ 480 = 3.4 inches

135 ft. * 12 in/ 480 = 3.4 inches

TABLE 1604.3
DEFLECTION LIMITS[a, b, c, h, i]

CONSTRUCTION	L	S or W^f	$D + L^{d,g}$
Roof members:[e]			
Supporting plaster or stucco ceiling	l/360	l/360	l/240
Supporting nonplaster ceiling	l/240	l/240	l/180
Not supporting ceiling	l/180	l/180	l/120
Floor members	l/360	—	l/240
Exterior walls and interior partitions:			
With plaster or stucco finishes	—	l/360	—
With other brittle finishes	—	l/240	—
With flexible finishes	—	l/120	—
Farm buildings	—	—	l/180
Greenhouses	—	—	l/120

For SI: 1 foot = 304.8 mm.

a. For structural roofing and siding made of formed metal sheets, the total load deflection shall not exceed l/60. For secondary roof structural members supporting formed metal roofing, the live load deflection shall not exceed l/150. For secondary wall members supporting formed metal siding, the design wind load deflection shall not exceed l/90. For roofs, this exception only applies when the metal sheets have no roof covering.

b. Interior partitions not exceeding 6 feet in height and flexible, folding and portable partitions are not governed by the provisions of this section. The deflection criterion for interior partitions is based on the horizontal load defined in Section 1607.14.

c. See Section 2403 for glass supports.

d. For wood structural members having a moisture content of less than 16 percent at time of installation and used under dry conditions, the deflection resulting from $L + 0.5D$ is permitted to be substituted for the deflection resulting from $L + D$.

e. The above deflections do not ensure against ponding. Roofs that do not have sufficient slope or camber to assure adequate drainage shall be investigated for ponding. See Section 1611 for rain and ponding requirements and Section 1503.4 for roof drainage requirements.

f. The wind load is permitted to be taken as 0.42 times the "component and cladding" loads for the purpose of determining deflection limits herein.

g. For steel structural members, the dead load shall be taken as zero.

h. For aluminum structural members or aluminum panels used in skylights and sloped glazing framing, roofs or walls of sunroom additions or patio covers, not supporting edge of glass or aluminum sandwich panels, the total load deflection shall not exceed l/60. For continuous aluminum structural members supporting edge of glass, the total load deflection shall not exceed l/175 for each glass lite or l/60 for the entire length of the member, whichever is more stringent. For aluminum sandwich panels used in roofs or walls of sunroom additions or patio covers, the total load deflection shall not exceed l/120.

i. For cantilever members, l shall be taken as twice the length of the cantilever.

TABLE 9.5(b) — MAXIMUM PERMISSIBLE COMPUTED DEFLECTIONS

Type of member	Deflection to be considered	Deflection limitation
Flat roofs not supporting or attached to nonstructural elements likely to be damaged by large deflections	Immediate deflection due to live load ***L***	**ℓ/180***
Floors not supporting or attached to nonstructural elements likely to be damaged by large deflections	Immediate deflection due to live load ***L***	**ℓ/360**
Roof or floor construction supporting or attached to nonstructural elements likely to be damaged by large deflections	That part of the total deflection occurring after attachment of nonstructural elements (sum of the long-term deflection due to all sustained loads and the immediate deflection due to any additional live load)†	**ℓ/480**‡
Roof or floor construction supporting or attached to nonstructural elements not likely to be damaged by large deflections		**ℓ/240**§

*Limit not intended to safeguard against ponding. Ponding should be checked by suitable calculations of deflection, including added deflections due to ponded water, and considering long-term effects of all sustained loads, camber, construction tolerances, and reliability of provisions for drainage.

†Long-term deflection shall be determined in accordance with 9.5.2.5 or 9.5.4.3, but may be reduced by amount of deflection calculated to occur before attachment of nonstructural elements. This amount shall be determined on basis of accepted engineering data relating to time-deflection characteristics of members similar to those being considered.

‡Limit may be exceeded if adequate measures are taken to prevent damage to supported or attached elements.

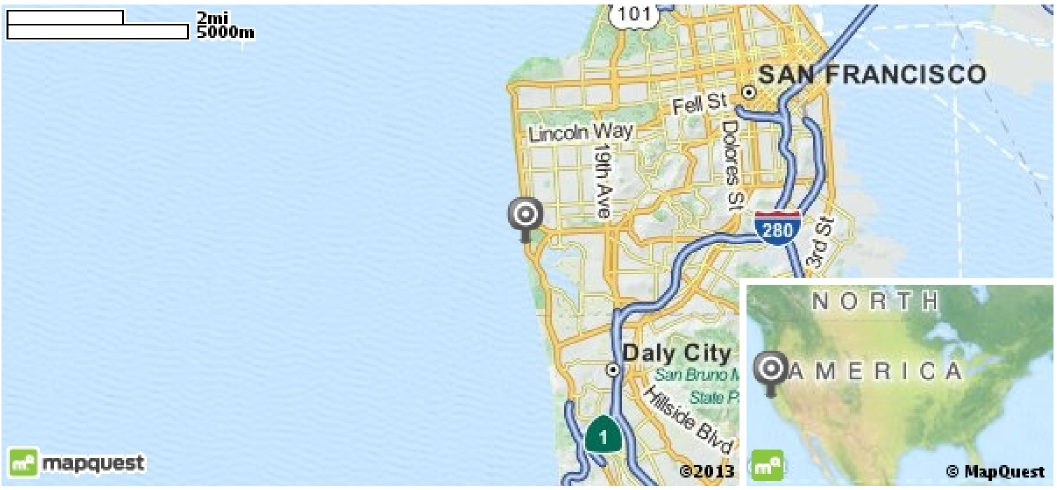
§Limit shall not be greater than tolerance provided for nonstructural elements. Limit may be exceeded if camber is provided so that total deflection minus camber does not exceed limit.

Design Maps Summary Report

Print   View Detailed Report

User–Specified Input

Building Code Reference Document	ASCE 7-10 Standard (which utilizes USGS hazard data available in 2008)
Site Coordinates	37.72994°N, 122.50662°W
Site Soil Classification	Site Class D – "Stiff Soil"
Risk Category	I/II/III

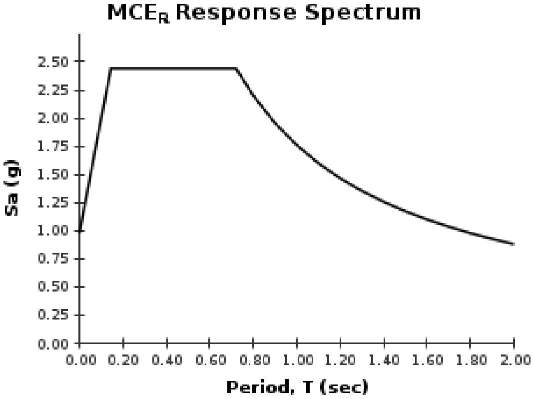


USGS–Provided Output

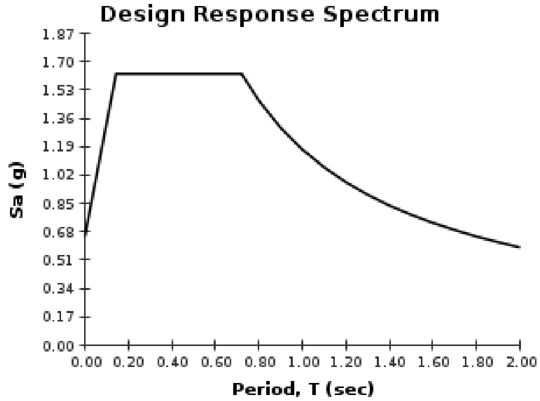
S_S = 2.439 g	S_{MS} = 2.439 g	S_{DS} = 1.626 g
S_1 = 1.172 g	S_{M1} = 1.759 g	S_{D1} = 1.172 g

For information on how the SS and S1 values above have been calculated from probabilistic (risk-targeted) and deterministic ground motions in the direction of maximum horizontal response, please return to the application and select the "2009 NEHRP" building code reference document.

MCE_R Response Spectrum



Design Response Spectrum



For PGA_M, T_L, C_{RS}, and C_{R1} values, please view the detailed report.

USGS Design Maps Detailed Report

Print View Summary Report

ASCE 7-10 Standard (37.72994°N, 122.50662°W)

Site Class D – "Stiff Soil", Risk Category I/II/III

Section 11.4.1 — Mapped Acceleration Parameters

Note: Ground motion values provided below are for the direction of maximum horizontal spectral response acceleration. They have been converted from corresponding geometric mean ground motions computed by the USGS by applying factors of 1.1 (to obtain S_s) and 1.3 (to obtain S_1). Maps in the 2010 ASCE-7 Standard are provided for Site Class B. Adjustments for other Site Classes are made, as needed, in Section 11.4.3.

From Figure 22-1	S_S = 2.439 g
From Figure 22-2	S_1 = 1.172 g

Section 11.4.2 — Site Class

The authority having jurisdiction (not the USGS), site-specific geotechnical data, and/or the default has classified the site as Site Class D, based on the site soil properties in accordance with Chapter 20.

Table 20.3–1 Site Classification

Site Class	$\bar{v}_s$	$\bar{N}$ or $\bar{N}_{ch}$	$\bar{s}_u$
A. Hard Rock	>5,000 ft/s	N/A	N/A
B. Rock	2,500 to 5,000 ft/s	N/A	N/A
C. Very dense soil and soft rock	1,200 to 2,500 ft/s	>50	>2,000 psf
D. Stiff Soil	600 to 1,200 ft/s	15 to 50	1,000 to 2,000 psf
E. Soft clay soil	<600 ft/s	<15	<1,000 psf
	Any profile with more than 10 ft of soil having the characteristics: • Plasticity index *PI* > 20, • Moisture content *w* ≥ 40%, and • Undrained shear strength $\bar{s}_u$ < 500 psf		
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		

For SI: 1ft/s = 0.3048 m/s 1lb/ft² = 0.0479 kN/m²

Section 11.4.3 — Site Coefficients and Risk–Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameters

Table 11.4–1: Site Coefficient F_a

Site Class	Mapped MCE $_R$ Spectral Response Acceleration Parameter at Short Period				
	$S_s \le 0.25$	$S_s = 0.50$	$S_s = 0.75$	$S_s = 1.00$	$S_s \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7 of ASCE 7				

Note: Use straight–line interpolation for intermediate values of S_s

For Site Class = D and S_s = 2.439 g, F_a = 1.000

Table 11.4–2: Site Coefficient F_v

Site Class	Mapped MCE $_R$ Spectral Response Acceleration Parameter at 1–s Period				
	$S_1 \le 0.10$	$S_1 = 0.20$	$S_1 = 0.30$	$S_1 = 0.40$	$S_1 \ge 0.50$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See Section 11.4.7 of ASCE 7				

Note: Use straight–line interpolation for intermediate values of S_1

For Site Class = D and S_1 = 1.172 g, F_v = 1.500

Equation (11.4–1): $S_{MS} = F_aS_S = 1.000 \times 2.439 = 2.439$ g

Equation (11.4–2): $S_{M1} = F_vS_1 = 1.500 \times 1.172 = 1.759$ g

Section 11.4.4 — Design Spectral Acceleration Parameters

Equation (11.4–3): $S_{DS} = ⅔\ S_{MS} = ⅔ \times 2.439 = 1.626$ g

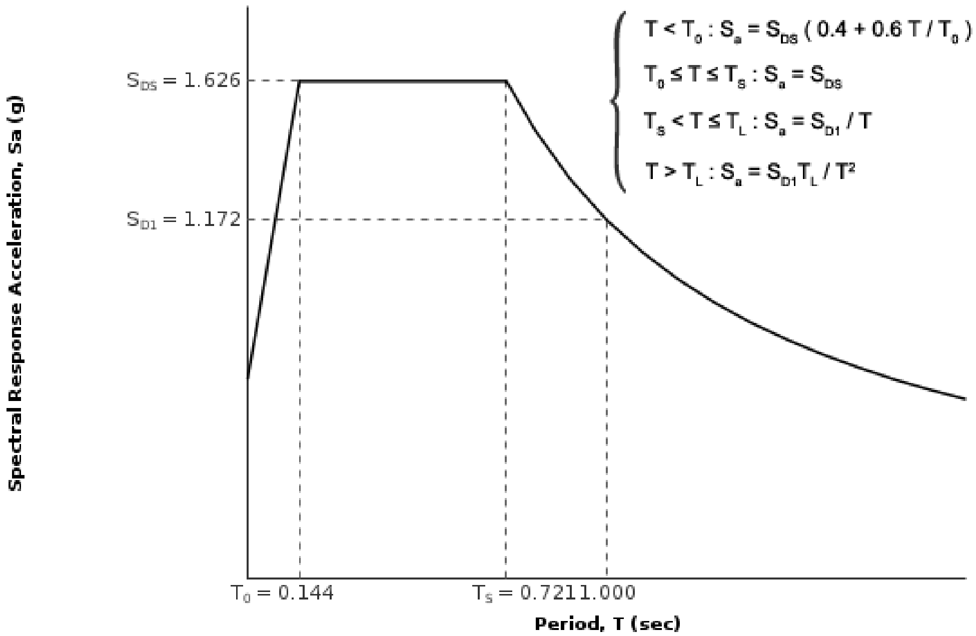
Equation (11.4-4): $S_{D1} = ⅔ S_{M1} = ⅔ \times 1.759 = 1.172$ g

---

Section 11.4.5 — Design Response Spectrum

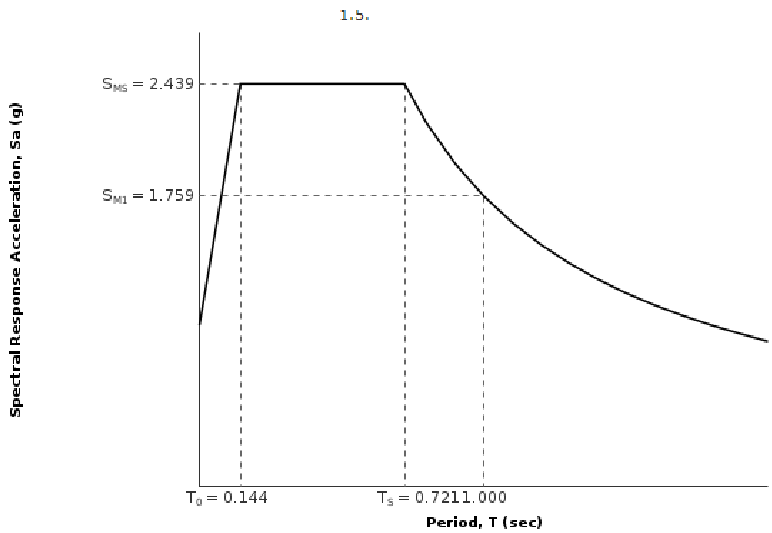
From Figure 22-12 $T_L = 12$ seconds

Figure 11.4-1: Design Response Spectrum



Section 11.4.6 — Risk-Targeted Maximum Considered Earthquake (MCE_R) Response Spectrum

The MCE_R Response Spectrum is determined by multiplying the design response spectrum above by



Section 11.8.3 — Additional Geotechnical Investigation Report Requirements for Seismic Design Categories D through F

From Figure 22-7	PGA = 0.938
Equation (11.8–1):	$PGA_M = F_{PGA}PGA = 1.000 \times 0.938 = 0.938$ g

Table 11.8–1: Site Coefficient F_{PGA}

Site Class	Mapped MCE Geometric Mean Peak Ground Acceleration, PGA				
	PGA ≤ 0.10	PGA = 0.20	PGA = 0.30	PGA = 0.40	PGA ≥ 0.50
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7 of ASCE 7				

Note: Use straight–line interpolation for intermediate values of PGA

For Site Class = D and PGA = 0.938 g, F_{PGA} = 1.000

Section 21.2.1.1 — Method 1 (from Chapter 21 – Site-Specific Ground Motion Procedures for Seismic Design)

From Figure 22-17	C_{RS} = 0.936
From Figure 22-18	C_{R1} = 0.904

Section 11.6 — Seismic Design Category

Table 11.6-1 Seismic Design Category Based on Short Period Response Acceleration Parameter

VALUE OF S_{DS}	RISK CATEGORY		
	I or II	III	IV
$S_{DS} < 0.167g$	A	A	A
$0.167g \le S_{DS} < 0.33g$	B	B	C
$0.33g \le S_{DS} < 0.50g$	C	C	D
$0.50g \le S_{DS}$	D	D	D

For Risk Category = I and S_{DS} = 1.626 g, Seismic Design Category = D

Table 11.6-2 Seismic Design Category Based on 1-S Period Response Acceleration Parameter

VALUE OF S_{D1}	RISK CATEGORY		
	I or II	III	IV
$S_{D1} < 0.067g$	A	A	A
$0.067g \le S_{D1} < 0.133g$	B	B	C
$0.133g \le S_{D1} < 0.20g$	C	C	D
$0.20g \le S_{D1}$	D	D	D

For Risk Category = I and S_{D1} = 1.172 g, Seismic Design Category = D

Note: When S_1 is greater than or equal to 0.75g, the Seismic Design Category is **E** for buildings in Risk Categories I, II, and III, and **F** for those in Risk Category IV, irrespective of the above.

Seismic Design Category ≡ "the more severe design category in accordance with Table 11.6-1 or 11.6-2" = E

Note: See Section 11.6 for alternative approaches to calculating Seismic Design Category

Soil type A	Vs > 1500 m/sec	Includes unweathered intrusive igneous rock. Occurs infrequently in the bay area. We consider it with type B (both A and B are represented by the color blue on the map). Soil types A and B do not contribute greatly to shaking amplification.
Soil type B	1500 m/sec > Vs > 750 m/sec	Includes volcanics, most Mesozoic bedrock, and some Franciscan bedrock. (Mesozoic rocks are between 245 and 64 million years old. The Franciscan Complex is a Mesozoic unit that is common in the Bay Area.)
Soil Type C	750 m/sec > Vs > 350 m/sec	Includes some Quaternary (less than 1.8 million years old) sands, sandstones and mudstones, some Upper Tertiary (1.8 to 24 million years old) sandstones, mudstones and limestone, some Lower Tertiary (24 to 64 million years old) mudstones and sandstones, and Franciscan melange and serpentinite.
Soil Type D	350 m/sec > Vs > 200 m/sec	Includes some Quaternary muds, sands, gravels, silts and mud. Significant amplification of shaking by these soils is generally expected.
Soil Type E	200 m/sec > Vs	Includes water-saturated mud and artificial fill. The strongest amplification of shaking due is expected for this soil type.

http://earthquake.usgs.gov/regional/nca/soiltype/

Category	Representative Buildings	Acceptable Risk
I	Buildings and structures that normally are not subject to human occupancy (e.g., equipment storage sheds, barns, and other agricultural buildings) and that do not contain equipment or systems necessary for disaster response or hazardous materials.	Low probability of earthquake-induced collapse.
II	Most buildings and structures of ordinary occupancy (e.g., residential, commercial, and industrial buildings) except those buildings contained in other categories.	Low probability of earthquake-induced collapse. Limited probability that shaking-imposed damage to nonstructural components will pose a significant risk to building occupants.
III	Buildings and structures that: • Have large numbers of occupants (e.g., high-rise office buildings, sports arenas, and large theaters), • Shelter persons with limited mobility (e.g., jails, schools, and some healthcare facilities); • Support lifelines and utilities important to a community's welfare; or • Contain materials that pose some risk to the public if released.	Reduced risk of earthquake-induced collapse relative to Occupancy Category II structures. Reduced risk of shaking-imposed damage to nonstructural components relative to Occupancy Category II structures. Low risk of release of hazardous materials or loss of function of critical lifelines and utilities.
IV	Buildings and structures that: • Are essential to post-earthquake response (e.g., hospitals, police stations, fire stations, and emergency communications centers) or • House very large quantities of hazardous materials.	Very low risk of earthquake induced-collapse. Low risk that the building or structure will be damaged sufficiently to impair use in post-earthquake response and recovery efforts. Very low risk of release of hazardous materials.

http://c.ymcdn.com/sites/www.nibs.org/resource/resmgr/BSSC/P-749_Chapter5.pdf

Table 1.5-1 Risk Category of Buildings and Other Structures for Flood, Wind, Snow, Earthquake, and Ice Loads

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life. Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure. Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	III
Buildings and other structures designated as essential facilities. Buildings and other structures, the failure of which could pose a substantial hazard to the community. Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released.[a] Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	IV

[a]Buildings and other structures containing toxic, highly toxic, or explosive substances shall be eligible for classification to a lower Risk Category if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2 that a release of the substances is commensurate with the risk associated with that Risk Category.

ASCE 7-10, Table 1.5-1 Risk Category of Buildings

Table 1.5-2 Importance Factors by Risk Category of Buildings and Other Structures for Snow, Ice, and Earthquake Loads[a]

Risk Category from Table 1.5-1	Snow Importance Factor, I_s	Ice Importance Factor—Thickness, I_i	Ice Importance Factor—Wind, I_w	Seismic Importance Factor, I_e
I	0.80	0.80	1.00	1.00
II	1.00	1.00	1.00	1.00
III	1.10	1.25	1.00	1.25
IV	1.20	1.25	1.00	1.50

[a]The component importance factor, I_p, applicable to earthquake loads, is not included in this table because it is dependent on the importance of the individual component rather than that of the building as a whole, or its occupancy. Refer to Section 13.1.3.

ASCE 7-10, Table 1.5-2 Importance Factors

Table 12.6-1 Permitted Analytical Procedures

Seismic Design Category	Structural Characteristics	Equivalent Lateral Force Analysis, Section 12.8[a]	Modal Response Spectrum Analysis, Section 12.9[a]	Seismic Response History Procedures, Chapter 16[a]
B, C	All structures	P	P	P
D, E, F	Risk Category I or II buildings not exceeding 2 stories above the base	P	P	P
	Structures of light frame construction	P	P	P
	Structures with no structural irregularities and not exceeding 160 ft in structural height	P	P	P
	Structures exceeding 160 ft in structural height with no structural irregularities and with $T < 3.5T_s$	P	P	P
	Structures not exceeding 160 ft in structural height and having only horizontal irregularities of Type 2, 3, 4, or 5 in Table 12.3-1 or vertical irregularities of Type 4, 5a, or 5b in Table 12.3-2	P	P	P
	All other structures	NP	P	P

[a]P: Permitted; NP: Not Permitted; $T_s = S_{D1}/S_{DS}$.

ASCE 7-10, Table 12.6-1 Permitted Analytical Procedures

Appendix B: Additional Passive HVAC Systems

In passive design strategies, the building massing is a fundamental and important aspect of the design development. The building mass refers to the size and shape of a building. If the building massing techniques are used correctly, the general size and shape of the building can be used to reduce heat load and maximize renewable energy sources. In colder climates, buildings can be massed for thermal comfort, with the east-west axis of the building being extended to take advantage of the solar gain from the northern and southern exposures. However, this technique may not work as effectively in thinner buildings in colder climates since there is an increased ratio of surface to volume. Thinner buildings operate more efficiently in warmer climates and, due to its surface to volume ratio, natural ventilation can effectively cool its envelope.

Thermal massing in buildings can be used to passively heat or cool a building and is composed of dense and heavy materials. In a direct solar gain system used in the winter, the mass absorbs heat during the daytime due its exposure and radiates the heat back into the space during the night. In the summer, the reverse occurs, with the mass keeping the room cooler by absorbing heat during the daytime. In an indirect solar gain system, the solar heat is collected and trapped in a narrow space between the window and the mass. After this heat passes through the windows, it is absorbed by the mass and this energy is used to heat the cooler air that circulates through the lower vents. The heated air then rises via convection and is pushed back into the room. During the night, dampers can be used to prevent warm air from escaping.

Additionally air can be cooled via the process of geothermal cooling. The earth absorbs 48% of the sun's energy and maintains temperature between 45 and 70 F underground. In a geothermal system, a water solution flows through underground pipes organized in a loop system. The pipes are placed approximately 6ft underground. During the summer, the heat is absorbed from the home (through the normal duct system or radiant heat system) and is transferred underground through the same loop system. There are four different types of geothermal loops: Horizontal Loop, Vertical Loop, Pond Loop, and Open Loop.

When adequate land area is available the horizontal loop system is most commonly used. To install this loop system, trenches are dug approximately 6-8 feet deep and the trench lengths range from 100 to 300 feet.

Vertical loop systems are used when there is limited land space available. To install this system, a drilling rig is used to bore holes 150 to 200 feet deep. Then, a high density U-shaped coiled is inserted and the holes are backfilled with a sealing solution.

A pond loop is used only if there is a large body of water available within 200 feet of the building. This system uses coils of pipes that are 300 to 500 feet in the length and are anchored to the bottom of the body of water.

Finally, an open loop system is used only if there is an abundant supply of high quality well water available. A proper discharge area such as a drainage ditch, river or pond must be available.

Appendix C: Topics for Evaluation in B-Term and C-Term

B-Term

AREAS	TOPIC
Mechanical	**HVAC** ▪ *Evaluate existing system* ▪ *Evaluate 100% outside Air* ▪ *Evaluate 1/3 reduced windows* ▪ *Evaluate suggested mechanical system* ▪ *Compare systems* **Fire Protection** ▪ *Research fire protection requirements* ▪ *Use program evaluate Hydraulic system and pipe sizing*
Structural	**Seismic Calculation for Earthquake Resistance** ▪ *Evaluate Alternative structure (K bracing)* ▪ *Evaluate Liquid Tuned Damper* ▪ *Evaluate Oil dampers* ▪ *Evaluate Shock absorbers* **Steel, Concrete and Composite Structure Evaluation** ▪ *Different design considerations* ▪ *Basic load calculations* ▪ *Column and gravity load specific* ▪ *Wind loads* ▪ *Seismic Calculation* ▪ *Compare systems*

C-Term

AREAS	TOPIC
Mechanical	**HVAC** ▪ *Continual analysis of picked system* ▪ *Finish calculation of HVAC systems seismically reinforced to the building* **Fire Protection** ▪ *Model in Fire Protection Sprinkler Analysis to evaluate Hydraulic system and pipe sizing* **Plumbing** ▪ *Research plumbing sizing requirements* ▪ *Use Fire Protection Sprinkler Analysis evaluate Hydraulic system and pipe sizing*
Structural	**Seismic** ▪ *Continual analysis and model in SAP 2000* **Structure** ▪ *Continual analysis on structure* ▪ *Design of foundation, walls, floor, roof, envelope*
Electrical	**Basic Lighting Calculations** ▪ *Lighting calculations (choose fixtures, foot candle requirement, ASHRAE, IES)* ▪ *Power (wattage output, light power density)* ▪ *2 gray scale models in Visual Lighting 2012 (1 model of typical floor plan and 1 model of the lobby)* ▪ *Create lighting fixture schedule* ▪ *Basic day lighting calculations* ▪ *Import design in Revit*
Project Management	**Scheduling** ▪ *Provide basic project schedule using Primerva* ▪ *Preliminary project planning* **Cost Analysis** ▪ *Delivery method* ▪ *Check means cost estimate for approximate budget on the systems* ▪ *Total cost* ▪ *Calculate the life cycle cost analysis of the building (cost of building/ rate of investment)*

Sustainability	**Environmental Analysis Tool** ▪ *Evaluate carbon emission, energy usage* ▪ *Check LEED points* ▪ *Sustainability requirements* ▪ *Water transport, treatment*
Design integration using multiple computer software	**BIM** ▪ *Navisworks* **Revit** ▪ *Choose a typical floor plan (financial, technological, legal) (floor level)* ▪ *Design typical floor plan layout* ▪ *Perform clash detection* ▪ *3-D Model* ▪ *Design lobby*
Competition	**Required Submittals** ▪ *Building integration design development process3* ▪ *Submittal report: (**Structural**: foundation, walls, lateral, floor, and roof framing systems. **Mechanical**: HVAC, plumbing, and fire protection systems. **Electrical**: power, lighting, and related systems. **Construction management and construction methods:** delivery methods, preliminary project planning, budget, and schedule)* ▪ ***Report**: (**Summary narrative**: 15 pgs. max for each category, **Supporting documentation:** 20 pgs. max for each category, **Drawings:** 10 pgs. max for each category)* ▪ ***Electronic Submission:** 2-17-2014 4:00 pm*
MQP	**Important Dates** ▪ *Project Due Date: 5-1-2014* ▪ *Project Presentation Day: 4-24-2014*

Appendix D: Load Calculations for Existing Design

Dead Loads

Basement:

							Dead load		
Basement 1			Ht	14.3333	slab	0.91667	Basement 1		
Total ext Wall	904.19	ft^2	volume	13788.9	ft^3		Total ext Wall	2,068,334.63	
Total Core Wall	402.26	ft^2		6134.47	ft^3		Total Core Wall	920,169.75	
Total Interior c.w	67.56	ft^2		1030.29	ft^3		Total Interior c.w	154,543.50	
Total random w.a	163.06	ft^2		2486.67	ft^3		Total random w.a	372,999.75	
Total Column	202.25	ft^2		3084.31	ft^3		Total Column	462,646.88	
Total Core Slab	1464.6	ft^2		824.34	ft^3		Total Core Slab	123,651.00	
Total Slab Area	15257.6	ft^2		11878	ft^3		Total Slab Area	1,781,707.13	
								5,884,052.63	lb
Basement2			Ht	10	SLAB	0.91667	Basement 2		
Total ext Wall	898.39	ft^2	volume	9807.42	ft^3		Total ext Wall	1,471,113.63	
Total Core Wall	424.257	ft^2		4631.47	ft^3		Total Core Wall	694,720.84	
Total Interior c.w	69.89	ft^2		762.966	ft^3		Total Interior c.w	114,444.88	
Total Column	202.25	ft^2		2207.9	ft^3		Total Column	331,184.38	
Total Core Slab	1416.94	ft^2		1298.86	ft^3		Total Core Slab	194,829.25	
Total Slab Area	14957.1	ft^2		11773.4	ft^3		Total Slab Area	1,766,017.41	
								4,572,310.38	lb
Basement3			Ht	10	Slab	0.91667	Basement 3		
Total ext Wall	984.5	ft^2	volume	10747.5	ft^3		Total ext Wall	1,612,118.75	
Total Core Wall	424.25	ft^2		4631.40	ft^3		Total Core Wall	694,709.38	
Total Interior c.w	69.89	ft^2		762.97	ft^3		Total Interior c.w	114,444.88	
Total Column	200.75	ft^2		2191.52	ft^3		Total Column	328,728.13	
Total Core Slab	1432.94	ft^2		1313.53	ft^3		Total Core Slab	197,029.25	
Total Slab Area	15010.62	ft^2		11809.2	ft^3		Total Slab Area	1,771,383.63	
								4,718,414.00	lb
Basement 4			ht	8	Slab	0.91667	Basement 4		
Total ext Wall	984.5	ft^2	volume	8778.46	ft^3		Total ext Wall	1,316,768.75	
Total Core Wall	475.13	ft^2		4236.58	ft^3		Total Core Wall	635,486.38	
Total Interior c.w	69.89	ft^2		623.19	ft^3		Total Interior c.w	93,477.88	
Total Column	200.75	ft^2		1790.02	ft^3		Total Column	268,503.13	
Total Core Slab	401.42	ft^2		3579.33	ft^3		Total Core Slab	536,899.25	
Total Slab Area	14971.1	ft^2		12671.9	ft^3		Total Slab Area	1,900,787.63	
								4,751,923.00	lb

Lobby:

Slab 1		
Gross Floor 1		
Length	137	Ft
Width	137	Ft
Depth	0.917	ft.
V	17204.91667	ft^3
D gross:	2580737.5	lb.
Cut out sections		
Single Elevator	96.4	ft^2
Entrance to parking	1067	ft^2
Elevator shafts and stairs in core	846.25	ft^2
Depth	0.917	ft.
v	1842.219907	ft^3
Columns		
Large		
area	171.5	ft^2
Small		
area	16.4012	ft^2
Depth	0.917	ft.
v	172.2427667	ft^3
Core Wall		
wall area	471.24	ft^2
Depth	0.917	ft.
v	431.97	ft^3
Total Net Volume		
Vt=	14758.48399	ft^3
D Net =	2213772.599	lb
subtract inner core slab		
D Net =	2095349.349	lb

Slab 2		
Gross Floor 2		
Area 1	3073.583	ft
Area 2	1522.5	ft
Area 3	189	ft
Area 4	1015	ft
Depth	0.917	ft
v	5316.743	ft^3
Core Wall		
wall area	471.24	ft^2
Depth	0.917	ft.
v	431.97	ft^3
Columns		
Large		
area	73.5	ft^2
Small		
area	6.75	ft^2
Depth	0.917	ft.
v	73.5625	ft^3
Cut out sections		
Single Elevator	96.4	ft^2
Elevator shafts and stairs in core	846.25	ft^2
Depth	0.917	ft.
v	864.1366	ft^3
Net V	3947.074	Ft^3
D Slab 2	592061.1	lb
subtract inner core slab		
D Net =	473637.8	lb

Columns		
Large		
	area	12.25 ft^2
	height	54.91666667 ft
	v	672.7291667 ft^3
	14 Columns	9418.208333 ft^3
	D Columns	1412731.25 lb
Small		
1)	area	2.25 ft^2
	height	18.91666667 ft
	v	42.5625 ft^3
	8 Columns	340.5 ft^3
2)	area	1.7689 ft^2
	height	18.91666667 ft
	v	33.46169167 ft^3
	1 Column	33.46169167 ft^3
	D Columns:	56094.25375 lb

Extra walls (1st floor)	
wall 1	4.777778 ft^2
Wall 2	3.333333 ft^2
wall 3	5 ft^2
wall 4	2.555556 ft^2
wall 5	22.01389 ft^2
wall 6	2.625 ft^2
wall 7	240 ft^2
Total	280.3056 ft^2
Height	18.91667 ft.
V	5302.447 ft^3
d walls	795367 lb

Core Wall					
Area outer	2178.75	ft^2			
Area inner	1707.51	ft^2	Lobby openings		
wall area	471.24	ft^2	Lobby 1		
			1	270	ft^3
Lobby 1			2	405	ft^3
height	18	ft	3	270	ft^3
v	6754.32	ft^3	4	594	ft^3
Lobby 2 -5th			5	189	ft^3
height	36	ft	Lobby 2		
v=	16156.35	ft^3	1	153.96	ft^3
d Core Wall	3436601	lb	2	192.45	ft^3
			3	269.43	ft^3
Inner Core Slab			4	192.45	ft^3
Area inner	1707.51	ft^2			
(I) + (RI)	846.25	ft^2			
Net Area	861.26	ft^2			
depth	0.916667	ft			
v	789.4883	ft^3			
d inner c.	118423.3	lb			
3 Core slabs	355269.8	lb			

Dead loads for lobby :	
Slab 1	2,095,349 lb
Slab 2	473,638 lb
Columns	1,468,826 lb
Core Wall	3,436,601 lb
Extra Walls	795,367 lb
Inner core slab	355,270 lb
Total	**8,625,050 lb**

Floors 5-21:

1	For Slabs on floors 6-30		
	Slab1:		Units
	Depth	0.916667	ft
	Width	123.3333	ft
	Length	115.8333	ft
		13095.6	ft^3
	D total Slab:	1964340	lb
	Columns		
	Depth	0.916667	ft
	Width	3.5	ft
	Length	3.5	ft
		11.22917	ft^3
	14 Columns	157.2083	
	D column 11":	23581.25	lb

	Core			
		Outter		Inner
	Width	41	Width	36.5
	Lenth	51.5	Length	47
		2111.5		1715.5
	Area	396	ft^2	
	Depth	0.916667	ft	
		363		
	D total Slab:	54450	lb	

2	For Columns		
	Slab section		
	Columns		
	Depth	0.91666667	ft
	Width	3.5	ft
	Length	3.5	ft
		11.2291667	ft^3
	14 Columns	157.208333	
	D column 11":	23581.25	lb
	Tenant space		
	Floors 5-21		
	Depth	10.9166667	ft
	Width	3.5	ft
	Length	3.5	ft
		133.729167	ft^3
	14 Columns	1872.20833	
	D column 11":	280831.25	lb

3	For Core Wall		
	Slab Section		
	Area	396	ft^2
	Depth	0.916667	ft
		363	
	D total Slab:	54450	lb
	Tenant space		
	Area	396	ft^2
	Depth	10.91667	ft
		4323	ft^3
	D total Slab:	482653.1	lb
	Total	537103.1	lb

4	Core slab			
	subtractions	depth	0.916667	ft
		1+2 (I)	389.5	ft^2
		1+2 (RI)	456.75	ft^2
		(I) + (RI)	846.25	ft^2
			775.7292	Ft^3
	Slab			
	area	1715.5	Ft^2	
	depth	0.916666667	Ft	
	V gross	1572.54	ft^3	
	V net	796.8125		
	D Core slab	119521.875	lb	

5	**For Cantileveler beam**		
	Section above the slab		
	Depth	1	ft
	Area 1	315	ft^2
	Area 2	291.25	ft^2
	Total	606.25	ft^3
	Columns	9.75	ft^2
	4 Columns	39	ft^2
		39	Ft^3
	Net Volume	567.25	
	D total Cant.		
	Beam	85087.5	lb

Entry space in core wall		
1	136.4583	ft^3
2	191.0417	ft^3
3	136.4583	ft^3
4	204.6875	ft^3
5	95.52083	ft^3
6	204.6875	ft^3
7	136.4583	ft^3
Total	1105.313	ft^3

	Per Floor		
	Total dead load:		
1	Slab	1,650,428	lb
2	Columns	0	lb
3	Core	537,103	lb
4	Inner Core Slab	119,522	lb
5	Cantilever beam	85,088	lb
	Total:	2,392,140	lb
	16 floors		
		38,274,244	lb

Floors 22-30:

Total Floor Slab Area (ft^2) (Inclusive of core)	15176.500
Total Core Slab Area (ft^2)	1692.000

Column Details	
No.	Area (ft^2)
1	5.03
2	5.03
3	5.03
4	5.03
5	5.03
6	5.03
7	5.03
8	5.03
9	5.03
10	5.03
11	5.03
12	5.03
13	5.03
14	5.03
Total Area	70.46

Chase Details	
Chasers located in Core	
No.	Area
1	15.26
2	11.06
3	4.06
4	13.00
Total Area	43.38
Chase located on Main Floor	
No.	Area
1	16.00
Total Area	16.00

Core Area Details	
Core Wall Areas	
Wall Location	Area
SE	72.00
NW	69.34
SW	72.80
NE	80.00
Total Area	294.14

Door Opening Areas	
No.	Area
1	9.66
2	11.34
3	6.66
4	9.66
5	13.34
6	1.66
Total Area	52.32

Stairwells & Shaft Areas	
	Area
SW Stairs	149.36
NE Stairs	144.00
Elev. Shafts (A-C)	216.00
Elev. Shafts (D-G)	334.35
Total Area	843.71

Final Area				
	Area	ht	Volume	Dead Loads(lb.)
Floor Slab Area (ft^2)	14,552	1	13,339	2,000,885
Core Slab Area (ft^2)	857	1	786	117,869
Core Wall Area (ft^2)	294	12	3,481	522,099
Column area (ft^2)	70	12	834	125,065
Cantilever Beam	606	1	606	90,938
			Total Floor	2,856,855

Stairs:

Stairs:		
Avg	25	Steps
Riser Ht	7"	
Thread D	11"	
N	70	Stairs
Stairs:	121.11	ft^3
Cutouts	24.5	ft^3
Stairs:	6762.7	ft^3
All Stairs	1014405	lb
Slab		
Short	1120	ft^3
d Short	168,000	lb
Long	2,520	ft^3
d Long	378,000	lb
Total	546,000	lb
Stair + Slab	1,560,405	lb

Roof:

Dead Loads		
Main slab		
Whole slab	1,964,340	lb.
non slab area	116,359	lb.
Inner core slab	119,522	lb.
Total Slab	1,728,459	lb.
Core (penthouse and mechanical)		
Core Slab	119,522	lb.
Cantilever Beam		
Area 1	504	ft^2
Area 2	466	ft^2
depth	1	
total	1,213	ft^3
dead load	181,875	lb

Mechanical Equipment		
Chiller 1	40,000	lb.
Chiller 2	44,000	lb.
4 HVAC units	1,000	lb. ea.
Generators	450,000	lb.
Total	535,000	lb.

Total Roof Loads		
Slab	1,728,459	lb
Core Slab	239,044	lb
Cantilever Beam	181,875	lb
Total	2,149,378	lb

Total Dead Loads:

Floors 5-21	67,413,819	lb
Individual Floors	2,696,552	lb
Floors 22-30	22,127,338	lb
Individual Floors	2,765,917	lb
Lobbys	8,625,050	lb
Individual		
Lobby 1	2,095,349	lb
Lobby 2	473,638	lb
Basements	19,926,700	
B1	5,884,053	lb
B2	4,572,310	lb
B3	4,718,414	lb
B4	4,751,923	lb
Stairs	1,560,405	lb
Mechanical	500,000	lb
Roof	2,149,378	lb
Total	122,302,691	lb

Live Loads

(ASCE 7-10 Table 4-1 Minimum Uniformly Distributed Live Loads, L_0, and Minimum Concentrated Loads)

Occupancy or Use	**Uniform (psf)**	**Conc. (lb.)**
Office use	50	2,000
Computer use	100	2,000
Lobby	100	2,000
Catwalks for maintenance access	40	
Corridors	100	
Dining rooms & restaurants	100	
Elevator machine room		300
Fire Escapes	100	
Garages- passenger vehicles	40	
Garages- trucks & buses	c	
Handrails, guardrails, & garb bars	5	
Roofs- primary roof members, exposed to work floor		2,000
Stairs & exit ways	100	300
Storage- Light	125	
Storage- Heavy	250	

(ASCE 7-10 Table 4-2 Live Load Element Factor, K_{LL})

Element	**K_{LL}**
Interior Columns	4
Interior Beams	2
Cantilever beams	1
Two- way slabs	1

$$L = L_0\left(0.25 + \frac{15}{\sqrt{K_{LL}A_T}}\right)$$

Garage

Sec	Area	KLL	KLL* Area	x	y	Triangles		No Reduction		Lo
A	543.12	4	2172.47	18.54	29.29			250		250
B	914.62	4	3658.47	29.58	30.92			250		
C	927.50	4	3710.00	30.00	30.92			250		
D	875.97	4	3503.89	28.33	30.92			250		
E	949.34	4	3797.35	30.54	31.08			250		
F	804.76	4	3219.03	25.08	32.08			250		
G	689.79	4	2759.17	25.08	27.50			250		
H	891.50	3	2674.51	25.08	22.96	315.63		250		
I	895.51	3	2686.54	23.04	25.17	315.63		250		
J	755.00	4	3020.00	30.00	25.17			250		
K	713.06	4	2852.22	28.33	25.17			250		
L	773.72	4	3094.89	30.54	25.33			250		
M	1186.93	4	4747.70	29.46	40.29			250		
N	1186.93	4	4747.70	29.46	40.29			250		
O	1394.89	1	1394.89	49.08	21.21	129.90	224.01	250		
P	1261.34	1	1261.34	21.13	38.50	224.01	224.01	250		
Q	1394.89	1	1394.89	49.08	21.21	129.90	224.01	250		
R	731.43	1	731.43	12.25	38.50	129.90	129.90	250		
								4,500	**13,500**	

Lobby 1

Sec	Area	KLL	KLL* Area	x	y	Triangles		No Reduction		Lo
A	543.12	4	2172.47	18.54	29.29			100		100
B	914.62	4	3658.47	29.58	30.92			100		
C	927.50	4	3710.00	30.00	30.92			100		
D	875.97	4	3503.89	28.33	30.92			100		
E	949.34	4	3797.35	30.54	31.08			100		
F	804.76	4	3219.03	25.08	32.08			100		
G	689.79	4	2759.17	25.08	27.50			100		
H	891.50	3	2674.51	25.08	22.96	315.63		100		
I	895.51	3	2686.54	23.04	25.17	315.63		100		
J	755.00	4	3020.00	30.00	25.17			100		
K	713.06	4	2852.22	28.33	25.17			100		
L	773.72	4	3094.89	30.54	25.33			100		
M	1186.93	4	4747.70	29.46	40.29			100		
N	1186.93	4	4747.70	29.46	40.29			100		
O	1394.89	1	1394.89	49.08	21.21	129.90	224.01	100		
P	1261.34	1	1261.34	21.13	38.50	224.01	224.01	100		
Q	1394.89	1	1394.89	49.08	21.21	129.90	224.01	100		
R	731.43	1	731.43	12.25	38.50	129.90	129.90	100		
								1,800		

Lobby 2

Sec	Area	K_{LL}	K_{LL}* Area	x	y	Triangles		No Reduction		L_o
A	524.81	4	2099.24	17.92	29.29			100		
B	914.62	4	3658.47	29.58	30.92			100		
C	927.50	4	3710.00	30.00	30.92			100		
D	875.97	4	3503.89	28.33	30.92			100		
E	949.34	4	3797.35	30.54	31.08			100		
F	784.70	4	3138.82	24.46	32.08			100		
G	672.60	4	2690.42	24.46	27.50			100		
H	681.32	3	2043.96	24.46	22.96	315.63		100		
I	681.95	3	2045.84	23.04	24.54	315.63		100		
J	736.25	4	2945.00	30.00	24.54			100		
K	695.35	4	2781.39	28.33	24.54			100		
L	411.81	4	1647.22	16.67	24.71			100		
M	1186.93	4	4747.70	29.46	40.29			100		
N	1186.93	4	4747.70	29.46	40.29			100		
O	1394.89	1	1394.89	49.08	21.21	129.90	224.01	100		
P	1261.34	1	1261.34	21.13	38.50	224.01	224.01	100		
Q	1394.89	1	1394.89	49.08	21.21	129.90	224.01	100		
R	731.43	1	731.43	12.25	38.50	129.90	129.90	100		
								1,800		

Floors 5-30

Sec	Area	K_{LL}	K_{LL}* Area	x	y	Triangles		$L_{reduced}$		L_o
A	377.26	4	1509.03	17.08	22.08			50.89		80
B	701.37	4	2805.49	29.58	23.71			42.66		
C	711.25	4	2845.00	30.00	23.71			42.50		
D	671.74	4	2686.94	28.33	23.71			43.15		
E	378.02	4	1512.08	15.83	23.88			50.86		
F	757.97	4	3031.87	23.63	32.08			41.79		
G	649.69	4	2598.75	23.63	27.50			43.54		
H	792.91	3	2378.74	23.63	22.96	250.52		44.60		
I	796.80	3	2390.41	23.04	23.71	250.52		44.54		
J	711.25	4	2845.00	30.00	23.71			42.50		
K	671.74	4	2686.94	28.33	23.71			43.15		
L	378.02	4	1512.08	15.83	23.88			50.86		
M	594.30	4	2377.21	14.75	40.29			44.61		
N	594.30	4	2377.21	14.75	40.29			44.61		
O	1394.89	1	1394.89	49.08	21.21	129.90	224.01	52.13		
P	1261.34	1	1261.34	21.13	38.50	224.01	224.01	53.79		
Q	1394.89	1	1394.89	49.08	21.21	129.90	224.01	52.13		
R	731.43	1	731.43	12.25	38.50	129.90	129.90	64.37		
								852.69	**22,170**	

Live Load Total: 39,269.8lbs

Wind Loads

Table of Values			
Building Height	415	ft	
Width	136	ft	
Risk Category	III		table 1.5-1
Wind Speed (V)	115	mph	Figure 26.5-1B
Wind Directionality	0.85	K_d	Table 26.6-1
Topographic Factor	1	K_{zt}	26.8.2
Effective Length	544>415	Good	Section26.9.2.1
Approx. Natural Frequency	66.7		Section 26.9.3
Gust Factor	0.84		Section 26.9
Enclosure Classification (enclosed) GC_{pi}	=+/-0.18	MWFRS	Table 26.11-1

1) Effective Length , 26.9.2.1				H*L/H	
Floors	Height (ft)	L1	L2	L1	L2
1	0.00	136.00	136.00		
2	18.00	136.00	136.00	2,448.00	2,448.00
5	54.00	136.00	136.00	7,344.00	7,344.00
6	67.17	136.00	136.00	9,134.67	9,134.67
7	80.33	136.00	136.00	10,925.33	10,925.33
8	93.50	136.00	136.00	12,716.00	12,716.00
9	106.67	136.00	136.00	14,506.67	14,506.67
10	119.83	136.00	136.00	16,297.33	16,297.33
11	133.00	136.00	136.00	18,088.00	18,088.00
12	146.17	136.00	136.00	19,879.12	19,879.12
14	159.33	136.00	136.00	21,668.88	21,668.88
15	172.50	136.00	136.00	23,460.00	23,460.00
16	185.67	136.00	136.00	25,251.12	25,251.12
17	198.83	136.00	136.00	27,040.88	27,040.88
18	212.00	136.00	136.00	28,832.00	28,832.00
19	225.17	136.00	136.00	30,623.12	30,623.12
20	238.33	136.00	136.00	32,412.88	32,412.88
21	251.50	136.00	136.00	34,204.00	34,204.00
22	264.67	136.00	136.00	35,995.12	35,995.12
23	277.83	136.00	136.00	37,785.29	37,785.29
24	291.00	136.00	136.00	39,576.00	39,576.00
25	304.17	136.00	136.00	41,367.12	41,367.12
26	317.33	136.00	136.00	43,156.88	43,156.88
27	330.50	136.00	136.00	44,948.00	44,948.00
28	343.67	136.00	136.00	46,739.12	46,739.12
29	356.83	136.00	136.00	48,528.88	48,528.88
30	370.00	136.00	136.00	50,320.00	50,320.00
Roof	384.17	136.00	136.00	52,247.12	52,247.12
EM Rm	394.67	136.00	136.00	53,675.12	53,675.12
Up Roof	404.33	136.00	136.00	54,989.33	54,989.33
Parapet	413.79	136.00	136.00	56,275.67	56,275.67
	6,914.97			940,435.65	940,435.65
			Leff 1	136.00	136.00
			Checks	415< 544.00	

$$L_{eff} = \frac{\sum_{i=1}^{n} h_i * L_i}{\sum_{i=1}^{n} h_i}$$

calculation from 26.9-1

2a) Cw, Section 26.9-5															
Floor	Ab (ft^2)	h (ft)	hi	Ai 1	Ai 2	Di 1	Di 2	h/hi	long	Sum	Cw 1	h/hi	long	Sum	Cw 2
1	18496	384.17	0.00			50	39								
2	18496	384.17	18.00	1089	1089	60.5	60.5	455.51	1,014.47	462,103.96	4,423	455.51	1,014.47	462,103.96	4,423
5	18496	384.17	54.00	3267	3267	60.5	60.5	50.61	1,966.61	99,535.46		50.61	1,966.61	99,535.46	
6	18496	384.17	67.17	4063.583	4063.6	60.5	60.5	32.71	2,008.69	65,713.25		32.71	2,008.69	65,713.25	
7	18496	384.17	80.33	4860.167	4860.2	60.5	60.5	22.87	1,972.96	45,120.51		22.87	1,972.96	45,120.51	
8	18496	384.17	93.50	5656.75	5656.8	60.5	60.5	16.88	1,896.71	32,020.29		16.88	1,896.71	32,020.29	
9	18496	384.17	106.67	6453.333	6453.3	60.5	60.5	12.97	1,802.59	23,382.28		12.97	1,802.59	23,382.28	
10	18496	384.17	119.83	7249.917	7249.9	60.5	60.5	10.28	1,703.34	17,506.28		10.28	1,703.34	17,506.28	
11	18496	384.17	133.00	8046.5	8046.5	60.5	60.5	8.34	1,605.71	13,397.13		8.34	1,605.71	13,397.13	
12	18496	384.17	146.17	8843.285	8843.3	60.5	60.5	6.91	1,512.99	10,451.24		6.91	1,512.99	10,451.24	
14	18496	384.17	159.33	9639.465	9639.5	60.5	60.5	5.81	1,426.68	8,294.30		5.81	1,426.68	8,294.30	
15	18496	384.17	172.50	10436.25	10436.3	60.5	60.5	4.96	1,347.04	6,681.12		4.96	1,347.04	6,681.12	
16	18496	384.17	185.67	11233.04	11233.0	60.5	60.5	4.28	1,273.99	5,454.19		4.28	1,273.99	5,454.19	
17	18496	384.17	198.83	12029.22	12029.2	60.5	60.5	3.73	1,207.19	4,506.72		3.73	1,207.19	4,506.72	
18	18496	384.17	212.00	12826	12826	60.5	60.5	3.28	1,146.05	3,763.37		3.28	1,146.05	3,763.37	
19	18496	384.17	225.17	13622.79	13622.8	60.5	60.5	2.91	1,090.08	3,173.09		2.91	1,090.08	3,173.09	
20	18496	384.17	238.33	14418.97	14419.0	60.5	60.5	2.60	1,038.81	2,699.14		2.60	1,038.81	2,699.14	
21	18496	384.17	251.50	15215.75	15215.8	60.5	60.5	2.33	991.70	2,313.93		2.33	991.70	2,313.93	
22	18496	384.17	264.67	16012.54	16012.5	60.5	60.5	2.11	948.35	1,998.05		2.11	948.35	1,998.05	
23	18496	384.17	277.83	16808.9	16808.9	60.5	60.5	1.91	908.40	1,736.82		1.91	908.40	1,736.82	
24	18496	384.17	291.00	17605.5	17605.5	60.5	60.5	1.74	871.46	1,518.83		1.74	871.46	1,518.83	
25	18496	384.17	304.17	18402.29	18402.3	60.5	60.5	1.60	837.24	1,335.56		1.60	837.24	1,335.56	
26	18496	384.17	317.33	19198.47	19198.5	60.5	60.5	1.47	805.49	1,180.56		1.47	805.49	1,180.56	
27	18496	384.17	330.50	19995.25	19995.3	60.5	60.5	1.35	775.94	1,048.41		1.35	775.94	1,048.41	
28	18496	384.17	343.67	20792.04	20792.0	60.5	60.5	1.25	748.39	935.17		1.25	748.39	935.17	
29	18496	384.17	356.83	21588.22	21588.2	60.5	60.5	1.16	722.67	837.65		1.16	722.67	837.65	
30	18496	384.17	370.00	22385	22385	60.5	60.5	1.08	698.58	753.11		1.08	698.58	753.11	
Roof	18496	384.17	384.17	23242.29	23242.3	60.5	60.5	1.00	674.34	674.34		1.00	674.34	674.34	
EM Rm			394.67							818,134.76				818,134.76	
Up Rf			404.33												
Parapet			413.79												
			6,914.97												
	Not Roof		5,702.17												

$$C_w = \frac{100}{A_B}\sum_{i=1}^{n}\left(\frac{h}{h_i}\right)^2 \frac{A_i}{[1+0.83(\frac{h_i}{D_i})^2]}$$

calculation from section 26.9-5

From Section 2.6.9.35 Flexible Structures or Dynamically Sensitive Buildings or Other Structures

Calculations

$$G_f = 0.925 * \frac{1 + 1.7 * I_z(\sqrt{g_q{}^2Q^2 + g_R{}^2R^2})}{1 + 1.7 * g_v * I_z}$$

$$I_z = c * \frac{33}{\hat{z}}^{1/6}$$

$$Q = \sqrt{\frac{1}{1 + 0.63 * \frac{B+h}{L_z}^{0.63}}}$$

$$g_R = \sqrt{2\ln(3600n_1)} + \frac{0.577}{\sqrt{2\ln(3600n_1)}}$$

$$R = \sqrt{\frac{1}{\beta}R_nR_hR_B(0.53 + 0.47R_L)}$$

2) Approximation Natural Frequency, Section 26.9.3			
	Cw	h	na
385	4,423	384.17	66.7

$$n_a = \frac{385(C_w{}^{0.5})}{h}$$

Calculation from section 26.9-5

Sub Calculations

$$L_z = l * \frac{\hat{z}}{33}^{\epsilon}$$

$$N_1 = \frac{n_1L_z}{V_z}$$

$$R_n = \frac{7.47N_1}{(1 + 10.3N_1)^{5/3}}$$

Rl Factor

$$R_l = \frac{1}{\eta} - \frac{1}{2\eta^2}(1 - e^{-2\eta})$$

for η>0 26.9-15a

R_l=1 for η=0 26.9-15b

$$R_l = R_h \; setting \; \eta = {}^{4.6 * n_1 * h}/_{V_z}$$

$$R_l = R_B \; setting \; \eta = {}^{4.6 * n_1 * B}/_{V_z}$$

$$R_l = R_L \; setting \; \eta = {}^{15.4 * n_1 * L}/_{V_z}$$

$$V_z = b * (\frac{\hat{z}}{33})^{\alpha} * \left(\frac{88}{60}\right) * V$$

$$G_f = 0.925 * \frac{1 + 1.7 * I_z(\sqrt{g_q{}^2Q^2 + g_R{}^2R^2})}{1 + 1.7 * g_v * I_z}$$

Iz	0.217
gQ	3.4
Q	0.7984
gr	5.09
R	0.1564
gV	3.4
Gf	0.84

Appendix E: STAAD Analysis of Existing Design

Definition: Whole Structure

Type	Seismic *IBC 2006/2009*
Zip Code	San Francisco- 94105
Ss	1.69
S1	0.838
TL	12 seconds
Importance factor	1
Response modification factor X (RX)	3
Response modification factor Z (RZ)	4
Site class	4

Loads: Whole Structure

No.	**Load Case Details**	**Loads Applied**
1	Seismic X	*IBC* Load X 1
2	Seismic -X	*IBC* Load –X 1
3	Seismic Z	*IBC* Load Z 1
4	Seismic -Z	*IBC* Load –Z 1
5	Dead Load	Selfweight Y-1
6	Live Load	All plates PR GY -0.8 kips/ft^2

Material Properties

Name	E kip/in2	Poisson's Ratio	Density kip/in3	Alpha /°F	Fy kip/in2	Fu kip/in2	Ry	Rt	Fcu kip/in2
STEEL	29000.000	300E-3	283E-6	6.5E-6	36.000	58.000	1.200	1.500	0.000
STAINLESSSTEEL	28000.000	300E-3	289E-6	9.9E-6	0.000	0.000	0.000	0.000	0.000
ALUMINUM	10000.000	330E-3	98E-6	12.8E-6	0.000	0.000	0.000	0.000	0.000
CONCRETE	3150.000	170E-3	87E-6	5E-6	0.000	0.000	0.000	0.000	4.000

Supports: Whole Structure

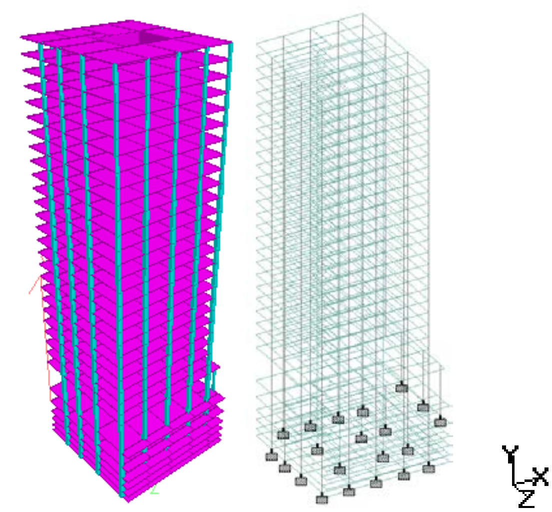
No.	**Description**	**Location**
1	Support 2	Fixed at all basement node points

Properties: Whole Structure

No.	**Section**	**Thickness** (YD x ZD)	**Location**	**Material**
1	Plate Thickness	3' x 3'	Core B4- Floor 5	Concrete

2	Plate Thickness	0.9167’ x 0.9167’	All Floor Slabs	Concrete
3	Plate Thickness	2.5’ x 2.5’	Core Floor 6 - 21	Concrete
4	Plate Thickness	2’ x 2’	Core Floor 22 - 30	Concrete
5	Rect Beam	3’ x 3’	Beams on Floor 1 - 21	Concrete
6	Rect Beam	1.5’ x 1.5’	Overhand Beams in Lobby	Concrete
7	Rect Beam	4’ x 3’	Beams on Floor B4- B1	Concrete
8	Rect Beam	2’ x 2;	Beams on Floor 22 - 30	Concrete

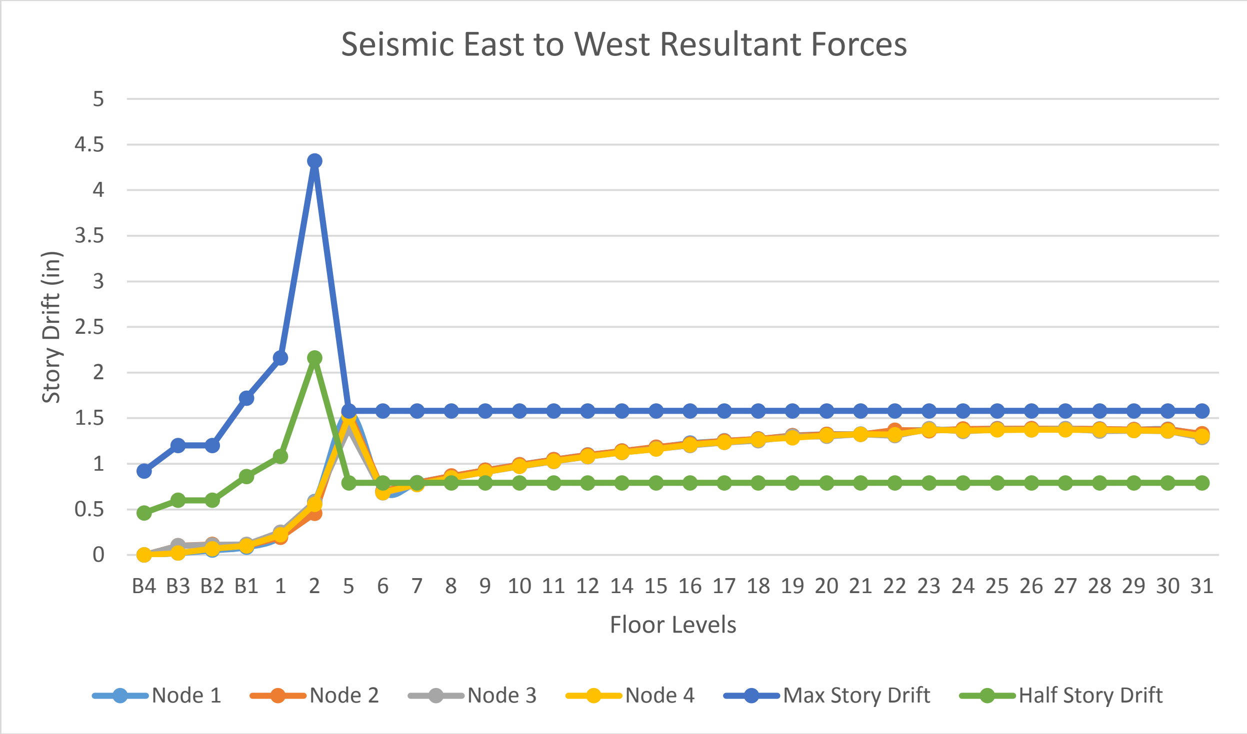
Design Summary Output

Element	**Value**
Image (3D, Geometry, Deflection (Load 1))	
Seismic X Forces Applied Load 1	***TOTAL APPLIED LOAD (POUN FEET) SUMMARY (LOADING 1) SUMMATION FORCE-X = 15670508.57 SUMMATION FORCE-Y = 0.00 SUMMATION FORCE-Z = 0.00 SUMMATION OF MOMENTS AROUND THE ORIGIN- MX= 0.0000000E+00 MY= 9.7406375E+08 MZ= -4.3512501E+09
Seismic X Max Displacements Load 1	MAXIMUM DISPLACEMENTS (INCH /RADIANS) (LOADING 1) MAXIMUMS AT NODE X = 3.26365E+01 1505 Y = -4.47706E+00 1513 Z = -8.76392E-01 1518 RX= 1.85268E-02 1727 RY= 2.40127E-03 578 RZ= 2.15786E-02 411

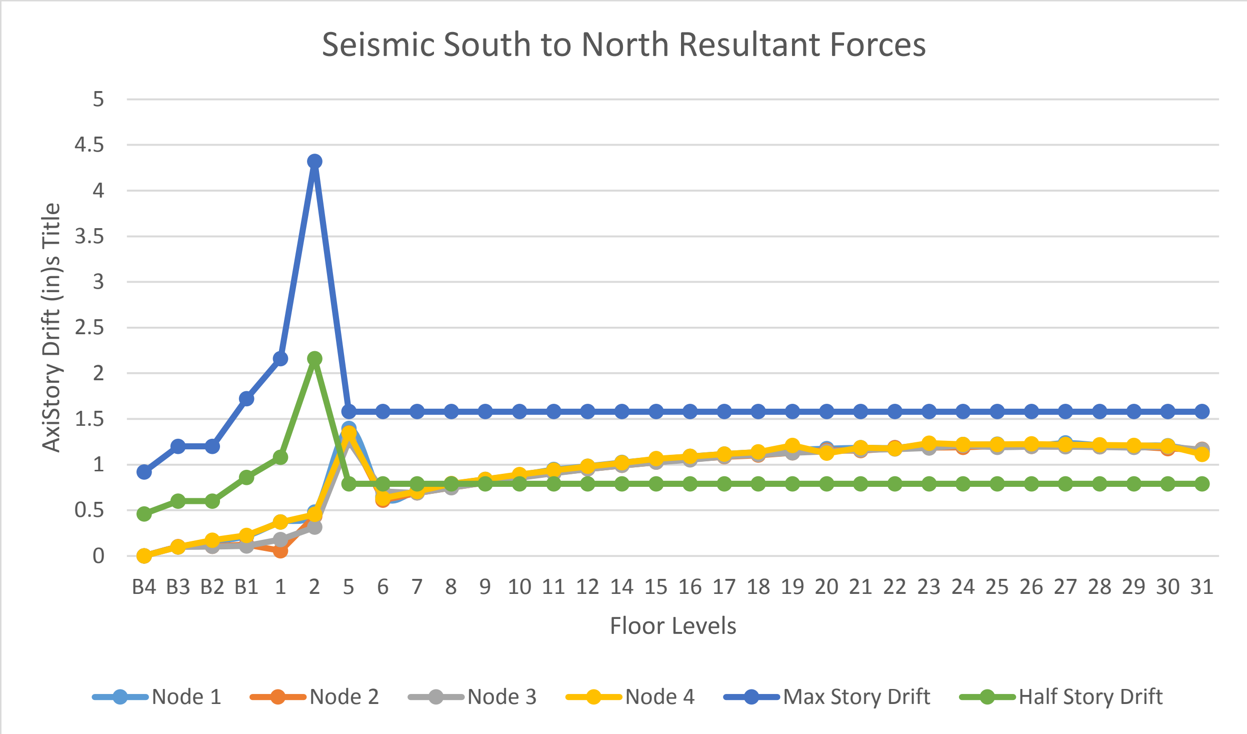
Seismic -X Forces Applied Load 2	***TOTAL APPLIED LOAD (POUN FEET) SUMMARY (LOADING 2) SUMMATION FORCE-X = -15670508.57 SUMMATION FORCE-Y = 0.00 SUMMATION FORCE-Z = 0.00 SUMMATION OF MOMENTS AROUND THE ORIGIN- MX= 0.0000000E+00 MY= -9.7406375E+08 MZ= 4.3512501E+09
Seismic -X Max Displacements Load 2	MAXIMUM DISPLACEMENTS (INCH /RADIANS) (LOADING 2) MAXIMUMS AT NODE X = -3.26365E+01 1505 Y = 4.47706E+00 1513 Z = 8.76392E-01 1518 RX= -1.85268E-02 1727 RY= -2.40127E-03 578 RZ= -2.15786E-02 411
Seismic Z Forces Applied Load 3	***TOTAL APPLIED LOAD (POUN FEET) SUMMARY (LOADING 3) SUMMATION FORCE-X = 0.00 SUMMATION FORCE-Y = 0.00 SUMMATION FORCE-Z = 11752881.14 SUMMATION OF MOMENTS AROUND THE ORIGIN- MX= 3.2634375E+09 MY= -6.9503737E+08 MZ= 0.0000000E+00
Seismic Z Max Displacements Load 3	MAXIMUM DISPLACEMENTS (INCH /RADIANS) (LOADING 3) MAXIMUMS AT NODE X = -1.10349E+00 1505 Y = 2.60471E+00 1363 Z = 2.94484E+01 1526 RX= -1.25158E-02 1104 RY= -1.10119E-03 578 RZ= -6.47979E-03 1098
Seismic -Z Forces Applied Load 4	***TOTAL APPLIED LOAD (POUN FEET) SUMMARY (LOADING 4) SUMMATION FORCE-X = 0.00 SUMMATION FORCE-Y = 0.00 SUMMATION FORCE-Z = -11752881.14 SUMMATION OF MOMENTS AROUND THE ORIGIN- MX= -3.2634375E+09 MY= 6.9503737E+08 MZ= 0.0000000E+00
Seismic –Z Max Displacements Load 4	MAXIMUM DISPLACEMENTS (INCH /RADIANS) (LOADING 4) MAXIMUMS AT NODE X = 1.10349E+00 1505 Y = -2.60471E+00 1363 Z = -2.94484E+01 1526 RX= 1.25158E-02 1104 RY= 1.10119E-03 578 RZ= 6.47979E-03 1098

Dead Load Forces Applied Load 5	***TOTAL APPLIED LOAD (POUN FEET) SUMMARY (LOADING 5) SUMMATION FORCE-X = 0.00 SUMMATION FORCE-Y = -92409527.08 SUMMATION FORCE-Z = 0.00 SUMMATION OF MOMENTS AROUND THE ORIGIN- MX= 5.8376120E+09 MY= 0.0000000E+00 MZ= -5.6467492E+09
Dead Load Max Displacements Load 5	MAXIMUM DISPLACEMENTS (INCH /RADIANS) (LOADING 5) MAXIMUMS AT NODE X = 1.64792E+00 1505 Y = -1.11855E+01 1528 Z = -1.31623E+00 1518 RX= -3.36237E-02 1528 RY= -1.39516E-04 1473 RZ= -1.76041E-02 603
Live Load Forces Applied Load 6	***TOTAL APPLIED LOAD (POUN FEET) SUMMARY (LOADING 6) SUMMATION FORCE-X = 0.00 SUMMATION FORCE-Y = -395067799.44 SUMMATION FORCE-Z = 0.00 SUMMATION OF MOMENTS AROUND THE ORIGIN- MX= 2.4817993E+10 MY= 0.0000000E+00 MZ= -2.3780799E+10
Live Load Max Displacements Load 6	MAXIMUM DISPLACEMENTS (INCH /RADIANS) (LOADING 6) MAXIMUMS AT NODE X = 8.72454E+00 1505 Y = -6.36152E+01 1528 Z = -7.45630E+00 1518 RX= -1.95780E-01 1528 RY= -7.68098E-04 1520 RZ= -1.02430E-01 603

Story Drift



Seismic East to West Resultant Forces
Story Drift (in)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
B4 B3 B2 B1 1 2 5 6 7 8 9 10 11 12 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Floor Levels
Node 1
Node 2
Node 3
Node 4
Max Story Drift
Half Story Drift



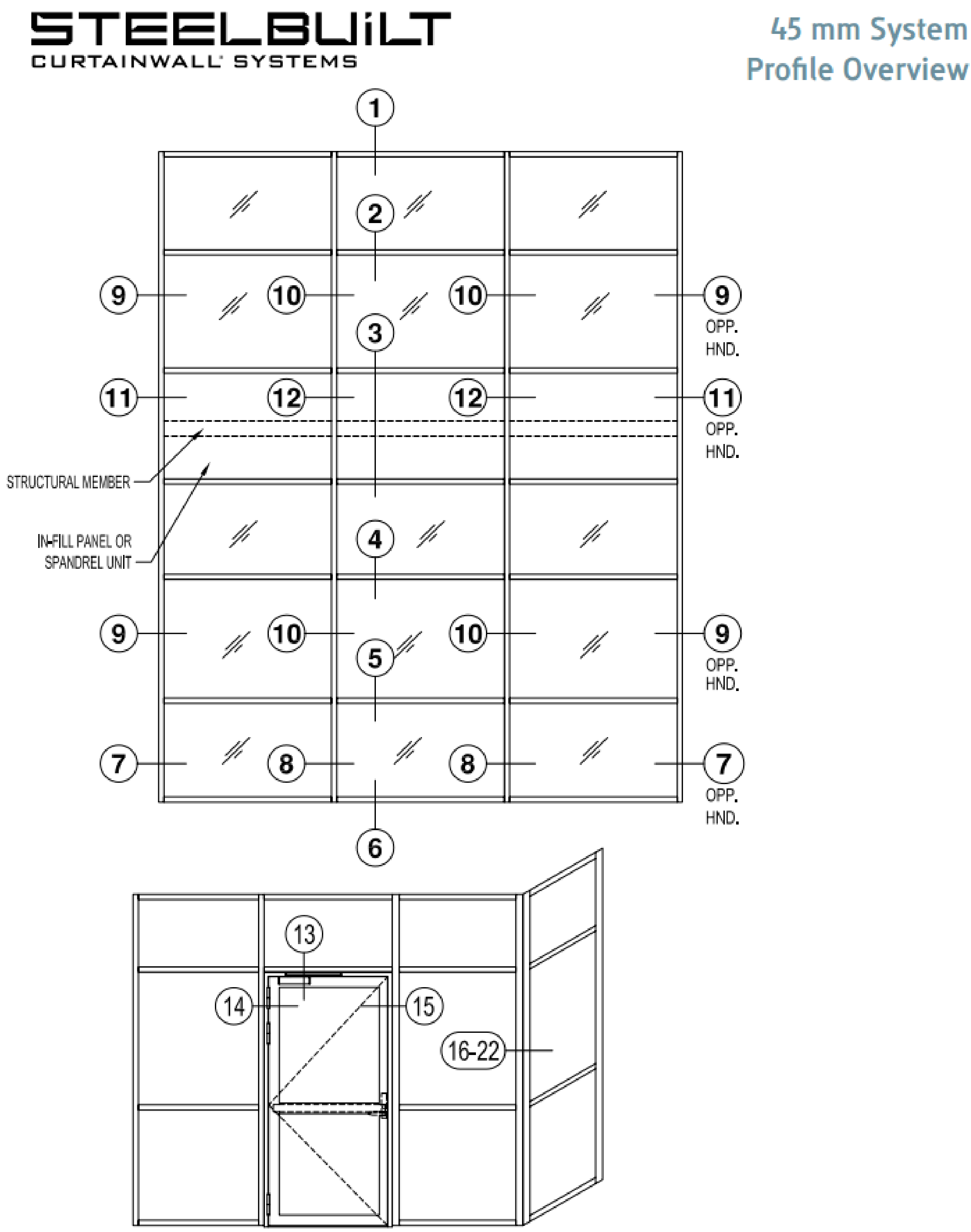
Seismic South to North Resultant Forces
AxiStory Drift (in)s Title
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
B4 B3 B2 B1 1 2 5 6 7 8 9 10 11 12 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Floor Levels
Node 1
Node 2
Node 3
Node 4
Max Story Drift
Half Story Drift

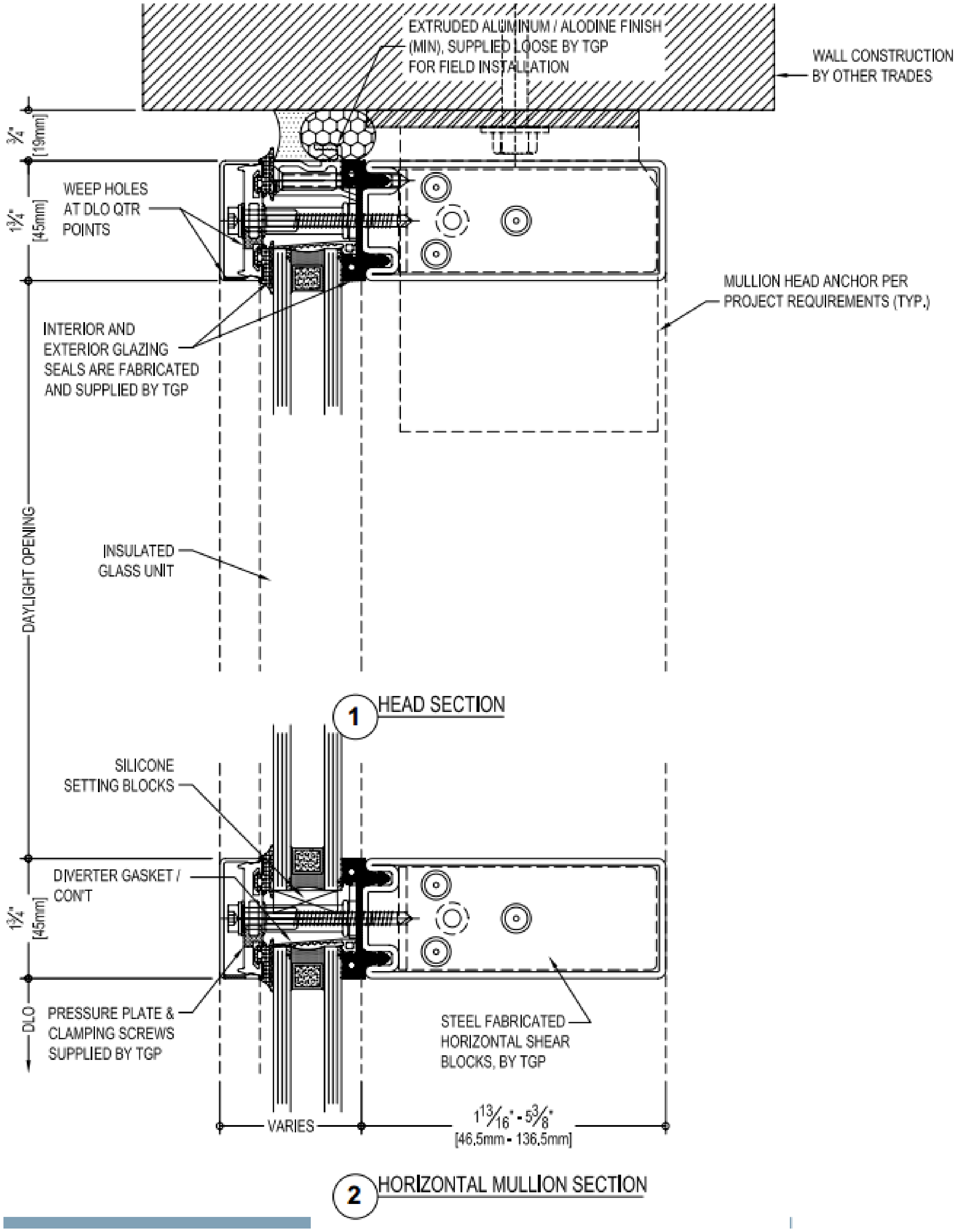
Level	Height (ft.)	in	ft.-in	Factor	Max drift (in)	1/2 Drift (in)
B4	7.67	12.00	92.04	0.01	0.92	0.46
B3-B1	10.00	12.00	120.00	0.01	1.20	0.60
B1-L1	14.33	12.00	171.96	0.01	1.72	0.86
L1-L2	18.00	12.00	216.00	0.01	2.16	1.08
L2-5	36.00	12.00	432.00	0.01	4.32	2.16
5-30	13.17	12.00	158.00	0.01	1.58	0.79

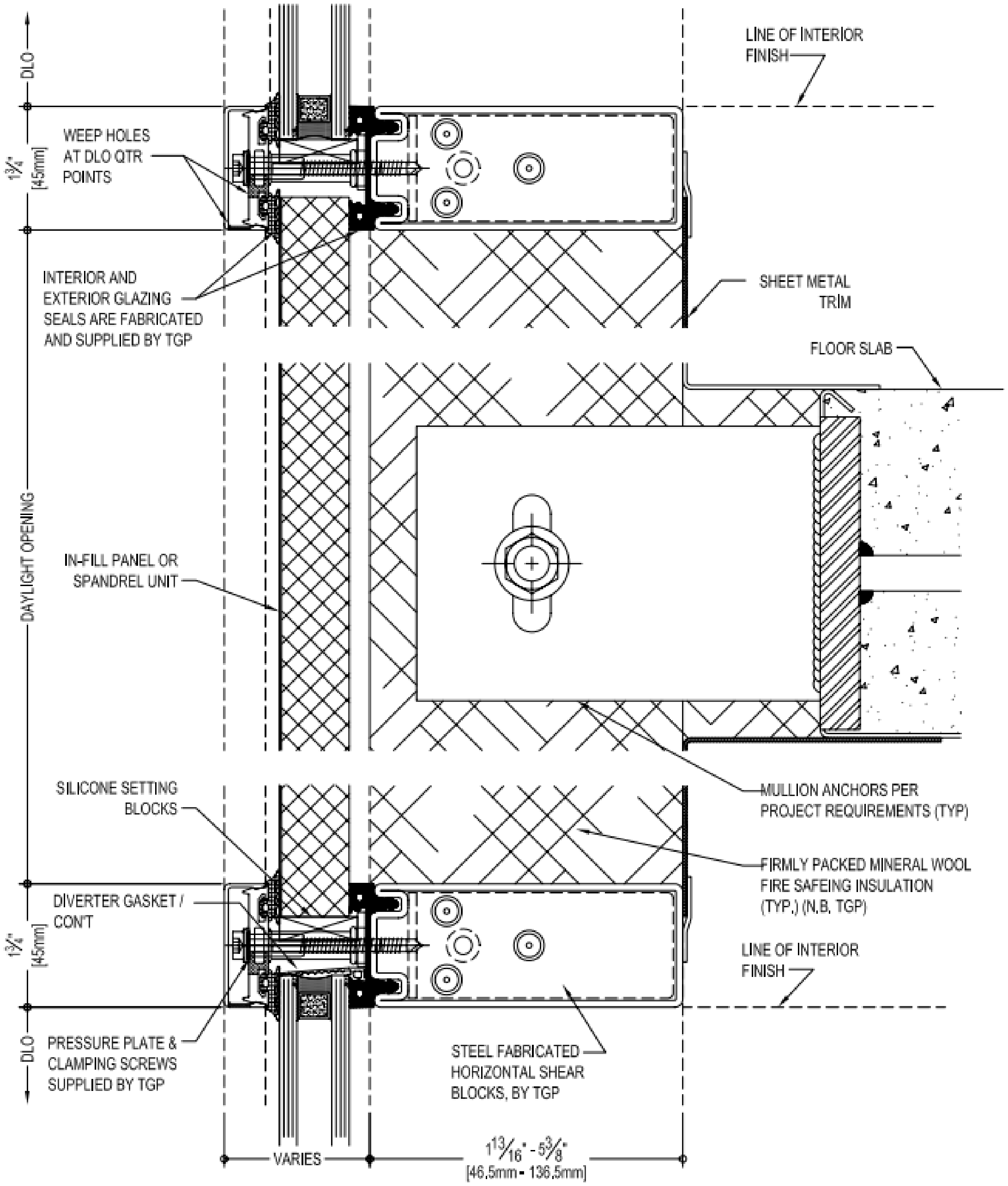
SOM Story Drift														
			Resultant (in)			Resultant (in)			Resultant (in)			Resultant (in)		
Floor	Height (ft)	Node	Seismic X	Seismic Z	Node 2	Seismic X	Seismic Z	Node 3	Seismic X	Seismic Z	Node 4	Seismic X	Seismic Z	
B4	-42	579	0	0	616	0	0	613	0	0	605	0	0	
B3	-34.33	498	0.007	0.059	575	0.102	0.102	532	0.102	0.098	524	0.021	0.098	
B2	-24.33	459	0.059	0.215	576	0.218	0.208	493	0.213	0.202	485	0.089	0.271	
B1	-14.33	420	0.145	0.432	577	0.316	0.333	454	0.328	0.312	446	0.189	0.496	
1	0.00	91	0.344	0.804	578	0.51	0.39	188	0.578	0.492	180	0.409	0.866	
2	18.00	127	0.931	1.285	129	0.966	0.823	161	1.158	0.806	153	0.964	1.32	
5	54.00	1	2.49	2.68	3	2.531	2.169	413	2.546	2.067	15	2.483	2.664	
6	67.17	617	3.192	3.327	619	3.23	2.78	632	3.225	2.772	630	3.168	3.295	
7	80.33	654	3.985	4.04	656	4.02	3.47	669	3.996	3.461	667	3.94	4	
8	93.50	691	4.849	4.825	693	4.885	4.219	706	4.84	4.208	704	4.785	4.791	
9	106.67	728	5.778	5.664	730	5.813	5.025	743	5.75	5.013	741	5.696	5.629	
10	119.83	765	6.768	6.55	767	6.802	5.884	780	6.721	5.871	778	6.668	6.521	
11	133.00	802	7.814	7.495	804	7.846	6.792	817	7.747	6.776	815	7.696	7.46	
12	146.17	839	8.911	8.478	841	8.941	7.744	854	8.824	7.729	852	8.775	8.44	
14	159.33	876	10.05	9.501	878	10.08	8.735	891	9.948	8.72	889	9.9	9.46	
15	172.50	913	11.23	10.558	915	11.263	9.762	928	11.112	9.747	926	11.06	10.525	
16	185.67	950	12.456	11.647	952	12.481	10.821	985	12.313	10.8	963	12.268	11.614	
17	198.83	987	13.707	12.763	989	13.73	11.907	1002	13.547	11.89	1000	13.503	12.73	
18	212.00	1024	14.98	13.9	1026	15	13.01	1039	14.8	13	1037	14.766	13.869	
19	225.17	1061	16.289	15.06	1063	16.308	14.14	1076	16.1	14.13	1074	16.05	15.08	
20	238.33	1098	17.613	16.235	1100	17.629	15.297	1113	17.4	15.276	1111	17.361	16.205	
21	251.50	1135	18.94	17.419	1137	18.95	16.45	1150	18.723	16.437	1148	18.685	17.391	
22	264.67	1172	20.298	18.603	1174	20.318	17.634	1187	20.03	17.607	1185	20.004	18.566	
23	277.83	1209	21.67	19.826	1211	21.68	18.82	1224	21.415	18.79	1222	21.377	19.8	
24	291.00	1246	23.047	21.045	1248	23.061	20.01	1261	22.77	20	1259	22.74	21.02	
25	304.17	1283	24.431	22.267	1285	24.443	21.213	1298	24.146	21.19	1296	24.11	22.24	
26	317.33	1320	25.817	23.47	1322	25.827	22.412	1335	25.518	22.388	1333	25.482	23.466	
27	330.50	1357	27.201	24.707	1359	27.21	23.61	1372	26.9	23.585	1370	26.854	24.685	
28	343.67	1394	28.582	25.921	1396	28.59	24.804	1409	28.258	24.78	1407	28.224	25.9	
29	356.83	1431	29.957	27.128	1433	29.964	26	1446	29.622	25.967	1444	29.59	27.11	
30	370.00	1468	31.336	28.334	1470	31.34	27.176	1483	30.98	27.164	1481	30.95	28.314	
31	383.17	1505	32.654	29.473	1507	32.668	28.342	1520	32.267	28.327	1518	32.252	29.426	

Appendix F: Steel Curtain Wall Mullion Details

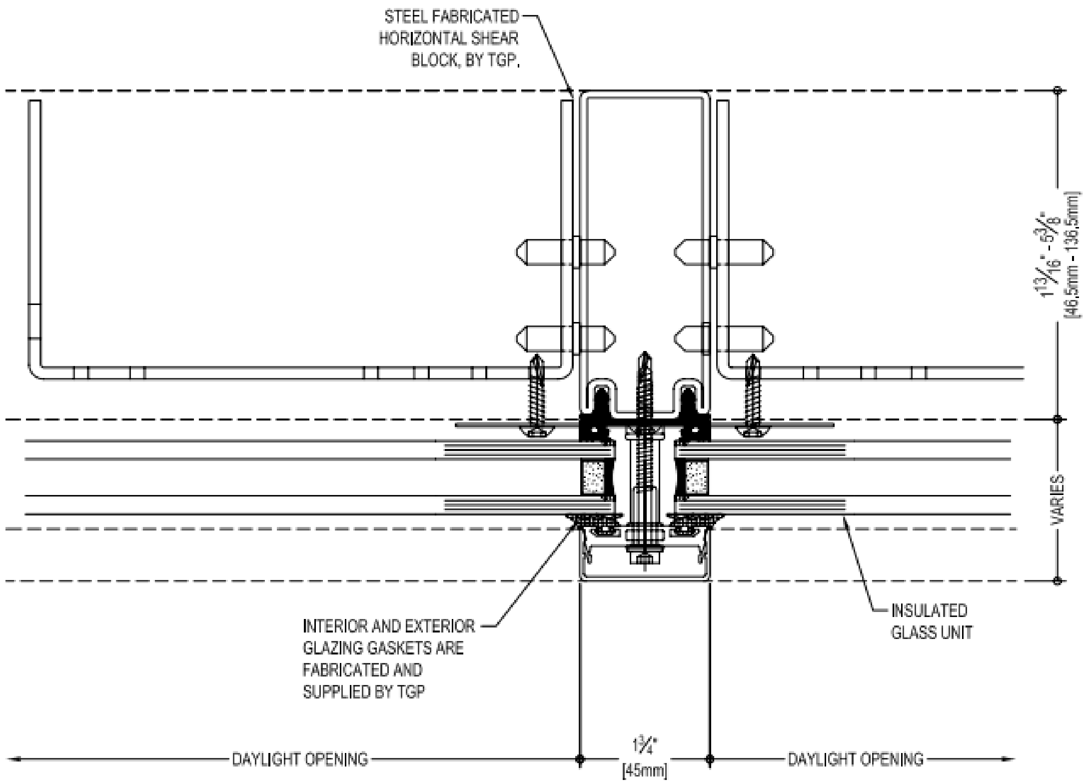
(from TGP America, Steelbuilt Curtain Wall Systems)



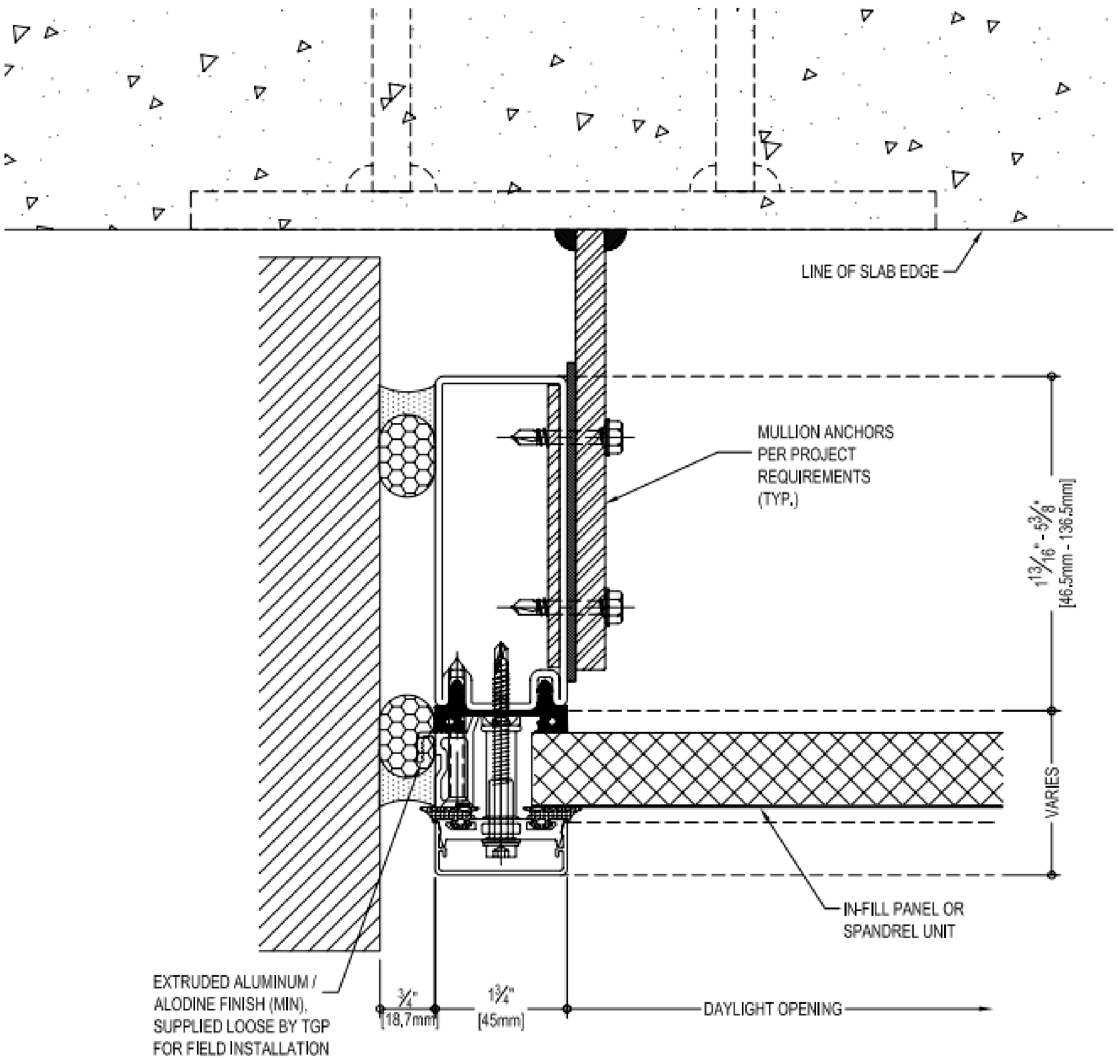

EXTRUDED ALUMINUM / ALODINE FINISH (MIN), SUPPLIED LOOSE BY TGP FOR FIELD INSTALLATION
WALL CONSTRUCTION BY OTHER TRADES
¾" [19mm]
1¾" [45mm]
WEEP HOLES AT DLO QTR POINTS
MULLION HEAD ANCHOR PER PROJECT REQUIREMENTS (TYP.)
INTERIOR AND EXTERIOR GLAZING SEALS ARE FABRICATED AND SUPPLIED BY TGP
DAYLIGHT OPENING
INSULATED GLASS UNIT
1 HEAD SECTION
SILICONE SETTING BLOCKS
DIVERTER GASKET / CON'T
1¾" [45mm]
DLO
PRESSURE PLATE & CLAMPING SCREWS SUPPLIED BY TGP
STEEL FABRICATED HORIZONTAL SHEAR BLOCKS, BY TGP
VARIES
1 13/16" - 5 3/8" [46.5mm - 136.5mm]
2 HORIZONTAL MULLION SECTION



3 HORIZONTAL MULLION SECTION AT SLAB EDGE



10 VERTICAL MULLION SECTION



11 VERTICAL MULLION SECTION AT SLAB

STEELBUILT CURTAINWALL SYSTEMS

Silicone Glazing Charts

DIMENSION					NARROWEST GLASS DIMENSION IN FT (Top Line of Chart)									
A	B	C	D	E	1'	2'	3'	4'	5'	6'	7'	8'	9'	10'
MULLION WIDTH	EXTERIOR WEATHER JOINT WIDTH	GASKET TAPE WIDTH	TOTAL B + C	SEALANT CONTACT WIDTH										
45 mm	12 mm	4 mm	20	12.5 mm / 1/2"	236	118	79	59	47	39	34	30	26	24
45 mm	19 mm	4 mm	27	9.0 mm / 5/16"	170	85	57	43	34	28	24	21	19	17
					MAXIMUM WIND LOAD IN PSF (Values in Table)									

CHART LEGEND:

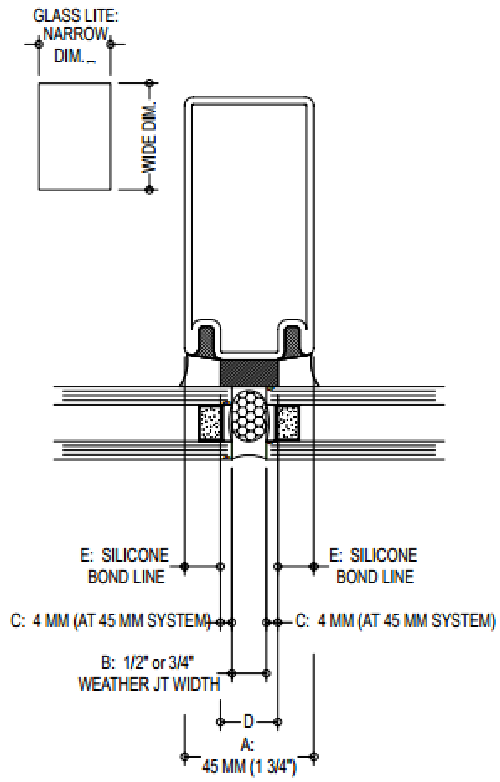
1. Select the row based on dimension column "B." This is the exterior weather joint between the lites of glass, the width is either 12 mm or 19 mm
2. To determine the sealant contact width, move to the right across the selected row to column "E" (sealant contact width)
3. To determine the maximum wind load in psf follow this row further to the right until you reach the appropriate narrowest glass dimension column (top row)

   a. **Note:** to determine the narrowest glass dimension, use narrowest dimension of either glass width or height, rounded up to the nearest foot

EXAMPLE:

1. For 45 mm mullion width system, select the 19 mm weather joint width (column B, row 2)
2. Follow row to sealant contact bond width column "E" (9.0 mm/ 5/16")
3. The largest lite on the project is 68" x 120". The narrowest measurement is 68", round up to 72" (6')
4. Continue across the row to the right and look up to the narrowest glass dimension in feet until you get to the 6' column. 28 psf is the maximum wind load

NOTE: chart and detail show possible configurations, exact conditions can vary project by project. Contact TGP or sealant manufacturer for specific questions about a given set of conditions or project.



1 SILICONE GLAZING DETAIL AT 45 mm SYSTEM

Appendix G: Architectural Floor Plans

Appendix H: Structural and STAAD Analysis of New Design

Definition: Whole Structure

Type	Seismic *IBC* 2006/2009
Zip Code	San Francisco- 94105
Ss	1.69
S1	0.838
TL	12 seconds
Importance factor	1
Response modification factor X (RX)	3
Response modification factor Z (RZ)	4
Site class	4

Loads: Whole Structure

No.	**Load Case Details**	**Loads Applied**
1	Seismic X	*IBC* Load X 1
2	Seismic -X	*IBC* Load –X 1
3	Seismic Z	*IBC* Load Z 1
4	Seismic -Z	*IBC* Load –Z 1
5	Dead Load	Selfweight Y-1
6	Live Load	All plates PR GY -0.8 kips/ft^2

Materials: Whole Structure

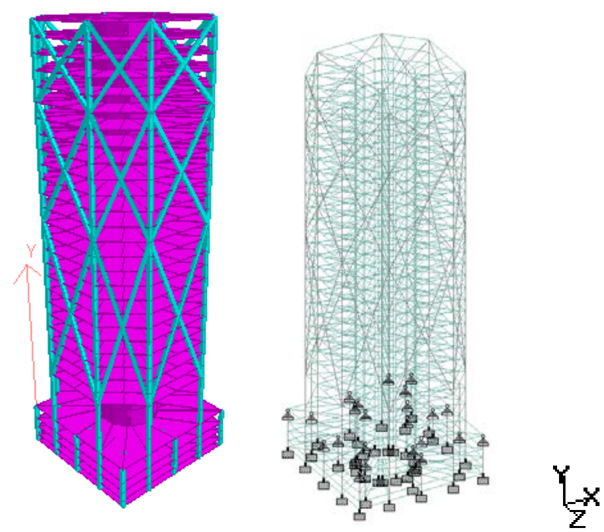
Name	E kip/in2	Poisson's Ratio	Density kip/in3	Alpha /°F	Fy kip/in2	Fu kip/in2	Ry	Rt	Fcu kip/in2
CONCRETE1	7000.000	170E-3	86.81E-6	5E-6	0.000	0.000	1.000	1.000	0.000
STEEL	29000.000	300E-3	283E-6	6.5E-6	36.000	58.000	1.500	1.200	0.000
STAINLESSSTEEL	28000.000	300E-3	289E-6	9.9E-6	0.000	0.000	0.000	0.000	0.000
ALUMINUM	10000.000	330E-3	98E-6	12.8E-6	0.000	0.000	0.000	0.000	0.000
CONCRETE	3150.000	170E-3	87E-6	5E-6	0.000	0.000	0.000	0.000	4.000

Properties: Whole Structure

No.	**Section**	**Thickness** (YD x ZD)	**Location**	**Material**
1	Plate Thickness	2.5’ x 2.5’	Core B4- Floor 21	Concrete1
2	Plate Thickness	1.167’ x 1.167’	All Floor Slabs	Concrete1
3	Plate Thickness	2’ x 2’	Core Floor 22-30	Concrete1
5	Rect Beam	3’ x 3’	All exterior columns	Concrete1
6	Rect Beam	2’ x 2’	Basement interior columns	Concrete1

7	Rect Beam	3’ x 3’	Steel bracing @ Floor 5,17,25,30	Steel

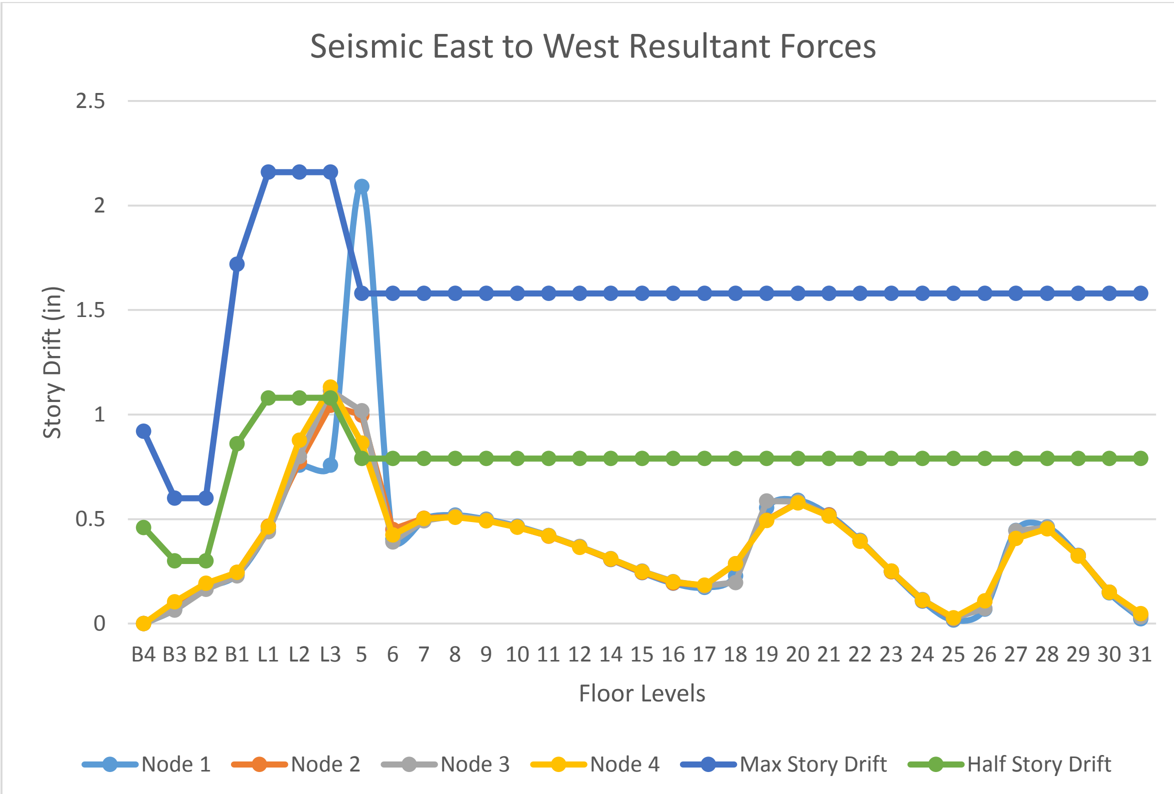
Design Summary Output

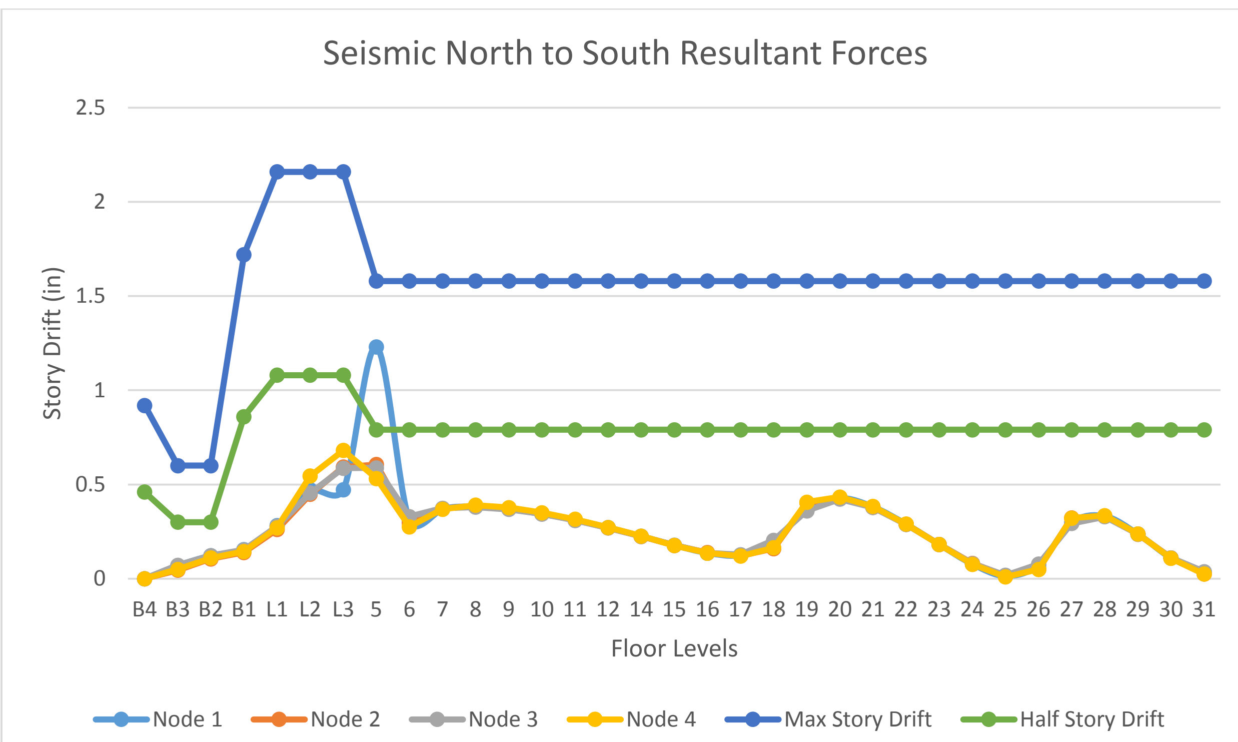
Element	Value
Image (3D, Geometry, Deflection (Load 1))	
Seismic X Forces Applied Load 1	***TOTAL APPLIED LOAD (KIP FEET) SUMMARY (LOADING 1) SUMMATION FORCE-X = 19078.27 SUMMATION FORCE-Y = 0.00 SUMMATION FORCE-Z = 0.00 SUMMATION OF MOMENTS AROUND THE ORIGIN- MX= 0.00 MY= 1297136.78 MZ= -5292322.62
Seismic X Max Displacements Load 1	MAXIMUM DISPLACEMENTS (INCH /RADIANS) (LOADING 1) MAXIMUMS AT NODE X = 2.21386E+01 2808 Y = 1.91444E+00 2486 Z = 3.95585E+00 506 RX= 4.46452E-03 1908 RY= 9.11160E-03 507 RZ= 6.29260E-03 1908
Seismic -X Forces Applied Load 2	***TOTAL APPLIED LOAD (KIP FEET) SUMMARY (LOADING 2) SUMMATION FORCE-X = -19078.27 SUMMATION FORCE-Y = 0.00 SUMMATION FORCE-Z = 0.00 SUMMATION OF MOMENTS AROUND THE ORIGIN- MX= 0.00 MY= -1297136.78 MZ= 5292322.62

Seismic -X Max Displacements Load 2	MAXIMUM DISPLACEMENTS (INCH /RADIANS) (LOADING 2) MAXIMUMS AT NODE X = -2.21386E+01 2808 Y = -1.91444E+00 2486 Z = -3.95585E+00 506 RX= -4.46452E-03 1908 RY= -9.11160E-03 507 RZ= -6.29260E-03 1908
Seismic Z Forces Applied Load 3	***TOTAL APPLIED LOAD (KIP FEET) SUMMARY (LOADING 3) SUMMATION FORCE-X = 0.00 SUMMATION FORCE-Y = 0.00 SUMMATION FORCE-Z = 15010.59 SUMMATION OF MOMENTS AROUND THE ORIGIN- MX= 4142296.00 MY= -1021581.39 MZ= 0.00
Seismic Z Max Displacements Load 3	MAXIMUM DISPLACEMENTS (INCH /RADIANS) (LOADING 3) MAXIMUMS AT NODE X = 3.29758E+00 2808 Y = 1.48991E+00 2474 Z = 1.31160E+01 2810 RX= 4.40794E-03 2355 RY= 4.78527E-03 509 RZ= 2.24361E-03 2816
Seismic -Z Forces Applied Load 4	***TOTAL APPLIED LOAD (KIP FEET) SUMMARY (LOADING 4) SUMMATION FORCE-X = 0.00 SUMMATION FORCE-Y = 0.00 SUMMATION FORCE-Z = -15010.59 SUMMATION OF MOMENTS AROUND THE ORIGIN- MX= -4142296.00 MY= 1021581.39 MZ= 0.00
Seismic –Z Max Displacements Load 4	MAXIMUM DISPLACEMENTS (INCH /RADIANS) (LOADING 4) MAXIMUMS AT NODE X = -3.29758E+00 2808 Y = -1.48991E+00 2474 Z = -1.31160E+01 2810 RX= -4.40794E-03 2355 RY= -4.78527E-03 509 RZ= -2.24361E-03 2816

Dead Load Forces Applied Load 5	***TOTAL APPLIED LOAD (KIP FEET) SUMMARY (LOADING 5) SUMMATION FORCE-X = 0.00 SUMMATION FORCE-Y = -136553.20 SUMMATION FORCE-Z = 0.00 SUMMATION OF MOMENTS AROUND THE ORIGIN- MX= 9259820.84 MY= 0.00 MZ= -9354141.97
Dead Load Max Displacements Load 5	MAXIMUM DISPLACEMENTS (INCH /RADIANS) (LOADING 5) MAXIMUMS AT NODE X = -5.28636E-01 1843 Y = -1.39999E+01 2684 Z = 3.55693E-01 512 RX= 3.01106E-02 2682 RY= 3.91963E-03 506 RZ= 3.13855E-02 2686
Live Load Forces Applied Load 6	***TOTAL APPLIED LOAD (KIP FEET) SUMMARY (LOADING 6) SUMMATION FORCE-X = 0.00 SUMMATION FORCE-Y = -417024.77 SUMMATION FORCE-Z = 0.00 SUMMATION OF MOMENTS AROUND THE ORIGIN- MX= 28255741.08 MY= 0.00 MZ= -28644227.98
Live Load Max Displacements Load 6	MAXIMUM DISPLACEMENTS (INCH /RADIANS) (LOADING 6) MAXIMUMS AT NODE X = -1.45672E+00 1843 Y = -6.64311E+01 2556 Z = 9.75569E-01 512 RX= 1.53111E-01 1914 RY= 1.08872E-02 506 RZ= 1.59383E-01 1918

Story Drift


Seismic East to West Resultant Forces
Story Drift (in)
2.5
2
1.5
1
0.5
0
B4 B3 B2 B1 L1 L2 L3 5 6 7 8 9 10 11 12 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Floor Levels
Node 1
Node 2
Node 3
Node 4
Max Story Drift
Half Story Drift


Seismic North to South Resultant Forces
Story Drift (in)
2.5
2
1.5
1
0.5
0
B4 B3 B2 B1 L1 L2 L3 5 6 7 8 9 10 11 12 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Floor Levels
Node 1
Node 2
Node 3
Node 4
Max Story Drift
Half Story Drift

Level	Height (ft.)	in	ft.-in	Factor	Max drift (in)	1/2 Drift (in)
B4	7.67	12.00	92.04	0.01	0.92	0.46
B3-B1	10.00	12.00	120.00	0.01	1.20	0.60
B1-L1	14.33	12.00	171.96	0.01	1.72	0.86
L1-L2	18.00	12.00	216.00	0.01	2.16	1.08
5-30	13.17	12.00	158.00	0.01	1.58	0.79

Our Story Drift													
			Resultant (in)			Resultant (in)			Resultant (in)			Resultant (in)	
Floor	Height (ft	Node	Seismic X	Seismic Z	Node 2	Seismic X	Seismic Z	Node 3	Seismic X	Seismic Z	Node 4	Seismic X	Seismic Z
B4	-42	2270	0	0	2773	0	0	2776	0	0	2779	0	0
B3	-34.33	2754	0.067	0.069	2757	0.099	0.045	2760	0.064	0.071	2763	0.105	0.049
B2	-24.33	2738	0.236	0.191	2741	0.288	0.15	2744	0.228	0.193	2747	0.298	0.158
B1	-14.33	2717	0.471	0.345	2721	0.533	0.289	2725	0.456	0.346	2729	0.543	0.302
L1	0.00	1865	0.92	0.627	1869	0.998	0.55	1873	0.895	0.624	1877	1.006	0.572
L2	18.00	1881	1.678	1.099	1885	1.771	0.998	1889	1.695	1.079	1893	1.884	1.117
L3	36.00	1881	1.678	1.099	2823	2.816	1.59	2827	2.809	1.665	2854	3.016	1.798
5	54.00	1897	3.77	2.329	1901	3.813	2.196	1905	3.827	2.253	1909	3.88	2.33
6	67.17	1929	4.175	2.634	1933	4.264	2.491	1937	4.218	2.583	1941	4.304	2.605
7	80.33	1961	4.678	3.005	1965	4.768	2.863	1969	4.71	2.957	1973	4.806	2.974
8	93.50	1993	5.197	3.388	1997	5.28	3.249	2001	5.225	3.337	2005	5.315	3.364
9	106.67	2025	5.696	3.76	2029	5.775	3.619	2033	5.721	3.705	2037	5.807	3.741
10	119.83	2057	6.162	4.107	2061	6.237	3.963	2065	6.184	4.048	2069	6.268	4.091
11	133.00	2089	6.583	4.419	2093	6.656	4.274	2097	6.605	4.357	2101	6.688	4.406
12	146.17	2121	6.95	4.69	2125	7.022	4.543	2129	6.974	4.626	2133	7.053	4.678
14	159.33	2153	7.256	4.915	2157	7.33	4.767	2161	7.285	4.85	2165	7.363	4.904
15	172.50	2185	7.5	5.092	2189	7.576	4.944	2193	7.536	5.028	2197	7.612	5.08
16	185.67	2217	7.693	5.228	2221	7.771	5.082	2225	7.737	5.164	2229	7.811	5.216
17	198.83	2249	7.866	5.353	2253	7.953	5.203	2257	7.917	5.291	2261	7.995	5.336
18	212.00	2281	8.095	5.553	2285	8.239	5.363	2289	8.114	5.495	2293	8.281	5.5
19	225.17	2313	8.649	5.92	2317	8.734	5.767	2321	8.7	5.855	2325	8.775	5.906
20	238.33	2345	9.239	6.347	2349	9.314	6.195	2353	9.284	6.277	2357	9.352	6.339
21	251.50	2377	9.76	6.728	2381	9.833	6.573	2385	9.798	6.655	2389	9.866	6.722
22	264.67	2209	10.158	7.017	2413	10.228	6.862	2417	10.193	6.943	2421	10.26	7.012
23	277.83	2441	10.406	7.198	2445	10.477	7.044	2449	10.444	7.125	2453	10.511	7.193
24	291.00	2407	10.514	7.275	2477	10.588	7.125	2481	10.559	7.205	2485	10.623	7.269
25	304.17	2505	10.531	7.289	2509	10.611	7.14	2513	10.584	7.223	2517	10.651	7.278
26	317.33	2537	10.601	7.362	2541	10.718	7.19	2545	10.657	7.3	2549	10.76	7.327
27	330.50	2569	11.047	7.659	2573	11.128	7.512	2577	11.102	7.593	2581	11.167	7.648
28	343.67	2601	11.51	7.99	2605	11.583	7.845	2609	11.561	7.922	2613	11.621	7.983
29	356.83	2633	11.836	8.227	2837	11.908	8.081	2641	11.885	8.158	2645	11.945	8.221
30	370.00	2665	11.983	8.336	2669	12.058	8.191	2673	12.035	8.268	2677	12.095	8.329
31	383.17	2697	12.007	8.371	2701	12.1	8.215	2705	12.068	8.305	2709	12.143	8.353

Appendix I: HVAC Calculations

Building Orientation	NO. of People	Occupant Load	Skin Load		Total	No. Chilled Beam Units	Chilled Beam Length	Chilled Beam Cooling Capacity (BTU/hr-lf)	Total	Chilled Beam Heating Capacity (Btu/hr-lf)	Total
N	4	800	3761		**4561**	2	6	580	**6960**	800	9600
NE	6	1200	2917		**4117**	2	6	580	**6960**	800	9600
ENE	6	1200	7517		**8717**	2	8	580	**9280**	800	12800
E	4.5	900	11108		**12008**	2	10	580	**11600**	800	16000
						2	4	580	**4640**	800	6400
ESE	6	1200	9531		**10731**	3	8	580	**13920**	800	19200
SE	6	1200	9913		**11113**	3	8	580	**13920**	800	19200
S	4	800	16695		**17495**	4	8	580	**18560**	800	25600
SW	6	1200	15146		**16346**	3	10	580	**17400**	800	24000
WSW	6	1200	12827		**14027**	2	10	580	**11600**	800	16000
W	4.5	900	14130		**15030**	2	10	580	**11600**	800	16000
						2	4	580	**4640**	800	6400
WNW	6	1200	7400		**8600**	3	6	580	**10440**	800	14400
NW	6	1200	3813		**5013**	2	6	580	**6960**	800	9600
			Total		127,758			Total	148,480		204800

Indoor Temp (F)	76		
Outdoor Temp (F)	82		
W_o (grw./lb d.a.)	80.3		
W_i (grw./lb d.a.)	76.2		
COOLING LOAD CALCULATION			
NET COOLING LOAD	115,450		
PEOPLE			
No.	91		
Sensible Heat (BTU/Hr)	250		
Latent Heat (BTU/Hr)	200		
LIGHTING			
Total Area	14704		
Capacity (Watts/ft^2)	4		
CLF	1		
Cooling Load (BTU/h)	199,974		
SENSIBLE HEAT GAIN			
People	22750		
LATENT HEAT GAIN			
	Total		
People	18,200		
EQUIPMENT			
	Number	Heat Gain	Total
Computer	82	800	65,600
Printer	2	1000	2,000
Copiers (large)	2	1000	2,000
		Total	69,600
VENTILATION			
Sensible C.L (BTU/hr)	9,704.64		
Latent C.L (BTU/hr)	768.65		
Room Cooling Load Sensible(BTU/hr)	394,729		
Room Cooling Latent Load (BTU/hr)	413,698		
Skin Loads Handled By Active Chilled Beams	148,480		
Loads Handled by AHU	246,249		

Indoor Temp (F)	70			
Outdoor Temp (F)	38			
100% Outside Air (CFM introduced)	3000			
HEATING LOAD CALCULATION				
ACH (due to infiltration)	0.25			
ACH (for offices)	5			
	Area	Height	CFM (infiltration)	CFM REQ.
CORE EXTERIOR				
Office 1	113	9	4.2375	203
Office 2	113	9	4.2375	203
Office 3	113	9	4.2375	203
Office 4	113	9	4.2375	203
Office 5	113	9	4.2375	203
Office 6	113	9	4.2375	203
Office 7	113	9	4.2375	203
Office 8	113	9	4.2375	203
Office 9	113	9	4.2375	203
Office 10	113	9	4.2375	203
Office 11	113	9	4.2375	203
Office 12	113	9	4.2375	203
Conference	178	9	6.675	320
Conference	178	9	6.675	320
Conference	178	9	6.675	320
Conference	178	9	6.675	320
Break Room	162	9	6.075	292
Break Room	162	9	6.075	292
CORE INTERIOR				
Bathroom (M)	384	9	14.4	0
Bathroom (F)	389	9	14.5875	0
PERIMETER OFFICES				
Office (LRG)	251	9	9.4125	452
Office (LRG)	251	9	9.4125	452
Office 1	145	9	5.4375	261
Office 2	145	9	5.4375	261
Office 3	145	9	5.4375	261
Office 4	145	9	5.4375	261
WORKFLOOR				
Workstations	10457	9	392.1	18,823.0
		Total	276	25,071
Net Heating Load	38,119	BTU/hr		
Infiltration (Sensible Heat Loss)	9,528	BTU/hr		
Ventilation				
Sensible	103,680	BTU/hr		
Duct Heat Loss	3,811.9	BTU/hr		
Duck Heat Leakage	15,247.6	BTU/hr		
Room Heating Load	170,387	BTU/hr		

17-Feb-2014	Project Identification 1		Roof Type	2			
PEAKLOAD	Project Identification 2		Susp'd Ceil'g?	0	(1=Y, 0=No)		
PEAK	Peak OSA Temp for --	Oakland, CA (Alameda NA	Indoor Temp	76	F	HEAT LOSS DATA	
	36 Degrees N. Lat		Daily Range	17	F	Inside	70 F
			CLFMED		Total Heat Gain 115,450	Outside	38 F

	Room	Orien-tation	.... Wall .... Area	Grp	U	.... Glass .... Area	U	SC	Room Area	Roof U	Peak Mnth	Peak Hour	Total S&T	.... Wall .... CLTD	BTUH	.... Glass .... SHGF	CLF	CLTD	BTUH	..... Roof ..... CLTD	BTUH	Heat Loss
WORKSTATION AREA	A	WNW	0	G	0.20	310.5	0.24	0.38	1096		9	15	7306	43	0	167	0.35	5.5	7306	59	0	2385
	A (Spandrel)	WNW	72	E	0.20	0	0.24	0.38	0		9	15	94	7	94	167	0.35	5.5	0	59	0	461
	B	NW	0	G	0.20	306	0.24	0.38	1022		9	15	3718	24	0	95	0.30	5.5	3718	59	0	2350
	B (Spandrel)	NW	72	E	0.20	0	0.24	0.38	0		9	15	43	3	43	95	0.30	5.5	0	59	0	461
	C	N	0	G	0.20	414	0.24	0.38	930		9	15	4253	12	0	31	0.76	5.5	4253	59	0	3180
	C (Spandrel)	N	96	E	0.20	0	0.24	0.38	0		9	15	58	3	58	31	0.76	5.5	0	59	0	614
	C2	NE	0	G	0.20	243	0.24	0.38	537		9	15	2777	14	0	95	0.28	5.5	2777	59	0	1866
	C2 (Spandrel)	NE	54	E	0.20	0	0.24	0.38	0		9	15	140	13	140	95	0.28	5.5	0	59	0	346
	D	ENE	0	G	0.20	382	0.24	0.38	1211		9	15	7292	14	0	167	0.28	5.5	7292	59	0	2934
	D (Spandrel)	ENE	90	E	0.20	0	0.24	0.38	0		9	15	225	13	225	167	0.28	5.5	0	59	0	576
	E	ESE	0	G	0.20	315	0.24	0.38	1080		9	15	9149	21	0	228	0.32	5.5	9149	59	0	2419
	E (Spandrel)	ESE	72	E	0.20	0	0.24	0.38	0		9	15	382	27	382	228	0.32	5.5	0	59	0	461
	F	SE	0	G	0.20	297	0.24	0.38	1051		9	15	9452	27	0	223	0.36	5.5	9452	59	0	2281
	F(Spandrel)	SE	72	E	0.20	0	0.24	0.38	0		9	15	461	32	461	223	0.36	5.5	0	59	0	461
	G	S	0	G	0.20	414	0.24	0.38	877		9	15	16138	43	0	187	0.53	5.5	16138	59	0	3180
	G(Spandrel)	S	96	E	0.20	0	0.24	0.38	0		9	15	557	29	557	187	0.53	5.5	0	59	0	614
	G	SW	0	G	0.20	315	0.24	0.38	781		9	15	14563	54	0	223	0.53	5.5	14563	59	0	2419
	G2 (Spandrel)	SW	54	G	0.20	0	0.24	0.38	0		9	15	583	54	583	223	0.53	5.5	0	59	0	346
	H	WSW	0	G	0.20	306	0.24	0.38	1031		9	15	12599	50	0	228	0.46	5.5	12599	59	0	2350
	H (Spandrel)	WSW	90	E	0.20	0	0.24	0.38	0		9	15	261	15	261	228	0.46	5.5	0	59	0	576
PERIMETER OFFICES	1	W		G	0.20	146.9	0.24	0.38	145		9	15	4883	45	0	210	0.40	5.5	4883	59	0	1128
	1 (Spandrel)	W	36	E	0.20	0	0.24	0.38	0		9	15	65	9	65	210	0.40	5.5	0	59	0	230
	2	W	0	G	0.20	126	0.24	0.38	251		9	15	4188	45	0	210	0.40	5.5	4188	59	0	968
	2 (Spandrel)	W	24	E	0.20	0	0.24	0.38	0		9	15	43	9	43	210	0.40	5.5	0	59	0	154
	3	W	0	G	0.20	147	0.24	0.38	145		9	15	4886	45	0	210	0.40	5.5	4886	59	0	1129
	3 (Spandrel)	W	36	E	0.20	0	0.24	0.38	0		9	15	65	9	65	210	0.40	5.5	0	59	0	230
	4	E	0	G	0.20	147	0.24	0.38	145		9	15	3596	19	0	210	0.29	5.5	3596	59	0	1129
	4 (Spandrel)	E	36	E	0.20	0	0.24	0.38	0		9	15	180	25	180	210	0.29	5.5	0	59	0	230
	5	E	0	G	0.20	147	0.24	0.38	251		9	15	3596	19	0	210	0.29	5.5	3596	59	0	1129
	5 (Spandrel)	E	24	E	0.20	0	0.24	0.38	0		9	15	120	25	120	210	0.29	5.5	0	59	0	154
	6	E	0	G	0.20	147	0.24	0.38	145		9	15	3596	19	0	210	0.29	5.5	3596	59	0	1129
	6 (Spandrel)	E	36	E	0.20	0	0.24	0.38	0		9	15	180	25	180	210	0.29	5.5	0	59	0	230

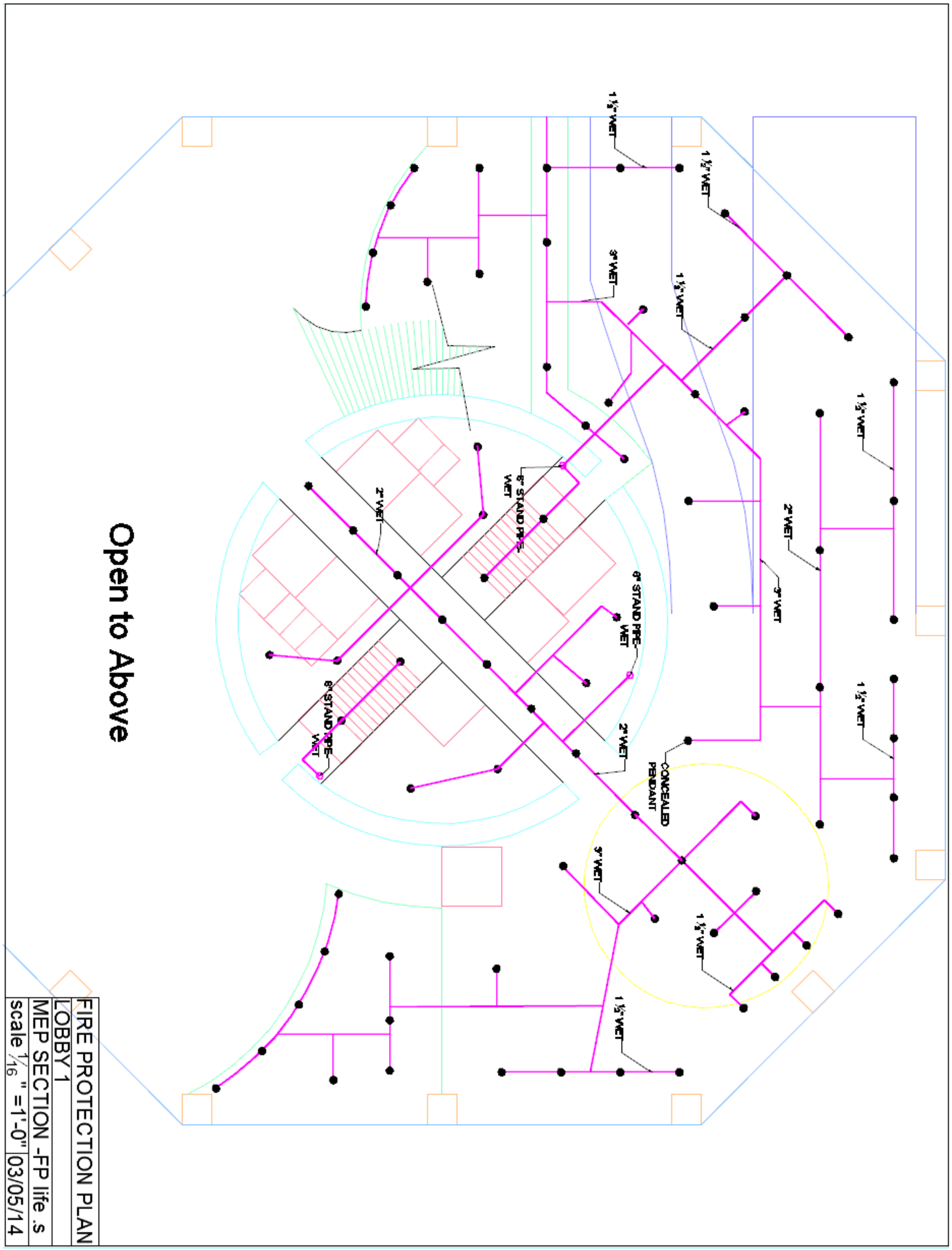
CFM CALCULATION FOR A TYPICAL FLOOR			
	Area	Height	CFM REQ.
CORE EXTERIOR			
Office 1	113	9	85
Office 2	113	9	85
Office 3	113	9	85
Office 4	113	9	85
Office 5	113	9	85
Office 6	113	9	85
Office 7	113	9	85
Office 8	113	9	85
Office 9	113	9	85
Office 10	113	9	85
Office 11	113	9	85
Office 12	113	9	85
Conference	178	9	134
Conference	178	9	134
Conference	178	9	134
Conference	178	9	134
Break Room	162	9	122
Break Room	162	9	122
PERIMETER OFFICES			
Office (LRG)	251	9	188
Office (LRG)	251	9	188
Office 1	145	9	109
Office 2	145	9	109
Office 3	145	9	109
Office 4	145	9	109
WORKFLOOR			
Workstations	10457	9	7843
		Total CFM	10448

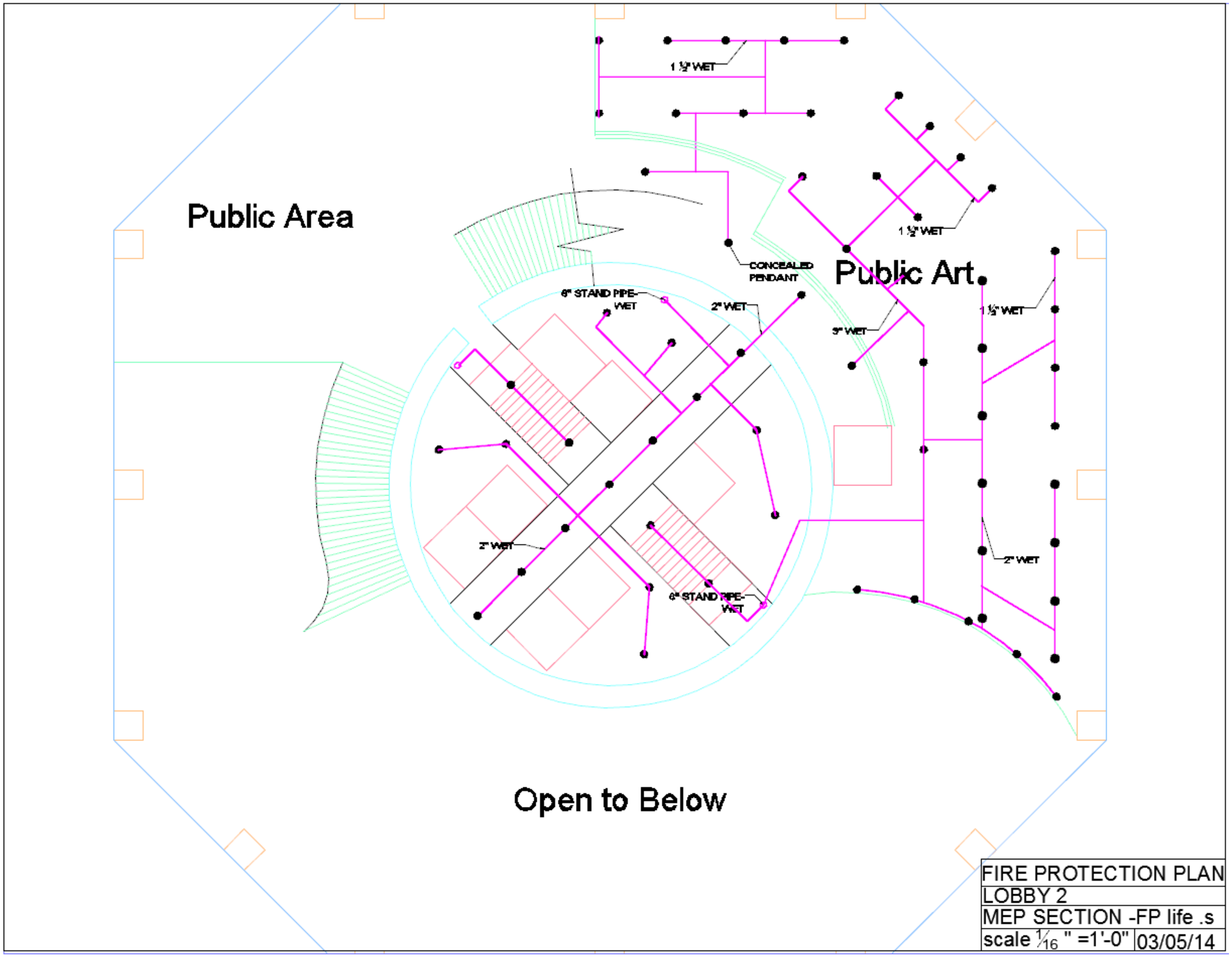
Appendix J: Fire Protection Calculations and Design

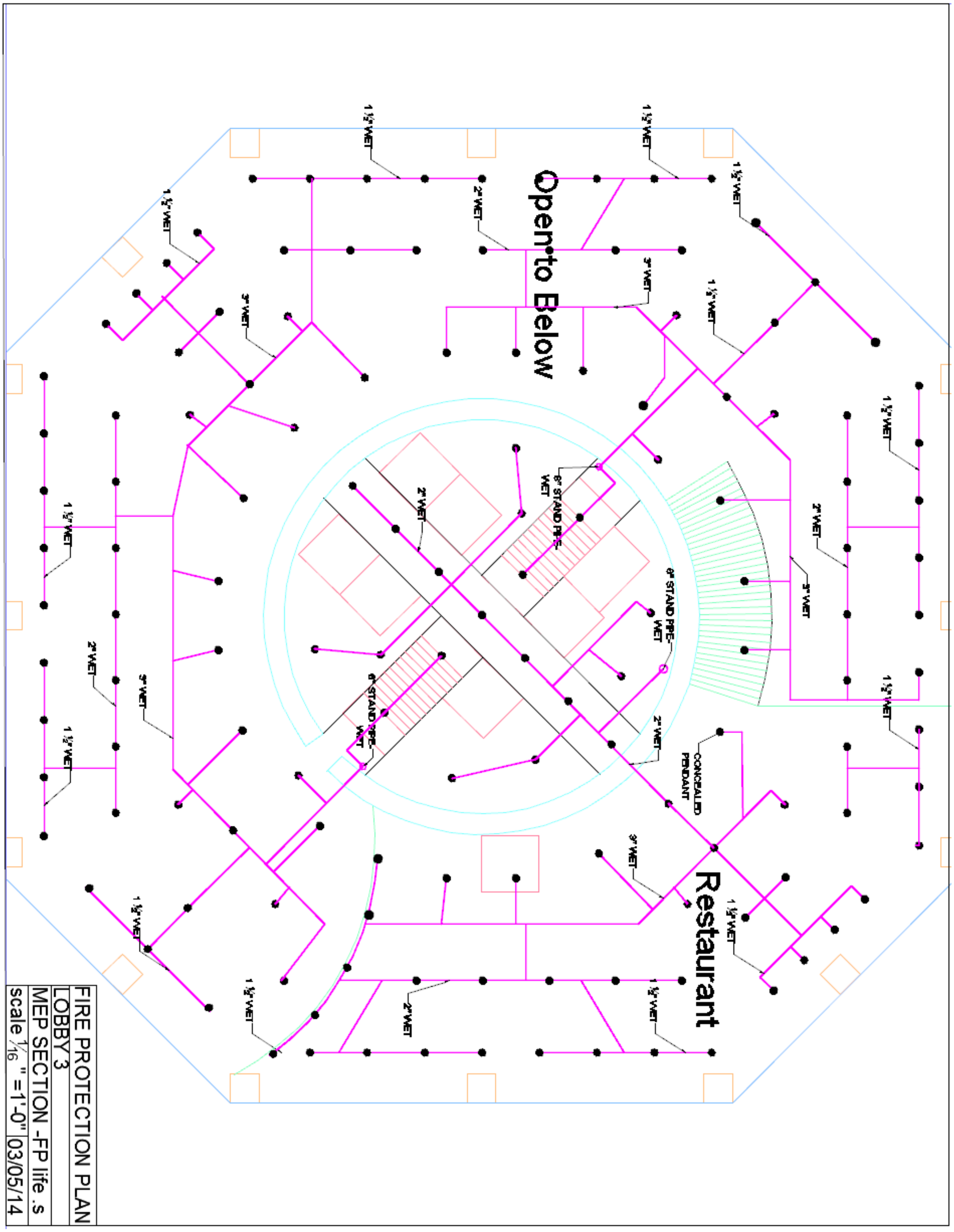
Chapter 10 table 1004.1.2				
Occupant Load				
Floor	Function of space	gross or net	area	Occupant Load
Parking Garage				
1				
	Parking Garage	200	15795.8 8	79
2				
	Parking Garage	200	15795.8 8	79
3				
	Parking Garage	200	15795.8 8	79
4				
	Parking Garage	200	15795.8 8	79
			total	316
Lobby				
1				
	Assembly (Standing)	5	5932	1186
	Mercantile (grade floor)	30	1403	47
	Mercantile (storage, shipping)	300	5921	20
2				
	Assembly (exhibit)	30	3416	114
	Assembly (unconcentrated)	15	3096	206
3				
	Assembly (concentrated)	30	3097	103
			total	
Offices				
5-30	Business	100	14755.8 8	148
	Conference Rooms Assembly (unconcentrated)	15	1040	17
			total	165
			total	481
Office or Tenant Space Floors 5-30				

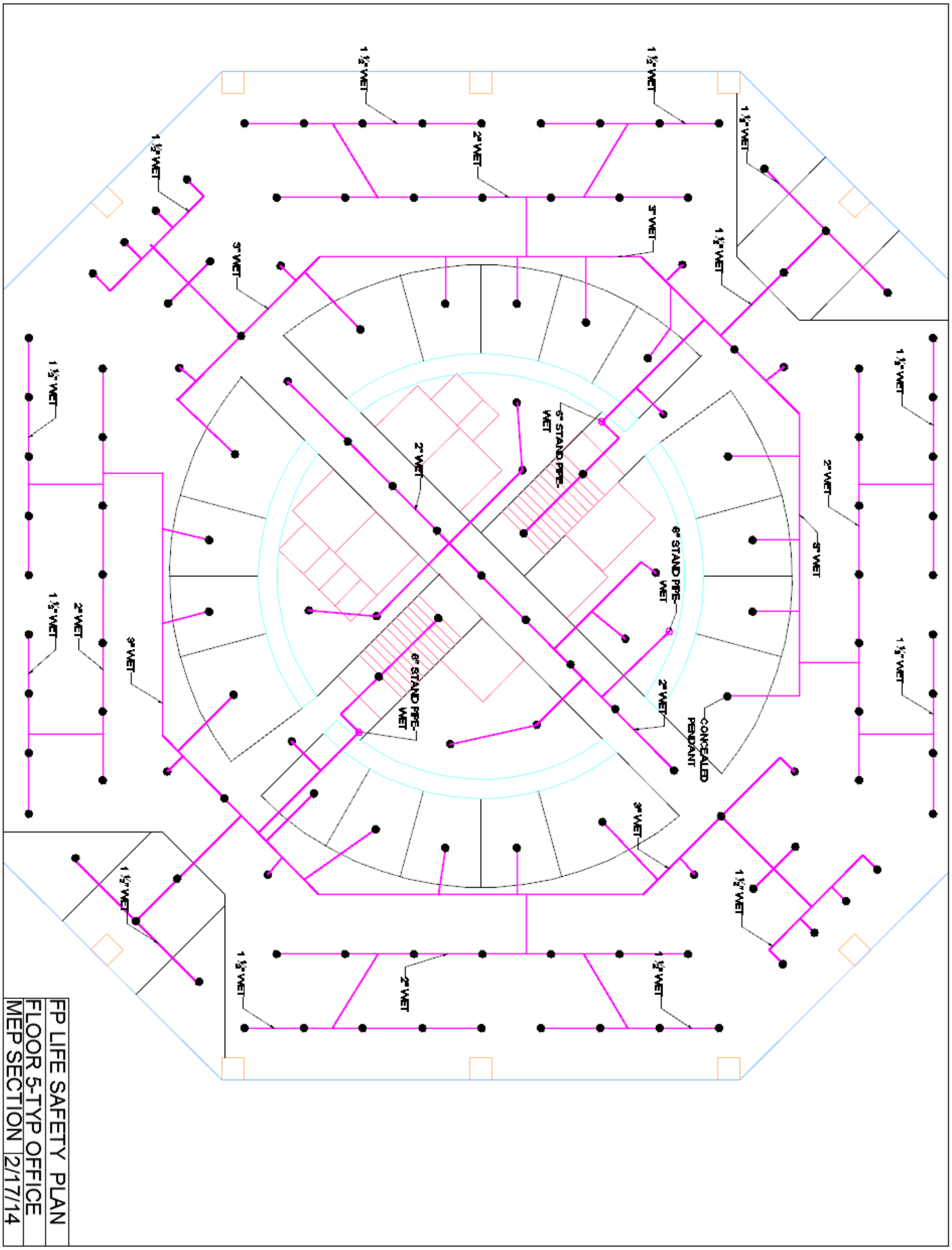
Egress Component	**Occupant Load Served**	**Minimum Required Calculated Width**	**Minimum Required Component Width**	**Minimum Required Width**	**Sections**
Aisle	148	29.6	36"	36"	1017.2
Corridor	165	33	44"	44"	1018.2
Stairway	165	49.5	44"	49.5	1009.1
Door	165	33	32"	33	1008.1.1
Lobby					
Egress Component	Occupant Load Served	Minimum Required Calculated Width	Minimum Required Component Width	Minimum Required Width	Sections
Stairway	0	0	44"	0	1009.1
Door	481	96	32"	96	1008.1.1

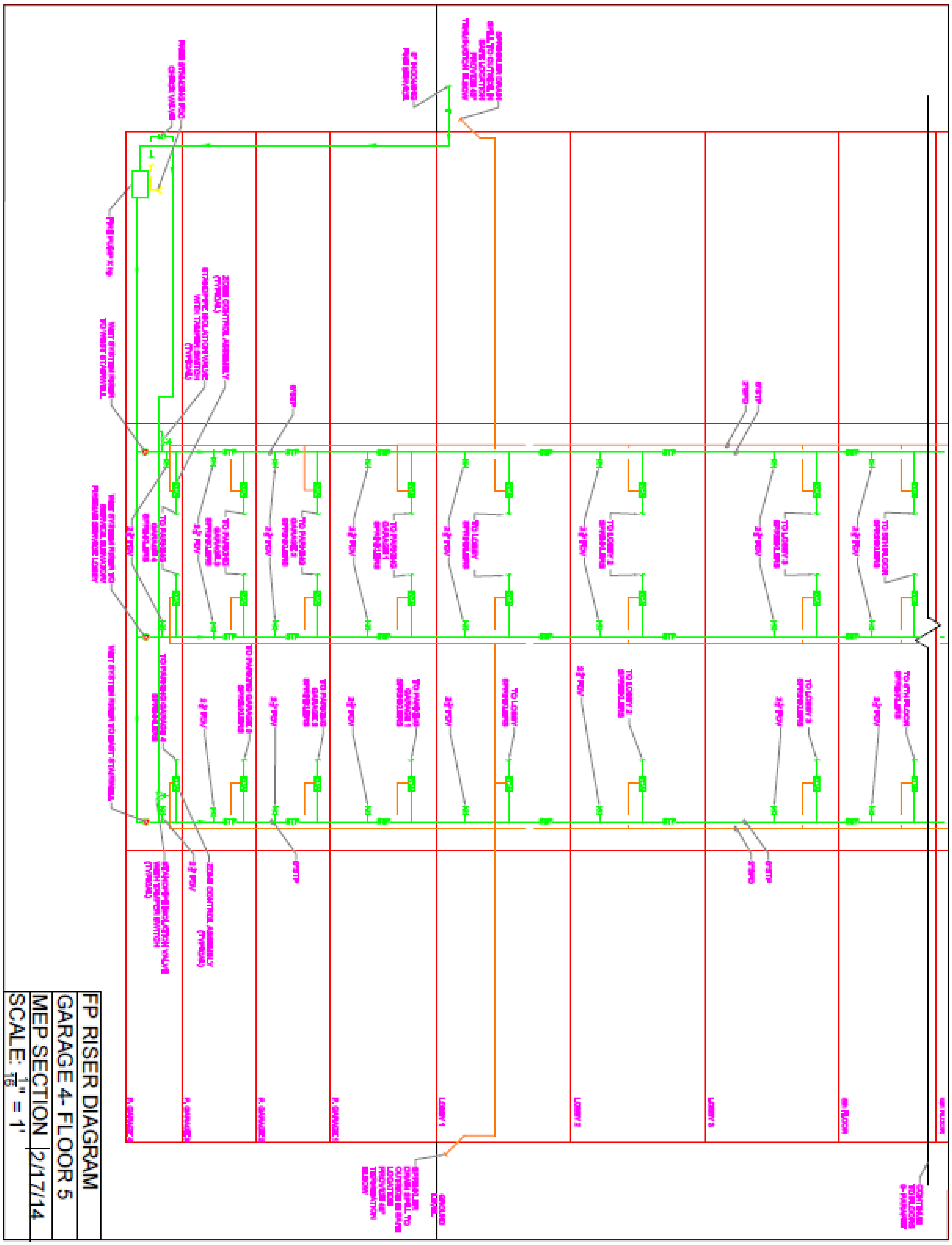
Chapter 4 and 10		
Allowable Separation between Stairs	193.175'	
Diagonal Distance	64.39'	
min distance door to door 1/3	30'	according to 403.5.1
min distance apart		


1 ½" WET
1 ½" WET
2" WET
3" WET
1 ½" WET
1 ½" WET
1 ½" WET
3" WET
CONCEALED PENDANT
6" STAND PIPE-WET
2" WET
1 ½" WET
1 ½" WET
3" WET
6" STAND PIPE-WET
2" WET
6" STAND PIPE-WET
Open to Above
FIRE PROTECTION PLAN
LOBBY 1
MEP SECTION -FP life .s
scale 1/16 " =1'-0"
03/05/14


Public Area
Public Art
Open to Below
1 ½" WET
CONCEALED PENDANT
6" STAND PIPE-WET
2" WET
3" WET
FIRE PROTECTION PLAN
LOBBY 2
MEP SECTION -FP life .s
scale 1⁄16 " =1'-0"
03/05/14

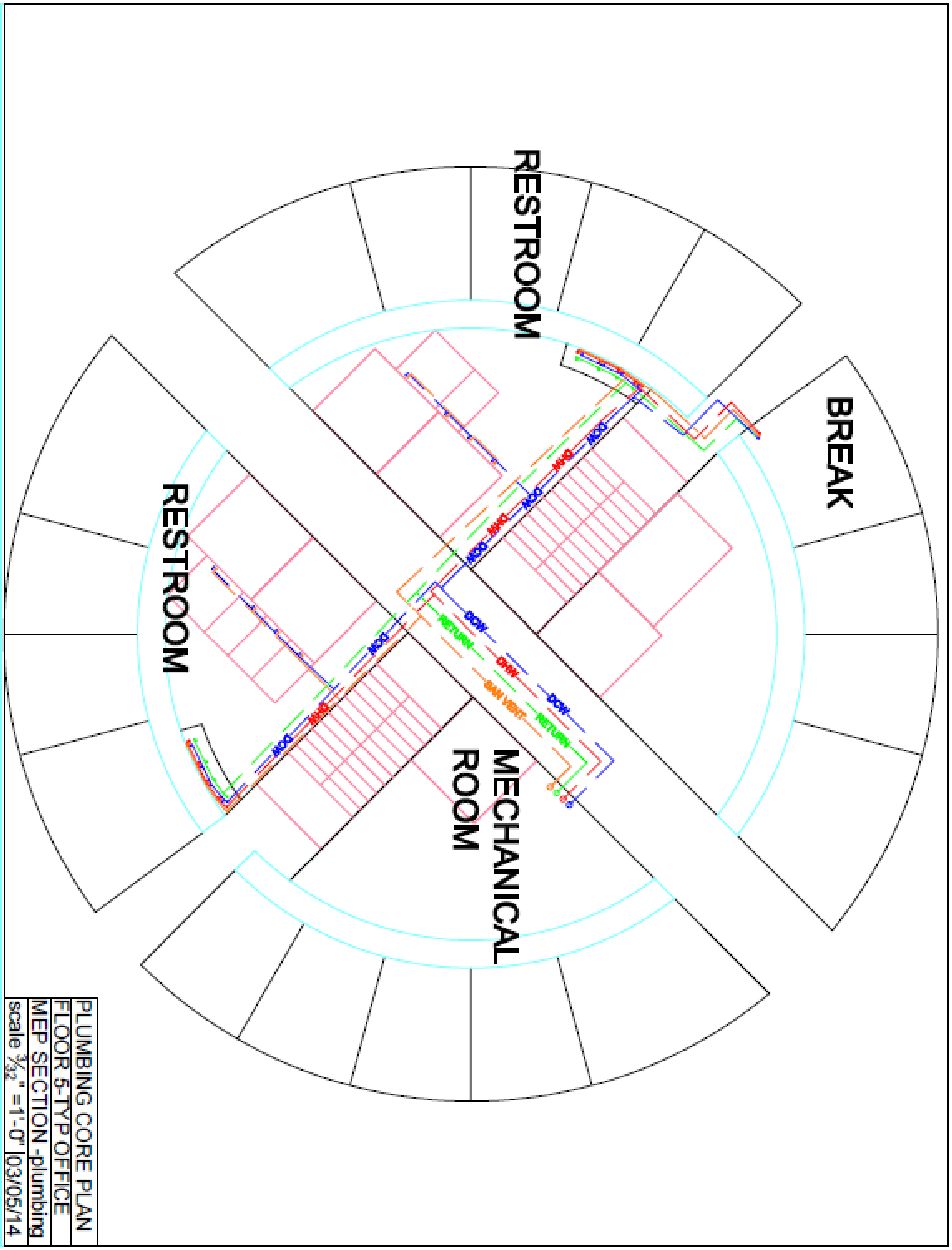

Open to Below
Restaurant
1 ½" WET
2" WET
3" WET
6" STAND PIPE- WET
CONCEALED PENDANT
FIRE PROTECTION PLAN
LOBBY 3
MEP SECTION -FP life .s
scale 1/16 " =1'-0"
03/05/14


FP LIFE SAFETY PLAN
FLOOR 5-TYP OFFICE
MEP SECTION
2/17/14
1 ½" WET
2" WET
3" WET
6" STAND PIPE-WET
CONCEALED PENDANT

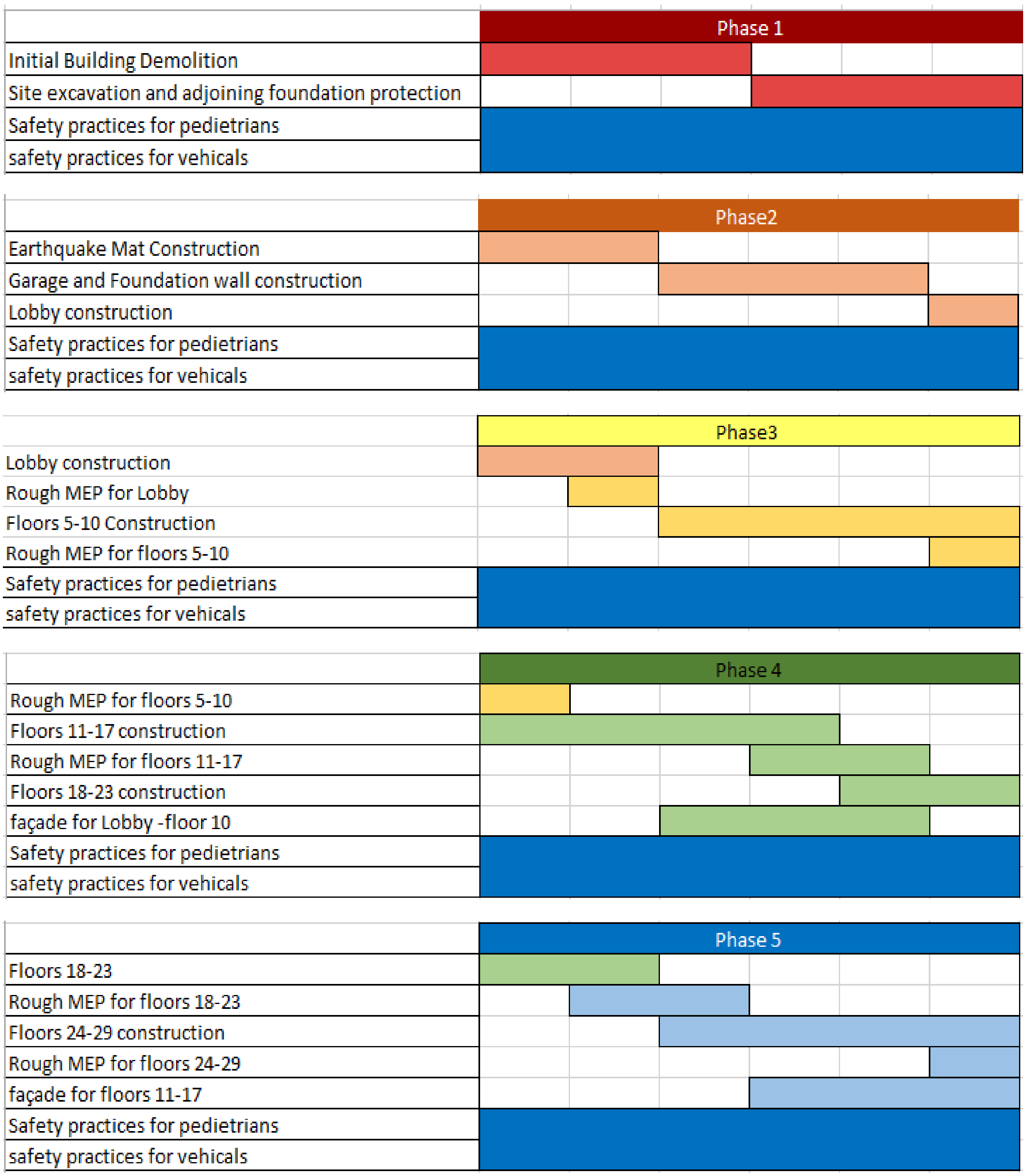


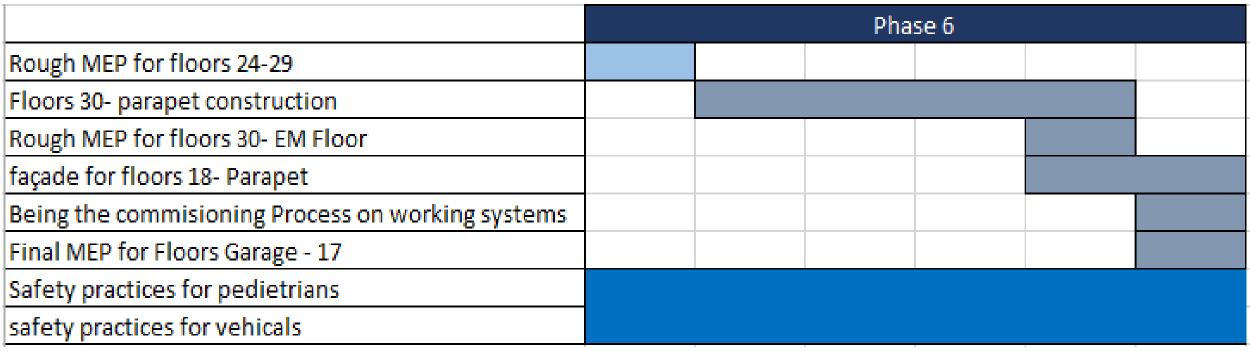
FP RISER DIAGRAM
GARAGE 4- FLOOR 5
MEP SECTION
2/17/14
SCALE: 1/16" = 1'

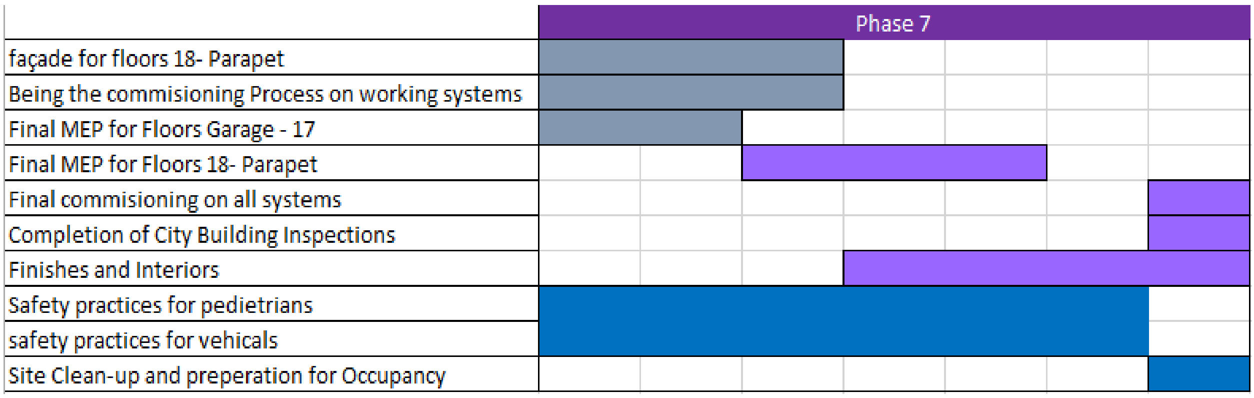
Appendix K: Plumbing System Design



Appendix L: Building Construction Schedule



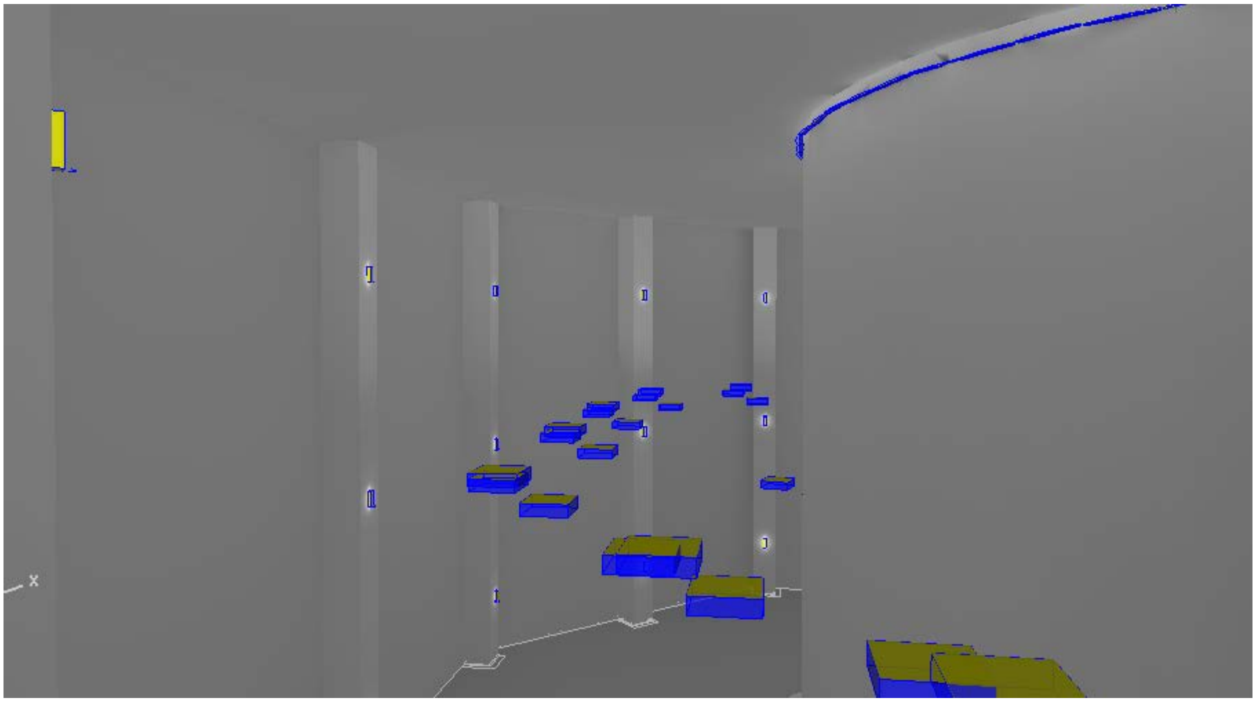

Phase 6
Rough MEP for floors 24-29
Floors 30- parapet construction
Rough MEP for floors 30- EM Floor
façade for floors 18- Parapet
Being the commisioning Process on working systems
Final MEP for Floors Garage - 17
Safety practices for pedietrians
safety practices for vehicals

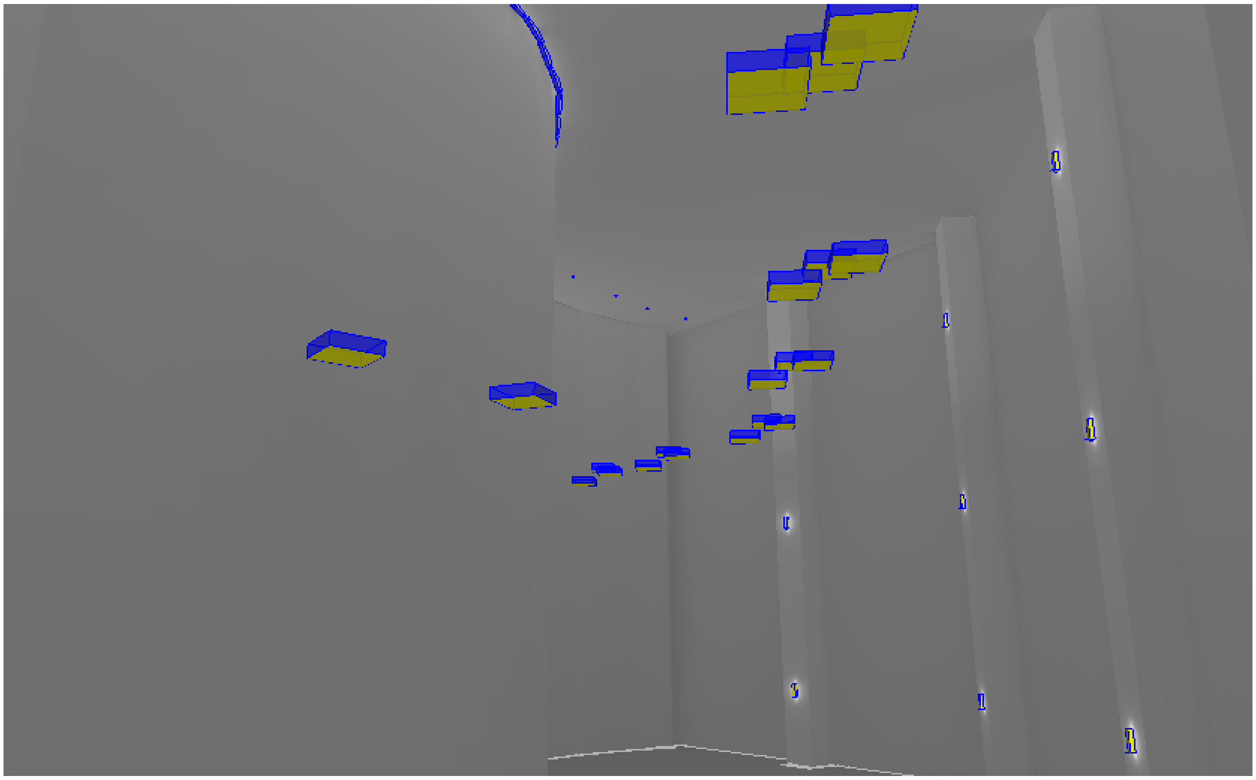

Phase 7
façade for floors 18- Parapet
Being the commisioning Process on working systems
Final MEP for Floors Garage - 17
Final MEP for Floors 18- Parapet
Final commisioning on all systems
Completion of City Building Inspections
Finishes and Interiors
Safety practices for pedietrians
safety practices for vehicals
Site Clean-up and preperation for Occupancy

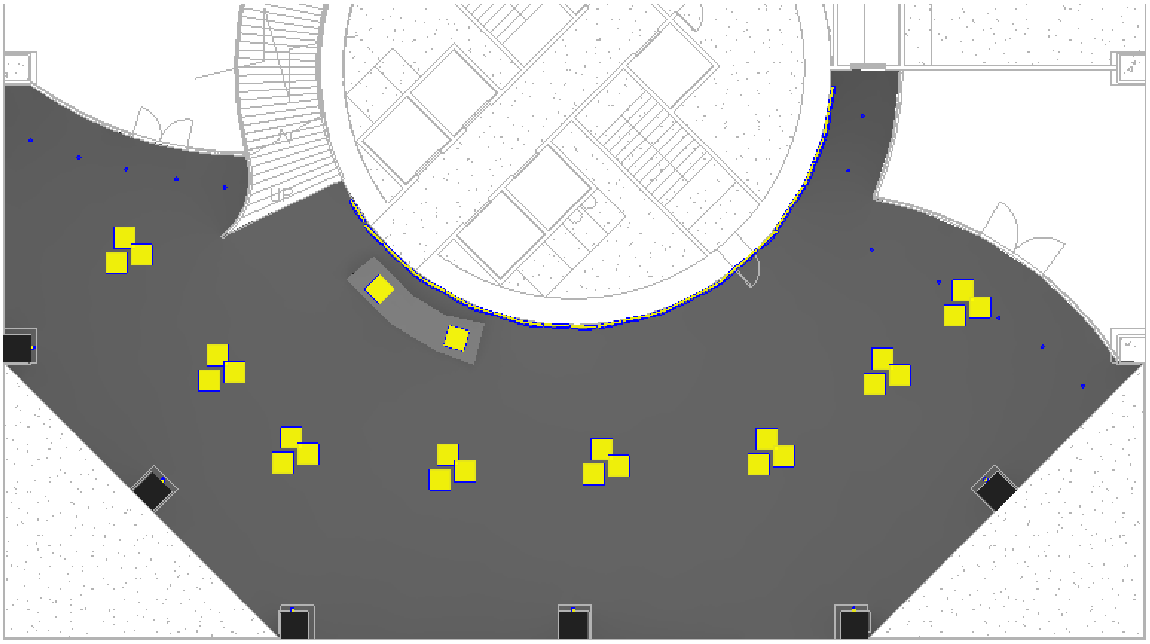

Final
Site Clean-up and preperation for Occupancy
Occupancy

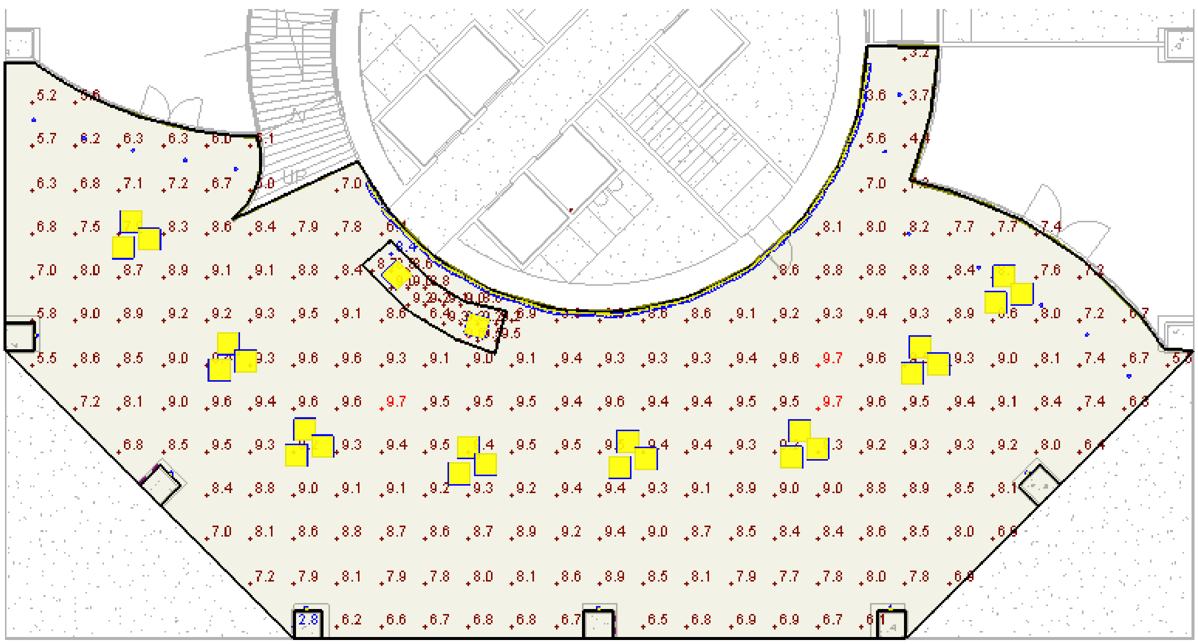
Appendix M: Lighting System Designs

Lobby Lighting

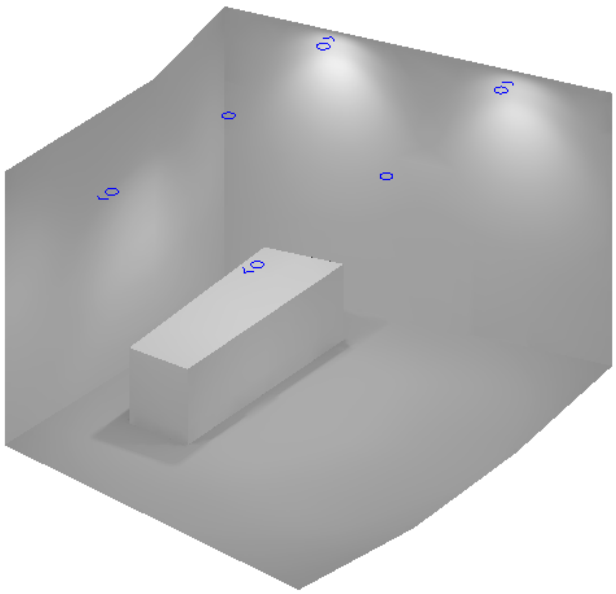


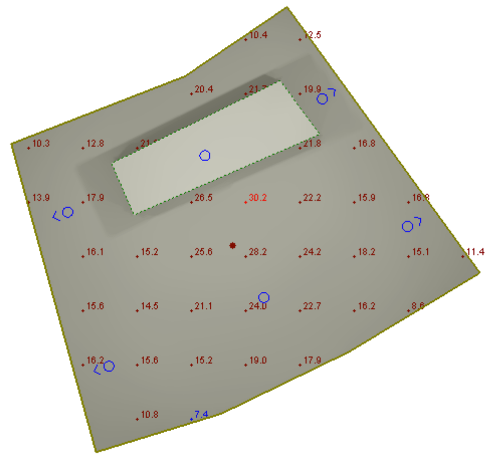






Break Room



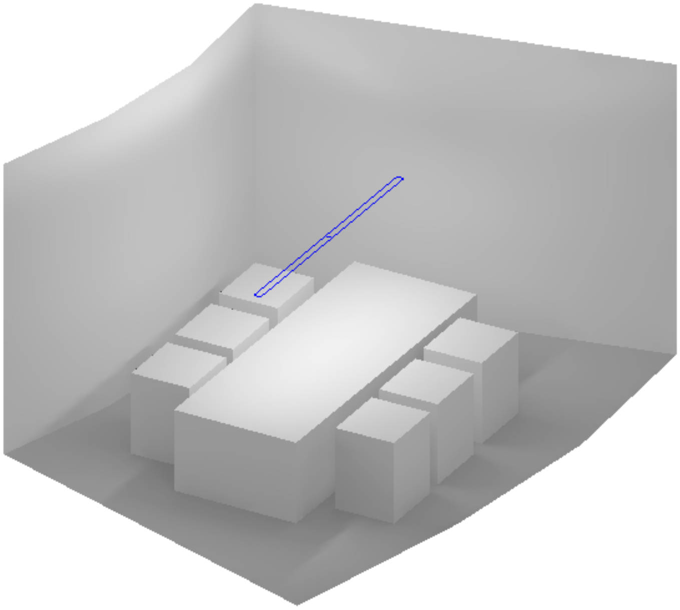


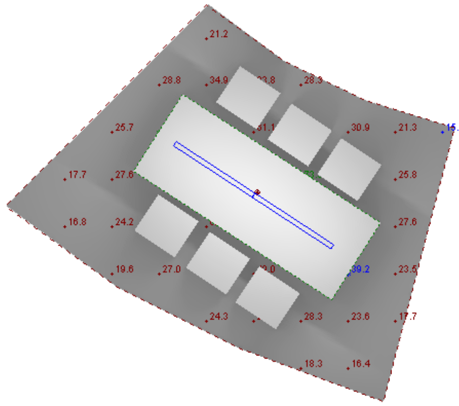
Luminaire Schedule					
Symbol	Label	Number Lamps	Lumens Per Lamp	Light Loss Factor	Wattage
	D1W	1	625.5557	0.8	23
	D1	1	1092.248	0.8	21

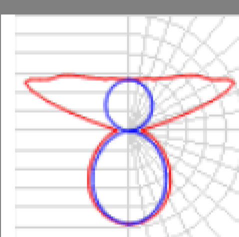
Statistics							
Description	Symbol	Avg	Max	Min	Max/Min	Avg/Min	Avg/Max
General Ambient		18.1 fc	30.2 fc	7.4 fc	4.1:1	2.4:1	0.6:1
Table		23.9 fc	25.5 fc	21.6 fc	1.2:1	1.1:1	0.9:1

Power Statistics				
Description	# Luminaires	Total Watts	Area	Density
LPD	6	134.0 W	161.2 ft²	0.8 W/ft²

Conference Room



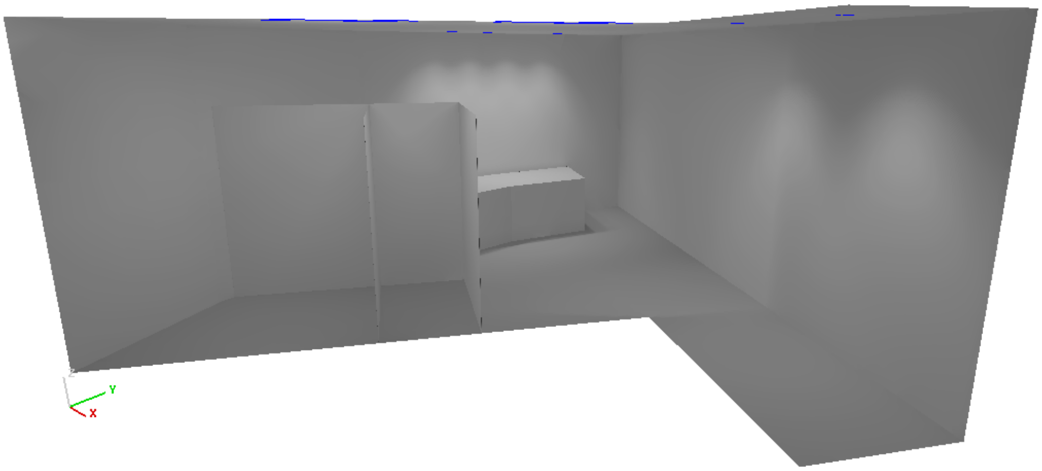


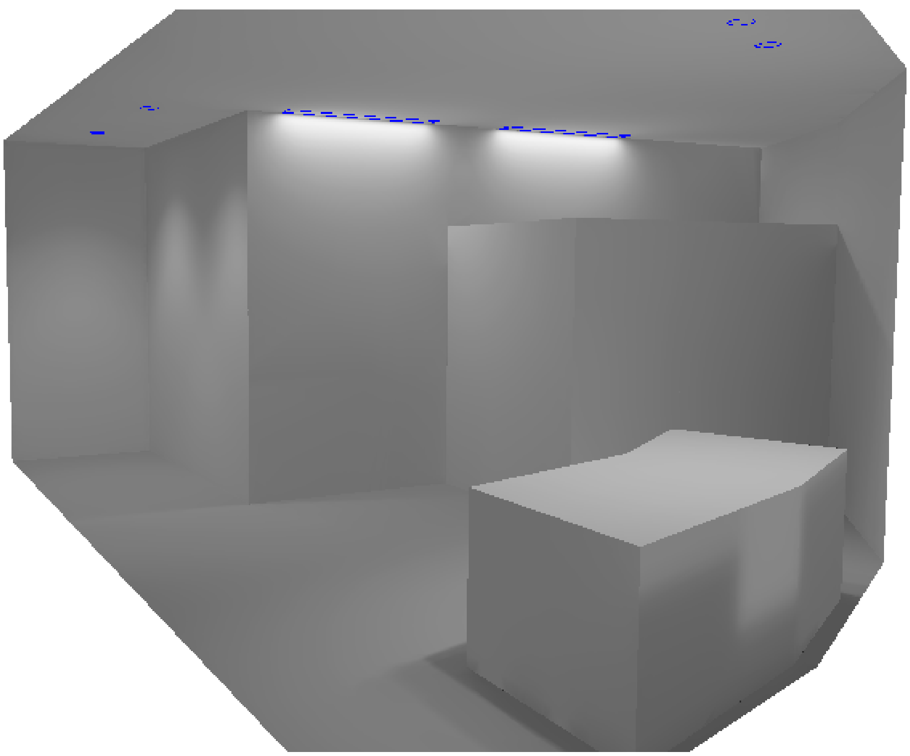
Luminaire Schedule							
Symbol	Label	QTY	Number Lamps	Lumens per Lamp	LLF	Wattage	
	R1	2	1	6105.565	0.8	81.72	 Max: 1362cd

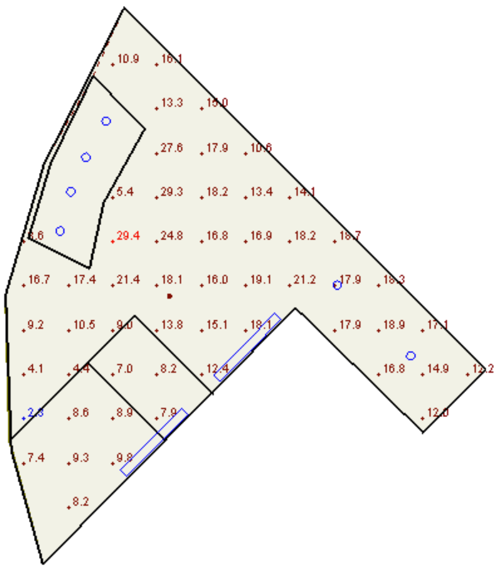
Statistics							
Description	Symbol	Avg	Max	Min	Max/Min	Avg/Min	Avg/Max
Desk		67.5 fc	95.4 fc	39.2 fc	2.4:1	1.7:1	0.7:1
General Ambient		39.2 fc	95.4 fc	15.8 fc	6.0:1	2.5:1	0.4:1

Power Statistics				
Description	# Luminaires	Total Watts	Area	Density
LPD	2	163.4 W	177.5 ft²	0.9 W/ft²

Bathrooms







Luminaire Schedule

Symbol	Label	Quantity	Number Lamps	Lumens Per Lamp	Light Loss Factor	Wattage
▯	F1	2	1	2106.492	0.8	25
○	D1	6	1	901.345	0.8	18

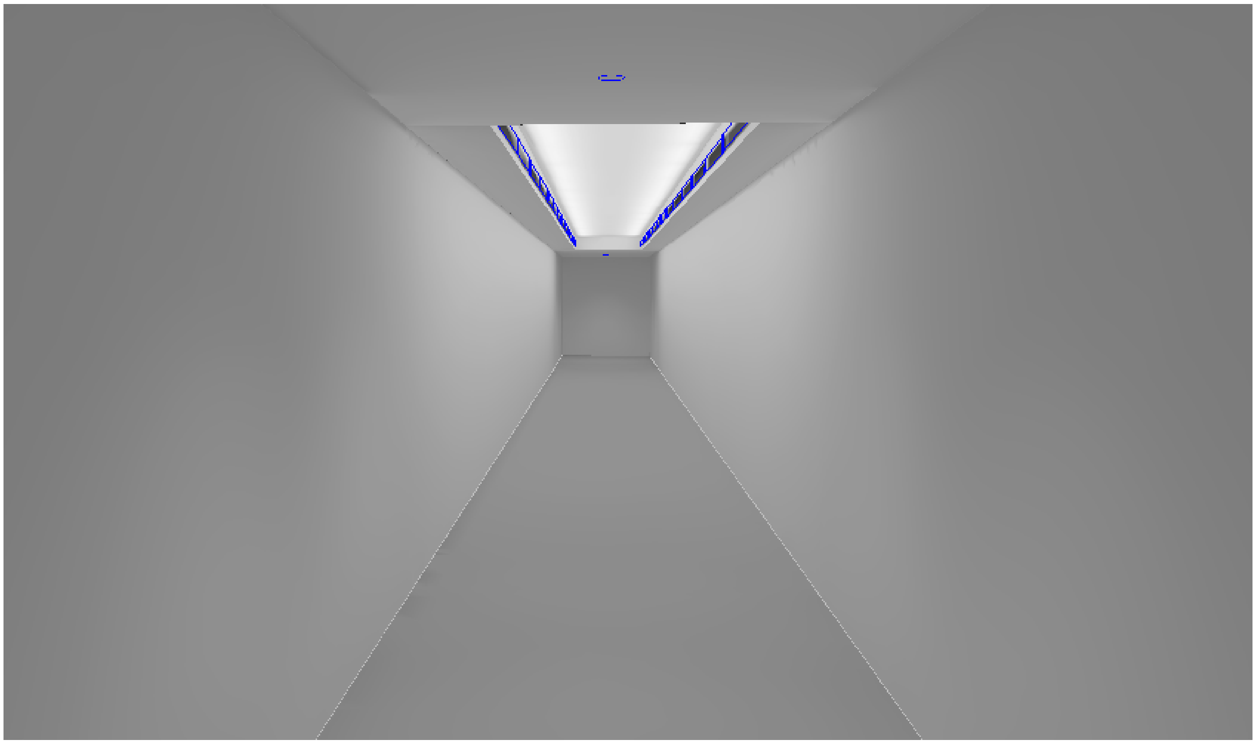
Statistics

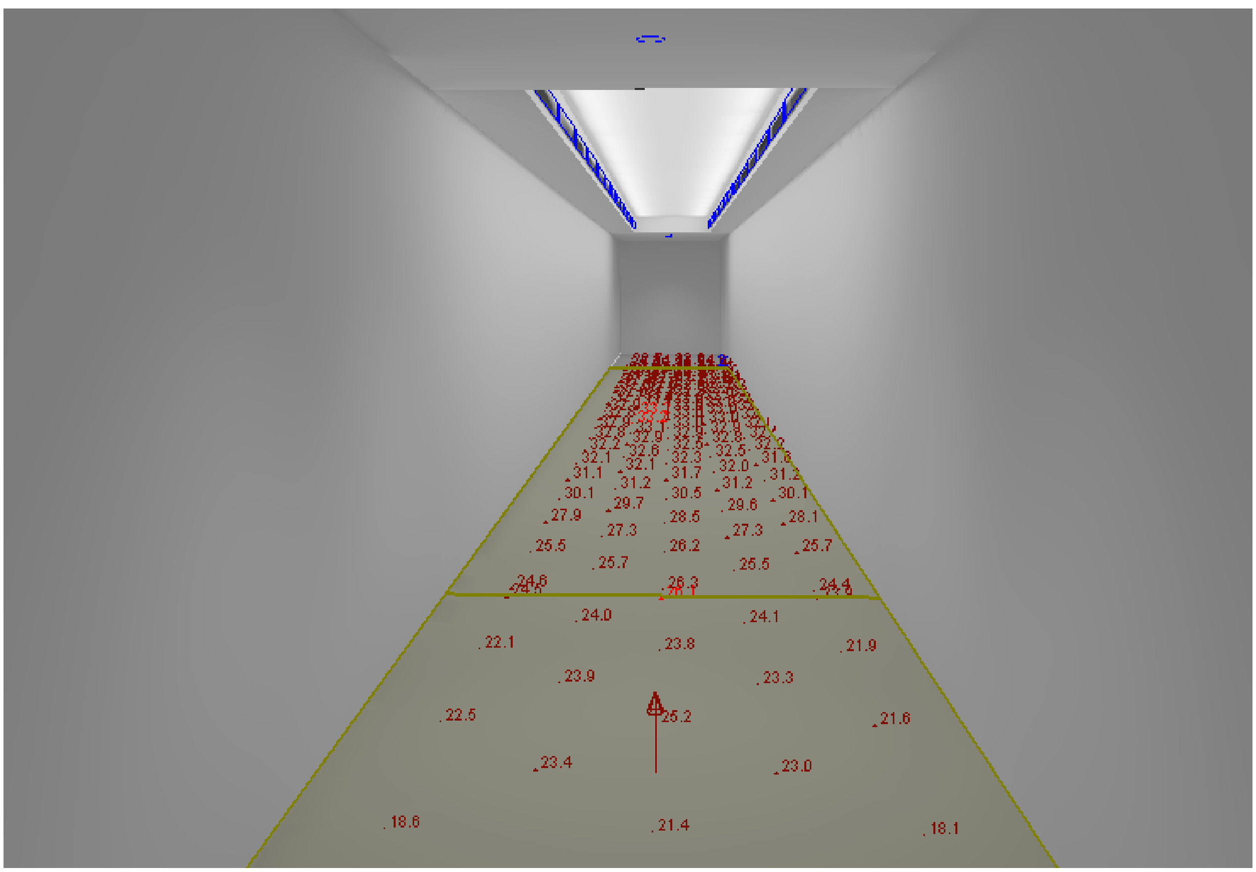
Description	Symbol	Avg	Max	Min	Max/Min	Avg/Min	Avg/Max
General Ambient	+	14.3 fc	29.4 fc	2.3 fc	12.8:1	6.2:1	0.5:1

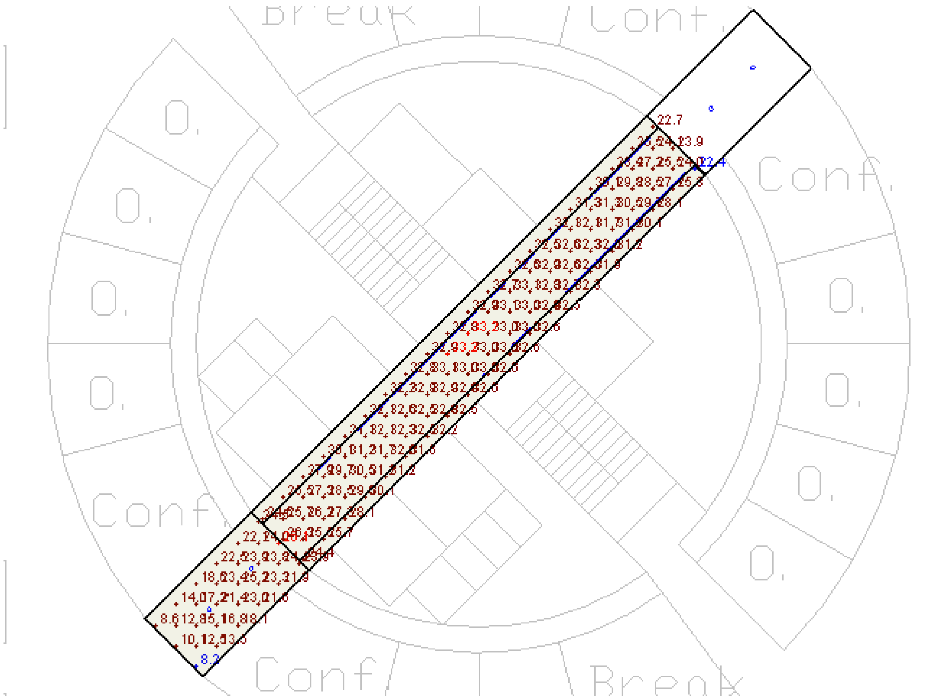
Power Statistics

Description	# Luminaires	Total Watts	Area	Density
LPD	8	158.0 W	237.7 ft²	0.7 W/ft²

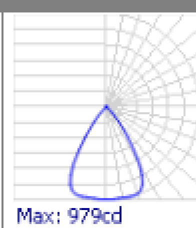
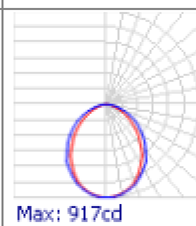
Core Walkway







Luminaire Schedule

Symbol	Label	QTY	Number Lamps	Lumens per Lamp	LLF	Wattage	
	D2	4	1	1101.899	0.8	23	
	C1	26	1	2106.492	0.8	25	

Statistics

Description	Symbol	Avg	Max	Min	Max/Min	Avg/Min	Avg/Max
Inside Core General Ambient	+	30.5 fc	33.2 fc	22.4 fc	1.5:1	1.4:1	0.9:1
Outside Core	+	19.3 fc	26.1 fc	8.2 fc	3.2:1	2.4:1	0.7:1

Power Statistics

Description	# Luminaires	Total Watts	Area	Density
Inside Core LPD	24	600.0 W	435.0 ft²	1.4 W/ft²
Outside Core LPD	2	46.0 W	116.5 ft²	0.4 W/ft²

Appendix N: LEED Points

LEED 2009 for New Construction

SUSTAINABLE SITES		26	Points
Prereq 1	Construction Activity Pollution Prevention	Required	
Credit 1	Site Selection	1	1
Credit 2	Development Density and Community Connectivity	5	5
Credit 3	Brownfield Redevelopment	1	
Credit 4.1	Alternative Transportation - Public Transportation Access	6	4
Credit 4.2	Alternative Transportation - Bicycle Storage and Changing Rooms	1	1
Credit 4.3	Alternative Transportation - Low-Emitting and Fuel-Efficient Vehicles	3	3
Credit 4.4	Alternative Transportation - Parking Capacity	2	2
Credit 5.1	Site Development - Protect or Restore Habitat	1	
Credit 5.2	Site Development - Maximize Open Space	1	1
Credit 6.1	Stormwater Design - Quantity Control	1	1
Credit 6.2	Stormwater Design - Quality Control	1	1
Credit 7.1	Heat Island Effect - Nonroof	1	
Credit 7.2	Heat Island Effect - Roof	1	
Credit 8	Light Pollution Reduction	1	1
WATER EFFICIENCY		10	Points
Prereq 1	Water Use Reduction	Required	
Credit 1	Water Efficient Landscaping	2 to 4	
	Reduce by 50%	2	
	No Potable Water Use or Irrigation	4	
Credit 2	Innovative Wastewater Technologies	2	1
Credit 3	Water Use Reduction	2 to 4	2
	Reduce by 30%	2	
	Reduce by 35%	3	
	Reduce by 40%	4	
ENERGY & ATMOSPHERE		35	Points
Prereq 1	Fundamental Commissioning of Building Energy Systems	Required	
Prereq 2	Minimum Energy Performance	Required	
Prereq 3	Fundamental Refrigerant Management	Required	

Credit 1	Optimize Energy Performance	1 to 19	11
	Improve by 12% for New Buildings or 8% for Existing Building Renovations	1	
	Improve by 14% for New Buildings or 10% for Existing Building Renovations	2	
	Improve by 16% for New Buildings or 12% for Existing Building Renovations	3	
	Improve by 18% for New Buildings or 14% for Existing Building Renovations	4	
	Improve by 20% for New Buildings or 16% for Existing Building Renovations	5	
	Improve by 22% for New Buildings or 18% for Existing Building Renovations	6	
	Improve by 24% for New Buildings or 20% for Existing Building Renovations	7	
	Improve by 26% for New Buildings or 22% for Existing Building Renovations	8	
	Improve by 28% for New Buildings or 24% for Existing Building Renovations	9	
	Improve by 30% for New Buildings or 26% for Existing Building Renovations	10	
	Improve by 32% for New Buildings or 28% for Existing Building Renovations	11	
	Improve by 34% for New Buildings or 30% for Existing Building Renovations	12	
	Improve by 36% for New Buildings or 32% for Existing Building Renovations	13	
	Improve by 38% for New Buildings or 34% for Existing Building Renovations	14	
	Improve by 40% for New Buildings or 36% for Existing Building Renovations	15	
	Improve by 42% for New Buildings or 38% for Existing Building Renovations	16	
	Improve by 44% for New Buildings or 40% for Existing Building Renovations	17	
	Improve by 46% for New Buildings or 42% for Existing Building Renovations	18	
	Improve by 48%+ for New Buildings or 44%+ for Existing Building Renovations	19	
Credit 2	On-Site Renewable Energy	1 to 7	
	1% Renewable Energy	1	
	3% Renewable Energy	2	
	5% Renewable Energy	3	
	7% Renewable Energy	4	
	9% Renewable Energy	5	
	11% Renewable Energy	6	
	13% Renewable Energy	7	
Credit 3	Enhanced Commissioning	2	1
Credit 4	Enhanced Refrigerant Management	2	
Credit 5	Measurement and Verification	3	3
Credit 6	Green Power	2	

MATERIALS & RESOURCES		14	Points
Prereq 1	Storage and Collection of Recyclables	Required	
Credit 1.1	Building Reuse - Maintain Existing Walls, Floors and Roof	1 to 3	
	Reuse 55%	1	
	Reuse 75%	2	
	Reuse 95%	3	
Credit 1.2	Building Reuse - Maintain Interior Nonstructural Elements	1	

Credit 2	Construction Waste Management	1 to 2	1
	50% Recycled or Salvaged	1	
	75% Recycled or Salvaged	2	
Credit 3	Materials Reuse	1 to 2	
	Reuse 5%	1	
	Reuse 10%	2	
Credit 4	Recycled Content	1 to 2	1
	10% of Content	1	
	20% of Content	2	
Credit 5	Regional Materials	1 to 2	1
	10% of Materials	1	
	20% of Materials	2	
Credit 6	Rapidly Renewable Materials	1	
Credit 7	Certified Wood	1	
INDOOR ENVIRONMENTAL QUALITY		15	Points
Prereq 1	Minimum Indoor Air Quality Performance	Required	
Prereq 2	Environmental Tobacco Smoke (ETS) Control	Required	
Credit 1	Outdoor Air Delivery Monitoring	1	1
Credit 2	Increased Ventilation	1	1
Credit 3.1	Construction Indoor Air Quality Management Plan - During Construction	1	1
Credit 3.2	Construction Indoor Air Quality Management Plan - Before Occupancy	1	1
Credit 4.1	Low-Emitting Materials - Adhesives and Sealants	1	1
Credit 4.2	Low-Emitting Materials - Paints and Coatings	1	1
Credit 4.3	Low-Emitting Materials - Flooring Systems	1	1
Credit 4.4	Low-Emitting Materials - Composite Wood and Agrifiber Products	1	
Credit 5	Indoor Chemical and Pollutant Source Control	1	1
Credit 6.1	Controllability of Systems - Lighting	1	1
Credit 6.2	Controllability of Systems - Thermal Comfort	1	1
Credit 7.1	Thermal Comfort - Design	1	1
Credit 7.2	Thermal Comfort - Verification	1	1
Credit 8.1	Daylight and Views - Daylight	1	1
Credit 8.2	Daylight and Views - Views	1	1
INNOVATION IN DESIGN		6	Points
Credit 1	Innovation in Design	1 to 5	4
	Innovation or Exemplary Performance	1	

	Innovation or Exemplary Performance	1	
	Innovation or Exemplary Performance	1	
	Innovation	1	
	Innovation	1	
Credit 2	LEED® Accredited Professional	1	1
REGIONAL PRIORITY		4	Points
Credit 1	Regional Priority	1 to 4	4
	Regionally Defined Credit Achieved	1	
	Regionally Defined Credit Achieved	1	
	Regionally Defined Credit Achieved	1	
	Regionally Defined Credit Achieved	1	
PROJECT TOTALS (Certification Estimates)		110	Points
Certified: 40-49 points Silver: 50-59 points Gold: 60-79 points Platinum: 80+ points			64

Appendix O: MQP Poster Presentation Day Poster