



NAZARBAYEV  
UNIVERSITY

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Capstone Project II

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**DESIGN OF A 12-STORY HIGH-RISE OFFICE BUILDING IN SAN  
JOSE, CALIFORNIA, USA**

Group 1

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## DECLARATION

We hereby declare that this report entitled «Design of a high-rise office building with a one-story basement in a high seismic zone in San Jose, California, USA» is the result of our own project work except for quotations and citations, which have been duly acknowledged. We also declare that it has not been previously or concurrently submitted for any other degree at Nazarbayev University.

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## **Abstract**

The proposed report is the integrated design of a new 12-story commercial office high-rise in downtown San Jose, California, in response to the requirement of the area to have modern and sustainable workspace. The design takes into consideration the architectural, structural, geotechnical, environmental and construction management studies in order to achieve high performance standards in a seismically active urban region.

The project location has the zoning of Downtown Primary Commercial (DC). The geotechnical engineering required observed high seismicity in the region and thus it is necessary to comply with high standards of the rigorous standards, hence the choice of the Seismic Design Category D. Geotechnical analysis showed that the structural load of 243 kN/m<sup>2</sup> exceeded the calculated allowable bearing capacity of shallow mat foundations 77.62 kN/m<sup>2</sup>.

The material that will be the main one used is the Reinforced Concrete with the use of C40 grade concrete, and G60 reinforcing steel. RC was also chosen over steel because it has better fire and corrosion resistance, which were considered the critical factors even based on the seismic profile of the region. The lateral force resisting system chosen is Special reinforced concrete Moment Frames.

Environmental Management: The total of the annual combined mass of waste of the facility is estimated as 109.5 tonnes of waste (60.23 tonnes in the office waste and 49.28 tonnes in the canteen waste). Environmental design centers on the fact that it is mandatory to meet California state laws (AB 341, AB 1826, SB 1383), where both the Wet (organics) and Dry (recyclables) streams have to be collected separately. Organic waste which forms 23.7% of mass requires a high collection rate (2-3 times a week) to avoid odor and contamination despite the zero economic yield.

The overall approximated project budget is \$73,365,913. The financial analysis indicates that the break-even point of the project occurs in Year 12 and the payback period stands at 11.3 years.

The installed systems comply with the IBC-2024 criteria and include the elements that help to achieve the LEED certification, including the usage of rainwater harvesting and special waste diversion systems.

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## 1. Introduction

This report is about the design and development of a 12 story office building in downtown San Jose, California. The structure is set to meet the escalating need to have contemporary offices in Silicon Valley, which has been characterized by high rates of technological innovations and entrepreneurial culture. The location of San Jose as the center of the Silicon Valley has led to a surge of technological firms and workers in the area who require high-end workplaces that encourage teamwork, creativity, and productivity among employees. Much of the current office infrastructure in the city, however, is old-fashioned, and this lacks the flexibility, technological integration and sustainability demanded by the businesses in the present day. The presented project bridges this gap by means of offering a flexible, modern, and sustainable office building that satisfies the functional requirements of the tech industry and the urban revitalization objectives of the city (Smith, 2024).

The project will be a practical working environment as well as a prototype of environmental sustainability. It will be fitted with state of the art structural systems to make it seismic safe, and sustainable design solutions to minimize the environmental impact of the building. The structure will be designed to meet the requirements of the LEED certification with energy-saving technologies, water-saving features, and sustainable materials (Jones, 2023). Other things that will be incorporated in the project are different layouts of the office, meeting rooms and common areas to facilitate creativity and cooperation between employees. Moreover, the site of the building in downtown San Jose will help the city to achieve its aim



of urban densification and revitalization, which benefits the local economy and modern infrastructure is offered in the most desirable location.

This report describes the design process which involves architectural design, structural design and geotechnical design and environmental and construction management strategies applied to guarantee success of the project. It also gives a detailed study of the energy efficiency, sustainability and the compliance of the building with the local regulations. The report is a technical document as well as a blue print to future development providing an insight to the methodologies and practices involved in the development of a high-performance office building in an urban environment that is rapidly growing.

## **1.1. Project Objectives**

### **Architectural Design:**

- Prepare architectural contours which are in line with the local building codes, with regard to seismic conditions and general stability.
- Design a modern and practical design that uses the space optimally and promotes collaboration and incorporates the elements of sustainability.

### **Structural Design:**

- Calculate the load and develop a structural model to consider the gravity and seismic forces.
- Develop a system that provides the structural integrity of the building, both in seismic activity and external loading with the help of reinforced concrete as an extra security measure.

### **Geotechnical Design:**

- Carry out an extensive site study to assess soil characteristics, groundwater table and seismic hazard.
- Prepare a suitable foundation system that carries the weight of the building with reference to the shallow and deep foundation depending on the condition of the site.

### **Construction Management:**

- To prepare a detailed construction management plan such as scheduling of the project, budgeting, and allocation of resources.
- To manage the process of the project implementation, control over the observance of the schedules, financial limitations, and the quality of the work, as well as to reduce possible risks.

### **Environmental Engineering:**

- To integrate the use of environmental sustainable practices and technologies that are compatible with LEED certification.
- To create energy-saving construction and choose the materials that would be greener to avoid the negative impact of the construction on the environment and carbon footprint.

## 1.2. Project Members

Table 1.1. Project members and responsibilities

| Members             | Roles                                |
|---------------------|--------------------------------------|
| Mariyam Zhaspenova  | Structural/Architectural Engineering |
| Rakhat Abdikul      | Structural/Architectural Engineering |
| Amina Smagulova     | Geotechnical Engineering             |
| Meruyert Yeszhanova | Geotechnical Engineering             |
| Medet Askar         | Environmental Engineering            |
| Nazym Turkebay      | Construction Management              |

## 1.3. Problem Statement

Being called "Capital of Silicon Valley," San Jose is right in the middle of the global technology industry, producing a significant economic output and job creation for the region. However, this rapid growth has stimulated a lack of modern office space that can meet the needs of today's leading technology companies. Much of the city's existing office stock is outdated, without the high technology, sustainable design, and opportunities for collaboration necessary for driving innovation and luring top talent. This issue also undermines the city's stated strategic priorities of urban densification and downtown redevelopment.

Therefore, a new high-rise office tower will be built in downtown San Jose to address this urgent problem. The project promises to provide world-class workspace that best serves the needs of the 21st century's workforce while integrating advanced sustainable technologies to reduce environmental impact, contribute to employee wellness, and ensure that downtown San Jose remains a first-rate global business center.

#### **1.4. Scope of the design**

This technical report provides the engineering and management choices of the project in details, divided into three key areas of discipline:

**Architectural and Site Analysis:** This section provides information on the geometry of the building (square shape to minimize torsional seismic impact), location and zoning approval, selection of material to be used in non-structural features (e.g. autoclaved aerated concrete to be used to construct the partition walls because of its light weight qualities, which is very important in a seismic region), and initial sustainability requirements (e.g. LEED certification criteria, use of rainwater harvesting, and maximum daylighting).

**Structural and Geotechnical Design:** In this section, the Reinforced Concrete structural system is defined, the analytical model in SAP2000 is developed, the gravity loads (dead, live, and snow loads) were calculated, seismic load parameters (Seismic Design Category D) and the foundation rigorously analyzed, and the conclusion was made that the deep pile foundations were necessary. The design is based on the International Building Code 2024 (IBC-2024) and the required FAA height limitations.

**Environmental and Construction Management:** The section will measure the Municipal Solid Waste (MSW) stream (109.5 tonnes/year) and outline the necessary commercial recycling structure required by the California state standards (SB 1383, AB 1826) and approximate the required logistics and the possible market opportunity of the recycled material. Lastly, the Construction Management section has the project charter, feasibility study, cost-benefit analysis (total costs of \$73.37 million), Work Breakdown Structure (WBS), scheduling, and the mitigation of the risks, which are required to undertake the project successfully between September 2026 and November 2027.

## 2. Architectural

### 2.1 Overview of the building

The existing parking lot will be demolished to build a 14,700 square meter 12-story office building with one-story underground parking. The maximum building height will be 38,700 square meters. The construction site is 14,447 square meters at the northwest corner of the intersection of Woz Way & S Almaden Blvd in Downtown San Jose, California, USA. The total number of offices is 106, with 9 on each floor and 7 on the first. The beverage space would be located on the first floor. There will be 1 kitchen, 1 rest area and 2 coworking spaces on each floor. There will be 2 stairs and 2 elevators. The height of the floor is 3,000 meters on the first floor and 2,700 on the upper floors. The rendered view of the building is presented in Figure 2.1.

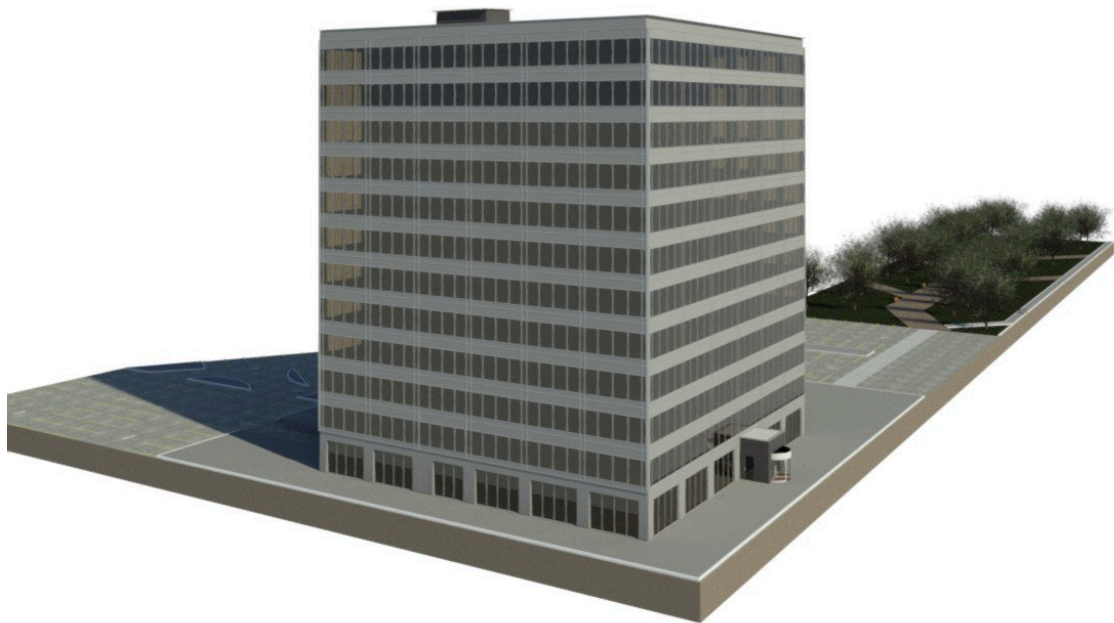


Figure 2.1. Rendered 3D view

### 2.2 Site selection

The project site is located at Woz Way & S Almaden Blvd, San Jose, California, USA, having a curved shape as represented in Figure 2.3. As mentioned earlier, San Jose is a "Capital of Silicon Valley" and has a great number of business centers. Being located at the center of the city, the project site is surrounded by commercial buildings and offices, as shown in Figure 2.4. The tech job market is having rapid growth, especially in computer and

math fields, with a 15.9% job growth rate in 2025 (Paul Reyes, 2025). Since San Jose is a major tech hub, office space is still needed to accommodate growing job workers and new companies. For this reason, the area on Woz Way & S Almaden Blvd, San Jose, California, was chosen for the office building.

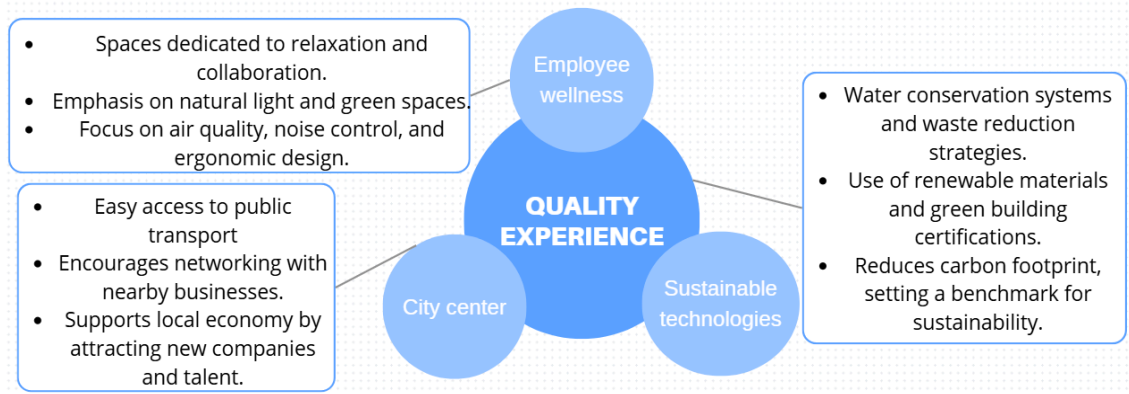


Figure 2.2. Design concept of the building



Figure 2.3. Location of the project area



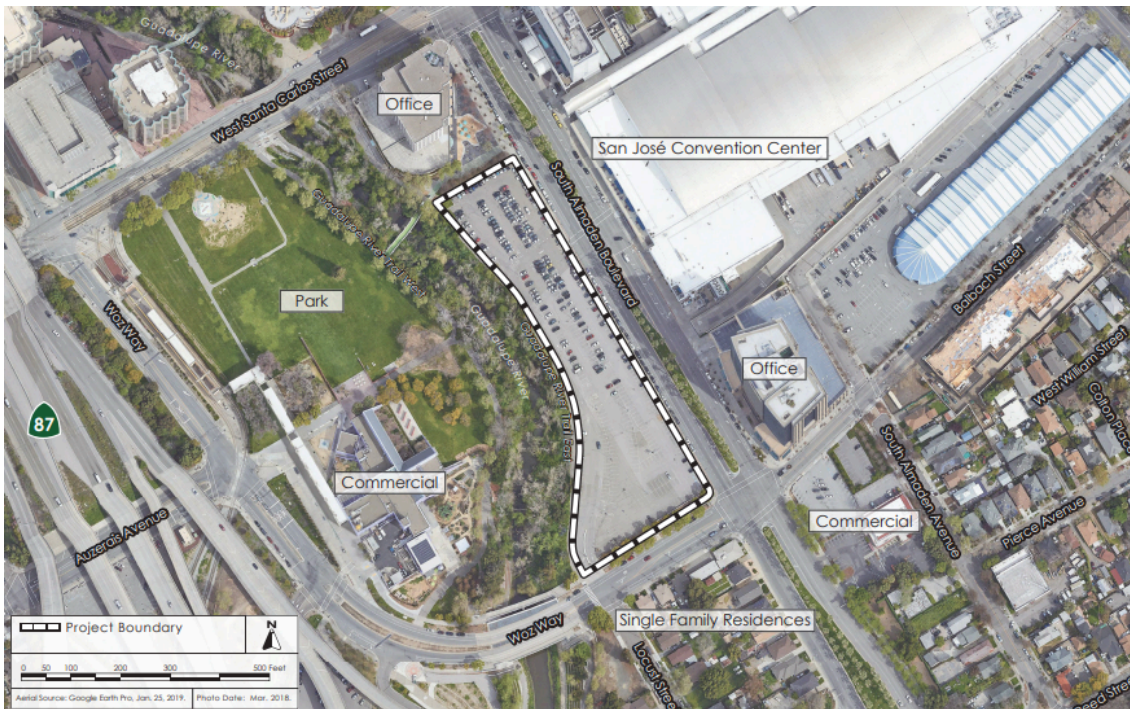


Figure 2.4. Surrounding land use

## 2.3 Site analysis

The project area is currently a paid public parking lot. Under the San Jose City's General Plan, the project site is allocated to Downtown. According to the San Jose zoning map, the site is intended to be used for commercial purposes and zoned as DC – Downtown Primary Commercial, which also aligns with the office type of the planned project. The figure below shows the aforementioned zoning map.

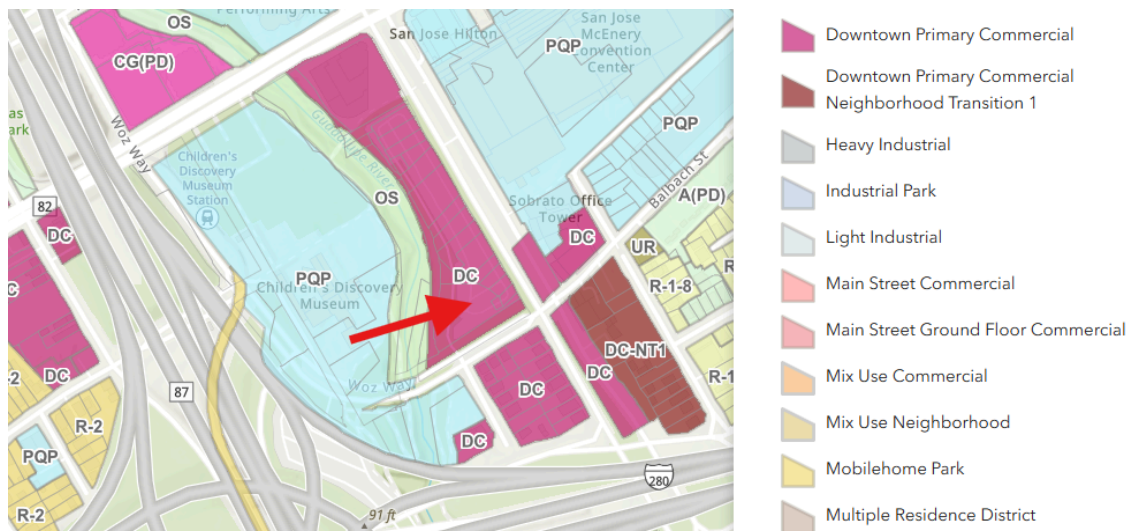


Figure 2.5. San Jose Downtown Zoning Map

Historically, the project site is near the Guadalupe River, so it has great historical value for the presence of artifacts. But the area has been studied nine times. In 1986, archaeologists observed the northern part of the project area, and no archaeological deposits were found there. In 2000, the southern part was investigated, and some relics related to the old Chinatown were found and stored. Thus, the site is now clear from historical artifacts and free to be exploited for building purposes.

Sunlight passes through all sides of the building throughout the day. As Figure 2.5 demonstrates, the sun rises from the west and dawns on the east, traveling through the southern side during the day. The building will be located on an angle, with one corner heading west and the other east. Thus, every side of the building will have solar access at some point of the day, although most of the sunlight will be absorbed by the southern side. The shadow length is 0.65 m at 12 pm on September 1, but it heavily depends on the time of the season.

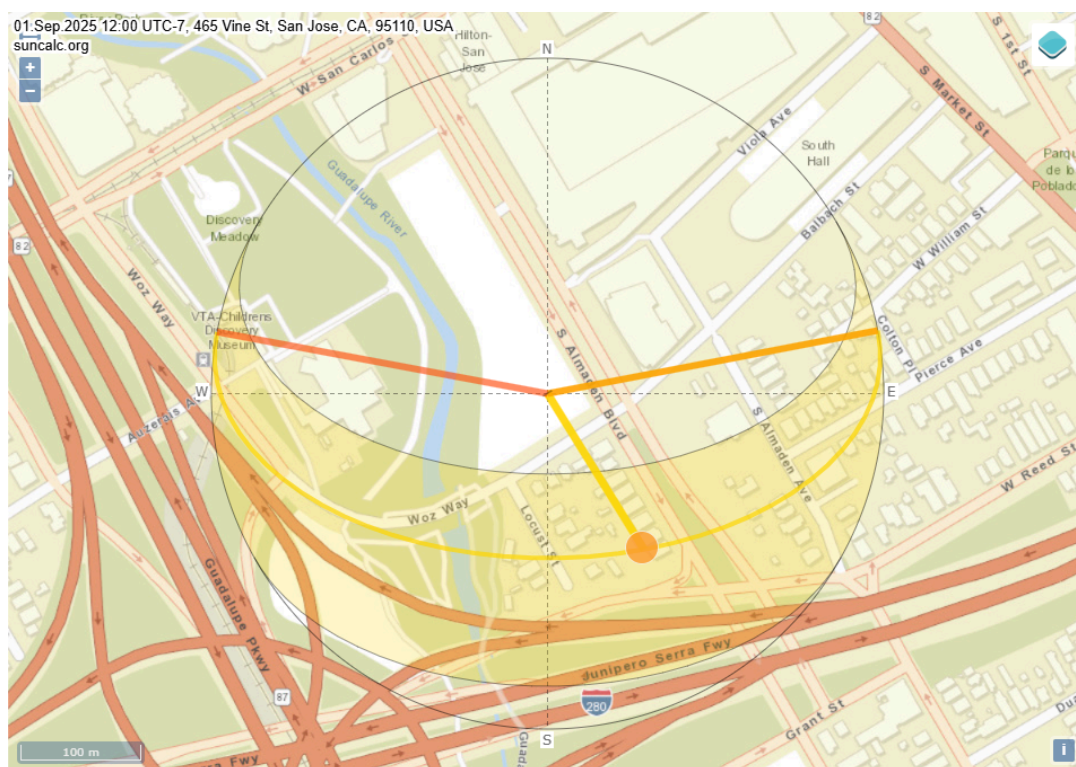


Figure 2.6. Sun direction at 12 pm on Sep 1 (Suncalc.com, 2025)

The cool breeze mostly comes from the northwesterly sea, typically during the afternoon. According to historical data and the wind speed of San Jose, the number of hours of wind blowing per year indicates that the typical wind direction is from northeast to



southwest. The graph representing the historical wind directions is shown in Figure 2.7. Additionally, the ASCE 7 Hazard Tool indicates that the wind speed on the site is 38 m/s for a return period of 50 years (ASCE 7 Hazard Tool, 2025). Thus, the site has good access to cool breezes and natural ventilation.

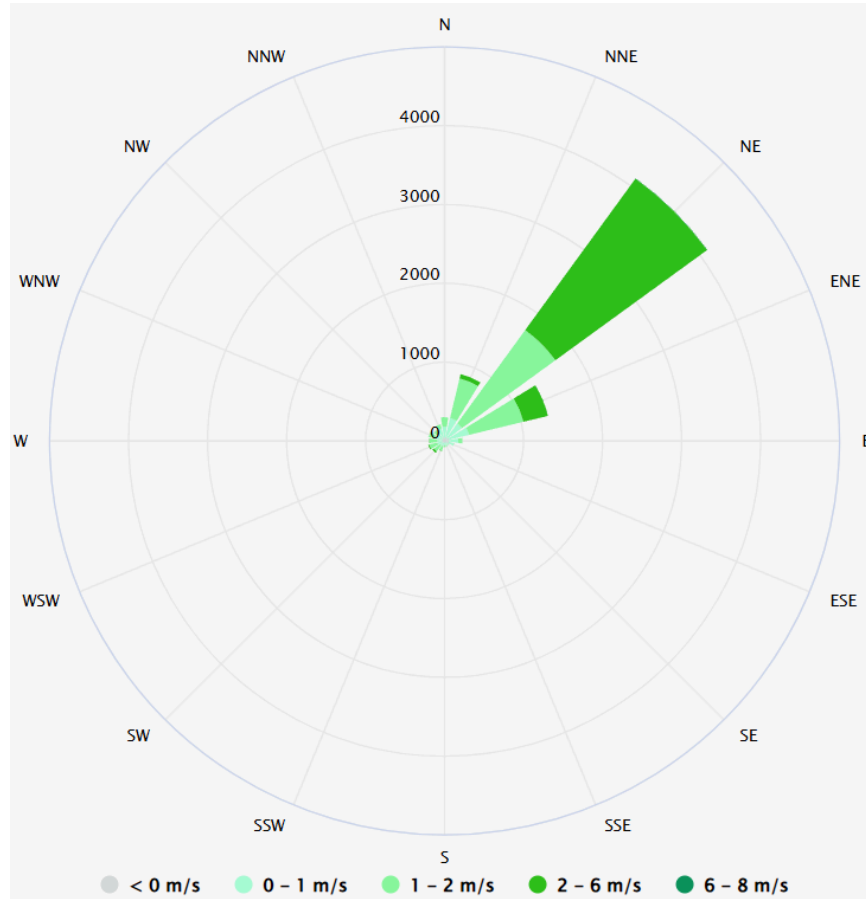


Figure 2.7. Wind Rose in San Jose (meteoblue.com, 2025)

Site-specific variables, such as temperature, humidity, snow, corrosion, methane, and sulfate attack are also considered in the site analysis. The temperature in the region is very high, according to the historical weather data from the Norman Y. Mineta San José International Airport (2024), the highest temperature in 2024 was 40°C in October, and the lowest was 1.7°C in February (Figure 2.8).

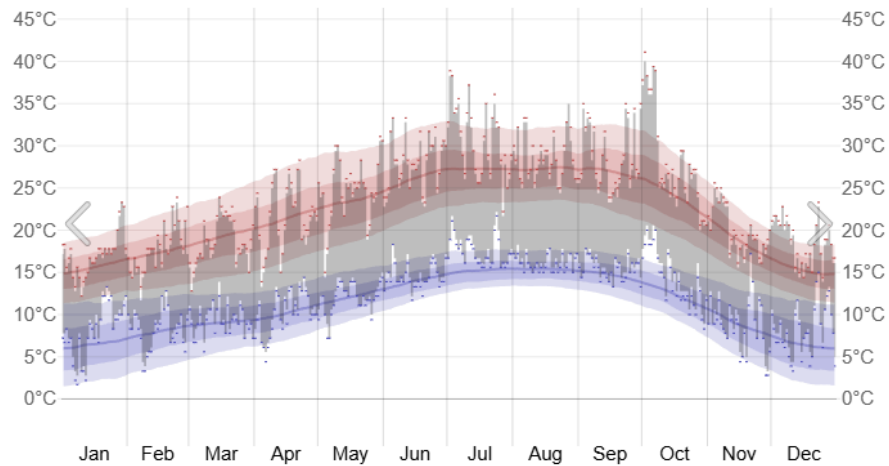


Figure 2.8. Temperature history in 2024 in San Jose (Weather Spark, 2025)

The humidity is very high in the region, showing an average relative humidity of 84% in the morning and 62% in the afternoon, which is above the normal humidity of 40-60% (cityrating.com, 2024). And the snow is a rare occasion in San Jose, and there is usually no snowfall within the year, with the last snowfall occurring in 1976 (Andrew Chamings, 2023).

According to the corrosivity test results shown in Table 2.1, soil in the project site has a corrosion potential. Sulfate amount ranges from 20 to 130 mg/kg, which is considered high, and for this reason, Type II cement and a concrete mix design should have a maximum water-cement ratio of 0.50. The pH value is more than 6.9, which is above the corrosivity minimum, so it does not lead to a corrosion threat to buried iron, steel, mortar-coated steel, and reinforced concrete structures. However, the resistivity value shows a “corrosive” classification for buried metal piping, so additional rebar coating may be required. The chloride ion concentration on the upper layer is 16 mg/kg, which is insufficient to destroy steel coated with concrete (ENGEO Incorporated, 2020).

Table 2.1. Corrosivity Test Results

| SAMPLE LOCATION | DEPTH (feet) | REDOX (mV) | pH   | RESISTIVITY (OHMS-CM) | SULFIDE (mg/kg) | CHLORIDE* (mg/kg) | SULFATE* (mg/kg) |
|-----------------|--------------|------------|------|-----------------------|-----------------|-------------------|------------------|
| 1-B1            | 26-26.5      | 23         | 7.65 | 1,400                 | N.D.            | 16                | 27               |
| 1-B1            | 44.5-45      | 250        | 8.00 | 2,100                 | N.D.            | N.D.              | 20               |
| B-3             | 5            | 370        | 6.9  | 950                   | -               | 57                | 130              |
| B-4             | 20.5         | 350        | 7.6  | 4,000                 | -               | 25                | 41               |

The site offers views of the city center and mountains. On the west side, the site is surrounded by trees. The design will incorporate large, expansive windows to take full advantage of the surrounding views.



Figure 2.9. View from the site (Google Earth, 2025)

The city of San Jose has terrain that is flat or with a minor incline of 0-8% (Municipality of San Jose de Buenavista, 2018). The site is also almost perfectly flat, so this minimizes problems associated with grading and foundation construction. According to the geotechnical report, the soil class on the site is stiff soil, which is perfect for building a high-rise building.

Another high-rise building is located next to the site, but there's no risk of it blocking the sun, since the sun moves across the opposite side of the site throughout the day. Other buildings are either low-rise or located further away from the site. Trees will also not block the sunlight, as they are located down the slope.





Figure 2.10. Overshadowing by nearby buildings (Google Earth, 2025)

The location of the site is conveniently connected to public transport, with the nearest bus stop and LRT station just 200 meters away and a bicycle station only 50 meters away, as shown in Figure 2.11. There are also many commercial facilities here, such as a convention center, museum, theater, hotels, and other business centers, making the building an attractive location for companies.

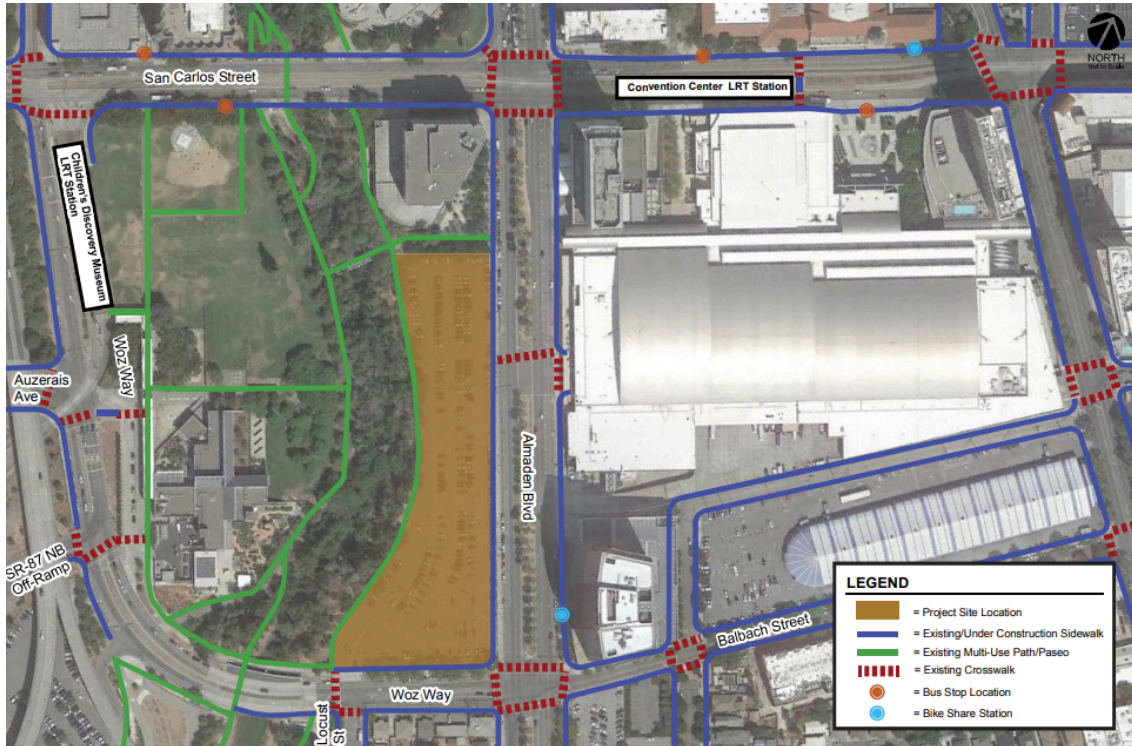


Figure 2.11. Pedestrian facilities and transport

This property is classified by the California Department of Forestry and Fire Protection as a Non-Fire Hazard Severity Zone. This classification indicates a low risk of wildfires due to its urban location, away from dense vegetation or areas prone to wildfires. Despite the low risk, standard fire safety measures should still be incorporated into the project, such as implementing non-combustible materials, fire sprinklers, and providing adequate access for emergency services (Cal Fire, 2023).

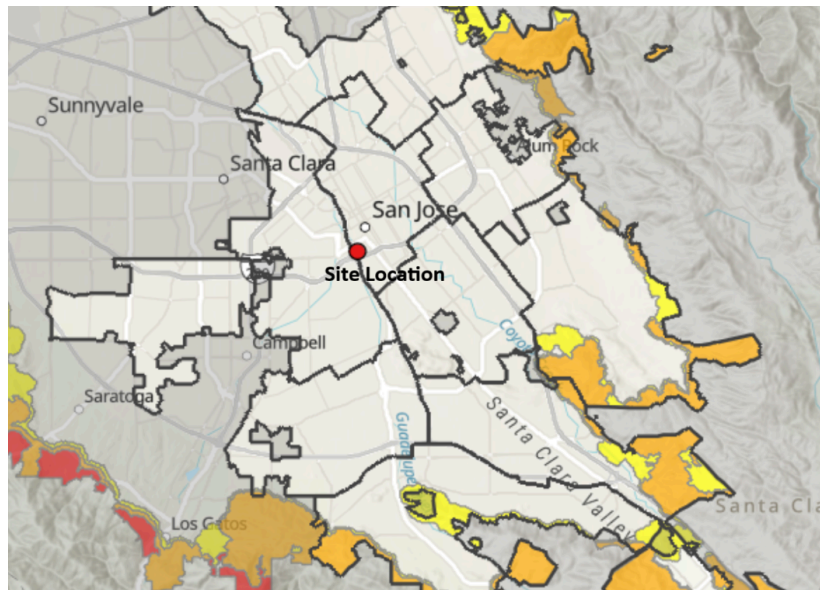


Figure 2.12. Bushfire risks in San Jose (San José Enterprise GIS, 2025)

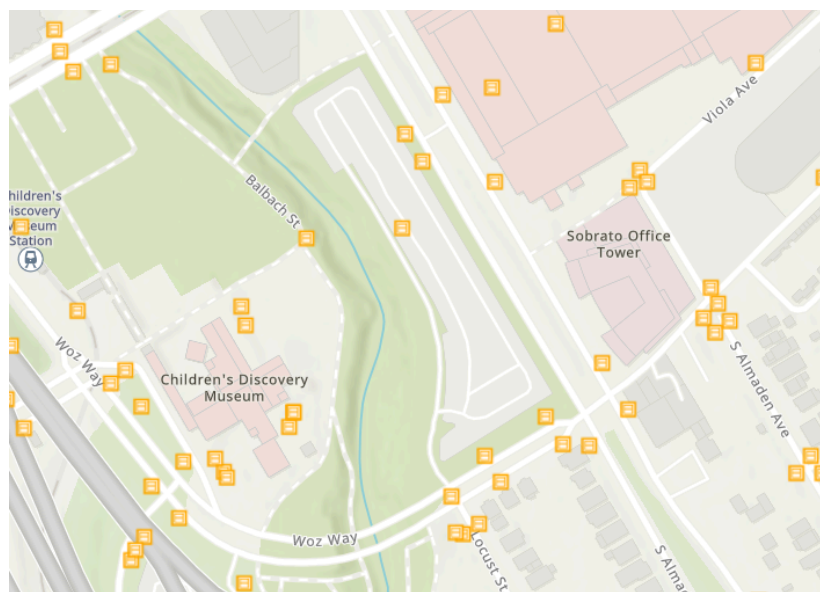


Figure 2.13. Storm inlets map (ArcGIS, 2025)

In regard to the stormwater drainage, in Figure 2.13 the situation near the site location depicts that there are numerous storm inlets that will absorb the stormwater drained, which will act as the primary drainage points of the building. These inlets will be incorporated in the current stormwater system, and they will also make sure that any excess runoff caused by the building is effectively handled and channeled out of the premises as shown in the storm inlets map (ArcGIS, 2025).

Also, more drainage characteristics are recommended to be introduced, including permeable pavements and a rainwater harvesting system. This will contribute towards limiting the amount of runoff and ensuring that the water is reused in the building, thus causing little strain on the drainage system of that specific city. The perforated discharge pipe will channel stormwater runoff within the premises to the catch basin positioned along the drainage systems within the area, which will guide stormwater runoff to the municipal system and avoid flooding (GeoPentech, 2022).

The stormwater management system will also be complemented by a detention system to temporarily store the surplus runoff during flood events so that it can be slowly discharged into the system of the city that will help minimize the overloading of the current infrastructure.

## 2.4 Design Condition

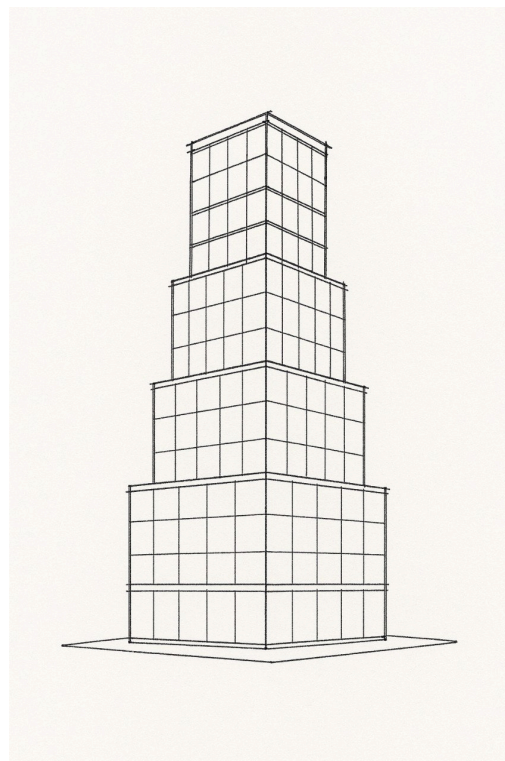


Figure 2.14. Initial sketch of the building

The initial idea for the building was to create a visually appealing and interesting design, as shown in the image above. However, after a thorough analysis of the site and a review of the surrounding buildings, it was decided to go with a square shape, as it was the most common shape for buildings in the area and was better suited to the site itself. Although

the new design was not aesthetically appealing, it was reliable and allowed for more efficient use of space, and did not have unnecessary balconies that are pointless for an office building, as in the previous project.

## **2.5 Literature Review on Design Codes**

Regarding the maximum building height for the region, there is no particular building code for this, but Federal Aviation Administration rules in San Jose require nearby structures to be less than 200 feet (about 16 stories), and since our construction site lies within the airport influence region, this limit also applies to our building (1).

To satisfy the architectural design requirements, the International Building Code 2024 (IBC-2024) was followed. The building is classified as Type I and Group B, and all of the following information is provided in accordance with this building type. The main requirements include the following aspects:

### **a) Specifications on exits**

According to section 1021, the minimum number of exits per story for an occupancy load of 1 to 500 people per story is two. Exits shall be continuous from the point of entry into the exit to the exit discharge. The exit doors shall be available, unobstructed, and placed at distance apart equal to not less than one-half of the length of the maximum overall diagonal dimension of the building or area to be served, measured in a straight line between exit doors (1015.2). The minimum width of an exit passageway shall not be less than 44 inches (1118 mm) (1011.2). The sprinklered building's stair capacity factor is 0.20 inch per occupant (1005.3.1). Also, high-rise buildings must include a fire-service elevator and firefighter recall circuitry (403.6.1–403.6.2). The maximum distance occupants may have to travel to reach an exit access is 300 feet for Group B (1017.2).



Figure 2.15. Main exits

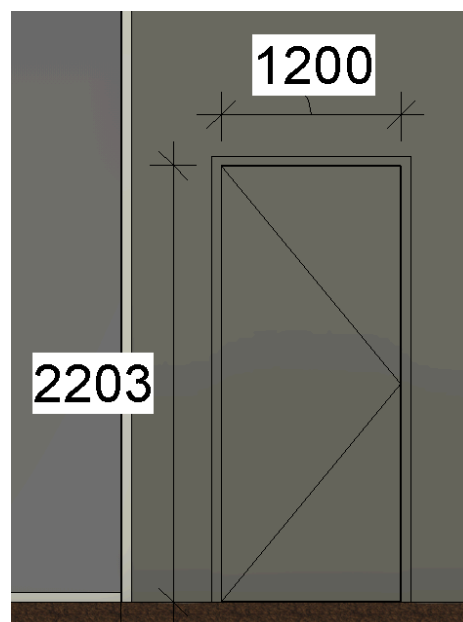


Figure 2.16. Emergency exit (East and West elevations)

#### b) Floor and Ceiling Height

The main lobby or entrance area ceiling was raised to 4 meters (13 feet). Although section 1208.2 provides a minimum ceiling height of 7 feet 6 inches (2.29 meters) in an occupied area, it is built higher in the lobby to enhance the space experience and functionality.

The typical office spaces will have a ceiling height of 3 meters (10 feet). This is larger than the required 7 feet 6 inches (2.29 meters) in Section 1208.2 on habitable spaces to allow lots of room for lighting and ventilation and comfort of the occupants.

#### c) Room and Space Dimensions



There is no fixed minimum area for an office room, so the areas inside building are not limited according to code Section 602.2. Kitchens shall have a 3-foot (914 mm) clear passageway between counter fronts and appliances or walls (1208.1). Thus 1000 mm wide door was chosen for kitchen.

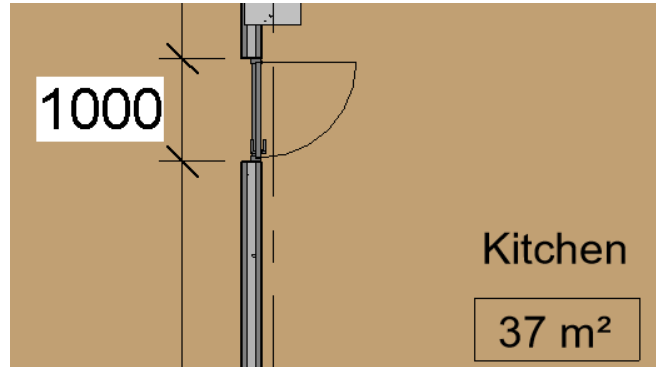


Figure 2.17. Kitchen's passageway

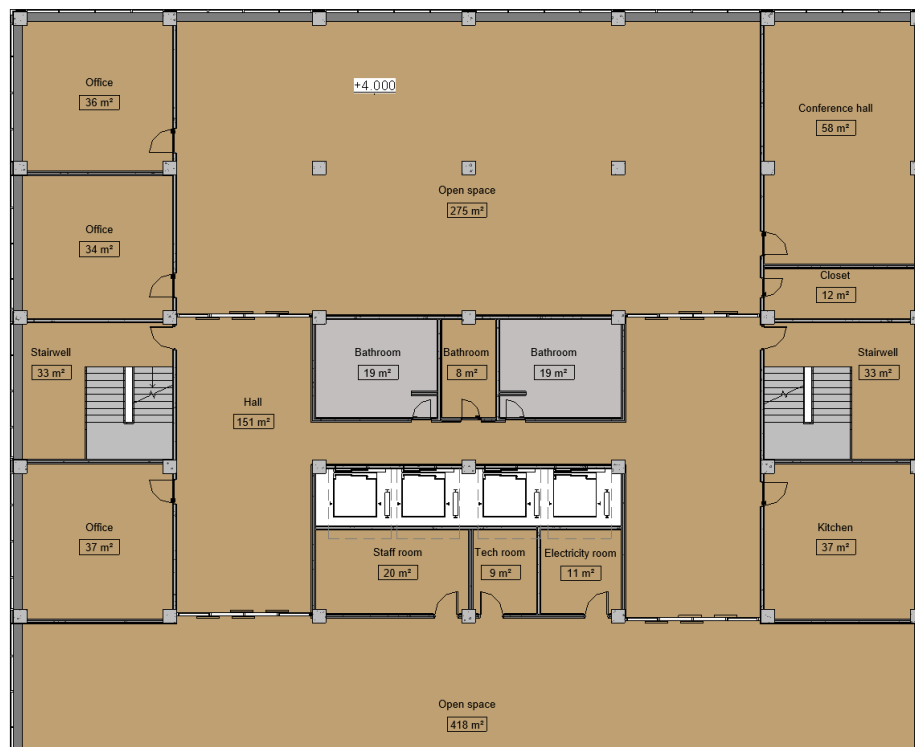


Figure 2.18. Room areas

#### d) Occupancy load

For the business area, the occupant load factor is 150 ft² per occupant according to Table 1004.5. Thus, a 907 m² useful area of the floor would accommodate about 64 people, and approximately 704 in the whole building.

#### e) Accessible Parking spaces

According to table 1106.2 (Accessible parking spaces) from IBC-2022, for 151-200 parking lots there should be at least 6 accessible spaces. These parking spaces were designed at the site of a building.

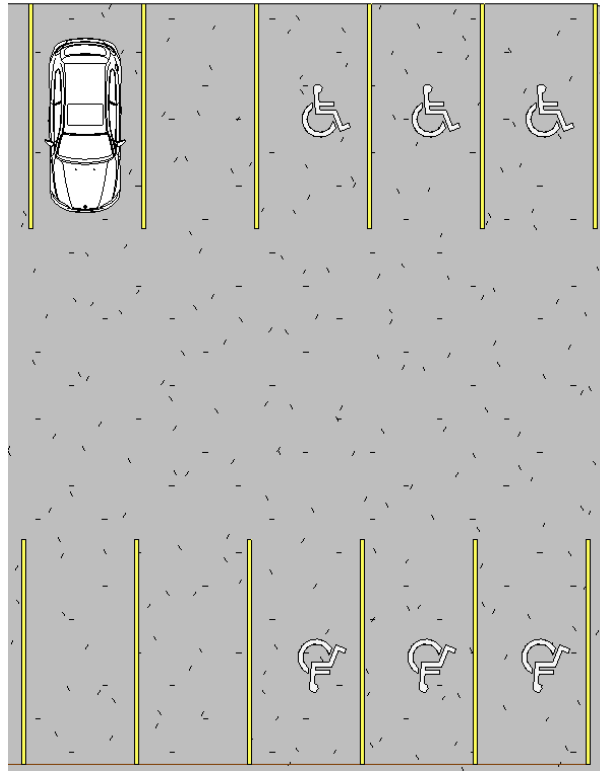


Figure 2.19. Accessible parking spaces

**f) Roof slope**

Section 1507.12.1 requires the minimum slope of 1/4 unit vertical in 12 units horizontal (2% or 1.2 degrees) for single-ply membrane roofs to ensure sufficient drainage of water. Thus, the slope of 2 degrees was chosen for our building.



Figure 2.20. Slope of roof on buildings cut

**g) Maximum distance from a room to the entrance of the building**

Left Entrance Maximum travel distance of the right entrance is 28.75 meters:

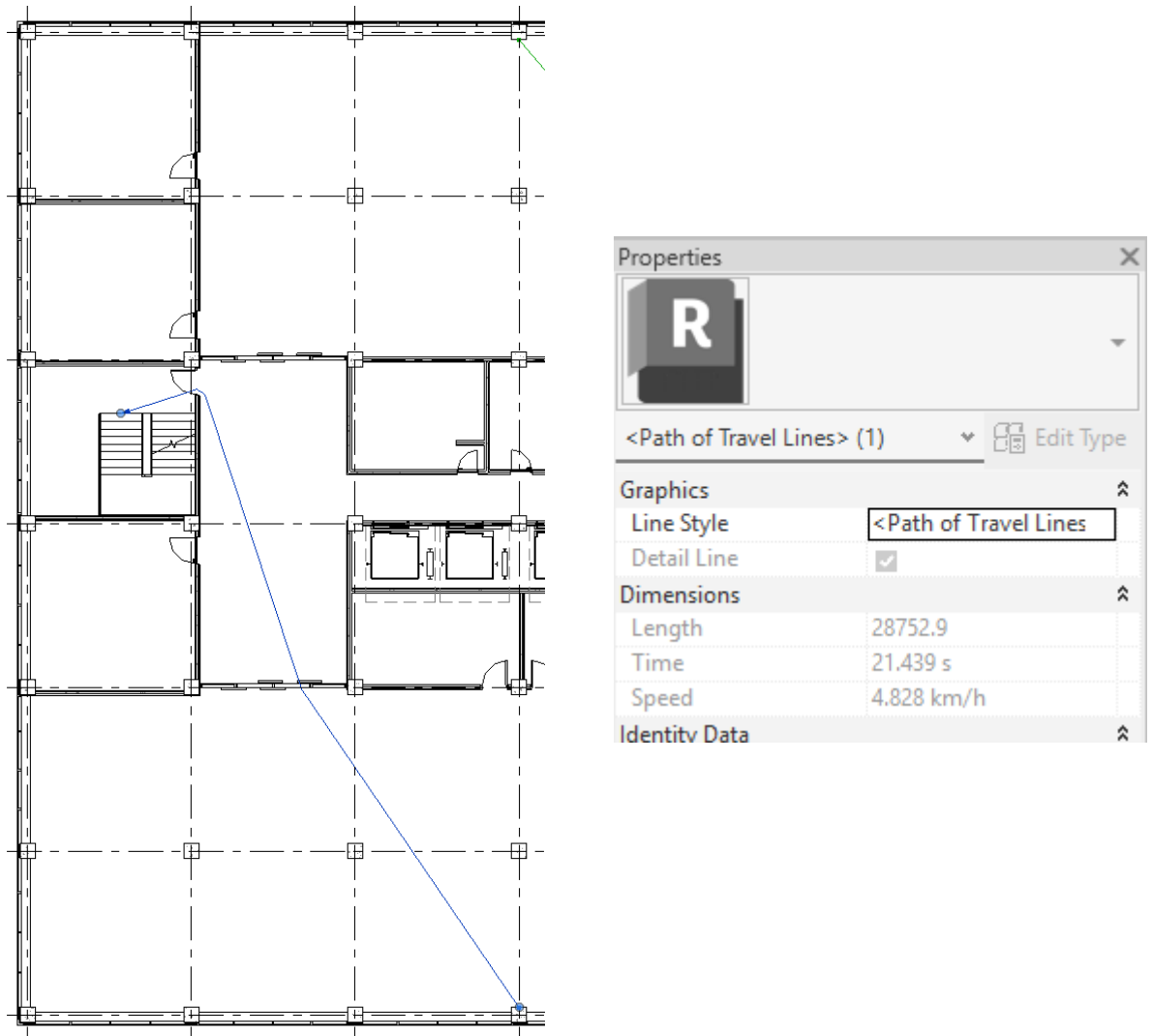


Figure 2.21. Maximum Travel Distance, Left Entrance

Right Entrance Maximum travel distance of the right entrance is 28.88 meters:



**Figure 2.22.** Maximum Travel Distance, Right Entrance

Thus, the maximum travel distance matches the maximum limit of 300 feet (91.3 meters)

#### **h) Number of elevators and stairs**

The occupancy load has been calculated to determine the minimum number of exits. For business area, the occupant load factor is 150 ft<sup>2</sup> per occupant according to Table 1004.5. Thus, a 907 m<sup>2</sup> useful area of the floor would accommodate about 64 people, and approximately 704 in the whole building. To calculate the maximum occupancy load, the useful area of space from the typical floor was taken. Further calculations are:

$$1 \text{ foot}^2 = 0.0929 \text{ m}^2$$

$$A_{\text{per occupant}} = 150 * 0.0929 = 13.94 \text{ m}^2$$

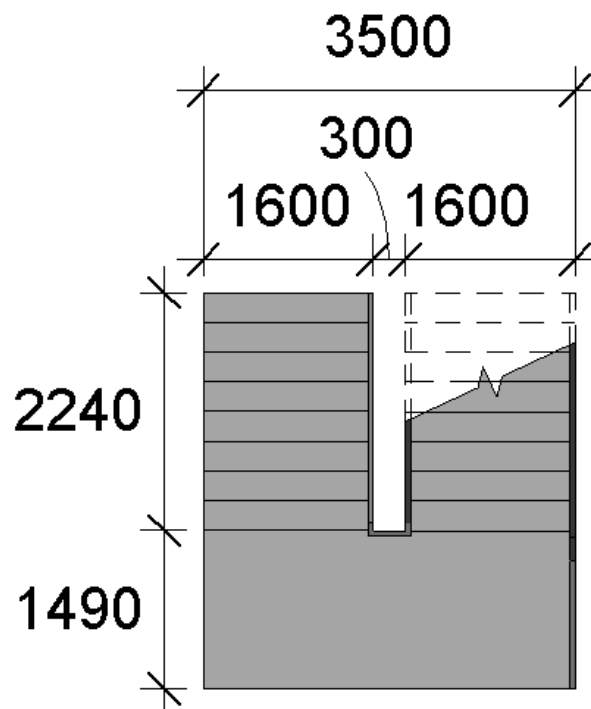
$$\text{Occupancy load per story} = \frac{907}{13.94} = 64$$

According to CBC Section 1006.2.1, the minimum number of exits is 1 for occupancy loads per space of 20 or fewer. Therefore, 64 of occupancy per story doesn't fall within the range of 20, meaning that at least 2 exits will be needed, ensuring adequate egress capacity for the business center. The maximum run length in our building is 28.88 meters, lying below the maximum of abovementioned limit of 91.3 meters., So, 2 exits will be provided per story.

From Section 1011, regarding the sizes of stair runs:

- Minimum width of the stair run is 1118
- Minimum headroom clearance is 2032 mm
- Minimum stair riser is 102 mm
- Minimum tread depth is 279 mm
- Minimum landing width is 1219 mm

Stair dimensions of our building:

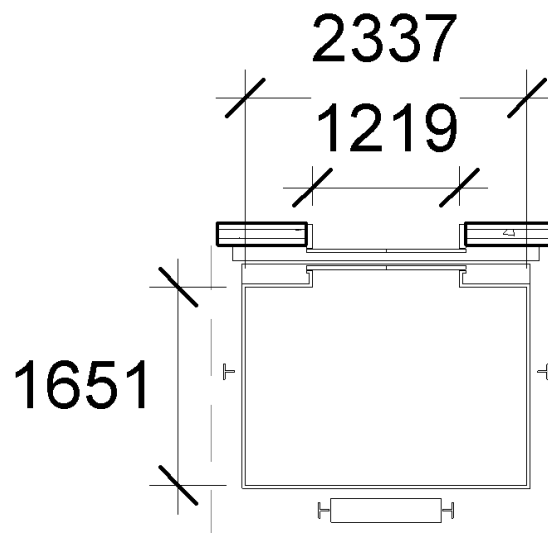


**Figure 2.23.** Stair dimensions

| Dimensions             |       |
|------------------------|-------|
| Desired Number of...   | 17    |
| Actual Number of ...   | 18    |
| Actual Riser Height    | 205.9 |
| Actual Tread Depth     | 280.0 |
| Tread/Riser Start N... | 1     |

**Figure 2.24.** Riser and Tread dimensions

According to Section 1009.1 minimum 3 elevators is needed for a building with morea than 3 stories and total occupancy load of more than 500, in our building 4 elevators of same dimensions are designed . According to 3007.4, minimum size of a cab is 2134 mm wide and 1372 mm deep and minimum of 914 mm wide for elevator entrance.



**Figure 2.25.** Elevator dimensions

## 2.6 Geometry design and site layout

The business center is located in San Jose, California, which is a seismically active region. It was decided to design it in the shape of a square rather than a rectangle because of less torsional effect. The facade will be of concrete panels covered with high-gloss painting with a panoramic window with the intention to match modern design trends.

The area of the floor in the building is  $1057 \text{ m}^2$  and all the stories match each other's areas. The layouts of the first, typical floors and the layout of the roof with their dimensions are shown below.

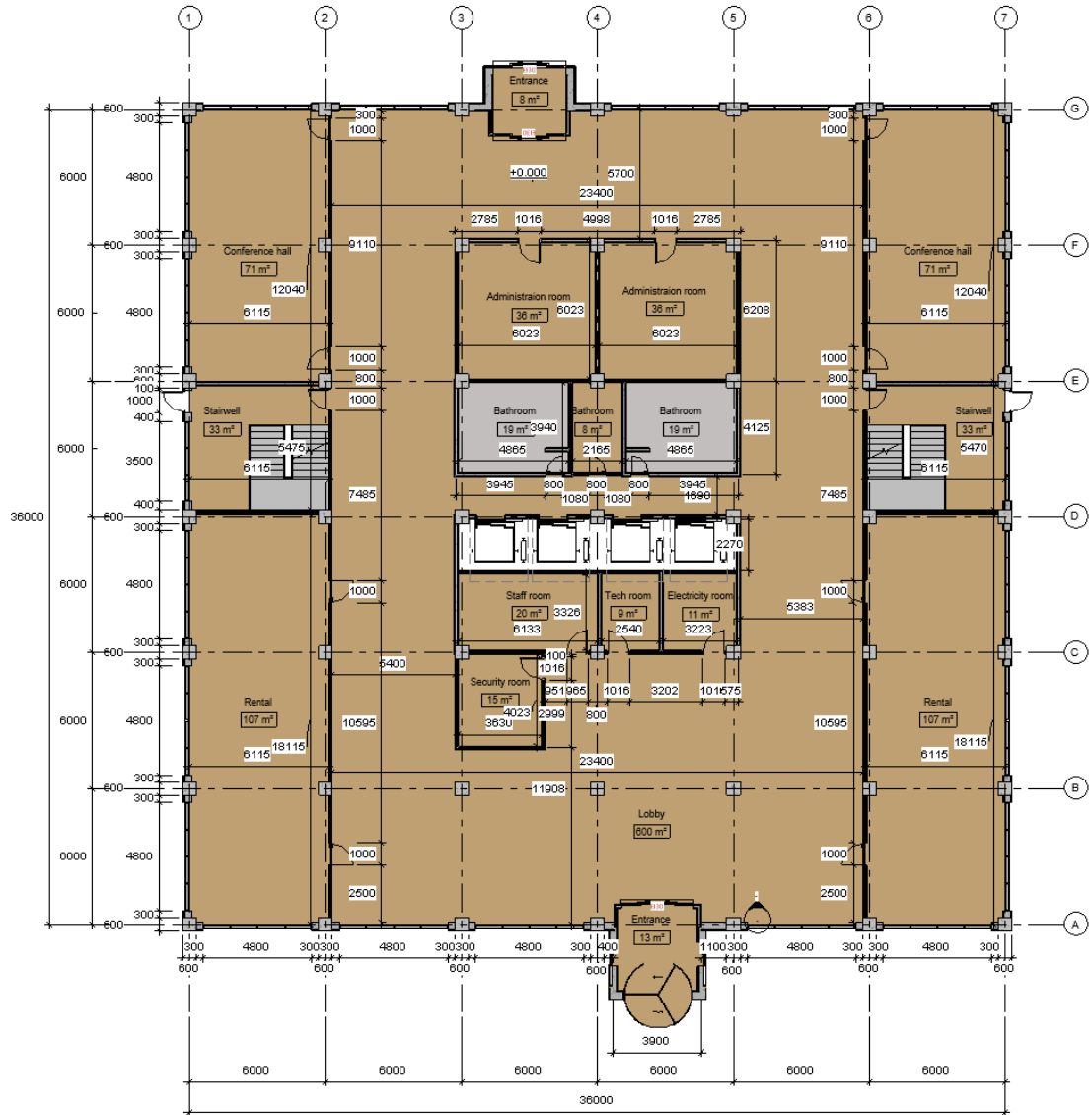


Figure 2.26. 1st floor layout

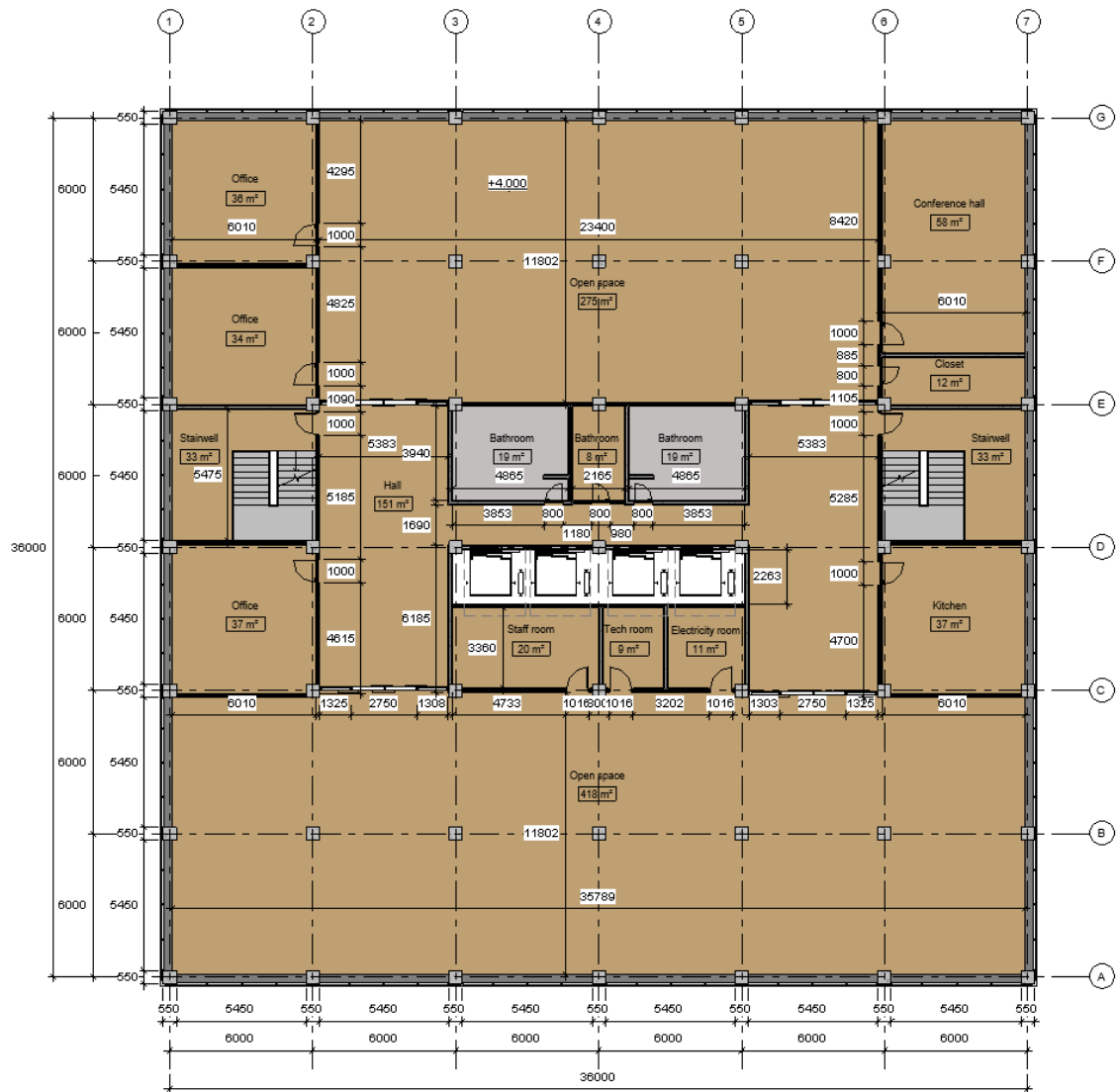


Figure 2.27. 2 - 12 floor layout



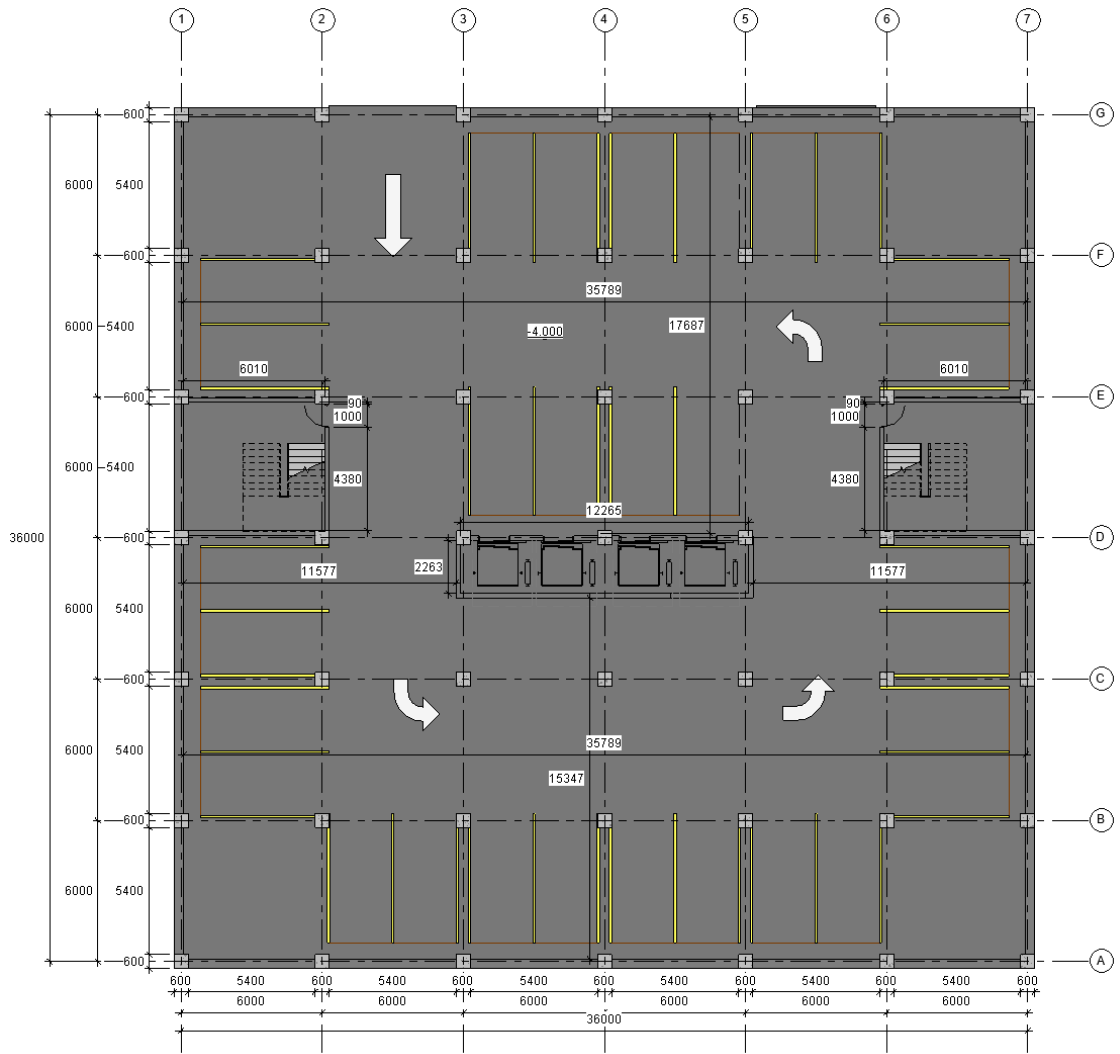


Figure 2.28. Basement layout

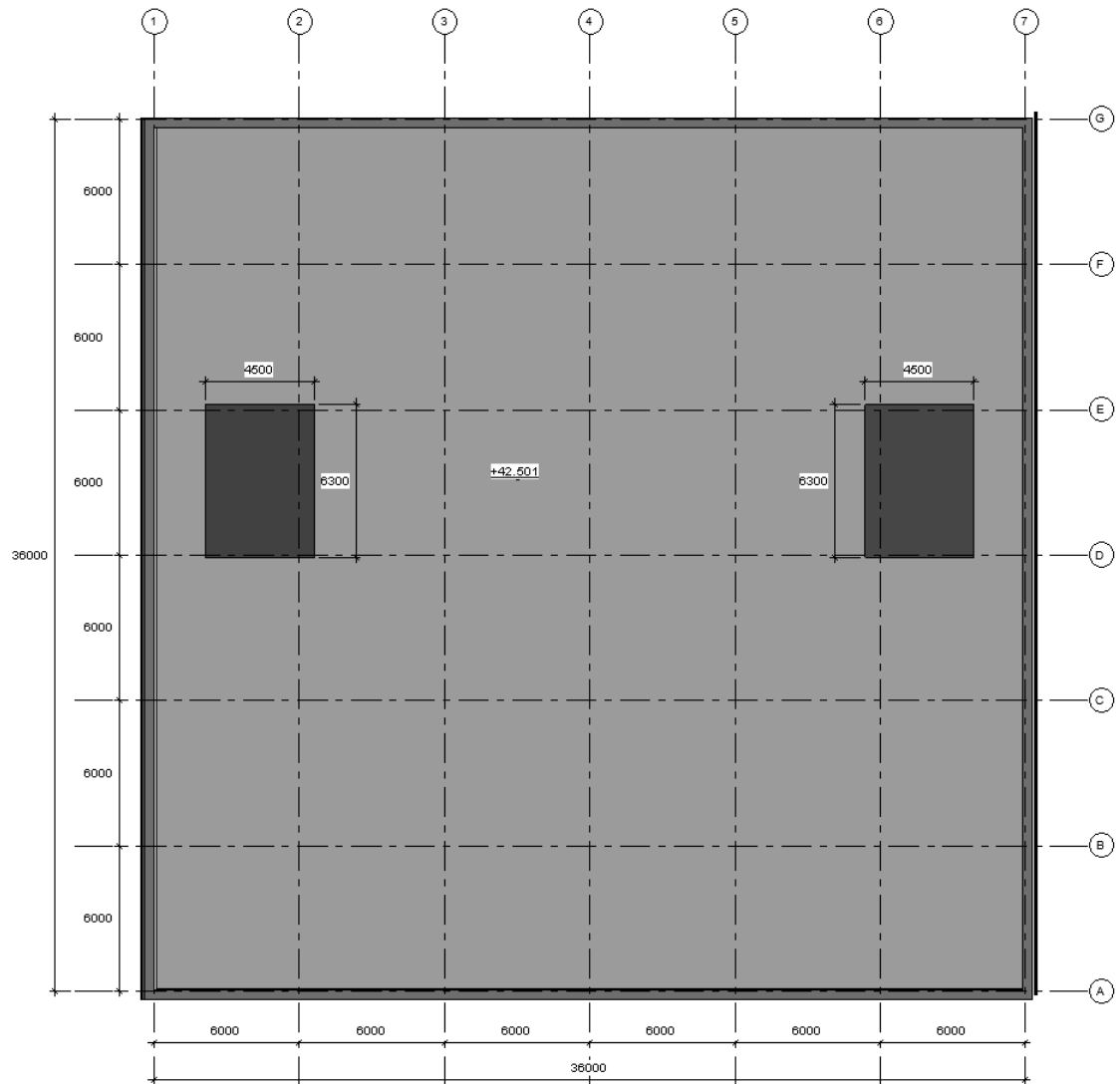


Figure 2.29. Roof layout

There is a parking area at the site layout and an underground basement. 200 parking lots are designed; 90 of each will be located on the site, and 110 in the underground parking. This value was calculated based on the occupancy load and average percentage of people driving the car. According to the SFMTA survey reports, 27% of workers travel to the workplace by car. Thus, 27% of the 704 occupancy load gives the 191 minimum total number of required parking lots.

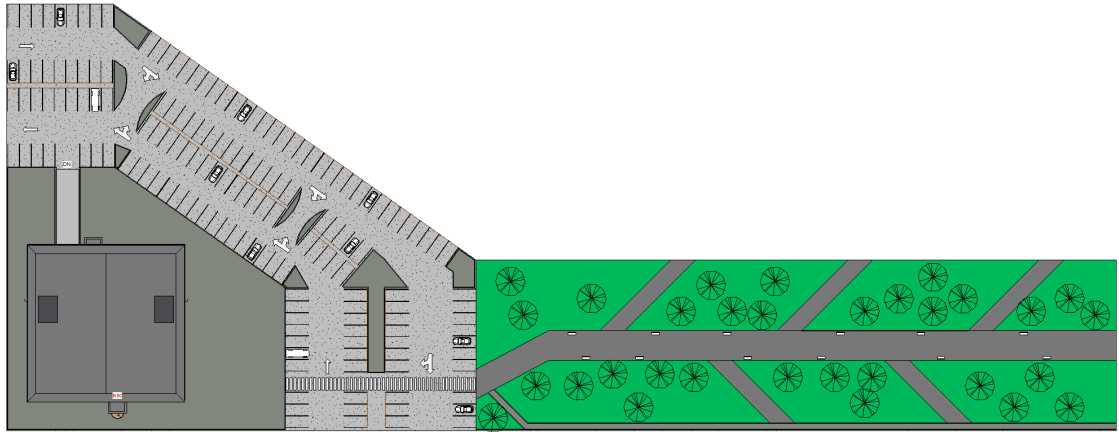


Figure 2.29. Site layout

The emergency exit plan includes the shortest way to leave the building and the placement of fire extinguishers. Plans for the 1st and 2nd-12th floors are shown below.

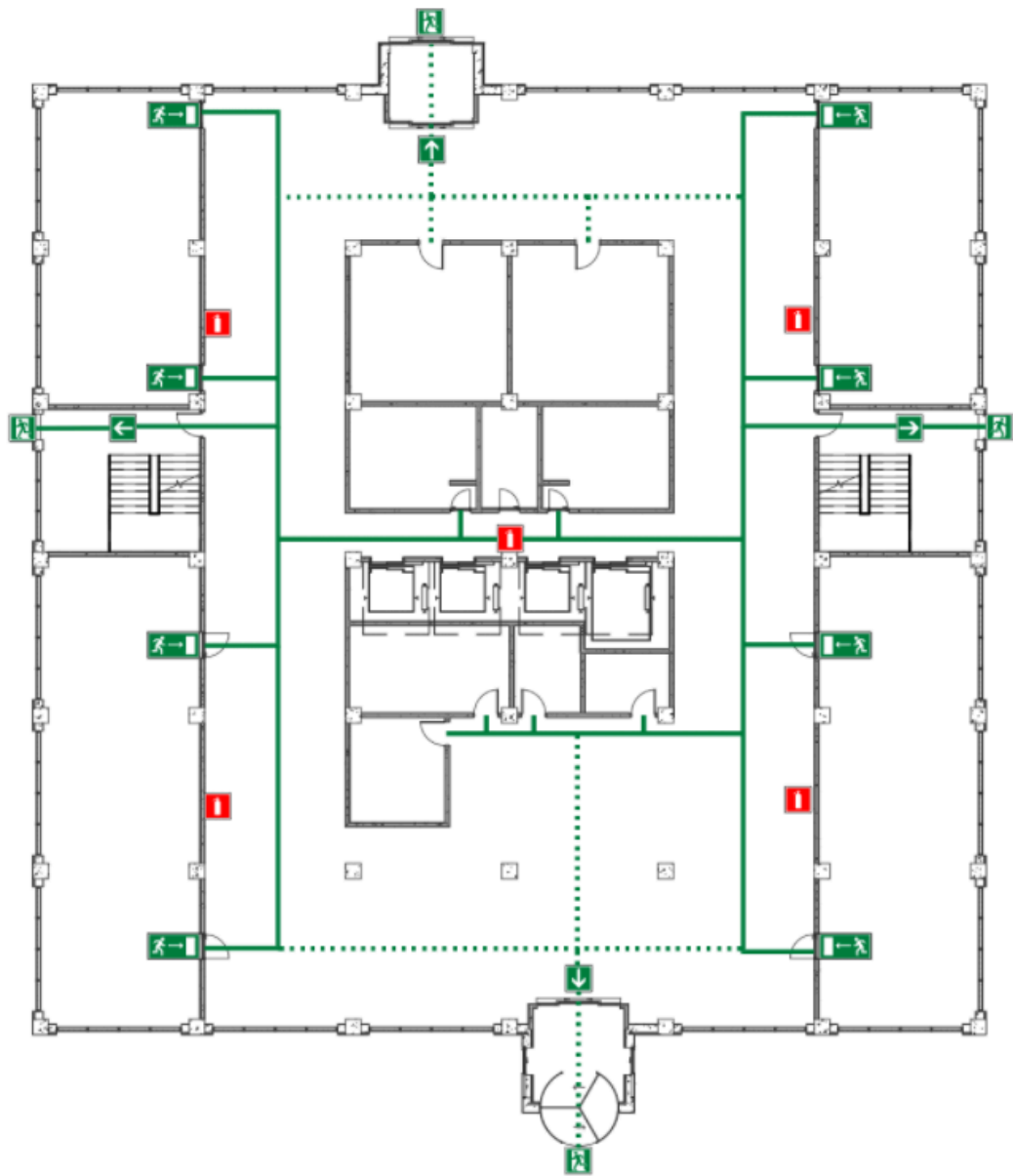


Figure 2.30. 1st floor emergency plan

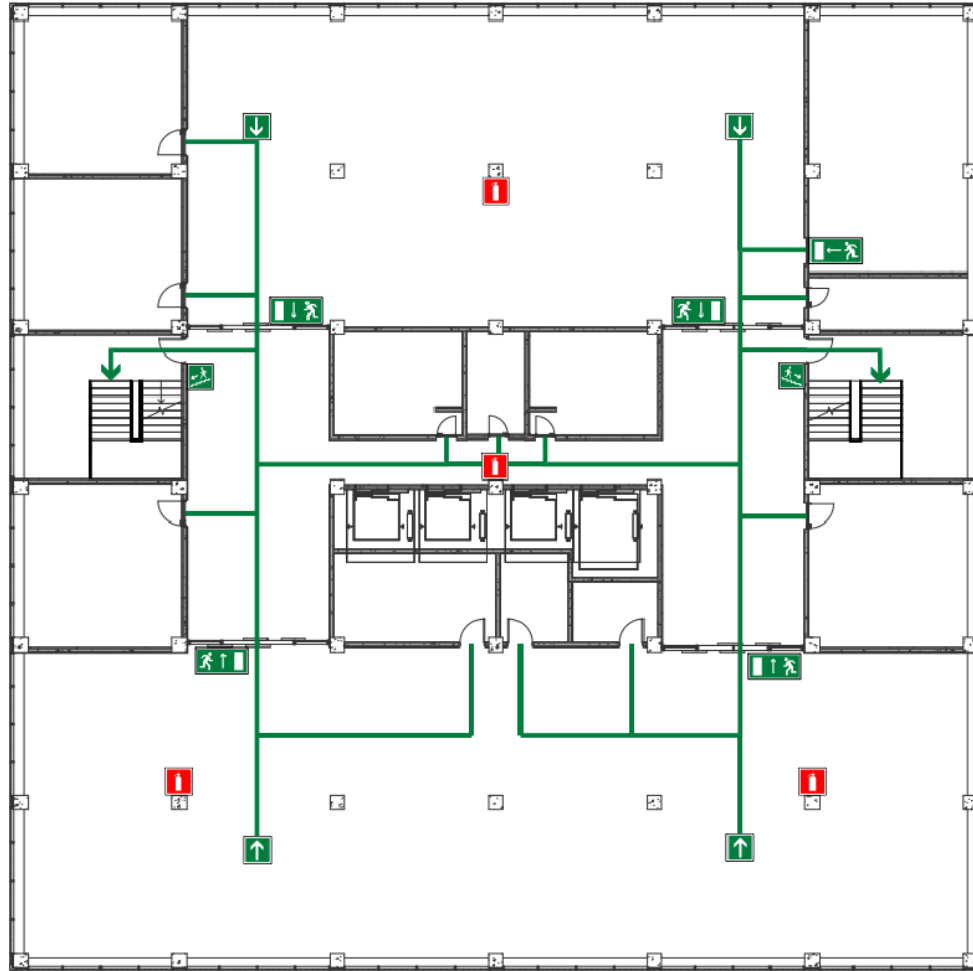


Figure 2.31. 2nd floor emergency plan

## 2.7 Non-structural members design

### 2.7.1 Floor Finishing

Material selection for floor finishing was based on the material characteristics, availability, building type, aesthetics, and the IBC-2024 Code. Hardwood is of common use in office-type buildings. A different cover material was used for the toilets, namely ceramic tiles, and a mortar bed thickness of 13 mm was chosen, as it is lighter and cheaper than a 26 mm thick screed. The floor finish of hardwood has an approximate radiant flux of  $2.2 \text{ kW/m}^2$ , whereas ceramic tile has  $4.5 \text{ kW/m}^2$  (Exova Warringtonfire, 2018), which is higher than the minimum requirement of  $2.2 \text{ kW/m}^2$  for this type of building according to IBC-2024 Code (Section 804.4.2). The thickness of the main floor totaled 97 mm, while other finishing was 107 mm, including only cover, leveling, waterproofing, and insulation. The chosen materials are listed below:

- Cover: hardwood or ceramic tile on 13-mm mortar bed
- Leveling: concrete screed
- Waterproofing: single-ply sheet membrane
- Insulation: mineral wool
- Structural Slab: reinforced concrete slab

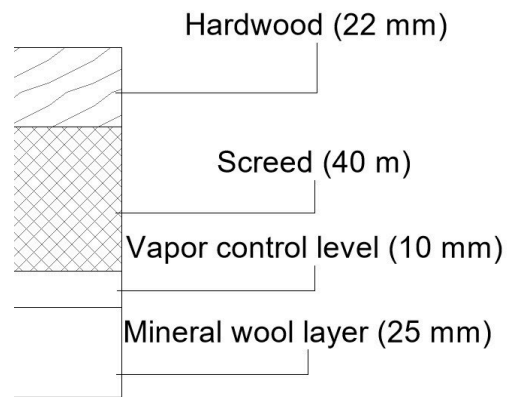


Figure 2.32. Sectional view of first floor finishing

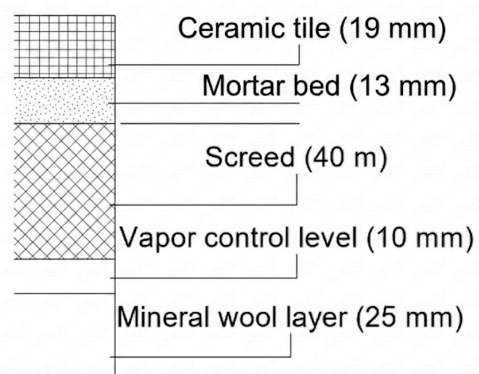


Figure 2.33. Sectional view of second floor finishing

### 2.7.2 Ceiling

For the ceiling design a typical set of materials was chosen. The ceiling will consist of the following three layers with a thickness of 293 mm:

- Acoustical fiber board
- Mechanical duct allowance (250 mm)
- Gypsum board (13 mm)

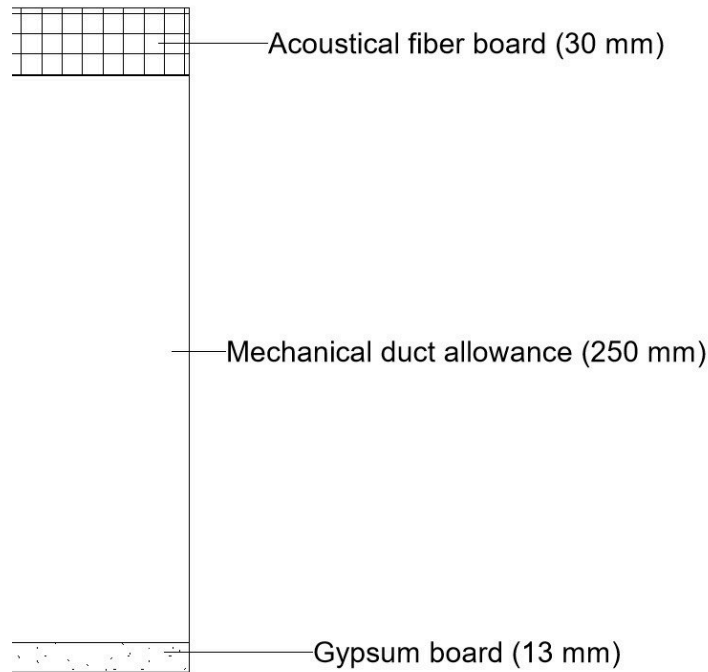


Figure 2.34. Sectional view of ceiling

The clear floor-to-floor height is 2960 mm on each floor.

### 2.7.3 Partition and exterior walls

For the partition wall, the autoclaved aerated concrete was selected for its lightweight properties, resistance to fire, good thermal insulation, and structural capabilities. Also, since some of the partition walls are located not along the floor framing direction, the use of lightweight material is essential for building stability. For the non-structural exterior walls, autoclaved aerated concrete was also selected, as the minimum mass of wall, hence less inertial force, is required for the seismic region. The partition and exterior walls are shown in Figures 2.34 and 2.35, respectively.

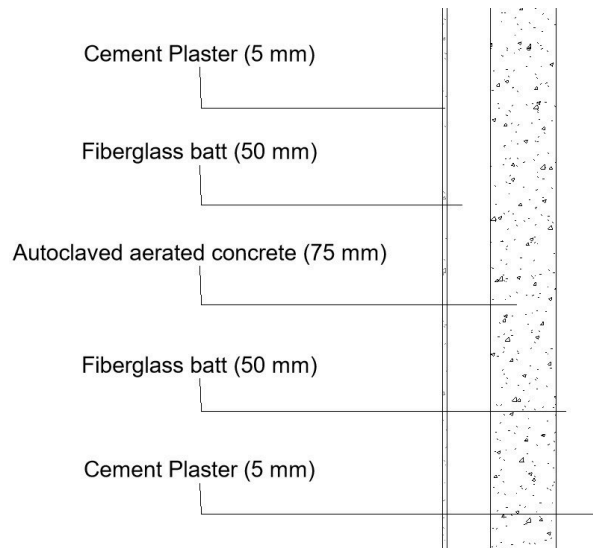


Figure 2.35. Sectional view of partition wall

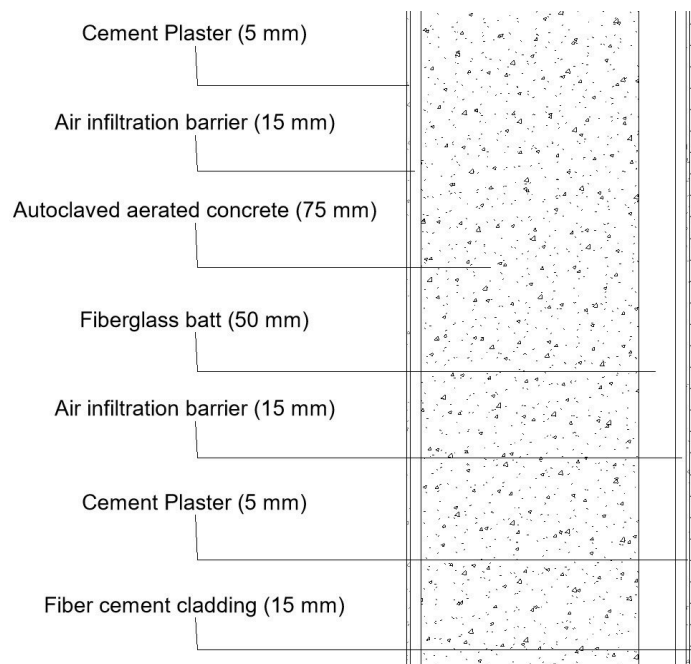


Figure 2.36. Sectional view of exterior wall

#### 2.7.4 Roof parapets

The height of the parapets was chosen to be 1.1 m, which satisfies the International Building Code requirement for 762 mm minimum roof height. The parapet section will be the same as that of the exterior wall to ensure a smooth transition of the exterior cladding between floors.



## 2.8 Green Building Certification

LEED - Leadership in Energy and Environmental Design, created by the USGBC (U.S. Green Building Council), is a globally known certification system assessing the environmental performance and sustainability of the building design. It considers the impact of the building on the environment. In this Capstone project, rainwater harvesting and renewable energy systems are proposed with the perspective of reducing the impact on the environment, increasing our LEED score. The structural part of the building includes reinforced concrete columns and steel beams, thus, providing stable and sustainable foundation.

LEED system assess these aspects of building:

- Energy efficiency
- Water conservation
- Sustainable material selection
- Indoor environmental quality
- Site sustainability

There are 4 levels of certification according to scorecard:

- Certified (40-49)
- Silver (50-59)
- Gold (60-79)
- Platinum (80+)

In the figure below the certificate of our building “Diplomat” is shown

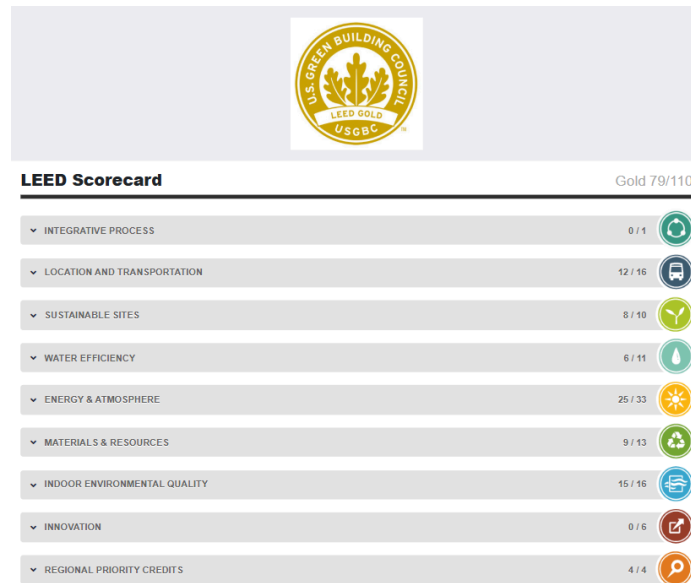


Figure 2.37. LEED Scorecard

### 2.8.1 Location and Transportation

The building is situated in a developed urban land, so it will not affect environmentally sensitive land. It is located in a dense mixed area with residential buildings, retail, offices and necessary services within walking distance. The location has a good access to transit, and the local bus and light rail networks minimise the automobile use. Moreover, the building contributes to sustainable transportation with special bicycle lanes and electric vehicles charging stations.

**Location and Transportation (12/16)**

☐ **Sensitive Land Protection**  
1pt This credit is intended to cultivate community resilience, avoid the development of environmentally sensitive lands that provide critical ecosystem services and reduce the environmental impact from the location of a building on a site. [Learn more about this credit.](#)

☐ **High Priority Site and Equitable Development**  
2pts This credit is intended to build the economic and social vitality of communities, encourage project location in areas with development constraints and promote the ecological, cultural, and community health of the surrounding area while understanding the needs and goals of existing residents and businesses. [Learn more about this credit.](#)

☒ **Surrounding Density and Diverse Uses**  
5pts This credit is intended to conserve land and protect farmland and wildlife habitat by encouraging development in areas with existing infrastructure. It is also intended to support neighborhood and local economies, promote walkability, and low or no carbon transportation, and reduce vehicle distance traveled for all. Furthermore, it is intended to improve public health by encouraging daily physical activity. [Learn more about this credit.](#)

☒ **Access to Quality Transit**  
5pts This credit is intended to encourage development in locations shown to have multimodal transportation choices or otherwise reduced motor vehicle use, thereby reducing greenhouse gas emissions, air pollution, and other environmental and public health harms associated with motor vehicle use. [Learn more about this credit.](#)

☒ **Bicycle Facilities**  
1pt This credit is intended to promote bicycling and transportation efficiency and reduce vehicle distance traveled. It is also intended to improve public health by encouraging utilitarian and recreational physical activity. [Learn more about this credit.](#)

☐ **Reduced Parking Footprint**  
1pt This credit is intended to minimize the environmental harms associated with parking facilities, including automobile dependence, land consumption, and rainwater runoff. [Learn more about this credit.](#)

☒ **Electric Vehicles**  
1pt This credit is intended to reduce pollution by promoting alternatives to conventionally fueled automobiles. [Learn more about this credit.](#)

Figure 2.38. Location and Transportation Scorecard

## 2.8.2 Sustainable Sites

The measures against erosion and dust were applied in the construction to avoid the soil erosion and water contamination. The sustainable design decisions were made with an analysis of the site conditions. The landscaping was planned to conserve the natural elements and to provide accessible outdoor space. Infiltration and detention systems are applied to handle stormwater at the site and minimize runoff as well as enhance the quality of water. Outside lighting is carefully designed and to prevent glare and spillage of light, protecting the surrounding environment and the night sky.

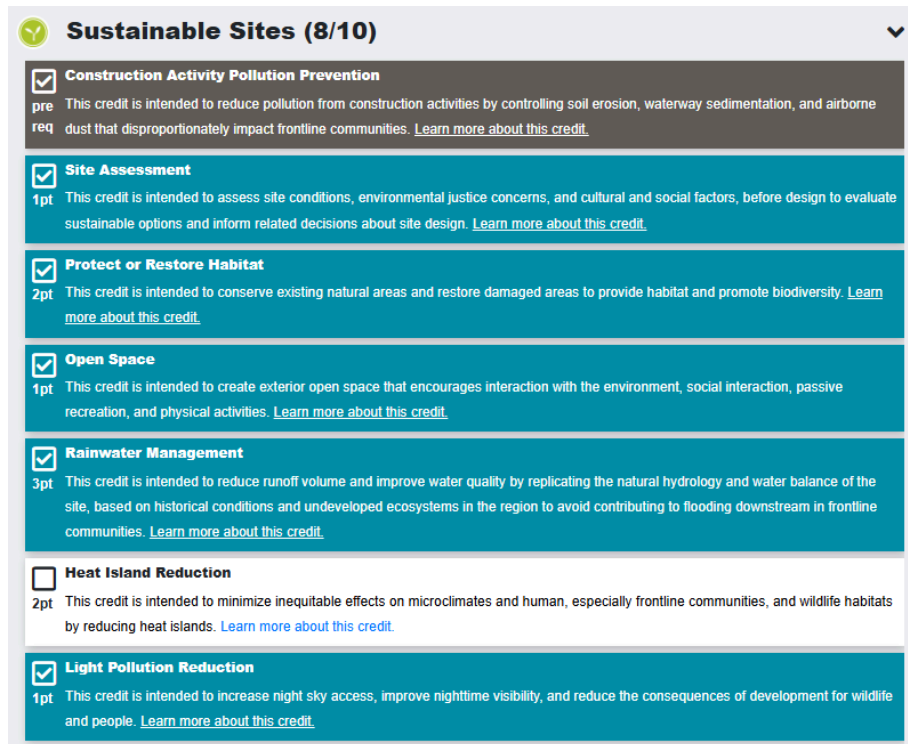


Figure 2.39. Sustainable Sites Scorecard

### 2.8.3 Water efficiency

The requirements for outdoor water are minimized by the use of drought resistant vegetation and an effective irrigation system that requires minimum amount of potable water. Plumbing fixtures and fittings of high efficiency lead to a significant reduction of indoor water usage compared to baseline standards. A water meter is placed on a building level to track the total water consumption and assist in the continued management. All these measures decreases the need of potable water and enhances the performance of water efficiency.

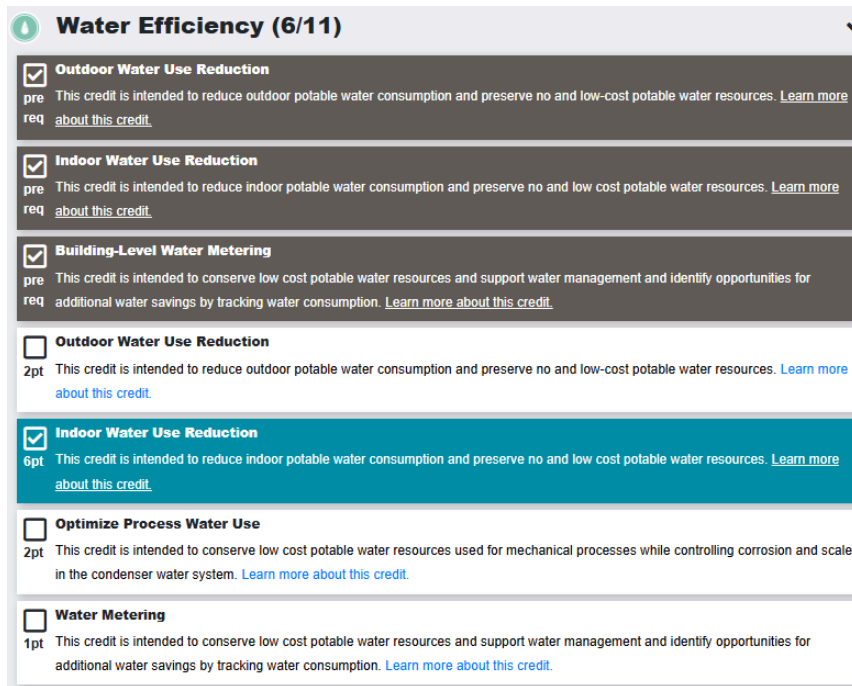


Figure 2.40. Water efficiency Scorecard

## 2.8.4 Energy and Atmosphere

Fundamental commissioning was met by testing the HVAC, lighting, and control systems in San Jose's temperate climate. Basic energy performance was achieved by out-performing Title 24 by five percent with efficient heat pumps, LED lighting and enhanced insulation. Building-level energy metering was achieved via a utility-grade energy meter measuring the entire building's electricity and gas consumption every 15 minutes. Basic refrigerant management was met by using zero-ozone-depletion low-GWP refrigerants. Improved commissioning was done through design review, ten-month post-occupancy commissioning, and building operator training. Energy efficiency was achieved with VRF heat pumps, occupancy and daylight sensors, automated window controls, and 28% less energy cost than Title 24. Energy metering was done using submeters on HVAC, lighting, plug loads and renewable energy generation to provide dashboards and alarms. Harmonization with the grid was achieved by participating in PG&E demand response with automated load curtailment and battery storage. Renewable energy was accomplished with rooftop PV arrays for twelve percent of annual demand plus a community solar subscription for a total of forty-five percent renewables. Optimized refrigerant control was achieved with low-GWP refrigerants (below ten GWP) with leak detection and logs.

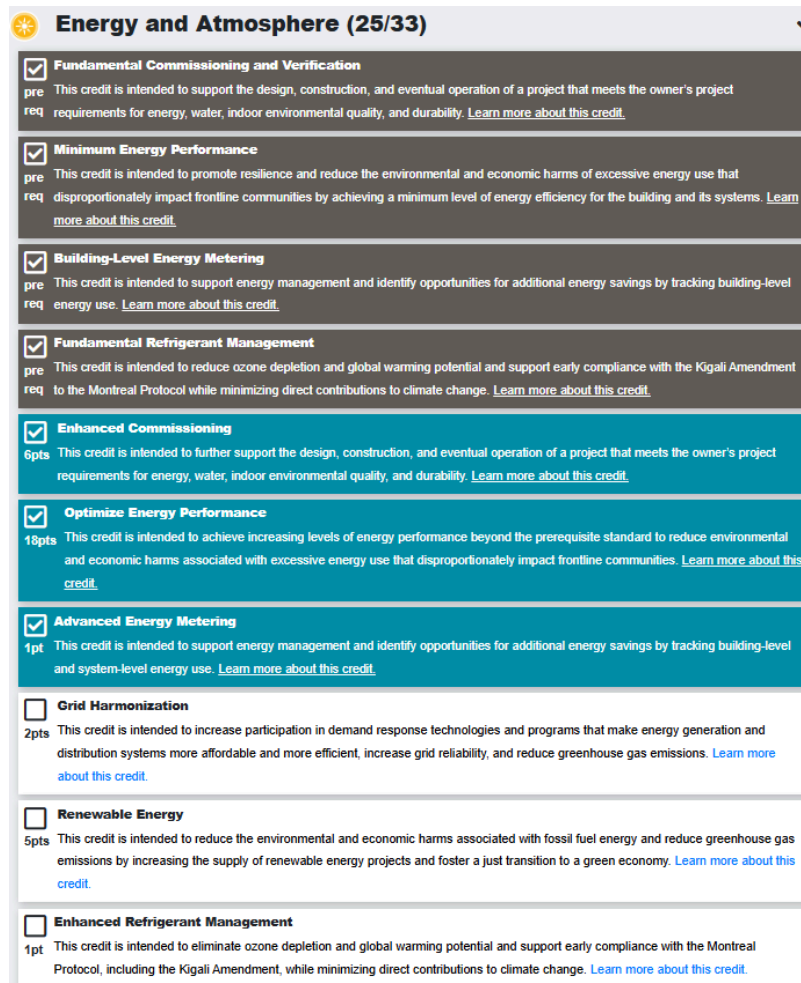


Figure 2.41. Energy and Atmosphere Scorecard

### 2.8.5 Material and resources

Recyclables storage and collection was obtained by providing bins and signage for paper, glass, plastics and metals. Reduction of building life-cycle impacts was achieved by reusing the existing structure and façade, and sourcing low-carbon concrete. Environmental product declarations were achieved with at least twenty products having an EPD from a third party. Sourcing of raw materials was met by sourcing high-recycled content materials and FSC-certified local wood. Material ingredients were met by choosing paints and sealants with Health Product Declarations that are free of harmful ingredients. Construction waste disposal was achieved with recycling of concrete, drywall, metal and wood resulting in more than 75% of waste diverted.

**Materials and Resources (9/13)**

☒
**Storage and Collection of Recyclables**

```
pre
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This credit is intended to reduce the disproportionate burden of landfills and incinerators that is generated by building occupants' waste hauled to and disposed of in landfills and incinerators through reduction, reuse and recycling service and education, and to conserve natural resources for future generations. [Learn more about this credit.](#)

☒
**Building Life-Cycle Impact Reduction**

5pts This credit is intended to encourage adaptive reuse and optimize the environmental performance of products and materials. [Learn more about this credit.](#)

☒
**Environmental Product Declarations**

2pts This credit is intended to encourage the use of products and materials for which life-cycle information is available and that have environmentally, economically, and socially preferable life-cycle impacts. It is also intended to reward project teams for selecting products from manufacturers who have verified improved environmental life-cycle impacts. [Learn more about this credit.](#)

☐
**Sourcing of Raw Materials**

2pts This credit is intended to encourage the use of products and materials for which life cycle information is available and that have environmentally, economically, and socially preferable life cycle impacts. It is also intended to reward project teams for selecting products verified to have been extracted or sourced in a responsible manner. [Learn more about this credit.](#)

☐
**Material Ingredients**

2pts This credit is intended to encourage the use of products and materials for which life-cycle information is available and that have environmentally, economically, and socially preferable life-cycle impacts. It is also intended to reward project teams for selecting products for which the chemical ingredients in the product are inventoried using an accepted methodology and for selecting products verified to minimize the use and generation of harmful substances. Furthermore, it is intended to reward raw material manufacturers who produce products verified to have improved life-cycle impacts. [Learn more about this credit.](#)

☒
**Construction and Demolition Waste Management**

2pts This credit is intended to reduce construction and demolition waste disposed of in landfills and incineration facilities through waste prevention and by reusing, recovering, and recycling materials, and conserving resources for future generations. Furthermore, it is intended to delay the need for new landfill facilities that are often located in frontline communities and create green jobs and materials markets for building construction services. [Learn more about this credit.](#)

Figure 2.42. Materials and Resources Scorecard

## 2.8.6 Indoor Environmental Quality

Indoor air quality was met by complying with ASHRAE 62.1 ventilation rates, carbon dioxide monitoring and high efficiency filters. Environmental tobacco smoke control was provided by a no-smoking policy in the building and 25 feet from all building entries, windows, and air intakes. Improved indoor air quality measures were provided by increasing fresh air supply, demand-controlled ventilation and walk-off mats at building entrances. Low-emitting products were used for all adhesives, sealants, paints, flooring and furniture to comply with California Section 01350. A construction indoor air quality plan was implemented, including MERV 8 filters on return air grilles and duct protection during construction. Post-construction pre-occupancy indoor air quality testing was conducted for formaldehyde and VOCs. Comfort was maintained with zone control and ASHRAE 55 compliance by annual surveys. Lighting was provided with dimmable LED lights, glare control, and individual task lighting. Daylight was provided with high windows, light shelves and motorized blinds to provide daylight to more than 75% of continuously occupied spaces. Views were offered from 90% of workstations, including views to landscaping, sky, and the San Jose hills. Sound considerations were achieved by installing acoustic ceiling panels, solid wall partitions, and masking sound to achieve noise criteria (NC) of less than 40.



Figure 2.43. Indoor Environmental Quality Scorecard

## 2.8.7 Regional priority

Our project gains regional priority points in San Jose by tackling local issues such as drought, energy and greenhouse gas emissions.

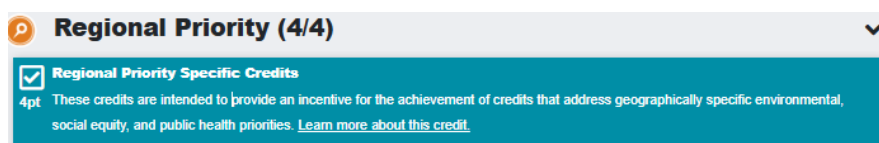


Figure 2.44. Regional Priority Scorecard

## 2.9 Concrete mixture

Viability of base case and five alternative concrete mixtures were tested with the help of Life 365 software to examine service life and cost of life cycle. These mixtures were designed to be in order to achieve a compressive strength of 4800 psi. Although the ratio of water to cementitious materials (w/cm) is maintained at 0.42 in order to maintain the permeability, the use of additional cementitious materials (SCMs) is regulated in such a way that the desired strength development is met or surpassed.



Mechanical properties and type of reinforcement (Black Steel) used in the Life 365 life-cycle model is a direct reflection of the materials used in the structural design calculations. A fixed w/cm ratio is necessary so that the structural load-bearing capacity of the structures to support the San Jose seismic and service loads is not lost due to the durability improvements offered by SCMs.

- Base case: w/c ratio 0.42, fly ash 0%, silica fume 0%, slag 0%
- Alternative 1: w/c ratio 0.42, fly ash 15%, silica fume 0%, slag 0% (+membrane)  
Fly ash added to increase durability and resistance to chloride, Thomas (2007).
- Alternative 2: w/c ratio 0.42, fly ash 15%, silica fume 0%, slag 25% (+sealer)  
Combination of slag and fly ash highly increases durability, Bilodeau & Malhotra (2000).
- Alternative 3: w/c ratio 0.42, fly ash 10%, silica fume 10%, slag 0%  
Silica fume and fly ash significantly increase resistance to chloride ingress, Mehta & Monteiro (2014).

The Calcium Nitrite of 5L/m<sup>3</sup> was added by default to control setting time (Ann et al, 2006). Also, it was decided to add sealers and membrane in different mixtures to check their impact on life cycle.

## 2.10 Life cycle cost

The following values of costs for materials were set as default for all mixtures

- Concrete - \$100/m<sup>3</sup>
- Black steel - \$0.99/kg
- Membrane - \$33/m<sup>2</sup>
- Sealer - \$7/m<sup>2</sup>
- Inhibitor - \$1.5/L
- Repair - \$399/m<sup>2</sup>

The chloride exposure and temperature regimes were set automatically after choosing the specific location of San Jose. For this region the chloride exposure is equal to 0.6% wt. Concrete and the temperature varies between -0.4°C and 24.7°C. The life cycles of each mixture are shown in the table below. Also, it can be seen that barriers and sealers increased the life cycle costs.

| Name          | Construction Cost | Barrier Cost | Repair Cost | Life Cycle Cost |
|---------------|-------------------|--------------|-------------|-----------------|
| Base case     | \$465,177         | \$0          | \$1,205,462 | \$1,670,639     |
| Alternative 1 | \$465,177         | \$0          | \$1,103,590 | \$1,568,767     |
| Alternative 2 | \$488,010         | \$0          | \$902,919   | \$1,390,929     |
| Alternative 3 | \$465,177         | \$0          | \$614,409   | \$1,079,586     |

Table 2.2. Total life cycle costs.

## 2.11 Service life

In LCC Report service life of each mixtures were calculated and shown in a table below. It is clear that alternative mixture 4 has the most service life.

| Name          | Service Life |
|---------------|--------------|
| Base case     | 23.92 yrs    |
| Alternative 1 | 32.50 yrs    |
| Alternative 2 | 51.42 yrs    |
| Alternative 3 | 80.92 yrs    |

Table 2.3. Service life

Alternative 3 concrete mixture was selected for its low repair construction cost (\$614,409) and exceptional life-cycle economy despite minimal barrier and repair expenses, the mixture achieves a favorable long-term cost profile. This combination of initial affordability and durability ensures high life-cycle performance.

In the corrosive environment of San Jose rebar corrosion is likely to take place, resulting in concrete spalling. To combat this we have offered two solutions:

**Traditional Patch Repair** is a method used for isolated concrete damage where all damaged concrete around the corroded rebar is removed, steel cleaned to a "white metal" finish and treated with a corrosion-retarding primer. This space is filled with a quality repair mortar to replace the concrete cover. Although useful for localised damage, patching alone can cause the "incipient anode effect" leading to further corrosion. So it is best used for small, superficial problems with other protective treatments.

**Galvanic Cathodic Protection (GCP)** is an electro-chemical process that prevents extensive corrosion by connecting sacrificial zinc anodes to the rebar. Zinc is more reactive than steel, and corrodes preferentially, delivering electrons to the rebar and creating a cathode. This approach is passive, requires no power source, and is long-lasting. GCP is often used either around patch repairs to avoid the incipient anode effect or over entire elements in corrosive conditions such as San Jose.

## 2.12 Corrosion prevention

Corrosion can be prevented by selecting appropriate concrete mixtures and ensuring sufficient concrete cover. To reduce concrete permeability and prevent chloride penetration,

silica fume should be added at 5–10% of the total cementitious material weight, in combination with Portland cement as the binder. Additionally, fly ash at 15–30% can further reduce permeability and enhance durability when combined with calcium hydroxide. Blast furnace slag, used at 30–50%, helps protect against sulfate attack and alkali-silica reaction. Sealing agents and corrosion inhibitors are also commonly applied to mitigate corrosion.

To protect reinforcing steel from corrosion, an adequate concrete cover, the distance between the reinforcement and the nearest concrete surface, is needed. For bored piles with a diameter of up to 600 mm, a concrete cover of 50 mm should be provided, while larger diameters require a 60 mm cover. The concrete cover may be reduced to 40 mm if a permanent casing or lining is present on the external face (Laloui & Rotta Loria, 2020).

### 3. Structural Design

#### 3.1 Material Selection

For the structural design material, reinforced concrete was chosen after a thorough selection. The comparisons were made between reinforced concrete and steel. Other materials like masonry and wood were rejected at the beginning for their evident incompatibility with high-rise building construction. For example, wood was disadvantageous for its low strength, high flammability, and price, whereas masonry also has a high cost, and time and labor demand. The following table represents the comparison made between reinforced concrete and steel:

Table 3.1. Comparison of reinforced concrete and steel for a structural material selection.

| Characteristic       | Reinforced Concrete                                                | Steel                                                    |
|----------------------|--------------------------------------------------------------------|----------------------------------------------------------|
| Strength             | High compressive strength                                          | High tensile strength                                    |
| Ductility            | Less ductile, but depends on the design of the steel reinforcement | Highly ductile, deforms significantly without fracturing |
| Weight               | Heavy, hence has a high dead load on the structure                 | Relatively lighter, hence less load                      |
| Cost                 | Lower material cost, but higher labor cost                         | Higher material cost, less labor cost                    |
| Construction Time    | Longer construction time due to on-site pouring and curing         | Less construction time due to prefabricated parts        |
| Corrosion Resistance | Resistant to corrosion                                             | Susceptible to corrosion                                 |

|                     |                                                                      |                                                             |
|---------------------|----------------------------------------------------------------------|-------------------------------------------------------------|
| Fire Resistance     | Resistant to fire, since concrete is non-combustible                 | Susceptible to fire, steel is highly vulnerable to heat     |
| Elasticity          | Less elastic, vulnerable to tensile load                             | Highly elastic, returns to its original shape after loading |
| Seismic Performance | Moderate, but can be fixed with shear walls and proper reinforcement | Good due to ductility and lower weight                      |

Although steel structures have higher tensile strength in terms of resistance to wind and seismic loads, reinforced concrete was chosen as the structural material for our building because it is more fire-resistant, has higher compressive strength, and is durable, since it is resistant to corrosion. Since the building's location is prone to high seismicity, corrosion, and the risk of fires, the chosen material is suitable for this project.

### **3.2 Analytical Model Development**

SAP 2000 software is widely used for both structural design and analysis. This section will cover all properties specified in the SAP 2000 model, including frame section materials, concrete and reinforcing steel properties, as well as boundary conditions and model geometry.

#### **3.2.1 Model Geometry**

The whole structure, including its beams, slabs, and columns, was developed in SAP2000 software. The geometry of the building is shown in the following figure:

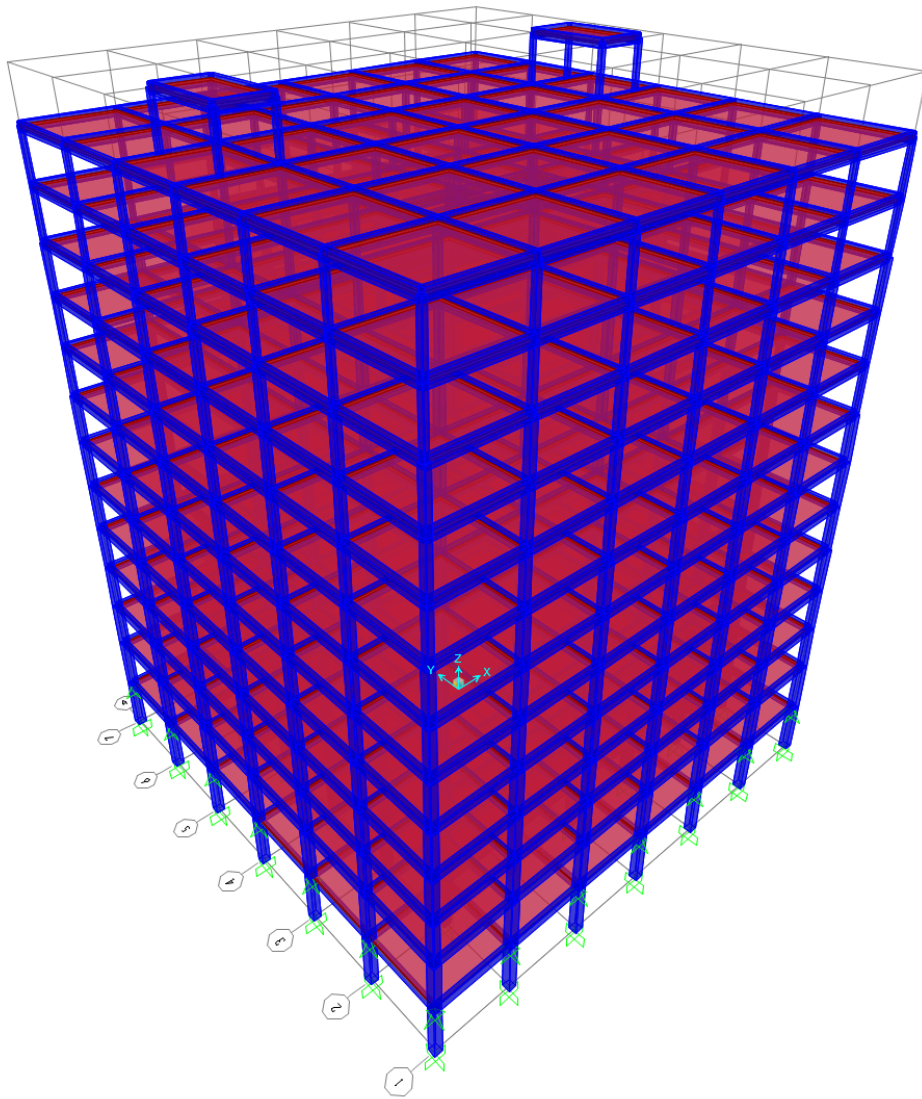


Figure 3.1. SAP model of building

### 3.2.2 Material Properties for SAP 2000

For software inputs and hand calculations, the same material parameters were inserted. To design the slab, column, and beam, C40 grade of concrete was used due to its common use for heavy buildings (Base Concrete, 2023). The material parameters of the concrete are shown below:

Table 3.2. Properties of the reinforced concrete

| $f'_c$ , MPa | $E_c$ , MPa | $\rho$ , kN/m <sup>3</sup> | $\nu$ | $G_c$ , MPa |
|--------------|-------------|----------------------------|-------|-------------|
|--------------|-------------|----------------------------|-------|-------------|

|    |          |    |     |       |
|----|----------|----|-----|-------|
| 40 | 29725.41 | 25 | 0.2 | 12386 |
|----|----------|----|-----|-------|

For the reinforcing steel, G60 grade was used, since it is widely used in seismic regions for its balanced energy dissipation (Trejo, D., Link, T. B., & Barbosa, A. R., 2016). The properties of this rebar are presented on the next table:

Table 3.3. Properties of reinforcing steel

| $f_y$ , MPa | $E_s$ , MPa | $\rho$ , % | $\rho$ , kN/m <sup>3</sup> | $\nu$ |
|-------------|-------------|------------|----------------------------|-------|
| 414         | 200000      | 1          | 77                         | 0.3   |

### 3.2.3. Sections

For the frame sections of columns, beams, slabs, and stairs, the following cracking moments of inertia were inserted into the software:

Table 3.4. Cracking moment of inertia factors of structural members

| Structural Member | Cracking moment of inertia factors |
|-------------------|------------------------------------|
| Column            | 0.7                                |
| Beam              | 0.35                               |
| Slab              | 0.7                                |
| Stairs            | 0.25                               |

### 3.2.4. Element Types and Connections

All slabs are shell elements with a two-way configuration, while frame elements were used to model columns and beams. The connection between joints was considered rigid.

### 3.2.5. Boundary Connections

Since the first-story columns are at the ground level, their horizontal and vertical movement is restricted, while rotational movement is unrestricted so that the structure can

shift when subjected to subsequent loads. Thus, pinned connections were assigned to exterior joints on the ground level, whereas bottommost joints were left with the fixed connections.

### 3.2.6 Scope requirement

For our project a combination of Earthquake and Corrosion environments appeared. The scope requirements were fulfilled by taking several steps. To resist the earthquake the square shape of the building was designed to be 36 by 36 meters in total with a 6 by 6 meter span between every column. This shape ensures there is no excessive load on one side of the building, spreading the load uniformly. To prevent corrosion, the proper thickness of concrete in reinforced beams and water drainage to avoid water accumulation were chosen.

## 3.3 Analysis and Design of Gravity Load Resisting System (GLRS)

### 3.3.1 Dead load calculation

The calculations of non-structural dead load for roof and floor loads were conducted in compliance with the guidelines outlined in ASCE 7-16, Chapter 3 (American Society of Civil Engineers, 2017). Two varieties of flooring materials were utilized to compute floor loads. The design of other structural elements, such as columns, was based on the most substantial load, obtained from the most critical tributary area distribution. The subsequent tables represent the computations of dead loads from floor coverings on the first floor, typical floor, and roof.

Table 3.5. Main floor finishing

| Material                         | Thickness, mm | Design load, kPa |
|----------------------------------|---------------|------------------|
| Hardwood (cover)                 | 22            | 0.19             |
| Screed (leveling)                | 40            | 0.92             |
| Single-ply sheet (waterproofing) | 10            | 0.03             |
| Mineral wool layer (insulation)  | 25            | 0.055            |
| Total                            | 97            | 1.195            |

Table 3.6. Floor finishing for restrooms

| Material                         | Thickness, mm | Design load, kPa |
|----------------------------------|---------------|------------------|
| Ceramic tile on 13-mm mortar bed | 32            | 0.77             |

|                                  |     |       |
|----------------------------------|-----|-------|
| (cover)                          |     |       |
| Screed (leveling)                | 40  | 0.92  |
| Single-ply sheet (waterproofing) | 10  | 0.03  |
| Mineral wool layer (insulation)  | 25  | 0.055 |
| Total                            | 107 | 1.775 |

Table 3.7. Ceiling

| Material                  | Thickness, mm | Design load, kPa |
|---------------------------|---------------|------------------|
| Acoustical fiber board    | 30            | 0.05             |
| Mechanical duct allowance | 250           | 0.19             |
| Gypsum board              | 13            | 0.104            |
| Total                     | 293           | 0.344            |

Table 3.8. Roof

| Material                                      | Thickness, mm | Design load, kPa |
|-----------------------------------------------|---------------|------------------|
| Three-ply ready roofing (cover)               | 10            | 0.05             |
| Fiberboard (insulation)                       | 12            | 0.0336           |
| Bituminous, smooth surface<br>(waterproofing) | 5             | 0.07             |
| Stone concrete (leveling)                     | 30            | 0.69             |
| Total                                         | 57            | 0.8436           |

Loads from partitions, exterior walls, and roof parapets were also calculated, as shown in the figures below. It was assumed that the weight of the partitions was evenly distributed across the floor area, while loads from exterior walls and roof parapets applied exclusively to the exterior beams.

Table 3.9. Exterior wall for the first floor

| Material | Thickness, mm | Height, mm | Density, kg/m <sup>3</sup> | Load, kN/m |
|----------|---------------|------------|----------------------------|------------|
|----------|---------------|------------|----------------------------|------------|



|                             |     |      |      |        |
|-----------------------------|-----|------|------|--------|
| Cement plaster              | 5   | 4000 | 2040 | 0.40   |
| Air infiltration barrier    | 15  | 4000 | 1270 | 0.75   |
| Autoclaved aerated concrete | 300 | 4000 | 1920 | 22.6   |
| Fiberglass batt             | 50  | 4000 | 22   | 0.04   |
| Air infiltration barrier    | 15  | 4000 | 1270 | 0.75   |
| Cement plaster              | 5   | 4000 | 2040 | 0.40   |
| Fiber cement cladding       | 15  | 4000 | 1500 | 0.88   |
| Total                       | 405 |      |      | 25.824 |

Table 3.10. Exterior wall for the typical floor

| Material                    | Thickness, mm | Height, mm | Density, kg/m <sup>3</sup> | Load, kN/m |
|-----------------------------|---------------|------------|----------------------------|------------|
| Cement plaster              | 5             | 3500       | 2040                       | 0.35       |
| Air infiltration barrier    | 15            | 3500       | 1270                       | 0.65       |
| Autoclaved aerated concrete | 300           | 3500       | 1920                       | 19.78      |
| Fiberglass batt             | 50            | 3500       | 22                         | 0.04       |
| Air infiltration barrier    | 15            | 3500       | 1270                       | 0.65       |
| Cement plaster              | 5             | 3500       | 2040                       | 0.35       |
| Fiber cement cladding       | 15            | 3500       | 1500                       | 0.77       |
| Total                       | 385           |            |                            | 22.596     |

As partition walls are distributed uniformly over the floor, their loads were multiplied by the length of the interior walls on the floor and divided by the gross floor area, as shown below:

$$\text{Load of partition wall} = 0.1 + 0.011 + 1.413 + 0.011 + 0.1 = 1.63 \text{ kPa}$$

$$\text{Floor area} = 1296 \text{ m}^2$$

$$\text{Distributed load of partition wall on first floor} = 1.63 \cdot 222.64 \cdot 4/1296 = 1.123 \text{ kPa}$$

$$\text{Distributed load of partition wall on typical floor} = 1.63 \cdot 202.74 \cdot 3.5/1296 = 0.895 \text{ kPa}$$

Table 3.11. Partition wall for the first floor

| Material                    | Thickness, mm | Density, kg/m <sup>3</sup> | Load, kPa |
|-----------------------------|---------------|----------------------------|-----------|
| Cement plaster              | 5             | 2040                       | 0.10      |
| Fiberglass batt             | 50            | 22                         | 0.011     |
| Autoclaved aerated concrete | 75            | 1920                       | 1.413     |
| Fiberglass batt             | 50            | 22                         | 0.011     |
| Cement plaster              | 5             | 2040                       | 0.10      |
| Total                       | 185           |                            | 1.123     |

Table 3.12. Partition wall for the typical floor

| Material                    | Thickness, mm | Density, kg/m <sup>3</sup> | Load, kPa |
|-----------------------------|---------------|----------------------------|-----------|
| Cement plaster              | 5             | 2040                       | 0.10      |
| Fiberglass batt             | 50            | 22                         | 0.011     |
| Autoclaved aerated concrete | 75            | 1920                       | 1.413     |
| Fiberglass batt             | 50            | 22                         | 0.011     |
| Cement plaster              | 5             | 2040                       | 0.10      |
| Total                       | 185           |                            | 0.895     |

Table 3.14. Parapets

| Material                    | Thickness, mm | Height, mm | Density, kg/m <sup>3</sup> | Load, kN/m |
|-----------------------------|---------------|------------|----------------------------|------------|
| Cement plaster              | 5             | 1100       | 2040                       | 0.11       |
| Autoclaved aerated concrete | 300           | 1100       | 1920                       | 6.22       |
| Fiberglass batt             | 50            | 1100       | 22                         | 0.012      |
| Air infiltration barrier    | 15            | 1100       | 1270                       | 0.21       |
| Cement plaster              | 5             | 1100       | 2040                       | 0.110      |
| Fiber cement cladding       | 15            | 1100       | 1500                       | 0.24       |

|       |     |  |       |
|-------|-----|--|-------|
| Total | 390 |  | 6.896 |
|-------|-----|--|-------|

In addition, the load on the staircase was calculated as 146.37 kN by determining the volume of the staircase in Revit and multiplying it by the density.

### 3.3.2 Live load calculation

The minimum uniformly distributed live loads for an office building, based on ASCE 7-16, were determined and presented below (American Society of Civil Engineers, 2017):

$L_0 = 2.4 \text{ kPa}$  for office building

$L_0 = 4.79 \text{ kPa}$  for lobby, dining rooms, retail area, stairs, and first-floor corridors

$L_0 = 3.83 \text{ kPa}$  for corridors above the first floor

$L_0 = 0.96 \text{ kPa}$  for ordinary flat roofs

According to ASCE 7-16, the live load reduction factor should be applied to all uniformly distributed loads, except for public spaces. The live load reduction for floors should be calculated using the following formula:

$$L = L_0 \left( 0.25 + \frac{4.57}{\sqrt{K_{LL} \cdot A_T}} \right) \quad (3.1)$$

Where live load element factor,  $K_{LL}$ , has the following values:

$K_{LL} = 4$  for interior columns, exterior columns and corner columns without cantilever slabs

$K_{LL} = 2$  for interior beams and edge beams without cantilever slabs

The roof live load was found using the following formula:

$$L_r = L_0 R_1 R_2, \quad 0.58 < L_r \leq 0.96 \quad (3.2)$$

The reduction factor  $R_1$  was obtained from:

$$R_1 = \begin{cases} 1 & \text{for } A_T \leq 18.58 \text{ m}^2 \\ 1.2 - 0.011 \cdot A_T & \text{for } 18.58 \text{ m}^2 < A_T < 55.74 \text{ m}^2 \\ 0.6 & \text{for } A_T \geq 55.74 \text{ m}^2 \end{cases} \quad (3.2)$$

The reduction factor  $R_2$  formula is presented below:

$$R_2 = \begin{cases} 1 & \text{for } F \leq 4 \\ 1.2 - 0.05 \cdot F & \text{for } 4 < F < 12 \\ 0.6 & \text{for } F \geq 12 \end{cases} \quad (3.3)$$

Since our building design uses an ordinary flat roof,  $R_2$  will be equal to 1.

Table 3.15. Floor live load for the office use

| Element          | $K_{LL}$ | Space, m | Span, m | $A_T, m^2$ | $L_0, kN/m^2$ | R     | L, $kN/m^2$ |
|------------------|----------|----------|---------|------------|---------------|-------|-------------|
| Interior columns | 4        | 6        | 6       | 36         | 2.4           | 0.631 | 1.514       |
| Exterior columns | 4        | 3        | 6       | 18         | 2.4           | 0.789 | 1.893       |
| Corner columns   | 4        | 3        | 3       | 9          | 2.4           | 1     | 2.4         |
| Edge beams       | 2        | 3        | 6       | 9          | 2.4           | 1     | 2.4         |
| Interior beams   | 2        | 6        | 6       | 18         | 2.4           | 1     | 2.4         |

Table 3.16. Floor live load for lobby, dining rooms, retail area, stairs, and first-floor corridors

| Element          | $K_{LL}$ | Space, m | Span, m | $A_T, m^2$ | $L_0, kN/m^2$ | R     | L, $kN/m^2$ |
|------------------|----------|----------|---------|------------|---------------|-------|-------------|
| Interior columns | 4        | 6        | 6       | 36         | 4.79          | 0.631 | 3.022       |
| Exterior columns | 4        | 3        | 6       | 18         | 4.79          | 0.789 | 3.777       |
| Corner columns   | 4        | 3        | 3       | 9          | 4.79          | 1     | 4.79        |
| Edge beams       | 2        | 3        | 6       | 9          | 4.79          | 1     | 4.79        |
| Interior beams   | 2        | 6        | 6       | 18         | 4.79          | 1     | 4.79        |

Table 3.17. Floor live load for corridors above the first floor

| Element          | $K_{LL}$ | Space, m | Span, m | $A_T, m^2$ | $L_0, kN/m^2$ | R     | L, $kN/m^2$ |
|------------------|----------|----------|---------|------------|---------------|-------|-------------|
| Interior columns | 4        | 6        | 6       | 36         | 3.83          | 0.631 | 2.416       |
| Exterior columns | 4        | 3        | 6       | 18         | 3.83          | 0.789 | 3.02        |

|                |   |   |   |    |      |   |      |
|----------------|---|---|---|----|------|---|------|
| Corner columns | 4 | 3 | 3 | 9  | 3.83 | 1 | 3.83 |
| Edge beams     | 2 | 3 | 6 | 9  | 3.83 | 1 | 3.83 |
| Interior beams | 2 | 6 | 6 | 18 | 3.83 | 1 | 3.83 |

Since the critical live load for both the first and typical floors is 4.79 kPa, this value will be utilized to calculate the design of the structural members.

Table 3.18. Roof live load

| Element          | $K_{LL}$ | Space, m | Span, m | $A_T$ , m <sup>2</sup> | $L_0$ , kN/m <sup>2</sup> | $R_1$ | F | $R_2$ | L, kN/m <sup>2</sup> |
|------------------|----------|----------|---------|------------------------|---------------------------|-------|---|-------|----------------------|
| Interior columns | 4        | 6        | 6       | 36                     | 0.96                      | 0.804 | 0 | 1     | 0.772                |
| Exterior columns | 4        | 3        | 6       | 18                     | 0.96                      | 1     | 0 | 1     | 0.96                 |
| Corner columns   | 4        | 3        | 3       | 9                      | 0.96                      | 1     | 0 | 1     | 0.96                 |
| Edge beams       | 2        | 3        | 6       | 9                      | 0.96                      | 1     | 0 | 1     | 0.96                 |
| Interior beams   | 2        | 6        | 6       | 18                     | 0.96                      | 1     | 0 | 1     | 0.96                 |

### 3.3.3 Snow load calculation

Although our site is located in a region without heavy snowfall, the ASCE Hazard Tool showed a ground snow load of 0.19 kPa for risk category II and soil stiffness class D, as shown below:

#### Snow

|                                              |                        |
|----------------------------------------------|------------------------|
| Ground Snow Load, $p_g$                      | 0.19 kN/m <sup>2</sup> |
| 20-year MRI Value, $p_g$                     | 0.05 kN/m <sup>2</sup> |
| Winter Wind Parameter, $W_2$                 | 0.25                   |
| Mapped Elevation                             | 30.6 m                 |
| Ground Snow Loads for IRC only, $p_{g(asd)}$ | 0.1 kN/m <sup>2</sup>  |

Figure 3.2. (ASCE Hazard Tool, 2025)

First, the flat roof snow load was calculated using the following formula:

$$p_f = 0.7 \times C_e \times C_t \times I_s \times p_g \quad (3.4)$$

The exposure factor  $C_e$  was determined using the following Table 7-2 from ASCE Chapter 7:

| Terrain Category                                                                        | Fully Exposed | Partially Exposed | Sheltered |
|-----------------------------------------------------------------------------------------|---------------|-------------------|-----------|
| B (see Section 26.7)                                                                    | 0.9           | 1.0               | 1.2       |
| C (see Section 26.7)                                                                    | 0.9           | 1.0               | 1.1       |
| D (see Section 26.7)                                                                    | 0.8           | 0.9               | 1.0       |
| Above the treeline in windswept mountainous areas.                                      | 0.7           | 0.8               | N/A       |
| In Alaska, in areas where trees do not exist within a 2-mile (3-km) radius of the site. | 0.7           | 0.8               | N/A       |

Figure 3.3. Exposure Factor,  $C_e$

Since our site is located in an urban region, the terrain category was selected to be B with partial exposure, so the exposure factor was taken as  $C_e = 1.0$ .

The thermal factor  $C_t$  was considered to be equal to 1.0 according to the following Table 7-3 from ASCE Chapter 7:

| Thermal Condition <sup>a</sup>                                                                                                                                                                                                                                                           | $C_t$ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| All structures except as indicated below                                                                                                                                                                                                                                                 | 1.0   |
| Structures kept just above freezing and others with cold, ventilated roofs in which the thermal resistance (R-value) between the ventilated space and the heated space exceeds $25^\circ\text{F} \times h \times \text{ft}^2/\text{Btu}$ ( $4.4 \text{ K} \times \text{m}^2/\text{W}$ ). | 1.1   |
| Unheated and open air structures                                                                                                                                                                                                                                                         | 1.2   |
| Structures intentionally kept below freezing                                                                                                                                                                                                                                             | 1.3   |
| Continuously heated greenhouses <sup>b</sup> with a roof having a thermal resistance (R-value) less than $2.0^\circ\text{F} \times h \times \text{ft}^2/\text{Btu}$ ( $0.4 \text{ K} \times \text{m}^2/\text{W}$ )                                                                       | 0.85  |

Figure 3.4. Thermal Factor,  $C_t$

The building risk category was obtained to be II for the office building type, according to Table 1.5-1 of ASCE Chapter 7. Using this information, the snow importance factor was taken as 1.0 using Table 1.5-2:

| Risk Category from Table 1.5-1 | Snow Importance Factor, $I_s$ | Ice Importance Factor—Thickness, $I_t$ | 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                             |

Figure 3.5. Importance Factor Table

Thus, the snow load on flat roofs was calculated as shown below:

$$p_f = 0.7 \times 1.0 \times 1.0 \times 1.0 \times 0.19 = 0.133 \text{ kN/m}^2$$

For  $p_g < 0.96 \text{ kN/m}^2$ , the minimum roof snow load for low-slope roofs is

$$p_m = I_s \times p_g = 1.0 \times 0.19 = 0.19 \text{ kN/m}^2$$

Since the calculated value of  $p_f$  is higher than the  $p_m$ , it remains unchanged.

The height of the snow is calculated to be the division of the flat roof snow load over snow density:

$$h_b = \frac{p_f}{\gamma_s} = \frac{0.19}{2.28} = 0.08 \text{ m} \quad (3.5)$$

The snow density  $\gamma_s$  is

$$\gamma_s = 0.426 \cdot p_g + 2.2 = 0.426 \cdot 0.19 + 2.2 = 2.28 \text{ kN/m}^3 \leq 4.7 \text{ kN/m}^3$$

The remaining available height for the drift is

$$h_c = h - h_b = 3.5 - 0.08 = 3.42 \text{ m}$$

To calculate the snow load due to the drift, the following formulas were used:

$$p_d = h_d \times \gamma_s \quad (3.6)$$

$$h_{d, leeward} = (0.43 \sqrt[3]{L_u} \times 3.28 \times \sqrt[4]{p_g + 10} - 1.5) \div 3.28$$

$$h_{d, windward} = 0.75 \times (0.43 \sqrt[3]{L_{u, windward}} \times \sqrt[4]{p_g + 10} - 1.5) \div 3.28$$

$$h_d = \text{MAX} \{h_{d, leeward}, h_{d, windward}\}$$

$$W_d = 4 \times h_d, h_d \leq h_c$$

When designing our building, eight wind direction options were used, four options for each direction for two roof structures. Since the building is situated at an angle of almost 45 degrees from latitude and longitude, the directions northwest-southeast, southeast-northwest, southwest-northeast, and northeast-southwest were used for convenience in illustrating the directions. The illustrations with of wind drift cases are shown below:

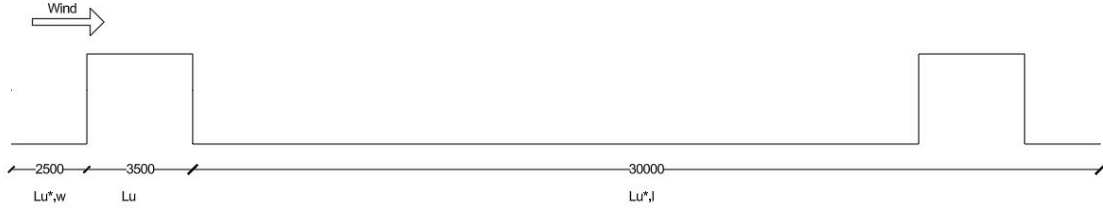


Figure 3.6. Snow drift case for SE⇒NW direction of 1st roof and NW⇒SE direction of 2nd roof

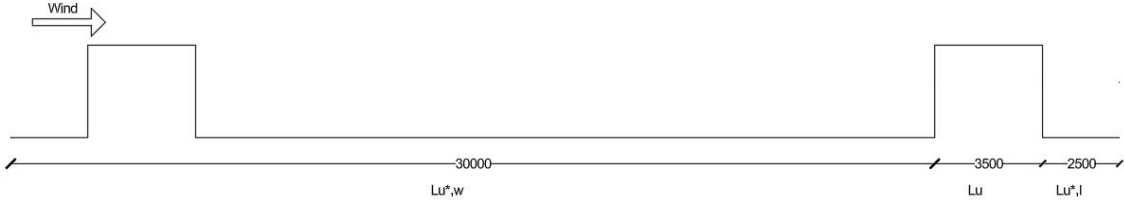


Figure 3.7. Snow drift case for NW⇒SE direction of 1st roof and SE⇒NW direction of 2nd roof

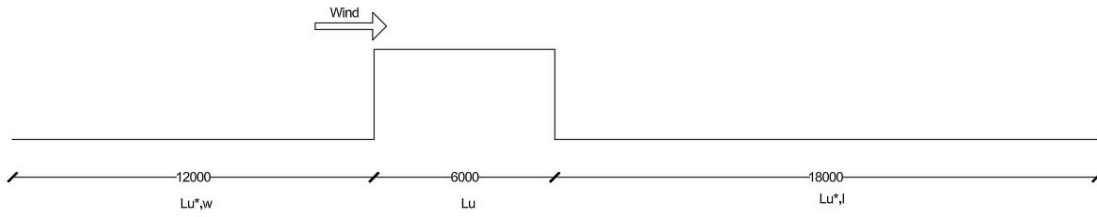


Figure 3.8. Snow drift case for SW⇒NE direction of 1st roof and SW⇒NE direction of 2nd roof

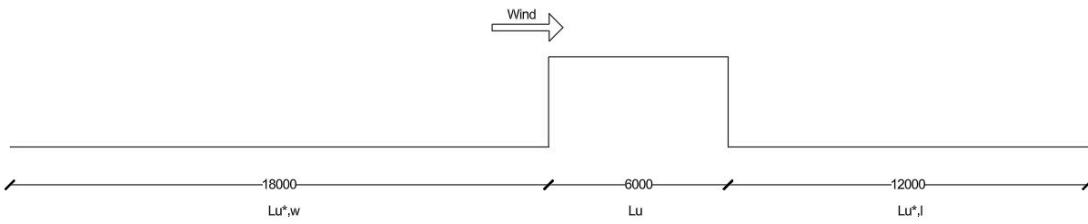


Figure 3.9. Snow drift case for SW⇒NE direction of 1st roof and SW⇒NE direction of 2nd roof

An example of snow drift calculation is presented below for the northwest-southeast direction of the first roof:

$$L_u = 3.5 \text{ m}, L_{u,windward} = 30 \text{ m}, L_{u,leeward} = 2.5 \text{ m}$$

$$h_{d,leeward} = (0.43 \times \sqrt[3]{3.5 \cdot 3.28} \cdot \sqrt[4]{0.19 \cdot 20.885 + 10} - 1.5) \div 3.28 = 0.11 \text{ m}$$



$$h_{d, windward} = 0.75 \times (0.43 \times \sqrt[3]{30 \cdot 3.28} \times \sqrt[4]{0.19 \cdot 20.885 + 10} - 1.5) \\ \div 3.28 = 0.53 \text{ m}$$

$$h_d = MAX \{h_{d, leeward}, h_{d, windward}\} = MAX \{0.11, 0.53\} = 0.53 \text{ m} \leq h_c = 3.42 \text{ m}$$

$$\gamma_s = 0.426 \times 0.19 + 2.2 = 2.28 < 4.7 \text{ kN/m}^3$$

$$p_d = h_d \times \gamma_s = 0.53 \cdot 2.28 = 1.22 \text{ kN/m}^2$$

$$W_d = 4 \cdot 0.53 = 2.14 \text{ m}$$

Table 3.19. Snow drift

|                          | Roof 1 |        |        |        | Roof 2 |        |        |        |
|--------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Direction                | NW=>SE | SE=>NW | SW=>NE | NE=>SW | NW=>SE | SE=>NW | SW=>NE | NE=>SW |
| $p_d, \text{ kN/m}^2$    | 1.22   | 0.26   | 0.69   | 0.91   | 0.26   | 1.22   | 0.69   | 0.91   |
| $L_u, \text{ m}$         | 3.5    | 3.5    | 6      | 6      | 3.5    | 3.5    | 6      | 6      |
| $L_{u,w}^*, \text{ m}$   | 30     | 2.5    | 12     | 18     | 2.5    | 30     | 12     | 18     |
| $L_{u,l}^*, \text{ m}$   | 2.5    | 30.0   | 18     | 12     | 30     | 2.5    | 18     | 12     |
| $h_b, \text{ m}$         | 0.08   | 0.08   | 0.08   | 0.08   | 0.08   | 0.08   | 0.08   | 0.08   |
| $h_{d1}, \text{ m}$      | 0.11   | 0.11   | 0.23   | 0.23   | 0.11   | 0.11   | 0.23   | 0.23   |
| $h_{d2}, \text{ m}$      | 0.53   | 0.04   | 0.30   | 0.40   | 0.04   | 0.53   | 0.30   | 0.40   |
| $h_d, \text{ m}$         | 0.53   | 0.23   | 0.30   | 0.40   | 0.23   | 0.53   | 0.30   | 0.40   |
| $h_c, \text{ m}$         | 3.42   | 3.42   | 3.42   | 3.42   | 3.42   | 3.42   | 3.42   | 3.42   |
| $W, \text{ m}$           | 2.14   | 0.91   | 1.21   | 1.59   | 0.91   | 2.14   | 1.21   | 1.59   |
| $\gamma, \text{ kN/m}^3$ | 2.28   | 2.28   | 2.28   | 2.28   | 2.28   | 2.28   | 2.28   | 2.28   |

Common distributed snow load was selected as the maximum value from the obtained values, thus

$$SL = 1.22 + 0.19 = 1.41 \frac{\text{kN}}{\text{m}^2}$$

### 3.3.4 Estimation of member sizes

#### 3.3.4.1. Determination of structural layout

The three GLRS layouts were considered for our design: a two-way slab with major beams only, a one-way slab with major beams and one minor beam, and a two-way slab with major beams and two minor beams.

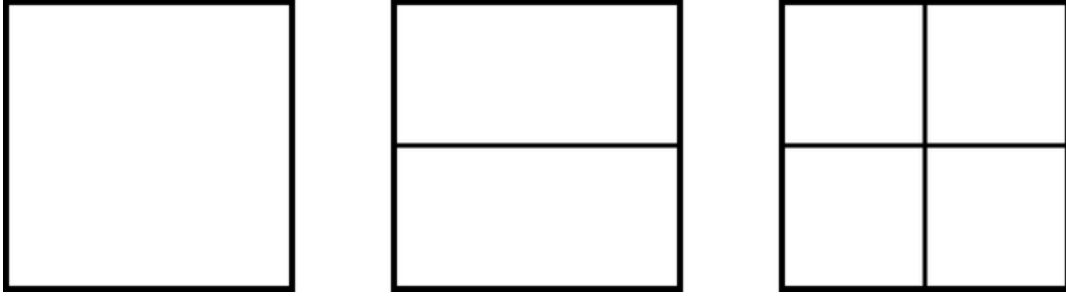


Figure 3.10. Possible GLRS layouts.

In order to compare three GLRS layouts, the preliminary member size estimation was conducted according to the specifications from ACI 318-19 Chapters 7 and empirical knowledge.

#### Two-way slab with major beams:

The length of slabs and beams was assumed to be 6 m, as it is a common construction dimension (Afrose, 2017). According to empirical data, the thickness of the major beam is equal to 10% of its length, and the width is equal to half of its thickness.

$$h_{major\ beam} = L \cdot 10\% = 6 \cdot 10\% = 0.6\ m \quad (3.7)$$

$$b_{major} = \frac{h}{2} = 0.3\ m$$

To determine the thickness of the slab, the ACI 318 Table 8.3.1.2 for the nonprestressed beam-to-slab formula was utilized (ACI, 2019). C40 concrete was selected for the slab and beam since it is commonly tailored for heavy-duty applications (iMix, 2014). The calculations are shown below:

$$E_{cb} = E_{cs} = 4700 \cdot \sqrt{f_c} \quad (3.8)$$

$$E_{cb} = E_{cs} = 4700 \cdot \sqrt{40} = 29725.4\ MPa$$

$$I_{beam} = \frac{0.35}{12} \cdot h_{beam}^3 \cdot b_{beam} \quad (3.9)$$

$$I_{beam} = \frac{0.35}{12} \cdot 0.6^3 \cdot 0.3 = 0.00189 \text{ mm}^4$$

$$\text{Assumption: } h_{slab} = 0.2 \text{ m}$$

$$I_{slab} = \frac{0.25}{12} \cdot h_{slab}^3 \cdot L_{yn} \quad (3.10)$$

$$I_{slab} = \frac{0.25}{12} \cdot 0.2^3 \cdot 6 = 0.001 \text{ mm}^4$$

The stiffness ratio is calculated in the following way:

$$\alpha_{f1} = \frac{E_{cb} \cdot I_b}{E_{cs} \cdot I_s} \quad (3.11)$$

$$\alpha_{f1} = \frac{29725 \cdot 0.00189}{29725 \cdot 0.001} = 1.89$$

$$\alpha_{fm} = \frac{\alpha_{f1} + \alpha_{f2} + \alpha_{f3} + \alpha_{f4}}{4} = \frac{1.89 + 1.89 + 1.89 + 1.89}{4} = 1.89$$

The minimum slab thickness is determined using the following formula:

$$0.2 < \alpha_{fm} < 2 \Rightarrow h_{min} = \frac{l_n (0.8 + \frac{f_y}{200000})}{36 + 5\beta(\alpha_{fm} - 0.2)} \geq 0.127 \text{ m}$$

$$\alpha_{fm} > 2 \Rightarrow h_{min} = \frac{l_n (0.8 + \frac{f_y}{200000})}{36 + 9\beta} \geq 0.0889 \text{ m}$$

$$\beta = \frac{L_{yn}}{L_{xn}} = \frac{6}{6} = 1$$

$$L_n = \max[L_{yn}, L_{xn}] = \max[6, 6] = 6 \text{ m}$$

$$l_n = L_n - \frac{b_{major}}{2} \cdot 2 = 6 - 0.3 \cdot 2 = 5.4 \text{ m}$$

$$h_{min} = \frac{5.4 \cdot (0.8 + \frac{60000 \text{ psi}}{200000})}{36 + 5 \cdot 1 \cdot (1.89 - 0.2)} = 0.1485 \text{ m} \approx 0.150 \text{ m} \geq 0.127 \text{ m}$$

Three iterations were performed, results are shown in the following table:

Table 3.20. Slab thickness

| Iteration | Height of the slab, m | Slab moment of inertia, m <sup>4</sup> | $\alpha_{f1}$ | $\alpha_{fm}$ | $h_{min}$ , m |
|-----------|-----------------------|----------------------------------------|---------------|---------------|---------------|
| 1         | 0.2                   | 0.001                                  | 1.89          | 1.89          | 0.148         |
| 2         | 0.148                 | 0.000409                               | 4.62          | 4.62          | 0.147         |
| 3         | 0.147                 | 0.000394                               | 4.79          | 4.79          | 0.147         |

The final result was rounded to 150 mm. Thus, the design volumes are:

$$V_{beam} = 6 \cdot 0.6 \cdot 0.3 \cdot 4 = 4.32 \text{ m}^3$$

$$V_{slab} = 6 \cdot 6 \cdot 0.15 = 5.40 \text{ m}^3$$

$$V_{total} = 4.32 + 5.40 = 9.72 \text{ m}^3$$

### Two-way slab with major and minor beams:

The same procedure is applied to this design. The thickness of the major beam is assumed to be 10% of the span, and the thickness of the simply supported minor beam is taken as  $\frac{l}{16}$ .

$$h_{major} = L \cdot 10\% = 6 \cdot 10\% = 0.6 \text{ m}$$

$$b_{major} = \frac{0.6}{2} = 0.3 \text{ m}$$

$$h_{minor} = \frac{L}{16} = \frac{6}{16} = 0.375 \text{ m}$$

$$b_{minor} = \frac{0.375}{2} = 0.188 \text{ m}$$

Then, the moment of inertia and stiffness ratio were calculated as follows:

$$I_{b,major} = \frac{0.35}{12} \cdot 0.6^3 \cdot 0.3 = 0.00189 \text{ mm}^4$$

$$I_{b,minor} = \frac{0.35}{12} \cdot 0.375^3 \cdot 0.188 = 0.000288 \text{ mm}^4$$

$$\text{Assumption: } h_{slab} = 0.2 \text{ m}$$

$$I_{slab} = \frac{0.25}{12} \cdot 0.2^3 \cdot 3 = 0.0005 \text{ mm}^4$$

$$\alpha_{f,major} = 3.78 \quad \text{and} \quad \alpha_{f,minor} = 0.577$$

$$\alpha_{fm} = \frac{\alpha_{f,major} + \alpha_{f,minor}}{2} = 2.178 > 2$$

The ratio of the span in the longitudinal direction to the span in the transverse direction of the slab is:

$$\beta = \frac{L_{yn}}{L_{xn}} = \frac{3 \text{ m}}{3 \text{ m}} = 1$$

The minimum thickness of slab is calculated as follows:

$$l_n = L - \frac{b_{major}}{2} - \frac{b_{minor}}{2} = 6 - 0.3 - 0.188 = 2.512 \text{ m}$$

$$h = \frac{l_n(0.8 + \frac{f_y}{200000})}{36 + 9\beta} = \frac{2.512(0.8 + \frac{60000 \text{ psi}}{200000})}{36 + 9 \cdot 1} = 0.0719 \text{ m} < 0.09 \text{ m}$$

Since the calculated thickness is less than the minimum of 0.09 m, it was rounded to 1 m. The volumes are presented below:

$$V_{b,major} = 6 \cdot 0.6 \cdot 0.3 \cdot 4 = 4.32 \text{ m}^3$$

$$V_{b,minor} = 6 \cdot 0.375 \cdot 0.188 \cdot 2 = 0.844 \text{ m}^3$$

$$V_{slab} = 3 \cdot 3 \cdot 0.1 \cdot 4 = 3.6 \text{ m}^3$$

$$V_{total} = 4.32 + 0.844 + 3.6 = 8.764 \text{ m}^3$$

### **One-way slab with major and minor beams:**

This design type has equivalent major beam and minor beam dimensions as calculated in the previous section. As for slab thickness, it is taken as  $\frac{l}{16}$  according to ACI 318-11.

$$h_{major} = 0.6 \text{ m}, b_{major} = 0.3 \text{ m}$$

$$h_{minor} = 0.375 \text{ m}, b_{minor} = 0.188 \text{ m}$$

$$h_{slab} = \frac{3}{16} = 0.15 \text{ m}$$

The volumes of structural members are calculated below:

$$V_{b,major} = 6 \cdot 0.6 \cdot 0.3 \cdot 4 = 4.32 \text{ m}^3$$

$$V_{b,minor} = 6 \cdot 0.375 \cdot 0.188 = 0.422 \text{ m}^3$$

$$V_{slab} = 3 \cdot 6 \cdot 0.15 \cdot 2 = 5.4 \text{ m}^3$$

$$V_{total} = 4.32 + 0.422 + 5.4 = 10.14 \text{ m}^3$$

Overall, three structural layout options were analyzed. Two-way slab with minor beams appeared to be most economical based on the volume. However, this design requires more formwork and labor work due to its complexity, which causes additional expenses. Given that the difference in volume between a two-way slab with major beams and with minor beams is little, the second option was chosen because of its simplicity and less construction time. Below the final structural layout is illustrated:

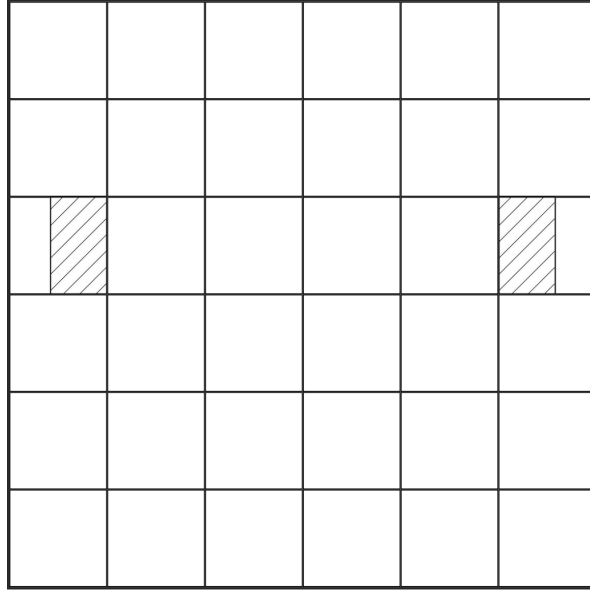


Figure 3.11. The structural layout of the building

### 3.3.4.2. Calculation of size dimensions of columns

The dimensions of the columns were calculated based on the axial loads on the columns, and these dimensions were changed every three floors. The basic formula for calculating the columns was based on equating the factored axial demand and nominal capacity with safety factors:

$$P_u = \phi P_n = \phi r(0.85f'_c A_c + f_y A_{st}) \quad (3.12)$$

where:

$$\phi = 0.65 \text{ for tied columns}$$

$$r = 0.8 \text{ for tied columns}$$

$$f'_c = 40 \text{ MPa for concrete}$$

$$f_y = 420 \text{ MPa for reinforcing steel}$$

The steel reinforcement ratio,  $\rho$ , was taken as 1% of the gross concrete area as a standard:

$$A_{st} = A_g \cdot 0.01$$

Rearrangement of the formula gives:

$$A_g = \frac{P_u}{0.8 \times \phi \times (0.99 \times \beta \times f'_c + 0.01 \times f)}$$

$$b_{column} = \sqrt{A_g}$$

The factored axial load applied to the columns was calculated using the following load combination:

$$P_u = \phi \cdot P_n = 1.2D + 1.6L + 0.5L_r \quad (3.13)$$

The tributary reaction force was calculated as:

$$R = A_T \cdot P_u \quad (3.14)$$

The self-weight of the column was added to the axial load and was calculated with the following formula:

$$W_1 = B^2 \cdot H \cdot \rho \quad (3.15)$$

where the density of the concrete,  $\rho$ , equals 25 kN/m<sup>3</sup>.

The calculation of the self-weight of major beams carried by each column is shown below:

$$W_{beam} = h_{beam} \cdot b_{beam} \cdot L_{beam} \cdot \rho_{conc} = 0.3 \times 0.6 \times 6 \times 25 = 27 \text{ kN}$$

$$\text{Weight exerted on interior columns} = 4 \cdot W_b/2 = 54 \text{ kN}$$

$$\text{Weight exerted on exterior columns} = 3 \cdot W_b/2 = 40.5 \text{ kN}$$

$$\text{Weight exerted on corner columns} = 2 \cdot W_b/2 = 27 \text{ kN}$$

The weight of exterior walls or parapets supported by columns is equal to the linear load multiplied by the length of the span:

$$W_{exterior, 1st} = 25.824 \cdot 6 = 154.94 \text{ kN}$$

$$W_{exterior, typ} = 22.596 \cdot 6 = 135.58 \text{ kN}$$

$$W_{parapets} = 6.896 \cdot 6 = 42.61 \text{ kN}$$

Table 3.21. Reaction force on interior columns calculations

|            | DL, kN/m <sup>2</sup> | RL, kN/m <sup>2</sup> | LL, kN/m <sup>2</sup> | SL, kN/m <sup>2</sup> | A <sub>T</sub> , m <sup>2</sup> | P <sub>u</sub> , kN/m <sup>2</sup> | R, kN  |
|------------|-----------------------|-----------------------|-----------------------|-----------------------|---------------------------------|------------------------------------|--------|
| Floor 0    | 6.329                 | 0                     | 3.022                 | 0                     | 36                              | 12.43                              | 547.45 |
| Floor 1-11 | 6.329                 | 0                     | 3.022                 | 0                     | 36                              | 12.43                              | 537.61 |
| Floor 12   | 4.854                 | 0.772                 | 0                     | 1.219                 | 36                              | 7.67                               | 379.53 |

Table 3.22. Reaction force on interior column calculations including self-weight of a beam

| Self-weight | $W_{\text{beam}}$ , kN | $1.2W_{\text{beam}}$ , kN | $R_{\text{total}}$ , kN |
|-------------|------------------------|---------------------------|-------------------------|
| Floor 0     | 54                     | 64.8                      | 612.3                   |
| Floor 1-11  | 54                     | 64.8                      | 602.4                   |
| Floor 12    | 27                     | 32.4                      | 411.9                   |

Table 3.23. Reaction force on exterior columns calculations

|            | DL, kN/m <sup>2</sup> | RL, kN/m <sup>2</sup> | LL, kN/m <sup>2</sup> | SL, kN/m <sup>2</sup> | $A_T$ , m <sup>2</sup> | $P_u$ , kN/m <sup>2</sup> | R, kN  |
|------------|-----------------------|-----------------------|-----------------------|-----------------------|------------------------|---------------------------|--------|
| Floor 0    | 6.329                 | 0                     | 3.777                 | 0                     | 18                     | 13.64                     | 345.49 |
| Floor 1-11 | 6.101                 | 0                     | 3.777                 | 0                     | 18                     | 13.36                     | 340.57 |
| Floor 12   | 6.101                 | 0.960                 | 0                     | 1.409                 | 18                     | 8.03                      | 217.54 |

Table 3.24. Reaction force on exterior column calculations including self-weight of a beam

| Self-weight | $W_{\text{beam}}$ , kN | $1.2W_{\text{beam}}$ , kN | $W_{\text{exterior / parapet}}$ , kN | $1.2W_{\text{exterior / parapet}}$ , kN | $R_{\text{total}}$ , kN |
|-------------|------------------------|---------------------------|--------------------------------------|-----------------------------------------|-------------------------|
| Floor 0     | 40.5                   | 48.6                      | 154.94                               | 185.93                                  | 575.10                  |
| Floor 1-11  | 40.5                   | 48.6                      | 135.58                               | 162.69                                  | 551.86                  |
| Floor 12    | 40.5                   | 48.6                      | 42.61                                | 51.13                                   | 268.67                  |

Table 3.25. Reaction force on corner columns calculations

|            | DL, kN/m <sup>2</sup> | RL, kN/m <sup>2</sup> | LL, kN/m <sup>2</sup> | SL, kN/m <sup>2</sup> | $A_T$ , m <sup>2</sup> | $P_u$ , kN/m <sup>2</sup> | R, kN  |
|------------|-----------------------|-----------------------|-----------------------|-----------------------|------------------------|---------------------------|--------|
| Floor 0    | 6.329                 | 0                     | 4.79                  | 0                     | 9                      | 15.26                     | 237.33 |
| Floor 1-11 | 6.101                 | 0                     | 4.79                  | 0                     | 9                      | 14.99                     | 234.87 |
| Floor 12   | 4.854                 | 0.96                  | 0                     | 1.41                  | 9                      | 6.53                      | 158.77 |
| Floor 13   | 4.854                 | 0.96                  | 0                     | 1.41                  | 5.25                   | 6.53                      | 134.28 |



Table 3.26. Reaction force on corner column calculations including self-weight of a beam

| Self-weight | $W_{\text{beam}}$ , kN | $1.2W_{\text{beam}}$ , kN | $W_{\text{exterior / parapet}}$ , kN | $1.2W_{\text{exterior / parapet}}$ , kN | $R_{\text{total}}$ , kN |
|-------------|------------------------|---------------------------|--------------------------------------|-----------------------------------------|-------------------------|
| Floor 0     | 27                     | 32.4                      | 154.94                               | 185.93                                  | 453.20                  |
| Floor 1-11  | 27                     | 32.4                      | 135.58                               | 162.69                                  | 429.96                  |
| Floor 12    | 27                     | 32.4                      | 42.61                                | 51.13                                   | 209.90                  |
| Floor 13    | 27                     | 32.4                      | 0                                    | 0                                       | 166.68                  |

Table 3.27. Axial forces by floor

| Column location | $P_{u, \text{interior}}$ , kN | $P_{u, \text{exterior}}$ , kN | $P_{u, \text{corner}}$ , kN |
|-----------------|-------------------------------|-------------------------------|-----------------------------|
| Floor 13        | 0                             | 0                             | 166.68                      |
| Floor 12        | 411.93                        | 268.67                        | 209.90                      |
| Floor 11        | 1014.34                       | 820.52                        | 639.86                      |
| Floor 10        | 1616.75                       | 1372.38                       | 1069.81                     |
| Floor 9         | 2219.16                       | 1924.24                       | 1499.77                     |
| Floor 8         | 2821.57                       | 2476.09                       | 1929.73                     |
| Floor 7         | 3423.98                       | 3027.95                       | 2359.68                     |
| Floor 6         | 4026.39                       | 3579.81                       | 2789.64                     |
| Floor 5         | 4628.80                       | 4131.67                       | 3219.59                     |
| Floor 4         | 5231.21                       | 4683.52                       | 3649.55                     |
| Floor 3         | 5833.62                       | 5235.38                       | 4079.51                     |
| Floor 2         | 6436.03                       | 5787.24                       | 4509.46                     |
| Floor 1         | 7038.45                       | 6339.09                       | 4939.42                     |
| Floor 0         | 9058.87                       | 6914.19                       | 5392.62                     |

Table 3.28. Iterations of interior column size calculations

|                            |
|----------------------------|
| Dimensions for columns 0-1 |
|----------------------------|

| Iteration                    | b, mm  | h, mm | W <sub>1</sub> , kN | P <sub>u</sub> +W <sub>1</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
|------------------------------|--------|-------|---------------------|-------------------------------------|---------------------------------|--------|-------------|
| 1                            | 700    | 4000  | 67.50               | 9164.17                             | 465488.81                       | 682.27 | 700         |
| 2                            | 682.3  | 4000  | 55.86               | 9114.73                             | 462977.47                       | 680.42 |             |
| 3                            | 680.4  | 4000  | 55.56               | 9114.43                             | 462962.16                       | 680.41 |             |
| Dimensions for columns 2-4   |        |       |                     |                                     |                                 |        |             |
| Iteration                    | b, mm  | h, mm | W <sub>1</sub> , kN | P <sub>u</sub> +W <sub>1</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 650    | 3500  | 44.36               | 6506.65                             | 330501.40                       | 574.89 | 600         |
| 2                            | 574.9  | 3500  | 34.70               | 6506.65                             | 330501.40                       | 574.89 |             |
| 3                            | 574.9  | 3500  | 34.70               | 6506.65                             | 330501.40                       | 574.89 |             |
| Dimensions for columns 5-7   |        |       |                     |                                     |                                 |        |             |
| Iteration                    | b, mm  | h, mm | W <sub>1</sub> , kN | P <sub>u</sub> +W <sub>1</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 500    | 3500  | 26.25               | 4671.85                             | 237304.10                       | 487.14 | 500         |
| 2                            | 487.14 | 3500  | 24.92               | 4671.85                             | 237304.10                       | 487.14 |             |
| 3                            | 487.14 | 3500  | 24.92               | 4671.85                             | 237304.10                       | 487.14 |             |
| Dimensions for columns 8-10  |        |       |                     |                                     |                                 |        |             |
| Iteration                    | b, mm  | h, mm | W <sub>1</sub> , kN | P <sub>u</sub> +W <sub>1</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 400    | 3500  | 16.80               | 2851.23                             | 144826.81                       | 380.56 | 400         |
| 2                            | 380.56 | 3500  | 15.21               | 2851.23                             | 144826.81                       | 380.56 |             |
| 3                            | 380.56 | 3500  | 15.21               | 2851.23                             | 144826.81                       | 380.56 |             |
| Dimensions for columns 11-12 |        |       |                     |                                     |                                 |        |             |
| Iteration                    | b, mm  | h, mm | W <sub>1</sub> , kN | P <sub>u</sub> +W <sub>1</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 400    | 3500  | 16.80               | 1210.14                             | 92202.57                        | 303.65 | 350         |
| 2                            | 303.65 | 3500  | 9.68                | 1203.02                             | 91660.18                        | 302.75 |             |
| 3                            | 302.75 | 3500  | 9.62                | 1202.96                             | 91655.84                        | 302.75 |             |

Table 3.29. Iterations of exterior column size calculations

| Dimensions for columns 0-1   |        |       |                     |                                     |                                 |        |             |
|------------------------------|--------|-------|---------------------|-------------------------------------|---------------------------------|--------|-------------|
| Iteration                    | b, mm  | h, mm | W <sub>l</sub> , kN | P <sub>u</sub> +W <sub>l</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 600    | 4000  | 43.20               | 6957.39                             | 353396.68                       | 594.47 | 600         |
| 2                            | 594.47 | 4000  | 42.41               | 6956.60                             | 353356.44                       | 594.44 |             |
| 3                            | 594.44 | 4000  | 42.40               | 6956.59                             | 353356.19                       | 594.44 |             |
| Dimensions for columns 2-4   |        |       |                     |                                     |                                 |        |             |
| Iteration                    | b, mm  | h, mm | W <sub>l</sub> , kN | P <sub>u</sub> +W <sub>l</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 550    | 3500  | 31.76               | 5819.00                             | 295572.68                       | 543.67 | 550         |
| 2                            | 543.67 | 3500  | 31.04               | 5818.27                             | 295535.73                       | 543.63 |             |
| 3                            | 543.63 | 3500  | 31.03               | 5818.27                             | 295535.54                       | 543.63 |             |
| Dimensions for columns 5-7   |        |       |                     |                                     |                                 |        |             |
| Iteration                    | b, mm  | h, mm | W <sub>l</sub> , kN | P <sub>u</sub> +W <sub>l</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 500    | 3500  | 26.25               | 4157.92                             | 211198.92                       | 459.56 | 500         |
| 2                            | 459.56 | 3500  | 22.18               | 4153.84                             | 210991.98                       | 459.34 |             |
| 3                            | 459.34 | 3500  | 22.15               | 4153.82                             | 210990.87                       | 459.34 |             |
| Dimensions for columns 8-10  |        |       |                     |                                     |                                 |        |             |
| Iteration                    | b, mm  | h, mm | W <sub>l</sub> , kN | P <sub>u</sub> +W <sub>l</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 300    | 3500  | 9.45                | 2485.54                             | 126251.81                       | 355.32 | 400         |
| 2                            | 355.32 | 3500  | 13.26               | 2489.35                             | 126445.16                       | 355.59 |             |
| 3                            | 355.59 | 3500  | 13.28               | 2489.37                             | 126446.19                       | 355.59 |             |
| Dimensions for columns 11-12 |        |       |                     |                                     |                                 |        |             |
| Iteration                    | b, mm  | h, mm | W <sub>l</sub> , kN | P <sub>u</sub> +W <sub>l</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 300    | 3500  | 9.45                | 1008.97                             | 76875.38                        | 277.26 | 300         |
| 2                            | 277.26 | 3500  | 8.07                | 1007.60                             | 76770.38                        | 277.07 |             |
| 3                            | 277.07 | 3500  | 8.06                | 1007.58                             | 76769.54                        | 277.07 |             |

Table 3.30. Iterations of corner column size calculations

| Dimensions for columns 0-1   |        |       |                     |                                     |                                 |        |             |
|------------------------------|--------|-------|---------------------|-------------------------------------|---------------------------------|--------|-------------|
| Iteration                    | b, mm  | h, mm | W <sub>l</sub> , kN | P <sub>u</sub> +W <sub>l</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 600    | 4000  | 43.20               | 5435.82                             | 276109.27                       | 525.46 | 550         |
| 2                            | 525.46 | 4000  | 33.13               | 5425.75                             | 275597.93                       | 524.97 |             |
| 3                            | 524.97 | 4000  | 33.07               | 5425.69                             | 275594.81                       | 524.97 |             |
| Dimensions for columns 2-4   |        |       |                     |                                     |                                 |        |             |
| Iteration                    | b, mm  | h, mm | W <sub>l</sub> , kN | P <sub>u</sub> +W <sub>l</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 550    | 3500  | 31.76               | 4541.23                             | 230668.99                       | 480.28 | 500         |
| 2                            | 480.28 | 3500  | 24.22               | 4533.68                             | 230285.88                       | 479.88 |             |
| 3                            | 479.88 | 3500  | 24.18               | 4533.64                             | 230283.84                       | 479.88 |             |
| Dimensions for columns 5-7   |        |       |                     |                                     |                                 |        |             |
| Iteration                    | b, mm  | h, mm | W <sub>l</sub> , kN | P <sub>u</sub> +W <sub>l</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 500    | 3500  | 26.25               | 3245.84                             | 164870.81                       | 406.04 | 450         |
| 2                            | 406.04 | 3500  | 17.31               | 3236.91                             | 164416.78                       | 405.48 |             |
| 3                            | 405.48 | 3500  | 17.26               | 3236.86                             | 164414.36                       | 405.48 |             |
| Dimensions for columns 8-10  |        |       |                     |                                     |                                 |        |             |
| Iteration                    | b, mm  | h, mm | W <sub>l</sub> , kN | P <sub>u</sub> +W <sub>l</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 300    | 3500  | 9.45                | 1939.18                             | 98499.28                        | 313.85 | 350         |
| 2                            | 313.85 | 3500  | 10.34               | 1940.07                             | 98544.61                        | 313.92 |             |
| 3                            | 313.92 | 3500  | 10.35               | 1940.07                             | 98544.86                        | 313.92 |             |
| Dimensions for columns 11-13 |        |       |                     |                                     |                                 |        |             |
| Iteration                    | b, mm  | h, mm | W <sub>l</sub> , kN | P <sub>u</sub> +W <sub>l</sub> , kN | A <sub>g</sub> , m <sup>2</sup> | b, mm  | Final b, mm |
| 1                            | 300    | 3500  | 9.45                | 828.31                              | 63109.96                        | 251.22 | 300         |
| 2                            | 251.22 | 3500  | 6.63                | 825.48                              | 62894.84                        | 250.79 |             |
| 3                            | 250.79 | 3500  | 6.60                | 825.46                              | 62893.12                        | 250.79 |             |

Since the dimensions of the interior columns are the most critical, they will be distributed across the floors. Thus, the final dimensions of the columns by floor are shown in the following table:

Table 3.31. Final column dimensions

| Floor | Column size, mm |
|-------|-----------------|
| 11-13 | 350             |
| 8-10  | 400             |
| 5-7   | 500             |
| 2-4   | 600             |
| 0-1   | 700             |

### 3.3.5 Assigning Gravity Forces to the SAP 2000 model

The dead, floor live, roof live, and snow loads were assigned into the SAP2000 model with the corresponding structural member dimensions. All the results will be outputted for Frame 2 as shown in the figure below:

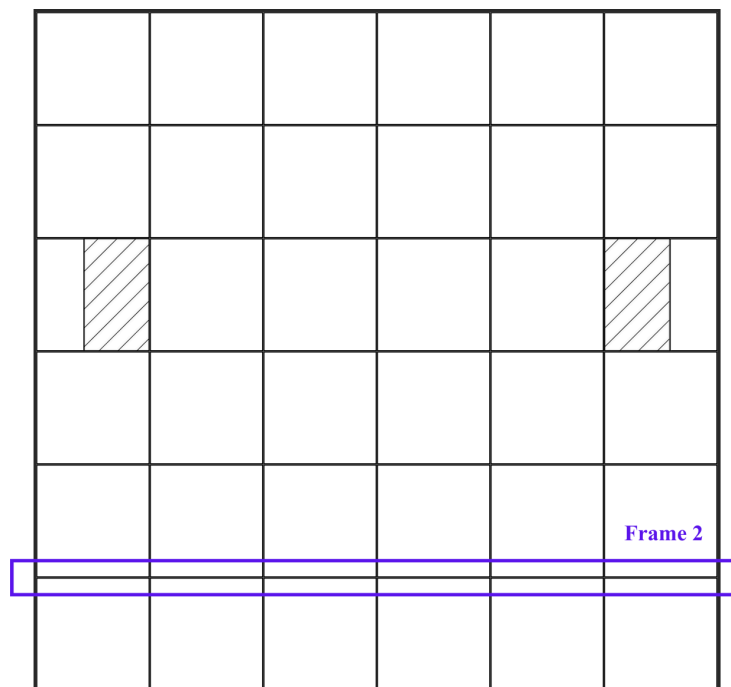


Figure 3.12. Chosen Frame for Load Assignment

Figure 3.13 below shows the material properties of concrete and reinforcing steel inputted into SAP 2000. These parameters exactly match with values used in calculations.

Figure 3.13. Material Property Data

The following joint restraint parameters were utilized in SAP2000. For the bottom joints, a fixed boundary condition was applied, whereas pinned conditions were assigned for edge joints above the ground.

Figure 3.14. Joint Restraints

As stated previously, the moment of inertia modifiers were applied to elements for cracking consideration, as shown below:

- Columns - 0.7
- Beams - 0.35
- Slab - 0.25

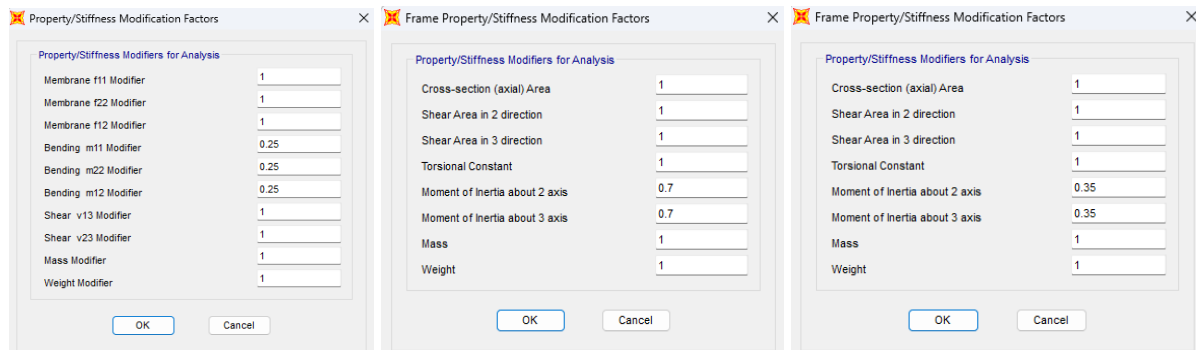


Figure 3.15. Modification factors

All slabs were created with a shell type and a two-way configuration as shown For modelling the columns and beams, the frame element type was used. Joints were assigned to be rigid. Diaphragm constraint was applied to each floor to make floor movement rigid under lateral loads.

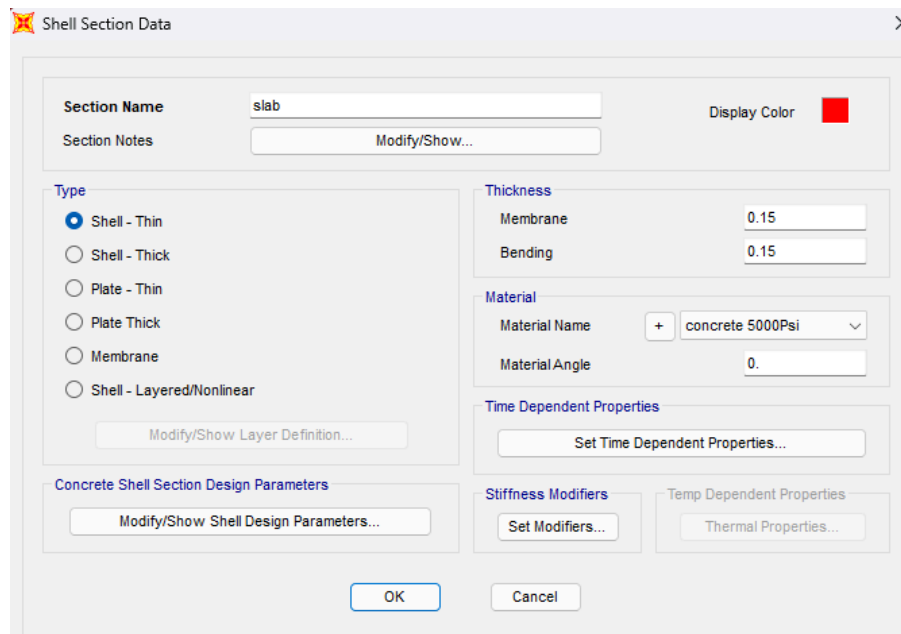


Figure 3.16. Slab section properties

**Rectangular Section**

Section Name: beam 600x300      Display Color: ■

Section Notes: [Modify/Show Notes...](#)

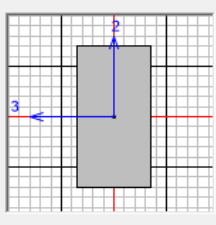
---

**Dimensions**

Depth (t3): 0.6

Width (t2): 0.3

**Section**



**Material**

+ concrete 5000Psi

**Property Modifiers**

[Set Modifiers...](#)

[Section Properties...](#)

[Time Dependent Properties...](#)

[Concrete Reinforcement...](#)

[OK](#)   [Cancel](#)

Figure 3.17. Beam section properties

**Rectangular Section**

Section Name: 600x600      Display Color: ■

Section Notes: [Modify/Show Notes...](#)

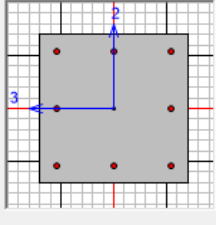
---

**Dimensions**

Depth (t3): 0.6

Width (t2): 0.6

**Section**



**Material**

+ concrete 5000Psi

**Property Modifiers**

[Set Modifiers...](#)

[Section Properties...](#)

[Time Dependent Properties...](#)

[Concrete Reinforcement...](#)

[OK](#)   [Cancel](#)

Figure 3.18. Critical column section properties



The calculated values of dead load, floor live load, roof live load, and snow load were used to estimate the applied distributed load in the SAP2000 model. Below are three calculations for each load type.

$$\text{Distributed Dead Load} = 4.85 * 6 = 29.10 \text{ kN/m}$$

$$\text{Distributed Live Load} = 4.79 * 6 = 28.74 \text{ kN/m}$$

$$\text{Distributed Roof Live Load} = 0.96 * 6 = 5.76 \text{ kN/m}$$

$$\text{Distributed Snow Load} = 1.44 * 6 = 8.64 \text{ kN/m}$$

The load assignments for dead, floor live, roof live, and snow loads in both 2D and 3D are presented below. The distributed loads were assigned on slabs, whereas line loads, representing exterior walls and parapets, were assigned on exterior beams.

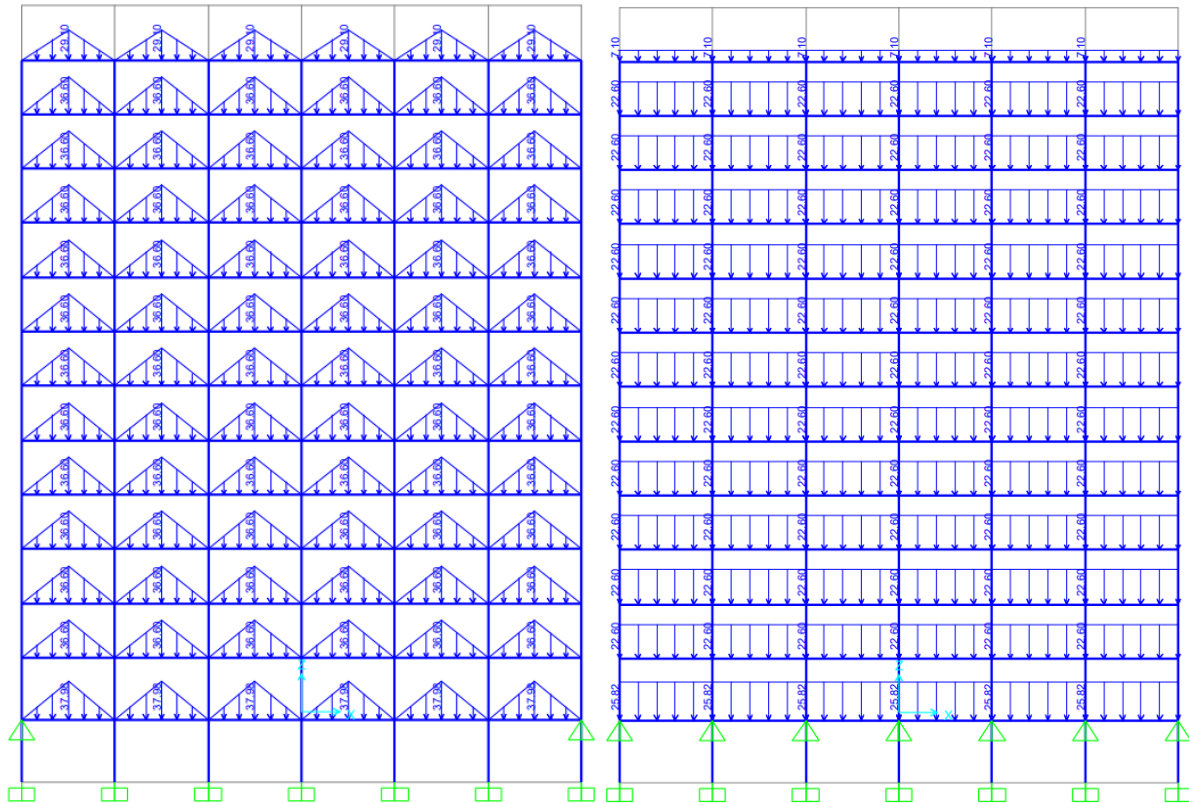


Figure 3.19. 2D Dead Load Assignment on slabs and beams

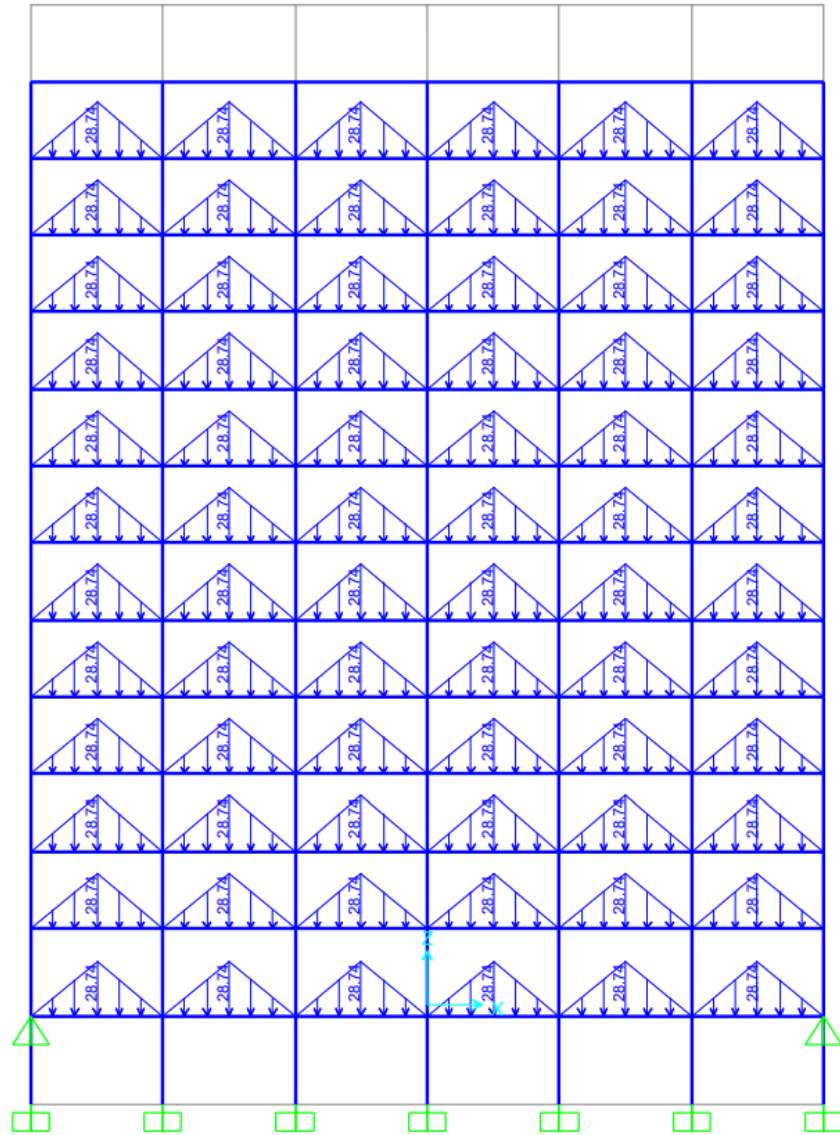


Figure 3.20. 2D Floor Live Load Assignment

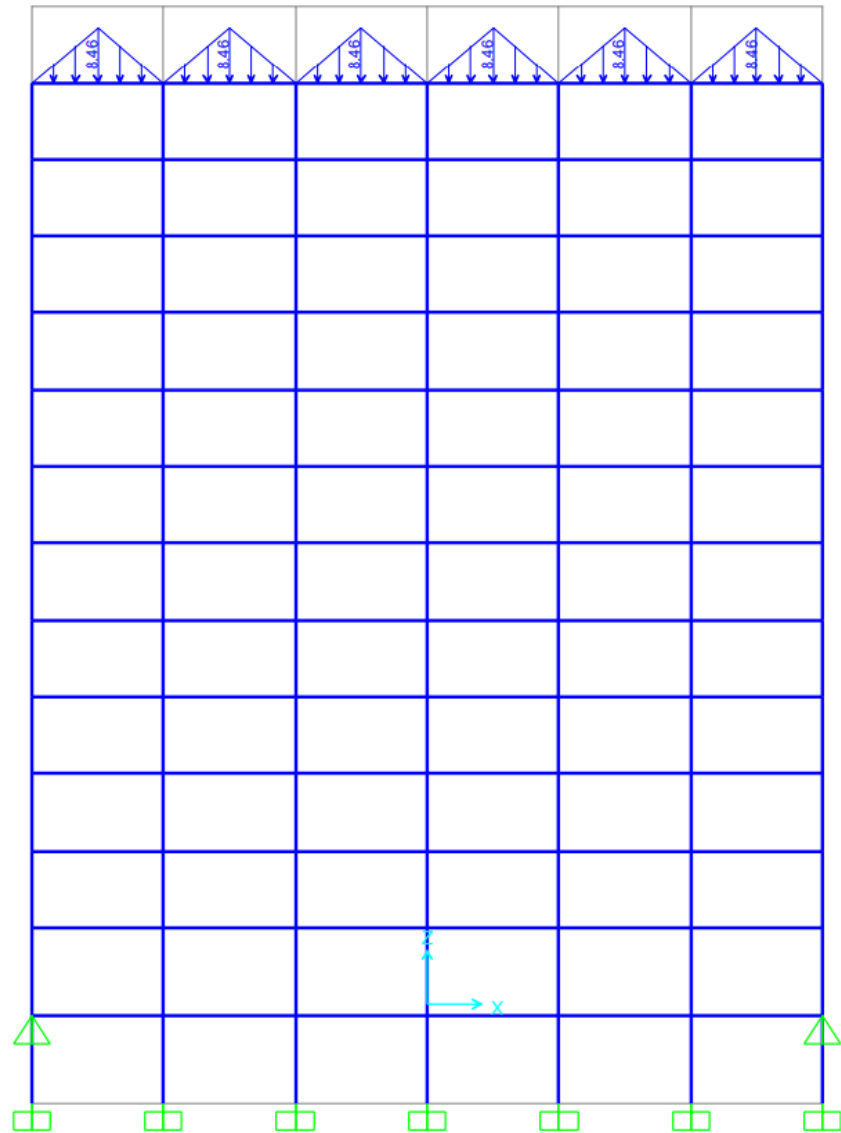


Figure 3.21. 2D Snow Load Assignment

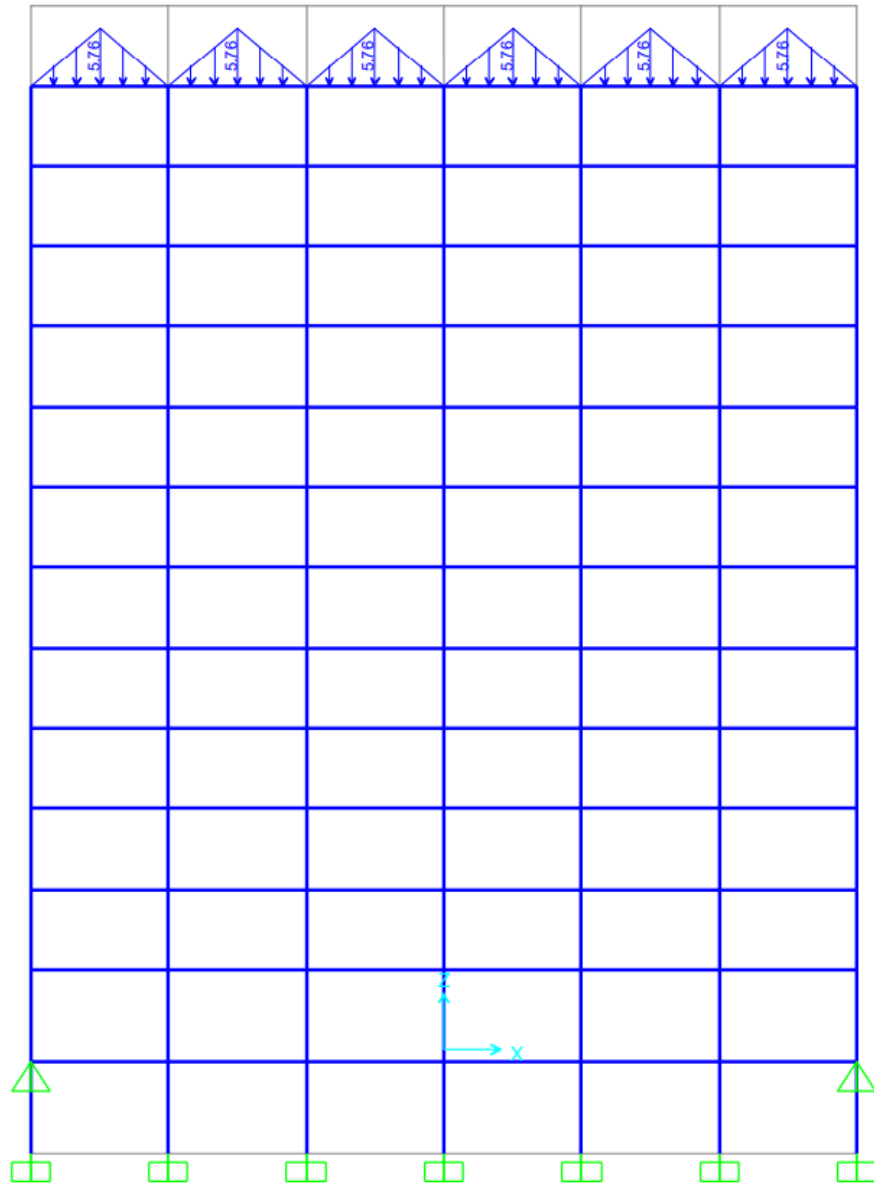


Figure 3.22. 2D Roof Live Load Assignment

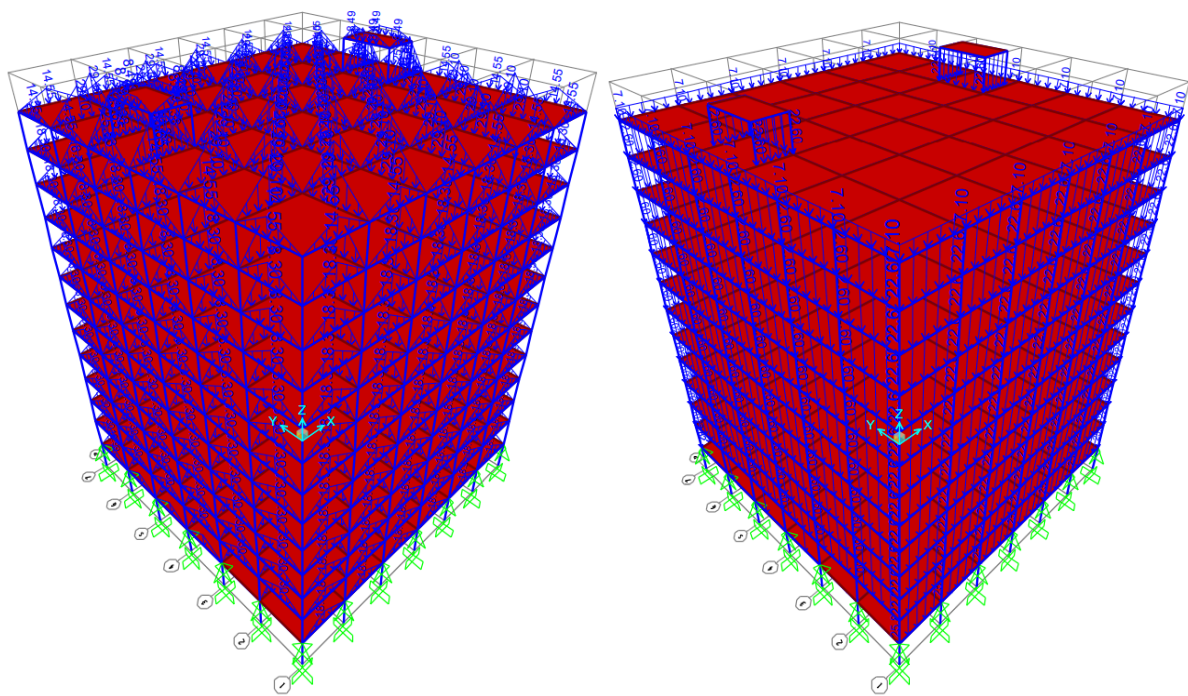


Figure 3.23. 3D Dead Load Assignment

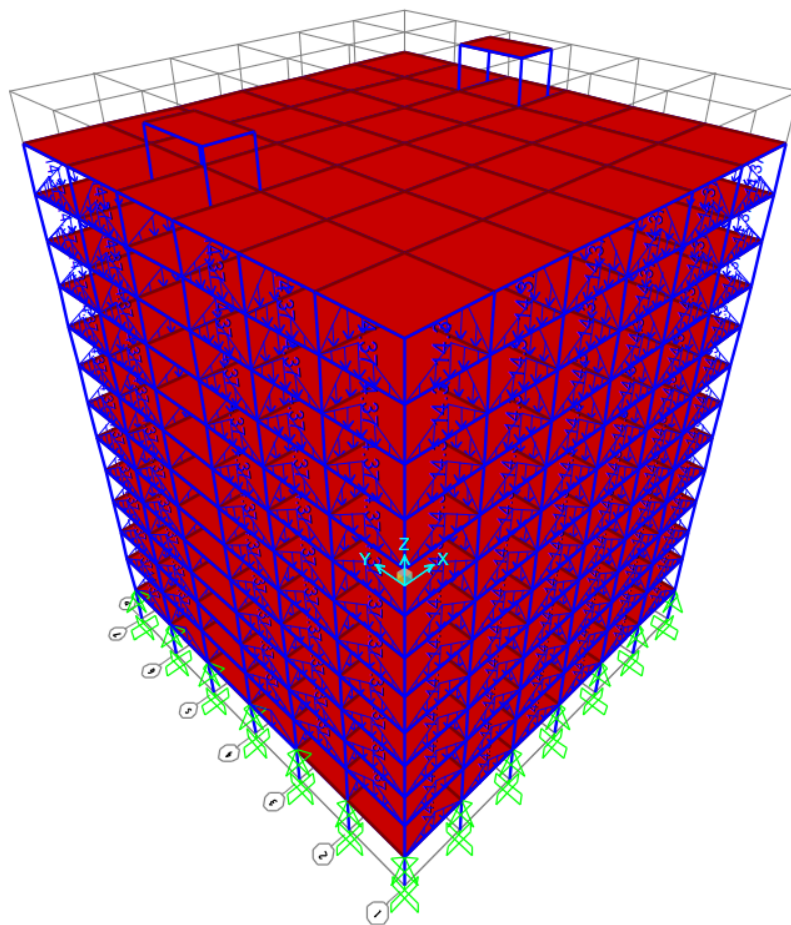


Figure 3.24. 3D Floor Live Load Assignment

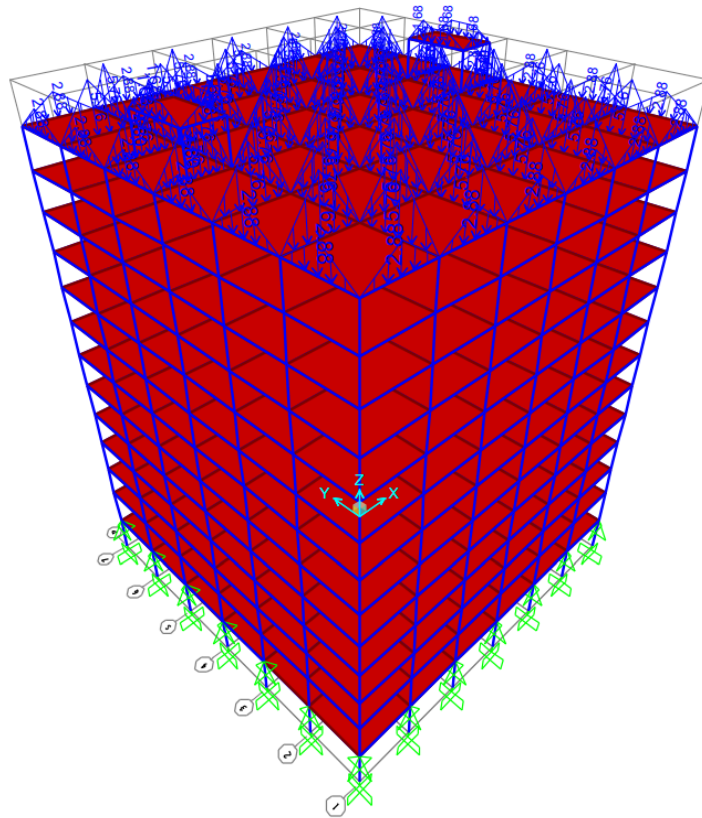


Figure 3.25. 3D Roof Live Load Assignment

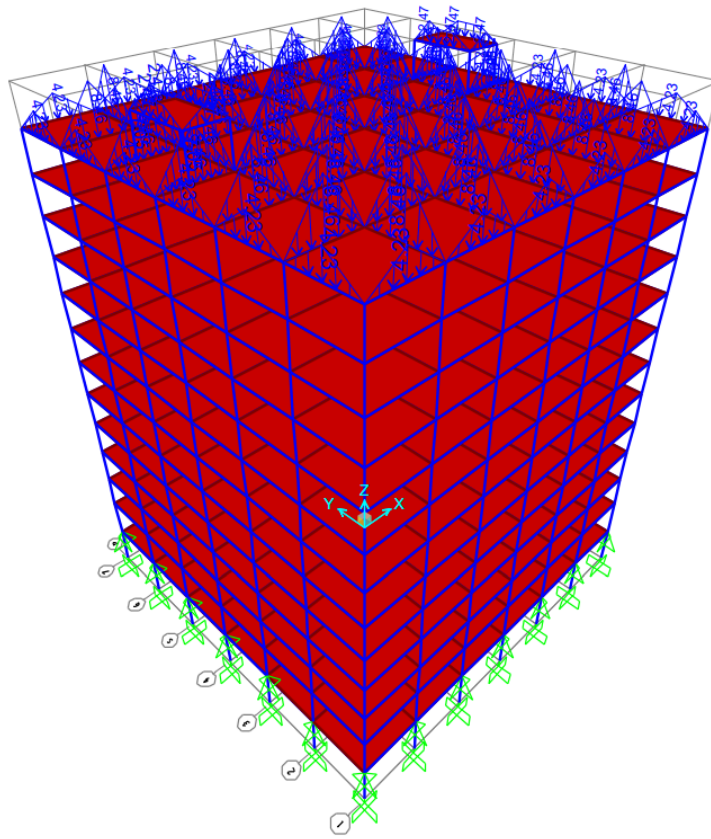


Figure 3.26. 3D Snow Load Assignment

### 3.4 Analysis and Design of Lateral Force Resisting System (LFRS)

#### 3.4.1 Wind load calculation

Risk category II was selected for the office building, and the importance factor I was taken as 1.0. At Woz Way & S Almaden Blvd, San Jose, USA, the wind speed used for calculations is  $v = 41$  m/s for a 700-year return period, according to the ASCE 7-22 Hazard Tool (2025). Knowing that the office is located in an urban area and being situated in the center of the city, the surface roughness B prevails in the upwind direction for a distance greater than 792 m, thus the constants for surface roughness B were used in the calculations.

Table 3.32. Constants for wind load calculations

| Exposure | $\alpha$ | $z_g$ , m | $\hat{a}$ | $\hat{b}$ | $\bar{\alpha}$ | $\bar{b}$ | c   | $l$ , m | $\bar{\epsilon}$ | $z_{min}$ , m |
|----------|----------|-----------|-----------|-----------|----------------|-----------|-----|---------|------------------|---------------|
| B        | 7        | 365.76    | 1/7       | 0.84      | 0.25           | 0.45      | 0.3 | 97.54   | 1/3              | 9.14          |

Since the site area is fully flat, the topographical effect,  $K_{zt}$ , is taken as 1.0. For the main wind load resisting system, the direction effect is  $K_d = 0.85$ .

The coefficient for wind pressure variation for different elevations is calculated using the following formula:

$$z \leq 4.572 \text{ m} \Rightarrow K_z = 2.01 \left( \frac{4.572}{z_g} \right)^{2/\alpha} \quad (3.16)$$

$$4.572 \leq z \leq z_g \Rightarrow K_z = 2.01 \left( \frac{z}{z_g} \right)^{2/\alpha} \quad (3.17)$$

Table 3.33. Height effect calculation

| Floor # | z, m | $K_z$ , m |
|---------|------|-----------|
| 1       | 4.0  | 0.5747    |
| 2       | 7.5  | 0.6620    |
| 3       | 11.0 | 0.7386    |
| 4       | 14.5 | 0.7992    |
| 5       | 18.0 | 0.8502    |
| 6       | 21.5 | 0.8944    |

|    |      |        |
|----|------|--------|
| 7  | 25.0 | 0.9338 |
| 8  | 28.5 | 0.9694 |
| 9  | 32.0 | 1.0021 |
| 10 | 35.5 | 1.0322 |
| 11 | 39.0 | 1.0603 |
| 12 | 42.5 | 1.0867 |
| 13 | 46.0 | 1.1115 |

To calculate the wind pressure on windward and leeward sides, the following formulas were used:

$$q_z = 0.613v^2 K_d K_z K_{zt} \quad (3.18)$$

$$q_h = 0.613v^2 K_d K_h K_{ht} \quad (3.19)$$

Table 3.34. Velocity pressure by floor level

| Floor # | $q_z$ , kPa | $q_h$ , kPa |
|---------|-------------|-------------|
| 1       | 0.5034      | 0.9736      |
| 2       | 0.5799      | 0.9736      |
| 3       | 0.6469      | 0.9736      |
| 4       | 0.7000      | 0.9736      |
| 5       | 0.7446      | 0.9736      |
| 6       | 0.7834      | 0.9736      |
| 7       | 0.8179      | 0.9736      |
| 8       | 0.8491      | 0.9736      |
| 9       | 0.8777      | 0.9736      |
| 10      | 0.9041      | 0.9736      |
| 11      | 0.9287      | 0.9736      |
| 12      | 0.9518      | 0.9736      |



|    |        |        |
|----|--------|--------|
| 13 | 0.9736 | 0.9736 |
|----|--------|--------|

The Gust effect for wind in the y-direction was calculated in the following way:

$$n_a = \frac{43.5}{H^{0.9}} = \frac{43.5}{(46 \times 3.28)^{0.9}} = 0.4761 < 1$$

$$h = 46 \text{ m} > 18 \text{ m} \Rightarrow \text{flexible structure}$$

$$\bar{z} = 0.6h = 0.6 \cdot 46 = 27.6 > z_{min} = 9.14 \text{ m}$$

$$I_{\bar{z}} = c\left(\frac{10}{\bar{z}}\right)^{\frac{1}{6}} = 0.3\left(\frac{10}{27.6}\right)^{\frac{1}{6}} = 0.2533$$

$$\bar{V}_{\bar{z}} = \bar{b}\left(\frac{\bar{z}}{10}\right)^{\bar{\alpha}} V = 0.45\left(\frac{27.6}{10}\right)^{0.25} \times 41 = 23.78 \text{ m/s}$$

$$n_1 = n_a = 0.4761, \quad L_{\bar{z}} = l\left(\frac{\bar{z}}{10}\right)^{\bar{\epsilon}} = 97.54\left(\frac{27.6}{10}\right)^{0.33} = 136.82 \text{ m}$$

$$N_1 = \frac{n_1 L_{\bar{z}}}{\bar{V}_{\bar{z}}} = \frac{0.4761 \cdot 136.82}{23.78} = 2.7394$$

$$R_n = \frac{7.47 N_1}{(1 + 10.3 N_1)^{5/3}} = \frac{7.47 \cdot 2.7394}{(1 + 10.3 \cdot 2.7394)^{5/3}} = 0.0738$$

$$\eta_h = \frac{4.6 n_1 H}{\bar{V}_{\bar{z}}} = \frac{4.6 \cdot 0.4761 \cdot 46}{23.78} = 4.2366$$

$$R_h = \frac{1}{\eta_h} - \frac{1}{2\eta_h^2} (1 - e^{-2\eta_h}) = 0.2082$$

$$\eta_b = \frac{4.6 n_1 B}{\bar{V}_{\bar{z}}} = \frac{4.6 \cdot 0.4761 \cdot 36}{23.78} = 3.3156 \Rightarrow R_b = 0.2562$$

$$\eta_L = \frac{15.4 n_1 L}{\bar{V}_{\bar{z}}} = \frac{15.4 \cdot 0.4761 \cdot 36}{23.78} = 11.1 \Rightarrow R_L = 0.086$$

$$R = \sqrt{\frac{R_n R_h R_b (0.53 + 0.47 R_L)}{\beta}} = \sqrt{\frac{0.2562 \cdot 0.2082 \cdot 0.0738 \cdot (0.53 + 0.47 \cdot 0.086)}{0.02}} = 0.3351$$

$$g_R = \sqrt{2 \ln(3600 n_1)} + \frac{0.577}{\sqrt{2 \ln(3600 n_1)}} = \sqrt{2 \ln(3600 \cdot 0.4761)} + \frac{0.577}{\sqrt{2 \ln(3600 \cdot 0.4761)}} = 4.0087$$

$$g_v = g_Q = 3.4 \text{ (for flexible buildings)}$$

$$Q = \sqrt{\frac{1}{1 + 0.63 \left(\frac{B+h}{L_{\bar{z}}}\right)^{0.63}}} = \sqrt{\frac{1}{1 + 0.63 \left(\frac{36+46}{136.8209}\right)^{0.63}}} = 0.8287$$

$$G_f = 0.925 \left( \frac{1 + 1.7 I_z \sqrt{g_Q^2 Q^2 + g_R^2 R^2}}{1 + 1.7 g_v I_z} \right) = 0.925 \left( \frac{1 + 1.7 \cdot 0.2533 \sqrt{3.4^2 \cdot 0.8287^2 + 4.0087 \cdot 0.3351^2}}{1 + 1.7 \cdot 3.4 \cdot 0.2533} \right) = 1.4296$$

Only one Gust factor was obtained for the typical floor, since the building has a square shape. Using the same methodology, another gust factor for the building roof was calculated, as it has different L and B values, 6 and 3.5 m, respectively. It was calculated to be  $G_f = 1.5626$  for the roof floor.

Next, external pressure coefficients were obtained from Figure 27.4-1 of ASCE 7-16. It was found that  $C_p^w = 0.8$ ,  $C_p^l = -0.5$  for all floors. However, the design wind pressure for the effect of parapets was determined using  $C_p^w = 1.5$ ,  $C_p^l = -1$  according to ASCE 7-16 Chapter 27.

The wind net pressure was calculated using the following formula:

$$p_w = q_w G_f C_p^w$$

$$p_l = q_l G_f C_p^l$$

$$p_{net} = |p_w| + |p_l| \geq 0.77 \text{ kPa}$$

Table 3.35. Design wind pressure at each floor level

| Floor # | $p_w$ , kPa | $p_l$ , kPa | $p_{net}$ , kPa |
|---------|-------------|-------------|-----------------|
| 1       | 0.5757      | -0.6959     | 1.2716          |
| 2       | 0.6632      | -0.6959     | 1.3591          |
| 3       | 0.7398      | -0.6959     | 1.4357          |
| 4       | 0.8006      | -0.6959     | 1.4965          |
| 5       | 0.8516      | -0.6959     | 1.5475          |
| 6       | 0.8960      | -0.6959     | 1.5919          |
| 7       | 0.9354      | -0.6959     | 1.6313          |
| 8       | 0.9711      | -0.6959     | 1.6670          |
| 9       | 1.0038      | -0.6959     | 1.6997          |
| 10      | 1.0340      | -0.6959     | 1.7299          |
| 11      | 1.0621      | -0.6959     | 1.7580          |
| 12      | 1.0886      | -0.6959     | 1.7845          |

Table 3.36. Design wind pressure at roof

| Y-direction |             |                 | X-direction |             |                 |
|-------------|-------------|-----------------|-------------|-------------|-----------------|
| $p_w$ , kPa | $p_l$ , kPa | $p_{net}$ , kPa | $p_w$ , kPa | $p_l$ , kPa | $p_{net}$ , kPa |
| 1.2170      | -0.7606     | 1.9777          | 1.2170      | -0.7606     | 1.9777          |

Table 3.37. Design wind pressure at parapets

| $p_w$ , kPa | $p_l$ , kPa | $p_{net}$ , kPa |
|-------------|-------------|-----------------|
| 1.4382      | -0.9588     | 2.3970          |

The wind forces at each floor level were calculated using the following formula:

$$F_i = (p_i \frac{h_i}{2} + p_{i-1} \frac{h_{i-1}}{2})B \quad (3.20)$$

$$F_{11} = p_{11} \frac{h_{11}}{2}B \quad (3.21)$$

Table 3.38. Design wind forces at each floor level

|         | Y-direction    |                          | X-direction    |                          |
|---------|----------------|--------------------------|----------------|--------------------------|
| Floor # | Wind force, kN | Wind force per frame, kN | Wind force, kN | Wind force per frame, kN |
| 1       | 177.18         | 25.31                    | 177.18         | 25.31                    |
| 2       | 176.07         | 25.15                    | 176.07         | 25.15                    |
| 3       | 184.73         | 26.39                    | 184.73         | 26.39                    |
| 4       | 191.77         | 27.40                    | 191.77         | 27.40                    |
| 5       | 197.78         | 28.25                    | 197.78         | 28.25                    |
| 6       | 203.06         | 29.01                    | 203.06         | 29.01                    |
| 7       | 207.79         | 29.68                    | 207.79         | 29.68                    |
| 8       | 212.10         | 30.30                    | 212.10         | 30.30                    |
| 9       | 216.06         | 30.87                    | 216.06         | 30.87                    |
| 10      | 219.74         | 31.39                    | 219.74         | 31.39                    |

|    |        |       |        |       |
|----|--------|-------|--------|-------|
| 11 | 223.18 | 31.88 | 223.18 | 31.88 |
| 12 | 207.34 | 29.62 | 207.34 | 29.62 |
| 13 | 20.77  | 10.38 | 24.23  | 6.06  |

Four wind load cases were considered, as shown in Figure 3.38. While cases I and III consider pure direct wind effects, cases II and IV take into account the influence of accidental torsion.

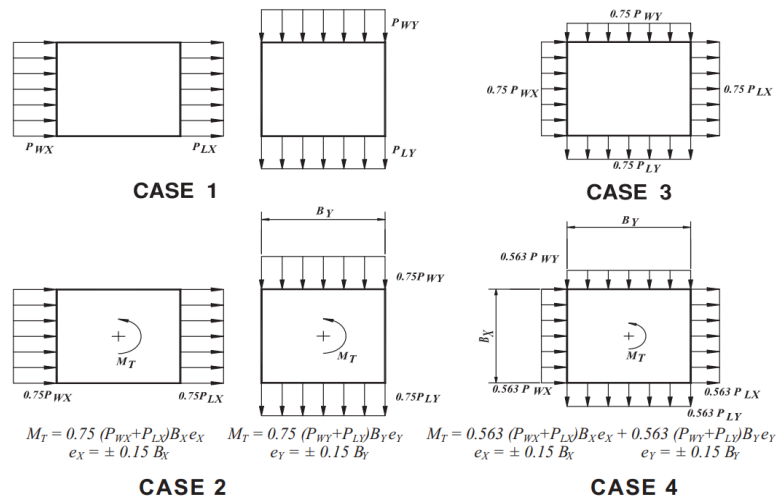


Figure 3.28. Design wind load cases (ASCE 7-16)

For Case I and Case III, the forces acting at each floor were uniformly distributed to each frame, since the stiffness on each floor is constant.

Table 3.39. Case I for Y-direction

| Floor | Forces per frame (kN) |       |       |       |       |       |       | Total force (kN) |
|-------|-----------------------|-------|-------|-------|-------|-------|-------|------------------|
|       | A                     | B     | C     | D     | E     | F     | G     |                  |
| 1     | 25.31                 | 25.31 | 25.31 | 25.31 | 25.31 | 25.31 | 25.31 | 177.18           |
| 2     | 25.15                 | 25.15 | 25.15 | 25.15 | 25.15 | 25.15 | 25.15 | 176.07           |
| 3     | 26.39                 | 26.39 | 26.39 | 26.39 | 26.39 | 26.39 | 26.39 | 184.73           |
| 4     | 27.40                 | 27.40 | 27.40 | 27.40 | 27.40 | 27.40 | 27.40 | 191.77           |
| 5     | 28.25                 | 28.25 | 28.25 | 28.25 | 28.25 | 28.25 | 28.25 | 197.78           |

|    |       |       |       |       |       |       |       |        |
|----|-------|-------|-------|-------|-------|-------|-------|--------|
| 6  | 29.01 | 29.01 | 29.01 | 29.01 | 29.01 | 29.01 | 29.01 | 203.06 |
| 7  | 29.68 | 29.68 | 29.68 | 29.68 | 29.68 | 29.68 | 29.68 | 207.79 |
| 8  | 30.30 | 30.30 | 30.30 | 30.30 | 30.30 | 30.30 | 30.30 | 212.10 |
| 9  | 30.87 | 30.87 | 30.87 | 30.87 | 30.87 | 30.87 | 30.87 | 216.06 |
| 10 | 31.39 | 31.39 | 31.39 | 31.39 | 31.39 | 31.39 | 31.39 | 219.74 |
| 11 | 31.88 | 31.88 | 31.88 | 31.88 | 31.88 | 31.88 | 31.88 | 223.18 |
| 12 | 29.62 | 29.62 | 29.62 | 29.62 | 29.62 | 29.62 | 29.62 | 207.34 |
| 13 | 0.00  | 0.00  | 0.00  | 10.38 | 10.38 | 0.00  | 0.00  | 20.77  |

Table 3.40. Case I for X-direction

| Floor | Forces per frame (kN) |       |       |       |       |       |       | Total force (kN) |
|-------|-----------------------|-------|-------|-------|-------|-------|-------|------------------|
|       | 1                     | 2     | 3     | 4     | 5     | 6     | 7     |                  |
| 1     | 25.31                 | 25.31 | 25.31 | 25.31 | 25.31 | 25.31 | 25.31 | 177.18           |
| 2     | 25.15                 | 25.15 | 25.15 | 25.15 | 25.15 | 25.15 | 25.15 | 176.07           |
| 3     | 26.39                 | 26.39 | 26.39 | 26.39 | 26.39 | 26.39 | 26.39 | 184.73           |
| 4     | 27.40                 | 27.40 | 27.40 | 27.40 | 27.40 | 27.40 | 27.40 | 191.77           |
| 5     | 28.25                 | 28.25 | 28.25 | 28.25 | 28.25 | 28.25 | 28.25 | 197.78           |
| 6     | 29.01                 | 29.01 | 29.01 | 29.01 | 29.01 | 29.01 | 29.01 | 203.06           |
| 7     | 29.68                 | 29.68 | 29.68 | 29.68 | 29.68 | 29.68 | 29.68 | 207.79           |
| 8     | 30.30                 | 30.30 | 30.30 | 30.30 | 30.30 | 30.30 | 30.30 | 212.10           |
| 9     | 30.87                 | 30.87 | 30.87 | 30.87 | 30.87 | 30.87 | 30.87 | 216.06           |
| 10    | 31.39                 | 31.39 | 31.39 | 31.39 | 31.39 | 31.39 | 31.39 | 219.74           |
| 11    | 31.88                 | 31.88 | 31.88 | 31.88 | 31.88 | 31.88 | 31.88 | 223.18           |
| 12    | 29.62                 | 29.62 | 29.62 | 29.62 | 29.62 | 29.62 | 29.62 | 207.34           |
| 13    | 6.06                  | 6.06  | 0.00  | 0.00  | 0.00  | 6.06  | 6.06  | 24.23            |

Table 3.41. Case III for Y-direction

| Floor | Forces per frame (kN) |       |       |       |       |       |       | Total force (kN) |
|-------|-----------------------|-------|-------|-------|-------|-------|-------|------------------|
|       | A                     | B     | C     | D     | E     | F     | G     |                  |
| 1     | 18.98                 | 18.98 | 18.98 | 18.98 | 18.98 | 18.98 | 18.98 | 132.78           |
| 2     | 18.86                 | 18.86 | 18.86 | 18.86 | 18.86 | 18.86 | 18.86 | 132.05           |
| 3     | 19.79                 | 19.79 | 19.79 | 19.79 | 19.79 | 19.79 | 19.79 | 138.55           |
| 4     | 20.55                 | 20.55 | 20.55 | 20.55 | 20.55 | 20.55 | 20.55 | 143.83           |
| 5     | 21.19                 | 21.19 | 21.19 | 21.19 | 21.19 | 21.19 | 21.19 | 148.34           |
| 6     | 21.76                 | 21.76 | 21.76 | 21.76 | 21.76 | 21.76 | 21.76 | 152.30           |
| 7     | 22.26                 | 22.26 | 22.26 | 22.26 | 22.26 | 22.26 | 22.26 | 155.85           |
| 8     | 22.73                 | 22.73 | 22.73 | 22.73 | 22.73 | 22.73 | 22.73 | 159.08           |
| 9     | 23.15                 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 162.05           |
| 10    | 23.54                 | 23.54 | 23.54 | 23.54 | 23.54 | 23.54 | 23.54 | 164.81           |
| 11    | 23.91                 | 23.91 | 23.91 | 23.91 | 23.91 | 23.91 | 23.91 | 167.38           |
| 12    | 22.22                 | 22.22 | 22.22 | 22.22 | 22.22 | 22.22 | 22.22 | 155.51           |
| 13    | 0.00                  | 0.00  | 0.00  | 7.79  | 7.79  | 0.00  | 0.00  | 15.57            |

Table 3.42. Case III for X-direction

| Floor | Forces per frame (kN) |       |       |       |       |       |       | Total force (kN) |
|-------|-----------------------|-------|-------|-------|-------|-------|-------|------------------|
|       | 1                     | 2     | 3     | 4     | 5     | 6     | 7     |                  |
| 1     | 18.98                 | 18.98 | 18.98 | 18.98 | 18.98 | 18.98 | 18.98 | 132.78           |
| 2     | 18.86                 | 18.86 | 18.86 | 18.86 | 18.86 | 18.86 | 18.86 | 132.05           |
| 3     | 19.79                 | 19.79 | 19.79 | 19.79 | 19.79 | 19.79 | 19.79 | 138.55           |
| 4     | 20.55                 | 20.55 | 20.55 | 20.55 | 20.55 | 20.55 | 20.55 | 143.83           |
| 5     | 21.19                 | 21.19 | 21.19 | 21.19 | 21.19 | 21.19 | 21.19 | 148.34           |
| 6     | 21.76                 | 21.76 | 21.76 | 21.76 | 21.76 | 21.76 | 21.76 | 152.30           |

|    |       |       |       |       |       |       |       |        |
|----|-------|-------|-------|-------|-------|-------|-------|--------|
| 7  | 22.26 | 22.26 | 22.26 | 22.26 | 22.26 | 22.26 | 22.26 | 155.85 |
| 8  | 22.73 | 22.73 | 22.73 | 22.73 | 22.73 | 22.73 | 22.73 | 159.08 |
| 9  | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 23.15 | 162.05 |
| 10 | 23.54 | 23.54 | 23.54 | 23.54 | 23.54 | 23.54 | 23.54 | 164.81 |
| 11 | 23.91 | 23.91 | 23.91 | 23.91 | 23.91 | 23.91 | 23.91 | 167.38 |
| 12 | 22.22 | 22.22 | 22.22 | 22.22 | 22.22 | 22.22 | 22.22 | 155.51 |
| 13 | 4.54  | 4.54  | 0.00  | 0.00  | 0.00  | 4.54  | 4.54  | 18.17  |

To consider the torsional effect, the following formulas were utilized:

$$e_a = 0.15 \cdot B \quad (3.22)$$

$$e_{ax} = e_{ay} = 0.15 \cdot 36 = 5.4 \text{ m}$$

$$M_T = F \cdot e_a \quad (3.23)$$

$$F_{torsion} = T \frac{x_i C_{fi}}{\Sigma x_i^2 C_{fi} + \Sigma y_i^2 C_{fi}} \quad (3.24)$$

$$F_{total} = F_{direct} + F_{torsion}$$

Table 3.43. Case II, torsional moments on each floor for wind force in Y-direction

| Floor | F (kN) | 0.75F (kN) | M <sub>T</sub> (kN-m) |
|-------|--------|------------|-----------------------|
| 1     | 177.18 | 132.78     | 717.56                |
| 2     | 176.07 | 132.05     | 713.09                |
| 3     | 184.73 | 138.55     | 748.16                |
| 4     | 191.77 | 143.83     | 776.68                |
| 5     | 197.78 | 148.34     | 801.01                |
| 6     | 203.06 | 152.30     | 822.40                |
| 7     | 207.79 | 155.85     | 841.57                |
| 8     | 212.10 | 159.08     | 859.01                |
| 9     | 216.06 | 162.05     | 875.06                |

|    |        |        |        |
|----|--------|--------|--------|
| 10 | 219.74 | 164.81 | 889.95 |
| 11 | 223.18 | 167.38 | 903.87 |
| 12 | 207.34 | 155.51 | 839.73 |
| 13 | 20.77  | 15.57  | 84.10  |

Table 3.44. Case II, torsional moments on each floor for wind force in X-direction

| Floor | F (kN) | 0.75F (kN) | M <sub>T</sub> (kN-m) |
|-------|--------|------------|-----------------------|
| 1     | 177.18 | 132.78     | 717.56                |
| 2     | 176.07 | 132.05     | 713.09                |
| 3     | 184.73 | 138.55     | 748.16                |
| 4     | 191.77 | 143.83     | 776.68                |
| 5     | 197.78 | 148.34     | 801.01                |
| 6     | 203.06 | 152.30     | 822.40                |
| 7     | 207.79 | 155.85     | 841.57                |
| 8     | 212.10 | 159.08     | 859.01                |
| 9     | 216.06 | 162.05     | 875.06                |
| 10    | 219.74 | 164.81     | 889.95                |
| 11    | 223.18 | 167.38     | 903.87                |
| 12    | 207.34 | 155.51     | 839.73                |
| 13    | 24.23  | 18.17      | 98.12                 |

Table 3.45. Case II, wind force by frame in Y-direction

| Floor | Forces per frame (kN) |       |       |       |       |       |       | Total force (kN) |
|-------|-----------------------|-------|-------|-------|-------|-------|-------|------------------|
|       | A                     | B     | C     | D     | E     | F     | G     |                  |
| 1     | 12.60                 | 15.64 | 18.68 | 21.72 | 24.76 | 27.80 | 30.84 | 152.03           |
| 2     | 12.52                 | 15.54 | 18.56 | 21.58 | 24.60 | 27.63 | 30.65 | 151.09           |



|    |       |       |       |       |       |       |       |        |
|----|-------|-------|-------|-------|-------|-------|-------|--------|
| 3  | 13.14 | 16.31 | 19.48 | 22.65 | 25.81 | 28.98 | 32.15 | 158.52 |
| 4  | 13.64 | 16.93 | 20.22 | 23.51 | 26.80 | 30.09 | 33.38 | 164.56 |
| 5  | 14.06 | 17.46 | 20.85 | 24.25 | 27.64 | 31.03 | 34.43 | 169.72 |
| 6  | 14.44 | 17.92 | 21.41 | 24.89 | 28.38 | 31.86 | 35.34 | 174.25 |
| 7  | 14.78 | 18.34 | 21.91 | 25.47 | 29.04 | 32.60 | 36.17 | 178.31 |
| 8  | 15.08 | 18.72 | 22.36 | 26.00 | 29.64 | 33.28 | 36.92 | 182.00 |
| 9  | 15.36 | 19.07 | 22.78 | 26.49 | 30.19 | 33.90 | 37.61 | 185.40 |
| 10 | 15.63 | 19.40 | 23.17 | 26.94 | 30.71 | 34.48 | 38.25 | 188.56 |
| 11 | 15.87 | 19.70 | 23.53 | 27.36 | 31.19 | 35.02 | 38.85 | 191.51 |
| 12 | 14.74 | 18.30 | 21.86 | 25.42 | 28.97 | 32.53 | 36.09 | 177.92 |
| 13 | 0.00  | 0.00  | 0.00  | 8.11  | 8.46  | 0.00  | 0.00  | 16.57  |

Table 3.46. Case II, wind force by frame in X-direction

| Floor | Forces per frame (kN) |       |       |       |       |       |       | Total force (kN) |
|-------|-----------------------|-------|-------|-------|-------|-------|-------|------------------|
|       | 1                     | 2     | 3     | 4     | 5     | 6     | 7     |                  |
| 1     | 12.60                 | 15.64 | 18.68 | 21.72 | 24.76 | 27.80 | 30.84 | 152.03           |
| 2     | 12.52                 | 15.54 | 18.56 | 21.58 | 24.60 | 27.63 | 30.65 | 151.09           |
| 3     | 13.14                 | 16.31 | 19.48 | 22.65 | 25.81 | 28.98 | 32.15 | 158.52           |
| 4     | 13.64                 | 16.93 | 20.22 | 23.51 | 26.80 | 30.09 | 33.38 | 164.56           |
| 5     | 14.06                 | 17.46 | 20.85 | 24.25 | 27.64 | 31.03 | 34.43 | 169.72           |
| 6     | 14.44                 | 17.92 | 21.41 | 24.89 | 28.38 | 31.86 | 35.34 | 174.25           |
| 7     | 14.78                 | 18.34 | 21.91 | 25.47 | 29.04 | 32.60 | 36.17 | 178.31           |
| 8     | 15.08                 | 18.72 | 22.36 | 26.00 | 29.64 | 33.28 | 36.92 | 182.00           |
| 9     | 15.36                 | 19.07 | 22.78 | 26.49 | 30.19 | 33.90 | 37.61 | 185.40           |
| 10    | 15.63                 | 19.40 | 23.17 | 26.94 | 30.71 | 34.48 | 38.25 | 188.56           |
| 11    | 15.87                 | 19.70 | 23.53 | 27.36 | 31.19 | 35.02 | 38.85 | 191.51           |

|    |       |       |       |       |       |       |       |        |
|----|-------|-------|-------|-------|-------|-------|-------|--------|
| 12 | 14.74 | 18.30 | 21.86 | 25.42 | 28.97 | 32.53 | 36.09 | 177.92 |
| 13 | 3.67  | 4.09  | 0.00  | 0.00  | 0.00  | 5.75  | 6.16  | 19.67  |

Table 3.47. Case IV, torsional moments on each floor

| Floor | $0.563F_x$ | $0.563F_y$ | $M_T$   |
|-------|------------|------------|---------|
| 1     | 2.37       | 2.37       | 923.40  |
| 2     | 2.36       | 2.36       | 917.65  |
| 3     | 2.48       | 2.48       | 962.78  |
| 4     | 2.57       | 2.57       | 999.48  |
| 5     | 2.65       | 2.65       | 1030.79 |
| 6     | 2.72       | 2.72       | 1058.31 |
| 7     | 2.79       | 2.79       | 1082.98 |
| 8     | 2.74       | 2.74       | 1105.42 |
| 9     | 2.90       | 2.90       | 1126.07 |
| 10    | 2.95       | 2.95       | 1145.24 |
| 11    | 2.99       | 2.99       | 1163.15 |
| 12    | 2.78       | 2.78       | 1080.62 |
| 13    | 0.28       | 0.32       | 117.24  |

Table 3.48. Case IV, wind force by frame in Y-direction

| Floor | Forces per frame (kN) |        |       |       |       |       |        | Total force (kN) |
|-------|-----------------------|--------|-------|-------|-------|-------|--------|------------------|
|       | A                     | B      | C     | D     | E     | F     | G      |                  |
| 1     | -35.04                | -11.57 | 11.90 | 35.38 | 58.85 | 82.32 | 105.79 | 247.63           |
| 2     | -34.82                | -11.50 | 11.83 | 35.15 | 58.48 | 81.81 | 105.13 | 246.08           |
| 3     | -36.54                | -12.06 | 12.41 | 36.88 | 61.36 | 85.83 | 110.30 | 258.18           |
| 4     | -37.93                | -12.52 | 12.78 | 38.29 | 63.70 | 89.10 | 114.51 | 268.03           |

|    |        |        |       |       |       |        |        |        |
|----|--------|--------|-------|-------|-------|--------|--------|--------|
| 5  | -39.12 | -12.92 | 13.29 | 39.49 | 65.69 | 91.89  | 118.10 | 276.42 |
| 6  | -40.16 | -13.26 | 13.64 | 40.54 | 67.44 | 94.35  | 121.25 | 283.80 |
| 7  | -41.10 | -13.57 | 13.96 | 41.49 | 69.02 | 96.55  | 124.07 | 290.42 |
| 8  | -41.95 | -13.85 | 14.25 | 42.35 | 70.45 | 98.55  | 126.65 | 296.44 |
| 9  | -42.73 | -14.11 | 14.52 | 43.14 | 71.76 | 100.39 | 129.01 | 301.98 |
| 10 | -43.46 | -14.35 | 14.76 | 43.87 | 72.98 | 102.10 | 131.21 | 307.11 |
| 11 | -44.14 | -14.57 | 14.99 | 44.56 | 74.13 | 103.69 | 133.26 | 311.92 |
| 12 | -41.01 | -13.54 | 13.93 | 41.40 | 68.87 | 96.34  | 123.80 | 289.79 |
| 13 | 0      | 0      | 0     | 26.82 | 36.68 | 0      | 0      | 63.5   |

Table 3.49. Case IV, wind force by frame in X-direction

| Floor | Forces per frame (kN) |        |       |       |       |        |        | Total force (kN) |
|-------|-----------------------|--------|-------|-------|-------|--------|--------|------------------|
|       | 1                     | 2      | 3     | 4     | 5     | 6      | 7      |                  |
| 1     | -35.04                | -11.57 | 11.90 | 35.38 | 58.85 | 82.32  | 105.79 | 247.63           |
| 2     | -34.82                | -11.50 | 11.83 | 35.15 | 58.48 | 81.81  | 105.13 | 246.08           |
| 3     | -36.54                | -12.06 | 12.41 | 36.88 | 61.36 | 85.83  | 110.30 | 258.18           |
| 4     | -37.93                | -12.52 | 12.78 | 38.29 | 63.70 | 89.10  | 114.51 | 268.03           |
| 5     | -39.12                | -12.92 | 13.29 | 39.49 | 65.69 | 91.89  | 118.10 | 276.42           |
| 6     | -40.16                | -13.26 | 13.64 | 40.54 | 67.44 | 94.35  | 121.25 | 283.80           |
| 7     | -41.10                | -13.57 | 13.96 | 41.49 | 69.02 | 96.55  | 124.07 | 290.42           |
| 8     | -41.95                | -13.85 | 14.25 | 42.35 | 70.45 | 98.55  | 126.65 | 296.44           |
| 9     | -42.73                | -14.11 | 14.52 | 43.14 | 71.76 | 100.39 | 129.01 | 301.98           |
| 10    | -43.46                | -14.35 | 14.76 | 43.87 | 72.98 | 102.10 | 131.21 | 307.11           |
| 11    | -44.14                | -14.57 | 14.99 | 44.56 | 74.13 | 103.69 | 133.26 | 311.92           |
| 12    | -41.01                | -13.54 | 13.93 | 41.40 | 68.87 | 96.34  | 123.80 | 289.79           |
| 13    | 2.37                  | 2.76   | 0     | 0     | 0     | 4.85   | 5.35   | 15.43            |

### 3.4.2 Seismic load calculation

By using the ASCE Hazard tool, the mapped acceleration parameters, such as  $S_s$ ,  $S_1$  and  $T_L$ , were found as shown in Figure 3.29 (ASCE Hazard Tool, 2025). The results were obtained with the input parameters of Risk Category II, the ASCE/SEI 7-22 standard, and D soil class. The soil class of D - stiff soil was found from the Geotechnical Investigation Report.

|                         |      |
|-------------------------|------|
| $S_s$                   | 1.5  |
| $S_1$                   | 0.62 |
| $S_{MS}$                | 1.62 |
| $S_{M1}$                | 1.7  |
| $S_{DS}$                | 1.08 |
| $S_{D1}$                | 1.13 |
| $T_L$                   | 12   |
| $PGA_M$                 | 0.54 |
| $V_{S30}$               | 260  |
| Seismic Design Category | D    |

Figure 3.29. ASCE Hazard Tool Seismic Data

Thus,  $S_s$ ,  $S_1$  and  $T_L$  were found to be 1.5, 0.62 and 12, respectively. The soil condition correction coefficients were identified from the following figures:

| Site Class | $S_s \leq 0.25$    | $S_s = 0.5$ | $S_s = 0.75$ | $S_s = 1.0$ | $S_s \geq 1.25$ |
|------------|--------------------|-------------|--------------|-------------|-----------------|
| 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 |             |              |             |                 |

Figure 3.30. Site Coefficient,  $F_a$

| Site Class | $S_I \leq 0.1$     | $S_I = 0.2$ | $S_I = 0.3$ | $S_I = 0.4$ | $S_I \geq 0.5$ |
|------------|--------------------|-------------|-------------|-------------|----------------|
| 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 |             |             |             |                |

Figure 3.31. Site Coefficient,  $F_v$

Thus,  $F_a$  and  $F_v$  are 1.0 and 1.5, respectively. To consider these correction coefficients, the following formulas were used:

$$S_{MS} = F_a S_s \quad (3.25)$$

$$S_{M1} = F_v S_1 \quad (3.26)$$

$$S_{MS} = 1.0 * 1.5 = 1.5 g$$

$$S_{M1} = 1.5 * 0.62 = 0.93 g$$

Adjustments based on design acceleration parameters:

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

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

$$S_{DS} = \frac{2}{3} * 1.5 = 1.0 g$$

$$S_{D1} = \frac{2}{3} * 0.93 = 0.62 g$$

The Seismic Design Category for our building was obtained from the figure below.

| Value of $S_{DS}$          | Risk Category  |    |
|----------------------------|----------------|----|
|                            | I or II or III | IV |
| $S_{DS} < 0.167$           | A              | A  |
| $0.167 \leq S_{DS} < 0.33$ | B              | C  |
| $0.33 \leq S_{DS} < 0.50$  | C              | D  |
| $0.50 \leq S_{DS}$         | D              | D  |

Figure 3.32. Seismic Design Category Based on Short Period Response Acceleration Parameter

| Value of $S_{D1}$           | Risk Category  |    |
|-----------------------------|----------------|----|
|                             | I or II or III | IV |
| $S_{D1} < 0.067$            | A              | A  |
| $0.067 \leq S_{D1} < 0.133$ | B              | C  |
| $0.133 \leq S_{D1} < 0.20$  | C              | D  |
| $0.20 \leq S_{D1}$          | D              | D  |

Figure 3.33. Seismic Design Category Based on 1-S Period Response Acceleration Parameter

From Figures 3.32 and 3.33, the seismic design category is D, as the Short Period Response Acceleration Parameter is higher than 0.50, and the 1-S Period Response Acceleration Parameter is higher than 0.20 with Risk Category II.

Next, the Design Coefficients and Factors for the Seismic Force-Resisting System are determined from the following figure:

| Seismic Force-Resisting System                                      | ASCE 7<br>Section<br>Where<br>Detailing<br>Requirements<br>Are Specified | Response<br>Modification<br>Coefficient,<br>$R^a$ | Overstrength<br>Factor, $\Omega_0^f$ | Deflection<br>Amplification<br>Factor, $C_d^b$ | Structural System<br>Limitations Including<br>Structural Height, $h_n$ (ft)<br>Limits <sup>c</sup> |     |                 |                 |                 |
|---------------------------------------------------------------------|--------------------------------------------------------------------------|---------------------------------------------------|--------------------------------------|------------------------------------------------|----------------------------------------------------------------------------------------------------|-----|-----------------|-----------------|-----------------|
|                                                                     |                                                                          |                                                   |                                      |                                                | Seismic Design Category                                                                            |     |                 |                 |                 |
|                                                                     |                                                                          |                                                   |                                      |                                                | B                                                                                                  | C   | D <sup>d</sup>  | E <sup>d</sup>  | F <sup>e</sup>  |
| <b>C. MOMENT-RESISTING FRAME SYSTEMS</b>                            |                                                                          |                                                   |                                      |                                                |                                                                                                    |     |                 |                 |                 |
| 1. Steel special moment frames                                      | 14.1 and 12.2.5.5                                                        | 8                                                 | 3                                    | 5½                                             | NL                                                                                                 | NL  | NL              | NL              | NL              |
| 2. Steel special truss moment frames                                | 14.1                                                                     | 7                                                 | 3                                    | 5½                                             | NL                                                                                                 | NL  | 160             | 100             | NP              |
| 3. Steel intermediate moment frames                                 | 12.2.5.7 and 14.1                                                        | 4½                                                | 3                                    | 4                                              | NL                                                                                                 | NL  | 35 <sup>h</sup> | NP <sup>h</sup> | NP <sup>h</sup> |
| 4. Steel ordinary moment frames                                     | 12.2.5.6 and 14.1                                                        | 3½                                                | 3                                    | 3                                              | NL                                                                                                 | NL  | NP <sup>i</sup> | NP <sup>i</sup> | NP <sup>i</sup> |
| 5. Special reinforced concrete moment frames <sup>a</sup>           | 12.2.5.5 and 14.2                                                        | 8                                                 | 3                                    | 5½                                             | NL                                                                                                 | NL  | NL              | NL              | NL              |
| 6. Intermediate reinforced concrete moment frames                   | 14.2                                                                     | 5                                                 | 3                                    | 4½                                             | NL                                                                                                 | NL  | NP              | NP              | NP              |
| 7. Ordinary reinforced concrete moment frames                       | 14.2                                                                     | 3                                                 | 3                                    | 2½                                             | NL                                                                                                 | NP  | NP              | NP              | NP              |
| 8. Steel and concrete composite special moment frames               | 12.2.5.5 and 14.3                                                        | 8                                                 | 3                                    | 5½                                             | NL                                                                                                 | NL  | NL              | NL              | NL              |
| 9. Steel and concrete composite intermediate moment frames          | 14.3                                                                     | 5                                                 | 3                                    | 4½                                             | NL                                                                                                 | NL  | NP              | NP              | NP              |
| 10. Steel and concrete composite partially restrained moment frames | 14.3                                                                     | 6                                                 | 3                                    | 5½                                             | 160                                                                                                | 160 | 100             | NP              | NP              |
| 11. Steel and concrete composite ordinary moment frames             | 14.3                                                                     | 3                                                 | 3                                    | 2½                                             | NL                                                                                                 | NP  | NP              | NP              | NP              |
| 12. Cold-formed steel—special bolted moment frame <sup>o</sup>      | 14.1                                                                     | 3½                                                | 3 <sup>o</sup>                       | 3½                                             | 35                                                                                                 | 35  | 35              | 35              | 35              |

Figure 3.34. Design Coefficients and Factors for Seismic Force-Resisting Systems  
 Since the special reinforced concrete moment frames type was chosen for the construction of this building, the following factors were outputted:

- Response modification coefficient,  $R$ , is 8
- Overstrength factor,  $\Omega$ , is 3
- Design amplification factor,  $C$ , is 5.5

For the Importance Factor,  $I$ , the following Figure 3.35 was considered:

| Risk Category from Table 1.5-1 | Snow Importance Factor, $I_s$ | Ice Importance Factor—Thickness, $I_t$ | 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                             |

Figure 3.35. Importance Factor Table

Thus, the Importance Factor,  $I_e$  is equal to 1.0.

| Design Spectral Response Acceleration<br>Parameter at 1 s, $S_{D1}$ |  | Coefficient $C_u$ |
|---------------------------------------------------------------------|--|-------------------|
| $\geq 0.4$                                                          |  | 1.4               |
| 0.3                                                                 |  | 1.4               |
| 0.2                                                                 |  | 1.5               |
| 0.15                                                                |  | 1.6               |
| $\leq 0.1$                                                          |  | 1.7               |

Figure 3.36. Coefficient for Upper Limit on Calculated Period

The  $C_u$  was taken as 1.4.

| Structure Type                                                                                                                                                                                                                                 | $C_t$                       | $x$  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|------|
| Moment-resisting frame systems in which the frames resist 100% of the required seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting where subjected to seismic forces: |                             |      |
| Steel moment-resisting frames                                                                                                                                                                                                                  | 0.028 (0.0724) <sup>a</sup> | 0.8  |
| Concrete moment-resisting frames                                                                                                                                                                                                               | 0.016 (0.0466) <sup>a</sup> | 0.9  |
| Steel eccentrically braced frames in accordance with Table 12.2-1 lines B1 or D1                                                                                                                                                               | 0.03 (0.0731) <sup>a</sup>  | 0.75 |
| Steel buckling-restrained braced frames                                                                                                                                                                                                        | 0.03 (0.0731) <sup>a</sup>  | 0.75 |
| All other structural systems                                                                                                                                                                                                                   | 0.02 (0.0488) <sup>a</sup>  | 0.75 |

Figure 3.37. Values of Approximate Period Parameters  $C_t$  and  $x$   
For concrete moment-resisting structures,  $C_t$  was obtained to be 0.0466 and  $x$  was 0.9.

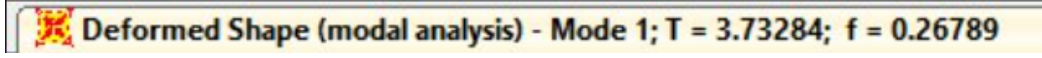


Figure 3.38. Modal analysis result

To obtain  $T^*$  value, modal analysis in SAP2000 was performed, and the results outputted that  $T^* = 3.73284$  sec (1st mode).

The approximate fundamental period calculation is shown below:

$$T_a = C_t * h_n^x \quad (3.27)$$

Where  $h_n$  is the height above the base to the highest level of the building. Thus,

$$T_a = 0.0466 * 46^{0.9} = 1.46$$

The original fundamental period was obtained with the use of the following formula:

$$T = C_u * T_a \quad (3.28)$$

$$T = 1.4 * 1.46 = 2.0464$$

Since  $T^*$  is greater than  $T$ , we proceeded with  $T$  value for the strength design.

The seismic response coefficient was calculated using the following formula::

$$C_s = \frac{S_{DS}}{\frac{R}{I_e}} \quad (3.29)$$

$$C_s = \frac{1}{\frac{8}{1}} = 0.125$$

This  $C_s$  value should not exceed the maximum limit:

$$1) \quad C_{s,max} = \frac{S_{D1}}{T^* \frac{R}{I_e}} \quad (3.30)$$

$$C_{s,max} = \frac{0.62}{2.0464 * \frac{8}{1}} = 0.03787$$

$$2) \quad C_{s,max} = \frac{S_{D1} * T_L}{T^{2 * \frac{R}{I_e}}} \quad (3.31)$$

$$C_{s,max} = \frac{0.62 * 12}{2.0464^2 * \frac{8}{1}} = 0.22207$$

Since  $T < T_L$ ,  $C_{s,max} = 0.03787$



The  $C_s$  value should not be less than the below number for  $S_1 > 0.6 g$ :

$$C_{s,min} = \frac{0.5S_1}{\frac{R}{I_e}}$$

$$C_{s,min} = \frac{0.5*0.62}{\frac{R}{I_e}} = 0.03875$$

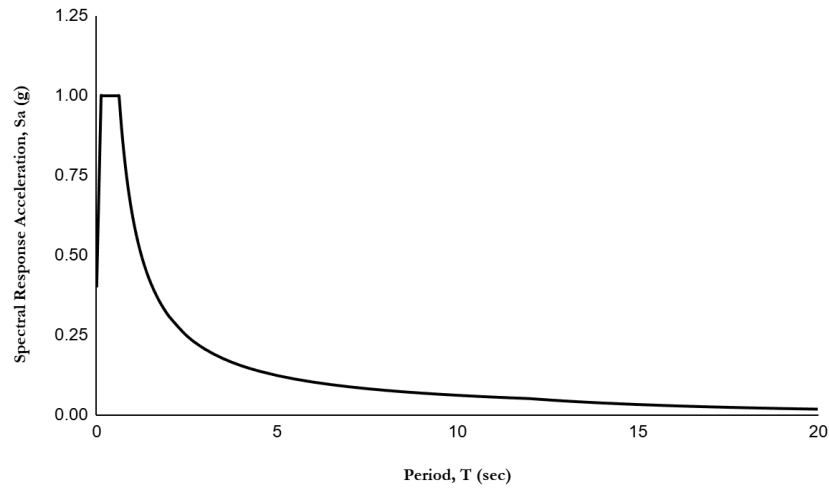


Figure 3.39. Spectral Response Acceleration curve

Next, each floor's total weight for foundation shear was calculated. For this purpose, the number of frame elements on each floor was identified. The numbers of columns and beams for each kind are shown in the table below.

Table 3.50. Number of column elements on each floor except roof

|                 | Tributary area, m <sup>2</sup> | # of columns |
|-----------------|--------------------------------|--------------|
| Interior column | 36                             | 25           |
| Exterior column | 18                             | 24           |
| Corner column   | 9                              | 4            |

Table 3.51. Number of beam elements on each floor except roof

|               | Tributary area, m <sup>2</sup> | # of beams |
|---------------|--------------------------------|------------|
| Interior beam | 18                             | 60         |

|           |   |    |
|-----------|---|----|
| Edge beam | 9 | 24 |
|-----------|---|----|

Table 3.52. Number of column elements on roof

|                 | Tributary area, m <sup>2</sup> | # of columns |
|-----------------|--------------------------------|--------------|
| Interior column | 36                             | 0            |
| Exterior column | 18                             | 0            |
| Corner column   | 5.25                           | 8            |

Table 3.53. Number of beam elements on roof

|               | Tributary area, m <sup>2</sup> | # of beams |
|---------------|--------------------------------|------------|
| Interior beam | 18                             | 0          |
| Edge beam     | 5.25                           | 8          |

Those quantities of the frame element are multiplied by each element's load to obtain the following building weight.

Table 3.54. Weight by floor

| Floors | Slab with finishing, kN/m <sup>2</sup> | Partition walls, kN/m <sup>2</sup> | Exterior walls, kN/m | Beams, kN | Columns, kN | Stairs, kN | Floor weight, kN |
|--------|----------------------------------------|------------------------------------|----------------------|-----------|-------------|------------|------------------|
| 1      | 5.21                                   | 1.12                               | 25.82                | 2268      | 2116.80     | 146.37     | 16451.83         |
| 2      | 5.21                                   | 0.90                               | 22.60                | 2268      | 1556.36     | 146.37     | 15131.36         |
| 3      | 5.21                                   | 0.90                               | 22.60                | 2268      | 1556.36     | 142.13     | 15127.12         |
| 4      | 5.21                                   | 0.90                               | 22.60                | 2268      | 1556.36     | 142.13     | 15127.12         |
| 5      | 5.21                                   | 0.90                               | 22.60                | 2268      | 1041.86     | 142.13     | 14612.62         |
| 6      | 5.21                                   | 0.90                               | 22.60                | 2268      | 1041.86     | 142.13     | 14612.62         |
| 7      | 5.21                                   | 0.90                               | 22.60                | 2268      | 1041.86     | 142.13     | 14612.62         |

|       |      |      |       |      |        |        |           |
|-------|------|------|-------|------|--------|--------|-----------|
| 8     | 5.21 | 0.90 | 22.60 | 2268 | 630.26 | 142.13 | 14201.02  |
| 9     | 5.21 | 0.90 | 22.60 | 2268 | 630.26 | 142.13 | 14201.02  |
| 10    | 5.21 | 0.90 | 22.60 | 2268 | 630.26 | 142.13 | 14201.02  |
| 11    | 5.21 | 0.90 | 22.60 | 2268 | 463.05 | 142.13 | 14033.81  |
| 12    | 5.21 | 0.90 | 29.70 | 2268 | 463.05 | 142.13 | 15056.44  |
| 13    | 4.01 | 0    | 22.60 | 2268 | 463.05 | 142.13 | 3900.27   |
| Total |      |      |       |      |        |        | 181268.89 |

The seismic design base shear was calculated using the following formula:

$$V = C_s * W \quad (3.32)$$

$$V = 0.03875 * 181268.89 = 7024.17 \text{ kN}$$

The story force was calculated below:

$$F_x = C_{vx} * V \quad (3.33)$$

$C_{vx}$  is a vertical distribution factor with the following formula:

$$C_{vx} = \frac{W_x * h_x^k}{\sum_{i=1}^n W_i * h_i^k} \quad (3.34)$$

where  $k$  is an exponent related to the structural period.

For period of 0.5 s or less,  $k = 1$

For period of 2.5 s or more,  $k = 2$

Since our  $T = 1.4617$ , the interpolation has been conducted.

$$\frac{1.4617-0.5}{2.5-0.5} = \frac{k-1}{2-1}$$

$$k = 1.4809$$

The calculated  $C_{vx}$  and  $F_x$  values are presented in the following table:

Table 3.55. Story forces

| Floors | $h_i$ , m | $W_x$ , kN | $W_x * h_x^k$ | $C_{vx}$ | $F_x$ , kN |
|--------|-----------|------------|---------------|----------|------------|
| 1      | 4         | 16451.83   | 128169.44     | 0.006    | 42.20      |
| 2      | 7.5       | 15131.36   | 299038.32     | 0.014    | 98.46      |

|       |      |          |            |       |         |
|-------|------|----------|------------|-------|---------|
| 3     | 11   | 15127.12 | 527132.44  | 0.025 | 173.57  |
| 4     | 14.5 | 15127.12 | 793573.49  | 0.037 | 261.29  |
| 5     | 18   | 14612.62 | 1055890.81 | 0.049 | 347.67  |
| 6     | 21.5 | 14612.62 | 1373698.67 | 0.064 | 452.31  |
| 7     | 25   | 14612.62 | 1717475.37 | 0.081 | 565.50  |
| 8     | 28.5 | 14201.02 | 2026517.92 | 0.095 | 667.26  |
| 9     | 32   | 14201.02 | 2405722.92 | 0.113 | 792.12  |
| 10    | 35.5 | 14201.02 | 2805437.86 | 0.132 | 923.73  |
| 11    | 39   | 14033.81 | 3186615.51 | 0.149 | 1049.24 |
| 12    | 42.5 | 15056.44 | 3882831.43 | 0.182 | 1278.47 |
| 13    | 46   | 3900.27  | 1130879.51 | 0.053 | 372.36  |
| Total |      |          | 21332983.7 |       | 7024.17 |

Afterwards, the torsional effect was considered for seismic load. For this eccentricity was first determined. The stiffness center was calculated in the following way:

$$x = \frac{36*36*18 - 3.5*6*4.25 - 3.5*6*31.75 - 12.265*2.27*18}{36*36 - 3.5*6*2 - 12.265*2.27} = 18 \text{ m}$$

$$y = \frac{36*36*18 - 3.5*6*21*2 - 12.265*2.27*16.865}{36*36 - 3.5*6*2 - 12.265*2.27} = 17.92 \text{ m}$$

Thus, the eccentricity was calculated as:

$$e_x = 18 - 18 = 0$$

$$e_y = 18 - 17.92 = 0.08$$

The accidental eccentricity is:

$$e_{ax} = e_{ay} = 0.05 * 36 = 1.8$$

The total eccentricity:

$$e_x = 0 + 1.8 = 1.8$$

$$e_y = 0.08 + 1.8 = 1.88$$

Frame stiffness is calculated as:

$$D = \frac{12E}{h^2} * \left( \frac{I_{b,cr} * I_{s,cr}}{L * I_{b,cr} + h * I_{s,cr}} \right) \quad (3.35)$$

$$C_f = D * h * \# \text{ of columns per frame} * \# \text{ of frames}$$

Table 3.56. Frame stiffnesses

| Floors | h <sub>i</sub> , m | I <sub>b,cr</sub> , mm <sup>4</sup> | I <sub>c,cr</sub> , mm <sup>4</sup> | D          | C <sub>f</sub> |
|--------|--------------------|-------------------------------------|-------------------------------------|------------|----------------|
| 1      | 4                  | 1890000000                          | 7560000000                          | 6019395.53 | 1011258448     |
| 2      | 3.5                | 1890000000                          | 5337864583                          | 7602224.03 | 1117526932     |
| 3      | 3.5                | 1890000000                          | 5337864583                          | 7602224.03 | 1117526932     |
| 4      | 3.5                | 1890000000                          | 5337864583                          | 7602224.03 | 1117526932     |
| 5      | 3.5                | 1890000000                          | 2392031250                          | 6278580.77 | 922951372.6    |
| 6      | 3.5                | 1890000000                          | 2392031250                          | 6278580.77 | 922951372.6    |
| 7      | 3.5                | 1890000000                          | 2392031250                          | 6278580.77 | 922951372.6    |
| 8      | 3.5                | 1890000000                          | 875364583.3                         | 4059532.12 | 596751222      |
| 9      | 3.5                | 1890000000                          | 875364583.3                         | 4059532.12 | 596751222      |
| 10     | 3.5                | 1890000000                          | 875364583.3                         | 4059532.12 | 596751222      |
| 11     | 3.5                | 1890000000                          | 472500000                           | 2751723.67 | 404503379.4    |
| 12     | 3.5                | 1890000000                          | 472500000                           | 2751723.67 | 404503379.4    |
| 13     | 3.5                | 1890000000                          | 472500000                           | 2751723.67 | 38524131.37    |
| Total  |                    |                                     |                                     |            | 9770477919     |

Table 3.57. Seismic forces by floor

|        |                     | Y-direction              |         | X-direction              |         |
|--------|---------------------|--------------------------|---------|--------------------------|---------|
| Floors | F <sub>x</sub> , kN | F <sub>direct</sub> , kN | T, kN-m | F <sub>direct</sub> , kN | T, kN-m |
| 1      | 42.20               | 6.03                     | 79.21   | 6.03                     | 75.96   |
| 2      | 98.46               | 14.07                    | 184.81  | 14.07                    | 177.23  |
| 3      | 173.57              | 24.80                    | 325.78  | 24.80                    | 312.42  |
| 4      | 261.29              | 37.33                    | 490.45  | 37.33                    | 470.33  |

|    |         |        |         |        |         |
|----|---------|--------|---------|--------|---------|
| 5  | 347.67  | 49.67  | 652.57  | 49.67  | 625.80  |
| 6  | 452.31  | 64.62  | 848.98  | 64.62  | 814.16  |
| 7  | 565.50  | 80.79  | 1061.44 | 80.79  | 1017.90 |
| 8  | 667.26  | 95.32  | 1252.44 | 95.32  | 1201.06 |
| 9  | 792.12  | 113.16 | 1486.79 | 113.16 | 1425.81 |
| 10 | 923.73  | 131.96 | 1733.83 | 131.96 | 1662.71 |
| 11 | 1049.24 | 149.89 | 1969.40 | 149.89 | 1888.62 |
| 12 | 1278.47 | 182.64 | 2399.68 | 182.64 | 2301.25 |
| 13 | 372.36  | 93.09  | 707.66  | 93.09  | 670.24  |

Table 3.58. Force distribution by frame in Y-direction

| Floor | Forces per frame (kN) |        |        |        |        |        |        | Total force (kN) |
|-------|-----------------------|--------|--------|--------|--------|--------|--------|------------------|
|       | A                     | B      | C      | D      | E      | F      | G      |                  |
| 1     | 5.88                  | 5.93   | 5.98   | 6.03   | 6.08   | 6.13   | 6.18   | 42.21            |
| 2     | 13.69                 | 13.82  | 13.94  | 14.07  | 14.19  | 14.32  | 14.45  | 98.47            |
| 3     | 24.13                 | 24.35  | 24.58  | 24.80  | 25.02  | 25.24  | 25.46  | 173.59           |
| 4     | 36.33                 | 36.66  | 37.00  | 37.33  | 37.67  | 38.00  | 38.33  | 261.32           |
| 5     | 48.57                 | 48.94  | 49.30  | 49.67  | 50.04  | 50.41  | 50.77  | 347.70           |
| 6     | 63.19                 | 63.67  | 64.14  | 64.62  | 65.10  | 65.58  | 66.05  | 452.35           |
| 7     | 79.00                 | 79.60  | 80.20  | 80.79  | 81.39  | 81.99  | 82.58  | 565.56           |
| 8     | 93.96                 | 94.42  | 94.87  | 95.33  | 95.78  | 96.24  | 96.69  | 667.30           |
| 9     | 111.54                | 112.09 | 112.63 | 113.17 | 113.71 | 114.25 | 114.79 | 792.16           |
| 10    | 130.08                | 130.71 | 131.34 | 131.97 | 132.60 | 133.23 | 133.86 | 923.78           |
| 11    | 148.44                | 148.93 | 149.41 | 149.90 | 150.38 | 150.87 | 151.35 | 1049.28          |
| 12    | 180.87                | 181.46 | 182.06 | 182.65 | 183.24 | 183.83 | 184.42 | 1278.53          |
| 13    | 0                     | 0      | 0      | 93.09  | 93.11  | 0      | 0      | 186.2            |

Table 3.59. Force distribution by frame in X-direction

| Floor | Forces per frame (kN) |        |        |        |        |        |        | Total force (kN) |
|-------|-----------------------|--------|--------|--------|--------|--------|--------|------------------|
|       | 1                     | 2      | 3      | 4      | 5      | 6      | 7      |                  |
| 1     | 5.89                  | 5.94   | 5.98   | 6.03   | 6.08   | 6.12   | 6.17   | 42.20            |
| 2     | 13.70                 | 13.82  | 13.95  | 14.07  | 14.19  | 14.31  | 14.43  | 98.46            |
| 3     | 24.16                 | 24.37  | 24.58  | 24.80  | 25.01  | 25.22  | 25.43  | 173.57           |
| 4     | 36.37                 | 36.69  | 37.01  | 37.33  | 37.65  | 37.97  | 38.29  | 261.29           |
| 5     | 48.61                 | 48.96  | 49.31  | 49.67  | 50.02  | 50.37  | 50.72  | 347.67           |
| 6     | 63.24                 | 63.70  | 64.16  | 64.62  | 65.07  | 65.53  | 65.99  | 452.31           |
| 7     | 79.07                 | 79.64  | 80.21  | 80.79  | 81.36  | 81.93  | 82.50  | 565.50           |
| 8     | 94.01                 | 94.45  | 94.89  | 95.32  | 95.76  | 96.20  | 96.63  | 667.26           |
| 9     | 111.60                | 112.12 | 112.64 | 113.16 | 113.68 | 114.20 | 114.71 | 792.12           |
| 10    | 130.15                | 130.75 | 131.36 | 131.96 | 132.57 | 133.17 | 133.77 | 923.73           |
| 11    | 148.49                | 148.96 | 149.43 | 149.89 | 150.36 | 150.82 | 151.29 | 1049.24          |
| 12    | 180.94                | 181.50 | 182.07 | 182.64 | 183.21 | 183.77 | 184.34 | 1278.47          |
| 11    | 148.49                | 148.96 | 0      | 0      | 0      | 150.82 | 151.29 | 599.56           |

### 3.4.3 Assigning Lateral Forces to SAP 2000

Wind and seismic loads were applied to the SAP2000 model. Frame 4 and Frame B were selected to extract 2D data. Case I was used to assign the wind load, and forces by frame with torsional effect were used to assign the seismic load.

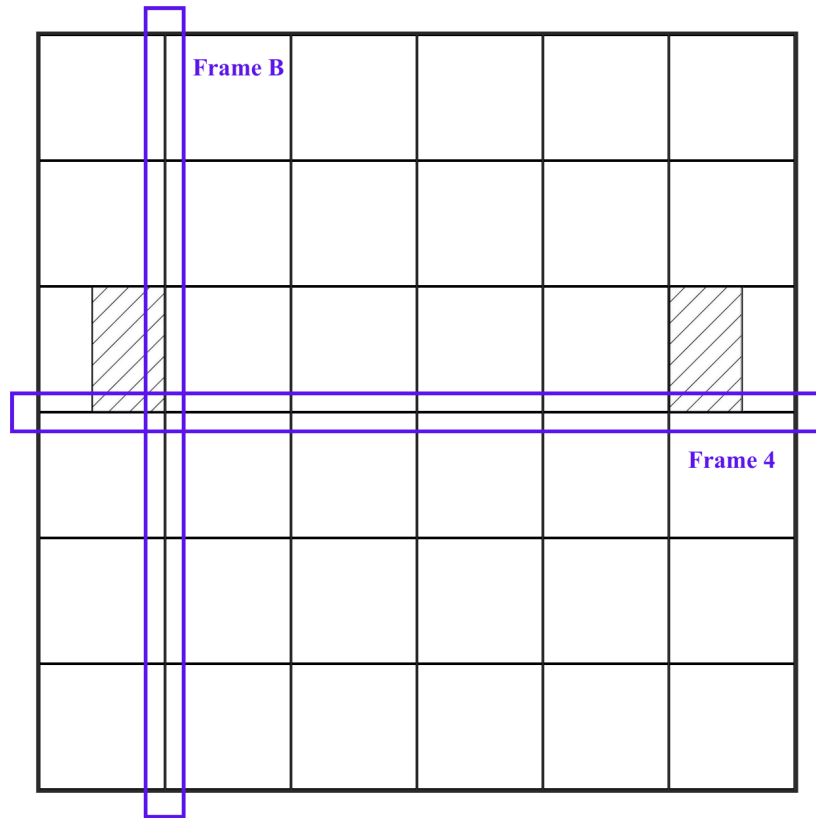


Figure 3.40. Frames for 2D load assignment visualization



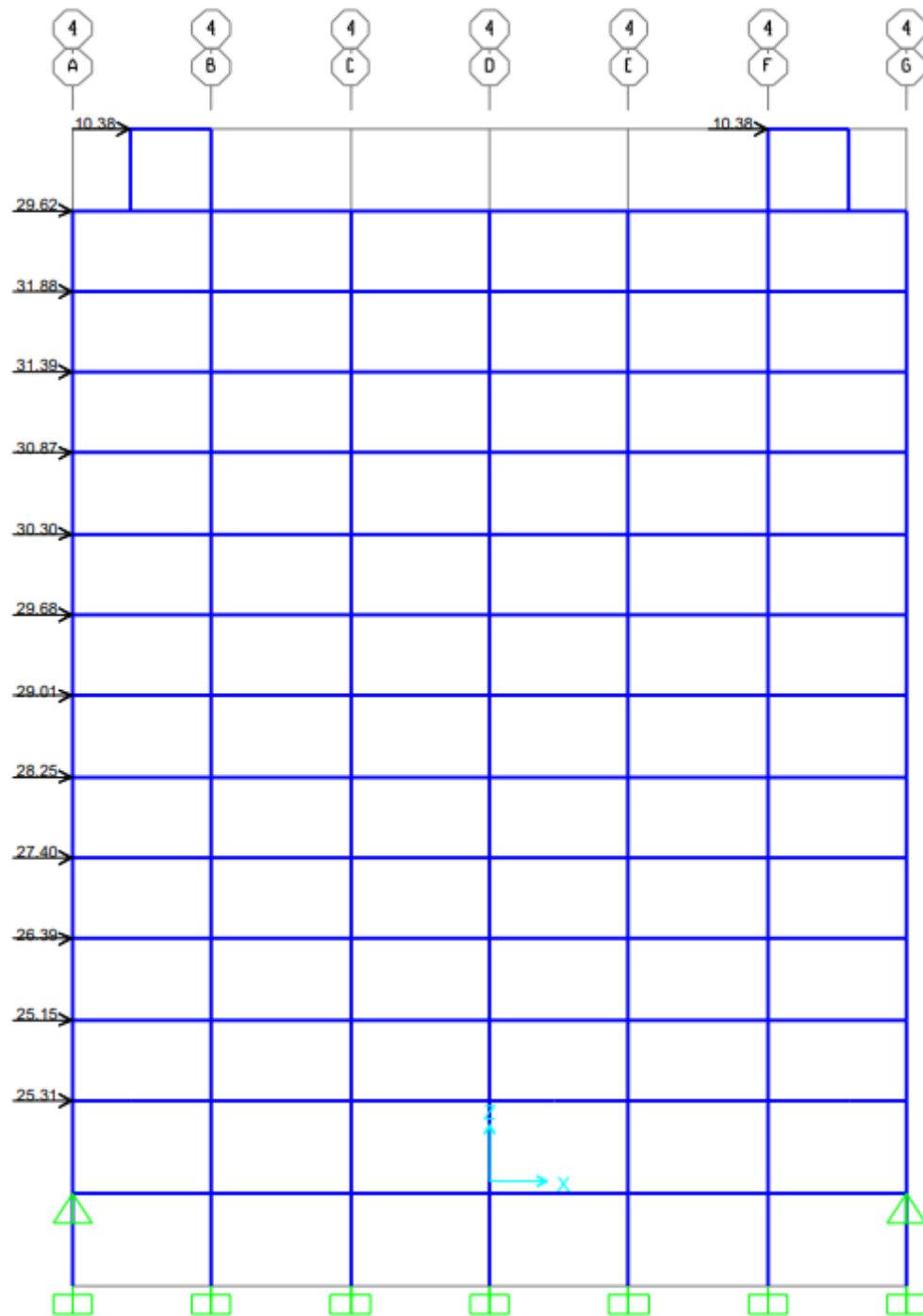


Figure 3.41. 2D Wind Load assignment in X-direction

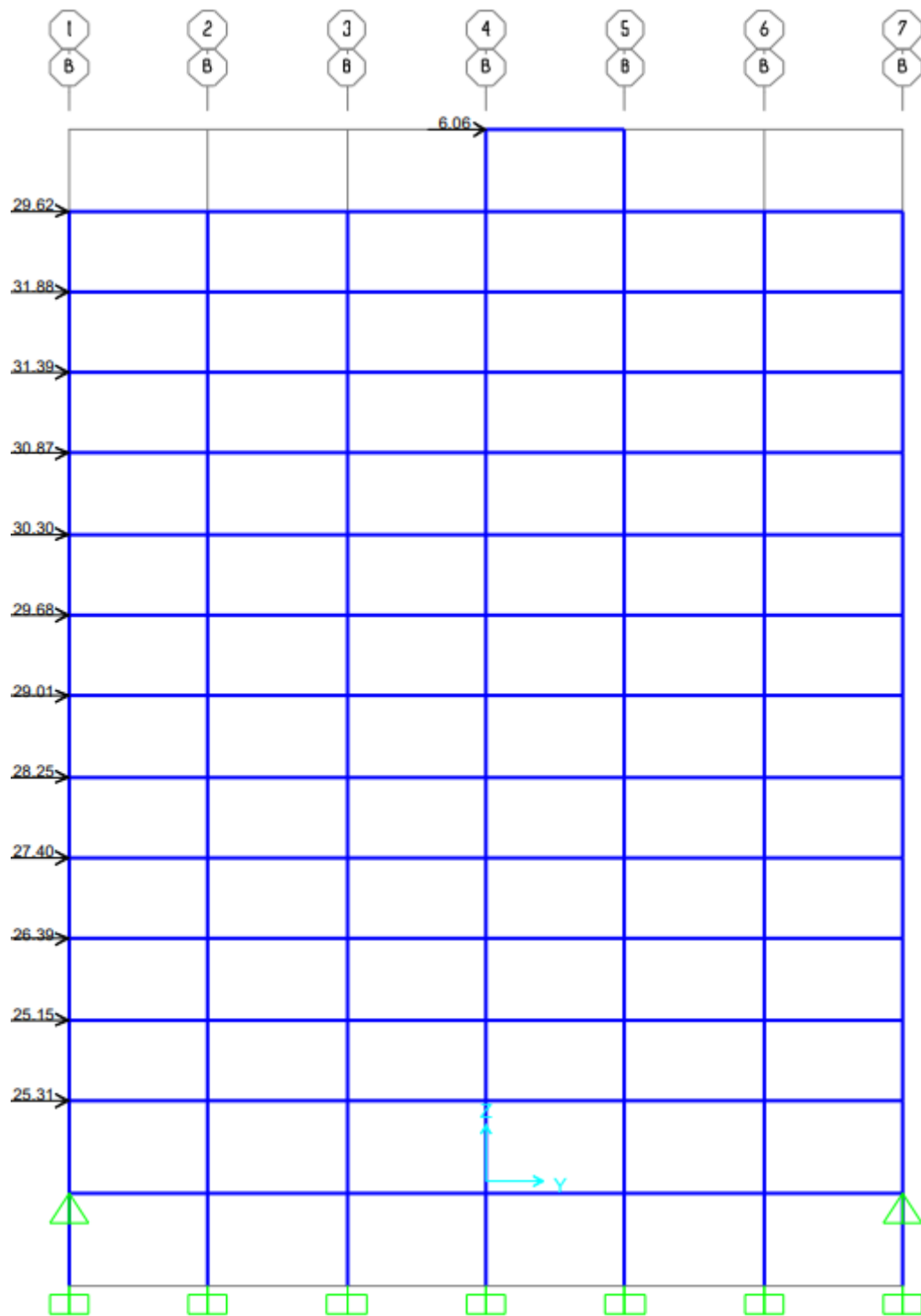


Figure 3.42. 2D Wind Load assignment in Y-direction

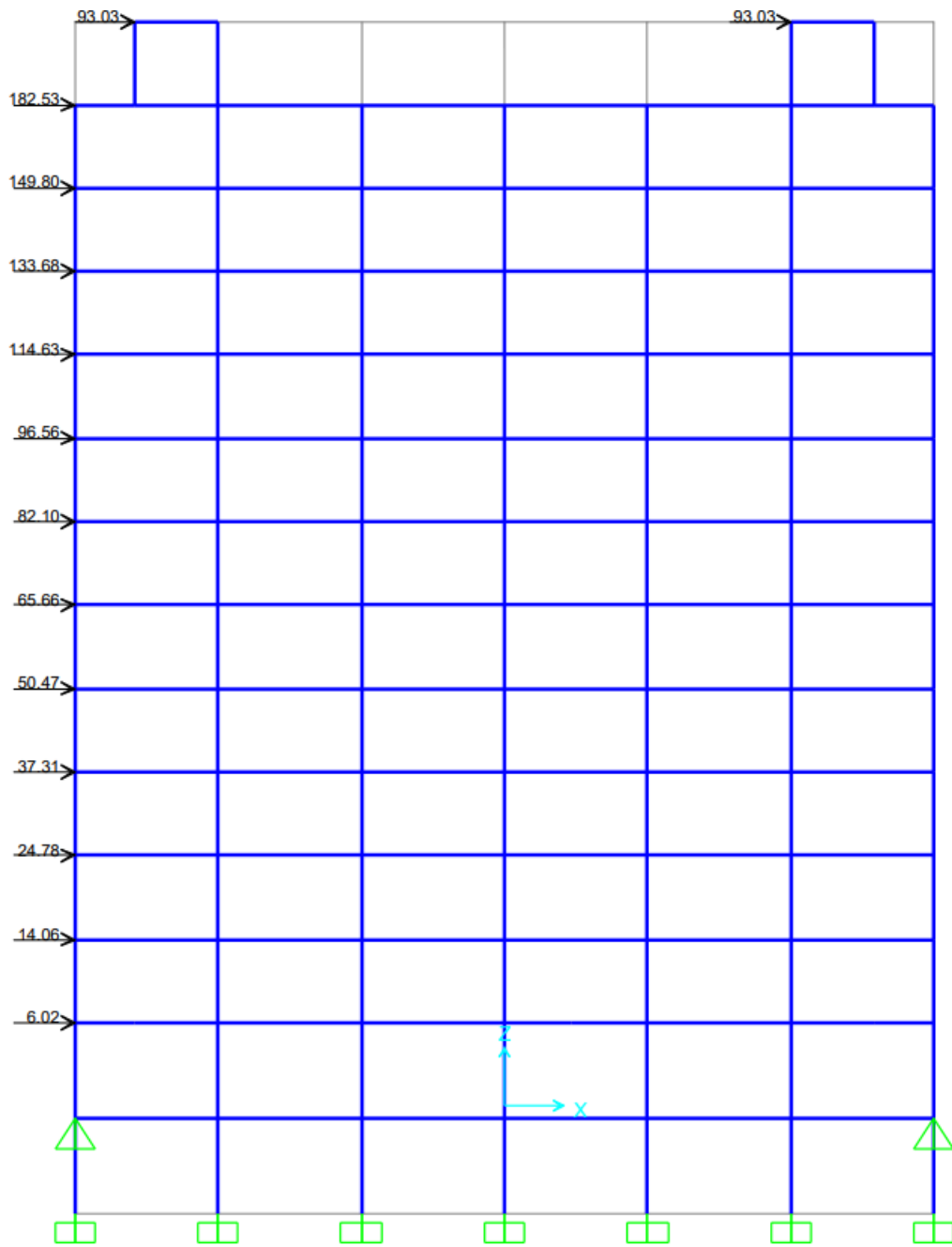


Figure 3.43. 2D Seismic Load assignment in X-direction

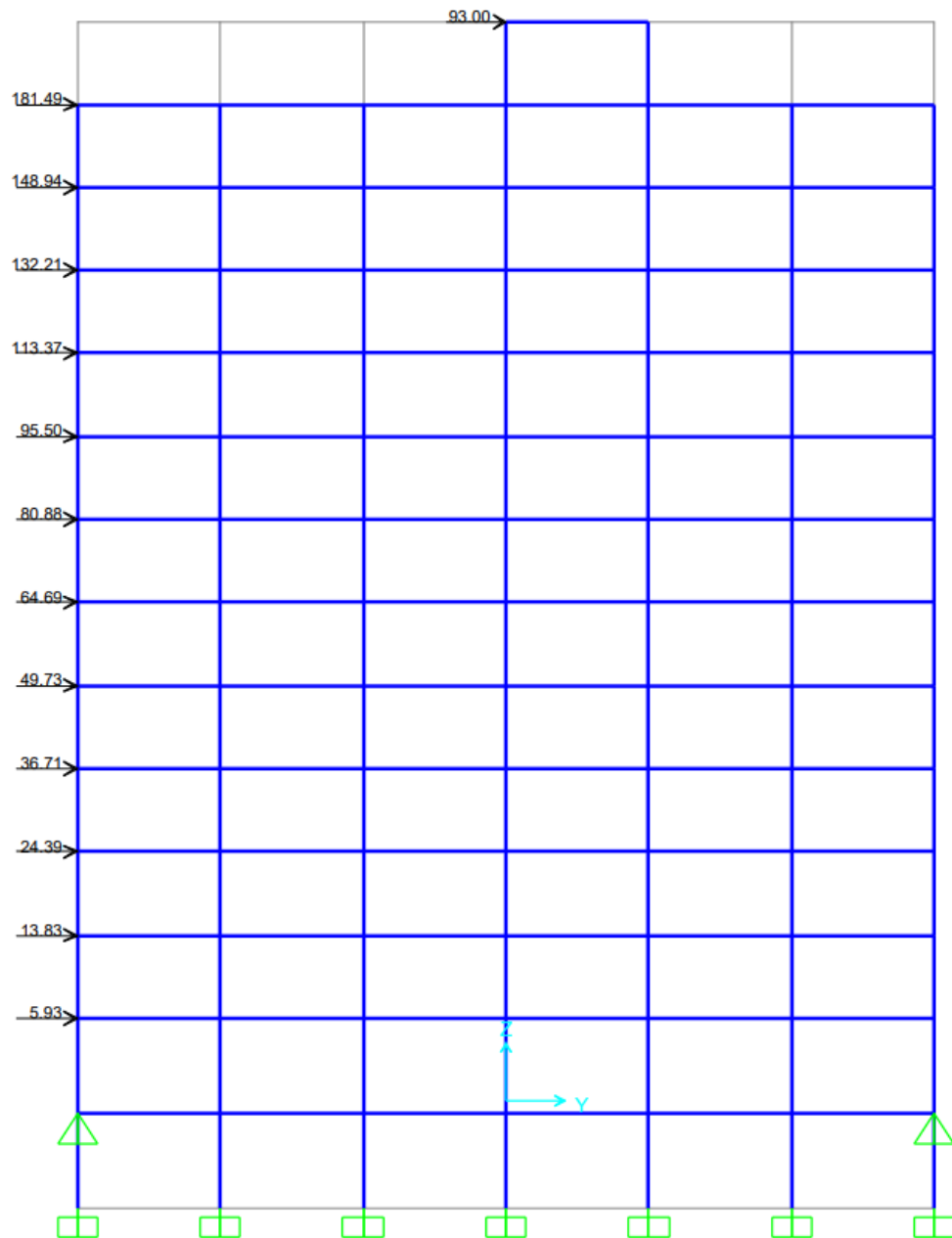


Figure 3.44. 2D Seismic Load assignment in Y-direction

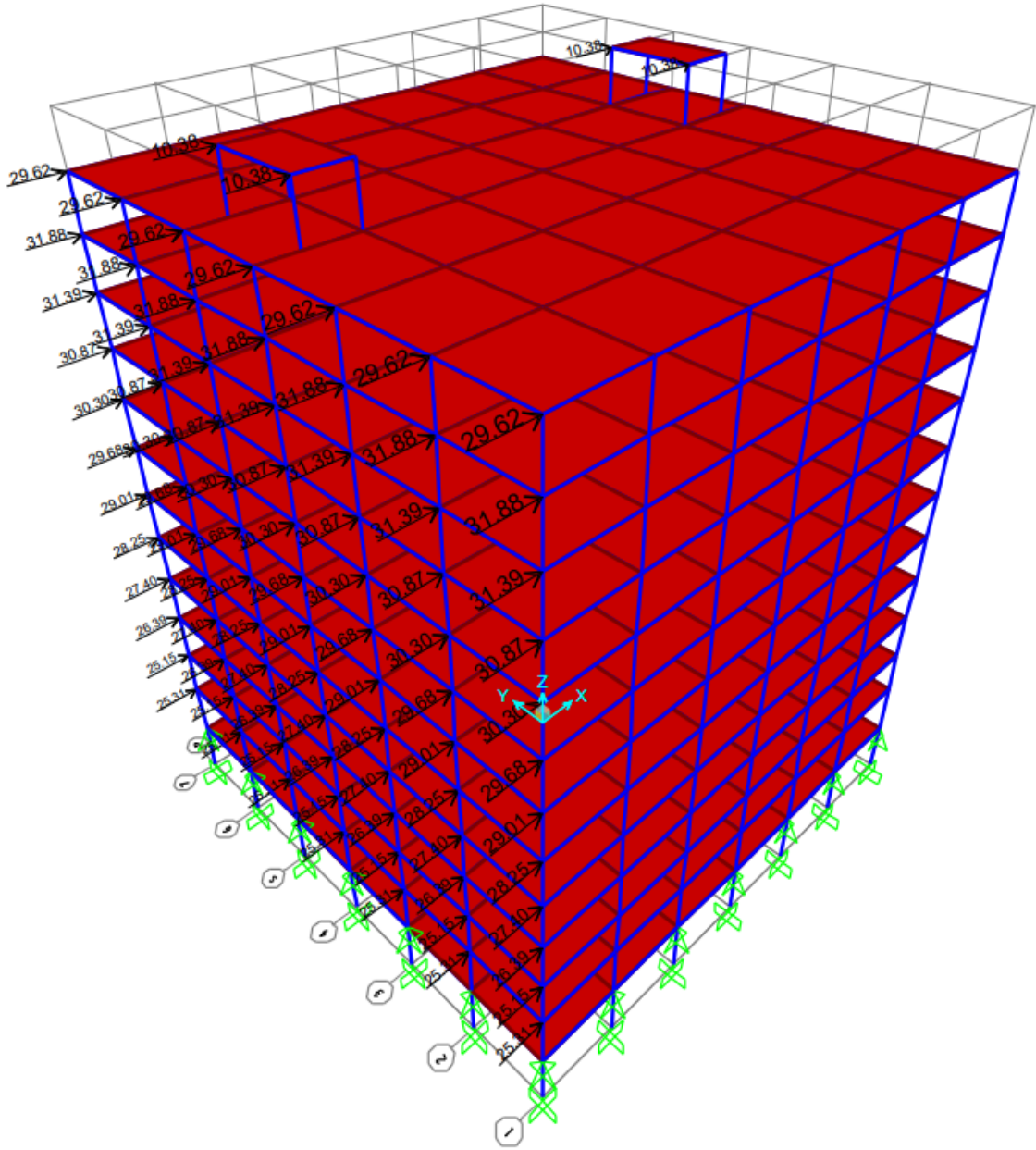
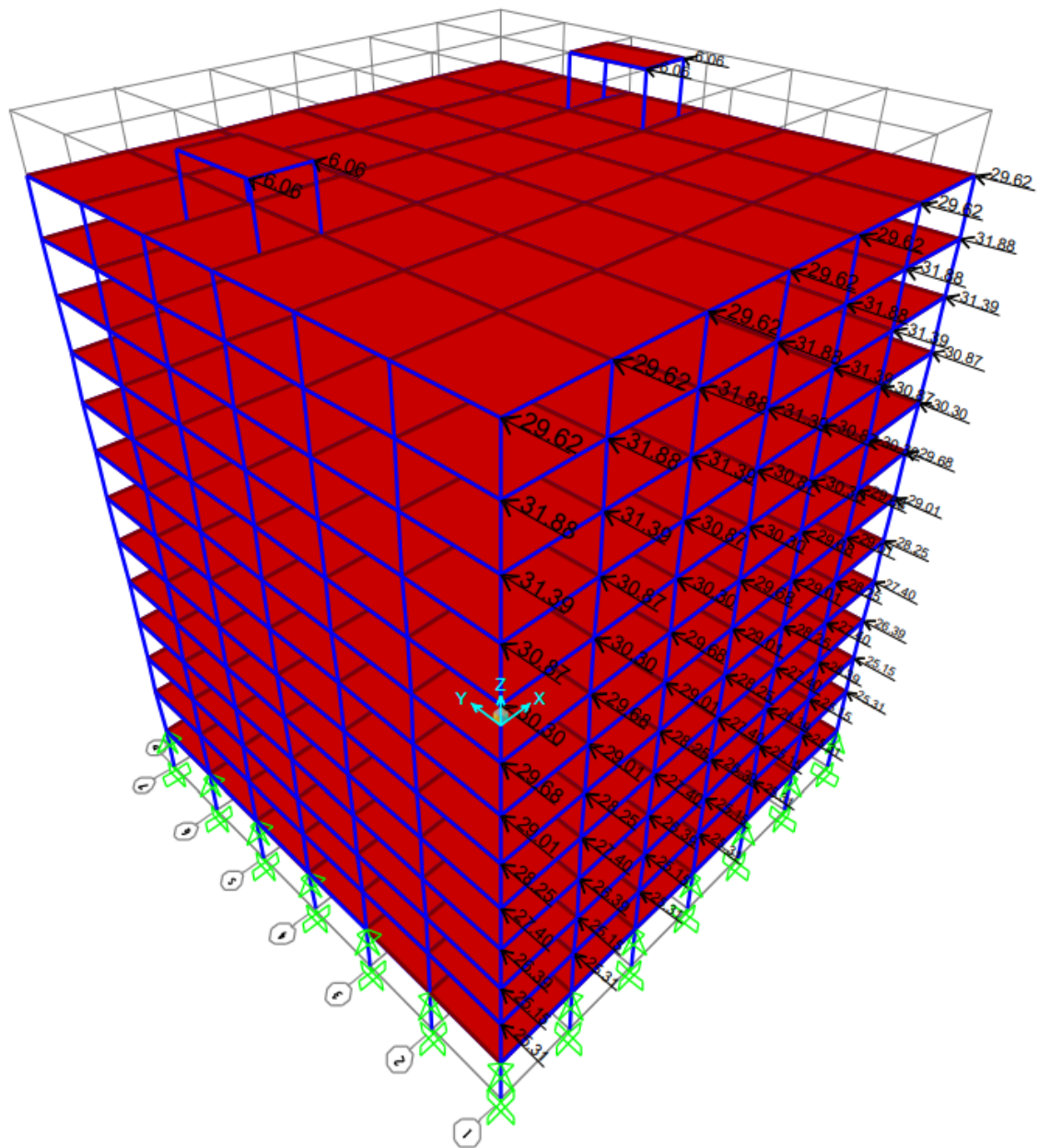


Figure 3.45. 3D Wind Load assignment in X-direction



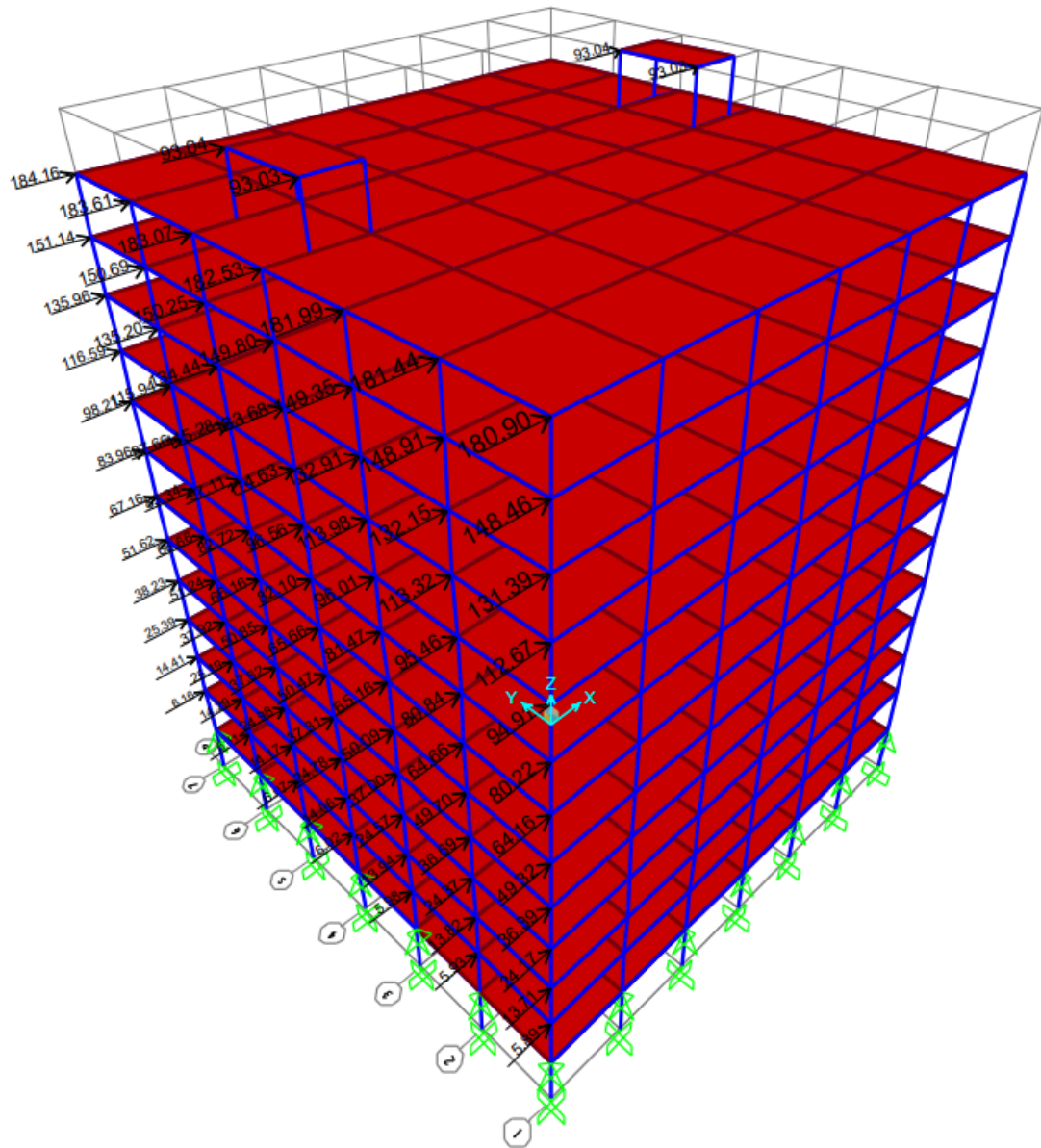


Figure 3.47. 3D Seismic Load assignment in X-direction

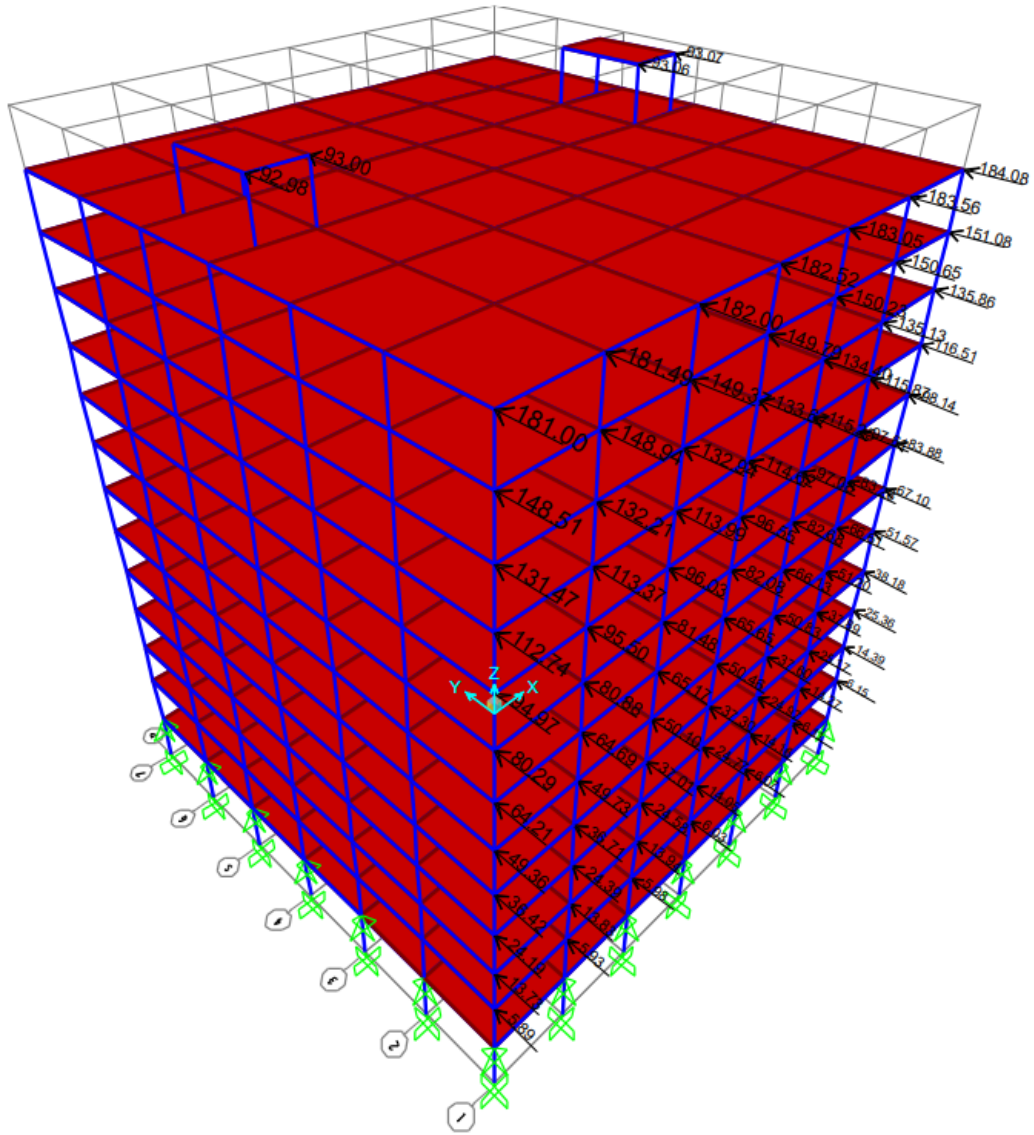


Figure 3.48. 3D Seismic Load assignment in Y-direction

### 3.4.4 Load Combinations

The following load combinations were applied to the SAP2000 model to identify the most critical reaction force at the base. All load combinations are in compliance with the ASCE-7 code.



1.  $1.4D$
2.  $1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$
3.  $1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (L \text{ or } 0.5W)$
4.  $1.2D + 1.0W + L + 0.5(L_r \text{ or } S \text{ or } R)$
5.  $1.2D + 1.0E + L + 0.2S$
6.  $0.9D + 1.0W$
7.  $0.9D + 1.0E$

Figure 3.49. Load Combinations

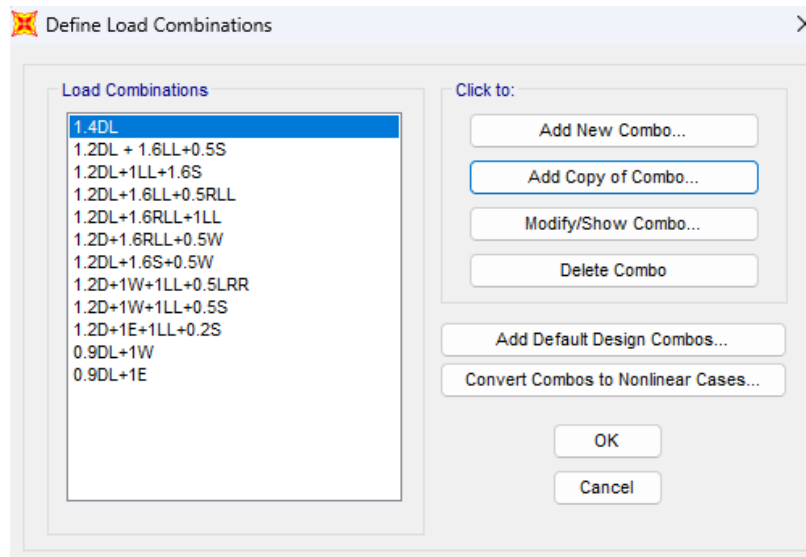


Figure 3.50. Applied load combinations on SAP2000

### 3.5. Lateral Drift Analysis and Check under Wind and Seismic Loads

#### 3.5.1. Wind and Seismic Drifts Calculations

Wind forces and seismic forces' effects on the drift of the structure were examined. Although the building has a square shape, the top roof was examined from X and Y directions for more accurate results. As a part of the drift analysis of the Lateral Force Resisting System, shear and flexural drift with PD effect were calculated.

Shear forces from both wind and seismic loads applied on each floor was calculated using the following formula:

$$V_i = F_i + V_{i+1} \quad (3.35)$$

The base shear on each column per each floor was determined by dividing the floor's shear force to number of frames:

$$V_{i-col} = \frac{V_i}{n} \quad (3.37)$$

Table 3.60. Shear force due to Wind Load

| Floor | $F_i$ (kN) | $V_i$ (kN) | $V_{i-col}$ (kN) | $V_{i-avg}$ (kN) |
|-------|------------|------------|------------------|------------------|
| 12    | 29.62      | 29.62      | 4.9              | 4.9              |
| 11    | 31.88      | 61.50      | 10.3             | 7.6              |
| 10    | 31.39      | 92.89      | 15.5             | 12.9             |
| 9     | 30.87      | 123.76     | 20.6             | 18.1             |
| 8     | 30.30      | 154.06     | 25.7             | 23.2             |
| 7     | 29.68      | 183.75     | 30.6             | 28.2             |
| 6     | 29.01      | 212.75     | 35.5             | 33.0             |
| 5     | 28.25      | 241.01     | 40.2             | 37.8             |
| 4     | 27.40      | 268.40     | 44.7             | 42.5             |
| 3     | 26.39      | 294.79     | 49.1             | 46.9             |
| 2     | 25.15      | 319.95     | 53.3             | 51.2             |
| 1     | 25.31      | 345.26     | 57.5             | 55.4             |
| 0     |            |            |                  | 57.5             |

The critical moments of inertia for both column and beam were calculated. The values are shown below.

Table 3.61. Critical moments of inertia for columns and beams

| Floor | Column size | Beam size | $h_i$ (mm) | $h_{i-avg}$ (mm) | $I_c$ (mm <sup>4</sup> ) | $I_b$ (mm <sup>4</sup> ) | $I_{c-avg}$ (mm <sup>4</sup> ) |
|-------|-------------|-----------|------------|------------------|--------------------------|--------------------------|--------------------------------|
| 12    | 350x350     | 600x300   | 3500       | 3500             | 875364583                | 1890000000               | 875364583                      |
| 11    | 350x350     | 600x300   | 3500       | 3500             | 875364583                | 1890000000               | 875364583                      |
| 10    | 400x400     | 600x300   | 3500       | 3500             | 1493333333               | 1890000000               | 1184348958                     |
| 9     | 400x400     | 600x300   | 3500       | 3500             | 1493333333               | 1890000000               | 1493333333                     |
| 8     | 400x400     | 600x300   | 3500       | 3500             | 1493333333               | 1890000000               | 1493333333                     |
| 7     | 500x500     | 600x300   | 3500       | 3500             | 3645833333               | 1890000000               | 2569583333                     |
| 6     | 500x500     | 600x300   | 3500       | 3500             | 3645833333               | 1890000000               | 3645833333                     |
| 5     | 500x500     | 600x300   | 3500       | 3500             | 3645833333               | 1890000000               | 3645833333                     |
| 4     | 600x600     | 600x300   | 3500       | 3500             | 7560000000               | 1890000000               | 5602916667                     |
| 3     | 600x600     | 600x300   | 3500       | 3500             | 7560000000               | 1890000000               | 7560000000                     |
| 2     | 600x600     | 600x300   | 3500       | 3500             | 7560000000               | 1890000000               | 7560000000                     |
| 1     | 700x700     | 600x300   | 4000       | 3750             | 14005833333              | 1890000000               | 10782916667                    |

|   |  |      |  |             |
|---|--|------|--|-------------|
| 0 |  | 2000 |  | 14005833333 |
|---|--|------|--|-------------|

The lateral shear drift for each floor was calculated using the below formulas:

$$\delta_b^i = \frac{V_{i-avg} h_i^2 L}{12EI_{b,cr}} \quad (3.38)$$

$$\delta_{b,top}^i = \frac{V_{i-avg} h_i^2 L}{48EI_{b,cr}} \quad (3.39)$$

$$\delta_c^i = \frac{V_{i-avg} h_i^3}{12EI_{c,cr}} \quad (3.40)$$

$$\delta_{c,top}^i = \frac{V_{i-avg} h_i^3}{24EI_{c,cr}} \quad (3.41)$$

$$\delta_{c,bot}^i = \frac{V_{i-avg} h_i^3}{3EI_{c,cr}} \quad (3.42)$$

$$\delta_t^i = \delta_b^i + \delta_c^i \quad (3.43)$$

$$\delta_i = \delta_t^i / 2 + \delta_t^{i-1} / 2 \quad (3.44)$$

$$\delta_{i,top} = \delta_t^i + \delta_t^{i-1} / 2 \quad (3.45)$$

$$\delta_{i,bot} = \delta_t^i / 2 + \delta_t^{i-1} \quad (3.46)$$

$$\Delta_i = \sum_i^n \delta_t^i \quad (3.47)$$

where,

$\delta_c^i$  – inter-story drift calculated for columns

$\delta_b^i$  – inter-story drift calculated for beams

$\delta_t^i$  – total inter-story drift

$\Delta_i$  – absolute drift

Table 3.62. Lateral Shear Drift due to Wind Load

| Floor | $\delta_b$ (mm) | $\delta_c$ (mm) | $\delta_t$ (mm) | $\delta_i$ (mm) | $\Delta_i$ (mm) |
|-------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 12    | 0.13            | 0.63            | 0.76            | 2.14            | 57.10           |
| 11    | 0.83            | 1.93            | 2.76            | 2.87            | 54.96           |
| 10    | 1.40            | 1.57            | 2.98            | 3.20            | 52.09           |
| 9     | 1.97            | 1.45            | 3.42            | 3.90            | 48.89           |
| 8     | 2.52            | 1.86            | 4.39            | 4.60            | 44.99           |
| 7     | 3.07            | 1.74            | 4.81            | 5.04            | 40.39           |

|   |      |      |      |      |       |
|---|------|------|------|------|-------|
| 6 | 3.60 | 1.66 | 5.26 | 5.64 | 35.35 |
| 5 | 4.12 | 1.90 | 6.02 | 5.99 | 29.71 |
| 4 | 4.63 | 1.32 | 5.95 | 6.06 | 23.73 |
| 3 | 5.12 | 1.06 | 6.17 | 6.20 | 17.66 |
| 2 | 5.16 | 1.06 | 6.22 | 6.95 | 11.47 |
| 1 | 6.40 | 1.27 | 7.67 | 4.52 | 4.52  |
| 0 |      | 0.68 | 0.68 |      |       |

For calculation of the lateral flexural drift, the moment of each level was determined by multiplying the height of the floor and shear base at the top of the floor, while considering all the forces from upper floors.

$$M_{top} = h_{top} \cdot V_{top} \quad (3.48)$$

$$M_i = h_i \cdot V_i + M_{i+1} \quad (3.49)$$

Then to determine the lateral deflection the following equations were used:

$$\phi_i = \frac{2M_i}{E(mL)^2 A_c} \quad (3.50)$$

$$\Delta\theta = \phi_i h_i \quad (3.51)$$

$$\theta_i = \sum_i^n \Delta\theta_i \rightarrow \Delta\theta_i + \theta_{i-1} \quad (3.52)$$

$$\delta_i = \theta_i h_i \quad (3.53)$$

$$\Delta_i = \sum_i^n \delta_i \quad (3.54)$$

Table 3.63. Lateral Flexural Drift due to Wind Load

| Floor | F <sub>i</sub> (kN) | V <sub>i</sub> (kN) | M <sub>i</sub> (k-m) | A <sub>ci</sub> (mm <sup>2</sup> ) | φ <sub>i</sub> (mm <sup>-1</sup> ) | Δθ <sub>i</sub> (rad) | θ <sub>i</sub> (rad) | δ <sub>i</sub> (mm) | Δ <sub>i</sub> (mm) |
|-------|---------------------|---------------------|----------------------|------------------------------------|------------------------------------|-----------------------|----------------------|---------------------|---------------------|
| 12    | 29.62               | 29.62               | 103.7                | 122500                             | 5.98E-11                           | 2.09E-07              | 2.82E-05             | 0.10                | 0.84                |
| 11    | 31.88               | 61.50               | 318.9                | 122500                             | 1.84E-10                           | 6.44E-07              | 2.79E-05             | 0.10                | 0.75                |
| 10    | 31.39               | 92.89               | 644.1                | 160000                             | 2.09E-10                           | 7.31E-07              | 2.73E-05             | 0.10                | 0.65                |
| 9     | 30.87               | 123.76              | 1077.2               | 160000                             | 3.50E-10                           | 1.22E-06              | 2.66E-05             | 0.09                | 0.55                |
| 8     | 30.30               | 154.06              | 1616.4               | 160000                             | 5.24E-10                           | 1.84E-06              | 2.53E-05             | 0.09                | 0.46                |
| 7     | 29.68               | 183.75              | 2259.5               | 250000                             | 5.79E-10                           | 2.03E-06              | 2.35E-05             | 0.08                | 0.37                |
| 6     | 29.01               | 212.75              | 3004.2               | 250000                             | 7.70E-10                           | 2.70E-06              | 2.15E-05             | 0.08                | 0.29                |
| 5     | 28.25               | 241.01              | 3847.7               | 250000                             | 9.86E-10                           | 3.45E-06              | 1.88E-05             | 0.07                | 0.21                |
| 4     | 27.40               | 268.40              | 4787.1               | 360000                             | 8.22E-10                           | 2.88E-06              | 1.53E-05             | 0.05                | 0.15                |

|   |       |        |        |        |          |          |          |      |      |
|---|-------|--------|--------|--------|----------|----------|----------|------|------|
| 3 | 26.39 | 294.79 | 5818.9 | 360000 | 9.99E-10 | 3.50E-06 | 1.25E-05 | 0.04 | 0.09 |
| 2 | 25.15 | 319.95 | 6938.7 | 360000 | 1.19E-09 | 4.17E-06 | 8.97E-06 | 0.03 | 0.05 |
| 1 | 25.31 | 345.26 | 8319.8 | 490000 | 1.20E-09 | 4.80E-06 | 4.80E-06 | 0.02 | 0.02 |

Using the same method and formulas, the drift caused by seismic load was calculated. The same procedure was applied, just different lateral loads were inputted and different limit checks were applied. The seismic load was recalculated using  $T^*$  as  $T$ .

Table 3.64. Shear force due to Seismic Load

| Floor | $F_i$ (kN) | $V_i$ (kN) | $V_{i-col}$ (kN) | $V_{i-avg}$ (kN) |
|-------|------------|------------|------------------|------------------|
| 12    | 182.38     | 182.38     | 30.4             | 30.4             |
| 11    | 149.68     | 332.06     | 55.3             | 42.9             |
| 10    | 133.57     | 465.63     | 77.6             | 66.5             |
| 9     | 114.54     | 580.16     | 96.7             | 87.1             |
| 8     | 96.48      | 676.64     | 112.8            | 104.7            |
| 7     | 80.67      | 757.32     | 126.2            | 119.5            |
| 6     | 64.52      | 821.84     | 137.0            | 131.6            |
| 5     | 49.60      | 871.44     | 145.2            | 141.1            |
| 4     | 37.28      | 908.71     | 151.5            | 148.3            |
| 3     | 24.76      | 933.47     | 155.6            | 153.5            |
| 2     | 14.05      | 947.52     | 157.9            | 156.7            |
| 1     | 6.02       | 953.54     | 158.9            | 158.4            |
| 0     |            |            |                  | 158.9            |

Table 3.65. Critical moments of inertia for columns and beams

| Floor | Column size | Beam size | $h_i$ (mm) | $h_{i-avg}$ (mm) | $I_c$ (mm <sup>4</sup> ) | $I_b$ (mm <sup>4</sup> ) | $I_{c-avg}$ (mm <sup>4</sup> ) |
|-------|-------------|-----------|------------|------------------|--------------------------|--------------------------|--------------------------------|
| 12    | 350x350     | 600x300   | 3500       | 3500             | 875364583                | 1890000000               | 875364583                      |
| 11    | 350x350     | 600x300   | 3500       | 3500             | 875364583                | 1890000000               | 875364583                      |
| 10    | 400x400     | 600x300   | 3500       | 3500             | 1493333333               | 1890000000               | 1184348958                     |
| 9     | 400x400     | 600x300   | 3500       | 3500             | 1493333333               | 1890000000               | 1493333333                     |
| 8     | 400x400     | 600x300   | 3500       | 3500             | 1493333333               | 1890000000               | 1493333333                     |
| 7     | 500x500     | 600x300   | 3500       | 3500             | 3645833333               | 1890000000               | 2569583333                     |
| 6     | 500x500     | 600x300   | 3500       | 3500             | 3645833333               | 1890000000               | 3645833333                     |
| 5     | 500x500     | 600x300   | 3500       | 3500             | 3645833333               | 1890000000               | 3645833333                     |
| 4     | 600x600     | 600x300   | 3500       | 3500             | 7560000000               | 1890000000               | 5602916667                     |

|   |         |         |      |      |             |            |             |
|---|---------|---------|------|------|-------------|------------|-------------|
| 3 | 600x600 | 600x300 | 3500 | 3500 | 7560000000  | 1890000000 | 7560000000  |
| 2 | 600x600 | 600x300 | 3500 | 3500 | 7560000000  | 1890000000 | 7560000000  |
| 1 | 700x700 | 600x300 | 4000 | 3750 | 14005833333 | 1890000000 | 10782916667 |
| 0 |         |         |      | 2000 |             |            | 14005833333 |

Table 3.66. Lateral Shear Drift due to Seismic Load

| Floor | $\delta_b$ (mm) | $\delta_c$ (mm) | $\delta_t$ (mm) | $\delta_i$ (mm) | $\Delta_i$ (mm) |
|-------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 12    | 0.34            | 3.16            | 3.50            | 8.76            | 111.45          |
| 11    | 1.86            | 8.66            | 10.52           | 11.15           | 102.70          |
| 10    | 2.76            | 9.03            | 11.78           | 11.98           | 91.54           |
| 9     | 3.46            | 8.72            | 12.18           | 13.11           | 79.56           |
| 8     | 3.99            | 10.05           | 14.04           | 12.16           | 66.46           |
| 7     | 4.38            | 5.91            | 10.28           | 9.61            | 54.30           |
| 6     | 4.65            | 4.29            | 8.94            | 9.11            | 44.68           |
| 5     | 4.83            | 4.45            | 9.28            | 8.52            | 35.57           |
| 4     | 4.94            | 2.82            | 7.76            | 7.41            | 27.05           |
| 3     | 5.00            | 2.07            | 7.07            | 7.09            | 19.64           |
| 2     | 5.03            | 2.08            | 7.11            | 7.50            | 12.55           |
| 1     | 5.78            | 2.12            | 7.90            | 5.05            | 5.05            |
| 0     |                 | 1.10            | 1.10            |                 |                 |

Table 3.67. Lateral Flexural Drift due to Seismic Load

| Floor | $F_i$ (kN) | $V_i$ (kN) | $M_i$ (k-m) | $A_{ci}$ (mm <sup>2</sup> ) | $\phi_i$ (mm <sup>-1</sup> ) | $\Delta\theta_i$ (rad) | $\theta_i$ (rad) | $\delta_i$ (mm) | $\Delta_i$ (mm) |
|-------|------------|------------|-------------|-----------------------------|------------------------------|------------------------|------------------|-----------------|-----------------|
| 12    | 182.4      | 182.4      | 638.3       | 122500                      | 5.01E-10                     | 1.75E-06               | 1.43E-04         | 0.50            | 3.92            |
| 11    | 149.7      | 332.1      | 1800.5      | 122500                      | 1.38E-09                     | 4.81E-06               | 1.41E-04         | 0.49            | 3.42            |
| 10    | 133.6      | 465.6      | 3430.2      | 160000                      | 1.87E-09                     | 6.54E-06               | 1.36E-04         | 0.48            | 2.93            |
| 9     | 114.5      | 580.2      | 5460.8      | 160000                      | 2.89E-09                     | 1.01E-05               | 1.30E-04         | 0.45            | 2.45            |
| 8     | 96.5       | 676.6      | 7829.1      | 160000                      | 4.04E-09                     | 1.41E-05               | 1.20E-04         | 0.42            | 2.00            |
| 7     | 80.7       | 757.3      | 10479.7     | 250000                      | 3.19E-09                     | 1.12E-05               | 1.05E-04         | 0.37            | 1.58            |
| 6     | 64.5       | 821.8      | 13356.1     | 250000                      | 3.98E-09                     | 1.39E-05               | 9.43E-05         | 0.33            | 1.21            |
| 5     | 49.6       | 871.4      | 16406.1     | 250000                      | 4.78E-09                     | 1.67E-05               | 8.04E-05         | 0.28            | 0.88            |
| 4     | 37.3       | 908.7      | 19586.6     | 360000                      | 3.75E-09                     | 1.31E-05               | 6.37E-05         | 0.22            | 0.60            |

|   |      |       |         |        |          |          |          |      |      |
|---|------|-------|---------|--------|----------|----------|----------|------|------|
| 3 | 24.8 | 933.5 | 22853.8 | 360000 | 4.30E-09 | 1.51E-05 | 5.05E-05 | 0.18 | 0.37 |
| 2 | 14.0 | 947.5 | 26170.1 | 360000 | 4.86E-09 | 1.70E-05 | 3.55E-05 | 0.12 | 0.20 |
| 1 | 6.0  | 953.5 | 29984.2 | 490000 | 4.62E-09 | 1.85E-05 | 1.85E-05 | 0.07 | 0.07 |

### 3.5.2. Comparison of lateral drifts for hand, 2D and 3D SAP calculations

The lateral drifts from SAP2000 2D and 3D models for Frame 2 were compared with lateral drifts hand calculations induced by wind and seismic loads. Each story must act as a separate resisting frame for accurate seismic resistance, so the inter-story seismic deflections were amplified to account for the maximum inelastic displacement ( $\delta_x$ ) by using the following equation: (ASCE, 2016).

$$\delta_x = \frac{C_d \delta_{xe}}{I_e} \quad (3.55)$$

Where  $\delta_{xe}$  is an interstory elastic deflection and  $C_d$  is the deflection amplification factor. The maximum inelastic displacement should not be greater than the allowable story drift limit:

$$\delta_{allow} = 0.020h_{sx} \quad (3.56)$$

Where  $h_{sx}$  is the story height for the floor being considered.

The allowable inter-story drift for the wind was assumed to be  $h/500$ . All the wind inter-story deflections passed this limit check.

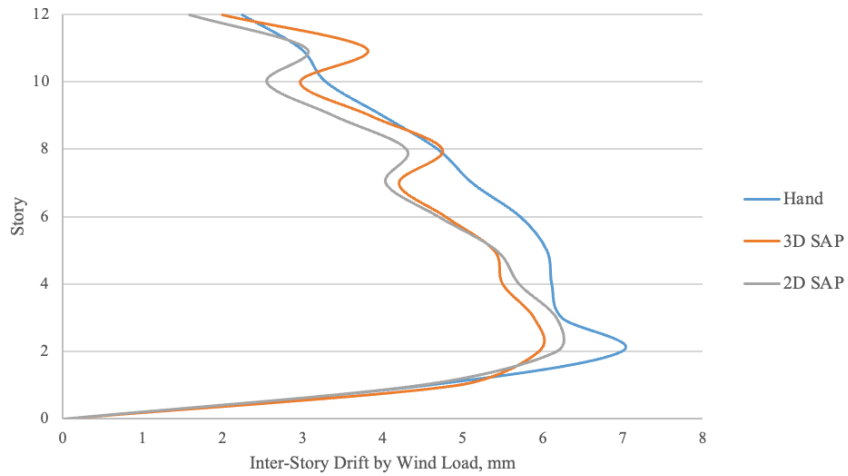


Figure 3.51. Comparison of inter-story deflections under wind loads for Frame 3

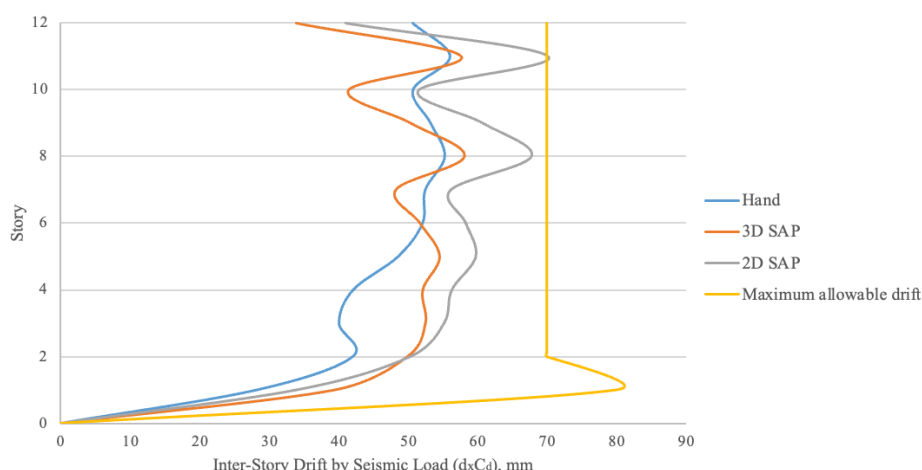


Figure 3.52. Comparison of inter-story deflections under seismic load for Frame 3

Figures 3.51 and 3.52 demonstrate that the wind and seismic deflection values for 2D, 3D and hand calculations are almost the same. Nevertheless, deflection found by hand calculation has a different pattern, particularly more plain and less curvy than the computational results. However, it should be noted that the different calculational methods were used by SAP2000 and hand calculation, with SAP2000 being more accurate and hand calculation elaborating some assumptions in the calculation. All the drifts were within the maximum allowable drift limits satisfying the structural safety.

### 3.5.3. Stability Analysis

The necessity of P-delta effect for the calculations of drift is identified through calculating stability coefficient ( $\theta$ ):

$$\theta = \frac{P_x \Delta I_e}{V_x h_{sx} C_d} \quad (3.57)$$

The stability coefficient should not exceed  $\theta_{max}$ :

$$\theta_{max} = \frac{0.5}{\beta C_d} \leq 0.25 \quad (3.58)$$

Where  $\beta$ , the ratio of shear demand to shear capacity, is taken as 1.0

In the current case, maximum stability coefficient is 0.1. By using the previously obtained values of shear and axial forces, the stability coefficient was calculated for each floor. The results are illustrated below:

Table 3.68. Stability Coefficient

| Story | Shear, mm  |          | Flexural, mm |          | Total, mm  |          | $V_u$ , kN | $P_u$ , kN | $\theta$ |
|-------|------------|----------|--------------|----------|------------|----------|------------|------------|----------|
|       | Interstory | Absolute | Interstory   | Absolute | Interstory | Absolute |            |            |          |
| 12    | 6.54       | 89.81    | 0.41         | 3.41     | 6.96       | 93.22    | 182.4      | 11611.2    | 0.0230   |
| 11    | 7.50       | 83.27    | 0.41         | 2.99     | 7.91       | 86.26    | 332.1      | 34528.4    | 0.0427   |
| 10    | 7.06       | 75.77    | 0.40         | 2.58     | 7.45       | 78.35    | 465.6      | 57445.6    | 0.0478   |



|   |      |       |      |      |      |       |       |          |        |
|---|------|-------|------|------|------|-------|-------|----------|--------|
| 9 | 7.77 | 68.72 | 0.38 | 2.19 | 8.16 | 70.90 | 580.2 | 80362.9  | 0.0587 |
| 8 | 8.41 | 60.95 | 0.36 | 1.80 | 8.78 | 62.75 | 676.6 | 103280.1 | 0.0696 |
| 7 | 8.31 | 52.53 | 0.33 | 1.44 | 8.64 | 53.97 | 757.3 | 126197.3 | 0.0748 |
| 6 | 8.57 | 44.22 | 0.30 | 1.11 | 8.87 | 45.33 | 821.8 | 149114.5 | 0.0836 |
| 5 | 8.24 | 35.65 | 0.26 | 0.81 | 8.50 | 36.46 | 871.4 | 172031.8 | 0.0872 |
| 4 | 7.36 | 27.41 | 0.20 | 0.55 | 7.56 | 27.96 | 908.7 | 194949.0 | 0.0843 |
| 3 | 7.17 | 20.05 | 0.16 | 0.35 | 7.33 | 20.40 | 933.5 | 217866.2 | 0.0889 |
| 2 | 7.69 | 12.88 | 0.12 | 0.18 | 7.80 | 13.07 | 947.5 | 240783.4 | 0.1030 |
| 1 | 5.20 | 5.20  | 0.07 | 0.07 | 5.26 | 5.26  | 953.5 | 263700.7 | 0.0662 |

As can be seen from the table, each stability coefficient value is less than 0.1, thus the gravity loads due to the P-delta can be neglected in the design.

#### 3.5.4. Torsional Irregularity Check

The torsional irregularity check was carried out on the seismic drift. For a building to have torsional irregularity, the maximum story drift at one end of the structure must be more than 1.2 times the average of the story drifts at the two ends of the structure. Thus, two more deflections were determined from Frame A and G, and compared through the ratio as shown on the table below:

Table 3.69. Torsional Irregularity Check

| Torsional Irregularity Check |       |
|------------------------------|-------|
| Story                        | Ratio |
| 12                           | 1.009 |
| 11                           | 1.010 |
| 10                           | 1.012 |
| 9                            | 1.013 |
| 8                            | 1.014 |
| 7                            | 1.014 |
| 6                            | 1.015 |
| 5                            | 1.015 |
| 4                            | 1.016 |
| 3                            | 1.016 |
| 2                            | 1.016 |
| 1                            | 1.016 |

Since ratios on each building are less than the limit of 1.2, no type of torsional irregularity is indicated.

### 3.6. Internal Force Analysis

For the internal force analysis dead and wind loads were chosen for the verification. Below you can find all the dead load and wind load internal force results provided by the SAP 2000 software for both 3D and 2D frames.

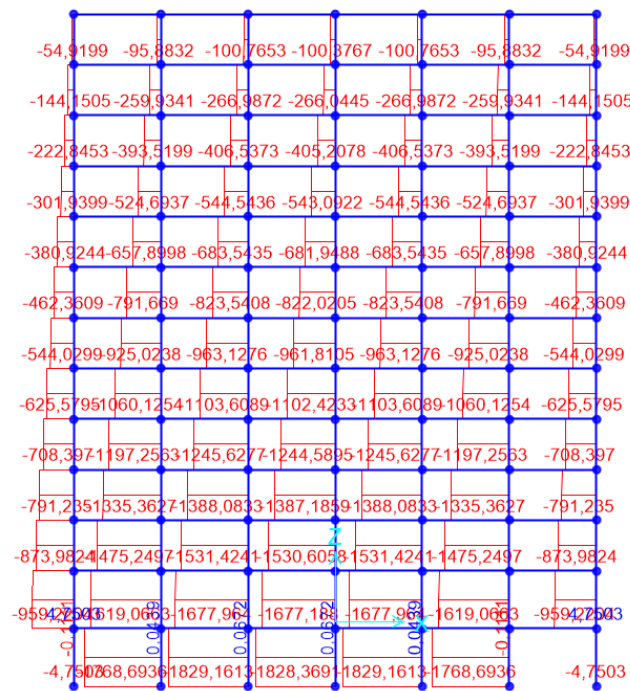


Figure 3.53. Axial Force of Dead Load from SAP2000 3D frame

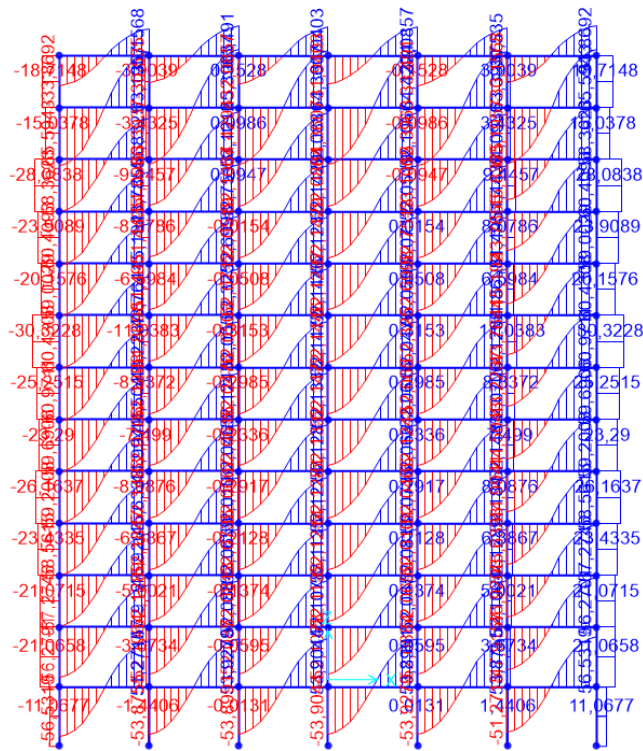


Figure 3.54. Shear Force of Dead Load from SAP2000 3D frame

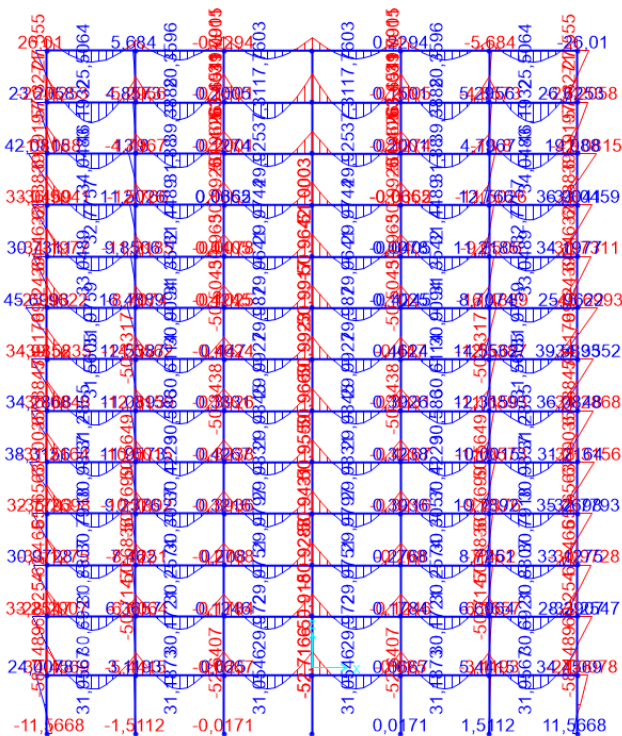


Figure 3.55. Moment Diagram of Dead Load from SAP2000 3D frame

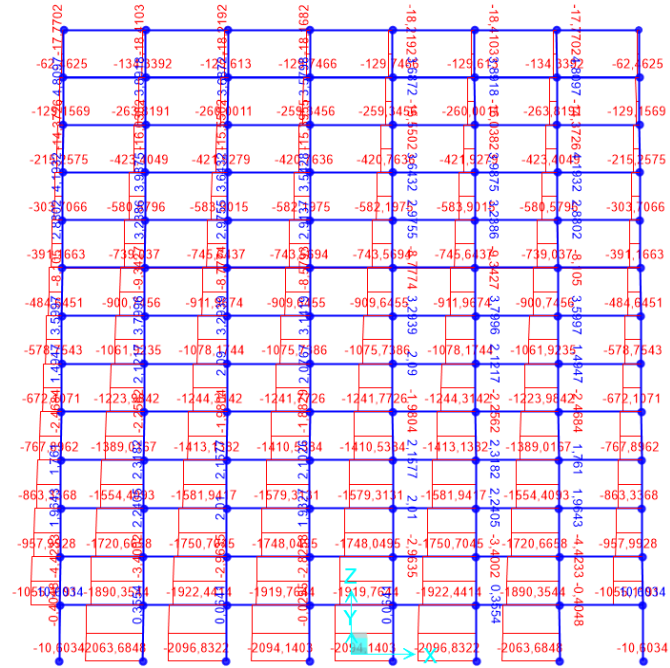


Figure 3.56. Axial Force of Dead Load from SAP2000 2D frame

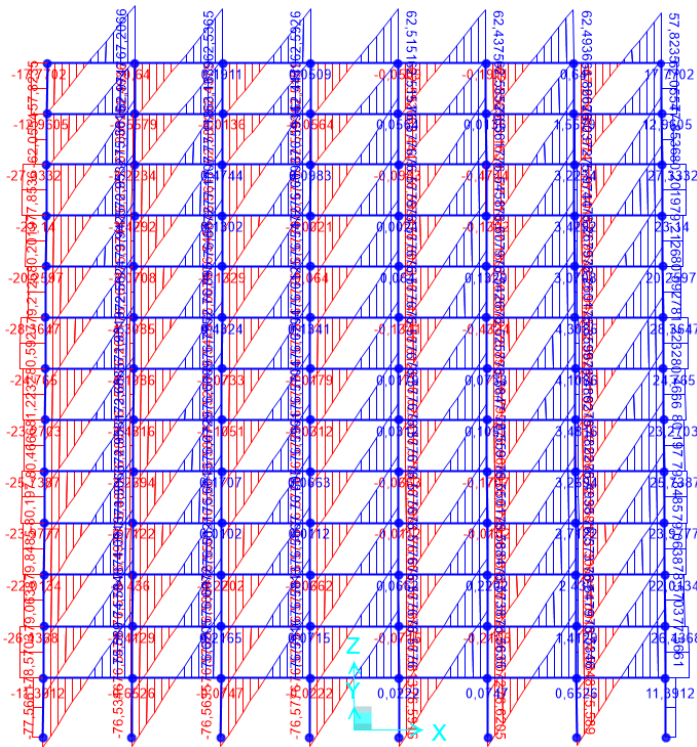


Figure 3.57. Shear Force of Dead Load from SAP2000 2D frame

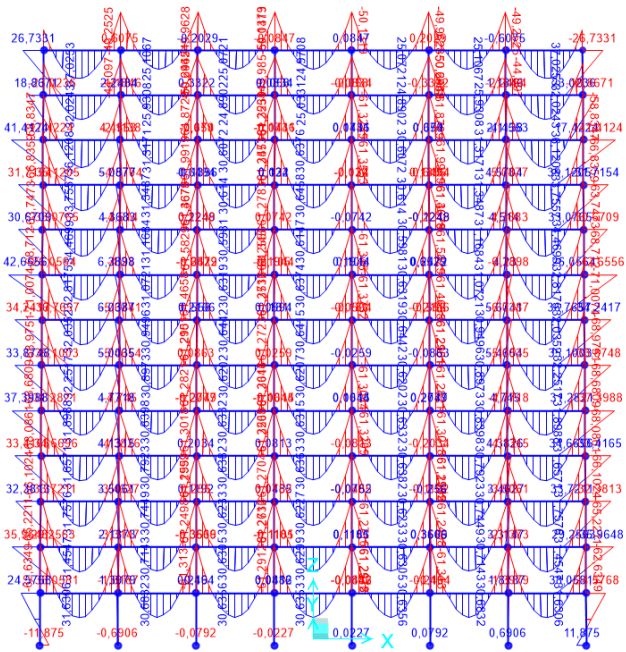


Figure 3.58. Moment Diagram of Dead Load from SAP2000 2D frame

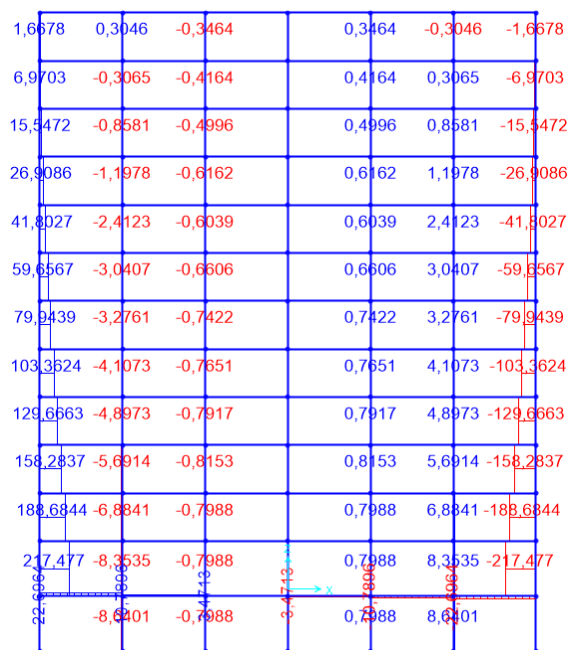


Figure 3.59. Axial Force of Wind Load from SAP2000 3D frame

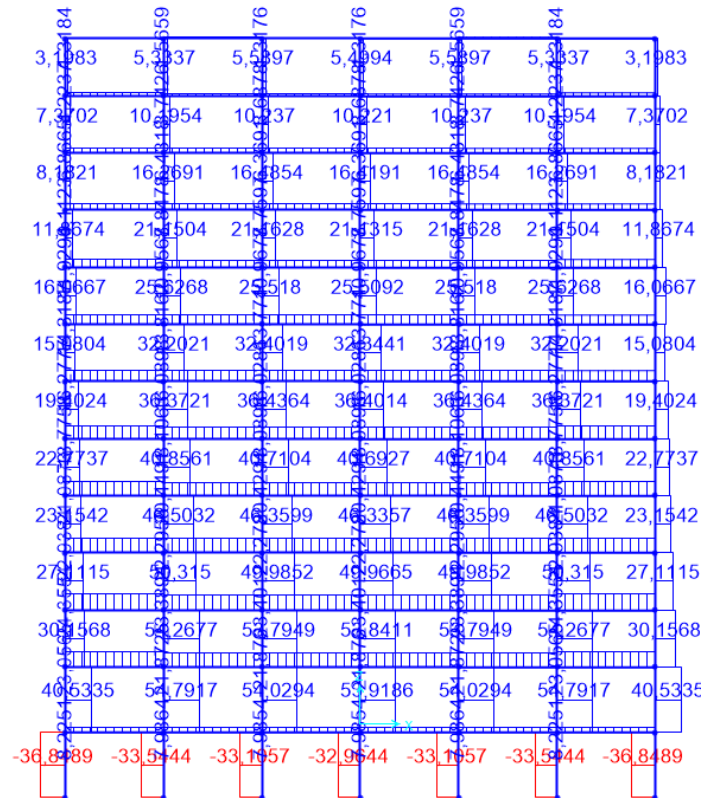


Figure 3.60. Shear Force of Wind Load from SAP2000 3D frame

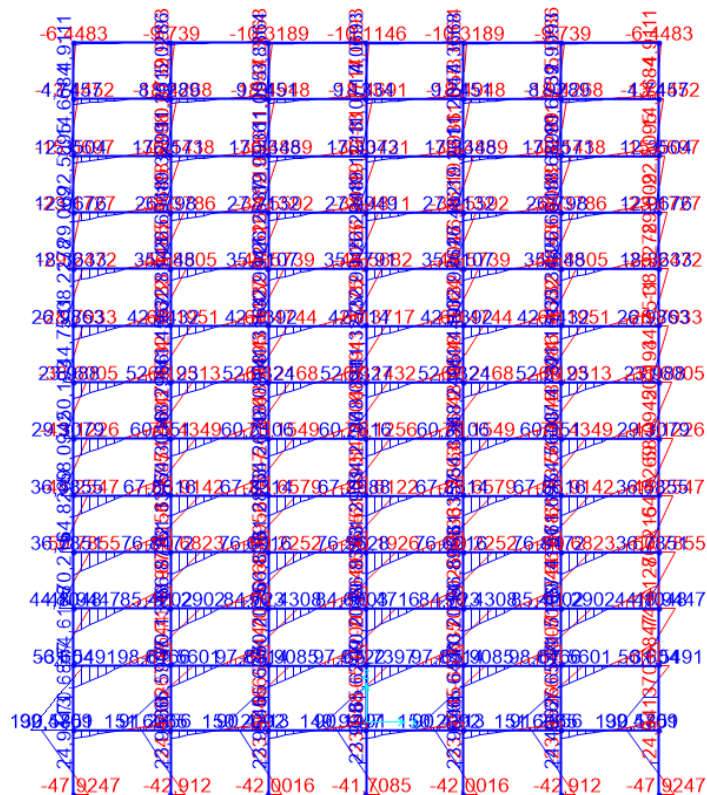


Figure 3.61. Moment Diagram of Wind Load from SAP2000 3D frame

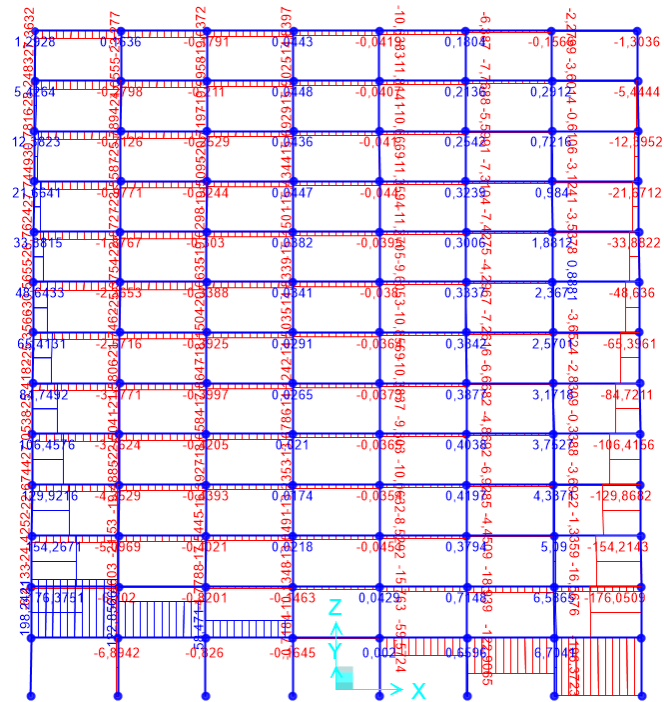


Figure 3.62. Axial Force of Wind Load from SAP2000 2D frame



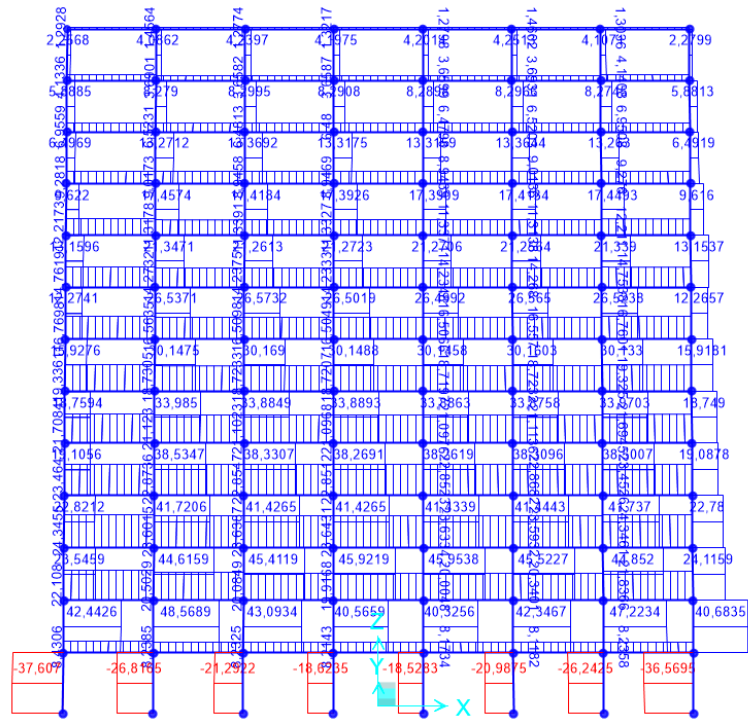


Figure 3.63. Shear Force of Wind Load from SAP2000 2D frame

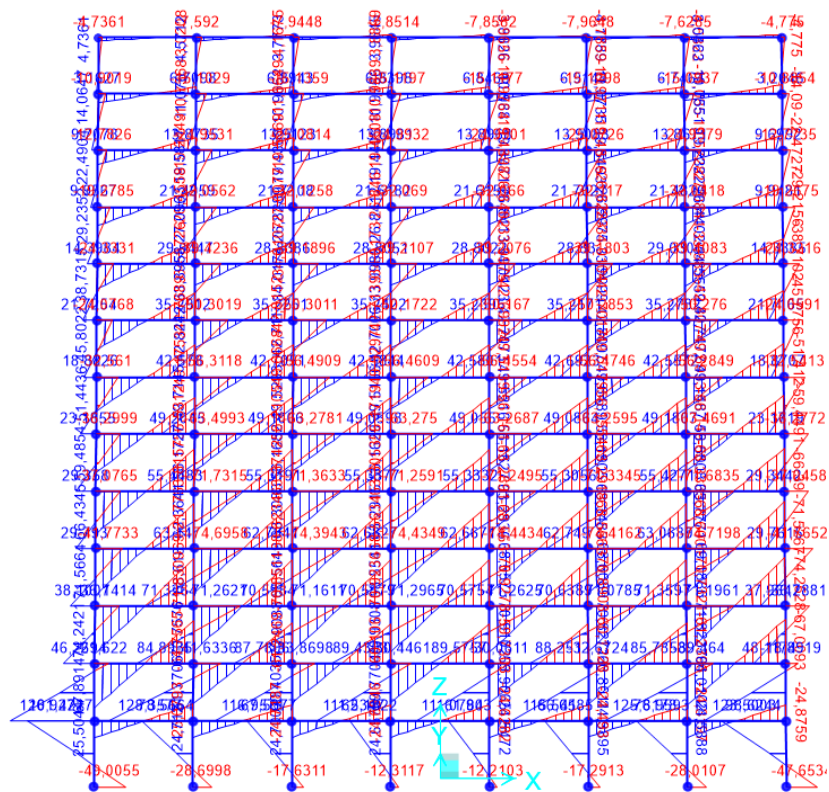


Figure 3.64. Moment Diagram of Wind Load from SAP2000 2D frame



### 3.6.1. Dead Load Internal Force Calculations

To verify the SAP2000 results, the internal forces under the dead load were first calculated using the approximate analysis of the statically indeterminate structures. For this inflection point was taken to be at 0.1L location from both sides. The general load arrangement on internal beams can be seen on the following figure:

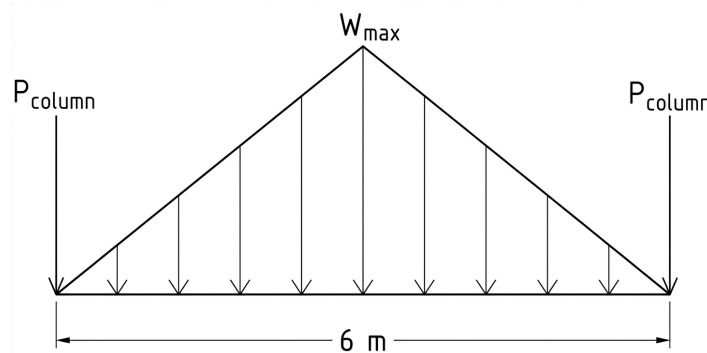


Figure 3.65. Load arrangement for internal beams

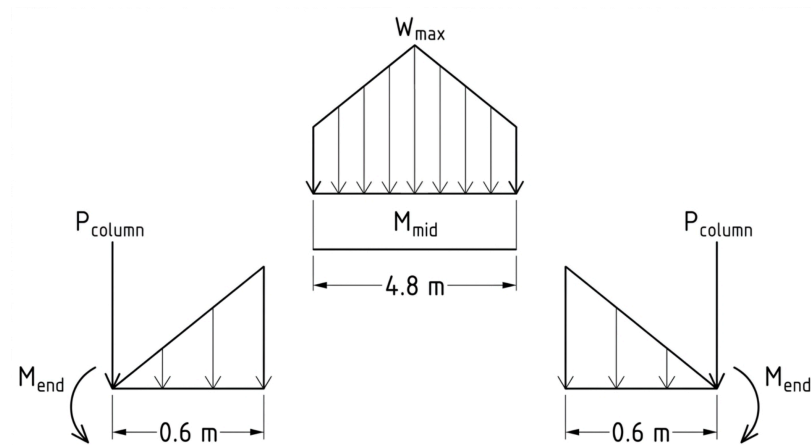


Figure 3.66. Load arrangement for approximate analysis method

The hand calculations were performed for every frame member. The detailed hand calculation procedure can be found in Appendix. The general results were illustrated in the following diagrams:

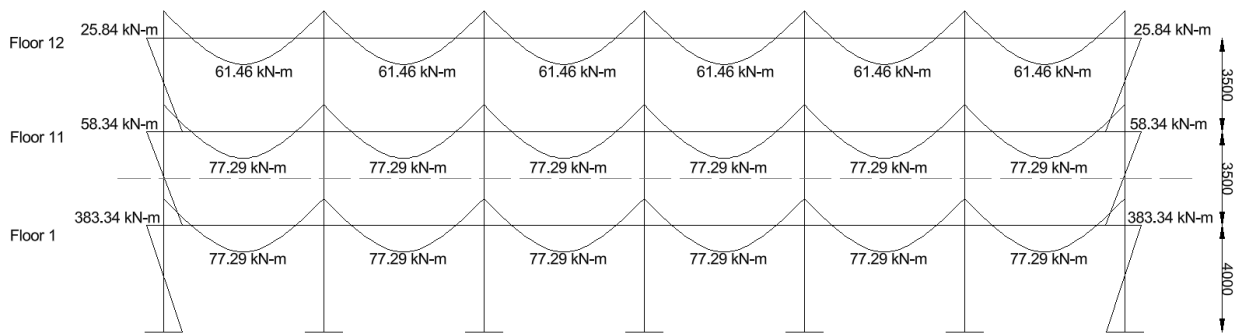


Figure 3.67. Moment frame diagram

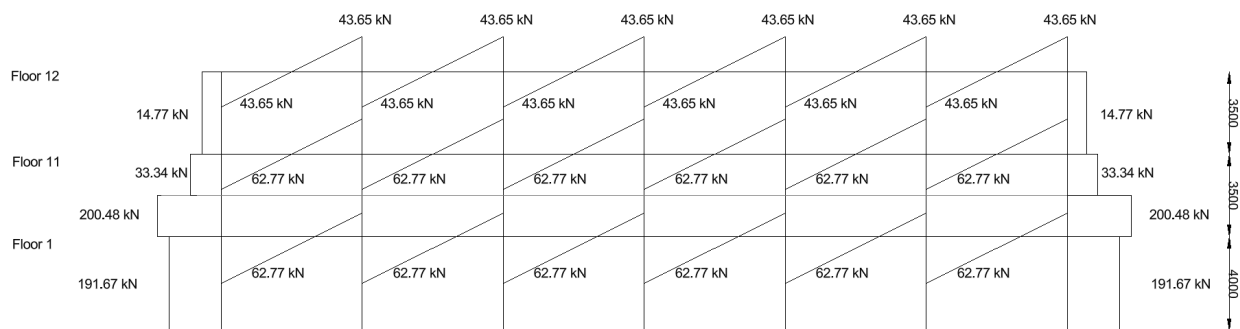


Figure 3.68. Shear force diagram

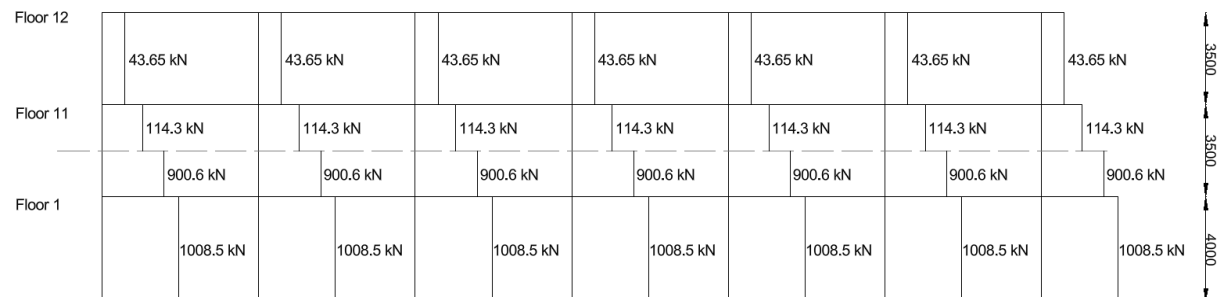


Figure 3.69. Axial force diagram

The comparative tables were made to illustrate the difference between the hand calculations and SAP 2000 results. On the following tables, comparisons between axial force, shear force and moment can be seen:

Table 3.70. Comparison of Column Axial Forces under Dead Load

| Story | Hand, kN | SAP 3D, kN | SAP 2D, kN |
|-------|----------|------------|------------|
| 12    | 43.7     | 68.0       | 59.8       |
| 11    | 114.3    | 173.7      | 121.4      |
| 10    | 184.9    | 268.4      | 193.5      |
| 9     | 261.3    | 363.9      | 266.7      |
| 8     | 337.6    | 459.0      | 339.4      |

|   |         |         |       |
|---|---------|---------|-------|
| 7 | 414.0   | 557.1   | 420.1 |
| 6 | 504.3   | 655.6   | 501.2 |
| 5 | 594.6   | 753.6   | 581.9 |
| 4 | 685.0   | 853.0   | 666.8 |
| 3 | 792.8   | 952.2   | 751.7 |
| 2 | 900.6   | 1,051.0 | 836.2 |
| 1 | 1,008.5 | 1,152.6 | 925.3 |

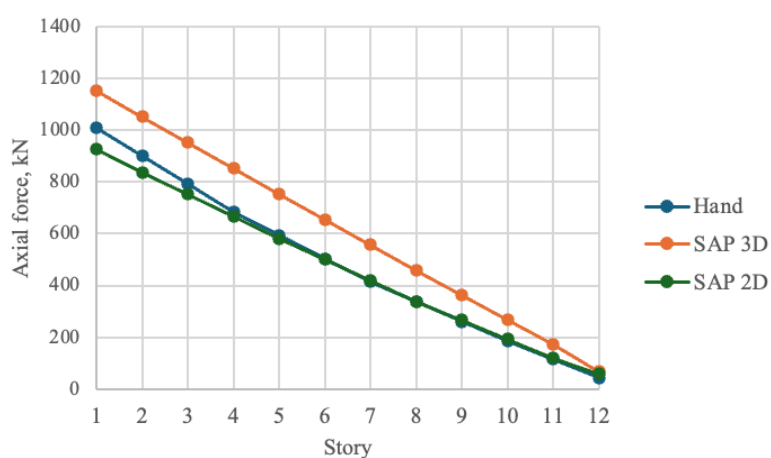


Figure 3.70. Comparison of Axial Force under Dead Load for Hand Calculations and SAP2000

Table 3.71. Comparison of Beam Shear Forces under Dead Load

| Story | Hand, kN | SAP 3D, kN | SAP 2D, kN |
|-------|----------|------------|------------|
| 12    | 20.00    | 20.57      | 15.82      |
| 11    | 22.29    | 15.26      | 11.26      |
| 10    | 22.29    | 30.38      | 22.93      |
| 9     | 22.29    | 25.95      | 19.50      |
| 8     | 22.29    | 22.22      | 17.08      |
| 7     | 22.29    | 33.27      | 23.94      |
| 6     | 22.29    | 28.29      | 20.94      |
| 5     | 22.29    | 26.59      | 19.70      |
| 4     | 22.29    | 30.33      | 21.81      |
| 3     | 22.29    | 28.31      | 20.35      |
| 2     | 22.29    | 26.26      | 18.73      |
| 1     | 22.29    | 27.45      | 22.52      |

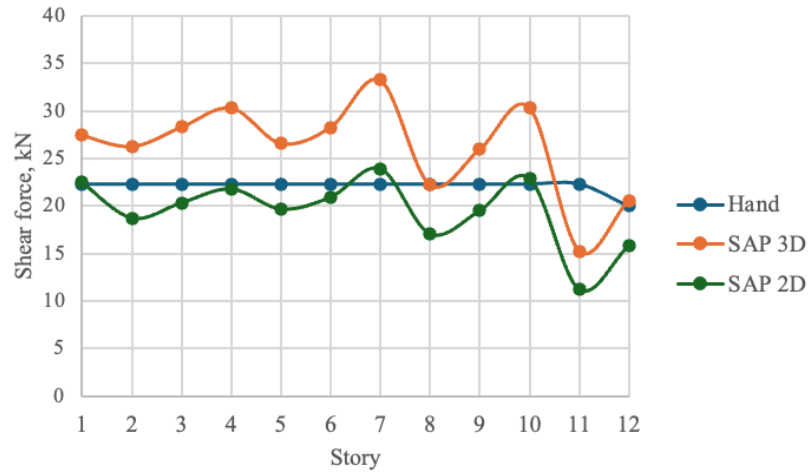


Figure 3.71. Comparison of Shear Force under Dead Load for Hand Calculations and SAP2000

Table 3.72. Comparison of Beam Moments under Dead Load

| Story | Hand, kN | SAP 3D, kN | SAP 2D, kN |
|-------|----------|------------|------------|
| 12    | 25.84    | 24.77      | 29.70      |
| 11    | 32.50    | 19.13      | 20.70      |
| 10    | 32.50    | 38.39      | 43.35      |
| 9     | 32.50    | 29.57      | 32.37      |
| 8     | 32.50    | 28.12      | 32.31      |
| 7     | 32.50    | 41.69      | 44.99      |
| 6     | 32.50    | 32.30      | 36.18      |
| 5     | 32.50    | 32.49      | 35.83      |
| 4     | 32.50    | 37.07      | 39.60      |
| 3     | 32.50    | 32.60      | 34.42      |
| 2     | 32.50    | 31.87      | 38.26      |
| 1     | 32.50    | 35.67      | 26.24      |

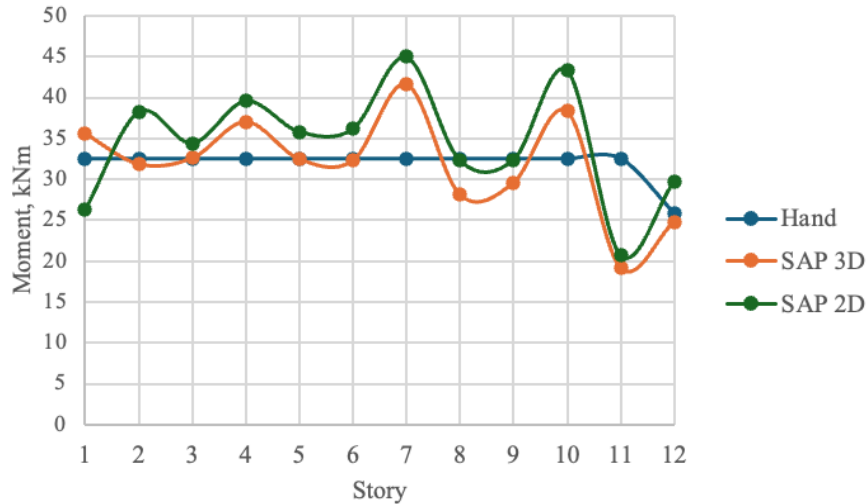


Figure 3.72. Comparison of Moment under Dead Load for Hand Calculations and SAP2000

### 3.6.2. Wind Load Internal Force Calculations

Then, the hand calculations were performed for internal forces under the wind load with the Portal Frame method. The method also has detailed steps and calculations that are given in the Appendix. These hand calculations show how internal forces are calculated and the same is repeated to all other floors.

As in the case of the earlier analyses, the results of hand calculations are compared with the results of SAP2000. Table X-X and Figures X-X provide a comparison of the two approaches. It is important to note that SAP2000 delivers more precise results because they are based on more sophisticated analytical procedures, and the Portal Frame approach offers approaches that are approximate.

The Portal Frame technique assumes that frame interior shear forces are twice that of exterior frame because the cumulative effect of the portals is considered, and also the mid-points bending of beams and columns are zero.

Table 3.73. Comparison of Axial Forces under Wind Load

| Story | Hand, kN | SAP 3D, kN | SAP 2D, kN |
|-------|----------|------------|------------|
| 12    | 1.73     | 1.57       | 1.29       |
| 11    | 7.04     | 6.69       | 5.43       |
| 10    | 16.05    | 15.11      | 12.38      |
| 9     | 28.68    | 26.32      | 21.66      |
| 8     | 44.88    | 41.06      | 33.88      |
| 7     | 61.58    | 58.77      | 48.64      |
| 6     | 83.70    | 78.90      | 65.41      |

|   |        |        |        |
|---|--------|--------|--------|
| 5 | 111.16 | 102.15 | 84.75  |
| 4 | 135.87 | 128.29 | 106.46 |
| 3 | 167.51 | 156.72 | 129.92 |
| 2 | 198.17 | 186.92 | 154.27 |
| 1 | 236.77 | 215.50 | 176.38 |

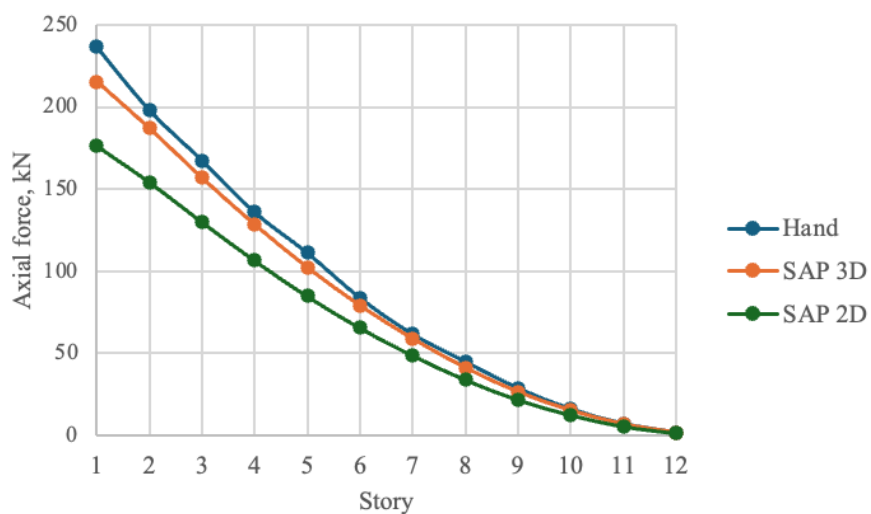


Figure 3.73. Comparison of Axial Force under Wind Load for Hand Calculations and SAP2000

Table 3.74. Comparison of Shear Forces under Wind Load

| Story | Hand, kN | SAP 3D, kN | SAP 2D, kN |
|-------|----------|------------|------------|
| 12    | 2.96     | 3.31       | 2.26       |
| 11    | 6.15     | 7.52       | 5.89       |
| 10    | 9.29     | 8.27       | 6.50       |
| 9     | 12.38    | 11.96      | 9.62       |
| 8     | 15.41    | 16.17      | 13.16      |
| 7     | 18.37    | 15.13      | 12.27      |
| 6     | 21.27    | 19.46      | 15.93      |
| 5     | 24.10    | 22.83      | 18.76      |
| 4     | 26.84    | 23.18      | 19.11      |
| 3     | 29.48    | 27.15      | 22.82      |

|   |       |       |       |
|---|-------|-------|-------|
| 2 | 31.99 | 30.19 | 23.55 |
| 1 | 34.53 | 40.66 | 42.44 |

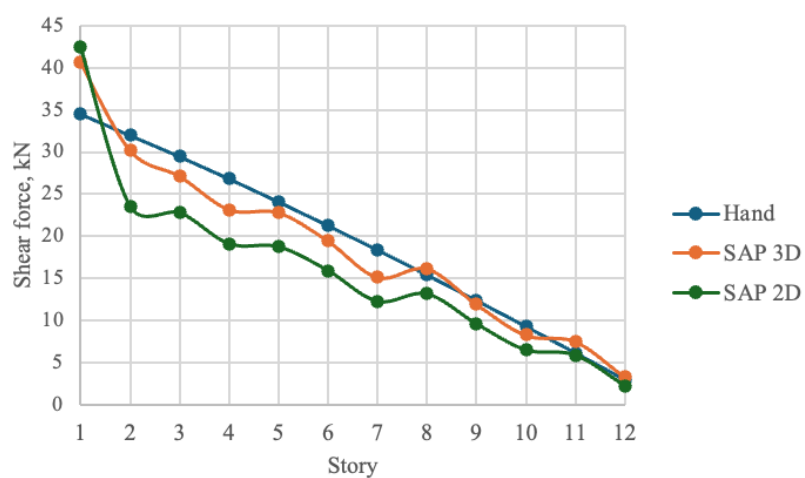


Figure 3.74. Comparison of Shear Force under Wind Load for Hand Calculations and SAP2000

Table 3.75. Comparison of Moments under Wind Load

| Story | Hand, kNm | SAP 3D, kNm | SAP 2D, kNm |
|-------|-----------|-------------|-------------|
| 12    | 5.18      | 6.64        | 3.16        |
| 11    | 10.76     | 13.71       | 9.71        |
| 10    | 16.25     | 15.82       | 9.96        |
| 9     | 21.65     | 23.36       | 14.40       |
| 8     | 26.96     | 29.42       | 21.73       |
| 7     | 32.151    | 28.88       | 18.88       |
| 6     | 37.23     | 38.74       | 23.19       |
| 5     | 42.17     | 43.24       | 29.36       |
| 4     | 46.97     | 44.31       | 29.79       |
| 3     | 51.58     | 50.85       | 38.10       |
| 2     | 55.98     | 48.90       | 46.27       |
| 1     | 60.41     | 56.77       | 126.93      |

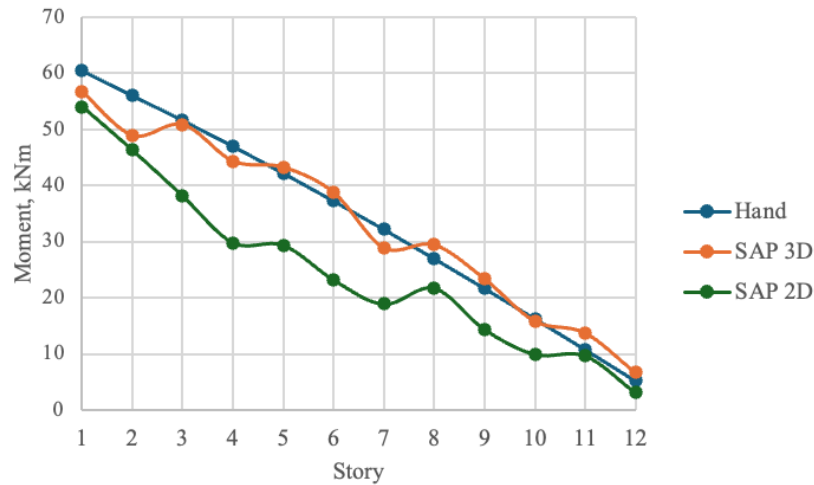


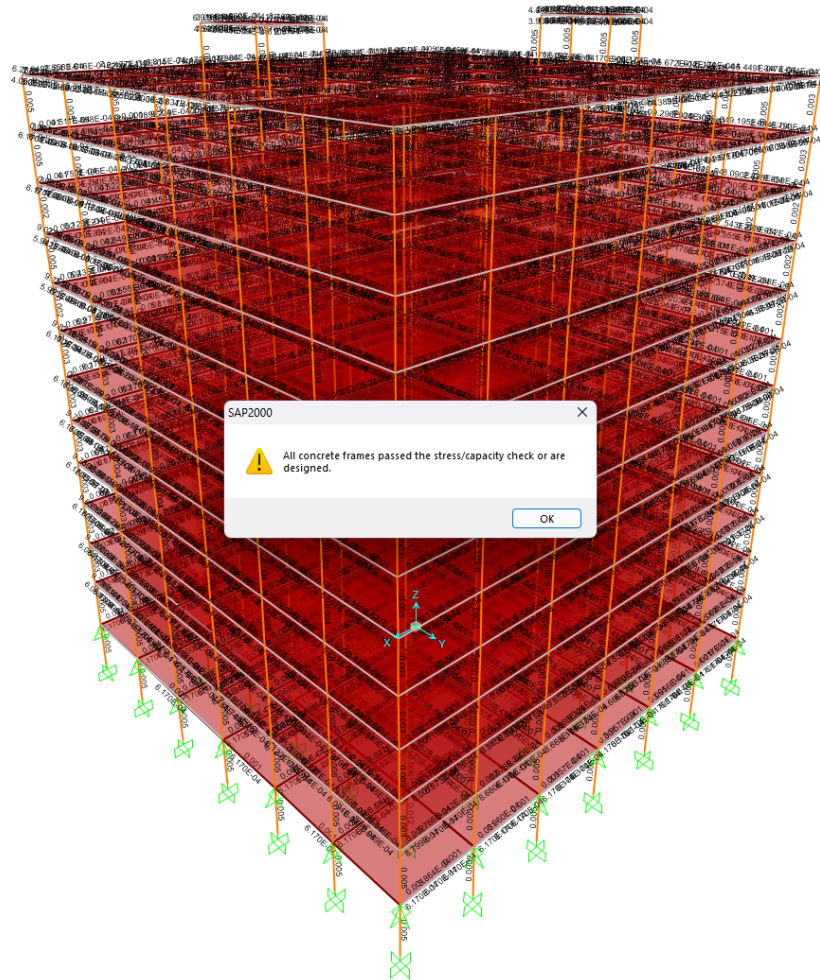
Figure 3.75. Comparison of Moments under Wind Load for Hand Calculations and SAP2000

### 3.7 Structural member design

During the design of the structural members the SAP 2000 was used widely. The software shows rebar percentages in particular cases under load combinations. All of the values taken from software were verified by manual calculations that are proposed below. SAP 2000 matches the requirements provided by ACI 318-19.

The Structural Design Verification procedure used to obtain whether the structural members are passing the loading combinations or not, the illustration is below in Figure X. As it can be observed all the frames passed all structural load combinations successfully, and thus, the designed model can be applied for structural members.





**Figure 3.76.** Capacity Check Verification

### **3.7.1. Major Beam Design**

#### **3.7.1.1. Longitudinal Reinforcement Design**

Figure X provides the design inputs and serves as a verification of the required reinforcement's validity. To illustrate the whole process of design, an end section of the major beam (location at 6 m) was chosen, as it represents the point of maximum moment across all beams, which is the negative moment of -397.01 kN/m. The top reinforcement will be designed using the negative moment, and the positive moment will be used to design a bottom reinforcement design. It should be noted that the same procedure was applied to all beam members, and the results can be seen in the Appendix.

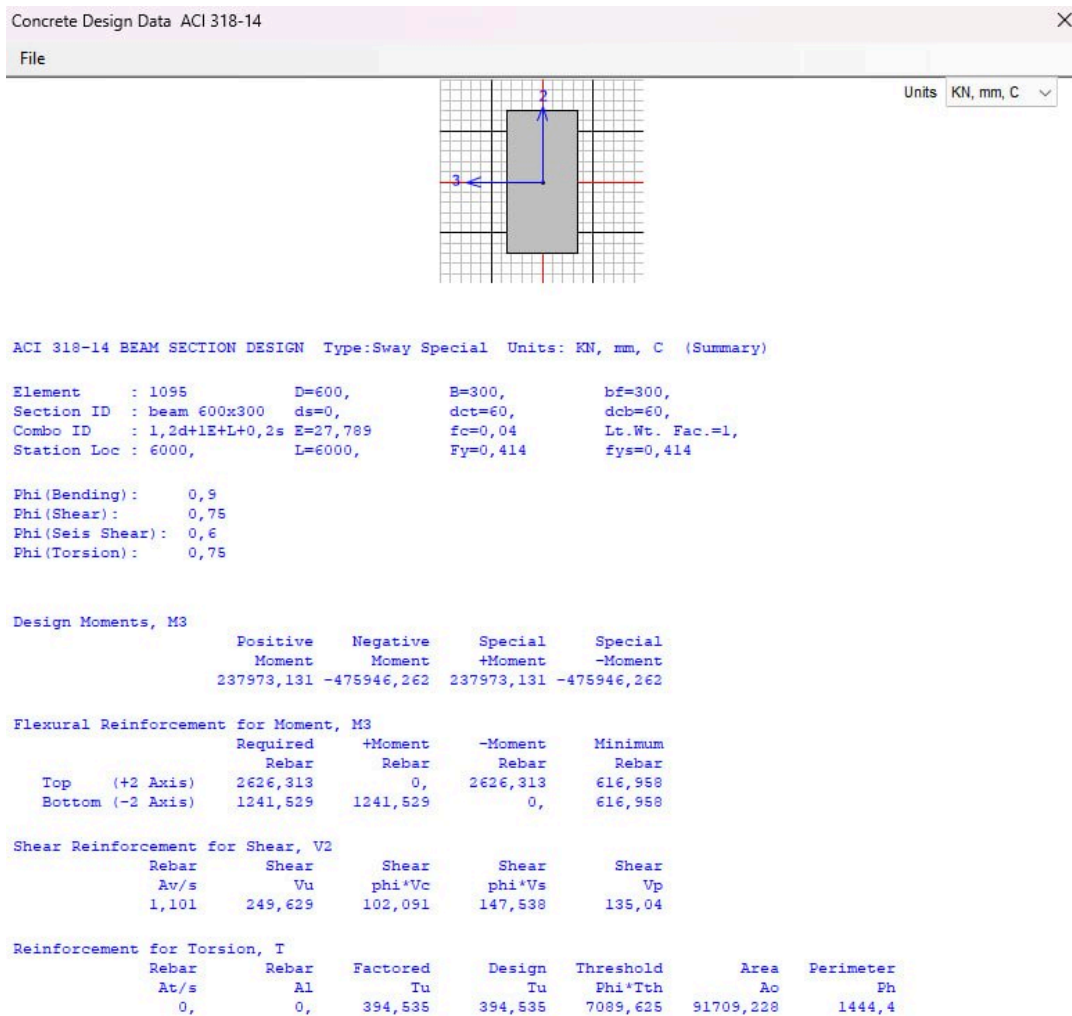


Figure 3.77. Major Beam Reinforcement Design from SAP2000

$$M_u = 475.946 \text{ kNm}$$

$$b = 300 \text{ mm}, h = 600 \text{ mm}, d = 600 - 2.5 \text{ in} \cdot 25.4 \text{ mm/in} = 536.5 \text{ mm}$$

$$f'_c = 40 \text{ MPa}, f_y = 517.1 \text{ MPa}$$

$$R_n = \frac{M_u}{\phi b d^2} = \frac{475.946}{0.9 \cdot 0.3 \cdot 0.536^2} = 6124.27 \text{ kN/m}^2$$

$$\rho = \frac{0.85 f'_c}{f_y} \left( 1 - \sqrt{1 - \frac{2 R_n}{0.85 f'_c}} \right) = 0.016$$

$$A_s = \rho b d = 0.016 \cdot 0.3 \cdot 0.536 = 2607.9 \text{ mm}^2$$

The value of  $A_s$  from SAP2000 is  $2607.90 \text{ mm}^2$ , which is higher than the value obtained above.

$$A_s f_y = 0.85 f'_c a b \rightarrow a = \frac{2607.90 \cdot 517.1}{0.85 \cdot 40 \cdot 300} = 107.38 \text{ mm}$$

$$\beta_1 = 0.85 - 0.05 \left( \frac{5801 - 4000}{1000} \right) = 0.76$$

$$c_1 = \frac{a}{\beta_1} = \frac{107.01}{0.76} = 141.3 \text{ mm}$$

$$\epsilon_1 = 0.003 \left( \frac{d - c}{c} \right) = 0.00839 > 0.005$$

Also, the error should be calculated:

$$\text{Error} = \frac{2626.3 - 2607.9}{2626.3} * 100\% = 0.70\%$$

There is a minor error of 0.70%, which is negligible. The minimum area of steel should be also checked as follows:

$$A_{s, \min} = 3 \sqrt{f'_c} b d / f_y \geq \frac{200 b d}{f_y} = 612.93 \text{ mm}^2 \geq 536.5 \text{ mm}^2$$

$$A_{s, \min} = 2626.31 \geq 612.93 \rightarrow \text{sufficient reinforcement}$$

The calculation above shows that steel area is enough. Thus, the area of steel  $A_s = 2626.3 \text{ mm}^2$  is used for bar size selection. Accordingly, at the negative moment locations, 7#7 bars will be chosen ( $A_s = 2709 \text{ mm}^2$ ). Therefore, the minimum width of the beam should be checked, assuming #3 stirrup and 40 mm cover.

$$b_{\min} = 7 * 22.225 + (7 - 1)25 + 2 * 9.525 + 40 * 2 = 404.63 \text{ mm}$$

$$b_{\min} = 404.63 \text{ mm} > 300 \text{ mm}$$

Due to beam width constraints, the required reinforcement cannot be placed in a single layer. According to ACI 318-19 Section 25.2, the bars must be arranged in two rows with a minimum vertical clear spacing of 25 mm. Hence, a recalculation of the section capacity should be performed using an updated effective depth:

$$d = 600 - 40 - 9.525 - 22.225 - 25/2 = 515.75 \text{ mm}$$

Following the same design procedure, the required area of steel is calculated as  $A_s = 2643.6 \text{ mm}^2$ . Thus, the design of 7#7 bars remains adequate and will be maintained.

Next the positive moment is taken for design of the bottom reinforcement also at the end section of the major beam:

$$M_u = 237.973 \text{ kNm}$$

$$b = 300 \text{ mm}, h = 600 \text{ mm}, d = 600 - 2.5 \text{ in} \cdot 25.4 \text{ mm/in} = 536.5 \text{ mm}$$

$$f'_c = 40 \text{ MPa}, f_y = 517.1 \text{ MPa}$$

$$R_n = \frac{M_u}{\Phi b d^2} = \frac{237.973}{0.9 * 0.3 * 0.536^2} = 3051.78 \text{ kN/m}^2$$

$$\rho = \frac{0.85 f'_c}{f_y} \left(1 - \sqrt{1 - \frac{2 R_n}{0.85 f'_c}}\right) = 0.008$$

$$A_s = \rho b d = 0.008 * 0.3 * 0.536 = 1231.67 \text{ mm}^2$$

$$A_s f_y = 0.85 f'_c a b \rightarrow a = \frac{1231.67 * 517.1}{0.85 * 40 * 300} = 50.54 \text{ mm}$$

$$\beta_1 = 0.85 - 0.05 \left(\frac{5801 - 4000}{1000}\right) = 0.76$$

$$c_1 = \frac{a}{\beta_1} = \frac{50.54}{0.76} = 66.50 \text{ mm}$$

$$\varepsilon_1 = 0.003 \left(\frac{d - c}{c}\right) = 0.0211 > 0.005$$

The value of  $A_s$  from SAP2000 is  $1241.53 \text{ mm}^2$ , which is greater than the calculated  $A_s$ .

$$\text{Error} = \frac{1241.53 - 1231.67}{1241.53} * 100\% = 0.79\%$$

The variance is not significant and is likely due to rounding or minor design assumptions. A check for the minimum area of longitudinal steel was also performed to confirm that the section is properly reinforced according to the limits:

$$A_{s, \min} = 3 \sqrt{f'_c} b d / f_y \geq \frac{200 b d}{f_y} = 612.93 \text{ mm}^2 \geq 536.5 \text{ mm}^2$$

$$A_{s, \min} = 1241.53 \geq 612.93 \rightarrow \text{sufficient reinforcement}$$

Based on a required steel area of  $1241.53 \text{ mm}^2$ , the bar design of 4#7 bars ( $A_s = 2.4 \text{ in}^2$ ) was selected for the bottom layer. Detailed member dimensions, reinforcement properties, clear cover, and spacings are provided in the Technical Drawings section. The final calculated END-MID-END bar design properties for the critical beam above are shown in Table X.

Table 3.76. Detailed Reinforcement Design for Major Beam 6 on Floor 4

|                      | Variables                                  | End          | Mid          | End          |
|----------------------|--------------------------------------------|--------------|--------------|--------------|
| Top Reinforcement    | SAP 2000 Compression Area, mm <sup>2</sup> | 198          | 617          | 2626         |
|                      | Calculated Steel Area, mm <sup>2</sup>     | 159          | 615          | 2608         |
|                      | Compression Bars                           | <b>7#7</b>   | <b>2#7</b>   | <b>7#7</b>   |
|                      | Bar area, mm <sup>2</sup>                  | 2709         | 774          | 2709         |
|                      | Reinforcement ratio, %                     | 1.65         | 0.47         | 1.65         |
| Bottom Reinforcement | SAP 2000 Tension Area, mm <sup>2</sup>     | 308          | 617          | 1242         |
|                      | Calculated Steel Area, mm <sup>2</sup>     | 234          | 597          | 1232         |
|                      | Tension Bars                               | <b>4#7</b>   | <b>2#7</b>   | <b>4#7</b>   |
|                      | Bar area, mm <sup>2</sup>                  | 1548         | 774          | 1548         |
|                      | Reinforcement ratio, %                     | 0.94         | 0.47         | 0.94         |
| Shear Reinforcement  |                                            | #3 at 130 mm | #3 at 150 mm | #3 at 130 mm |

It should be noted that, due to the unsymmetrical moment diagram resulting from the seismic load combination, the required steel area differed at the two beam ends. One end required significantly less reinforcement than the other, hence the maximum design bar arrangement was adopted at the more critical end.

Design values for all remaining beams are presented in the Appendix. All reinforcement designs satisfy the minimum and maximum code requirements, with bar sizes exceeding the minimum #5. A uniform bar size was adopted to maintain continuity along the beams. Additionally, all beam designs are consistent with the results obtained from SAP2000.

### 3.7.1.2. Shear strength check

From SAP2000, shear force value is 249.629 kN.  $\lambda$  is taken as 1 for normal-weight concrete. To determine the required shear reinforcement, the following calculations were performed:

$$V_u = 249.629 \text{ kN}$$

$$\Phi V_c = \phi \cdot 2\lambda \sqrt{f'_c} b_w d = 0.75 \cdot 2 \cdot 1 \sqrt{5801} \cdot 11.81 \cdot 21.12 = 28501.43 \text{ lb} = 126.78 \text{ kN}$$

$$\Phi V_c = 126.78 \text{ kN} < V_u = 249.629 \text{ kN}$$

$$V_{c1} = 4 \sqrt{f'_c} b_w d = 4 \sqrt{5801} \cdot 11.81 \cdot 21.12 = 76003.82 \text{ lb} = 338.08 \text{ kN}$$

$$V_{c2} = 8 \sqrt{f'_c} b_w d = 8 \sqrt{5801} \cdot 11.81 \cdot 21.12 = 152007.65 \text{ lb} = 676.16 \text{ kN}$$

$$V_s = \frac{V_u - \Phi V_c}{\phi} = 163.80 \text{ kN} < V_{c2} \Rightarrow \text{dimensions are sufficient}$$

Two legged stirrup #3 bar is assumed for this design, as this is the minimum requirement.

$$A_v = 2 * 0.11 = 0.22 \text{ in}^2 = 142 \text{ mm}^2$$

$$s_1 = \frac{A_v f_{yt} d}{V_s} = \frac{0.22 * 60000 * 21.12}{36823.2} = 7.57 \text{ in} = 192.319 \text{ mm}$$

To determine the maximum allowable spacing, the following formulas were used:

$$s_2 = \frac{d}{4} = \frac{21.12}{4} = 5.28 \text{ in} = 134.125 \text{ mm} \leq 12 \text{ in} = 304.8 \text{ mm for } V_{c1} < V_s < V_{c2}$$

$$s_3 = \frac{A_v f_{yt}}{50 b_w} \geq \frac{A_v f_{yt}}{0.75 \sqrt{f'_c} b_w}$$

$$s_3 = \frac{0.22 * 60000}{50 * 11.81} = 22.35 \text{ in} = 567.740 \text{ mm} \geq \frac{0.22 * 60000}{0.75 \sqrt{5801} * 11.81} = 19.56 \text{ in}$$

$$s_{max} = \min(s_2, s_3) = \min(5.28, 22.35) = 5.28 \text{ in} < s_1$$

Since  $s_1$  is greater than calculated  $s_{max}$ , the latter is used for the stirrup spacing to the nearest smaller half inch, which is 5.0 inch, hence 130 mm.

$$\frac{A_v}{s} = \frac{142}{130} = 1.092 \frac{\text{mm}^2}{\text{mm}}$$

Since the  $\frac{A_v}{s}$  outputted from SAP2000 is 1.101 mm<sup>2</sup>/mm, the error is the following:

$$\text{Error} = \frac{1.092 - 1.101}{1.092} * 100\% = 0.80 \%$$

The deviation is very small and can be neglected. The final shear reinforcement to be used is #3 at spacing 130 mm center-to-center.

### 3.7.1.2. Torsional Reinforcement Analysis

To calculate the torsional reinforcement, the following formula was used:

$$T_n = \phi \lambda \sqrt{f'_c} \frac{A_{cp}^2}{P_{cp}} = 62745.81 \text{ lb} - \text{in} = 7.089 \text{ kN} - \text{m} > T_u = 0.394 \text{ kN} - \text{m}$$

Since the calculated nominal torsional strength is greater than the factored torsional moment of 0.394 kNm from SAP2000, the torsional reinforcement design is ignored.

### 3.7.1.3. Cut-Off Point

The cut-off points for beam reinforcement were determined by calculating the design moment capacity  $\phi M_n$  for the reinforcement remaining after bar cut-off. For the beam being analyzed, it is 2#7 continuous bars with  $A_s = 774 \text{ mm}^2$  both for top and bottom.

$$\phi M_n = \phi A_s f_y \left( d - \frac{a}{2} \right)$$

$$a = \frac{A_s f_y}{0.85 f'_c b}$$

$$a = \frac{774 \cdot 420}{0.85 \cdot 40 \cdot 300} = 31.87 \text{ mm}$$

$$\phi M_n = 0.9 \cdot 774 \cdot 420 \left( 539 - \frac{31.87}{2} \right) = 153.0 \text{ kN} \cdot \text{m}$$

This capacity was then compared with the factored moment demand  $M_u$  along the beam, and the location where  $\phi M_n$  became equal to  $M_u$  was identified through SAP2000.

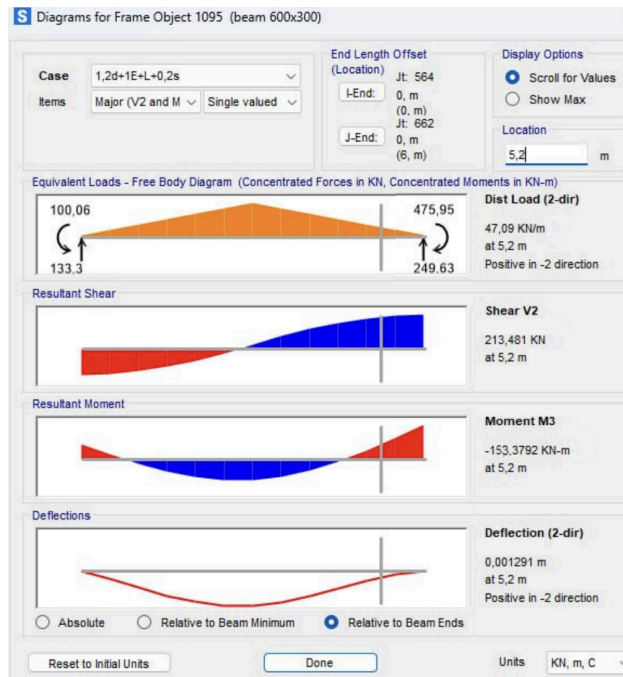


Figure 3.78. SAP2000 Moment Demand Diagram for Top Bars

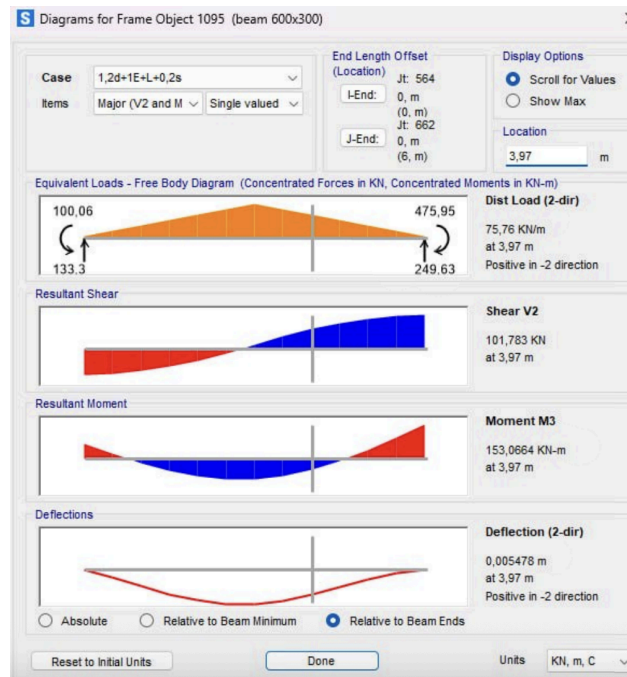


Figure 3.79. SAP2000 Moment Demand Diagram for Bottom Bars

These points were found at locations X and Y m for top and bottom bars, accordingly. The theoretical cutoff point was then extended by the required development length and the minimum ACI code specified extension to ensure proper force transfer.

$$Extension = \max(d, 12d_b, l_d)$$

$$d = 539 \text{ mm}$$

$$12d_b = 267 \text{ mm}$$

$$l_d = 310 \text{ mm}$$

$$Extension = \max(539, 267, 310) = 539 \text{ mm}$$

### 3.7.2. Column design

For the column design, the interior column was taken, its design details can be seen in Figure 3.64.



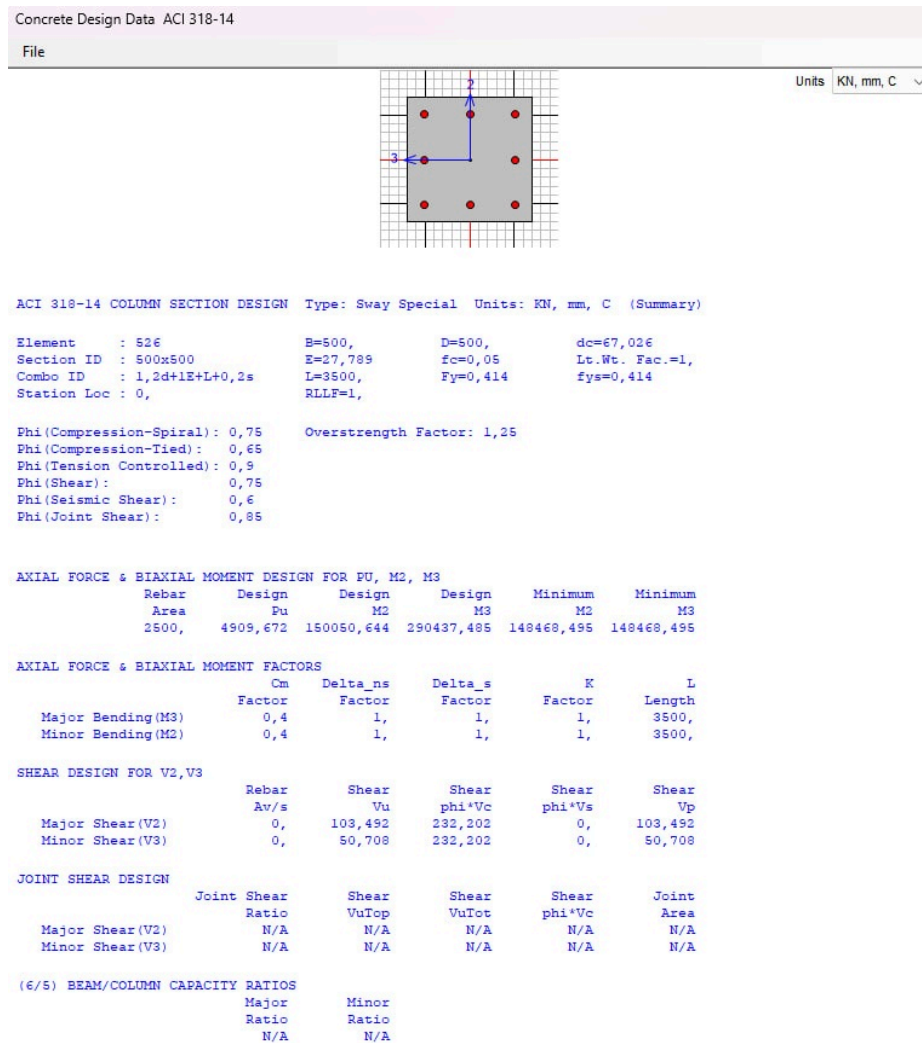


Figure 3.80. Column Reinforcement Design from SAP2000

### 3.7.2.1. Slenderness ratio check

Steel reinforcement was designed for every column type within each floor of the building. For this example, a 0.5m x 0.5m interior column on Floor 7 was selected for hand calculation. The first step is to evaluate the slenderness ratio to determine if the column behaves as a short or slender member. Because the structure doesn't have shear walls and lateral bracing, the columns are classified as sway members. The slenderness check for this sway column is shown below:

$$I_{column} = 0.00365 \, m^4, I_{beam} = 0.00189 \, m^4$$

$$L_{column} = 3.5 \, m, L_{beam} = 6 \, m$$

$$\psi_{A,int} = \frac{\sum EI/l_c \text{ of columns}}{\sum EI/l_c \text{ of beams}} = \frac{2*0.00365/3.5}{4*0.00189/6} = 1.653$$

$$\psi_{B,int} = \frac{\sum EI/l_c \text{ of columns}}{\sum EI/l_c \text{ of beams}} = \frac{2*0.00365/3.5}{4*0.00189/6} = 1.653$$

Using the following chart from ACI 318 R6.2.5.1, the effective length factor, k, for interior column was determined as 1.5:

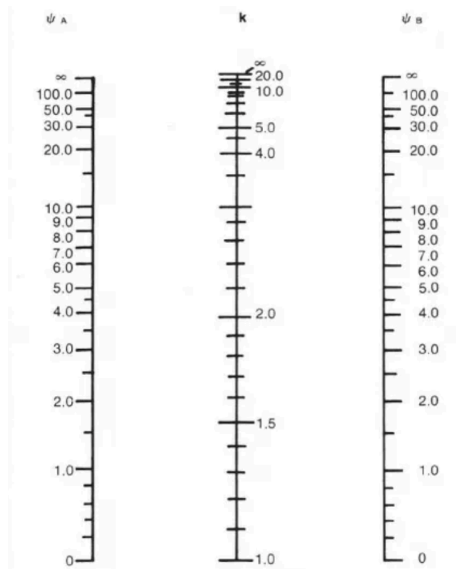


Figure 3.81. Alignment chart of effective length factors for columns in unbraced frames

$$\frac{kl_u}{r} = 43.47 > 22 \rightarrow \text{slender column}$$

Since the actual  $\frac{kl_u}{r}$  value is greater than the boundary value for sway frames, it must be designed as a slender column. Subsequently, for slender column design the sway magnification is required. The procedure of moment magnification is shown below.

$$P_c = \frac{\pi^2 EI}{(Kl_u)^2} = 36279.13 \text{ kN}$$

$$\delta_s = \frac{1}{1 - \frac{\sum P_u}{0.75 \sum P_c}} = 1.139 < 2.5$$

$$\frac{l_u}{r} < \frac{35}{\sqrt{P_u/(f'_c A_g)}} = 28.983 < 49.951 \rightarrow \text{No need for further magnification}$$

$$M_1 = \delta_s M_1 = 170.87 \text{ kN} - m$$

$$M_2 = \delta_s M_2 = 330.73 \text{ kN} - m$$

### 3.7.2.2. Longitudinal reinforcement

To calculate the column reinforcement ratio, the following formulas were used:  
From SAP2000,  $P_u = 4909.67 \text{ kN}$

$$P_n = \frac{P_u}{\Phi} = 7553.34 \text{ kN}$$

$$M_n = \frac{M_{critical}}{\Phi} = 508.81 \text{ kN} - m$$

$$e = \frac{M_n}{P_n} = 0.067 \text{ m}$$

$$K_n = \frac{P_n}{f'_c A_g} = 0.755 \text{ m}$$

$$R_n = \frac{K_n e}{h} = 0.0145$$

$$\gamma = \frac{h-2d'}{h} = 0.7$$

According to the interaction diagram for rectangular columns from ACI 318-19, the column reinforcement ratio is equal to 1%.

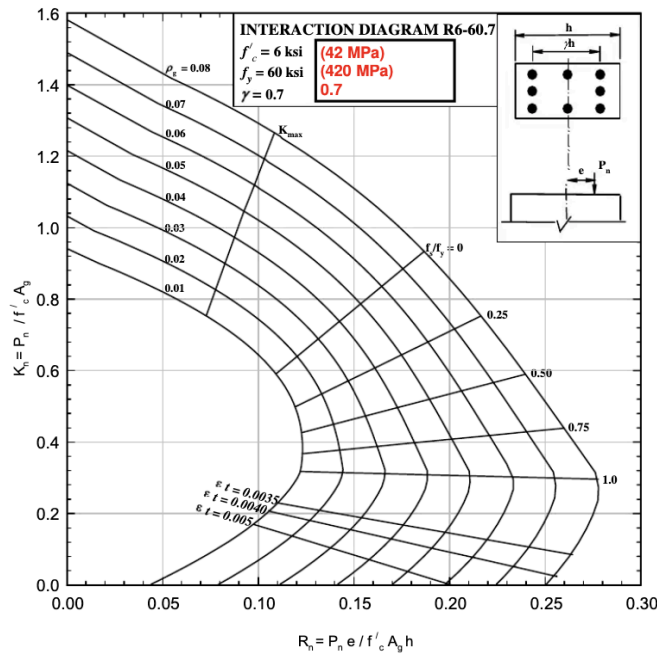


Figure 3.82. ACI column interaction diagram

$$\rho = 0.01$$

$$A_s = 0.0025 m^2$$

In accordance with the design calculations, 8#7 longitudinal bars were specified at a 190 mm center-to-center spacing. The column cover was taken as 40 mm for interior columns, and 50 mm for exterior columns to prevent corrosion in accordance with ACI 318.

### 3.7.2.3. Shear Reinforcement

To verify the column's shear capacity, the shear force  $V_c$  was be calculated:

$$\phi V_c = 0.65[0.17(1 + \frac{P_u}{14A_g})\lambda\sqrt{f'_c}b_w d] = 223.456 kN$$

$$\frac{\phi V_c}{2} = 111.728 > V_u = 103.49 \rightarrow \text{Only minimum amount of reinforcement is required}$$

Since the minimum bar is required for the shear reinforcement, #3 bar size with 9.525 mm diameter was selected for the design. For determining the spacing between those bars, the minimum of the following dimensions were selected based on ACI 318 code for structure in seismic design category:

$$s \leq \min(6d_b, 150 \text{ mm}, \frac{1}{4}b_{min})$$

$$6 \cdot d_b = 152.4 \text{ mm}$$

$$\frac{1}{4}b_{min} = 150 \text{ mm}$$

$$s \leq \min(152.4, 150, 150) = 150 \text{ mm}$$

Thus, the spacing is 150mm.

Also 135° hook was chosen for stirrups due to the seismic region. The extension length for such a hook should be maximum of  $6d_b$  or 75 mm:

$$l \geq \max(6d_b, 75 \text{ mm})$$

$$6d_b = 6 * 9.525 = 57 \text{ mm}$$

$$L = \max(57, 75) = 75 \text{ mm}$$

### 3.7.2.4. Biaxial Bending

To ensure the column can safely withstand biaxial bending, its capacity should be evaluated using the Bresler Reciprocal Load Method. From SAP2000, the following inputs were obtained:

$$M_{ux} = 170.87 kN - m$$

$$M_{uy} = 330.73 kN - m$$

$$P_u = 4909.67 kN$$

The Bresler Reciprocal Load Method procedure is outlined below:

$$M_{nx} = \frac{M_{ux}}{\phi} = 262.87 \text{ kN} - m$$

$$M_{ny} = \frac{M_{uy}}{\phi} = 508.81 \text{ kN} - m$$

$$P_n = \frac{P_u}{\phi} = 7553.34 \text{ kN}$$

$$\gamma_x = \gamma_y = 0.7$$

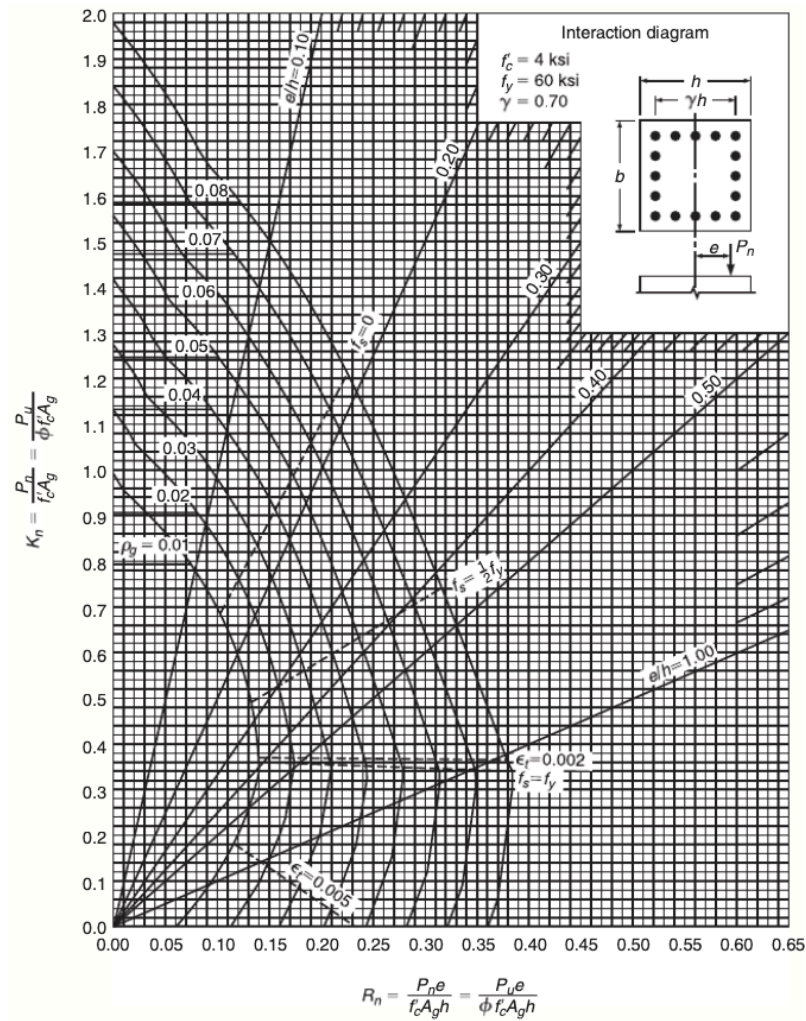
$$e_x = \frac{M_{nx}}{P_n} = 0.0348 \text{ m}$$

$$e_y = \frac{M_{ny}}{P_n} = 0.0674 \text{ m}$$

$$\rho = \frac{A_s}{A_g} = 0.00545$$

$$\frac{e_x}{h} = 0.01$$

$$\frac{e_y}{h} = 0.0192$$



$$P_{nx} = \frac{K_{nx} f_c' A_g}{\phi} = 16153.85 \text{ kN}$$

$$P_{ny} = \frac{K_{ny} f_c' A_g}{\phi} = 15692.31 \text{ kN}$$

$$P_0 = 0.85 f_c' A_g + A_{st} (f_y - 0.85 f_c') = 9079.00 \text{ kN}$$

$$\frac{1}{P_n} = \frac{1}{P_{nx}} + \frac{1}{P_{ny}} - \frac{1}{P_0} \rightarrow P_n = 39381.15 \text{ kN} > 0.1 P_0 \rightarrow \text{valid}$$

$$\phi P_n = 25597.75 \text{ kN} > P_u \rightarrow \text{the column is safe against biaxial bending}$$

### 3.7.3. Two-way slab

The design of the two-way slab was carried out using the direct design method. The input plan dimensions were 6000 mm × 6000 mm and assumed thickness of 150 mm.

#### 3.7.3.1. Flexural analysis

$$\bar{y} = \frac{450000 \cdot 75 + 135000 \cdot 375}{450000 + 135000} = 144 \text{ mm}$$

$$I_{beam} = \frac{3000 \cdot 150^3}{12} + 450000(144 - 75)^2 + \frac{300 \cdot 450^3}{12} + 150(375 - 144)^2 = 5.27 \times 10^9 \text{ mm}^4$$

$$I_{slab} = \frac{3000 \cdot 150^3}{12} = 8.4 \times 10^8 \text{ mm}^4$$

$$\alpha_{fm} = \alpha_f = \frac{EI_b}{EI_s} = 6.27 > 2$$

Since  $\alpha_{fm}$  is more than 2, the minimum slab thickness is calculated as follows:

$$h_{min} = \frac{l_n(0.8 + f_y/1400)}{36 + 9\beta} = \frac{2625(0.8 + 420/1400)}{36 + 9 \cdot 1} = 64.49 \text{ mm}$$

Factored load is calculated:

$$q_u = 1.2q_d + 1.6q_l = 10.89 \text{ kPa}$$

Total static moment:

$$M_0 = \frac{q_u l_2^2 l_n^2}{8} = \frac{10.89 \cdot 6^2 \cdot 5.5^2}{8} = 362.43 \text{ kNm}$$

$$M(-) = 0.65 * M_0 = 0.65 * 362.43 = 235.58 \text{ kN}\cdot\text{m}$$

$$M(+) = 0.35 * M_0 = 0.35 * 362.43 = 126.85 \text{ kN}\cdot\text{m}$$

$$\alpha_{fm} = \alpha_s = 6.27 > 1.0$$

$$\frac{l_2}{l_1} = 1.0$$

Table 3.77. Two-Way Slab Design Procedure for interior panel

|                | Column Strip |          |          | Middle Strip |          |          |
|----------------|--------------|----------|----------|--------------|----------|----------|
|                | Negative     | Positive | Negative | Negative     | Positive | Negative |
| M, %           | 75           | 75       | 75       | 25           | 25       | 25       |
| M <sub>u</sub> | 141.39       | 76.14    | 141.39   | 47.13        | 25.38    | 47.13    |

|                                        |            |            |            |            |            |            |
|----------------------------------------|------------|------------|------------|------------|------------|------------|
| b, m                                   | 3          | 3          | 3          | 3          | 3          | 3          |
| M <sub>u,slab</sub>                    | 21.21      | 11.42      | 21.21      | 47.13      | 25.38      | 47.13      |
| R <sub>n</sub>                         | 621.77     | 334.80     | 621.77     | 1381.71    | 744.00     | 1381.71    |
| ρ                                      | 0.00152    | 0.00081    | 0.00152    | 0.00341    | 0.00182    | 0.00341    |
| A <sub>s</sub> , m <sup>2</sup>        | 0.00051    | 0.00027    | 0.00051    | 0.00115    | 0.00061    | 0.00115    |
| A <sub>s</sub> , in <sup>2</sup>       | 0.79       | 0.43       | 0.79       | 1.78       | 0.95       | 1.78       |
| A <sub>s,min</sub> , in <sup>2</sup>   | 1.26       | 1.26       | 1.26       | 1.26       | 1.26       | 1.26       |
| A <sub>s,final</sub> , in <sup>2</sup> | 1.26       | 1.26       | 1.26       | 1.78       | 1.26       | 1.78       |
| bar design                             | <b>7#4</b> | <b>7#4</b> | <b>7#4</b> | <b>9#4</b> | <b>7#4</b> | <b>9#4</b> |
| s, mm                                  | 430        | 430        | 430        | 330        | 430        | 330        |
| s <sub>min</sub> , mm                  | 25.4       | 25.4       | 25.4       | 25.4       | 25.4       | 25.4       |
| s <sub>max</sub> , mm                  | 450        | 450        | 450        | 450        | 450        | 450        |

Table 3.78. Two-Way Slab Design Procedure for exterior panel

|                                        | Column Strip |            |            | Middle Strip |            |            |
|----------------------------------------|--------------|------------|------------|--------------|------------|------------|
|                                        | Negative     | Positive   | Negative   | Negative     | Positive   | Negative   |
| M, %                                   | 97.3         | 75         | 75         | 27.1         | 25         | 25         |
| M <sub>u</sub>                         | 183.42       | 76.14      | 141.39     | 51.09        | 25.38      | 47.13      |
| b, m                                   | 3            | 3          | 3          | 3            | 3          | 3          |
| M <sub>u,slab</sub>                    | 27.51        | 11.42      | 21.21      | 51.09        | 25.38      | 47.13      |
| R <sub>n</sub>                         | 806.56       | 334.80     | 621.77     | 1497.77      | 744.00     | 1381.71    |
| ρ                                      | 0.00197      | 0.00081    | 0.00152    | 0.00370      | 0.00182    | 0.00341    |
| A <sub>s</sub> , m <sup>2</sup>        | 0.00067      | 0.00027    | 0.00051    | 0.00125      | 0.00061    | 0.00115    |
| A <sub>s</sub> , in <sup>2</sup>       | 1.03         | 0.43       | 0.79       | 1.93         | 0.95       | 1.78       |
| A <sub>s,min</sub> , in <sup>2</sup>   | 1.26         | 1.26       | 1.26       | 1.26         | 1.26       | 1.26       |
| A <sub>s,final</sub> , in <sup>2</sup> | 1.26         | 1.26       | 1.26       | 1.93         | 1.26       | 1.78       |
| bar design                             | <b>7#4</b>   | <b>7#4</b> | <b>7#4</b> | <b>10#4</b>  | <b>7#4</b> | <b>9#4</b> |
| s, mm                                  | 430          | 430        | 430        | 300          | 430        | 330        |
| s <sub>min</sub> , mm                  | 25.4         | 25.4       | 25.4       | 25.4         | 25.4       | 25.4       |
| s <sub>max</sub> , mm                  | 450          | 450        | 450        | 450          | 450        | 450        |

### 3.7.3.2. Shear analysis

$$d_{average} = 5.9 - 0.98 - 3/4 - 5/8 = 3.755 \text{ in} = 95.885 \text{ mm}$$

$$V_u = [l_1 l_2 - (b + d_{avg})(h + d_{avg})]q_u$$

$$V_u = [6 * 6 - (3 + 0.096)(6 + 0.096)]10.89 = 186.43 \text{ kN}$$

$$\lambda = 1.0$$

$$\phi V_{c1} = \phi(0.17\lambda\sqrt{f'_c} + \frac{N_u}{6A_g})b_w d = 247.63 \text{ kN}$$

$$\phi V_{c2} = \phi(0.66\lambda\rho^{1/3}\sqrt{f'_c} + \frac{N_u}{6A_g})b_w d = 21.18 \text{ kN}$$

### 3.7.4. Joint design

The joint was designed in accordance with Chapter 15 of ACI 318-19. A detailed calculation procedure is outlined in the design book by Wight and MacGregor (2009). The free-body diagram of the interior beam-column joint is shown below:

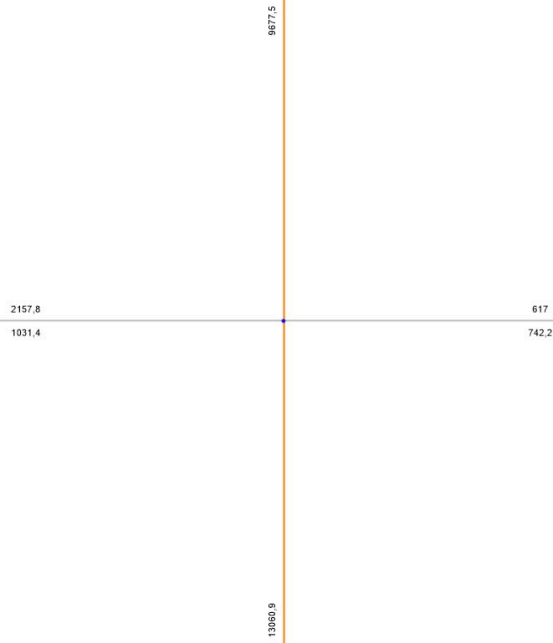


Figure 3.83. Free body diagram of the beam-column joint

An interior beam-column joint's shear was calculated using the following formula:

$$V_{u,joint} = T_{pr1} + C_{pr2} - V_{col}$$

To calculate the joint shear, the reinforcement details were taken from SAP2000 for the joint between interior beam and column on Frame 3 and floor 4.

$$T_{pr1} = \alpha A_s f_y = 1.25 \cdot 2157.8 \cdot 0.413 = 1113.9 \text{ kN}$$

$$C_{pr1} = \alpha A_s f_y = 1.25 \cdot 1031.4 \cdot 0.413 = 532.5 \text{ kN}$$

According to SAP2000,  $V_{col} = 199.2 \text{ kN}$ .

Thus,

$$V_{u,joint} = 1113.9 + 532.5 - 199.2 = 1447.2 \text{ kN}$$

To find the shear strength of joint, firstly the effective width of joint was calculated:

$$b_j = \frac{b_b + b_{col}}{2} = \frac{300+500}{2} = 400 \text{ mm} < b_b + h_{col} = 300 + 500 = 800 \text{ mm}$$

$$b_j = 400 \text{ mm} < b_b + 2x = 300 + 500 = 800 \text{ mm}$$

To calculate the shear capacity of the joint, the following equation is applied:



$$V_n = \gamma \sqrt{f'_c} A$$

Where  $\gamma = 1.7$  for confined interior joints and  $A_j$  is the product of  $b_j$  and  $h_{col}$ . Thus,

$$V_n = \gamma \sqrt{f'_c} A = 1.7 \sqrt{40} \cdot 400 \cdot 500 = 2513.2 \text{ kN}$$

The nominal shear strength must be  $\phi V_n \geq V_u$ . The value of  $\phi$  also must be taken as 0.85 to consider the strain hardening of the reinforcement.

$$0.85 \cdot 2513.2 = 2136.2 \text{ kN} \geq V_u = 1447.2 \text{ kN}$$

Consequently, the joint provides adequate shear resistance. A similar evaluation was conducted for the remaining directions, confirming that the joint's shear capacity is sufficient.

Furthermore, reinforcement spacing was determined in accordance with ACI 318-19, Section 15.4.2, using the following expression:

$$A_v = \max\left(\frac{0.062 \sqrt{f'_c} b_c s}{f_{yt}}, \frac{0.35 b_c s}{f_{yt}}\right)$$

$$s = \min\left(\frac{A_v f_{yt}}{0.062 \sqrt{f'_c} b_c}, \frac{A_v f_{yt}}{0.35 b_c}\right)$$

The minimum spacing for 2#3 ties is computed in the following way:

$$s = \min\left(\frac{2 \cdot 71 \cdot 420}{0.062 \sqrt{40} \cdot 500}, \frac{2 \cdot 71 \cdot 420}{0.35 \cdot 500}\right) = \min(304.19, 340.8) = 304.19 \text{ mm}$$

Accordingly, the design uses two #3 ties at 300 mm spacing. Additionally, the joint must be checked to confirm that plastic hinging occurs within the beams to prevent a column-failure mechanism.

$$\sum M_{nc} \geq 1.2 \sum M_{nb}$$

$$306.414 + 312.366 = 618.78 \text{ kNm} \geq 1.2(199.338 + 92.498) = 350.2 \text{ kNm}$$

### 3.7.5 Bar Selection

The selected rebars for the columns and slabs are summarized in Table X and Y, respectively. Detailed reinforcement designs for all major beams are provided in the Appendix, as each beam member requires a unique bar configuration.

Table 3.79. Final selected column bars

| Column Floor | Longitudinal Bars | Stirrups   |
|--------------|-------------------|------------|
| 1            | 8#10              | #3 @150 mm |
| 2            | 8#10              | #3 @150 mm |
| 3            | 8#9               | #3 @150 mm |
| 4            | 8#8               | #3 @150 mm |
| 5            | 8#9               | #3 @150 mm |
| 6            | 8#8               | #3 @150 mm |
| 7            | 8#7               | #3 @150 mm |

|    |     |            |
|----|-----|------------|
| 8  | 8#9 | #3 @150 mm |
| 9  | 8#9 | #3 @150 mm |
| 10 | 8#8 | #3 @150 mm |
| 11 | 8#8 | #3 @150 mm |
| 12 | 8#8 | #3 @150 mm |

Table 3.80. Final selected slab bars

| Component                  | Exterior |        | Interior |        |
|----------------------------|----------|--------|----------|--------|
|                            | Top      | Bottom | Top      | Bottom |
| Slab 0-1 Floor (700x700)   | 9#4      | 7#4    | 9#4      | 7#4    |
| Slab 2-4 Floor (600x600)   | 10#4     | 7#4    | 9#4      | 7#4    |
| Slab 5-7 Floor (500x500)   | 10#4     | 7#4    | 9#4      | 7#4    |
| Slab 8-10 Floor (400x400)  | 10#4     | 7#4    | 10#4     | 7#4    |
| Slab 11-12 Floor (350x350) | 10#4     | 7#4    | 10#4     | 7#4    |

### 3.7.6. Development length

For the development length calculations Chapter 25 and section 25.4 of ACI 318-19 was used. Bar size of #7 was chosen for the design. To calculate the tension reinforcement the following equation for bars with a size greater than #7 was used:

$$\frac{l_d}{d_b} = \frac{f_y \psi_t \psi_e \psi_g}{20 \lambda \sqrt{f'_c}}$$

$$l_d = 44.72 \text{ in} = 1136 \text{ mm} > 600 \text{ mm}$$

Since the development length is greater than the column capacity, the hooked bar is required to accommodate the entire length of the longitudinal reinforcement. The equation for the hooked rebars:

$$l_{dh} = \frac{f_y \psi_r \psi_e \psi_o \psi_c}{55 \lambda \sqrt{f'_c}} d_b^{1.5}$$

$$l_{dh} = 11.57 \text{ in} = 293.8 \text{ mm} > 8d_b = 177.8 \text{ mm}$$

For the 90° hook's parameters the following formula was used:

$$D = 6d_b = 133.4 \text{ mm}, r = D/2 = 66.7 \text{ mm}$$

The hook distance:

$$12d_b = 267 \text{ mm}$$

Additionally, the stirrup at a maximum allowable stirrup spacing will be provided for the development length:

$$s_{max} = 3d_b = 66.7 \text{ mm}$$

For the compression reinforcement, the development length was calculated using the following formula:

$$l_{dc} = \frac{f_y \psi_r}{50 \lambda \sqrt{f'_c}} d_b \geq 0.0003 f_y \psi_r d_b$$

$$l_{dc} = 12.19 \text{ in} = 310 \text{ mm} < 354.5 \text{ mm}$$

The calculated values confirm that all ACI 318-19 development length requirements are met.

### 3.7.7. Lap splices

Lap splice lengths were calculated for each individual member. For tension-controlled beams, the required lap splice lengths are as follows:

$$l_{st} = l_{dh} = 294 \text{ mm}$$

For beams in compression with bar number less than No.11, the required lap splice lengths are as follows:

$$l_{sc} = 0.0005f_y d_b \geq 12 \text{ in}$$

$$l_{sc} = 30 \text{ in} = 762 \text{ mm} \geq 12 \text{ in}$$

Columns of special moment frames must be designed as tension lap splices in accordance with ACI 318 Section 18.7.4.4. The following table was used to determine the required lap splice length under conditions:

**TABLE A-13 Lap-Splice Lengths for Grade-60 Bars in Columns (in.)**

|                                                                                                                                                              | Bar No. |      |      |      |      |      |      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|------|------|------|------|------|------|
| $f'_c$ (psi)                                                                                                                                                 | 5       | 6    | 7    | 8    | 9    | 10   | 11   |
| <b>Compression lap splices</b>                                                                                                                               |         |      |      |      |      |      |      |
| Lap splice length = (length from table) $\times$ (factors in note <sup>a</sup> )                                                                             |         |      |      |      |      |      |      |
| <3000                                                                                                                                                        | 26      | 31   | 35   | 40   | 46   | 51   | 56   |
| $\geq 3000$                                                                                                                                                  | 19      | 23   | 26   | 30   | 34   | 38   | 42   |
| <b>Tension lap splices</b>                                                                                                                                   |         |      |      |      |      |      |      |
| Lap splice length = (length from table) $\times \psi_e/\lambda$ (note <sup>b</sup> )                                                                         |         |      |      |      |      |      |      |
| Class A tension lap splice: half or fewer of the bars spliced at any location<br>and $0 \leq f_s \leq 0.5f_y$ in tension (ACI Code Section 12.17.2.2)        |         |      |      |      |      |      |      |
| 3000                                                                                                                                                         | 27.4    | 32.9 | 48.0 | 54.8 | 61.8 | 69.6 | 77.3 |
| 4000                                                                                                                                                         | 23.7    | 28.4 | 41.5 | 47.4 | 53.5 | 60.2 | 66.8 |
| 5000                                                                                                                                                         | 21.2    | 25.4 | 37.1 | 42.4 | 47.8 | 53.8 | 59.8 |
| 6000                                                                                                                                                         | 19.4    | 23.3 | 33.9 | 38.7 | 43.7 | 49.1 | 54.6 |
| Class B tension lap splices: more than half of the bars spliced at any section<br>and/or $f_s$ greater than $0.5f_y$ in tension (ACI Code Section 12.17.2.2) |         |      |      |      |      |      |      |
| 3000                                                                                                                                                         | 35.6    | 42.7 | 62.3 | 71.2 | 80.4 | 90.5 | 100  |
| 4000                                                                                                                                                         | 30.8    | 37.0 | 53.9 | 61.6 | 69.5 | 78.3 | 86.9 |
| 5000                                                                                                                                                         | 27.5    | 33.0 | 48.2 | 55.1 | 62.1 | 70.0 | 77.7 |
| 6000                                                                                                                                                         | 25.2    | 30.2 | 44.0 | 50.3 | 56.7 | 63.9 | 70.9 |

<sup>a</sup>Compression lap splices may be multiplied by 0.83 or 0.75 if enclosed by ties or spirals satisfying ACI Code Sections 12.17.2.4 or 12.17.2.5.

<sup>b</sup> $\psi_e$  = coating factor,  $\lambda$  = lightweight – concrete factor.

Figure 3.84. Lap splice lengths bars in columns

Because the tensile stress in the reinforcement exceeds  $0.5f_y$ , it is classified as a Class B tension lap splice. Therefore, the required lap splice length for Floor 5 is 53.9 in or 1369 mm. According to ACI 318 requirements, these splices are permitted only within the center half of the column length.

Table 3.81. Lap splices for columns.

| Component         | Lap splice, mm |
|-------------------|----------------|
| Column 0-1 floors | 1765           |

|                    |      |
|--------------------|------|
| Column 2-4 floors  | 1565 |
| Column 5-8 floors  | 1369 |
| Column 9-10 floors | 782  |

### 3.8. Special seismic provisions for reinforcement detailing

#### 3.8.1. Beams

Since the building is located in a high seismic region, the building design has certain seismic reinforcement features to guarantee stability. The beams were geometrically proportioned in their clear span and also the ratio of width to depth. This was strictly configured to comply with the ACI 318-19 standard Section 18.6. In order to ensure structural continuity, there are at least two longitudinal reinforcing bars that are both at the top and bottom of the members, and meet the requirements of Section 18.6.3.1. It was also made sure that the positive moment strength at the joint interface is not less than half of the negative moment strength at the joint interface. In structural confinement, special hoops are used to wrap the members over a length of twice the depth of the beam on the support face. Such hoops have a spacing based on the minimum of one quarter the effective depth, 6 times the longitudinal bar diameter, or 150 mm. Lastly, the first hoop is located 50 mm far away from the face of support.

#### 3.8.2. Columns

Under the detailing of the seismic in the columns, Section 18.7 of ACI 318-19 was considered to ensure that the vertical members are actually capable of supporting the lateral loads. The longitudinal steel was retained at 1 to 6 percent of the gross cross-sectional area, since anything below 1% is not sufficient enough to provide the strength needed and anything above 6 percent is close to impossible to pour the concrete at all. To avoid collapsing of the column at the ends where stress is maximum, an additional transverse reinforcement has been provided on a length that is determined as  $l_0$ . According to the code, the greatest of the member depth, 1/6 of the clear span and 450 mm is required to be the  $l_0$ . In this particular design, 1/6 of the clear span, equal to 400 mm, was taken.

#### 3.8.3. Joints

The longitudinal bars were extended to the far face of the column joints to fix the beams. It was made sure that the depth of the column,  $h$ , was not less than  $20d_b$ . The development lengths of the bars were designed so they meet the following criteria:

$$l_{dh} \geq \begin{cases} \frac{f_y d_b}{65 \lambda \sqrt{f'_c}} \\ 8d_b \\ 6 \text{ in.} \end{cases}$$

### 3.9. Structural serviceability design

#### 3.9.1. Minimum Deflection

The members' deflection must be checked to identify the building serviceability as established by ACI 318-14. If the member thickness is over the minimum requirement, it is not required to calculate the deflection. For the beam member with  $f_y$  of 60000 psi, the following formula can be used to check the minimum thickness:

$$h_b = \frac{l}{21} = \frac{6000}{21} = 286 \text{ mm}$$
$$b_w = 300 \text{ mm} > h_b$$

Since the beam's width satisfies the minimum thickness requirement, the deflections can be ignored.

#### 3.9.2. Crack width

In order to verify the structural safety under applied loads, it is important to verify the crack widths to be within the allowable limits defined by building codes. To evaluate the maximum flexural crack width, the following equation from McCormac and Brown (2016) will be used:

$$w = 0.076\beta_h f_s \sqrt[3]{d_c A}$$

Where,

$w$  - the estimated crack width,

$\beta_h$  - the ratio between the distance from the extreme tension fiber to the neutral axis and the distance from the centroid of the reinforcement, assumed as 1.2,

$f_s$  - the steel stress,

$d_c$  - the concrete cover, 2.5 inch,

$A$  - the effective tension area.

Thus,

$$A = \frac{5 \cdot 11.811}{4} = 14.76 \text{ in}$$

$$w = 0.076 \cdot 1.2 \cdot (2/3 \cdot 60) \sqrt[3]{2.5 \cdot 14.76} = 0.0121 < 0.016 \text{ in}$$

Since the calculated crack width is less than the allowable crack width for this structure, the crack width is considered acceptable. Additionally, the maximum allowable spacing for the longitudinal reinforcement was determined using the following formula:

$$s = 15 \frac{40}{f_s} - 2.5 C_c$$

$$s = 15 \frac{40}{\frac{2}{3} \cdot 60} - 2.5 \cdot 2.5 = 8.75 \text{ in} = 225 \text{ mm}$$

Thus, the shear reinforcement spacing must not exceed 225 mm to satisfy the serviceability criteria.

## 4. Geotechnical Design

### 4.1 Site analysis

The project site is located inside an urban block where the 12-story business center is planned to be built. The nearby area consists of buildings that reach mid to high height levels together with pavements. Subsurface information comes from a geotechnical investigation and includes data from rotary borings with SPT (borings from B-1 to B-7 and deeper B-1 from new testing) and cone penetration testing with downhole seismic (CPT/ SCPT). These borings extend to about 37 meters deep below the ground surface.

SPT blow counts were recorded using the standard 140-lb, 30-in hammer; the boring logs report raw N-values per 0.3 m penetration. CPT and surface-wave tests provided shear-wave velocity ( $V_s$ ) profiles for seismic site classification. This dataset forms the basis of the engineering soil profile and geotechnical parameter selections.

#### 4.1.1 Soil profile

It was found that the local soil predominantly contains a layered sequence of fine-grained soils, including silty clays (CL-ML), lean clays (CL), and high plasticity clays (CH) with interbedded poorly graded sands (SP) and silts (ML). This generalized stratigraphy can be seen on Figure 4.1. Because each of the boring penetrated to different depths, logs provide complementary depth coverage data. Therefore, for the soil profile analysis, presented in Table 4.1, we synthesized all boring data, including the new boring log, and compiled a composite dataset from all borings.

To make the analysis easier to perform while preserving accuracy, the soil profile was simplified down to eight primary layers, matching the main soil layers shown in Figure 4.1, with complementary data from deeper soils from the latest borings. Soil types with small thickness (less than 1 m) were joined to the adjacent layers unless they were critical for specific checks. When multiple soil types occurred within the same soil layer, for instance soil types CL and CH in the near-surface zone, the parameters of the weaker one were adopted to ensure conservatism.

For fine grained soils undrained behavior was assumed with  $\phi' = 0^\circ$ , and for granular soils, drained parameters with  $c' = 0$ ,  $\phi'$  (from SPT or CPT correlations). The resulting engineering soil profile is presented in Table 4.1, and represents a safer side envelope of the site conditions for the further analysis.

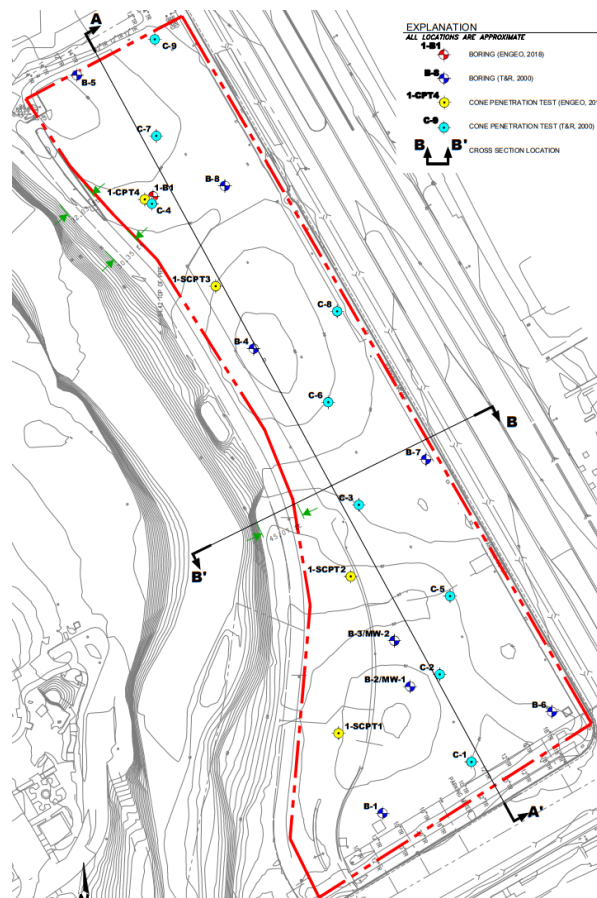


Figure 4.1. Boreholes' location map

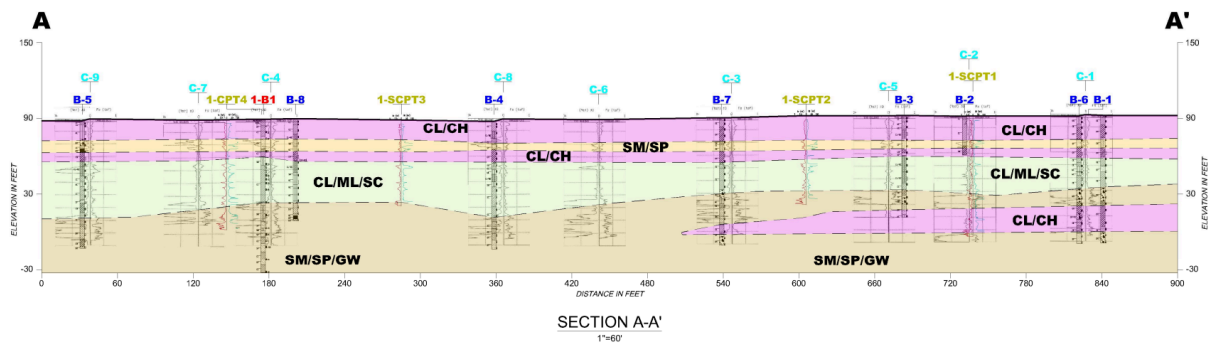


Figure 4.2. Cross-sectional view of soil layers A-A

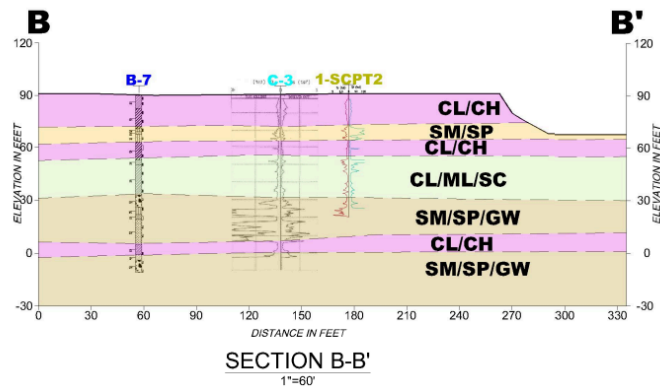


Figure 4.3. Cross-sectional view of soil layers B-B

Table 4.1. Given values for soil layers

| Depth,<br>m    | Thickne<br>ss H, m | USCS<br>Classifi<br>cation | Descrip<br>tion                   | SPT<br>N-value | $\omega$ , % | $\gamma_{d'}$<br>$kg/m^3$ | $c_u, kPa$ | Borehol<br>e # |
|----------------|--------------------|----------------------------|-----------------------------------|----------------|--------------|---------------------------|------------|----------------|
| 0.3 -<br>6.1   | 5.8                | CH                         | Clay,<br>medium<br>stiff          | 2              | 27.2         | 1585.83                   | 31.12      | B-7            |
| 6.1 -<br>7.3   | 1.2                | SP                         | Sand,<br>medium<br>dense          | 16             | 21.7         | 1729.99                   |            | B-3            |
| 7.3 -<br>14.0  | 6.7                | CL                         | Clay,<br>stiff                    | 10             | 26.9         | 1569.81                   | 52.67      | B-1            |
| 14.0 -<br>19.5 | 5.5                | CL                         | Clay                              | 13             | 23.9         | 1649.90                   | 57.46      | B-7            |
| 19.5 -<br>20.7 | 1.2                | SP                         | Poorly<br>graded<br>Sand,<br>very | 56             | 18.1         | 1832.51                   |            | B-1<br>new     |



|                |     |    |                                            |    |      |         |        |            |
|----------------|-----|----|--------------------------------------------|----|------|---------|--------|------------|
|                |     |    | dense                                      |    |      |         |        |            |
| 20.7-27<br>.7  | 2   | CH | Clay                                       | 17 | 22.7 | 1681.94 | 110.12 | B-1        |
| 27.7-28<br>.4  | 0.7 | SP | Poorly<br>graded<br>sand,<br>very<br>dense | 53 | 18.9 | 1811.69 |        | B-1<br>new |
| 28.4 -<br>36.9 | 8.5 | CL | Clay                                       | 2  | 24   |         |        | B-1<br>new |

Note: values of  $c_u$  are only applicable for cohesive soil layers.

#### SPT correction to N<sub>60</sub>

To standardize the field SPT values, corrections were applied to hammer energy, borehole diameter, sampler type, and rod length, following Seed et al. (1985) and Skempton (1986). Since the hammer efficiency was 60%, borehole diameter 4.5 in, and no liners were used, only rod length correction factors were applied based on the midpoint depth of each layer. This provided consistent  $N_{60}$  values suitable for liquefaction assessment and soil property correlations.

$$N_{60} = \frac{N \eta_H \eta_B \eta_S \eta_R}{60} \quad (4.1)$$

where  $\eta_H = 0.6$  (USA Safety hammer efficiency),

$\eta_B = 1$ , because the hole diameter is 4.5 inch = 114.3 mm

$\eta_S = 1$ , because standard sampler with no liner was used,

$\eta_R$  = rod length correction factor, based on the midpoint depth of each layer the rod has entered

Because no explicit rod length was provided,  $\eta_R$  values were selected from Figure 4.4.

| 4. Variation of $\eta_R$ |          |
|--------------------------|----------|
| Rod length<br>m          | $\eta_R$ |
| >10                      | 1.0      |
| 6–10                     | 0.95     |
| 4–6                      | 0.85     |
| 0–4                      | 0.75     |

Figure 4.4. Rod length correction factor values (Seed et al., 1985; Skempton, 1986)

#### Correlation between modulus of elasticity and $N_{60}$

A first-order empirical estimation for Young's modulus  $E_s$  for granular soil was given by Kulhawy and Mayne (1990) as:

$$\frac{E_s}{p_a} = \alpha \times N_{60} \quad (4.2)$$

$$E_s = \alpha \times p_a N_{60}$$

where

$p_a$  = atmospheric pressure ( $\approx 100 \text{ kN/m}^2$ ),

$N_{60}$  = corrected blow count,

$\alpha = 5$  for sands with fines.

Equation (4.2) corresponds to sands with moderate fines content, as is appropriate for SP layers on the site. The resulting modulus values are included in Table 4.

And Young's modulus for the clay layers was calculated by this formula for undrained, working-strain response of saturated clay:

$$E = 0.3 \times S_u \quad (4.3)$$

Friction angles  $\phi'$  for the granular layers were estimated from corrected SPT values using the correlation of Peck et al.(1974):

$$\phi' = 27.1 + 0.3 \times (N_1)_{60} \quad (4.4)$$

Estimated  $\phi'$  for the sand layers can be found in Table 4.2. Cohesive layers (CL/CH) were not assigned  $\phi'$  because short-term analyses are conducted under undrained conditions.

Table 4.2. Found values for soil layers

| Depth, m    | USCS soil classification | $N_{60}$ | Poisson's ratio | $\phi', ^\circ$ | $E, MPa$ |
|-------------|--------------------------|----------|-----------------|-----------------|----------|
| 0.3 - 6.1   | CH                       | 1.5      | 0.1             |                 | 9.34     |
| 6.1 - 7.3   | SP                       | 15.2     | 0.2             | 30.05           | 7.60     |
| 7.3 - 14.0  | CL                       | 10       | 0.4             |                 | 15.80    |
| 14.0 - 19.5 | CL                       | 13       | 0.4             |                 | 17.24    |
| 19.5 - 20.7 | SP                       | 56       | 0.2             | 37.96           | 28.00    |
| 20.7-27.7   | CH                       | 17       | 0.4             |                 | 33.04    |
| 27.7-28.4   | SP                       | 53       | 0.2             |                 | 26.50    |
| 28.4 - 36.9 | CL                       | 2        | 0.4             |                 |          |

#### 4.1.2 Groundwater level

According to the geotechnical investigation, the groundwater levels ranged from 14-17 ft. due to seasonal wet-weather trends throughout 13 months of observation. To ensure the design accommodates the most unfavourable conditions, the groundwater depth was taken conservatively as 4.5 m.

#### 4.1.3 Corrosivity Data

The site soils are neutral to mildly alkaline (pH 6.9–8.0), so not acidic; sulfate and chloride are low by ACI criteria, but low electrical resistivity at some depths indicates

“corrosive” to “moderately corrosive” conditions for buried metal—design corrosion protection should consider resistivity rather than acidity.

#### 4.1.4 Seismicity Analysis

According to the 2023 US National Seismic Hazard Model (USGS, 2023), the city of San Jose, California is located in the highest seismic hazard zone. As part of the San Francisco Bay area, in the following 30 years there is a 72% probability that San Jose will experience a 6.7 magnitude earthquake, 51% chance of a magnitude 7 earthquake and 20% chance of a 7.5 and higher magnitude earthquake (Field et al., 2015). Therefore, ground seismicity analysis and design is necessary for ensuring safety of the construction project.

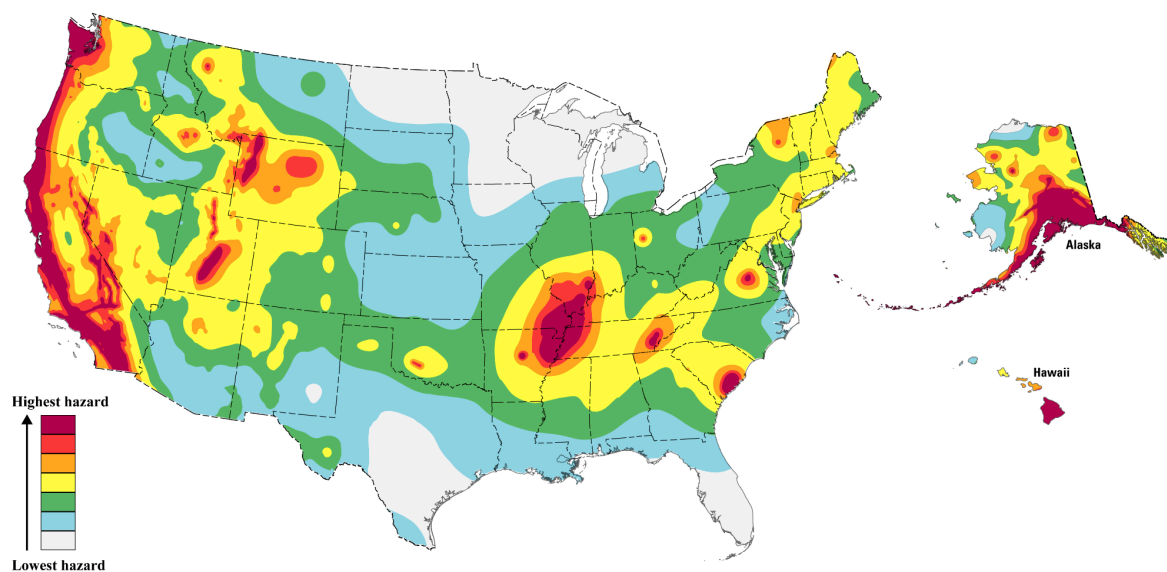


Figure 4.5. US seismic hazard map for 2% in 50-year probability of exceedance (USGS, 2023)

According to the test results from the geotechnical report of the site, the 30-meter shear wave velocity  $V_{s30}$  equaled to 239 m/s. The value corresponds to site class D, Stiff soil profile (UpCodes, 2009).

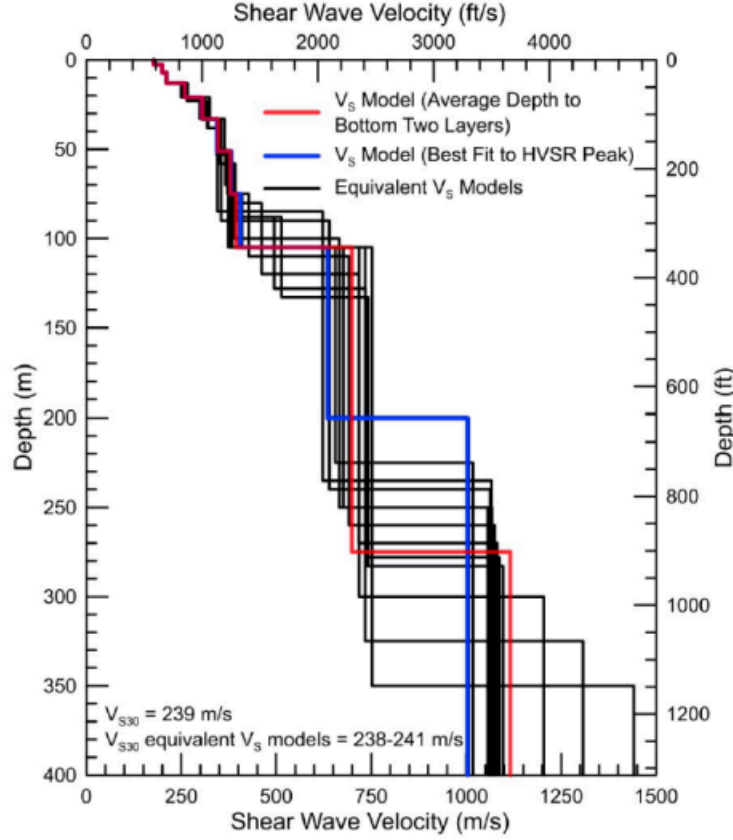


Figure 4.6. Shear Wave Velocity Chart

#### 4.1.5 Liquefaction Potential

Liquefaction potential index was calculated using formula by Iwasaki et al. (1978, 1982):

$$LPI = \int_0^{20} F(z) \times w(z) dz \quad (4.5)$$

in which the depth weighting factor:

$$w(z) = 10 - 0.5z \quad (4.6)$$

and  $z$  - depth (m). The integration is performed from the surface to 20 m depth, meaning that layers deeper than 20 m do not contribute. The function of the factor of safety against liquefaction,  $F(z)$ , is defined by:

$$F(z) = 1 - FS(z) \text{ for } FS \leq 1 \quad (4.7)$$

$$F(z) = 0 \text{ for } FS > 1 \quad (4.8)$$

The factor of safety against liquefaction ( $FS$ ) is calculated by:

$$FS = \frac{CRR}{CSR} \quad (4.9)$$

The Cyclic Stress Ratio (CSR) formula was proposed by Seed and Idriss (1971):

$$CSR = 0.65 \times r_d \times \frac{a_{max}}{g} \times \frac{\sigma_v}{\sigma_v'} \times \frac{1}{MSF} \times \frac{1}{K_\sigma} \quad (4.10)$$

The stress reduction factor  $r_d$  was evaluated using two commonly adopted relationships: a linear depth-dependent expression and the depth- and magnitude-dependent exponential function proposed by Youd et al. (2001). For each soil layer, values from both methods were computed, and their average was taken to provide a balanced estimate of  $r_d$  for use in liquefaction analysis.

$$r_{d1} = 1 - 0.015 * z \quad (4.11)$$

$$r_{d2} = \exp(\alpha(z) + \beta(z) * M_w) \quad (4.12)$$

$$\alpha(z) = -1.012 - 1.126 * \sin\left(\frac{z}{11.73} + 5.133\right) \quad (4.13)$$

$$\beta(z) = 0.106 + 0.118 * \sin\left(\frac{z}{11.28} + 5.142\right) \quad (4.14)$$

Table 4.3.  $r_d$  calculation

| Depth, m    | Soil description, USCS              | $r_{d1}$ | $\alpha(z)$ | $\beta(z)$ | $r_{d2}$ | $r_d$ |
|-------------|-------------------------------------|----------|-------------|------------|----------|-------|
| 6.1 - 7.3   | Sand, medium dense (SP)             | 0.89     | -0.44       | 0.05       | 0.90     | 0.89  |
| 19.5 - 20.0 | Poorly graded Sand, very dense (SP) | 0.70     | -1.66       | 0.18       | 0.64     | 0.67  |

The Magnitude-Scaling Factor ( $MSF$ ) was calculated using Boulanger & Idriss (2008) formula:

$$MSF = 6.9e^{-M_w/4} - 0.058 < 1.8 \quad (4.15)$$

The maximum moment magnitude ( $M_w$ ) in this formula was estimated in the Working Group on California Earthquake Probabilities study by USGS (2016) as 6.7 for the Hayward Fault,

which is considered the most likely to control the seismic shaking at the site, with an estimated 33% of occurring before 2043.

And according to the California Building Code (2016) the Peak Ground Acceleration (PGA or  $\alpha_{max}$ ) at the site is 0.5 g.

The overburden correction factor  $K_\sigma$  was found using formula suggested by Boulanger & Idriss (2008):

$$K_\sigma = 1 - C_\sigma \ln\left(\frac{\sigma'_v}{P_a}\right) \quad (4.16)$$

where  $P_a = 100 \text{ kPa} (1 \text{ atm})$ .

The coefficient  $C_\sigma$  for SPT data found by the following formula:

$$C_\sigma = \frac{1}{18.9 - 2.55\sqrt{N_{1(60)}}} \quad (4.17)$$

The Cyclic Resistance Ratio (CRR) was found by Boulanger & Idriss (2008) formula:

$$CRR = \exp\left[\frac{N_{1(60)}}{14.1} + \left(\frac{N_{1(60)}}{126}\right)^2 + \left(\frac{N_{1(60)}}{23.6}\right)^3 + \left(\frac{N_{1(60)}}{25.4}\right)^4 - 2.8\right] \quad (4.18)$$

In order to CRR value, the raw  $N_{60}$  values for granular soils must be corrected for overburden pressure effects:

$$(N_1)_{60} = C_N N_{60} \quad (4.19)$$

The resulting  $(N_1)_{60}$  values provide a standardized measure of penetration resistance that can be directly applied in liquefaction triggering correlations. The overburden correction factor  $C_N$  proposed by Liao and Whitman's relationship (1986):

$$C_N = \left[ \frac{1}{\left(\frac{\sigma'_v}{P_a}\right)} \right]^{0.5} \quad (4.20)$$

$\sigma'_v$  = effective vertical overburden pressure

$$\sigma'_v = \gamma * H \quad (4.21)$$

$\gamma$  = bulk unit weight,  $kN/m^3$

$H$  = depth of the layer,  $m$

$$\gamma = \gamma_d(1 + \omega) \quad (4.22)$$

$\gamma_d$  = dry unit weight,  $kN/m^3$

$\omega$  = moisture content, %

GWT = 4.5 m,

$$u = \gamma_w(z - z_{wt}) \quad (4.23)$$

$$\gamma' = \gamma - \gamma_w \quad (4.24)$$

For layers above GWT  $\gamma$  was used, and for layers below formula (3.14) was used.

Table 4.4. Calculation of  $(N_1)_{60}$

| USCS | Depth,<br>$m$  | Layer<br>thickn<br>ess, $m$ | $\gamma_d$ ,<br>$kN/m^3$ | $\gamma$ ,<br>$kN/m^3$ | $\gamma'$ ,<br>$kN/m^3$ | $\sigma'_{v'}$ ,<br>$kPa$ | $C_N$ | $(N_1)_{60}$ |
|------|----------------|-----------------------------|--------------------------|------------------------|-------------------------|---------------------------|-------|--------------|
| CH   | 0.3 -<br>4.5   | 4.2                         | 15.56                    | 19.79                  | -                       | 83.11                     |       |              |
| CH   | 4.5 -<br>6.1   | 1.6                         | 15.56                    | 19.79                  | 9.98                    | 15.97                     |       |              |
| SP   | 6.1 -<br>7.3   | 1.2                         | 16.97                    | 20.65                  | 10.84                   | 13.01                     | 0.65  | 9.82         |
| CL   | 7.3 -<br>14.0  | 6.7                         | 15.40                    | 19.54                  | 9.73                    | 65.21                     |       |              |
| CL   | 14.0 -<br>19.5 | 5.5                         | 16.19                    | 20.05                  | 10.24                   | 56.34                     |       |              |
| SP   | 19.5 -<br>20.0 | 0.5                         | 17.98                    | 21.23                  | 11.42                   | 5.71                      | 0.65  | 36.20        |



|       |  |  |  |  |  |        |  |  |
|-------|--|--|--|--|--|--------|--|--|
| Total |  |  |  |  |  | 239.35 |  |  |
|-------|--|--|--|--|--|--------|--|--|

Table 4.5. LPI calculation

| Dep<br>th,<br>m | US<br>CS | $r_d$ | $MSF$ | $a_{max}$ | $C_\sigma$ | $K_\sigma$ | $CSR$ | $CRR$ | $FS$ | $F(z)$ | $w(z)$ | LPI  |
|-----------------|----------|-------|-------|-----------|------------|------------|-------|-------|------|--------|--------|------|
| 6.1 -<br>7.3    | SP       | 0.89  | 1.23  | 0.5       | 0.09       | 0.92       | 0.30  | 0.12  | 0.48 | 0.52   | 6.65   | 4.11 |

Layers deeper than 20 m with  $\omega_i = 0$  do not contribute to liquefaction potential because the LPI calculation only considers the upper 20 m. The sand layer with LPI = 4.1 indicates very low liquefaction potential, meaning surface manifestations such as settlements or minor cracking are possible in that zone.

#### 4.2 Site response analysis

For this analysis the PLAXIS 2D software was used. At the beginning of the analysis the soil parameters were inserted into the program. After inserting parameters, the acceleration time history data from the Gilroy #4 stations recorded during the 1989 Loma Prieta earthquake were obtained from CESMD. After which the seismic input signal was obtained.

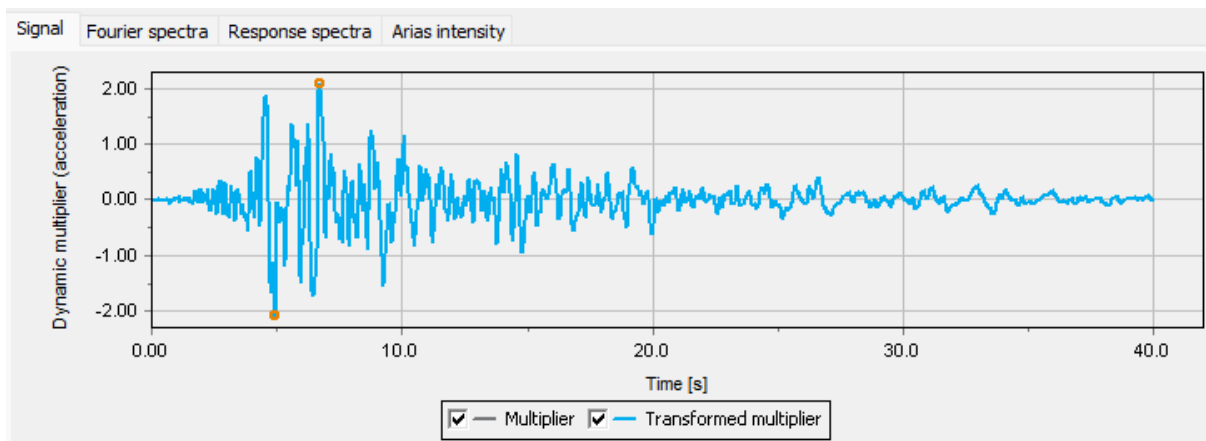


Figure 4.8. Signal graph

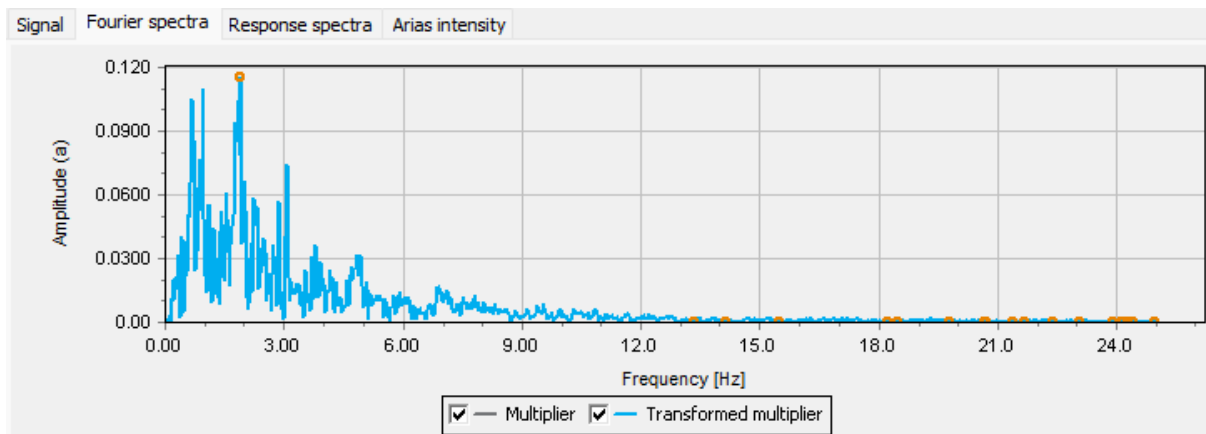


Figure 4.8. Fourier spectra graph

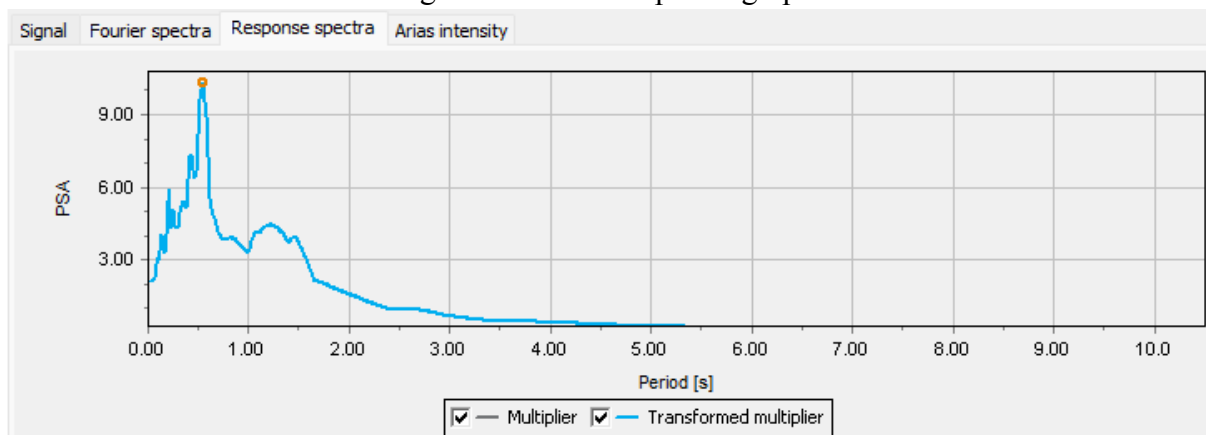


Figure 4.8. Response spectra graph

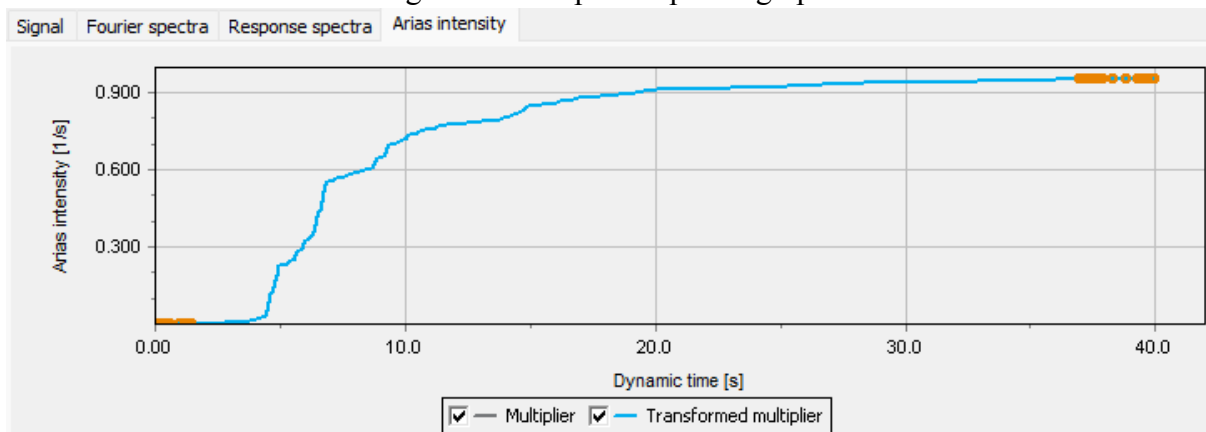


Figure 4.8. Response spectra graph

### 4.3 Foundation design

The foundation is a structural part of the building used for transferring building loads to the underlying soil. For it to be safe both the bearing capacity of the soil and the level of settlement should be within allowable ranges. For the foundation design two types of foundation were considered, shallow and deep.

The total structural load of the building was taken as 314786 kN, and the distributed unit load per area  $q_{gross}$  was taken as 243 kN/m<sup>2</sup>.

The basement excavation depth is 4 m, and the base of a hypothetical shallow foundation will therefore lie within the CH clay layer.

#### 4.3.1 Shallow Foundation

For the shallow foundation pad and mat foundations were proposed.

For shallow foundations, the factor of safety FS was chosen as 3 based on Das & Sivakugan (2019).

##### 4.3.1.1 Pad foundation

For the pad foundations square footing with  $B = L = 2\text{ m}$  was considered. The embedded depth was chosen as  $D_f = 2\text{ m}$ , an upper limit from the range of 0 - 2 m (Das and Sivakugan, 2019). Thus, the pad foundation will be 6 m deep in the soil layer, which corresponds to the clay CH layer.

Terzaghi's method

For the calculation formula proposed by Terzaghi with the modification for square footing was used:

$$q_u = 1.3c'N_c + qN_q + 0.4\gamma BN_\gamma \quad (4.25)$$

where

$c'$  = cohesion,  $\frac{kN}{m^2}$

$q$  = effective stress at the bottom of the foundation,  $\frac{kN}{m^2}$

$\gamma$  = soil unit weight,  $\frac{kN}{m^3}$

$B$  = foundation width,  $m$

$N_c, N_q, N_\gamma$  = bearing capacity factors

For the  $\phi' = 0^\circ$  the bearing capacity factors were taken as:

$$N_c = 5.70$$

$$N_q = 1.00$$

$$N_\gamma = 0.00$$

This simplifies the equation to:

$$q_u = 1.3c'N_c + q$$

Compute the overburden stress:

$$q_u = \gamma D_f = 19.79 \times 2 = 39.58 \text{ kPa} \quad (4.26)$$

$$q_{all} = \frac{q_u}{FS} \quad (4.27)$$

$$Q_{all} = q_{all} B^2 = q_{all} B^2 \quad (4.28)$$

And compute the ultimate bearing capacity:

$$q_u = 1.3 \times 31.12 \times 5.70 + 39.58 \times 1.00 + 0$$

$$q_u = 270.18 \frac{\text{kN}}{\text{m}^2}$$

Allowable bearing pressure:

$$q_{all} = \frac{270.18}{3} = 90.06 \frac{\text{kN}}{\text{m}^2}$$

This is significantly lower than the required applied foundation pressure  $q_{gross} = 243 \text{ kN/m}^2$

. Thus, the pad foundation fails the bearing capacity criterion.

Meyerhof's method

This method takes into account the shearing resistance along the failure surface in the soil above the bottom of the foundation. It also considers that the load on the foundation may have inclination, however the load from the structure is vertical, thus inclination factors are taken as unity. The suggested general bearing capacity equation:

$$q_u = c'N_c F_{cs} F_{cd} F_{ci} + qN_q F_{qs} F_{qd} F_{qi} + \frac{1}{2}\gamma B N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i} \quad (4.29)$$

Where

$F_{cs}, F_{qs}, F_{\gamma s}$  = shape factors

$F_{cd}, F_{qd}, F_{\gamma d}$  = depth factors

$F_{ci}, F_{qi}, F_{\gamma i}$  = inclination factors

For the  $\phi' = 0^\circ$  the bearing capacity factors were taken as:

$$N_c = 5.14$$

$$N_q = 1.00$$

$$N_\gamma = 0.00$$

Shape factor relationships proposed by DeBeer (1970):

$$F_{cs} = 1 + \left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right) \quad (4.30.1)$$

$$F_{qs} = 1 + \left(\frac{B}{L}\right)\tan\phi' \quad (4.30.2)$$

$$F_{\gamma s} = 1 - 0.4\left(\frac{B}{L}\right) \quad (4.30.3)$$

Depth factor relationships as proposed by Hansen (1970):

for  $\frac{D_f}{B} = 1$  and  $\phi' = 0$ :

$$F_{cd} = 1 + 0.4\left(\frac{D_f}{B}\right) \quad (4.31.1)$$

$$F_{qd} = 1 \quad (4.31.2)$$

$$F_{\gamma d} = 1 \quad (4.31.3)$$

The shape factors were calculated to be  $F_{cs} = 1.19$ ,  $F_{qs} = 1$ , and  $F_{\gamma s} = 0.6$ . The depth factor was  $F_{cd} = 1.4$ .

$$q_u = 31.12 \times 5.14 \times 1.19 \times 1.4 \times 1 + 39.58 \times 1 \times 1 \times 1 \times 1 + 0$$

$$q_u = 307.08 \frac{kN}{m^2}$$

Allowable bearing capacity:

$$q_{all} = \frac{307.08}{3} = 102.36 \frac{kN}{m^2}$$

And the pad foundation is not suitable since:

$$q_{gross} = 243 \text{ kN/m}^2 > q_{all}$$

#### 4.3.1.2 Mat foundation

A mat foundation was also considered due to high column loads and high-story configuration of the structure. This type of foundation distributes loads over a large area,

reducing contact pressure compared to isolated footings. However, they still rely on the bearing capacity of the underlying soils.

#### Bearing capacity calculation

For a mat on clay, Meyerhof's general equation also applies, with the same undrained parameters used in pad footing:

$$q_u = 1.3c'N_c + qN_q + 0.4\gamma BN_\gamma \quad (4.32)$$

$$q_u = c'N_c F_{cs} F_{cd} F_{ci} + qN_q F_{qs} F_{qd} F_{qi} + \frac{1}{2}\gamma BN_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i} \quad (4.33)$$

where

$c'$  = cohesion,  $\frac{kN}{m^2}$

$q$  = effective stress at the bottom of the foundation,  $\frac{kN}{m^2}$

$\gamma$  = soil unit weight,  $\frac{kN}{m^3}$

$B$  = foundation width,  $m$

$N_c, N_q, N_\gamma$  = bearing capacity factors

$F_{cs}, F_{qs}, F_{\gamma s}$  = shape factors

$F_{cd}, F_{qd}, F_{\gamma d}$  = depth factors

$F_{ci}, F_{qi}, F_{\gamma i}$  = inclination factors

FS = 3 for mats on clay under service loads (Das & Sivakugan, 2019).

Df is assumed to be 1m.

$$F_{cs} = 1 + \frac{B}{L} \left( \frac{N_q}{N_c} \right) = 1 + \left( \frac{B}{L} \right) \left( \frac{1}{5.14} \right) = 1 + 0.195 \left( \frac{B}{L} \right) = 1.195$$

$$F_{cd} = 1 + 0.4 \left( \frac{D_f}{B} \right) = 1.2$$

$$q_u = 5.14c_u \left( 1 + 0.195 \frac{B}{L} \right) \left( 1 + 0.4 \frac{D_f}{B} \right) + q = c_u N_c F_{cs} F_{cd} + q = 232.85 \text{ kPa}$$

$$q_{u(net)} = q_u - q = 5.14c_u \left( 1 + 0.195 \frac{B}{L} \right) \left( 1 + 0.4 \frac{D_f}{B} \right) = 193.27 \text{ kPa}$$

Allowable capacity:

$$q_{all} = 77.62 \text{ kPa}$$

$$q_{gross} = 243 \text{ kN/m}^2 > q_{all}$$

Thus, mat foundation also fails the bearing capacity requirement.

#### 4.3.1.3 Settlement on shallow foundations

For a shallow foundation on clay, total settlement is usually split into:

$$S_{total} = S_i + S_c + S_s \quad (4.34)$$

where  $S_i$  = immediate, or elastic, settlement,

$S_c$  = primary consolidation settlement,

$S_s$  = secondary consolidation

The total settlement is dominated by the primary consolidation of the first near-surface clay layer. Settlements in deeper layers, both granular and cohesive, are expected to be smaller due to the decrease in stress with depth.

$$q_{net} = q_{gross} - \gamma \times D_f$$

$$q_{net} = 243 - 19.79 \times 2 = 203.42 \text{ kN/m}^2$$

#### 4.3.1.4 Settlement for pad foundation

##### Elastic settlement

$$S_i = \frac{q_{net} \times B \times (1 - \mu_s^2)}{E_s} \times I_s \quad (4.35)$$

where  $I_s$  = influence factor which depends on the shape of the foundation and the thickness of the compressible layer,

$q_{net}$  = net pressure applied by the foundation to the underlying soil,

$B$  = width of the foundation,

$E_s$  = modulus of elasticity of the soil,

$\mu_s$  = Poisson's ratio of the soil.

Schleicher (1926):

$$I_{s,center} = 2 \times \frac{1}{\pi} \times (m' \times \ln(\frac{1 + \sqrt{m'^2 + 1}}{m'}) + \ln(m' + \sqrt{m'^2 + 1})) \quad (4.36)$$

where  $m' = L/B$ .

Substituting  $m' = 2/2 = 1$  into the formula (xyz):

$$I_{s,center} = 2 \times \frac{1}{\pi} \times (1 \times \ln(\frac{1 + \sqrt{1+1}}{1}) + \ln(1 + \sqrt{1 + 1})) = 1.12$$

$$S_i = \frac{203.42 \times 2 \times (1 - 0.5^2)}{9340} \times 1.12 = 0.037 \text{ m} = 37 \text{ mm}$$

Stress increment from the footing was found using the 2:1 method:

$$\Delta\sigma = q_{net} \times \frac{B \times L}{(B+z) \times (L+z)}$$

with the  $B = L = 2 \text{ m}$ ,  $z_1 = 1 \text{ m}$ :

$$\Delta\sigma = 203.42 \times \frac{4}{3 \times 3} = 90.4 \text{ kPa}$$

### Consolidation settlement

Due to the low permeability of clays and likely capillary saturation above the water table, part of clay layer located above the water table (0.3 - 4.5 m of Clay CH layer) is assumed saturated and analysed under undrained conditions ( $\mu_s$ ) for immediate settlement.

For normally consolidated clays:

$$S_c = \frac{C_c H_c}{1 + e_0} \log \frac{\sigma'_0 + \Delta\sigma'_{av}}{\sigma'_0} \quad (4.37)$$

where  $C_c$  = compression index,

$e_0$  = the initial void ratio,

$H_c$  = thickness of the sublayer,

$\sigma'_0$  = the initial effective vertical stress,

$\Delta\sigma'_{av}$  = the stress increment induced by the foundation load to the mid-depth of the sublayer.

The clay parameters are given as liquid limit  $LL = 41$ , natural water content  $w_n = 27.2\%$ , and assumed the clay is saturated,  $G_s = 2.7$ .

$$C_c = 0.009(LL - 10) = 0.009 \times (41 - 10) = 0.28$$

$$e_0 = w_n \times G_s = 0.272 \times 2.7 = 0.73$$

Depth to mid-layer:

$$D_f + \frac{H}{2} = 1 + \frac{5.8}{2} = 3.9 \text{ m}$$

$$\sigma'_0 = \gamma' \times 3.9 = 19.79 \times 3.9 = 77.18 \text{ kN/m}^2$$

$$\Delta\sigma'_{av} = \frac{q_{net}}{(1 + \frac{z}{B})} = \frac{203.42}{(1 + \frac{2.9}{2})} = 83.03 \text{ kN/m}^2$$



$$S_c = \frac{0.28 \times 5.8}{1+0.8} \log \frac{77.18+83.03}{77.18} = 0.286 \text{ m} = 286 \text{ mm}$$

Thus, settlement for the strip foundation:

$$S_{total} = 37 + 286 = 323 \text{ mm}$$

The computed consolidation settlement of the first layer alone is approximately 0.32 m. This value already exceeds the typical allowable settlement thresholds (25 - 50 mm). Since deeper clay layers would only increase the total settlement, a full multi-layer consolidation analysis is not required in order to demonstrate that this type of shallow foundation cannot be used for this project.

#### 4.3.1.4 Settlement on mat foundations

A preliminary settlement analysis was conducted for a mat foundation.

$$\Delta\sigma = q_{net} \times I_z$$

2:1 (V:H) stress distribution method is used:

$$\Delta\sigma_z = \frac{q_{net} \times B \times L}{(b+z) \times (L+z)}$$

$$S_i = \frac{135 \times 121 \times (1-0.5^2)}{9340} \times 1.2 = 1.5 \text{ m} = 1570 \text{ mm}$$

$$S_c = \frac{0.3 \times 5.8}{1+0.8} \times \log_{10} \left( \frac{178}{50} \right) = 0.553 \text{ m} = 553 \text{ mm}$$

$$S_{total} = 1570 + 553 = 2123 \text{ mm}$$

The calculated settlement, dominated by both immediate and consolidation settlement in the thick, soft clay layer exceeded 2 m. This is larger than the typical allowable settlement limits for mat foundations by an order of magnitudes. Therefore, a mat foundation is not feasible, and a deep foundation system is needed to transfer loads to a deeper strata with settlement levels within allowable limits.

### 4.3.2 Deep Foundation

#### 4.3.2.1 Design for a single pile

The bearing capacity for a single pile is given by the sum of its point bearing capacity and skin friction.

$$Q_u = Q_p + Q_s$$

Where

$Q_u$  = ultimate bearing capacity

$Q_p$  = point bearing capacity

$Q_s$  = skin friction

$$Q_{all} = \frac{Q_u}{FS}$$

Precast concrete driven piles were chosen for their high load bearing capacity, corrosion resistance and ease of installation. According to California regulations for driven piles (Caltrans, 2021), a nominal pile diameter of 0.3 m was chosen. Therefore,

$$A_p = \pi R^2 = 3.14 \cdot 0.15^2 = 0.0707 \text{ m}^2$$

$$P = \pi D = 3.14 \cdot 0.3 = 0.942 \text{ m}$$

For hand calculation examples, nominal pile length was assumed to be 16.7 m. Since the basement height is 4 m, the pile tip will be at 20.7 m, which corresponds to layer 5, SP very dense poorly graded sand in Table 3. The pile will penetrate the dense sand layer, acting as a base for end bearing capacity. However, both point bearing capacity and skin friction were calculated for all layers to determine optimal pile length.

$$Q_p = A_p q_p = A_p (c'N_c^* + q'N_q^*)$$

$$Q_s = \sum f p \Delta L$$

### **Qp and Qs for clay layers**

#### **Point bearing capacity in Clay**

##### **Meyerhof's Method**

According to the Meyerhof method for point bearing capacity in undrained clays (Das & Sivakugan, 2019),

$$Q_p \approx N_c^* c_u A_p = 9 c_u A_p$$

Where

$Q_p$  = point bearing capacity

$c_u$  = undrained cohesion of soil at the tip of the pile

$A_p$  = cross-sectional area of pile

$$Q_b = 9 \cdot 110.12 \cdot 0.196 = 197.47 \text{ kN}$$

##### **Vesic's Method**

Vesic's point bearing capacity in undrained clays (Das & Sivakugan, 2019)

$$Q_p = A_p c_u N_c^*$$

$$I_{rr} = I_r = \frac{E_s}{3c_u}$$

$$I_{rr} = \frac{E_s}{3c_u} = 100$$

$$N_c^* = 10.04$$

$$Q_p = 0.196 * 110.12 * 10.04 = 312.44 \text{ kN}$$

Ir for all layers was 100, thus  $N_c^*$  was 10.04 for all those layers respectively.

Table 4.6. Point bearing capacity,  $Q_p$  in clay layers

| Layer depth, m | Pile length, m | Soil classification - USCS | $c_u$ , kPa | Young's modulus (Pa) | $I_{rr}$ | $N_c^*$ | Meyerhof's $Q_p$ , kN | Vesic's $Q_p$ , kN |
|----------------|----------------|----------------------------|-------------|----------------------|----------|---------|-----------------------|--------------------|
| 0.3 - 6.1      | 3              | Clay CH                    | 31.12       | 9340                 | 100      | 10.04   | 35.196                | 39.280             |
| 7.3 - 14.0     | 11             | Clay CL                    | 52.67       | 15800                | 100      | 10.04   | 59.568                | 66.481             |
| 14.0 - 19.5    | 17             | Clay CL                    | 57.46       | 17240                | 100      | 10.04   | 64.986                | 72.527             |
| 20.7-27.7      | 24             | Clay CH                    | 110.12      | 33040                | 100      | 10.04   | 124.543               | 138.995            |

### Friction Resistance in Clay

$\lambda$  -,  $\alpha$  -,  $\beta$  - methods and correlation with SPT values

$\lambda$  - **method**

$$f_{av} = \lambda(\overline{\sigma'_0} + 2c_u)$$

$\overline{\sigma'_0}$  - mean effective vertical stress for the entire embedment length

$c_u$  - mean undrained shear strength for  $\phi = 0$

$$Q_s = pL f_{av}$$

$$\overline{\sigma'}_o = \frac{A_1 + A_2 + A_3 + \dots}{L}$$

$$c_u = \frac{c_{u(1)} * L_1 + c_{u(2)} * L_2 + \dots}{L}$$

$A_1, A_2, A_3, \dots$  - areas of the vertical effective stress diagrams

#### $\alpha$ –method

$$f = \alpha c_u$$

$$f_{av} = 0.5(c_u \sigma'_0)^{0.5}$$

or

$$f_{av} = 0.5(c_u)^{0.75} (\sigma'_0)^{0.25}$$

$$\alpha =$$

$$Q_s = \Sigma f p \Delta L = \Sigma \alpha c_u p \Delta L$$

#### $\beta$ – method

$$f = \beta \overline{\sigma'_0}$$

$$\beta = K \tan \phi'_R$$

$\phi'_R$  = drained friction angle of remolded clay

Since there was no data for drained friction angles of clay layers, this method was not applied.

Table 4.7. Interim calculation values for  $\lambda$  and  $\alpha$ -method

| Depth, m    | USCS soil classification | $\lambda$ | lambda f | $\alpha$ | alpha f |
|-------------|--------------------------|-----------|----------|----------|---------|
| 0.3 - 6.1   | CH                       |           | 288.384  | 0.811    | 275.931 |
| 6.1 - 7.3   | SP                       |           | 820.497  | 0.6638   | 717.488 |
| 7.3 - 14.0  | CL                       |           | 1348.291 | 0.635    | 1095.77 |
| 14.0 - 19.5 | CL                       |           | 1644.022 | 0.4497   | 1282.46 |

|             |    |  |         |  |   |
|-------------|----|--|---------|--|---|
| 19.5 - 20.7 | SP |  | 612.914 |  | 0 |
|-------------|----|--|---------|--|---|

Table 4.8. Individual skin friction,  $Q_s$  for clay layers

| Depth, m    | Soil description,<br>USCS  | $Q_s$ , kN<br>$\alpha$ method | $Q_s$ , kN<br>$\lambda$ method |
|-------------|----------------------------|-------------------------------|--------------------------------|
| 0.3 - 6.1   | Clay, medium stiff<br>(CH) | 193.110                       | 65.715                         |
| 7.3 - 14.0  | Clay, stiff (CL)           | 257.902                       | 31.144                         |
| 14.0 - 19.5 | Clay (CL)                  | 227.913                       | 28.870                         |
| 20.7-27.7   | Clay (CH)                  | 118.673                       | 22.360                         |

### **$Q_p$ and $Q_s$ for sand layers**

#### **Point bearing capacity in Sand**

##### **Meyerhof method (Das & Sivakugan, 2019)**

$$Q_p = A_p N_q^* q' \leq A_p q_l$$

$$q_l = 0.5 p_a N_q^* \tan \phi'$$

$$q'(20.7) = 324.368 + (20.7 - 19.5) \cdot 1832.51 = 386.886 \frac{kN}{m^2}$$

$$N_q^* = 56.7$$

$$Q_p = 0.196 \cdot 56.7 \cdot 386.886 = 6208 \text{ kN}$$

##### **Vesic's method**

$$Q_p = A_p \bar{\sigma}_0' N_{\sigma}^*$$

$$\bar{\sigma}_0' = \left( \frac{1+2K_0}{3} \right) q'$$

$$K_0 = 1 - \sin \phi'$$

$$N_{\sigma}^* = \frac{3N_q^*}{1+2K_0}$$

$$K_0 = 1 - \sin 30 = 0.5$$

$$N_{\sigma}^* = \frac{3 \cdot 56.7}{1 + 2 \cdot 0.5} = 85.05$$

#### Coyle and Castello's Method

$$Q_p = q' N_q^* A_p$$

$$\frac{L}{D} = \frac{20.7 - 4}{0.6} = 27.833$$

$$N_q^* = 60$$

$$Q_p = q' N_q^* A_p$$

#### Correlations with SPT Results in Granular Soil

$$q_p = 0.4 p_a N_{60} \frac{L}{D} \leq 4 p_a N_{60}$$

$$q_p \approx q_c$$

Table 4.9. Effective vertical stress values for all soil layers

| Depth, m    | Soil description, USCS   | $H_i, m$ | Unit dry density, kg/ m <sup>3</sup> | $\gamma', \frac{kN}{m^3}$ | $\gamma' \cdot H_i, \frac{kN}{m^2}$ | cumulative $eq', \frac{kN}{m^2}$ |
|-------------|--------------------------|----------|--------------------------------------|---------------------------|-------------------------------------|----------------------------------|
| 0.3 - 6.1   | Clay, medium stiff (CH)  | 5.8      | 1585.83                              | 15.557                    | 90.231                              | 90.231                           |
| 6.1 - 7.3   | Sand, medium dense (SP)  | 1.2      | 1729.99                              | 16.971                    | 20.365                              | 110.596                          |
| 7.3 - 14.0  | Clay, stiff (CL)         | 6.7      | 1569.81                              | 15.400                    | 103.179                             | 213.775                          |
| 14.0 - 19.5 | Clay (CL)                | 5.5      | 1649.90                              | 16.186                    | 89.020                              | 302.795                          |
| 19.5 - 20.7 | Poorly graded sand, very | 1.2      | 1832.51                              | 17.977                    | 21.572                              | 324.368                          |

|           |                                              |     |         |        |        |         |
|-----------|----------------------------------------------|-----|---------|--------|--------|---------|
|           | dense (SP)                                   |     |         |        |        |         |
| 20.7-27.7 | Clay (CH)                                    | 2   | 1681.94 | 16.500 | 33.000 | 357.367 |
| 27.7-28.4 | Poorly<br>graded<br>sand, very<br>dense (SP) | 0.7 | 1811.69 | 17.773 | 12.441 | 369.808 |

Table 4.10. Point bearing capacity,  $Q_p$  in sand layers

| Depth, m | Soil<br>description<br>, USCS                | $Q_p, kN$<br>(Meyerhof) | $Q_p, kN$<br>(Vesic) | $Q_p, kN$<br>(Coyle&Ca<br>stello) | $Q_p, kN$<br>(SPT<br>Meyerhof) | $Q_p, kN$<br>(SPT<br>Briaud) |
|----------|----------------------------------------------|-------------------------|----------------------|-----------------------------------|--------------------------------|------------------------------|
| 7.3      | Sand,<br>medium<br>dense (SP)                | 833.874                 | 833.874              | 347.448                           | 5016                           | 5247.228                     |
| 20.7     | Poorly<br>graded<br>sand, very<br>dense (SP) | 10190.307               | 10190.307            | 2445.674                          | 22400.000                      | 8391.004                     |
| 28.4     | Poorly<br>graded<br>sand, very<br>dense (SP) | 11617.864               | 11617.864            | 2555.930                          | 21200.000                      | 8226.319                     |

### Friction Resistance in Sand

#### General formula

According to Das & Sivakugan (2019),

$$Q_s = \Sigma p \Delta L f$$

$$f = K \sigma'_0 \tan \delta'$$

$$\delta' = 0.5\phi' = 15$$

For high-displacement driven pile (reinforced precast concrete pile),

$$K_0 = 1.5$$

### Coyle and Castello

$$Q_s = (K\bar{\sigma}_0' \tan \delta') pL$$

$$Q_s = K\bar{\sigma}_0' \tan(0.8\phi') pL$$

### Correlation with SPT by Meyerhof (1976)

For a high-displacement concrete pile with circular cross section,

$$f_{av} = 0.02 p_a (\overline{N}_{60})$$

$p_a$  = atmospheric pressure ( $\approx 100$  kN/m<sup>2</sup>)

$N_{60}$  = average value of standard penetration resistance

$$Q_s = pL f_{av}$$

### Correlation with SPT by Briaud et al. (1985)

$$f_{av} = 0.224 p_a (\overline{N}_{60})^{0.29}$$

### Negative skin friction

When fine grained clay layers are located above granular sand layers, there can be a negative skin friction effect.

#### Clay Fill over Granular Soil

$$Q_n = \frac{pK'\gamma_f H_f^2 \tan \delta'}{2}$$

$K'$  = earth pressure coefficient =  $K_0 = 1 - \sin \phi'$

$\gamma_f$  = effective unit weight of fill

$\delta'$  = soil–pile friction angle  $\approx (0.5-0.7)\phi'$

$H_f$  = height of the clay fill. If the fill is above the water table, the effective unit weight should be replaced by the moist unit weight.

Due to the  $\tan \delta' = \tan((0.5-0.7)\phi')$  member the negative skin friction for all clay layers over granular soil was 0, since in our case all  $\phi'$  of clay layers = 0 and  $\tan(0)=0$ .

#### Granular Soil Fill over Clay



$$Q_n = (pK'\gamma'_f H_f \tan\delta')L_1 + \frac{L_1^2 pK'\gamma' \tan\delta'}{2}$$

$$L_1 = \frac{(L-H_f)}{L_1} \left[ \frac{L-H_f}{2} + \frac{\gamma'_f H_f}{\gamma'} \right] - \frac{2\gamma'_f H_f}{\gamma'}$$

For layer 2 SP at 6.1-7.3 m,

$$L_1 = \frac{(14-1.2)}{L_1} \left[ \frac{14-1.2}{2} + \frac{16.97*1.2}{15.4} \right] - \frac{2*16.97*1.2}{15.4}$$

$$L_1^2 = 98.846 - 2.6447L_1$$

$$L_1 = 8.707$$

$$Q_n = 224.071 \text{ kN}$$

For layer 5 SP at 19.5-20.7 m

$$L_1 = \frac{(27.7-1.2)}{L_1} \left[ \frac{27.7-1.2}{2} + \frac{17.977*1.2}{16.5} \right] - \frac{2*17.977*1.2}{16.5}$$

$$L_1 = 18.38$$

$$Q_n = 949.615 \text{ kN}$$

Table 4.11. Skin resistance, individual Qs for sand layers

| Depth, m    | Soil description, USCS              | $Q_s$ , kN<br>General | $Q_s$ , kN<br>Coyle&Castello | $Q_s$ , kN<br>SPT<br>Meyerhof | $Q_s$ , kN<br>SPT<br>Briaud | $Q_n$ , kN |
|-------------|-------------------------------------|-----------------------|------------------------------|-------------------------------|-----------------------------|------------|
| 6.1 - 7.3   | Sand, medium dense (SP)             | 67.148                | 55.794                       | 28.953                        | 75.480                      | 149.381    |
| 19.5 - 20.7 | Poorly graded sand, very dense (SP) | 252.347               | 85.982                       | 101.335                       | 108.546                     | 633.077    |
| 27.7-28.4   | Poorly graded sand, very dense (SP) | 167.824               | 40.845                       | 55.945                        | 62.315                      | -          |

Based on hand calculations, lowest values of  $Q_p$  and  $Q_s$  were chosen as a conservative measure, and negative friction has been subtracted from  $Q_s$  where applicable. The results were filled in Table 4.12.

Table 4.12. Individual and cumulative skin resistance, ultimate and allowable bearing capacity for single piles for all layers

| Depth, m    | Soil description, USCS              | Individual $Q_s$ , kN | Cumulative $Q_s$ , kN | $Q_p$ , kN | $Q_u$ , kN | $FS$ | $Q_{all}$ , kN |
|-------------|-------------------------------------|-----------------------|-----------------------|------------|------------|------|----------------|
| 0.3 - 6.1   | Clay, medium stiff (CH)             | 65.715                | 65.715                | 35.196     | 100.911    | 3    | 33.637         |
| 6.1 - 7.3   | Sand, medium dense (SP)             | 55.794                | 121.509               | 347.448    | 319.576    |      | 106.525        |
| 7.3 - 14.0  | Clay, stiff (CL)                    | 31.144                | 152.653               | 59.568     | 212.221    |      | 70.740         |
| 14.0 - 19.5 | Clay (CL)                           | 28.870                | 181.523               | 64.986     | 246.509    |      | 82.170         |
| 19.5 - 20.7 | Poorly graded sand, very dense (SP) | 85.982                | 267.505               | 2445.674   | 2080.102   |      | 693.367        |
| 20.7-27.7   | Clay (CH)                           | 22.360                | 289.865               | 124.543    | 414.408    |      | 138.136        |
| 27.7-28.4   | Poorly graded sand, very            | 40.845                | 330.710               | 2555.930   | 2886.640   |      | 962.213        |

|  |            |  |  |  |  |  |  |
|--|------------|--|--|--|--|--|--|
|  | dense (SP) |  |  |  |  |  |  |
|--|------------|--|--|--|--|--|--|

#### 4.3.2. Group pile design

The efficiency of the load-bearing capacity of a group pile

$$\eta = \frac{Q_{g(u)}}{\Sigma Q_u}$$

$Q_{g(u)}$  = ultimate load-bearing capacity of the group pile

$Q_u$  = ultimate load-bearing capacity of each pile without the group effect

$$Q_{g(u)} = (n_1 * n_2) * Q_u$$

$n_1, n_2$  = number of piles

$$\eta = \frac{2(n_1+n_2-2)d+4D}{p*n_1*n_2}$$

If  $\eta \geq 1$ ,

$$Q_{g(u)} = \Sigma Q_u$$

$$Q_{g(u)} = \eta \Sigma Q_u$$

$$L_g = (n_1 - 1)d + 2(D/2)$$

$$B_g = (n_2 - 1)d + 2(D/2)$$

Center to center spacing was assumed to be 3D

$$d=3D=3*0.4=1.2 \text{ m}$$

$$\eta = \frac{2(4+3-2)2+4*0.4}{1.257*4*4} = 0.902$$

$$Q_{g(u)} = \Sigma Q_u = (n_1 * n_2) * Q_u = 4 \times 3 \times 693.367 = 7501.823 \text{ kN}$$

$$L_g = (4 - 1)2 + 2(0.4/2) = 6.4 \text{ m}$$

$$B_g = (4 - 1)2 + 2(0.4/2) = 6.4 \text{ m}$$

Table 4.13. Group pile design specifications

| Column type      | Interior     | Exterior     | Corner       |
|------------------|--------------|--------------|--------------|
| $n_1 \times n_2$ | $4 \times 3$ | $3 \times 3$ | $4 \times 2$ |
| D, m             | 0.4          | 0.4          | 0.4          |

|                   |       |       |       |
|-------------------|-------|-------|-------|
| p, m              | 1.257 | 1.257 | 1.257 |
| A, m <sup>2</sup> | 0.126 | 0.126 | 0.126 |
| L, m              | 15    | 15    | 15    |
| C-c spacing d, m  | 1.4   | 1.4   | 1.4   |
| Bg, m             | 2.8   | 2.8   | 1.6   |
| Lg, m             | 2.8   | 4     | 4     |

Table 4.14. Group pile configuration

| Column   | $n_1 \times n_2$ | Group efficiency, $\eta$ | $\Sigma Q_u, kN$ | $Q_{g(u)}, kN$ | Pu, kN  |
|----------|------------------|--------------------------|------------------|----------------|---------|
| Interior | 4 × 3            | 0.902                    | 8320.404         | 7501.823       | 7024.24 |
| Exterior | 3 × 3            | 0.990                    | 6240.303         | 6177.900       | 6033.11 |
| Corner   | 4 × 2            | 1.114                    | 5546.936         | 5546.936       | 4466.94 |

### 4.3.3 Settlement on deep foundations

#### Elastic settlement for single pile

$$s_e = s_{e(1)} + s_{e(2)} + s_{e(3)}$$

$$s_{e(1)} = \frac{(Q_{wp} + \xi Q_{ws})L}{A_p E_p}$$

$$E_p = 4700\sqrt{f'_c} = 4700\sqrt{30000} = 814063.9 \text{ MPa}$$

$$Q_{wp} = \frac{Q_b}{FS} = \frac{2445.674}{3} = 815.225 \text{ kN}$$

$$Q_{ws} = \frac{Q_s}{FS} = \frac{267.505}{3} = 89.168 \text{ kN}$$

$$\xi = 0.67$$

$$s_{e(1)} = \frac{(815.225 \text{ kN} + 0.67 \cdot 89.168 \text{ kN})16.7 \text{ m}}{0.126 \cdot 814063.9 \cdot 10^3 \text{ kN}} = 0.142456 \text{ mm}$$

$$s_{e(2)} = \frac{q_{wp} D}{E_s} (1 - \mu_s^2) I_{wp}$$

$$\mu_s^2 = 0.3$$

$$q_{wp} = \frac{Q_{wp}}{A_p} = \frac{815.225}{0.126} = 6470.04 \text{ kN/m}^2$$

$$s_{e(2)} = \frac{6470.04 \cdot 0.4}{70000} (1 - 0.35^2) 0.85 = 24 \text{ mm}$$

$$s_{e(2)} = \frac{Q_{wp} C_p}{D q_p} = \frac{815.225 \cdot C_p}{0.6 \cdot q_p}$$

$$s_{e(3)} = \frac{Q_{ws}}{pL} \frac{D}{E_s} (1 - \mu_s^2) I_{ws} = \frac{89.168}{1.257 \cdot 16.7} \frac{0.4}{28000} (1 - 0.3^2) 4.2615 = 2.3532 \cdot 10^{-4} \text{ m}$$

$$I_{ws} = 2 + 0.35 \sqrt{\frac{L}{D}} = 2 + 0.35 \sqrt{\frac{16.7}{0.4}} = 4.2615$$

$$s_e = 4.5 \cdot 10^{-3} + 0.027 + 2.3532 \cdot 10^{-4} = 0.0287 \text{ m}$$

### Elastic settlement for group of piles

#### Vesic

$$s_{g(e)} = \sqrt{\frac{B_g}{D}} s_e$$

A specific condition for group piles in sand or gravel

#### Meyerhof

$$s_{g(e), mm} = \frac{0.96 q \sqrt{\frac{B_g}{D}} I}{N_{60}}$$

$$q = \frac{Q_g}{L_g B_g}$$

$$I = 1 - \frac{L}{8B_g}$$

Table 4.15. Elastic settlement for group of piles, Vesic's method

| Column   | D, m | $B_g$ , m | $s_e$ , mm | $\sqrt{\frac{B_g}{D}}$ | $s_{g(e)}$ , mm<br>(Vesic) |
|----------|------|-----------|------------|------------------------|----------------------------|
| Interior | 0.4  | 2.8       | 0.0287     | 2.65                   | 0.08                       |
| Exterior | 0.4  | 2.8       | 0.0287     | 2.65                   | 0.08                       |

|        |     |     |        |   |      |
|--------|-----|-----|--------|---|------|
| Corner | 0.4 | 1.6 | 0.0287 | 2 | 0.06 |
|--------|-----|-----|--------|---|------|

Table 4.16. Elastic settlement for group of piles, Meyerhof's method

| Column   | $q$      | $B_g, \text{ m}$ | $I$<br>*replace if<br><0.5 | $N_{60}$ | $s_{g(e)}, \text{ mm}$<br>(Meyerhof) |
|----------|----------|------------------|----------------------------|----------|--------------------------------------|
| Interior | 895.9487 | 2.8              | 0.254464                   | 56       | 12.85036                             |
| Exterior | 627.1641 | 2.8              | 0.254464                   | 56       | 8.995253                             |
| Corner   | 1097.537 | 1.6              | -0.30469                   | 56       | 11.8996                              |

### Consolidation settlement for group of piles

$$\Delta\sigma'_i = \frac{Q_g}{(B_g + z'_i)(L_g + z'_i)}$$

$\Delta\sigma'_i$  = increase in effective stress at the middle of layer i

$z'_i$  = distance from  $z=0$  to the middle of the clay layer i

$$\Delta s_{c(i)} = \left[ \frac{\Delta e_{(i)}}{1 + e_{0(i)}} \right] H_i$$

$\Delta s_{c(i)}$  = consolidation settlement of layer i

$\Delta e_{(i)}$  = change of void ratio caused by the increase in stress in layer i

$e_{0(i)}$  = initial void ratio of layer i (before construction)

$H_i$  = thickness of layer i

$$\Delta s_{c(g)} = \Sigma \Delta s_{c(i)}$$

For normally consolidated clays,

$$\Delta s_{c(i)} = \left[ \frac{C_{c(1)} H_i}{1 + e_{0(1)}} \right] \log \left[ \frac{\sigma'_{0(1)} + \Delta\sigma'_{(1)}}{\sigma'_{0(1)}} \right]$$

$$C_c = \frac{D_{30}^2}{D_{10} \times D_{60}}$$

Table 4.17. Consolidation settlement values for clay layers

| Depth, m    | $H_i$ , m | USC<br>S soil<br>classi-<br>fication | Bore<br>hole<br># | $e_{0(i)}$ | $D_{10}$ | $D_{30}$ | $D_{60}$ | $C_c$    | $z_i$ , m |
|-------------|-----------|--------------------------------------|-------------------|------------|----------|----------|----------|----------|-----------|
| 0.3 - 6.1   | 5.8       | CH                                   | B-7               | 0.587      | 0.01     | 0.05     | 0.1      | 2.5      | 4.166667  |
| 7.3 - 14.0  | 6.7       | CL                                   | B-1               | 0.77       | 0.01     | 0.07     | 0.3      | 1.633333 | 11.766667 |
| 14.0 - 19.5 | 5.5       | CL                                   | B-7               | 0.6881     | 0.01     | 0.02     | 0.05     | 0.8      | 17.666667 |
| 20.7-27.7   | 2         | CH                                   | B-1               | 0.77       | 0.01     | 0.02     | 0.05     | 0.8      | 22.033333 |
| 28.4 - 36.9 | 8.5       | CL                                   | B-1<br>new        | 0.6624     | 0.01     | 0.02     | 0.05     | 0.8      | 34.066667 |

Table 4.18. Consolidation settlement values for interior columns

| Depth, m    | USCS soil<br>classification | $\Delta\sigma'_{(i)}$ , kN/m <sup>2</sup> | $\Delta s_{c(i)}$ , m | $\Delta s_{c(g)}$ , m |
|-------------|-----------------------------|-------------------------------------------|-----------------------|-----------------------|
| 0.3 - 6.1   | CH                          | 144.7269                                  | 3.797553              | 4.267                 |
| 7.3 - 14.0  | CL                          | 33.10389                                  | 0.386584              | 0.469                 |
| 14.0 - 19.5 | CL                          | 16.76892                                  | 0.061015              | 0.083                 |
| 20.7-27.7   | CH                          | 11.39015                                  | 0.012317              | 0.022                 |
| 28.4 - 36.9 | CL                          | 5.168108                                  | 0.009245              | 0.009                 |

Table 4.19. Consolidation settlement values for exterior columns

| Depth, m    | USCS soil classification | $\Delta\sigma'_{(i)}$ , kN/m <sup>2</sup> | $\Delta s_{c(i)}$ , m | $\Delta s_{c(g)}$ , m |
|-------------|--------------------------|-------------------------------------------|-----------------------|-----------------------|
| 0.3 - 6.1   | CH                       | 106.040                                   | 3.084                 | 3.462                 |
| 7.3 - 14.0  | CL                       | 26.269                                    | 0.311                 | 0.379                 |
| 14.0 - 19.5 | CL                       | 13.605                                    | 0.050                 | 0.068                 |
| 20.7-27.7   | CH                       | 9.332                                     | 0.010                 | 0.018                 |
| 28.4 - 36.9 | CL                       | 4.299                                     | 0.008                 | 0.008                 |

Table 4.20. Consolidation settlement values for corner columns

| Depth, m    | USCS soil classification | $\Delta\sigma'_{(i)}$ , kN/m <sup>2</sup> | $\Delta s_{c(i)}$ , m | $\Delta s_{c(g)}$ , m |
|-------------|--------------------------|-------------------------------------------|-----------------------|-----------------------|
| 0.3 - 6.1   | CH                       | 94.851                                    | 2.851                 | 3.158                 |
| 7.3 - 14.0  | CL                       | 21.196                                    | 0.254                 | 0.307                 |
| 14.0 - 19.5 | CL                       | 10.701                                    | 0.039                 | 0.053                 |
| 20.7-27.7   | CH                       | 7.260                                     | 0.008                 | 0.014                 |
| 28.4 - 36.9 | CL                       | 3.290                                     | 0.006                 | 0.006                 |

Table 4.21. Group pile total settlement

| Pile group            | Interior | Exterior | Corner |
|-----------------------|----------|----------|--------|
| $s_{g(e)}$ , m        | 0.013    | 0.009    | 0.012  |
| $\Delta s_{c(g)}$ , m | 0.022    | 0.018    | 0.014  |
| $s_{total}$           | 0.035    | 0.027    | 0.026  |



The calculated total settlement for group piles as the sum of elastic and consolidation settlement was 98 mm for interior, 94 mm for exterior and 90 mm for corner column groups. According to Code of Practice for Foundations (2017), the maximum allowable settlement should be no more than 30mm. However, it also states that the overall differential settlement between piles should be no more than 10 mm. In our case, maximum differential settlement is

$$s_{\text{differential}} = 0.098 - 0.09 = 8 \text{ mm}$$

Therefore, although the maximum settlement is higher than allowable, the relatively low differential settlement will prevent the most drastic effects of uneven sinking such as cracks in the structural elements and tilting.

#### 4.3.4 Axial bearing capacity hand calculations

The efficiency of the load-bearing capacity of a group pile

$$\eta = \frac{Q_{g(u)}}{\Sigma Q_u}$$

$Q_{g(u)}$  = ultimate load-bearing capacity of the group pile

$Q_u$  = ultimate load-bearing capacity of each pile without the group effect

$$Q_{g(u)} = (n_1 * n_2) * Q_u$$

$n_1, n_2$  = number of piles

$$\eta = \frac{2(n_1 + n_2 - 2)d + 4D}{p * n_1 * n_2}$$

If  $\eta \geq 1$ ,

$$Q_{g(u)} = \Sigma Q_u$$

$$Q_{g(u)} = \eta \Sigma Q_u$$

$$L_g = (n_1 - 1)d + 2(D/2)$$

$$B_g = (n_2 - 1)d + 2(D/2)$$

Center to center spacing was assumed to be 3D

$$d = 3D = 3 * 0.4 = 1.2 \text{ m}$$

$$\eta = \frac{2(4+3-2)2+4*0.4}{1.257*4*4} = 0.902$$

$$Q_{g(u)} = \Sigma Q_u = (n_1 * n_2) * Q_u = 4 \times 3 \times 693.367 = 7501.823 \text{ kN}$$

$$L_g = (4 - 1)2 + 2(0.4/2) = 5 \text{ m}$$

$$B_g = (3 - 1)2 + 2(0.4/2) = 3.6 \text{ m}$$

Table 4.13. Group pile design specifications

| Column type      | Interior     | Exterior     | Corner       |
|------------------|--------------|--------------|--------------|
| $n_1 \times n_2$ | $4 \times 3$ | $3 \times 3$ | $4 \times 2$ |
| D, m             | 0.4          | 0.4          | 0.4          |
| p, m             | 1.257        | 1.257        | 1.257        |
| $A, m^2$         | 0.126        | 0.126        | 0.126        |
| L, m             | 15           | 15           | 15           |
| C-c spacing d, m | 1.4          | 1.4          | 1.4          |
| Bg, m            | 3.6          | 3.6          | 2.2          |
| Lg, m            | 5            | 3.6          | 5            |

Table 4.14. Group pile configuration

| Column   | $n_1 \times n_2$ | Group efficiency, $\eta$ | $\Sigma Q_u, kN$ | $Q_{g(u)}, kN$ | Pu, kN  |
|----------|------------------|--------------------------|------------------|----------------|---------|
| Interior | $4 \times 3$     | 0.902                    | 8320.404         | 7501.823       | 7024.24 |
| Exterior | $3 \times 3$     | 0.990                    | 6240.303         | 6177.900       | 6033.11 |
| Corner   | $4 \times 2$     | 1.114                    | 5546.936         | 5546.936       | 4466.94 |

Figure 4.. Group pile layout

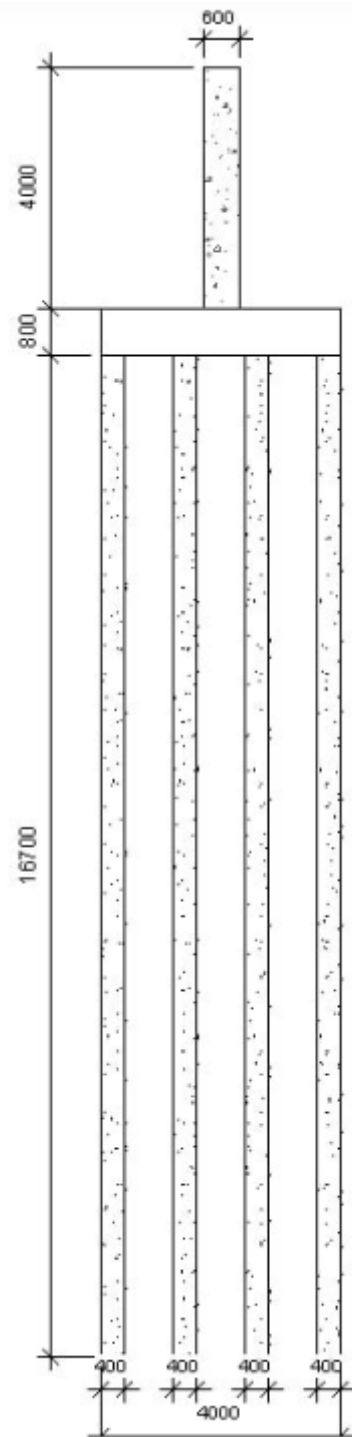


Figure 4.8. Group pile cross section

#### 4.3.5 Lateral bearing capacity hand calculations

Table 4.15. Nominal lateral loads given by SAP2000

| Column type | Load combination | $F_x, kN$ | $F_y, kN$ | Number of piles | Lateral load |
|-------------|------------------|-----------|-----------|-----------------|--------------|
| Interior    | 1.2D+1L+1Ey      | -94.627   | 15.621    | 12              | 7.99         |

|          |  |          |        |   |       |
|----------|--|----------|--------|---|-------|
| Exterior |  | -133.783 | -1.505 | 9 | 14.87 |
| Corner   |  | -56.354  | -6.875 | 8 | 7.096 |

Assumptions for uneven load distribution

According to Das & Sivakugan (2019), characteristic length of the soil–pile system is

$$T = \sqrt[5]{\frac{\eta_h}{E_p I_p}}$$

Where

$\eta_h$  – constant modulus of horizontal subgrade reaction

$E_p$  – modulus of elasticity in the pile material, MPa

$I_p$  – moment of inertia of the pile section,  $m^4$

$$E_p = 4700\sqrt{f'_c}$$

$f'_c$  – compressive strength of concrete, DL

According to the LA Building Code (2022), minimum  $f'_c$  for precast concrete piles in a seismic category D site is 35 MPa.

$$E_p = 4700\sqrt{35} = 27805.6 \text{ MPa}$$

$$I_p = \frac{\pi D^4}{64}$$

$$I_p = \frac{\pi 0.4^4}{64} = 0.007854 \text{ m}^4$$

$$k_z = \eta_h z$$

Representative values of  $\eta_h$  were taken conservatively from the ranges in Table 12.16 (Das & Sivakugan, 2019). The corresponding  $k_z$  and T values were recorded in Table X. To determine whether piles are long or rigid, the relationship between pile length L and the highest T value should be checked. If  $L \leq 2T$ , the pile is rigid, and if  $L \geq 5T$  the pile is long. From Table 4.16, T<sub>max</sub> = 2.62, for pile length L = 15m,

$$5T = 5 * 2.62 = 13.1$$

$$L = 15 > 13.1$$

Therefore, the piles will behave like long piles.

Table 4.16. Constant modulus of subgrade and subgrade modulus of each soil layer

| Depth, m   | Thickness H, m | USCS Classification | Description        | $\eta_h, \frac{kN}{m^3}$ | $k_z, \frac{kN}{m^2}$ | T, m |
|------------|----------------|---------------------|--------------------|--------------------------|-----------------------|------|
| 0.3 - 6.1  | 5.8            | CH                  | Clay, medium stiff | 5000                     | 4000                  | 1.87 |
| 6.1 - 7.3  | 1.2            | SP                  | Sand, medium dense | 4000                     | 8000                  | 1.79 |
| 7.3 - 14.0 | 6.7            | CL                  | Clay, stiff        | 20000                    | 174000                | 2.47 |

|             |     |    |                                |       |        |      |
|-------------|-----|----|--------------------------------|-------|--------|------|
| 14.0 - 19.5 | 5.5 | CL | Clay                           | 20000 | 284000 | 2.47 |
| 19.5 - 20.7 | 1.2 | SP | Poorly graded Sand, very dense | 12000 | 184800 | 2.23 |
| 20.7-27.7   | 2   | CH | Clay                           | 27000 | 604800 | 2.62 |
| 27.7-28.4   | 0.7 | SP | Poorly graded sand, very dense | 12000 | 277200 | 2.23 |
| 28.4 - 36.9 | 8.5 | CL | Clay                           | 2500  | 79000  | 1.63 |

According to the method of Broms, the ultimate lateral resistance of long piles in sand is

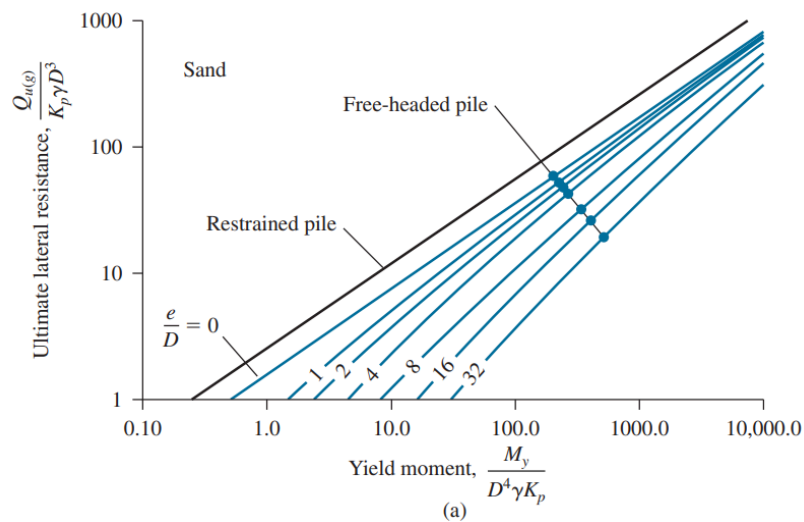


Figure 4.9. Broms' solution for ultimate lateral resistance (Das & Sivakugan, 2019)

$$\frac{Q_{u(g)}}{K_p \gamma D^3} = \frac{M_y}{D^4 \gamma K_p}$$

$K_p$  -Rankine passive pressure coefficient

$\gamma$ -unit weight of soil

$$K_p = \tan^2(45 + \frac{\phi'}{2})$$

$\gamma=17.97\text{kN}$  for SP layer (19.5-20.7 m depth)

For RC piles,

$$M_y = S F_y = A_s F_y z$$

$A_s$  - area of steel reinforcement

$z$ -lever arm

$F_y$  - yield stress of the pile material

$$S = \frac{\pi D^3}{32} = \frac{3.14 \cdot 0.4^3}{32} = 6.2832 \text{ mm}^3$$

$$F_y = 420 \text{ MPa, reinforcing steel}$$

Assuming 6 reinforcement bars of 20mm diameter, 75 mm cover

$$A_s = 6 * \frac{\pi * 20^2}{4} = 1885 \text{ mm}^2$$

$$z = d - a/2 = 285.89 \text{ mm}$$

$$d = D - \text{cover} - \frac{\phi}{2}$$

$$d = 400 - 75 - 20/2 = 315 \text{ mm}$$

$$a = \frac{A_s F_y}{0.85 f_c' b} = \frac{1885 * 420}{0.85 * 40 * 400} = 58.21 \text{ mm}$$

$$M_y = 1885 * 10^{-6} * 420 * 0.2859 = 226.35 \text{ kN} \cdot \text{m}$$

$$\frac{M_y}{D^4 \gamma K_p} = \frac{226.35}{0.4^4 * 17.97 * \tan^2(45 + \frac{37.96}{2})} = 117.2534$$

From Figure 12.42a, for restrained pile  $\frac{Q_{u(g)}}{K_p \gamma D^3} \approx 90$

$$Q_{u(g)} = 90 K_p \gamma D^3 = 90 * \tan^2(45 + \frac{37.96}{2}) * 17.97 * 0.4^3 = 434.35 \text{ kN}$$

$$Q_{all} = \frac{Q_{u(g)}}{FS}$$

According to Das & Sivakugan, a FS = 3 is appropriate for such cases

$$Q_{all} = \frac{434.35}{3} = 144.8 \text{ kN}$$

Table 4.17. Lateral load bearing capacity and actual lateral load per individual pile in group

| Column type | $Q_{u(g)}, \text{ kN}$ | $Q_{all}, \text{ kN}$ | $Q_{lateral}, \text{ kN}$ |
|-------------|------------------------|-----------------------|---------------------------|
| Interior    | 434.35                 | 144.8                 | 7.99                      |
| Exterior    |                        |                       | 14.87                     |
| Corner      |                        |                       | 7.096                     |

As Table 4.17 demonstrates, for each pile group  $Q_{all} > Q_{lateral}$ . Therefore, the lateral bearing capacity of individual piles surpasses their lateral load with a FS=3, satisfying the design criteria.

#### 4.3.6 Deflection hand calculations

$$\eta = \sqrt[5]{\frac{\eta_h}{E_p I_p}}$$

Deflection of a pile at any depth can be found as

$$x_z(z) = A_x \frac{Q_g T^3}{E_p I_p} + B_x \frac{M_g T^2}{E_p I_p}$$

Coefficients  $A_x, B_x$  were taken from Table 12.15 in Das & Sivakugan (2019). To determine the coefficients, the nondimensional depth Z was determined as

$$Z = \frac{z}{T}$$

Practice shows that in long piles, coefficients for  $Z > 5$  do not change, therefore all values of  $Z$  which exceeded 5 were assigned the same coefficients  $A_x, B_x$ . For  $Z$  between 0 and 5, linear interpolation was applied.

For clays, the deflection is found via a different formula, where  $R$  is the characteristic length instead of  $T$

$$x_z(z) = A'_x \frac{Q_g R^3}{E_p I_p} + B'_x \frac{M_g R^2}{E_p I_p}$$

$$R = \sqrt[4]{\frac{E_p I_p}{k}}$$

$$k = 0.65 \sqrt[12]{\frac{E_s D^4}{E_p I_p}} \cdot \frac{E_s}{1 - \mu_s^2}$$

$$k \approx \frac{E_s}{1 - \mu_s^2}$$

Where

$E_s$  – soil's modulus of elasticity

$\mu_s$  – soil's Poisson's ratio

$$k = 0.65 \sqrt[12]{\frac{E_s D^4}{E_p I_p}} \cdot \frac{E_s}{1 - \mu_s^2}$$

$$k \approx \frac{E_s}{1 - \mu_s^2}$$

$$R = \sqrt[4]{\frac{E_p I_p}{k}}$$

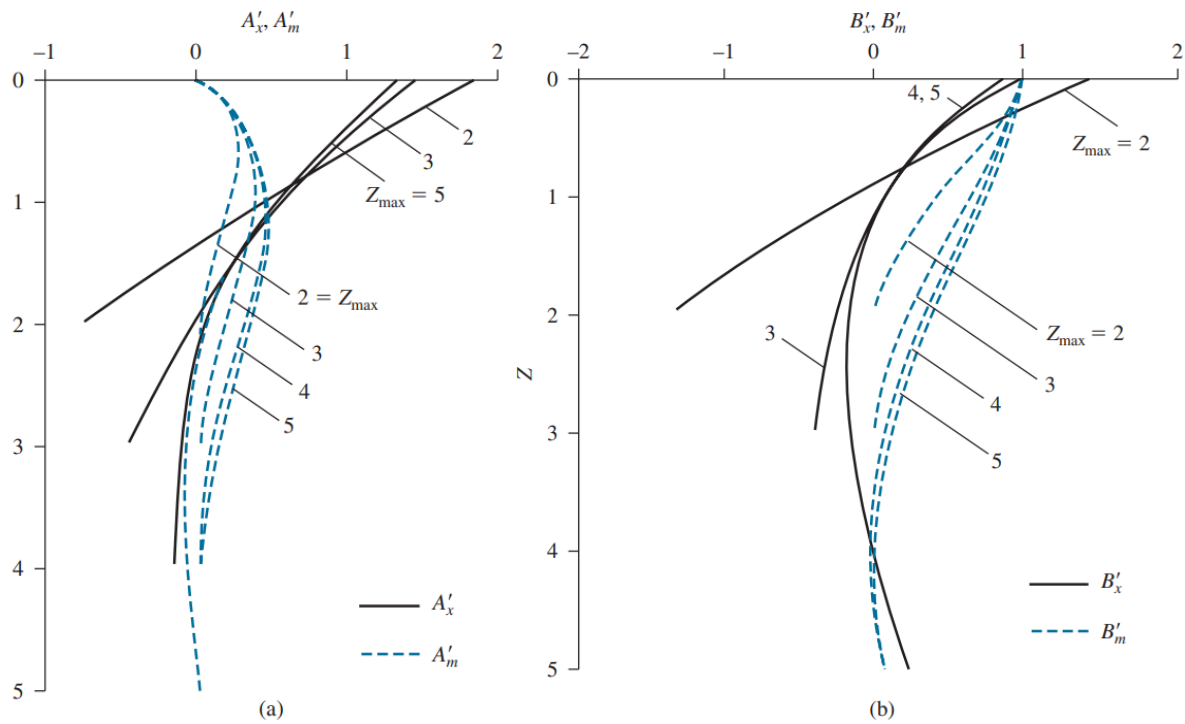


Figure 4.10.  $A'_x$ ,  $B'_x$  variation with depth (Das & Sivakugan 2019)

Table 4.18. Lateral single pile deflection at varying depth for sand layers

| Depth $z$ , m | Thickness $H$ , m | USCS Classification | $Z$   | $A_x$  | $B_x$ | $x_{z, \text{interior}}$ , mm | $x_{z, \text{exterior}}$ , mm | $x_{z, \text{corner}}$ , mm |
|---------------|-------------------|---------------------|-------|--------|-------|-------------------------------|-------------------------------|-----------------------------|
| 7.3           | 1.2               | SP                  | 1.12  | 0.828  | 0.279 | 1.63                          | 1.34                          | 1.20                        |
| 20.7          | 1.2               | SP                  | 6.91  | -0.009 | 0.000 | -0.03                         | -0.03                         | -0.03                       |
| 28.4          | 0.7               | SP                  | 10.37 | -0.009 | 0.000 | -0.03                         | -0.03                         | -0.03                       |

Table 4.19. Lateral single pile deflection at varying depth for clay layers

| Depth $z$ , m | Thickness $H$ , m | USCS Classification | $Z$   | $A'_x$ | $B'_x$ | $k$   | $R$  | $x_{z, \text{interior}}$ , mm | $x_{z, \text{exterior}}$ , mm | $x_{z, \text{corner}}$ , mm |
|---------------|-------------------|---------------------|-------|--------|--------|-------|------|-------------------------------|-------------------------------|-----------------------------|
| 0.3 - 6.1     | 5.8               | CH                  | 0.43  | 1.1    | 0.45   | 3.47  | 2.82 | 8.43                          | 6.95                          | 6.24                        |
| 14.0          | 6.7               | CL                  | 3.52  | -0.1   | -0.1   | 7.24  | 1.18 | -0.06                         | -0.05                         | -0.04                       |
| 19.5          | 5.5               | CL                  | 5.75  | -0.15  | 0.3    | 7.95  | 0    | 0                             | 0                             | 0                           |
| 27.7          | 2                 | CH                  | 8.55  | -0.15  | 0.3    | 16.09 | 0    | 0                             | 0                             | 0                           |
| 36.9          | 8.5               | CL                  | 19.41 | -0.15  | 0.3    | 0     | 0    | 0                             | 0                             | 0                           |



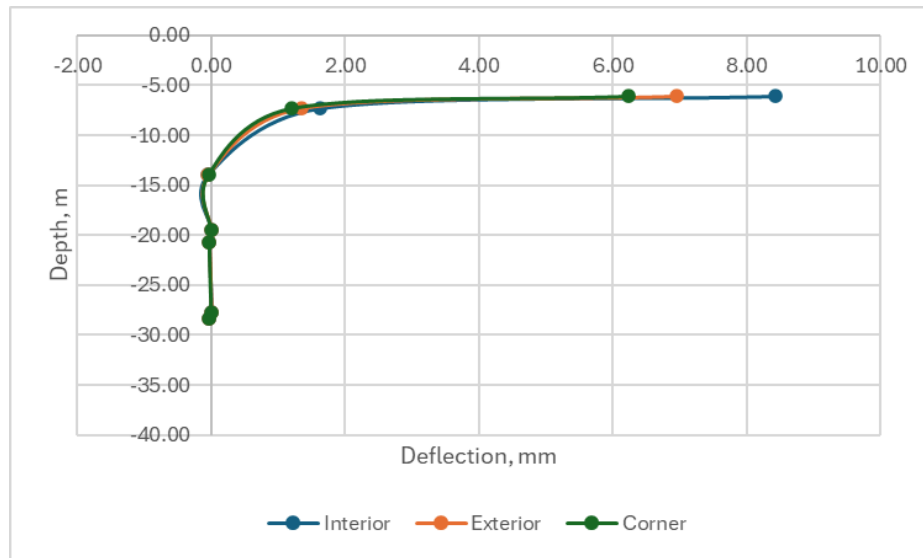


Figure 4.11. Single pile deflection at varying depth

#### 4.4 Software analysis

The analysis was performed in PLAXIS 3D Ultimate with Geotechnical SELECT Entitlements enabled. The Geotechnical SELECT Entitlements is an additional licence which was used to apply seismic conditions to the deflection analysis. The Licence Configuration window is presented in Figure X.

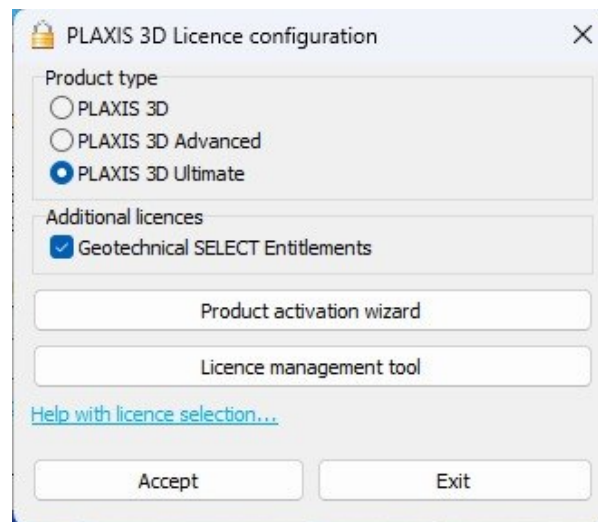


Figure 4.12. Plaxis 3D Licence Configuration window

##### 4.4.1 Software analysis of each pile group types

The soil model was built using the Mohr-Coulomb material model, a widely known linear elastic perfectly-plastic model. It was selected for its simplicity, computational efficiency due to using constant average stiffness, and its suitability in representing the general materials strength. For the pile group model the piles were assigned a material type of embedded beams. The pile caps were modeled as plates, and the load combinations retrieved from the structural analysis part were applied to the plate. Structural columns have varied loads even for the same type of column, and these different loads are transferred to the

foundation. However, to maximize the safety and minimize the modeling time, most critical load combinations were chosen to be applied to the group of piles. These values can be seen in Table XYZ. The geometric configuration of pile groups, design check for bearing capacity, and settlement check from Geo5 software are presented from Figure XX to Figure XY. The deflection analysis results from PLAXIS 3D are presented in Figures

Table 4.20. Most critical load combinations for column types

| Column type | Load combination     | $F_{x'}$ , kN | $F_{y'}$ , kN | $F_{z'}$ , kN | $M_{x'}$ , kN × m | $M_{y'}$ , kN × m | $M_{z'}$ , kN × m |
|-------------|----------------------|---------------|---------------|---------------|-------------------|-------------------|-------------------|
| Exterior    | 1.2D + 1.6L + 0.5RLL | -124.79       | -4.71         | 6108.98       | 1.83              | 90.50             | -0.04             |
| Corner      | 1.2D + 1.6L + 0.5RLL | -56.35        | -6.88         | 3342.69       | 0                 | 0                 | 0                 |
| Interior    | 1.2D + 1.6L - 0.5Lr  | 32.03         | -3.50         | 10870.21      | 4.37              | 40.46             | -0.06             |

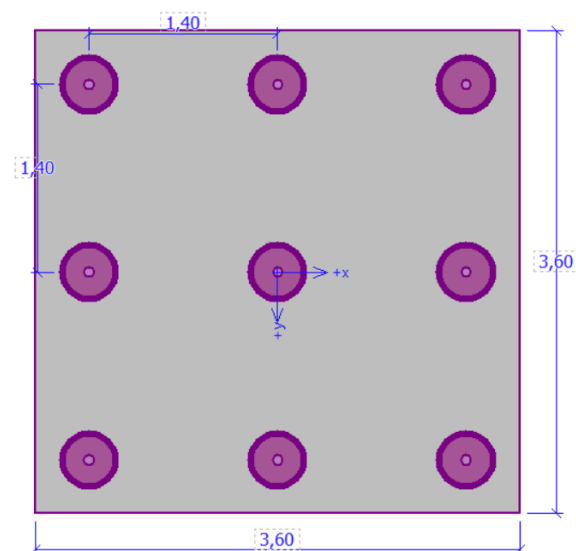


Figure 4.13. Geometry of a single exterior pile group

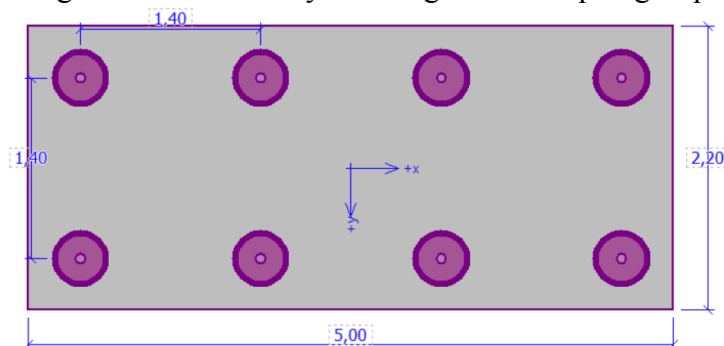


Figure 4.14. Geometry of a single corner pile group

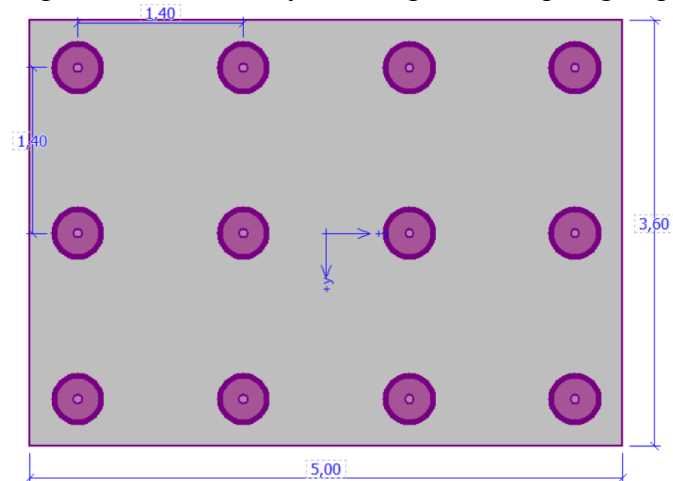


Figure 4.15. Geometry of a single interior pile group

**Analysis of bearing capacity of pile group in cohesive soils**

Max. vertical force includes self-weight of pile cap.

|                                                  |          |   |          |     |
|--------------------------------------------------|----------|---|----------|-----|
| Average undrained shear strength along the piles | $c_{us}$ | = | 23,88    | kPa |
| Undrained shear strength at base of pile group   | $c_{ub}$ | = | 70,00    | kPa |
| Cohesion group bearing capacity factor           | $N_{cg}$ | = | 9,00     |     |
| Vertical bearing capacity of pile group          | $R_g$    | = | 13666,26 | kN  |
| Maximum vertical force                           | $V_d$    | = | 6344,15  | kN  |
| Safety factor = 2,15 > 2,00                      |          |   |          |     |

Vertical bearing capacity of pile group is SATISFACTORY

Figure 4.16. Bearing capacity check for a single exterior group pile on Geo5 software

**Analysis of settlement of pile group in cohesive soils**

Max. vertical force includes self-weight of pile cap.

|                                |     |   |         |    |
|--------------------------------|-----|---|---------|----|
| The depth of substitute found. | $d$ | = | 10,67   | m  |
| Maximum service load           | $N$ | = | 6344,15 | kN |
| Depth of influence zone        | $h$ | = | 9,19    | m  |
| Settlement of pile group       | $s$ | = | 23,5    | mm |

Figure 4.17. Settlement results for a single exterior group pile on Geo5 software

**Analysis of bearing capacity of pile group in cohesive soils**

Max. vertical force includes self-weight of pile cap.

|                                                  |          |   |          |     |
|--------------------------------------------------|----------|---|----------|-----|
| Average undrained shear strength along the piles | $c_{us}$ | = | 23,88    | kPa |
| Undrained shear strength at base of pile group   | $c_{ub}$ | = | 70,00    | kPa |
| Cohesion group bearing capacity factor           | $N_{cg}$ | = | 8,16     |     |
| Vertical bearing capacity of pile group          | $R_g$    | = | 11784,66 | kN  |
| Maximum vertical force                           | $V_d$    | = | 4730,94  | kN  |
| Safety factor = 2,49 > 2,00                      |          |   |          |     |

Vertical bearing capacity of pile group is SATISFACTORY

Figure 4.18. Bearing capacity check for a single corner group pile on Geo5 software

| <b>Analysis of settlement of pile group in cohesive soils</b> |                |
|---------------------------------------------------------------|----------------|
| Max. vertical force includes self-weight of pile cap.         |                |
| The depth of substitute found.                                | d = 10,67 m    |
| Maximum service load                                          | N = 4730,94 kN |
| Depth of influence zone                                       | h = 7,99 m     |
| Settlement of pile group                                      | s = 18,2 mm    |

Figure 4.19. Settlement results for a single corner group pile on Geo5 software

| <b>Analysis of bearing capacity of pile group in cohesive soils</b> |                              |
|---------------------------------------------------------------------|------------------------------|
| Max. vertical force includes self-weight of pile cap.               |                              |
| Average undrained shear strength along the piles                    | $c_{us} = 23,88 \text{ kPa}$ |
| Undrained shear strength at base of pile group                      | $c_{ub} = 70,00 \text{ kPa}$ |
| Cohesion group bearing capacity factor                              | $N_{cg} = 8,58$              |
| Vertical bearing capacity of pile group                             | $R_g = 17381,99 \text{ kN}$  |
| Maximum vertical force                                              | $V_d = 7249,65 \text{ kN}$   |
| Safety factor = 2,40 > 2,00                                         |                              |
| Vertical bearing capacity of pile group is SATISFACTORY             |                              |

Figure 4.20. Bearing capacity check for a single interior group pile on Geo5 software

| <b>Analysis of settlement of pile group in cohesive soils</b> |                |
|---------------------------------------------------------------|----------------|
| Max. vertical force includes self-weight of pile cap.         |                |
| The depth of substitute found.                                | d = 10,67 m    |
| Maximum service load                                          | N = 7249,65 kN |
| Depth of influence zone                                       | h = 9,72 m     |
| Settlement of pile group                                      | s = 22,0 mm    |

Figure 4.21. Settlement results for a single interior group pile on Geo5 software

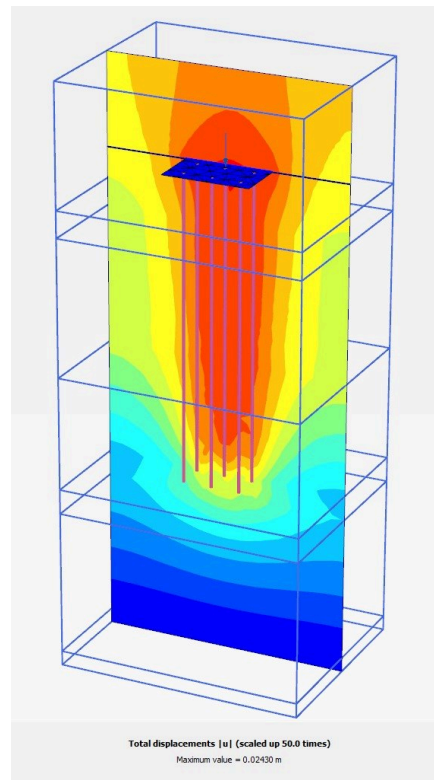


Figure 4.22. Settlement analysis for an exterior pile group on Plaxis 3D

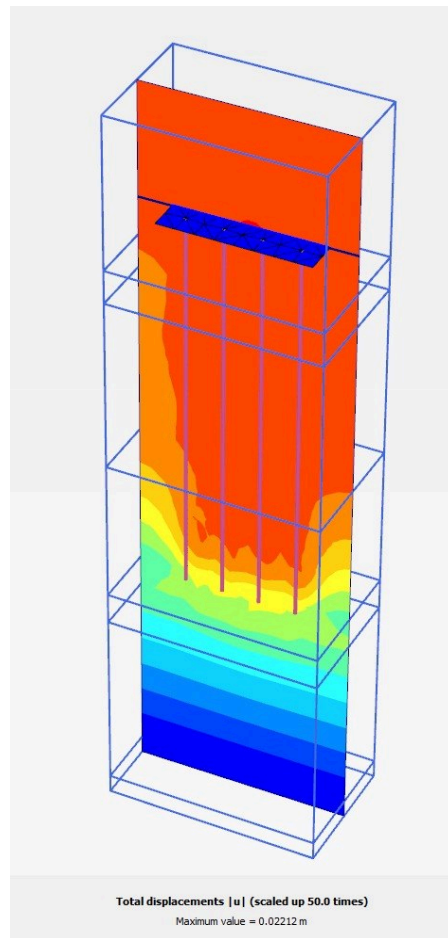


Figure 4.23. Settlement analysis for a corner pile group on Plaxis 3D

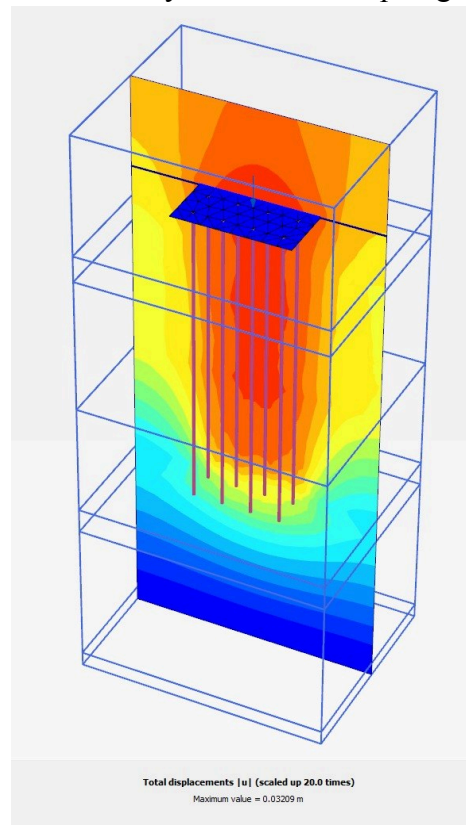


Figure 4.24. Settlement analysis for an interior pile group on Plaxis 3D

Table 4.21. Comparison of hand calculations and PLAXIS 3D settlement results

| Group pile type | $n_1 \times n_2$ | $P_u, kN$ | Hand calculation S, m | Plaxis 3D S, mm | Geo5 S, mm |
|-----------------|------------------|-----------|-----------------------|-----------------|------------|
| Exterior        | 3 x 3            | 6033.11   | 0.027                 | 0.024           | 0.024      |
| Corner          | 2 x 4            | 5546.94   | 0.026                 | 0.022           | 0.018      |
| Interior        | 3 x 4            | 6817.65   | 0.035                 | 0.032           | 0.022      |

Both hand calculated settlement values and PLAXIS 3D results show consistent values within allowable limits. The difference between these values, especially in Geo5 results, may be attributed to calculation procedures or standards used in software. Overall. The results show the satisfactory design for these pile group types under most critical loads from structure.

#### 4.4.2 Software analysis of lateral bearing capacity

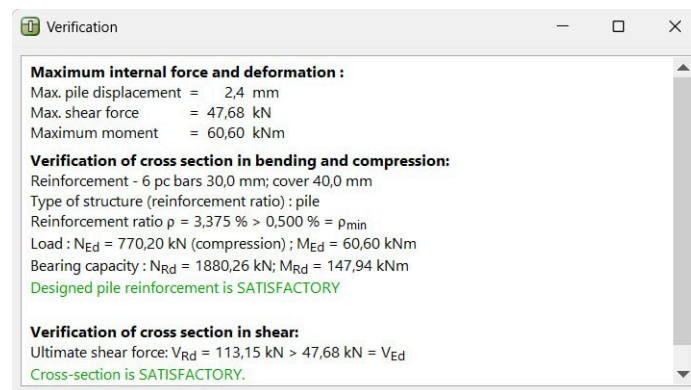


Figure 4.25. Interior pile lateral bearing capacity check

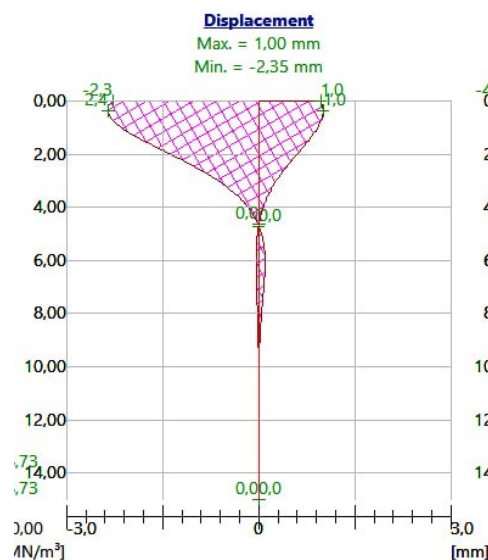


Figure 4.26. Interior pile displacement

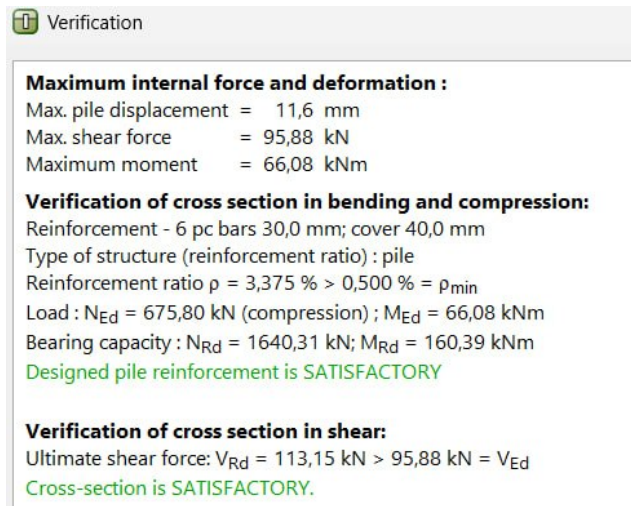


Figure 4.27. Exterior pile lateral bearing capacity check

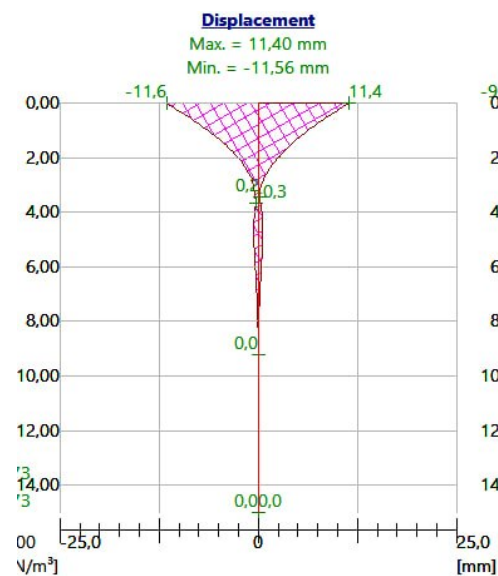


Figure 4.28. Exterior pile displacement

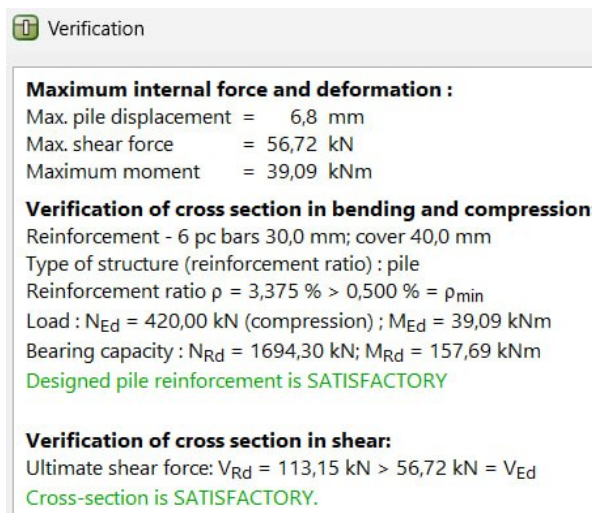




Figure 4.29. Corner pile lateral bearing capacity check

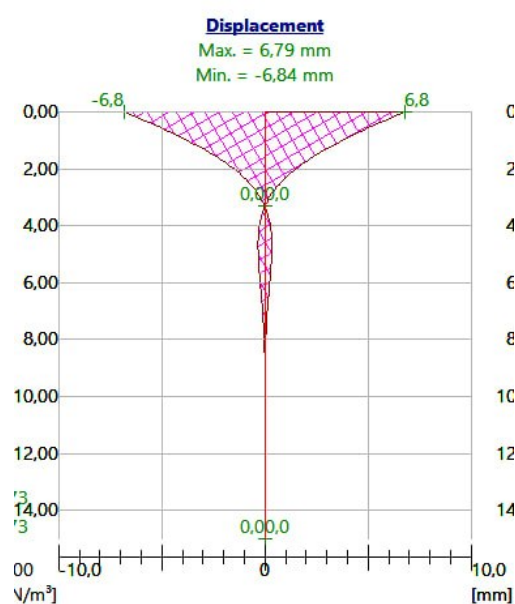


Figure 4.30. Corner pile displacement

Table 4.22. Comparison of hand calculations and software lateral bearing capacity, single piles

| Column type | $Q_{u(g)}, kN$ (Hand calc.) | $Q_{all'}, kN$ (Hand calc.) | $V_{Rd'}, kN$ (Geo5) |
|-------------|-----------------------------|-----------------------------|----------------------|
| Interior    | 434.35                      | 144.8                       | 113.15               |
| Exterior    |                             |                             |                      |
| Corner      |                             |                             |                      |

Table 4.23. Hand calculations and software deflection of single piles at the pile head(z=0)

| Column type | Deflection, mm (Elastic method) | Deflection, mm (Geo5) |
|-------------|---------------------------------|-----------------------|
| Interior    | 8.43                            | 2.4                   |
| Exterior    | 6.95                            | 11.6                  |
| Corner      | 6.24                            | 6.8                   |

#### 4.4.3 Pile cap reinforcement design

$$E = 0.5d_p = 0.5 * 0.4 = 0.2 \text{ m}$$

$$S = 3d_p = 3 * 0.4 = 1.2 \text{ m}$$

$$L = (n - 1)S + d_p + 2E$$

$$L_{interior} = (4 - 1)1.2 + 0.4 + 2 * 0.2 = 4.4 \text{ m}$$

$$B = (n - 1)S + d_p + 2E$$

$$B_{interior} = (3 - 1)1.2 + 0.4 + 0.4 = 3.2 \text{ m}$$

$$h_{min} = 1.5D = 1.5 * 0.4 = 0.6 \text{ m}$$

Table 4.24. Pile cap dimensions

| Column   | $n_1 \times n_2$ | $L, \text{ m}$ | $B, \text{ m}$ |
|----------|------------------|----------------|----------------|
| Interior | $4 \times 3$     | 4.4            | 3.2            |
| Exterior | $3 \times 3$     | 3.2            | 3.2            |
| Corner   | $4 \times 2$     | 4.4            | 2              |

Loads acting on the pile cap are recorded in Table 4.25. The unit weights of concrete and backfill were assumed to be 24 kN/m<sup>3</sup> and 17.5 kN/m<sup>3</sup> accordingly.

Table 4.25. Pile cap loads analysis

| Pile group | $DL, \text{ kN/m}^2$ | $LL, \text{ kN/m}^2$ | $W_{pc}, \text{ kN/m}^2$<br>$h_{min} * \gamma_c$ | $W_{bf}, \text{ kN/m}^2$<br>$h_{bf} * \gamma_{soil}$ | $W_{sc}, \text{ kN/m}^2$ |
|------------|----------------------|----------------------|--------------------------------------------------|------------------------------------------------------|--------------------------|
| Interior   | 89.11                | 42.55                | 14.4                                             | 8.75                                                 | 78.75                    |
| Exterior   | 64.81                | 38.7                 | 14.4                                             | 8.75                                                 | 78.75                    |
| Corner     | 55.7                 | 42.2                 | 14.4                                             | 8.75                                                 | 78.75                    |

$$LC_1 = 1.2D + 1.6L$$

$$LC_2 = 1.2D + 1L + 1W$$

$$LC_3 = 1.2D + 1L + 1E_x$$

$$W = W_{pc} + W_{bf} + W_{load} =$$

Load factors:  $1.2W =$ ,  $1.4W =$

For  $1.2W$ :  $M'_{11} = M'_{22} =$

For  $1.4W$ :  $M'_{11} = M'_{22} =$

$$Q = \frac{P}{R} \pm \frac{M_{xx}y}{I_{xx}} \pm \frac{M_{yy}x}{I_{yy}}$$

$$P = (1.2 \text{ or } 1.4)N + W_{pc} + W_{bf}$$

$$M_{xx} = M_x + Ne_y + H_y h + M_x^*$$

$$M_{yy} = M_y + Ne_x + H_x h + M_y^*$$

$$I_{xx} = \Sigma y^2 \text{ about x-axis}$$

$$\begin{aligned}
I_{yy} &= \Sigma x^2 \text{ about y-axis} \\
M''_{11} &= 1.4(Q_3 + Q_4) \\
M''_{22} &= 0.5(Q_1 + Q_2 + Q_3) \\
M_{11} &= M'_{11} + M''_{11} \\
M_{22} &= M'_{22} + M''_{22}
\end{aligned}$$

Use

#### 4.4.5 Single pile reinforcement design

The piles were assessed for structural capacity under combined axial loading and extreme lateral bending, and designed as driven precast concrete piles with a length of 15.0 m. Based on the characteristic length  $T$  of the pile–soil system, the piles were analytically classified as flexible slender piles, since  $L = 15 > 4T$ .

For the analysed pile section, a circular pile with a diameter of 0.40 m was adopted. To maintain stresses within the axial load–moment (P–M) interaction envelope, six 20 mm diameter longitudinal reinforcement bars were provided, arranged symmetrically with a concrete cover of 75 mm, as shown in the reinforcement layout in Figure XYZ. This reinforcement configuration provides a total steel area of:

$$A_s = 6 * \pi * 20^2 * 0.25 = 1885 \text{ mm}^2$$

The corresponding reinforcement ratio is:

$$\rho = A_s / A_g = 1885 / (\pi * 400^2) * 0.25 = 1.50\%$$

The final reinforcement arrangement was verified using GEO5, where checks for shear resistance, combined bending and compression, and reinforcement adequacy were carried out using the relevant safety factors. The verification results are presented in the corresponding design figures.

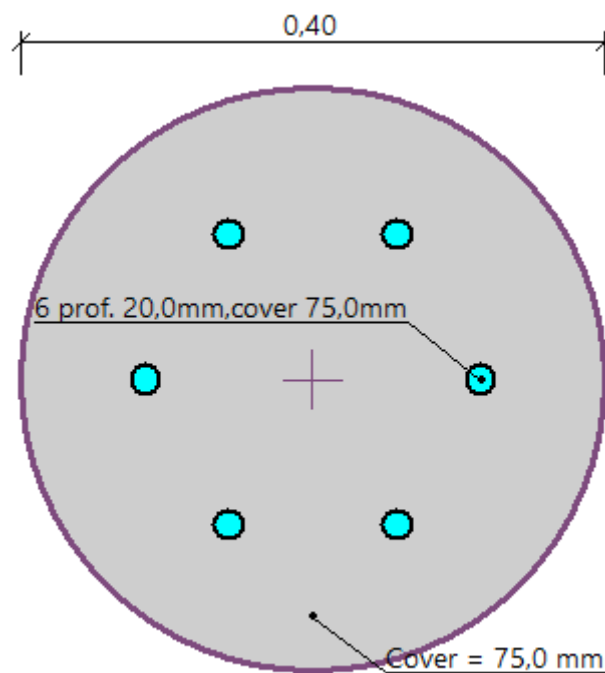


Figure 4.31. Reinforcement configuration of a single pile group

|                       |         |
|-----------------------|---------|
| SHEAR :               |         |
| <b>SATISFACTORY</b>   | (72,8%) |
| BENDING + COMPR. :    |         |
| <b>SATISFACTORY</b>   | (40,4%) |
| Reinforcement ratio : |         |
| <b>SATISFACTORY</b>   | (59,3%) |

Figure 4.32. Reinforcement verification for a corner pile group

|                       |         |
|-----------------------|---------|
| SHEAR :               |         |
| <b>SATISFACTORY</b>   | (68,8%) |
| BENDING + COMPR. :    |         |
| <b>SATISFACTORY</b>   | (36,8%) |
| Reinforcement ratio : |         |
| <b>SATISFACTORY</b>   | (59,3%) |

Figure 4.33. Reinforcement verification for an exterior pile group

| Results               |         |
|-----------------------|---------|
| SHEAR :               |         |
| <b>SATISFACTORY</b>   | (66,4%) |
| BENDING + COMPR. :    |         |
| <b>SATISFACTORY</b>   | (34,6%) |
| Reinforcement ratio : |         |
| <b>SATISFACTORY</b>   | (59,3%) |

Figure 4.34. Reinforcement verification for an interior pile group

#### 4.4.5 Group pile displacement analysis

PLAXIS 3D was used to evaluate the deformation behaviour of the pile foundation under combined axial and lateral loading conditions. For the numerical analysis, the complete building layout was modelled, including all columns and their governing critical load combinations. Three pile group configurations were considered: corner, exterior, and interior groups. In addition, the pile caps and sheet piles were also incorporated into the model. Appropriate boundary conditions were assigned in all directions. The piles were represented using embedded beam elements, while the pile caps were modelled as plate elements assigned to the basement floor slab. The overall numerical model layout is presented in Figure 4.35 and 4.36.

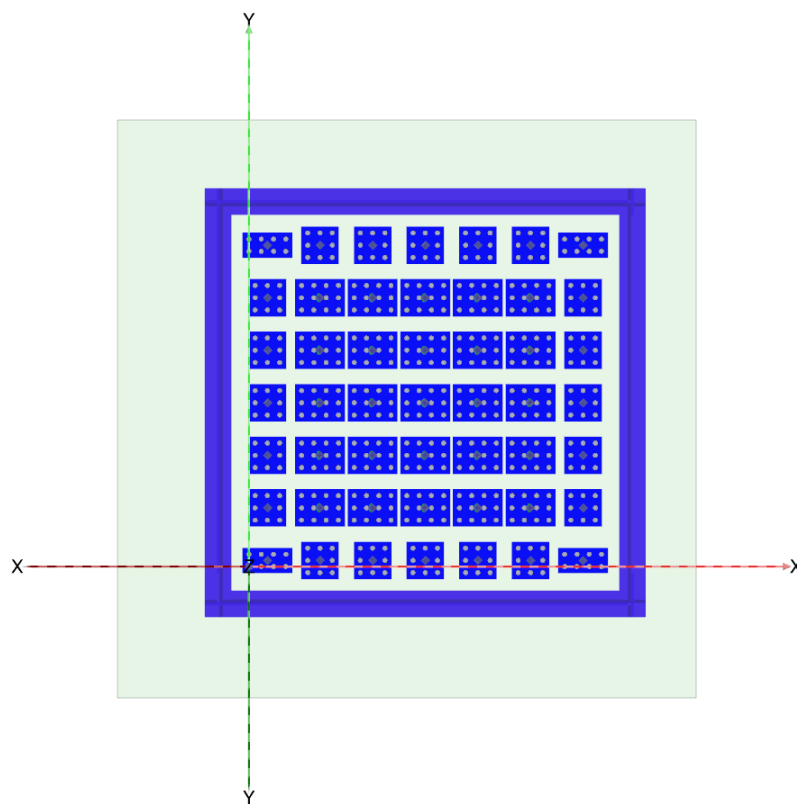


Figure 4.35. Foundation and retaining wall layout, top view

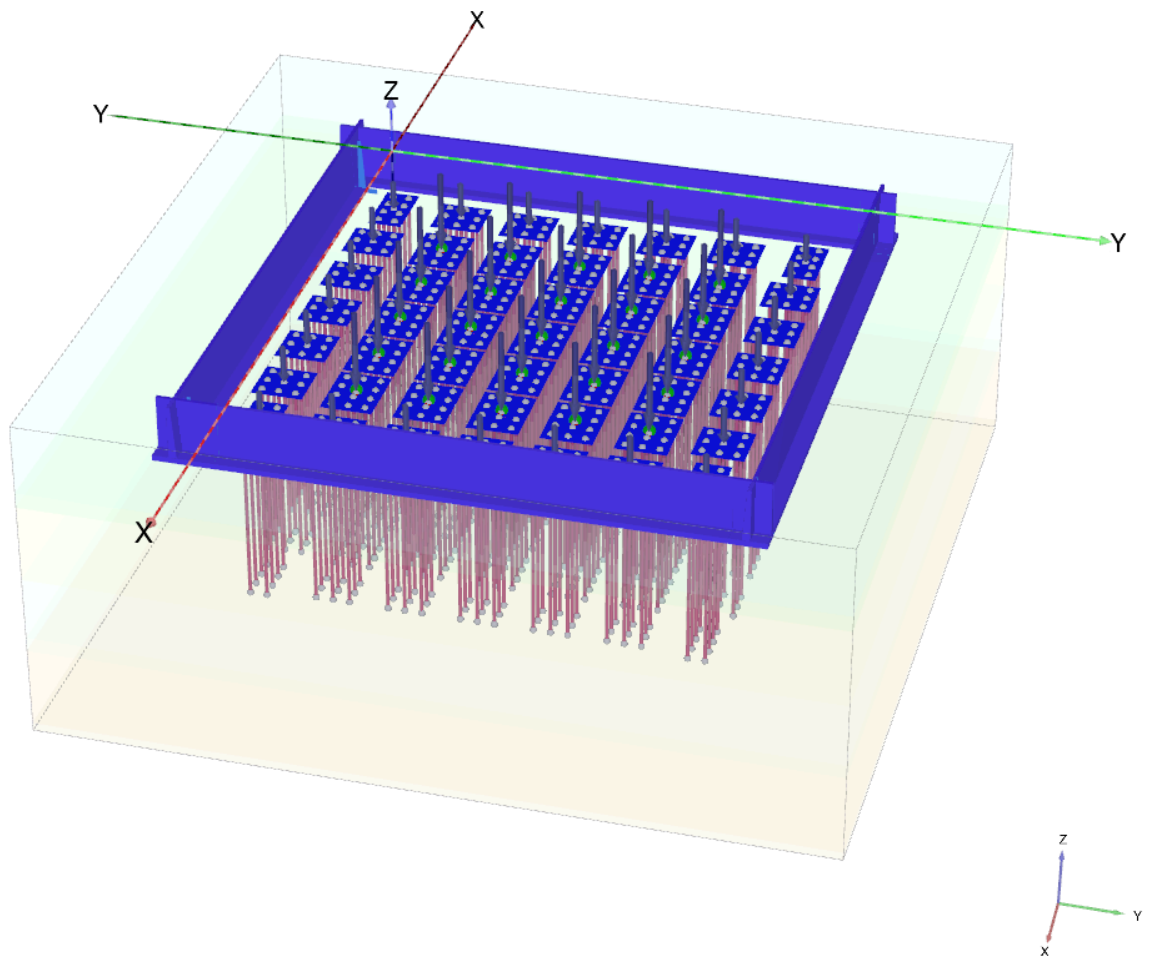


Figure 4.36. Foundation and retaining wall layout, isometric view

The numerical analysis carried out in PLAXIS 3D indicated that the maximum deformation of the entire building was 23.95 mm. The deflection of the model is shown in Figure 4.37.

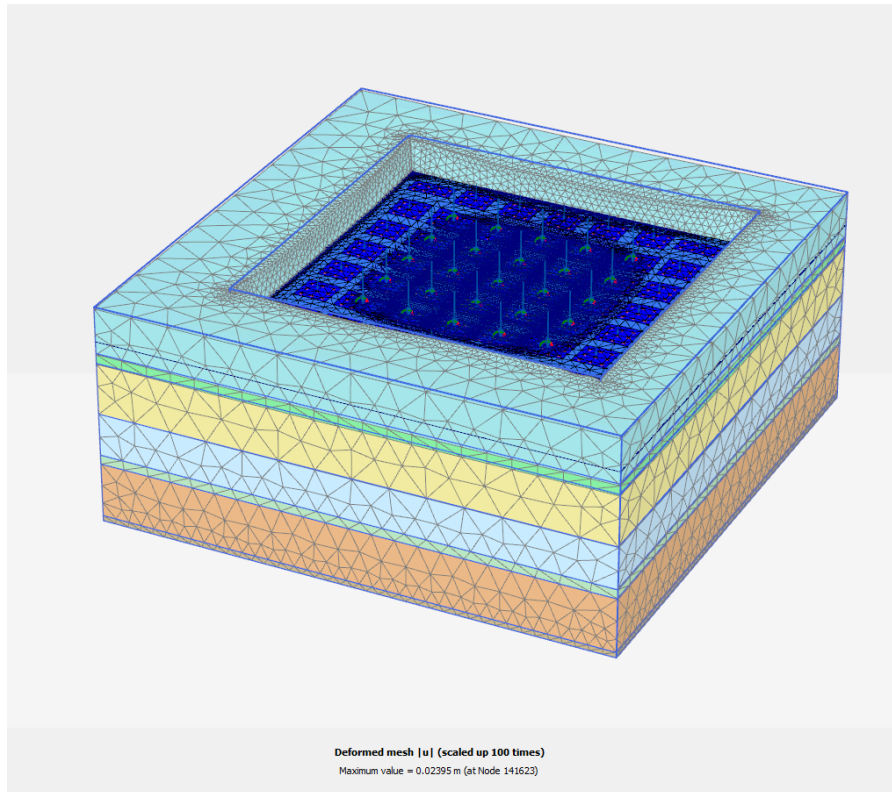


Figure 4.37. Foundation and retaining wall deflection check with loads  
The dynamic loading resulted in 42.03 mm displacement modeled with 5 s of seismic activity with 0.5 acceleration retrieved from site response analysis for the area slot from section 4.2.

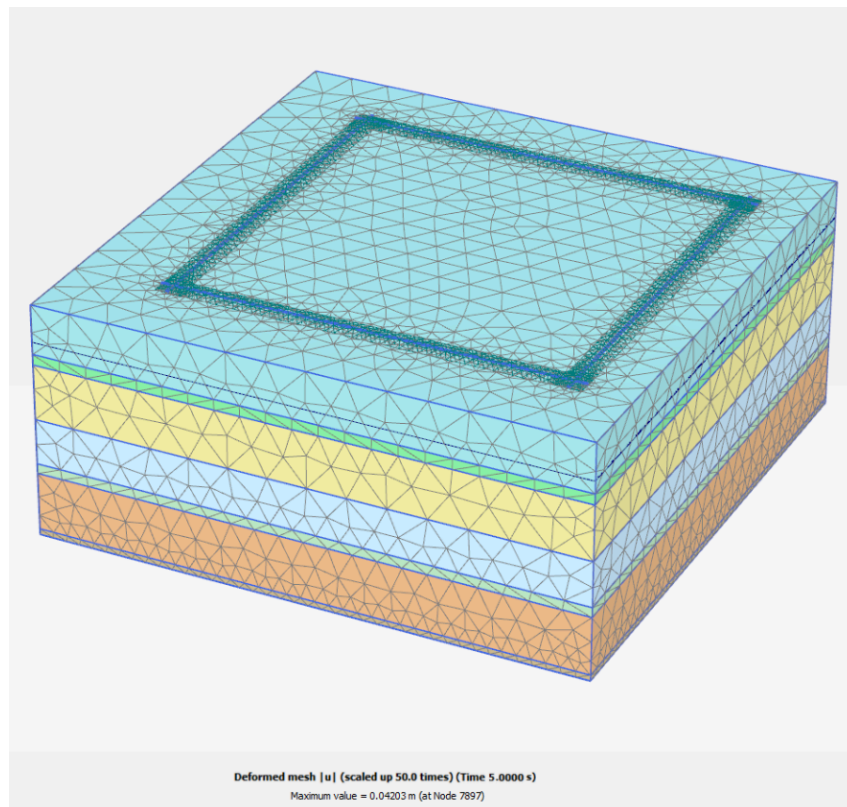


Figure 4.38. Dynamic loading application check

The pile foundation system was modelled in five construction stages: the initial phase, excavation, construction of walls and beams, installation of piles and pile caps, application of structural loads, and finally, dynamic analysis. The phase sequence can be seen in figure 4.39.

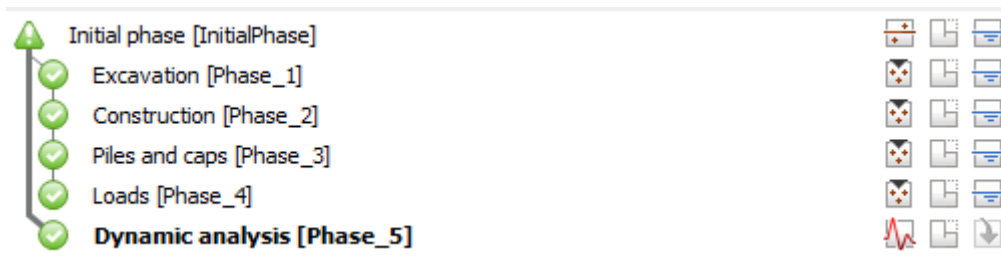


Figure 4.39. PLAXIS 3D construction stages

Model configurations are presented in Figures 4.40-44.

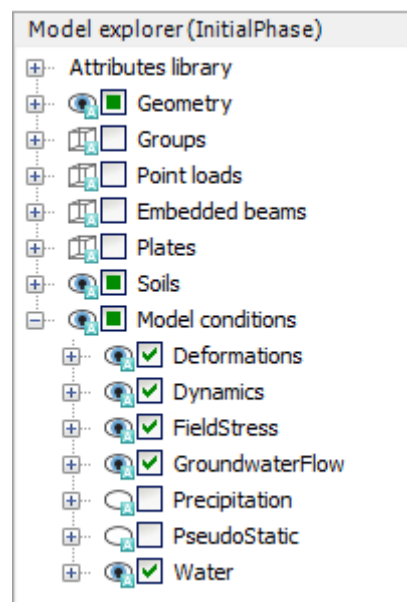


Figure 4.40. Initial phase model explorer window



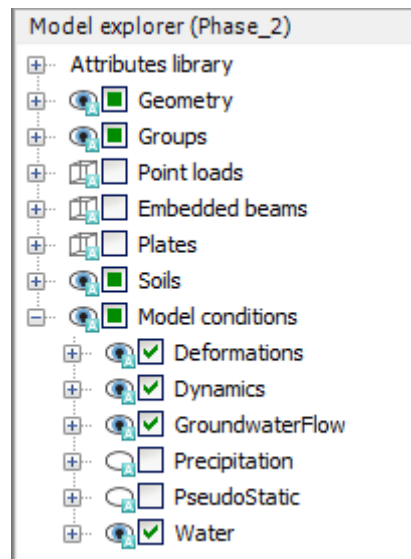


Figure 4.41. Construction phase model explorer window

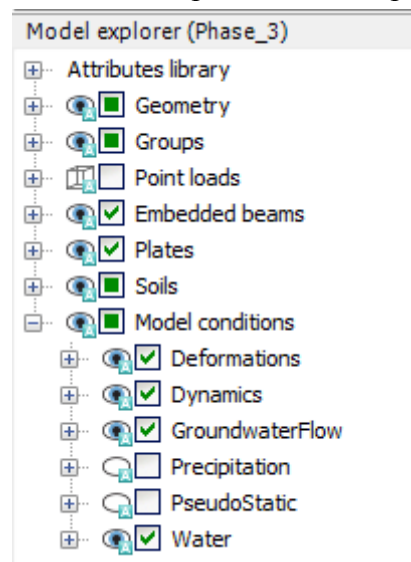


Figure 4.42. Piles and caps installation phase model explorer window

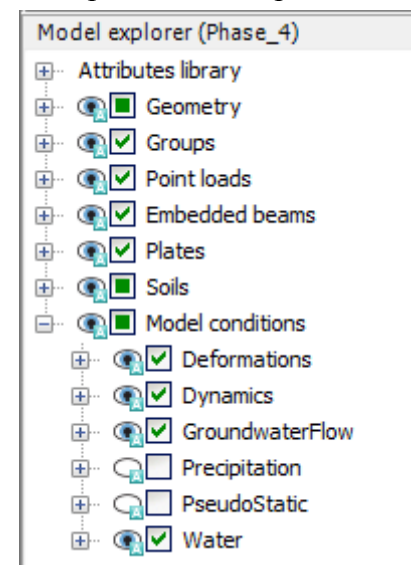


Figure 4.43. Load application phase model explorer window

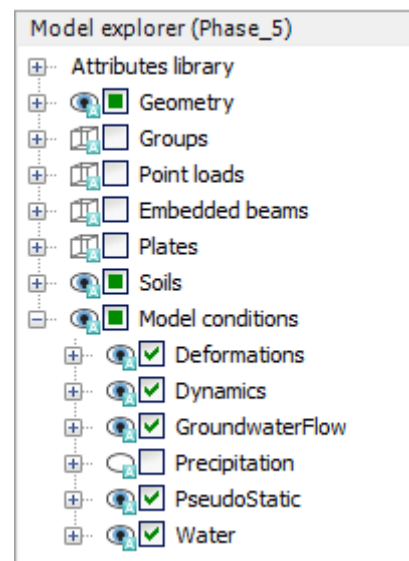


Figure 4.44. Dynamic testing phase model explorer window

#### 4.4 Retaining wall design

The basement requires a retaining wall to resist lateral earth pressures from the surrounding soils, and to create stable underground space. The retaining wall methodology follows the limit state approach, which ensures the stability of the wall against overturning, sliding, and bearing capacity failures (Das & Sivakugan, 2019). According to California Building Code (CBC), the vertical clearance for parking spaces should be at least 2489 mm (ICC, 2025). Since the project will include underground parking, additional height allowance should be included for mechanical ducts and floor thickness. Therefore, the total wall height is set at  $H = 4.6 \text{ m}$ , with a  $H' = 4 \text{ m}$  basement height and  $D = 0.6 \text{ m}$  embedded depth to mobilize the passive resistance.

This section details calculations of lateral earth pressures, design of a retaining wall, and stability checks against failure.

##### 4.4.1 Soil replacement and backfill material

The subsurface exploration showed that the wall is to be founded in a clay layer of medium stiffness (CH) with low undrained shear strength. The groundwater table is also located at approximately 4.5 m, which also coincides with the basement wall depth. As the construction process incorporates open excavation works, and because the native clay retains water and may develop excess pore pressures if left, drainage procedures will be held throughout the construction phase to keep the groundwater level at 6 m. Besides, to improve the long-term drainage and reduce the potential long-term water pressure buildup, a

well-graded sand was chosen as a backfill material, as it provides a reliable drainage and predictable lateral earth pressure responses. The selected backfill material has a unit weight of  $\gamma_{backfill} = 18.5 \text{ kN/m}^3$ , an effective friction angle of  $\phi'_{backfill} = 32^\circ$ , and effective cohesion of  $c'_{backfill} = 0 \text{ kPa}$ . Additionally, the upper Clay (CH) layer was assessed to not have bearing capacity to support the retaining wall, thus 1.4 m of soil beneath the retaining wall and basement will be replaced with silty sand with higher parameters regarding bearing capacity:  $\gamma_{replacement} = 17.5 \text{ kN/m}^3$ , an effective friction angle of  $\phi'_{replacement} = 35^\circ$ , and effective cohesion of  $c'_{replacement} = 15 \text{ kPa}$  (Das & Sivakugan).

#### 4.4.2 Lateral Earth Pressure Calculation

Both active and passive lateral earth pressures are evaluated using Rankine's theory. Important to note that while active earth pressure is mobilized in the granular backfill layer, the passive resistance acting on the embedded part of the wall is located in the silty sand layer.

##### 4.4.2.1 Rankine Active Earth Pressure

Rankine's theory assumes a vertical wall, horizontal backfill surface and no friction between wall and the backfill soil. Under such conditions, the active earth pressure coefficient is expressed as:

$$K_a = \tan^2\left(45 - \frac{\phi'_{backfill}}{2}\right)$$

For the selected backfill soil with  $\phi'_{backfill} = 32^\circ$ , the active coefficient is:

$$K_a = \tan^2\left(45 - \frac{32}{2}\right) = 0.31$$

And the active lateral pressure distribution was found by:

$$\sigma'_a = K_a \times \gamma_{backfill} \times H - 2c'_{backfill}\sqrt{K_a}$$

At the base of the wall at  $H = 4.6 \text{ m}$ :

$$\sigma'_{a,max} = 0.31 \times 18.5 \times 4.6 - 2 \times 0 \times \sqrt{0.31} = 26.15 \text{ kN/m}^2$$

The resultant active force per unit length of wall is:

$$P_a = \frac{1}{2} \gamma H^2 K_a - 2c'H\sqrt{K_a}$$

$$P_a = \frac{1}{2} \times 18.5 \times 4.6^2 \times 0.29 - 2 \times 0 \times 4.6 \times \sqrt{0.29} = 60.14 \text{ kN/m}$$

The line of action of the resultant force is located at the one-third of the retained height from the base:

$$z_a = \frac{H}{3} = \frac{4.6}{3} = 1.53 \text{ m above the base}$$

or equivalently:

$$z = 4.6 - 1.53 = 3.07 \text{ m from the top of the wall.}$$

#### 4.4.2.2 Rankine Passive Earth Pressure

The passive earth pressure is mobilized only within the embedded depth of the wall, which equals  $D = 0.6 \text{ m}$ . Rankine's passive earth pressure coefficient becomes:

$$K_p = \tan^2(45 + \frac{\phi'_{\text{replacement}}}{2})$$

$$K_p = \tan^2(45 + \frac{35}{2}) = 3.69$$

The passive lateral stress in silty sand consists of a rectangular component, and a triangular component, which comes from soil's unit weight. Thus, the total passive stress at the base of the embedment depth is:

$$\sigma'_p = \gamma D K_p + 2C_u \sqrt{K_p}$$

Substituting values:

$$\sigma'_p = 3.69 \times 17.5 \times 0.6 + 2 \times 15 \times \sqrt{3.69} = 96.38 \text{ kN/m}^2$$

The resultant passive force per unit length of wall is:

$$P_p = \frac{1}{2} \gamma D^2 K_p + 2C_u D \sqrt{K_p} \quad (4.38)$$

$$P_p = \frac{1}{2} \times 17.5 \times 0.6^2 \times 3.69 + 2 \times 15 \times 0.6 \times \sqrt{3.69} = 46.20 \text{ kN/m}$$

The force consists of a triangular component, representing the soil weight contribution  $P_{tri} = 11.62 \text{ kN/m}$ , and a rectangular part from cohesion contribution  $P_{rect} = 34.58 \text{ kN/m}$ . The line of action of the resultant passive force, thus, is calculated by taking moments of the two components:

$$z = ((P_{tri} \times \frac{D}{3}) + (P_{rect} \times \frac{D}{2})) / (P_{tri} + P_{rect})$$

$$z = ((11.62 \times \frac{0.6}{3}) + (34.58 \times \frac{0.6}{2})) / 46.20 = 0.27 \text{ m above the base of the wall}$$

or, measured from the basement floor:

$$z = 0.6 - 0.27 = 0.33 \text{ m from the basement floor level.}$$

### 4.4.3 Proposed Wall Design

#### 4.4.4 Stability Analysis

The proposed wall geometry was used for evaluating its geotechnical stability under the calculated lateral earth pressures. Using the active force  $P_a$  and the passive resistance  $P_p$ , the wall was assessed against sliding, overturning, and bearing capacity failures. The results of these are presented in the subsequent subsections, together with factors of safety and acceptable design limits.

##### 4.4.4.1 Check for overturning

The factor of safety against overturning is calculated as:

$$FS_{\text{overturning}} = \frac{\Sigma M_R}{\Sigma M_o}$$

where  $\Sigma M_R$  = sum of the moments resisting the overturning about the toe,

and  $\Sigma M_o$  = sum of the overturning moments about the toe.

The overturning moment is created by the active earth pressure force  $P_a$ , acting at a height of  $H'/3$  above the base. Thus, for a vertical wall with no friction the overturning moment is calculated by the formula below:

$$\Sigma M_o = P_h \left( \frac{H'}{3} \right)$$

Since the wall is vertical:

$$P_h = P_a \cos \alpha = P_a = 60.14 \text{ kN/m}.$$

$$\Sigma M_o = 60.14 \times \left( \frac{4.6}{3} \right) = 92.21 \text{ kN} \times \text{m/m}$$

The resisting moment  $\Sigma M_R$  consists of the weights of the soil above the heel, the self-weight of the concrete wall, and the vertical component of the active force. The unit weight of the concrete is taken as  $\gamma_c = 24 \text{ kN/m}^3$  and unit weight of the corresponding soil in the backfill is  $\gamma_{\text{backfill}} = 18.5 \text{ kN/m}^3$ . Since the wall is vertical:

$$P_v = P_a \sin \alpha = 0 \text{ kN/m}$$

And the moment of the force  $P_v$ ,  $M_v$  was found by:

$$M_v = P_v B = 0 \text{ kN} \times \text{m/m}$$

To calculate the resisting moment  $\Sigma M_R$  Table 4.22 was prepared.

Table 4.26. Consolidation settlement values for clay layers

| Section | Area, $m^2$ | Weight per unit length of wall, $kN/m$ | Moment arm measured from C, $m$ | Moment about C, $kN \times m/m$ |
|---------|-------------|----------------------------------------|---------------------------------|---------------------------------|
| 1       | 0.32        | 7.68                                   | 0.57                            | 4.35                            |
| 2       | 1.20        | 28.80                                  | 2.61                            | 75.17                           |
| 3       | 1.06        | 25.39                                  | 1.15                            | 29.20                           |
| 4       | 6.16        | 113.96                                 | 1.61                            | 183.48                          |

Total vertical load:

$$W_1 = A_1 \times \gamma_c$$

...

$$W_4 = A_4 \times \gamma_{backfill}$$

Total vertical load:

$$\Sigma V = W_1 + W_2 + W_3 + W_4$$

$$\Sigma V = 175.83 \text{ kN/m}$$

And the total resisting moment:

$$\Sigma M_R = M_1 + M_2 + M_3 + M_4 + M_v$$

$$\Sigma M_R = 292.20 \text{ kN} \cdot \text{m/m}$$

Factor of safety:

$$FS_{overturning} = \frac{292.2}{92.21} = 3.17$$

The acquired value for  $FS_{overturning}$  is larger than the minimum requirements for overturning with granular backfill, commonly recommended as 1.5 (Teng, 1962). Therefore, the retaining wall is considered safe against overturning.

#### 4.4.4.2 Check for sliding along the base

The factor of safety against sliding is calculated as:

$$FS_{sliding} = \frac{\Sigma F_{R'}}{\Sigma F_d}$$

where  $\Sigma F_{R'}$  = sum of the horizontal resting forces,

$\Sigma F_d$  = sum of the horizontal driving forces.

The only horizontal driving force is the active lateral earth pressure:

$$\Sigma F_d = P_a \cos \alpha$$

$$\Sigma F_d = P_a \cos 0^\circ = 60.14 \text{ kN/m}$$

The resisting force consists of three components - frictional resistance along the base of the wall, adhesion between the wall base and the underlying clay layer, and passive resistance in front of the embedded toe. The frictional part is given by  $\Sigma V \times \tan \delta'$ , where  $\delta'$  is the interface friction angle. It is taken as  $\delta' = k_1 \phi'$  with  $k_1 = 2/3$ . And  $c'_a = k_2 c'$  with  $k_2 = 2/3$ . Substituting these values:

$$\Sigma F_{R'} = \Sigma V \times \tan(k_1 \phi'_{clay}) + B \times c'_a + P_p$$

$$\Sigma F_{R'} = 175.83 \times \tan\left(\frac{2}{3} \times 35\right) + 2.3 \times \frac{2}{3} \times 15 + 46.20 = 145.0$$

Thus, the factor of safety against sliding is:

$$FS_{sliding} = \frac{145.0}{60.14} = 2.4$$

The minimum required factor of safety against sliding is typically taken as 1.5 (Das & Sivakugan, 2019). The calculated value is larger than this threshold value, which indicates that the retaining structure is safe against sliding.

#### 4.4.4.3 Check for bearing capacity failure

In evaluating the bearing capacity of the soil underneath the retaining wall base, its slab may be treated as a strip footing subjected to a vertical load  $V$  and the horizontal pressure component  $P_h$ , which combine into a resultant force  $R$  acting at a horizontal distance  $X$  from the toe. The location of this resultant force is calculated as:

$$\bar{X} = \frac{\Sigma M_R - \Sigma M_o}{\Sigma V}$$

$$\bar{X} = \frac{292.20 - 92.21}{175.83} = 1.14 \text{ m}$$

The corresponding eccentricity is then determined as:

$$e = \frac{B}{2} - \bar{X}$$

$$e = \frac{2.3}{2} - 1.14 = 0.01 \text{ m}$$

This indicates that the resultant force  $R$  is shifted 0.01 m from the center of the base of the wall towards the toe. Moreover, the magnitude of eccentricity is very small:

$$e = 0.01 \text{ m} < \frac{B}{6} = 0.383 \text{ m}$$

$$q_{\max} = q_{\text{toe}} = \frac{\Sigma V}{B} \left(1 + \frac{6e}{B}\right) = \frac{175.83}{2.3} \left(1 + \frac{6 \times 0.01}{2.3}\right) = 78.97 \text{ kN/m}^2$$

$$q_{\min} = q_{\text{heel}} = \frac{\Sigma V}{B} \left(1 - \frac{6e}{B}\right) = \frac{175.83}{2.3} \left(1 - \frac{6 \times 0.01}{2.3}\right) = 73.93 \text{ kN/m}^2$$

$$q = \gamma \times D = 17.5 \times 0.6 = 10.5 \text{ kN/m}^2$$

And the bearing capacity factors for  $\phi = 35^\circ$  are  $N_c = 46.12$ ,  $N_q = 33.30$ , and  $N_\gamma = 43.03$ .

The shape, depth, and inclination factors were calculated to be  $F_{cd} = 1.11$ ,  $F_{qd} = 1$ ,  $F_{\gamma d} = 1$ ,  $F_{ci} = 0.62$ , and  $F_{qi} = 0.99$ .

$$F_{cd} = 1 + 0.4 \left(\frac{D}{B}\right) = 1 + 0.4 \left(\frac{0.6}{2.27}\right) = 0.26$$

$$q_u = 15 \times 46.12 \times 1.11 \times 0.62 + 10.50 \times 33.30 \times 1 \times 0.99 \times 0 = 477.55 \text{ kPa}$$

Factor of safety against bearing capacity failure:

$$FS_{\text{bearing capacity}} = \frac{q_u}{q_{\max}} = \frac{477.55}{78.97} = 6.05$$

The minimum required factor of safety against bearing capacity failure is usually taken as 3 (Das & Sivakugan, 2019). The resulting factor of safety is larger than this threshold value, which indicates that the retaining structure is safe against bearing capacity failure of the soil underneath it.

#### 4.4.5 Software analysis of retaining wall

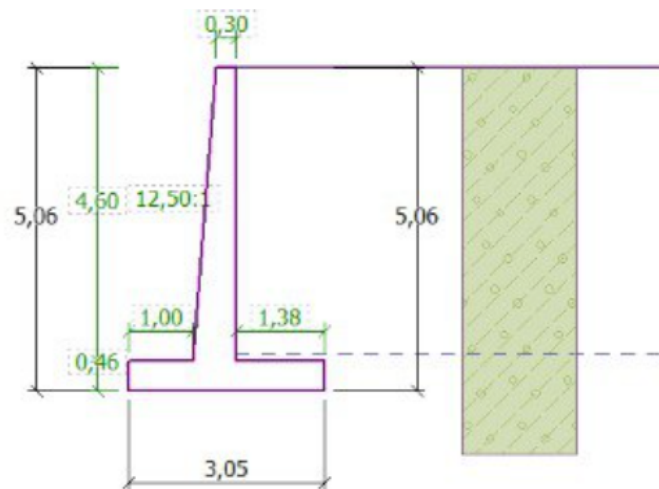




Figure 4.45. Retaining wall design without reinforcement

**Verification of bearing capacity**

Max. stress at footing bottom  $\sigma = 110,83 \text{ kPa}$

Bearing capacity of foundation soil  $R_d = 478,00 \text{ kPa}$

Safety factor =  $4,31 > 1,50$

Bearing capacity of foundation soil is SATISFACTORY

Overall verification - bearing capacity of found. soil is SATISFACTORY

Figure 4.46. Bearing capacity results check for retaining wall on Geo5

**Check for overturning stability**

Resisting moment  $M_{res} = 289,30 \text{ kNm/m}$

Overturning moment  $M_{ovr} = 179,54 \text{ kNm/m}$

Safety factor =  $1,61 > 1,50$

Wall for overturning is SATISFACTORY

Figure 4.47. Overturning check results for retaining wall on Geo5

**Check for slip**

Resisting horizontal force  $H_{res} = 130,33 \text{ kN/m}$

Active horizontal force  $H_{act} = 74,64 \text{ kN/m}$

Safety factor =  $1,75 > 1,50$

Wall for slip is SATISFACTORY

Overall check - WALL is SATISFACTORY

Figure 4.48. Sliding check results for retaining wall on Geo5

Also, reinforced retaining wall design is proposed with the same reinforcement material used for piles. The reinforced wall is using B500 grade steel with a yield strength of 500 MPa. It was provided with six longitudinal reinforcement bars of 20 mm diameter, with a concrete cover of 75 mm. The design of the reinforced retaining wall is shown in Figure 4.49. Subsequent satisfactory checks for reinforced wall are presented in Figures 4.50-53

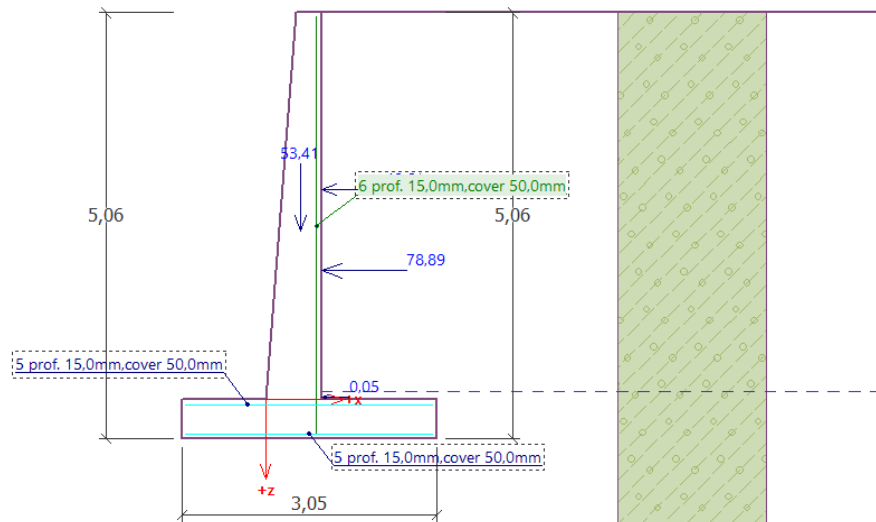


Figure 4.49. Reinforced retaining wall design

**Wall stem check - back reinf.**

Wall check at the construction joint 4,60 m from the wall crest

Reinforcement and dimensions of the cross-section

6 prof. 15,0 mm, cover 50,0 mm

Inputted reinforcement area = 1060,3 mm<sup>2</sup>

Required reinforcement area = 929,9 mm<sup>2</sup>

Cross-section width = 1,00 m

Cross-section height = 0,67 m

Reinforcement ratio  $\rho$  = 0,17 % > 0,13 % =  $\rho_{min}$

Position of neutral axis  $x$  = 0,04 m < 0,38 m =  $x_{max}$

Ultimate shear force  $V_{Rd}$  = 188,39 kN > 128,55 kN =  $V_{Ed}$

Ultimate moment  $M_{Rd}$  = 273,42 kNm > 240,65 kNm =  $M_{Ed}$

Cross-section is SATISFACTORY.

**Wall jump check**

Reinforcement and dimensions of the cross-section

5 prof. 15,0 mm, cover 50,0 mm

Inputted reinforcement area = 883,6 mm<sup>2</sup>

Required reinforcement area = 638,6 mm<sup>2</sup>

Cross-section width = 1,00 m

Cross-section height = 0,46 m

Reinforcement ratio  $\rho$  = 0,22 % > 0,13 % =  $\rho_{min}$

Position of neutral axis  $x$  = 0,04 m < 0,25 m =  $x_{max}$

Ultimate shear force  $V_{Rd}$  = 140,25 kN > 104,50 kN =  $V_{Ed}$

Ultimate moment  $M_{Rd}$  = 149,09 kNm > 108,86 kNm =  $M_{Ed}$

Cross-section is SATISFACTORY.

**Wall heel check**

Reinforcement and dimensions of the cross-section

5 prof. 15,0 mm, cover 50,0 mm

Inputted reinforcement area = 883,6 mm<sup>2</sup>

Required reinforcement area = 777,5 mm<sup>2</sup>

Cross-section width = 1,00 m

Cross-section height = 0,46 m

Reinforcement ratio  $\rho$  = 0,22 % > 0,13 % =  $\rho_{min}$

Position of neutral axis  $x$  = 0,04 m < 0,25 m =  $x_{max}$

Ultimate shear force  $V_{Rd}$  = 140,25 kN > 88,01 kN =  $V_{Ed}$

Ultimate moment  $M_{Rd}$  = 149,09 kNm > 131,78 kNm =  $M_{Ed}$

Cross-section is SATISFACTORY.

Figure 4.50. Reinforced retaining wall design

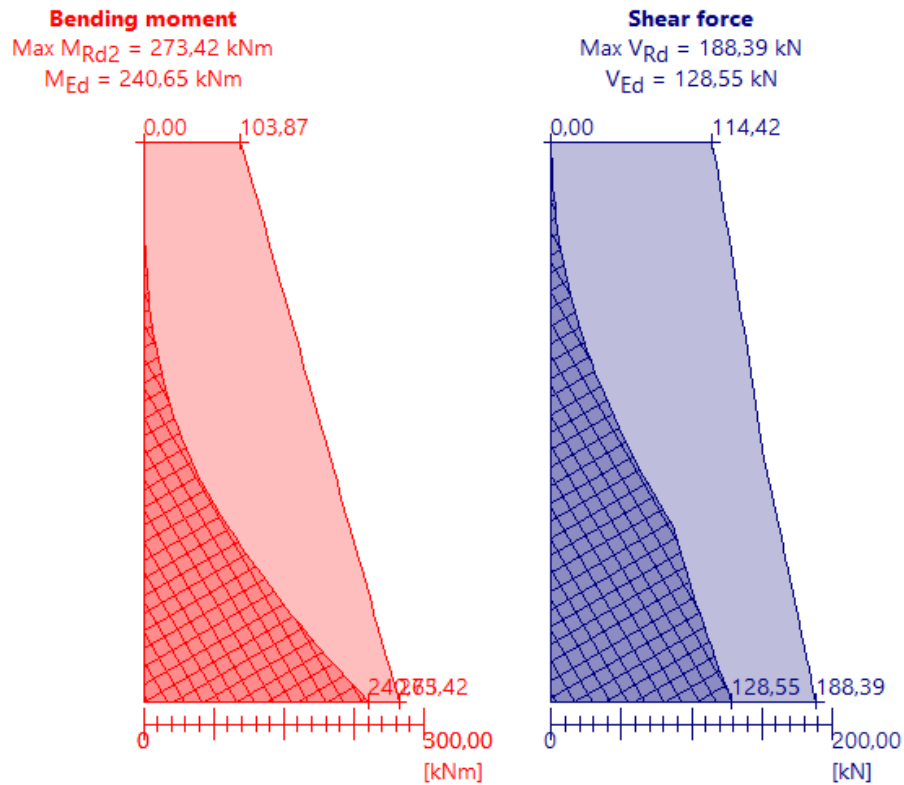


Figure 4.51. Reinforced retaining wall design

**Design load acting at the center of footing bottom**

| No. | Moment<br>[kNm/m] | Norm. force<br>[kN/m] | Shear Force<br>[kN/m] | Eccentricity<br>[-] | Stress<br>[kPa] |
|-----|-------------------|-----------------------|-----------------------|---------------------|-----------------|
| 1   | 125,59            | 178,32                | 87,22                 | 0,231               | 108,77          |

**Service load acting at the center of footing bottom**

| No. | Moment<br>[kNm/m] | Norm. force<br>[kN/m] | Shear Force<br>[kN/m] |
|-----|-------------------|-----------------------|-----------------------|
| 1   | 125,59            | 178,32                | 87,22                 |

**Verification of foundation soil**

Stress in the footing bottom : rectangle

**Eccentricity verification**

Max. eccentricity of normal force  $e = 0,231$

Maximum allowable eccentricity  $e_{alw} = 0,333$

Eccentricity of the normal force is SATISFACTORY

**Verification of bearing capacity**

Max. stress at footing bottom  $\sigma = 108,77$  kPa

Bearing capacity of foundation soil  $R_d = 478,00$  kPa

Safety factor = 4,39 > 1,50

Bearing capacity of foundation soil is SATISFACTORY

Overall verification - bearing capacity of found. soil is SATISFACTORY

Figure 4.52. Reinforced retaining wall design

### **Verification of complete wall**

#### **Check for overturning stability**

Resisting moment  $M_{res} = 342,59 \text{ kNm/m}$

Overturning moment  $M_{ovr} = 196,42 \text{ kNm/m}$

Safety factor =  $1,74 > 1,50$

Wall for overturning is SATISFACTORY

#### **Check for slip**

Resisting horizontal force  $H_{res} = 141,25 \text{ kN/m}$

Active horizontal force  $H_{act} = 87,22 \text{ kN/m}$

Safety factor =  $1,62 > 1,50$

Wall for slip is SATISFACTORY

Overall check - WALL is SATISFACTORY

Figure 4.53. Reinforced retaining wall design

### **4.5 Construction Procedure**

The excavation of a 4.5 m depth will require use of temporary support, typically sheet piles or soldier piles, to maintain stability during construction. A free-draining backfill is placed behind the permanent retaining wall, which allows the design to avoid long term hydrostatic pressure buildup. After staged excavation and installation of piles, the cantilever retaining wall and basement slabs are cast, joining and completing the permanent system.

### **4.6 Future work**

In the future, the hand calculations should be verified by the numerical analysis programs such as Plaxis 3D. Based on the analysis results, the properties and dimensions of pile foundation, retaining wall and other structures should be adjusted and detailed designs shall be provided. Moreover, since the settlement was higher than the standard acceptable value of 25 mm, suggestions for soil improvement such as soil pre-loading will be performed.

## 5. Environmental part

### 5.1. Legal regulations.

A multi-layered regulatory framework controls the operation and design of the solid waste management system of a 12-story commercial office block in San Jose, California. This structure has a downward flow, grounded on general state-wide legislative requirements, local implementation, and enforcement guidelines. At the state level, San Jose has some state regulations requiring certain types of waste materials to be recycled by commercial facilities. Commercial facilities legally required to separate both organics and general recyclables (California Legislative Information, 2011; California Legislative Information, 2014).

#### 5.1.1. State Legislative Mandates:

Assembly Bill 341 (AB 341): Requires all commercial businesses to organize and participate in general commercial recycling services.

Assembly Bill 1826 (AB 1826): Specifically requires commercial organizations to recycle organic waste, thereby necessitating a separate collection stream.

Senate Bill 1383 (SB 1383): It is a newer and stricter law that seeks to decrease the amount of organic waste disposed of. It establishes a standard for all businesses to gather, sort, and track their organic waste streams on the basis of contamination, to reduce methane emissions (California Legislative Information, 2016).

#### 5.1.2. Mandatory Commercial Waste Recycling

The state law is implemented by Assembly Bill (AB) 341, which mandates that all firms, including office buildings, that produce four or more cubic yards of solid waste per week recycle their general waste (paper, glass, plastics, metal, etc.).

California Assembly Bill (AB) 1826 is the state law that requires all businesses that generate two or more cubic yards of organic waste per week to recycle it (food scraps and yard trimmings).

### 5.1.3. Waste Separation Requirements

The state rules are administered by the California Department of Resources Recycling and Recovery (CalRecycle), and local implementation and compliance monitoring is performed by the City of San Jose Environmental Services department (CalRecycle, 2025b; City of San Jose, n.d.-b).

To meet state-required waste separation requirements, your facility must use at least two different types of bins. According to the report you are required to have separate collection arrangements on:

- “Wet” organic waste stream (e.g., food, yard trimmings)
- “Dry” general recyclables (e.g., paper, cardboard, plastics).

It is also customary to have a third bin for residual waste (trash) that cannot be recycled or composted. Yet, the legal requirements focus on the obligation to separate wet and dry materials within landfills.

### 5.1.4. Requirements for Businesses

Given the mandatory regulatory framework established by the State of California and enforced locally by the City of San José, commercial entities, including our office building at the chosen location, are legally required to contract with Republic Services, the exclusive franchised waste collector, for all routine solid waste and recycling management services. Compliance is non-negotiable and requires maintaining separate hauling agreements for distinct "Dry" (general recyclables and residual waste) and "Wet" (organic material) streams, in accordance with California state mandates.

- Must have collection bins for organics with employees, contractors, tenants, and customers, where found, in garbage receptacles, except in restrooms (City of San Jose, n.d.-b).
- All containers indicating what materials can and cannot go in should be appropriately labeled.

- Make sure that there are enough, large, and convenient containers with appropriate labels or colour-coding. (e.g., Blue cart with a green lid for “wet” stream, Blue cart with a black lid for “dry” stream, Blue cart with a blue lid for residual bins).



Figure 5.1. Colour-coding of required containers.

Although SB 1383 does not specify a collection frequency, it requires that organic waste be separated appropriately and recycled to avoid contamination and increase recycling rates (California Legislative Information, 2016). In this regard, companies might decide to collect more regularly so that the regulations are fulfilled so that organic waste would be appropriately stored, without the threat of contamination or overflow.

#### 5.1.5. Waste Volume and Contamination Control

The San Jose commercial property laws do not specify a collection frequency; instead, collection is a contractual matter determined by the service agreement between the company and the franchised hauler, Republic Services (City of San Jose, n.d.-a). The schedule is also adjusted to fit the real waste generation of a commercial entity.

The quantity of organic waste produced by companies may differ dramatically. Organic waste can be substantial in large businesses such as restaurants, cafeterias, and factories. When collected infrequently, waste may overflow, pose health risks, and produce foul smells, thereby contributing to contamination (City of San Jose, n.d.-b). Thus, haulers suggest making pickups more frequent, such as 2-3 times a week, in cases when business has a significant quantity of organic waste. This gives it an advantage of being in a position to eliminate waste before it hits the capacity limit, and thus the risk of contamination is eliminated, thus making the environment cleaner. (City of San José, n.d.-b).



### 5.1.6. Environmental and Community Issues

The increased frequency of organic waste collection will help the city achieve its overall environmental objectives, such as minimizing landfill waste and increasing diversion rates. It also helps the local community sustain local health by reducing the environmental impact of waste. Regular accumulation not only helps reduce odor and pest problems but also helps process organic material into compost or other recyclable forms rather than burying it in landfills, which aligns with the objectives of SB 1383, which aims to reduce the amount of organic waste sent to landfills by 75% compared to 2014 levels by 2025. (CalRecycle, 2025b).

The collection frequency for dry waste (including recyclables such as paper, plastics, and metals) and residual waste can be less frequent than that for organic waste in commercial buildings, due to inherent differences in waste properties and their environmental impacts.

The biological stability of the waste stream and the potential for nuisance are the two primary factors that determine solid waste collection requirements. Dry waste is mainly composed of non-putrescible substances (paper, cardboard, plastics, glass, and metals), which are chemically stable and also naturally have low moisture content (1-10%). This construction allows it to break down slowly, resulting in less odor, leachate, and pest activity and, therefore, a less frequent collection schedule, such as once a week (US EPA, 2019).

Table 5.1. Requirements for waste containers

| Waste Stream      | Required Constituents                                                          | Container Description   | Collection Frequency (per week) |
|-------------------|--------------------------------------------------------------------------------|-------------------------|---------------------------------|
| Wet (Organics)    | Organic materials, food scraps, green waste (yard trimmings).                  | Blue bin with green lid | 2-3 times                       |
| Dry (Recyclables) | General recyclables include paper, cardboard, plastics, metal cans, and glass. | Blue bin with black lid | 1                               |

|                                |                                          |                        |   |
|--------------------------------|------------------------------------------|------------------------|---|
| Customized<br>(Residual/Mixed) | Residual trash, non-recyclable<br>waste. | Blue bin with blue lid | 1 |
|--------------------------------|------------------------------------------|------------------------|---|

#### Sources used:

CalRecycle. (2025b, September 10). *SB 1383: Short-lived Climate Pollutants (Organic Waste) program*. <https://www.calrecycle.ca.gov/climate/sb1383>

U.S. Environmental Protection Agency. (2019). *Waste Management Guidelines: reducing environmental impacts of solid waste*.

#### Strengths:

- **Credibility and Authority:** Both sources, CalRecycle and the EPA, are reputable government agencies highly qualified in waste management and environmental policy.
- **In-depth Information:** The EPA source provides a general overview of waste management principles, including the environmental effects of different types of waste, which supports the argument for the various collection frequencies. CalRecycle source makes the California legislative framework (SB 1383) concrete, outlining the policy objectives and goals for waste reduction and diversion rates.
- **Relevance:** The sources are highly relevant to the current discussion, covering several important points related to waste, including its biological stability, smell, and pests, among other things, which are the main points of the waste collection frequency issue.

#### Weaknesses:

- **Narrow Scope:** Both sources are concerned with the United States and especially California in the majority of their work which might restrict their relevance in specific areas with varying waste management systems or environmental policy.
- **Absence of Specific Data:** The sources do not include any specific empirical data or case studies that provide practical, real-life illustrations of the effects of frequent collection of organic waste or its comparison with other types of waste. This restricts their ability to present quantitative evidence to support their assertions.
- **Generalization:** Both sources give generalized statements regarding the composition of waste and its biological stability which can be different in particular settings, e.g. in

other buildings or waste streams, which may ignore the more subtle or localized waste nature.

## 5.2. The Main waste generation and Composition analysis

The generation of a preliminary waste generation rate and a composition profile was used as a starting point for waste disposal planning. According to ASTM D5231 guidelines, data from a physical on-site waste audit may be used to substitute final estimates (ASTM International, 2020).

### 5.2.1. Office waste generation rate

The waste generation rate is 0.55 kilogram/person/day (~ 1.2 lb/person/day). It was derived from the compilation of 114 waste audits of commercial office buildings across the United States cited in study named “Waste Characterization Study of Pre-Covid-19 Commercial Office Buildings”. This baseline is backed by the “Estimated Solid Waste Generation Rates” report from CalRecycle, where they indicate 1.24 lb/employee/day for office waste generation. According to our calculations, there are 300 employees.

Source used:

CalRecycle. (n.d.-a). *Estimated solid waste generation rates*.

<https://www2.calrecycle.ca.gov/wastecharacterization/general/rates>

Dengler, A., Arrigo, L., & Fuller, R. (2022). Waste characterization Study of Pre-COVID-19 commercial office buildings. *The Journal of Solid Waste Technology and Management*, 48(2), 294–308. <https://doi.org/10.5276/jswtm/2022.294>

Strengths:

- **Credibility and Authority:** The study of Waste Characterization is founded on a massive sample of waste audits conducted in the real-life office environment, and CalRecycle is a reputable agent of the waste management system of California. The power and methodology used in the efforts of the two sources give their findings a lot of credence.
- **Comprehensive Diverse Dataset:** The study “Waste characterization Study of Pre-COVID-19 commercial office buildings” relies on the data of 114 waste audits of commercial office buildings located in the USA, giving a wide varied range of data.

CalRecycle report provides California-specific data in addition to the regional knowledge. These two sources can be used in combination to provide a more holistic view of office waste generation at both the national and regional levels.

- Alignment of Data: The rates of waste generation proposed in both sources are similar 0.55 kg/person/day (~1.2 lb/person/day) and 1.24 lb/employee/day. The values are slightly different, though the correlation between the two sources in their overall findings proves the validity and reliability of the information.

#### Weaknesses:

- Time Lag: The data of the Waste Characterization study refers to the pre-COVID period, which might not capture the changes in the amount of office waste production as a result of the pandemic changes, including more remote working or less occupancy. Likewise, the CalRecycle report might not mirror changes in the material recovery rates or the effect of changing policies, and as such, it is not suitable in real-time use.

#### 5.2.2. Office waste composition

The office waste composition by waste streams was taken from CalRecycle “Waste Characterization Business Groups Listing”, as Business Type: Not Elsewhere classified in the list provided; Employment type: Full-time equivalent (FTE); Employee count: 300. The mass of the waste streams were divided by total waste mass to determine the percentages.

- The office waste generation rate was multiplied by the number of employees to determine the total daily mass.
- The total daily mass =  $0.55 \text{ kg/person/day} \times 300 \text{ employees} = 165 \text{ kg/day}$
- The amount was multiplied by the percentage of each waste stream to determine its mass.
- Daily mass of paper waste =  $165 \text{ kg/day} \times 45\% = 74.25 \text{ kg/day of paper}$
- Weekly mass of paper waste =  $74.25 \text{ kg/day} \times 7 \text{ days/week} = 519.75 \text{ kg/week}$
- Annual mass of paper waste =  $74.25 \text{ kg/day} \times 365 \text{ day/year} = 27,101.25 \text{ kg/year} = 27.1 \text{ ton/year}$
- The total annual office waste mass is projected as 60.2 tonnes.

Table 5.2. Office Waste Stream Composition and Mass by Period

| Waste Stream  | Office Waste Composition (%) | Daily Mass (kg/day) | Weekly Mass (kg/week) | Annual Mass (kg/year) | Annual Mass (tonnes) |
|---------------|------------------------------|---------------------|-----------------------|-----------------------|----------------------|
| Paper         | 45%                          | 74.25               | 519.75                | 27,101                | 27.1                 |
| Cardboard     | 10%                          | 16.5                | 115.5                 | 6,023                 | 6.0                  |
| Plastics      | 12%                          | 19.8                | 138.6                 | 7,227                 | 7.2                  |
| Organics      | 7%                           | 11.55               | 80.85                 | 4,216                 | 4.2                  |
| Glass         | 3%                           | 4.95                | 34.65                 | 1,807                 | 1.8                  |
| Metals        | 2%                           | 3.3                 | 23.1                  | 1,205                 | 1.2                  |
| E-Waste       | 4%                           | 6.6                 | 46.2                  | 2,409                 | 2.4                  |
| Textiles      | 2%                           | 3.3                 | 23.1                  | 1,205                 | 1.2                  |
| Miscellaneous | 15%                          | 24.75               | 173.25                | 9,034                 | 9.0                  |
| Total         | 100%                         | 165                 | 1155                  | 60,225                | 60.2                 |

Source used:

CalRecycle. (n.d.-b). *Waste characterization Business groups listing*.

<https://www2.calrecycle.ca.gov/WasteCharacterization/BusinessGroup>

#### Strengths

- **Credible and Reliable:** CalRecycle is a well-known state-level entity, the author of high-quality data, which is connected directly to the waste tracking and management processes in California, thereby making the data credible and relevant.
- **Granular Waste Stream Breakdown:** The source includes breakdowns of different waste streams (e.g., paper, plastics, metals) and even further breakdowns of specific waste stream components which are important in correctly planning the recycling and diversion activities based on the specific material.
- **Open Process:** The data contains daily mass and composition decomposition, which provides a clear way of data collection on the waste production patterns. This

transparency aids decision-making in the planning of sound waste management systems.

### Weaknesses

- Generic Business Category: Waste profile is pegged upon the category of Business Type: Not Elsewhere Classified, which is not always inclusive of the exact waste production patterns of a given office building. This general categorization may not pay enough attention to individual waste features of a particular office type or sector.
- Statics Composition Percentages Assumptions: The source follows the assumptions of static composition percentages over time and scale, yet in reality, the waste mix may vary depending on the type of year, the office size, policies like paperless programs. This renders the waste profile less responsive to real-life situations.
- Broad Miscellaneous Category: The 15% of the total waste makes up the Miscellaneous waste category which has been over-broadened and could hide significant differences within the category. This restricts its utility in detailed and targeted waste management planning, whereby particular types of materials should be more clear.

### 5.3. The Second waste generation and Composition analysis

The engineering analysis and the regulatory requirements trade off to implement the canteen as a discrete waste stream. Contrary to a generalized waste profile, which generally combines office waste, food service operations produce organic waste and specialized recyclables, which is very different as compared to office products. The waste stream generated by a food service business, therefore, has distinct features, namely, a greater amount of organic waste and a larger percentage of liquid-heavy materials. In this way, by modelling the canteen waste stream separately, a more accurate perception of this material heterogeneity is possible, which allows optimizing the infrastructure and constructing the arrangements that address the requirements of both the operation and the regulations.

This separation is required to guarantee adherence to the requirements provided by such laws like SB 1383 and AB 1826, which require the diversion of organic waste out of landfills. The waste management system might not take the unique infrastructure needs that

food waste collection, sanitation and organic waste diversion may require unless it separates the canteen waste stream and the office waste stream. Considering the highly putrescible and liquid nature of food waste, this stream has to be dimensioned separately, to guarantee that this stream does not violate regulatory requirements and that it does not undermine the overall effectiveness and compliance of the waste management system.

#### 5.3.1. Canteen waste generation rate

The waste generation rate was derived from “Estimated Solid Waste Generation Rates” report from CalRecycle, where they indicate 0.45 kg/person/day (1lb/seat/day) for office waste generation.

The design occupancy is based on the total number of employees (300) rather than a canteen meal-purchase rate. This is based on the practical reality that while employees not purchasing on-site food service from the canteen may not purchase a meal, they still use the canteen space to consume food brought from home (lunch boxes, takeout containers, drinks, and snacks) and dispose of related packaging (plastic containers, wrapping, cutlery, napkins, aluminium foil, drink bottles) into canteen waste receptacles. The canteen is therefore the main food consumption area of the building, and the post-consumer waste of all occupants, regardless of their food source, is disposed of in the canteen. The 0.45 kg/seat/day rate used by CalRecycle is also a function of the total seat capacity, and not of meal purchases. Although the individual mass of waste per person may be less for those not purchasing on-site meals (home-prepared lunches, for example, generally produce less packaging than freshly-cooked food service meals), this is compensated for by the design safety factor of 2.0 applied to all waste generation rates in Section 5.10.1. A site-specific occupancy study during the operational phase would refine this assumption by measuring actual canteen utilization rates across meal periods.

- The office waste generation rate was multiplied by the number of employees to determine the total daily office wastemass.
- The total daily office waste =  $0.45 \text{ kg/person/day} \times 300 \text{ employees} = 135 \text{ kg/day}$
- The amount was multiplied by the percentage of each waste stream to determine its mass.

- Daily mass of paper waste =  $135 \text{ kg/day} \times 1.7\% = 2.30 \text{ kg/day}$  of paper
- Weekly mass of paper waste =  $2.30 \text{ kg/day} \times 7 \text{ days/week} = 16.07 \text{ kg/week}$
- Annual mass of paper waste =  $2.30 \text{ kg/day} \times 365 \text{ day/year} = 837.675 \text{ kg/year} = 0.838 \text{ ton/year}$
- The total annual canteen waste mass is 49.3 tonnes.

Table 5.3. Canteen Waste Mass Breakdown

| Waste Stream    | Canteen Waste Composition (%) | Daily Mass (kg/day) | Weekly Mass (kg/week) | Annual Mass (kg/year) | Annual Mass (tonnes) |
|-----------------|-------------------------------|---------------------|-----------------------|-----------------------|----------------------|
| Organics        |                               |                     |                       |                       |                      |
| Food leftover   | 44%                           | 59.40               | 415.80                | 21,681                | 21.68                |
| Recyclables     |                               |                     |                       |                       |                      |
| Plastic bottles | 24%                           | 32.40               | 226.80                | 11,826                | 11.83                |
| Metal cans      | 21%                           | 28.35               | 198.45                | 10,348                | 10.35                |
| Glass bottles   | 5%                            | 6.75                | 47.25                 | 2,464                 | 2.46                 |
| Plastic bags    | 4%                            | 5.40                | 37.80                 | 1,971                 | 1.97                 |
| Paper           | 1.7%                          | 2.30                | 16.07                 | 838                   | 0.84                 |
| Others          |                               |                     |                       |                       |                      |
| Non-recoverable | 0.3%                          | 0.41                | 2.84                  | 148                   | 0.15                 |
| Total           | 100%                          | 135.00              | 945.00                | 49,275                | 49.28                |

The article called Characterisation, Recovery and Recycling Potential of Solid Waste in a University of a Developing Economy by Owojori et al. (2020) explores the nature of solid waste in a college environment, namely, in the kitchens. Although it is based on the University of Venda in South Africa, the information used in the study is directly applicable in interpreting the waste production in such institutional context as in office canteens at San Jose, California.



### 5.3.2. Canteen waste composition

The paper gives a detailed account of the waste produced in the kitchen region during a period of three weeks as indicated below:

- Recyclable Waste (55.7%). Incorporates the paper, food wrapping, plastic bottles, glass bottles, and aluminum cans.
- Compostable Waste (44%). Majorly made up of pre-consumer organic food waste.
- Non-Recoverable Waste (0.3%). Things that can neither be recycled nor composted.

These findings indicate that recyclable and compostable material represents a substantial part of the waste stream. Therefore, sound waste diversion measures, recycling and composting, can be of great help to lower the environmental impact of kitchen waste.

### 5.3.3. Relevance to San Jose

According to the empirical data on waste composition by constituents provided by Owojori et al. (2020), the research in university dining halls, which are functionally comparable to San Jose office canteens. The main similarities in the functioning of both environments mean that the results are very relevant:

Dining sites in a university and also the canteens in offices have a predetermined number of meals per day (~300 meals/day). The waste generation study incorporates statistical values of mean and standard deviation, which show a uniform and repeatable rate of waste generation. This predictability is essential in terms of sizing waste-collection facilities in a business environment like the San Jose office canteens.

The wastes produced in both environments are the end product of the same manufacturing processes: batch meal preparation, single-use packaging and post-consumer plate scrapings. These processes have waste streams which are materially similar, irrespective of place. As an illustration, Coca-Cola PET bottles, aluminum beverage cans, and Tetra Pak containers are sold in both South Africa and the USA, which generates a similar recyclable fraction (55.7%) that can be directly shipped between the two places.

Since university dining halls and office canteens operate similarly, the waste stream percentages reported in the Owojori et al. (2020) study can be applied to preliminary engineering design. Both settings produce similar ratios of leftover food materials and packaging materials that are post-consumer, and this guarantees that the results of the study can be confidently applied to the office canteens in San Jose in the initial stages of project planning. For future plan, the waste audit should be conducted to get more reliable data to improve the current engineering design.

Source used:

Owojori, O., Edokpayi, J. N., Mulaudzi, R., & Odiyo, J. O. (2020). Characterisation, recovery and recycling potential of solid waste in a university of a developing economy. *Sustainability*, 12(12), 5111. <https://doi.org/10.3390/su12125111>

Strengths:

- Based on primary waste audit data gathered at a physical site at an institutional facility, which allows it to be directly used to measure the composition of waste instead of only using secondary estimates.
- Uses accepted methodology (ASTM D5321-92 when using unprocessed municipal solid waste) and thus increases the methodological credibility.
- Breaks down into finer detail of recyclable, compostable and non-recoverable contents (e.g., 55.7% recyclable, 44% compostable, 0.3% non-recoverable) that is a potent quantitative datum enabling the evaluation of material recovery potential.
- Catering to a developing-economy institutional setting, an aspect that has not been researched previously in areas where waste characterisation literature usually lacks.
- To offer a finer granularity of waste generation data in the campus setting, data is disaggregated by the activity zones (residential halls, cafeteria, administrative buildings) where data are generated.

Weaknesses:

- The case study is specific to one institution (University of Venda in South Africa) and thus may have limited generalisability to other geographic regions, climates, building types or operational settings (such as the San Jose office/canteen context). Some of

the waste composition results may reflect institutional or campus-specific behaviours that differ significantly from commercial office canteen environments, limiting direct transferability.

- Data collection was limited to a specific period (three-week audit in May) which may not capture seasonal variations, peak usage periods or long-term trends.

#### 5.4. Combined waste mass for two sources

Table 5.4. Total Waste Mass Breakdown from the office and canteen.

| Waste Stream      | Office Waste Composition (%) | Office waste mass (tonnes/year) | Canteen Waste Composition | Canteen waste mass (tonnes/year) | Total waste mass (tonne/year) | Total waste composition |
|-------------------|------------------------------|---------------------------------|---------------------------|----------------------------------|-------------------------------|-------------------------|
| Paper & Cardboard | 55.0%                        | 33.12                           | 1.7%                      | 0.84                             | 33.96                         | 31.0%                   |
| Plastics          | 12.0%                        | 7.23                            | 28%                       | 13.80                            | 21.02                         | 19.2%                   |
| Organics          | 7.0%                         | 4.22                            | 44%                       | 21.68                            | 25.90                         | 23.7%                   |
| Glass             | 3.0%                         | 1.81                            | 5%                        | 2.46                             | 4.27                          | 3.9%                    |
| Metals            | 2.0%                         | 1.20                            | 21%                       | 10.35                            | 11.55                         | 10.6%                   |
| E-Waste           | 4.0%                         | 2.41                            | 0%                        | 0.00                             | 2.41                          | 2.2%                    |
| Textiles          | 2.0%                         | 1.20                            | 0%                        | 0.00                             | 1.20                          | 1.1%                    |
| Miscellaneous     | 15.0%                        | 9.03                            | 0.3%                      | 0.15                             | 9.18                          | 8.4%                    |
| <b>Total</b>      | <b>100.0%</b>                | <b>60.23</b>                    | <b>100%</b>               | <b>49.28</b>                     | <b>109.50</b>                 | <b>100.0%</b>           |

The total combined waste mass of 109.5 tonnes per year, comprising 60.23 tonnes of office waste and 49.28 tonnes of canteen waste, defines the required capacity for the facility's waste management infrastructure. The paper (31.0%), plastics (19.2%) and organics (23.7%)

make up the largest portion of the total waste stream, and each of them requires dealing with particular aspects to consider in the system design.

The pre-eminent material, paper, needs a considerable concentration in sorting and storing infrastructure. As it is voluminous, it should be installed with sufficient space to facilitate smooth collection and processing including compactors to save on storage space and transportation expenses. Likewise, plastics, which constitute a large percentage of the waste at canteen, require strong sorting and compaction facilities to maximize recycling and reduce operational inefficiencies.

The presence of a high percentage of organics in the waste stream of the canteen waste stream, which is dominated by putrescible products, requires frequent collection and special storage to avoid contamination and odor. The use of systems to manage organic wastes is vital in order to meet the state requirements, such as SB 1383, which requires organic wastes to be diverted out of landfills. This also requires that the schedule of frequent collection cycles and “wet” waste handling systems are designed in order to satisfy regulatory requirements and reduce environmental impact.

#### 5.5. Waste streams recycling rate.

The recycling rates values in the table were obtained from California state in “50 States of Recycling” report by Ball Corporation. In this 2021 report, the recycling rate has been analyzed in detail utilizing the 2019 population data by each state. The waste streams that are taken into account from the report are Paper, Cardboard, PET plastics, HDPE plastics, Aluminium and Non-aluminium metals. Although naming conventions might have minor differences, these categories are very similar to those of the table. The table has, as an instance, the category Non-aluminium metals, which is listed in the same category as the rate of recycling of Steel cans in the Ball report. The validity of the recycling rates is justified by the rigorous approach of the Ball 2021 report based on the state-level population statistics and the established recycling rates, which guarantee that the rates reported in the report are correct in measuring the material recovery in California.

In the case of organic waste, the 41% recycling rate was the authoritative data to compare the overall performance of the waste handling in California. This number, as

reported by CalRecycle, is the Statewide Recycling Rate in 2022 as provided in the “Baseline Report of the Zero Waste Plan” (July 1, 2024). The figure encompasses total material diversion, such as recycling, composting and source reduction as a whole, which gives an official and dependable baseline of waste diversion trends.

Regarding e-waste, the U.S. EPA “Advancing Sustainable Materials Management: 2018 Tables and Figures” report shows that the recycling rate is about 15% (US EPA, 2020). On the same note, recycling of textiles is 14.7% (~15%) (US EPA, 2020), covering cloths, footwear, towels, sheets, and pillowcases. The same is expected of the Miscellaneous waste recycling rate, as it is diverse in its nature and not easily recycled.

In the case of the recycling rate of glass, the greatest obstacle to glass recycling is that large volumes of the waste are broken glass. which is hard to recycle and cannot often be used to manufacture other glass products, therefore, the recycling rate is 0%.

Plastic waste is mainly composed of two of the most marketable types of plastic – PET and HDPE. In 2018, the total generation of plastics in the United States amounted to approximately 35.68 million tonnes of municipal solid waste (MSW), as reported by the U.S. EPA article “Plastics: Material-Specific Data” (US EPA, 2020). Of this, two key plastic types—Polyethylene Terephthalate (PET) and High-Density Polyethylene (HDPE)—comprised a significant portion of the waste stream, particularly in the form of bottles and containers. Specifically, the amounts of PET and HDPE compared to total plastic waste were approximately 5.29 and 6.3 million tonnes, respectively. Dividing the types of plastic waste by total plastic waste in the USA yields shares of 14.83% and 17.66% for PET and HDPE, respectively (US EPA, 2020). Then these percentages were multiplied to the total plastic waste mass to estimate the PET and HDPE plastic waste mass. These percentages were obtained from the U.S. EPA report "Advancing Sustainable Materials Management: 2018 Tables and Figures", Table 8. Plastics in Products In MSW.

Based on data from the same U.S. EPA report, aluminum waste accounted for 15.2% of the total metal waste generated in the United States municipal solid waste (MSW) stream. This is derived from the 3.89 million tonnes of aluminum waste within a total metal waste generation of 25.6 million tonnes as shown in Table 7. Metal Products in MSW (US EPA, 2020). The remaining 84.8% of the metal waste stream was composed of ferrous metals, which were taken as a percentage of “Non-aluminium metals” out of the overall metal waste.

Table 5.5. The total recyclable waste mass.

| Waste Stream        | Total Annual Mass (tonnes) | Recycle rate (%) | Recyclable Mass (tonnes) |
|---------------------|----------------------------|------------------|--------------------------|
| Paper               | 27.94                      | 60%              | 16.76                    |
| Cardboard           | 6.02                       | 60%              | 3.61                     |
| PET plastics        | 3.12                       | 56%              | 1.75                     |
| HDPE plastics       | 3.71                       | 24%              | 0.89                     |
| Organics            | 25.90                      | 41%              | 10.62                    |
| Glass               | 4.27                       | 0%               | 0.00                     |
| Alum Metals         | 1.76                       | 77%              | 1.35                     |
| Non-aluminum metals | 9.80                       | 29%              | 2.84                     |
| E-Waste             | 2.41                       | 15%              | 0.36                     |
| Textiles            | 1.20                       | 15%              | 0.18                     |
| Miscellaneous       | 9.18                       | 15%              | 1.38                     |
| <b>Total</b>        |                            |                  | <b>39.74</b>             |

Sources used:

CalRecycle. (2024, July 1). *Baseline Report for the Zero Waste Plan*.

<https://www2.calrecycle.ca.gov/Publications/Download/1916>

U.S. Environmental Protection Agency. (2020). *Advancing Sustainable Materials Management: Facts and Figures*.

<https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling>

#### Strengths

- **Credibility:** U.S. Environmental Protection Agency (EPA) is the publisher of the report, which is a leading expert in the field of environmental policy and data, which

attests to the credibility and authority of the mentioned information. Likewise, the report published by CalRecycle carries institutional authority.

- Detailed Data: It is an elaborate material flow, waste production, recycling and disposal information in the U.S. on a national and statewide scale, and it serves as a useful reference point to the waste management practices in California and the U.S.
- Transparency of both: The methodology is well described and the data is provided in convenient tables that can be easily extracted and reproduced to obtain major figures.
- Timeliness: Both reports rely on recent data, and offer a decent point of reference in terms of assessing the trends and performance in waste management.

#### Weaknesses

- Data Lag: The U.S. EPA report relies on 2018 data which may not best reflect recent trends, technologies and alterations in regulation policies, and which is therefore limited in its applicability to current analysis.
- Absence of Regional Granularity: The U.S. EPA data is reported on a national basis which might not be specific enough to localized studies or applications that might need a more specific regional or facility-based point of view.

#### 5.6. Market value of recyclables

Not every stream of recyclable waste can be used to generate revenue. The six main waste streams were therefore identified to estimate the estimated cashback in a year. These marketable waste products are paper, cardboard, PET, HDPE plastics, aluminium, and non-aluminium metals. Other waste streams, like the organic waste, on the other hand can be recycled into compost although this does not fetch any financial gain. The main purpose of recycling organic waste is ecological one and compliance with the legal requirements. Moreover, other wastes such as e-waste, textiles, and miscellaneous wastes do not have a well-developed recycling system that would bring in revenue at the moment.

Table 5.6. Total Marketable recyclable waste mass

| Waste Stream | Total Annual Mass (tonnes) | Recycle rate (%) | Recyclable Mass (tonnes) |
|--------------|----------------------------|------------------|--------------------------|
|--------------|----------------------------|------------------|--------------------------|

|                      |              |     |              |
|----------------------|--------------|-----|--------------|
| Paper                | 27.94        | 60% | 16.76        |
| Cardboard            | 6.0          | 60% | 3.61         |
| PET plastics         | 3.12         | 56% | 1.75         |
| HDPE plastics        | 3.71         | 24% | 0.89         |
| Aluminium            | 1.76         | 77% | 1.35         |
| Non-aluminium metals | 9.80         | 29% | 2.84         |
| <b>Total</b>         | <b>52.34</b> |     | <b>27.21</b> |

Estimates of possible revenue were calculated by multiplying the mass of each of the six marketable recyclable streams by the scrap prices, obtained from South San Francisco Scavenger, a waste management hauler, and the CalRecycle “Statewide Average Monthly Scrap Value Notice” report, based on figures as of July 2025. Paper, cardboard, PET plastics, HDPE plastics, aluminum, and non-aluminum metals are assumed to be evaluated at conservative values, consistent with the valuation methodology in the provisional analysis.

Calculating the costs of paper and cardboard was done according to the waste management company, just outside of San Jose – the Scavenger South San Francisco, and their 2023 price list.

In order to find out a cost-effective price of two of the most marketable kinds of plastic waste streams – PET (\$230.89/ton) and HDPE (\$265.76/ ton) the values highlighted in the official July 2025 scrap values analysis by CalRecycle have been used. Industry standards can verify the prices and provide detailed price changes over the years for recyclables. This enables a closer estimate of the possible revenues of the recycling of these plastic waste streams that eventually helps in the development of a cost-effective waste management plan.

Glass: After transportation and processing costs are considered, the market value of the glass exceeds the possible return value from recycling. The value of \$0 per ton has been chosen as the most sensible estimate, although CalRecycle shows the scrap value of \$7.90 per ton, as of July 2025 (CalRecycle, 2025a). The main reason is that much of the glass waste comprises broken glass, which, though recycled, will make only a small, insignificant portion



of the total recycling stream. Therefore, the economic feasibility of recycling broken glass commercially is not possible.

The primary factor that makes metal waste be classified into two groups, as aluminum and non-aluminum, is the fact that aluminum has a high scrap value. Although aluminum cans make up only 15.2% of total metal waste, they are recycled at a much higher value of \$1,658/ton (CalRecycle, 2025a).

On the contrary, the non-aluminum metal waste rate, such as bimetal, is \$106.96 per ton, according to CalRecycle. The massive difference in scrap values highlights the economic value of separating aluminum from other metal waste streams, as it adds significant value to the recycling process, not only in material value but also in market demand.

Using conservative recovery rates and local scrap prices, a provisional estimate is calculated for the recoverable mass and its corresponding monetized value of the chosen recyclables. The overall market value of the recyclables indicates an approximate annual revenue of \$4,500 from recyclables. Therefore, although the estimate is low, a practical, grounded outlook is offered, thus providing a helpful base for planning and budgeting. This is a conservative estimate that reflects the intricacies of recycling systems, in which changes in scrap prices, transportation costs, and processing charges may affect the final value of marketable recyclable waste.

Table 5.7. Total annual price for marketable recyclable mass

| Recyclable Stream    | Annual Mass (tonnes) | Assumed Price (\$/ton) | Annual Value (\$/year) |
|----------------------|----------------------|------------------------|------------------------|
| Paper                | 16.76                | \$70.00                | \$1,173                |
| Cardboard            | 3.61                 | \$40.00                | \$145                  |
| PET plastics         | 1.75                 | \$230.89               | \$403                  |
| HDPE plastics        | 0.89                 | \$265.73               | \$237                  |
| Aluminium            | 1.35                 | \$1,658.06             | \$2,242                |
| Non-aluminium metals | 2.84                 | \$106.96               | \$304                  |

|              |              |  |                |
|--------------|--------------|--|----------------|
| <b>Total</b> | <b>27.21</b> |  | <b>\$4,504</b> |
|--------------|--------------|--|----------------|

### 5.7. Summary of the waste mass

Of the total annual waste of 109.5 tonnes, more than one-third (36%), or 39.7 tonnes, is recyclable, and approximately 25% or 27.2 tonnes, is expected to generate revenue.

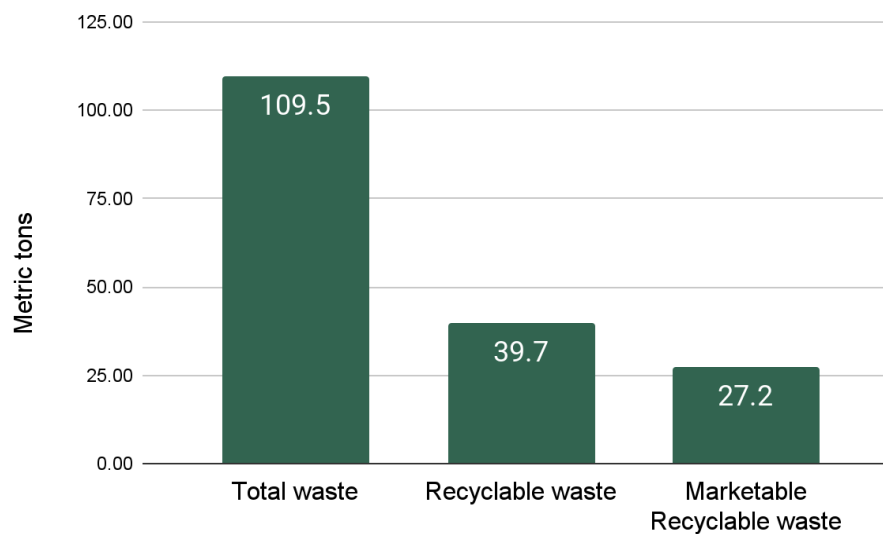


Figure 5.2. Annual Waste Composition: Total, Recyclable, and Marketable Recyclable Waste

#### 5.7.1. The Critical role of Organic waste system design

The analysis has shown that this has a significant limitation: 25.9 metric tonnes of organic waste are produced every year, of which 21.7 tonnes are generated by the canteen itself (44% of the 49.3-ton canteen stream). This is equivalent to around 59.4 kg/day of organic waste from food service operations. This value validates the required frequency of 2-3 times per week of the obligatory collection of the "wet" stream. To further subdivide, the canteen produces about 415.8 kg/week of organic waste; once-per-week collection (similar to "dry" waste stream) of this organic waste amount would result in a container of decomposing food waste lasting up to seven days, leading to deplorable conditions, including odor, pest attraction, and possible health violations. In comparison, increased collection frequency of

2-3 times/week decreases the maximum holding period to 2.3-3.5 days. These measures preserve biological stability and meet the contamination-monitoring standards offered by SB 1383. This shows that organic waste diversion regulatory recommendations are directly tied to the amount of putrescible waste produced, rather than being whimsical operational constraints.

#### 5.7.2. Economics of Recyclable Revenue

Of the 39.7 tonnes that are recyclable, only 27.2 tonnes (69%) have market value and generate an estimated \$4,504 a year. 1.35 tonnes of aluminum (4.9% of marketable mass) generates \$2,242 (49% of revenue). Its per-ton value (\$1,658) is roughly 24 times that of paper (\$70). This value concentration in a single material means the recycling program's economic viability hinges on efficient capture of clean aluminum, hence the emphasis on avoiding contamination (described in Section 5.9.4 above).

In contrast, glass (4.27 tonnes/year) produces no revenue even though it is present in high volume because the cost of processing and transporting the material exceeds the reported value of scrap (\$7.90/ton) from CalRecycle. Success is not guaranteed by high waste mass - it depends on the specific business case for each waste.

Paper/cardboard: together these two waste streams provide 18.7 tonnes (68.8% of marketable mass) that generate \$1,451 - suggesting that infrastructure investments should be based on value-per-ton, not total mass.

#### 5.7.3. The Cost of Regulatory Compliance

Organic waste makes up 23.7% of total waste (25.9 tonnes/year) and no revenue. This is not a system failure, but rather an aspect of California's regulatory structure. SB 1383 mandates diversion of organics with no cost recovery. The 25.9 tonnes of organics must be composted or anaerobically digested at the building operator's cost, stored in sealed bins, collected 2-3 times per week, and transported to a permitted composting facility.

The revenue imbalance is substantial: 27.2 tonnes of marketable recyclables generate ~\$4,500/year, while a comparable 25.9 tonnes of organics generate \$0 despite requiring more frequent collection. This site therefore has a two-stream diversion system that only generates revenue from one stream.

The design implication: This case study shows that a compliant waste management system cannot be designed solely on cost optimisation. Organics collection frequency is determined by putrescibility and public health (59.4 kg/day of food waste cannot be stored for seven days), not by income. Environmental compliance means accepting non-revenue-generating operational costs.

## 5.8. Waste management options

### 5.8.1. Recycling Potential

The total realistic mass that can be recycled of the non-organic waste streams is 29,130 kg/year consisting of paper and cardboard, plastics, glass, metals, e-waste, textiles, and miscellaneous waste streams.

Paper, cardboard, PET/HDPE plastics and metals are obtained by the Ball Corporation, 50 States of Recycling (2019), which offers a specific evaluation of the California State-level recycling rates in 2018. As it is future potential, the highest recycle rates were obtained for Plastics and Metals categories: 77% rate for aluminium for the metals and 56% rate for the plastics waste stream potential.

The rates of these less common streams like e-Waste, textiles, and miscellaneous will be pegged on the national data of the U.S. EPA report in 2018 of "Advancing Sustainable Materials Management" where it establishes the recycling potential of both at around 15 percent.

The glass recycling rate will be at 0%. This has not been the case because glass cannot be recycled, but due to the processing and transportation expense, which is higher than the scrap value, commercial recycling is not worthwhile economically.

Table 5.8. The recyclable waste amount.

| Waste Stream | Total Annual Mass (tonnes) | Recycle rate (%) | Recyclable Mass (tonnes) |
|--------------|----------------------------|------------------|--------------------------|
| Paper        | 33.96                      | 60%              | 20.38                    |
| Plastics     | 21.02                      | 56%              | 11.77                    |
| Glass        | 4.27                       | 0%               | 0.00                     |
| Metals       | 11.55                      | 77%              | 8.90                     |
| E-waste      | 2.41                       | 15%              | 0.36                     |

|               |       |     |       |
|---------------|-------|-----|-------|
| Textiles      | 1.20  | 15% | 0.18  |
| Miscellaneous | 9.18  | 15% | 1.38  |
| Total         | 83.60 |     | 42.96 |

### 5.8.2. Composting Potential

The cumulative realistic compostable mass amounts to 10,620kg/annum. The data set has only one waste stream that can be composted and this is the organics stream, which is predominantly made up of food waste and yard trimming. The remaining streams that are listed (paper, cardboard, PET/HDPE plastics, glass, metals, e-waste, textiles, miscellaneous) are either sent to recycling or to landfill and are not specified in the table as having been designated to go through composting.

The 41% value is the Californian Statewide Recycling Rate of 2022 mentioned on CalRecycle. This official rate is used to include all the material diversion such as composting and is an effective reference to potential recovery. But Senate Bill, SB 1383 set an organic diversion rate goal to reach mandated 75% facility recovery efficiency by 2025, results are not yet posted.

Table 5.9. The compostable waste amount.

| Waste Stream | Total Annual Mass (tonnes) | Recycle rate (%) | Recyclable Mass (tonnes) |
|--------------|----------------------------|------------------|--------------------------|
| Organics     | 25.90                      | 75%              | 19.42                    |

### 5.8.3. Incineration Potential

Once the waste mass has been separated to be used in recycling and composting, there is the combustible fraction of the waste stream that can be used to recover energy by incineration. The total waste of 109.5 tonnes was assumed to be available to incinerate on an annual basis. The non-combustible materials such as glass, metals and e-waste are not part of this process and their mass of incineration is zero. Combustion of this mass may have a realistic recovery of 1.4 million MJ or 389, 300 kWh of energy.

Calculation Method

The total energy parameter is the addition of the energy obtained through the burning of the unrecycled parts of paper, plastics, organics, textiles and miscellaneous waste streams.

$$\text{Energy (MJ)} = [\text{Incineration Mass(kg)} \times \text{HHV(kJ/kg)}] \div 1000 \text{ (converting kJ to MJ)}$$

$$\text{Energy (kWh)} = \text{Energy(MJ)} / 3.6 \text{ (converting MJ to kWh)} = 389,300 \text{ kWh}$$

The average HHV value shows the weighted average energy content of the whole waste combination. It was calculated by multiplying the percentage of each category of waste constituents (paper, plastics, and organics) by its respective HHV and adding up the values given. The HHV of the organic waste fraction was found to be 5,900 kJ/kg.

HHV for organic waste was calculated as the average HHV of food and green yard waste –  $(5500+6300)/2 = 5900 \text{ kJ/kg}$

Table 5.10. The incinerable waste amount.

| Waste Stream  | Total waste composition | Incineration mass (ton/year) | HHV (kJ/kg) | Energy (MJ/year) |
|---------------|-------------------------|------------------------------|-------------|------------------|
| Paper         | 31.02%                  | 33.96                        | 15,800      | 536,591          |
| Plastics      | 19.20%                  | 21.02                        | 32,800      | 689,587          |
| Organics      | 23.65%                  | 25.90                        | 5,900       | 152,791          |
| Glass         | 3.90%                   | 4.27                         |             | 0                |
| Metals        | 10.55%                  | 11.55                        |             | 0                |
| E-Waste       | 2.20%                   | 2.41                         |             | 0                |
| Textiles      | 1.10%                   | 1.20                         | 18,700      | 22,524           |
| Miscellaneous | 8.39%                   | 9.18                         |             | 0                |
| Total         | 100.00%                 | 109.50                       |             | 1,401,493        |

## 5.9. Waste management plan

### 5.9.1. Implement a Mandatory Three-Stream Source Separation Program

This is the plan of compliance that has to be firmly implemented at all levels of the 12-story building. The system is in direct compliance with the collection requirements of the City of San Jose Environmental Services department.

- Wet Stream (Organics):

Containers: blue bins with green lid.

Accepted Materials: This stream is only allowed to receive all food scraps of the canteen and office kitchens, and any plant trimmings.

Placement: Bins must be placed legally in any place where employees, tenants, and customers discard garbage. This is particularly important in the canteen that produces 21.7 out of 25.9 tonnes of organic waste that is annually produced by the building.

- Dry Stream (Recyclables):

Containers: blue bins with black lid.

Accepted Materials: Any type of common recyclable such as paper, cardboard, plastic bottles and containers (PET and HDPE), glass, and metal cans are all accepted.

Placement: These should be placed beside the residual trash bins on every office floor, in the common places and throughout the canteen to ensure that recycling becomes as easy as disposal.

- Residual (Trash) Stream:

Containers: blue bins with blue lids.

Accepted Materials: Only non-recyclable/non-compostable waste.

Placement: Accompanied with recycling bins to make up the sorting station in every disposal point.

#### 5.9.2. Establish Legally Compliant Hauling Contracts and Schedules with Republic Services

This is a mandatory move because there is an exclusive franchise agreement between the City of San Jose and the Republic Services. The office has the legal responsibility of awarding the contract to all solid waste and the recycling collection to Republic Services.

Wet Stream pick-up: This agreement is used in the collection of all food scrap and other compostable material. After collection, Republic Services will truck this material to a commercial composting plant, in this case, the Jepson Prairie Organics plant in Vacaville, CA where it is processed into high-quality compost.

Dry Stream recyclable and residual waste collection pick-up: This contract includes non-organic materials. Everything that is mixed with the recycling will be taken to the Republic Services facility to Newby Island Resource Recovery Park, 1601 Dixon Landing Road, Milpitas, CA. This Materials Recovery Facility (MRF) sorts, balances and recycles materials and sends them to manufacturers to create new products. It is the major processing facility in the area in terms of commercial recycling. This is because of its close location and incorporation into the municipal contract, which makes it the certain destination of dry-recycled materials of your building.

Residual Stream pick-up: The waste, which cannot be recycled or composted is discarded. Although this generally refers to a landfill, waste-to-energy (Waste to Energy) is one of the alternatives.

Practical Feasibility Test: The closest waste-to-energy plant is Stanislaus County Resource Recovery Facility in 4040 Fink Road, Crows Landing, CA 95313, approximately 105 miles (170 km) away in San Jose. Although energy recovery is theoretically feasible, the following operational limiting considerations have to be considered:

The typical residual waste of Republic Services in San Jose is directed to regional landfills (e.g., Newby Island) rather than WtE facilities, by the standard hauling contract in San Jose.

The cost of transportation to Crows Landing would be an extra usage of fuel amounting to about \$0.50-0.75/mile in a 20-ton truck, which would entail an added cost of approximately \$105-157 round trip on top of the regular hauling costs.

The hauler determines the route of waste to either WtE or landfill as per the terms of the contract and is not normally within the control of the building operator.

Thus, although the energy recovery calculation shows the calorific value of the waste stream, the operation plan is cautious that the waste stream will go to landfill as the default residual destination, WtE as an aspirational alternative, which will be part of the hauler contract negotiation.



### Collection Frequency and Processing:

**Wet Organics stream:** The collection must be planned twice or thrice a week. It was found that the building produces 59.4 kg of food service-related organic waste every day. A weekly collection would enable the food to decay over up to seven days, which would cause a lot of odor, pests, and would be against the contamination-observation criteria of SB 1383.

**Recyclables and Residuals:** It is possible to collect these streams once a week because the materials are not of biological activity and are not a threat of direct health-related or nuisance dangers.

Table 5.11. Legally Compliant Hauling Contracts with Republic Services

| Waste Stream    | Collection Frequency | Destination Facility                                 | Processing                                           |
|-----------------|----------------------|------------------------------------------------------|------------------------------------------------------|
| Wet Organics    | 2-3 times/week       | Jepson Prairie Organics<br>Vacaville, CA             | Commercial composting into high-quality compost      |
| Dry Recyclables | Once/week            | Newby Island Resource Recovery Park,<br>Milpitas, CA | MRF sorting, baling, and sale to manufacturers       |
| Residual Trash  | Once/week            | Newby Island Landfill / Stanislaus County WtE*       | Landfill (default) or waste-to-energy (aspirational) |

### 5.9.3. On-Site Internal Collection and Consolidation Plan

This section outlines the daily operational plan for accumulating waste from all 12 floors of the office building and consolidating it at the central loading dock for external collection. The system is designed to maintain the integrity of the three-stream separation (Wet Organics, Dry Recyclables, Residual Trash) from the point of generation to the final disposal container.

## Daily Internal Collection Route and Personnel

Personnel will be formed by three janitorial members to collect all wastes generated in the building on a daily basis. Their path is going to be through all the 216 interior bins of the 12 office floors.

The daily collection procedure is in the following way:

**Floor-by-Floor Collection:** These will be conducted by personnel moving large empty, multi-compartment, rolling carts with different streams to collect organics, recyclables and residual waste.

**Bin Service:** In every collection station, workers will dump the contents of the separate bins into the appropriate section of their carts on wheels.

**Liner Replacement:** Each bin will be emptied with fresh liners in it to be used to prevent dirt and germs.

**Vertical Transport:** When a given waste constituent is placed in one of the rolling carts, it will be transported and sorted to the outdoor dumpster.

**Canteen Service:** Canteen, producing a large amount of heavy wet organic waste will have the first run of service, and another run will be made following the peak lunch time to avoid the release of odors and overflow.

## Loading Dock Consolidation and Compaction.

At the loading dock, the received materials are emptied out of the rolling carts into a centralized system consisting of large containers outside of the building that are meant to reduce the volume so as to be easily hauled.

- **Dry Stream (Recyclables) - Stationary Compactor:**

The Dry Recyclables stream will have a separate stationary compactor. The average size is 2 cubic yards, most of them can fit 30-40 cubic yard dumpsters. It suits us because of

the high quantity of dry waste that reaches up to 29,000 liters or 38 cubic yards per week. The entire paper, cardboard, plastic bottles and the metal cans will go into this compactor.

The volume of these low-density materials is minimized by the compaction with an estimated ratio of 3:1. The waste volume of the design can be reduced to approximately 10,000 liters or 12 cy.

- Vertical Compactor: Residual Stream (Trash):

The stream of Residual Trash will have a vertical compactor installed. This unit will deal with up to 8 cy of all non-recyclable as well as non-compostable wastes. It is the best option we can make in terms of the design quantity of about 7.7 cy.

The volume of this stream is also minimized with the use of compacting into a 3:1 ratio, the anticipated volume after compacting is slightly less than 2,200 liters.

- Wet Stream (Organics): Sealed Dumpsters:

There will be no compacting of organic waste. It is high in moisture content and putrescible thus will be deposited in a regular, sealed 4 cy dumpster.

This will contain liquids and odors and comply with the frequency schedule 2 to 3 times a week necessary to comply with SB 1383 requirements.

## On-Site Equipment

The following key equipment will be required in the internal system of collection and consolidation:

- Indoor Bins: 216 total, 72 three-stream stations, 18 bins on each of the 12 levels.
- Internal Collection Carts: Janitorial staff carts are multi-compartment rolling carts that carry the waste materials of office/canteen bins to the loading dock.
- Stationary Compactor: There will be one stationary compactor in the loading dock for Dry Recyclables.
- Vertical compactor: One at the loading dock for Residual trash.
- Organic Waste Dumpsters: Standard Waterside, sealed dumpsters.

#### 5.9.4. Develop an Ongoing Education and Monitoring Program

The management and engagement is needed continuously to achieve long-term compliance. Onboarding of tenants and employees: Add mandatory training on the three-stream sorting system to the onboarding process of all new tenants and employees.

Monitoring and Audit of performance:

Do periodic visual inspections of waste containers to determine areas of contamination and give specific feedback.

Conduct a formal physical waste audit periodically based on the standard of ASTM D5231. It will give specific information about the diversion rates and the level of contamination, which will enable making changes in the program based on the data.

Strategic Emphasis on Aluminum: Although all the recyclables are to be gathered, special operational emphasis should be given on the capturing of the aluminum cans in a clean manner. It is analyzed that the program has a large majority of financial value in the form of aluminum which will produce an expected \$2,242 in a year. The most important task is to preserve this high-value stream by eliminating contamination and maximize the limited revenue of the recycling program.

#### 5.10. Waste collection plan

This plan outlines the system for collecting, storing, and managing solid waste generated by the building, ensuring compliance with state and local regulations, including California's AB 341, AB 1826, and SB 1383. The plan is based on a three-stream source-separation model and a mandated hauling contract with Republic Services.

The following matrix maps each applicable regulation to the specific design response implemented in this plan. This ensures that every legal requirement has a traceable compliance measure.

Table 5.12. Regulatory Compliance Matrix

| Regulation              | Requirement                                                                       | Plan Response                                                                                   | Verification                                                 |
|-------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| AB 341 (2011)           | Mandatory commercial recycling for businesses generating 4+ cy/week of waste      | Three-stream sorting stations on all 12 floors; Dry stream directed to Newby Island MRF         | Monthly hauling reports from Republic Services               |
| AB 1826 (2014)          | Mandatory commercial organics recycling for businesses generating 4+ cy/week      | Dedicated Wet (organics) stream with 2-3x/week collection; hauled to Jepson Prairie Organics    | Hauler receipts confirming organic diversion tonnage         |
| SB 1383 (2016/2022)     | 75% organic waste diversion by 2025; edible food recovery                         | Sealed organic dumpsters; high-frequency collection to prevent contamination; education program | Annual ASTM D5231 waste audit; contamination monitoring      |
| San Jose Municipal Code | Exclusive franchise hauling with Republic Services; mandatory 3-stream separation | All hauling contracts with Republic Services; three color-coded bin system building-wide        | Active hauling contract documentation; bin station inventory |
| CalRecycle Reporting    | Annual diversion rate reporting for commercial generators                         | Tracking of all three streams by mass; annual waste audit per ASTM D5231                        | Audit report filed annually with facility management         |

#### 5.10.1. Waste Volume calculation

##### Design Waste Generation with Safety Factor

A safety factor of 2.0 is applied to all projected waste generation rates as specified by the project supervisor. This factor accounts for:

- Seasonal peak loads (holiday periods, corporate events)
- Tenant turnover and variable occupancy rates
- Future building expansion or change of use
- Uncertainty in long-term waste generation projections over the 10-year equipment design life

The building's total baseline waste is 109.5 tonnes per year, generated by the office (60.23 tonnes) and canteen (49.28 tonnes).

Table 5.13. The design mass is broken down by material stream for detailed planning.

| Waste Stream  | Weekly office mass (kg/week) | Design office mass (kg/week) SF=2 | Weekly canteen mass (kg/week) | Design canteen mass (kg/week) SF=2 | Design mass (kg/week) |
|---------------|------------------------------|-----------------------------------|-------------------------------|------------------------------------|-----------------------|
| Paper         | 635.25                       | 1270.50                           | 16.065                        | 32.13                              | 1302.63               |
| Plastics      | 138.60                       | 277.20                            | 264.6                         | 529.2                              | 806.40                |
| Organics      | 80.85                        | 161.70                            | 415.8                         | 831.6                              | 993.30                |
| Glass         | 34.65                        | 69.30                             | 47.25                         | 94.5                               | 163.80                |
| Metals        | 23.10                        | 46.20                             | 198.45                        | 396.9                              | 443.10                |
| E-Waste       | 46.20                        | 92.40                             | 0                             | 0                                  | 92.40                 |
| Textiles      | 23.10                        | 46.20                             | 0                             | 0                                  | 46.20                 |
| Miscellaneous | 173.25                       | 346.50                            | 2.835                         | 5.67                               | 352.17                |
| Total         | 1155.00                      | 2310.00                           | 945                           | 1890                               | 4200.00               |

#### Calculation of Weighted Average Density

The mass of the design in kilograms of each stream needed to be converted into a realistic volume (liters) and that required the calculation of the density of the waste. Whereas the "Wet stream is mostly composed of organics which has a known density (514 kg/m<sup>3</sup>), the "Dry" and "Residual" streams are composite mixtures of other materials each having a unique density, the data was taken as the medium values from Waste Materials Densities Data (Sustainable Learning, n.d.).

The weighted average density was computed of the composite streams. This has been done through the implementation of the detailed waste composition data that determines the mass percentage and specific density of each constituent material, see Appendices. As an illustration, paper in the office waste stream contributes 55% of the total mass with a density of 152 kg/m<sup>3</sup> and plastics occupy 12% with a density of 75 kg/m<sup>3</sup>. The weighted average density of any stream is determined by adding the contributions of every material, with the following principle:

Weighted Density =  $\Sigma$  (Percentage of Constituent x Density of Constituent) / (Total percentage of Constituents)

By doing so, the ultimate figure of the density would truly be an indicator of the true nature of the mixed waste stream.

Table 5.14. Office waste composition and density.

| Waste Stream  | Waste density (kg/m <sup>3</sup> ) | Daily waste mass (kg/day) | Total waste composition |
|---------------|------------------------------------|---------------------------|-------------------------|
| Paper         | 152                                | 90.75                     | 55.0%                   |
| Plastics      | 75                                 | 19.8                      | 12.0%                   |
| Organics      | 514                                | 11.55                     | 7.0%                    |
| Glass         | 411                                | 4.95                      | 3.0%                    |
| Metals        | 130                                | 3.3                       | 2.0%                    |
| E-Waste       | 113                                | 6.6                       | 4.0%                    |
| Textiles      | 91                                 | 3.3                       | 2.0%                    |
| Miscellaneous | 170                                | 24.75                     | 15.0%                   |
| Total         |                                    | 165                       | 100.0%                  |

Table 5.15. Canteen waste composition and density.

| Waste Stream  | Waste density (kg/m <sup>3</sup> ) | Daily waste mass (kg/day) | Total waste composition |
|---------------|------------------------------------|---------------------------|-------------------------|
| Paper         | 152                                | 2.30                      | 1.7%                    |
| Plastics      | 75                                 | 37.80                     | 28%                     |
| Organics      | 514                                | 59.40                     | 44%                     |
| Glass         | 411                                | 6.75                      | 5%                      |
| Metals        | 130                                | 28.35                     | 21%                     |
| E-Waste       | 113                                | 0                         | 0%                      |
| Textiles      | 91                                 | 0                         | 0%                      |
| Miscellaneous | 170                                | 0.41                      | 0.3%                    |
| Total         |                                    | 135.00                    | 100%                    |

### Mass to Volume Conversion.

Having the design mass and weighted average density of each stream, the ultimate design volume was determined based on the basic equation:

$$\text{Volume (L)} = [ \text{Mass (kg)} / \text{Density(kg/m}^3\text{)} ] * 1000 \text{ (convert m}^3\text{ to L)}$$

The volumes obtained are the necessary data to determine the physical capacity of the waste management infrastructure. As an example, the weekly design mass of the office (1,663.20 kg) in dry waste was divided by its actual weighted average density, to find out what size should be obtained in the collection.

These calculations including the design mass of the particular design, its density, and the resulting weekly volume of each stream in the office and the canteen were summarized in the project data tables. These end volume values directly instruct on the choice of bin size, the capacity of collection carts, and the size of the external compactors and dumpsters needed

Table 5.16. Waste Volumes of two main sources categorized by type of waste bin.

| Waste Source | Waste Type | Design mass (kg) | Density | Volume (L) |
|--------------|------------|------------------|---------|------------|
| Office       | Wet        | 161.70           | 514.0   | 315        |
|              | Dry        | 1663.20          | 149.3   | 11,136     |
|              | Residual   | 485.10           | 151.6   | 3,199      |
| Canteen      | Wet        | 415.8            | 514.0   | 809        |
|              | Dry        | 526.365          | 128.2   | 4,104      |
|              | Residual   | 2.835            | 170.0   | 17         |

### Consolidation of Wastes and External Containers Sizing.

The last phase of the waste collection plan will be to combine the individual wastes that will be produced by the office and the canteen to find out the total volume of the daily and weekly waste that will be produced by the centralized disposal system. Such consolidated



information is necessary in the accurate sizing of the external dumpsters and compactors to be used in the loading dock, considering the factor of safety.

This has been demonstrated to be a total uncompacted waste of all sources of around 3,000 liters a day, and over 19,000 liters a week. The weekly amount of this consists of over 1,000 liters of wet organic waste, 15,000 liters of dry recyclable, and 3,200 liters of residual trash.

In order to handle these high volumes effectively and reduce the costs of hauling, stationary compactors are used to handle the dry and residual streams. Considering the 3:1 ratio of the compactors, the weekly volume of dry recyclables and the volume of residual waste are significantly decreased to around 5,000 and 1,000 liters respectively by the compaction process. The wet organic stream is not compressed and it has the same amount as it was created, which is approximately 1,000 liters each week.

In accordance with these end post-processing volumes, the necessary external container capacity has been established. The findings, which are given in units of standard industry cubic yards, are summarized as below. Such sizing facilitates the fact that the containers are large enough to accommodate a week's volume of the incremental and processed waste, and coordinating the physical infrastructure with the output of the building.

Table 5.17. Combined Waste Volume categorized by type of waste bin.

| Waste Type | Volume (L/day) | Volume (L/week) | Volume (cy/week) | Compacted (L/week) | Compaction (cy/week) | Container type       |
|------------|----------------|-----------------|------------------|--------------------|----------------------|----------------------|
| Wet        | 160.5          | 1,124           | 1.47             | 1,124              | 1.47                 | 4 cy dumpster        |
| Dry        | 2177.2         | 15,241          | 19.93            | 5,080              | 6.64                 | Stationary compactor |
| Residual   | 459.4          | 3,216           | 4.21             | 1,072              | 1.40                 | Vertical Compactor   |
| Total      | 2,797          | 19,580          | 25.61            | 7,276              | 9.52                 |                      |

## Capacity Utilization Analysis

This scaling is directly related to physical infrastructure requirements. The evaluation shows that the normal dumpsters cannot accommodate the large amount of dry recyclable materials that is produced weekly (20,000 liters). A compactor should be installed to match the storage capacity and the frequency of visiting the location (weekly). A compactor will decrease the space occupied by waste materials such as paper and plastic at least 3:1 resulting in the total storage space needed being around 7,500 liters. The containers that are used in the organics and residual waste offer sufficient buffer capacity.

Precisely, the plan will have a stationary compactor to reduce dry recyclables to under 7 cubic yards, and vertical compactor to reduce residuals to 1.4 cubic yards, and 1.5 cubic yard dumpster for wet waste.

A stationary compactor is right fit because it is ideal for dry waste such as paper, cardboard, and plastic waste. In addition, it has a capacity of up to 720 standard trash bags, which is up to 30 cubic yards. It is perfect for our case with a design waste volume of 20 cubic yards. Meanwhile Vertical compactor was chosen because of its less capacity of 3-8 yards which will be enough for residual trash.

Stationary and vertical compactors will be placed at the loading dock in the rear of the building featuring these three containers. This location is to ensure that they are easily accessible to construct the staff and there is a well-defined and safe collection point of the Republic Services that will pick up the contents of these dumpsters based on an agreed schedule. Such an entire installation has the benefit of providing adequate capacity, and the interplay of the internal waste management system in the building and external hauling is complemented.

The following analysis demonstrates that the selected infrastructure is appropriately sized for both baseline and design (SF=2) conditions, with neither over-provisioning nor risk of overflow.

Table 5.18. Capacity Utilization

| Equipment                                  | Rated Capacity (L) | Baseline Load(L/week) | Baseline Utilization |
|--------------------------------------------|--------------------|-----------------------|----------------------|
| Sealed Dumpster (Wet, 4 cy)                | 3,058              | 1,124                 | 37%                  |
| Stationary Compactor (Dry, 12 cy receiver) | 9,174              | 5,080                 | 55%                  |

|                                        |       |       |     |
|----------------------------------------|-------|-------|-----|
| Vertical Compactor<br>(Residual, 4 cy) | 3,058 | 1,072 | 35% |
|----------------------------------------|-------|-------|-----|

Notes: At full SF=2 design load, the waste constituents do not exceed single-week capacity. This is managed by the weekly collection schedule with Republic Services, which empties the receiver container before the next week's accumulation, providing an ample buffer.

#### 5.10.2. Optimal Bin Location and Accumulation Plan of the floor.

The plan is to install the waste sorting sites at generation points. Every station will comprise a collection of three colored bins with the following specifications: Wet (Organics), Dry (Recyclables), and Residual (Trash).



Figure 5.3. Ground floor waste station placement.

### Bin Placement for Ground Floor

The ground floor has a different layout with high-traffic public areas and rental spaces.

Table 5.19. Projected bin placements on the ground floor.

| Location/Room                 | Number of 3-Bin Stations | Rationale                                                                    |
|-------------------------------|--------------------------|------------------------------------------------------------------------------|
| Main Lobby (600+ m²)          | 2                        | Positioned strategically at main entry points to manage high public traffic. |
| Conference Halls (71 m² each) | 2                        | To manage waste from events and meetings.                                    |

|                                         |                            |                                                                                                       |
|-----------------------------------------|----------------------------|-------------------------------------------------------------------------------------------------------|
| Rental Spaces (107 m <sup>2</sup> each) | 2                          | Provides high-capacity service for future tenants, who may operate retail or food service businesses. |
| Total for Ground Floor                  | 6 Stations (18 bins total) | Full coverage for all public, administrative, and tenant spaces.                                      |

### Bin Location Typical Office Floors (Floors 2-12)

The floor plan between the 2nd and up to the 12th floor will be similar so that a standardized bin placement plan can be adopted and repeated across all the 11 floors. The assumed number of bins is the same for all floors, so the total number of bins will be 216.

### Flooring waste discharge stations.

An important aspect of the internal collection process is a specific storage place on every floor that the janitorial personnel can use to combine the garbage prior to placing them in the central loading area.

### Location:

The service corridor area as close to the stairwells, service elevator, and utility rooms as possible is the optimal location to place the accumulation station on each floor (1-12) (Tech/Staff). The space is not visible to people and it has direct access to the service elevator which ensures easy transportation downwards.

### Equipment and Process:

- The accumulation stations will be set up on every floor each having three large, wheeled carts (e.g. 200-liter or 7.25-cubic foot storage capacity offers 40% more space than traditional carts) with the colour-coded stations Wet, Dry and Residual.
- Janitorial personnel will empty the smaller bins in the offices, kitchen and common areas to these large, moving carts, on their daily routes.
- After each floor has been serviced, the complete carts are carried straight down to the service elevator and loaded at the loading dock located at the ground floor.
- It is a two-step process that allows avoiding the staff to carry single small bags of waste throughout the building and quickens and streamlines the end-stage sorting into the external compactors and dumpsters.

### 5.10.3. Staffing needs and Estimated pay.

Proper waste management of such a large building in the field is achieved by having individual staff members. Its day to day activities involve emptying more than 200 indoor bins, hauling trash to the loading dock, handling the external receptacles, and using the compactor.

It is proposed that a specific team of three full-time workers should be assigned to the task of collecting solid waste at the company on a daily basis. The following operational requirements were used to arrive at this number:

- Volume of Business: The number of individual bins attached to be serviced in 12 floors (216) is a big responsibility of the day that demands a systematic and efficient way of doing it.
- Physical Requirements: The job entails walking, lifting, and pushing heavy rolling carts on a regular basis, which is physically exhausting. The team-based methodology will make them safe and reduce fatigue.
- Task Division and Efficiency: The type of team of three enables the division of labor in an efficient manner. There can be two members who are going to be used as a main collection team in the office floors and the third dealing with the high-volume management of the canteen and loading dock.
- Redundancy and Reliability: This level of staffing offers the required coverage during sick days, vacations or even on urgent cleaning with no interference to the daily collection schedule.
- Jobs and Major Duty: The crew will be one (1) lead environmental technician and two (2) environmental technicians. These titles indicate the specialization of the process of management of separate waste streams according to the current environmental standards.

### Environmental Technicians

The two full-time Environmental Technicians will be the key to the daily collection team with the main target being the office floors (Floors 2-12).

#### Primary Responsibilities:

- Daily Waste Collection: Visit all the three-stream bin stations on the office floors, emptying the contents to the relevant compartments of their multi-stream rolling carts.
- Material Transport: Take the full rolling carts down to the service elevator and the loading dock on the ground floor, and consolidate.
- Sanitation: Change bin liners daily and clean the surfaces of the bin stations when the need arises.

- **Quality Control:** Visual check major contamination at every bin and report problematic issues (e.g. consistent missorting on specific floors) to the Lead Technician.

## Lead Environmental Technician

The Lead Environmental Technician will be in charge full-time of the whole on-site collection process, the high volume areas, and will serve as the interface to the outside world.

### Primary Responsibilities:

- **Canteen and Ground Floor Management:** Be the main driver in the servicing of the high volume canteen including an additional collection run following the lunch rush to ensure the food waste is well taken care of.
- **Loading Dock Operations:** Control the last point of disposal through working with the stationary compactors, the correct separation of glasses and control over the level of the organic waste dumpsters.
- **Hauler Coordination:** Be the on-site contact that is the first point of contact with a Republic Services collection driver, and that compactor and dumpster are unimpeded.
- **Training and Education:** Provide basic reminders and instructions to building tenants when issues of contamination are detected e.g. put information notices on wrongly used bins.
- **Supply Management:** Check and reorder of the required supplies, such as bin liners and cleaning supplies.
- **Team Coordination and Coverage:** Organize the day to day routes of the technicians and fill up in case of any absence to maintain the collection schedule by all means.
- **Shifts and Scheduling** The whole team will operate on a regular working day (e.g., 8:00 AM to 4:30 PM, Monday-Friday) schedule to match the normal working hours of the building. This time frame enables a complete morning collection run to be carried out prior to the office activity escalating and a second run in the afternoon to cater to production waste generated during the day which will keep the facility clean and within the boundaries.

## Daily Operational Timeline

The following timeline structures the daily workflow to align with building operating hours and prevent waste accumulation during peak occupancy.

Table 5.20. Expected daily operational timeline of personnel.

| Time        | Activity                     | Personnel   | Notes                       |
|-------------|------------------------------|-------------|-----------------------------|
| 07:30-08:00 | Shift start, equipment check | All 3 staff | Inspect carts, stock liners |

|             |                                       |                 |                                                             |
|-------------|---------------------------------------|-----------------|-------------------------------------------------------------|
| 08:00-10:30 | Morning collection:<br>Floors 2-7     | 2 Technicians   | Service all bin stations;<br>replace liners                 |
| 08:00-10:00 | Canteen first run +<br>ground floor   | Lead Technician | Service high-volume<br>canteen<br>bins before lunch<br>prep |
| 10:30-11:00 | Cart emptying at<br>loading dock      | All 3 staff     | Empty carts into<br>compactors<br>and dumpsters             |
| 11:00-12:30 | Morning collection:<br>Floors 8-12    | 2 Technicians   | Complete upper<br>floors                                    |
| 11:00-12:00 | Compactor operation<br>and monitoring | Lead Technician | Run compaction<br>cycle;<br>check fill levels               |
| 12:30-13:30 | Lunch break                           | All 3 staff     | Staggered if needed                                         |
| 13:30-14:30 | Post-lunch canteen run                | Lead Technician | Critical: manage<br>peak<br>organic waste after<br>lunch    |
| 13:30-15:30 | Afternoon spot-check:<br>all floors   | 2 Technicians   | Address overflow<br>bins;<br>contamination<br>checks        |
| 15:30-16:00 | Loading dock final<br>consolidation   | All 3 staff     | Prepare containers<br>for<br>next hauler pickup             |
| 16:00-16:30 | End-of-day reporting<br>and cleanup   | All 3 staff     | Log fill levels; note<br>contamination<br>issues            |

### 5.11. Integrated solid waste management plan

The apparent aim of the waste management plan is minimizing the costs of waste hauling by reducing its volume.

The waste management plan will be intended to attain this objective by operational efficiency and sizing of the infrastructure: a high-capacity system, free internal waste flow, separation of materials at the entry point to end-disposal. All design choices, bin location, frequency of collection, compaction equipment, and hauling contract, are assessed in terms of whether they can decrease the quantity of waste that the external hauler must pick up, since the cost of hauling is the only recurrent cost that can be directly influenced by on-site design.

#### 5.11.1. Overview of the Solid Waste Management Plan.

Infrastructure Sizing with Data.



The basis of the plan is proper evaluation of waste production so that equipment and containers are sized accordingly to maximize loads. The plan uses a safety factor of 2 on all the estimated waste generation rates to avoid system failure under peak loads or in the event of future increases, to minimize the cost of hauling, to ensure that the system operates at its peak efficiency, and to avoid an overflow,

**Waste Quantification:** The plan initiates with determining the current waste production of the whole building with division into the sources (office and canteen) and materials. These figures are multiplied by a safety factor of 2 to get a design mass which will take into consideration future growth and peak periods.

**Mass-to-Volume Conversion:** In order to choose the appropriate containers, the mass of a particular waste stream in the design will be changed to volume. Because both the "Dry" (recyclable) and the "Residual" (trash) streams are mixtures of materials of varying densities a weighted average density is computed on both in order to make the volume conversion accurate. The stream (organic) with the known density is referred to as the Wet stream.

**Compaction and Container Sizing:** The analysis indicates that the total weekly volume of waste that is not compacted is around 20,000 liters with dry recycle volume of more than 15,000 liters. In order to efficiently handle this high volume, the dry and residual streams are specified with stationary compactors with a 3:1 compaction ratio, which decreases the storage volumes of the latter to around 5,000 liters and 1,000 liters, respectively. According to these last volumes, the plan needs the following external containers at the loading dock:

- A single dry recycling compactor.
- A 4-cubic-yard uncompacted dumpster of wet organics.
- Residual waste has one vertical compactor.

#### Normalized Three-Stream Collection System.

In order to ensure material separation integrity all through the building, a mandatory and distinct program of three-stream source separation is adopted.

**Bin Placement:** There are 72 total (216 single bin) sorting stations that are strategically located at the waste generation points in all 12 floors. The placement of bins is general to office floors and specific to the ground floor since ground floor experiences heavy traffic and this location should be convenient to access and to influence the appropriate sorting. The streams are color-coded as Wet (organics), Dry (recyclables), and Residual (trash).

Floor-Level Consolidation: To establish a smooth internal traffic, a janitorial staff will pick up trash per floor on a daily basis using a portable dedicated accumulation carts. They contain huge, color-coded, roller carts with 205 liter or 7.25 cubic foot carts to enable Janitorial personnel to effectively consolidate waste products in smaller office bins prior to transportation, instead of having to carry a large number of individual bags through the building.

#### Effective On-site Operations and Staff.

The plan should be implemented on a daily basis, and a team should be dedicated to that purpose with a structured workflow.

Staffing Needs: There is a need to have a three Full-Time Equivalent (FTEs) to oversee the daily pick-up of more than 350 bins in 12 stories. The staff are made up of one Lead Environmental Technician and two Environmental Technicians. Such staffing provides not only the opportunity to complete all tasks, but also a backup against absenteeism.

Workflow and Collection Route: The operation plan has provided a two-step collection process.

Floor Collection: Technicians work their way through individual floors emptying the small sorting bins into the large multi-compartment rolling cart at the floor-level accumulation points.

Vertical Transport: After each floor has been serviced the full carts are transported via a service elevator straight into the loading dock on the ground floor. It is there that the materials are dumped into the corresponding external compactors or dumpsters. It will avoid the staffs using small bags in their hands.

Collection Frequency: The plan defines the collection frequencies of waste type to uphold hygiene and ensure that the regulations such as SB 1383 are followed.

It will eliminate carrying personal small bags around the premises and keep the area clean by avoiding smells and spillage. This will make sure that waste management system will not disrupt business objectives of the office building.

Wet Organics: 2-3 times/week collection to eliminate odors and pests.

Dry Recycling and Residual: Picked up every week, since these products are not a source of the same health or nuisance.

Continued Compliance: To maintain the success in the long term the plan presupposes obligatory training of all new tenants and employees on the sorting system, periodic visual inspection and regular audit of the waste, to be able to monitor the contamination and diversion rates.

### Process flow chart

This flowchart provides a visual summary of the end-to-end Integrated Solid Waste Management plan. The system is designed as a closed-loop process, beginning with meticulous source-separation and concluding with a feedback mechanism. The flowchart can be read as a whole as a map of the cost-minimization strategy: every node either decreases the volume to be paid by the hauler, safeguards the purity of streams allowing said decrease, or checks whether the decrease is being maintained.

The flowchart below illustrates the end-to-end waste management process. Each waste stream is traced by a distinct arrow color that corresponds to the color of its bin lid, providing a consistent visual language from the sorting station through to the final disposal destination.

Table 5.21. Arrow Color Legend (corresponds to bin lid colors)

| Arrow                                                                               | Stream            | Bin Lid Color | Description                                            |
|-------------------------------------------------------------------------------------|-------------------|---------------|--------------------------------------------------------|
|  | Wet (Organics)    | Green lid     | Food scraps, plant trimmings, compostable materials    |
|  | Dry (Recyclables) | Black lid     | Paper, cardboard, PET/HDPE plastics, glass, metal cans |
|  | Residual (Trash)  | Blue lid      | Non-recyclable, non-compostable waste                  |

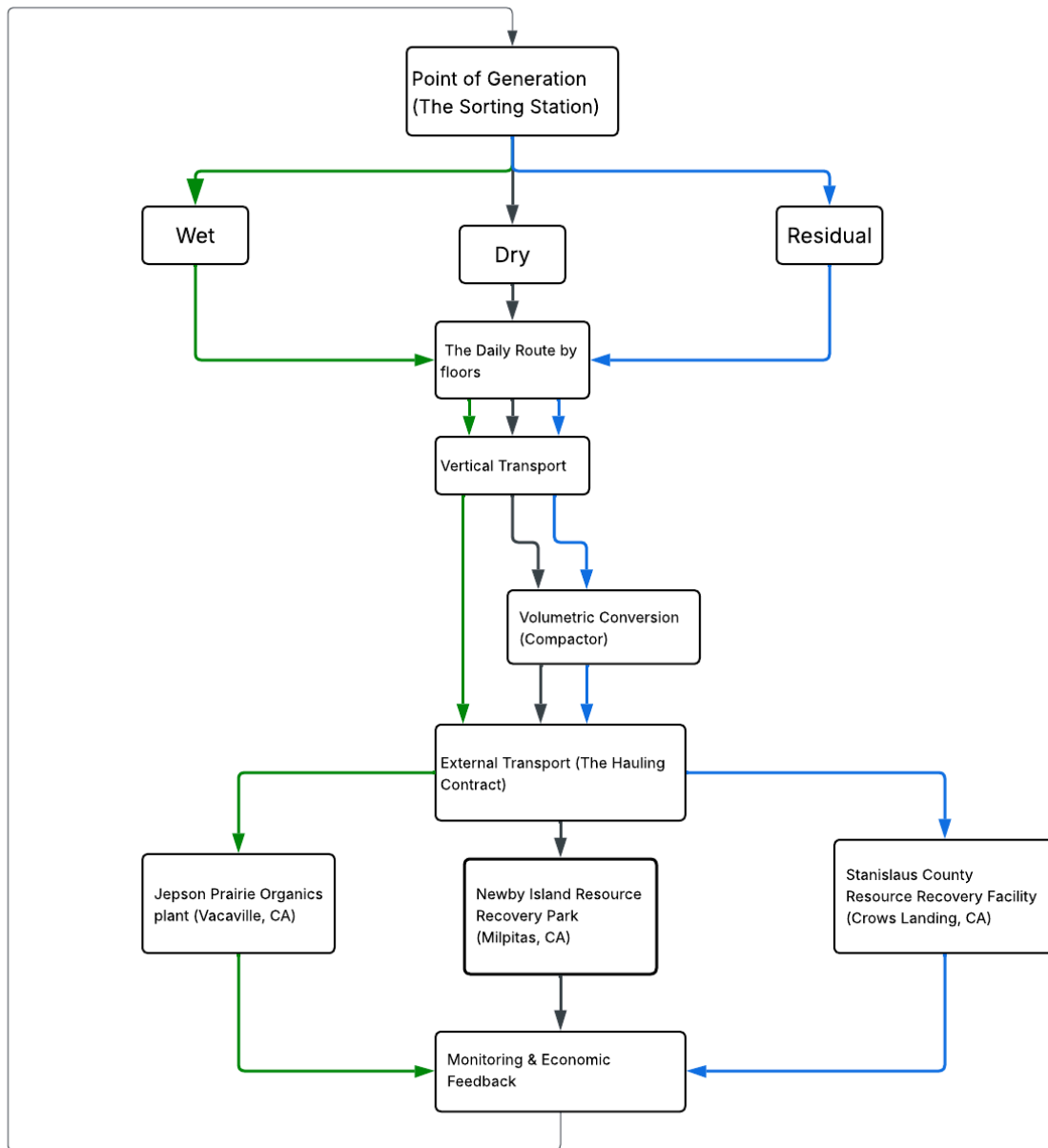


Figure 5.4. Flow chart of the integrated waste management system.

## Flow chart process description

The stages are described below. The arrows are coloured to match the colours of the bin lids throughout the building: green for Wet (organics), black for Dry (recyclables) and blue for Residual (trash).

### Stage 1: Source (The Sorting Station)

All waste will enter the system at the 72 three-bin sorting stations described in Section 5.9.1. Right sorting here is the foundation for all subsequent cost reduction - a contaminated dry stream will be rejected at the MRF (materials recovery facility) and will be sent to landfill at increased costs. Source separation is thus a compliance and cost-protecting measure.

### Stage 2: Daily Route by Floors

The three streams merge into the daily trash collection route by the three-person janitorial crew (Section 5.9.3). The canteen is serviced twice a day - before and after lunch peak period - to avoid odours and overflow of the organic bins. Untreated overflows would create unscheduled loads for the hauler Republic Services, which would cost more, increasing total haul costs.

### Stage 3: Vertical Transport

Full multi-compartment carts are transferred to the loading dock via the service elevator. The streams remain separated - the Wet, Dry and Residual streams are kept separate in the carts.

### Stage 4: Volume Reduction (Compactor)

This is the most important economic step, as volume reduction leads to hauling cost reduction. The three streams are processed differently:

The Wet stream is too wet to compact, and is simply tipped into the 4-cubic-yard sealed dumpster. The Dry stream is processed by the fixed compactor to compress 30,481 liters/week down to around 10,160 liters (at a 3:1 ratio) - without compaction, 4-5 dumpsters would be needed each week. The Residual stream is compacted by the vertical compactor from 6,432 liters to 2,144 liters at the same ratio.

According to industry sources, compactors can reduce the number of hauls by 75% when compared to non-compacted units, which translates into a reduction in hauling costs that is proportional to the reduction in volume (U-Pak, 2024; Gradeall International, 2026b). Waste streams producing more than 1 tonne per week have a two to three year payback period (Gradeall International, 2026a). This building generates 9 tonnes/week. The ROI calculation for this site is given in Section 5.12.8.

#### Stage 5: Hauling (The Hauling Contract)

Republic Services picks up all three containers on the contracted weekly collection schedule: 2-3 times a week for Wet organics, once a week for Dry recyclables and Residual trash. The compaction equipment at Stage 4 makes it possible to reduce the collection frequency for the Dry and Residual streams, and allows the total annual haul cost to remain at \$15,690 (compared to \$46,014 without compactors, see Section 5.12.8).

#### Stage 6: Destination Facilities

Each stream receives off-site processing at: Wet organics composting at Jepson Prairie Organics (Vacaville, CA); Dry stream separation and baling at Newby Island Resource Recovery Park (Milpitas, CA); Residual landfilling at Newby Island, with waste-to-energy at Stanislaus County Resource Recovery Facility (Crows Landing, CA) as an aspirational alternative subject to hauler contract negotiation.

#### Stage 7: Monitoring and Economic Feedback

Monitoring metrics are used to inform the on-site education and operations program, allowing long-term cost savings to be realised. The monitoring plan includes monthly visual inspection for contamination, quarterly review of hauling receipts to ensure billed volumes accurately reflect the compacted volumes, annual ASTM D5231 physical waste audit to confirm diversion rates, and ongoing aluminium revenue monitoring (contamination can reduce aluminium commodity value by 30-50%, so this is another measure of sorting effectiveness).

The seven stages comprise a single cost-minimisation system: Stages 1-3 perform stream segregation, Stage 4 reduces volume, Stage 5 provides low-cost collection, Stage 6 recycles value, and Stage 7 monitors cost savings.

### 5.11.2. Communication and Education Strategy.

To ensure that the system works as intended, the integrated waste management plan depends on the use of educational signages and worker training to change physical infrastructure to behavioral outcomes. The objective is to create a building-wide ethos of environmental responsibility by easy, simple, and uniform teaching of the three-stream model. It is only through the active involvement of all building occupants and proper sorting that the operational plan can accomplish its goal of cost-minimization, contamination in the dry stream will directly minimize the savings in the hauling cost that the compactor investment will produce.

#### High-Impact Visual Signage (Point-of-Disposal Education)

Education can be most critical at the moment when a person is standing in front of a bin. The way pointing should be immediate and clear.

**Standardized Posters:** A poster will be professionally designed and color-coded with each three-bin sorting station having one poster above it. The poster will be separated into three vertical panels that will correspond with the colors of bin lids. The panels will have good photographs of common items of that stream, a simple list of YES/NO written in plain language ( What Goes Here and What to Avoid ), and simple words - Food Scraps and Trash instead of Organic Waste and Residual. There will be one slogan which will be used on all materials and this will be SORT it Right: Clean, Dry, and Empty.

**Bin Decals:** Each individual bin will have a sticker on its front or lid that is large and durable with color-coded 3-5 example photographs of what is/is not acceptable on the bin to ensure a quick-reference guide. This supports the message to those people who fail to read the entire poster.

**Location-Specific Posters:** The canteen and kitchen will be covered with location-specific posters which refer to the specific products produced in the area, which include coffee cups, food containers, utensils and condiment packets, and instructions such as

Empty and Rinse Containers and No Liquids in Bins. Signage will be placed in copy and print rooms that will be paper, cardboard, toner cartridges, and plastic wrap orientated.

#### Digital Communication and Onboarding.

Contacting employees at their workstations and training new employees at the very first day is a key to long term success.

Official Program Launch Email: The email will go out to all occupants a week before the actual launch date and will include an explanation of the system, along with its purpose, and a link to an online sorting guide.

Digital Sorting Guide: A one-page PDF guide will be stored on the company intranet - graphically representing the three streams and answering the commonly asked questions. It will be distributed, printable and made available in all the workstations.

New Staff Onboarding: Every new employee will be given an onboarding package that will include the sorting guide and a brief overview of the programme, and will guarantee 100% coverage on his or her first day.

Intranet and Digital Screens: Reminder slides will be put in the lobbies, elevators, and break rooms on digital screens that will be rotated.

#### Engagement and interactive Training.

Passive reading does not create lasting behavior change like active participation.

Information Booths on Launch Day: A manned stand in the main canteen sorting station, during the first two days of operation, where the Lead Environmental Technician and Waste Champions will address any questions and offer real-time advice.

Newsletter: Green Tips Monthly: A short column in the company newsletter will cover the success metrics (e.g., tonnes of food waste diverted last month), a Contaminant of the Month, and a sorting tip of the month.



Contamination Feedback Tags: A pre-printed tag is put on a bin when it is discovered to be heavily contaminated stating the exact sorting error in non-confrontational terms (e.g., Food scraps were found in the recycling bin). Please place food in the green-lid Wet bin). This provides short-term correction with a focused approach at the failure point.

Through this multi-layered approach to education, this plan directly addresses the goal of keeping the streams separated at the point of generation, which is the behavioral basis upon which all the cost savings downstream will be based.



Figure 5.5. Proposed educational poster sample above the bins.

### 5.12. Financial Analysis.

This financial analysis is a detailed budget estimate of the implementation and maintenance of the Integrated Solid Waste Management (ISWM). These costs are classified into two key groups: initial set-up Capital Costs (CapEx) that are the upfront investment in the setup and Annual Operational Costs (OpEx) that are recurring costs. All the numbers are in USD and the 2026 fiscal year is calibrated to the San Jose market conditions.

### 5.12.1. Capital Costs (CapEx)

The capital investment is all the initial purchases and setting up costs of installing the three-stream waste management infrastructure. The equipment was chosen to be commercial grade and be able to withstand the heavy daily use of a 12 story, multi-tenant office building. In 2026, the prices have been checked against the existing retail and distributor listings to make sure that the budget will represent the real-life market conditions and not a generic assumption.

Table 5.22. Capital Costs – CapEx. Verified Market Pricing.

| Item                                      | Quantity | Unit Cost | Cost            | Justification & Source                                                                                                                                          |
|-------------------------------------------|----------|-----------|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Indoor Sorting Bins (60L, Wet stream)     | 72       | \$74      | \$5,328         | Rubbermaid Slim Jim 16 gal (model 1971257); <a href="#">Zoro.com</a> , \$73.50/unit (Zoro, 2026)                                                                |
| Indoor Sorting Bins (30L, Dry + Residual) | 144      | \$12      | \$1,728         | Rubbermaid Deskside 7 gal FG295673; <a href="#">Zoro.com</a> , \$11.79/unit (Zoro, 2026)                                                                        |
| Janitorial Collection Carts               | 4        | \$865     | \$3,458         | Rubbermaid High Capacity FG9T7200BLA; <a href="#">Wasserstrom</a> , \$864.48/unit (Wasserstrom, 2026)                                                           |
| Stationary Compactor (Dry Recyclables)    | 1        | \$22,319  | \$22,319        | Stationary Compactor C-2; <a href="#">Global Trash Solutions</a> (Global Trash Solutions, 2026)                                                                 |
| Vertical Compactor (Residual Trash)       | 1        | \$18,300  | \$18,300        | Cram-A-Lot VCH model; <a href="#">Global Trash Solutions</a> (Global Trash Solutions, 2026)                                                                     |
| Sealed Dumpsters (Organic, 4 cy)          | 1        | \$2,000   | \$2,000         | Toter FR040 Series, 4 cy; <a href="#">WebstaurantStore</a> (WebstaurantStore, 2026)                                                                             |
| Educational Materials                     | 1        | –         | \$4,000         | Design (\$1,500) + printing (\$2,160; <a href="#">Printing San Jose</a> ) + decals (\$250; <a href="#">Sticker Mule</a> ); ZipRecruiter (2026) rate: \$34.67/hr |
| <b>Subtotal: Equipment</b>                |          |           | <b>\$57,133</b> |                                                                                                                                                                 |

|                    |   |         |                 |                                                                                                                                          |
|--------------------|---|---------|-----------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Installation Labor | 2 | \$40/hr | \$1,600         | 2 workers × 20 hrs × \$40/hr; BLS OEWS San Jose MSA mean wage (\$39.28/hr); <a href="#">Bureau of Labor Statistics (BLS)</a> (BLS, 2024) |
| Contingency (15%)  |   |         | \$8,570         | AACE RP 56R-08 Class 3 estimate range 10–15%; <a href="#">AACE International</a> (AACE International, 2020)                              |
| <b>TOTAL CapEx</b> |   |         | <b>\$67,303</b> |                                                                                                                                          |

The capital expenditure of \$67,303 is the total investment which is a one-time cost of bringing up the physical infrastructure of the three stream waste management system. Unit prices are verified to existing US supplier listings, as of 2026. The highest cost line items in terms of value are the stationary compactor (\$22,319) and vertical compactor (\$18,300) that make up 60% of equipment expenses. The following compactors are vital to the sustainability of the plan. Without compaction, a dry recyclable stream would need over 30,000 liters of weekly storage, which is four or five standard 8-yard dumpsters. It would signify a considerable increase in the frequency and costs of hauling, calculated further in this report. The prices of the compactor have been obtained in the Global Trash Solutions - the leading waste service company in the USA.

### Indoor Sorting Bins

The bin procurement plan adopts two different tiers of products that are geared towards the locations and volume of waste. The Wet (Organics) stream is allocated 60-liter Rubbermaid Slim Jim containers (model 1971257) with a verified retail price of \$73.50 per unit at Zoro.com, taken as \$74 as the budget allocation (Zoro, 2026). These handle-type heavy-duty bins are chosen to fit into the wet organics stream as they are to be used multiple times to handle high moisture content waste and are constructed to commercial standards. There are 72 units needed - one Wet bin per three-bin sorting station at all 72 stations in the building. In the case of the Dry (Recyclables) and Residual (Trash) streams, it is defined as the 30-liter Rubbermaid Deskside FG295673 containers that cost \$11.79 per item, which was confirmed on Zoro.com as well and round to \$12 (Zoro, 2026). It is estimated that 144 units are needed, two per station.

### Janitorial Collection Carts

The Four Rubbermaid High Capacity multi-compartment janitorial carts (model FG9T7200BLA) are ordered at \$864.48 a unit, which was obtained by Wasserstrom restaurant supply (Wasserstrom, 2026). The rationale behind the choice of these carts is that since they have a multi-compartment design, the janitorial staff can pick up all three waste streams at the same time through a single pass of the floor, preserving the integrity of source separation. It has four units, which furnish one cart each of the two daily collection teams of office floors, one devoted to the high-volume canteen and one spare to the loading dock staging and maintenance coverage. Wasserstrom has an option with much bigger waste capacity – 7.25 cubic feet or 55 gallons, compared to 34 gallons in Zoro.

### Compaction Equipment

The fixed-rate compactor costs \$22,319 according to the latest list prices of the company Global Trash Solutions (Global Trash Solutions, 2026), one of the few that publicly posts prices of compactor. This unit is in charge of this dry recyclables stream of the building that produces an uncompacted volume of about 30,481 liters per week - a volume that is way much larger than the normal dumpster volume. This is minimized to about 10,160 liters at a 3:1 compaction ratio by the compactor, allowing Republic Services to collect once a week. The vertical compactor will cost \$18,300, namely the Cram-A-Lot VCH brand (Global Trash Solutions, 2026). The residual stream is cut down to about 2,144 liters per week after 3:1 compaction, which can be fit in a vertical compactor.

### Sealed Dumpsters (Organics)

A single Toter FR040 Series 4-cubic-yard sealed dumpster will cost \$2,000 and be obtained at WebstaurantStore (WebstaurantStore, 2026). The reason why organic waste is not compacted is that the waste contains a lot of moisture and is instead placed directly in closed containers to trap liquids and odors as required by SB 1383. The 2,247 liters of wet organics per week (about 2.94 cubic yards) is contained in one 4-cubic-yard dumpster, collected two to three times per week to avoid decomposition, odor generation and attraction of pests.

### Educational Materials

The budget is estimated to be about \$4,000 on professional graphic design services and quality printing of all learning materials. This educational materials budget includes three items: design costs, printing, and bin decals since all items deal with a specific and

non-substitutable interface with the occupants and the three-stream system. Poster sorting and bin decal provide instructions at the point-of-disposal, which peer-reviewed studies have found to be the most effective intervention to reduce contamination: in a longitudinal field study and three experiments, Cakanlar et al. (2025) demonstrated that point-of-disposal signage reduces contamination directly when it is designed with clear and item-specific guidance.

Designing expenses: \$1,500, which is approximately one work week including revisions and presentations. According to ZipRecruiter (2026), the national average hourly wage of a freelance graphic designer in the U.S. is \$34.67/hr, which translates to a contract price of  $34.67 \times 40 \text{ hours} = 1386.80/\text{week}$  and is rounded to \$1500. The rounding buffer of \$113.20 is used to reimburse small out-of-scope revision requests. There is no San Jose premium as the deliverables are digital in nature and the designer could be hired anywhere in the country.

Poster printing costs: \$2,160. Printing San Jose (2026) quotes 18"x24" next day posters at \$10.50 a piece; a 200-page order on 16pt cardstock, full color, matte finish, 3-business day delivery was found to yield a confirmed price of around \$1930, or about \$10 per unit. Scaled to 216 sheets, the cost is expected to be \$2,160.

Bin decals: \$250. One of the biggest sticker wholesale stores – Sticker Mule (n.d.) lists prices of die-cut vinyl stickers of about \$228 for 200 units and \$300 for 300 units; 216 units extrapolates to be under \$250.

#### Installation Labor

The labor cost of installing the equipment is estimated at \$1,600 because the Bureau of Labor Statistics (BLS, 2024) Occupational Employment and Wage Statistics of the San Jose-Sunnyvale-Santa Clara Metropolitan Statistical Area show an average hourly wage of \$39.28 in the Installation, Maintenance and Repair occupational group. It needs a two-person team, which will charge at a rate of  $\$39.28 \times 2 = \$78.56/\text{hr}$  which is rounded off to \$80/hr. The 72 three-bin stations take about 15 minutes each. Active installation time is 1,080 minutes (18 hours elapsed by the team) at 72 stations, 15 minutes. Another 2 hours would be added to inter-floor travel and per-floor-setup throughout the 12-story structure, resulting in a total elapsed team time of 20 hours. Total cost:  $\$80 \text{ per hour} \times 20 \text{ hours} = \$1,600$ .

## Contingency

A 15% contingency (\$8,570) is added to the equipment total to cover unexpected expenses like delivery charges, some minor structural modifications to accommodate the location of the compactor, regulatory permit charges, and initial installation difficulties. According to the Association for the Advancement of Cost Engineering (AACE) International Recommended Practice No. 56R-08 (AACE International, 2020), this rate is determined based on Class 3 budget estimates of building and general construction projects which are used when the scope is 10-40% complete as here where equipment is selected and priced but installation drawings, structural clearances and permits are still pending. According to RP 56R-08, the contingency of Class 3 estimates is 10-15. The upper limit of 15% is used since three risks which cannot be quantified, such as the compactor placement structural clearance, the variability of the San Jose permit fee and the fact that it is the first time that this particular building would be executed, all lead to considering contingency to the top of the Class 3 range and not in the middle. AACE International (2020) is a professional organization in the field of cost estimation standards, which was established in 1956, and its Recommended Practices are peer-reviewed by certified cost engineers worldwide.

### 5.12.2. Annual Personnel Costs

The biggest single element of the annual operating budget (OpEx) is personnel. All the wage information is based on the data published in U.S. Bureau of Labor Statistics Occupational Employment and Wage Statistics of Standard Occupational Classification code SOC 19-4042 — Environmental Science and Protection Technicians, Including Health — released May 2023 (BLS, 2023). This category describes the roles of the proposed team of waste management accurately, which include working in a regulated structure of environmental compliance within the framework of AB 341, AB 1826 and SB 1383 in California.

Table 5.23. Annual Personnel Costs

| Cost Component | Lead (1 FTE) | Techs (2 FTEs) | Total | Justification                                             |
|----------------|--------------|----------------|-------|-----------------------------------------------------------|
| Hourly Rate    | \$43.39      | \$24.35        |       | BLS SOC 19-4042, San Jose MSA; <a href="#">BLS (2023)</a> |

|                           |          |           |                     |                                                                            |
|---------------------------|----------|-----------|---------------------|----------------------------------------------------------------------------|
| Annual Salary             | \$90,250 | \$101,320 | \$191,570           |                                                                            |
| FICA (7.65%)              | \$6,904  | \$7,751   | \$14,655            | Mandatory employer contribution; <a href="#">IRS Topic 751</a> (IRS, 2026) |
| FUTA (California: 1.8%)   | \$126    | \$252     | \$378               | CA FUTA credit reduction 2025; <a href="#">California Payroll (2025)</a>   |
| CA SUI+ETT (3.5%)         | \$245    | \$490     | \$735               | New employer statutory rate; <a href="#">CA EDD (2026)</a>                 |
| Health Insurance          | \$20,730 | \$34,512  | \$55,242            | CA employer costs; <a href="#">CHCF (2025)</a> via KFF (2025)              |
| Workers' Comp             | \$3,610  | \$4,053   | \$7,663             | NCCI Class 9014 CA-adjusted; <a href="#">Kickstand Insurance (2024)</a>    |
| 401(k) Match (4%)         | \$3,610  | \$4,053   | \$7,663             | Market-competitive rate; <a href="#">BLS MLR (2015)</a> ; Carry (2026)     |
| <b>Total Fully Loaded</b> |          |           | <b>\$277,905.60</b> |                                                                            |

## Salary Determination

The hourly rate of Lead Environmental Technician of \$43.39 is the 90<sup>th</sup> percentile wage of SOC 19-4042 in the San Jose-Sunnyvale-Santa Clara Metropolitan Statistical Area (BLS, 2023). This higher percentile is based upon the fact that the Lead Technician position has supervisory, training, hauler coordination and compliance reporting duties beyond normal technician duties. At 2,080 annual working hours (52 weeks × 40 hours), the annual base salary is \$90,250. The median (50<sup>th</sup> percentile) wage of the two Environmental Technicians in the same occupational classification and geographic area is \$24.35 per hour (BLS, 2023). The technicians receive a salary of \$50,648 each year. The total salary of both FTEs amounts to \$101,320 and the total base payroll of the three jobs is \$191,570.

## Employer Payroll Taxes

FICA (7.65%). The Federal Insurance Contributions Act (FICA) mandates employers to contribute the same amount as the employees on social security (6.2%) and Medicare (1.45%) that come up to 7.65% of gross wages. According to the Internal Revenue Service

(IRS, 2026), the Social Security wage base ceiling in 2026 will be \$184,500 and the Medicare rate of 1.45% will not have a wage base limit. The three salaries in this plan are all significantly less than the Social Security wage base ceiling, that is, the entire 7.65% will be applied on all the amount of wages paid. Therefore to the Lead's salary ( $\$90,250 \times 7.65\% = \$6,904$ ) and to both Technicians' combined salary ( $\$101,320 \times 7.65\% = \$7,751$ ), the total employer FICA obligation is \$14,655 annually.

FUTA (1.8%, California-adjusted). The Federal Unemployment Tax Act (FUTA) applies 6.0% to the first \$7,000 of the wages of every employee, but up to 5.4% credit is given to the employer. California employers must pay an adjusted FUTA rate of net 1.8%, if they also pay state unemployment insurance (SUI) and pay it on time, claiming Form 940 as a result of California loan on federal unemployment insurance on the 2025 tax year (California Payroll, 2025). At 1.8%, the obligation is  $\$7,000 \times 0.018 = \$126$  for the Lead and \$252 for both Technicians combined, totaling \$378.

CA SUI + ETT (3.5%). According to the California Employment Development Department (EDD, 2026), as a new employer, the organization will be assigned the California State Unemployment Insurance (SUI) rate of 3.4% and the Employment Training Tax (ETT) rate of 0.1% that will add 3.5% to the first \$7,000 of the wage of any employee. This yields \$245 of the Lead and \$490 of the Technicians together and \$735.

## Employee Benefits

Health Insurance. According to the 2025 California Health Benefits Survey published by the California Health Care Foundation (CHCF, 2025) based on the Kaiser Family Foundation (KFF, 2025) Employer Health Benefits Survey, the premiums on employer-sponsored coverage in California in 2025 are, on average, \$10,033 for single coverage and \$28,397 for family coverage. Covered workers in California usually contribute from their own salary, approximately 14% for the single coverage and 27% for the family coverage, meaning the employer share is around 86% and 73%, respectively. The Lead Environmental Technician is assumed to have family coverage, the two Environmental Technicians are assumed to have single coverage. This produces an employer health insurance cost of  $\$28,397 \times 73\% = \$20,730$  for the Lead and  $\$10,033 \times 86\% \times 2 = \$17,256$  for both Technicians, totaling \$37,986 annually.



Workers' Compensation (~4%, Class Code 9014). The California Workers Compensation Insurance Rating Bureau (WCIRB) regulates California workers compensation and establishes pure premiums based on its own rates, not on the national rates of the National Council on Compensation Insurance (NCCI). The national average rate on the Class Code 9014 - Standard/Commercial Janitorial Services provided by NCCI is 2.43% of payroll (Kickstand Insurance, 2024). The rates used by California WCIRB of similar classifications were historically 30-80% higher than the national rates of NCCI, attributed to the higher levels of statutory benefits and the high medical cost climate in California. The 4% planning rate used here is a conservative estimate of California-premium-adjusted. Multiplied by the total gross payroll of \$191,570, the compensation is \$7,663.

401(k) Employer Match (4%). According to the U.S. Bureau of Labor Statistics National Compensation Survey, the overall average maximum employer 401(k) match rate is 3.5% (BLS, 2015). The 4% full dollar-for-dollar match used here is above the median of 4% of the BLS but at the lower end of the 4-6% range cited as the current market average by Carry (2026). The waste management team would find itself competing with technology-sector employees in the San Jose labor market, which features qualified candidates looking at both the waste management team and other employers with premium benefit packages, with a below-median retirement match affecting recruitment and retention significantly. Applied to base salaries, the cost is  $\$90,250 \times 4\% = \$3,610$  for the Lead and  $\$101,320 \times 4\% = \$4,053$  for both Technicians combined, totaling \$7,663.

### 5.12.3. Annual Hauling and Disposal Costs

Benchmarked against [City of San Jose / Republic Services approved rate as of 2025](#).

Organic waste rate: 0.5 cy per collection for three collections per week. 0.5 cubic yards equal to approximately 96 gallons.

Compacted waste rate: \$36.39/collection/cy for dry or residual waste per collection. As we have chosen 1 collection per week.

Monthly Hauling cost = Waste Volume (cy) \* Compacted Waste rate

Ex:  $6.64 \text{ cy} \times \$36.39/\text{collection/cy} = \$241.63/\text{month}$

## San José Commercial Service Rates

Effective July 1, 2025

Service Rates

Cart Service

Bin Service

Roll-Off Service

Standard Cart Service

Standard Bin Service

**Front Load  
Compactor Service**

Additional Collections

### Front Load Compactor Service Rates

#### DRY/CUSTOMIZED:

\$36.39 per collection per cubic yard

#### WET (no glass):

\$45.50 per collection per cubic yard

Figure 5.6. Maximum commercial rate for City of San Jose for compacted waste.

## WET (no glass)

| Cart Size<br>(gallons) | Collections Per Week |          |                 |          |          |          |
|------------------------|----------------------|----------|-----------------|----------|----------|----------|
|                        | 1                    | 2        | 3               | 4        | 5        | 6        |
| 32                     | \$109.85             | \$216.90 | \$324.00        | \$431.06 | \$538.14 | \$645.20 |
| 64                     | \$130.71             | \$258.15 | \$385.54        | \$512.96 | \$640.37 | \$767.80 |
| 96                     | \$163.39             | \$322.66 | <b>\$481.94</b> | \$641.21 | \$800.50 | \$959.75 |

Figure 5.7. Standard bin services for wet waste.

## 2025-2026 Cart & Bin Service Rate Calculator

Service Rates

Cart Service

Bin Service

Roll-Off Service

### Service Type

Standard Cart Service ▾

### Container Size

96 Gallon ▾

### Number of Containers

1 2 3 4 5 6  
☒ ☐ ☐ ☐ ☐ ☐

### Collections per week

1 2 3 4 5 6  
☐ ☐ ☒ ☐ ☐ ☐

### Wet or Dry

☒ Wet ☐ Dry

Calculate Rate

View Saved Rates

☐ Compare Rate

### Service Rate for:

**Standard Cart Service  
96 Gallon**

**1 container**

**Wet waste**

**3 collections per week.**

**\$481.94/month**

**\$5,783.28/year**

Additional pickup on regular collection day: \$56.55/container

Additional pickup on non-regular collection day: \$186.26/container

### Additional fees that may affect your bill.

| Type of Service                            | Rate Information    | Rate     |
|--------------------------------------------|---------------------|----------|
| Hasp & Lock for Cart/Bin (one time charge) | Per Occurrence Rate | \$31.14  |
| Replace Lock                               | Per Occurrence Rate | \$72.63  |
| Steam Cleaning                             | Per Occurrence Rate | \$103.76 |

Figure 5.8. Bin service calculator

The total weekly organic waste volume is under 3 cubic yards, thus we choose to collect it 3 times a week by 0.5 cubic yard.

Table 5.24. Annual Hauling and Disposal Costs

| Waste Stream    | Volume (cy/week) | Rate Basis                           | Monthly Cost | Annual Cost |
|-----------------|------------------|--------------------------------------|--------------|-------------|
| Wet Organics    | 1.47             | \$481.94/month<br>(96gal, 3x/wk)     | \$481.94     | \$5,783     |
| Dry Recyclables | 6.64             | Compactor Service:<br>Per cubic yard | \$241.63     | \$2,899.56  |
| Residual Trash  | 1.40             | Compactor Service:<br>Per cubic yard | \$50.95      | \$611.35    |
| Total           | 9.51             |                                      | \$774.52     | \$9,294.19  |

Total hauling and disposal costs amount to \$9,294.19 annually. This small percentage is a direct consequence of the on-site compaction approach: since the volume of dry recycle and leftover waste is reduced by 3:1 ratio, prior to collection, the plan will reduce the number of pickups and the effective cubic yardage that Republic Services will have to transport per stop.

The rate structure will be based on the maximum service rate documents provided by the City of San Jose Council which are publicly available. Wet organics stream is the costliest to collect at \$481.94/month due to the increased frequency of collection (96 gal of waste collected 3 times per week) of the organic waste and the contamination-prevention needs of SB 1383. By keeping it collected once a week, it would take up to seven days to decompose, which would lead to a terrible odor, attracting pests, and the risk of non-compliance with regulatory requirements, thus the increased frequency of collection is an essential operational requirement.

The Dry Recyclables and Residual Trash streams will be billed at the rate of compacted waste of \$36.39/collection/cy. This rate is by far much lower per unit volume than the organic rate since these materials are non-biological, are not an immediate source of health or nuisance and can safely be stored a full week between collections. The reduction in the volume of the compactor has a direct proportional correlation to the number of cubic yards billed per pickup, giving the relatively small annual totals of \$2,900 and \$611 for Dry and Residual streams respectively. Note that these rates can be annual adjusted by City Council approval and can change depending on the contract renegotiation with Republic Services.

#### 5.12.4. Annual Maintenance, Supplies, and Other Costs

Table 5.25. Annual Maintenance, Supplies, and Other Costs

| Item                      | Annual Cost     | Justification                                                                                                               |
|---------------------------|-----------------|-----------------------------------------------------------------------------------------------------------------------------|
| Equipment Maintenance     | \$2,000         | Service contract for two compactors 4-5% of compactor capital cost (\$40,619); <a href="#">UpKeep / SMRP</a> (UpKeep, n.d.) |
| Bin Liners                | \$16,500        | 55,000 liners/yr @ \$0.30/liner; wholesale contract rate; <a href="#">CleanCo Solutions</a> (CleanCo Solutions, 2026)       |
| PPE and Cleaning Supplies | \$3,000         | Nitrile gloves, safety vests, cleaners, mop heads, masks; <a href="#">Uline</a> (Uline, 2026)                               |
| Ongoing Education         | \$2,500         | Annual poster/decal reprints + campaigns; <a href="#">Printing San Jose</a> (Printing San Jose, 2026)                       |
| <b>Total</b>              | <b>\$24,000</b> |                                                                                                                             |

#### Equipment Maintenance

The two compactors have a total capital of \$40,619 (\$22,319 + \$18,300). The benchmark data of UpKeep (n.d.), which is based on the information published by the Society of Maintenance and Reliability Professionals (SMRP), defines that facilities ought to spend about 2-5% of Replacement Asset Value (RAV) on annual maintenance expenditure. World-class facilities attain 3% or lower. Applying the upper bound of 5% to \$40,619 yields \$2,031 — the budget rounds down to \$2,000. We take the upper limit of the 3-5% range instead of the middle range since this is a new installation and no history of maintenance exists, no service contract is in effect, and we do not know (first year) how often the filters

need to be washed, how much hydraulic fluid is required, or how often the blades are to be inspected.

## Bin Liners

The given product is the Royalty Low Density Trash Can Liner, 40 x 46 inches, 1.3 mil, Black, sold by CleanCo Solutions (2026) at \$35.98 a 100 liners of the product (\$0.36 a liner) and \$85.98 a 250 liners (\$0.344 a liner). The liner rate of \$0.30 per liner that the budget entails is a negotiated wholesale contract rate. This program should be given full pallet-scale purchasing at a purchase volume of 54,000 liners or 216 cases of 250 units annually. According to Mazer Wholesale (2016), full-pallet orders are a regular feature that include extra discounts of 15-20% below normal wholesale rate; a 12.8% cut of \$0.344 to 0.30 is thus a commercial reality at this volume. The budget has a 1,000-liner buffer over and above the 54,000-liner calculated requirement (216 bins x 250 working days) to accommodate the 72 wet organics bins which often need a second liner change due to high liquid content in food waste that saturates a liner mid-day in addition to spikes in volume during seasonal catered events. Total at \$0.30 per liner:  $55,000 \times \$0.30 = \$16,500$ .

## PPE and Cleaning Supplies

Every price is obtained through Uline (2026), the biggest distributor of industrial and facility supply in the US, and publicly available catalog pricing. Uline hosts all the necessary product groups in a single catalog, making it possible to order them in one place and have free shipping limits. The table below shows the detailed build-up of the costs.

Table 5.26. PPE and Cleaning Supplies cost breakdown

| Item                                             | Quantity/<br>Year | Unit Cost    | Annual Cost | Uline Source                                |
|--------------------------------------------------|-------------------|--------------|-------------|---------------------------------------------|
| Nitrile gloves, industrial 4 mil, 100/box        | 52 boxes          | ~\$18/box    | \$936       | <a href="#">S-23309</a> (Uline, 2026)       |
| Class 2 hi-vis safety vests (2/person × 3 staff) | 6 units           | ~\$10/vest   | \$60        | <a href="#">S-12517G</a> (Uline, 2026)      |
| All-purpose cleaner, 1-gallon refill             | 6 bottles         | ~\$25/bottle | \$150       | <a href="#">S-19456</a> (Uline, 2026)       |
| Trigger spray bottles, 32 oz                     | 4 units           | ~\$5/bottle  | \$20        | <a href="#">Spray Bottles</a> (Uline, 2026) |

|                                                   |         |            |                |                                                   |
|---------------------------------------------------|---------|------------|----------------|---------------------------------------------------|
| Economy wet mop heads, 24 oz                      | 4 heads | ~\$10/head | \$40           | <a href="#">S-7121W</a> (Uline, 2026)             |
| Cleaning rags/wipers, bag of 50                   | 6 bags  | ~\$15/bag  | \$90           | <a href="#">Janitorial Supplies</a> (Uline, 2026) |
| Replacement bin lids/handles (breakage allowance) | —       | —          | \$400          | <a href="#">Janitorial Supplies</a> (Uline, 2026) |
| Dust masks, standard, box of 50                   | 4 boxes | ~\$9/box   | \$36           | <a href="#">S-5687</a> (Uline, 2026)              |
| Safety glasses, economy clear, box of 12          | 2 boxes | ~\$12/box  | \$24           | <a href="#">PPE</a> (Uline, 2026)                 |
| Sub-Total                                         |         |            | \$1,756        |                                                   |
| Buffer (71%)                                      |         |            | \$1,244        |                                                   |
| <b>Total</b>                                      |         |            | <b>\$3,000</b> |                                                   |

The 71% buffer above the sub-total of \$1,756 is fueled by the fluctuations in the consumption of nitrile gloves and other supplies. The initial estimate of one box per week is based on the assumption of 1.4 pairs of gloves per worker on a daily basis. Practically, the employees who deal with wet organic waste regularly replace the gloves many times during the shift since direct contact with food acids, compost leachate, and cleaning agents demand more replacements. An empirical maximum of two to three pair changes per shift by workers handling organics would increase the annual costs of gloves to \$1,872-\$2,808. The overall budget of \$3,000, hence, gives some buffer which realistically encompasses the actual wet-waste consumption trends without necessitating a budget adjustment mid-year.

### Ongoing Education

Research on behavioral change in commercial waste programs consistently identifies a performance decay effect: without ongoing reinforcement, occupant sorting compliance declines measurably in the 60–120 days following program launch. The CalRecycle Commercial Organics Programs guidelines consider the long-lasting occupant education as the key tool to sustain the SB 1383 compliance. The continuing education budget thus covers the yearly reprinting, replacement and active campaign requirements of the program past the initial release. The build-up of the costs is represented below.

Table 5.27. Ongoing Education cost breakdown

| Item                                                                 | Est. Annual Cost | Source                                                                                        |
|----------------------------------------------------------------------|------------------|-----------------------------------------------------------------------------------------------|
| Poster reprints (~15 panels, 18"×24", 20% annual attrition)          | \$158            | <a href="#">Printing San Jose, \$10.50/panel</a> (Printing San Jose, 2026)                    |
| Bin decal replacements (~22 decals, 10% annual attrition)            | \$77             | <a href="#">Sticker Mule, ~\$3.50/unit</a> (Printing San Jose, 2026)                          |
| Monthly Green Tips newsletter inserts (12 months × ~50 copies)       | \$600            | <a href="#">Printing San Jose flyer printing, ~\$50/month</a> (Printing San Jose, 2026)       |
| Annual awareness campaign (Oops Tags, table cards, elevator posters) | \$500            | <a href="#">Printing San Jose multi-format print</a> (Printing San Jose, 2026)                |
| Staff refresher training cards (laminated reference sheets)          | \$200            | <a href="#">Printing San Jose next-day printing</a> (Printing San Jose, 2026)                 |
| Floor-specific campaign updates (est. 2 tenant renovations/year)     | \$292            | <a href="#">Printing San Jose, poster + decal reprint per floor</a> (Printing San Jose, 2026) |
| Sub-Total                                                            | \$1,827          |                                                                                               |
| Buffer (37%)                                                         | \$673            | (Unplanned contamination campaigns)                                                           |
| <b>Total</b>                                                         | <b>\$2,500</b>   |                                                                                               |

Printing San Jose (2026) is the main print supplier of all reprinting requirements since it is a local San Jose, CA business printer that has a quick delivery with a published cost of 18"x 24 posters of \$10.50 each directly applicable to the San Jose market meaning reprinting can be done on the same day or the next without having any impact on the operations of the

building. The assigned vendor to replace bin decals is Sticker Mule, who has a four-day standard delivery with free shipping at volume pricing of 22 to 50 units that correspond with the estimated \$3.50 per unit to replace the decals. The 37% buffer on top of the sub-total of itemized above 1,827 gives flexibility to react to one to two unscheduled contamination cases annually that require immediate reprint of specific materials without the necessity of a budget amendment.

#### 5.12.5. Depreciation Schedule

Table 5.28. Depreciation Schedule.

| Asset                | Initial Cost       | Useful Life (yr) | Salvage Value | Depreciable Base   | Annual Depr.      |
|----------------------|--------------------|------------------|---------------|--------------------|-------------------|
| Stationary Compactor | \$22,319           | 10               | \$2,232 (10%) | \$20,087           | \$2,009           |
| Vertical Compactor   | \$18,300           | 10               | \$1,830 (10%) | \$16,470           | \$1,647           |
| Janitorial Carts     | \$3,458            | 7                | \$173 (5%)    | \$3,285            | \$469             |
| Sealed Dumpsters     | \$2,000            | 7                | \$100 (5%)    | \$1,900            | \$271             |
| Indoor Sorting Bins  | \$7,056            | 5                | \$0           | \$7,056            | \$1,411           |
| <b>Total</b>         | <b>\$53,133.00</b> |                  | <b>\$0.00</b> | <b>\$48,798.00</b> | <b>\$5,807.00</b> |

Capital assets are depreciated using the straight-line method of depreciation, which spreads the depreciable base (cost -salvage value) evenly over the assumed useful life of the asset. The straight-line method was chosen for its simplicity, ease of understanding, and its commonality in reporting public infrastructure assets and other facility assets under US GAAP (IRS, 2024; CPCON, 2026). The total depreciation charge is \$5,807 annually.

Useful-life and salvage value assumptions are consistent with the manufacturer's specifications, the IRS MACRS class-life guidelines (Publication 946, Appendix B), and published salvage values for industrial equipment:

Stationary and Vertical Compactors have useful life of 10 years and salvage value of 10%. SP Industries, a compactor manufacturer, prescribes a 10-20 year useful life for stationary industrial compactors operating under continuous 24-hour use (SP Industries, n.d.); independent manufacturer Gradeall International also reports 10-20 year useful life for well-maintained waste compactors (Gradeall, 2026). A 10-year useful life represents the low end of this range, and is consistent with single-shift commercial operation. The 10% salvage value reflects the scrap and secondary-market value of heavy steel frames, hydraulic



cylinders and motors, and is at the lower end of the 10-25% range reported for heavy plant and machinery (Tractian, 2026; emuMoney, n.d.; Getclue, 2026).

Janitorial Carts and Sealed Dumpsters have useful life of 7 years and salvage value of 5%. Seven years is the class life of office furniture, fixtures and equipment under the IRS MACRS, Appendix B, in IRS Publication 946 (IRS, 2024; Accounting Insights, 2025). These moving assets are subject to daily rolling impacts, load stress, exposure to the elements and waste liquids, which supports a class-life recovery period. A 5% salvage value represents the scrap value of the steel and rigid-plastic components at obsolescence, and is based on published residual-value rules of thumb of 5-20% for small mixed-material equipment (Tractian, 2026; emuMoney, n.d.).

Indoor Sorting Bins have useful life of 5 years, and no salvage value. Plastic (HDPE/PP) sorting bins are handled continuously, subject to impact damage, UV degradation near windows (a failure mode that manufacturers aim to prevent with UV stabilizers in the resin - ORBIS, n.d.), and staining. Five years is at the high end of the 3-5 year class-life range for reusable plastic containers (Sustainability Directory, 2026). No salvage value is given to these items, as waste containers with stains and contaminants are unsuitable for resale and have little value as scrap after downcycling costs.

Educational material (\$5,000) does not face depreciation and is charged in full during the year of purchase since they are consumable costs which cannot have residual value or offer a service life over a period of years. It is worth mentioning that depreciation is a non-cash cost: it does not represent the real cash outlay within a certain year, but it just splits the initial capital investment by dividing it over the life of the assets that might be used to provide the proper financial reporting and taxation.

#### 5.12.6. Potential revenue from recyclables

CalRecycle commodity-priced revenue and local Bay Area hauler estimates. The major revenue generator stands at \$1,600/ton of aluminum.

Estimated Annual Revenue: ~\$4,504

The projected \$4,504 recyclable materials yearly revenue is a small compensation to operational expenses as opposed to a profit center. This revenue is established based on

material-specific commodity prices obtained at CalRecycle and local San Francisco-based haulers, and applied to the estimated recyclable output of the building by material.

The most valuable material in the waste stream is aluminum with a commodity price of over \$1,600 per ton. Aluminum is the largest contributor to recycling income, with 1.76 tonnes/year (only 1.6% of total waste mass) generating an estimated cost of \$2,242/year, almost half of total recycling income. This unequal value highlights the operational focus that is given to clean aluminum capture in Section 5.9.4 of the waste management plan. The aluminum stream (e.g. food residue on cans) may decrease its value by 30-50% due to contamination, which makes the emphasis of the education program on empty and rinse messages directly related to financial performance.

Other recyclable products bring in smaller yet significant returns: paper and cardboard will earn only moderate returns as they have high volume but low per-ton value (\$50-100/ton), and PET and HDPE plastics will earn minimal returns because of the fluctuating commodity prices and the sorting fees charged by MRF operators. The zero revenue is produced by Glass as presented before. The amount of total revenue of \$4,504 is considered a low starting point; the amount of actual revenue will depend on the conditions of the commodity markets and success of the sorting program to reduce contamination.

#### 5.12.7. Financial Summary

Table 5.29. Total CapEx and OpEx

| Category                | Amount           |
|-------------------------|------------------|
| <b>Total CapEx</b>      | <b>\$67,303</b>  |
| Personnel               | \$277,906        |
| Hauling & Disposal      | \$9,294          |
| Maintenance & Supplies  | \$24,000         |
| Depreciation            | \$5,807          |
| Less: Potential Revenue | -\$4,504         |
| <b>Net Annual OpEx</b>  | <b>\$312,503</b> |

In long-term financial planning, the first year cash outlay must be differentiated with the sustainable ongoing cost. The annual cost of the program is also lowered to the Net Annual OpEx of about \$312,500 per year as capital expenditures of \$67,300 will no longer be incurred after Year 2.

The financial analysis reveals that, although the integrated solid waste management program is an important operational commitment, it is designed to provide optimal value in terms of verified market-rate equipment acquisitions, compaction-based hauling cost-saving, and a workforce of the right size that matches the needs of a 12-story, 109.5-ton-per-year waste generation profile.

#### 5.12.8. Compactor Payback Period.

##### Purpose and Scope

This section quantifies the full financial impact of installing two mechanical compactors as part of the Integrated Solid Waste Management (ISWM) plan for a 12-story commercial office building in San Jose, California. The analysis covers three cost dimensions:

- Hauling cost savings - the amount that the building will save annually for Republic Services since compacted volumes will result in fewer waste volume and less collection trips.
- Compactor maintenance - the continuous expense of maintaining the equipment in working condition which is estimated to be about 4-5% of the purchase price annually (\$2,000/yr).
- Depreciation - the non-cash accounting expense of depleting the assets of capital over their useful lives, the straight-line method being used.

All hauling rates are based upon the 2025 City of San Jose / Republic Services accepted rate schedule. The net annual benefit, payback period and 10 year financial outlook are provided both on a simple basis (hauling saving-maintenance) and a depreciation-adjusted basis to give a full accounting transparency.

##### Step-by-Step Calculation Procedure

1. Establish Compacted Volumes

Table 5.24. of the solid waste management plan lists the volumes of the hauling post-compaction. These are the foundation blocks - the price the building pays as per the implemented plan.

## 2. Reverse-Engineer Uncompacted Volumes

The 3:1 compaction ratio is inverted to find out what hauling costs would be without compactors. Every compressed volume is multiplied by 3 to get the original uncompacted cubic yardage and rounded off to the nearest feasible Republic Services collection set up.

Dry Recyclables: Uncompacted volume =  $6.64 \text{ cy} \times 3 = 19.92 \text{ cy/week} \approx 20 \text{ cy/week}$

At 4 cy per container load, clearing 20 cy/week requires 5 collections per week

Residual Trash: Uncompacted volume =  $1.40 \text{ cy} \times 3 = 4.2 \text{ cy/week} \approx 4.5 \text{ cy/week}$

At 1.5 cy per load, clearing 4.5 cy/week requires 3 collections per week

## 3. Calculate Annual Hauling Cost without Compactors

The 2025 rate shown as “Standard Bin Services Rates”, is implemented on the rounded uncompacted volumes. The monthly fee is the per-collection cubic yardage times the number of collection events per month at the given rate shown below.

### Standard Bin Service Rates



#### DRY/CUSTOMIZED

| Bin Size<br>(cubic<br>yards) | Collections Per Week |          |            |            |            |            |
|------------------------------|----------------------|----------|------------|------------|------------|------------|
|                              | 1                    | 2        | 3          | 4          | 5          | 6          |
| 1                            | \$201.65             | \$390.47 | \$577.43   | \$766.78   | \$956.06   | \$1,143.06 |
| 1.5                          | \$220.80             | \$427.60 | \$632.31   | \$839.61   | \$1,046.90 | \$1,251.65 |
| 2                            | \$239.97             | \$464.66 | \$687.16   | \$912.44   | \$1,137.73 | \$1,360.25 |
| 3                            | \$281.63             | \$543.52 | \$805.42   | \$1,072.99 | \$1,332.06 | \$1,596.76 |
| 4                            | \$323.29             | \$623.93 | \$924.54   | \$1,225.15 | \$1,525.83 | \$1,826.47 |
| 6                            | \$404.58             | \$780.85 | \$1,157.12 | \$1,537.42 | \$1,913.69 | \$2,294.00 |
| 8                            | \$489.87             | \$945.39 | \$1,401.02 | \$1,851.69 | \$2,307.25 | \$2,762.80 |

Figure 5.9. Service rate for uncompacted waste.

Dry Recyclables — Without Compactors

$$4 \text{ cy} \times 5 \text{ collections/week} \rightarrow \$1525.83 / \text{month} \times 12 = \$18,309.96 / \text{year}$$

Residual Trash — Without Compactors

$$1.5 \text{ cy} \times 3 \text{ collections/week} \rightarrow \$632.31 / \text{month} \times 12 = \$7,587.72 / \text{year}$$

Wet Organics — Unchanged in Both Scenarios

Wet organics cannot be mechanically compacted. Their high moisture content causes leachate leakage and accelerates biological decomposition. The flat rate of organic waste hauling is identical whether compactors are installed or not.

Total Annual Hauling Cost without Compactors

$$\$5,783 + \$18,309.96 + \$7,587.72 = \$31,680.96 / \text{year}$$

Table 5.30. Annual Hauling Costs without Compactors

| Waste Stream    | Volume (cy/week) | Rate Basis                    | Monthly Cost | Annual Cost |
|-----------------|------------------|-------------------------------|--------------|-------------|
| Wet Organics    | 1.47             | \$481.94/month (96gal, 3x/wk) | \$481.94     | \$5,783     |
| Dry Recyclables | 19.92            | \$1525.83/mo (4cy,5x/wk)      | \$1,525.83   | \$18,309.96 |
| Residual Trash  | 4.2              | \$632.31/mo (3cy, 3x/wk)      | \$632.31     | \$7,587.72  |
| Total           | 25.59            |                               | \$2,640.08   | \$31,680.96 |

#### 4. Gross Annual Hauling Saving

The gross saving is the difference in total hauling cost between the two scenarios, before any operating costs of the compactors themselves are subtracted:

$$\text{Gross Annual Saving} = \$31,680.96 - \$9,294.19 = \$22,386.77 / \text{year}$$

Table 5.31. Gross Annual Hauling Savings Comparison

| Stream       | No Compactor | With Compactor | Annual Saving | % Saved |
|--------------|--------------|----------------|---------------|---------|
| Wet Organics | \$5,783      | \$5,783        | \$0.00        | 0.00%   |

|                 |             |            |             |        |
|-----------------|-------------|------------|-------------|--------|
| Dry Recyclables | \$18,309.96 | \$2,900    | \$15,410.40 | 84.16% |
| Residual Trash  | \$7,587.72  | \$611      | \$6,976.37  | 91.94% |
| Total           | \$31,680.96 | \$9,294.19 | \$22,386.77 | 58.70% |

The dry recyclables stream costs over 6 times more without a compactor and residual trash costs nearly 13 times more. Volume reduction eliminates entire collection trips — each avoided trip saves the full per-event charge, not just a proportional fraction.

#### 5. Annual Compactor Maintenance Cost

The compactors are mechanical equipment containing hydraulics, wear parts and electrical components that need service periodically to ensure they will continue to be operational and maintain their compaction ratio. A maintenance budget of \$2,000 is used annually, or about 4.9% of the total compactor purchase cost.

#### 6. Depreciation Schedule

##### Methodology

Depreciation of all capital assets is based on the straight-line method - net depreciable cost is uniformly divided across the useful life of the asset. Compactors have 10 years of useful life and 10% salvage value.

Table 5.32. Compactor Depreciation Schedule.

| Asset                | Initial Cost | Useful Life | Salvage Value (10%) | Depreciable Base | Annual Depr. |
|----------------------|--------------|-------------|---------------------|------------------|--------------|
| Stationary Compactor | \$22,319     | 10 yr       | \$2,232             | \$20,087         | \$2,009      |
| Vertical Compactor   | \$18,300     | 10 yr       | \$1,830             | \$16,470         | \$1,647      |
| Total                | \$40,619.00  |             | \$4,062.00          | \$36,557.00      | \$3,656.00   |

#### 8. Depreciation-Adjusted Financial Analysis

Net Benefit = Gross annual hauling saving - annual maintenance - annual depreciation

Net Benefit After Maint. + Depr. = \$22,386.77 - \$2,000.00 - \$3,656.00 = \$18,530

Using net benefit after compactor-specific depreciation:

Adjusted Payback =  $\$40,619 \div \$18,530 = 2.2 \text{ years} \approx 26 \text{ months}$

## 9. Ten-Year Financial Outlook

In practice, San José commercial solid-waste hauling rates are reviewed and approved annually by the City Council and have historically risen at or above the general rate of inflation. This section layers two escalation factors onto the outlook to produce a more realistic projection.

**Hauling-Rate Escalation (5.5 % per annum).** The City of San José / Republic Services franchise agreement ties annual rate adjustments to cost-of-living increases and operational cost changes. In the past five years, the hauling rate of City Council has varied from 2.32% to 8.47%, according to Commercial Garbage and Recycling Services Rate Changes Frequently Asked Questions. The assumption that we made suggests average rate increase of  $(2.32+8.47)/2=5.4\%$  that was further rounded up to 5.5 % for upcoming years. This compound annual escalation is therefore applied to the gross hauling savings in each year of the outlook. Because the compactors eliminate collection trips entirely, every rate increase that would have applied to the uncompacted service is captured as additional avoided cost. Thus this rate increases as more money is saved using compactors.

**Maintenance Inflation (3.0 % per annum).** The \$2,000/yr maintenance budget is escalated at general CPI. The U.S. Bureau of Labor Statistics reported CPI-U of 2.7 % for the 12 months ending December 2025 and 3.3 % for the 12 months ending March 2026. A 3.0 % annual escalation is used as a conservative central estimate for hydraulic-equipment service contracts over the projection window.

**Depreciation and Salvage.** Straight-line depreciation (\$3,656/yr) is unchanged because it is a non-cash accounting charge anchored to historical cost. The 10 % salvage value (\$4,062) is similarly unaffected by inflation.

The table illustrates the cumulative hauling saving, cumulative maintenance cost and annual depreciation with each passing year of the 10 years useful life of the compactors. The net position is reported on a simple basis (savings - CapEx - maintenance) and on a depreciation-adjusted basis.

Table 5.33. 10-Year Financial Outlook.

| Yr | Annual Saving | Cumul. Saving | Annual Maint. | Cumul. Maint. | Depr.   | Net (Adj.) |
|----|---------------|---------------|---------------|---------------|---------|------------|
| 1  | \$22,387      | \$22,387      | \$2,000       | \$2,000       | \$3,656 | -\$21,558  |
| 2  | \$23,618      | \$46,005      | \$2,060       | \$4,060       | \$3,656 | -\$2,330   |
| 3★ | \$24,917      | \$70,922      | \$2,122       | \$6,182       | \$3,656 | \$20,465   |
| 4  | \$26,287      | \$97,209      | \$2,185       | \$8,367       | \$3,656 | \$44,567   |
| 5  | \$27,733      | \$124,943     | \$2,251       | \$10,618      | \$3,656 | \$70,049   |
| 6  | \$29,259      | \$154,201     | \$2,319       | \$12,937      | \$3,656 | \$96,989   |
| 7  | \$30,868      | \$185,069     | \$2,388       | \$15,325      | \$3,656 | \$125,469  |
| 8  | \$32,566      | \$217,635     | \$2,460       | \$17,785      | \$3,656 | \$155,575  |
| 9  | \$34,357      | \$251,991     | \$2,534       | \$20,318      | \$3,656 | \$187,398  |

|    |          |           |         |          |         |           |
|----|----------|-----------|---------|----------|---------|-----------|
| 10 | \$36,246 | \$288,238 | \$2,610 | \$22,928 | \$3,656 | \$221,035 |
|----|----------|-----------|---------|----------|---------|-----------|

Notes: ★ = break-even year. Net (Adj.) = Cumulative savings - CapEx(\$40,619) - Cumulative maintenance -Cumulative depreciation.

#### Summary of the Compactor ROI (Return on Investment)

The analysis reveals that the two compactors defined in the ISWM plan provide an attractive payback on investment, despite considering the cost of maintenance that the two compactors require annually, and the non-cash depreciation of all capital assets in the programme.

The 3:1 compactor ratio increases the volume of the dry and residual streams threefold, without compaction, causing disproportionately more frequent waste collections. The dry recyclables hauling cost increases almost a five-fold and residual trash almost eight-fold since removed collection trips incur the per-event fee in entirety. The gross saving of hauling is \$22,387/yr. Which was then multiplied by 1.055 for haul rate increase.

Then, we subtract the cumulative maintenance budget, which was increased by 3% inflation (benchmarked at about 4.9% of the cost of the compactor, in accordance with the industry standard of 3-5% of hydraulic equipment service contract). Using the depreciation-compactor specific method of depreciation of \$3,656/year, the depreciation-adjusted payback period should be 26 months - slightly better than Gradeall International (2026a) suggested. The building generates over 9 tonnes/week, 9 times more than the threshold of one tonne of waste per week, therefore a standard payback period of two to three years on compaction equipment is decreased for our case of high waste volume.

Over the full decade, the programme generated a gross hauling saving of \$288,000. After deducting the compactor purchase price, cumulative maintenance, and compactor depreciation the net gain is \$221,000. The compactors are not merely equipment — they are cost-reduction assets with a measurable, well-documented, and rapidly realised financial return, proving to make a decent effort to achieve the key purpose of the ISWM plan.



## 6. Construction Management

### 6.1 Project Charter

Table 6.1 shows the Project Charter, which outlines the key elements of the project, including the project's goal, objectives, scope, stakeholders, and constraints. It is a document that establishes the project's purpose, direction, and expectations for all project participants. It is used as a guide for further planning activities, decision-making, and project implementation.

Table 6.1. Project Charter

| General Information |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                  |                       |
|---------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-----------------------|
| Project title       | Design of a 12-story “Dream Construction” Business Center in San Jose, California, USA                                                                                                                                                                                                                                                                                                                                                                                                                                               |                  |                       |
| Project description | One-story basement and 12-story commercial high-rise building, approximately 250-story structured parking, and rooftop green garden, one-story retail space. The project will be situated in 447 S Almaden Boulevard, San Jose, CA 95110 United States. The location is in downtown San Jose, a vibrant mixed-use area adjacent to Discovery Meadow Park, key transit hubs, restaurants and entertainment centers. The site has very good connectivity and strong business demand thus extremely feasible as a Class-A office tower. |                  |                       |
| Project start date  | September 2026                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Project end date | November 2027         |
| Project manager     | Nazym                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Project Sponsor  | Nazarbayev University |

|                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |  |  |
|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|--|
|                      | Turkebay                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |  |  |
| Purpose              | <p>The Dream Construction Business Center 12 story is planned to be constructed to offer modern, Class -A office and retail space within the downtown San Jose environment. It is targeted to appeal to technology companies, professional services, and retailers who need a central and transit-friendly location that offers high-quality services. The project is to spur local economic development by attracting new jobs in the construction process and long-term jobs as well as providing sustainable, energy-efficient building to improve the vision of a liveliest mixed-use urban core in San Jose.</p>                                                                                                                                                                            |  |  |
| Project scope        | <ul style="list-style-type: none"> <li>• The proposed project entails the construction of a 12 story commercial high-rise business centre that will have ground floor business retail areas, a single basement level and organized parking area of about 250 vehicles.</li> <li>• Develop a rooftop garden and landscaped open areas to avail open-air space in terms of meeting and relaxation to tenants and visitors.</li> <li>• Provide quality Class-A office suites to technology companies and professional services in need of a central downtown location at San Jose.</li> <li>• Fully adhere to zoning regulations of the City of San Jose, California Building Standards Code, and sustainability standards with the use of energy-saving systems and recycling programs.</li> </ul> |  |  |
| Project deliverables | <ol style="list-style-type: none"> <li>1. A 12 storey high rise business centre with Class-A office space and retail outlets on the ground floor.</li> <li>2. A basement that is one-storey and has a well organized parking space of about 250 cars.</li> <li>3. An open air garden and lawned areas on the roof to be used by tenants and visitors.</li> <li>4. Code compliant and energy efficient construction that satisfy California Building Standards and sustainability.</li> </ol>                                                                                                                                                                                                                                                                                                     |  |  |

|                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |          |             |
|--------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|-------------|
| Risk and issues          | <ol style="list-style-type: none"> <li>1. Cost escalation due to market fluctuations in materials, labor, or financing.</li> <li>2. Environmental and seismic regulations that may require design changes or additional mitigation measures.</li> <li>3. Community opposition or stakeholder concerns related to traffic, noise, or neighborhood impact.</li> <li>4. Permitting and construction delays caused by complex approvals, inspections, or unforeseen site conditions.</li> </ol>                                                                                                                                                                                                                                  |          |             |
| Assumptions/dependencies | <ul style="list-style-type: none"> <li>• The site at 447 S Almaden Blvd is fully available and free of legal disputes before construction begins.</li> <li>• All permits, zoning changes, and CEQA environmental approvals will be secured on schedule.</li> <li>• Adequate financing will remain in place for the full duration of the project.</li> <li>• Key materials (steel, concrete, façade systems) and skilled labor will be available at expected market rates.</li> <li>• Utility companies (power, water, sewer, telecom) will complete required connections in line with the project schedule.</li> <li>• Weather conditions in San Jose will not cause extended delays beyond normal contingencies.</li> </ul> |          |             |
| Estimated budget         | \$ 90,138,250                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |          |             |
| Milestones               | Stage                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Deadline | Status      |
|                          | Project Planning                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 19/02/26 | In progress |
|                          | Site preparation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 21/08/26 | Not started |

|  |                   |          |             |
|--|-------------------|----------|-------------|
|  | Construction      | 31/05/27 | Not started |
|  | MEP Systems       | 08/07/27 | Not started |
|  | Interior Finishes | 14/08/27 | Not started |
|  | Exterior Works    | 09/09/27 | Not started |
|  | Close-Out         | 14/10/27 | Not started |

## 6.2. Feasibility study

Feasibility assessment of the 12-story Dream Construction Business Center at 447 S Almaden Boulevard, San Jose, California has been assessed. The research examines the site conditions, design of buildings, the environment, legal considerations, economic considerations and the project timelines in all the phases.

### *Site Analysis*

It is located in downtown San Jose and is close to Discovery Meadow Park, restaurants and major transport centers. The site size is large such that it could accommodate a tower of 12 stories with a one-story basement, retail stores on the ground floor, and underground parking that can accommodate approximately 250 vehicles. The site has free-flowing traffic and secure pedestrian passages and access to freeways and public transportations.

### *Design and Development*

The idea, which is designed in Revit, utilizes reinforced-concrete core and steel framing to make the building strong in a highly seismic area. It offers flexible floors in offices, energy saving glazing, and a rooftop green garden. This building is designed in

accordance with California Building Standards Code and the zoning laws of the City of San Jose. The sustainability characteristics in terms of LED lighting, low-impact materials, and effective HVAC systems will be developed to achieve LEED certification criteria.

#### *Environmental Review*

According to geotechnical studies, the soil is safe to bear a high-rise building with a basement. The project will be done in accordance with the California Environmental Quality Act (CEQA) with the seismic safety and flood control measures. Building wastes will be kept to the minimum and repurposed where necessary and the building that will be constructed will incorporate a water and energy saving system to make it have a reduced carbon footprint.

#### *Legal and Regulatory*

Construction will be done with all the necessary permits, zoning clearances and environmental approvals. The contracts with the contractors and suppliers will specify explicitly scope, quality standard and schedule. The legal control will also ensure that the laws of labor and safety are observed and insurance like builder risk and workers compensation will cover the unexpected problems.

### 6.3. Cost/benefit analysis - RS Means

Using RSMeans, a cost–benefit evaluation was carried out to calculate the cost of construction and assess the viability of the project. RSMeans data offers consistent cost data from the current market, making it possible to accurately estimate costs for materials, labor and equipment. It's findings are presented in tables below, which displays the estimated cost of construction, the anticipated revenues and the profitability measures.

Table 6.2. Construction Costs Breakdown

| Cost type             | Amount       |
|-----------------------|--------------|
| Land Acquisition Cost | \$28,587,000 |

|                         |              |
|-------------------------|--------------|
| Substructure            | \$9,185,000  |
| Shell                   | \$22,545,000 |
| Interiors               | \$10,855,000 |
| Services                | \$24,215,000 |
| Equipment & Furnishings | \$4,175,000  |
| Subtotal                | \$70,975,000 |
| Contractor Fees         | \$8,517,000  |
| Architectural Fees      | \$7,097,500  |
| Total Cost              | \$90,138,250 |

Table 6.3. Revenue Breakdown

| Cost Type                  | Rate (\$/SF/yr) | Sq Ft   | Amount (\$) |
|----------------------------|-----------------|---------|-------------|
| Commercial Area<br>Renting | 65.00           | 125,147 | 8,874,060   |
| Total Revenue (First Year) |                 |         | 8,874,060   |

Table 6.4. Net Profit Analysis for the first year

| Cost Type  | Amount (\$) |
|------------|-------------|
| Net Profit | -65,231,358 |

Table 6.5. Payback and Profitability Analysis

| Indicator                 | Value             |
|---------------------------|-------------------|
| Total Costs (Capex)       | \$90,138,250      |
| Annual Revenue (Gross)    | \$8,134,555       |
| Annual Operating Expenses | \$1,626,911 (20%) |
| Net Annual Income (NOI)   | \$6,507,644       |
| Payback Period            | 11.3 years        |
| Break-even Point          | From Year 12      |

The analysis shown above indicates that the project is appealing, since the benefits exceed the costs.

#### 6.4. Work Breakdown Structure

WBS is a significant component of our project management plan. It breaks down all the project work into distinct levels to ensure that all the projects stages are easy to comprehend and accomplish.

In the case of our Business Center Construction Project, the WBS is based on the approved project scope and it separates the entire job into major areas which include Project Planning, Site Preparation, Construction, MEP Systems, Interior Finishes, Landscaping and close-out.

All of the major sections are then divided into smaller tasks such as Feasibility study, excavation, foundation, superstructure, HVAC installation, interior finishing and final inspections.

WBS enables the team members and other stakeholders to view the interrelation of the activities. It is also applied to determine the costs, assess the risks, and plan the time required in each task.

As Figure 6.1 depicts, the entire WBS developed in Primavera P6 reflects in a visual manner all the levels of work involved in the Business Center project.

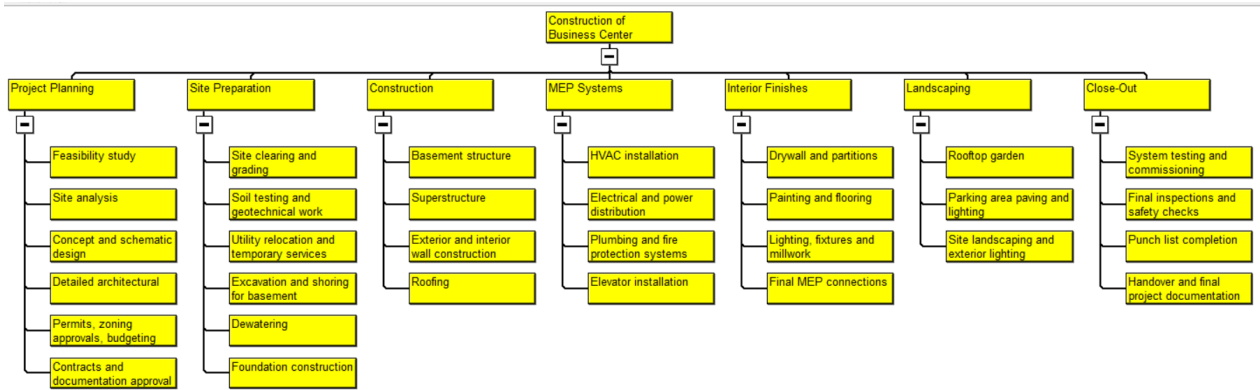


Figure 6.1. Work Breakdown Structure (Primavera P6).

## 6.5. Scheduling

The schedule for our Business Center project was developed with guidance from construction management. All tasks and timelines were entered and organized in Primavera P6, where the full Gantt chart shows the start and finish dates for every stage of the work.

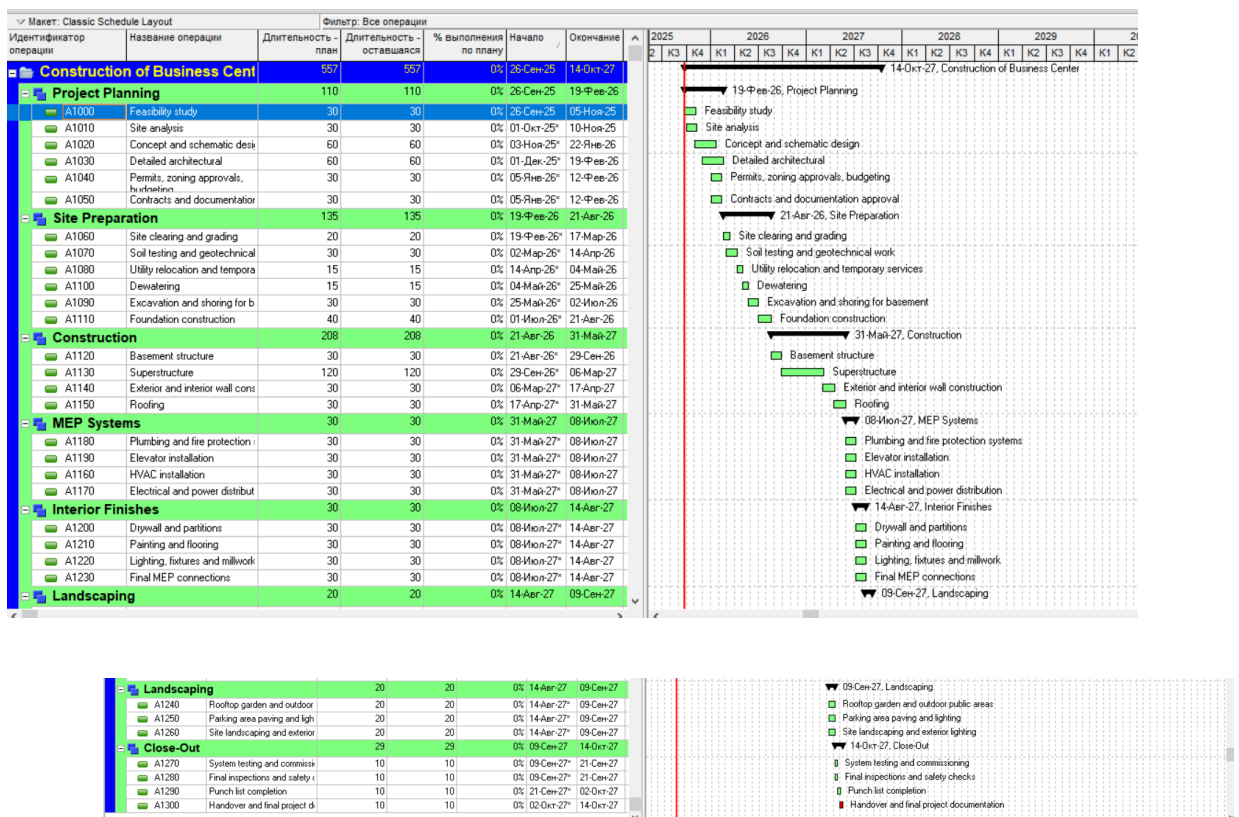


Figure 6.2. Gantt chart (Primavera P6).

## 6.6. Risk management

Risks may occur in any construction project in an unexpected manner and this is the reason why it is very important to identify and deal with risks early. Proper risk



management makes the development of the project a comfortable process and prevents the occurrence of critical issues that can be loss of money or time wastes.

The first stage is the identification of potential risks, getting to know what they are and determining how probable the risks are to occur. Risk management does not just involve foreseeing the issues, but involves planning as well to mitigate the issues.

The project team carefully researches on all possible issues and makes a decision based on clear analysis in order to manage these risks. Each risk is considered by taking all the key factors and the possibility of every risk to help make a decision, based on whether to insure against the risk or not, or whether to accept the risk or attempt to eliminate it entirely.

There are various categories of risks in our Construction of business center project as given in the table below. It contains a brief explanation of every risk, the probability of it occurring, the severity it might have, and our proposed measures in mitigating or avoiding it. These risks were determined through research on the local building regulations, safety standards and previous building projects related to our project.

Table 6.6. Risk Assessment Table

| <b>Risk Type</b>    | <b>Risk Description</b>                                                     | <b>Probability</b> | <b>Severity</b> | <b>Mitigation Strategy</b>                                                 |
|---------------------|-----------------------------------------------------------------------------|--------------------|-----------------|----------------------------------------------------------------------------|
| <b>Design Risks</b> | Errors in architectural or engineering drawings leading to rework or delays | Medium             | High            | Conduct detailed design reviews and peer checks before construction starts |
|                     | Late approvals                                                              | Medium             | Medium          | Engage early                                                               |

|                            |                                                             |        |        |                                                                                  |
|----------------------------|-------------------------------------------------------------|--------|--------|----------------------------------------------------------------------------------|
|                            | of design changes or materials                              |        |        | with regulators and speed up approval process                                    |
| <b>Financial Risks</b>     | Cost overruns from rising prices of labor and materials     | High   | High   | Set a contingency budget, monitor costs weekly, lock in fixed-price contracts    |
|                            | Inaccurate cost estimates causing funding gaps              | Medium | Medium | Use independent cost reviews and update estimates during each project phase      |
|                            | Slow payments or cash-flow issues from investors or lenders | Low    | Medium | Diversify funding sources and maintain reserve funds                             |
| <b>Environmental Risks</b> | Bad weather delaying critical tasks                         | Medium | Medium | Develop a weather-delay contingency plan and adjust the schedule in Primavera P6 |

|  |                                                         |        |        |                                                                       |
|--|---------------------------------------------------------|--------|--------|-----------------------------------------------------------------------|
|  | Unexpected soil contamination or underground hazards    | Low    | Medium | Perform early site assessments and arrange quick remediation if found |
|  | Noise or dust affecting nearby businesses and residents | Medium | Medium | Implement dust-control measures and communicate with the community    |

After identifying the risks, a risk management matrix was created. This tool helps evaluate the chance of each risk happening and the possible impact on the project. The figure below shows how the risks are grouped by severity levels: low, medium, and high. Most of the risks were rated as having a medium impact.

| <b>Probability \ Severity</b> | <b>Low</b>        | <b>Medium</b>                     | <b>High</b> |
|-------------------------------|-------------------|-----------------------------------|-------------|
| <b>High</b>                   |                   | <b>D2, D4, F2, F4, E1, E2, E3</b> | <b>F1</b>   |
| <b>Medium</b>                 |                   | <b>D1</b>                         |             |
| <b>Low</b>                    | <b>D3, F3, E3</b> |                                   |             |

Figure 6.3. Risk Management Matrix

## 6.7. Quality management

### 6.7.1 Quality Control Measures

The office building under construction in San Jose should be built according to the California Building Code (CBC). The principal building code applied in California is the CBC. It is founded on the International Building Code, yet contains some extra regulations that are California specific such as earthquake and fire safety.

San Jose is also in an area that is highly active seismically since it is near the major fault lines. Due to this fact, the building will have to be designed as per seismic requirements as stipulated in ASCE 7, embraced by the CBC. Depending on the seismic hazards of the location and the height of the building, the building would most probably be classified as a Seismic Design Category D or E. This implies that the building will have to contain special seismic detailing in order to withstand the strong forces of earthquakes.

The structure system (reinforced concrete) should be built according to the ACI 318. This standard gives specifications in concrete strength, reinforcement details, ductility, anchorage, and safety of structure. Special reinforcement detailing on moment frames or shear walls is specified in ACI 318 in high seismic areas such as San Jose to make sure that the building is capable of absorbing and dissipating the energy produced by earthquakes without collapsing abruptly.

CBC Chapter 17 also requires special inspections due to the fact that this project is a multi-story building. The specified inspections have to be conducted by certified special inspectors that are approved by a local Authority Having Jurisdiction (AHJ). Special tests involve inspection of the placement of reinforcement before pouring concrete, inspection of concrete placement and hardening, inspection of welding, inspection of the anchored bolt placement and inspection of fire proofing. Such inspections are required at high seismic areas and assist in ensuring that structural work is done as per approved drawings and specifications.

Moreover, when the building is in the category of a high-rise (that is, the occupied floor is in excess of 75 feet above the level of the fire department access), additional safety conditions should be adhered to within the CBC Chapter 4. The requirements involve the improved fire-resistance of the structural elements, the installation of automatic sprinkler systems, emergency power supply of elevators and fire pumps, smoke control systems, and fire command center. Such systems must enhance safety in life and enable evacuation during the event of emergency.

The project shall also be in conformance with California Green Building Standards Code (CALGreen). The center of this code is on the issues of environmental protection and sustainable practices in constructions. It entails good storm water management,

construction waste minimization, energy management and a water saving system. Adherence to the CALGreen would ensure the building meets the sustainability standards of the state of California.

Safety of workers during construction should be in accordance with the California Division Occupational Safety and Health laws. These standards guarantee that the workers are not exposed to risks like falling, use of heavy machinery and crane works that are frequent in the construction of high-rise buildings.

In general, the California Building Code, seismic design standards, special inspection requirements, fire safety regulations, and environment codes will control the 12-story office building so that it will reach the structural stability, earthquake resistance, fire safety, environmental performance, and durability in case of use. These compliance requirements are the basis of the quality management system of the project and it promotes safe and reliable performance of the building during its service life.

#### 6.7.2 Quality Control Checklist

The Quality Control Checklist presented in Table 6.4 is a list of items designed to meet requirements of standard, specifications and design drawings for all construction components. The checklist is designed to be used as a guide during field inspections, enabling engineers and supervisors to check the quality of materials, workmanship, and finished elements throughout the construction process. This checklist helps to detect and address issues at early stages, thereby minimising rework and ensuring quality of the project.

## Office Building Construction Quality Control Checklist

### Project Information

- **Project Name:** 12-Story High-Rise Office Building
- **Location:** San Jose, California, USA
- **Date of Inspection:** 10.04.26
- **Project Manager:** Nazym Turkebay

#### Inspection Team Members:

- Mariyam Zhaspenova
- Rakhat Abdikul

### Phase 1: Pre-Construction Checklist

#### Site Preparation

- ☐ Verify site clearing and removal of debris
- ☐ Confirm grading and leveling according to site plans
- ☐ Check erosion and sediment control measures
- ☐ Ensure access routes for construction equipment
- ☐ Verify site layout and survey accuracy

#### Foundation Works

- ☐ Confirm excavation depth and alignment as per drawings
- ☐ Verify soil conditions match geotechnical report
- ☐ Inspect reinforcement (size, spacing, concrete cover)
- ☐ Check formwork stability and dimensions
- ☐ Verify concrete mix, placement, and curing procedures

### Phase 2: Structural Construction

#### Framing and Structural Elements

- ☐ Verify columns, beams, and slabs installation
- ☐ Check reinforcement placement and anchorage
- ☐ Inspect formwork alignment and stability
- ☐ Confirm concrete quality (slump test, cube test)
- ☐ Ensure proper curing

#### Structural Stability

- ☐ Verify vertical and horizontal alignment
- ☐ Check structural connections and joints
- ☐ Confirm compliance with wind and seismic design
- ☐ Inspect lateral load-resisting system

#### Exterior and Roofing

- ☐ Inspect exterior walls and cladding installation
- ☐ Verify waterproofing systems
- ☐ Check roofing materials and drainage
- ☐ Ensure insulation is properly installed

### Phase 3: Interior and Finishing

#### Interior Installations

- ☐ Inspect partitions and drywall accuracy
- ☐ Verify mechanical, electrical, and plumbing (MEP) systems
- ☐ Check pipe routing and electrical wiring
- ☐ Confirm fire-stopping and soundproofing

#### Finishing Works

- ☐ Check plastering quality and uniformity
- ☐ Inspect flooring level and alignment
- ☐ Verify ceiling installation
- ☐ Inspect doors, windows, and fixtures
- ☐ Check painting quality

### Phase 4: Final Inspection

- ☐ Test all systems (HVAC, fire alarm, plumbing, electrical)
- ☐ Verify completion of punch list items
- ☐ Ensure building is cleaned and ready for handover
- ☐ Check safety compliance
- ☐ Obtain permits and occupancy certification

Figure 6.4. Quality control checklists

### 6.7.3 Quality metrics

The quality metrics provided in Figure 6.5 are used to measure the construction activities during the project. They offer tangible measures of quality, enabling ongoing analysis and evaluation of whether the project is being delivered according to the specified standards and criteria. By monitoring critical parameters like defect percentages, compliance rates and inspection outcomes, the team can detect deviations and take proactive measures to address them.

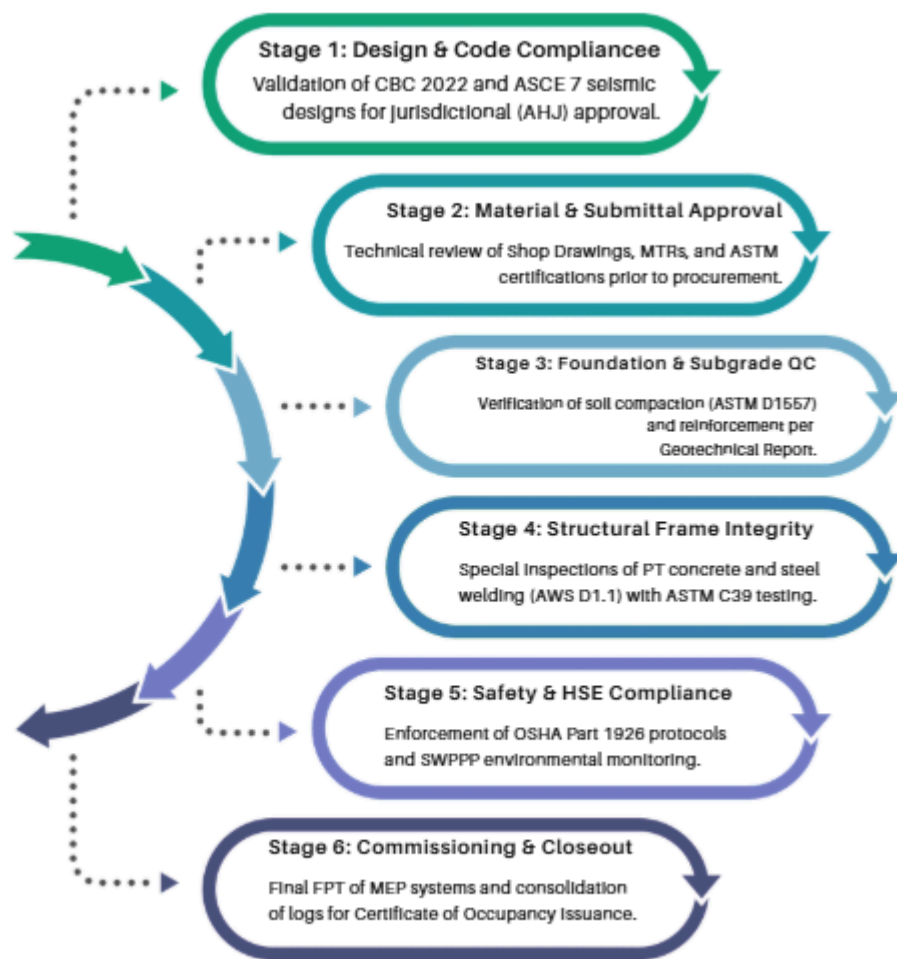


Figure 6.5. Quality metrics.

## 6.8. Procurement planning

Table 6.7 maps the main stakeholders in the project and their roles, interests and power. They are grouped as either internal or external stakeholders. The project sponsor, project manager, development team and support team are considered internal stakeholders as they are engaged in project planning, delivery and ongoing maintenance. External groups are end users, customers, suppliers and regulators who interact with or affect the project from outside the enterprise.

The table also shows the relative levels of influence of stakeholders. For example, the project sponsor, project manager, clients and end users are classified as high-influence stakeholders because of their decision-making status and influence on project delivery. The development team, support team and suppliers are considered medium-influence stakeholders, as they provide operational support, but do not have a strong decision -

making role. External, high-influence stakeholders include the regulatory bodies, who influence operations via regulatory compliance.

Table 6.7. Stakeholder list.

| Stakeholder                                           | Role in Project                         | Interest | Influence Level |
|-------------------------------------------------------|-----------------------------------------|----------|-----------------|
| Project Owner                                         | Provides funding and defines objectives | High     | High            |
| Project Manager                                       | Manages schedule, cost, and quality     | High     | High            |
| General Contractor                                    | Executes construction works             | High     | High            |
| Structural Engineer                                   | Designs structural system               | High     | Medium          |
| Architect                                             | Designs layout and facade               | High     | Medium          |
| MEP Engineer                                          | Designs building systems                | High     | Medium          |
| Suppliers                                             | Provide materials and equipment         | Medium   | Medium          |
| Subcontractors                                        | Perform specialized works               | High     | Medium          |
| Special Inspectors                                    | Verify compliance (CBC Chapter 17)      | High     | Medium          |
| Local Authority (City Building Department)            | Approves permits and inspections        | High     | High            |
| California Division of Occupational Safety and Health | Enforces worker safety regulations      | High     | Medium          |



|                       |                                 |        |     |
|-----------------------|---------------------------------|--------|-----|
| Community / Neighbors | Affected by construction impact | Medium | Low |
|-----------------------|---------------------------------|--------|-----|

The hierarchy of project stakeholders and the lines of responsibility and communication are shown in Figure 6.6. The project sponsor is at the highest level, setting the vision and financial resources. The project coordinator, who is responsible for project success, follows.

The development and support teams make up the operational level of the hierarchy, responsible for performing work tasks and keeping the system running. External stakeholders, such as clients, end users, and regulatory agencies, engage with the project in terms of defining requirements, using the system, providing feedback, and ensuring regulatory compliance. End users are integral in providing ongoing feedback, which enables the evolution of the system.

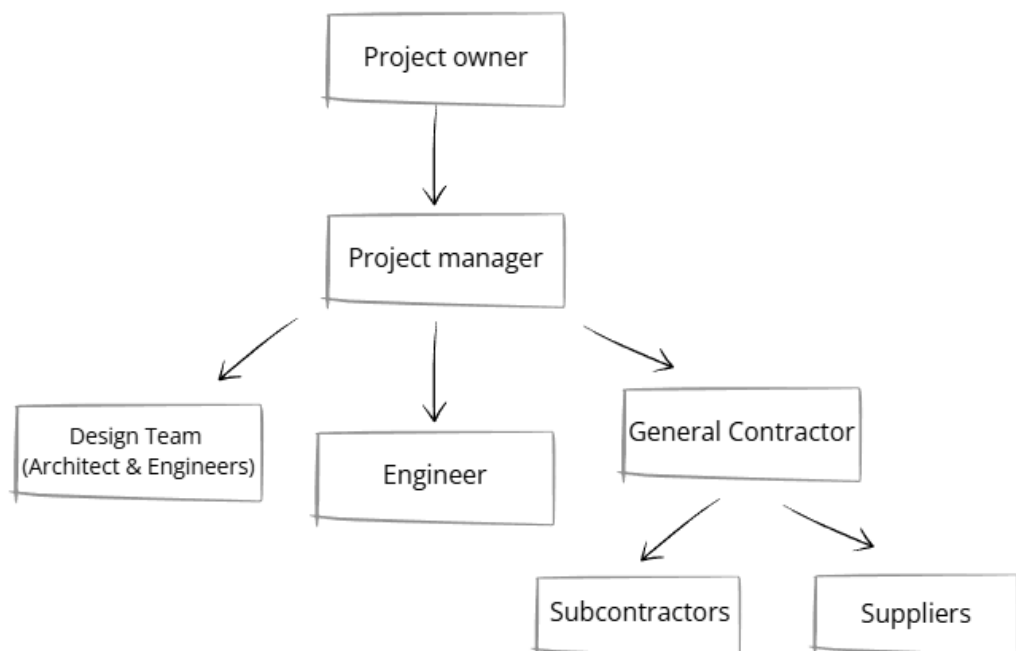


Figure 6.6. Stakeholders Hierarchy.

In summary, the hierarchy shows the flow of authority, communication and feedback between various groups of stakeholders, and how project goals align with stakeholder expectations.

## 6.9. Construction safety

This chapter focuses on the recognition and control of potential safety hazards in construction. This includes the identification and control of potential hazards to create a safe working environment during the entire project duration. Safe construction is an important aspect of project management and its focus is to prevent accidents, injuries and to comply with safety regulations and practices.

Table 6.8. Risk Identification

| <b>Risk Identification</b>     | <b>Likelihood<br/>(1–5)</b> | <b>Severity<br/>(1–5)</b> | <b>Risk<br/>Rating</b> | <b>Risk<br/>Level</b> |
|--------------------------------|-----------------------------|---------------------------|------------------------|-----------------------|
| Seismic Activity               | 5                           | 5                         | 25                     | Critical              |
| Foundation Instability         | 3                           | 4                         | 12                     | High                  |
| Material Supply Delays         | 4                           | 3                         | 12                     | High                  |
| Stormwater Drainage<br>Failure | 3                           | 3                         | 9                      | Medium                |
| Structural Integrity Issues    | 2                           | 5                         | 10                     | Medium                |
| Worker Safety Violations       | 4                           | 4                         | 16                     | High                  |
| Non-Compliance with<br>LEED    | 2                           | 2                         | 4                      | Low                   |
| Budget Overruns                | 3                           | 4                         | 12                     | High                  |
| Electrical System Failures     | 3                           | 3                         | 9                      | Medium                |
| Noise Pollution                | 3                           | 2                         | 6                      | Low                   |
| Environmental Impact           | 3                           | 3                         | 9                      | Medium                |
| Delays in Permit<br>Approvals  | 4                           | 2                         | 8                      | Medium                |

Table 6.8 presents the major risks involved in the construction phase of the project. These involve risks associated with site management, equipment, environmental factors, and human aspects. Each risk is evaluated in terms of probability and consequence to project goals, safety and schedule.

The aim of this risk identification is to capture all potential hazards during the project's early stages. This enables the establishment of mitigation measures and minimises the likelihood of accidents and disruptions. The table is intended as a basis for determining risk management and safety plans during construction operations.

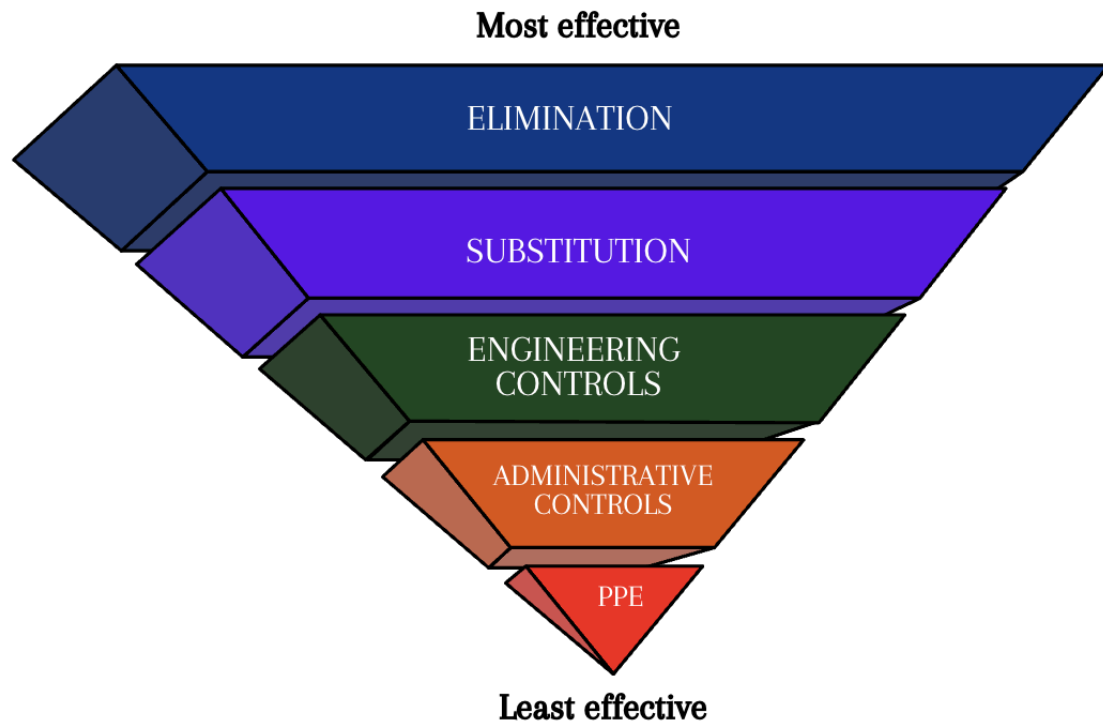


Figure 6.7 Hierarchy of Controls

The Hierarchy of Controls, shown in Figure 6.7, is a method of managing risks in the workplace. The table ranks control measures from most to least effective.

The first control measure is elimination, or removing the hazard. Substitution involves substituting a process or material with a less hazardous one. The third level is engineering controls, which isolate people from hazards through physical design measures. This is followed by administrative controls, such as policies, procedures, training and work practices. The least effective is personal protective equipment (PPE), which offer complete protection for the worker.

This hierarchy follows the principle of hazard control that allows hazards to be managed in the most effective way possible, while looking beyond the use of personal protective equipment as an immediate solution.

#### 6.10. Construction site planning

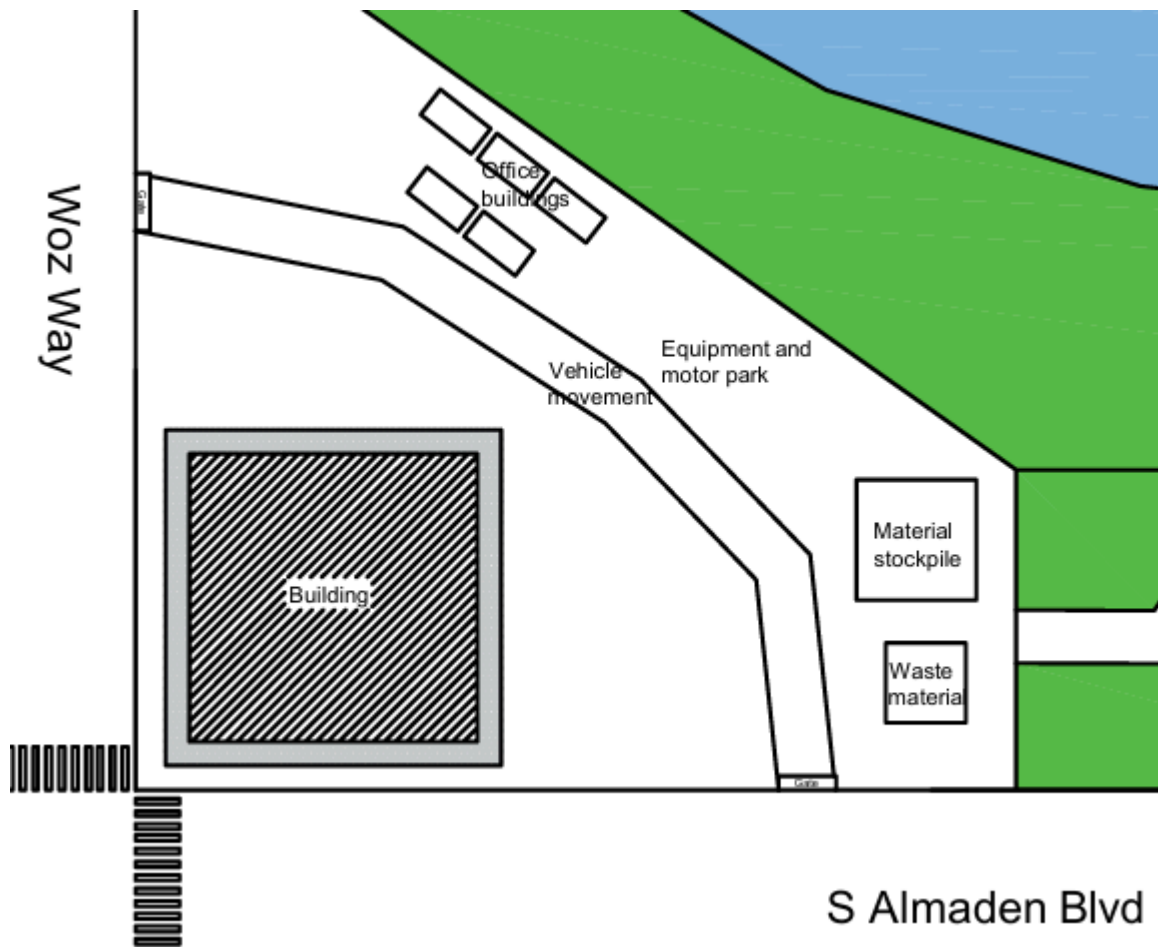


Figure 6.8 Construction site plan.

The site plan (Figure 6.8) shows the construction site layout, outlining the project's site and placement of site elements. It depicts the arrangement of buildings, access and egress points, storage spaces, machinery placement and work zones on site.

The site plan plays a crucial role in site logistics, safety of personnel and equipment movement, and optimisation of space. It identifies entrance and exit routes, safety passages and segregation zones to distinguish between high-risk and safer zones on the construction site. It also facilitates communication and coordination between work teams by delineating work zones and storage zones.

In conclusion, the construction site plan provides a crucial basis for project planning, execution and safety, reducing potential site clashes and enhancing coordination of work processes during construction activities.

## References

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## Appendix

Table 7.1. Final bars for interior beams

| Floor               | Variables        | End          | Mid          | End          |
|---------------------|------------------|--------------|--------------|--------------|
| 1                   | Compression Bars | 5#6          | 2#6          | 5#6          |
|                     | Tension Bars     | 2#7          | 2#7          | 2#7          |
| 2                   | Compression Bars | 6#7          | 2#7          | 6#7          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 3                   | Compression Bars | 6#7          | 2#7          | 6#7          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 4                   | Compression Bars | 6#7          | 2#7          | 6#7          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 5                   | Compression Bars | 6#7          | 2#7          | 6#7          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 6                   | Compression Bars | 6#7          | 2#7          | 6#7          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 7                   | Compression Bars | 6#7          | 2#7          | 6#7          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 8                   | Compression Bars | 6#7          | 2#7          | 6#7          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 9                   | Compression Bars | 5#7          | 2#7          | 5#7          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 10                  | Compression Bars | 6#6          | 2#6          | 6#6          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 11                  | Compression Bars | 6#6          | 2#6          | 6#6          |
|                     | Tension Bars     | 2#7          | 2#7          | 2#7          |
| 12                  | Compression Bars | 6#6          | 2#6          | 6#6          |
|                     | Tension Bars     | 2#7          | 2#7          | 2#7          |
| Shear Reinforcement |                  | #3 at 130 mm | #3 at 150 mm | #3 at 130 mm |

Table 7.2. Final bars for exterior beams on the first span

| Floor | Variables        | End | Mid | End |
|-------|------------------|-----|-----|-----|
| 1     | Compression Bars | 5#6 | 2#6 | 5#6 |
|       | Tension Bars     | 2#7 | 2#7 | 2#7 |
| 2     | Compression Bars | 5#7 | 2#7 | 5#7 |
|       | Tension Bars     | 3#7 | 2#7 | 3#7 |
| 3     | Compression Bars | 6#7 | 2#7 | 6#7 |
|       | Tension Bars     | 3#7 | 2#7 | 3#7 |
| 4     | Compression Bars | 6#7 | 2#7 | 6#7 |
|       | Tension Bars     | 3#7 | 2#7 | 3#7 |
| 5     | Compression Bars | 5#7 | 2#7 | 5#7 |
|       | Tension Bars     | 3#7 | 2#7 | 3#7 |
| 6     | Compression Bars | 5#7 | 2#7 | 5#7 |

|                     |                  |              |              |              |
|---------------------|------------------|--------------|--------------|--------------|
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 7                   | Compression Bars | 5#7          | 2#7          | 5#7          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 8                   | Compression Bars | 5#7          | 2#7          | 5#7          |
|                     | Tension Bars     | 2#7          | 2#7          | 2#7          |
| 9                   | Compression Bars | 4#7          | 2#7          | 4#7          |
|                     | Tension Bars     | 2#7          | 2#7          | 2#7          |
| 10                  | Compression Bars | 5#6          | 2#6          | 5#6          |
|                     | Tension Bars     | 2#7          | 2#7          | 2#7          |
| 11                  | Compression Bars | 5#6          | 2#6          | 5#6          |
|                     | Tension Bars     | 2#7          | 2#7          | 2#7          |
| 12                  | Compression Bars | 5#6          | 2#6          | 5#6          |
|                     | Tension Bars     | 2#7          | 3#7          | 2#7          |
| Shear Reinforcement |                  | #3 at 130 mm | #3 at 150 mm | #3 at 130 mm |

Table 7.3. Final bars for exterior beams on the last span

| Floor               | Variables        | End          | Mid          | End          |
|---------------------|------------------|--------------|--------------|--------------|
| 1                   | Compression Bars | 6#6          | 2#6          | 6#6          |
|                     | Tension Bars     | 2#7          | 2#7          | 2#7          |
| 2                   | Compression Bars | 7#7          | 2#7          | 7#7          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 3                   | Compression Bars | 7#7          | 2#7          | 7#7          |
|                     | Tension Bars     | 4#7          | 2#7          | 4#7          |
| 4                   | Compression Bars | 7#7          | 2#7          | 7#7          |
|                     | Tension Bars     | 4#7          | 2#7          | 4#7          |
| 5                   | Compression Bars | 7#7          | 2#7          | 7#7          |
|                     | Tension Bars     | 4#7          | 2#7          | 4#7          |
| 6                   | Compression Bars | 7#7          | 2#7          | 7#7          |
|                     | Tension Bars     | 4#7          | 2#7          | 4#7          |
| 7                   | Compression Bars | 7#7          | 2#7          | 7#7          |
|                     | Tension Bars     | 4#7          | 2#7          | 4#7          |
| 8                   | Compression Bars | 7#7          | 2#7          | 7#7          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 9                   | Compression Bars | 6#7          | 2#7          | 6#7          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 10                  | Compression Bars | 8#6          | 3#6          | 8#6          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 11                  | Compression Bars | 7#6          | 3#6          | 7#6          |
|                     | Tension Bars     | 3#7          | 2#7          | 3#7          |
| 12                  | Compression Bars | 6#6          | 2#6          | 6#6          |
|                     | Tension Bars     | 2#7          | 2#7          | 2#7          |
| Shear Reinforcement |                  | #3 at 130 mm | #3 at 150 mm | #3 at 130 mm |

Table 7.4. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 1, location 6 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 1264                    | 1253                     | 5#6      | 1420                      | 0.88                   | 617                     | 611                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 1387                    | 1374                     | 5#6      | 1420                      | 0.88                   | 675                     | 668                      | 2#7      | 774                       | 0.48                   |
| 3                                    | 1389                    | 1374                     | 5#6      | 1420                      | 0.88                   | 675                     | 668                      | 2#7      | 774                       | 0.48                   |
| 4                                    | 1389                    | 1374                     | 5#6      | 1420                      | 0.88                   | 675                     | 668                      | 2#7      | 774                       | 0.48                   |
| 5                                    | 1385                    | 1373                     | 5#6      | 1420                      | 0.88                   | 673                     | 668                      | 2#7      | 774                       | 0.48                   |
| 6                                    | 1500                    | 1485                     | 6#6      | 1704                      | 1.06                   | 727                     | 720                      | 2#7      | 774                       | 0.48                   |

Table 7.5. Major Beam bar design for Floor 1, location 3 m

| Major Beam for Floor 1, location 3 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 406                     | 395                      | 2#6      | 568                       | 0.35                   | 617                     | 600                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 444                     | 429                      | 2#6      | 568                       | 0.35                   | 617                     | 580                      | 2#7      | 774                       | 0.48                   |
| 3                                    | 444                     | 429                      | 2#6      | 568                       | 0.35                   | 617                     | 580                      | 2#7      | 774                       | 0.48                   |
| 4                                    | 444                     | 429                      | 2#6      | 568                       | 0.35                   | 617                     | 580                      | 2#7      | 774                       | 0.48                   |
| 5                                    | 443                     | 429                      | 2#6      | 568                       | 0.35                   | 617                     | 585                      | 2#7      | 774                       | 0.48                   |
| 6                                    | 478                     | 462                      | 2#6      | 568                       | 0.35                   | 617                     | 595                      | 2#7      | 774                       | 0.48                   |

Table 7.6. Major Beam bar design for Floor 1, location 0 m

| Major Beam for Floor 1, location 0 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 708                     | 704                      | 5#6      | 1420                      | 0.88                   | 466                     | 345                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 629                     | 627                      | 5#6      | 1420                      | 0.88                   | 415                     | 309                      | 2#7      | 774                       | 0.48                   |
| 3                                    | 632                     | 627                      | 5#6      | 1420                      | 0.88                   | 417                     | 309                      | 2#7      | 774                       | 0.48                   |
| 4                                    | 632                     | 627                      | 5#6      | 1420                      | 0.88                   | 416                     | 309                      | 2#7      | 774                       | 0.48                   |
| 5                                    | 631                     | 627                      | 5#6      | 1420                      | 0.88                   | 416                     | 309                      | 2#7      | 774                       | 0.48                   |
| 6                                    | 617                     | 498                      | 6#6      | 1704                      | 1.06                   | 332                     | 249                      | 2#7      | 774                       | 0.48                   |

Table 7.7. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 2, location 6 m |  |  |  |  |  |  |  |  |  |  |
|--------------------------------------|--|--|--|--|--|--|--|--|--|--|
|--------------------------------------|--|--|--|--|--|--|--|--|--|--|



| Beam # | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|--------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
|        | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1      | 1913                    | 1892                     | 5#7      | 1935                      | 1.20                   | 919                     | 909                      | 3#7      | 1161                      | 0.72                   |
| 2      | 2088                    | 2067                     | 6#7      | 2322                      | 1.44                   | 999                     | 989                      | 3#7      | 1161                      | 0.72                   |
| 3      | 2092                    | 2067                     | 6#7      | 2322                      | 1.44                   | 1002                    | 989                      | 3#7      | 1161                      | 0.72                   |
| 4      | 2092                    | 2067                     | 6#7      | 2322                      | 1.44                   | 1002                    | 989                      | 3#7      | 1161                      | 0.72                   |
| 5      | 2089                    | 2067                     | 6#7      | 2322                      | 1.44                   | 1000                    | 989                      | 3#7      | 1161                      | 0.72                   |
| 6      | 2360                    | 2340                     | 7#7      | 2709                      | 1.68                   | 1132                    | 1112                     | 3#7      | 1161                      | 0.72                   |

Table 7.8. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 2, location 3 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 602                     | 581                      | 2#7      | 774                       | 0.48                   | 617                     | 601                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 617                     | 594                      | 2#7      | 774                       | 0.48                   | 617                     | 570                      | 2#7      | 774                       | 0.48                   |
| 3                                    | 617                     | 594                      | 2#7      | 774                       | 0.48                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |
| 4                                    | 617                     | 594                      | 2#7      | 774                       | 0.48                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |
| 5                                    | 617                     | 594                      | 2#7      | 774                       | 0.48                   | 617                     | 570                      | 2#7      | 774                       | 0.48                   |
| 6                                    | 617                     | 615                      | 2#7      | 774                       | 0.48                   | 617                     | 554                      | 2#7      | 774                       | 0.48                   |

Table 7.9. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 2, location 0 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 156                     | 123                      | 5#7      | 1935                      | 1.20                   | 153                     | 117                      | 3#7      | 1161                      | 0.72                   |
| 2                                    | 159                     | 141                      | 6#7      | 2322                      | 1.44                   | 177                     | 132                      | 3#7      | 1161                      | 0.72                   |
| 3                                    | 177                     | 150                      | 6#7      | 2322                      | 1.44                   | 168                     | 120                      | 3#7      | 1161                      | 0.72                   |
| 4                                    | 195                     | 156                      | 6#7      | 2322                      | 1.44                   | 165                     | 120                      | 3#7      | 1161                      | 0.72                   |
| 5                                    | 168                     | 132                      | 6#7      | 2322                      | 1.44                   | 186                     | 132                      | 3#7      | 1161                      | 0.72                   |
| 6                                    | 162                     | 135                      | 7#7      | 2709                      | 1.68                   | 222                     | 166                      | 3#7      | 1161                      | 0.72                   |

Table 7.10. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 3, location 6 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 2001                    | 1985                     | 6#7      | 2322                      | 1.44                   | 960                     | 951                      | 3#7      | 1161                      | 0.72                   |
| 2                                    | 2241                    | 2220                     | 6#7      | 2322                      | 1.44                   | 1069                    | 1058                     | 3#7      | 1161                      | 0.72                   |
| 3                                    | 2249                    | 2220                     | 6#7      | 2322                      | 1.44                   | 1072                    | 1058                     | 3#7      | 1161                      | 0.72                   |
| 4                                    | 2247                    | 2220                     | 6#7      | 2322                      | 1.44                   | 1072                    | 1058                     | 3#7      | 1161                      | 0.72                   |
| 5                                    | 2244                    | 2220                     | 6#7      | 2322                      | 1.44                   | 1070                    | 1058                     | 3#7      | 1161                      | 0.72                   |
| 6                                    | 2558                    | 2534                     | 7#7      | 2709                      | 1.68                   | 1211                    | 1199                     | 4#7      | 1548                      | 0.96                   |

Table 7.11. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 3, location 3 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 617                     | 560                      | 2#7      | 774                       | 0.48                   | 617                     | 611                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 617                     | 591                      | 2#7      | 774                       | 0.48                   | 617                     | 570                      | 2#7      | 774                       | 0.48                   |
| 3                                    | 617                     | 591                      | 2#7      | 774                       | 0.48                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |
| 4                                    | 617                     | 591                      | 2#7      | 774                       | 0.48                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |
| 5                                    | 617                     | 591                      | 2#7      | 774                       | 0.48                   | 617                     | 570                      | 2#7      | 774                       | 0.48                   |
| 6                                    | 617                     | 613                      | 2#7      | 774                       | 0.48                   | 617                     | 585                      | 2#7      | 774                       | 0.48                   |

Table 7.12. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 3, location 0 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 171                     | 156                      | 6#7      | 2322                      | 1.44                   | 192                     | 147                      | 3#7      | 1161                      | 0.72                   |
| 2                                    | 162                     | 150                      | 6#7      | 2322                      | 1.44                   | 235                     | 174                      | 3#7      | 1161                      | 0.72                   |
| 3                                    | 156                     | 126                      | 6#7      | 2322                      | 1.44                   | 232                     | 174                      | 3#7      | 1161                      | 0.72                   |
| 4                                    | 177                     | 147                      | 6#7      | 2322                      | 1.44                   | 231                     | 174                      | 3#7      | 1161                      | 0.72                   |
| 5                                    | 183                     | 171                      | 6#7      | 2322                      | 1.44                   | 240                     | 179                      | 3#7      | 1161                      | 0.72                   |
| 6                                    | 162                     | 135                      | 7#7      | 2709                      | 1.68                   | 279                     | 208                      | 4#7      | 1548                      | 0.96                   |

Table 7.13. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 4, location 6 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 1943                    | 1927                     | 6#7      | 2322                      | 1.44                   | 933                     | 925                      | 3#7      | 1161                      | 0.72                   |
| 2                                    | 2255                    | 2238                     | 6#7      | 2322                      | 1.44                   | 1075                    | 1064                     | 3#7      | 1161                      | 0.72                   |
| 3                                    | 2266                    | 2250                     | 6#7      | 2322                      | 1.44                   | 1080                    | 1069                     | 3#7      | 1161                      | 0.72                   |
| 4                                    | 2263                    | 2250                     | 6#7      | 2322                      | 1.44                   | 1079                    | 1069                     | 3#7      | 1161                      | 0.72                   |
| 5                                    | 2265                    | 2250                     | 6#7      | 2322                      | 1.44                   | 1080                    | 1069                     | 3#7      | 1161                      | 0.72                   |
| 6                                    | 2626                    | 2596                     | 7#7      | 2709                      | 1.68                   | 1241                    | 1226                     | 4#7      | 1548                      | 0.96                   |

Table 7.14. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 4, location 3 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 611                     | 548                      | 2#7      | 774                       | 0.48                   | 611                     | 606                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 617                     | 591                      | 2#7      | 774                       | 0.48                   | 617                     | 569                      | 2#7      | 774                       | 0.48                   |
| 3                                    | 617                     | 597                      | 2#7      | 774                       | 0.48                   | 617                     | 564                      | 2#7      | 774                       | 0.48                   |
| 4                                    | 617                     | 597                      | 2#7      | 774                       | 0.48                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |
| 5                                    | 617                     | 597                      | 2#7      | 774                       | 0.48                   | 617                     | 570                      | 2#7      | 774                       | 0.48                   |
| 6                                    | 617                     | 615                      | 2#7      | 774                       | 0.48                   | 617                     | 597                      | 2#7      | 774                       | 0.48                   |

Table 7.15. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 4, location 0 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 186                     | 168                      | 6#7      | 2322                      | 1.44                   | 211                     | 153                      | 3#7      | 1161                      | 0.72                   |
| 2                                    | 168                     | 156                      | 6#7      | 2322                      | 1.44                   | 255                     | 188                      | 3#7      | 1161                      | 0.72                   |
| 3                                    | 180                     | 144                      | 6#7      | 2322                      | 1.44                   | 251                     | 188                      | 3#7      | 1161                      | 0.72                   |
| 4                                    | 153                     | 123                      | 6#7      | 2322                      | 1.44                   | 249                     | 183                      | 3#7      | 1161                      | 0.72                   |
| 5                                    | 201                     | 168                      | 6#7      | 2322                      | 1.44                   | 265                     | 200                      | 3#7      | 1161                      | 0.72                   |
| 6                                    | 198                     | 159                      | 7#7      | 2709                      | 1.68                   | 308                     | 234                      | 4#7      | 1548                      | 0.96                   |

Table 7.16. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 5, location 6 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 1873                    | 1858                     | 5#7      | 1935                      | 1.20                   | 901                     | 893                      | 3#7      | 1161                      | 0.72                   |
| 2                                    | 2219                    | 2203                     | 6#7      | 2322                      | 1.44                   | 1059                    | 1053                     | 3#7      | 1161                      | 0.72                   |
| 3                                    | 2230                    | 2208                     | 6#7      | 2322                      | 1.44                   | 1064                    | 1053                     | 3#7      | 1161                      | 0.72                   |
| 4                                    | 2227                    | 2208                     | 6#7      | 2322                      | 1.44                   | 1063                    | 1053                     | 3#7      | 1161                      | 0.72                   |
| 5                                    | 2225                    | 2208                     | 6#7      | 2322                      | 1.44                   | 1062                    | 1053                     | 3#7      | 1161                      | 0.72                   |
| 6                                    | 2625                    | 2602                     | 7#7      | 2709                      | 1.68                   | 1241                    | 1226                     | 4#7      | 1548                      | 0.96                   |

Table 7.17. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 5, location 3 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 590                     | 529                      | 2#7      | 774                       | 0.48                   | 617                     | 616                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 617                     | 589                      | 2#7      | 774                       | 0.48                   | 617                     | 575                      | 2#7      | 774                       | 0.48                   |
| 3                                    | 617                     | 591                      | 2#7      | 774                       | 0.48                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |
| 4                                    | 617                     | 591                      | 2#7      | 774                       | 0.48                   | 617                     | 570                      | 2#7      | 774                       | 0.48                   |
| 5                                    | 617                     | 591                      | 2#7      | 774                       | 0.48                   | 617                     | 575                      | 2#7      | 774                       | 0.48                   |
| 6                                    | 617                     | 618                      | 2#7      | 774                       | 0.48                   | 617                     | 601                      | 2#7      | 774                       | 0.48                   |

Table 7.18. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 5, location 0 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 204                     | 147                      | 5#7      | 1935                      | 1.20                   | 170                     | 125                      | 3#7      | 1161                      | 0.72                   |
| 2                                    | 165                     | 153                      | 6#7      | 2322                      | 1.44                   | 220                     | 164                      | 3#7      | 1161                      | 0.72                   |
| 3                                    | 180                     | 144                      | 6#7      | 2322                      | 1.44                   | 212                     | 159                      | 3#7      | 1161                      | 0.72                   |
| 4                                    | 195                     | 177                      | 6#7      | 2322                      | 1.44                   | 209                     | 159                      | 3#7      | 1161                      | 0.72                   |
| 5                                    | 147                     | 129                      | 6#7      | 2322                      | 1.44                   | 226                     | 169                      | 3#7      | 1161                      | 0.72                   |
| 6                                    | 201                     | 183                      | 7#7      | 2709                      | 1.68                   | 294                     | 234                      | 4#7      | 1548                      | 0.96                   |

Table 7.19. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 6, location 6 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 1778                    | 1761                     | 5#7      | 1935                      | 1.20                   | 857                     | 846                      | 3#7      | 1161                      | 0.72                   |
| 2                                    | 2151                    | 2132                     | 6#7      | 2322                      | 1.44                   | 1028                    | 1015                     | 3#7      | 1161                      | 0.72                   |
| 3                                    | 2162                    | 2143                     | 6#7      | 2322                      | 1.44                   | 1033                    | 1021                     | 3#7      | 1161                      | 0.72                   |
| 4                                    | 2159                    | 2137                     | 6#7      | 2322                      | 1.44                   | 1032                    | 1021                     | 3#7      | 1161                      | 0.72                   |
| 5                                    | 2150                    | 2132                     | 6#7      | 2322                      | 1.44                   | 1027                    | 1015                     | 3#7      | 1161                      | 0.72                   |
| 6                                    | 2585                    | 2565                     | 7#7      | 2709                      | 1.68                   | 1223                    | 1210                     | 4#7      | 1548                      | 0.96                   |

Table 7.20. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 6, location 3 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 562                     | 499                      | 2#7      | 774                       | 0.48                   | 632                     | 627                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 617                     | 568                      | 2#7      | 774                       | 0.48                   | 617                     | 575                      | 2#7      | 774                       | 0.48                   |
| 3                                    | 617                     | 573                      | 2#7      | 774                       | 0.48                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |
| 4                                    | 617                     | 573                      | 2#7      | 774                       | 0.48                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |
| 5                                    | 617                     | 568                      | 2#7      | 774                       | 0.48                   | 617                     | 575                      | 2#7      | 774                       | 0.48                   |
| 6                                    | 617                     | 608                      | 2#7      | 774                       | 0.48                   | 617                     | 590                      | 2#7      | 774                       | 0.48                   |

Table 7.21. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 6, location 0 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 294                     | 218                      | 5#7      | 1935                      | 1.20                   | 146                     | 110                      | 3#7      | 1161                      | 0.72                   |
| 2                                    | 192                     | 171                      | 6#7      | 2322                      | 1.44                   | 300                     | 228                      | 3#7      | 1161                      | 0.72                   |
| 3                                    | 198                     | 165                      | 6#7      | 2322                      | 1.44                   | 272                     | 198                      | 3#7      | 1161                      | 0.72                   |
| 4                                    | 174                     | 150                      | 6#7      | 2322                      | 1.44                   | 264                     | 198                      | 3#7      | 1161                      | 0.72                   |
| 5                                    | 177                     | 168                      | 6#7      | 2322                      | 1.44                   | 298                     | 218                      | 3#7      | 1161                      | 0.72                   |
| 6                                    | 180                     | 162                      | 7#7      | 2709                      | 1.68                   | 306                     | 227                      | 4#7      | 1548                      | 0.96                   |

Table 7.22. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 7, location 6 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 1637                    | 1625                     | 5#7      | 1935                      | 1.20                   | 791                     | 782                      | 3#7      | 1161                      | 0.72                   |
| 2                                    | 2081                    | 2061                     | 6#7      | 2322                      | 1.44                   | 996                     | 983                      | 3#7      | 1161                      | 0.72                   |
| 3                                    | 2093                    | 2073                     | 6#7      | 2322                      | 1.44                   | 1002                    | 989                      | 3#7      | 1161                      | 0.72                   |
| 4                                    | 2088                    | 2073                     | 6#7      | 2322                      | 1.44                   | 1000                    | 989                      | 3#7      | 1161                      | 0.72                   |
| 5                                    | 2087                    | 2073                     | 6#7      | 2322                      | 1.44                   | 999                     | 989                      | 3#7      | 1161                      | 0.72                   |
| 6                                    | 2547                    | 2528                     | 7#7      | 2709                      | 1.68                   | 1206                    | 1193                     | 4#7      | 1548                      | 0.96                   |

Table 7.23. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 7, location 3 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 520                     | 462                      | 2#7      | 774                       | 0.48                   | 621                     | 616                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 617                     | 549                      | 2#7      | 774                       | 0.48                   | 617                     | 580                      | 2#7      | 774                       | 0.48                   |
| 3                                    | 617                     | 555                      | 2#7      | 774                       | 0.48                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |
| 4                                    | 617                     | 555                      | 2#7      | 774                       | 0.48                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |
| 5                                    | 617                     | 555                      | 2#7      | 774                       | 0.48                   | 617                     | 575                      | 2#7      | 774                       | 0.48                   |
| 6                                    | 617                     | 603                      | 2#7      | 774                       | 0.48                   | 617                     | 585                      | 2#7      | 774                       | 0.48                   |

Table 7.24. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 7, location 0 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 340                     | 249                      | 5#7      | 1935                      | 1.20                   | 338                     | 248                      | 3#7      | 1161                      | 0.72                   |
| 2                                    | 153                     | 141                      | 6#7      | 2322                      | 1.44                   | 222                     | 162                      | 3#7      | 1161                      | 0.72                   |
| 3                                    | 183                     | 150                      | 6#7      | 2322                      | 1.44                   | 174                     | 132                      | 3#7      | 1161                      | 0.72                   |
| 4                                    | 183                     | 165                      | 6#7      | 2322                      | 1.44                   | 159                     | 120                      | 3#7      | 1161                      | 0.72                   |
| 5                                    | 189                     | 174                      | 6#7      | 2322                      | 1.44                   | 231                     | 162                      | 3#7      | 1161                      | 0.72                   |
| 6                                    | 168                     | 135                      | 7#7      | 2709                      | 1.68                   | 287                     | 214                      | 4#7      | 1548                      | 0.96                   |

Table 7.25. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 8, location 6 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 1563                    | 1552                     | 5#7      | 1935                      | 1.20                   | 757                     | 751                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 1981                    | 1962                     | 6#7      | 2322                      | 1.44                   | 950                     | 941                      | 3#7      | 1161                      | 0.72                   |
| 3                                    | 1988                    | 1974                     | 6#7      | 2322                      | 1.44                   | 954                     | 967                      | 3#7      | 1161                      | 0.72                   |
| 4                                    | 1983                    | 1968                     | 6#7      | 2322                      | 1.44                   | 951                     | 941                      | 3#7      | 1161                      | 0.72                   |
| 5                                    | 1962                    | 1945                     | 6#7      | 2322                      | 1.44                   | 942                     | 936                      | 3#7      | 1161                      | 0.72                   |
| 6                                    | 2435                    | 2414                     | 7#7      | 2709                      | 1.68                   | 1156                    | 1145                     | 3#7      | 1161                      | 0.72                   |

Table 7.26. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 8, location 3 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 498                     | 444                      | 2#7      | 774                       | 0.48                   | 645                     | 642                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 617                     | 541                      | 2#7      | 774                       | 0.48                   | 617                     | 580                      | 2#7      | 774                       | 0.48                   |
| 3                                    | 617                     | 541                      | 2#7      | 774                       | 0.48                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |
| 4                                    | 617                     | 546                      | 2#7      | 774                       | 0.48                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |
| 5                                    | 617                     | 535                      | 2#7      | 774                       | 0.48                   | 617                     | 580                      | 2#7      | 774                       | 0.48                   |
| 6                                    | 617                     | 593                      | 2#7      | 774                       | 0.48                   | 617                     | 559                      | 2#7      | 774                       | 0.48                   |

Table 7.27. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 8, location 0 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 458                     | 411                      | 5#7      | 1935                      | 1.20                   | 364                     | 268                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 396                     | 366                      | 6#7      | 2322                      | 1.44                   | 150                     | 135                      | 3#7      | 1161                      | 0.72                   |
| 3                                    | 366                     | 264                      | 6#7      | 2322                      | 1.44                   | 144                     | 129                      | 3#7      | 1161                      | 0.72                   |
| 4                                    | 396                     | 324                      | 6#7      | 2322                      | 1.44                   | 156                     | 144                      | 3#7      | 1161                      | 0.72                   |
| 5                                    | 300                     | 258                      | 6#7      | 2322                      | 1.44                   | 153                     | 135                      | 3#7      | 1161                      | 0.72                   |
| 6                                    | 279                     | 240                      | 7#7      | 2709                      | 1.68                   | 211                     | 165                      | 3#7      | 1161                      | 0.72                   |

Table 7.28. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 9, location 6 m |  |  |  |  |  |  |  |  |  |  |
|--------------------------------------|--|--|--|--|--|--|--|--|--|--|
|--------------------------------------|--|--|--|--|--|--|--|--|--|--|

| Beam # | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|--------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
|        | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1      | 1479                    | 1468                     | 4#7      | 1548                      | 0.96                   | 718                     | 710                      | 2#7      | 774                       | 0.48                   |
| 2      | 1835                    | 1818                     | 5#7      | 1935                      | 1.20                   | 883                     | 878                      | 3#7      | 1161                      | 0.72                   |
| 3      | 1835                    | 1818                     | 5#7      | 1935                      | 1.20                   | 883                     | 878                      | 3#7      | 1161                      | 0.72                   |
| 4      | 1832                    | 1818                     | 5#7      | 1935                      | 1.20                   | 882                     | 878                      | 3#7      | 1161                      | 0.72                   |
| 5      | 1778                    | 1751                     | 5#7      | 1935                      | 1.20                   | 857                     | 851                      | 3#7      | 1161                      | 0.72                   |
| 6      | 2235                    | 2220                     | 6#7      | 2322                      | 1.44                   | 1066                    | 1052                     | 3#7      | 1161                      | 0.72                   |

Table 7.29. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 9, location 3 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 482                     | 420                      | 2#7      | 774                       | 0.48                   | 689                     | 684                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 579                     | 496                      | 2#7      | 774                       | 0.48                   | 617                     | 590                      | 2#7      | 774                       | 0.48                   |
| 3                                    | 579                     | 496                      | 2#7      | 774                       | 0.48                   | 617                     | 564                      | 2#7      | 774                       | 0.48                   |
| 4                                    | 578                     | 496                      | 2#7      | 774                       | 0.48                   | 617                     | 564                      | 2#7      | 774                       | 0.48                   |
| 5                                    | 562                     | 483                      | 2#7      | 774                       | 0.48                   | 617                     | 590                      | 2#7      | 774                       | 0.48                   |
| 6                                    | 617                     | 565                      | 2#7      | 774                       | 0.48                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |

Table 7.30. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 9, location 0 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|--------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                               | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                      | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                    | 354                     | 396                      | 4#7      | 1548                      | 0.96                   | 211                     | 155                      | 2#7      | 774                       | 0.48                   |
| 2                                    | 290                     | 268                      | 5#7      | 1935                      | 1.20                   | 144                     | 110                      | 3#7      | 1161                      | 0.72                   |
| 3                                    | 379                     | 358                      | 5#7      | 1935                      | 1.20                   | 189                     | 142                      | 3#7      | 1161                      | 0.72                   |
| 4                                    | 384                     | 358                      | 5#7      | 1935                      | 1.20                   | 192                     | 142                      | 3#7      | 1161                      | 0.72                   |
| 5                                    | 382                     | 358                      | 5#7      | 1935                      | 1.20                   | 190                     | 142                      | 3#7      | 1161                      | 0.72                   |
| 6                                    | 198                     | 192                      | 6#7      | 2322                      | 1.44                   | 216                     | 159                      | 3#7      | 1161                      | 0.72                   |

Table 7.31. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 10, location 6 m |     |  |  |  |  |        |  |  |  |  |
|---------------------------------------|-----|--|--|--|--|--------|--|--|--|--|
|                                       | Top |  |  |  |  | Bottom |  |  |  |  |

Beam #



|   | SAP As,<br>mm <sup>2</sup> | Hand<br>As,<br>mm <sup>2</sup> | Bar size | Bar<br>area,<br>mm <sup>2</sup> | Reinforc<br>ement<br>ratio, % | SAP As,<br>mm <sup>2</sup> | Hand<br>As,<br>mm <sup>2</sup> | Bar size | Bar<br>area,<br>mm <sup>2</sup> | Reinforc<br>ement<br>ratio, % |
|---|----------------------------|--------------------------------|----------|---------------------------------|-------------------------------|----------------------------|--------------------------------|----------|---------------------------------|-------------------------------|
| 1 | 1276                       | 1264                           | 5#6      | 1420                            | 0.88                          | 621                        | 616                            | 2#7      | 774                             | 0.48                          |
| 2 | 1704                       | 1698                           | 6#6      | 1704                            | 1.06                          | 825                        | 820                            | 3#7      | 1161                            | 0.72                          |
| 3 | 1706                       | 1692                           | 6#6      | 1704                            | 1.06                          | 824                        | 814                            | 3#7      | 1161                            | 0.72                          |
| 4 | 1701                       | 1687                           | 6#6      | 1704                            | 1.06                          | 822                        | 814                            | 3#7      | 1161                            | 0.72                          |
| 5 | 1655                       | 1641                           | 6#6      | 1704                            | 1.06                          | 800                        | 793                            | 3#7      | 1161                            | 0.72                          |
| 6 | 2119                       | 2102                           | 8#6      | 2272                            | 1.41                          | 1014                       | 1005                           | 3#7      | 1161                            | 0.72                          |

Table 7.32. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 10, location 3 m |                            |                                |          |                                 |                               |                            |                                |          |                                 |                               |
|---------------------------------------|----------------------------|--------------------------------|----------|---------------------------------|-------------------------------|----------------------------|--------------------------------|----------|---------------------------------|-------------------------------|
| Beam #                                | Top                        |                                |          |                                 |                               | Bottom                     |                                |          |                                 |                               |
|                                       | SAP As,<br>mm <sup>2</sup> | Hand<br>As,<br>mm <sup>2</sup> | Bar size | Bar<br>area,<br>mm <sup>2</sup> | Reinforc<br>ement<br>ratio, % | SAP As,<br>mm <sup>2</sup> | Hand<br>As,<br>mm <sup>2</sup> | Bar size | Bar<br>area,<br>mm <sup>2</sup> | Reinforc<br>ement<br>ratio, % |
| 1                                     | 410                        | 365                            | 2#6      | 568                             | 0.35                          | 663                        | 656                            | 2#7      | 774                             | 0.48                          |
| 2                                     | 542                        | 473                            | 2#6      | 568                             | 0.35                          | 617                        | 590                            | 2#7      | 774                             | 0.48                          |
| 3                                     | 541                        | 473                            | 2#6      | 568                             | 0.35                          | 617                        | 564                            | 2#7      | 774                             | 0.48                          |
| 4                                     | 539                        | 473                            | 2#6      | 568                             | 0.35                          | 617                        | 564                            | 2#7      | 774                             | 0.48                          |
| 5                                     | 525                        | 460                            | 2#6      | 568                             | 0.35                          | 617                        | 590                            | 2#7      | 774                             | 0.48                          |
| 6                                     | 617                        | 542                            | 3#6      | 852                             | 0.53                          | 617                        | 570                            | 2#7      | 774                             | 0.48                          |

Table 7.33. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 10, location 0 m |                            |                                |          |                                 |                               |                            |                                |          |                                 |                               |
|---------------------------------------|----------------------------|--------------------------------|----------|---------------------------------|-------------------------------|----------------------------|--------------------------------|----------|---------------------------------|-------------------------------|
| Beam #                                | Top                        |                                |          |                                 |                               | Bottom                     |                                |          |                                 |                               |
|                                       | SAP As,<br>mm <sup>2</sup> | Hand<br>As,<br>mm <sup>2</sup> | Bar size | Bar<br>area,<br>mm <sup>2</sup> | Reinforc<br>ement<br>ratio, % | SAP As,<br>mm <sup>2</sup> | Hand<br>As,<br>mm <sup>2</sup> | Bar size | Bar<br>area,<br>mm <sup>2</sup> | Reinforc<br>ement<br>ratio, % |
| 1                                     | 617                        | 553                            | 5#6      | 1420                            | 0.88                          | 400                        | 299                            | 2#7      | 774                             | 0.48                          |
| 2                                     | 410                        | 351                            | 6#6      | 1704                            | 1.06                          | 251                        | 190                            | 3#7      | 1161                            | 0.72                          |
| 3                                     | 507                        | 435                            | 6#6      | 1704                            | 1.06                          | 310                        | 230                            | 3#7      | 1161                            | 0.72                          |
| 4                                     | 512                        | 441                            | 6#6      | 1704                            | 1.06                          | 314                        | 230                            | 3#7      | 1161                            | 0.72                          |
| 5                                     | 506                        | 439                            | 6#6      | 1704                            | 1.06                          | 307                        | 230                            | 3#7      | 1161                            | 0.72                          |
| 6                                     | 338                        | 306                            | 8#6      | 2272                            | 1.41                          | 256                        | 189                            | 3#7      | 1161                            | 0.72                          |

Table 7.34. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 11, location 6 m |                            |                                |          |                                 |                               |                            |                                |          |                                 |                               |
|---------------------------------------|----------------------------|--------------------------------|----------|---------------------------------|-------------------------------|----------------------------|--------------------------------|----------|---------------------------------|-------------------------------|
| Beam #                                | Top                        |                                |          |                                 |                               | Bottom                     |                                |          |                                 |                               |
|                                       | SAP As,<br>mm <sup>2</sup> | Hand<br>As,<br>mm <sup>2</sup> | Bar size | Bar<br>area,<br>mm <sup>2</sup> | Reinforc<br>ement<br>ratio, % | SAP As,<br>mm <sup>2</sup> | Hand<br>As,<br>mm <sup>2</sup> | Bar size | Bar<br>area,<br>mm <sup>2</sup> | Reinforc<br>ement<br>ratio, % |

|   |      | mm <sup>2</sup> |     | mm <sup>2</sup> | ratio, % |     | mm <sup>2</sup> |     | mm <sup>2</sup> | ratio, % |
|---|------|-----------------|-----|-----------------|----------|-----|-----------------|-----|-----------------|----------|
| 1 | 1191 | 1177            | 5#6 | 1420            | 0.88     | 617 | 574             | 2#7 | 774             | 0.48     |
| 2 | 1549 | 1535            | 6#6 | 1704            | 1.06     | 751 | 746             | 2#7 | 774             | 0.48     |
| 3 | 1539 | 1529            | 6#6 | 1704            | 1.06     | 746 | 741             | 2#7 | 774             | 0.48     |
| 4 | 1538 | 1529            | 6#6 | 1704            | 1.06     | 745 | 741             | 2#7 | 774             | 0.48     |
| 5 | 1462 | 1451            | 6#6 | 1704            | 1.06     | 710 | 704             | 2#7 | 774             | 0.48     |
| 6 | 1841 | 1824            | 7#6 | 1988            | 1.24     | 886 | 877             | 3#7 | 1161            | 0.72     |

Table 7.35. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 11, location 3 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|---------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                                | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                       | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                     | 383                     | 341                      | 2#6      | 568                       | 0.35                   | 702                     | 694                      | 2#7      | 774                       | 0.48                   |
| 2                                     | 493                     | 431                      | 2#6      | 568                       | 0.35                   | 617                     | 601                      | 2#7      | 774                       | 0.48                   |
| 3                                     | 490                     | 431                      | 2#6      | 568                       | 0.35                   | 617                     | 564                      | 2#7      | 774                       | 0.48                   |
| 4                                     | 490                     | 431                      | 2#6      | 568                       | 0.35                   | 617                     | 564                      | 2#7      | 774                       | 0.48                   |
| 5                                     | 467                     | 407                      | 2#6      | 568                       | 0.35                   | 617                     | 565                      | 2#7      | 774                       | 0.48                   |
| 6                                     | 581                     | 474                      | 3#6      | 852                       | 0.53                   | 617                     | 590                      | 2#7      | 774                       | 0.48                   |

Table 7.36. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 11, location 0 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|---------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                                | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                       | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                     | 617                     | 601                      | 5#6      | 1420                      | 0.88                   | 335                     | 249                      | 2#7      | 774                       | 0.48                   |
| 2                                     | 493                     | 438                      | 6#6      | 1704                      | 1.06                   | 245                     | 179                      | 2#7      | 774                       | 0.48                   |
| 3                                     | 593                     | 529                      | 6#6      | 1704                      | 1.06                   | 294                     | 219                      | 2#7      | 774                       | 0.48                   |
| 4                                     | 592                     | 529                      | 6#6      | 1704                      | 1.06                   | 294                     | 219                      | 2#7      | 774                       | 0.48                   |
| 5                                     | 598                     | 536                      | 6#6      | 1704                      | 1.06                   | 296                     | 219                      | 2#7      | 774                       | 0.48                   |
| 6                                     | 332                     | 248                      | 7#6      | 1988                      | 1.24                   | 266                     | 198                      | 3#7      | 1161                      | 0.72                   |

Table 7.37. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 12, location 6 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|---------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                                | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                       | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                     | 1312                    | 1297                     | 5#6      | 1420                      | 0.88                   | 639                     | 631                      | 2#7      | 774                       | 0.48                   |

|   |      |      |     |      |      |     |     |     |     |      |
|---|------|------|-----|------|------|-----|-----|-----|-----|------|
| 2 | 1523 | 1512 | 6#6 | 1704 | 1.06 | 739 | 730 | 2#7 | 774 | 0.48 |
| 3 | 1517 | 1512 | 6#6 | 1704 | 1.06 | 736 | 730 | 2#7 | 774 | 0.48 |
| 4 | 1518 | 1512 | 6#6 | 1704 | 1.06 | 736 | 730 | 2#7 | 774 | 0.48 |
| 5 | 1437 | 1429 | 6#6 | 1704 | 1.06 | 698 | 694 | 2#7 | 774 | 0.48 |
| 6 | 1511 | 1501 | 6#6 | 1704 | 1.06 | 733 | 725 | 2#7 | 774 | 0.48 |

Table 7.38. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 12, location 3 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|---------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                                | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                       | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                     | 421                     | 377                      | 2#6      | 568                       | 0.35                   | 900                     | 894                      | 3#7      | 1161                      | 0.72                   |
| 2                                     | 485                     | 425                      | 2#6      | 568                       | 0.35                   | 705                     | 699                      | 2#7      | 774                       | 0.48                   |
| 3                                     | 483                     | 425                      | 2#6      | 568                       | 0.35                   | 673                     | 668                      | 2#7      | 774                       | 0.48                   |
| 4                                     | 483                     | 425                      | 2#6      | 568                       | 0.35                   | 672                     | 668                      | 2#7      | 774                       | 0.48                   |
| 5                                     | 459                     | 401                      | 2#6      | 568                       | 0.35                   | 709                     | 704                      | 2#7      | 774                       | 0.48                   |
| 6                                     | 482                     | 396                      | 2#6      | 568                       | 0.35                   | 776                     | 772                      | 2#7      | 774                       | 0.48                   |

Table 7.39. Major Beam bar design for Floor 1, location 6 m

| Major Beam for Floor 12, location 0 m |                         |                          |          |                           |                        |                         |                          |          |                           |                        |
|---------------------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|-------------------------|--------------------------|----------|---------------------------|------------------------|
| Beam #                                | Top                     |                          |          |                           |                        | Bottom                  |                          |          |                           |                        |
|                                       | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | SAP As, mm <sup>2</sup> | Hand As, mm <sup>2</sup> | Bar size | Bar area, mm <sup>2</sup> | Reinforcement ratio, % |
| 1                                     | 617                     | 584                      | 5#6      | 1420                      | 0.88                   | 364                     | 269                      | 2#7      | 774                       | 0.48                   |
| 2                                     | 737                     | 730                      | 6#6      | 1704                      | 1.06                   | 485                     | 360                      | 2#7      | 774                       | 0.48                   |
| 3                                     | 808                     | 804                      | 6#6      | 1704                      | 1.06                   | 530                     | 396                      | 2#7      | 774                       | 0.48                   |
| 4                                     | 808                     | 804                      | 6#6      | 1704                      | 1.06                   | 531                     | 396                      | 2#7      | 774                       | 0.48                   |
| 5                                     | 811                     | 804                      | 6#6      | 1704                      | 1.06                   | 532                     | 396                      | 2#7      | 774                       | 0.48                   |
| 6                                     | 617                     | 606                      | 6#6      | 1704                      | 1.06                   | 400                     | 299                      | 2#7      | 774                       | 0.48                   |

Table 7.40. Interior column bar design

| Interior column |                         |                   |                           |                        |            |
|-----------------|-------------------------|-------------------|---------------------------|------------------------|------------|
| Floor           | SAP As, mm <sup>2</sup> | Longitudinal bars | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | Stirrups   |
| 1               | 4900                    | 8#9               | 5160                      | 1                      | #3 @150 mm |
| 2               | 7255                    | 8#10              | 6552                      | 2.02                   | #3 @150 mm |
| 3               | 4572                    | 8#9               | 5160                      | 1.27                   | #3 @150 mm |
| 4               | 3600                    | 8#8               | 4072                      | 1                      | #3 @150 mm |
| 5               | 7100                    | 8#10              | 6552                      | 2.84                   | #3 @150 mm |

|    |      |     |      |      |            |
|----|------|-----|------|------|------------|
| 6  | 3200 | 8#8 | 4072 | 1.28 | #3 @150 mm |
| 7  | 2500 | 8#7 | 3096 | 1    | #3 @150 mm |
| 8  | 4150 | 8#9 | 5160 | 2.59 | #3 @150 mm |
| 9  | 4700 | 8#9 | 5160 | 2.94 | #3 @150 mm |
| 10 | 3300 | 8#8 | 4072 | 2.06 | #3 @150 mm |
| 11 | 3467 | 8#8 | 4072 | 2.83 | #3 @150 mm |
| 12 | 3400 | 8#8 | 4072 | 2.78 | #3 @150 mm |

Table 7.41. Exterior column bar design

| Exterior column |                         |                   |                           |                        |            |
|-----------------|-------------------------|-------------------|---------------------------|------------------------|------------|
| Floor           | SAP As, mm <sup>2</sup> | Longitudinal bars | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | Stirrups   |
| 1               | 4900                    | 8#9               | 5160                      | 1                      | #3 @150 mm |
| 2               | 3600                    | 8#8               | 4072                      | 1                      | #3 @150 mm |
| 3               | 3600                    | 8#8               | 4072                      | 1                      | #3 @150 mm |
| 4               | 3600                    | 8#8               | 4072                      | 1                      | #3 @150 mm |
| 5               | 2500                    | 8#7               | 3096                      | 1                      | #3 @150 mm |
| 6               | 2500                    | 8#7               | 3096                      | 1                      | #3 @150 mm |
| 7               | 2500                    | 8#7               | 3096                      | 1                      | #3 @150 mm |
| 8               | 4700                    | 8#9               | 5160                      | 2.94                   | #3 @150 mm |
| 9               | 4500                    | 8#9               | 5160                      | 2.81                   | #3 @150 mm |
| 10              | 3700                    | 8#8               | 4072                      | 2.31                   | #3 @150 mm |
| 11              | 3300                    | 8#8               | 4072                      | 2.69                   | #3 @150 mm |
| 12              | 3400                    | 8#8               | 4072                      | 2.78                   | #3 @150 mm |

Table 7.42. Corner column bar design

| Corner column |                         |                   |                           |                        |            |
|---------------|-------------------------|-------------------|---------------------------|------------------------|------------|
| Floor         | SAP As, mm <sup>2</sup> | Longitudinal bars | Bar area, mm <sup>2</sup> | Reinforcement ratio, % | Stirrups   |
| 1             | 4900                    | 8#9               | 5160                      | 1                      | #3 @150 mm |
| 2             | 3600                    | 8#8               | 4072                      | 1                      | #3 @150 mm |
| 3             | 3600                    | 8#8               | 4072                      | 1                      | #3 @150 mm |
| 4             | 3600                    | 8#8               | 4072                      | 1                      | #3 @150 mm |
| 5             | 2500                    | 8#7               | 3096                      | 1                      | #3 @150 mm |
| 6             | 2500                    | 8#7               | 3096                      | 1                      | #3 @150 mm |
| 7             | 2500                    | 8#7               | 3096                      | 1                      | #3 @150 mm |
| 8             | 1800                    | 8#6               | 2272                      | 1.13                   | #3 @150 mm |

|    |      |     |      |      |            |
|----|------|-----|------|------|------------|
| 9  | 2000 | 8#6 | 2272 | 1.25 | #3 @150 mm |
| 10 | 1700 | 8#6 | 2272 | 1.06 | #3 @150 mm |
| 11 | 3600 | 8#8 | 4072 | 2.94 | #3 @150 mm |
| 12 | 3300 | 8#8 | 4072 | 2.69 | #3 @150 mm |

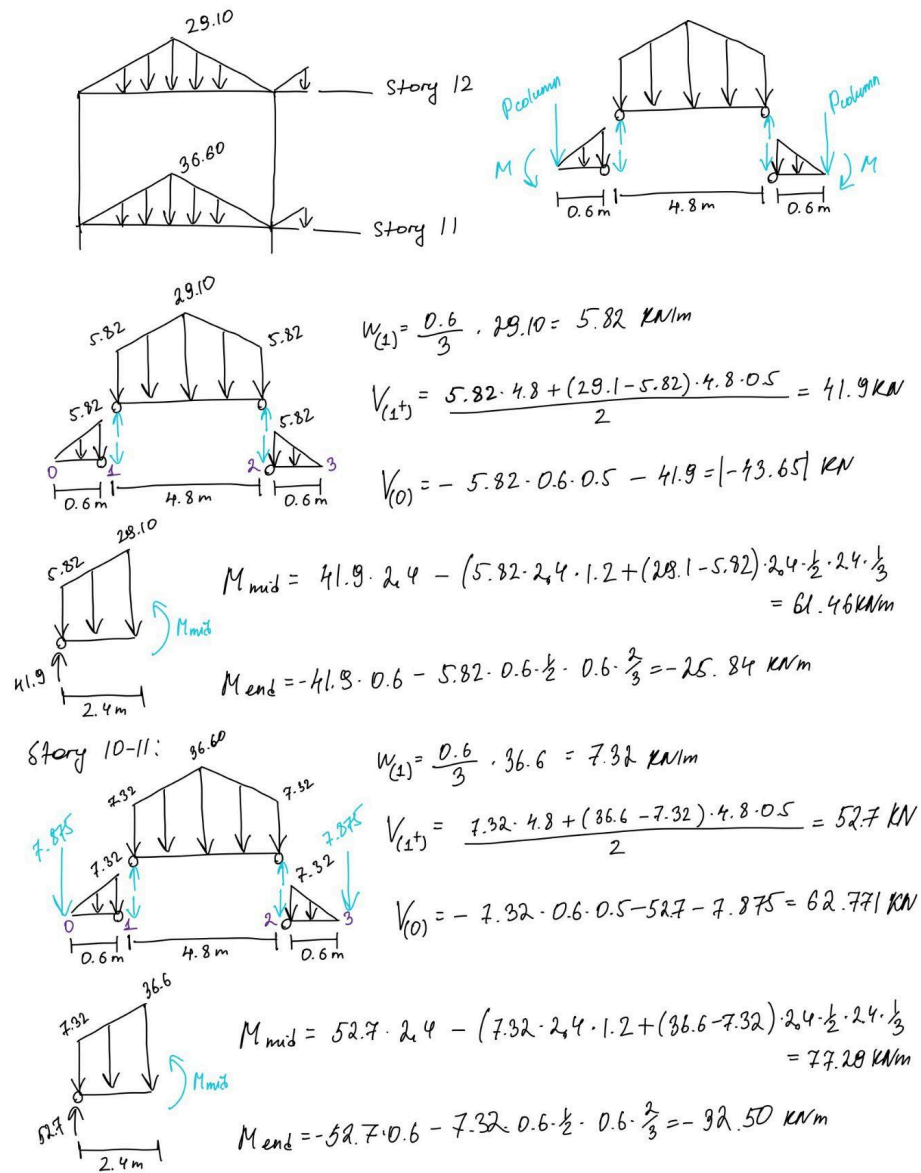


Figure 7.43. Hand calculations of the internal forces under dead load

Case I : floor 12

$\sum F_x = 10V$   
 $V = \frac{\sum F_x}{10}$   
 $V_{12} = \frac{F_{12}}{10}$

①:  $\frac{F_{12}}{a} \rightarrow \frac{b}{a} \downarrow \frac{3}{a} \rightarrow$   $\sum F_x = 0: 2 + F_{12} - V_{12} = 0 \Rightarrow 2 = V_{12} - F_{12}$   
 $\sum M = 0: 1 \cdot b - V_{12} \cdot a = 0 \Rightarrow 1 = \frac{V_{12} \cdot a}{b}$   
 $\sum F_y = 0: 1 + 3 = 0 \Rightarrow 3 = -1$

②:  $\frac{2}{a} \leftarrow \frac{3}{a} \frac{b}{a} \frac{6}{a} \downarrow \frac{5}{a} \rightarrow$   $\sum F_x = 0: 5 - 2 - 2V_{12} = 0 \Rightarrow 5 = 2 + 2V_{12}$   
 $\sum M = 0: 4b - 2V_{12}a - 3 \cdot 2b = 0 \Rightarrow 4 = \frac{2V_{12} \cdot a + 3 \cdot 2b}{b}$   
 $\sum F_y = 0: 3 - 6 - 4 = 0 \Rightarrow 6 = 3 - 4$

③:  $\frac{5}{a} \leftarrow \frac{6}{a} \frac{b}{a} \frac{6}{a} \downarrow \frac{8}{a} \rightarrow$   $\sum F_x = 0: 8 - 5 - 2V_{12} = 0 \Rightarrow 8 = 5 + 2V_{12}$   
 $\sum M = 0: 7b - 2V_{12}a - 6 \cdot 2b = 0 \Rightarrow 7 = \frac{2V_{12} \cdot a + 6 \cdot 2b}{b}$   
 $\sum F_y = 0: 6 - 9 - 7 = 0 \Rightarrow 9 = 6 - 7$

④:  $\frac{9}{a} \leftarrow \frac{8}{a} \frac{b}{a} \frac{6}{a} \downarrow \frac{11}{a} \rightarrow$   $\sum F_x = 0: 11 - 8 - 2V_{12} = 0 \Rightarrow 11 = 8 + 2V_{12}$   
 $\sum M = 0: 10b - 2V_{12}a - 9 \cdot 2b = 0 \Rightarrow 10 = \frac{2V_{12} \cdot a + 9 \cdot 2b}{b}$   
 $\sum F_y = 0: 9 - 12 - 10 = 0 \Rightarrow 12 = 9 - 10$

⑤:  $\frac{11}{a} \leftarrow \frac{8}{a} \frac{b}{a} \frac{6}{a} \downarrow \frac{14}{a} \rightarrow$   $\sum F_x = 0: 14 - 11 - 2V_{12} = 0 \Rightarrow 14 = 11 + 2V_{12}$   
 $\sum M = 0: 13b - 2V_{12}a - 12 \cdot 2b = 0 \Rightarrow 13 = \frac{2V_{12} \cdot a + 12 \cdot 2b}{b}$   
 $\sum F_y = 0: 12 - 15 - 13 = 0 \Rightarrow 15 = 12 - 13$

Figure 7.44. Hand calculations of the internal forces under wind load Part-1

$\textcircled{6}:$ 
 $\sum F_x = 0: 17 - 14 - 2V_{12} = 0 \Rightarrow 17 = 14 + 2V_{12}$   
 $\sum M = 0: 16 \cdot 6 - 2V_{12} \cdot a - 15 \cdot 2 \cdot 6 = 0 \Rightarrow 16 = \frac{2V_{12} \cdot a + 15 \cdot 2 \cdot 6}{6}$   
 $\sum F_y = 0: 15 - 18 - 16 = 0 \Rightarrow 18 = 15 - 16$

$\textcircled{7}:$ 
 $\sum F_y = 0: 19 = 18$

## Case II: Typical Floor

$F_{xi}$ 
 $V_i = \frac{F_{xi}}{10}$

$\textcircled{1}:$ 
 $\sum F_x = 0: V_{12} + F_{xi} - V_1 + 2 = 0 \Rightarrow 2 = V_1 - V_{12} - F_{xi}$   
 $\sum M = 0: 1 \cdot 6 - V_1 \cdot a - V_{12} \cdot a - 1^{(12)} \cdot 6 = 0$   
 $1 = \frac{V_1 \cdot a + V_{12} \cdot a + 1^{(12)} \cdot 6}{6}$

$\textcircled{2}:$ 
 $\sum F_y = 0: 1^{(12)} - 1 - 3 = 0 \Rightarrow 3 = 1^{(12)} - 1$   
 $\sum F_x = 0: 5 + 2V_{12} - 2V_1 - 2 = 0 \Rightarrow 5 = 2V_1 + 2 - 2V_{12}$   
 $\sum M = 0: 4 \cdot 6 - 2V_1 \cdot a - 2V_{12} \cdot a - 4^{(12)} \cdot 6 - 3 \cdot 2 \cdot 6 = 0$   
 $4 = \frac{2V_1 \cdot a + 2V_{12} \cdot a + 4^{(12)} \cdot 6 + 3 \cdot 2 \cdot 6}{6}$   
 $\sum F_y = 0: 3 + 4^{(12)} - 6 - 4 = 0 \Rightarrow 6 = 3 - 4 + 4^{(12)}$

$\textcircled{3}:$ 
 $\sum F_x = 0: 8 + 2V_{12} - 2V_1 - 5 = 0 \Rightarrow 5 = 2V_1 + 8 - 2V_{12}$   
 $\sum M = 0: 7 \cdot 6 - 2V_1 \cdot a - 2V_{12} \cdot a - 7^{(12)} \cdot 6 - 6 \cdot 2 \cdot 6 = 0$   
 $7 = \frac{2V_1 \cdot a + 2V_{12} \cdot a + 7^{(12)} \cdot 6 + 6 \cdot 2 \cdot 6}{6}$

Figure 7.45. Hand calculations of the internal forces under wind load Part-2

$\sum F_y = 0: 6 + 7^{(n)} - 9 - 7 = 0 \Rightarrow 9 = 6 - 7 + 7^{(12)}$   
 $\sum F_x = 0: 11 + 2N_{12} - 2V_i - 8 = 0 \Rightarrow 11 = 2V_i + 8 - 2N_{12}$   
 $\sum M = 0: 10 \cdot 6 - 2V_i \cdot a - 2N_{12} \cdot a - 10^{(12)} \cdot 6 - 9 \cdot 2b = 0$   
 $10 = \frac{2V_i \cdot a + 2N_{12} \cdot a + 10^{(12)} \cdot 6 + 9 \cdot 2b}{6}$   
 $\sum F_y = 0: 9 + 10^{(n)} - 12 - 10 = 0 \Rightarrow 12 = 9 - 10 + 10^{(12)}$   
 $\sum F_x = 0: 14 + 2N_{12} - 2V_i - 11 = 0 \Rightarrow 14 = 2V_i + 11 - 2N_{12}$   
 $\sum M = 0: 13 \cdot 6 - 2V_i \cdot a - 2N_{12} \cdot a - 13^{(12)} \cdot 6 - 12 \cdot 2b = 0$   
 $13 = \frac{2V_i \cdot a + 2N_{12} \cdot a + 13^{(12)} \cdot 6 + 12 \cdot 2b}{6}$   
 $\sum F_y = 0: 12 + 13^{(n)} - 13 - 15 = 0 \Rightarrow 15 = 12 - 13 + 13^{(12)}$   
 $\sum F_x = 0: 17 + 2N_{12} - 2V_i - 14 = 0 \Rightarrow 17 = 2V_i + 14 - 2N_{12}$   
 $\sum M = 0: 16 \cdot 6 - 2V_i \cdot a - 2N_{12} \cdot a - 16^{(12)} \cdot 6 - 15 \cdot 2b = 0$   
 $16 = \frac{2V_i \cdot a + 2N_{12} \cdot a + 16^{(12)} \cdot 6 + 15 \cdot 2b}{6}$   
 $\sum F_y = 0: 15 + 16^{(n)} - 18 - 16 = 0 \Rightarrow 18 = 15 - 16 + 16^{(12)}$   
 $\sum F_y = 0: 19 = 18 + 19^{(12)}$

Case III: Base Floor

$\sum F_x = 0: A_x = -V^{(2)}$   
 $\sum F_y = 0: A_y = 1^{(2)}$   
 $\sum M_A = 0: M_A = V^{(2)} \cdot a$

Figure 7.46. Hand calculations of the internal forces under wind load Part-3



$$\begin{array}{l}
 \textcircled{2}: \quad \begin{array}{c} \downarrow 4^{(2)} \rightarrow 2V^{(2)} \\ | \\ \text{---} \\ \text{---} \\ \text{---} \\ \text{---} \end{array} \quad \begin{array}{l} \sum F_x = 0: B_x = -2V^{(2)} \\ \sum F_y = 0: B_y = 4^{(2)} \\ \sum M_B = 0: M_B = V^{(2)} \cdot a \end{array} \\
 \quad \quad \quad \begin{array}{c} \xrightarrow{B_x} \\ \uparrow B_y \end{array}
 \end{array}$$

$$\begin{array}{l}
 \textcircled{3}: \quad \begin{array}{c} \downarrow 7^{(2)} \rightarrow 2V^{(2)} \\ | \\ \text{---} \\ \text{---} \\ \text{---} \\ \text{---} \end{array} \quad \begin{array}{l} \sum F_x = 0: C_x = -2V^{(2)} \\ \sum F_y = 0: C_y = 7^{(2)} \\ \sum M_C = 0: M_C = V^{(2)} \cdot a \end{array} \\
 \quad \quad \quad \begin{array}{c} \xrightarrow{C_x} \\ \uparrow C_y \end{array}
 \end{array}$$

$$\begin{array}{l}
 \textcircled{4}: \quad \begin{array}{c} \downarrow 10^{(2)} \rightarrow 2V^{(2)} \\ | \\ \text{---} \\ \text{---} \\ \text{---} \\ \text{---} \end{array} \quad \begin{array}{l} \sum F_x = 0: D_x = -2V^{(2)} \\ \sum F_y = 0: D_y = 10^{(2)} \\ \sum M_D = 0: M_D = V^{(2)} \cdot a \end{array} \\
 \quad \quad \quad \begin{array}{c} \xrightarrow{D_x} \\ \uparrow D_y \end{array}
 \end{array}$$

$$\begin{array}{l}
 \textcircled{5}: \quad \begin{array}{c} \downarrow 13^{(2)} \rightarrow 2V^{(2)} \\ | \\ \text{---} \\ \text{---} \\ \text{---} \\ \text{---} \end{array} \quad \begin{array}{l} \sum F_x = 0: E_x = -2V^{(2)} \\ \sum F_y = 0: E_y = 13^{(2)} \\ \sum M_E = 0: M_E = V^{(2)} \cdot a \end{array} \\
 \quad \quad \quad \begin{array}{c} \xrightarrow{E_x} \\ \uparrow E_y \end{array}
 \end{array}$$

Figure 7.47. Hand calculations of the internal forces under wind load Part-4

$$\begin{array}{l}
 \textcircled{6}: \quad \begin{array}{c} \downarrow 16^{(2)} \rightarrow 2V^{(2)} \\ | \\ \text{---} \\ \text{---} \\ \text{---} \\ \text{---} \end{array} \quad \begin{array}{l} \sum F_x = 0: F_x = -2V^{(2)} \\ \sum F_y = 0: F_y = 16^{(2)} \\ \sum M_F = 0: M_F = V^{(2)} \cdot a \end{array} \\
 \quad \quad \quad \begin{array}{c} \xrightarrow{F_x} \\ \uparrow F_y \end{array}
 \end{array}$$

$$\begin{array}{l}
 \textcircled{7}: \quad \begin{array}{c} \downarrow 19^{(2)} \rightarrow 2V^{(2)} \\ | \\ \text{---} \\ \text{---} \\ \text{---} \\ \text{---} \end{array} \quad \begin{array}{l} \sum F_x = 0: G_x = -2V^{(2)} \\ \sum F_y = 0: G_y = 19^{(2)} \\ \sum M_G = 0: M_G = V^{(2)} \cdot a \end{array} \\
 \quad \quad \quad \begin{array}{c} \xrightarrow{G_x} \\ \uparrow G_y \end{array}
 \end{array}$$

Figure 7.48. Hand calculations of the internal forces under wind load Part-5

Table 7.49. Density of waste constituents



## Waste Materials – Density Data

| Waste Material                      | Density - kilograms per cubic metre |        |           |
|-------------------------------------|-------------------------------------|--------|-----------|
|                                     | Low                                 | Medium | Compacted |
| Paper                               | 76                                  | 152    | 228       |
| Cardboard – Compacted Dry           | 130                                 | 130    | 130       |
| Cardboard - Compacted Wet           | 260                                 | 260    | 260       |
| Cardboard - Loose Dry               | 55                                  | 55     | 55        |
| Cardboard - Loose Wet               | 190                                 | 190    | 190       |
| Cardboard - Waxed                   | 55                                  | 92     | 130       |
| Food - Kitchen                      | 343                                 | 514    | 1029      |
| Food - Dense                        | 514                                 | 1029   | 1029      |
| Vegetation - Garden                 | 91                                  | 227    | 445       |
| Garden - Grass                      | 91                                  | 227    | 445       |
| Garden - Trees                      | 150                                 | 450    | 900       |
| Wood - Timber                       | 156                                 | 156    | 156       |
| Wood - Pallets                      | 156                                 | 156    | 156       |
| Wood - Furniture                    | 160                                 | 170    | 400       |
| Wood - Fencing                      | 170                                 | 170    | 170       |
| Wood - MDF                          | 156                                 | 156    | 156       |
| Wood - Posts                        | 900                                 | 1000   | 1100      |
| Leather - Textiles Furniture        | 90                                  | 100    | 450       |
| Leather - Textiles                  | 91                                  | 91     | 240       |
| Leather - Textiles Car              | 100                                 | 150    | 350       |
| Mattress                            | 50                                  | 50     | 50        |
| Foam                                | 30                                  | 30     | 90        |
| Tyres - Rubber                      | 200                                 | 200    | 400       |
| Other - Rubber                      | 200                                 | 200    | 400       |
| Glass                               | 411                                 | 411    | 411       |
| Glass Jars                          | 250                                 | 250    | 411       |
| Plasticbags                         | 39                                  | 78     | 156       |
| Plastic - Hard                      | 72                                  | 72     | 72        |
| Polystyrene                         | 14                                  | 21     | 28        |
| Garbage Bags                        | 87                                  | 170    | 348       |
| Metal - Ferrous                     | 120                                 | 120    | 120       |
| Metal - NonFerrous                  | 139                                 | 139    | 139       |
| Low Level Contaminated Soil         | 922                                 | 922    | 922       |
| Cleanfill / Soil                    | 950                                 | 950    | 950       |
| Rubble                              | 1048                                | 1048   | 1048      |
| Clay                                | 1150                                | 1150   | 1150      |
| Concrete                            | 830                                 | 830    | 830       |
| Tiles                               | 900                                 | 1500   | 2000      |
| Bricks                              | 828                                 | 828    | 828       |
| Sand                                | 1000                                | 1000   | 1000      |
| Asphalt                             | 680                                 | 680    | 680       |
| Plasterboard                        | 227                                 | 227    | 227       |
| Linoleum                            | 100                                 | 150    | 350       |
| Insulation                          | 60                                  | 100    | 350       |
| Clinical Waste                      | 227                                 | 227    | 227       |
| Electronics                         | 105                                 | 113    | 120       |
| Whitegoods                          | 105                                 | 113    | 120       |
| Batteries                           | 900                                 | 1000   | 1500      |
| Fluorescent Tubes                   | 285                                 | 285    | 285       |
| Sawdust                             | 250                                 | 300    | 350       |
| Cement Sheets                       | 830                                 | 830    | 830       |
| Hospital General Waste Garbage Bags | 87                                  | 170    | 348       |