



# NAZARBAYEV UNIVERSITY

School of Engineering and Digital Sciences, Nazarbayev University

Department of Civil and Environmental Engineering

## **ENG 400: Capstone Project**

### **Design of a 9-story “Adzharat” business-hotel in New York City, USA**

#### Final Report

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## DECLARATION

We hereby declare that this report entitled “Design of a 9-story “Adzharat” business-hotel in New York City, 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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## **1. Introduction**

### **1.1 Problem Statement**

The Queens County in New York is a progressively growing area, having a projected population of 2.339 million in 2025 and an annual growth rate of 1% (Cubit Planning, 2025). According to the New York City Department of City Planning (2017), the demand for accommodation in Queens County is driven by several strategic factors. First of all, Jamaica is one of the largest commercial centers that has direct access to JFK and LaGuardia Airports, which makes this area suitable for international business travelers and city guests. Secondly, with the creation of the AirTrain and its connection with Long Island Rail Road (LIRR), the connectivity of the area has significantly increased, making it a convenient destination. Besides, comparatively low land prices in Jamaica compared to the central parts of the city provide a low-cost advantage to construct hotels at affordable average daily rates. Therefore, the infrastructure around Queens County makes this site well-connected and ideally suited for a business-oriented hotel, offering convenience for both local and international visitors.

### **1.2 Project Description**

The project is a 9-story “Adzharat hotel” building with an additional one-story basement in a non-seismic zone. The proposed construction site is located in Queens County, New York, USA (40°40'02.8" N 73°47'50.6"W). The location was chosen based on the Structural and Architectural requirements, as well as Geotechnical area considerations and Environmental factors. This project aims to create a high-class hotel with a business-oriented environment. The design incorporates wind-resistant architecture and provides a snow-resistant roofing system that will withstand the strong wind and heavy snow environmental conditions of the city.

The preliminary geotechnical site investigation was carried out to satisfy the deep groundwater table and unsaturated soil conditions. The field exploration was conducted by finding a geotechnical report containing bore log readings and assessing laboratory testing, such as Cone Penetration testing and Seismic Piezocone Penetration testing. The existing site conditions include developed residential, commercial, and retail zones along with transportation connections.

### 1.3 Project Objectives

#### Architectural Design:

- Develop technical drawings and a design that meets all local building codes and environmental factors.
- Create an aesthetically pleasing and functional design that integrates modern trends

#### Structural Design:

- Conduct a load summary and develop a structural model for the building structure.
- Implement wind-resistant and snow-resistant systems.

#### Geotechnical Design:

- Complete a site analysis, considering factors such as deep groundwater, unsaturated soil mechanics, and the potential need for both shallow and deep foundation designs.
- Design the basement and ensure that the foundation is suitable for the soil conditions.

#### Construction Management:

- Provide a project delivery plan, cost estimation, and final project cost breakdown.
- Develop a Gantt chart, work breakdown structure, and a risk management plan to ensure timely and cost-efficient project completion.

#### Environmental Engineering:

- Address the management of waste and other environmental factors associated with hotel operations, considering New York's regulatory requirements.

### 1.4 Project Members

**Table 1.1** Project members and responsibilities

| Role                   | Members      | Percentage |
|------------------------|--------------|------------|
| Structural Engineering | Rassul Kaden | 35%        |

|                           |                                                        |     |
|---------------------------|--------------------------------------------------------|-----|
|                           | Zhangir Azhimuratov                                    |     |
| Geotechnical Engineering  | Tasmin Khairullina<br>Diana Mirtayeva<br>Akezhan Bolat | 35% |
| Environmental Engineering | Adelina Muratova                                       | 15% |
| Construction Management   | Akzhol Seitkhaliyev                                    | 15% |

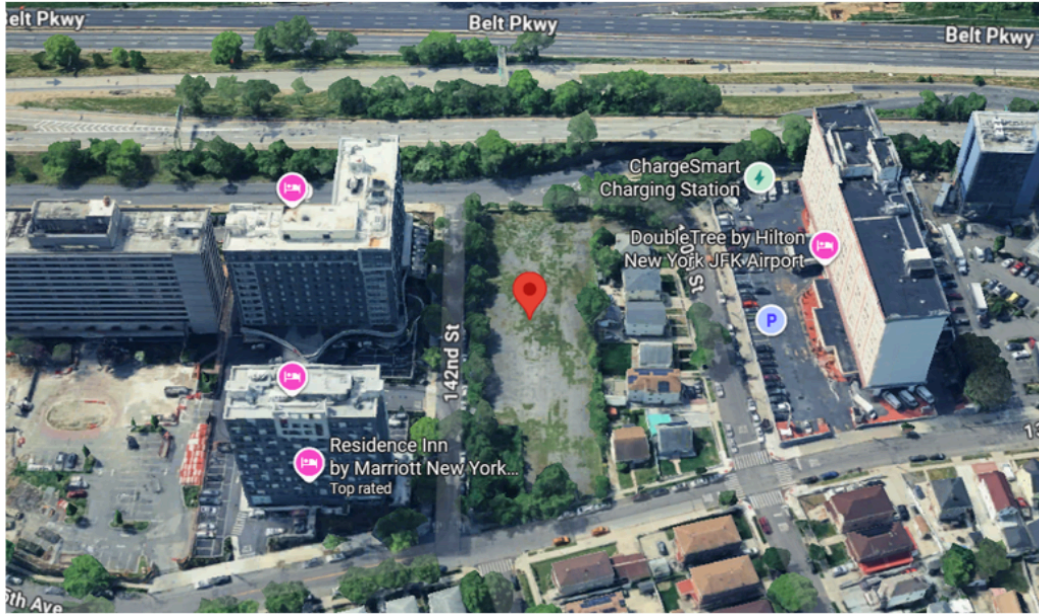
## 2. Architectural Design

### 2.1 Site Analysis

#### 2.1.1 Site Location and Historical Background

The selected site at 135 Avenue, 11436, Jamaica is located near the area of South Ozone Park, which grew significantly in the middle of the 20th century because of the rapid suburbanization of Queens. The construction of John F. Kennedy International Airport to the south of the project site was one of the main factors that contributed to the development of the area by offering economic possibilities and enhancing residential growth (NYC Department of City Planning, 2023). Historically, the neighborhood experienced the building of single-family and multi-family houses in order to provide accommodation for the expanding population in NYC during the period after World War II (Queens Historical Society, 2023). At the current time, the location is vacant and not utilized for specific infrastructure as can be seen in Figure 2.1.1. It also borders suburban residential areas located along 135th Avenue street. To the east and south of the site, there are existing hotels such as DoubleTree by Hilton New York JFK Airport, Marriott New York, and Hampton Inn NY-JFK.

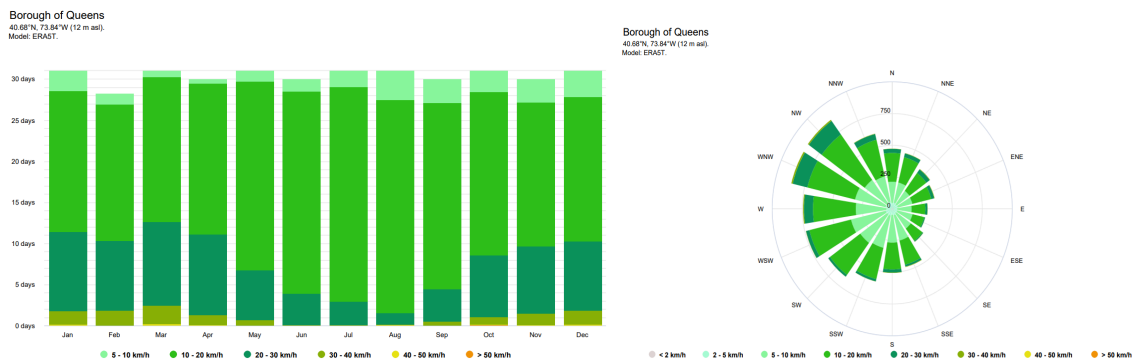




**Figure 2.1.1** Site View (Google maps, 2025)

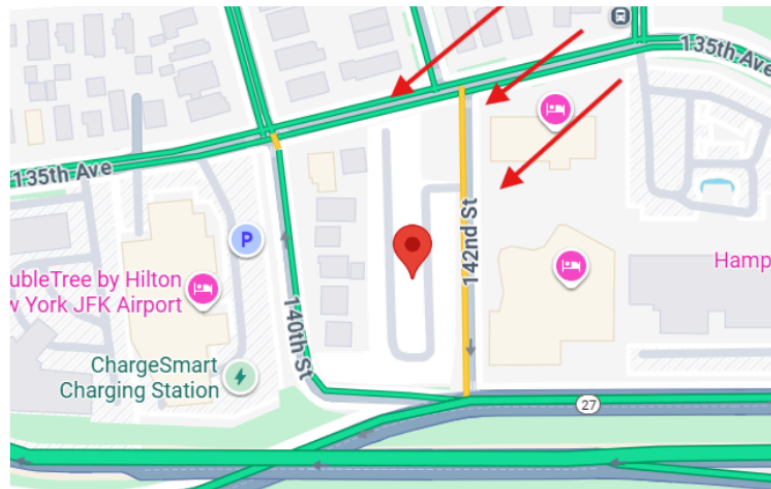
## 2.1.2 Cool breeze access

The wind factor is an important parameter to be considered while analyzing the building's structural stability and designing its architectural model. As can be seen from Figure 2.1.2, the wind speed diagram for Queens borough indicates that yearly speed variation is not intense. Most days in all months have been categorized to have wind speeds in the range of 10-20 km/h, which implies that the wind conditions are usually moderate. The winds in the range of 20-30 km/h are a major constituent, particularly in the cold months from November to April, whereas stronger winds exceeding 40 km/h appear only for 1-2 days per month.



**Figure 2.1.2** Wind Speed in Queens County (meteoblue.com, 2025)

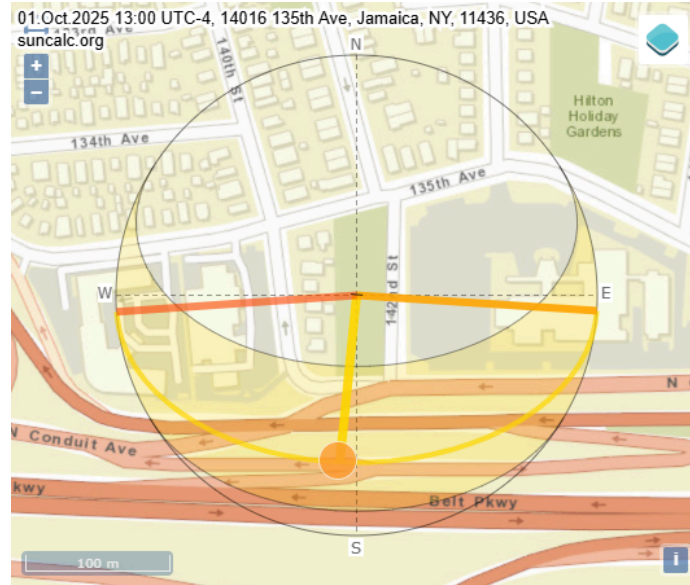
According to the wind rose graph (Figure 2.1.2), the wind directions predominantly come from West, West-Northwest, and Northwest with an average wind frequency of 10-20 km/h. The higher winds of 20-30 km/h also blow from the main directions of W and WNW, indicating that the site has satisfactory natural ventilation and cooling. In addition, the ASCE 7 Hazard Tool shows that the wind speed on the site is 44.7 m/s for a return period of 100 years (ASCE 7 Hazard Tool, 2025).



**Figure 2.1.3** Wind direction on the site

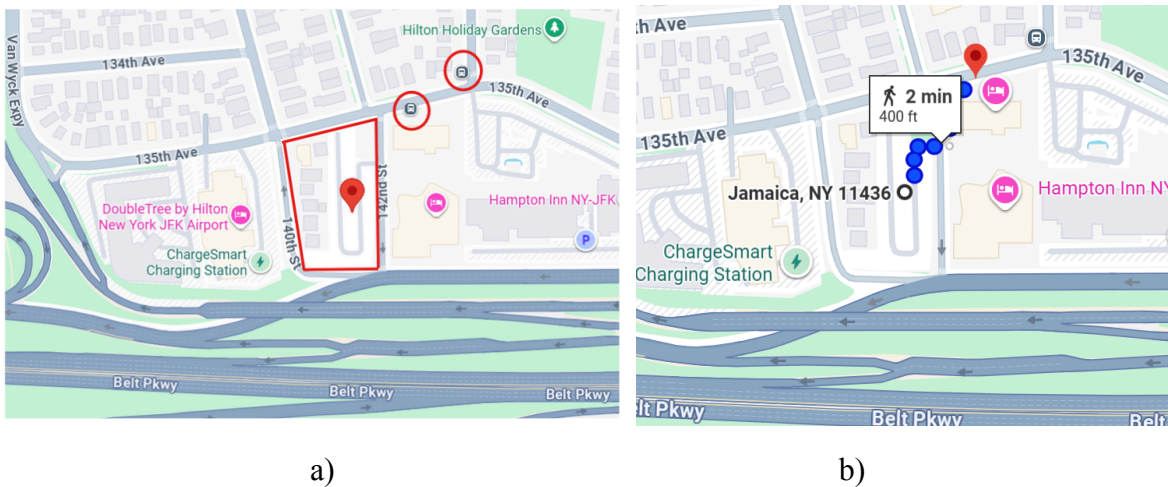
### 2.1.3 Solar Access

According to the solar map provided by SunCalc (2025), the site in Jamaica has good solar access. As illustrated in Figure 2.1.4, it can be observed that the solar path of the site travels east-southeast in the morning to the west-southwest in the evening. The total sunlight duration is 11 hours 45 minutes, and the shadow is 0.98 m long, pointing to the north. This implies that the site receives full and direct sunlight on the south at midday. Based on the map, the sun is located in the east in the morning, and it moves to the west later in the afternoon. The shadows move from the lower right side to the upper left side of the site during the day. In addition, it can be noted that the north side has limited access to direct sunlight because of being overshadowed by existing low-rise buildings, while the south side, which faces the open area of Belt Parkway, has great sunlight access.



**Figure 2.1.4** Solar Map (suncalc.org, 2025)

## 2.1.4 Access and Transportation



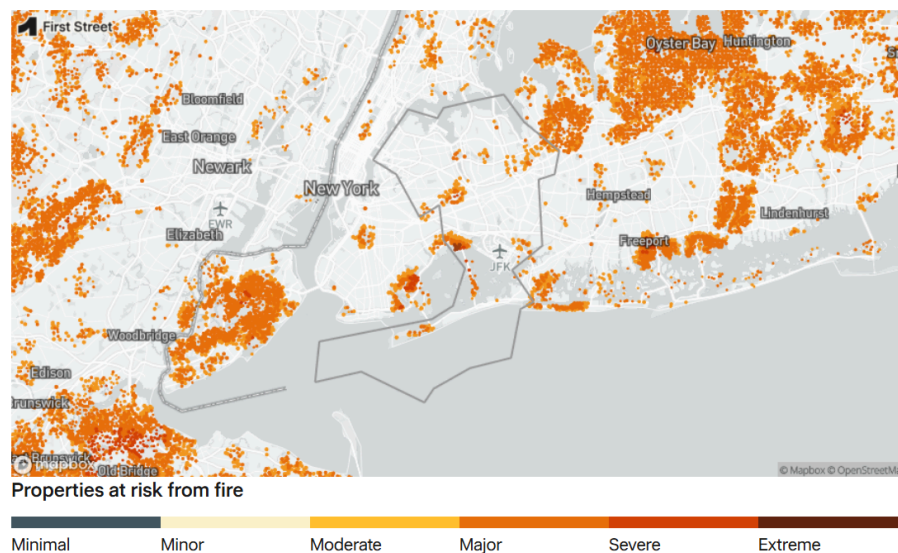
**Figure 2.1.5** a) Bus stop stations nearby b) Direction to the nearest bus stop station  
(Google Maps, 2025)

The project site is situated within an urban network in Jamaica, Queens that offers excellent access to local highways and regional transportation infrastructure. The location is convenient by its proximity to the John F. Kennedy International Airport, which is located to the north. To the east, there is I-678/Van Wyck Expressway, which serves as a main airport travel route and links

JFK International Airport to Long Island and midtown Manhattan. In the south, there is access to Belt Parkway, one of the major arterial roads that connects the site with Brooklyn and Staten Island. From Figure 2.1.5, it is seen that public transportation is also available nearby, with the nearest 2 bus stops 135 Av/142 St and 143 St/135 Av, which are located only within 2 and 5 minutes walking by foot, respectively.

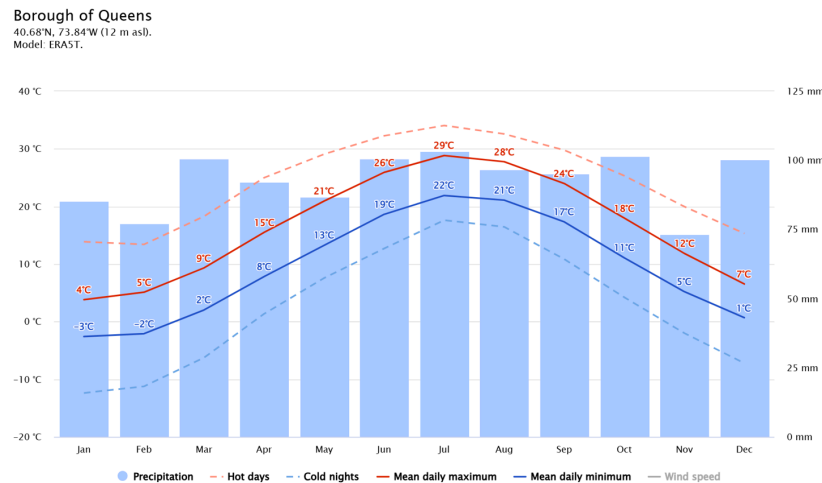
### 2.1.5 Bushfire Risks

According to the wildfire risk map classification provided by [Firststreet.org](https://www.firststreet.org) (2025), the Queens County in NYC lies within a moderate risk zone (Figure 2.1.6). According to the source, this level of risk is based on the probability of fire risk that residential and infrastructure properties (approximately 17,000 buildings in Queens) may face during the next 30 years. The New York State Department of Environmental Conservation (2025) also provides the Fire danger rating area map for different counties in NYC. This map indicates that the Long Island region, which includes Queens County, typically belongs to a low fire danger rating throughout the year. This is primarily because of the high urban density in Queens, where the natural vegetation cover is minimal, and the land is occupied by buildings, roads, and pavements that do not allow for fire distribution. Consequently, the bushfire risk for the site is minimal, requiring on taking structural fire safety measurements for the hotel, specified by NYCBC.



**Figure 2.1.6** Wildfire risk map for Queens County ([firststreet.org](https://www.firststreet.org), 2025)

## 2.1.6 Weather Conditions



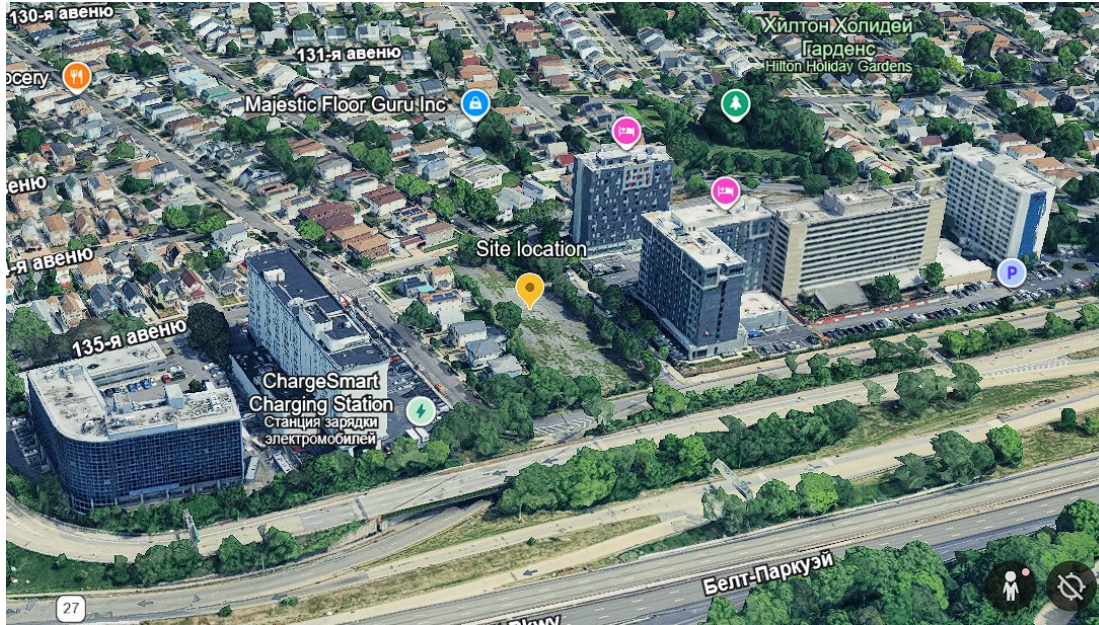
**Figure 2.1.7** Precipitation and average temperature (meteoblue, 2025)

Figure 2.1.7 from Meteoblue (2025) depicts that the average high temperatures fall between 4°C in January and 29°C in July, corresponding to the coldest month of January and the hottest month of July. In addition, the precipitation across the year shows that the highest precipitation was recorded in July (95 mm) and the lowest precipitation was recorded in November (73 mm). Low temperatures in winter range between -2 °C and -3 °C, and the annual average snow is 29.8 inches, with February having the greatest snowfall (Weather Spark, 2023). The humidity rates are moderate, with the highest rates of about 68 percent in September and the lowest rates of about 55 percent in April (Weather-and-Climate, 2023).

### 2.1.7 Site Survey

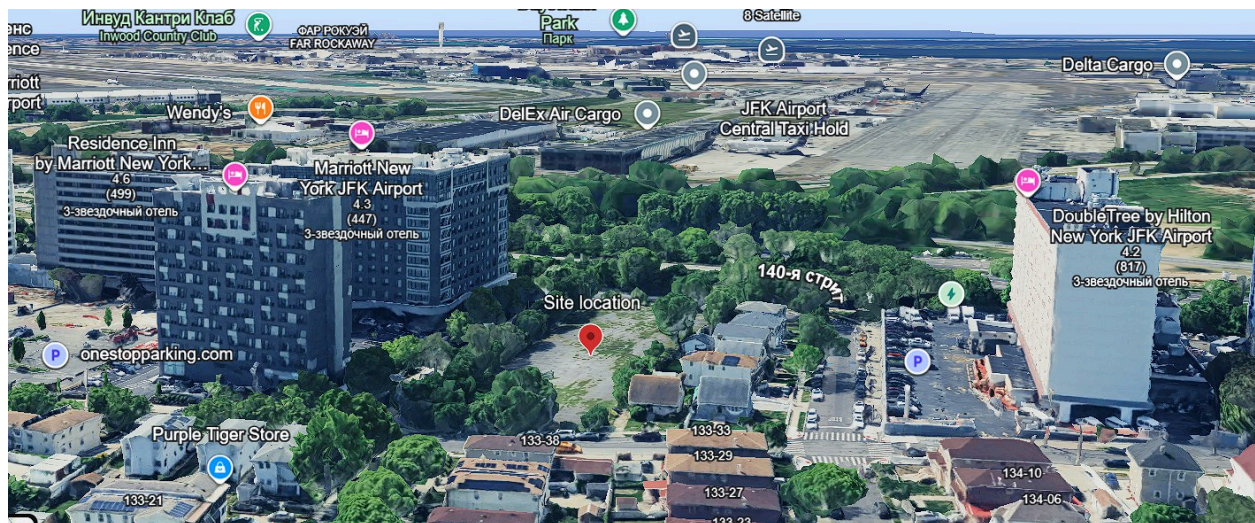
According to the site survey, the overshadowing situation is mainly determined by the surrounding constructed environment instead of natural terrain. To the East and southeast the site is bounded by mid-rise hotel buildings that have a height of about 10 to 12 stories. These buildings will create large shadows within the proposed site during the morning hours. On the other hand, the North side of the site is adjacent to low-rise, two-story detached residential houses.





**Figure 2.1.8** Site overshadowing view ([google.earth.pro](https://www.google.com/earth/pro/), 2025)

Also, as it is seen from Figure 2.1.9, there is a row of trees along the Belt Parkway, that helps in providing shade at ground level, and which are not very tall to block the views or the light from the upper floors in our proposed hotel.



**Figure 2.1.9** Site view to the airport

Geographically, the site is located on the flat plain of the Southern Queens, with a minimal slope between 0% and 3%, which implies the absence of any obstacles to solar access such as hills or

cliffs (United States Geological Survey, 2022). According to the project's geotechnical report, the soil type beneath the ground consists of cohesionless silty sand. This type of soil is common in the Jamaica region, which is covered by deep deposits of glacial sand and gravel. For our project, this type of soil is good for supporting the foundation of a high-rise hotel because it compacts well and can safely hold heavy loads.

### **2.1.8 Services**

#### **Power**

The provider for electrical power services is Consolidated Edison (Con Edison). Con Edison provides electricity for neighbourhoods such as Bellaire, Jamaica Hills, Springfield Gardens, Queens Village, and Southern Jamaica, serving approximately 166,000 customers (Con Edison, 2025). For our business hotel, Con Edison will be involved in managing the electrical grid. Since the standard single-phase residential power is insufficient, the site requires a three-phase, four-wire electrical service to support heavy loads such as elevators and commercial kitchen equipment.

#### **Gas**

The natural gas for Jamaica area is mainly supplied by National grid and also incorporates the area of North Queens. The national grid supports the links between gas lines used in heating, cooking, and hot water systems required in hotel operations. The company also adheres to safety standards through inspection and maintenance. Their service includes installation and continuous delivery of gas to commercial buildings, which facilitates the stable performance of the appliances and equipment in the hotel.

#### **Phone**

For providing telecommunications services on the site, the companies such as Spectrum Business, Verizon Fios, and Optimum will be considered. Their services include offering a high speed internet and phone lines specifically designed to meet the business requirement. Our business hotel will need a strong network infrastructure to facilitate the internet connection for the guests, conference rooms, and also offices. In order to meet the changing guest demand, the

service providers will equip the wiring and equipment needed to ensure constant and high-speed connections.

## **Water**

Under the New York City Department of Environmental Protection (NYC DEP), potable water is provided to Jamaica through large surface reservoir systems, including the Catskill and Delaware watersheds. For our hotel project, the NYC DEP will supply commercial water accounts and install meters in order to measure the consumption rate. In addition, the water supply system will be adjusted to the daily needs of the hotel, including guest rooms, kitchens, and laundry facilities.

## **Sewer**

The wastewater from the hotel will be linked to the municipal sewer system operated by NYC DEP. For the Queens site, the wastewater in the buildings within the service area is collected and taken to Jamaica Water Resource Recovery Facility in southeast Queens. It is one of the largest wastewater treatment facilities in NYC and has the capacity to treat up to 100 million gallons of wastewater daily.

## **2.2 Literature Review on Building Codes**

There were many considerations regarding which building codes to use for the project. Since its location is in New York City, Queens, the New York City Building Code (NYCBC, 2022) was the primary source for architectural solutions and insights. It is widely used by local companies because it is a revised version of the International Building Code (IBC) from 2015 with modifications for a better integration with the New York environment, local regulations, and other engineering considerations. However, in any specific sections or technical specifications that are not explicitly outlined in the NYCBC 2022, this review falls to the guidelines of the International Building Code (IBC) 2021. Applying IBC 2021 guarantees the compliance with the most recent international standards.



### **2.2.1 Use and Occupancy Classification**

According to NYCBC Chapter 3, our transient hotel is classified as a residential building, under R-1 group for use and occupancy (Section 310). However, since the hotel will include a restaurant, GYM&SPA zone, and a shopping mall, they are classified separately as Assembly group A-2, group A-3, and Mercantile group M, respectively. In addition, the second floor of the hotel will be dedicated to the business area, which will include conference rooms and offices, which corresponds to Section 304 Business group B occupancy.

### **2.2.2 Construction Classification**

The hotel is going to have a moment frame structure based on reinforced concrete and a steel truss system to incorporate the large spans of 20 meters. Since the occupancy and use is classified as R-1 and the building is a high-rise one, it must be classified I-A type based on NYCBC. Therefore, the materials must be noncombustible with the high fire resistance ratings, typically 2-3 hours.

### **2.2.3 General Building Height, Area, and Occupancy Separations**

According to the BC Section 504, the general height and number of stories of the building should be established in accordance with occupancy classification and type of construction. From Table 504.3 and Table 504.4, for occupancy groups R-1, A-2, A-3, M and B, in the mix with I-A construction type, the building can have unlimited height and number of stories only when the automatic sprinkler system is installed throughout the building, therefore it must be present in the hotel.

The area for R-1, A-2, A-3 and M occupancy and I-A construction type is unlimited too.

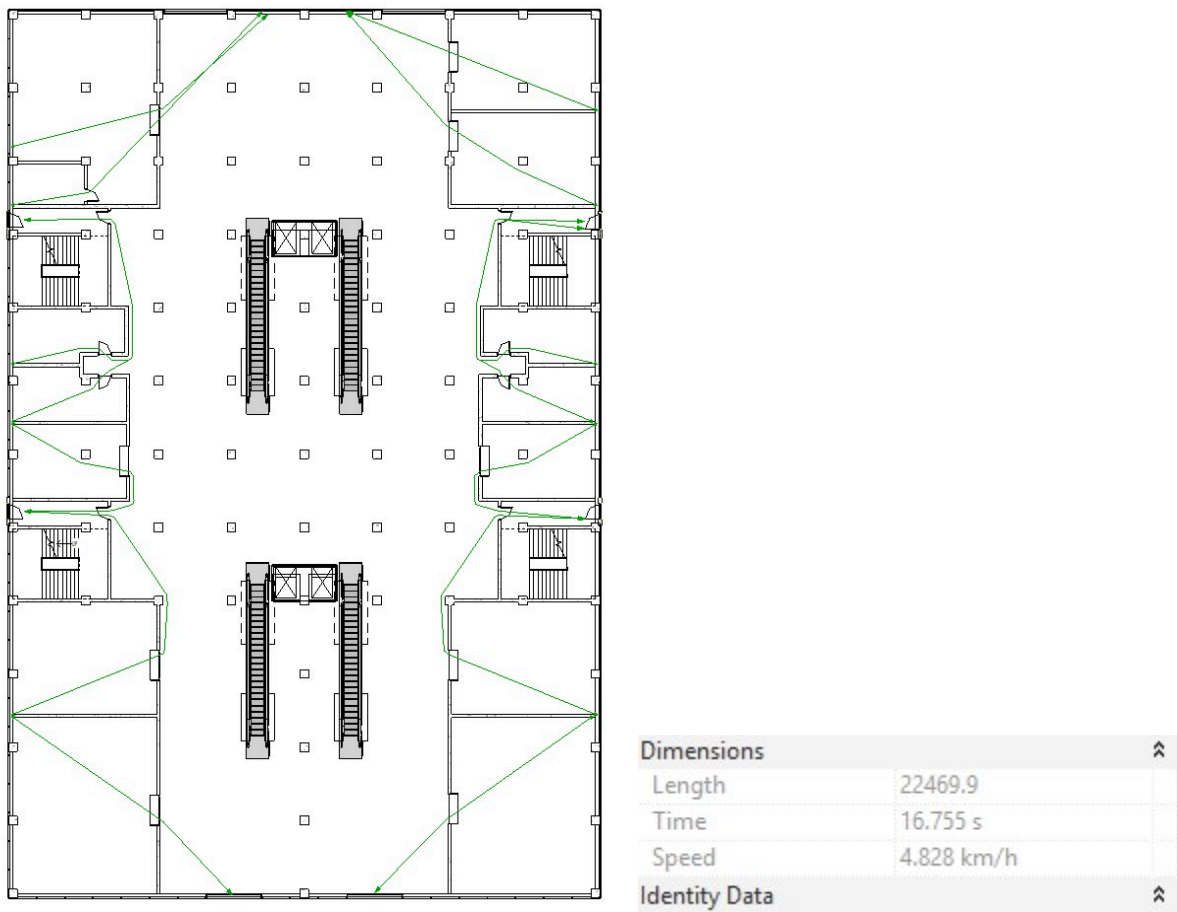
There should be a fire separation between the different occupancy sections and practically, it should be 2 hours horizontally and/or vertically.

### **2.2.4 Fire and Smoke Protection Features**

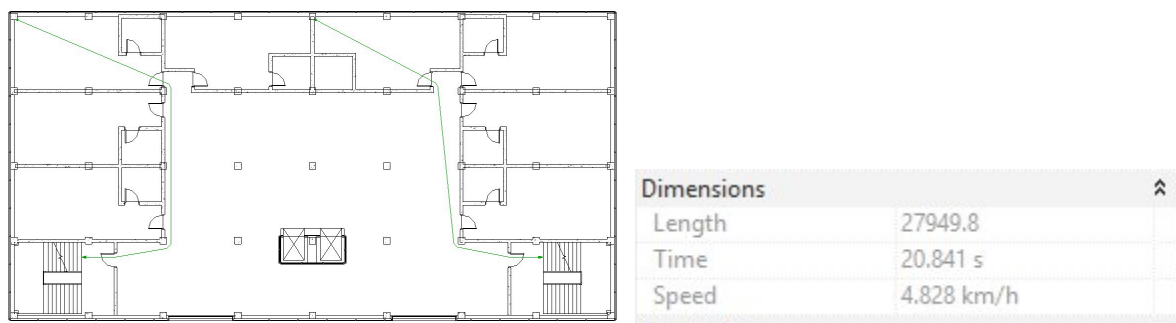
For our building, the fire barriers must have a minimum of a 2-hour fire-resistance rating. The automatic sprinkler system has to be installed. The NYCBC provides a table with the requirements for a minimum thickness of a fire resisting insulations for the different types of structures.

### 2.2.5 Emergency evacuation path

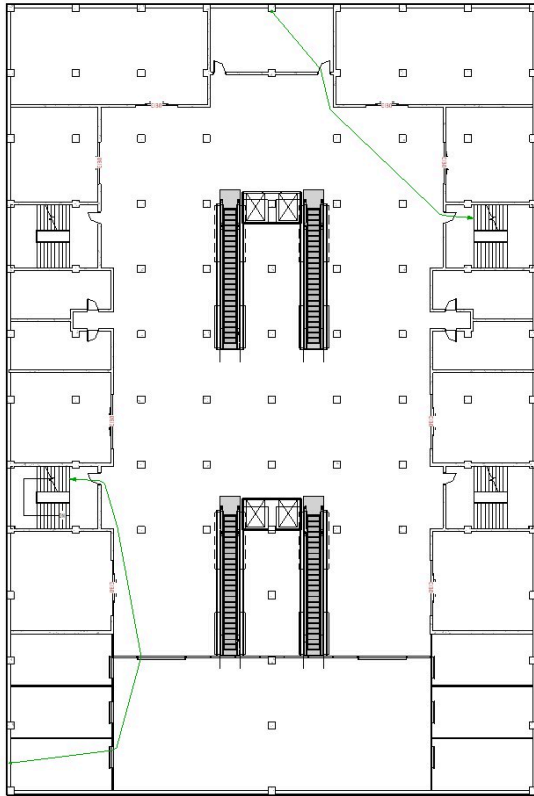
According to NYC BC section 1017.2, the maximum exit access distance from the room for the R occupancy building should not exceed 200 feet 60.96 m assuming the presence of an automatic sprinkler system, and 150 feet or 45.72 m without a sprinkler system. In our hotel, the maximum travel distance from the room to the exit is found to be at floor 2, which is 31.8 m (Figure 2.2.2).



**Figure 2.2.1** Maximum travel path for floor 1

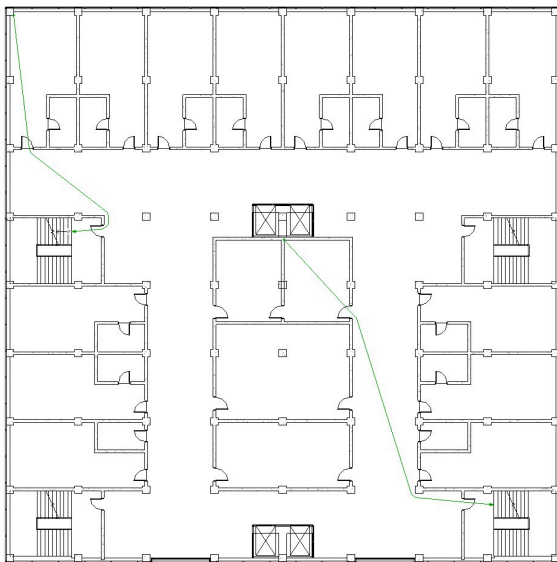


**Figure 2.2.2** Maximum travel path for floors 6-9



| Dimensions    |            | ⌵ |
|---------------|------------|---|
| Length        | 31788.6    |   |
| Time          | 23.703 s   |   |
| Speed         | 4.828 km/h |   |
| Identity Data |            | ⌵ |

**Figure 2.2.3** Maximum travel path for floor 2



| Dimensions    |            |  |
|---------------|------------|--|
| Length        | 27478.5    |  |
| Time          | 20.489 s   |  |
| Speed         | 4.828 km/h |  |
| Identity Data |            |  |

**Figure 2.2.4** Maximum travel path for floors 3-5

### 2.2.6 Number of elevators and stairs

In order to identify the required number of distinct exits, the occupancy load must be calculated for each story of the hotel. The BC Section 1004 clearly states the occupant load factor directly corresponds to the function of the space. From Table 1004.5 “Maximum floor area allowances per occupant”, it is shown that the occupant load factor for business area is 150 gross square feet, for residential area is 200 gross square feet, and for kitchen/commercial areas is also 200 gross square feet. To calculate the maximum occupancy load per story, the areas of all rooms will be summed and divided by the occupant load factor. Thus, an example of calculation for first floor is as follows:

$$\text{Occupant load factor} = 200 \text{ square feet} = 200 * 0.0929 \text{ m}^2 = 18.58 \text{ m}^2$$

$$\text{Room area per story} = 746 \text{ m}^2$$

$$\text{Occupant load per story} = \frac{746}{18.58} = 40.15 = 41$$

**Table 2.2.1** Occupancy Load for each floor

| Floor levels | Area, $\text{m}^2$ | Occupant load factor, square feet | Occupant load per story |
|--------------|--------------------|-----------------------------------|-------------------------|
| 1            | 746                | 200                               | 41                      |
| 2            | 762                | 150                               | 74                      |
| 3-5          | 568                | 200                               | 31                      |
| 6-9          | 334                | 200                               | 18                      |

Section 1006 provides the minimum conditions of safe egress ensuring that people would have alternative escape routes in case of an emergency. Particularly, Section 1006.3 specifies the required number of exits per story depending on its total occupant load. The Table 1006.3.3 “Minimum Number of Exits per Story” states that the occupant load of any story with 1-500 persons must have at least 2 different exits. Based on the calculations, the maximum occupant

load for this project is 74. Since this number is less than the 500 person limit, this story must have at least two exits to satisfy the design requirements.

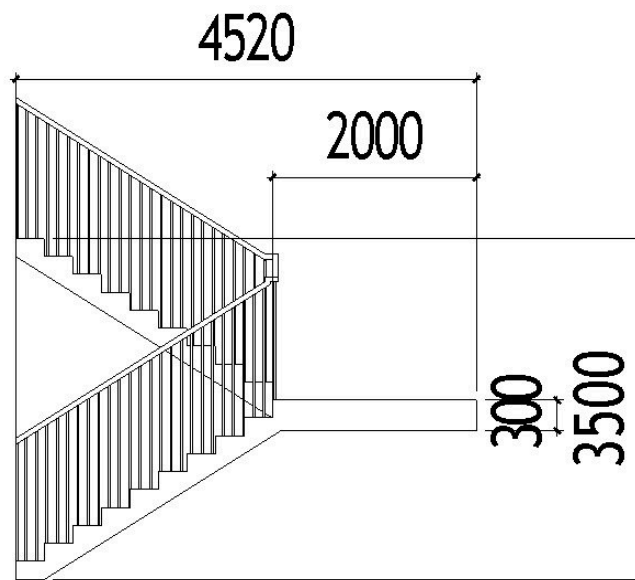
After careful consideration, it was decided to provide 4 exit stairways and 4 elevators for floors 1-5, considering their large territories, while remaining stories 6-9 will have 2 stairway exits and 2 elevators.

### 2.2.7 Stair dimensions

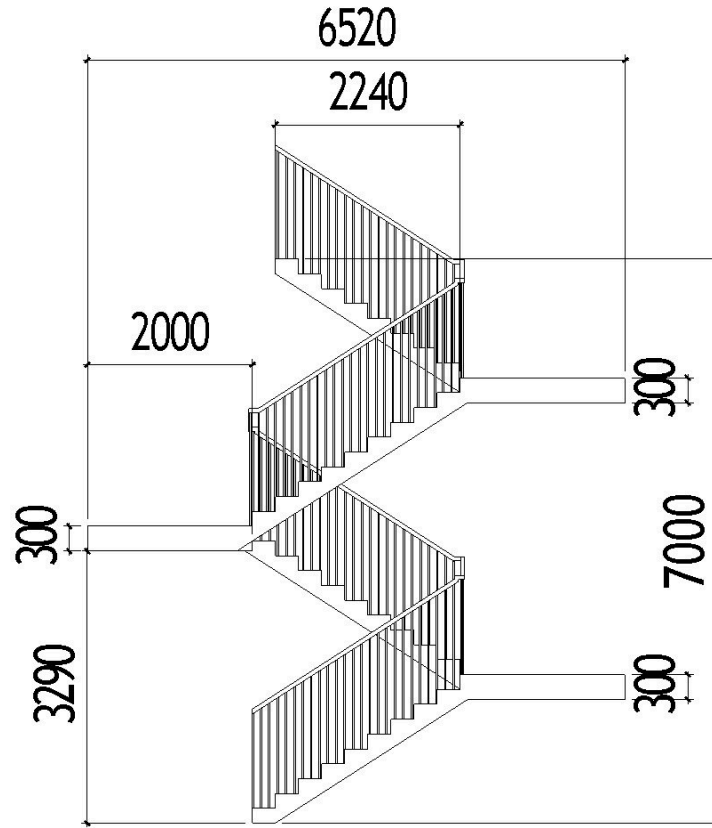
According to the Section NYCBC 1011, the stairways should comply with the following requirements:

- The minimum clear width should not be less than 1117.6 mm
- The maximum height of stair riser should be 177.8 mm and minimum height 101.6 mm
- Rectangular tread depth should be at least 279.4 mm
- The stairway headroom clearance should be minimum 2133.6 mm
- Landing should have a minimum depth of 1219 mm

In our hotel, there are two staircases that have a landing depth of 2000 mm, a rise of 180 mm, and a depth of 300 mm.



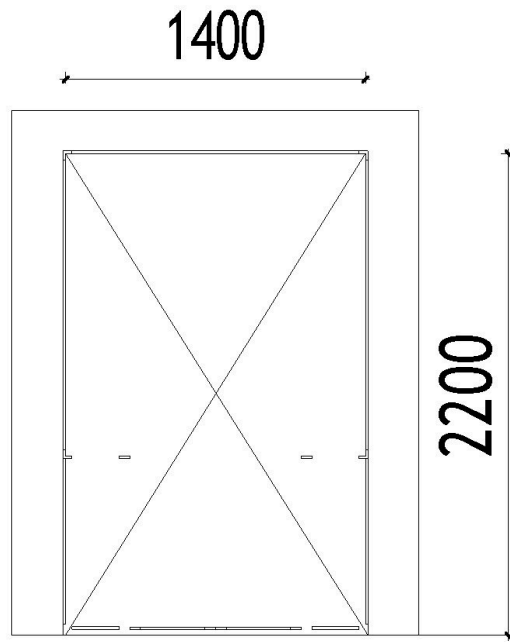
a)



**Figure 2.2.5** a) Stairway at the floors 2-9, b) Stairway at the first floor

### 2.2.8 Elevator dimensions

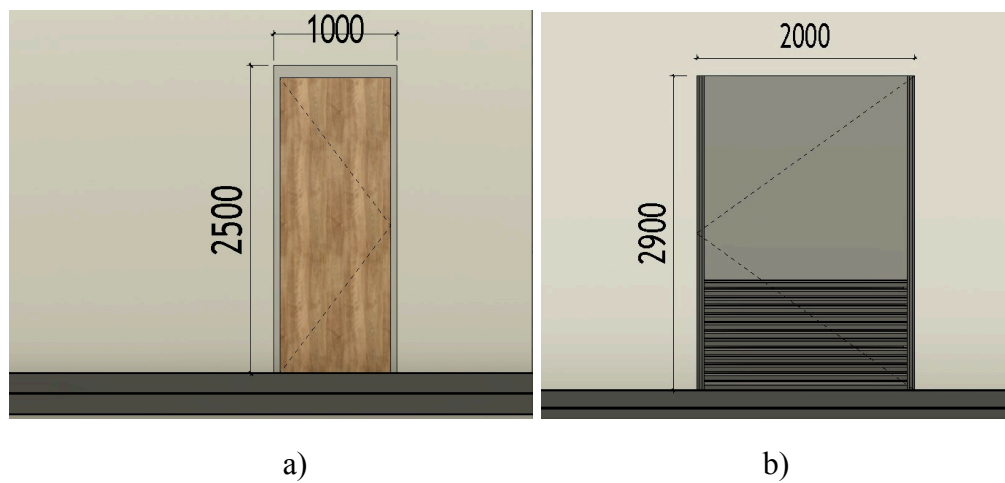
According to NYCBC Section 3002.4, for buildings having five and more floors, or with four and more floors underground, a minimum one elevator must be provided to access all floors. In addition, at least one elevator is required to accommodate an ambulance stretcher having dimensions of 610 mm by 2134 mm. In our hotel, all four elevators have dimensions of 1400 mm by 2200 mm as shown in Figure 2.2.6 below.



**Figure 2.2.6** Elevator dimensions

### 2.2.9 Door dimensions

From NYCBC Section 1010, the required minimum width of the door should be 812 mm, while the height should be at least 2032 mm. In our business hotel, there are a variety of doors that were chosen based on functionality and suitability to specific types of rooms and spaces. As can be seen from Figure 2.2.7, the width and height of each door exceed the required dimensions.





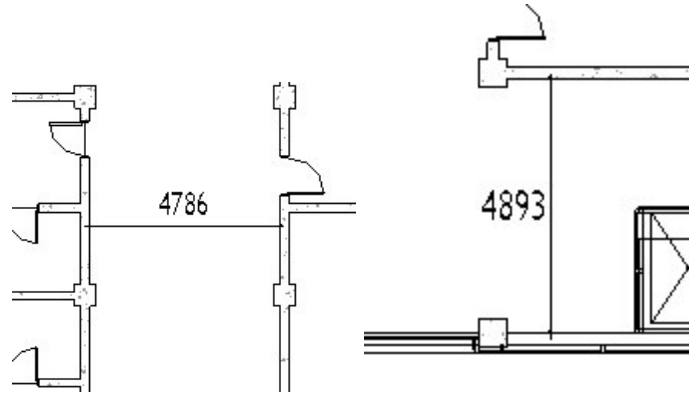
**Figure 2.2.7** Doors dimensions

- a) Typical room door b) Boutique door c) Emergency exit door  
d) Main entrance door e) Office door

### 2.2.10 Corridor dimensions

The NYCBC Section 1020 states the requirements for corridor dimensions. From table 1020.2, for R-1 type of buildings, the minimum width of the corridor should be 36 inches or 914.4 mm. In our hotel, the minimum width of the corridor exceeds 4000 mm.





**Figure 2.2.8** Corridor widths

### 2.2.11 Parking area

According to the International Zoning Code (2018), the parking space requirements should satisfy the following standards based on building use, as shown in Table 2.2.2:

**Table 2.2.2** Required number of parking slots

| Building use | Number of parking slots required | Room number/dimensions |
|--------------|----------------------------------|------------------------|
| hotel        | 1 per room                       | 74 rooms               |
| restaurant   | 1 per 100 gross square feet      | 132 $m^2$              |
| office       | 1 per 300 gross square feet      | 723 $m^2$              |
| retail       | 1 per 200 gross square feet      | 240 $m^2$              |

After estimating dimensions of specified accommodations in our hotel, the following calculations were done:

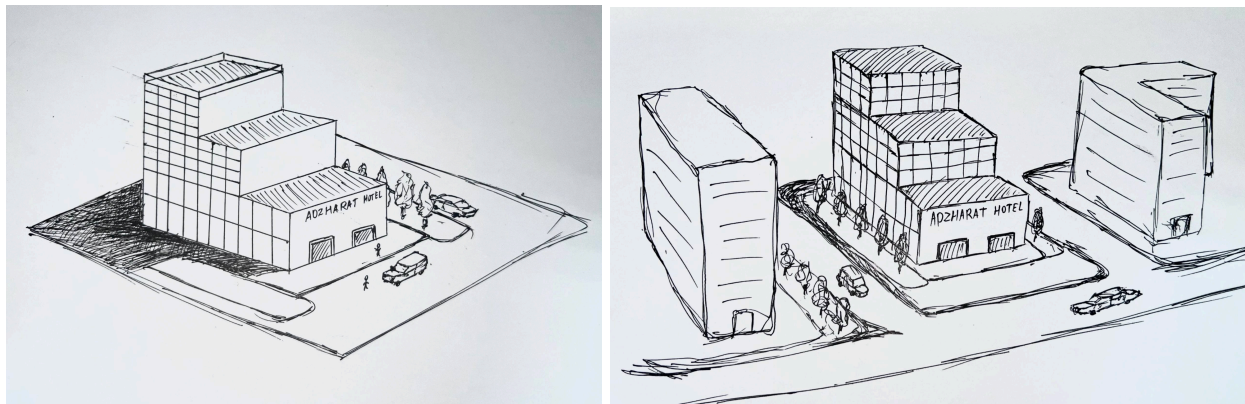
$$1 \text{ square feet} = 0.0929 \text{ m}^2$$

$$\text{Required number of parking slots} = 74 + \frac{132}{9.29} + \frac{723}{27.87} + \frac{240}{18.58} = 74 + 15 + 26 + 13 = 128$$

According to the New York Accessibility Code (2003), the minimum parking space width should be at least 2440 mm. Taking into consideration the given requirement, the off-street parking in the basement only accommodates 66 parking spaces, therefore remaining 62 parking lots were placed outside, on the building site.

## 2.3 Design process

The business hotel design originated as a result of brainstorming ideas to develop an architectural design that would balance the aesthetics of the architectural structure with the structural sustainability of a large span structure. Having estimated a number of possibilities, our team chose an unusual ladder-shaped or terraced massing as the main idea, as can be seen in the following Figure 2.3.1. This design makes a dynamic silhouette that divides the bulk of the building and possesses considerable functional advantages.

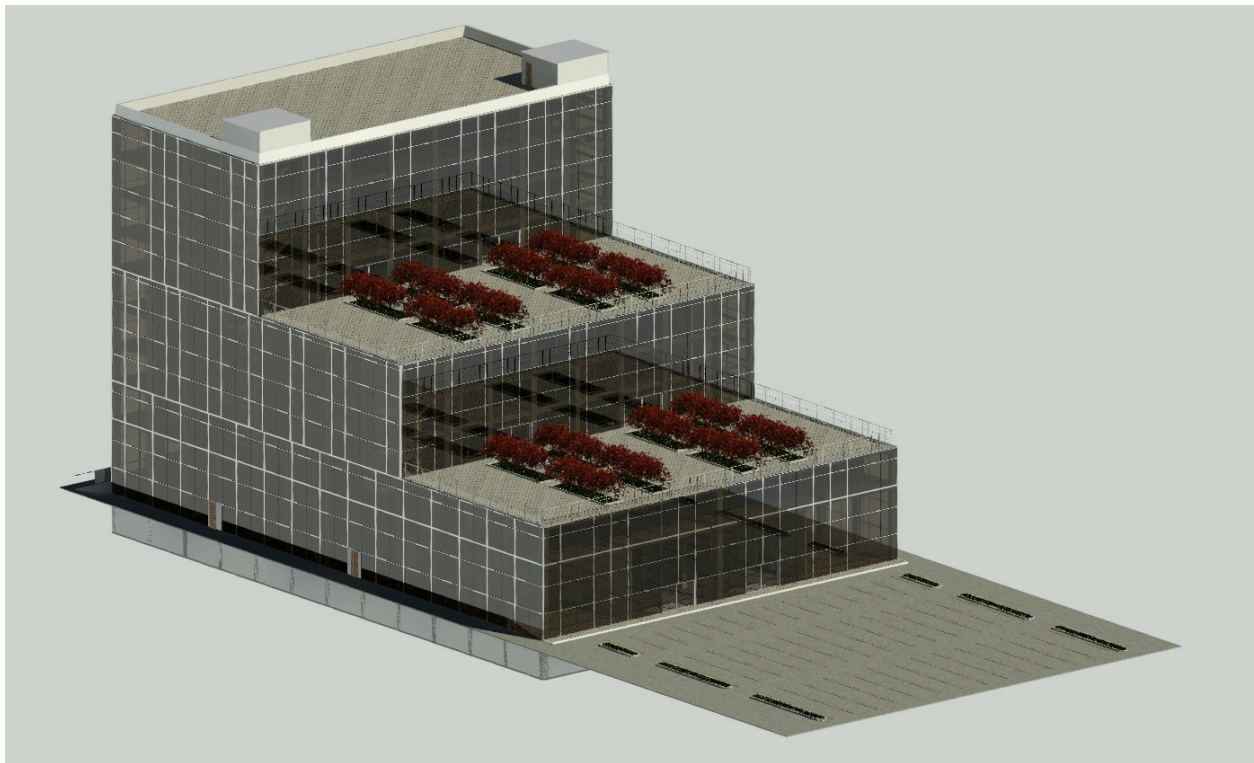


**Figure 2.3.1** Preliminary design concept

Massing of the building occurs in a vertical manner. The first two floors create a maximum footprint of 60 m by 40 m. The terraced profile starts with a decline in the floor area between the third and fifth floors, and then the decline in floor area between the sixth and ninth floors, which completes the cascading effect. This vertical massing is aligned with the definite functional zoning strategy, which divides the open and personal areas. The grand hotel lobby, restaurants, and retail are to be located on the first floor, which has a height of 7 meters. The second floor carries business facilities such as large conference rooms, several offices, individual meeting rooms, and an open networking area. Then, the third floor through the ninth floor are all levels

that are devoted solely to hotel rooms and suites. A smooth curtain wall surface was to be used to complete the modern look of the building, with extensive glass surfaces that will maximize the natural light and give panoramic views.

The existing architectural massing and the suggested primary structural grid have been visualized in a 3D model created in Autodesk Revit as shown in Figure 2.3.2. Preliminary floor plans have also been drawn to show the space layout and functional layouts of critical levels. The combination of these documents gives an overall description of the design intent.

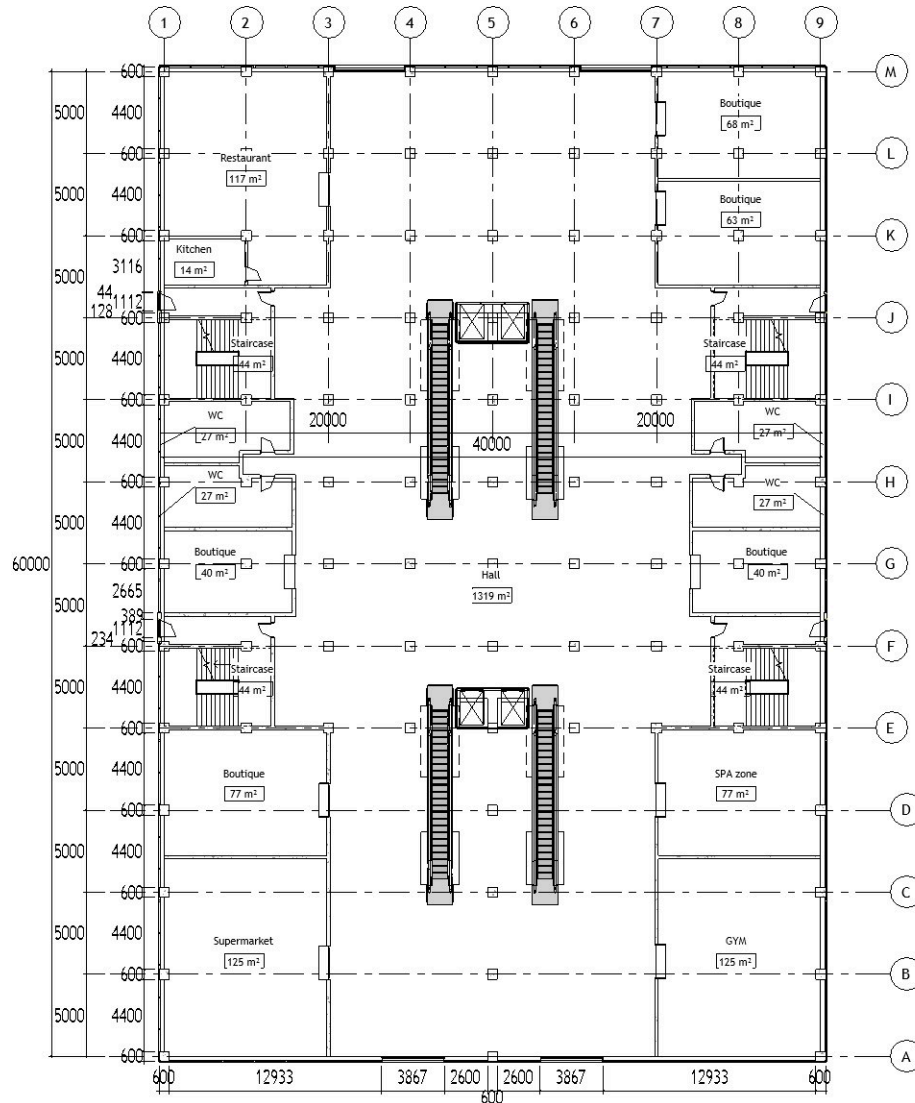


**Figure 2.3.2** Rendered 3D model

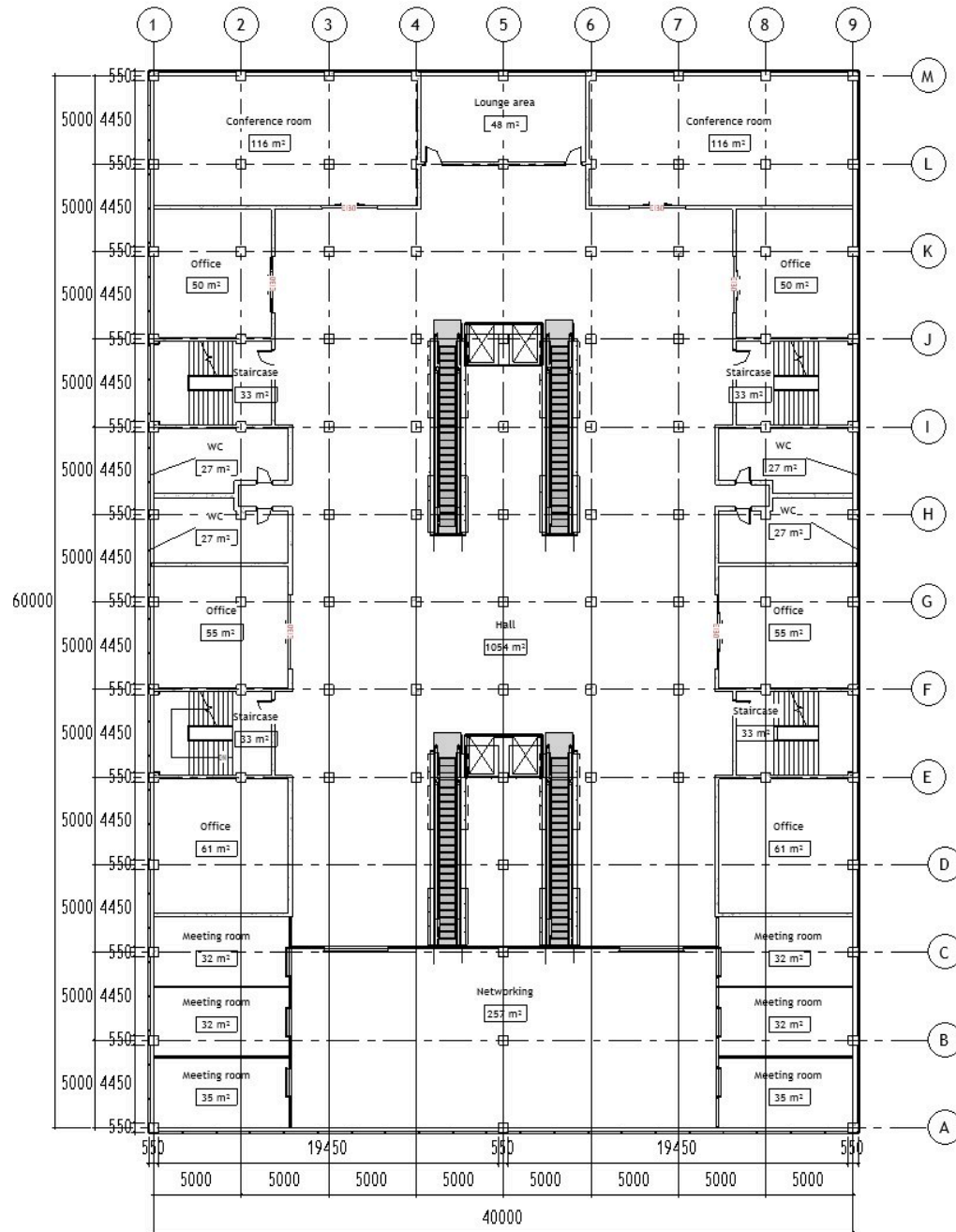
The main structural grid encompasses the building of 60 m by 40 m. The length of the building is cut into three large 20-meter spans, as this provides as much flexibility as possible to retail and restaurants and reduces the number of interior columns. In contrast, the columns are spaced at 5 meters, which is not only structurally efficient, but also very convenient with typical layouts of hotel rooms on the higher levels. The 20-meter spans will be problematic and will necessitate a strong floor framing system, therefore the alternatives could be deep steel trussing, long-span

composite beam, or post-tensioned concrete system, which was under discussion. One of the critical points in the future analysis will be the load transfers in the points of reduction of the floors area on the third and the sixth level.

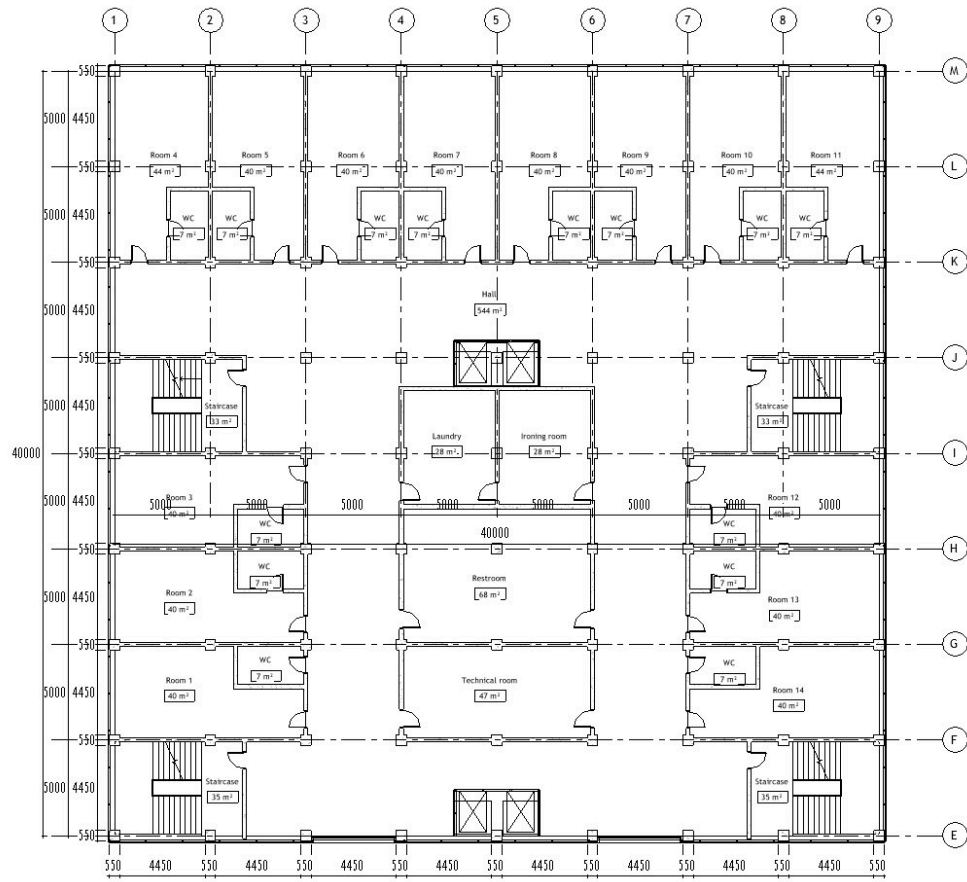
### 2.3.1 Layout and floor plans



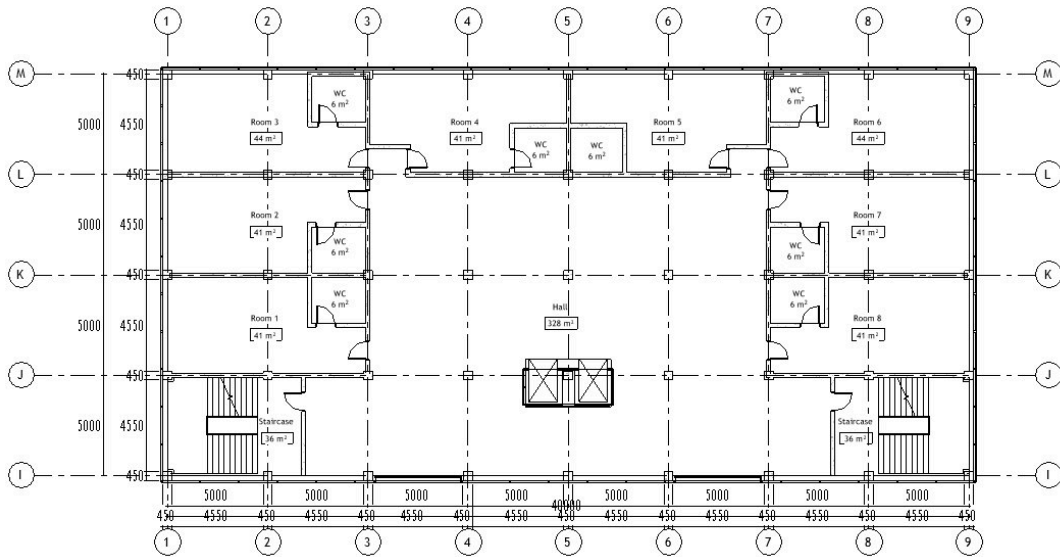
**Figure 2.3.3** Floor plan for 1st floor



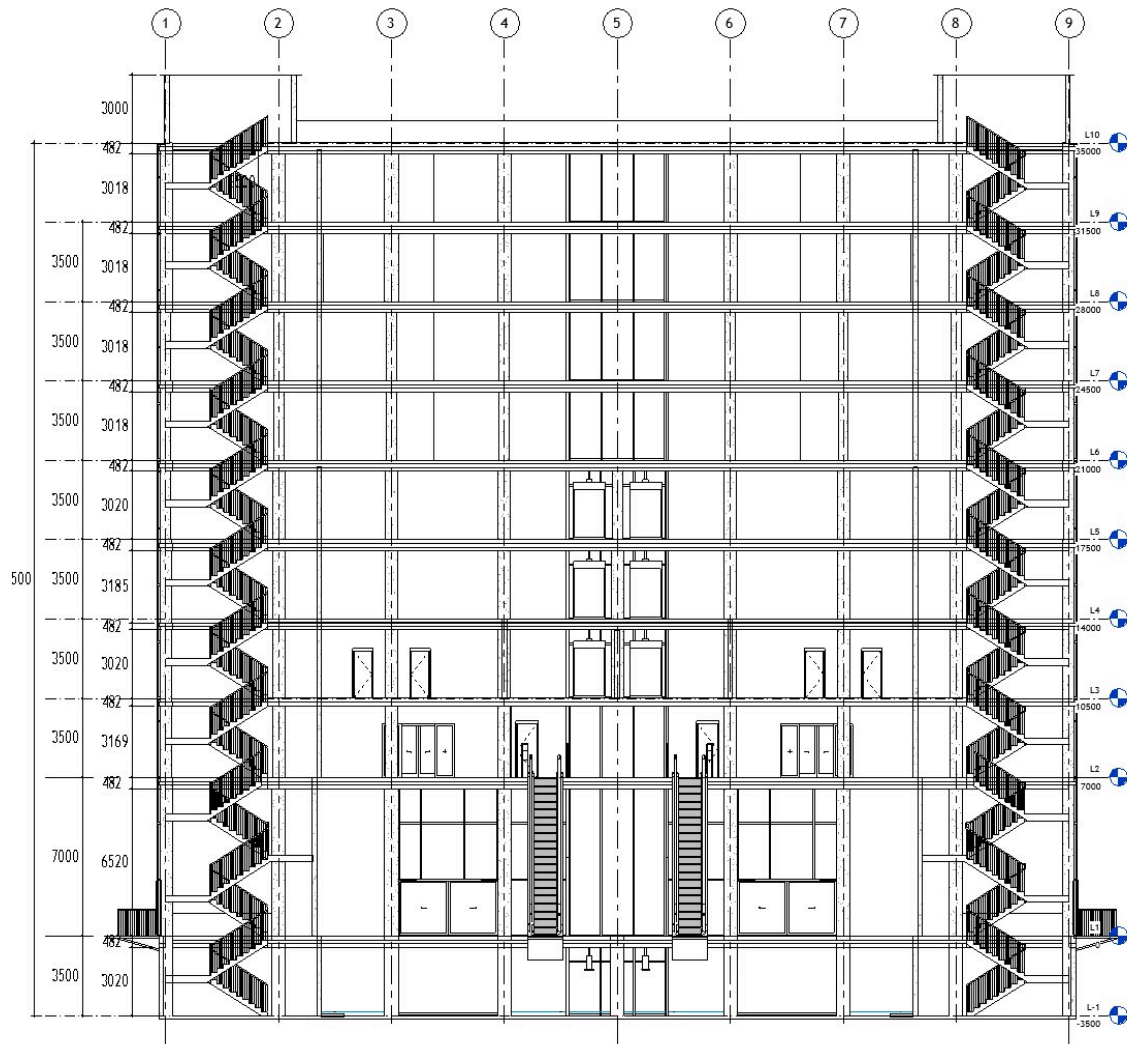
**Figure 2.3.4** Floor plan for 2nd floor



**Figure 2.3.5** Floor plan for floors 3-5

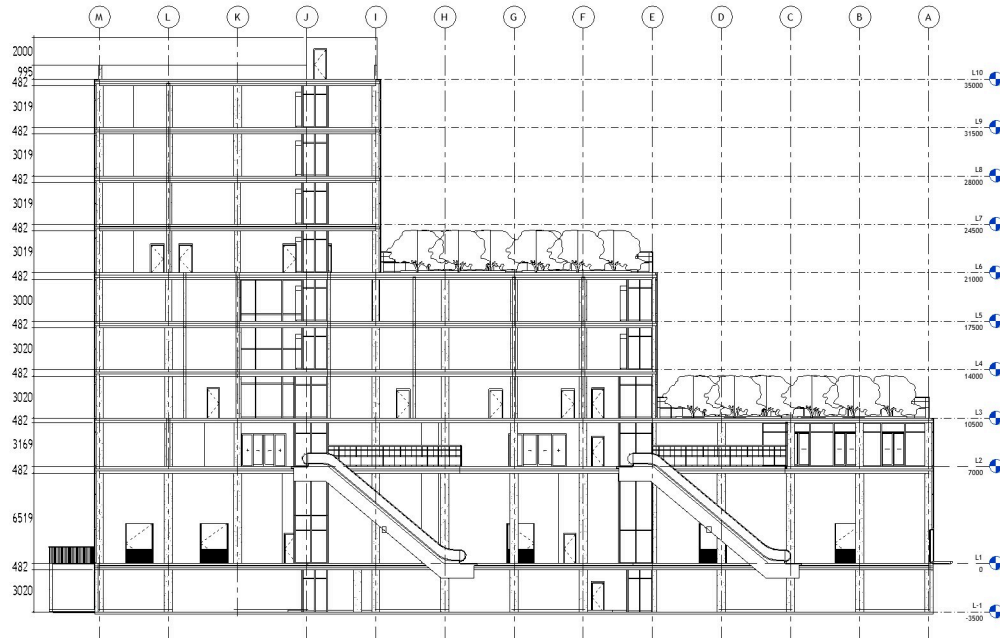


**Figure 2.3.6** Floor plan for floors 6-9



**Figure 2.3.7** Section view with stairs





**Figure 2.3.8 Elevation View**

## **2.4 LEED for green building design, construction, operation and performance**

### **2.4.1 LEED Definition**

According to the U.S. Green Building Council, Leadership in Energy and Environmental Design (LEED) certification is the most recognizable measurement of the green building rating around the world. It gives a guideline for healthy, cost-effective, and efficient green projects of various types, including their beginning, exterior and interior finishes, operations and maintenance, which will be aligned with profit for the environment and society. LEED certification is an advantage for the new projects, which will show their environmental consideration and is highly valued by the united community of organizations and individuals who are responsible for influencing the construction market changes.

The LEED certification evaluates many construction aspects from the energy and water supply to the selection of materials. The projects have to meet minimum requirements in order to be considered for the next process where they are given points the score of which will determine



their level of certification. There are four of them: certified (40-49 points), silver (50-59 points), gold (60-79 points), and platinum (80+ points).

### 2.4.2 LEED Requirements

The rating system and versions of it have a number of variations, our project is suitable for the “LEED BD+C: New Construction rating system” and the version should be LEED v4 based on the experience of the majority of the hotels in New York City.

The minimum requirements are as follows:

- 1) The project must be in a permanent location on existing land.
- 2) The LEED boundaries have to be explicitly defined, such as the use of occupancy to ensure that the project is reasonably evaluated. In our case, we have parking.
- 3) The project has to have a minimum of 93 square meters of gross floor area.

Our hotel is aimed to achieve LEED Gold certification, and there are a number of criteria to be met to accomplish this goal. In total, there are eight categories of evaluation: location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation, and regional priority. Each category has a list of credits that can be earned if the building meets them. Depending on the site conditions of the area of Queens, NYC, and the structural strategies used, our team has focused on a total of 61 points.

### 2.4.3 LEED Project Scorecard

#### *Location and Transportation*

| Y | P | N |
|---|---|---|
| Y | 1 | N |

Credit

| 0 | 13 | 0 | Location and Transportation |                                            | 16 |
|---|----|---|-----------------------------|--------------------------------------------|----|
| Y |    |   | Credit                      | LEED for Neighborhood Development Location | 16 |
| Y | 1  |   | Credit                      | Sensitive Land Protection                  | 1  |
|   |    | N | Credit                      | High Priority Site                         | 2  |
| Y | 5  |   | Credit                      | Surrounding Density and Diverse Uses       | 5  |
| Y | 5  |   | Credit                      | Access to Quality Transit                  | 5  |
| Y | 1  |   | Credit                      | Bicycle Facilities                         | 1  |
| Y | 1  |   | Credit                      | Reduced Parking Footprint                  | 1  |
|   |    | N | Credit                      | Green Vehicles                             | 1  |

**Figure 2.4.1** Score for Location and Transportation

As it is seen from Figure 2.4.1, this type of category shows a major strength due to its convenient location in Jamaica, Queens, which resulted in 13 points of credit. The location is a high-density urban area with established infrastructure, where a survey of the vicinity within a 400-meter walking radius revealed a wide range of functions such as restaurants, banks, pharmacies, and residential areas. This density gives the project 5 points and eliminates the necessity to travel by personal vehicles. In addition, the Adzharat Hotel is characterized by outstanding transit connectivity, which will provide an extra 5 points in terms of Access to Quality Transit. The location is within close proximity to the JFK AirTrain, the Long Island Rail Road (LIRR) Jamaica Station, and a variety of NYC Subway lines that allow the international community and local employees to easily access the location. In addition to this strategy, the design minimizes the parking area by locating majority of parking lots underground, which will earn 1 point, with a second point received by incorporating safe bicycle parking spots in basement parking. Lastly, since the construction site was previously used as a parking lot, the project will score 1 point in Sensitive Land Protection since it will not cause disturbance to prime farmland or endangered habitats.

#### *Sustainable Sites*

| 0 | 7 | 0 | Sustainable Sites |                                               | 10       |
|---|---|---|-------------------|-----------------------------------------------|----------|
| Y |   |   | Prereq            | Construction Activity Pollution Prevention    | Required |
| Y | 1 |   | Credit            | Site Assessment                               | 1        |
| Y | 1 |   | Credit            | Site Development - Protect or Restore Habitat | 2        |
| Y | 1 |   | Credit            | Open Space                                    | 1        |
| Y | 2 |   | Credit            | Rainwater Management                          | 3        |
| Y | 1 |   | Credit            | Heat Island Reduction                         | 2        |
| Y | 1 |   | Credit            | Light Pollution Reduction                     | 1        |

**Figure 2.4.2** Score for Sustainable Site

In order to incorporate the building into the local ecosystem, 7 points are covered in the category of Sustainable Sites. One of the main priorities is the minimization of the Urban Heat Island effect, which is a significant problem in New York City. To prevent this, the roof will be completed with a high-albedo white membrane having a Solar Reflectance Index of over 78, and

parking will be installed underground to avoid hot asphalt surfaces. The rainwater will be managed by installing a stormwater detention tank in the basement. This system will also collect roof runoff during stormy seasons and reduce the load on NYC's municipal sewer system, helping to prevent flooding in the city. Also, exterior lighting fixtures will be Dark Sky compliant, meaning that they will face light downward to avoid light intrusion into other residential structures nearby.

### *Water Efficiency*

| 0 | 7 | 0 | <b>Water Efficiency</b> |                               | <b>11</b> |
|---|---|---|-------------------------|-------------------------------|-----------|
| Y |   |   | Prereq                  | Outdoor Water Use Reduction   | Required  |
| Y |   |   | Prereq                  | Indoor Water Use Reduction    | Required  |
| Y |   |   | Prereq                  | Building-Level Water Metering | Required  |
| Y | 2 |   | Credit                  | Outdoor Water Use Reduction   | 2         |
| Y | 4 |   | Credit                  | Indoor Water Use Reduction    | 6         |
|   |   | N | Credit                  | Cooling Tower Water Use       | 2         |
| Y | 1 |   | Credit                  | Water Metering                | 1         |

**Figure 2.4.3** Score for Water Efficiency

Since our hotel will consume high amounts of water on a daily basis, the design employs strict measures to achieve sufficient use of water resources. In order to achieve an indoor water usage minimization, the EPA WaterSense labelled fixtures will be utilized in all guest rooms and shared toilets. These fixtures contain 1.28 gallons/flush toilets, 1.75 gallons/min showers, and 0.5 gpm faucets, estimated to reduce the amount of indoor water usage by 35 percent compared to the LEED standard. The landscaping plan will use the native, drought-tolerant plants on the outside which are adapted to the New York climate. Together with a smart drip irrigation system with moisture sensors, it will also reduce by over 50 percent the amount of potable water that is used in irrigation.

## Energy and Atmosphere

| 0 | 16 | 0 | <b>Energy and Atmosphere</b> |                                            | <b>33</b> |
|---|----|---|------------------------------|--------------------------------------------|-----------|
| Y |    |   | Prereq                       | Fundamental Commissioning and Verification | Required  |
| Y |    |   | Prereq                       | Minimum Energy Performance                 | Required  |
| Y |    |   | Prereq                       | Building-Level Energy Metering             | Required  |
| Y |    |   | Prereq                       | Fundamental Refrigerant Management         | Required  |
| Y | 4  |   | Credit                       | Enhanced Commissioning                     | 6         |
| Y | 10 |   | Credit                       | Optimize Energy Performance                | 18        |
| Y | 1  |   | Credit                       | Advanced Energy Metering                   | 1         |
|   |    | N | Credit                       | Demand Response                            | 2         |
| Y | 1  |   | Credit                       | Renewable Energy Production                | 3         |
|   |    | N | Credit                       | Enhanced Refrigerant Management            | 1         |
|   |    | N | Credit                       | Green Power and Carbon Offsets             | 2         |

**Figure 2.4.4** Score for Energy and Atmosphere

In order to satisfy the credit requirements for the Energy and Atmosphere category, our building will implement several features. First of all, the building envelope and mechanical systems will be developed to be as efficient as possible in the humid continental climate of New York. A Variable Refrigerant Flow system will be used in guest rooms to ensure that the heating and cooling of multiple zones may be controlled at the same time, whereas a high-performance curtain wall system will be used with Low-E triple glazing to reduce potentially wasted heat in the cold winters of NYC. Moreover, the rooftop photovoltaic solar panels will be installed to cover a part of the electricity needs.

## Materials and Resources

| 0 | 6 | 0 | <b>Materials and Resources</b> |                                                                                   | <b>13</b> |
|---|---|---|--------------------------------|-----------------------------------------------------------------------------------|-----------|
| Y |   |   | Prereq                         | Storage and Collection of Recyclables                                             | Required  |
| Y |   |   | Prereq                         | Construction and Demolition Waste Management Planning                             | Required  |
| Y | 3 |   | Credit                         | Building Life-Cycle Impact Reduction                                              | 5         |
| Y | 1 |   | Credit                         | Building Product Disclosure and Optimization - Environmental Product Declarations | 2         |
| Y | 1 |   | Credit                         | Building Product Disclosure and Optimization - Sourcing of Raw Materials          | 2         |
|   |   | N | Credit                         | Building Product Disclosure and Optimization - Material Ingredients               | 2         |
| Y | 1 |   | Credit                         | Construction and Demolition Waste Management                                      | 2         |

**Figure 2.4.5** Score for Materials and Resources

This category of Materials and Resources focuses on the structural durability of the building. From Figure 2.4.5, the credit “Building Life-Cycle Impact Reduction” was obtained by means of a detailed life cycle assessment of concrete that was carried out with the help of Life-365 software. The project will implement the Alternative 2 concrete mix that involves a high-performance concrete mix with a calcium nitrite corrosion inhibitor and a 40% Ground Granulated Blast-Furnace Slag. This approach projected the future service life of the base to more than 73 years, which would have a strong positive effect on the amount of carbon that could be avoided due to material repair and replacement when compared to a typical building that is code-compliant. In addition, a waste management strategy will be implemented to redirect 75 percent of the construction waste out of landfills through sorting of recyclables such as packaging, scraps of rebar, and wood.

#### *Indoor Environmental Quality*

| 0 | 11 | 0 | Indoor Environmental Quality                           | 16       |
|---|----|---|--------------------------------------------------------|----------|
| Y |    |   | Prereq Minimum Indoor Air Quality Performance          | Required |
| Y |    |   | Prereq Environmental Tobacco Smoke Control             | Required |
| Y | 1  |   | Credit Enhanced Indoor Air Quality Strategies          | 2        |
| Y | 2  |   | Credit Low-Emitting Materials                          | 3        |
| Y | 1  |   | Credit Construction Indoor Air Quality Management Plan | 1        |
|   |    | N | Credit Indoor Air Quality Assessment                   | 2        |
| Y | 1  |   | Credit Thermal Comfort                                 | 1        |
| Y | 2  |   | Credit Interior Lighting                               | 2        |
| Y | 3  |   | Credit Daylight                                        | 3        |
|   |    | N | Credit Quality Views                                   | 1        |
| Y | 1  |   | Credit Acoustic Performance                            | 1        |

**Figure 2.4.6** Score for Indoor Environmental Quality

As shown in Figure 2.4.6, the project aims at achieving 11 points under Indoor Environmental Quality to support the health and comfort of the guests. This will be achieved by source control with an emphasis on the utilization of low-emitting materials, meaning that all interior paints, adhesives, sealants, and flooring systems will be Low-VOC to avoid off-gassing. An IAQ management plan will be adopted during the construction, where ductwork will be closed, and absorbent materials will be covered against moisture. Also, to ensure comfortable conditions for occupants, the guest rooms have individual thermal controls and individual lighting dimmers (2

points). The architecture and glazing of the building will guarantee that more than three-quarters of habitually used areas receive adequate natural daylight and offer direct views to the outside urban landscape.

### *Innovation and Regional Priority*

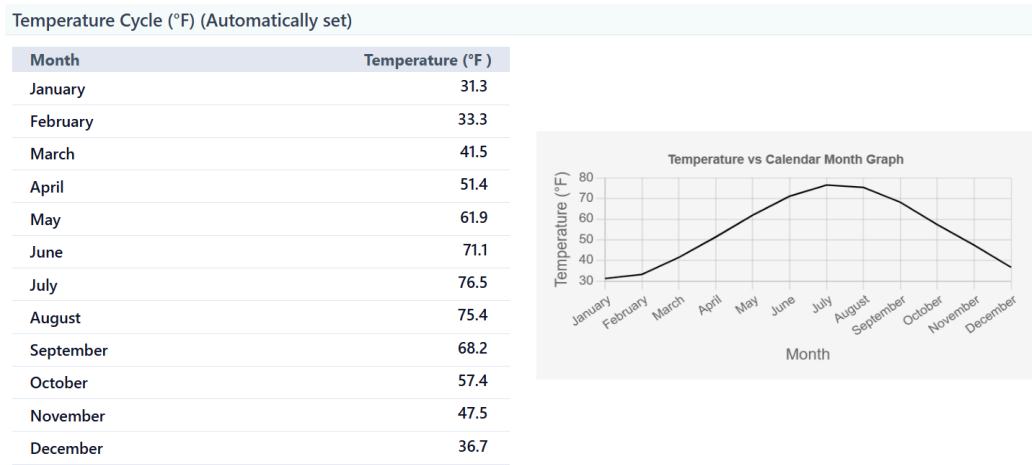
|   |   |   |                          |                                    |          |
|---|---|---|--------------------------|------------------------------------|----------|
| 0 | 0 | 0 | <b>Innovation</b>        |                                    | <b>6</b> |
|   |   | N | Credit                   | Innovation                         | 5        |
|   |   | N | Credit                   | LEED Accredited Professional       | 1        |
| 0 | 0 | 0 | <b>Regional Priority</b> |                                    | <b>4</b> |
|   |   | N | Credit                   | Regional Priority: Specific Credit | 1        |
|   |   | N | Credit                   | Regional Priority: Specific Credit | 1        |
|   |   | N | Credit                   | Regional Priority: Specific Credit | 1        |
|   |   | N | Credit                   | Regional Priority: Specific Credit | 1        |

**Figure 2.4.7** Score for Innovation and Regional Priority

In conclusion, the “Adzharat” business-hotel is projected to achieve a total of 61 points, securing LEED Gold Certification. In our case, it is necessary to improve the Innovation category by incorporating a new policy under which the hotel will ensure the health priority of all guests and clients, as well as working staff.

## **2.5 Life Cycle Cost Analysis Using Life-365 Software**

Life-365 software was utilized to predict the service life and life-cycle costs of reinforced concrete structures. The main aim of this analysis was to model the chloride exposure into the concrete matrix and determine the time it took before corrosion had started on the basement parking slab, which is the most susceptible structural component to the environmental degradation. The simulation parameters were adjusted to the conditions of a certain climate and operation in New York City, with daily temperature variations shown in Figure 2.5.1.



**Figure 2.5.1** NYC temperature input parameters

Since the area has harsh winters and that de-icing salts are widely used on the roads, the exposure model presupposed that cars would bring chloride-boiled slush into the parking area. As a result, the highest allowable level of chloride of surface was established by 0.80 percent of mass of cement with an accumulation period of 7.5 years, which is an example of the Severe level of exposure that is characteristic of urban parking buildings in the Northeast. In addition, to have a realistic financial analysis, the economic inputs used a 3.5 percent inflation rate and a 3.0 percent real discount rate with high repair costs due to the high rate of labour and logistical complications of construction in New York City. The cost for construction materials was also established based on the current economic report, as shown in Figure 2.5.2.

| Cost Parameters              |                                  |                                |
|------------------------------|----------------------------------|--------------------------------|
| <u>Concrete &amp; Steel</u>  | <u>Barriers &amp; Inhibitors</u> | <u>Repairs</u>                 |
| Concrete (\$/cub. yd.) *     | Membrane (\$/sq. ft.) *          | Repair (\$/sq. ft.) *          |
| 180,00                       | 6,00                             | 85,00                          |
| Black Steel (\$/lb) *        | Sealer (\$/sq. ft.) *            | Area to repair (%) *           |
| 0,95                         | 1,10                             | 10,00                          |
| Epoxy Coated Steel (\$/lb) * | Inhibitor (\$/gal) *             | Fixed repair intervals (yrs) * |
| 1,20                         | 9,50                             | 10,00                          |
| Stainless Steel (\$/lb) *    |                                  |                                |
| 4,50                         |                                  |                                |

**Figure 2.5.2** Cost parameters

The structural component for analysis was chosen to be a slab with a thickness of 165 mm and a 50 mm cover for reinforcement (Figure 2.5.3).

Select Structure Type & Dimensions

Type Of Structure \*

slabs and walls (1-D) ▾

Thickness (in) \*

6,50

Reinf. Depth (in) \*

2,00

Area (sq. ft.) \*

25834,00

Volume Of Concrete : 518.27 cub. yd.

Chloride concentration units : % **wt. conc.**

6.50 in

2.00 in

**Figure 2.5.3** Reinforced concrete dimensions

As presented in Table 2.5.1 below, four concrete mix designs were tested to find the best combination between the initial construction cost, structural longevity, and environmental sustainability. In order to align the durability analysis with the structural design calculations, a number of baseline parameters were constant among all the mixes under consideration. Firstly, the ratio of water to cementitious materials was fixed to 0.40 to attain a concrete compressive strength of 35 MPa according to the ACI 318 standard code. Also, the structural models presupposed the reinforcement with the use of standard black steel and did not utilize additional physical protection like epoxy-coating.

**Table 2.5.1** Concrete mixes

| Concrete Mixture | w/cm ratio | SCMs                  | Inhibitors                  | Barrier | Rebar type  | Rebar volume | Service life |
|------------------|------------|-----------------------|-----------------------------|---------|-------------|--------------|--------------|
| Base             | 0.40       | none                  | A&E (1 gal/cub. yd.)        | none    | Black steel | 1.2%         | 23.33 yrs    |
| Alternative 1    | 0.40       | Class F Fly ash (25%) | Ca Nitrite (3 gal/cub. yd.) | none    | Black steel | 1.2%         | 63.00 yrs    |
| Alternative 2    | 0.4        | Slag (40%)            | Ca Nitrite (3 gal/cub. yd.) | none    | Black steel | 1.2%         | 73.08 yrs    |
| Alternative 3    | 0.4        | Slag                  | Ca Nitrite (3               | none    | Black steel | 1.2 %        | 120.67 yrs   |

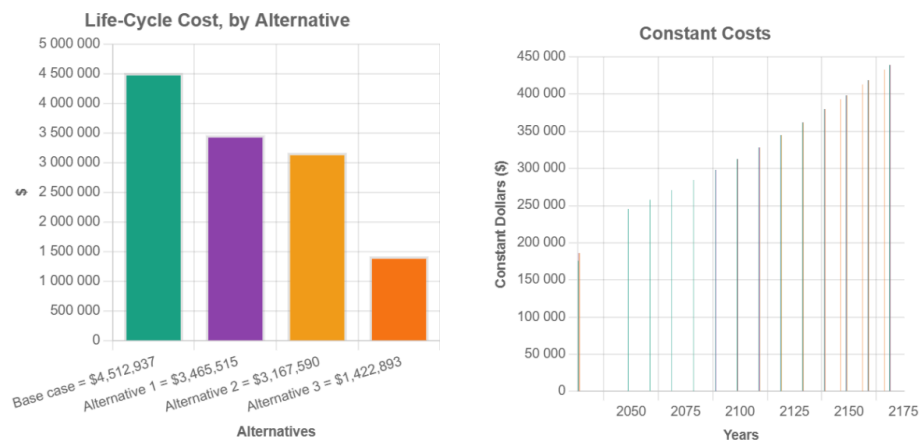


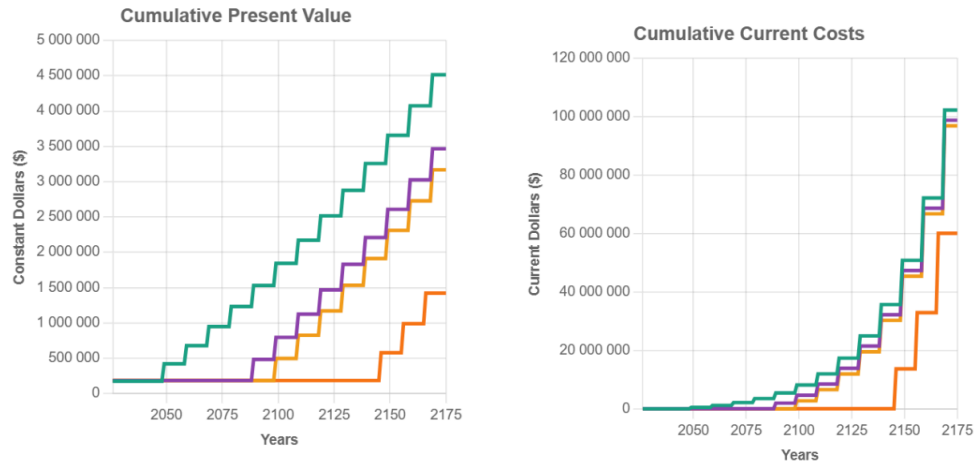
|  |  |                               |               |  |  |  |  |
|--|--|-------------------------------|---------------|--|--|--|--|
|  |  | (30%),<br>silica<br>fume (5%) | gal/cub. yd.) |  |  |  |  |
|--|--|-------------------------------|---------------|--|--|--|--|

| Name          | Construction Cost | Barrier Cost | Repair Cost | Life-Cycle Cost |
|---------------|-------------------|--------------|-------------|-----------------|
| Base case     | \$175,642         | \$0          | \$4,337,296 | \$4,512,937     |
| Alternative 1 | \$185,586         | \$0          | \$3,279,929 | \$3,465,515     |
| Alternative 2 | \$185,586         | \$0          | \$2,982,004 | \$3,167,590     |
| Alternative 3 | \$185,586         | \$0          | \$1,237,307 | \$1,422,893     |

**Figure 2.5.4** Cost report

As a result, the Alternative 2 concrete mix was selected as an optimal choice for the business-hotel project. The main reason for selecting this mix is the increased durability obtained by the 40% replacement of the Portland cement by slag. Such replacement fills the capillary pores in concrete, thus creating an impermeable structure. This physical barrier limits the migration of moisture and chloride ions through the concrete cover to corrode the black steel, resulting in the service life increase from 23 years (basic mix) to more than 73 years. Also, a 40% slag mix enhances the workability of the wet concrete without adding superplasticizers, and reduces the heat of hydration that causes thermal cracking.





**Figure 2.5.5** Life-Cycle Cost results

### **Concrete repair method against corrosion**

When parking slabs and columns eventually start to be exposed to corrosion caused by chloride and concrete spalling, the repair methods should be considered. For our hotel building, the formal Cathodic Protection method will be used to regain the structural integrity and strength. Since corrosion is an electrochemical reaction in which the rebar is an anode that loses electrons, Cathodic Protection will cause structural steel to act as the cathode where the electrons flow and thus retard the rusting process. The cathodic protection starts with saw-cutting the edge of the damaged concrete section and accessing the steel. After that, the steel is sandblasted to clean and remove existing rust. Then, zinc anodes are wired directly to the cleaned steel before the new concrete is poured. By installing the zinc, it intentionally corrodes over time and protects the structural steel from damage.

### 3. Structural Design

#### 3.1 Reference documents

##### 3.1.1 Design Codes

The business hotel was structurally designed in accordance with the International Building Code, American Concrete Institute, and American Society of Civil Engineers. The following codes were used: IBC 2019, ASCE 7-10, and ACI 318-14.

##### 3.1.2 Contract Documents

The technical drawings of the “ADZHARAT” hotel should be referred wherever needed.

##### 3.1.3 Reference Documents

The Capstone I report of the “ADZHARAT” hotel should be referred wherever needed.

#### 3.2 Type of Structure

In the beginning of the scratches our team has considered many options for structural design of our project. The primary concerns were to overcome the lateral force coming from the strong wind and a large span with a relatively long distance between the centres of the columns. The table below provides a summary of the considered lateral resisting force systems (LRFS).

**Table 3.2.1** Comparison of structural construction systems

| LRFS                                                      | General description                                                                        | Advantages                                                                          | Disadvantages                                                                                        |
|-----------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Reinforced concrete (RC) or steel moment-resisting Frames | Rigid connection between structural units, lateral resistance is overcome by frame flexure | 1) Open interiors<br>2) Architectural flexibility<br>3) Simple design<br>4) Ductile | 1) Lower stiffness<br>2) Strong connections required<br>3) Not perfectly appropriate for large spans |

|                    |                                                                       |                                                                           |                                                                                                                                     |
|--------------------|-----------------------------------------------------------------------|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| Steel braced frame | Diagonal bracing which form a lateral truss system on the bays        | 1) High stiffness<br>2) Efficiency                                        | 1) Architectural constraints                                                                                                        |
| Shear Walls        | Reinforced concrete walls resist lateral load through in-plane action | 1) High Stiffness<br>2) Can be aligned with the elevators and stair cores | 1) Due to heavy weight adds additional load on foundation<br>2) Architectural constraints<br>3) Walls will interfere in large spans |

Other LFRS variations like mega trusses, outrigger were not considered, because our project is only a 9-story building which is comparatively not as tall as the practically used structural examples for which these resisting systems were appropriate to use.

Based on the comparative analysis, our team has decided to use the RC moment frame for structural sustainability. However, the large span that appeared between columns in certain sections of our hotel would have caused problems associated with the deflection of the beams. Therefore, the material for these parts of the hotel will be prestressed concrete (PC).

Our team believes that the chosen structural decisions will work appropriately and overcome the loads effectively. Despite that, they will remain flexible and might change until the simulations and hand calculations are performed to ensure safety.

### 3.3 Material Selection

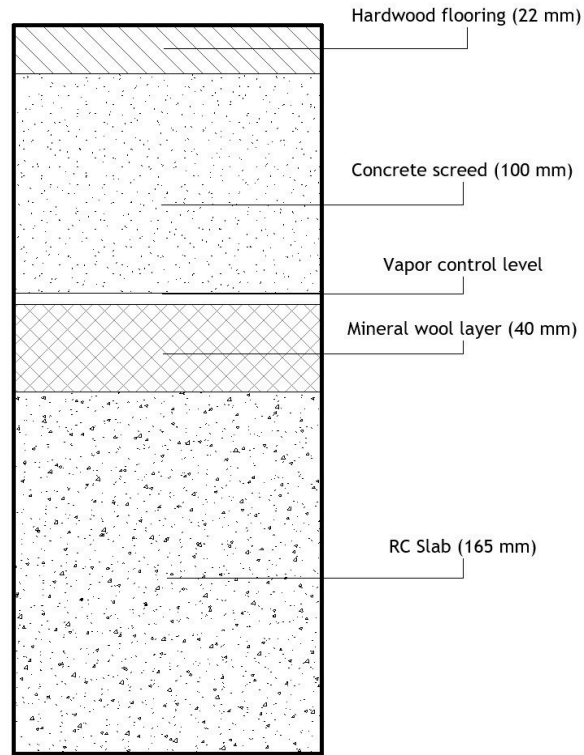
#### 3.3.1 Floor finishing

The summary of materials used for floor finishing is shown on the Table 3.3.1 below. Materials such as concrete screed, vapor control layer, mineral wool layer and RC slabs are used for all types of rooms present in the hotel. While the Reinforced concrete slab acts as a main structural

element that distributes the weight of building's components, the concrete creed provides smooth bases for other layers. Vapor control layer is used as a thin layer that minimizes the moisture damage, and mineral wool layer helps for thermal insulation and soundproofing between floors. For the hotel rooms the hardwood flooring is used for its aesthetically pleasing appearance that suits the strong and official design of the business hotel. Ceramic tiles are suitable for areas having high levels of humidity such as bathrooms due to their non-porous and water resistant nature. Terrazzo is used as a floor finishing of a restaurant since it provides great durability and strength features which are important for places having intense and high traffic of visitors.

**Table 3.3.1.** Floor finishing materials

| Floor locations   | Material                        | Thickness (mm) |
|-------------------|---------------------------------|----------------|
| Hotel rooms       | hardwood flooring               | 22             |
| SPA and bathrooms | ceramic tiles                   | 19             |
| Restaurant        | Terrazzo on stone–concrete fill | 25             |
| Fitness           | Carpet                          | 11             |
| Other locations   | Marble                          | 30             |
| All floors        | Concrete screed                 | 100            |
| All floors        | Vapor control layer             | 0              |
| All floors        | Mineral wool layer              | 40             |
| All floors        | RC Slab                         | 165            |



**Figure 3.3.1** Typical room floor material composition

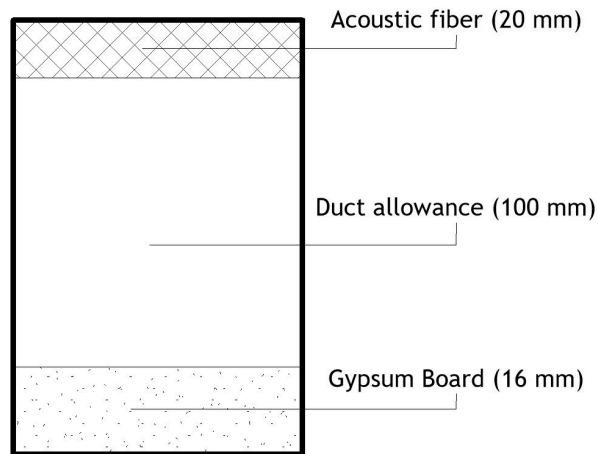
### 3.3.2 Ceiling finishing

As presented in Table 3.3.2, the finishing materials for the ceiling consists of three layers. The gypsum board is used as a lightweight material that contributes to the sound insulation that reduces the noise and more importantly, to the fire resistivity. The acoustic fiber also prevents excessive noise between floors, while mechanical duct allowance leaves the space for the necessary functional systems such as electrical wires, air ventilation, and different pipes.

**Table 3.3.2.** Ceiling finishing materials

| Material       | Thickness (mm) |
|----------------|----------------|
| Gypsum board   | 30             |
| Acoustic Fiber | 20             |

|                           |     |
|---------------------------|-----|
| Mechanical duct allowance | 100 |
|---------------------------|-----|



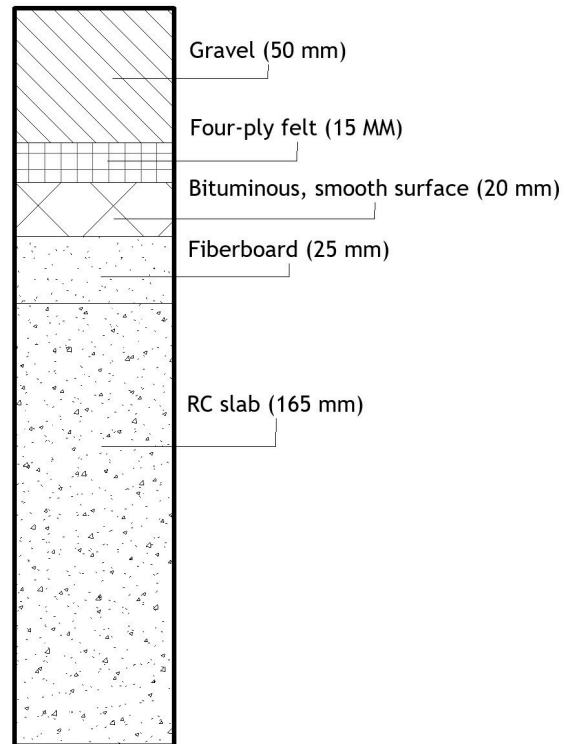
**Figure 3.3.2** Ceiling materials composition

### 3.3.3 Roof finishing

From Table 3.3.3 below, the materials for the roof are fiberboard, bituminous smooth surface and four-ply felt and gravel. Four-ply felt is used as a barrier to water penetration alongside with gravel that provides heat resistance. The fiberboard is utilized for its good insulation that helps to control heat gain or loss in the building through the roofing system. In addition, the bituminous surface layer is used against the water leakages that are crucial for snowy and rainy areas like New York city.

**Table 3.3.3.** Roof materials

| Material                   | Thickness, mm |
|----------------------------|---------------|
| Four-ply felt              | 15            |
| Gravel                     | 50            |
| Fiberboard                 | 25            |
| Bituminous, smooth surface | 20            |
| RC slab                    | 165           |



**Figure 3.3.3** Roof materials composition

### 3.3.4 Interior Walls

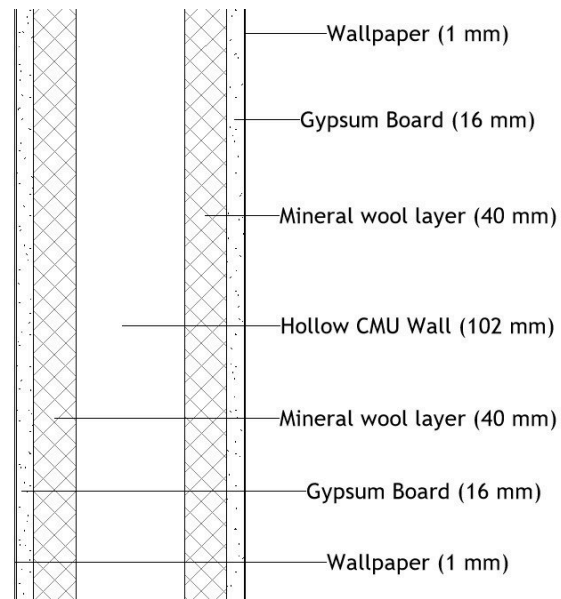
Table 3.3.4 shows materials that are used for interior walls. The wallpaper is used for aesthetic purposes as a decorative element of the wall. The gypsum plaster is a suitable material for interior wall finishing since it provides sufficient acoustic insulation and fire resistance. The third layer of mineral wool also maintains thermal insulation, ensuring that hotel rooms have a stable indoor temperature. The hollow CMU wall is used for providing structural stability and its hollow nature reduces the overall weight of the wall.

**Table 3.3.4.** Interior walls materials

| Material                  | Thickness, mm |
|---------------------------|---------------|
| Wallpaper                 | 1             |
| Gypsum Plaster (cover)    | 16            |
| Mineral Wool (insulation) | 40            |



|                           |     |
|---------------------------|-----|
| Hollow CMU Wall           | 102 |
| Mineral Wool (insulation) | 40  |
| Gypsum Plaster (cover)    | 16  |
| Wallpaper                 | 1   |



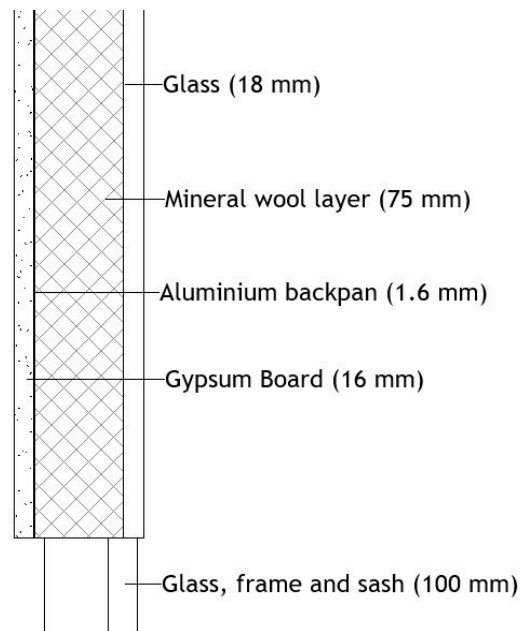
**Figure 3.3.4** Interior wall composition

### 3.3.5 Exterior Walls

Table 3.3.5 depicts materials that are used for exterior walls. The vision zone of the wall includes a combination of windows, glass, frame and sash. These components provide light transmission to the interior space and views to the outside area. The frame and sash also ensure window stability and support for glazing. On the other hand, the spandrel zone includes glass, mineral wool, aluminum backpan and gypsum plaster. The glass is used as a main decorative element for the exterior facade of the building, providing natural transmissivity and light accessibility. The mineral wool helps to regulate energy (heat) transfer within the building, while aluminum backpan acts as a securing material for structural integrity of the wall. The gypsum plaster provides a smooth finish to the exterior wall that can withstand the weather conditions and protect the underlying layers.

**Table 3.3.5** Exterior walls materials

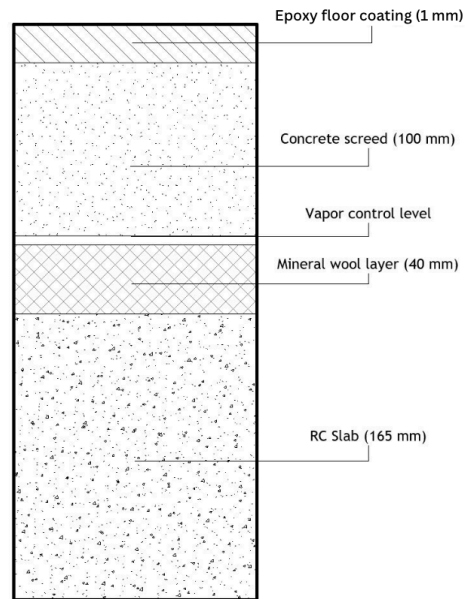
| Material                       | Thickness, mm |
|--------------------------------|---------------|
| Vision Zone                    |               |
| Windows, glass, frame and sash | 100           |
| Spandrel Zone                  |               |
| Glass                          | 18            |
| Mineral Wool                   | 75            |
| Aluminum Backpan               | 1.6           |
| Gypsum Plaster                 | 16            |



**Figure 3.3.5** Exterior wall composition

### 3.3.6 Parking lot floor

The parking lot floor was designed similarly to the usual slab section. It consisted of the components as shown in Figure 3.3.6 below:



**Figure 3.3.6** Parking lot floor material composition

The material is the epoxy floor coating with a thickness of 1 mm and a typical density of 1300 kN/m<sup>3</sup>. As a result, the dead load created by the parking floor is equal to 7,61 kPa.

### 3.4 Load Summary

#### 3.4.1 Dead Loads

According to the Capstone I report, the dead load was calculated with consideration of non-structural loads as guided in ASCE-7. The summary of the loads can be obtained from Table 3.4.1 below.

**Table 3.4.1** Dead load summary

| Floor     | Space       | DL (kPa) | Average DL (kPa) | Linear load from exterior walls (kN/m) |
|-----------|-------------|----------|------------------|----------------------------------------|
| Roof      | Roof        | 4,77     | 4,77             | 0,00                                   |
| Floor 6-9 | Hotel rooms | 8,18     | 8,88             | 1,76                                   |

|             |                                                  |      |      |      |
|-------------|--------------------------------------------------|------|------|------|
|             | Corridor                                         | 9,57 |      |      |
| Floor 3-5   | Hotel rooms                                      | 8,21 | 8,91 | 1,76 |
|             | Corridor                                         | 9,6  |      |      |
| Floor 2     | Fitness, kids area,<br>conference rooms<br>(kPa) | 7,44 | 8,22 | 1,76 |
|             | Corridor                                         | 9    |      |      |
| Floor 1     | Restaurant                                       | 9,39 | 8,65 | 3,51 |
|             | SPA zone                                         | 8,31 |      |      |
|             | Fitness, kids area,<br>conference rooms<br>(kPa) | 7,44 |      |      |
|             | Corridor                                         | 9,44 |      |      |
| Parking lot | Parking floor                                    | 7.61 | 7.61 | 1,76 |

### 3.4.2 Live Loads

The live loads were calculated as per ASCE-7, the hotel floors and roof will experience 1,92 kPa and 0,96 kPa, respectively.

### 3.4.3 Snow loads

| Snow Details                 |                                            |
|------------------------------|--------------------------------------------|
| Ground Snow Load, $p_g$      | 47 lb/ft <sup>2</sup>                      |
| 20-year MRI Value, $p_g$     | 16.42 lb/ft <sup>2</sup>                   |
| Winter Wind Parameter, $W_2$ | 0.55                                       |
| Mapped Elevation             | 17.0 ft                                    |
| Data Source                  | ASCE/SEI 7-22, Figures 7.6-1 and 7.6-2 A-D |

**Figure 3.4.1** Snow details (ASCE 7 hazard tool, 2025)

## Flat roof snow load

$$p_f = 0.7 \cdot C_e \cdot C_t \cdot I_s \cdot p_g$$

$$p_f = 0.7 \cdot 1 \cdot 1 \cdot 1 \cdot 47 = 32.9 \text{ psf}$$

$$p_f = 1.5753 \text{ KPa}$$

$$p_g = 47 \text{ lb/ft}^2 > 20 \text{ lb/ft}^2 \Rightarrow p_m = 20 \cdot I_s = 20 \cdot 1 = 20 \text{ lb/ft}^2$$

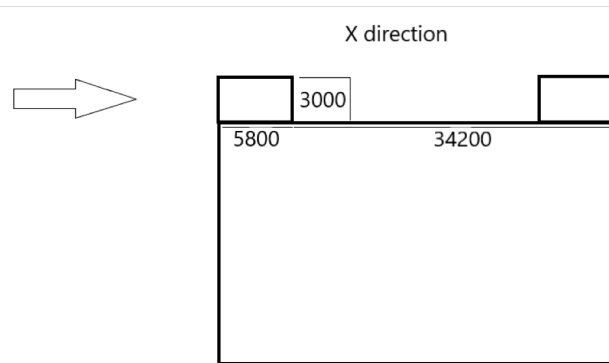
$$Y = 0.426 \cdot p_g + 2.2 = 0.426 \cdot 1.5753 + 2.2 = 2.871 \text{ KPa} < 4.7 \text{ KPa}$$

$$h_b = \frac{p_f}{Y} = \frac{1.5753}{2.871} = 0.5487 \text{ m}$$

$$h_c = h - h_b = 3 - 0.5487 = 2.4513 \text{ m}$$

## X direction

### Case 1:



**Figure 3.4.2** Visual Illustration of Case 1

$$\begin{aligned} h_d(\text{Leeward}) &= 0.43 \cdot \sqrt[3]{L_u(ft)} \cdot \sqrt[4]{p_g(\text{psf}) + 10} - 1.5 = \\ &= 0.43 \cdot \sqrt[3]{19.02} \cdot \sqrt[4]{47 + 10} - 1.5 = 1.654 \text{ ft} \end{aligned}$$

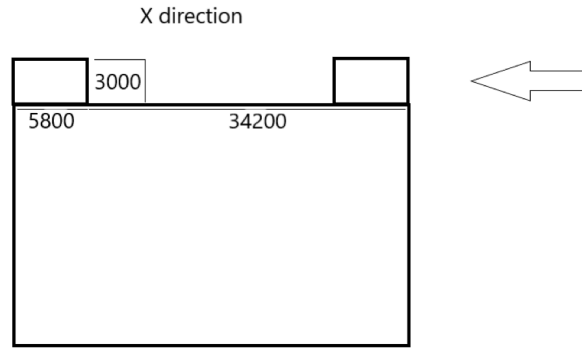
$$h_d(\text{Windward}) = 0.75 \cdot (0.43 \cdot \sqrt[3]{L_u(ft)} \cdot \sqrt[4]{p_g(psf)} + 10 - 1.5)$$

Windward  $h_d$  does not exist since the shaft is on the edge,  $L_u^* = 0$ , therefore, no snow drift

$$h_d(\text{max}) = 1.654 \text{ ft} = 0.504 \text{ m} < h_c \Rightarrow w = 4 \cdot h_d = 4 \cdot 0.504 = 2.016 \text{ m}$$

$$P_d = h_d \cdot Y = 0.504 \cdot 2.363 = 1.191 \text{ KN/m}^2$$

### Case 2:



**Figure 3.4.3** Visual Illustration of Case 2

$$h_d(\text{Leeward}) = 0.43 \cdot \sqrt[3]{L_u(ft)} \cdot \sqrt[4]{p_g(psf)} + 10 - 1.5$$

Leeward  $h_d$  does not exist since the shaft is on the edge,  $L_u^* = 0$ , therefore, no snow drift

$$h_d(\text{Windward}) = 0.75 \cdot (0.43 \cdot \sqrt[3]{L_u(ft)} \cdot \sqrt[4]{p_g(psf)} + 10 - 1.5)$$

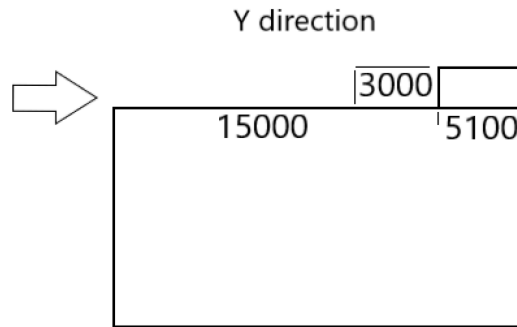
$$h_d(\text{Windward}) = 0.75 \cdot (0.43 \cdot \sqrt[3]{112.2} \cdot \sqrt[4]{47} + 10 - 1.5) = 3.149 \text{ ft}$$

$$h_d(\text{max}) = 3.149 \text{ ft} = 0.96 \text{ m} < h_c \Rightarrow w = 4 \cdot h_d = 4 \cdot 0.96 = 3.84 \text{ m}$$

$$P_d = h_d \cdot Y = 0.96 \cdot 2.363 = 2.2685 \text{ KN/m}^2$$

### Y direction

**Case 1:**



**Figure 3.4.4** Visual Illustration of Case 1

$$h_d(Leeward) = 0.43 \cdot \sqrt[3]{L_u(ft)} \cdot \sqrt[4]{p_g(psf)} + 10 - 1.5 =$$

$$= 0$$

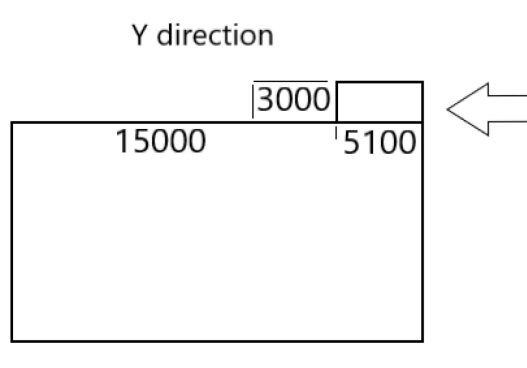
$$h_d(Windward) = 0.75 \cdot (0.43 \cdot \sqrt[3]{L_u(ft)} \cdot \sqrt[4]{p_g(psf)} + 10 - 1.5)$$

$$h_d(Windward) = 0.75 \cdot (0.43 \cdot \sqrt[3]{49.2} \cdot \sqrt[4]{47} + 10 - 1.5) = 2.122 \text{ ft}$$

$$h_d(max) = 2.122 \text{ ft} = 0.647 \text{ m} < h_c \Rightarrow w = 4 \cdot h_d = 4 \cdot 0.647 = 2.588 \text{ m}$$

$$P_d = h_d \cdot Y = 0.647 \cdot 2.363 = 1.53 \text{ KN/m}^2$$

**Case 2:**



**Figure 3.4.5** Visual Illustration of Case 2

$$h_d(Leeward) = 0.43 \cdot \sqrt[3]{L_u(ft)} \cdot \sqrt[4]{p_g(psf) + 10} - 1.5 =$$

$$= 0.43 \cdot \sqrt[3]{16.73} \cdot \sqrt[4]{47 + 10} - 1.5 = 1.522 \text{ ft}$$

$$h_d(Windward) = 0.75 \cdot (0.43 \cdot \sqrt[3]{L_u(ft)} \cdot \sqrt[4]{p_g(psf) + 10} - 1.5) = 0$$

$$h_d(max) = 1.522 \text{ ft} = 0.464 \text{ m} < h_c \Rightarrow w = 4 \cdot h_d = 4 \cdot 0.464 = 1.856 \text{ m}$$

$$P_d = h_d \cdot \gamma = 0.464 \cdot 2.363 = 1.096 \text{ KN/m}^2$$

### 3.4.4 Wind Loads

| Wind Details |        |
|--------------|--------|
| Wind Speed   | 53 m/s |
| 10-year MRI  | 34 m/s |
| 25-year MRI  | 38 m/s |
| 50-year MRI  | 41 m/s |
| 100-year MRI | 44 m/s |

**Figure 3.4.6** Wind Details (ASCE 7 hazard tool, 2025)





**Figure 3.4.7** Elevation Map

| Exposure | $\alpha$ | $z_g$ (m) | $\hat{\alpha}$ | $\hat{b}$ | $\bar{\alpha}$ | $\bar{b}$ | c    | $\ell$ (m) | $\bar{\epsilon}$ | $z_{min}$ (m)* |
|----------|----------|-----------|----------------|-----------|----------------|-----------|------|------------|------------------|----------------|
| <b>B</b> | 7.0      | 365.76    | 1/7            | 0.84      | 1/4.0          | 0.45      | 0.30 | 97.54      | 1/3.0            | 9.14           |
| <b>C</b> | 9.5      | 274.32    | 1/9.5          | 1.00      | 1/6.5          | 0.65      | 0.20 | 152.4      | 1/5.0            | 4.57           |
| <b>D</b> | 11.5     | 213.36    | 1/11.5         | 1.07      | 1/9.0          | 0.80      | 0.15 | 198.12     | 1/8.0            | 2.13           |

**Figure 3.4.8** Constant values used for calculations of gust effect (ASCE 7-2022)

50-year MRI: 41 m/s

Surface roughness - B

Exposure category - B

$H > 18\text{m}$ , therefore the building is not categorized as low rise.

$$H = 37.5 \text{ m} = \frac{37.5}{0.3048} = 123.03 \text{ ft}$$

$$K_z = 2.01(z/z_g)^{2/\alpha} \text{ for } 15\text{ft.} \leq z \leq z_g$$

$$K_z = 2.01(15ft/z_g)^{2/\alpha} = 2.01(4.572/z_g)^{2/\alpha} \text{ for } 15ft > z$$

**Table 3.4.2**  $K_z$  values by story

| Story | z (m) | Kz           |
|-------|-------|--------------|
| 9     | 35    | 1.02805555   |
| 8     | 31.5  | 0.9975691571 |
| 7     | 28    | 0.9645572434 |
| 6     | 24.5  | 0.9284507664 |
| 5     | 21    | 0.8884463855 |
| 4     | 17.5  | 0.8433503154 |
| 3     | 14    | 0.7912604097 |
| 2     | 10.5  | 0.728823982  |
| 1     | 7     | 0.6490988899 |

Gust effect:

For structural steel and concrete buildings:

$$n_a = \frac{43.5}{h^{0.9}} = \frac{43.5}{114.829^{0.9}} = 0.6087 \text{ Hz} < 1 \text{ Hz} \Rightarrow \text{The building is flexible}$$

$$H = 35m = 114.829ft$$

Gust effect:

$$\bar{z} = 0.6 \cdot H = 0.6 \cdot 35 = 21m > z_{min} = 9.14m$$

$$\bar{V}_z = \bar{b} \left( \frac{\bar{z}}{10} \right)^{\bar{\alpha}} \cdot v = 0.45 \cdot \left( \frac{21}{10} \right)^{1/4} \cdot 41 = 22.21m/s$$

$$I_z = c \left( \frac{10}{z} \right)^{1/6} = 0.3 \cdot \left( \frac{10}{21} \right)^{1/6} = 0.2651$$

$$L_z = l \left( \frac{\bar{z}}{10} \right)^{\bar{\epsilon}} = 97.54 \cdot \left( \frac{21}{10} \right)^{1/3} = 124.908m$$

$$N_1 = \frac{n_1 L_z}{\bar{V}_z} = \frac{0.6087 \cdot 124.908}{22.21} = 3.4233$$

$$R_n = \frac{7.47 N_1}{(1+10.3 N_1)^{5/3}} = \frac{7.47 \cdot 3.4233}{(1+10.3 \cdot 3.4233)^{5/3}} = 0.06437$$

$$\eta_h = \frac{4.6 n_1 h}{\bar{V}_z} = \frac{4.6 \cdot 0.6087 \cdot 35}{22.21} = 4.4125$$

$$R_h = \frac{1}{\eta_h} - \frac{1}{2\eta_h^2} (1 - e^{-2\eta_h}) = \frac{1}{4.4125} - \frac{1}{2 \cdot 4.4125^2} (1 - e^{-2 \cdot 4.4125}) = 0.201$$

$$L=20, B=40$$

$$\eta_B = \frac{4.6 n_1 B}{\bar{V}_z} = \frac{4.6 \cdot 0.6087 \cdot 40}{22.21} = 5.043$$

$$R_B = \frac{1}{\eta_B} - \frac{1}{2\eta_B^2} (1 - e^{-2\eta_B}) = 0.179$$

$$\eta_L = \frac{4.6 n_1 L}{\bar{V}_z} = \frac{4.6 \cdot 0.6087 \cdot 20}{22.21} = 2.5214$$

$$R_L = \frac{1}{\eta_L} - \frac{1}{2\eta_L^2} (1 - e^{-2\eta_L}) = 0.3185$$

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

$$= \sqrt{\frac{1}{0.02} \cdot 0.06437 \cdot 0.201 \cdot 0.179 \cdot (0.53 + 0.47 \cdot 0.3185)} = 0.28055$$

$$g_r = \sqrt{2 \ln(3600 n_1)} + \frac{0.577}{\sqrt{2 \ln(3600 n_1)}} = \sqrt{2 \ln(3600 \cdot 0.6087)} + \frac{0.577}{\sqrt{2 \ln(3600 \cdot 0.6087)}} = 4.069$$

$$Q = \sqrt{\frac{1}{1+0.63 \left(\frac{B+h}{L_z}\right)^{0.63}}} = \sqrt{\frac{1}{1+0.63 \left(\frac{32.5+35}{124.908}\right)^{0.63}}} = 0.837$$

$$G_f = 0.925 \left( \frac{1+1.7I_z \sqrt{g_Q^2 Q^2 + g_R^2 R^2}}{1+1.7g_v I_z} \right) = 0.925 \left( \frac{1+1.7 \cdot 0.2651 \cdot \sqrt{3.4^2 \cdot 0.837^2 + 4.069^2 \cdot 0.28055^2}}{1+1.7 \cdot 3.4 \cdot 0.2651} \right) = 0.87005$$

Topographical factor:  $K_{zt} = 1$  building is not located in the hill

$$K_d = 0.85$$

| Structure Type                                                            | Directionality Factor $K_d^*$ |
|---------------------------------------------------------------------------|-------------------------------|
| <b>Buildings</b>                                                          |                               |
| Structure Type                                                            | Directionality Factor $K_d^*$ |
| <b>Buildings</b>                                                          |                               |
| Main Wind Force Resisting System                                          | 0.85                          |
| Components and Cladding                                                   | 0.85                          |
| <b>Arched Roofs</b>                                                       | 0.85                          |
| <b>Chimneys, Tanks, and Similar Structures</b>                            |                               |
| Square                                                                    | 0.90                          |
| Hexagonal                                                                 | 0.95                          |
| Round                                                                     | 0.95                          |
| <b>Solid Freestanding Walls and Solid Freestanding and Attached Signs</b> | 0.85                          |
| <b>Open Signs and Lattice Framework</b>                                   | 0.85                          |
| <b>Trussed Towers</b>                                                     |                               |
| Triangular, square, rectangular                                           | 0.85                          |
| All other cross sections                                                  | 0.95                          |

**Figure 3.4.9**  $K_d$  values (ASCE 7-2022)

$$q_z = 0.613 K_z K_{zt} K_d V^2$$

$$P = P_w - P_L = q G_f C_p - q_h G_f C_{pi}$$

**Table 3.4.3** Net pressure for wind direction X axis

| Floor # | Cwp | Clp  | Gf   | qh    | qz    | Pw    | Pl     | Pnet  |
|---------|-----|------|------|-------|-------|-------|--------|-------|
| 10      | 0.8 | -0.5 | 0.87 | 0.922 | 0.922 | 0.642 | -0.401 | 1.043 |
| 9       | 0.8 | -0.5 | 0.87 | 0.922 | 0.900 | 0.627 | -0.401 | 1.028 |
| 8       | 0.8 | -0.5 | 0.87 | 0.922 | 0.874 | 0.608 | -0.401 | 1.009 |
| 7       | 0.8 | -0.5 | 0.87 | 0.922 | 0.845 | 0.588 | -0.401 | 0.989 |
| 6       | 0.8 | -0.5 | 0.87 | 0.922 | 0.813 | 0.566 | -0.401 | 0.967 |
| 5       | 0.8 | -0.5 | 0.87 | 0.922 | 0.778 | 0.542 | -0.401 | 0.943 |
| 4       | 0.8 | -0.5 | 0.87 | 0.922 | 0.739 | 0.514 | -0.401 | 0.915 |
| 3       | 0.8 | -0.5 | 0.87 | 0.922 | 0.693 | 0.482 | -0.401 | 0.883 |
| 2       | 0.8 | -0.4 | 0.87 | 0.922 | 0.638 | 0.444 | -0.321 | 0.765 |
| 1       | 0.8 | -0.4 | 0.87 | 0.922 | 0.569 | 0.396 | -0.321 | 0.717 |

**Table 3.4.4** Net pressure for wind direction Y axis

| Floor # | Cwp | Clp  | Gf   | qh    | qz    | Pw    | Pl     | Pnet  |
|---------|-----|------|------|-------|-------|-------|--------|-------|
| 10      | 0.8 | -0.5 | 0.87 | 0.922 | 0.922 | 0.642 | -0.401 | 1.043 |
| 9       | 0.8 | -0.3 | 0.87 | 0.922 | 0.900 | 0.627 | -0.241 | 0.867 |
| 8       | 0.8 | -0.3 | 0.87 | 0.922 | 0.874 | 0.608 | -0.241 | 0.849 |
| 7       | 0.8 | -0.3 | 0.87 | 0.922 | 0.845 | 0.588 | -0.241 | 0.829 |
| 6       | 0.8 | -0.3 | 0.87 | 0.922 | 0.813 | 0.566 | -0.241 | 0.807 |
| 5       | 0.8 | -0.5 | 0.87 | 0.922 | 0.778 | 0.542 | -0.401 | 0.943 |
| 4       | 0.8 | -0.5 | 0.87 | 0.922 | 0.739 | 0.514 | -0.401 | 0.915 |
| 3       | 0.8 | -0.5 | 0.87 | 0.922 | 0.693 | 0.482 | -0.401 | 0.883 |
| 2       | 0.8 | -0.5 | 0.87 | 0.922 | 0.638 | 0.444 | -0.401 | 0.845 |

|   |     |      |      |       |       |       |        |       |
|---|-----|------|------|-------|-------|-------|--------|-------|
| 1 | 0.8 | -0.5 | 0.87 | 0.922 | 0.569 | 0.396 | -0.401 | 0.797 |
|---|-----|------|------|-------|-------|-------|--------|-------|

**Table 3.4.5** Force in every floor in X and Y directions

| Floor | Height, m | Force on Y | Force on X |
|-------|-----------|------------|------------|
| Roof  | 3.00      | 7.82       | 8.602      |
| 9     | 3.50      | 35.97      | 60.713     |
| 8     | 3.50      | 35.32      | 59.412     |
| 7     | 3.50      | 34.62      | 58.003     |
| 6     | 3.50      | 33.85      | 56.462     |
| 5     | 3.50      | 65.98      | 65.984     |
| 4     | 3.50      | 64.06      | 64.059     |
| 3     | 3.50      | 61.84      | 61.836     |
| 2     | 3.50      | 88.76      | 59.172     |
| 1     | 7.00      | 167.31     | 111.540    |

The formula for typical floor:

$$F = P_{net} * \frac{h_i}{2} * B$$

**Table 3.4.6** Dead load, Ib, Ic calculations

| Floor | Height, m | Ic(common)    | Ib              | E         | D        |
|-------|-----------|---------------|-----------------|-----------|----------|
| roof  | 3.00      | 0.00239203125 | 0.0009114583333 | 27805.570 | 4491.066 |
| 9     | 3.50      | 0.00239203125 | 0.0009114583333 | 27805.570 | 3299.559 |
| 8     | 3.50      | 0.00239203125 | 0.0009114583333 | 27805.570 | 3299.559 |
| 7     | 3.50      | 0.00239203125 | 0.0009114583333 | 27805.570 | 3299.559 |

|   |      |                |                 |           |          |
|---|------|----------------|-----------------|-----------|----------|
| 6 | 3.50 | 0.00239203125  | 0.0009114583333 | 27805.570 | 3299.559 |
| 5 | 3.50 | 0.005337864583 | 0.0009114583333 | 27805.570 | 3714.851 |
| 4 | 3.50 | 0.005337864583 | 0.0009114583333 | 27805.570 | 3714.851 |
| 3 | 3.50 | 0.005337864583 | 0.0009114583333 | 27805.570 | 3714.851 |
| 2 | 3.50 | 0.005337864583 | 0.0009114583333 | 27805.570 | 3714.851 |
| 1 | 7.00 | 0.00756        | 0.0009114583333 | 27805.570 | 957.476  |

$$I_{c,cr} = 0.7 * \frac{1}{12} * \left(\frac{h}{1000}\right)^4$$

$$I_{b,cr} = 0.35 * \frac{1}{12} * \left(\frac{h}{1000}\right)^3 * \left(\frac{b}{1000}\right)$$

$$D = 12 * E * 10^6 * \left(\frac{I_{b,cr} * I_{c,cr}}{5 * I_{c,cr} + I_{b,cr} * h}\right) * \frac{1}{h^2}$$

To find  $I_{c,cr}$  and  $I_{b,cr}$  beams and columns dimensions are needed. This values were taken from GLRS part

**Table 3.4.7** Beam and column sizes

| Column (mm) |     | Beam (mm) |     | Large span beam |
|-------------|-----|-----------|-----|-----------------|
| 6-9 floor   | 450 | b         | 250 | 400             |
| 2-5 floor   | 550 | h         | 500 | 750             |
| 1 floor     | 600 |           |     |                 |

**Table 3.4.8** Cf calculations in X axis

| Frame | 1     | 2      | 3      | 4      | 5      | 6     | 7     | 8     | 9     | Roof  | level |
|-------|-------|--------|--------|--------|--------|-------|-------|-------|-------|-------|-------|
| 1     | 80428 | 156024 | 104016 | 104016 | 104016 | 52008 | 52008 | 52008 | 52008 | 13473 | 0     |
| 2     | 0     | 0      | 104016 | 104016 | 104016 | 52008 | 52008 | 52008 | 52008 | 13473 | 5     |
| 3     | 0     | 0      | 104016 | 104016 | 104016 | 52008 | 52008 | 52008 | 52008 | 0     | 10    |

|     |        |        |        |        |        |        |        |        |        |       |    |
|-----|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|----|
| 4   | 0      | 0      | 104016 | 104016 | 104016 | 52008  | 52008  | 52008  | 52008  | 0     | 15 |
| 5   | 80428  | 156024 | 104016 | 104016 | 104016 | 52008  | 52008  | 52008  | 52008  | 0     | 20 |
| 6   | 0      | 0      | 104016 | 104016 | 104016 | 52008  | 52008  | 52008  | 52008  | 0     | 25 |
| 7   | 0      | 0      | 104016 | 104016 | 104016 | 52008  | 52008  | 52008  | 52008  | 0     | 30 |
| 8   | 0      | 0      | 104016 | 104016 | 104016 | 52008  | 52008  | 52008  | 52008  | 13473 | 35 |
| 9   | 80428  | 156024 | 104016 | 104016 | 104016 | 52008  | 52008  | 52008  | 52008  | 13473 | 40 |
| Sum | 241284 | 468071 | 936143 | 936143 | 936143 | 468071 | 468071 | 468071 | 468071 | 53893 |    |

**Table 3.4.9** Cf calculations in Y direction

| Frame | 1      | 2       | 3      | 4      | 5      | 6      | 7      | 8      | 9      | roof  | level |
|-------|--------|---------|--------|--------|--------|--------|--------|--------|--------|-------|-------|
| A     | 13405  | 26004   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0     | 0     |
| B     | 13405  | 26004   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0     | 5     |
| C     | 13405  | 26004   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0     | 10    |
| D     | 13405  | 26004   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0     | 15    |
| E     | 53619  | 104016  | 104016 | 104016 | 104016 | 0      | 0      | 0      | 0      | 0     | 20    |
| F     | 53619  | 104016  | 104016 | 104016 | 104016 | 0      | 0      | 0      | 0      | 0     | 25    |
| G     | 53619  | 104016  | 104016 | 104016 | 104016 | 0      | 0      | 0      | 0      | 0     | 30    |
| H     | 53619  | 104016  | 104016 | 104016 | 104016 | 0      | 0      | 0      | 0      | 0     | 35    |
| I     | 53619  | 104016  | 104016 | 104016 | 104016 | 92388  | 92388  | 92388  | 92388  | 26946 | 40    |
| J     | 53619  | 104016  | 104016 | 104016 | 104016 | 92388  | 92388  | 92388  | 92388  | 26946 | 45    |
| K     | 53619  | 104016  | 104016 | 104016 | 104016 | 92388  | 92388  | 92388  | 92388  | 0     | 50    |
| L     | 53619  | 104016  | 104016 | 104016 | 104016 | 92388  | 92388  | 92388  | 92388  | 0     | 55    |
| M     | 53619  | 104016  | 104016 | 104016 | 104016 | 92388  | 92388  | 92388  | 92388  | 0     | 60    |
| sum   | 536186 | 1040158 | 936143 | 936143 | 936143 | 461938 | 461938 | 461938 | 461938 | 53893 |       |



The calculation of  $C_f$  was done accordingly:

$$C_f = D * h_i * \text{number of spans}$$

**Table 3.4.10** Estimation of MC and SC and Essentricities

| Mass Center |    | Stiffness center |       | Ey    | Ex |
|-------------|----|------------------|-------|-------|----|
| Y(1-2)      | 30 | Y                | 36.75 | -6.75 |    |
| Y(3-5)      | 40 | Y                | 40    | 0     |    |
| Y(6-9)      | 50 | Y                | 50    | 0     |    |
| X(1-8)      | 20 | X                | 20    |       | 0  |

Mass Center:

$$\bar{y} = \frac{\sum m_i y_i}{\sum m_i}$$

$$\bar{x} = \frac{\sum m_i x_i}{\sum x_i}$$

Stiffness center:

$$\bar{y} = \frac{\sum C_{fx} * y(SC)}{\text{Sum of } C_{fx}}$$

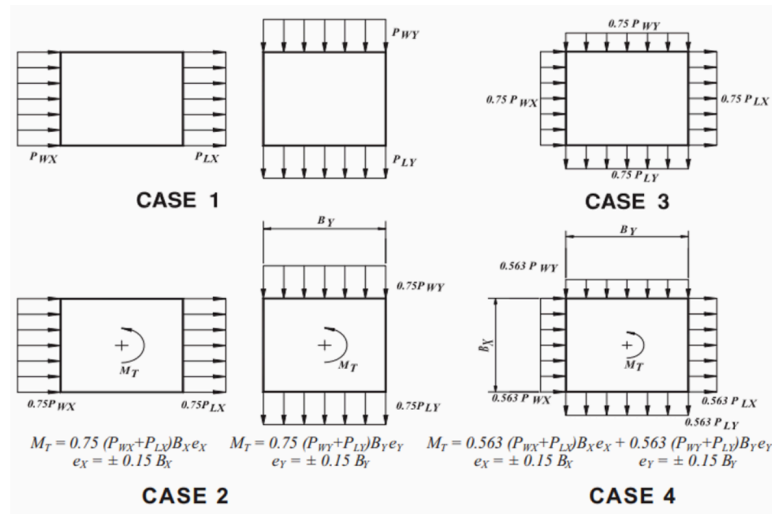
$$\bar{x} = \frac{\sum C_{fy} * x(SC)}{\text{Sum of } C_{fy}}$$

Essentricity:

$$e_y = \bar{y}(MC) - \bar{y}(SC)$$

$$e_x = \bar{x}(MC) - \bar{x}(SC)$$

Afterwards, the 4 cases were calculated, the figure below represents these cases of wind load calculations.



**Figure 3.4.10** 4 cases of LFRS calculations

### Case 1: Direct wind

**Table 3.4.11** Case 1 wind load calculations Y axis

| Floor | A | B | C | D | E    | F    | G    | H    | I    | J    | K    | L    | M    | Total |
|-------|---|---|---|---|------|------|------|------|------|------|------|------|------|-------|
| Roof  |   |   |   |   |      |      |      |      | 3.91 | 3.91 | 0.00 | 0.00 | 0.00 | 7.82  |
| 9.00  |   |   |   |   |      |      |      |      | 7.19 | 7.19 | 7.19 | 7.19 | 7.19 | 35.97 |
| 8.00  |   |   |   |   |      |      |      |      | 7.06 | 7.06 | 7.06 | 7.06 | 7.06 | 35.32 |
| 7.00  |   |   |   |   |      |      |      |      | 6.92 | 6.92 | 6.92 | 6.92 | 6.92 | 34.62 |
| 6.00  |   |   |   |   |      |      |      |      | 6.77 | 6.77 | 6.77 | 6.77 | 6.77 | 33.85 |
| 5.00  |   |   |   |   | 7.33 | 7.33 | 7.33 | 7.33 | 7.33 | 7.33 | 7.33 | 7.33 | 7.33 | 65.98 |
| 4.00  |   |   |   |   | 7.12 | 7.12 | 7.12 | 7.12 | 7.12 | 7.12 | 7.12 | 7.12 | 7.12 | 64.06 |
| 3.00  |   |   |   |   | 6.87 | 6.87 | 6.87 | 6.87 | 6.87 | 6.87 | 6.87 | 6.87 | 6.87 | 61.84 |

|      |      |      |      |      |       |       |       |       |       |       |       |       |       |        |
|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| 2.00 | 2.22 | 2.22 | 2.22 | 2.22 | 8.88  | 8.88  | 8.88  | 8.88  | 8.88  | 8.88  | 8.88  | 8.88  | 8.88  | 88.76  |
| 1.00 | 4.18 | 4.18 | 4.18 | 4.18 | 16.73 | 16.73 | 16.73 | 16.73 | 16.73 | 16.73 | 16.73 | 16.73 | 16.73 | 167.31 |

**Table 3.4.12** Case 1 wind load calculations X axis

| Floor | 1     | 2    | 3    | 4    | 5     | 6    | 7    | 8    | 9     | Total  |
|-------|-------|------|------|------|-------|------|------|------|-------|--------|
| Roof  | 2.15  | 2.15 | 0.00 | 0.00 | 0.00  | 0.00 | 0.00 | 2.15 | 2.15  | 8.60   |
| 9     | 6.75  | 6.75 | 6.75 | 6.75 | 6.75  | 6.75 | 6.75 | 6.75 | 6.75  | 60.71  |
| 8     | 6.60  | 6.60 | 6.60 | 6.60 | 6.60  | 6.60 | 6.60 | 6.60 | 6.60  | 59.41  |
| 7     | 6.44  | 6.44 | 6.44 | 6.44 | 6.44  | 6.44 | 6.44 | 6.44 | 6.44  | 58.00  |
| 6     | 6.27  | 6.27 | 6.27 | 6.27 | 6.27  | 6.27 | 6.27 | 6.27 | 6.27  | 56.46  |
| 5     | 7.33  | 7.33 | 7.33 | 7.33 | 7.33  | 7.33 | 7.33 | 7.33 | 7.33  | 65.98  |
| 4     | 7.12  | 7.12 | 7.12 | 7.12 | 7.12  | 7.12 | 7.12 | 7.12 | 7.12  | 64.06  |
| 3     | 6.87  | 6.87 | 6.87 | 6.87 | 6.87  | 6.87 | 6.87 | 6.87 | 6.87  | 61.84  |
| 2     | 19.72 |      |      |      | 19.72 |      |      |      | 19.72 | 59.17  |
| 1     | 37.18 |      |      |      | 37.18 |      |      |      | 37.18 | 111.54 |

$$F_i = (P_{i+1} \cdot \frac{h_{i+1}}{2} + P_i \cdot \frac{h_i}{2}) \cdot \frac{B}{\text{num of frames}}$$

The formula differs because the area of the floors are different. Therefore B value and number of frames change also.

$$F_i = (P_{i+1} \cdot \frac{h_{i+1}}{2} + P_i \cdot \frac{h_i}{2}) \cdot \frac{B}{\text{num of frames}}$$

Additionally, since the part of the building is large spanned, the calculations were performed separately with the according formulas. Since the number of frames changes, B=40m and the number of frames is equal to 3 in x direction in the first 2 floors.

## Case 2:

For case 2 the calculation of eccentricities needed:

$$e_x = 0.15 \cdot B = 0.15 \cdot 40 = 6 \text{ m}$$

$$e_{y1} = 0.15 \cdot L_1 = 0.15 \cdot 20 = 3 \text{ m (6-9 floors)}$$

$$e_{y2} = 0.15 \cdot L_2 = 0.15 \cdot 40 = 6 \text{ m (3-5 floors)}$$

$$e_{y3} = 0.15 \cdot L_3 = 0.15 \cdot 60 = 9 \text{ m (1-2 floors)}$$

To calculate the torsional moment, the following formula were used:

$$M_t = 0.75(P_W + P_L) \cdot B \cdot e$$

$$e = e_1 + e_2$$

$$F_{Torsion} = \frac{M_T \cdot y_i^i \cdot C_f}{\sum (y_i^2 \cdot C_f + x_i^2 \cdot C_f)}$$

**Table 3.4.13** Case 2 wind load moment calculations for each floor from Y direction

| Floor | Force  | 0.75*force | Mt     |
|-------|--------|------------|--------|
| Roof  | 7.82   | 5.86       | 17.59  |
| 9.00  | 35.97  | 26.98      | 80.93  |
| 8.00  | 35.32  | 26.49      | 79.47  |
| 7.00  | 34.62  | 25.96      | 77.89  |
| 6.00  | 33.85  | 25.38      | 76.15  |
| 5.00  | 65.98  | 49.49      | 296.93 |
| 4.00  | 64.06  | 48.04      | 288.27 |
| 3.00  | 61.84  | 46.38      | 278.26 |
| 2.00  | 88.76  | 66.57      | 149.78 |
| 1.00  | 167.31 | 125.48     | 282.33 |

**Table 3.4.14** Case 2 wind load moment calculations for each floor from X direction

| Floor | Force  | 0.75*Force | Mt     |
|-------|--------|------------|--------|
| Roof  | 8.60   | 6.45       | 38.71  |
| 9.00  | 60.71  | 45.53      | 273.21 |
| 8.00  | 59.41  | 44.56      | 267.35 |
| 7.00  | 58.00  | 43.50      | 261.01 |
| 6.00  | 56.46  | 42.35      | 254.08 |
| 5.00  | 65.98  | 49.49      | 296.93 |
| 4.00  | 64.06  | 48.04      | 288.27 |
| 3.00  | 61.84  | 46.38      | 278.26 |
| 2.00  | 59.17  | 44.38      | 266.27 |
| 1.00  | 111.54 | 83.65      | 501.93 |

**Table 3.4.15** Case 2 wind load calculations Y direction

| Floor | A    | B    | C    | D    | E     |       | G     | H     | I     | J     | K     | L     | M     | Total  |
|-------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Roof  |      |      |      |      |       |       |       |       | 2.95  | 2.95  | 0.03  | 0.03  | 0.04  | 6.00   |
| 9     |      |      |      |      |       |       |       |       | 5.46  | 5.49  | 5.52  | 5.55  | 5.58  | 27.58  |
| 8     |      |      |      |      |       |       |       |       | 5.36  | 5.39  | 5.42  | 5.45  | 5.48  | 27.08  |
| 7     |      |      |      |      |       |       |       |       | 5.25  | 5.28  | 5.31  | 5.34  | 5.37  | 26.54  |
| 6     |      |      |      |      |       |       |       |       | 5.13  | 5.16  | 5.19  | 5.22  | 5.25  | 25.95  |
| 5     |      |      |      |      | 5.28  | 5.39  | 5.50  | 5.61  | 5.72  | 5.83  | 5.94  | 6.05  | 6.17  | 51.49  |
| 4     |      |      |      |      | 5.12  | 5.23  | 5.34  | 5.45  | 5.55  | 5.66  | 5.77  | 5.88  | 5.99  | 49.99  |
| 3     |      |      |      |      | 4.94  | 5.05  | 5.15  | 5.26  | 5.36  | 5.47  | 5.57  | 5.67  | 5.78  | 48.25  |
| 2     | 1.58 | 1.59 | 1.61 | 1.62 | 6.54  | 6.60  | 6.66  | 6.71  | 6.77  | 6.82  | 6.88  | 6.94  | 6.99  | 67.32  |
| 1     | 2.98 | 3.00 | 3.03 | 3.06 | 12.34 | 12.44 | 12.55 | 12.65 | 12.76 | 12.86 | 12.97 | 13.08 | 13.18 | 126.91 |

**Table 3.4.16** Case 2 wind load calculations X direction

| Floor | 1    | 2    | 3     | 4     | 5    | 6    | 7    | 8    | 9    | Total |
|-------|------|------|-------|-------|------|------|------|------|------|-------|
| Roof  | 1.50 | 1.53 | -0.06 | -0.03 | 0.00 | 0.03 | 0.06 | 1.70 | 1.73 | 6.45  |

|   |       |       |       |       |       |      |      |      |       |       |
|---|-------|-------|-------|-------|-------|------|------|------|-------|-------|
| 9 | 4.27  | 4.46  | 4.66  | 4.86  | 5.06  | 5.26 | 5.46 | 5.65 | 5.85  | 45.53 |
| 8 | 4.17  | 4.37  | 4.56  | 4.76  | 4.95  | 5.15 | 5.34 | 5.53 | 5.73  | 44.56 |
| 7 | 4.08  | 4.27  | 4.45  | 4.64  | 4.83  | 5.02 | 5.21 | 5.40 | 5.59  | 43.50 |
| 6 | 3.97  | 4.15  | 4.34  | 4.52  | 4.71  | 4.89 | 5.07 | 5.26 | 5.44  | 42.35 |
| 5 | 4.64  | 4.85  | 5.07  | 5.28  | 5.50  | 5.71 | 5.93 | 6.15 | 6.36  | 49.49 |
| 4 | 4.50  | 4.71  | 4.92  | 5.13  | 5.34  | 5.55 | 5.76 | 5.97 | 6.18  | 48.04 |
| 3 | 4.35  | 4.55  | 4.75  | 4.95  | 5.15  | 5.35 | 5.56 | 5.76 | 5.96  | 46.38 |
| 2 | 14.02 | -0.58 | -0.39 | -0.19 | 14.79 | 0.19 | 0.39 | 0.58 | 15.57 | 44.38 |
| 1 | 26.43 | -1.09 | -0.73 | -0.36 | 27.88 | 0.36 | 0.73 | 1.09 | 29.34 | 83.65 |

### Case 3

Case 3 is the multiplication of Case 1 values by 0.75. So it is 75% of Case 1 forces.

**Table 3.4.17** Case 3 wind load calculations Y direction

| Floor | A    | B    | C    | D    | E     | F     | G     | H     | I     | J     | K     | L     | M     | Total  |
|-------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Roof  |      |      |      |      |       |       |       |       | 2.93  | 2.93  | 0.00  | 0.00  | 0.00  | 5.86   |
| 9     |      |      |      |      |       |       |       |       | 5.40  | 5.40  | 5.40  | 5.40  | 5.40  | 26.98  |
| 8     |      |      |      |      |       |       |       |       | 5.30  | 5.30  | 5.30  | 5.30  | 5.30  | 26.49  |
| 7     |      |      |      |      |       |       |       |       | 5.19  | 5.19  | 5.19  | 5.19  | 5.19  | 25.96  |
| 6     |      |      |      |      |       |       |       |       | 5.08  | 5.08  | 5.08  | 5.08  | 5.08  | 25.38  |
| 5     |      |      |      |      | 5.50  | 5.50  | 5.50  | 5.50  | 5.50  | 5.50  | 5.50  | 5.50  | 5.50  | 49.49  |
| 4     |      |      |      |      | 5.34  | 5.34  | 5.34  | 5.34  | 5.34  | 5.34  | 5.34  | 5.34  | 5.34  | 48.04  |
| 3     |      |      |      |      | 5.15  | 5.15  | 5.15  | 5.15  | 5.15  | 5.15  | 5.15  | 5.15  | 5.15  | 46.38  |
| 2     | 1.66 | 1.66 | 1.66 | 1.66 | 6.66  | 6.66  | 6.66  | 6.66  | 6.66  | 6.66  | 6.66  | 6.66  | 6.66  | 66.57  |
| 1     | 3.14 | 3.14 | 3.14 | 3.14 | 12.55 | 12.55 | 12.55 | 12.55 | 12.55 | 12.55 | 12.55 | 12.55 | 12.55 | 125.48 |

**Table 3.4.18** Case 3 wind load calculations X direction

| Floor | 1     | 2     | 3      | 4      | 5     | 6     | 7     | 8     | 9     | Total |
|-------|-------|-------|--------|--------|-------|-------|-------|-------|-------|-------|
| Roof  | 1.125 | 1.146 | -0.042 | -0.021 | 0.000 | 0.021 | 0.042 | 1.273 | 1.294 | 4.838 |

|   |        |        |        |        |        |       |       |       |        |        |
|---|--------|--------|--------|--------|--------|-------|-------|-------|--------|--------|
| 9 | 3.200  | 3.348  | 3.497  | 3.646  | 3.795  | 3.943 | 4.092 | 4.241 | 4.389  | 34.151 |
| 8 | 3.131  | 3.277  | 3.422  | 3.568  | 3.713  | 3.859 | 4.004 | 4.150 | 4.295  | 33.419 |
| 7 | 3.057  | 3.199  | 3.341  | 3.483  | 3.625  | 3.767 | 3.909 | 4.051 | 4.193  | 32.627 |
| 6 | 2.976  | 3.114  | 3.252  | 3.391  | 3.529  | 3.667 | 3.805 | 3.944 | 4.082  | 31.760 |
| 5 | 3.478  | 3.639  | 3.801  | 3.962  | 4.124  | 4.286 | 4.447 | 4.609 | 4.770  | 37.116 |
| 4 | 3.376  | 3.533  | 3.690  | 3.847  | 4.004  | 4.161 | 4.317 | 4.474 | 4.631  | 36.033 |
| 3 | 3.259  | 3.410  | 3.562  | 3.713  | 3.865  | 4.016 | 4.168 | 4.319 | 4.471  | 34.783 |
| 2 | 10.515 | -0.435 | -0.290 | -0.145 | 11.095 | 0.145 | 0.290 | 0.435 | 11.674 | 33.284 |
| 1 | 19.821 | -0.820 | -0.546 | -0.273 | 20.914 | 0.273 | 0.546 | 0.820 | 22.006 | 62.741 |

#### Case 4:

For case 4 the following formula were used:

$$M_t = 2 \cdot 0.563(P_w + P_L) \cdot B \cdot e$$

The eccentricities were taken the same as in case 2.

**Table 3.4.19** Case 4 moment calculations

| Floor | 0.563*Force Y | 0.563*Force X | Mt          |
|-------|---------------|---------------|-------------|
| Roof  | 4.403         | 4.843         | 42.26410098 |
| 9     | 20.251        | 34.181        | 265.8423079 |
| 8     | 19.885        | 33.449        | 260.3490487 |
| 7     | 19.489        | 32.656        | 254.4007229 |
| 6     | 19.055        | 31.788        | 247.8947961 |
| 5     | 37.149        | 37.149        | 445.7853412 |
| 4     | 36.065        | 36.065        | 432.7841624 |
| 3     | 34.814        | 34.814        | 417.7666636 |
| 2     | 49.970        | 33.314        | 301.6497742 |

|   |        |        |             |
|---|--------|--------|-------------|
| 1 | 94.194 | 62.797 | 567.3859361 |
|---|--------|--------|-------------|

**Table 3.4.20** Case 4 wind load calculations from Y axis

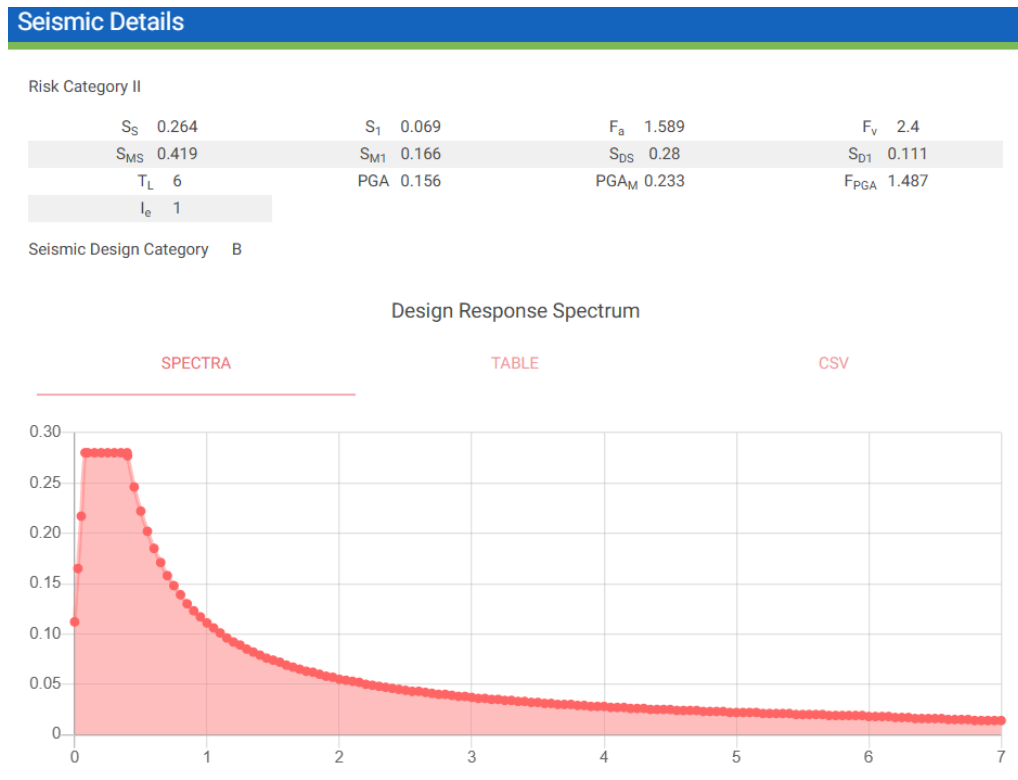
| Floor | A    | B    | C    | D    | E    | F    |      | H    | I    | J    | K     | L     | M     | Total |
|-------|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|
| Roof  |      |      |      |      |      |      |      |      | 2.39 | 2.48 | 0.67  | 0.81  | 0.94  | 7.29  |
| 9     |      |      |      |      |      |      |      |      | 4.24 | 4.33 | 4.72  | 4.86  | 4.99  | 23.13 |
| 8     |      |      |      |      |      |      |      |      | 4.17 | 4.26 | 4.64  | 4.79  | 4.91  | 22.77 |
| 7     |      |      |      |      |      |      |      |      | 4.09 | 4.18 | 4.56  | 4.71  | 4.84  | 22.37 |
| 6     |      |      |      |      |      |      |      |      | 4.00 | 4.09 | 4.48  | 4.62  | 4.75  | 21.94 |
| 5     |      |      |      |      | 3.79 | 3.96 | 4.13 | 4.23 | 4.32 | 4.41 | 4.79  | 4.94  | 5.07  | 39.63 |
| 4     |      |      |      |      | 3.68 | 3.85 | 4.01 | 4.10 | 4.20 | 4.29 | 4.67  | 4.82  | 4.94  | 38.56 |
| 3     |      |      |      |      | 3.56 | 3.71 | 3.87 | 3.97 | 4.06 | 4.15 | 4.54  | 4.68  | 4.81  | 37.33 |
| 2     | 1.07 | 1.05 | 1.13 | 1.16 | 4.76 | 4.88 | 5.00 | 5.09 | 5.19 | 5.28 | 5.66  | 5.81  | 5.93  | 52.02 |
| 1     | 2.02 | 2.08 | 2.13 | 2.19 | 8.98 | 9.20 | 9.42 | 9.52 | 9.61 | 9.70 | 10.09 | 10.23 | 10.36 | 95.52 |

**Table 3.4.21** Case 4 wind load calculations from X axis

| Floor | 1      | 2      | 3      | 4      | 5      | 6     | 7     | 8     | 9      | Total  |
|-------|--------|--------|--------|--------|--------|-------|-------|-------|--------|--------|
| Roof  | 1.088  | 1.119  | -0.061 | -0.031 | 0.000  | 0.031 | 0.061 | 1.303 | 1.333  | 4.843  |
| 9     | 3.706  | 3.706  | 3.737  | 3.767  | 3.798  | 3.829 | 3.859 | 3.890 | 3.921  | 34.212 |
| 8     | 3.655  | 3.625  | 3.655  | 3.686  | 3.717  | 3.747 | 3.778 | 3.809 | 3.839  | 33.510 |
| 7     | 3.598  | 3.536  | 3.567  | 3.598  | 3.628  | 3.659 | 3.690 | 3.720 | 3.751  | 32.748 |
| 6     | 3.532  | 3.440  | 3.471  | 3.501  | 3.532  | 3.563 | 3.593 | 3.624 | 3.655  | 31.911 |
| 5     | 4.158  | 4.036  | 4.066  | 4.097  | 4.128  | 4.158 | 4.189 | 4.220 | 4.250  | 37.302 |
| 4     | 4.069  | 3.915  | 3.946  | 3.977  | 4.007  | 4.038 | 4.069 | 4.099 | 4.130  | 36.249 |
| 3     | 3.960  | 3.776  | 3.807  | 3.838  | 3.868  | 3.899 | 3.930 | 3.960 | 3.991  | 35.029 |
| 2     | 11.227 | -0.092 | -0.061 | -0.031 | 11.105 | 0.031 | 0.061 | 0.092 | 11.227 | 33.559 |



### 3.4.5 Seismic loads



**Figure 3.4.11** ASCE Hazard Tool Seismic Details

**Table 3.4.22** Values for Seismic Design

|     |        |
|-----|--------|
| SS  | 0.0264 |
| S1  | 0.069  |
| SMS | 0.419  |
| SM1 | 0.166  |
| SDS | 0.28   |
| SD1 | 0.111  |
| TL  | 8      |

|                |       |
|----------------|-------|
| SDC            | D     |
| F <sub>a</sub> | 1.589 |
| F <sub>v</sub> | 2.4   |

Calculation of  $S_{MS}$ ,  $S_{M1}$ ,  $S_{DS}$ ,  $S_{D1}$  values

$$S_{MS} = F_a * S_s = 1.589 * 0.264 = 0.419$$

$$S_{M1} = F_v * S_1 = 2.4 * 0.069 = 0.166$$

$$S_{DS} = \frac{2 * S_{MS}}{3} = \frac{2 * 0.419}{3} = 0.28$$

$$S_{D1} = \frac{2 * S_{M1}}{3} = \frac{2 * 0.166}{3} = 0.11$$

| Seismic Force-Resisting System                            | ASCE 7<br>Section<br>Where<br>Detailing<br>Requirements<br>Are Specified | Response<br>Modification<br>Coefficient,<br>R <sup>a</sup> | Overstrength<br>Factor, $\Omega_0^g$ | Deflection<br>Amplification<br>Factor, C <sub>d</sub> <sup>b</sup> | Structural System<br>Limitations Including<br>Structural Height, h <sub>n</sub> (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>b</sup> | NP <sup>b</sup> | NP <sup>b</sup> |
| 4. Steel ordinary moment frames                           | 12.2.5.6 and 14.1                                                        | 3½                                                         | 3                                    | 3                                                                  | NL                                                                                                          | NL | NP <sup>j</sup> | NP <sup>j</sup> | NP <sup>j</sup> |
| 5. Special reinforced concrete moment frames <sup>n</sup> | 12.2.5.5 and 14.2                                                        | 8                                                          | 3                                    | 5½                                                                 | NL                                                                                                          | NL | NL              | NL              | NL              |

**Figure 3.4.12** ASCE 7-10 Design Coefficients and Factors for Seismic Force-Resisting Systems

**Table 3.4.23** Coefficients for special reinforced concrete moment frames

| Special reinforced concrete moment frames |     |
|-------------------------------------------|-----|
| R                                         | 8   |
| $\Omega_0$                                | 3   |
| Cd                                        | 5.5 |
| Ie                                        | 1   |

| 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 3.4.13**  $C_u$  determination with  $S_{D1}$ 

The of  $S_{D1} = 0.111$  0.395, therefore  $C_u$  coefficient would be equal to 1.678 using linear interpolation.

| Structure Type                                                                                                                                                                                                                                 | $C_t$                       | $\alpha$ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|----------|
| 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 3.4.14** Values of Approximate Period Parameters  $C_t$  and  $\alpha$

For concrete moment-resisting frames  $C_t = 0.0466$  and  $x = 0.9$

$C_t$  – building period coefficient

In order to determine the approximate fundamental period we use the following formula:

$$T_a = C_t * h_n^x = 0.0466 * 38^{0.9}$$

$h_n$  = height above the base to highest level of building

$$T = C_u * T_a = 1.678 * 1.2308 = 2.065$$

$T$  – original fundamental period

The formula for the seismic response coefficient:

$$C_s = \frac{S_{DS}}{R/I_e} = \frac{0.28}{8/1} = 0.035$$

$R$  – response modification factor

$I_e$  – importance factor

The value of  $C_s$  should be less than:

$$C_{s,max} = \frac{S_{D1}}{T * R/I_e} = \frac{0.111}{2.2065 * 8/1} = 0.0067, \quad T \leq T_L$$

$$C_{s,max} = \frac{S_{D1} * T_L}{T^2 * R/I_e} = \frac{0.111 * 8}{2.065^2 * 8/1} = 0.026, \quad T > T_L$$

Also,  $C_s$  should not exceed:

$$C_{s,min} = \max(0.044 S_{DS} * I_e, 0.01) \text{ if } S_1 < 0.6g$$

$$C_{s,min} = \frac{0.5 * S_1}{R/I_e} = \frac{0.5 * 0.348}{8/1} = 0.034144 \text{ if } S_1 \geq 0.6g$$

**Table 3.4.24** Calculated values

|          |                |
|----------|----------------|
| Cu       | 1.678          |
| Ct       | 0.0466         |
| x        | 0.9            |
| Ta       | 1.23081039     |
| T        | 2.065299834    |
| Cs       | 0.035          |
| Cs, max  | 0.006718152866 |
| Cs, max  | 0.02602296386  |
| Cs, min  | 0.01232        |
| final Cs | 0.01232        |

The value of k using linear interpolation is equal to 1.782

**Table 3.4.25** Weights of walls, columns, beams and floors

| Floor | Interior wall weight (kN) | Exterior wall weight (kN) | Column weight (kN) | Beam weight (kN) | Floor weight (kN) | Total weight (kN) |
|-------|---------------------------|---------------------------|--------------------|------------------|-------------------|-------------------|
| 1     | 2724.68                   | 709.8                     | 5859               | 2470.08          | 20760             | 32523.56          |
| 2     | 1622.4                    | 354.9                     | 2461.59375         | 2470.08          | 19728             | 26636.97          |
| 3     | 2078.7                    | 287.3                     | 2143.96875         | 2121.12          | 14256             | 20887.08          |
| 4     | 2078.7                    | 287.3                     | 2143.96875         | 2121.12          | 14256             | 20887.08          |
| 5     | 2078.7                    | 287.3                     | 2143.96875         | 2121.12          | 14256             | 20887.08          |
| 6     | 1022.45                   | 211.25                    | 797.34375          | 14.73            | 7104              | 9149.77           |
| 7     | 1022.45                   | 211.25                    | 797.34375          | 2511             | 7104              | 11646.04          |
| 8     | 1022.45                   | 211.25                    | 797.34375          | 2511             | 7104              | 11646.044         |

|       |         |        |           |      |      |           |
|-------|---------|--------|-----------|------|------|-----------|
| 9     | 1022.45 | 211.25 | 797.34375 | 2511 | 7104 | 11646.044 |
| Roof  | 0       | 66.264 | 121.5     | 2511 | 3816 | 6514.764  |
| Total |         |        |           |      |      | 172424.47 |

In the formulas below the calculation of loads could be observed.

$$\text{Interior wall weight} = W_{\text{int. wall system load}} * h_i * L_{\text{walls}}$$

$$\text{Exterior wall weight} = W_{\text{ext. wall system load}} * h_i * L_{\text{walls}}$$

$$\text{Column weight} = b^2 * \rho * h_i * n_{\text{column}}$$

$$\text{Beam weigh} = a * b * L_{\text{beam}} * \rho * n_{\text{beams}}$$

$$\text{Floor weight} = (W_{\text{floor system load}} * W_{\text{ceiling}}) * A_{\text{floor}}$$

$h_i$  – story height

$\rho$  – density

$L_{\text{walls}}$  – length of walls

$L_{\text{beam}}$  – length of beam

$n_{\text{column}}$  – number of columns

$n_{\text{beams}}$  – number of beams

$W$  – system loads

After that the V value were calculated

$$V = \text{Total Weight} * C_{s, \min} = 172424 * 0.01232 = 2124 \text{ kN}$$

**Table 3.4.26** Floor Force calculation

| Floors | hi , m | Wx , kN  | Wxhx^k   | Cvx  | Fx , kN |
|--------|--------|----------|----------|------|---------|
| 1      | 7      | 32523.56 | 32523.56 | 0.19 | 400.69  |
| 2      | 10.5   | 26636.97 | 26636.97 | 0.15 | 328.17  |
| 3      | 14     | 20887.09 | 20887.09 | 0.12 | 257.33  |

|       |      |          |           |      |         |
|-------|------|----------|-----------|------|---------|
| 4     | 17.5 | 20887.09 | 20887.09  | 0.12 | 257.33  |
| 5     | 21   | 20887.09 | 20887.09  | 0.12 | 257.33  |
| 6     | 24.5 | 9149.77  | 9149.77   | 0.05 | 112.73  |
| 7     | 28   | 11646.04 | 11646.04  | 0.07 | 143.48  |
| 8     | 31.5 | 11646.04 | 11646.04  | 0.07 | 143.48  |
| 9     | 35   | 11646.04 | 11646.04  | 0.07 | 143.48  |
| 10    | 38.5 | 6514.76  | 6514.76   | 0.04 | 80.26   |
| Total |      |          | 172424.47 |      | 2124.27 |

In order to calculate  $C_{vx}$  and  $F_x$  we use:

$$C_{vx} = \frac{W * h_x^k}{\sum W * h_{15}^k}$$

$$F_x = C_{vx} * V$$

### Case 1

**Table 3.4.27** Case 1 in Y direction

| Floor | A | B | C | D | E    | F    | G    | H    | I    | G    | K    | L    | M    | Total |
|-------|---|---|---|---|------|------|------|------|------|------|------|------|------|-------|
| Roof  |   |   |   |   |      |      |      |      | 40.1 | 40.1 | 0.0  | 0.0  | 0.0  | 80.3  |
| 9     |   |   |   |   |      |      |      |      | 28.7 | 28.7 | 28.7 | 28.7 | 28.7 | 143.5 |
| 8     |   |   |   |   |      |      |      |      | 28.7 | 28.7 | 28.7 | 28.7 | 28.7 | 143.5 |
| 7     |   |   |   |   |      |      |      |      | 28.7 | 28.7 | 28.7 | 28.7 | 28.7 | 143.5 |
| 6     |   |   |   |   |      |      |      |      | 22.5 | 22.5 | 22.5 | 22.5 | 22.5 | 112.7 |
| 5     |   |   |   |   | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 257.3 |
| 4     |   |   |   |   | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 257.3 |
| 3     |   |   |   |   | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 257.3 |

|   |      |      |      |      |      |      |      |      |      |      |      |      |      |        |
|---|------|------|------|------|------|------|------|------|------|------|------|------|------|--------|
| 2 | 8.2  | 8.2  | 8.2  | 8.2  | 32.8 | 32.8 | 32.8 | 32.8 | 32.8 | 32.8 | 32.8 | 32.8 | 32.8 | 328.2  |
| 1 | 10.0 | 10.0 | 10.0 | 10.0 | 40.1 | 40.1 | 40.1 | 40.1 | 40.1 | 40.1 | 40.1 | 40.1 | 40.1 | 400.7  |
|   |      |      |      |      |      |      |      |      |      |      |      |      |      | 2124.3 |

**Table 3.4.28** Case 1 in X direction

| Floors | 1     | 2    | 3    | 4    | 5     | 6    | 7    | 8    | 9     | Total<br>(kN) |
|--------|-------|------|------|------|-------|------|------|------|-------|---------------|
| Roof   | 20.1  | 20.1 | 0.0  | 0.0  | 0.0   | 0.0  | 0.0  | 20.1 | 20.1  | 80.3          |
| 9      | 15.9  | 15.9 | 15.9 | 15.9 | 15.9  | 15.9 | 15.9 | 15.9 | 15.9  | 143.5         |
| 8      | 15.9  | 15.9 | 15.9 | 15.9 | 15.9  | 15.9 | 15.9 | 15.9 | 15.9  | 143.5         |
| 7      | 15.9  | 15.9 | 15.9 | 15.9 | 15.9  | 15.9 | 15.9 | 15.9 | 15.9  | 143.5         |
| 6      | 12.5  | 12.5 | 12.5 | 12.5 | 12.5  | 12.5 | 12.5 | 12.5 | 12.5  | 112.7         |
| 5      | 28.6  | 28.6 | 28.6 | 28.6 | 28.6  | 28.6 | 28.6 | 28.6 | 28.6  | 257.3         |
| 4      | 28.6  | 28.6 | 28.6 | 28.6 | 28.6  | 28.6 | 28.6 | 28.6 | 28.6  | 257.3         |
| 3      | 28.6  | 28.6 | 28.6 | 28.6 | 28.6  | 28.6 | 28.6 | 28.6 | 28.6  | 257.3         |
| 2      | 109.4 | 0.0  | 0.0  | 0.0  | 109.4 | 0.0  | 0.0  | 0.0  | 109.4 | 328.2         |
| 1      | 133.6 | 0.0  | 0.0  | 0.0  | 133.6 | 0.0  | 0.0  | 0.0  | 133.6 | 400.7         |

Torsion effect also should be considered.

## Case 2

We used wind force values identified in the table . Then multiplied to the factor of 0.75.

$$M_t = \frac{0.75F}{e_{x1} + e_{x2}}$$



**Table 3.4.29** Mt calculation in Y direction

| Floors | F <sub>x</sub> (kN) | 0.75*F <sub>x</sub> | Mt     |
|--------|---------------------|---------------------|--------|
| Roof   | 80.3                | 60.2                | 180.6  |
| 9      | 143.5               | 107.6               | 322.8  |
| 8      | 143.5               | 107.6               | 322.8  |
| 7      | 143.5               | 107.6               | 322.8  |
| 6      | 112.7               | 84.5                | 253.6  |
| 5      | 257.3               | 193.0               | 1158.0 |
| 4      | 257.3               | 193.0               | 1158.0 |
| 3      | 257.3               | 193.0               | 1158.0 |
| 2      | 328.2               | 246.1               | 553.8  |
| 1      | 400.7               | 300.5               | 676.2  |

**Table 3.4.30** Mt calculation in X direction

| Floors | F <sub>x</sub> (kN) | 0.75*F <sub>x</sub> | Mt     |
|--------|---------------------|---------------------|--------|
| Roof   | 80.3                | 60.2                | 361.2  |
| 9      | 143.5               | 107.6               | 645.7  |
| 8      | 143.5               | 107.6               | 645.7  |
| 7      | 143.5               | 107.6               | 645.7  |
| 6      | 112.7               | 84.5                | 507.3  |
| 5      | 257.3               | 193.0               | 1158.0 |
| 4      | 257.3               | 193.0               | 1158.0 |
| 3      | 257.3               | 193.0               | 1158.0 |
| 2      | 328.2               | 246.1               | 1476.8 |
| 1      | 400.7               | 300.5               | 1803.1 |

**Table 3.4.31** Case 2 in Y direction

| Floor | A   | B   | C   | D   | E    | F    | G    | H    | I    | G    | K    | L    | M    | Total |
|-------|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|-------|
| Roof  |     |     |     |     |      |      |      |      | 30.2 | 30.2 | 0.2  | 0.3  | 0.3  | 60.6  |
| 9     |     |     |     |     |      |      |      |      | 21.6 | 21.7 | 21.7 | 21.8 | 21.9 | 107.9 |
| 8     |     |     |     |     |      |      |      |      | 21.6 | 21.7 | 21.7 | 21.8 | 21.9 | 107.9 |
| 7     |     |     |     |     |      |      |      |      | 21.6 | 21.7 | 21.7 | 21.8 | 21.9 | 107.9 |
| 6     |     |     |     |     |      |      |      |      | 17.0 | 17.0 | 17.1 | 17.2 | 17.2 | 84.9  |
| 5     |     |     |     |     | 21.3 | 21.3 | 21.4 | 21.4 | 21.5 | 21.6 | 21.6 | 21.7 | 21.8 | 192.4 |
| 4     |     |     |     |     | 21.3 | 21.3 | 21.4 | 21.4 | 21.5 | 21.6 | 21.6 | 21.7 | 21.8 | 192.4 |
| 3     |     |     |     |     | 21.3 | 21.3 | 21.4 | 21.4 | 21.5 | 21.6 | 21.6 | 21.7 | 21.8 | 192.4 |
| 2     | 5.8 | 5.9 | 6.1 | 6.1 | 24.5 | 24.5 | 24.5 | 24.6 | 24.7 | 24.7 | 24.8 | 24.9 | 25.0 | 246.1 |
| 1     | 7.1 | 7.2 | 7.4 | 7.5 | 29.9 | 30.0 | 30.0 | 30.1 | 30.1 | 30.2 | 30.3 | 30.3 | 30.4 | 300.4 |

**Table 3.4.32** Case 2 in X direction

| Floors | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | Total |
|--------|------|------|------|------|------|------|------|------|------|-------|
| Roof   | 14.0 | 14.3 |      |      |      |      |      | 15.8 | 16.1 | 60.2  |
| 9      | 10.1 | 10.6 | 11.4 | 11.7 | 12.0 | 12.2 | 12.5 | 12.7 | 13.0 | 106.2 |
| 8      | 10.1 | 10.6 | 11.4 | 11.7 | 12.0 | 12.2 | 12.5 | 12.7 | 13.0 | 106.2 |
| 7      | 10.1 | 10.6 | 11.4 | 11.7 | 12.0 | 12.2 | 12.5 | 12.7 | 13.0 | 106.2 |
| 6      | 7.9  | 8.3  | 8.9  | 9.1  | 9.4  | 9.7  | 9.9  | 10.2 | 10.4 | 83.8  |
| 5      | 18.1 | 18.9 | 20.9 | 21.2 | 21.4 | 21.7 | 22.0 | 22.2 | 22.5 | 188.9 |
| 4      | 18.1 | 18.9 | 20.9 | 21.2 | 21.4 | 21.7 | 22.0 | 22.2 | 22.5 | 188.9 |
| 3      | 18.1 | 18.9 | 20.9 | 21.2 | 21.4 | 21.7 | 22.0 | 22.2 | 22.5 | 188.9 |
| 2      | 77.8 | -3.2 | -0.5 | -0.3 | 82.0 | 0.3  | 0.5  | 0.8  | 83.1 | 240.5 |

|   |      |  |  |  |       |  |  |  |       |       |
|---|------|--|--|--|-------|--|--|--|-------|-------|
| 1 | 94.9 |  |  |  | 100.2 |  |  |  | 101.2 | 293.2 |
|---|------|--|--|--|-------|--|--|--|-------|-------|

### 3.5 Analytical Model Development

This section focuses on the development of the analytical model using the SAP2000 software of the “ADZHARAT” hotel. It describes the materials, elements, connections, and boundary conditions used during the structural modelling. Moreover, the methods used for analysis of gravitational and lateral loads. In order to verify the software obtained results, they were compared with hand calculations.

#### 3.5.1 Materials

##### 3.5.1.1 Concrete

The following Table 3.5.1 represents the concrete properties used during the software development. There is a distinction between the usual structural members (5000 psi) and PS beam (8000 psi) in these properties due to the fact that the PS beam is subjective for the more significant loads due to its comparingly long length, therefore it demands stronger concrete properties.

**Table 3.5.1** Concrete Properties

| Component                   | $f'_c$ (MPa) | $\rho$ ( $kg/m^3$ ) | $E_c$ (GPa) | $\nu$ | $G_c$ (GPa) | $f'_r$ (MPa) |
|-----------------------------|--------------|---------------------|-------------|-------|-------------|--------------|
| Beams,<br>columns,<br>slabs | 35,00        | 2356,00             | 27,81       | 0,20  | 11,59       | 3,73         |
| PS beams                    | 55,00        | 2356,00             | 34,86       | 0,20  | 14,52       | 4,67         |

The Modulus of Elasticity was calculated as guided in ACI 318 for normal weight concrete:

$$E_c = 4700\sqrt{f'_c}$$

The Poisson’s ratio typically varies between 0,15-0,25 values, so the average of them, 0,2 was taken for the model.

The Shear Modulus was obtained using the following expression:

$$G_c = \frac{E_c}{2(1+\nu)}$$

The Modulus of Rupture was found using the following equation as per ACI 318:

$$f'_r = 0,63\sqrt{f'_c}$$

### 3.5.1.2 Reinforcement

The properties of reinforcement are given in the following Table 2.4.

**Table 3.5.2** Reinforcement Properties

| $\rho$ ( $kg/m^3$ ) | E (MPa) | $\nu$ | G (MPa) | $f_y$ (MPa) | $f_u$ (MPa) |
|---------------------|---------|-------|---------|-------------|-------------|
| 76,96               | 199     | 0,3   | 76      | 413,69      | 620,53      |

### 3.5.1.3 Prestress Tendons

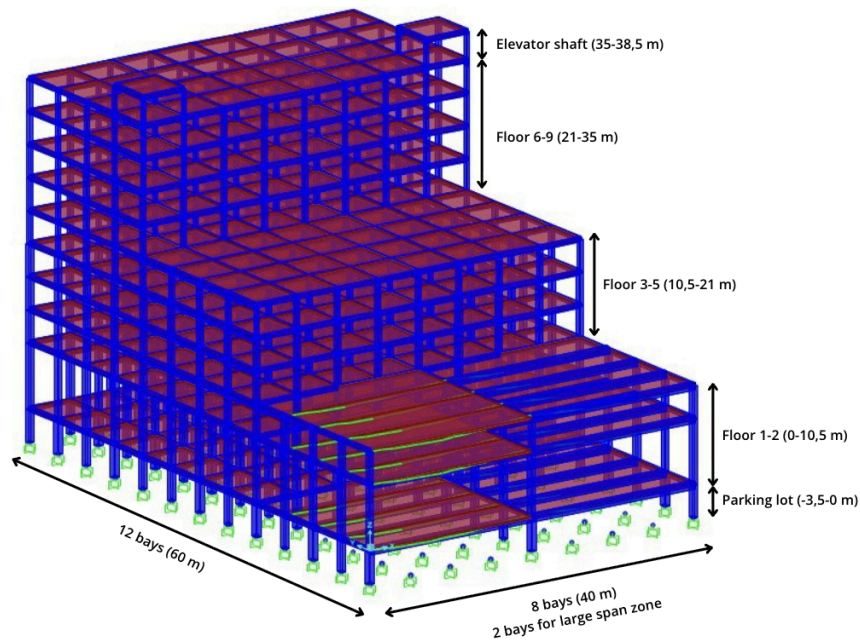
The properties of prestress tendons of PS beam are summarised in the next Table 3.5.3 below.

**Table 3.5.3** Prestress Tendon Properties

| $\rho$ ( $kg/m^3$ ) | E (MPa) | $f_y$ (MPa) | $f_u$ (MPa) |
|---------------------|---------|-------------|-------------|
| 76,97               | 197     | 1689,91     | 1861,58     |

### 3.5.2 Model Geometry

The “ADZHARAT” hotel was structurally modelled in SAP2000. The model includes all the main structural elements such as beams, columns, slabs and PS beams. The Figure 3.5.1 illustrates the overall model geometry of the building.



**Figure 3.5.1** Model Geometry in SAP2000 3D

### 3.5.3 Elements and connections

Number of structural elements were used to represent the analysis model, such as slabs, frames, beams and columns. The floors were modeled with shell elements to capture the semi-rigid behaviour of the floors. The hinged joints were applied at the frame and shear wall to resist axial and shear loads. All other joints were considered to be rigid.

### 3.5.4 Boundary Conditions

According to the ASCE 7 guidelines, for foundation level the fixed supports were applied. Therefore, there will be only limited lateral movement when the structure is under lateral load.

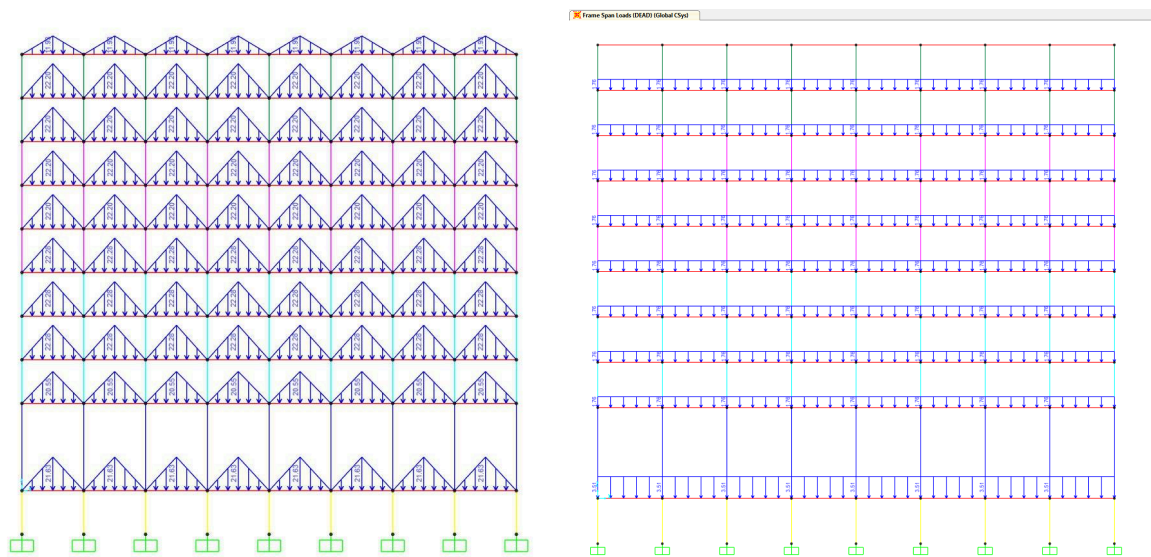
## 3.6 Structural Analysis

### 3.6.1. Verification of internal forces

#### 3.6.1.1. Verification of gravitational loads

In order to verify the gravitational loads, it was decided to compare the software 2D/3D models and hand calculations's results of the axial, shear and moments created due to the dead load in the frame M.

The dead loads assigned to the frame in the SAP2000 3D model are shown in figure below.



**Figure 3.6.1.1** a) Area Load to frame; b) Wall dead load

Since the slab is two-way, the area loads are transformed into triangular loads. The value of the maximum on the triangular shape can be calculated through the tributary area formula below, the results are summed in Table 3.6.1.

$$pressure(kPa) * length(m) = linear\ load\ (kN/m),$$

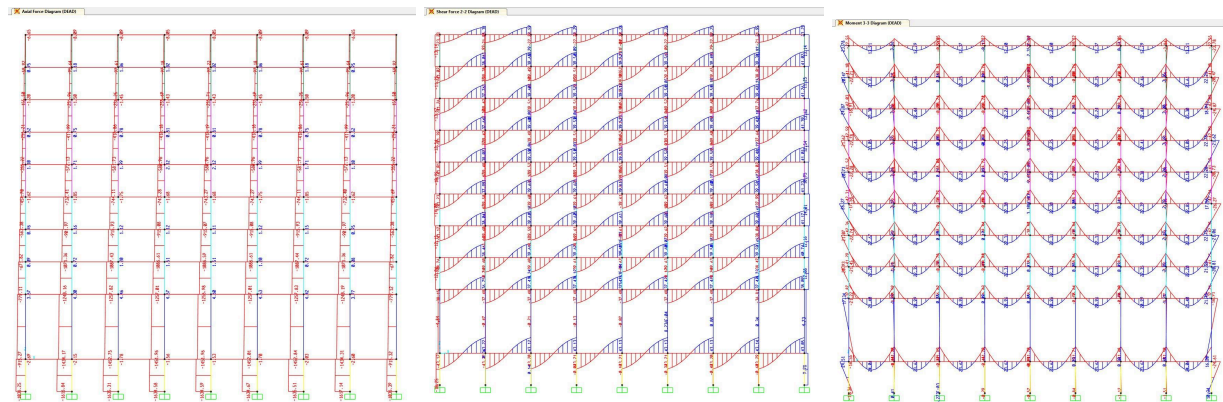
where length is only  $5m/2=2.5\ m$ , since the M frame is on the back edge of the hotel, so only one slab is connected to the major beam.

**Table 3.6.1.1** Pressure to max triangular load transformation by floor

| Floor | Average DL (kPa) | Max Triangular |
|-------|------------------|----------------|
|-------|------------------|----------------|

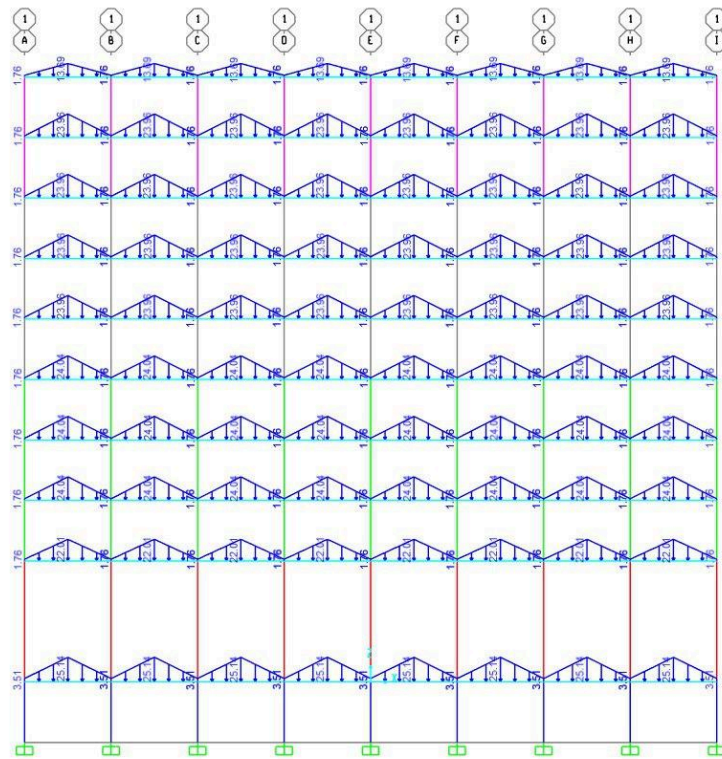
|           |      | Load (kN/m) |
|-----------|------|-------------|
| Roof      | 4,77 | 11,93       |
| Floor 6-9 | 8,88 | 22,20       |
| Floor 3-5 | 8,91 | 22,28       |
| Floor 2   | 8,22 | 20,55       |
| Floor 1   | 8,65 | 21,63       |

The obtained triangular loads will be used further in SAP 2D model and hand calculations. The SAP2000 3D has calculated the following results for the M frame of the building which are summarized in the Figure 3.6.1.2 below.



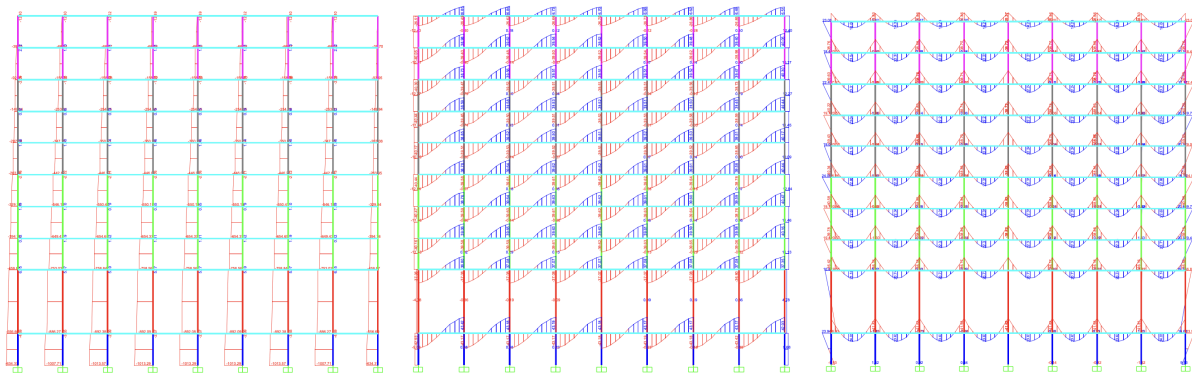
**Figure 3.6.1.2** M frame's a) axial force diagram, b) shear force diagram, c) Moment diagram in 3D model

The SAP2000 2D model was created similar to the 3D model, the elements and the loads were assigned the same as per 3D model. The resultant M frame is shown in the Figure 3.6.1.3.



**Figure 3.6.1.3** SAP2000 2D model, M frame

The analysis of the model has listed the following axial, shear and moment diagrams which are illustrated in the Figure 3.6.1.4.



**Figure 3.6.1.4** M frame's a) axial force diagram, b) shear force diagram, c) Moment diagram in 2D model



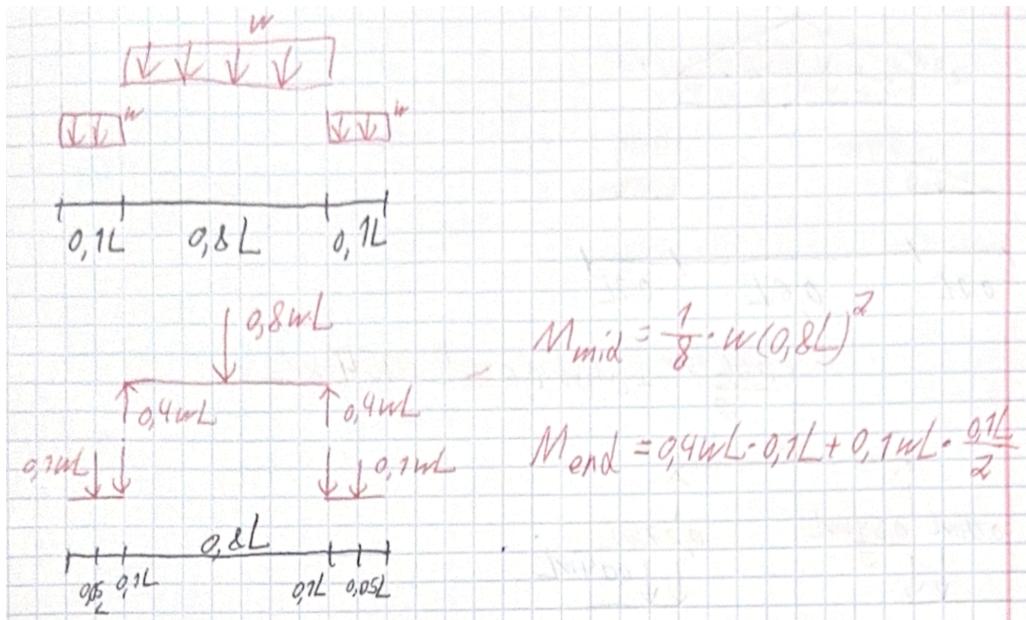
In order to accurately compare the results of the 2D, 3D models and hand calculations, it was decided to select the edge column for shear and axial load comparison, and the major beam connected to the edge column for the moments in the end and middle of it.

The hand calculations followed the procedure outlined by steps below:

- 1) Calculation of the moment in the middle and the end of the major beam.

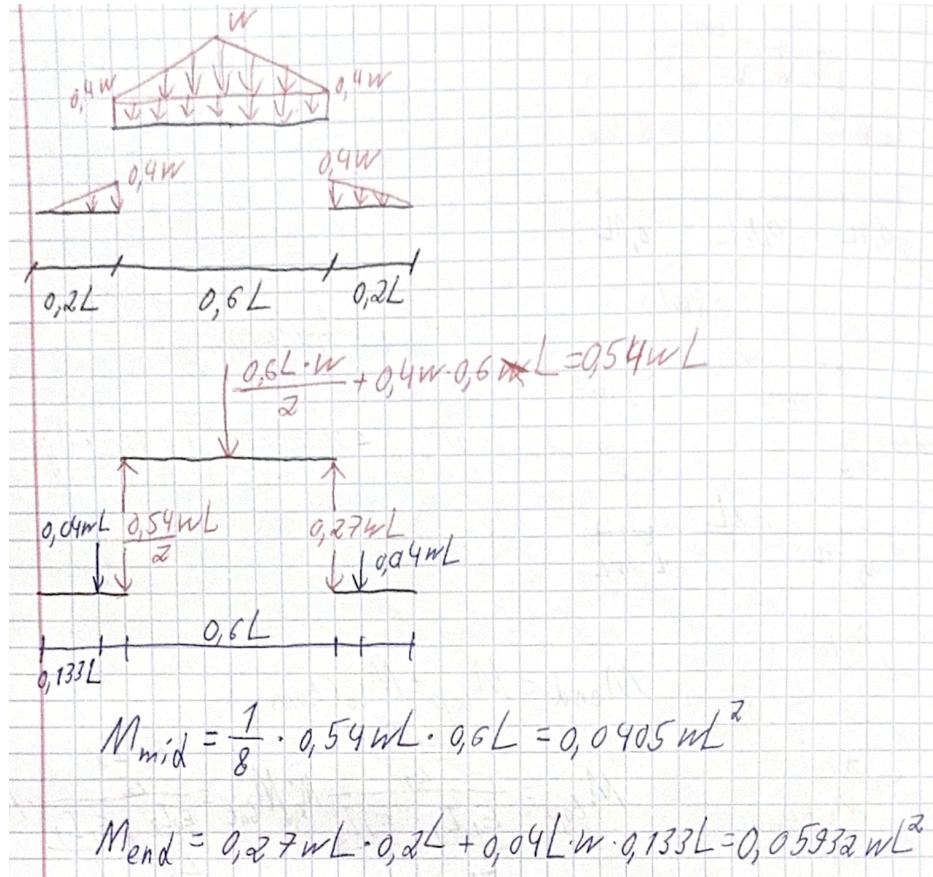
In order to accomplish this step, first of all, it is necessary to understand that the M frame is located on the exterior wall side of the building, therefore the moments will be created due to the triangular load and exterior wall load separately. So they will be calculated and summarized by superposition principle.

The approximate analysis was used to accomplish this goal, the calculation of the moments due to the exterior wall is straightforward with an approximate inflection point located at 0,1 of the length of the beam on ends and shown in the Figure 3.6.1.5 below.



**Figure 3.6.1.5**  $M_{mid}$ ,  $M_{end}$  due to exterior walls hand calculation

The calculation of  $M_{mid}$  and  $M_{end}$  due to the triangular load follows a similar approach, however the inflection point was decided to be approximately on the 0,2 of the length of the beam because 0,1L resulted in a big error, and according to the SAP2000 models it should be at about 0,2L. The procedure is summarized in Figure 3.6.1.6.



**Figure 3.6.1.6**  $M_{mid}$ ,  $M_{end}$  due to exterior walls hand calculation

The results of the moments per floor are shown in Table 3.6.1.2 below.

**Table 3.6.1.2** Total  $M_{mid}$  and  $M_{end}$  hand calculation results

| Floor # | Max triangular load, $w$ (kN/m) | UDL from exterior walls (kN/m) | $M_{mid}$ due to triangular load (kN·m) | $M_{mid}$ due to exterior walls (kN·m) | Total $M_{mid}$ (kN·m) | $M_{end}$ due to triangular load (kN·m) | $M_{end}$ due to exterior walls (kN·m) | Total $M_{end}$ (kN·m) |
|---------|---------------------------------|--------------------------------|-----------------------------------------|----------------------------------------|------------------------|-----------------------------------------|----------------------------------------|------------------------|
| Roof    | 11,93                           | 1,76                           | 12,07                                   | 3,52                                   | 15,59                  | 17,68                                   | 3,96                                   | 21,64                  |
| Floor 9 | 22,20                           | 1,76                           | 22,48                                   | 3,52                                   | 26,00                  | 32,92                                   | 3,96                                   | 36,88                  |
| Floor 8 | 22,20                           | 1,76                           | 22,48                                   | 3,52                                   | 26,00                  | 32,92                                   | 3,96                                   | 36,88                  |

|         |       |      |       |      |       |       |      |       |
|---------|-------|------|-------|------|-------|-------|------|-------|
| Floor 7 | 22,20 | 1,76 | 22,48 | 3,52 | 26,00 | 32,92 | 3,96 | 36,88 |
| Floor 6 | 22,20 | 1,76 | 22,48 | 3,52 | 26,00 | 32,92 | 3,96 | 36,88 |
| Floor 5 | 22,28 | 1,76 | 22,55 | 3,52 | 26,07 | 33,03 | 3,96 | 36,99 |
| Floor 4 | 22,28 | 1,76 | 22,55 | 3,52 | 26,07 | 33,03 | 3,96 | 36,99 |
| Floor 3 | 22,28 | 1,76 | 22,55 | 3,52 | 26,07 | 33,03 | 3,96 | 36,99 |
| Floor 2 | 20,55 | 1,76 | 20,81 | 3,52 | 24,33 | 30,48 | 3,96 | 34,44 |
| Floor 1 | 21,63 | 3,51 | 21,90 | 7,02 | 28,92 | 32,07 | 7,90 | 39,97 |

2) Calculation of the shear load of the edge column.

The procedure follows the equations illustrated below:

$$I = b^4 / 12$$

$$M_{top} = \frac{\frac{E_1 I_1}{L_1}}{\frac{E_1 I_1}{L_1} + \frac{E_2 I_2}{L_2}} \cdot M_{end}$$

$$M_{bottom} = \frac{\frac{E_2 I_2}{L_2}}{\frac{E_1 I_1}{L_1} + \frac{E_2 I_2}{L_2}} \cdot M_{end}$$

Since, the Young's modulus is the same for all columns, the calculation of  $M_{top}$  and  $M_{bottom}$  can be simplified.

$$M_{top} = \frac{\frac{I_1}{L_1}}{\frac{I_1}{L_1} + \frac{I_2}{L_2}} \cdot M_{end}$$

$$M_{bottom} = \frac{\frac{I_2}{L_2}}{\frac{I_1}{L_1} + \frac{I_2}{L_2}} \cdot M_{end}$$

$$V = \frac{M_{top} + M_{bottom}}{h}$$

The results are summarized in Table 3.6.1.3:

**Table 3.6.1.3** Shear force acting on the edge column hand calculation results

| Floor # | Dimensions of the column, b=h, (m) | Moment of Inertia, ( $m^4$ ) | Height of the column (m) | Total $M_{end}$ (kN·m) | $M_{top}$ (kN·m) | $M_{bottom}$ (kN·m) | Shear force on column (kN) |
|---------|------------------------------------|------------------------------|--------------------------|------------------------|------------------|---------------------|----------------------------|
| Floor 9 | 0,400                              | 0,013                        | 3,500                    | 21,645                 | -                | -                   | 11,453                     |
| Floor 8 | 0,400                              | 0,013                        | 3,500                    | 36,883                 | 18,441           | 18,441              | 9,920                      |
| Floor 7 | 0,450                              | 0,017                        | 3,500                    | 36,883                 | 16,279           | 20,603              | 11,156                     |
| Floor 6 | 0,450                              | 0,017                        | 3,500                    | 36,883                 | 18,441           | 18,441              | 10,538                     |
| Floor 5 | 0,450                              | 0,017                        | 3,500                    | 36,883                 | 18,441           | 18,441              | 9,507                      |
| Floor 4 | 0,550                              | 0,025                        | 3,500                    | 36,994                 | 14,834           | 22,160              | 11,616                     |
| Floor 3 | 0,550                              | 0,025                        | 3,500                    | 36,994                 | 18,497           | 18,497              | 10,570                     |
| Floor 2 | 0,550                              | 0,025                        | 3,500                    | 36,994                 | 18,497           | 18,497              | 11,453                     |
| Floor 1 | 0,600                              | 0,030                        | 7,000                    | 34,436                 | 21,589           | 12,846              | 4,919                      |

3) Axial load acting on the edge column.

The axial load consists of the dead load from triangular load and exterior wall load, and self-weight of the column. The procedure is as follows:

$$R_{triangular\ load} = 0,04wL + 0,27wl \text{ (refer to Figure X.)}$$

$$R_{exterior\ wall} = 0,5wl \text{ (refer to Figure X.)}$$

$$R_{total} = R_{triangular\ load} + R_{exterior\ wall}$$

Since the edge column carries two beam, the reaction force should be twice as big as  $R_{total}$ .

$$Weight_{column} = b^2 h \cdot \frac{9,81\rho}{1000}$$

$$Total\ weight = 2 \cdot R_{total} + Weight_{column}$$

Finally, the axial load is the cumulative summation of the total weight.

The obtained results are shown in Table 3.6.1.4 below.

**Table 3.6.1.4** Axial force acting on the edge column hand calculation results

| Floor # | Reaction on the top of the column due to triangular load (kN) | Reaction on the top of the column due to exterior wall load (kN) | Total reaction force (kN) | Edge Column carries two beams, multiply by 2 (kN) | Column self-weight (kN) | Total weight (kN) | Cumulative table for Axial force (kN) |
|---------|---------------------------------------------------------------|------------------------------------------------------------------|---------------------------|---------------------------------------------------|-------------------------|-------------------|---------------------------------------|
| Floor 9 | 18,48                                                         | 4,40                                                             | 22,88                     | 45,77                                             | 12,94                   | 58,71             | 58,71                                 |
| Floor 8 | 34,41                                                         | 4,40                                                             | 38,81                     | 77,62                                             | 12,94                   | 90,56             | 149,27                                |
| Floor 7 | 34,41                                                         | 4,40                                                             | 38,81                     | 77,62                                             | 16,38                   | 94,00             | 243,27                                |
| Floor 6 | 34,41                                                         | 4,40                                                             | 38,81                     | 77,62                                             | 16,38                   | 94,00             | 337,28                                |
| Floor 5 | 34,41                                                         | 4,40                                                             | 38,81                     | 77,62                                             | 16,38                   | 94,00             | 431,28                                |
| Floor 4 | 34,53                                                         | 4,40                                                             | 38,93                     | 77,85                                             | 24,47                   | 102,32            | 533,60                                |
| Floor 3 | 34,53                                                         | 4,40                                                             | 38,93                     | 77,85                                             | 24,47                   | 102,32            | 635,92                                |
| Floor 2 | 34,53                                                         | 4,40                                                             | 38,93                     | 77,85                                             | 24,47                   | 102,32            | 738,24                                |
| Floor 1 | 31,85                                                         | 4,40                                                             | 36,25                     | 72,51                                             | 58,24                   | 130,75            | 868,99                                |

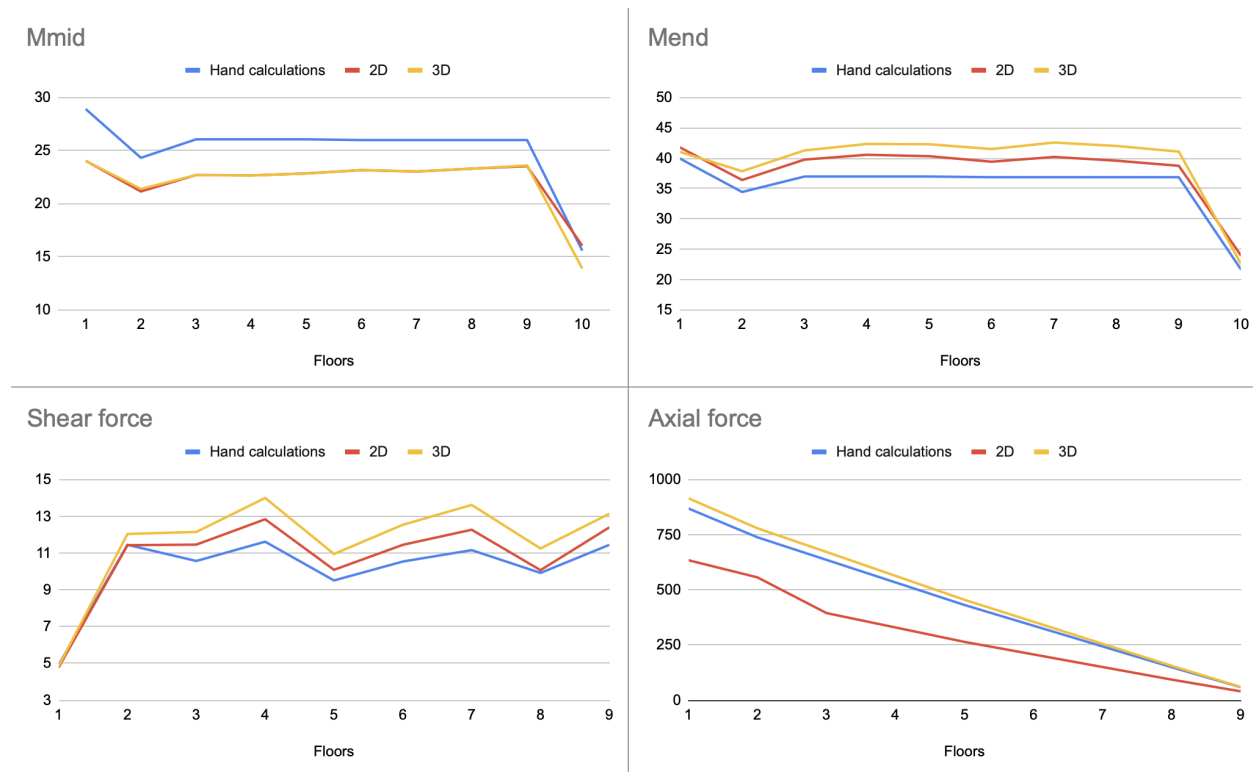
The results for axial, shear, end and mid moments for the M frame from SAP2000 2D model, 3D model and hand calculations can be summarized in the following Table 3.6.1.5.

**Table 3.6.1.5** Summary of the results for internal force, dead load verification

| Floor # | HAND CALCULATIONS |            |                  |                  | SAP2000 2D MODEL |            |                  |                  | SAP2000 3D MODEL |            |                  |                  |
|---------|-------------------|------------|------------------|------------------|------------------|------------|------------------|------------------|------------------|------------|------------------|------------------|
|         | Mmid (kNm)        | Mend (kNm) | Shear force (kN) | Axial force (kN) | Mmid (kNm)       | Mend (kNm) | Shear force (kN) | Axial force (kN) | Mmid (kNm)       | Mend (kNm) | Shear force (kN) | Axial force (kN) |
| Roof    | 15,59             | 21,64      |                  |                  | 16,06            | 23,93      |                  |                  | 13,91            | 22,55      |                  |                  |
| Floor 9 | 26,00             | 36,88      | 11,45            | 58,71            | 23,54            | 38,76      | 12,4             | 39,7             | 23,61            | 41,1       | 13,14            | 59,92            |
| Floor 8 | 26,00             | 36,88      | 9,92             | 149,27           | 23,31            | 39,6       | 10,07            | 92,95            | 23,3             | 42,03      | 11,25            | 155,5            |
| Floor 7 | 26,00             | 36,88      | 11,16            | 243,27           | 23,04            | 40,22      | 12,27            | 149,94           | 23,05            | 42,59      | 13,62            | 255,21           |

|         |       |       |       |        |       |       |       |        |       |       |       |        |
|---------|-------|-------|-------|--------|-------|-------|-------|--------|-------|-------|-------|--------|
| Floor 6 | 26,00 | 36,88 | 10,54 | 337,28 | 23,17 | 39,43 | 11,45 | 207,08 | 23,18 | 41,52 | 12,54 | 355,22 |
| Floor 5 | 26,07 | 36,99 | 9,51  | 431,28 | 22,86 | 40,34 | 10,09 | 263,95 | 22,85 | 42,31 | 10,95 | 454,7  |
| Floor 4 | 26,07 | 36,99 | 11,62 | 533,60 | 22,67 | 40,58 | 12,84 | 329,34 | 22,67 | 42,36 | 14    | 563,38 |
| Floor 3 | 26,07 | 36,99 | 10,57 | 635,92 | 22,71 | 39,78 | 11,46 | 394,76 | 22,7  | 41,29 | 12,15 | 671,82 |
| Floor 2 | 24,33 | 34,44 | 11,45 | 738,24 | 21,16 | 36,42 | 11,43 | 556,6  | 21,4  | 37,87 | 12,04 | 779,11 |
| Floor 1 | 28,92 | 39,97 | 4,92  | 868,99 | 24,05 | 41,81 | 4,78  | 634,37 | 24,04 | 41,06 | 4,84  | 915,27 |

Based on the results above, the following graphs were obtained.



**Figure 3.6.1.7** Result comparison graphs of 2D, 3D models and hand calculations of dead load

It is visible on all of the graphs that all line graphs follow a similar pattern, however there are some irregularities.

First of all, the hand calculations results for the moments deviate from the 2D, 3D model results, this could be explained by the fact that the approximate method would not provide as accurate results as the SAP2000 models, so that even the inflection point appropriate selection does not guarantee the accuracy of the calculated results.

Secondly, shear force results comparably have reasonably similar answers, the deviations could be explained by the difference of the geometry models between hand, 2D, and 3D models.

Finally, the axial force has the major deviation of 2D model results because this model does not include the orthogonal beams connected to the edge column which leads to the decreased results since the edge column does not carry the additional weight coming for the other connected beam.

Overall, there are no other major differences between the SAP2000 models and hand calculations, therefore it is logical to conclude that the gravitational loads were successfully verified.

### 3.6.1.2. Verification of lateral loads

Similarly to the calculations of the gravity loads, the lateral load check was done by comparing the obtained SAP2000 software results of the 2D and 3D numerical models of Frame 1 with the hand calculations. The wind loads that had been calculated in Frame 1 were assumed to estimate the storey shear forces. It has used the portal method to determine the shear force on each column where the storey shear had been equally divided among the columns at every level of the storey. As per assumptions of the portal method, the bending moment of each column was accomplished by multiplying the shear force of one column with a half of the storey height. The axial force in the column was then calculated using bending moment/span length.

**Table 3.6.1.6** Hand calculations of Moments, Shear and Axial forces for Frame 1.

| Floor # | Fi (kN) | Vi (kN) | V column (kN) | h (m) | M column (kN·m) | Axial (kN) |
|---------|---------|---------|---------------|-------|-----------------|------------|
| 9       | 6.7     | 8.9     | 1.1           | 3.5   | 3.9             | 0.19       |
| 8       | 6.6     | 15.5    | 1.9           | 3.5   | 6.8             | 0.34       |
| 7       | 6.4     | 21.9    | 2.7           | 3.5   | 9.6             | 0.48       |
| 6       | 6.3     | 28.2    | 3.5           | 3.5   | 12.3            | 0.62       |
| 5       | 7.3     | 35.5    | 2.2           | 3.5   | 7.8             | 0.19       |
| 4       | 7.1     | 42.7    | 2.7           | 3.5   | 9.3             | 0.23       |
| 3       | 6.9     | 49.5    | 3.1           | 3.5   | 10.8            | 0.27       |
| 2       | 19.7    | 69.3    | 2.9           | 3.5   | 10.1            | 0.17       |

|   |      |       |     |     |      |      |
|---|------|-------|-----|-----|------|------|
| 1 | 37.2 | 106.4 | 4.4 | 7.0 | 31.0 | 0.52 |
|---|------|-------|-----|-----|------|------|

$$V_i = F_i + V_{i+1}$$

$$V_{column} = \frac{V_i}{n_i}$$

$$M_{column} = V_{column} \frac{h_i}{2}$$

$$F_{axial} = \frac{M_{column}}{L_i}$$

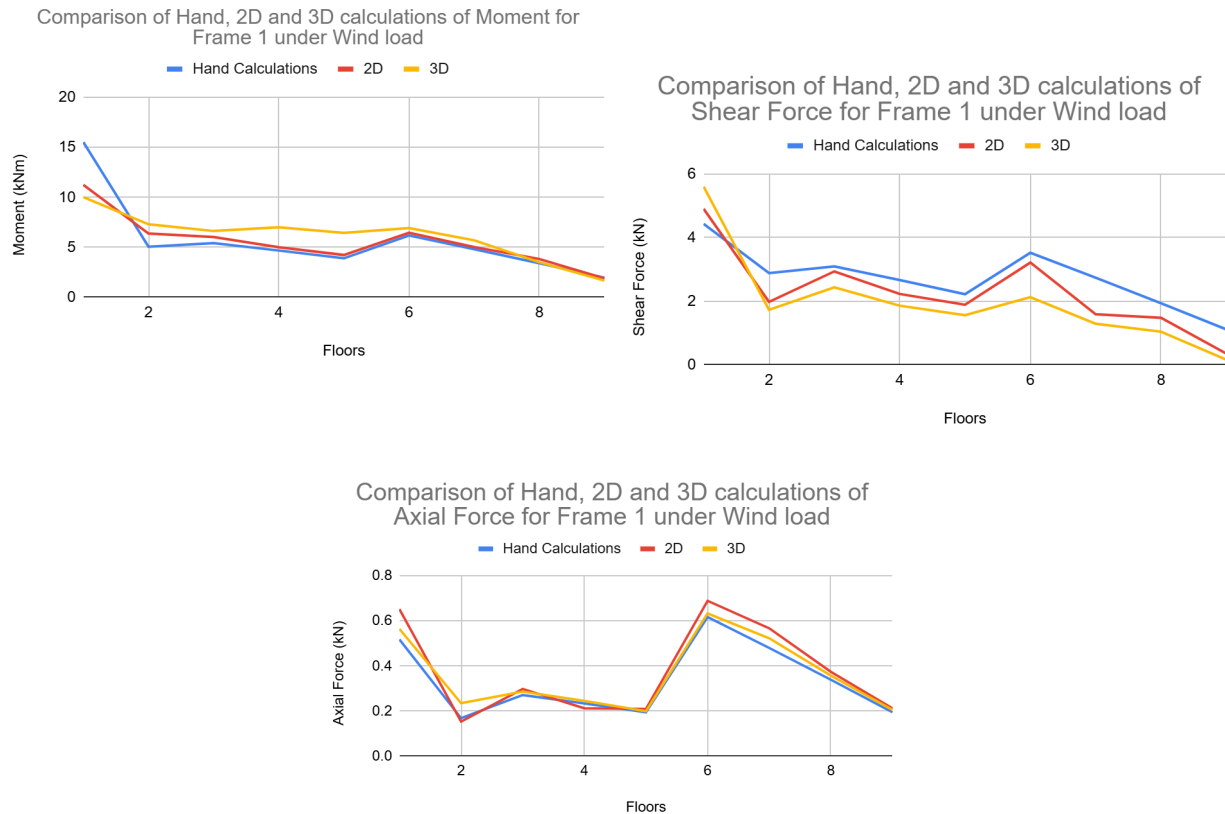
$n_i$  – number of columns on the span

$L_i$  – length of the span

**Table 3.6.1.7** Summary of the results for internal force, wind load verification

|         | HAND CALCULATIONS |                        |                        | SAP2000 2D MODEL |                        |                        | SAP2000 3D MODEL |                        |                        |
|---------|-------------------|------------------------|------------------------|------------------|------------------------|------------------------|------------------|------------------------|------------------------|
| Floor # | M<br>(kNm)        | Shear<br>force<br>(kN) | Axial<br>force<br>(kN) | M<br>(kNm)       | Shear<br>force<br>(kN) | Axial<br>force<br>(kN) | M<br>(kNm)       | Shear<br>force<br>(kN) | Axial<br>force<br>(kN) |
| Floor 9 | 1.946             | 1.112                  | 0.195                  | 1.88             | 0.35                   | 0.212                  | 1.66             | 0.16                   | 0.205                  |
| Floor 8 | 3.390             | 1.937                  | 0.339                  | 3.82             | 1.48                   | 0.374                  | 3.5              | 1.04                   | 0.357                  |
| Floor 7 | 4.800             | 2.743                  | 0.480                  | 5.02             | 1.59                   | 0.567                  | 5.69             | 1.29                   | 0.523                  |
| Floor 6 | 6.172             | 3.527                  | 0.617                  | 6.45             | 3.22                   | 0.689                  | 6.91             | 2.13                   | 0.633                  |
| Floor 5 | 3.888             | 2.222                  | 0.194                  | 4.22             | 1.89                   | 0.209                  | 6.44             | 1.56                   | 0.199                  |
| Floor 4 | 4.667             | 2.667                  | 0.233                  | 5                | 2.23                   | 0.212                  | 6.99             | 1.86                   | 0.245                  |
| Floor 3 | 5.418             | 3.096                  | 0.271                  | 6.02             | 2.94                   | 0.298                  | 6.62             | 2.44                   | 0.286                  |
| Floor 2 | 5.050             | 2.886                  | 0.168                  | 6.37             | 1.98                   | 0.153                  | 7.3              | 1.73                   | 0.235                  |
| Floor 1 | 15.522            | 4.435                  | 0.517                  | 11.24            | 4.91                   | 0.652                  | 10.01            | 5.61                   | 0.564                  |





**Figure 3.6.1.8** Visual representation of lateral wind forces verification

As can be seen in the graphs, the plots of the lines tend to exhibit a similar trend but some discrepancies do exist. First, the bending moment values achieved through hand calculations display visible discrepancies with the values achieved through the 2D and 3D numerical models. This disparity can be explained by an approximate analytical technique which by default gives imprecise data as opposed to the SAP2000 modelling. Therefore, although a reasonable assumption of the location points of inflection points has been made, one cannot anticipate absolute correspondence to numerical findings.

Second, the shear force results show a fairly acceptable degree of agreement between the hand calculations, 2D model and the 3D model. These small discrepancies are probably as a result of the variation in the geometry representation and the assumptions used in the simplified hand method as compared to the numerical models.

Lastly, the axial force results are the most deviated in the 2D model. This is attributed to the fact that the 2D representation has no orthogonal beams attached to the edge column.

Consequently, the edge column in the 2D model fails to consider the extra axial forces passed on by the beams in perpendicular direction and hence the axial forces values are lower than those of the 3D model.

In general, there were no critical differences found in the outcomes of the SAP2000 and the hand calculations. Thus, it can be concluded that the effects of wind loads that had to act on the structure were also checked.

**3.6.2 Wind drift hand calculations**

The proposed building design underwent structural analysis through hand calculations that included verification procedures to assess safety and stability while meeting all design standards. The structural assessment focused on measuring lateral displacements and internal forces and analyzing how the structure responded to wind and seismic forces. The wind drift calculation process required analysis of both shear and flexural components at each storey to produce precise horizontal displacement measurements throughout the building's entire height. The P-Δ analysis examined second-order deformations which occur when axial loads push laterally displaced members, which serves as an essential method to evaluate the structural system's stability. The seismic drift calculations applied equivalent lateral force methods which included shear and flexural and P-Δ components to assess the building's earthquake response.

The study determined axial forces by measuring building segments because this method enabled accurate assessment of load distribution to the foundation system. The engineering calculations used standard formulas which designers checked against design codes to ensure that strength and serviceability requirements remained within acceptable limits. The structural system demonstrates sufficient stiffness and strength to control lateral movements and prevent excessive deformation during wind and seismic events. The chosen structural design proves to be dependable because it will maintain building security and operational efficiency throughout expected load duration.

**Table 3.6.2.1.** Ib and Ic summary

|          |          |        |
|----------|----------|--------|
| Ic (mm4) | Ib (mm4) | Ic avg |
|----------|----------|--------|

|          |          |          |
|----------|----------|----------|
| 2.39E+09 | 9.11E+08 | 1.20E+09 |
| 2.39E+09 | 9.11E+08 | 2.39E+09 |
| 2.39E+09 | 9.11E+08 | 2.39E+09 |
| 2.39E+09 | 9.11E+08 | 2.39E+09 |
| 2.39E+09 | 9.11E+08 | 2.39E+09 |
| 5.34E+09 | 9.11E+08 | 3.86E+09 |
| 5.34E+09 | 9.11E+08 | 5.34E+09 |
| 5.34E+09 | 9.11E+08 | 5.34E+09 |
| 5.34E+09 | 9.11E+08 | 5.34E+09 |

**Table 3.6.2.2** Frame 1 wind shear drift calculations

| Floor | Column size | Beam size | hi (mm) | hi-avg (mm) | Fi   | Vi     | Vi col | Vi avg | db    | dc    | dt    | di    | Di     |
|-------|-------------|-----------|---------|-------------|------|--------|--------|--------|-------|-------|-------|-------|--------|
| roof  | 450         | 500x250   | 3500    | 3000        | 2.15 | 2.150  | 2.150  | 1.075  | 0.172 | 0.079 | 0.250 | 0.427 | 14.208 |
| 9     | 450         | 500x250   | 3500    | 3500        | 6.75 | 8.896  | 2.224  | 2.187  | 0.476 | 0.127 | 0.603 | 0.721 | 13.782 |
| 8     | 450         | 500x250   | 3500    | 3500        | 6.60 | 15.498 | 3.874  | 3.049  | 0.663 | 0.177 | 0.840 | 1.065 | 13.060 |
| 7     | 450         | 500x250   | 3500    | 3500        | 6.44 | 21.942 | 5.486  | 4.680  | 1.018 | 0.272 | 1.290 | 1.509 | 11.995 |
| 6     | 450         | 500x250   | 3500    | 3500        | 6.27 | 28.216 | 7.054  | 6.270  | 1.364 | 0.364 | 1.728 | 1.592 | 10.486 |
| 5     | 550         | 500x250   | 3500    | 3500        | 7.33 | 35.548 | 4.443  | 5.749  | 1.251 | 0.206 | 1.457 | 1.324 | 8.894  |
| 4     | 550         | 500x250   | 3500    | 3500        | 7.12 | 42.665 | 5.333  | 4.888  | 1.063 | 0.127 | 1.190 | 1.297 | 7.570  |
| 3     | 550         | 500x250   | 3500    | 3500        | 6.87 | 49.536 | 6.192  | 5.763  | 1.254 | 0.150 | 1.403 | 1.430 | 6.273  |
| 2     | 550         | 500x250   | 3500    | 3500        | 19.7 | 69.260 | 5.772  | 5.982  | 1.301 | 0.156 | 1.457 | 2.786 | 4.843  |
| 1     | 600         | 500x250   | 7000    | 5250        | 37.2 | 106.44 | 8.870  | 7.321  | 3.583 | 0.532 | 4.115 | 2.057 | 2.057  |

**Table 3.6.2.3** Frame 1 wind flexural drift calculations

| Floor | Column size | Beam size | hi (mm) | Hi | Fi | Vi | Mi | Aci | fi (1/mm) | Dqi (rad) | qi (rad) | di (mm) | Di (mm) |
|-------|-------------|-----------|---------|----|----|----|----|-----|-----------|-----------|----------|---------|---------|
|-------|-------------|-----------|---------|----|----|----|----|-----|-----------|-----------|----------|---------|---------|

|      |     |         |      |       |       |       |        |        |          |          |          |       |       |
|------|-----|---------|------|-------|-------|-------|--------|--------|----------|----------|----------|-------|-------|
| roof | 450 | 500x250 | 3000 | 38000 | 2.150 | 2.150 | 6.451  | 202500 | 9.90E-11 | 2.97E-07 | 2.27E-04 | 0.681 | 6.867 |
| 9    | 450 | 500x250 | 3500 | 35000 | 6.746 | 8.896 | 37.588 | 202500 | 5.77E-10 | 2.02E-06 | 2.27E-04 | 0.794 | 6.185 |
| 8    | 450 | 500x250 | 3500 | 31500 | 6.601 | 15.5  | 91.830 | 202500 | 1.41E-09 | 4.93E-06 | 2.25E-04 | 0.787 | 5.391 |
| 7    | 450 | 500x250 | 3500 | 28000 | 6.445 | 21.94 | 168.62 | 202500 | 2.59E-09 | 9.06E-06 | 2.20E-04 | 0.770 | 4.604 |
| 6    | 450 | 500x250 | 3500 | 24500 | 6.274 | 28.21 | 267.38 | 202500 | 4.10E-09 | 1.44E-05 | 2.11E-04 | 0.738 | 3.835 |
| 5    | 550 | 500x250 | 3500 | 21000 | 7.332 | 35.55 | 391.80 | 302500 | 4.03E-09 | 1.41E-05 | 1.96E-04 | 0.688 | 3.097 |
| 4    | 550 | 500x250 | 3500 | 17500 | 7.118 | 42.66 | 541.13 | 302500 | 5.56E-09 | 1.95E-05 | 1.82E-04 | 0.638 | 2.409 |
| 3    | 550 | 500x250 | 3500 | 14000 | 6.871 | 49.54 | 714.51 | 302500 | 7.34E-09 | 2.57E-05 | 1.63E-04 | 0.570 | 1.771 |
| 2    | 550 | 500x250 | 3500 | 10500 | 19.72 | 69.26 | 956.92 | 302500 | 9.83E-09 | 3.44E-05 | 1.37E-04 | 0.480 | 1.200 |
| 1    | 600 | 500x250 | 7000 | 7000  | 37.18 | 106.4 | 1702   | 360000 | 1.47E-08 | 1.03E-04 | 1.03E-04 | 0.720 | 0.720 |

**Table 3.6.2.4** Frame 1 wind P-D effect calculations

| Floor | Column size | Beam size | P <sub>ui</sub> | F <sub>i</sub> | V <sub>i</sub> | d <sub>i</sub> total | D <sub>i</sub> total | h <sub>i</sub> (mm) | Q     | b <sub>2</sub> | d <sub>i</sub> ,PD (mm) | D <sub>i</sub> ,PD (mm) |
|-------|-------------|-----------|-----------------|----------------|----------------|----------------------|----------------------|---------------------|-------|----------------|-------------------------|-------------------------|
| roof  | 450         | 500x250   |                 | 2.150          | 2.150          | 1.108                | 21.075               | 3000                |       | 1.00           | 1.108                   | 79.568                  |
| 9     | 450         | 500x250   | 2114.1          | 6.746          | 8.896          | 1.515                | 19.967               | 3500                | 0.103 | 1.11           | 1.689                   | 78.460                  |
| 8     | 450         | 500x250   | 7836.3          | 6.601          | 15.498         | 1.852                | 18.451               | 3500                | 0.268 | 1.37           | 2.528                   | 76.771                  |
| 7     | 450         | 500x250   | 17166           | 6.445          | 21.942         | 2.278                | 16.599               | 3500                | 0.509 | 2.04           | 4.643                   | 74.243                  |
| 6     | 450         | 500x250   | 30104           | 6.274          | 28.216         | 2.330                | 14.321               | 3500                | 0.710 | 3.45           | 8.046                   | 69.600                  |
| 5     | 550         | 500x250   | 48342           | 7.332          | 35.548         | 2.011                | 11.991               | 3500                | 0.782 | 4.58           | 9.208                   | 61.554                  |
| 4     | 550         | 500x250   | 73089           | 7.118          | 42.665         | 1.935                | 9.979                | 3500                | 0.947 | 18.96          | 36.690                  | 52.347                  |
| 3     | 550         | 500x250   | 104344          | 6.871          | 49.536         | 2.000                | 8.044                | 3500                | 1.204 | 1.00           | 2.000                   | 15.657                  |
| 2     | 550         | 500x250   | 145521          | 19.724         | 69.260         | 3.266                | 6.044                | 3500                | 1.961 | 1.00           | 3.266                   | 13.657                  |
| 1     | 600         | 500x250   | 196557          | 37.180         | 106.44         | 2.777                | 2.777                | 7000                | 0.733 | 3.74           | 10.390                  | 10.390                  |

**Table 3.6.2.5** Axial forces for each building segment

|         |         |         |
|---------|---------|---------|
| 9 story | 5 story | 2 story |
|---------|---------|---------|

| Column Location | Axial force,kN | Column Location | Axial force,kN | Column Location | Axial force,kN |
|-----------------|----------------|-----------------|----------------|-----------------|----------------|
| Slab 9          | 422.83         | Slab 9          |                | Slab 9          |                |
| Slab 8          | 1144.43        | Slab 8          |                | Slab 8          |                |
| Slab 7          | 1866.03        | Slab 7          |                | Slab 7          |                |
| Slab 6          | 2587.63        | Slab 6          |                | Slab 6          |                |
| Slab 5          | 3309.23        | Slab 5          | 422.83         | Slab 5          |                |
| Slab 4          | 4032.48        | Slab 4          | 1146.08        | Slab 4          |                |
| Slab 3          | 4755.73        | Slab 3          | 1869.34        | Slab 3          |                |
| Slab 2          | 5478.99        | Slab 2          | 2592.59        | Slab 2          | 852.9          |
| Slab 1          | 6161.31        | Slab 1          | 3274.91        | Slab 1          | 1782.31        |

**Table 3.6.2.6** Frame I wind shear drift calculations

| Floor | Column size | Beam size | hi (mm) | hi-avg (mm) | Fi (kN) | Vi (kN) | Vi-col (kN) | Vi-avg (kN) | db (mm)  | dc (mm)  | dt (mm)  | di (mm) | Di (mm) |
|-------|-------------|-----------|---------|-------------|---------|---------|-------------|-------------|----------|----------|----------|---------|---------|
| roof  | 450         | 500x250   | 3000    | 3000        | 3.91    | 3.910   | 3.910       | 1.955       | 0.312    | 0.143    | 0.455    | 0.593   | 11.314  |
| 9     | 450         | 500x250   | 3500    | 3500        | 7.19    | 11.104  | 1.388       | 2.649       | 0.576    | 0.154    | 0.730    | 0.617   | 10.721  |
| 8     | 450         | 500x250   | 3500    | 3500        | 7.06    | 18.168  | 2.271       | 1.829       | 0.398    | 0.106    | 0.504    | 0.625   | 10.104  |
| 7     | 450         | 500x250   | 3500    | 3500        | 6.92    | 25.091  | 3.136       | 2.704       | 0.588    | 0.157    | 0.745    | 0.863   | 9.480   |
| 6     | 450         | 500x250   | 3500    | 3500        | 6.77    | 31.860  | 3.983       | 3.559       | 0.774    | 0.207    | 0.981    | 1.053   | 8.617   |
| 5     | 550         | 500x250   | 3500    | 3500        | 7.33    | 39.192  | 4.899       | 4.441       | 5.34E+09 | 9.11E+08 | 3.86E+09 | 0.966   | 0.159   |
| 4     | 550         | 500x250   | 3500    | 3500        | 7.12    | 46.309  | 5.789       | 5.344       | 5.34E+09 | 9.11E+08 | 5.34E+09 | 1.162   | 0.139   |
| 3     | 550         | 500x250   | 3500    | 3500        | 6.87    | 53.180  | 6.648       | 6.218       | 5.34E+09 | 9.11E+08 | 5.34E+09 | 1.353   | 0.162   |
| 2     | 550         | 500x250   | 3500    | 3500        | 8.88    | 62.056  | 7.757       | 7.202       | 5.34E+09 | 9.11E+08 | 5.34E+09 | 1.567   | 0.187   |

|   |     |         |      |      |       |        |       |       |          |          |          |       |       |
|---|-----|---------|------|------|-------|--------|-------|-------|----------|----------|----------|-------|-------|
|   |     |         |      |      |       |        |       |       | 09       | 08       | 09       |       |       |
| 1 | 600 | 500x250 | 7000 | 3750 | 16.73 | 78.787 | 9.848 | 8.803 | 7.56E+09 | 9.11E+08 | 6.45E+09 | 2.198 | 0.233 |

**Table 3.6.2.7** Frame I wind flexural drift calculations

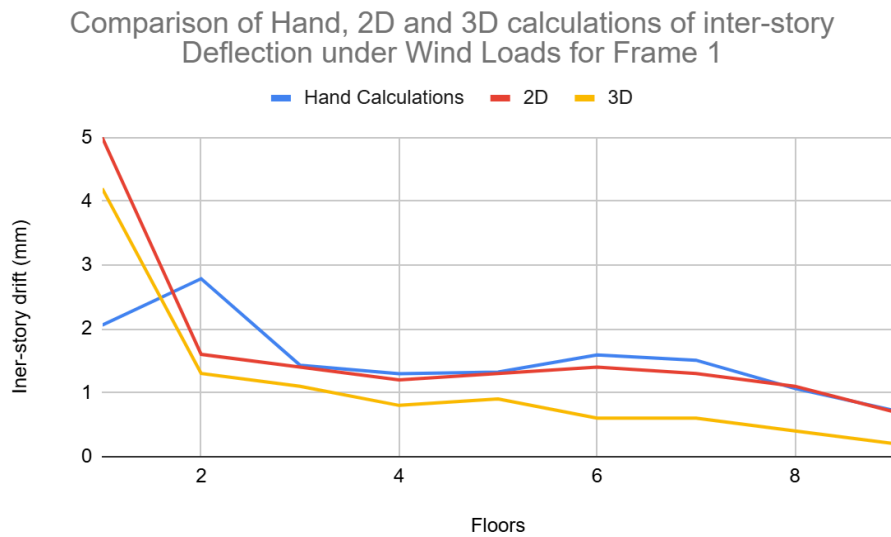
| Floor | Column size | Beam size | h <sub>i</sub> (mm) | H <sub>i</sub> (mm) | F <sub>i</sub> (kN) | V <sub>i</sub> (kN) | M <sub>i</sub> (k-m) | A <sub>ci</sub> (mm <sup>2</sup> ) | f <sub>i</sub> (1/mm) | D <sub>qi</sub> (rad) | q <sub>i</sub> (rad) | d <sub>i</sub> (mm) | D <sub>i</sub> (mm) |
|-------|-------------|-----------|---------------------|---------------------|---------------------|---------------------|----------------------|------------------------------------|-----------------------|-----------------------|----------------------|---------------------|---------------------|
| roof  | 450         | 500x250   | 3000                | 38000               | 3.910               | 3.910               | 11.729 60174         | 20250                              | 2.81E-12              | 8.44E-09              | 3.68E-06             | 0.011               | 0.108               |
| 9     | 450         | 500x250   | 3500                | 35000               | 7.194               | 11.104              | 50.593 54982         | 20250                              | 1.21E-11              | 4.25E-08              | 3.67E-06             | 0.013               | 0.097               |
| 8     | 450         | 500x250   | 3500                | 31500               | 7.064               | 18.168              | 114.18 15783         | 20250                              | 2.74E-11              | 9.58E-08              | 3.63E-06             | 0.013               | 0.084               |
| 7     | 450         | 500x250   | 3500                | 28000               | 6.923               | 25.091              | 202.00 06348         | 20250                              | 4.84E-11              | 1.70E-07              | 3.53E-06             | 0.012               | 0.071               |
| 6     | 450         | 500x250   | 3500                | 24500               | 6.769               | 31.860              | 313.51 14475         | 20250                              | 7.52E-11              | 2.63E-07              | 3.36E-06             | 0.012               | 0.059               |
| 5     | 550         | 500x250   | 3500                | 21000               | 7.332               | 39.192              | 450.68 25573         | 30250                              | 7.23E-11              | 2.53E-07              | 3.10E-06             | 0.011               | 0.047               |
| 4     | 550         | 500x250   | 3500                | 17500               | 7.118               | 46.309              | 612.76 559           | 30250                              | 9.84E-11              | 3.44E-07              | 2.84E-06             | 0.010               | 0.036               |
| 3     | 550         | 500x250   | 3500                | 14000               | 6.871               | 53.180              | 798.89 61085         | 30250                              | 1.28E-10              | 4.49E-07              | 2.50E-06             | 0.009               | 0.026               |
| 2     | 550         | 500x250   | 3500                | 10500               | 8.876               | 62.056              | 1016.0 91503         | 30250                              | 1.63E-10              | 5.71E-07              | 2.05E-06             | 0.007               | 0.018               |
| 1     | 600         | 500x250   | 7000                | 7000                | 16.731              | 78.787              | 1567.5 97349         | 36000                              | 2.11E-10              | 1.48E-06              | 1.48E-06             | 0.010               | 0.010               |

**Table 3.6.2.8** Frame I wind P-D effect calculations

| Floor | Column size | Beam size | P <sub>ui</sub> | F <sub>i</sub> (kN) | V <sub>i</sub> (kN) | d <sub>i,total</sub> (mm) | D <sub>i,total</sub> (mm) | h <sub>i</sub> (mm) | Q     | b <sub>2</sub> | d <sub>i,PD</sub> (mm) | D <sub>i,PD</sub> (mm) |
|-------|-------------|-----------|-----------------|---------------------|---------------------|---------------------------|---------------------------|---------------------|-------|----------------|------------------------|------------------------|
| 10    | 450         | 500x250   | 0               | 3.910               | 3.910               | 0.604                     | 11.422                    | 3000                | 0.000 | 1.000          | 0.604                  | 18.566                 |
| 9     | 450         | 500x250   | 3805.47         | 7.194               | 11.104              | 0.630                     | 10.818                    | 3500                | 0.062 | 1.066          | 0.671                  | 17.962                 |
| 8     | 450         | 500x250   | 14105.34        | 7.064               | 18.168              | 0.637                     | 10.188                    | 3500                | 0.141 | 1.165          | 0.742                  | 17.291                 |
| 7     | 450         | 500x250   | 30899.61        | 6.923               | 25.091              | 0.875                     | 9.551                     | 3500                | 0.308 | 1.445          | 1.265                  | 16.549                 |
| 6     | 450         | 500x250   | 54188.28        | 6.769               | 31.860              | 1.065                     | 8.676                     | 3500                | 0.517 | 2.073          | 2.207                  | 15.284                 |
| 5     | 550         | 500x250   | 83971.35        | 7.332               | 39.192              | 1.224                     | 7.611                     | 3500                | 0.749 | 3.992          | 4.887                  | 13.077                 |
| 4     | 550         | 500x250   | 120263.67       | 7.118               | 46.309              | 1.418                     | 6.387                     | 3500                | 1.052 | 1.000          | 1.418                  | 8.190                  |
| 3     | 550         | 500x250   | 163065.24       | 6.871               | 53.180              | 1.643                     | 4.969                     | 3500                | 1.439 | 1.000          | 1.643                  | 6.773                  |
| 2     | 550         | 500x250   | 212376.15       | 8.876               | 62.056              | 2.100                     | 3.326                     | 3500                | 2.053 | 1.000          | 2.100                  | 5.130                  |
| 1     | 600         | 500x250   | 267827.94       | 16.731              | 78.787              | 1.226                     | 1.226                     | 7000                | 0.595 | 2.471          | 3.030                  | 3.030                  |

For Frame 1, the wind shear drift was evaluated across all levels, showing a total drift (D<sub>i</sub>) of 14.208mm at the roof, where columns are 450mm and beams are 500x250mm. This lateral displacement is further examined through flexural drift calculations, which for the same roof level, resulted in a component displacement (d<sub>i</sub>) of 0.681mm. To ensure a complete understanding of structural behavior under wind loading, P-Delta effect calculations were integrated, resulting in an amplified roof drift (D<sub>i,PD</sub>) of 79.568mm, which accounts for secondary moments as the building displaces.

Additionally, as a verification the hand calculations, SAP 2D and 3D Wind drift results were compared and can be seen below at the Figure 3.6.2.1.



**Figure 3.6.2.1** Comparison of Hand, 2D and 3D inter-story deflection under Wind Loads

### 3.6.3 Seismic drift hand calculations

**Table 3.6.3.1** Frame 1 seismic shear drift calculations

| Floor | Column size | Beam size | h <sub>i</sub> (mm) | h <sub>i-av</sub> (mm) | F <sub>i</sub> (kN) | V <sub>i</sub> (kN) | V <sub>i-co</sub> (kN) | V <sub>i-av</sub> (kN) | d <sub>b</sub> (mm) | d <sub>c</sub> (mm) | d <sub>t</sub> (mm) | d <sub>i</sub> (mm) | Di (mm) |
|-------|-------------|-----------|---------------------|------------------------|---------------------|---------------------|------------------------|------------------------|---------------------|---------------------|---------------------|---------------------|---------|
| roof  | 450         | 500x250   | 3000                | 3250                   | 20.4                | 20.36               | 1.696                  | 0.848                  | 0.159               | 0.079               | 0.238               | 0.446               | 33.491  |
| 9     | 450         | 500x250   | 3500                | 3500                   | 16.2                | 36.53               | 3.044                  | 2.370                  | 0.516               | 0.138               | 0.653               | 0.839               | 33.046  |
| 8     | 450         | 500x250   | 3500                | 3500                   | 16.2                | 52.70               | 4.392                  | 3.718                  | 0.809               | 0.216               | 1.025               | 1.210               | 32.207  |
| 7     | 450         | 500x250   | 3500                | 3500                   | 16.2                | 68.87               | 5.740                  | 5.066                  | 1.102               | 0.294               | 1.396               | 1.562               | 30.997  |
| 6     | 450         | 500x250   | 3500                | 3500                   | 12.7                | 81.58               | 6.798                  | 6.269                  | 1.364               | 0.364               | 1.727               | 1.878               | 29.435  |
| 5     | 550         | 500x250   | 3500                | 3500                   | 29.0                | 110.59              | 9.216                  | 8.007                  | 1.742               | 0.288               | 2.029               | 2.284               | 27.556  |



|   |     |             |      |      |       |            |            |            |            |       |            |            |        |
|---|-----|-------------|------|------|-------|------------|------------|------------|------------|-------|------------|------------|--------|
| 4 | 550 | 500x<br>250 | 3500 | 3500 | 29.0  | 139.5<br>9 | 11.63<br>3 | 10.42<br>4 | 2.268      | 0.271 | 2.539      | 2.833      | 25.272 |
| 3 | 550 | 500x<br>250 | 3500 | 3500 | 29.0  | 168.6<br>0 | 14.05<br>0 | 12.84<br>1 | 2.793      | 0.334 | 3.127      | 3.838      | 22.439 |
| 2 | 550 | 500x<br>250 | 3500 | 3500 | 111.0 | 279.5<br>7 | 23.29<br>8 | 18.67<br>4 | 4.062      | 0.486 | 4.548      | 10.40<br>8 | 18.602 |
| 1 | 600 | 500x<br>250 | 7000 | 5250 | 135.5 | 415.0<br>7 | 34.58<br>9 | 28.94<br>3 | 14.16<br>6 | 2.102 | 16.26<br>9 | 8.194      | 8.194  |

**Table 3.6.3.2** Frame 1 seismic flexural drift calculations

| Floor | Colum<br>n size | Beam<br>size | h <sub>i</sub><br>(mm) | H <sub>i</sub><br>(mm) | F <sub>i</sub><br>(kN) | V <sub>i</sub><br>(kN) | M <sub>i</sub><br>(k-m) | A <sub>ci</sub><br>(mm <sup>2</sup> ) | f <sub>i</sub><br>(1/mm) | D <sub>qi</sub><br>(rad) | q <sub>i</sub><br>(rad) | d <sub>i</sub><br>(mm) | D <sub>i</sub><br>(mm) |
|-------|-----------------|--------------|------------------------|------------------------|------------------------|------------------------|-------------------------|---------------------------------------|--------------------------|--------------------------|-------------------------|------------------------|------------------------|
| roof  | 450             | 500x2<br>50  | 3000                   | 38000                  | 20.4                   | 20.36                  | 61.1                    | 20250<br>0                            | 6.51E-<br>12             | 1.95E-<br>08             | 2.16E-<br>06            | 0.006                  | 0.067                  |
| 9     | 450             | 500x2<br>50  | 3500                   | 35000                  | 16.2                   | 36.53                  | 127.9                   | 20250<br>0                            | 1.36E-<br>11             | 4.77E-<br>08             | 2.14E-<br>06            | 0.007                  | 0.060                  |
| 8     | 450             | 500x2<br>50  | 3500                   | 31500                  | 16.2                   | 52.70                  | 184.5                   | 20250<br>0                            | 1.97E-<br>11             | 6.88E-<br>08             | 2.09E-<br>06            | 0.007                  | 0.053                  |
| 7     | 450             | 500x2<br>50  | 3500                   | 28000                  | 16.2                   | 68.87                  | 241.1                   | 20250<br>0                            | 2.57E-<br>11             | 8.99E-<br>08             | 2.03E-<br>06            | 0.007                  | 0.046                  |
| 6     | 450             | 500x2<br>50  | 3500                   | 24500                  | 12.7                   | 81.58                  | 285.5                   | 20250<br>0                            | 3.04E-<br>11             | 1.07E-<br>07             | 1.94E-<br>06            | 0.007                  | 0.039                  |
| 5     | 550             | 500x2<br>50  | 3500                   | 21000                  | 29.0                   | 110.59                 | 387.1                   | 30250<br>0                            | 2.76E-<br>11             | 9.66E-<br>08             | 1.83E-<br>06            | 0.006                  | 0.032                  |
| 4     | 550             | 500x2<br>50  | 3500                   | 17500                  | 29.0                   | 139.59                 | 488.6                   | 30250<br>0                            | 3.49E-<br>11             | 1.22E-<br>07             | 1.73E-<br>06            | 0.006                  | 0.025                  |
| 3     | 550             | 500x2<br>50  | 3500                   | 14000                  | 29.0                   | 168.60                 | 590.1                   | 30250<br>0                            | 4.21E-<br>11             | 1.47E-<br>07             | 1.61E-<br>06            | 0.006                  | 0.019                  |
| 2     | 550             | 500x2<br>50  | 3500                   | 10500                  | 111.0                  | 279.57                 | 978.5                   | 30250<br>0                            | 6.98E-<br>11             | 2.44E-<br>07             | 1.46E-<br>06            | 0.005                  | 0.014                  |

|   |     |         |      |      |       |        |        |       |          |          |          |       |       |
|---|-----|---------|------|------|-------|--------|--------|-------|----------|----------|----------|-------|-------|
| 1 | 600 | 500x250 | 7000 | 7000 | 135.5 | 415.07 | 2905.5 | 36000 | 1.74E-10 | 1.22E-06 | 1.22E-06 | 0.009 | 0.009 |
|---|-----|---------|------|------|-------|--------|--------|-------|----------|----------|----------|-------|-------|

**Table 3.6.3.3** Frame 1 seismic P-D effect calculations

| Floor | Column size | Beam size | P <sub>ui</sub> (kN) | F <sub>i</sub> (kN) | V <sub>i</sub> (kN) | d <sub>i,total</sub> (mm) | D <sub>i,total</sub> (mm) | h <sub>i</sub> (mm) | Q        | b <sub>2</sub> | d <sub>i,PD</sub> (mm) | D <sub>i,PD</sub> (mm) |
|-------|-------------|-----------|----------------------|---------------------|---------------------|---------------------------|---------------------------|---------------------|----------|----------------|------------------------|------------------------|
| roof  | 450         | 500x250   |                      | 20.4                | 20.36               | 4.52E-01                  | 3.36E+01                  | 3000                | 0.00E+00 | 1.00E+00       | 0.45                   | 113.08                 |
| 9     | 450         | 500x250   | 2114.15              | 16.2                | 36.53               | 8.46E-01                  | 3.31E+01                  | 3500                | 1.40E-02 | 1.01E+00       | 0.86                   | 112.63                 |
| 8     | 450         | 500x250   | 7836.3               | 16.2                | 52.70               | 1.22E+00                  | 3.23E+01                  | 3500                | 5.17E-02 | 1.05E+00       | 1.28                   | 111.77                 |
| 7     | 450         | 500x250   | 17166.45             | 16.2                | 68.87               | 1.57E+00                  | 3.10E+01                  | 3500                | 1.12E-01 | 1.13E+00       | 1.77                   | 110.49                 |
| 6     | 450         | 500x250   | 30104.6              | 12.7                | 81.58               | 1.89E+00                  | 2.95E+01                  | 3500                | 1.99E-01 | 1.25E+00       | 2.35                   | 108.72                 |
| 5     | 550         | 500x250   | 59887.67             | 29.0                | 110.59              | 2.29E+00                  | 2.76E+01                  | 3500                | 3.54E-01 | 1.55E+00       | 3.55                   | 106.37                 |
| 4     | 550         | 500x250   | 96179.99             | 29.0                | 139.59              | 2.84E+00                  | 2.53E+01                  | 3500                | 5.59E-01 | 2.27E+00       | 6.44                   | 102.82                 |
| 3     | 550         | 500x250   | 138981.56            | 29.0                | 168.60              | 3.84E+00                  | 2.25E+01                  | 3500                | 9.05E-01 | 1.05E+00       | 40.52                  | 96.38                  |
| 2     | 550         | 500x250   | 210208.43            | 111.0               | 279.57              | 1.04E+01                  | 1.86E+01                  | 3500                | 2.24E+00 | 1              | 10.41                  | 55.86                  |
| 1     | 600         | 500x250   | 290305.46            | 135.5               | 415.07              | 8.20E+00                  | 8.20E+00                  | 7000                | 8.20E-01 | 5.54E+00       | 45.45                  | 45.45                  |

**Table 3.6.3.4** Frame I seismic shear drift calculations

| Floor | Column size | Beam size | h <sub>i</sub> (mm) | h <sub>i</sub> -avg (mm) | F <sub>i</sub> (kN) | V <sub>i</sub> (kN) | V <sub>i</sub> -co <sub>l</sub> (kN) | V <sub>i</sub> -avg (kN) | d <sub>b</sub> (mm) | d <sub>c</sub> (mm) | d <sub>t</sub> (mm) | d <sub>i</sub> (mm) | D <sub>i</sub> (mm) |
|-------|-------------|-----------|---------------------|--------------------------|---------------------|---------------------|--------------------------------------|--------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|-------|-------------|-----------|---------------------|--------------------------|---------------------|---------------------|--------------------------------------|--------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|

|    |     |         |      |      |      |        |       |       |      |      |       |      |       |
|----|-----|---------|------|------|------|--------|-------|-------|------|------|-------|------|-------|
| 10 | 450 | 500x250 | 3000 | 3000 | 40.7 | 40.71  | 5.09  | 2.54  | 0.41 | 0.19 | 0.59  | 1.25 | 50.34 |
| 9  | 450 | 500x250 | 3500 | 3500 | 29.1 | 69.82  | 8.73  | 6.91  | 1.50 | 0.40 | 1.90  | 2.41 | 49.09 |
| 8  | 450 | 500x250 | 3500 | 3500 | 29.1 | 98.93  | 12.37 | 10.55 | 2.29 | 0.61 | 2.91  | 3.41 | 46.69 |
| 7  | 450 | 500x250 | 3500 | 3500 | 29.1 | 128.05 | 16.01 | 14.19 | 3.09 | 0.82 | 3.91  | 4.36 | 43.28 |
| 6  | 450 | 500x250 | 3500 | 3500 | 22.9 | 150.92 | 18.86 | 17.44 | 3.79 | 1.01 | 4.80  | 5.02 | 38.92 |
| 5  | 550 | 500x250 | 3500 | 3500 | 29.0 | 179.92 | 22.49 | 20.68 | 4.50 | 0.74 | 5.24  | 5.58 | 33.90 |
| 4  | 550 | 500x250 | 3500 | 3500 | 29.0 | 208.93 | 26.12 | 24.30 | 5.29 | 0.63 | 5.92  | 6.36 | 28.32 |
| 3  | 550 | 500x250 | 3500 | 3500 | 29.0 | 237.94 | 29.74 | 27.93 | 6.08 | 0.73 | 6.80  | 7.28 | 21.96 |
| 2  | 550 | 500x250 | 3500 | 3500 | 33.3 | 271.23 | 33.90 | 31.82 | 6.92 | 0.83 | 7.75  | 9.26 | 14.68 |
| 1  | 600 | 500x250 | 7000 | 3750 | 40.6 | 311.88 | 38.98 | 38.98 | 9.74 | 1.03 | 10.77 | 5.42 | 5.42  |

**Table 3.6.3.5** Frame I seismic flexural drift calculations

| Floor | Column size | Beam size | h <sub>i</sub> (mm) | H <sub>i</sub> (mm) | F <sub>i</sub> (kN) | V <sub>i</sub> (kN) | M <sub>i</sub> (k-m) | A <sub>ci</sub> (mm <sup>2</sup> ) | f <sub>i</sub> (1/mm) | D <sub>qi</sub> (rad) | q <sub>i</sub> (rad) | d <sub>i</sub> (mm) | D <sub>i</sub> (mm) |
|-------|-------------|-----------|---------------------|---------------------|---------------------|---------------------|----------------------|------------------------------------|-----------------------|-----------------------|----------------------|---------------------|---------------------|
| 10    | 450         | 500x250   | 3000                | 38000               | 40.7                | 40.71               | 122.1358224          | 302500                             | 3.49E-11              | 1.05E-07              | 6.61E-06             | 0.02                | 0.18                |
| 9     | 450         | 500x250   | 3500                | 35000               | 29.1                | 69.82               | 244.3813257          | 302500                             | 6.97E-11              | 2.44E-07              | 6.50E-06             | 0.02                | 0.16                |
| 8     | 450         | 500x250   | 3500                | 31500               | 29.1                | 98.93               | 346.2708586          | 302500                             | 9.88E-11              | 3.46E-07              | 6.26E-06             | 0.02                | 0.14                |

|   |     |             |      |       |      |        |                 |            |              |              |              |      |      |
|---|-----|-------------|------|-------|------|--------|-----------------|------------|--------------|--------------|--------------|------|------|
| 7 | 450 | 500x2<br>50 | 3500 | 28000 | 29.1 | 128.05 | 448.16<br>03915 | 30250<br>0 | 1.28E-<br>10 | 4.48E-<br>07 | 5.92E-<br>06 | 0.02 | 0.12 |
| 6 | 450 | 500x2<br>50 | 3500 | 24500 | 22.9 | 150.92 | 528.21<br>04234 | 30250<br>0 | 1.51E-<br>10 | 5.28E-<br>07 | 5.47E-<br>06 | 0.02 | 0.10 |
| 5 | 550 | 500x2<br>50 | 3500 | 21000 | 29.0 | 179.92 | 629.73<br>1581  | 42250<br>0 | 1.29E-<br>10 | 4.50E-<br>07 | 4.94E-<br>06 | 0.02 | 0.08 |
| 4 | 550 | 500x2<br>50 | 3500 | 17500 | 29.0 | 208.93 | 731.25<br>27386 | 42250<br>0 | 1.49E-<br>10 | 5.23E-<br>07 | 4.49E-<br>06 | 0.02 | 0.06 |
| 3 | 550 | 500x2<br>50 | 3500 | 14000 | 29.0 | 237.94 | 832.77<br>38962 | 42250<br>0 | 1.70E-<br>10 | 5.96E-<br>07 | 3.97E-<br>06 | 0.01 | 0.04 |
| 2 | 550 | 500x2<br>50 | 3500 | 10500 | 33.3 | 271.23 | 949.29<br>53893 | 42250<br>0 | 1.94E-<br>10 | 6.79E-<br>07 | 3.37E-<br>06 | 0.01 | 0.03 |
| 1 | 600 | 500x2<br>50 | 7000 | 7000  | 40.6 | 311.88 | 2183.1<br>34647 | 49000<br>0 | 3.85E-<br>10 | 2.69E-<br>06 | 2.69E-<br>06 | 0.02 | 0.02 |

**Table 3.6.3.6** Frame I seismic P-D effect calculations

| Floor | Colum<br>n size | Beam<br>size | P <sub>ui</sub><br>(kN) | F <sub>i</sub> (kN) | V <sub>i</sub> (kN) | d <sub>i,total</sub><br>(mm) | D <sub>i,total</sub><br>(mm) | h <sub>i</sub><br>(mm) | Q            | b <sub>2</sub> | d <sub>i,PD</sub><br>(mm) | D <sub>i,PD</sub><br>(mm) |
|-------|-----------------|--------------|-------------------------|---------------------|---------------------|------------------------------|------------------------------|------------------------|--------------|----------------|---------------------------|---------------------------|
| 10    | 450             | 500x25<br>0  | 0                       | 40.7                | 40.71               | 1.27E+<br>00                 | 5.05E+<br>01                 | 3000                   | 0.00E+<br>00 | 1              | 1.27                      | 50.52                     |
| 9     | 450             | 500x25<br>0  | 3805.4<br>7             | 29.1                | 69.82               | 2.43E+<br>00                 | 4.93E+<br>01                 | 3500                   | 2.69E+<br>00 | 1              | 2.43                      | 49.25                     |
| 8     | 450             | 500x25<br>0  | 10299.<br>87            | 29.1                | 98.93               | 3.43E+<br>00                 | 4.68E+<br>01                 | 3500                   | 7.63E+<br>00 | 1              | 3.43                      | 46.83                     |
| 7     | 450             | 500x25<br>0  | 16794.<br>27            | 29.1                | 128.05              | 4.38E+<br>00                 | 4.34E+<br>01                 | 3500                   | 1.32E+<br>01 | 1              | 4.38                      | 43.40                     |
| 6     | 450             | 500x25<br>0  | 23288.<br>67            | 22.9                | 150.92              | 5.04E+<br>00                 | 3.90E+<br>01                 | 3500                   | 1.99E+<br>01 | 1              | 5.04                      | 39.02                     |
| 5     | 550             | 500x25<br>0  | 29783.<br>07            | 29.0                | 179.92              | 5.60E+<br>00                 | 3.40E+<br>01                 | 3500                   | 2.73E+<br>01 | 1              | 5.60                      | 33.98                     |
| 4     | 550             | 500x25<br>0  | 36292.<br>07            | 29.0                | 208.93              | 6.38E+<br>00                 | 2.84E+<br>01                 | 3500                   | 3.90E+<br>01 | 1              | 6.38                      | 28.38                     |

|   |     |             |              |      |        |              |              |      |              |   |      |       |
|---|-----|-------------|--------------|------|--------|--------------|--------------|------|--------------|---|------|-------|
|   |     | 0           | 32           |      |        | 00           | 01           |      | 01           |   |      |       |
| 3 | 550 | 500x25<br>0 | 42801.<br>57 | 29.0 | 237.94 | 7.29E+<br>00 | 2.20E+<br>01 | 3500 | 5.96E+<br>01 | 1 | 7.29 | 22.00 |
| 2 | 550 | 500x25<br>0 | 49310.<br>91 | 33.3 | 271.23 | 9.27E+<br>00 | 1.47E+<br>01 | 3500 | 1.15E+<br>02 | 1 | 9.27 | 14.71 |
| 1 | 600 | 500x25<br>0 | 55451.<br>79 | 40.6 | 311.88 | 5.44E+<br>00 | 5.44E+<br>00 | 7000 | 1.78E+<br>02 | 1 | 5.44 | 5.44  |

Seismic analysis followed a similar methodology, where shear drift for Frame 1 at the roof level was calculated to be 33.491mm under a seismic force (Fi) of 20.4 kN, while the seismic flexural displacement remained minimal at 0.006mm. Beyond lateral stability, the report details axial force distribution for different building heights, recording forces such as 6161.31 kN for the 9-story segment and 3274.91 kN for the 5-story segment at Slab 1. To maintain the integrity of these structural findings, the project tracks critical quality metrics, aiming for 100% compliance in structural integrity and material quality while targeting a rework percentage of  $\leq 5\%$  to ensure the final construction accurately reflects the analytical design.

### 3.7 Structural Design

#### 3.7.1 Beam design verification

The data required for flexural and shear analysis of the standard beam can be extracted from SAP2000 model, it is shown in the Figure 3.7.1.1 below:

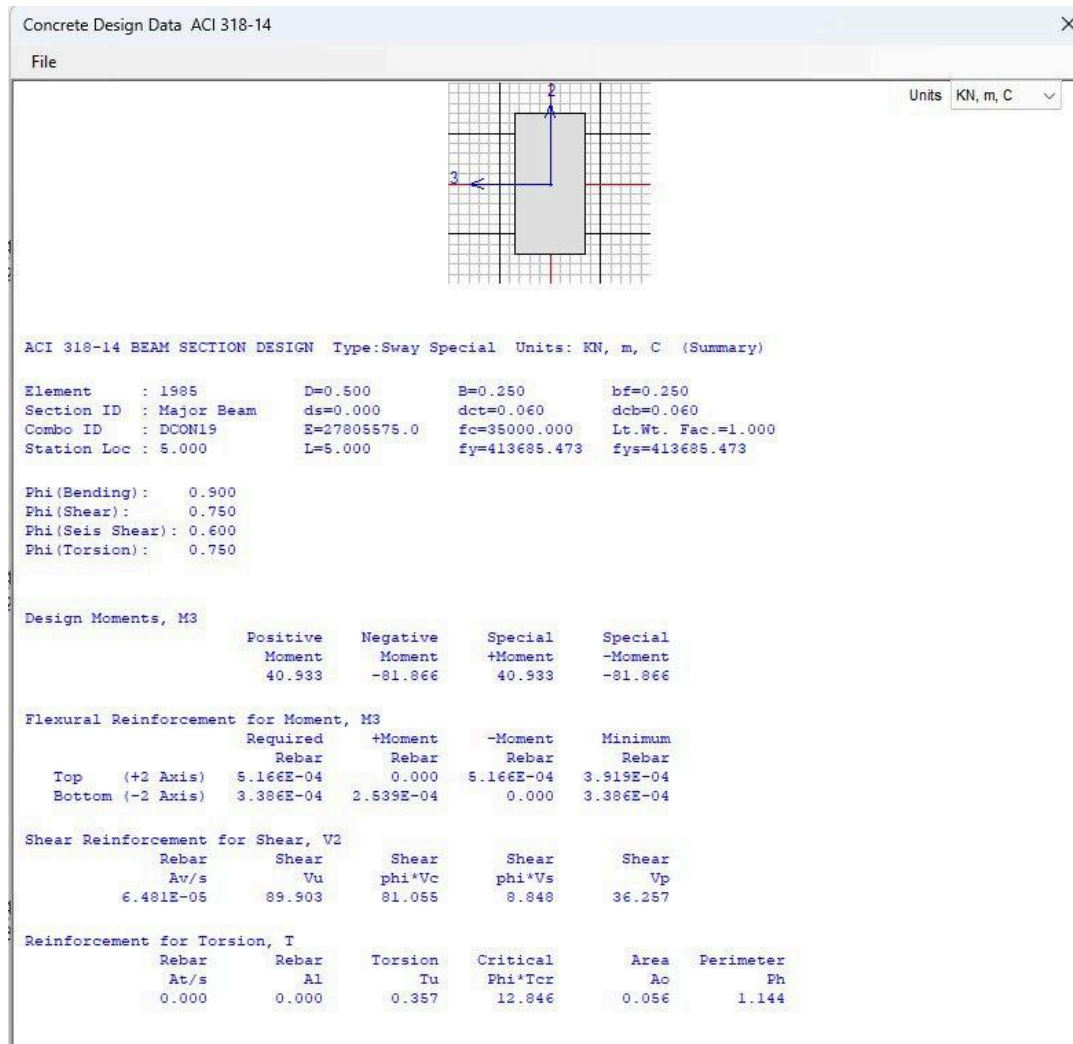


Figure 3.7.1.1 Standard Beam's design data

### 3.7.1.1. Flexural analysis

The amount of reinforcement required to resist the design moment, and checking if the minimum amount of flexural reinforcement is sufficient for the design can be verified by the following calculations.

Top reinforcement:

- $$R_n = \frac{M_u}{\phi * b * d^2} = \frac{81.866}{0.9 * 0.25 * 0.4365^2} = 1909.64$$
- $$\rho = \frac{0.85 * 35000}{413685} \left[ 1 - \sqrt{1 - \frac{2 * 1909.64}{0.85 * 35}} \right] = 0.00477$$
- $$A_s = \rho * b * d = 0.00477 * 0.4365 * 0.25 = 5.21 * 10^{-4} m^2 = 0.807 in^2$$

- $$A_{s,min} = 3\sqrt{f'_c}bd/f_y = 1.69 * 10^{-4} m^2 = 0.261 in^2$$
- $a = \frac{A_s f_y}{0.85 f'_c b} = \frac{5.21 * 10^{-4} * 413685}{0.85 * 35000 * 0.25} = 0.029$
  - $c = \frac{a}{\beta_1} = \frac{0.0163}{0.8} = 0.03625 m$
  - $\epsilon_t = \frac{d-c}{c} (0.003) = \frac{0.4365-0.03625}{0.03625} (0.003) = 0.03 > 0.005$
  - Tension controlled and ductile

In comparison with SAP2000 results the deviation is 6.9% , which is relatively small and exceeds the minimum required area of  $0.261 in^2$

$$Deviation = \frac{0.867-0.807}{0.867} = 6.9\%$$

Bottom reinforcement:

- $R_n = \frac{M_u}{\Phi * b * d^2} = \frac{40.933}{0.9 * 0.25 * 0.4365^2} = 954.82$
- $\rho = \frac{0.85 * 35000}{413685} \left[ 1 - \sqrt{1 - \frac{2 * 954.82}{0.85 * 35}} \right] = 0.00234$
- $A_s = \rho * b * d = 0.00234 * 0.4365 * 0.5 = 2.925 * 10^{-4} m^2 = 0.453 in^2$
- $a = \frac{A_s f_y}{0.85 f'_c b} = \frac{2.925 * 10^{-4} * 413685}{0.85 * 35000 * 0.25} = 0.0163$
- $c = \frac{a}{\beta_1} = \frac{0.0163}{0.8} = 0.02 m$
- $\epsilon_t = \frac{d-c}{c} (0.003) = \frac{0.4365-0.02}{0.02} (0.003) = 0.06 > 0.005$
- Tension controlled and ductile

$$Deviation = \frac{0.453-0.42}{0.453} = 7.28\%$$

Shear reinforcement:

- $\phi V_c = 2 * \lambda * \phi * \sqrt{f'_c} * b * d = 0.75 * 2\sqrt{35000} * 0.25 * 0.4365 = 30.623 \text{ kN}$
- $V_s = \frac{V_u - \phi V_c}{\phi} = \frac{89.903 - 30.623}{0.75} = 79.04 \text{ kN}$
- $V_{c1} = 4 * \sqrt{f'_c} * b * d = 4 * \sqrt{35000} * 0.25 * 0.4365 = 81.66 \text{ kN}$

$$V_{c2} = 8\sqrt{f'_c}bd = 8 * \sqrt{35000} * 0.25 * 0.4365 = 163.32 \text{ kN}$$

- $S_1 = A_v f_{yt} d / V_s = \frac{1.42 * 10^{-4} * 413685 * 0.4365}{79.04} = 0.324 \text{ m}$
- $S_{max} = d/2 = 0.4365/2 = 0.21825 \text{ m}$
- $S_1 > S_{max} \Rightarrow S = 0.218 \text{ m}$ .
- $\frac{A_v}{s} = \frac{1.42 * 10^{-4}}{0.21825} = 6.51 * 10^{-4} \text{ m}^2/\text{m}$

$$S_2 = d/2 = 0.500/2 = 0.250 \text{ m}$$

$$S_3 = \frac{A_v f_{yt}}{50b} = \frac{1.42 * 10^{-4} * 413685}{50 * 0.25} = 4.7 \text{ m} \geq \frac{A_v f_{yt}}{0.75\sqrt{f'_c}b} = \frac{1.42 * 10^{-4} * 413685}{0.75\sqrt{35000} * 0.25} = 1.67 \text{ m}$$

The calculations above verify the amount of reinforcement required to resist design moment and check if the minimum amount of flexural reinforcement is sufficient. Note that for calculation of bottom and top flexural reinforcement SAP2000 considers only bottom or top reinforcement in analysis. We therefore neglect top reinforcement for checking the positive moment and neglect bottom reinforcement for the check of negative moment. Further information can be found in SAP2000 documentation. Afterwards, the same procedure was applied in order to identify beam design values in other floors.

**Table 3.7.1.1** Beam design for 1st floor

| 1 floor              |       |       |       |
|----------------------|-------|-------|-------|
| Major beam for       | Left  | Mid   | Right |
| Area,in <sup>2</sup> | 0.955 | 0.309 | 0.954 |



|                      |       |       |       |
|----------------------|-------|-------|-------|
| Tension Bars         | 5#4   | 2#4   | 5#4   |
| Area,in <sup>2</sup> | 0.607 | 0.443 | 0.607 |
| Compression Bars     | 4#4   | 3#4   | 4#4   |

**Table 3.7.1.2** Beam design for 2-5 floors

| 2-5 floor            |       |       |       |
|----------------------|-------|-------|-------|
| Major beam for       | Left  | Mid   | Right |
| Area,in <sup>2</sup> | 0.87  | 0.282 | 0.867 |
| Tension Bars         | 5#4   | 2#4   | 5#4   |
| Area,in <sup>2</sup> | 0.569 | 0.433 | 0.569 |
| Compression Bars     | 3#4   | 3#4   | 3#4   |

**Table 3.7.1.3** Beam design for 6-9 floors

| 6-9 floor            |       |       |       |
|----------------------|-------|-------|-------|
| Major beam for       | Left  | Mid   | Right |
| Area,in <sup>2</sup> | 0.689 | 0.226 | 0.694 |
| Tension Bars         | 4#4   | 2#4   | 4#4   |
| Area,in <sup>2</sup> | 0.452 | 0.421 | 0.456 |
| Compression Bars     | 3#4   | 3#4   | 3#4   |

### 3.7.2 Column design verification

The data required for flexural and shear analysis of the standard column can be extracted from SAP2000 model, it is shown in the Figure 3.7.2.1 below:

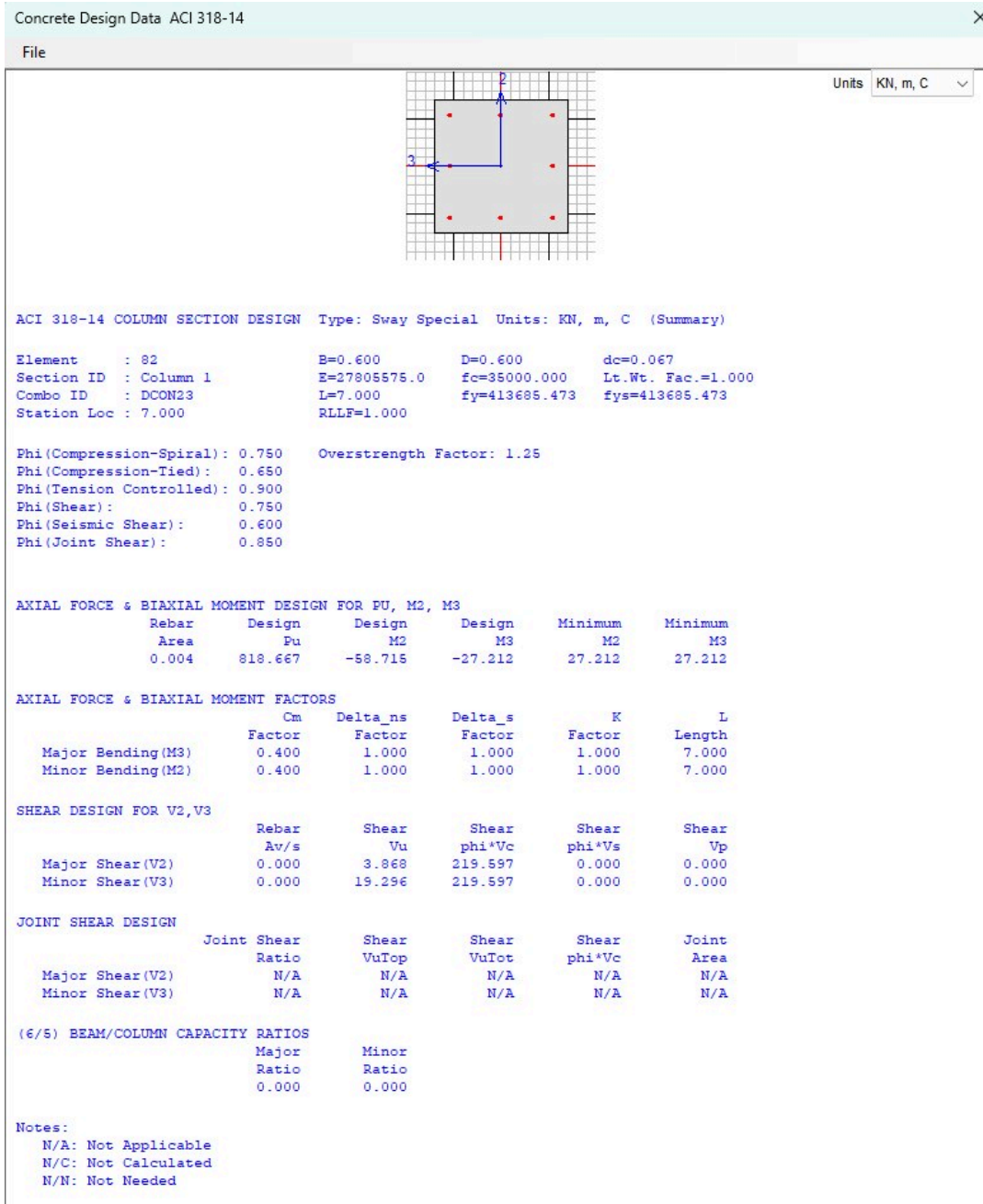


Figure 3.7.2.1 Standard column design data

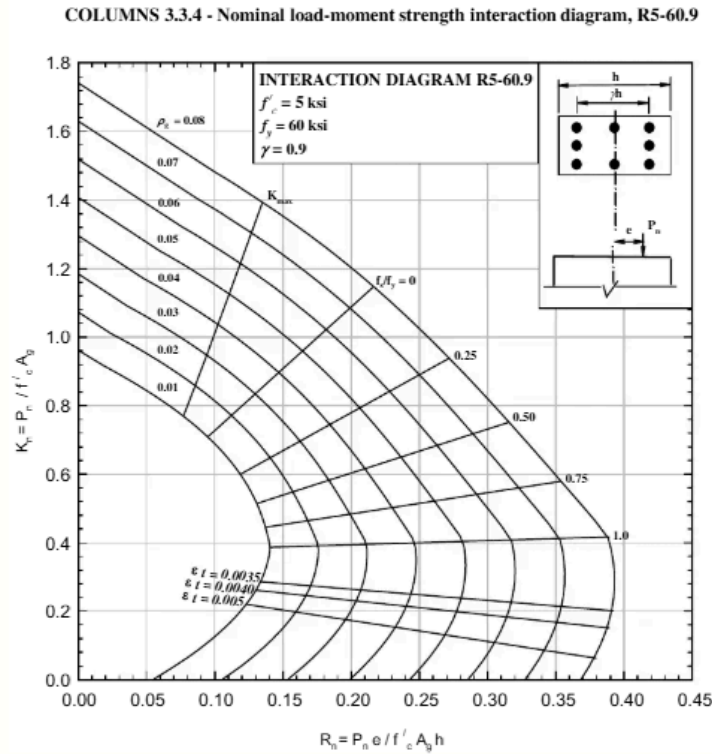
$$P_u = 818.667 \text{ kN}; \quad M_u = 27.312 \text{ kN} \cdot \text{m};$$

$$A_{g,req} = \frac{P_u}{0.6f'_c} = 0.0342 \text{ m}^2, \text{ while chosen column area is } A_g = 0.6 * 0.6 = 0.36 \text{ m}^2;$$

$$e = \frac{M_u}{P_u} = 0.0334 \text{ m}; \quad P_n = \frac{P_u}{\phi} = 1259.49 \text{ kN};$$

$$K_n = \frac{P_n}{f'_c A_g} = 0.09995; \quad R_n = \frac{P_n e}{f'_c A_g h} = 0.000477;$$

From rectangular column interaction diagram  $p_g = 0.01$ ;



$$A_s = p_g A_g = 0.0036 \text{ m}^2 = 5.58 \text{ in}^2 \text{ (Choose 8\#8)}$$

The reinforced concrete column was made with the resistance to the simultaneous action of compression and bending. The column was subjected to the factored axial load of 717.25 kN and the factored bending moment was 22.77 kNm.

The gross cross-sectional area of the column as a minimum was computed to be  $0.0342 \text{ m}^2$  in accordance with the minimum axial load requirement that is required and the compressive strength of the concrete. A square column having dimensions equal to 0.6 m by 0.6 m was chosen and offered a gross cross-sectional area of  $0.36 \text{ m}^2$ . This chosen section is well more than

the minimum needed area and consequently guarantees that there is sufficient axial load-carrying capacity.

The gross cross-sectional area was then multiplied by the reinforcement ratio to obtain the required area of longitudinal reinforcement which is  $0.0036 \text{ m}^2$  or  $5.58 \text{ in}^2$ . Therefore, 8#8 bars were chosen with the area of  $6.28 \text{ in}^2$ . This reinforcement area has the benefit of ensuring that the column is strong enough and stable to withstand the applied axial load and bending moment as per the requirements of the reinforced concrete designs.

### Slenderness effect

$$I_c = 0.7 * \frac{0.6 * 0.6^3}{12} = 0.00756 \text{ m}^4$$

$$I_b = 0.35 * \frac{0.25 * 0.5^3}{12} = 0.00091 \text{ m}^4$$

$$\psi = \frac{\Sigma(EI/l), \text{ compression members}}{\Sigma(EI/l), \text{ flexural members}} = \frac{0.00756/3.5}{(0.00091/5) + (0.00091/5)} = 6.004$$

$$\psi = \frac{\Sigma(EI/l), \text{ compression members}}{\Sigma(EI/l), \text{ flexural members}} = \frac{2 * (0.00756/3.5)}{(0.00091/5) + (0.00091/5)} = 12.008$$

$$l_u = 3.5 - (0.25 + 0.25) = 3 \text{ m}$$

$$\frac{kl_u}{r} = \frac{1.5 * 3}{0.25 * 0.5} = 36 > 22 \text{ (Slender Column)}$$

### Biaxial bending check

| AXIAL FORCE & BIAXIAL MOMENT DESIGN FOR PU, M2, M3 |              |              |              |               |               |  |
|----------------------------------------------------|--------------|--------------|--------------|---------------|---------------|--|
| Rebar<br>Area                                      | Design<br>Pu | Design<br>M2 | Design<br>M3 | Minimum<br>M2 | Minimum<br>M3 |  |
| 5.580                                              | 444.735      | -366.089     | 582.007      | 582.007       | 582.007       |  |

**Figure 3.7.2.2** First floor column design SAP2000 values

$$\frac{1}{P_n} = \frac{1}{P_{nx}} + \frac{1}{P_{ny}} - \frac{1}{P_{n0}} = \frac{1}{18732.52} + \frac{1}{29901.6} - \frac{1}{13763.54} \Rightarrow P_n = 70569.6 \text{ psi}$$

$$P_n = 70569.6 \text{ psi} \geq 0.1P_{n0} = 1376.3 \text{ psi}$$

$$P_u = 444.735 \text{ psi}$$

$$\phi P_n = 70569.6 * 0.65 = 45870.24$$

$$\phi P_n \geq P_u \text{ (the structure is safe)}$$

### Shear reinforcement design

$$V_{u1} = 278.637 \text{ kN}$$

$$V_{u2} = 38.171 \text{ kN}$$

$$\phi V_c = 0.17 * (1 + \frac{444.735}{14 * 600^2}) * 1 * \sqrt{35000} * 600 * 600 = 10601 \text{ kN}$$

$$V_u < 0.5 \phi V_c \Rightarrow \text{reinforcement}$$

$$16d_b = 16 * 0.0254 = 0.4064 \text{ m}$$

$$48d_{bt} = 48 * 0.009525 = 0.4572 \text{ m}$$

$$\text{least column dimension} = 450 \text{ mm}$$

Choose #3 ties at 400 mm

### 3.7.3 Two-way slab design verification

The slab was designed as a two-way slab supported by columns. The overall slab thickness was taken as 200 mm, with an effective depth of 165 mm. The supporting columns had plan dimensions of 550 mm. The compressive strength of concrete was assumed as 35 MPa, and a strength reduction factor of 0.75 was adopted for shear.

The slab was subjected to dead and live loads, expressed as uniformly distributed surface loads. The factored design load intensity was calculated using the ultimate limit state load combination:

$$w_u = 1.2D + 1.6L$$

where D is the dead load intensity and L is the live load intensity. The resulting factored load was used for all subsequent strength checks.

Punching shear was checked around the column by considering a critical perimeter located at a distance of half the effective depth from the column face. The length of the critical perimeter was denoted as  $b_0$ .

The applied punching shear force at the critical section was calculated from the factored slab load and denoted as  $V_u$ .

The nominal punching shear capacity of the concrete slab was evaluated using:

$$V_c = 0.17\sqrt{f'_c} b_0 d$$

The design punching shear resistance was then obtained as  $\phi V_c$ .

The punching shear condition was verified by ensuring:

$$\phi V_c \geq V_u$$

The slab moments were determined using a two-way slab moment distribution method. The total slab moment was divided into column strips and middle strips, in exterior and interior panel regions.

For each strip, the design bending moments were separated into negative moments (over columns) and positive moments (mid-span). The moments for each region were obtained by applying percentage allocations and distribution factors to a reference slab moment:

$$M_u = (\text{moment percentage}) * (\text{distribution factor}) * M_0$$

where:

- $M_0$  – reference slab moment
- $M_u$  – factored design moment for the corresponding strip

Afterwards, for each strip and moment region, the required flexural reinforcement was calculated using the factored bending moment.

A normalized moment parameter was first evaluated as:

$$R_n = \frac{M_u}{0.9bd^2}$$

where:

- $b$  – strip width
- $d$  – effective depth of the slab

The required reinforcement ratio was then determined from reinforced concrete design relationships or interaction charts:

$$\rho = fR_n$$

The required area of flexural reinforcement was calculated as:

$$A_s = \rho bd$$

The calculated reinforcement area for each strip was compared with the minimum reinforcement requirement:

$$A_s \geq A_{s,min}$$

Where the required flexural reinforcement was less than the minimum, the minimum reinforcement governed the design.

Final reinforcement detailing was selected using uniform bar sizes and spacing to satisfy both strength and constructability requirements. Bar spacing was verified against minimum and maximum spacing limits specified by the design code:

$$s_{min} < s < s_{max}$$

The two-way slab was designed by verifying punching shear capacity at column supports. Also, distributing slab moments into column and middle strips for flexural design. Reinforcement was determined for both positive and negative moment regions. Minimum reinforcement governing in several locations was determined. The final reinforcement layout satisfies strength, spacing, and detailing requirements for two-way slab behavior. In the tables below, the summary of calculations of interior and exterior slabs can be found.

**Table 3.7.3.1** Two-Way Slab Design for Interior Slabs

| Interior | Column Strip | Middle Strip |
|----------|--------------|--------------|
|----------|--------------|--------------|

|                                       | Negative | Positive | Negative | Negative | Positive | Negative |
|---------------------------------------|----------|----------|----------|----------|----------|----------|
| % of moment                           | 75.00    | 75.00    | 75.00    | 25.00    | 25.00    | 25.00    |
| $M_u, kN - m$                         | 83.05    | 44.72    | 83.05    | 27.68    | 14.90    | 27.68    |
| $M_{u, slab}, kN - m$<br>-15% to slab | 12.46    | 6.71     | 12.46    | 4.15     | 2.24     | 4.15     |
| b, m                                  | 2.2      | 2.2      | 2.2      | 2.2      | 2.2      | 2.2      |
| $R_n, kPa$                            | 1910.41  | 1028.70  | 1910.41  | 636.73   | 342.75   | 636.73   |
| $\rho$                                | 0.00477  | 0.00253  | 0.00477  | 0.00155  | 0.00083  | 0.00155  |
| $A_s, m^2$                            | 0.00166  | 0.00088  | 0.00166  | 0.00054  | 0.00029  | 0.00054  |
| $A_s, in^2$                           | 2.57088  | 1.36234  | 2.57088  | 0.83746  | 0.44852  | 0.83746  |
| $A_{s, min}, in^2$                    | 1.15165  | 1.15165  | 1.15165  | 1.15165  | 1.15165  | 1.15165  |
| $A_{s, final}, in^2$                  | 2.57088  | 1.36234  | 2.57088  | 1.15165  | 1.15165  | 1.15165  |
| Bar selected                          | 6#6      | 4#6      | 6#6      | 3#6      | 3#6      | 3#6      |
| Spacing, m                            | 0.6      | 0.5      | 0.6      | 0.4      | 0.4      | 0.4      |
| Minimum spacing, mm                   | 25.4     | 25.4     | 25.4     | 25.4     | 25.4     | 25.4     |

**Table 3.7.3.2** Two-Way Slab Design for Exterior Slabs

| Exterior               | Column Strip |          |          | Middle Strip |          |          |
|------------------------|--------------|----------|----------|--------------|----------|----------|
|                        | Negative     | Positive | Negative | Negative     | Positive | Negative |
| % of moment            | 90.0         | 75.0     | 75.0     | 10.0         | 25.0     | 25.00    |
| Distribution of moment | 0.2          | 0.6      | 0.7      | 0.2          | 0.6      | 0.70     |
| $M_{u, slab}, kN - m$  | 37.5         | 111.2    | 136.6    | 4.2          | 37.1     | 45.54    |
| b, m                   | 2.2          | 2.2      | 2.2      | 2.2          | 2.2      | 2.2      |



|                     |           |         |         |         |         |          |
|---------------------|-----------|---------|---------|---------|---------|----------|
| $R_n, kPa$          | 687.3     | 2040.5  | 2505.9  | 76.4    | 680.2   | 835.31   |
| $\rho$              | 0.00168   | 0.00511 | 0.00634 | 0.00018 | 0.00166 | 0.00205  |
| $A_s, m^2$          | 0.0006171 | 0.00084 | 0.00104 | 0.00003 | 0.0002  | 0.000338 |
| $A_s, in^2$         | 0.95662   | 1.30798 | 1.62057 | 0.04727 | 0.42541 | 0.52385  |
| $A_{s,min}, in^2$   | 1.24      | 1.24    | 1.24    | 1.24    | 1.24    | 1.24     |
| $A_{s,final}, in^2$ | 1.24      | 1.24    | 1.24    | 1.24    | 1.24    | 1.24     |
| Bar selected        | 3#6       | 3#6     | 3#6     | 3#6     | 3#6     | 3#6      |
| Spacing, m          | 0.4       | 0.4     | 0.4     | 0.4     | 0.4     | 0.4      |
| Minimum spacing, mm | 25.4      | 25.4    | 25.4    | 25.4    | 25.4    | 25.4     |

### 3.7.4 One-way slab design verification

The thickness of the one-way slab was taken as 165 mm similar to the two-way slab. The following procedure was followed to find the required area of steel and the spacing between the bars:

$$R_u = \frac{M_u}{bd^2}$$

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

$$A_s = \rho bd$$

$$S = \frac{12A_b}{A_s}$$

The moment coefficients were taken based on the ACI-318, Mu values were taken from SAP2000 model. The results are summarised in the table below.

**Table 3.7.4.1** One-Way Slab Reinforcement Design Summary

|  | SPAN 1 | SPAN 2 |
|--|--------|--------|
|--|--------|--------|

|                        | Left     | Mid    | Right    | Left     | Mid    | Right    |
|------------------------|----------|--------|----------|----------|--------|----------|
| Moment coefficient     | -1/16    | 1/14   | -1/9     | -1/9     | 1/14   | -1/16    |
| Mu, k-in               | -1546.80 | 705.29 | -1417.70 | -1417.70 | 705.29 | -1546.80 |
| b, in                  | 196.85   | 196.85 | 196.85   | 196.85   | 196.85 | 196.85   |
| d, in                  | 6.50     | 6.50   | 6.50     | 6.50     | 6.50   | 6.50     |
| Ru, psi                | 558.62   | 636.78 | 768.00   | 768.00   | 636.78 | 558.62   |
| Steel %                | 0.02     | 0.02   | 0.02     | 0.02     | 0.02   | 0.02     |
| As, in^2               | 1.97     | 2.30   | 2.91     | 2.91     | 2.30   | 1.97     |
| Bar selection          | #14      | #18    | #18      | #18      | #18    | #14      |
| New As, in^2           | 2.25     | 4.00   | 4.00     | 4.00     | 4.00   | 2.25     |
| s, spacing, mm         | 363.64   | 363.64 | 363.64   | 363.64   | 363.64 | 363.64   |
| s, spacing rounded, mm | 400.00   | 400.00 | 400.00   | 400.00   | 400.00 | 400.00   |

### 3.7.5 Post Tentioned (PT) Beam design verification

#### 3.7.5.1 Stage 1: Axial and bending effects

The hotel has sections with PT beams for large span perimeters. Their design includes both bending and axial effects, and the effective width to be used for their designs are not the same.

According to ACI 318, the effective width is tributary and the smallest of the following: 8 times the flange width from both sides, quarter of the span and tributary length for axial and bending effects respectively. The flange is taken to be the part of the slab, while the web is the beam itself making a T shaped beam.

Effective width for axial effects:

$$b_{eff} = 5000 \text{ mm}$$

Effective width for bending effects:

$$b_{eff} = \min(5000, \frac{20000}{4}, 600 + 2 \cdot 8 \cdot 165) = 3240 \text{ mm}$$

Then, the following procedure is done to find the axial and bending effects using the given geometry of the beam and effective widths

Area:

$$A = A_f(\text{Area of a flange}) + A_w(\text{Area of a web}) = h_f b_{eff} + hb$$

Centroid:

$$\text{flange: } c_f = h_f/2; \text{ web: } c_w = h_f + h/2$$

Neutral axis:

$$\bar{y} = \frac{A_f y_f + A_w y_w}{A_f + A_w}$$

Second moment of area:

$$I_f = \frac{b_{eff} h_f^3}{12} + A_f (y - y_f)^2$$

$$I_w = \frac{b(h-h_f)^3}{12} + A_w (y_w - y)^2$$

$$\text{Total } I = I_f + I_w$$

Section modulus:

$$S_{top} = \frac{I}{Y_t}, S_{bottom} = \frac{I}{Y_b}$$

Where  $Y_t$  and  $Y_b$  are the distances from the neutral axis to top and bottom fibers respectively.

Radius of Gyration:

$$r = \sqrt{\frac{I}{A}}$$

K-values:

$$k_{top} = \frac{S_{top}}{A} \text{ and } k_{bottom} = \frac{S_{bottom}}{A}$$

The results can be summarized on the following table.

**Table 3.7.5.1** Summary of the axial and bending effect of a PT Beam

|              | Property | Axial Effects | Bending Effects |
|--------------|----------|---------------|-----------------|
| <b>INPUT</b> | h,mm     | 800.00        | 800.00          |
|              | hf,mm    | 165.00        | 165.00          |
|              | b,mm     | 600.00        | 600.00          |

|               |                              |                |                |
|---------------|------------------------------|----------------|----------------|
|               | beff.m                       | 5000.00        | 3240.00        |
|               | A flange,<br>mm <sup>2</sup> | 825000.00      | 534600.00      |
|               | A web, mm <sup>2</sup>       | 480000.00      | 480000.00      |
|               | Area, mm <sup>2</sup>        | 1305000.00     | 1014600.00     |
|               | flange<br>centroid, mm       | 82.50          | 82.50          |
|               | web centroid,<br>mm          | 565.00         | 565.00         |
| <b>OUTPUT</b> | y, mm                        | 259.97         | 310.77         |
|               | Yt, mm                       | 259.97         | 310.77         |
|               | Yb, mm                       | 705.03         | 654.23         |
|               | I,f mm <sup>4</sup>          | 1871718750.00  | 1212873750.00  |
|               | I,w mm <sup>4</sup>          | 25600000000.00 | 25600000000.00 |
|               | y, flange, mm                | 177.47         | 228.27         |
|               | y, web, mm                   | 305.03         | 254.23         |
|               | I total, mm <sup>4</sup>     | 98116373922.41 | 85693167658.93 |
|               | Stop, mm <sup>3</sup>        | 377412381.18   | 275747056.91   |
|               | Sbot, mm <sup>3</sup>        | 139166489.20   | 130982702.83   |
|               | ktop, mm                     | 289.20         | 271.78         |
|               | kbot, mm                     | 106.64         | 129.10         |
|               | rad. of<br>gyration          | 274.20         | 290.62         |

### 3.7.5.2 Stage 2: Material Properties

Concrete:

The large span beam requires a stronger concrete in comparison with the standard selection, and more advanced properties. It was decided to use 6000 psi concrete which accounts for about  $f'_c = 41.4 \text{ MPa}$  of compressive strength. The elastic modulus is calculated using the following expression:

$$E_c = 4700\sqrt{f'_c} = 30241,131 \text{ MPa}$$

The creep coefficient was assumed to be equal to 2, and analysis type to be full integration in SAP2000 according to time dependent type of ACI 209R-92 parameters.

**Figure 3.7.5.1** Concrete Property Data for PT Beam in SAP2000 model

**Time Dependent Properties for Concrete**

Material Name: 6000Psi

Material Type: Concrete

Symmetry Type: Isotropic

Time Dependent Type: ACI 209R-92

Units: KN, m, C

Time Dependence Considered For:

| Item                                                                                | Factor |
|-------------------------------------------------------------------------------------|--------|
| <input type="checkbox"/> Compressive Strength and Stiffness (Modulus of Elasticity) |        |
| <input checked="" type="checkbox"/> Creep                                           | 2      |
| <input type="checkbox"/> Shrinkage                                                  |        |

Creep Analysis Type:

☒ Full Integration

☐ Dirichlet Series With  Terms

ACI 209R-92 Parameters:

Relative Humidity, %: 50

Shrinkage Start Age, days:

Compressive Strength Factor, a:

Compressive Strength Factor, Beta:

Curing Type: Moist

Slump: 0.06858

Fine Aggregate Percentage, %: 50

Air Content, %: 6

Cement Content, lb/yd<sup>3</sup>:

Show Plot...

OK Cancel

**Figure 3.7.5.2** Concrete Time Dependent Property Data for PT Beam in SAP2000 model

Finally, it is an important step to find initial strength at transfer when the prestress is first applied, it was conservatively assumed to be 70%.

$$f_{ci} = 0,7f'_c$$

Reinforcement Rebars:

The following parameters were used for 75 grade rebars with the strength reduction coefficient of  $\phi = 0,9$ .

The image shows a 'Material Property Data' dialog box for a material named 'A615Gr75'. The dialog is organized into several sections:

- Material Name:** A615Gr75
- Material Type:** Rebar
- Symmetry Type:** Uniaxial
- Modulus of Elasticity:** E1 = 1.999E+08
- Weight and Mass:**
  - Weight per Unit Volume: 76.9729
  - Mass per Unit Volume: 7.849
- Units:** KN, m, C (selected)
- Poisson:** U12 = 0.3
- Coeff of Thermal Expansion:** A1 = 1.170E-05
- Shear Modulus:** G12 = 76903069
- Other Properties for Rebar Materials:**
  - Minimum Yield Stress, Fy: 517106.8
  - Minimum Tensile Stress, Fu: 689475.8
  - Expected Yield Stress, Fye: 568817.5
  - Expected Tensile Stress, Fue: 758423.4
- Advanced Material Property Data:**
  - Nonlinear Material Data...
  - Material Damping Properties...
  - Time Dependent Properties...
  - Thermal Properties...

At the bottom are 'OK' and 'Cancel' buttons.

**Figure 3.7.5.3** Reinforcement Rebars Property Data for PT Beam in SAP2000 model

Prestressing Tendons:

ASTM416 Grade 270 was selected for prestressing tendons which accounts for ultimate tensile strength  $f_{pu} = 1861 \text{ MPa}$  and yield strength  $f_y = 1690 \text{ MPa}$  with a nominal diameter of 15,2 mm and area of  $140 \text{ mm}^2$  for a single tendon. In addition, the long-term stress for unbonded system was assumed to be 70% of the ultimate tensile strength  $f_{se} = 0,7f_{pu} = 1302,7 \text{ MPa}$ .

**Figure 3.7.5.4** Tendon Property Data for PT Beam in SAP2000 model

### 3.7.5.3 Stage 3: Design Parameters

1) Allowable tensile stresses:

ACI 318 defines 3 possible cases for one-way systems for service conditions which are the following:

- Uncracked (U):  $tensile\ stress < 0,62\sqrt{f'_c}$
- Transition (T):  $0,62\sqrt{f'_c} < tensile\ stress < \sqrt{f'_c}$
- Cracked (C):  $tensile\ stress > \sqrt{f'_c}$

They depend on the magnitude of the calculated tensile stress on the extreme fibers. In the scope of this project, the target stress was selected to be conservatively  $0,75\sqrt{f'_c}$  on the top surface which belongs to the range from transition to cracked cases.



2) Allowable compressive stresses:

According to ACI 318 the following load conditions are specified:

- Sustained load condition:  $\text{compressive stress} = 0,45f'_c = 18,63 \text{ MPa}$
- Total load condition:  $\text{compressive stress} = 0,6f'_c = 24,84 \text{ MPa}$

3) Finally using the above coefficients the following allowable stresses can be determined for service and initial conditions according to ACI 318.

Service conditions:

For extreme bottom fiber:  $\sqrt{f'_c} = 6,43 \text{ MPa}$  of tension

For extreme top fiber:  $0,75\sqrt{f'_c} = 4,83 \text{ MPa}$  of tension

Initial conditions:

Tension:  $0,25\sqrt{f'_{ci}} = 1,35 \text{ MPa}$

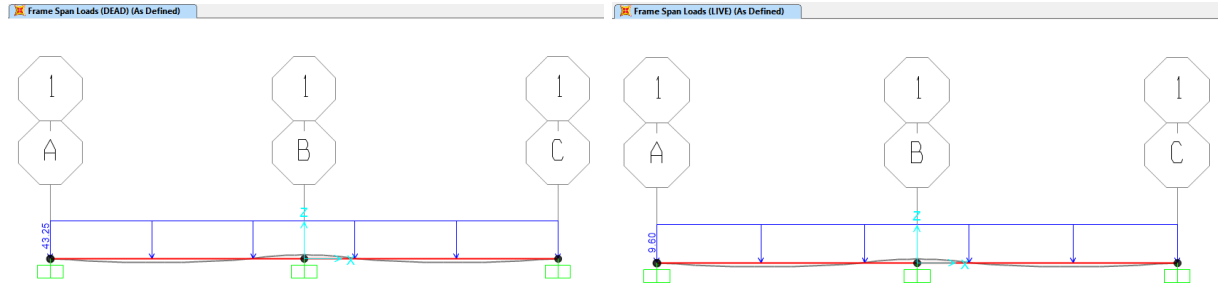
Compression:  $0,6f'_{ci} = 17,39 \text{ MPa}$

#### 3.7.5.4 Stage 4: Action due to live and dead loads

First of all, the acting dead and live loads were calculated according to the tributary area resulting in the linear forces. In addition, the DL due to the self-weight of the beam was calculated using the following formula,  $DL_{\text{self-weight}} = hbp$ .

**Table 3.7.5.2** Summary of the acting loads on the PT beams

| Floor   | DL (kPa) | DL (kN/m) | DL due to the self-weight | LL (kPa) | LL (kN/m) |
|---------|----------|-----------|---------------------------|----------|-----------|
| Floor 3 | 8.91     | 44.55     | 11.52                     | 1.92     | 9.6       |
| Floor 2 | 8.22     | 41.1      | 11.52                     | 1.92     | 9.6       |
| Floor 1 | 8.65     | 43.25     | 11.52                     | 1.92     | 9.6       |



**Figure 3.7.5.5** Assigned DL and LL on the PT beam in SAP2000

The next step was to find the critical moments acting on the joints and apparently in the middle of each span of PT beam according to the following 4 load cases: DL, LL, DL+LL, and DL+0,3LL (for serviceability LL was assumed to be reduced to 30%). The results are shown in the table below.

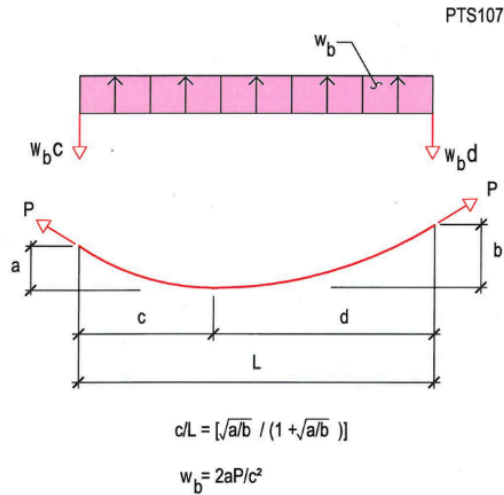
**Table 3.7.5.3** Summary of the acting moments, SAP2000

| Span #     | SPAN 1   |        |          | SPAN 2   |        |          |
|------------|----------|--------|----------|----------|--------|----------|
| Position   | Left     | Mid    | Right    | Left     | Mid    | Right    |
| MD(kN- m)  | -1747.65 | 796.87 | -1601.79 | -1601.79 | 796.87 | -1747.65 |
| ML (kN-m)  | -303.23  | 138.24 | -277.92  | -277.92  | 138.24 | -303.23  |
| MD + 0.3ML | -1838.62 | 838.34 | -1685.17 | -1685.17 | 838.34 | -1838.62 |
| MD+ML      | -2050.88 | 925.00 | -1879.72 | -1879.72 | 925.00 | -2050.88 |

### 3.7.5.5 Stage 5: Post Tensioning Procedure

Before starting the procedure it was important to define maximum and minimum precompression stress to be 2 and 1 MPa respectively. The goal was to balance at least 60% of the load.

The force for 1 tendon is equal to  $F_{per\ tendon} = f_{se} A = 1302,7 \cdot \frac{140}{1000} = 182,38\ kN$ . In order to find the equivalent distributed load acting upward the following procedure was used according to the figure X below.



Geometry and Actions of a Parabolic Tendon

FIGURE 6.2-1

**Figure 3.7.5.6** Procedure to determine  $w_b$  resulting from tendons

The initial guess for a number of strands is accomplished using the following formula:

$$Force_{PT} = Area \cdot Min. Avg. Pressure = 1.305 m^2 \times 1000 kPa = 1305 kN$$

$$N_{strands} = \frac{Force_{PT}}{Force_{per tendon}} = 7,16 \rightarrow choose 8$$

$$P = 8 \times 182,38 kN = 1459,02 kN$$

Clear cover is equal to 165 mm which leads to:

$$e_{max} = h - 165 = 635 mm$$

$$a = b = e_{max} - 165 = 470 mm$$

$$L = 20 m, c = 20 \cdot \frac{\sqrt{1/1}}{1 + \sqrt{1/1}} = 10 m$$

$$w_b = 2 \cdot 470 \cdot 1459,02/10^2 = 13,71 kN/m$$

$$\%DL_{balanced} = \frac{13,71 kN/m}{43.25 kN/m} = 0,32 < 0,6 \text{ not OKAY}$$

Based on the results, it is needed to adjust a number of strands using the proportion:

$$new N_{strands} = \frac{0,6}{0,32} \times 8 \approx 15 \rightarrow choose 15$$

$$new P = 15 \times 182,38 kN = 2735,67 kN$$

$$new w_b = 2 \cdot 470 \cdot 2735,67/10^2 = 25,72 \text{ kN/m}$$

$$new \%DL \text{ balanced} = \frac{25,72 \text{ kN/m}}{43,25 \text{ kN/m}} \approx 0,6 \geq 0,6 \text{ OKAY}$$

As a result, the 15 strand ASTM416 Grade 270 tendons with a nominal diameter of 15,2 mm were verified to be used for the selected large-span beam.

### 3.7.5.6 Stage 6: Serviceability check

#### 1. Deflection check

First of all, the maximum deflection results were extracted for the Dead Load (DL), Post-tensioning (PT), DL+PT, and Live Load (LL) combinations from the SAP2000 model, they are summarized in the following table.

**Table 3.7.5.4** Summary of the deflections, SAP2000

| Load Combination | Deflection (mm) |
|------------------|-----------------|
| DL               | 26.77           |
| PT               | -12.44          |
| DL+PT            | 14.33           |
| LL               | 4.64            |

The deflection due to live load check is done using the following procedure:

$$\delta_{LL} < \frac{L}{360}$$

$$4,64 \text{ mm} < \frac{20000}{360} = 55,55 \text{ mm}; \text{ OKAY}$$

The long term deflection check is done using the following procedure:

$$\delta_{long \text{ term}} = (creep \text{ factor} + 1)(\delta_{DL} + \delta_{PT} + 0,3\delta_{LL}) < \frac{L}{240}$$

$$\delta_{long \text{ term}} = (2 + 1)(26,77 - 12,81 + 0,3 \cdot 4,64) = 47,17 \text{ mm} < \frac{20000}{240} = 83,33 \text{ mm}; \text{ OKAY}$$

#### 2. Stress check

The section properties are listed in the table below.

**Table 3.7.5.5** Section properties

| Section Properties |              |
|--------------------|--------------|
| Yt                 | 310.77       |
| Yb                 | 654.23       |
| Stop               | 275747056.91 |
| Sbot               | 130982702.83 |
| A                  | 1014600      |
| P/A                | -1.977289572 |

Two load combinations were checked for serviceability of the stresses which are DL+0.3LL+PT and DL+LL+PT. The procedure is as follows:

$$\sigma_{top} = -(M_{DL} + 0,3M_{LL} + M)/S_{top} + P/A < \sigma_{allowable\ on\ top}$$

$$\sigma_{bottom} = (M_{DL} + 0,3M_{LL} + M)/S_{bottom} + P/A < \sigma_{allowable\ on\ bottom}$$

The summary can be visible on the table below.

**Table 3.7.5.6** Section properties

| Load Combination | Stresses | Point A | Point B | Point C | Point D | Point E | Point F |
|------------------|----------|---------|---------|---------|---------|---------|---------|
| DL+0.3LL+PT      | ft, MPa  | 1.03    | -4.39   | 0.71    | 0.71    | -4.39   | 1.03    |
|                  | fb, MPa  | -10.53  | 0.88    | -9.88   | -9.88   | 0.88    | -10.53  |
|                  | Ft, MPa  | 4.83    | -18.63  | 4.83    | 4.83    | -18.63  | 4.83    |
|                  | Fb, MPa  | -18.63  | 4.83    | -18.63  | -18.63  | 4.83    | -18.63  |
|                  | Status   | OK      | OK      | OK      | OK      | OK      | OK      |
| DL+LL+PT         | ft, MPa  | 1.80    | -4.74   | 1.42    | 1.42    | -4.74   | 1.80    |
|                  | fb, MPa  | -12.15  | 1.62    | -11.36  | -11.36  | 1.62    | -12.15  |
|                  | Ft, MPa  | 4.83    | -18.63  | 4.83    | 4.83    | -24.84  | 4.83    |
|                  | Fb, MPa  | -24.84  | 6.43    | -24.84  | -24.84  | 6.43    | -24.84  |

|  |        |    |    |    |    |    |    |
|--|--------|----|----|----|----|----|----|
|  | Status | OK | OK | OK | OK | OK | OK |
|--|--------|----|----|----|----|----|----|

Finally, the effective moment reduction factor can be found using the following expression:

$$I_e \text{ factor} = 1 - 0,3 \left( \frac{f_{t(DL+LL+PT \text{ on middle})} - 0,5\sqrt{f'_c}}{0,5\sqrt{f'_c}} \right) = 1.17 > 1, \text{ thus no moment reduction is}$$

needed.

### 3.7.5.7 Stage 7: Design for Flexure

The main goal of a flexural design is to satisfy the following requirement:  $\phi M_n \geq M_u$ . First thing to do is to check if the tendons alone could carry the moment without cracks. In order to accomplish it, the following must be true:

$$\phi M_n^{PT} (\text{from tendons only}) \geq 1,2 M_{cr}$$

Note: the 1,2 coefficient is empirical, not a code requirement.

$$M_{cr} = (f_r + P/A) \cdot S_{\text{top or bottom}}$$

$$\phi M_n^{PT} = 0,9 N_{\text{strands}} \cdot A_{\text{strand}} f_{pu} \cdot 0,9 d$$

$$d = h + h_f - SGS$$

CGS is a distance from the top or bottom to the center of the ducts of strands located in parallel which is determined to be 165 mm.

The results are collected in the table below:

**Table 3.7.5.7** Flexural capacity of the tendons

| Parameters               | Point A   | Point B   | Point C   | Point D   | Point E   | Point F   |
|--------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Stop, (mm <sup>3</sup> ) | 275747056 | 0.00      | 275747056 | 275747056 | 0.00      | 275747056 |
| Sbot, (mm <sup>3</sup> ) | 0.00      | 130982702 | 0.00      | 0.00      | 130982702 | 0.00      |
| P (kN)                   | 2735.67   | 2735.67   | 2735.67   | 2735.67   | 2735.67   | 2735.67   |
| P/A, (MPa)               | -2.70     | -2.70     | -2.70     | -2.70     | -2.70     | -2.70     |
| fr + (P/A),              | 6.72      | 6.72      | 6.72      | 6.72      | 6.72      | 6.72      |

|                |         |         |         |         |         |         |
|----------------|---------|---------|---------|---------|---------|---------|
| (MPa)          |         |         |         |         |         |         |
| Mcr, (kN-m)    | 1852.39 | 879.91  | 1852.39 | 1852.39 | 879.91  | 1852.39 |
| 1.2Mcr, (kN-m) | 2222.87 | 1055.89 | 2222.87 | 2222.87 | 1055.89 | 2222.87 |
| phi Mn, (kN-m) | 2532.45 | 2532.45 | 2532.45 | 2532.45 | 2532.45 | 2532.45 |
| Status         | OK      | OK      | OK      | OK      | OK      | OK      |

Note: OK - satisfied the  $\phi M_n^{PT} \geq 1,2 M_{cr}$  condition.

Since the tendons satisfy the flexural demand, it is reasonable to provide only the minimum reinforcement to this beam using the following expression:

$$A_s \geq A_{s,min} = MAX(\frac{0,25\sqrt{f_c'}}{f_y} b_w d; \frac{1,4}{f_y} b_w d)$$

According to ACI-318, for statically indeterminate structures such as continuous beams, the width of the web can be taken into the formula to avoid excessive reinforcement congestion, provided that the design satisfies the crack control requirements. 60 grade steel is going to be used as a reinforcement whose  $f_y$  is equal to 414 MPa.

$$A_{s,min} = MAX(\frac{0,25\sqrt{41,4}}{414} \cdot 600 \cdot 800; \frac{1,4}{414} \cdot 600 \cdot 800) \approx 1865 \text{ mm}^2$$

It was decided to use the 7#6 rebars placed horizontally with a diameter of 19,05 mm<sup>2</sup>

$(7\pi(\frac{19,05}{2})^2 = 1996 \text{ mm}^2 > 1865 \text{ mm}^2)$ . It meets the requirements of the spacing which is the following:

$$clear \text{ spacing} = max(d_b, 25 \text{ mm}, 1,33 \cdot d_{max \text{ aggregate}})$$

Where  $d_b$  is bar size, and  $d_{max \text{ aggregate}}$  is #4 which is 12,7 mm.

$$clear \text{ spacing} = max(19,06 \text{ mm}, 25 \text{ mm}, 1,33 \cdot 12,7 \text{ mm}) = 25 \text{ mm}$$

### 3.7.5.8 Stage 8: Design for Shear

First of all, the probable moment needs to be found using the following equation:

$$M_{pr} = T_s d_s + T_p d_p - C_c \cdot \frac{a}{2} - C_s' d'$$

$$\text{Where, } C_c = 0,85 f_c' ab$$

$$C_s' = A_s' f_s' \text{ (if compression steel yields)}$$

$$T_s = A_s f_{ps}$$

$$T_p = A_{ps} f_{pu}$$

$$a = \beta_1 c$$

$$f_s = 1,25 f_y$$

As a result,  $M_{pr} = 2992,15 \text{ kN}$ .

Next thing is to determine the shear capacity at critical stations and towards the midspan. The shear loading under dead load, live load and prestressing is taken from SAP2000. The next expression were calculated as follows:

$$V_u = 1,2V_{DL} + 1,6V_{LL} + V_{PT}$$

$$V_{eq} = M_{pr} \cdot (\text{span length} = 20 \text{ m})$$

$$V_g = 1,2V_{DL} + 0,5V_{LL}$$

$$V_e = V_{eq} + V_g$$

The results are summarized in the tables below:

**Table 3.7.5.8** Shear capacity at critical stations

| Shear Capacity at Critical Stations |          |          |           |          |
|-------------------------------------|----------|----------|-----------|----------|
|                                     | Point A  | Point C  | Point D   | Point F  |
| VD                                  | -552.489 | 544.863  | -544.862  | 552.489  |
| VL                                  | -95.937  | 94.584   | -94.584   | 95.937   |
| Vpt                                 | 257.032  | -253.406 | 253.406   | -257.032 |
| Vu                                  | -559.454 | 551.764  | -551.7628 | 559.454  |
| Ve <sub>q</sub>                     | 231.64   | 231.64   | 231.64    | 231.64   |
| V <sub>g</sub>                      | 710.96   | 701.13   | 701.13    | 710.96   |
| V <sub>e</sub>                      | 942.59   | 932.76   | 932.76    | 942.59   |



**Table 3.7.5.9** Shear capacity at stations towards midspan

| <b>Shear Capacity at Stations towards Midspan</b> |               |              |               |              |
|---------------------------------------------------|---------------|--------------|---------------|--------------|
|                                                   | 1.93 m to 4 m | 4 - mid span | 1.93 m to 4 m | 4 - mid span |
| VD                                                | -428.323      | -320.46      | -405.016      | -326.239     |
| VL                                                | -74.319       | -55.556      | -70.224       | -56.571      |
| Vg                                                | 551.15        | 412.33       | 521.13        | 419.77       |
| Ve <sub>q</sub>                                   | 231.64        | 231.64       | 231.64        | 231.64       |
| Ve <sub>q</sub>                                   | 782.78        | 643.97       | 752.77        | 651.41       |

The final step is to calculate the minimum required reinforcement and maximum spacing between the stirrups. In order to accomplish this goal, the following procedure was followed:

$$V_c = 0,17\lambda\sqrt{f'_c}b_w d, \text{ where } \lambda = 1.0 \text{ for normal weight concrete}$$

Check if the additional reinforcement required:  $V_e > \phi_v V_c$ , where  $\phi_v = 0,75$

$$V_e = 932.76 \text{ kN} > \phi_v V_c = 447,54 \text{ kN}$$

$$\text{Need } V_s = \frac{V_e}{\phi_v} - V_c = 646,96 \text{ kN}$$

$$\text{The spacing can be found by } s = \frac{A_v f_y d}{V_s}$$

Typically, the #4 stirrup is the minimum used in practice as a shear reinforcement, therefore it was decided to provide 4-legged #4 stirrups with 12,7 mm diameter.

$$A_v = 2 \cdot 129 = 258 \text{ mm}^2$$

$$s = \frac{A_v f_y d}{V_s} = 152,6 \text{ mm}$$

$$\text{The maximum spacing is } s_{max} = \min\left(\frac{d}{4}, 6d_b, 150 \text{ mm}\right) = 114,36 \text{ mm}$$

The spacing provided is going to be the minimum of the  $s_{max}$  and  $s$  calculated.

As a result, the 4-legged #4 stirrups @ 100 mm were provided. Also, the parts towards the midspan resulted in the same spacing. There will be more labor to implement such a big number of stirrups, however, the safety of the future citizens is the first priority of the project.

The torsional effects are negligible because the loads are distributed symmetrically over the whole length and there were no eccentricities for this beam.

As a result, the following beam was accurately designed for the interior large span beam for the 1-3 floors.

### Cuts 1-1, 3-3

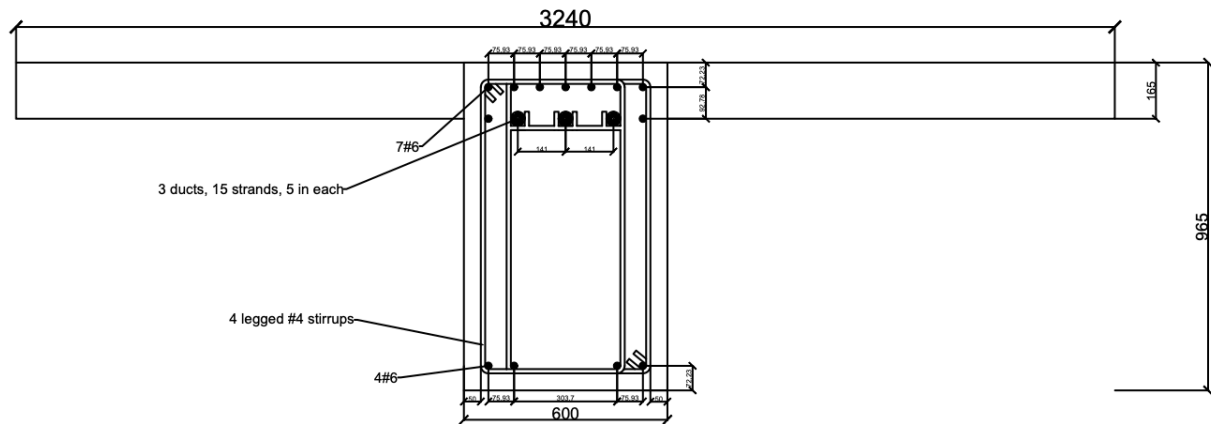


Figure 3.7.5.7 PT Interior Beam; cuts 1-1, 3-3; dimensions in mm

### Cuts 2-2

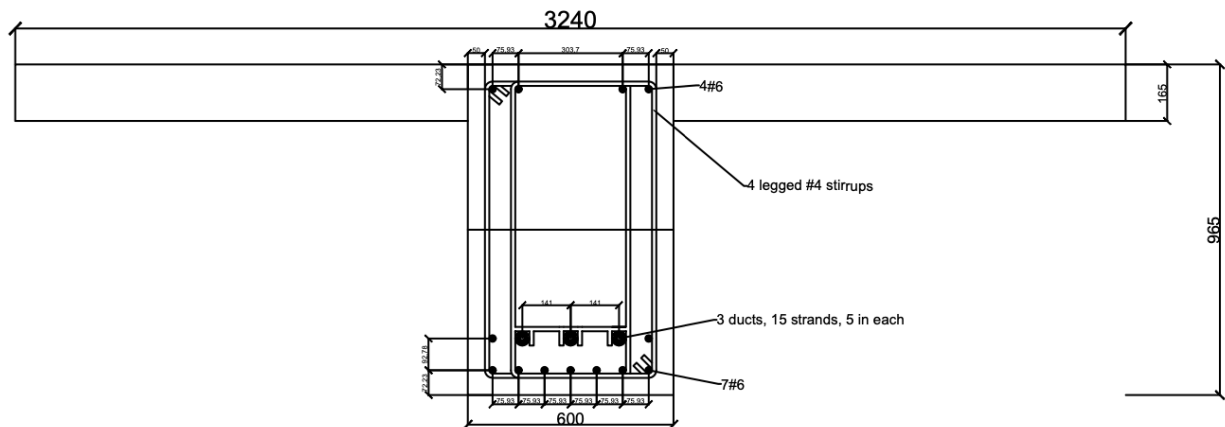
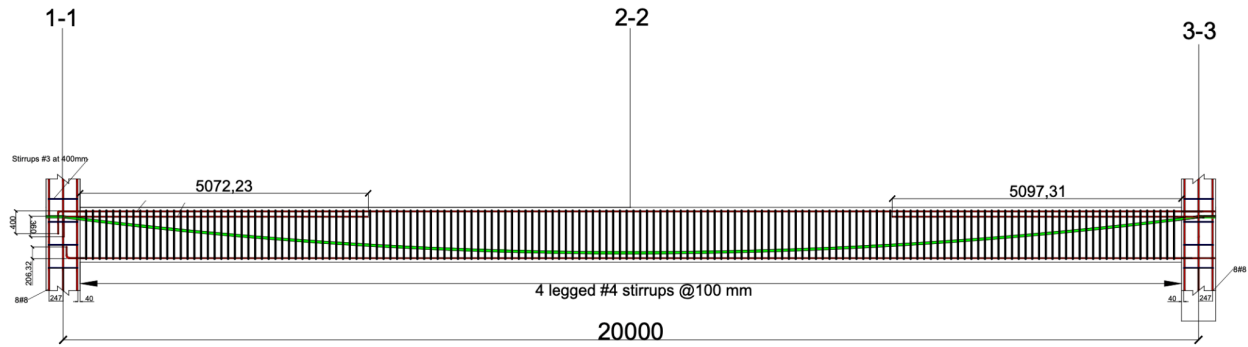


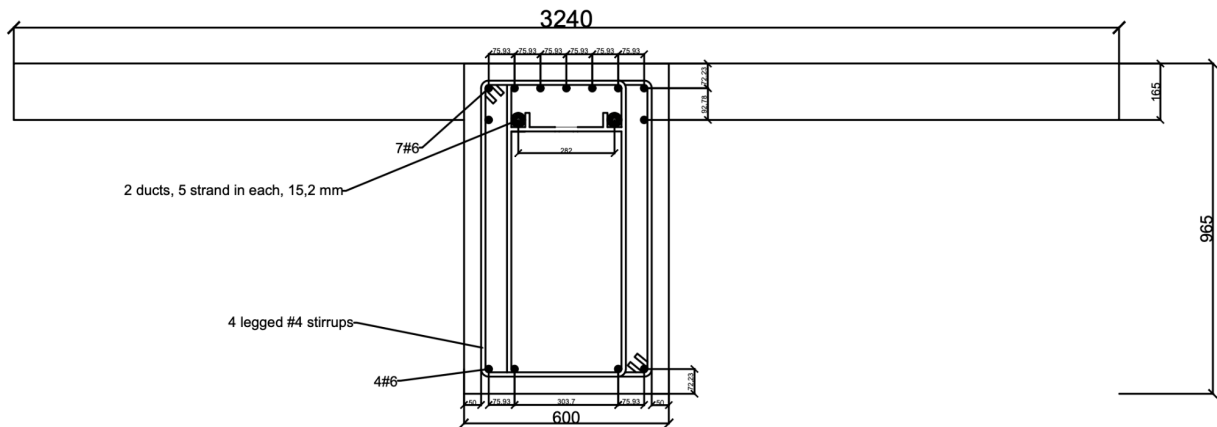
Figure 3.7.5.8 PT Interior Beam; cuts 2-2; dimensions in mm



**Figure 3.7.5.9** PT Interior Beam; side view; dimensions in mm

Following the same procedure the PT Edge Beam was designed.

### Cuts 1-1, 3-3



**Figure 3.7.5.10** PT Edge Beam; cuts 1-1, 3-3; dimensions in mm

3240

165

4#6

4 legged #4 stirrups

2 ducts, 5 strand in each, 15,2 mm

7#6

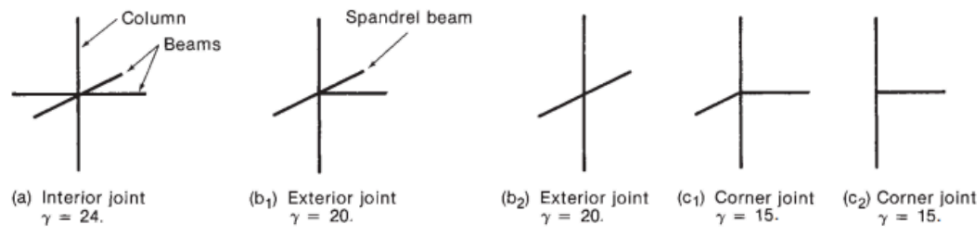
600

Diagram showing the elevation view of a reinforced concrete beam. The beam has a total length of 20000 mm. The stirrups are labeled as "4 legged #4 stirrups @100 mm". The beam is divided into three sections by vertical lines labeled 1-1, 2-2, and 3-3. The distance between 1-1 and 2-2 is 5072.23 mm, and the distance between 2-2 and 3-3 is 5097.31 mm. The beam is supported by two columns. The left column has a width of 400 mm and a height of 1000 mm. The right column has a width of 400 mm and a height of 1000 mm. The beam is reinforced with longitudinal bars and stirrups. The stirrups are labeled as "Stirrups #3 at 400mm". The beam is shown with a green line indicating the centerline. The beam is supported by two columns. The left column has a width of 400 mm and a height of 1000 mm. The right column has a width of 400 mm and a height of 1000 mm. The beam is reinforced with longitudinal bars and stirrups. The stirrups are labeled as "Stirrups #3 at 400mm". The beam is shown with a green line indicating the centerline.

### 3.7.6 Joint design

Three types of joints based on the location:

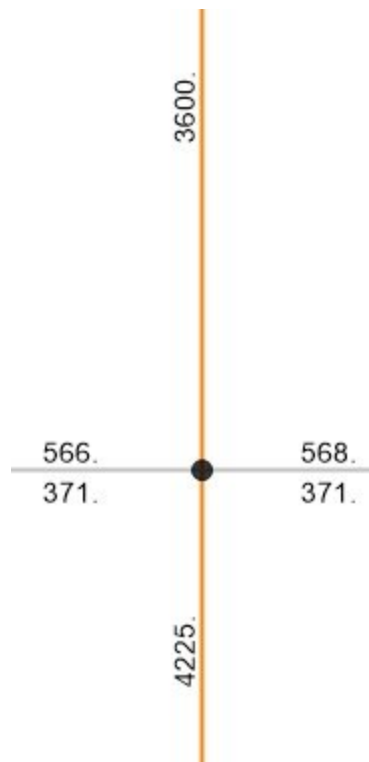
- 150



**Figure 3.7.6.1** Joint types

Where the joint shear is equal to the probable force in the top steel in the joint, minus the shear in the columns due to sway of the columns. An interior joint has beams on both sides that contribute to the shear in the joint.

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



**Figure 3.7.6.2** The joint at floor 1

The force is the tension in the reinforcement in the beam at its probable capacity. Thus,

$$T_{pr1} = \alpha A_s f_y = 1.25 * 568 * 0.413 = 293.03 \text{ kN}$$

$$C_{pr2} = \alpha A_s f_y = 1.25 * 371 * 0.413 = 191.53 \text{ kN}$$

$$V_{col} = 70.64 \text{ kN}$$

$$V_{u,joint} = 293.03 + 191.53 - 145.95 = 414.416 \text{ kN}$$

$$b_b + b_{col} = 250 + 600 = 850 \text{ mm}$$

$$h_b + 2x = 250 + 2 * 175 = 600 \text{ mm}$$

The shear strength on a horizontal plane at mid height of the joint is:

$$V_n = \gamma \sqrt{f'_c} * A_j = 1.7 * \sqrt{35} * 600 * 600 = 3620.6 \text{ kN}$$

$$\phi V_n \geq V_{u,joint}$$

$$0.85 * 3620.6 = 3077.5 \text{ kN} \geq 414.416 \text{ kN}$$

$$A_v = \max\left(\frac{0.062\sqrt{f'_c}b_c s}{f_{yt}}; \frac{0.35b_c s}{f_{yt}}\right) = \max\left(\frac{0.062\sqrt{35}*600*212.9}{0.413}; \frac{0.35*600*212.9}{0.413}\right) = 113.45$$

$$s = \min\left(\frac{A_v f_{yt}}{0.062\sqrt{f'_c}b_c}; \frac{A_v f_{yt}}{0.35b_c}\right) = \min\left(\frac{113.45*413}{0.062\sqrt{35}*600}; \frac{113.45*413}{0.35*600}\right)$$

$$s = \min(212.9; 223.1) = 212.9 \text{ mm}$$

2#3 ties with 200mm spacing would be considered

### 3.7.7 Lap splices

$$l_{sc} = 0.0005 f_y d_b$$

**Table 3.7.7.1** Lap splices design of columns

| Column     | Lap splice, mm |
|------------|----------------|
| Floors 1-2 | 762            |
| Floors 2-5 | 667            |
| Floors 6-9 | 572            |

### 3.7.8 Development length tension

To provide sufficient anchorage in the joint area, the longitudinal reinforcement of the beam was brought to the far face of the column. Beam reinforcement at the joint was verified by passing through the column dimension that meets the requirement of ACI 318 and this is to ensure that the column width is more than 20 times of the beam reinforcement bar diameter.

The joint area transverse reinforcement was developed to meet the requirements of ACI 318 (Sections 18.7.5.2-18.7.5.4) that offers adequate confinement and shear resistance.

The length of time that hooked bars take to develop in the joint was determined as:

$$l_{dh} = \max\left(\frac{f_y d_b}{5.4\lambda\sqrt{f'_c}}, 8d_b, 150 \text{ mm}\right)$$

For this study, the following parameters were used:

- Concrete compressive strength:  $f'_c = 35 \text{ MPa}$
- Steel yield strength:  $f_y = 414 \text{ MPa}$
- Concrete type factor:  $\lambda = 1.0$

Substituting the values:

**Table 3.7.8.1** Bar development length ending in standard hook in joint

| Bar | Diameter, mm | $l_{dh}$ , mm |
|-----|--------------|---------------|
| D10 | 9.53         | 150           |
| D13 | 12.7         | 170           |
| D16 | 15.9         | 210           |
| D19 | 19.1         | 250           |

|     |      |     |
|-----|------|-----|
| D22 | 22.2 | 290 |
| D25 | 25.4 | 330 |
| D29 | 28.6 | 380 |
| D32 | 31.8 | 420 |
| D36 | 34.9 | 460 |

These are the values of the formula result and minimum check requirements. In the case of D29 Bar, the formula approximately takes about 380 mm.

$$D = 6d_b = 171\text{mm}$$

$$r = D/2 = 85.5\text{mm}$$

$$\text{Hook distance} = 12d_b = 342\text{mm}$$

### 3.7.9 Development length compression

$$l_{dc} = \left( \frac{f_y \psi_r}{5.4 \lambda \sqrt{f_c}} \right) * d_b$$

$$\psi_s = 1.0; \psi_t = 1.3; \psi_e = 1.0$$

$$K_{tr} = \frac{40A_n}{sn} = \frac{40 * 1.13 * 10^{-4}}{6 * 0.05} = 0.015$$

$$\frac{c_b + K_{tr}}{d_b} = \frac{0.025 + 0.015}{0.0286} = 1.398 < 2.5$$

$$d_b = 28.6\text{ mm}$$

$$l_{dc} = 332.76\text{ mm}$$



### 3.7.10 Exterior glazing

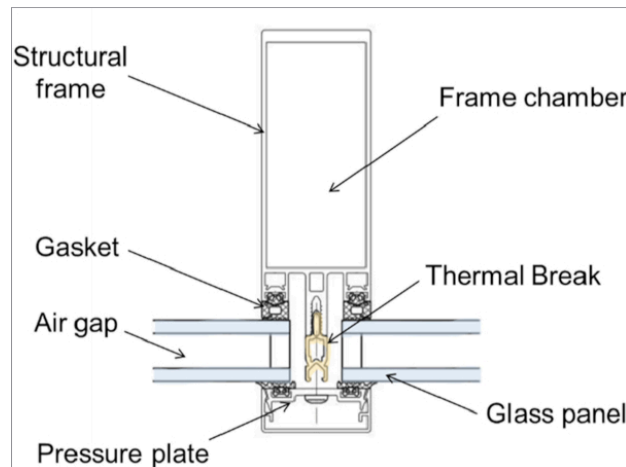
The exterior of the ADZHARAT hotel is developed as a thermally broken unitized aluminum curtain wall system with the high-performance insulating glazing units. The reinforced concrete (RC) structural frame supports the system at each floor level with adjustable steel brackets attached to slab edges or edge beam.

The glazing system is divided into smaller units to facilitate serviceability and structural efficiency even though the main structural grid is made of columns with spacing of 5.0 m. Vertical aluminum mullions are added at a spacing of around 1.5-1.67 m and this leaves three glazing panels in each structural bay.

The curtain wall is composed of:

- Floor-to-floor vertical aluminum mullions.
- Horizontal transoms with glazing panels.
- Energy efficiency in terms of triple-glazed insulating glass units (IGUs).
- Steel support brackets that offer loading to the RC frame.

An intermediate horizontal transom separates two 3.5 m glazing areas on the ground floor facade whose height is 7.0 m to minimize the span of the glass and the structural requirement.



**Figure 3.7.10.1** Thermal model for curtain wall metal frame (Lugaresi et al., 2023)

## 4. Geotechnical Engineering

### 4.1 Literature review on design codes

The project is planned to be constructed as a business hotel in New York with 9 stores and one basement. Geotechnical designing for this project will correspond to the legal building code adopted by the city and national standards. The following design codes standards can be applicable:

- New York City Building Code (NYCBC 2022) - for New York City, all constructions are governed by the NYCBC [4], which is based on the International Building Code (IBC 2015) [5], but some improvements were made to meet conditions in the area. In chapter 18 (soils and foundations) of the NYCBC, site investigations, classifications of soils, calculation of the allowable bearing capacity, foundation embedment, and assessment of settlement specifications are provided. In allowable stress design, the code specifies a minimum factor of safety of 3.0 of bearing capacity failure in shallow foundation [4]. Also the code requires specific attention to the groundwater table, especially when the water table is located within the area of influence of the foundation. In this case, it is mandatory that the application of design parameters is based on field and laboratory testing.
- ASCE 7-16/ ASCE 7-22 - Minimum Design Loads and Associated Criteria for Buildings and Other Structures  
ASCE 7 is the national standard that defines design loads on structures. This code gives guidelines to calculate the dead, live, wind, snow, and seismic loads [6]. In the geotechnical part, the classifications of seismic sites according to ASCE 7 are determined by shear wave velocity and SPT  $N_{60}$ , or CPT data [6]. But in this project, a non-seismic area is chosen so shear wave velocity is not needed. ASCE 7 is mandatory for structural and geotechnical load determination.

When dealing with the business hotel project, geotechnical design should be conducted according to the New York City Building Code (2022), settlement checks and foundation capacity are to be conducted in accordance with the requirements of Chapter 18. The foundation system will have structural loads calculated as per the ASCE 7-16/22 which determines seismic

site classification of the project. The design philosophy thus incorporates local legal standards (NYCBC), national standards of loads (ASCE 7) and acceptable geotechnical engineering, so that the foundation system would be safe, maintainable, and code-compliant.

## 4.2 Soil profile analysis

Formulas used to calculate the values for some soil properties:

$$N_{60} = \frac{N\eta_H\eta_B\eta_S\eta_R}{60} \quad (1)$$

Where:

$N$  – *uncorrected number of blows*

$\eta_H$  – *Hammer energy efficiency factor*

$\eta_B$  – *Borehole diameter correction factor*

$\eta_S$  – *Sampler correction factor*

$\eta_R$  – *Rod length correction factor*

$$\gamma = 16 + 0.1N_{60} \quad (2)$$

$$E_s = 320(N_{1(60)} + 15) \text{ (Bowles, 1996)} \quad (3)$$

$$E_s = 300(N_{1(60)} + 6) \text{ (Bowles, 1996)} \quad (4)$$

$$E_s = 5p_\alpha N_{1(60)} \text{ (Kulhawy \& Mayne, 1990)} \quad (5)$$

$$\phi = 27.1 + 0.3(N_{1(60)}) - 0.00054 (N_{1(60)})^2 \quad (6)$$

$$\phi = \tan^{-1} \left( \frac{N_{60}}{12.2 + 20.3 \left( \frac{\sigma'_0}{p_\alpha} \right)} \right)^{0.34} \quad (7)$$

$$\phi = \sqrt{15.4 * N_{1(60)}} + 20 \quad (8)$$

Where:

$\gamma$  – unit weight of soil,  $kN/m^3$

$E_s$  – Elastic Modulus of soil, MPa

$\phi$  – friction angle, °

$N_{60}$  – SPT blow count corrected for 60% energy efficiency (standardized SPT value)

$p_\alpha$  – atmospheric pressure, kPa

$\sigma'_0$  – effective vertical stress, kPa

**Table 4.2.1** Borehole log table

| Layer | Depth (m)       | Thickness (m) | Soil type                        | USCS  | Mid-depth z (m) | $\gamma$ (kN/m <sup>3</sup> ) | Avg SPT N (blows) | N60 (blows) | (N1)60 (blows) | $\sigma_v$ total (kPa) | u (kPa) | $\sigma'_v$ (kPa) | c' (kPa) | $\phi$ (°) | E (MPa) | v   |
|-------|-----------------|---------------|----------------------------------|-------|-----------------|-------------------------------|-------------------|-------------|----------------|------------------------|---------|-------------------|----------|------------|---------|-----|
| 1     | 0 - 1.8288      | 1.829         | silty sand with asphalt and mica | SM    | 0.93            | 17.5                          | 12                | 12          | 30             | 32.00                  | 0.000   | 32.00             | 0        | 35         | 20.00   | 0.3 |
| 2     | 1.8288 - 4.572  | 2.743         | silty sand with mica             | SM    | 3.20            | 18                            | 9                 | 9           | 11.95          | 81.37                  | 0.000   | 81.37             | 0        | 33         | 45.18   | 0.3 |
| 3     | 4.572 - 6.096   | 1.524         | silty sand with gravel and mica  | SM    | 5.33            | 18.5                          | 20                | 20          | 20.47          | 109.6                  | 0.000   | 109.6             | 0        | 35         | 78.17   | 0.3 |
| 4     | 6.096 - 25.908  | 19.812        | silty sand with mica             | SM    | 16.0            | 18                            | 20                | 20          | 13.85          | 466.2                  | 79.5    | 386.7             | 0        | 33         | 86.62   | 0.3 |
| 5     | 25.908 - 27.432 | 1.524         | silty sand                       | SM    | 26.7            | 18                            | 18                | 18          | 10.47          | 493.6                  | 184.4   | 309.2             | 0        | 33         | 103.2   | 0.3 |
| 6     | 27.432 - 30.48  | 3.048         | silty sand with gravel and mica  | SM    | 28.9            | 18.5                          | 20                | 20          | 11.26          | 549.9                  | 206.0   | 343.9             | 0        | 33         | 142.0   | 0.3 |
| 7     | 30.48 - 32.004  | 1.524         | silty sand with mica             | SM    | 31.2            | 18                            | 18                | 18          | 9.84           | 577.3                  | 228.6   | 348.7             | 0        | 30         | 109.8   | 0.3 |
| 8     | 32.004 - 33.528 | 1.524         | silty sand fine gravelly         | SM-SW | 32.8            | 18.5                          | 20                | 20          | 10.73          | 605.5                  | 244.3   | 361.2             | 0        | 33         | 149.2   | 0.3 |

|    |                              |           |                         |           |      |    |   |   |      |       |       |       |    |    |       |      |
|----|------------------------------|-----------|-------------------------|-----------|------|----|---|---|------|-------|-------|-------|----|----|-------|------|
| 9  | 33.528<br>-<br>34.747<br>2   | 1.21<br>9 | silty clay<br>with mica | CL-<br>ML | 34.1 | 19 | 4 | 4 | 2.11 | 628.7 | 257.0 | 371.7 | 40 | 22 | 56.91 | 0.36 |
| 10 | 34.747<br>2 -<br>35.356<br>8 | 0.61<br>0 | silty clay<br>sandy     | CL-<br>ML | 35.1 | 19 | 4 | 4 | 2.08 | 640.3 | 266.8 | 373.5 | 40 | 22 | 57.57 | 0.36 |

In total, there were 10 layers identified from the geotechnical site investigation report on borehole DM-B-47. The layer of silty sand goes down till 33.528 m, after which starts the layer of silty clay. The values on this Table 3.5.1 were calculated using the equations from (1) to (8). Further these calculated values will be used in a bearing capacity analysis and foundation design.

#### 4.2.1 Groundwater table

The depth and location of the groundwater table is one of the critical values that directly affects the construction of the building. According to an analysis of data from borehole DM-B-47, the groundwater table is located at a depth of approximately 7.9 meters. This depth is sufficient to be considered a deep groundwater table.

#### 4.2.2 Seismicity

According to the existing seismic hazard regional data, the site is not located in any specific seismic zone and is thus described to be located in a region of low seismicity and considered as Seismic Design Category B (*ASCE Hazard Tool*, n.d.). Because of the low frequency of the earthquakes in the vicinity, no large active faults can be found in the immediate vicinity of the site. As a result, the probability of vigorous ground movement is limited, and the seismic design coefficients that the local building codes require are also modest. However, because of the occurrence of saturated silty-sand layers below the groundwater table (about 7.9 under the ground surface), qualitative evaluation of the likelihood of liquefaction should be done to follow the accepted geotechnical practice. The likelihood of liquefaction or large amounts of seismic-induced settlement is low, with the seismic hazard in the area being low as well as the subsurface materials being relatively dense. Based on this, the special seismic ground-enhancement works on the design of the proposed hotel foundation are not necessary.

### 4.2.3 Liquefaction potential

Subsurface profile and field test results analysis show that the site consists mainly of silty sand (SM), which has varying mica content and random gravel inclusions, to a depth of about 33.5m and is surpassed by silty clay (CLML). The groundwater table lies at a depth of 7.9 m. Therefore, any strata below this point will be submerged and thus could be vulnerable to liquefaction under cyclic load. The blow counts in the upper sandy strata are between 9 and 20 and the respective corrected values (N<sub>1</sub>)<sub>60</sub> are between 12 and 30 which indicates a loose to medium-dense soil condition.

Although the site is not within an officially declared seismic zone, the sand layers, particularly those layers having the (N<sub>1</sub>)<sub>60</sub> value of less than 15 may experience partial strength loss or settlement under the effect of intense ground shaking. Greater depths of silty sand which are more N-value and more effective overburden pressures show lower liquefaction susceptibility. On the other hand, basal clayey layers cannot be liquefied which can be attributed to their cohesiveness and high plasticity. On the whole, the liquefaction risk on the site is low to moderate, mostly located in the high saturated silty sands layers. However, as a measure of the stability of the liquefaction factor of safety, a quantitative estimation based on either the Seed and Idriss (1971) correlations or Youd et al. (2001) correlations is suggested to provide support of the stability of the site under design-level seismic condition.

## 4.3 Soil engineering properties

### 4.3.1 Bearing capacity calculation:

#### 4.3.1.1 Shallow Foundation: Unsaturated soil mechanics

A pad foundation is a type of shallow foundation that is designed to spread out the load of a column in a way that the soil beneath it can safely bear it (The Constructor, 2018). In standard geotechnical practice, the ultimate bearing capacity is usually determined by means of the general equation which was introduced by Meyerhof in 1963 or by using a saturated-soil-based equation which is somewhat similar to that:

$$q_u = c'F_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + 0.5B\gamma N_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i} \quad (9)$$

For soils, with their voids filled partly with water and partly with air, this formula has to be altered to incorporate the matric suction ( $u_a - u_w$ ) which is the difference of the pore-air pressure ( $u_a$ ) and the pore-water pressure ( $u_w$ ). The main factor that influences such a change is shear strength ( $\tau$ ) of the soil, which is the controlling parameter for bearing capacity. The shear strength of the unsaturated soil:

$$\tau_{unsat} = c' + (\sigma_n - u_a)\tan\phi' + (u_a - u_w)\tan\phi^b \quad (10)$$

$c'$  – *effective cohesion*;

$\phi'$  – *effective internal friction angle*;

$(\sigma_n - u_a)$  – *net normal stress*;

$\phi^b$  – *the angle indicating the rate of increase in shear strength relative to the matric suction*;

#### Enhanced Ultimate Bearing Capacity Formula

The matric suction applied to soil results in the rise of the ultimate bearing capacity up to the shear strength of the soil. However, the suction effect is commonly included in the total by treating it as an imaginary cohesion. The most common practice to determine the ultimate bearing capacity of unsaturated soils is to modify the general bearing capacity equation:

$$q_u = [c' + (u_a - u_w)\tan\phi^b]N_c F_{cs} F_{cd} F_{ci} + q N_q F_{qs} F_{qd} F_{qi} + 0.5 B \gamma N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i} \quad (11)$$

$q_u$  – *ultimate bearing capacity*;

$c'$  – *cohesion*;

$q$  – *effective stress*;

$\gamma$  – *unit weight of soil*;

$B$  – *width of the foundation*;

$N_c, N_q, N_\gamma$  – bearing capacity factors;

$F_{cs}, F_{qs}, F_{\gamma s}$  – shape factors;

$F_{cd}, F_{qd}, F_{\gamma d}$  – depth factors;

$F_{ci}, F_{qi}, F_{\gamma i}$  – load inclination factors;

$(u_a - u_w)$  – matric suction;

$\phi^b$  – angle describing how much suction contributes to strength ( $\phi^b = 0.5\phi'$ );

One of the main factors that affect bearing capacity is effective friction angle of soil. So, the values of  $N_c, N_q, N_\gamma$  were found according to the table.

To find shape factors following equations are used:

$$F_{cs} = 1 + 0.2 \frac{B}{D_f} * \tan^2(45 + \frac{\phi}{2}) \quad (12)$$

$$F_{qs} = F_{\gamma s} = 1 + 0.1 \frac{B}{D_f} * \tan^2(45 + \frac{\phi}{2}) \quad (13)$$

$L$  – length of the foundation;

To find the depth factor:

$$F_{cd} = 1 + 0.2 \frac{D_f}{B} * \tan(45 + \frac{\phi}{2}) \quad (14)$$

$$F_{qd} = F_{\gamma d} = 1 + 0.1 \frac{D_f}{B} * \tan(45 + \frac{\phi}{2}) \quad (15)$$

As there are no inclination ,  $F_{ci} = F_{qi} = F_{\gamma i} = 1$ .



As stated by Das and Sivakugan (2019), classical methods like Terzaghi's bearing capacity theory are not appropriate even for saturated soils anymore since they do not fully account for shearing resistance in the soil failure zone above the foundation base. In the case of unsaturated soils, ignoring matric suction causes very conservative (underestimated) ultimate bearing capacity which might unintentionally result in costly foundation design.

#### 4.3.1.2 Pad foundation:

To find which type of shallow foundation can be used for this project let's compare pad foundation with the mat foundation. To do so, some assumptions are going to be made about the dimensions of the foundation.

$$D_f = 1.5 \text{ m} \quad B = 3 \text{ m} \quad L = 3 \text{ m} \quad \phi = 35^\circ \quad c' = 0 \rightarrow \text{silty sand}$$

$$1) \quad N_c = 46.12; \quad N_q = 33.30; \quad N_\gamma = 37.152$$

$$2) \quad F_{cs} = 1 + 0.2 \frac{3}{1.5} * \tan^2(45 + \frac{35}{2}) = 2.48$$

$$F_{qs} = F_{\gamma s} = 1 + 0.1 \frac{3}{1.5} * \tan^2(45 + \frac{35}{2}) = 1.74$$

$$F_{cd} = 1 + 0.2 \frac{1.5}{3} * \tan(45 + \frac{35}{2}) = 1.19$$

$$F_{qd} = F_{\gamma d} = 1 + 0.1 \frac{1.5}{3} * \tan(45 + \frac{35}{2}) = 1.09$$

$$F_{ci} = F_{qi} = F_{\gamma i} = 1$$

$$3) \quad q = \gamma * D_f = 17.5 * 1.5 = 26.25 \text{ kN/m}^2$$

$$4) \quad q_u = [0 + (40)\tan 0.25] * 46.12 * 2.48 * 1.19 + 26.25 * 33.30 * 1.74 * 1.09 + 0.5 * 17.5 * 3 \\ * 37.152 * 1.74 * 1.09 = 3531.3 \text{ kN}$$

$$FS = 1.5 \rightarrow q_{all} = \frac{q_u}{FS} = \frac{3531.3}{1.5} = 2354.2 \text{ kN}$$

#### 4.3.1.3 For mat foundation:

The decision that individual pad foundations could not be used for the structure led to the selection of a mat foundation (raft foundation, in this case) as the appropriate design option. Mat foundations are the best choice when the soil underneath has extremely low bearing capacity or when a lot of column loads need to be combined. The main ground engineering advantage of one big concrete slab is that it can take many lines of columns and at the same time, it will cause very little differential settlement under the whole building area (Das & Sivakugan, 2019). With no implied pressure for the recommendation, the design choice will provide the needed stability and performance at the local site.

$$D_f = 1 \text{ m} \quad B = 25 \text{ m} \quad L = 50 \text{ m} \quad \phi = 35^\circ \quad c' = 0 \rightarrow \text{ silty sand}$$

$$1) \quad N_c = 46.12; \quad N_q = 33.30; \quad N_\gamma = 37.152$$

$$2) \quad F_{cs} = 1 + 0.2 \frac{25}{1} * \tan^2(45 + \frac{35}{2}) = 19.45$$

$$F_{qs} = F_{\gamma s} = 1 + 0.1 \frac{25}{1} * \tan^2(45 + \frac{35}{2}) = 10.23$$

$$F_{cd} = 1 + 0.2 \frac{1}{25} * \tan(45 + \frac{35}{2}) = 1.02$$

$$F_{qd} = F_{\gamma d} = 1 + 0.1 \frac{1}{25} * \tan(45 + \frac{35}{2}) = 1.01$$

$$F_{ci} = F_{qi} = F_{\gamma i} = 1$$

$$3) \quad q = \gamma * D_f = 17.5 * 1 = 17.5 \text{ kN/m}^2$$

$$4) \quad q_u = [0 + (40)\tan 0.25] * 46.12 * 19.45 * 1.02 + 17.5 * 33.30 * 10.23 * 1.01 + 0.5 * 17.5 * 25$$

$$* 37.152 * 10.23 * 1.01 = 90151.4 \text{ kN}$$

$$FS = 1.5 \rightarrow q_{all} = \frac{q_u}{FS} = \frac{90151.4}{1.5} = 60100.9 \text{ kN}$$

Mat foundation shows higher allowable bearing capacity (60100.9 kN), while for pad foundation this value is 25 times lower (2354.2 kN). From this hand calculation, it is shown that in this project one of the possible foundation types that can be used is mat foundation.

#### 4.3.1.4 Settlement for shallow foundation

After the ultimate bearing capacity of the mat foundation was found out, the main design step was the settlement evaluation which is essential to guarantee that the structure will perform within the limits imposed as acceptable. The settlement of the ground under the structure must be analyzed so that an estimate can be made of how much the soil under the building will deform when the load according to the design is applied (Geoengineer.org, 2025).

The settlement in total will be mainly due to elastic (immediate) settlement, which is in agreement with the site conditions that include 4-meter basement excavation, 1-meter mat thickness, and presence of granular soils (sand and gravel) being confirmed. In granular soils, this settlement occurs almost instantly upon load application and is the only significant deformation that needs to be calculated.

Consequently, the prediction of settlement will be based on elastic theories. Since the soil profile does not contain any cohesive layers, the primary consolidation settlement (which is time-dependent and caused by pore water pressure dissipation in clays and silts) is practically zero and will not be assessed (Das & Sivakugan, 2019).

$$S_e = q_0 * B \frac{(1-\mu_s^2)}{E_s} * I_f \quad (16)$$

$q_0$  – net applied pressure on foundation;

$\mu_s$  – Poisson's ratio of soil;

$E_s$  – average modulus of elasticity of the soil;

$B$  – width of foundation;

$I_f$  – influence factor;

$$E_s = \frac{\sum E_s \cdot \Delta z}{z} = \frac{\sum (20000 \cdot 0.93) + (45180 \cdot 3.20) + (78170 \cdot 5.33) + (86620 \cdot 16)}{25.908} = 75873.9 \text{ kPa}$$

$$S_e = 150 * 25 * \frac{(1-0.3^2)}{75873.9} * 0.766 = 0.0345 \text{ m} = 34.5 \text{ mm}$$

The influence factor ( $I_f$ ) was taken according to the table of Bowles (1996), where in the ratio of  $L/B = 2$ ,  $I_f = 0.766$ . In our case, the consolidation settlement was not calculated, as in our soil profile the clay layer is located in more than 30 meter depth. In general, the settlement for mat foundation was 34.5 mm which exceeds the required 25 mm limit. So even though the mat foundation can hold the building's load and has a large bearing capacity, still the settlement is a little bit more than it was expected. Therefore, next the deep foundation will be examined, to find the most suitable foundation for our building.

#### 4.4 Deep Foundation

A deep foundation is a system of foundation that transfers structural loads using weak, compressible surface soil to lower level, stronger layers that can withstand the stresses imposed (Das and Sivakugan, 2018). According to the subsurface conditions at Borehole DM-B-47, the near-surface layers comprises of silty sand mixed with bits of gravel and asphalt fill, overlying silty sands (SM to SM-SW) down to some depth of about 33.5 m below ground surface, with a thin silty clay base layer (CL-ML) all the way down to 33.5 m to 35.4 m. The level of groundwater is measured to be 7.9 m below the ground level and the majority of the sand strata are saturated.

Considering this profile of the soil, primarily coarse-grained, dense to medium-dense sands and covering a thin cohesive stratum, the deep foundation system was chosen in which the building loads are transferred to the more competent sandy layers, as well as to minimize settlement and secure long-term reliability.

##### 4.4.1 Pile Material Selection

There are a number of pile materials in use with some being steel, concrete and timber.

In this project, precast reinforced concrete piles were selected because of high levels of corrosion resistance, long life span, and the fact that they are available in the New York region. Piles made of concrete also blend with the reinforced-concrete superstructure of the project, making structural continuity and connection detailing a lot easier.

Steel piles might be more effective since they offer greater load-carrying capacity, but they are not as effective in this site since they are prone to corrosion in the subsurface due to the effect of groundwater, and they are also expensive.

Timber piles were deemed unsustainable because of the low bearing capacity and probable biological degradation especially in semi-saturated soil areas (Das & Sivakugan, 2018).

#### **4.4.2 Pile Installation Method**

There are two major types of installations in geotechnical construction: drilled shaft (cast-in-place) and driven precast piles. The driven precast concrete piles should be used in this project based on the local groundwater and soil characteristics.

The Texas Disposal Systems (2021) have reported the following as the major benefits of precast concrete piles:

1. Streamlined material preparation: Concrete, reinforcement and conduits are cast under regulated conditions at the plant, and no on site formwork or independent handling of the materials are to be used.
2. Less time in installation: Driven piles do away with form setup, in-situ casting and curing time, which makes the process of foundation installation quicker and less messy.
3. Better quality and strength: Precast elements are subjected to the best temperature and humidity conditions and guarantee the high compressive strength and uniformity of the material performance.
4. Considering the above advantages and the depth of groundwater (7.9 m), driven precast piles would be a better choice than cast-in-place shafts, which would be hard to build beneath the water table.

#### 4.4.3 Pile Shape Selection

Square and circular shapes of a pile are the most widely used ones in construction. Square piles have a good ratio of perimeter to area and bending strength around the major axes. Circular piles however provide uniformity in the strength of the bending strength in all directions, the stability of the columns as well as being more durable since the piles do not have sharp corners, which could spall or easily corrode.

The manufacturing cost is a little high, but the performance and aesthetic values of circular piles are better and therefore, the weakness is counterbalanced (Gerwick, 1968). Circular precast concrete piles were therefore chosen in this project.

#### 4.4.4 Installation Deepening and Negative Friction of the Skin

The top layer on the site is made of fill (silty sand containing asphalt and gravel) covered by silty sand of medium density. These are moderately compressible sub-surface materials that have the potential of causing negative skin friction in the event that piles are set directly off the ground.

But, the proposed basement and foundation slab go down to about 3.47 m deep where the silty sand (SM) layer becomes denser and more homogenous.

The use of piles that are installed at this depth will circumvent the effect of the compressible surface fill.

The level of the soil profile is below this and the soil becomes a medium dense to dense silty sands, and the influence of negative skin friction insignificant.

The design of pile foundation usually involves three empirical procedures to estimate the shaft (skin) resistance based on the soil type and drainage conditions, and these are: the a-method, b-method, and l-method. The a-method is used in cohesive soils (clays) where the resistance of the shaft to piles during undrained conditions is based on the adhesion of the soil to the piles.

The unit skin friction is obtained as:

$$Q_s = \alpha * c_{u(sat)} \left[ 1 + \frac{(u_a - u_w)}{\frac{p_a}{101.3}} s^v / \mu \right] \pi dL \quad (17)$$

Where,

$s$  – degree of saturation ( $v = 1$  – coarse grained,  $v = 2$  – fine grained)

$\mu = 9$  – PI between 8 % and 15.5 %

$\mu = 2.1e^{0.0903PI}$  – PI between 15.5 % and 60 %

For b-method, cohesionless soils (sands, silts, gravels) are applied under drained conditions and interface friction is also relied on, as shear resistance is determined by effective stress. It is expressed as:

$$Q_s = [c'_a + \beta * \sigma'_z + (u_a - u_w)^k s^{\tan \phi'}] \pi dL \quad (18)$$

Where,

$c'_a$  – adhesion;

$k = -0.0016 * (PI)^2 + 0.0975 * (PI) + 1$  – depends on PI

The lambda-method is applied to stiff or overconsolidated clays under partially drained (long-term) conditions, where the shear resistance is more of a frictional process with its strength controlled by effective stress and not by undrained cohesion. It is written as:

$$Q_s = \lambda [\sigma'_{v(ave)} + 2 c_{u(sat)} (1 + \frac{(u_a - u_w)}{\frac{p_a}{101.3}} s^v \mu)] \quad (19)$$

The piles will thus get their major resistance to the shaft by friction (b-method) between the layers of silty sand.

As the groundwater table is in approximately ~ 7.9 m depth, after 8 meters the soil was considered as saturated and the suction was zero, so to analyze the foundation design further, traditional methods to calculate the surface friction were used:

$\alpha$  - method:

$$Q_s = \alpha c_u \pi dL \quad (20)$$

$\beta$  - method:

$$Q_s = \beta * \sigma'_v \pi dL \quad (21)$$

$\lambda$  - method:

$$Q_s = \lambda [\sigma'_{v(ave)} + 2 c_u] * \pi dL \quad (22)$$

To estimate point bearing capacity in deep foundation Meyerhof's Theory was applied:

$$Q_p = A_p q' N_q^* \leq 0.5 A_p p_a N_q^* \tan \varphi \quad (23)$$

$Q_p$  – point bearing capacity;

$A_p$  – area of pile tip;

$q'$  – effective stress at pile tip;

$\varphi$  – friction angle;

$p_a$  – atm. pressure (100 kPa);

$N_q^*$  – constant dependent on soil;

To calculate the friction resistance Coyle and Castello Method was used:

$$Q_s = f_{av} p L = (K \sigma_{av} \tan(0.8\varphi)) p L \quad (24)$$

$$K = 1 - \sin \varphi \quad (25)$$

$$\sigma_{av} = \frac{\sigma_1 + \sigma_2}{2} \quad (26)$$

$Q_s$  – friction resistance;

$p$  – pile perimeter;

$L$  – length of the pile;

$\sigma_{av}$  – average effective overburden pressure;

$K$  – lateral earth pressure coefficient;

To calculate ultimate bearing capacity ( $Q_u$ ) of deep foundation:

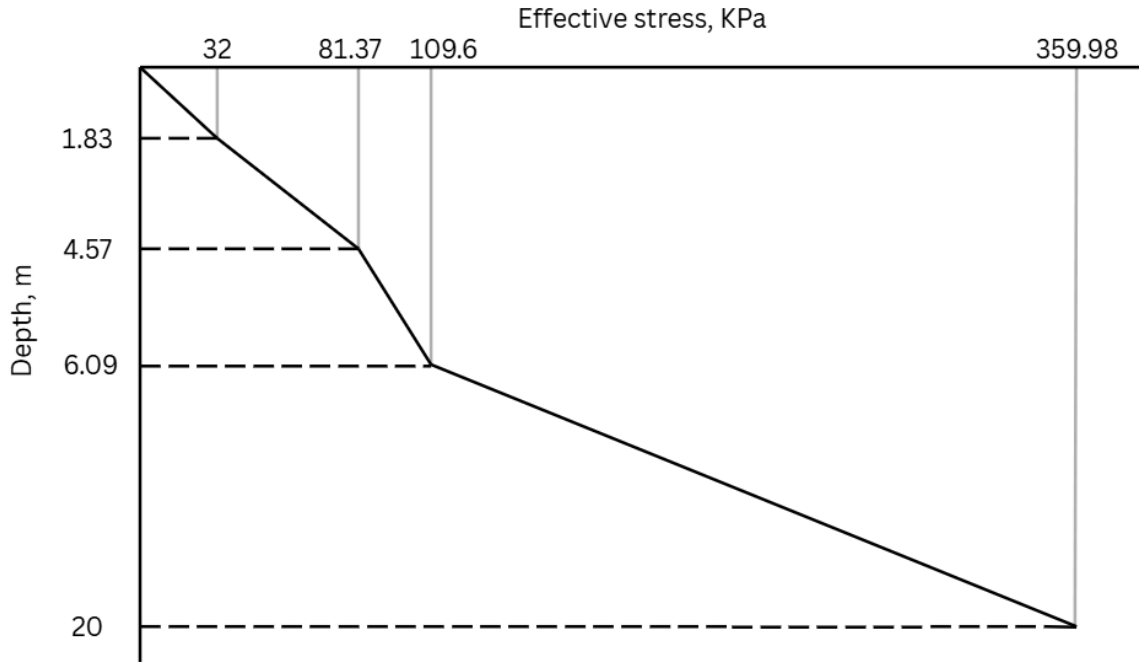


$$Q_u = Q_s + Q_p \quad (27)$$

Calculation: for unsaturated zone

Let's assume:  $D = 0.5 \text{ m}$     $L = 6 \text{ m}$     $n1 = 3$     $n2 = 2$     $d = 2.5 \text{ m}$

$$L_g = (3 - 1) * 2.5 + 1 = 6 \quad B_g = (2 - 1) * 2.5 + 1 = 3.5 \quad A_p = \frac{\pi D^2}{4} = 0.196$$



**Figure 4.4.4.1.** Effective vertical stress diagram

$$Q_p = A_p * [(c' + (u_a - u_w) \tan \phi_b) * N_c + \sigma_v' * N_q + 0.5 * \gamma * N_\gamma]$$

$$Q_s = [c_a' + \beta * \sigma_z' + (u_a - u_w) s^k \tan \phi'] \pi d L$$

$$k = -0.0016 * (PI)^2 + 0.0975 * (PI) + 1$$

$$Q_p = 0.196 * [0 + 30 * \tan 35 * 46.12 + 95.49 * 33.03 + 0.5 * 18.5 * 0.3 * 37.152]$$

$$= 848.1 \text{ kN}$$

$$k = -0.0016 * (0.05)^2 + 0.0975 * (0.05) + 1 = 1.004871$$

$$Q_s = [0 + 0.50 * 95.49 + 30 * 0.8^{1.004871} \tan 35] * \pi * 2.5 * 6 = 323.68 \text{ kN}$$

$$Q_u = 848.1 + 323.68 = 1171.8 \text{ kN}$$

$$Q_{all} = \frac{1171.8}{1.5} = 781.2 \text{ kN for a single pile}$$

**Table 4.4.4.1** Bearing capacity calculation for a single pile.

| D/L  | 6      | 7      | 10     | 15     | 16     | 17     | 18     | 19     | 20     |
|------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 0,3  | 624,3  | 1500,8 | 1536,9 | 1906,5 | 1957,3 | 2000,4 | 2035,8 | 2063,5 | 2083,5 |
| 0,4  | 862,4  | 2072,5 | 1708,2 | 2077,8 | 2128,6 | 2171,7 | 2207,1 | 2234,8 | 2254,8 |
| 0,45 | 1007,9 | 2419,5 | 1812   | 2181,5 | 2232,3 | 2275,4 | 2310,8 | 2338,5 | 2358,6 |
| 0,5  | 1171,8 | 2808,8 | 1928,2 | 2297,7 | 2348,5 | 2391,6 | 2427   | 2454,7 | 2474,8 |

#### 4.4.5 Group Piles

The foundation system architecture should be designed with regards to both the technical performance and cost-efficiency. In the case of the present project site where the underlying soil material is silty sand and gravelly sand (SM - SM - SW) with a thin layer of silty clay (CL - ML) at deep level, individual piles cannot be used safely to support the column loads on its own. Rather than making each pile too large in terms of diameter or length, it is simpler and cheaper to stack piles together. The piling up of piles enhances the collective load bearing capacity besides aiding in minimizing the settlement through mobilization of the supporting mass of soil.

It is important to have space between piles, so that stressing areas between piles are not over-lapped against one another, as this may decrease bearing capacity and may tend to accelerate settlement. As Das and Sivakugan (2019) state, the friction piles in fine soils

(granular) normally require at least 2.5D (D is the diameter of the pile) between their centers. Since the soils at the site are largely granular (silty sand), this is the minimum spacing requirement that can be used to design it.

Pile group efficiency ( $\eta$ ), is a ratio of the final load capacity of a pile group to the total product of the individual pile capacities and can be used to assess the behavior of a pile group. Generally, two cases are taken into consideration:

1.  $\eta < 1$  – *acting as a block*
2.  $\eta > 1$  – *acting individually*

This efficiency test can be used to find out which effects of groups or individual pile behavior should be used to design.

$$\eta = \left[ \frac{2(n_1+n_2-2)d+4D}{pn_1n_2} \right] \quad (28)$$

Load bearing capacity of group piles are calculated in a following way:

$$\eta < 1 \rightarrow Q_{g(u)} = \eta \sum Q_u \quad (29)$$

$$\eta \geq 1 \rightarrow Q_{g(u)} = \sum Q_u \quad (30)$$

$$\eta = \left[ \frac{2(3+3-2)2.5+4*1}{3.14*3*3} \right] = 0.849 < 1 \rightarrow \text{acting as a block}$$

$$Q_{pg} = 6 * 3.5 * 0.196 * [0 + 30 * \tan 35 * 46.12 + 95.49 * 33.03 + 0.5 * 18.5 * 0.3 * 37.152] \\ = 17810.1 \text{ kN}$$

$$Q_{sg} = 2 * (6 + 3.5) * [0 + 0.50 * 95.49 + 30 * 0.8^{1.004871} \tan 35] * \pi * 2.5 * 6 \\ = 6149.92 \text{ kN}$$

$$Q_{ug} = 17810.1 + 6149.92 = 23960.02 \text{ kN}$$

$$Q_{g(all)} = \frac{23960.02}{1.5} = 15973.35 \text{ kN}$$

In these calculations the pile was located in the unsaturated zone, so the unsaturated soil mechanics principles are applied. But as it can be seen, in unsaturated soils, the pile foundation shows comparably low bearing capacity. For now, we will take the length of a single pile as 18 meters and the diameter as 0.5 meters without changing the number of piles, and using these dimensions calculate the bearing capacity for this group of piles.

$$Q_{pg} = 6 * 3.5 * 0.5 * 100 * 96 * \tan 33 = 65460.3 \text{ kN}$$

$$Q_{sg} = 2 * (6 + 3.5) * 1815.528 = 34495 \text{ kN}$$

$$Q_{ug} = 65460.3 + 34495 = 99955.3 \text{ kN}$$

$$Q_{g(all)} = \frac{99955.3}{1.5} = 66636.9 \text{ kN}$$

So when the soil is saturated and with a longer pile, the bearing capacity of the pile increases significantly. Next, we will check these dimensions with the settlement calculation to see whether the value exceeds the requirement or not.

**Table 4.4.5.1.** Bearing capacity of a group of piles.

|          | D, m | d, m | n1 | n2 | Bg  | Lg  | Qall, kN | Qdesign, kN |
|----------|------|------|----|----|-----|-----|----------|-------------|
| Exterior | 0,4  | 1,2  | 2  | 3  | 2,9 | 1,7 | 16849,92 | 4253,64     |
| Interior | 0,5  | 1,5  | 3  | 3  | 3,5 | 3,5 | 25434,97 | 6525,22     |
| Edge     | 0,4  | 1,2  | 3  | 3  | 2,9 | 2,9 | 10221,75 | 2622,34     |

#### 4.4.6 Settlement for pile foundation

To begin with, the settlement for a single pile will be calculated using the formula:

$$S_e = S_{e1} + S_{e2} + S_{e3} \quad (31)$$

Where,

$S_{e1}$  – elastic settlement of the pile

$S_{e2}$  – settlement at the end of the pile (created by load)

$S_{e3}$  – settlement along the pile

$$S_{e1} = \frac{(Q_{wp} + \xi Q_{ws}) * L}{A_p * E_p} \quad (32)$$

Where,

$Q_{wp}$  – load under the working condition

$Q_{ws}$  – load by friction under the working condition

$A_p$  – cross – sectional area of the pile

$E_p$  – modulus of elasticity of pile =  $21 * 10^6$  ksi

$$Q_{wp} = \frac{Q_p}{FoS} = \frac{611.514}{1.5} = 407.675$$

$$Q_{ws} = \frac{Q_s}{FoS} = \frac{1815.528}{1.5} = 1210.352$$

$$S_{e2} = \frac{q_{wp} * D}{E_s} * (1 - \mu_s^2) * I_{wp} \quad (33)$$

Where,

$q_{wp}$  – load per unit area

$E_s$  – modulus of elasticity of soil

$D$  – diameter of the pile

$\mu_s$  – Poisson's ratio for soil

$I_{wp}$  – influence factor = 0.85

$$q_{wp} = \frac{Q_{wp}}{A_p} = \frac{407.675}{0.1963} = 2076.796$$

$$S_{e3} = \left(\frac{Q_{ws}}{pL}\right) * \left(\frac{D}{E_s}\right) * (1 - \mu_s^2) * I_{ws} \quad (34)$$

Where,

$p$  – perimeter of the pile

$L$  – length of the pile

$I_{ws}$  – influence factor

$$I_{ws} = 2 + 0.37 * \sqrt{\frac{L}{D}} = 2 + 0.37 * \sqrt{\frac{18}{0.5}} = 4.22$$

$$S_{e1} = \frac{(407.675 + 0.5 * 1210.352) * 18}{0.1963 * 21 * 10^6} = 0.00442 \text{ m} = 4.42 \text{ mm}$$

$$S_{e2} = \frac{2076.796 * 18}{109.2 * 10^6} * (1 - 0.3^2) * 0.85 = 0.000265 \text{ m} = 0.265 \text{ mm}$$

$$S_{e3} = \left( \frac{1210.352}{1.57 * 18} \right) * \left( \frac{0.5}{109.2 * 10^6} \right) * (1 - 0.3^2) * 4.22 = 7.53 * 10^{-7} \text{ m} \approx 0 \text{ mm}$$

$$S_e = 4.42 + 0.265 + 0 = 4.685 \text{ mm}$$

So for a single pile with the length of 18 meters and diameter of 0.5 meters the settlement is 4.685 mm, which is a really satisfying result. In the following step, we will use this calculation to find the settlement of the group of piles and we will compare results of all foundations, to find the most suitable one to our project.

$$S_{g(e)} = \sqrt{\frac{B_g}{D}} * S_e \quad (35)$$

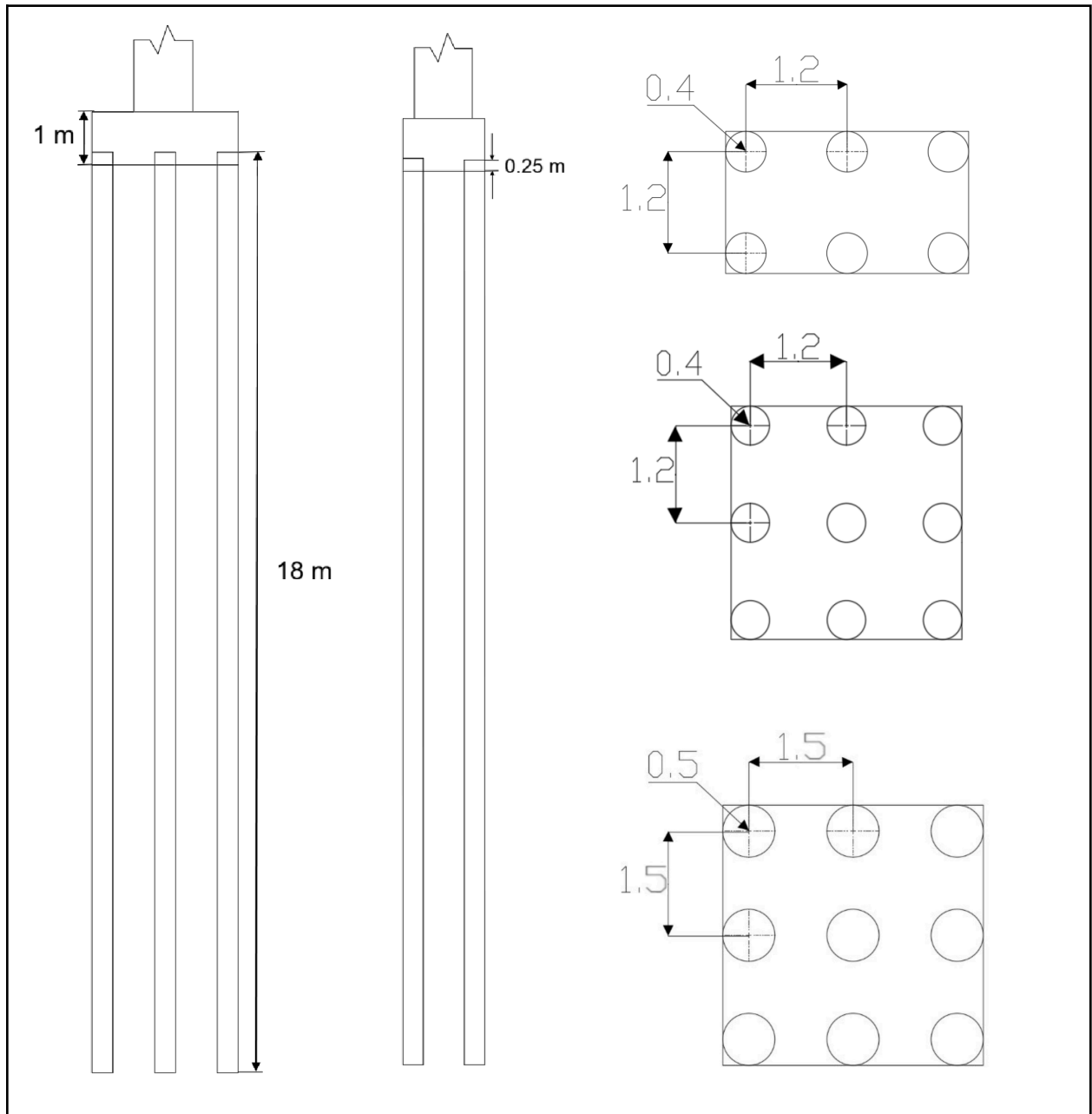
$$S_{g(e)} = \sqrt{\frac{3.5}{0.5}} * 4.685 \text{ mm} = 12.4 \text{ mm}$$

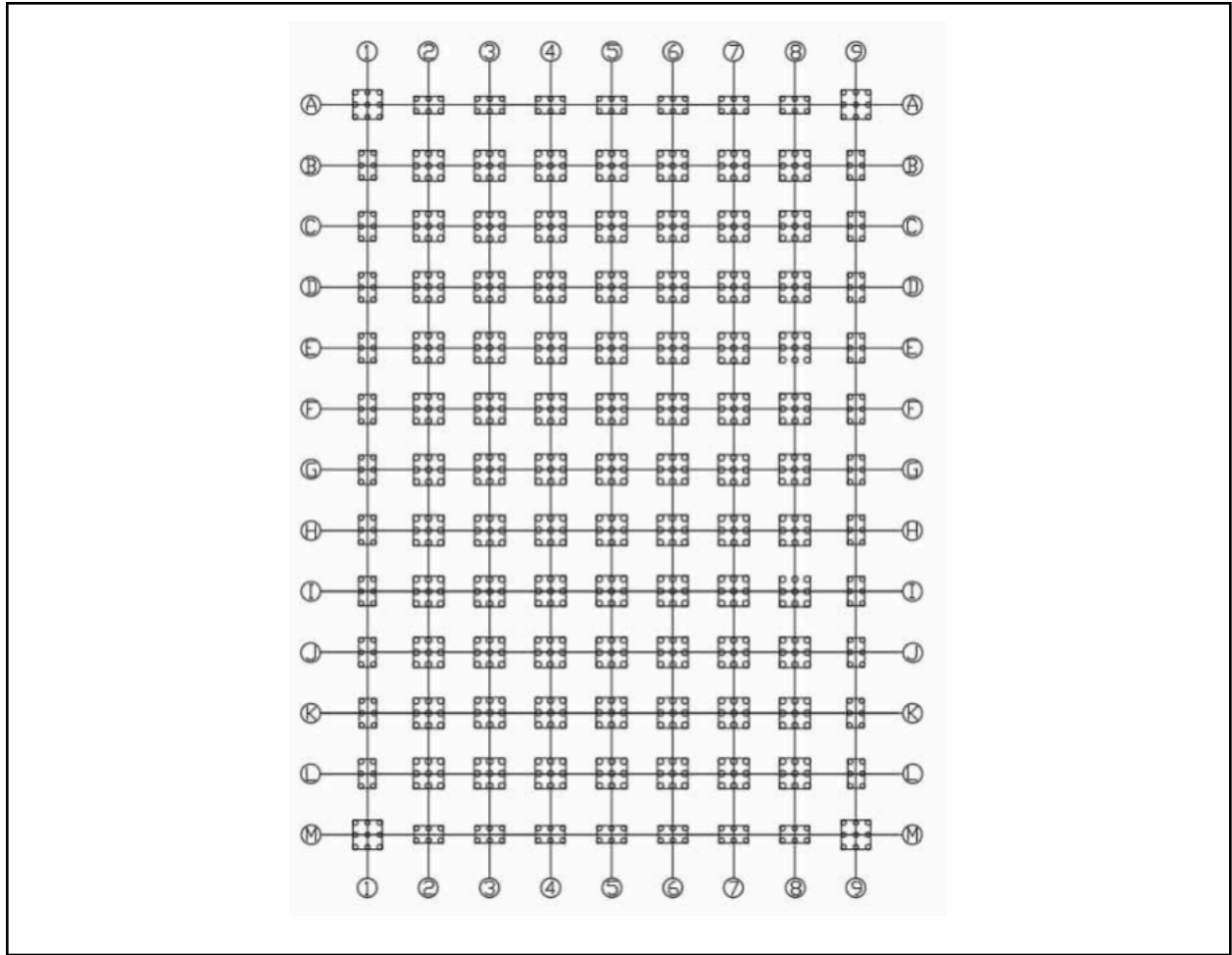
**Table 4.4.6.1** Settlement of a group of piles.

|          | Qq, kN   | Lg,m | Bg,m | q, kN/m <sup>2</sup> | $S_{g(e)}$ , m |
|----------|----------|------|------|----------------------|----------------|
| Exterior | 16849,92 | 1,7  | 2,9  | 3417,83              | 0.011          |
| Interior | 25434,97 | 3,5  | 3,5  | 2076,32              | 0.012          |
| Edge     | 10221,75 | 2,9  | 2,9  | 1215,43              | 0.011          |

As it can be seen from the table above, even in different positions, the settlement of a group of piles does not exceed 25 mm. So far, among the pad, mat and pile foundation, the latest one shows good results as a group of piles both in bearing capacity and settlement calculations.

Therefore, our final choice will be the pile foundation that shown in Figure 4.4.6.1:





**Figure 4.4.6.1** Pile foundation design

#### 4.4.7 Lateral bearing capacity

The lateral bearing capacity of the pile foundation was assessed by the Broms method for cohesionless soils assuming the pile to be fixed at the head and formed in silty sand having a friction angle of  $33^\circ$  and a unit weight of  $18 \text{ kN/m}^3$ . The study took into consideration pile shape and rigidity having 0.5 m diameter, 18 m total embedded length, and  $21 \times 10^6 \text{ kPa}$  modulus of elasticity. The positioning of a factor of safety of 1.5 and the mobilization of passive earth-pressure resistance along the effective depth of the pile, which is the maximum horizontal load that can be safely supported without stressing the soil and causing excessive bending in the pile, leads to the lateral bearing capacity. This evaluation serves to provide a trustworthy estimate of the pile's resistance to horizontal forces from wind, seismic actions, or structural eccentricities



that would happen otherwise; thus, the lateral stability of the foundation system would be secured.

$$I = \frac{\pi D^4}{64} \quad (36)$$

$I$  – second moment of area for pile

$$I = \frac{\pi * 0.5^4}{64} = 0.003068 \text{ m}^4$$

$$\text{Flexural rigidity: } EI = 21 * 10^6 * 0.003068 = 6.44 * 10^7 \text{ Nm}^2$$

$$\text{Characteristic length (Winkler): } L_b = \left(\frac{4EI}{k}\right)^{1/4} = \left(\frac{4 * 6.44 * 10^7}{5 * 10^6}\right)^{1/4} = 2.68 \text{ m} \quad (37)$$

$$z_{mob} = \min(L, 3L_b) \Rightarrow 3L_b = 3 * 2.68 = 8.04 \text{ m} (< \text{total length}) \quad (38)$$

$$K_p = \tan^2(45 + \phi/2) = \tan^2(45 + 33/2) = 3.392 \quad (39)$$

$$H_u = \int_0^{z_{mob}} K_p \gamma z D dz = 0.5 * K_p * \gamma * D * z_{mob}^2 \quad (40)$$

$$H_u = 0.5 * 3.392 * 18 * 18 * 8.04^2 = 986000 \text{ N} = 986 \text{ kN}$$

$$H_{allow} = \frac{986}{1.5} = 657.3 \text{ kN}$$

## 4.5 Retaining wall design

### 4.5.1 Lateral earth pressure at rest:

To design a retaining wall, it is necessary to find the lateral earth pressure. Our hotel parking lot will be 3.5 meters below the surface. On Table 4.5.1.1 it can be seen that our parking lot is at the level of the first two soil layers: *silty sand with asphalt and mica*, and *silty sand with mica*, with the following values needed for calculations:

$$d = 0 - 1.8288 \text{ m} \text{ with } \gamma_1 = 17.5 \text{ kN/m}^3 \text{ and } \phi_1 = 35^\circ$$

$$d = 1.8288 - 4.572 \text{ m} \text{ with } \gamma_2 = 18.0 \text{ kN/m}^3 \text{ and } \phi_2 = 33^\circ$$

In order to calculate earth pressure at rest, first it is needed to find coefficient of Earth pressure at rest ( $K_0$ ) using the equation below:

$$K_0 = 1 - \sin(\phi^\circ) \quad (41)$$

**Table 4.5.1.1** Calculated values of  $K_0$

| Layer | Depth, m       | $K_0$  |
|-------|----------------|--------|
| 1     | 0 - 1.8288     | 0.4264 |
| 2     | 1.8288 - 4.572 | 0.4554 |

It is needed to calculate vertical effective stress using Equation 41:

$$\sigma'_v = d * \gamma$$

Where,

$d$  – thickness of the layer

$\gamma$  – bulk unit weight of the soil

**Table 4.5.1.2** Calculated values of  $\sigma'_v$

| Layer | Depth, m       | $\sigma'_v$ , kN/m <sup>2</sup> |
|-------|----------------|---------------------------------|
| 1     | 0 - 1.8288     | 32.03                           |
| 2     | 1.8288 - 4.572 | 39.06                           |

After that calculation of horizontal effective stress is needed, which can be found using Equation 42 below:

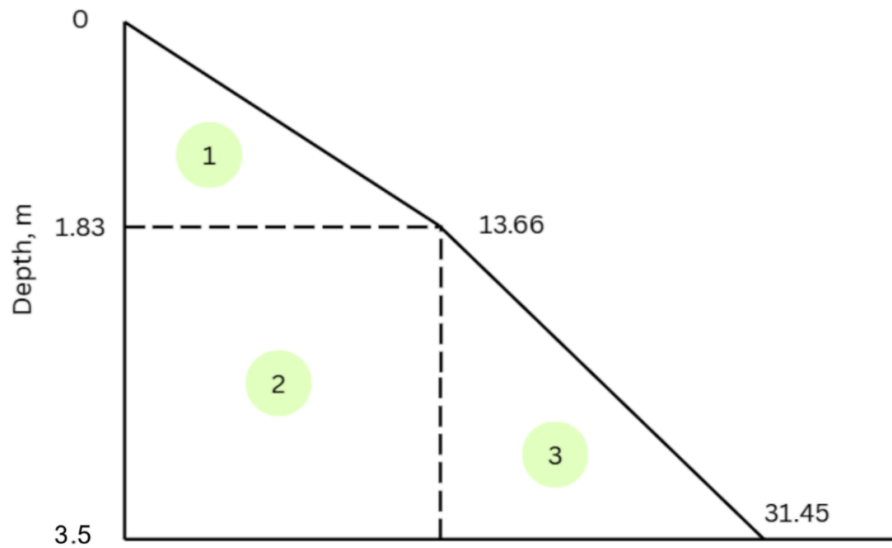
$$\sigma'_h = K_0 * \sigma'_v \quad (42)$$

**Table 4.5.1.3** Calculated values of  $\sigma'_h$

| Layer | Depth, m | $\sigma'_h$ , kN/m <sup>2</sup> |
|-------|----------|---------------------------------|
|-------|----------|---------------------------------|

|   |                |       |
|---|----------------|-------|
| 1 | 0 - 1.8288     | 13.66 |
| 2 | 1.8288 - 4.572 | 17.79 |

By calculating horizontal effective stress, an effective stress profile can be drawn (Figure 4.5.1.1).



**Figure 4.5.1.1** Effective stress profile

In order to find horizontal force that will affect the wall, it is necessary to find areas of the zones numbered on Figure 4.5.1.1.

**Table 4.5.1.4** Calculated values of  $P_0$

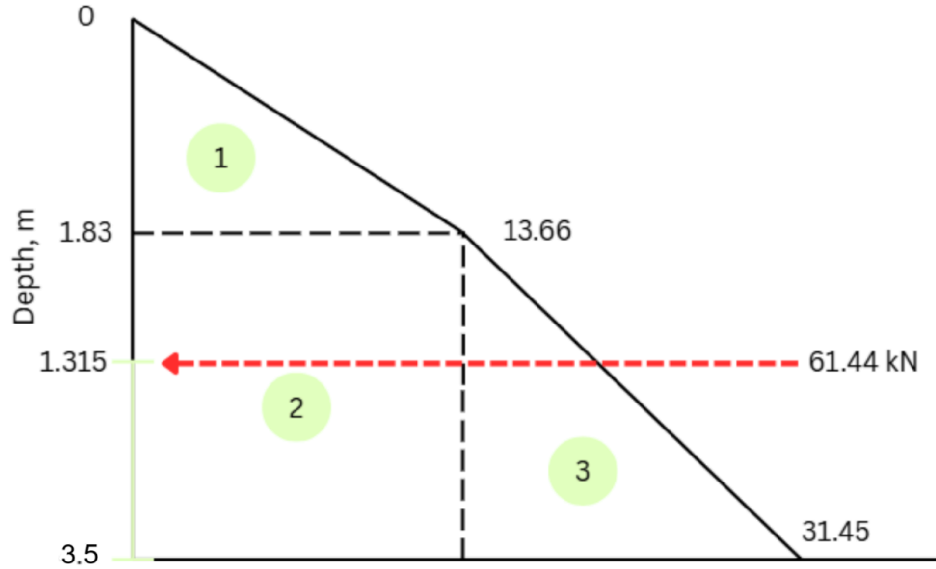
| Zone | Depth, m       | $P_0$ , kN |
|------|----------------|------------|
| 1    | 0 - 1.8288     | 12.5       |
| 2    | 1.8288 - 4.572 | 29.64      |
| 3    | 1.8288 - 4.572 | 19.3       |

In order to find centroid, it is needed to calculate overall  $P_0$

$$P_0 = 12.5 + 29.64 + 19.3 = 61.44 \text{ kN}$$

Centroid of the structure can be found using Equation 43:

$$\bar{z} = \frac{(z \cdot P_0 \cdot n)}{P_0} \quad (43)$$



**Figure 4.5.1.2** Location of the centroid

On Figure 4.5.1.2 the location of the point of action is shown at 1.315 meters from the bottom part.

#### 4.5.2 Rankine active and passive earth pressures

The retaining wall can be recessed behind the backfill so that the mass of soil is in an expansion state thus reducing the lateral pressure that applies to the wall with no change in the vertical overburden pressure. In that case, the soil reaches an active state and the coefficient of Rankine active earth pressure is given as:

$$K_a = \tan^2(45^\circ - \phi'/2) \quad (44)$$

And the lateral earth pressure acting on retaining wall when the wall moves toward the soil, so the soil reaches passive state, coefficient of which calculated using formula below:

$$K_p = \tan^2(45^\circ + \phi'/2) \quad (45)$$

The wall is located on sand layer, so the cohesion value is equal to 0, and the formula of Rankine active and passive earth pressures are calculated using these formulas:

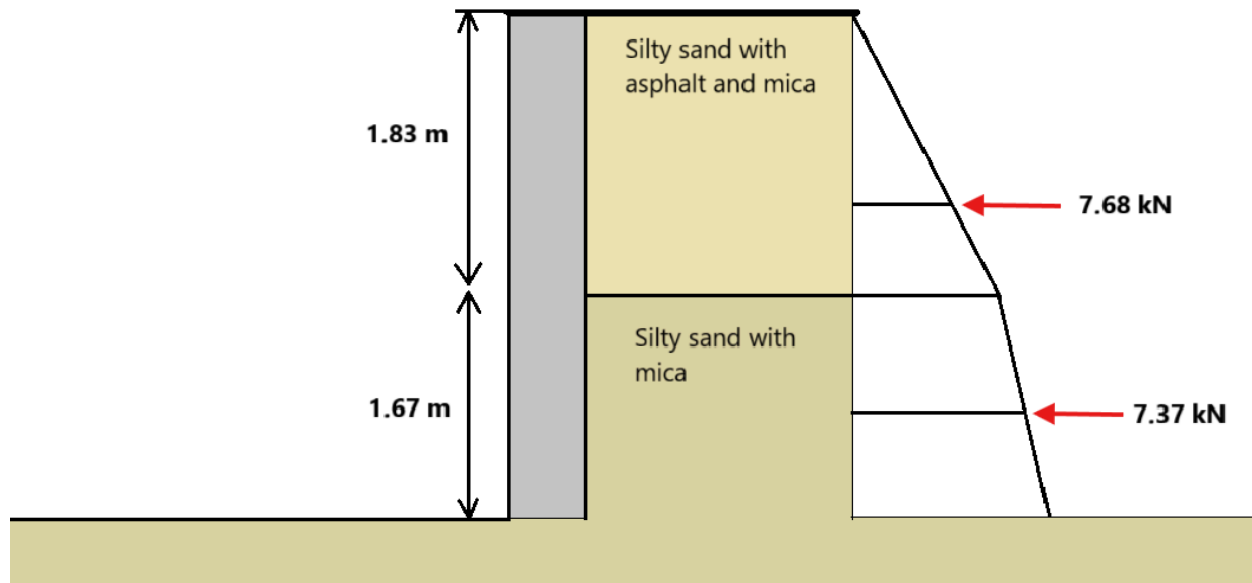
$$\sigma'_a = \sigma'_v K_a \quad (46)$$

$$\sigma'_p = \sigma'_v K_p \quad (47)$$

After the calculations of Rankine active and passive pressure coefficients and the pressures itself the values are the given on Table 4.5.2.1:

**Table 4.5.2.1** Rankine active pressure coefficient and pressure results

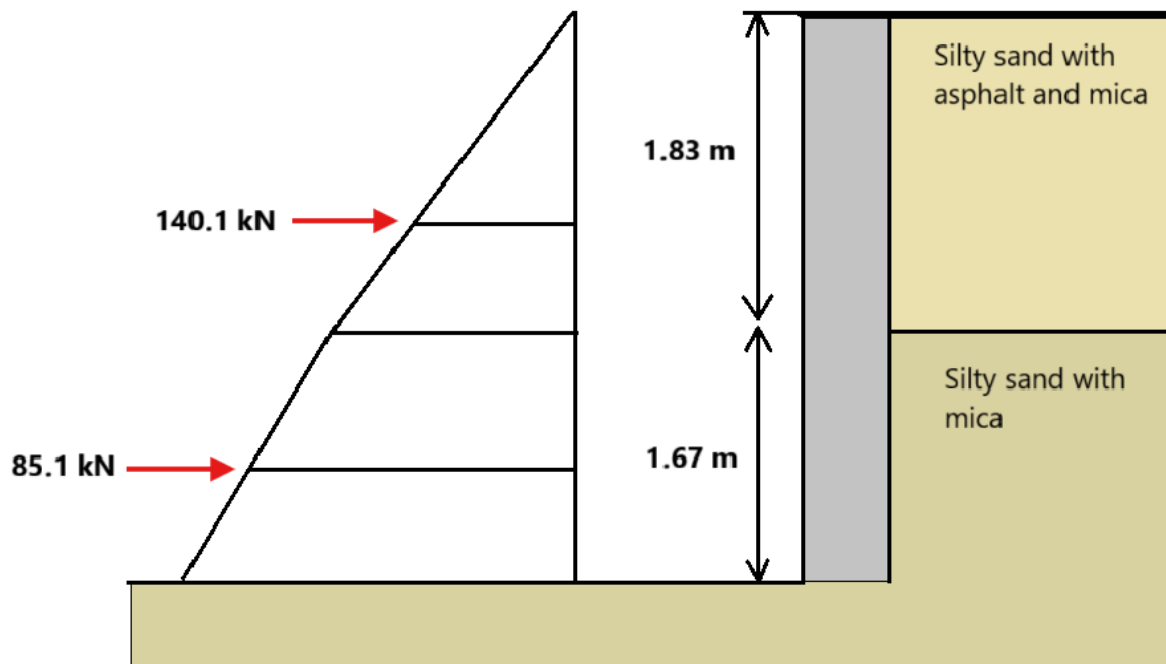
| Depth, m | $K_a$ | $\sigma'_v$ | $\sigma'_a$ |
|----------|-------|-------------|-------------|
| 0-1.83   | 0.27  | 32.03       | 8.65        |
| 1.83-3.5 | 0.29  | 39.06       | 11.33       |



**Figure 4.5.2.1** Rankine active lateral earth pressure

**Table 4.5.2.2** Rankine active and passive pressure values

| Depth, m | $\sigma'_v$ | $K_a$ | $\sigma'_a$ | Pa   | $K_p$ | $\sigma'_p$ | Pp    |
|----------|-------------|-------|-------------|------|-------|-------------|-------|
| 0        | 0           | 0.27  | 0           | 0    | 3.69  | 0           | 0     |
| 1.83+    | 32.03       | 0.27  | 8.65        | 7.68 | 3.69  | 132.4       | 140.1 |
| 1.83-    | 32.03       | 0.27  | 8.65        |      | 3.69  | 132.4       |       |
| 3.50     | 39.06       | 0.29  | 11.33       | 7.37 | 3.39  | 154.4       | 85.1  |



**Figure 4.5.2.2** Rankine passive lateral earth pressure

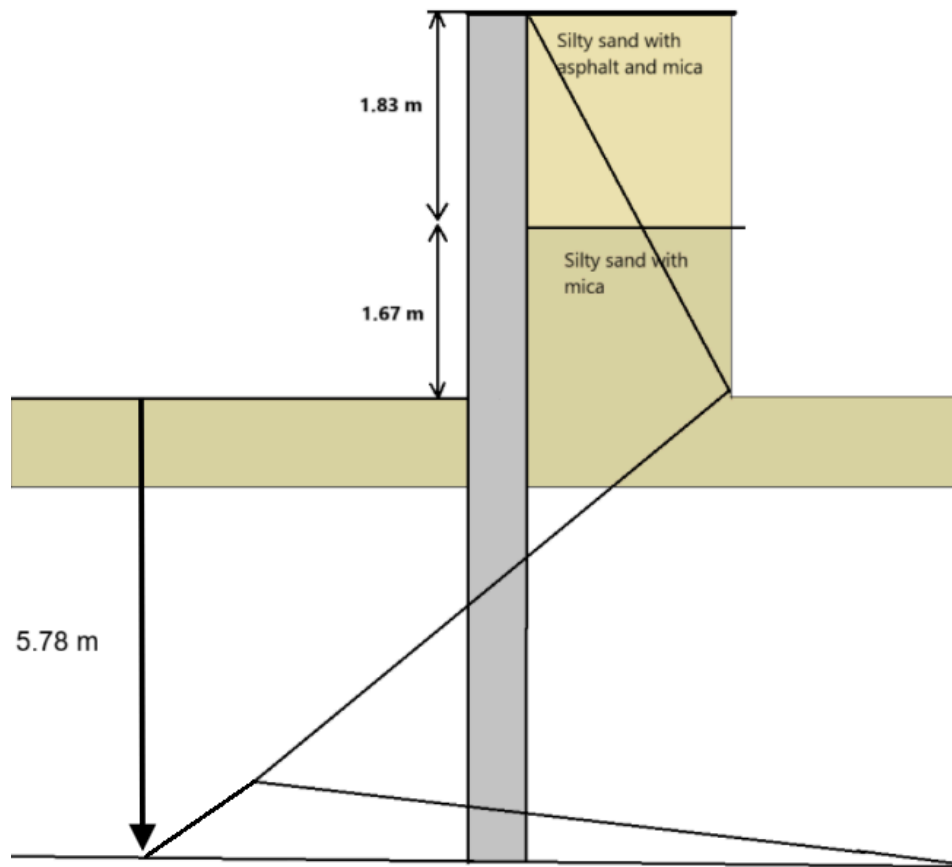
## 4.6 Diaphragm Retaining Wall

The retaining wall known as the diaphragm is the best solution to be used in this project due to the complicated environment and hydrology of the subsurface. Since the groundwater table is at about 7.9 m and the site is mostly made up of sand, which is a rigid and low-permeability system, a rigid system is urgently required thereby ensuring the site remains stable during the excavation. Diaphragm walls are better in resisting both active and passive earth pressures in addition to working well in sandy substrates where lateral deformation should be reduced to minimum. Their concrete panels that are continuously laid are also an effective cut-off wall which minimizes inflow during a deep excavation and consequently deems the construction safer. As such the diaphragm wall offers the best blend of strength, stiffness and hydraulic management needed in the particular site.

In order to design diaphragm retaining wall active and passive earth pressure coefficients, active and passive earth pressures, overturning and resisting moments are needed. Overturning and resisting moments calculated using formulas below:

$$M_A = P_a * \frac{5+d}{3} \quad (48)$$

$$M_A = \frac{1}{F} * 0.5 * P_p \quad (49)$$



**Figure 4.6.1** Retaining wall design

The next phase of work ought to be the re-evaluation of the pile design with the use of refined soil parameters and present loading factors. Further computations to re-calculate expected settlements are necessary to make sure that total and differential settlements are within reasonable levels. Further refinement of active and passive earth pressure assessment should be provided through the use of more detailed geotechnical data, which will increase the accuracy of the further evaluation of the lateral loads. Lastly, the design of the retaining wall will have to be re-evaluated, and the updated data on earth pressure and structural requirements should be implemented to ensure safety, stability, and compliance with the relevant standards.



## **4.7 Site Preparation and Excavation**

Site preparation, excavation, and retaining works constitute the initial and critical stages of construction for the proposed nine-storey hotel with plan dimensions of  $40 \times 60$  m. These works are designed to ensure structural safety, excavation stability, and compliance with geotechnical and environmental requirements.

### **4.7.1 Site Preparation**

Site preparation involves clearing the construction area from vegetation, debris, and any existing surface obstructions. The topsoil layer is removed and stockpiled for future landscaping purposes. Temporary site facilities, including fencing, access roads, material storage zones, and safety signage, are installed to ensure safe and organized construction operations.

Prior to excavation, all existing underground utilities are identified through site surveys. Necessary protective or relocation measures are implemented for water supply, sewerage, electrical, and communication networks. Surface drainage measures are arranged to prevent water accumulation and to maintain safe working conditions throughout the construction period.

### **4.7.2 Excavation Works**

Open excavation is **not applied** in this project. Excavation works are limited to localized foundation and underground structural elements and are carried out in a controlled manner to minimize soil disturbance.

The excavation is performed primarily using mechanical equipment, with manual excavation used where higher precision is required. Excavated soil is either reused for backfilling after completion of foundation works or transported to approved disposal sites. Continuous monitoring of excavation geometry and ground behavior is conducted to ensure compliance with design and safety requirements.

### **4.7.3 Retaining System Selection**

Due to the absence of open excavation, vertical retaining structures are required to ensure excavation stability. Based on the project conditions, a cantilever diaphragm retaining wall is selected as the excavation support system.

The hotel is founded on predominantly sandy soil extending to a depth of approximately 28 m. Sandy soils are prone to lateral deformation and instability, particularly in the presence of groundwater. The groundwater table is located at a depth of about 8 m, which means that excavation will intersect saturated soil layers.

#### **4.7.4 Cantilever Diaphragm Retaining Wall**

The cantilever diaphragm retaining wall is a reinforced concrete wall constructed in situ prior to excavation. It provides high stiffness and bending resistance, allowing effective control of horizontal soil movements during excavation. Compared to sheet pile walls, diaphragm walls offer superior deformation control, which is essential for a multi-storey hotel building with large plan dimensions.

In addition to structural stability, the diaphragm wall acts as a partial groundwater cut-off, significantly reducing water inflow into the excavation and limiting the need for extensive dewatering systems. This is particularly advantageous given the shallow groundwater level.

The project site is located in an area of low seismic activity, allowing the retaining system to be designed primarily for static earth pressures. This simplifies design while maintaining adequate safety margins.

The diaphragm wall can also serve as a permanent structural element, integrated into the basement or underground portions of the hotel, improving long-term performance and justifying the higher initial construction cost.

#### **4.8 Software Used for Geotechnical Analysis and Verification**

To ensure the accuracy and reliability of geotechnical calculations, specialized numerical and analytical software packages are used in this project. The primary software tools adopted are GEO5 and PLAXIS, which are applied for different but complementary purposes. The use of

multiple software platforms allows verification of results and increases confidence in the adopted design solutions.

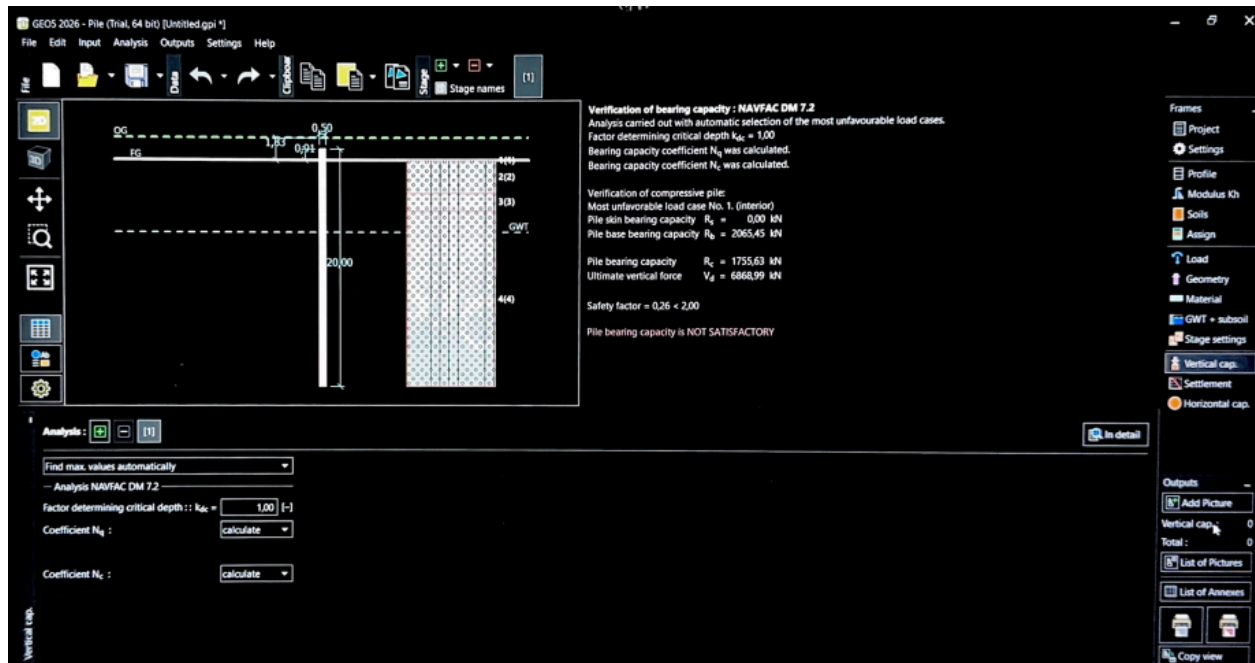
#### **4.8.1 GEO5 Software**

The GEO5 software package is used primarily for analytical geotechnical calculations based on established design standards. In this project, GEO5 is applied to evaluate the bearing capacity of the foundation soil, which is a critical parameter for foundation design.

PLAXIS does not directly calculate bearing capacity in accordance with conventional analytical methods; therefore, bearing capacity must be determined using alternative software or hand calculations. GEO5 provides a reliable solution for this task by implementing recognized bearing capacity theories and design approaches, such as those based on limit state methods.

Using GEO5, the bearing capacity is calculated considering soil parameters, foundation geometry, and loading conditions. The results obtained from GEO5 serve as the basis for determining allowable stresses and for preliminary sizing of the foundation system.

Our capstone project needs both GEO5 and PLAXIS to function as essential components of their design needs. The analysis will start with GEO5 which will establish baseline results for comparison with building codes (such as NYCBC 2022) while assessing the initial size requirements for pile groups and retaining walls. Advanced numerical modeling will use PLAXIS as its main tool. Traditional analytical formulas provide GEO5 with a "sanity check" function which enables users to validate their results, while PLAXIS simulates the complex interactions between soil and structures that occur in saturated sandy layers which exist below the groundwater table. The design process requires these tools to be used in succession because this method produces a design that meets both computational standards and essential geotechnical requirements.



**Figure 4.8.1.1** Bearing capacity calculation for a single pile in GEO5

The results from the initial GEO5 single pile analysis were deemed unsatisfactory because the calculated capacity could not safely support the massive structural loads from the 9-story section of the hotel. The main reasons for this situation occurred because the 9-story building interior columns produced point loads that reached 6868.99 kN, which exceeded the maximum load capacity that a single 0.5m diameter pile could support. The presence of saturated silty sand layers with low blow counts  $(N1)_{60} < 15$  created soil conditions that raised concerns about excessive settlement and potential strength loss. A single pile foundation system would exceed settlement limits established by the NYCBC according to preliminary evaluation results.

To improve these results in the next stages of the capstone the design will use pile groups instead of single piles because this approach will help distribute heavy column loads across more soil volume. The "group effect" will be modeled using PLAXIS, which creates accurate results for how closely spaced piles interact. This model will improve on the analytical methods that GEO5 uses.

Pile skin bearing capacity  $R_s = 228,22 \text{ kN}$   
Pile base bearing capacity  $R_b = 1998,80 \text{ kN}$

Pile bearing capacity  $R_c = 2227,02 \text{ kN}$   
Ultimate vertical force  $V_d = 1001,97 \text{ kN}$

Safety factor =  $2,22 > 2,00$

Pile bearing capacity is SATISFACTORY

**Exterior group of pile**

Pile skin bearing capacity  $R_s = 146,40 \text{ kN}$   
Pile base bearing capacity  $R_b = 1279,23 \text{ kN}$

Pile bearing capacity  $R_c = 1425,64 \text{ kN}$   
Ultimate vertical force  $V_d = 712,53 \text{ kN}$

Safety factor =  $2,00 > 2,00$

Pile bearing capacity is SATISFACTORY

**Interior group of pile**

Pile skin bearing capacity  $R_s = 146,40 \text{ kN}$   
Pile base bearing capacity  $R_b = 1279,23 \text{ kN}$

Pile bearing capacity  $R_c = 1425,64 \text{ kN}$   
Ultimate vertical force  $V_d = 491,81 \text{ kN}$

Safety factor =  $2,90 > 2,00$

Pile bearing capacity is SATISFACTORY

**Edge group of pile**

---

**Figure 4.8.1.2** GEO5 bearing capacity and safety factor results for pile group

In the Figure 4.8.1.2 the information on the pile group was given and we checked the difference between our hand calculation and the software results. In GEO5, our design showed satisfactory results and the bearing capacity was high enough to support our building. In the following table the comparison of the hand calculation and software was summarized and presented in a more structured way.

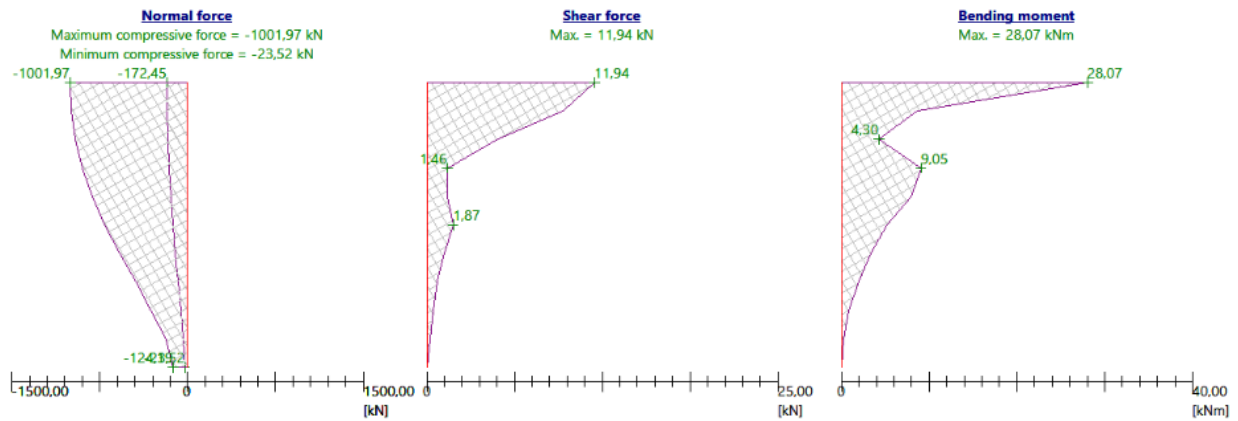


Figure 4.8.1.3 Forces on interior group of pile

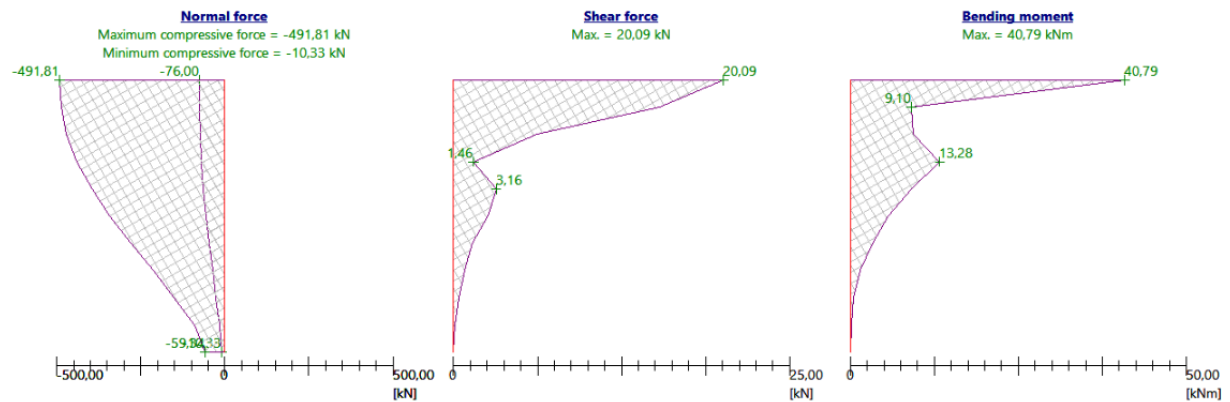
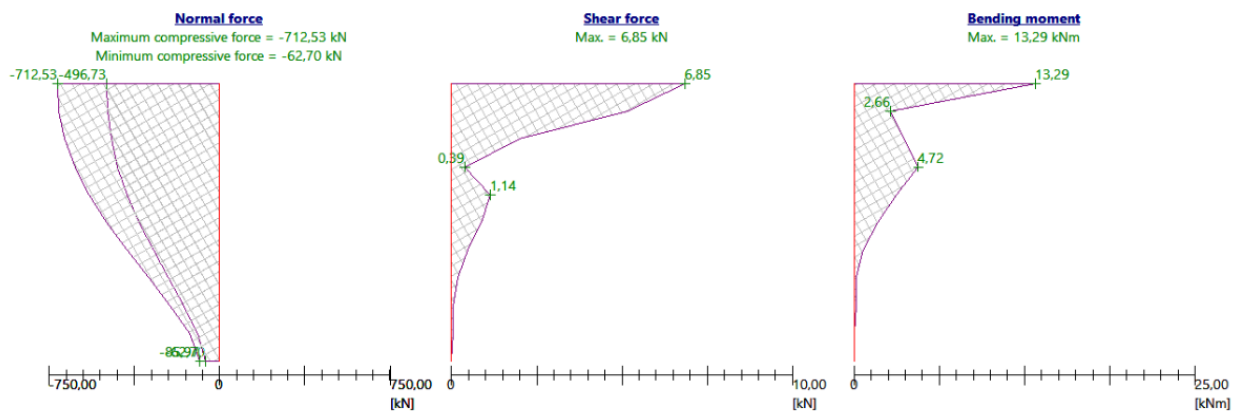


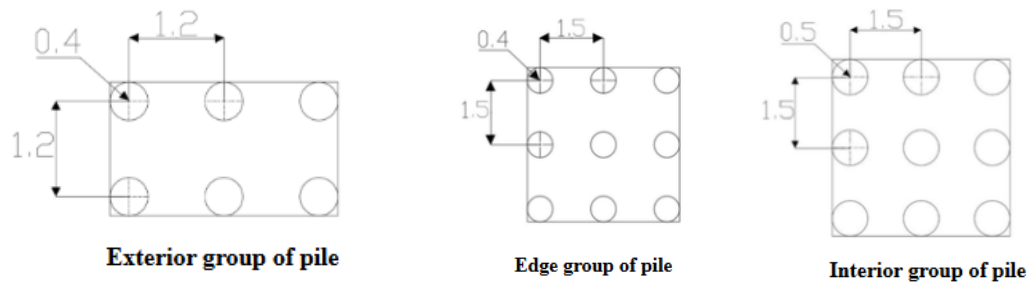
Figure 4.8.1.4 Forces on edge group of pile



**Figure 4.8.1.4** Forces on exterior group of pile

**Table 4.8.1** Comparison of bearing capacity (hand calculations and GEO5 software)

|                      | Interior         |               | Exterior         |               | Edge             |               |
|----------------------|------------------|---------------|------------------|---------------|------------------|---------------|
|                      | Hand calculation | Software Geo5 | Hand calculation | Software Geo5 | Hand calculation | Software Geo5 |
| Qu, kN (single pile) | 2207.10          | 2227.02       | 2427.00          | 1425.64       | 2207.10          | 1425.64       |
| Qu, kN (pile group)  | 25434.97         | 14564.71      | 16849.92         | 8553.84       | 10221.75         | 9326.53       |
| Qall, kN             | 16956.65         | 6560.68       | 11233.28         | 4276.92       | 6814.50          | 3215.06       |
| Qdesign, kN          | 6525.22          | 6525.22       | 4253.64          | 4253.64       | 2622.34          | 2622.34       |
| FS                   | 1.50             | 2.22          | 1.50             | 2.00          | 1.50             | 2.90          |



**Figure 4.8.1.3** Group of pile design for exterior, interior and edge walls

In Figure 4.8.1.2 the final design choice for the group of piles is presented. The design meets all requirements and in the following steps we will calculate the settlement of these pile groups using Plaxis software.

#### 4.8.2 PLAXIS Software

PLAXIS is employed for advanced numerical modeling using the finite element method. In this project, PLAXIS is used to analyze soil–structure interaction, deformation behavior, and stress distribution in the ground and structural elements.

PLAXIS allows detailed simulation of excavation stages, retaining wall performance, groundwater conditions, and construction sequences. It is particularly useful for evaluating displacements, settlements, and stability of the diaphragm retaining wall and the surrounding soil mass.

However, PLAXIS is not intended for direct calculation of bearing capacity according to standard analytical formulations. Instead, it is used to validate the overall behavior of the foundation system and to confirm that stresses and deformations remain within acceptable limits.

#### **4.8.3 Combined Use of GEO5 and PLAXIS**

The combined application of GEO5 and PLAXIS ensures a comprehensive geotechnical assessment. GEO5 is used to calculate bearing capacity, while PLAXIS is used to verify the results through numerical modeling and to assess deformation and stability under realistic construction conditions.

This integrated approach improves the reliability of the design, reduces uncertainties, and ensures that the adopted foundation and retaining wall systems satisfy both analytical design criteria and numerical performance requirements.

### **4.9 Settlement Analysis and Verification**

Settlement control is a critical aspect of foundation design for the proposed nine-storey hotel building. Excessive total or differential settlements can adversely affect structural performance and serviceability. In this project, settlement evaluation is carried out using GEO5 software, which allows precise analytical calculations in accordance with recognized geotechnical design standards.

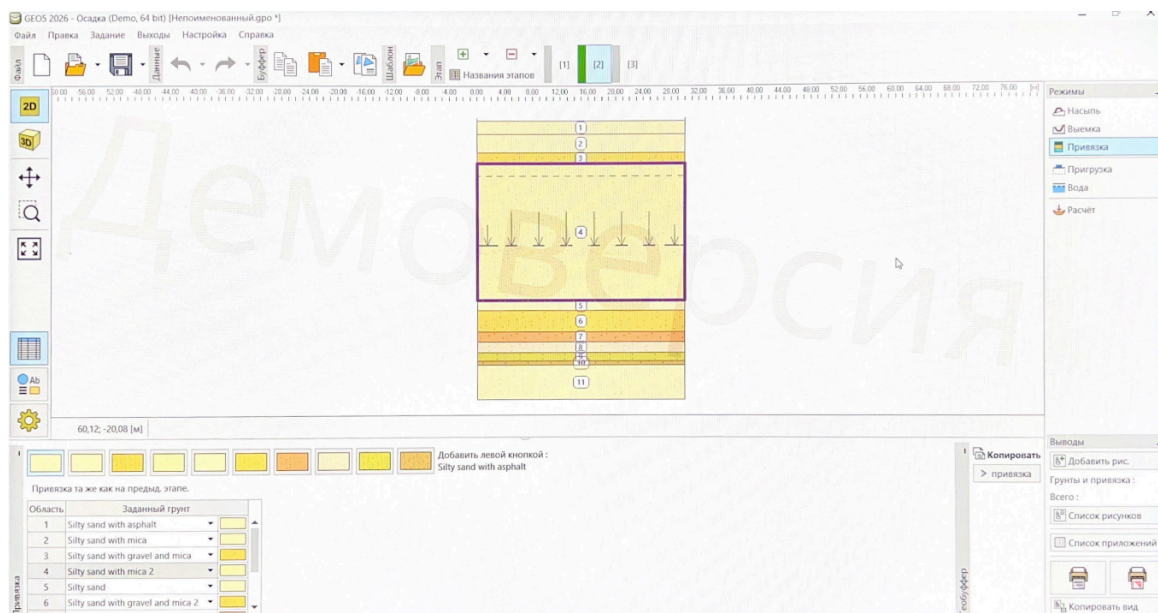
#### **4.9.1 Settlement Calculation Using GEO5**

The settlement of the hotel foundation is calculated based on soil parameters, foundation geometry, and applied loads using GEO5. The analysis considers the stress distribution beneath



the foundation and the deformation characteristics of the sandy soil profile. Since the soil is predominantly sand, settlements are primarily immediate and elastic settlements, while long-term consolidation effects are considered negligible since our soil type is mostly sand.

The results obtained in GEO5 were checked against expected behavior, and the calculated settlements were found to be within acceptable limits for a multi-storey hotel structure. This confirms the suitability of the foundation design under serviceability limit state conditions.



**Figure 4.9.1.1** Creating soil profile

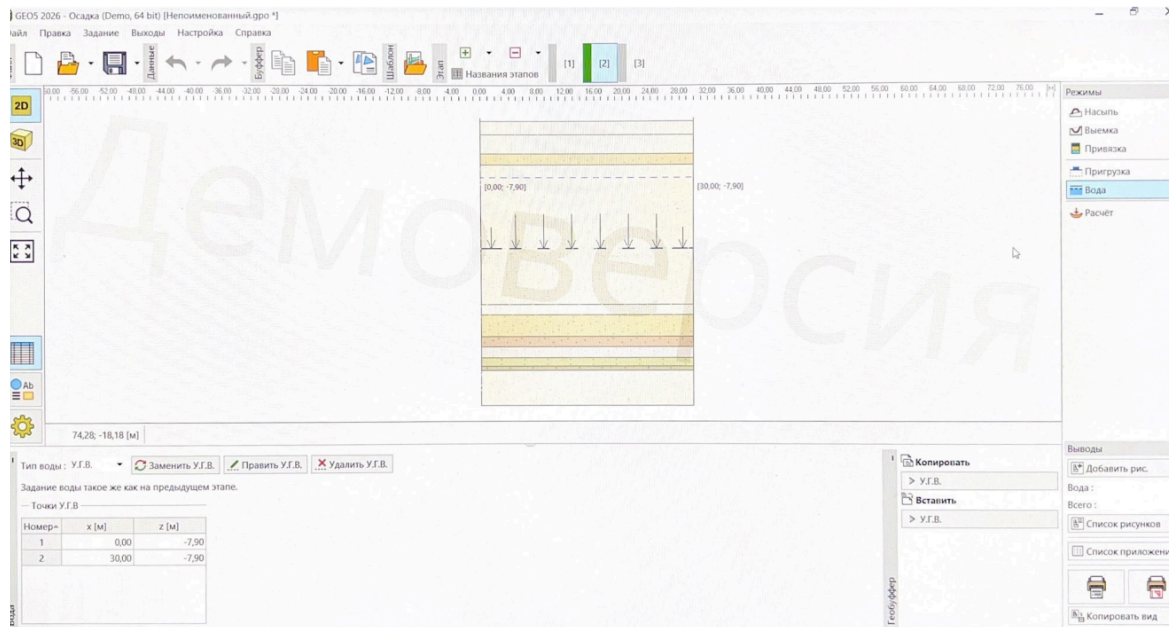


Figure 4.9.1.2 Assigning groundwater table

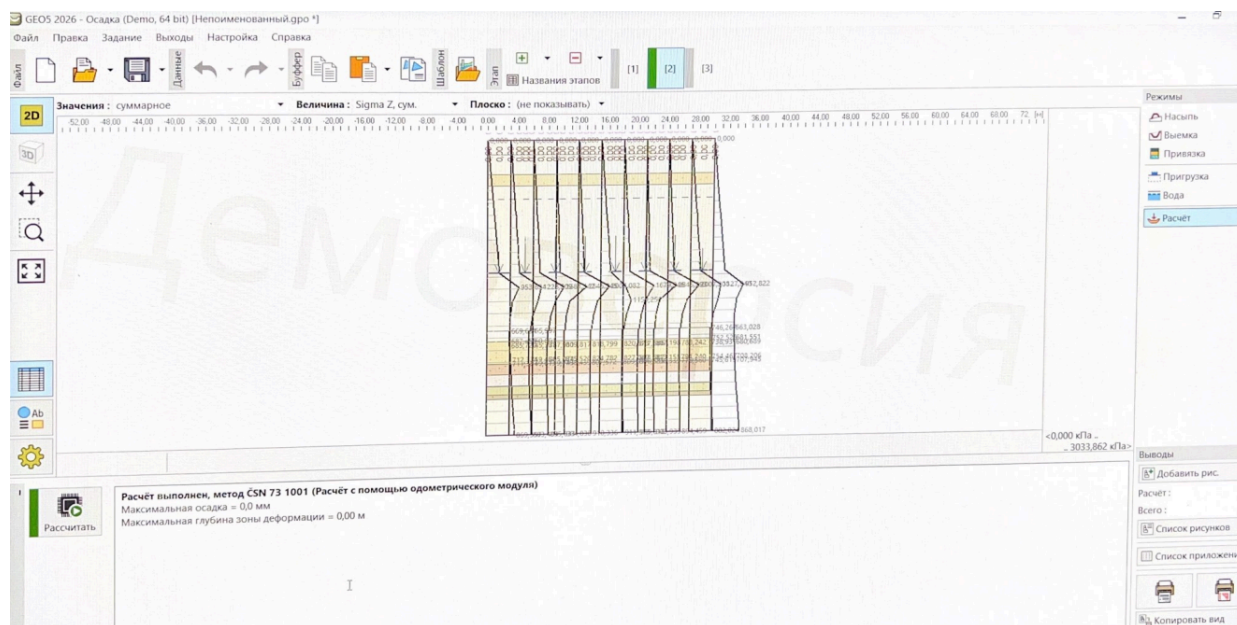


Figure 4.9.1.3 Running the settlement analysis

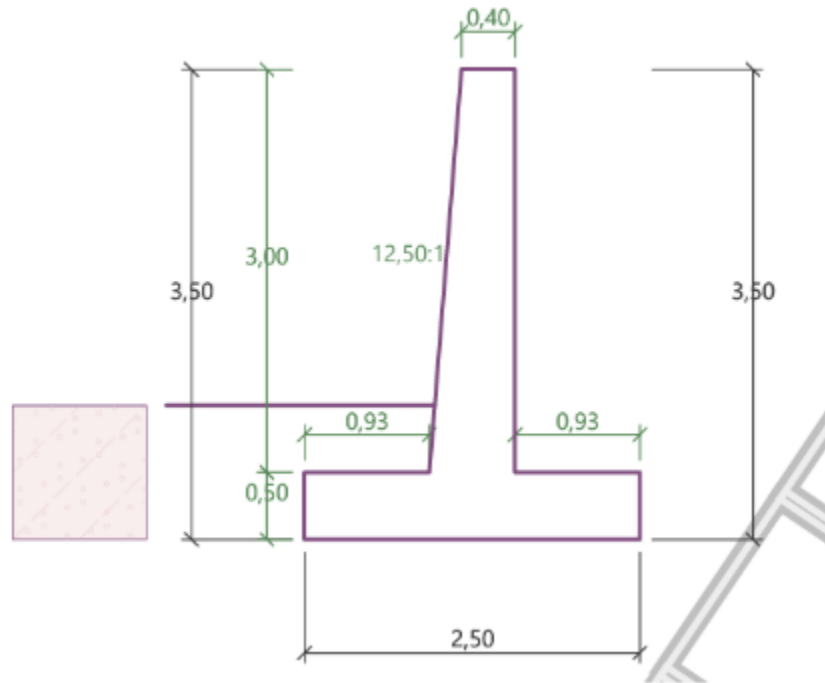
The settlement value is 0.005 m which is almost the same as the calculated one 0.011m. Since the results are not exactly the same, analysis of software will be done again, by rechecking all the assigned values within the software.

| <b>Interior group of pile</b>                      |                               |
|----------------------------------------------------|-------------------------------|
| Group settlement factor                            | $g_f = 2,83$                  |
| Load at the onset of mobilization of skin friction | $R_{yu} = 2100,83 \text{ kN}$ |
| The settlement for the force $R_{yu}$              | $s_y = 5,4 \text{ mm}$        |
| Total resistance                                   | $R_c = 2372,11 \text{ kN}$    |
| Maximum settlement                                 | $s_{lim} = 25,0 \text{ mm}$   |
| <b>Exterior group of pile</b>                      |                               |
| Group settlement factor                            | $g_f = 2,53$                  |
| Load at the onset of mobilization of skin friction | $R_{yu} = 2100,83 \text{ kN}$ |
| The settlement for the force $R_{yu}$              | $s_y = 4,9 \text{ mm}$        |
| Total resistance                                   | $R_c = 2412,87 \text{ kN}$    |
| Maximum settlement                                 | $s_{lim} = 25,0 \text{ mm}$   |
| <b>Edge group of pile</b>                          |                               |
| Group settlement factor                            | $g_f = 2,83$                  |
| Load at the onset of mobilization of skin friction | $R_{yu} = 1341,53 \text{ kN}$ |
| The settlement for the force $R_{yu}$              | $s_y = 3,7 \text{ mm}$        |
| Total resistance                                   | $R_c = 1587,96 \text{ kN}$    |
| Maximum settlement                                 | $s_{lim} = 25,0 \text{ mm}$   |

**Figure 4.9.1.4** Settlement results for pile groups

Here are the results of settlement using the GEO5 software. So we had a limit of 25 mm of settlement in our project and as it can be seen from this figure, for all pile groups the settlement doesn't exceed the allowed amount and rather the results are much smaller than when we did hand calculations. So far from GEO5 software, we found the bearing capacity values and the factor of safety. Then we checked the settlement and for now all results are satisfactory.

#### 4.10 Retaining wall design

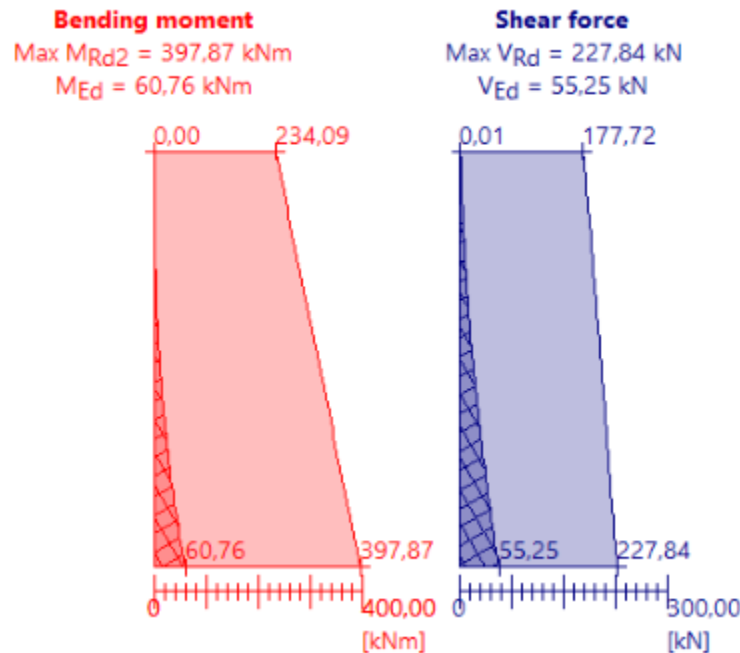


**Figure 4.10.1** Retaining wall design in GEO5

GEO5 is very popular in the analysis and design of retaining walls due to its ability to support both geotechnical as well as structural verification in a single platform. Under retaining wall analysis GEO5 enables its users to model the soil layers, groundwater conditions, material properties as well as the wall geometry with accuracy. The software does the calculation of earth pressures (active, passive, and at-rest), surcharge loads, and water pressure using pre-assigned design standards (e.g., Eurocode) automatically.

To analyze the stability, GEO5 overturning, sliding, and bearing capacity are checked through force comparison of resisting forces, driving forces and give transparent safety factors. It also creates bending moment and shear force diagrams, which are necessary in the reinforcement design of reinforced concrete walls. In case of any unsatisfactory check, there can be an adjustment of parameters like base width, wall thickness, soil properties or the conditions of drainage so as to achieve stability.

In general, GEO5 makes the design of retaining walls easier through visual representation of the design, robust calculation reports, and optimization, thus, a stable tool in safe and economical retaining wall construction.



**Figure 4.10.2** Retaining wall bending moment and shear force analysis

A retaining wall refers to a structural component, which is designed to resist the soil and the lateral earth pressure, so that failure of slope or ground movement occurs due to Earth pressure. As depicted in the figure, stability in the wall is checked through checking overturning, sliding, bending moment and shear force. The resisting moment (192.57 kNm/m) is much more than the overturning moment (32.60 kNm/m), the safety factor is 5.91, which implies sufficient stability against overturning. To slide, resisting horizontal force (78.04 kN/m) is more than the active horizontal force (29.99 kN/m), and the safety factor is therefore 2.60 and this is also satisfactory. The bending moment diagram depicts that the maximum design moment was 397.87 kNm with a maximum shear of 227.84 kN depicted in the shear force diagram. The overall height of the wall is 3.5 m but with a base width of 2.5 m to provide adequate weight and base pressure to overcome the soil pressure. All in all, according to these checks, the retaining wall is structurally safe and satisfactory.

**Check for overturning stability**

Resisting moment  $M_{res} = 192,57 \text{ kNm/m}$

Overturning moment  $M_{ovr} = 32,60 \text{ kNm/m}$

Safety factor =  $5,91 > 1,50$

Wall for overturning is SATISFACTORY

**Check for slip**

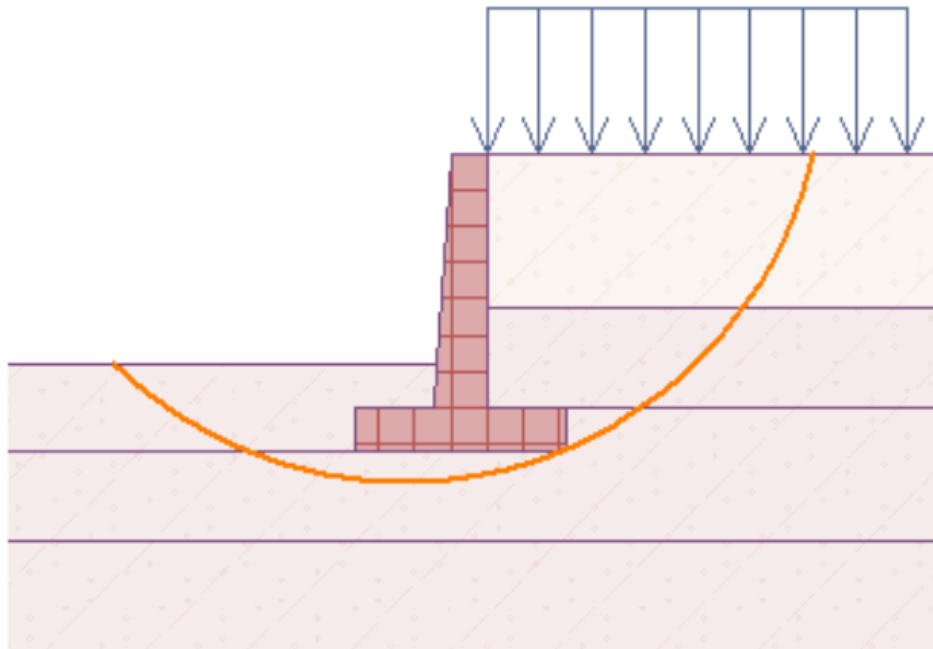
Resisting horizontal force  $H_{res} = 78,04 \text{ kN/m}$

Active horizontal force  $H_{act} = 29,99 \text{ kN/m}$

Safety factor =  $2,60 > 1,50$

Wall for slip is SATISFACTORY

Overall check - WALL is SATISFACTORY



**Figure 4.10.4** Stability analysis of a retaining wall

### Slope stability verification (Bishop)

Sum of active forces :  $F_a = 105,60 \text{ kN/m}$

Sum of passive forces :  $F_p = 250,83 \text{ kN/m}$

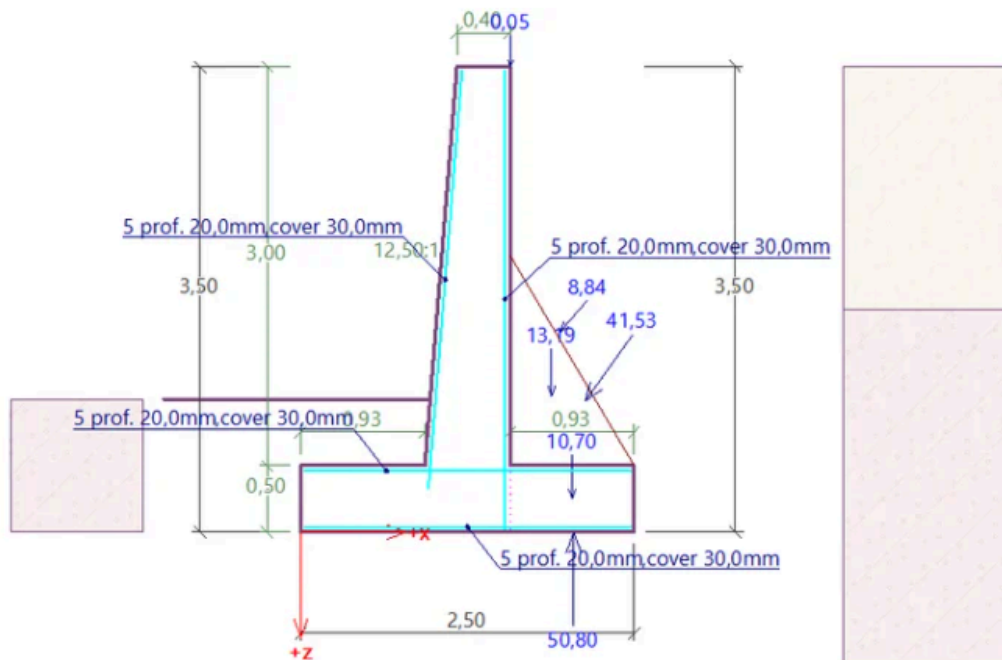
Sliding moment :  $M_a = 523,79 \text{ kNm/r}$

Resisting moment :  $M_p = 1244,10 \text{ kNm/r}$

Factor of safety =  $2,38 > 1,50$

Slope stability ACCEPTABLE

**Figure 4.10.5** Stability analysis of a retaining wall (numerical values).



**Figure 4.10.6** Structural cross-section of the retaining wall detailing reinforcement profiles, concrete cover, and primary dimensions.

The stability and design of the retaining wall were assessed through an in-depth analysis of global slip and reinforced concrete design. As shown in the global stability model, it was verified against deep-seated rotational failure with a critical slip surface through the soils below the footing. In response to these destabilising effects and the resultant lateral pressures, the wall was designed with a stem of 3.50 m height and a 2.50 m wide footing. The structural integrity of the



wall is supported by the placement of 20.0 mm reinforcement profiles along critical tension areas in both the stem and the footing, with a constant 30.0 mm concrete cover to protect against corrosion and deterioration. This arrangement guarantees a safe transfer of the lateral design loads, with a maximum of approximately 41.53 kN/m<sup>2</sup> at the base of the wall, to the foundation and a satisfactory factor of safety against overturning and sliding.

#### Wall stem check - back reinf.

Wall check at the construction joint 3,00 m from the wall crest

Reinforcement and dimensions of the cross-section

5 prof. 20,0 mm, cover 30,0 mm

Inputted reinforcement area = 1570,8 mm<sup>2</sup>

Required reinforcement area = 904,7 mm<sup>2</sup>

Cross-section width = 1,00 m

Cross-section height = 0,64 m

Reinforcement ratio  $\rho$  = 0,26 % > 0,15 % =  $\rho_{min}$

Position of neutral axis  $x$  = 0,04 m < 0,37 m =  $x_{max}$

Ultimate shear force  $V_{Rd}$  = 227,84 kN > 55,25 kN =  $V_{Ed}$

Ultimate moment  $M_{Rd}$  = 397,87 kNm > 60,76 kNm =  $M_{Ed}$

Cross-section is SATISFACTORY.

#### Wall jump check

Reinforcement and dimensions of the cross-section

5 prof. 20,0 mm, cover 30,0 mm

Inputted reinforcement area = 1570,8 mm<sup>2</sup>

Required reinforcement area = 693,7 mm<sup>2</sup>

Cross-section width = 1,00 m

Cross-section height = 0,50 m

Reinforcement ratio  $\rho$  = 0,34 % > 0,15 % =  $\rho_{min}$

Position of neutral axis  $x$  = 0,04 m < 0,28 m =  $x_{max}$

Ultimate shear force  $V_{Rd}$  = 198,94 kN > 33,29 kN =  $V_{Ed}$

Ultimate moment  $M_{Rd}$  = 302,50 kNm > 43,10 kNm =  $M_{Ed}$

Cross-section is SATISFACTORY.



### Wall heel check

Reinforcement and dimensions of the cross-section

5 prof. 20,0 mm, cover 30,0 mm

Inputted reinforcement area = 1570,8 mm<sup>2</sup>

Required reinforcement area = 693,7 mm<sup>2</sup>

Cross-section width = 1,00 m

Cross-section height = 0,50 m

Reinforcement ratio  $\rho$  = 0,34 % > 0,15 % =  $\rho_{min}$

Position of neutral axis  $x$  = 0,04 m < 0,28 m =  $x_{max}$

Ultimate shear force  $V_{Rd}$  = 198,94 kN > 13,56 kN =  $V_{Ed}$

Ultimate moment  $M_{Rd}$  = 302,50 kNm > 17,66 kNm =  $M_{Ed}$

Cross-section is SATISFACTORY.

Figure 4.10.7 Cross-section check for retaining wall.

| Wall stem check - back reinf. |              |                        |
|-------------------------------|--------------|------------------------|
| SHEAR :                       | SATISFACTORY | (24,2%) Depth = 3,00 m |
| BENDING :                     | SATISFACTORY | (15,3%) Depth = 3,00 m |
| DESIGN PRINCIPLES :           | SATISFACTORY | (57,6%)                |

| Wall jump check     |              |         |
|---------------------|--------------|---------|
| SHEAR :             | SATISFACTORY | (16,7%) |
| BENDING :           | SATISFACTORY | (14,2%) |
| DESIGN PRINCIPLES : | SATISFACTORY | (44,2%) |

| Wall heel check     |              |         |
|---------------------|--------------|---------|
| SHEAR :             | SATISFACTORY | (6,8%)  |
| BENDING :           | SATISFACTORY | (5,8%)  |
| DESIGN PRINCIPLES : | SATISFACTORY | (44,2%) |

Figure 4.10.8 Structural verification summary.

## 4.11 Foundation design under lateral loads

### 4.11.1 Calculation of lateral resistance

The calculation of lateral bearing capacity was performed via using the lateral forces and moment values generated by the SAP2000 analysis. In order to analyze the lateral load-carrying capacity, the critical maximum loads were considered for the internal, exterior, and corner columns. The structural loads obtained from the software analysis were based on the given load combination:

$$1.2D + 1.0E + 1.0L$$

The total resultant lateral load per pile was obtained by the following equation:

$$Lateral\ load = \frac{\sqrt{F_x^2 + F_y^2}}{number\ of\ piles}$$

**Table 4.11.1** Lateral loads

| Group of piles | Number of piles | $V, kN$  | $F_x, kN$ | $F_y, kN$ | Lateral load, kN | $M_x, kN-m$ | $M_y, kN-m$ |
|----------------|-----------------|----------|-----------|-----------|------------------|-------------|-------------|
| Interior       | 9               | 4346.995 | 43.626    | 71.045    | 9.263            | -221.611    | 165.468     |
| Exterior       | 6               | 2413.735 | 80.131    | 75.279    | 18.324           | -203.928    | 152.638     |
| Corner         | 9               | 1742.115 | 97.295    | 101.293   | 15.606           | -233.489    | 141.383     |

When subjected to horizontal loads, a pile resists the lateral loads by generating a passive earth pressure (Das & Sivakugan, 2019). The pressure distribution is mainly controlled by the following three factors such as soil stiffness, pile stiffness, and the boundary conditions at the pile ends. In addition, the laterally loaded piles are usually classified as short or long piles.

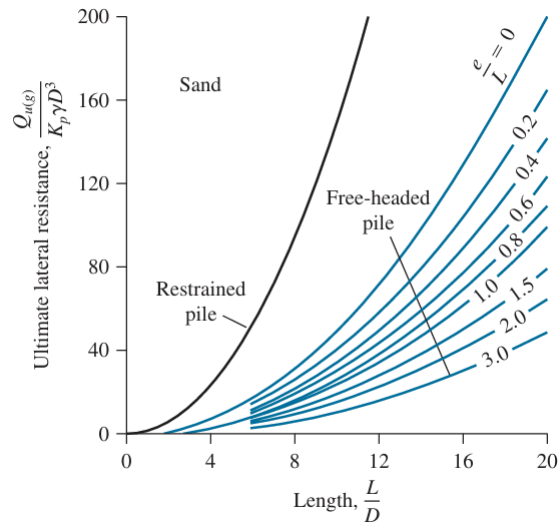
In order to calculate the ultimate lateral bearing capacity of the deep foundations, we will utilize Broms' method (1965). For the short pile, the Broms' method suggests that failure is driven by the shear failure of the soil, whereas for the long pile, the failure is caused by structural bending

of the pile (Das & Sivakugan, 2019). In the calculations, both cases should be checked and justified. For this purpose, we will rely on Figures 4.11.1 and 4.11.2 for short and long piles, respectively.

Since the total pile length is taken as 18 meters, the pile is installed in a silty sand layer with a friction angle  $\phi' = 33^\circ$  and unit weight  $\gamma = 18 \text{ kN/m}^3$ .

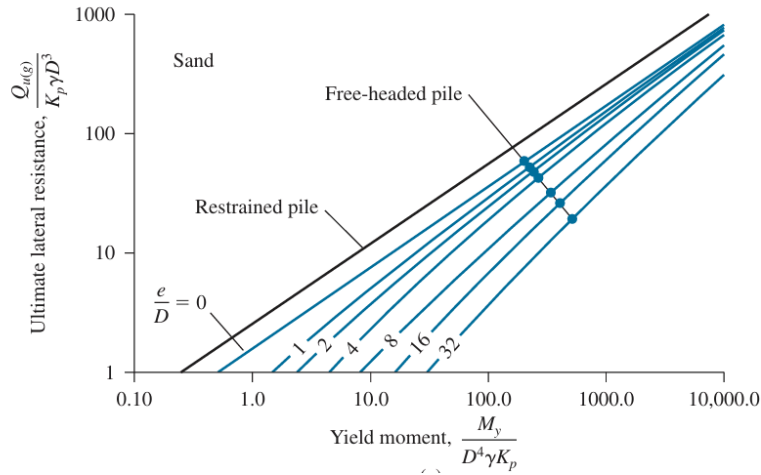
Rankine passive earth pressure for this friction angle is calculated as follows:

$$K_p = \tan^2\left(45 + \frac{\phi'}{2}\right) = \tan^2(45 + 16.5) = 3.39$$



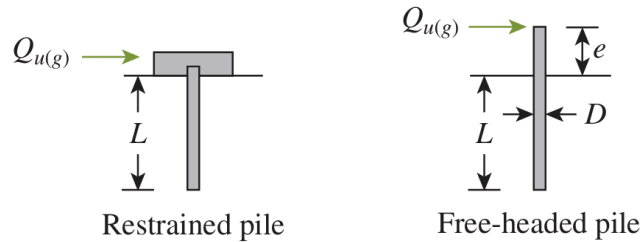
**Figure 4.11.1** Broms' solution for short piles in a sand

$\frac{L}{D} = \frac{18}{0.4} = 45 \geq 20$ , pile cannot be considered a short pile. Therefore, the further calculations will be based on Broms' specific solution for the long pile.



**Figure 4.11.2** Broms' solution for long piles in sand

For the long pile, lateral bearing capacity analysis is performed considering both free-headed and restrained piles. This approach is undertaken to compare the bearing capacities and justify the effectiveness of the pile cap design.



**Figure 4.11.3** Types of pile heads

The solution is developed for exterior, interior and corner groups of piles. First of all, the yield moment of the pile is calculated and the corresponding value for  $\frac{Q_{u(g)}}{K_p \gamma D^3}$  is found from Figure 4.11.2. Yield stress of the pile material is taken as  $f_y = 460 \text{ MPa}$ . The factor of safety is taken to be 3.

#### Exterior and corner group piles:

Section modulus of pile:

$$S = \frac{\pi D^3}{32} = \frac{\pi * 0.4^3}{32} = 6.28 * 10^{-3} \text{ m}^3$$

$$M_y = S * f_y = 0.00628 * 460 = 2890.3 \text{ kN} * \text{m}$$

$$\text{Yield moment } \frac{M_y}{D^4 \gamma K_p} = \frac{2890.3 \text{ kN*m}}{(0.4 \text{ m})^4 * 18 \text{ kN/m}^3 * 3.39} = 1850.3$$

From the Figure X:

$$\text{Restrained pile: } \frac{Q_{u(g)}}{K_p \gamma D^3} = 325$$

$$Q_{u(g)} = 325 * K_p * \gamma * D^3 = 325 * 3.39 * 18 * 0.4^3 = 1269.2 \text{ kN}$$

$$Q_{allowable} = \frac{Q_{u(g)}}{FS} = \frac{1269.2}{3} = 423.1 \text{ kN}$$

$$\text{Free-headed pile: } \frac{e}{D} = 0$$

Ultimate lateral resistance

$$\frac{Q_{u(g)}}{K_p \gamma D^3} = 230$$

$$Q_{u(g)} = 230 * K_p * \gamma * D^3 = 230 * 3.39 * 18 * 0.4^3 = 898.2 \text{ kN}$$

$$Q_{allowable} = \frac{Q_{u(g)}}{FS} = \frac{898.2}{3} = 299.4 \text{ kN}$$

**Interior group pile:**

Section modulus of pile:

$$S = \frac{\pi D^3}{32} = \frac{\pi * 0.5^3}{32} = 0.01227 \text{ m}^3$$

$$M_y = S f_y = 0.01227 \text{ m}^3 * 460000 \text{ kN/m}^2 = 5644.2 \text{ kN} * \text{m}$$

$$\frac{M_y}{D^4 \gamma K_p} = \frac{5644.2 \text{ kN*m}}{(0.5 \text{ m})^4 * 18 \text{ kN/m}^3 * 3.39} = 1480.0$$

From the Figure X:

$$\text{Restrained pile: } \frac{Q_{u(g)}}{K_p \gamma D^3} = 280$$

$$Q_{u(g)} = 280 * K_p * \gamma * D^3 = 280 * 3.39 * 18 * 0.5^3 = 2135.7 \text{ kN}$$

$$Q_{allowable} = \frac{Q_{u(g)}}{FS} = \frac{2135.7}{3} = 711.9 \text{ kN}$$

$$\text{Free-headed pile: } \frac{e}{D} = 0$$

$$\frac{Q_{u(g)}}{K_p \gamma D^3} = 200$$

$$Q_{u(g)} = 200 * K_p * \gamma * D^3 = 200 * 3.39 * 18 * 0.5^3 = 1525.5 \text{ kN}$$

$$Q_{allowable} = \frac{Q_{u(g)}}{FS} = \frac{1525.5}{3} = 508.5 \text{ kN}$$

**Table 4.11.2** Lateral bearing capacity of a long pile

| Group Piles                 | Exterior    |            | Interior    |            | Corner      |            |
|-----------------------------|-------------|------------|-------------|------------|-------------|------------|
|                             | Free-headed | Restrained | Free-headed | Restrained | Free-headed | Restrained |
| $Q_{u(g)}, \text{ kN}$      | 898.2       | 1269.2     | 1525.5      | 2135.7     | 898.2       | 1269.2     |
| $Q_{allowable}, \text{ kN}$ | 299.4       | 423.1      | 508.5       | 711.9      | 299.4       | 423.1      |
| $GEO5, \text{ kN}$          | 188.3       |            | 292.8       |            | 144.2       |            |

#### 4.11.2 Calculation of pile head deflection

The calculation of pile deflection is performed by two methods of Elastic solution and Broms' solution. In lateral load analysis, Winkler's elastic method treats the elastic soil medium as a series of independent elastic springs acting against the pile. According to this approach, the modulus of subgrade reaction is calculated by the following equation:

$$k_z = n_h * z$$

Where,

$k_z$  — modulus of subgrade reaction

$n_h$  — constant modulus of horizontal subgrade reaction

$z$  — depth from ground surface

The constant modulus of horizontal subgrade reaction was derived from Table 12.16 for dry or moist sand (Das and Sivakugan, 2019). The  $n_h$  value was estimated to be  $7000 \text{ kN/m}^3$  for the silty sand, which is medium dense soil.

**TABLE 12.16** Representative Values of  $n_h$

| Soil              | $n_h$<br>kN/m <sup>3</sup> |
|-------------------|----------------------------|
| Dry or moist sand |                            |
| Loose             | 1800–2200                  |
| Medium            | 5500–7000                  |
| Dense             | 15,000–18,000              |
| Submerged sand    |                            |
| Loose             | 1000–1400                  |
| Medium            | 3500–4500                  |
| Dense             | 9000–12,000                |

**Figure 4.11.4** Values for  $n_h$

**Table 4.11.3** Modulus of subgrade reaction at depth  $z$

| # | Soil type                        | Depth, m | Thickness, m | $n_h$ | $k_z$  |
|---|----------------------------------|----------|--------------|-------|--------|
| 1 | Silty sand with asphalt and mica | 1.83     | 1.83         | 6500  | 11895  |
| 2 | Silty sand with mica             | 4.57     | 2.74         | 7000  | 31990  |
| 3 | Silty sand with gravel and mica  | 6.09     | 1.52         | 7000  | 42630  |
| 4 | Silty sand with mica             | 25.91    | 19.81        | 7000  | 181370 |
| 5 | Silty sand                       | 27.43    | 1.52         | 7000  | 192010 |
| 6 | Silty sand with gravel and mica  | 30.48    | 3.05         | 7000  | 213360 |
| 7 | Silty sand with mica             | 32.00    | 1.52         | 7000  | 224000 |

For an elastic solution, first of all, the characteristic length of the soil-pile system is obtained depending on the  $n_h$  value.

$$T = \sqrt[5]{\frac{E_p I_p}{n_h}}$$

Where,

$E_p$  – modulus of elasticity of the pile ( $kN/m^2$ ), which is calculated as follows for concrete compressive strength of 35 MPa:

$$E_p = 4700 * \sqrt{f_c} = 4700 * \sqrt{35} = 27800 \text{ MPa} = 278 * 10^5 \text{ kN/m}^2$$

$I_p$  – moment of inertia of the pile section ( $m^4$ ), which is equal to:

$$I_p = \frac{\pi * d^4}{64}$$

In elastic solution, if  $L \geq 5T$ , the pile is considered to be a long pile, whereas for  $L \leq 2T$ , the pile is considered to be a rigid short pile. In our case,

$$18 \text{ m} \geq 5 * 1.38 = 6.9 \text{ m (exterior and corner group piles)}$$

$$18 \text{ m} \geq 5 * 1.65 = 8.25 \text{ m (interior group piles)}$$

Therefore, the analysis will be performed for a long elastic pile, utilizing coefficients and equations for a long pile embedded in a granular soil. The pile deflection at any depth is found by the following equation:

$$x_z(z) = A_x \frac{Q_g T^3}{E_p I_p} + B_x \frac{M_g T^2}{E_p I_p}$$

Where,

$A_x, B_x$  – coefficients

The maximum allowable displacement occurs at the top of the pile, therefore, we will consider deflection at  $z=0$  m, and the non-dimensional length is  $Z = \frac{z}{T} = 0$ . The corresponding coefficient is found from Table 12.15 (Das and Sivakugan, 2019).

**Table 4.11.4** Pile head deflection by elastic solution

| Group piles | $I_p, m^4$ | $T, m$ | $A_x$ | $B_x$ | $Q_g, kN$ | $M_g, kN - m$ | $x_z, mm$ |
|-------------|------------|--------|-------|-------|-----------|---------------|-----------|
|-------------|------------|--------|-------|-------|-----------|---------------|-----------|



|          |                  |      |       |       |        |         |      |
|----------|------------------|------|-------|-------|--------|---------|------|
| Exterior | $1.26 * 10^{-3}$ | 1.38 | 2.435 | 1.623 | 18.324 | 152.638 | 16.8 |
| Interior | $3.07 * 10^{-3}$ | 1.65 | 2.435 | 1.623 | 9.263  | 165.468 | 9.75 |
| Corner   | $1.26 * 10^{-3}$ | 1.38 | 2.435 | 1.623 | 15.606 | 141.383 | 15.3 |

According to Broms' method, the deflection at the pile head is obtained through graph 4.12.5.

For this purpose, the value for dimensionless length is calculated:

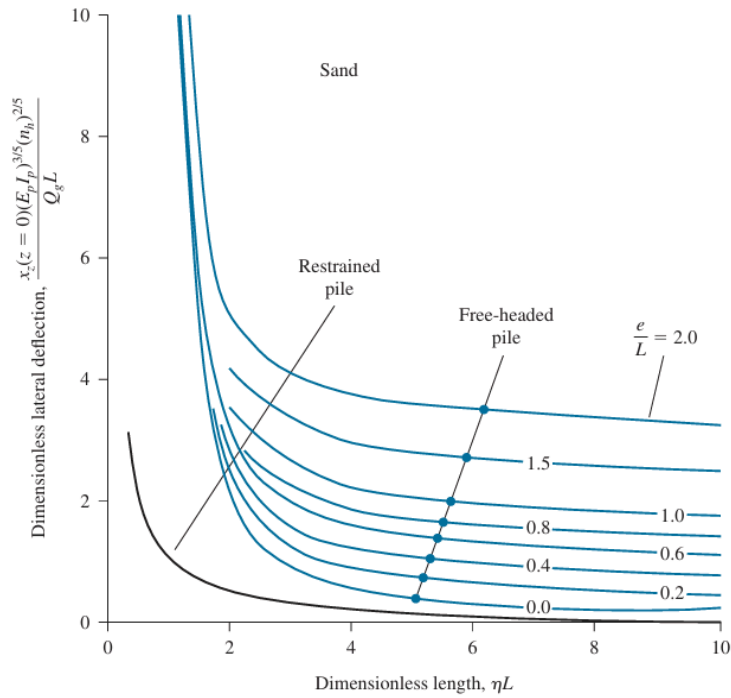
$$\text{dimensionless length} = \eta L$$

$$\eta = \sqrt[5]{\frac{n_h}{E_p I_p}}, m^{-1}$$

Assuming the restrained pile, the dimensionless lateral deflection is obtained from the graph:

$$\frac{x_z(E_p I_p)^{3/5}(n_h)^{2/5}}{Q_g L} = 0.1$$

$$x_z(z = 0) = \frac{0.1 * Q_g L}{(E_p I_p)^{3/5}(n_h)^{2/5}}$$



**Figure 4.11.5** Broms' solution for deflection of pile head in sand

**Table 4.11.5** Deflection at the pile head

| Group Piles | Elastic Method, mm | Broms' method, mm |
|-------------|--------------------|-------------------|
| Exterior    | 16.8               | 18.4              |
| Interior    | 9.75               | 14.1              |
| Corner      | 15.3               | 16.7              |

## 4.12 Reinforcement design

### 4.12.1 Single pile reinforcement

The individual pile reinforcement should be designed to safely resist the vertical axial load and lateral bending moments. First of all, the pile is checked for slenderness effects. The effective length can be found as follows:

$$l_e = \beta * l_0$$

Where,

$l_0$  - actual unsupported length of the pile, m

$\beta$ - effective length factor, which is equal to 1.2 for a fixed-head pile

For the pile length of 18 meters, the effective length is  $l_e = 1.2 * 18 = 21.6$  meters. This length is then used to identify the slenderness ratio:

$$\text{Slenderness ratio} = \frac{l_e}{d}$$

Where,

$l_e$  - effective length of the pile, m

$d$ - pile diameter, m

If  $\frac{l_e}{d} \geq 10$ , it suggests that the pile is slender, which verifies the need for a moment magnification. Since the slender pile tends to buckle, it will cause an additional buckling moment inside the pile shaft, which then must be added to the initial lateral moment.

$$M_{add} = N * a$$

Where,

$N$ - vertical axial load, kN

$a$ - deflection factor, m

$$a = \frac{l_e^2}{2000d}$$

After determining the additional moment, the total magnified design moment is obtained by summation:

$$M_{mag} = M_{initial} + M_{add}$$

The required steel area is calculated using this equation:

$$A_{st} = \frac{\pi d^2}{4} * \rho$$

Where,

$d$ - pile diameter, m

$\rho$ - reinforcement ratio, %

The detailed calculation procedure for reinforcement design is provided for the interior pile:

*Slenderness check*

$$l_e = 1.2 * 18 = 21.6 \text{ m}$$

$$\frac{l_e}{d} = \frac{21.6}{0.5} = 43.2 \geq 10 \rightarrow \text{slender pile}$$

*Moment calculations*

$$a = \frac{21.6^2}{2000 * 0.5} = 0.467 \text{ m}$$

$$M_{add} = 483 \text{ kN} * 0.467 \text{ m} = 225.6 \text{ kN} - \text{m}$$

$$M_{initial} = 9.263 \text{ kN} * 1.65 \text{ m} = 15.3 \text{ kN} - \text{m}$$

$$M_{mag} = 225.6 + 15.3 = 240.9 \text{ kN} - \text{m}$$

### Reinforcement check

The cover thickness is taken as 75 mm. Assume T22 bars ( $d_{bar} = 22 \text{ mm}$ ):

$$A_{bar} = \frac{\pi * 22^2}{4} = 380.1 \text{ mm}^2$$

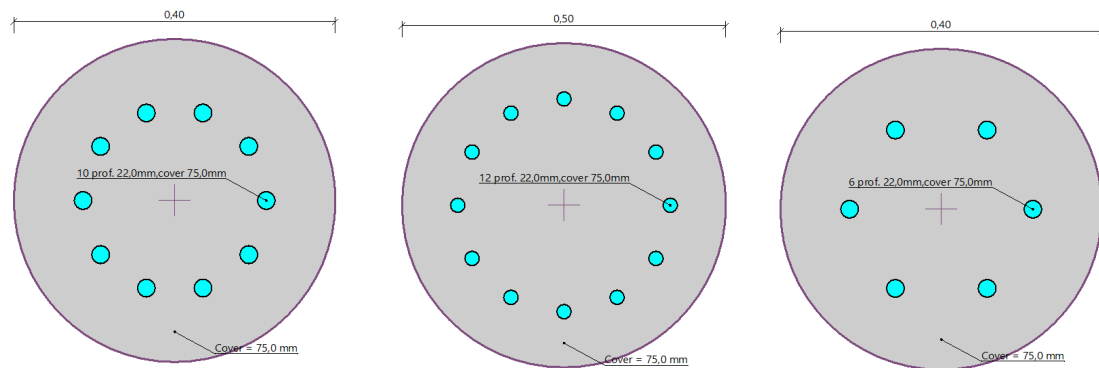
$$A_{st} = 0.023 * \frac{\pi * 500^2}{4} = 4516 \text{ mm}^2$$

$$\# \text{ of bars} = \frac{4516}{380.1} = 11.9 \approx 12 \text{ bars} \rightarrow \text{use 12T22}$$

**Table 4.12.1** Single pile reinforcement design

| Group piles | $d, \text{ m}$ | $\frac{l_e}{d}$ | $M_{add'}$<br>kN-m | $M_{mag'}$<br>kN-m | $\frac{M}{d^3}$ | $\rho, \%$ | $A_{st}, \text{ mm}^2$ | Design   |
|-------------|----------------|-----------------|--------------------|--------------------|-----------------|------------|------------------------|----------|
| Exterior    | 0.4            | 54.0            | 234.5              | 259.8              | 4.06            | 3.0        | 3770                   | 10#22 mm |
| Interior    | 0.5            | 43.2            | 225.6              | 240.9              | 1.93            | 2.3        | 4516                   | 12#22 mm |
| Corner      | 0.4            | 54.0            | 112.9              | 134.4              | 2.10            | 1.8        | 2262                   | 6#22 mm  |

To verify the hand calculations, a numerical model for individual piles was developed via using GEO5 software. The software analysis showed satisfactory results for shear check, bending and compression, and confirmed the adequate ratio for reinforcement requirement.



|                                                      |                                                      |                                                      |
|------------------------------------------------------|------------------------------------------------------|------------------------------------------------------|
| SHEAR :<br><b>SATISFACTORY</b> (48,3%)               | SHEAR :<br><b>SATISFACTORY</b> (13,2%)               | SHEAR :<br><b>SATISFACTORY</b> (46,2%)               |
| BENDING + COMPR. :<br><b>SATISFACTORY</b> (61,0%)    | BENDING + COMPR. :<br><b>SATISFACTORY</b> (23,1%)    | BENDING + COMPR. :<br><b>SATISFACTORY</b> (53,3%)    |
| Reinforcement ratio :<br><b>SATISFACTORY</b> (27,5%) | Reinforcement ratio :<br><b>SATISFACTORY</b> (16,5%) | Reinforcement ratio :<br><b>SATISFACTORY</b> (21,5%) |

**Figure 4.12.1** Single pile reinforcement in GEO5 software

#### 4.12.2 Pile cap reinforcement

The pile cap design was conducted in accordance with the design procedure of Eurocode 2. The material properties assumed for the design included the concrete compressive strength  $f_{cu}$  of 35 MPa and reinforcement steel yield strength  $f_y$  of 460 MPa. The concrete unit weight is taken as 24 kN/m<sup>3</sup>. In order to provide the protection against corrosion and moisture, a concrete cover of 75 mm was utilized in the design.

First of all, the pile cap thickness is sized based on the pile diameter:

$$d_{pile} \leq 550 \text{ mm}: h = 2d_{pile} + 100$$

$$d_{pile} \geq 550 \text{ mm}: h = \frac{1}{3} (8d_{pile} + 600)$$

By assuming that the pile cap acts as a rigid body, the load from the column is distributed to the piles based on their geometric position relative to the center of the cap. Thus, the combined stress formula is written as follows (Bowls, 1996):

$$P_p = \frac{Q}{n} \pm \frac{M_y x}{\Sigma x^2} \pm \frac{M_x y}{\Sigma y^2}$$

Where,

$M_x, M_y$  – moments about axes x and y

$Q$  – total load including the self-weight of the pile cap

$x, y$  – distance from x and y axes to the pile

$\Sigma x^2, \Sigma y^2$  – moments of inertia

Then, the required area of steel reinforcement is calculated by using the K factor method. The K factor helps to determine whether the compression steel is needed if  $K \leq 0.156$ :

$$K = \frac{M}{f_{cu} * b * d}$$

$$\text{effective depth} = d = h - \text{cover} - \frac{d_{bar}}{2}$$

Next step consists of calculating the effective lever arm  $z$ , which is limited to  $0.95d$ :

$$z = d[0.5 + \sqrt{0.25 - (\frac{K}{0.9})}]$$

As a result, the required area of steel is obtained through the equation below:

$$A_s = \frac{M}{\phi * f_y * z}$$

Where,

$\phi = 0.9$  –strength reduction factor

The total number of bars and spacing is calculated as follows:

$$\# \text{ of bars} = \frac{A_s}{A_{bar}}$$

$$\text{Spacing} = \frac{\text{width of the pile cap}}{\# \text{ of bars}}$$

The further calculations will be provided for the *interior pile cap* design, and the summary for each pile group is provided in Table 4.12.7.

*Pile cap dimensions:*

$$h = 2 * 500 + 100 = 1100 \text{ mm}$$

$$L = B = 4 \text{ m}$$

$$\text{Pile spacing} = 0.5 \text{ m}$$

*Pile loads:*

$$\text{Load from column: } 4346.995 \text{ kN}$$

$$\text{Moments: } M_x = 221.611 \text{ kN} * \text{m}, M_y = 165.468 \text{ kN} * \text{m}$$

Self-weight of the cap:

$$\text{Volume} * \text{unit weight} = (4\text{m} * 4\text{m} * 1.1\text{m}) * 24\text{kN/m}^3 = 422.4 \text{ kN}$$

Total vertical load:  $346.995 \text{ kN} + 422.4 * 1.2 = 4853.88 \text{ kN}$

Average load per one pile:  $\frac{4853.88}{9} = 539.32 \text{ kN}$

Moment of inertia in both directions:

$$I_{xx} = I_{yy} = 3 * 1.5^2 + 3 * 0^2 + 3 * (-1.5)^2 = 13.5 \text{ m}^2$$

*Design bending moment M:*

Moment from piles:  $1691.82 \text{ kN} * 1.5 \text{ m} = 2537.73 \text{ kN} * \text{m}$

Moment from self-weight:  $M_{sw} = w * B * \frac{L^2}{2} = \frac{506.88}{484} * 4 * \frac{2^2}{2} = 253.44 \text{ kN} * \text{m}$

Net design moment:  $2537.73 - 253.44 = 2284.29 \text{ kN} * \text{m}$

*Reinforcement sizing and spacing:*

Assuming T25 bars ( $d_{bar} = 25 \text{ mm}$ ):

Effective depth:  $d = 1100 - 75 - 25 = 1000 \text{ mm}$

$$K = \frac{M}{f_{cu} * b * d^2} = \frac{2284.29 * 10^6}{35 * 4000 * 1000^2} = 0.016, K \leq 0.156, \text{ therefore no compression steel is needed}$$

Lever arm  $z = d[0.5 + \sqrt{0.25 - (\frac{K}{0.9})}] = 0.98d$ , since it is greater than  $0.95d$ :

Limiting factor  $z = 0.95d = 950 \text{ mm}$

$$\text{Required area of steel: } A_s = \frac{M}{\phi * f_y * z} = \frac{2284.29 * 10^6}{0.9 * 460 * 950} = 6008 \text{ mm}^2$$

$$\text{For T25 bars: } A_{bar} = \frac{\pi d^2}{4} = \frac{\pi * 25^2}{4} = 491 \text{ mm}^2$$

$$\text{Number of bars: } \frac{6008}{491} = 12.2 \approx 13 \text{ bars}$$

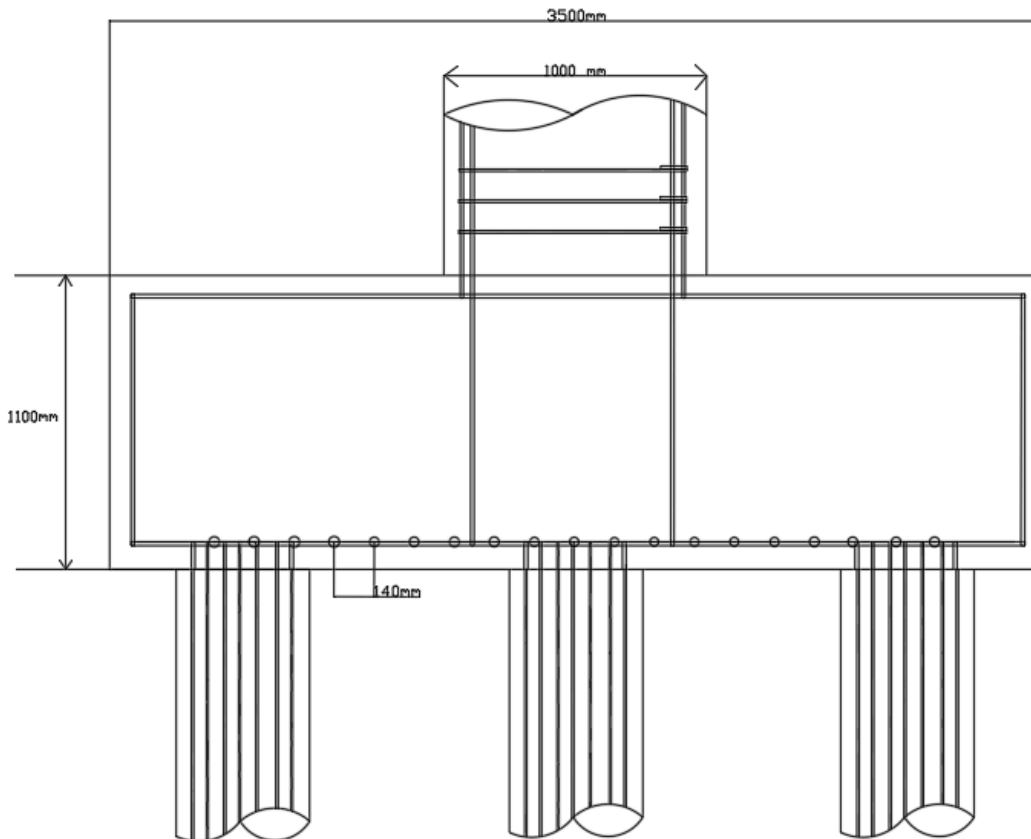
$$\text{Spacing: } \frac{4000}{13} = 307 \text{ mm}$$

Final design: 12 T25 @ 300 mm for both directions

**Table 4.12.2** Pile cap reinforcement design

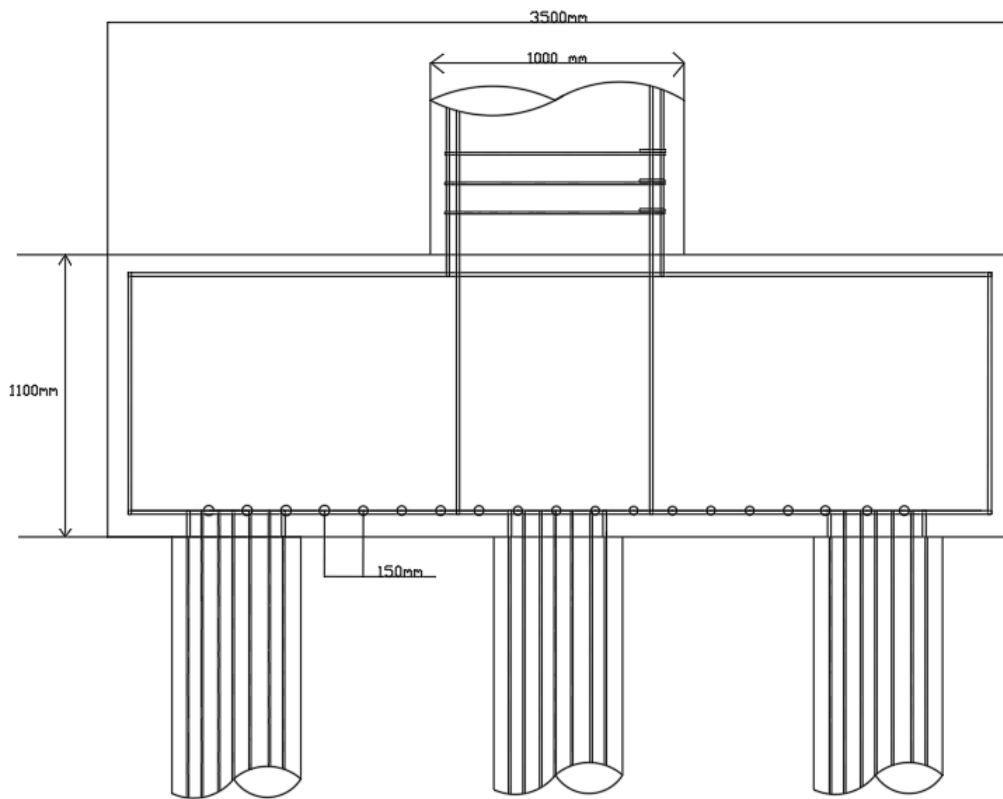
| Group Piles | $d_{pile}$ , mm | L x B, m  | $h$ , mm | $d_x$ , mm | $d_y$ , mm | Load, kN | Reinforcement in X | Reinforcement in Y |
|-------------|-----------------|-----------|----------|------------|------------|----------|--------------------|--------------------|
| Exterior    | 400             | 3.2 x 2.0 | 900      | 812.5      | 815.0      | 2413.7   | 7T25 @ 280         | 12T20 @ 260        |

|          |     |           |      |        |        |        |                |                |
|----------|-----|-----------|------|--------|--------|--------|----------------|----------------|
|          |     |           |      |        |        |        | mm             | mm             |
| Interior | 500 | 4.0 x 4.0 | 1100 | 1012.5 | 1012.5 | 4347.0 | 13T25 @ 300 mm | 13T25 @ 300 mm |
| Corner   | 400 | 3.8 x 3.8 | 900  | 815.0  | 815.0  | 1742.1 | 15T20 @ 250 mm | 15T20 @ 250 mm |

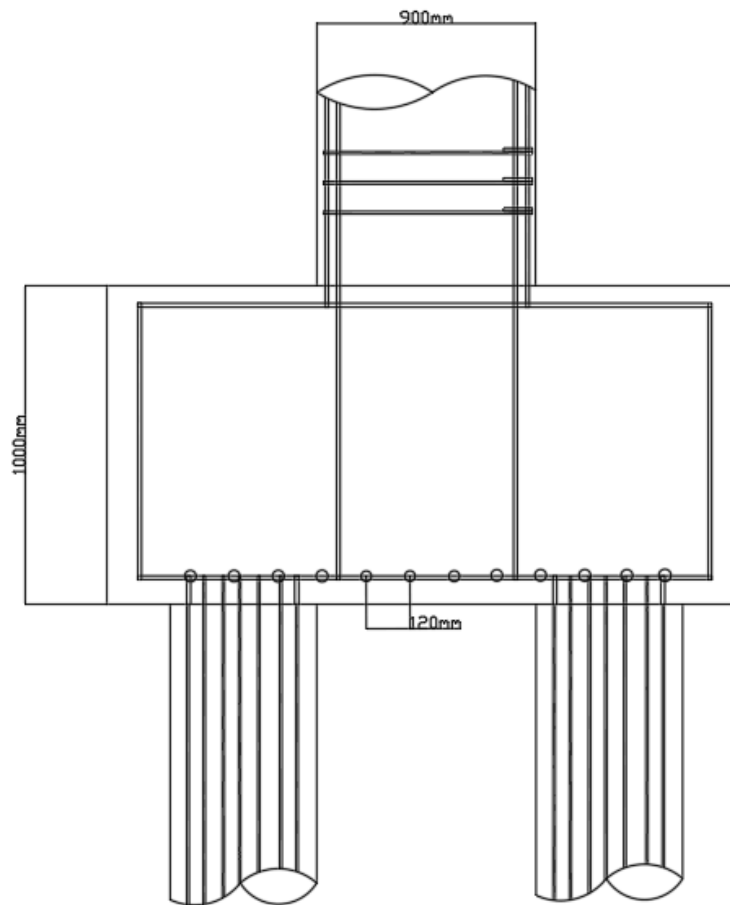


**Figure 4.12.2** Pile cap reinforcement and its connection to piles - Edge.

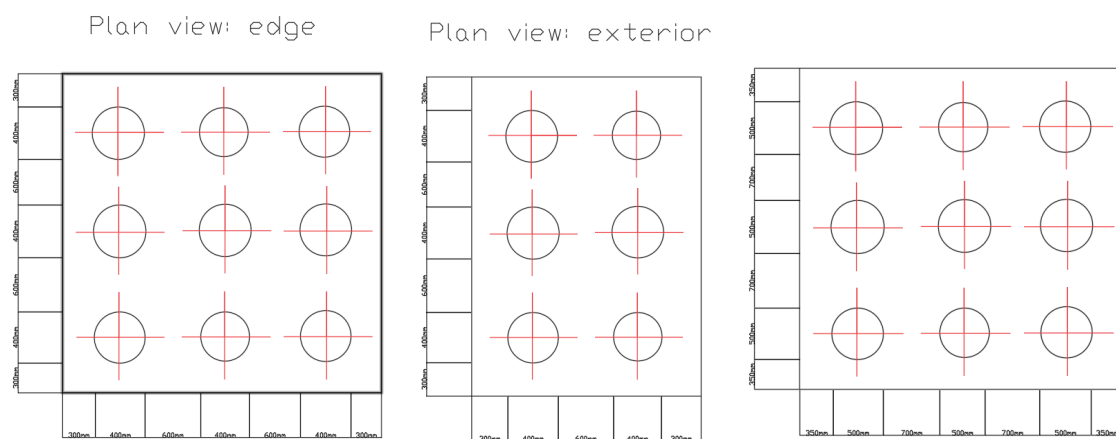


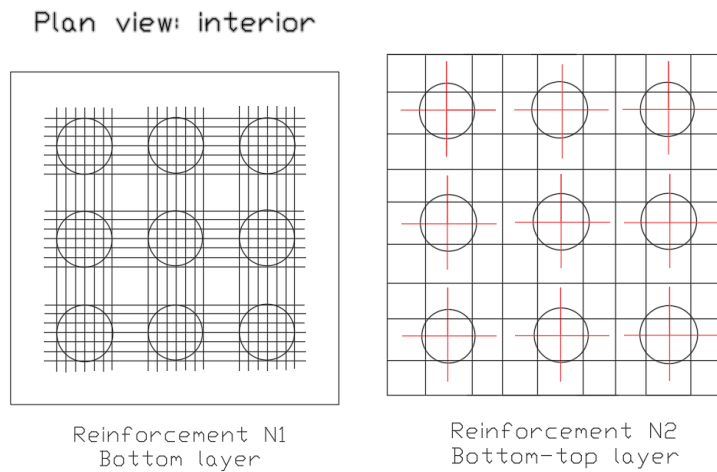


**Figure 4.12.3** Pile cap reinforcement and its connection to piles - Interior.



**Figure 4.12.4** Pile cap reinforcement and its connection to piles - Exterior.





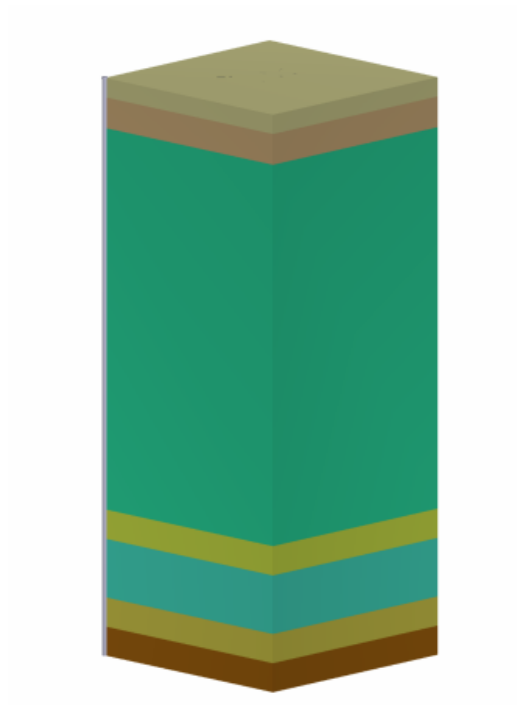
**Figure 4.12.5** Plan view of pile cap

## 4.13 Plaxis 3D analysis

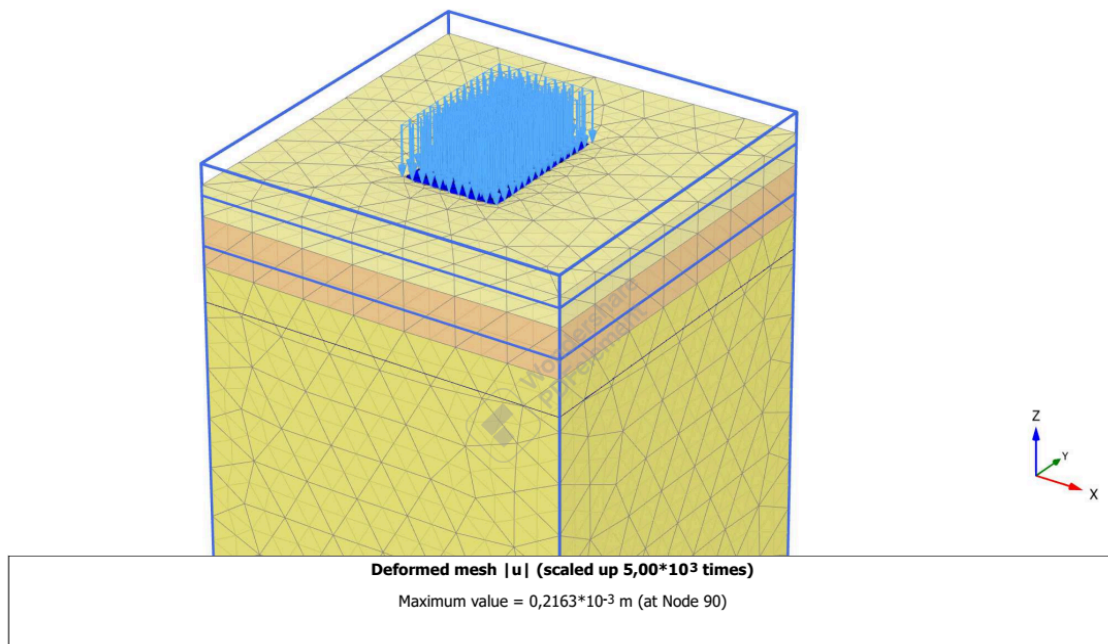
### 4.13.1 Settlement analysis

To evaluate the expected settlement behavior of the foundation system, a numerical analysis was performed using PLAXIS 3D. The software was utilized to simulate soil–structure interaction under the applied loading conditions and to obtain a more realistic prediction compared to simplified analytical calculations.

First, the soil profile was modeled (Figure 4.13.1) based on the available geotechnical investigation data. Each soil layer was defined according to its engineering properties, including unit weight, stiffness parameters, strength characteristics, and permeability where required. Appropriate constitutive models were selected to represent the mechanical behavior of the soils. Boundary conditions were applied to eliminate rigid body movement while allowing realistic deformation of the soil mass.

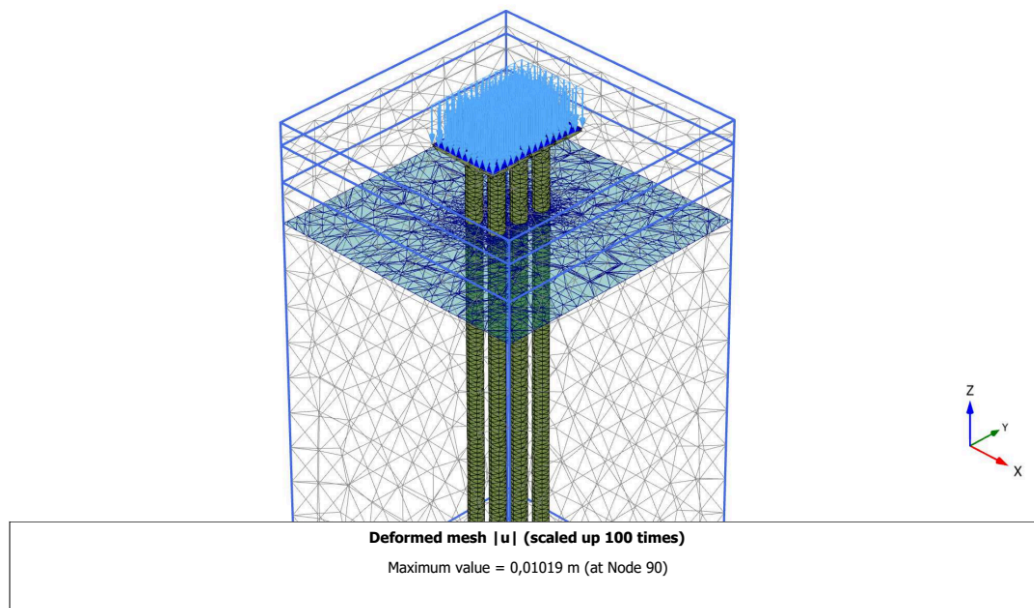


**Figure 4.13.1** Soil profile



**Figure 4.13.2** Making mesh after each step

After running the calculation phases (Figure 4.13.3), vertical displacements were analyzed to determine total settlement and differential settlement. The results obtained from PLAXIS 3D allowed us to visualize deformation patterns, stress distribution, and potential zones of higher strain concentration. The numerical results were then compared with preliminary hand calculations to verify consistency and assess the reliability of the design.



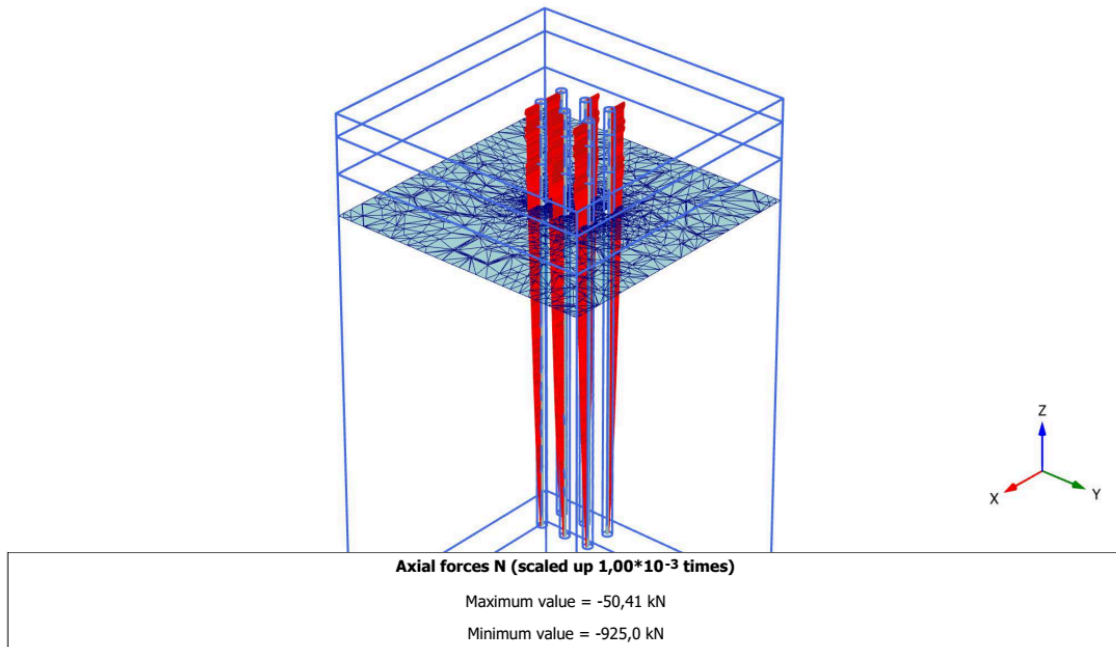
**Figure 4.13.3** Calculating deformation results

The numerical analysis yielded a maximum settlement of **10.2 mm**. This value is in close agreement with the settlement obtained from analytical hand calculations, demonstrating consistency between the simplified theoretical method and the advanced three-dimensional finite element model implemented in PLAXIS 3D.

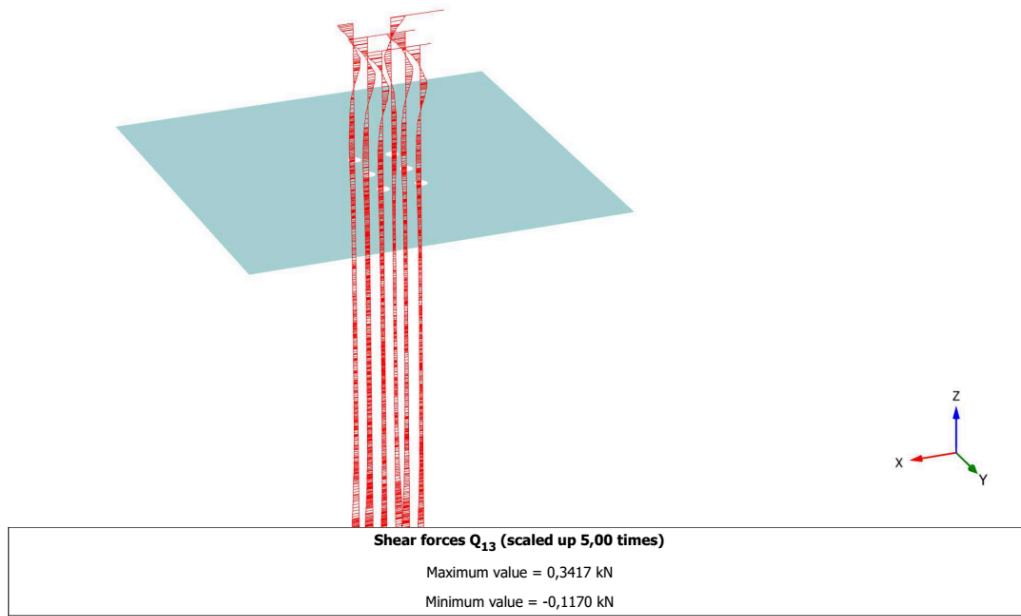
#### 4.13.2 Force and moment analysis

In addition to settlement evaluation, PLAXIS 3D was used to analyze the internal forces and bending moments developed within the foundation system. The software allows for detailed assessment of structural behavior by calculating axial forces, shear forces, and bending moments resulting from applied loads and soil-structure interaction.

The structural elements were modeled according to their actual geometry and material properties. After defining the loading conditions and construction stages, the calculation phases were executed to determine the distribution of internal forces under service loading. The results were obtained from the structural output section, where axial force (N), shear force (Q), and bending moment (M) diagrams were generated.

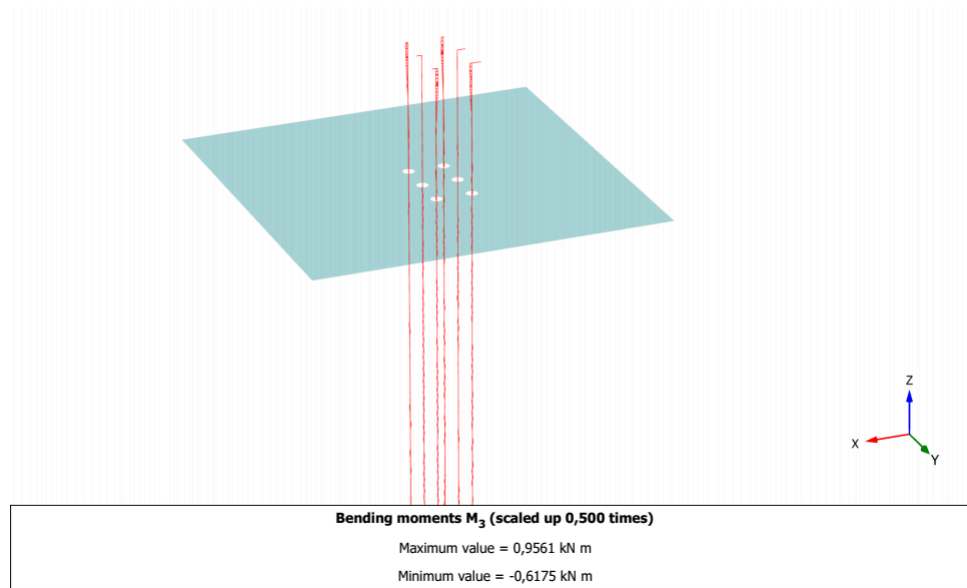


**Figure 4.13.4** Axial Forces results



**Figure 4.13.5** Shear force results

The bending moment distribution was carefully examined to identify critical sections where maximum tensile and compressive stresses may occur. These critical values are essential for structural design verification, reinforcement detailing, and overall safety assessment. The numerical results from PLAXIS 3D provide a three-dimensional representation of force distribution, which offers a more realistic assessment compared to simplified two-dimensional analytical methods. This approach ensures that both soil behavior and structural response are considered simultaneously, leading to a more accurate and reliable design evaluation.



**Figure 4.13.6** Bending moment results

## 5. Environmental Engineering

Construction of a new hotel inevitably comes with waste generated by its visitors, making effective waste management crucial to ensure sustainability of the project. This section examines waste related aspects such as compliance with relevant legal requirements, calculation of waste generation rates, and analyzing waste composition. We also strive to minimize environmental impact and thus we analyze recyclable fractions of waste, their quantities, and market values.

### 5.1 Legal requirements

To ensure proper waste management, it is first necessary to familiarize with the laws of New York City, and in Queens in particular. Title 16(Sanitation) of the New York City Administrative Code establishes the legal framework for waste management in New York city. This code gives The New York City Department of Sanitation (DSNY) responsibility for solid waste management and recycling.

The New York City Department of Sanitation (DSNY) is the municipal agency responsible for main sanitation services(waste management, street cleaning, and other). DSNY's powers and



responsibilities are based on the NYC Administrative Code, Title 16 (Sanitation) and the Rules of the City of New York (RCNY), Title 16. DSNY rules say that all businesses must separate recyclable materials from general trash. It is also necessary for businesses to contract with a private carter for collection of separated recyclable materials. They also must provide labeled containers for recycling to customers. However, businesses are not required to use the same color-coded bins as residential buildings.

In 2019, Local Law 199 instituted the Commercial Waste Zone (CWZ) system, which divides the city into 20 zones served by designated private waste collection companies. Therefore, hotels in Queens must contract with authorized private carter. Each business schedules their own waste collections as it depends on the terms of the contracts. Also, since March 1, 2024, as part of the CWZ regulations, DSNY obligates all businesses to use waste containers with secure lids.

Local Law No. 146 of 2013, about Commercial Organics Requirements states that large food processing establishments, including food services within a hotel, must separate organic waste from general trash. To be precise, these regulations apply to hotels with 100 or more rooms that offer on-site food service, as well as large restaurants ( $\geq 7,000$  sq ft).

#### **5.1.1 Waste collection schedule and bins**

The above rules apply to our hotel. As a commercial business, our hotel must dispose of its waste using authorized private carter in its designated commercial waste zone (CWZ). Of the 20 commercial zones that New York City is divided into, our hotel belongs to the Queens Southeast zone. Three private waste haulers are officially assigned to this zone, and a contract will be signed with one of them: Liberty Ashes, Recycle Track Systems NYC, and Royal Waste Services.

Regulations require businesses to separate recyclables from general waste, so there will be a separate container for recyclable materials, which include metals, paper, plastic, and glass. In case of organic/food waste, a small hotel like ours (74 rooms only) is not legally required to separate organic waste according to Local Law No. 146 of 2013, but since our hotel strives to follow sustainable trends and produce less waste, we will still separate organic waste and

designate a separate container for it. Thus, waste will be sorted into three categories: trash, recyclables, and organics. As previously stated, businesses do not have a strict color code for trash bins like residential areas. However, we will repeat the same color code to make it more familiar for users. Black bins are for trash, green/blue for recyclables, and brown for organics.



**Figure 5.1.1** Waste containers

The volume for each type of bin can be selected as follows:

- A 1 cubic yard container for trash. This is based on the fact that in hotels trash accumulates in a very short time and in large quantities.
- A 1 cubic yard container for recyclable waste. Recyclables usually are bulky even when weight is low and therefore require a lot of space.
- A 95 gallon container for organic waste. Organic waste is dense and not as bulky as recyclable and trash, therefore it requires less space.

The waste collection schedule for a business operating with private carter is chosen on its own. Our hotel is going to follow the schedule demonstrated below:

**Table 5.1.1** Waste collection schedule

| Waste type           | Collecting frequency     | Reason                                                                                         |
|----------------------|--------------------------|------------------------------------------------------------------------------------------------|
| General waste(trash) | 7 days/week              | Hotels generate continuous waste stream that can produce odors and must not be stored too long |
| Recyclables          | 3 days/week(Tue-Thu-Sat) | Recyclables are mostly dry materials                                                           |

|          |             |                                                                                                         |
|----------|-------------|---------------------------------------------------------------------------------------------------------|
|          |             | that do not create odors or hygiene problems when stored for several days                               |
| Organics | 7 days/week | Organics decompose rapidly, creating strong odors and sanitation risks and must be collected frequently |

Thus, waste is separated into three streams, which are sorted into three different containers and removed according to schedule via private carter. The containers are separated by color and size and have leak-proof lids to block spills and odors. All legal requirements are met.

## 5.2 Solid waste generation rate

Waste generation rate refers to the amount of solid waste produced by a source, such as hotels, during a given period of time. For hotels, waste generation rate might be influenced by factors such as the type and size of the hotel, occupancy level and consumers' habits. The presence of such food services as restaurants in a hotel also significantly affects the amount of waste generated. Therefore, in our calculations we take into account two main sources of waste: the hotel (guests in the rooms) and the largest restaurant located on the ground floor of the hotel.

### 5.2.1 Solid waste generated by hotel guests

A literature review revealed a lack of data on the average tourist's daily waste production in a New York hotel. To make a reasonable estimate, three of the most reliable sources from developed countries were selected, as their consumption habits are most similar to those of the United States.

The first source indicates that globally, one tourist produces 1 kg of waste per day (International Hotel Environmental Initiative, 2002). This data can be considered reliable, as it has been cited in numerous scientific publications (Bohdanowicz, 2006). The second source is based on a study conducted by the European Commission across several European countries and reports that the average tourist produces 1.05 kg of waste per night in a hotel (European Commission Green Forum, n.d.). A third European source also reports that tourists produce 1 kg of waste per night in a hotel (Zorpas et al., 2012). The 1 kg per night figure also matches that of numerous non-scientific sources for Europe and the UK, but we will not consider them in this analysis.

Therefore, to estimate the waste generated per guest per night at a hotel, we will use the generation rates from the three sources described above. We calculate their average value:

$$\frac{1+1.05+1}{3} = 1.017 \approx 1.02 \text{ kg/guest/night}$$

Knowing the amount of waste generated per guest per day, we can calculate the amount of waste generated per guest per year. Similarly, using data on the maximum number of guests and the average occupancy rate of the hotel throughout the year, we calculate the hotel's annual waste generation. The results are presented in the following table.

**Table 5.2.1.** Waste generation by hotel guests

| WGR<br>(kg/person/day) | WGR<br>(kg/person/year) | Maximum<br>number of<br>guests | Average occupancy<br>(%)            | Total waste<br>generated in hotel<br>(kg/year) |
|------------------------|-------------------------|--------------------------------|-------------------------------------|------------------------------------------------|
| 1.02                   | 372.3                   | 162                            | 86 (New York City<br>Tourism, 2023) | 51869                                          |

**Table 5.2.1.1** Strengths and Weaknesses of the sources used

|            |                                                                                                       |
|------------|-------------------------------------------------------------------------------------------------------|
| Strengths  | All sources are academic publications and provide data on developed countries to align with US trends |
| Weaknesses | The sources do not provide data on the US. Some sources are outdated (2002, 2006, 2012)               |

### 5.2.2 Solid waste generated by restaurant

The second major source of waste is the full-service restaurant located on the hotel's ground floor. The restaurant occupies 131 square meters with a 36 square meter kitchen and 90 seats. The restaurant operates during three meal periods (breakfast, lunch, and dinner) and is open not only to hotel guests but also to regular visitors from the outside. Since data on the waste

generated by restaurant patrons in New York City is lacking, the following methods based on the best available sources will be used for calculations.

The following formula will be used to calculate the waste generated by the restaurant:

$$W_{total} = W_m * S * T$$

Where:

$W_m$  – *waste generated per one meal*

$S$  – *number of seats*

$T$  – *seat turnover rate*

Seat turnover indicates how many times each seat is occupied during a given meal period. According to data collected by Horwath HTL & EDG Design (Horwath HTL & EDG Design, 2024) among various hotels worldwide, the average value of turnover for one meal period is 1.2. It is also noted that breakfast often serves half of the hotel's guests, so its turnover can be estimated as 0.6. Thus, all daily turnovers can be added up and then used in the formula:

$$W_m = 0.6 + 1.2 + 1.2 = 3$$

It represents that on average one seat is occupied 3 times in all meal periods, which corresponds to overall daily value.

According to Pettey (1992), one meal in an American restaurant generates 0.665 kg of solid municipal waste(Chan & Lam, 2001). In addition to food waste, which accounts for the majority of this figure, it also includes waste generated during the cooking process, packaging waste, and napkin waste.

Plugging all the data into the formula:

$$W_{total} = 0.665 * 90 * 3 = 179.55 \text{ kg/day}$$

This suggests that the restaurant generates 211.47 kg of solid municipal waste per day. This value is taken to calculate the annual waste generation rate for the restaurant. All results are summarised in the Table 5.2.2.

**Table 5.2.2.** Waste generation rate for hotel restaurant

| WGR<br>per meal | Maximum number<br>of seats | Seat turnover | WGR<br>per day (kg/day) | Total waste generated in<br>the restaurant (kg/year) |
|-----------------|----------------------------|---------------|-------------------------|------------------------------------------------------|
| 0.665           | 90                         | 3             | 179.55                  | 65536                                                |

**Table 5.2.2.1** Strengths and Weaknesses of the sources used

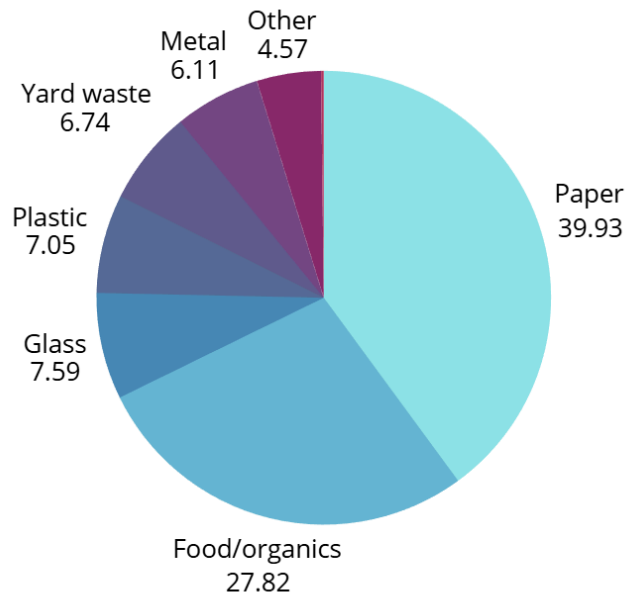
|            |                                                                                                                                             |
|------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Strengths  | The first source cites data on food turnover from its own survey. The data for waste per meal is taken specifically from the United States. |
| Weaknesses | The source providing data on waste per meal is outdated and the original publication was not found, only citations                          |

### 5.3 Solid waste composition

#### 5.3.1 Solid waste composition by hotel guests

According to the Environmental Protection Agency(EPA) municipal solid waste consists of everyday items such as product packaging, bottles, food scraps, and other. In our project, we consider the components of waste from a hotel and from a hotel restaurant separately, since they differ significantly.

Based on statistics provided for New York city hotels in New York City Department of Sanitation 20 Year Solid Waste Management Plan of 1992 the following diagram was made. (Winter & Azimi, 1996)



**Figure 5.3.1** Hotel waste composition in pie chart

Diagram shows that material of waste generated in a hotel are paper (39.93%), food/organics (27.82%), glass (7.59%), plastic (7.05%), yard waste (6.74%), metal (6.11%), other (4.57%) and hazardous waste (0.19%). The information source from 1992 might be outdated for current reality, however, since no other data is available specifically for New York City hotels, this source will be used.

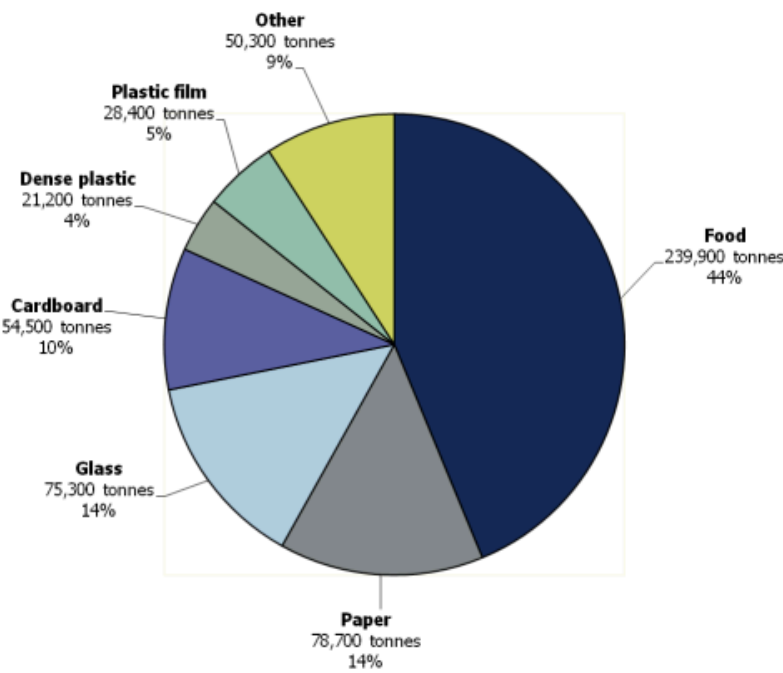
**Table 5.3.1.1** Strengths and Weaknesses of the sources used

|            |                                                                                 |
|------------|---------------------------------------------------------------------------------|
| Strengths  | The data is taken specifically for New York hotels.                             |
| Weaknesses | The data is outdated and the original publication was not found, only citations |

### 5.3.2 Solid waste composition by hotel restaurant

The data for MSW of restaurants in the USA was also not found. Most of the internet sources mention only generated food waste, whereas data on all types of municipal solid waste is required. Therefore, the composition of hotel restaurant waste was taken from a research study made in the UK area. The values from this study will be suitable for our calculations because both the UK and the USA are developed countries with high-income economies with similar

consumer habits. Moreover, the study was conducted not on one restaurant, but on 42, which allows for a more objective assessment.(WRAP, 2011)



**Figure 5.3.2.** Restaurant waste composition

The diagram reports that the average composition of 42 restaurants in the UK was determined as food/organics(44%), paper(14%), glass(14%), cardboard(10%), dense plastic(4%), plastic film(5%), and other(9%). The main difference between restaurant waste and hotel waste is the large proportion of organic waste in restaurants, which is logical.

**Table 5.3.2.1** Strengths and Weaknesses of the sources used

|            |                                                                                                                                    |
|------------|------------------------------------------------------------------------------------------------------------------------------------|
| Strengths  | The data is taken from a country with similar consumer habits to the United States (UK). The data is based on the original survey. |
| Weaknesses | The data is not taken for the USA.                                                                                                 |



#### 5.4 Solid waste total quantity

By combining data on the composition and quantity of waste generated, it is possible to calculate the quantity of each constituent category produced per year. The following formula is used to for calculations:

$$\text{Annual quantity of solid waste constituent} = \% \text{ of waste constituent} * \text{total waste quantity}$$

For example, starting with quantities corresponding to waste generated by guests:

$$\text{Annual quantity of paper} = 0.3993 * 51869 \approx 20711 \text{ kg/year}$$

All other categories were calculated in the same way and are demonstrated in Table 5.4.1.

**Table 5.4.1.** Annual quantity of solid waste constituents produced by hotel quests

| Constituent   | %     | Annual quantity(kg/year) |
|---------------|-------|--------------------------|
| Paper         | 39.93 | 20711                    |
| Food/organics | 27.82 | 14430                    |
| Glass         | 7.59  | 3937                     |
| Plastic       | 7.05  | 3657                     |
| Yard waste    | 6.74  | 3496                     |
| Metal         | 6.11  | 3169                     |
| Hazardous     | 0.19  | 99                       |
| Other         | 4.57  | 2370                     |

Quantities for the hotel restaurant were calculated similarly, by multiplying a consistent percentage to 65536 kg/year. Results are summarised in Table 5.4.2.

**Table 5.4.2.** Annual quantity of solid waste constituents produced by the hotel restaurant

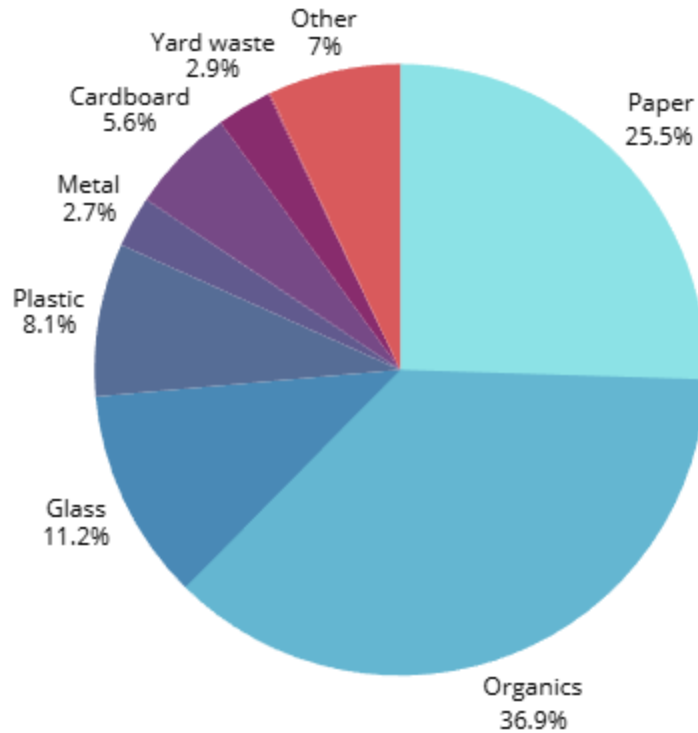
| Constituent   | %  | Annual quantity(kg/year) |
|---------------|----|--------------------------|
| Food/organics | 44 | 28836                    |

|               |    |      |
|---------------|----|------|
| Paper         | 14 | 9175 |
| Glass         | 14 | 9175 |
| Cardboard     | 10 | 6554 |
| Dense plastic | 4  | 2621 |
| Plastic film  | 5  | 3277 |
| Other         | 9  | 5898 |

By combining values from the both calculations it was possible to derive overall waste quantities of each constituent generated by hotel's major waste contributors(guests + restaurant) in a year. The results are illustrated in the following table:

**Table 5.4.3.** Total annual quantity of solid waste constituents produced by the hotel.

| Constituent   | Hotel guests quantity(kg/year) | Hotel restaurant quantity(kg/year) | Total quantity (kg/year) | % of total quantity |
|---------------|--------------------------------|------------------------------------|--------------------------|---------------------|
| Paper         | 20711                          | 9175                               | 29886                    | 25.5                |
| Food/organics | 14430                          | 28836                              | 43266                    | 36.9                |
| Glass         | 3937                           | 9175                               | 13112                    | 11.2                |
| Plastic       | 3657                           | 2621+3277=5898                     | 9555                     | 8.1                 |
| Yard waste    | 3496                           | -                                  | 3496                     | 2.9                 |
| Metal         | 3169                           | -                                  | 3169                     | 2.7                 |
| Hazardous     | 99                             | -                                  | 99                       | 0.1                 |
| Cardboard     | -                              | 6554                               | 6554                     | 5.6                 |
| Other         | 2370                           | 5898                               | 8268                     | 7                   |
| <b>Total</b>  |                                |                                    | <b>117405</b>            | <b>100</b>          |



**Figure 6.4.1** Total waste composition for hotel and restaurant

### 5.5 Total quantities of solid waste recyclables

The most commonly recycled materials on this list are paper, plastic, metal, and glass. However, not all of these materials are recycled for various reasons. Many materials are contaminated with food or non-recyclable materials, making them unsuitable for recycling. Recycling of some materials is also limited by the lack of specialized facilities and the high cost of producing virgin materials. According to EPA data for 2018, the overall recycling rate of municipal solid waste in the United States was 32%(United States Environmental Protection Agency, 2024). The EPA also provided recycling rates for mentioned components, from which the quantities of recycled materials were calculated(United States Environmental Protection Agency, 2020). The results are displayed in a table.

**Table 5.5.1.** The quantity of recyclables

| Constituent | Total quantity(kg/year) | Recycling rate(%) | Recycled quantity(kg/year) |
|-------------|-------------------------|-------------------|----------------------------|
|-------------|-------------------------|-------------------|----------------------------|

|              |       |      |       |
|--------------|-------|------|-------|
| Paper        | 29886 | 68.2 | 20382 |
| Plastic      | 9555  | 8.7  | 831   |
| Metal        | 3169  | 34.1 | 1081  |
| Glass        | 13112 | 25   | 3278  |
| <b>Total</b> |       |      | 25572 |

Thus, it can be seen that the overall quantity of recyclables in one year of hotel operation equals 25572 kg/year.

**Table 5.5.1.1** Strengths and Weaknesses of the sources used

|            |                                                                                                          |
|------------|----------------------------------------------------------------------------------------------------------|
| Strengths  | The data is taken from an official source(EPA) and collected from the USA.                               |
| Weaknesses | The data is not specific to New York. The data does not take into account the hotel's commercial nature. |

## 5.6 Market value of recyclables

Our hotel, like all commercial buildings, uses private carter for waste disposal. Private carters deliver recyclable waste to recycling facilities, where the recyclable waste can be sold. However, publicly available, detailed pricing data for commercial recyclables in New York City is difficult to obtain, as much depends on contracts(between carter and recycling facility) and recyclables' condition. Therefore, general market prices for various recyclables were found among the market data.

Of all our recycled material, we consider five categories for sale: PET, HDPE, paper, aluminum cans, non-aluminum metals.

### PET

PET is a plastic type commonly found in beverage bottles, and it can be recycled into new packaging and textile materials. It was found that PET makes up 10% of all plastic waste(Bodzay & Bánhegyi, 2016), so it was calculated that its mass from all recycled plastic is 0.083 tons/year:

$$0,831 * 0,1 = 0,0831 \approx 0,083 \text{ tonne/year}$$

To get the total annual value, obtain a number multiplied by the market price taken from an official government source and equal to \$230/kg(California Department of Resources Recycling and Recovery, 2025).

$$0,083 * 230 = 19,09 \approx 19 \$/\text{year}$$

### **HDPE**

HDPE is a plastic used in containers such as milk jugs and detergent bottles. In the same way as for PET, it was found that its fraction from all plastic waste is 19%(Bodzay & Bánhegyi, 2016) and thus its annual quantity is 0.158 tonne/year. The market value was found to be 265 \$/tonne(California Department of Resources Recycling and Recovery, 2025), which resulted in 42 \$/year total annual value.

### **Paper**

Paper is a commonly recycled material whose market value is influenced by the cleanliness. "Mixed Paper" is a lower-grade recyclable that includes a mix of all paper types. It typically has a lower value due to higher contamination and variability. The market price for mixed paper could not be found on the previous official government website, so it was taken from another source, which took data from [RecyclingMarkets.net](https://www.recyclingmarkets.net) (subscription based market data service), which publishes current recyclable material prices in different regions of the United States. According to this source, the paper price in New York in October 2025 was \$27.50/ton(West Virginia Solid Waste Management Board, 2025), which if converted to metric tons is 30.32 \$/tonne $\approx$ 30 \$/tonne. Multiplied by the total amount of paper recycled(20.382 kg/year), the total annual value is 612 \$/year.

### **Aluminum cans**

Aluminum cans have high recycling values due to their infinite recyclability. It was calculated based on the EPA data(United States Environmental Protection Agency, 2020) that aluminum's fraction from total metal waste is equal to 7.68%. Thus, total recycled quantity of aluminum is equal to 0.083 tonne/year. Market value taken from official source (California Department of Resources Recycling and Recovery, 2025) is 1658 \$/tonne, which gives 138 \$/year total annual value.

### **Non-Aluminum**

Non-aluminum metals can be divided into ferrous and non-ferrous. Since in our hotel we have only guest generated waste, it may include ferrous metal (food cans). However, other non-ferrous metals (copper, brass, stainless steel) do not appear in our guest generated waste and are

therefore excluded from calculations. Then, it was also calculated from EPA(United States Environmental Protection Agency, 2020) data that the fraction of non-aluminum metals equals 92.32%, which after multiplying to total metal quantity(1.081 tonne/year) results in 0.998 tonne/year. The market price for non-aluminum metals also could not be found on official governmental source, therefore it was taken from the website of a metal recycling company in the USA. According to the company's data for September 2025, the price of ferrous metals ranged from 100-165 \$/tonne(Okon Recycling, n.d.), by taking the average value, 133 \$/tonne was used in our calculation. The final total value of non-aluminum metals is 133\$/year.

The following table summarises all calculations of recyclables' total market value.

**Table 5.6.1** Market value of recyclables

| Recyclable | Recycled quantity (tonne/year) | Recyclable subcategory | Fraction from total recyclable(%) | Recyclable subcategory quantity (tonne/year) | Market value (\$/tonne) | Total Annual value (\$/year) |
|------------|--------------------------------|------------------------|-----------------------------------|----------------------------------------------|-------------------------|------------------------------|
| Plastic    | 0.831                          | PET                    | 10                                | 0.083                                        | 230                     | 19                           |
|            |                                | HDPE                   | 19                                | 0.158                                        | 265                     | 42                           |
| Paper      | 20.382                         | Mixed paper            | 100                               | 20.382                                       | 30                      | 612                          |
| Metal      | 1.081                          | Aluminum cans          | 7.68                              | 0.083                                        | 1658                    | 138                          |
|            |                                | Non-Aluminum           | 92.32                             | 0.998                                        | 133                     | 133                          |
|            |                                |                        | Total                             | 21.704                                       |                         | 944                          |

**Table 5.6.2** Strengths and Weaknesses of the sources used

|           |                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Strengths | <p>The data for plastic composition fractions(PET, HDPE) is taken from scientific research</p> <p>The data for metal composition fractions(aluminum, non-aluminum) is taken from official source(EPA)</p> <p>The data for PET, HDPE, Aluminum market values is taken from official governmental source(CalRecycle)</p> <p>The data for Paper market value is taken specifically for New York and is based on subscription based service</p> |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

|            |                                                                                                                                                                                                                                                                                                                          |
|------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Weaknesses | <p>The data for plastic composition fractions(PET, HDPE) might be outdated(2016) and is not specific for New York</p> <p>The data for metal composition fractions(aluminum, non-aluminum) is not specific for New York</p> <p>The data for Paper, non-aluminum market values are taken from not governmental sources</p> |
|------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## 5.7 Waste management options

Municipal solid waste treatment requires the assessment of different waste management options in order to minimize environmental impacts and improve resource recovery. The most widely used options include recycling, composting, and incineration. Recycling enables the recovery of paper, plastics, metals, and glass, reducing the need for raw material extraction. Composting is applied to biodegradable organic waste like food waste and yard waste, transforming it into valuable soil additives. Incineration is used for combustible waste fractions, enabling significant volume reduction and energy recovery.

### 5.7.1 Recycling potential

Recycling materials such as paper, plastic, metals and glass reduces the demand for primary raw materials and the negative impact on the environment.

According to Table 4.4.3 and Table 6.5.1 there are 117405 kg of solid waste produced by the hotel in one year, among which 25572 kg are recyclables. In order to determine recycling potential, the total weight of recyclables is divided by the total weight of solid waste.

$$\text{Recycling potential} = \frac{25572}{117405} * 100\% = 21.8\%$$

Thus, the hotel sector's waste recycling potential is 21.8%. This can be explained by the fact that the majority of hotel waste contributes to food waste and other organic waste, while the share of pure recyclables is significantly lower. Achieving higher results in hotels is often challenging due to mixed packaging and its contamination. While 21.8% does not represent a significant portion of waste, this share still aligns with our goal to minimize reliance on landfills and supports the hotel's sustainability goals.

### 5.7.2 Composting potential

Composting is a managed, aerobic biological process in which microorganisms decompose organic materials into a soil-like product (EPA, 2025). Organic materials suitable for composting

are carbon-based and include food scraps and yard waste. According to Table 4.4.3 our hotel generates 43266 kg of food waste and 3496 kg of yard waste per year. To calculate composting potential these values at first are needed to be multiplied by composting rate.

One research shows that composting of food waste can reach an average efficiency of approximately 77%(Galanakis, 2017). Additionally, according to EPA, the rate of yard trimmings composting was 63 %. Thus, the composting fraction is:

$$\text{Food waste composted} = 43266 * 0.77 = 33314.82 = 33315 \text{ kg}$$

$$\text{Yard waste composted} = 3496 * 0.63 = 2202.48 = 2203 \text{ kg}$$

These values are added together to be divided by total amount of waste to find composting potential:

$$\text{Composting potential} = \frac{33315+2203}{117405} * 100\% = 30.25\% = 30.3\%$$

Thus, it was determined that 30.3% of all waste is suitable for composting. This value is realistic for the hotel, where guests and the restaurant generate a significant portion of organic waste, while also accounting for practical limitations such as contamination, incomplete degradation, and moisture loss during the composting process. Although 30.3% does not represent the majority of the waste mass, it is still a meaningful contribution to reducing landfill disposal. It can significantly reduce methane emissions associated with anaerobic decomposition and can create compost that will be beneficially reused.

### **5.7.3 Incineration potential and energy recovery**

According to the U.S. Environmental Protection Agency (EPA), energy recovery from waste involves converting non-recyclable waste into usable heat, electricity, or fuel through controlled processes such as incineration (EPA, 2025). However, not all waste fractions are suitable for incineration for energy recovery. Metals and glass are excluded because they are non-combustible. Hazardous waste is also excluded from incineration due to potential risks to human health and the environment and must be processed separately. Therefore, the following waste fractions should be considered for incineration: paper, plastic, cardboard, food waste, yard waste. It is assumed that 100% of the combustible waste is incinerated

$$\text{Incinerated paper} = 29886 \text{ kg}$$

$$\text{Incinerated plastic} = 9555 \text{ kg}$$



*Incinerated cardboard* = 6554 kg  
*Incinerated food waste* = 43266 kg  
*Incinerated yard waste* = 3496 kg

$$\text{Incineration potential} = \frac{(\text{Incinerated paper} + \text{Incinerated plastic} + \text{Incinerated cardboard} + \text{Incinerated food waste} + \text{Incinerated yard waste}) * 0.8}{\text{Total weight of SW}}$$

$$\text{Incineration potential} = \frac{29886 + 9555 + 6554 + 43266 + 3496}{117405} = \frac{92757}{117405} * 100\% = 79\%$$

The incineration potential of hotel waste is estimated at 79%. This relatively high value demonstrates the large share of combustible materials within the waste composition. Such a result suggests that incineration could play a major role in reducing landfill disposal.

The energy recovered from the burned materials can now be calculated. To do this, the materials' heating values must be known. According to the Japan International Cooperation Agency (JICA, 2023) the heating value for paper is 16747 kJ/kg, for plastic 32564 kJ/kg, and for cardboard 16282 kJ/kg. The values are also presented in Figure 5.7.3

| No. | Component       | Heating value (KJ/kg) |                | Heating value (Cal/g) |                |
|-----|-----------------|-----------------------|----------------|-----------------------|----------------|
|     |                 | Range                 | Specific value | Range                 | Specific value |
| 1   | Food            | 3,489 – 6,978         | 4,652          | 837 – 1,675           | 1,116          |
| 2   | Paper           | 11,630 – 18,608       | 16,747         | 2,791 – 4,466         | 4,019          |
| 3   | Carton          | 13,956 – 17,445       | 16,282         | 3,349 – 4,187         | 3,908          |
| 4   | Plastic         | 27,912 – 37,216       | 32,564         | 6,699 – 8,932         | 7,815          |
| 5   | Textile         | 15,119 – 18,608       | 17,445         | 3,629 – 4,466         | 4,187          |
| 6   | Rubber          | 20,934 – 27,912       | 23,260         | 5,024 – 6,699         | 5,582          |
| 7   | Leather         | 15,119 – 19,771       | 17,445         | 3,629 – 4,745         | 4,187          |
| 8   | Garden waste    | 2,326 – 18,608        | 6,513          | 558 – 4,466           | 1,563          |
| 9   | Wood            | 17,445 – 19,771       | 18,608         | 4,187 – 4,745         | 4,466          |
| 10  | Glass           | 116 – 223             | 140            | 28 – 54               | 34             |
| 11  | Tin can         | 233 – 1163            | 689            | 56 – 279              | 165            |
| 12  | Other metals    | 233 – 1163            | 689            | 56 - 279              | 165            |
| 13  | Dust, ash, etc. | 2,326 – 11,630        | 6978           | 558 – 2,791           | 1,675          |
| 14  | MSW (mixture)   | 9,304 – 13,956        | 11,630         | 2,233 – 3,349         | 2,791          |

Source: Tchobanoglous et al., 1993.

**Figure 5.7.3** Heating values of MSW components

The heating values of food waste and yard waste are taken from Figure 5.7.4. The value for food waste is 1800 Btu/lb, which equals 4187 KJ/kg. The value for yard waste is 2600 Btu/lb, which

equals 6048 KJ/kg. The lower heating values of food waste and yard waste compared to paper, plastic and cardboard can be explained by high moisture content.

**Table 2-8 Heat Values of Some Refuse Components**

| Component        | As Collected | Btu/lb        |                        |
|------------------|--------------|---------------|------------------------|
|                  |              | Moisture-Free | Moisture- and Ash-Free |
| Cardboard        | 7040         | 7400          | 7840                   |
| Food waste       | 1800         | 6000          | 7180                   |
| Magazines        | 5250         | 5480          | 7160                   |
| Newspapers       | 7980         | 8480          | 8610                   |
| Paper (mixed)    | 6800         | 7570          | 8050                   |
| Plastics (mixed) | 14,100       | 14,390        | 16,020                 |
| HDPE             | 18,700       | 18,700        | 18,900                 |
| PS               | 16,400       | 16,400        | 16,400                 |
| PVC              | 9750         | 9770          | 9980                   |
| Steel cans       | 0            | 0             | 0                      |
| Yard waste       | 2600         | 6500          | 6580                   |

**Figure 5.7.4** Heat values of some refuse components

Thus, the recovered energy can be calculated as followed:

$$\text{Energy from incinerated paper} = 29886 * 16747 = 500500842 \text{ KJ}$$

$$\text{Energy from incinerated plastic} = 9555 * 32564 = 311149020 \text{ KJ}$$

$$\text{Energy from incinerated cardboard} = 6554 * 16282 = 106712228 \text{ KJ}$$

$$\text{Energy from incinerated food waste} = 43266 * 4187 = 181154742 \text{ KJ}$$

$$\text{Energy from incinerated yard waste} = 3496 * 6048 = 21143808 \text{ KJ}$$

$$\text{Total energy} = 500500842 + 311149020 + 106712228 + 181154742 + 21143808 = 1120660640 \text{ KJ} = 1120660 \text{ MJ}$$

Thus, 1120660 MJ of energy can be recovered from hotel waste, which equals 311294 kWh.

## 5.8 Waste management plan

In our hotel mainly three waste management options to be utilized: recycling, composting and incineration. This order of methods is consistent with the EPA's Waste Management Hierarchy

shown in Figure 5.8(EPA, 2025). These waste management methods are widely used in modern hotel complexes as they align with sustainable development goals. Instead of ending up in landfills, waste is recycled, biodegraded, or converted into energy.

Landfill disposal should be considered a last resort as it is the least effective and causes the greatest harm to the environment if it is not engineered according to the local standards. It requires large areas of land and leads to the irreversible loss of materials and energy that could otherwise be recovered through recycling, composting, or incineration.



**Figure 5.8** EPA Waste Management Hierarchy

All waste collected from the hotel and restaurant will be stored in a separate area in the rear yard, as in accordance with Title 16 of the New York City Administrative Code and applicable Health and Building Code provisions. It states that commercial establishments are required to provide designated refuse storage areas that prevent litter, odor, and pest infestation and allow proper collection by licensed private haulers.

Our hotel will align with EPA Waste Management Hierarchy and thus will sort garbage to allocate it to recycling, composting, incinerating and landfilling according to relevant potentials.

#### 1. Recycling

Recyclable waste (25572 kg/year) will be collected in blue bins across the hotel and restaurant. (4 **gallon** bins are located in guest rooms, boutiques, offices, restaurant; 12 **gallon** bins in public areas) and then will be stored in a 1 **cubic yard** container in the rear yard. Private carter will arrive at 8AM according to the waste collection schedule (3 days/week: Tue-Thu-Sat) and collect recyclable waste. Private carter then is responsible for transporting recyclables to Material Recovery Facility, such as Sims Municipal Recycling in Brooklyn where waste will be further

sorted, cleaned, compacted and sold to manufacturers as secondary raw materials. As the result, 21.8% of the total waste will be recycled, according to recycling potential.

Moreover, additional containers in public areas will be provided for e-waste and hazardous waste, to be transported by licensed haulers to special facilities, which are listed at DSNY official website. Since e-waste and hazardous waste accumulate more slowly than regular waste, they are not collected on a daily basis but are stored in designated area in the rear yard, to be further removed by licensed specialized contractors.

## 2. Composting

Since composting is one of the best options for dealing with organic waste, on-site composting will be organized in the hotel. To do on-site composting our hotel will follow regulations regarding the sanitation rules. They state that the composting apparatus must be installed on an impermeable surface away from guest areas. Regular monitoring and hygiene practices are required to prevent odor, flies and environmental contamination. Thus, composting will be done in the rear yard waste area with a purchased TMK-200 Kitchen Waste Compost Machine, with capacity 200 kg/day, which is twice as enough to cover the daily production of organic waste. The machine uses deodorization technique to control odors, which helps to comply with sanitation requirements for on-site composting. This organic waste composting machine operates silently at just 20 dB, and thus will not disturb hotel and restaurant guests.



**Figure 5.8.1** TMK-200 Kitchen Waste Compost Machine



**Figure 5.8.2** Scheme of composting process

Waste at first will be collected in brown bins(4 **gallon** bins are located in guest rooms, boutiques, offices, restaurant; 12 **gallon** bins in public areas) and then will be stored in a **95 gallon** container in the rear yard before composting. After composting, 30.3% of the total waste will be transformed into compost, with reduced waste volume up to 90% and might be used for roof gardens or might be donated. The waste composting machine installed in the hotel helps mitigate climate change by eliminating the production of methane that contributes to climate change.

### 3. Incineration & landfilling

Incineration is applied only to the residual waste that cannot be recycled or composted. This refers to general waste that includes non-recyclable and non-biodegradable combustible materials, such as contaminated plastics and mixed packaging. General waste will be collected in black bins(4 **gallon** bins are located in guest rooms, boutiques, offices, restaurant; 12 **gallon** bins in public areas) and then will be stored in a **1 cubic yard** container in the rear yard. Private carter will collect general waste 7 days a week at 9 AM and transport it to incineration plant, such as Reworld Hempstead. After all possible energy is recovered, all ashes and inert waste will be transported to landfill, with reduced volume up to 85%.

**Table 5.8** Summary of waste management plan

| Waste component | Total, kg/year | Recycling, kg/year | Composting, kg/year | Incineration/landfill, kg/year |
|-----------------|----------------|--------------------|---------------------|--------------------------------|
|-----------------|----------------|--------------------|---------------------|--------------------------------|

|                 |        |       |       |                |
|-----------------|--------|-------|-------|----------------|
| Paper           | 29886  | 20382 | -     | 9504           |
| Food            | 43266  | -     | 33315 | 9951           |
| Glass           | 13112  | 3278  | -     | 9834(landfill) |
| Plastic         | 9555   | 831   | -     | 8724           |
| Yard waste      | 3496   | -     | 2203  | 1293           |
| Metal           | 3169   | 1081  | -     | 2088(landfill) |
| Hazardous waste | 99     | -     | -     | -              |
| Cardboard       | 6554   | -     | -     | 6554           |
| Other           | 8268   | -     | -     | 8268           |
| Total           | 117405 | 25572 | 35518 | 56216          |

## 5.9 Waste collection plan

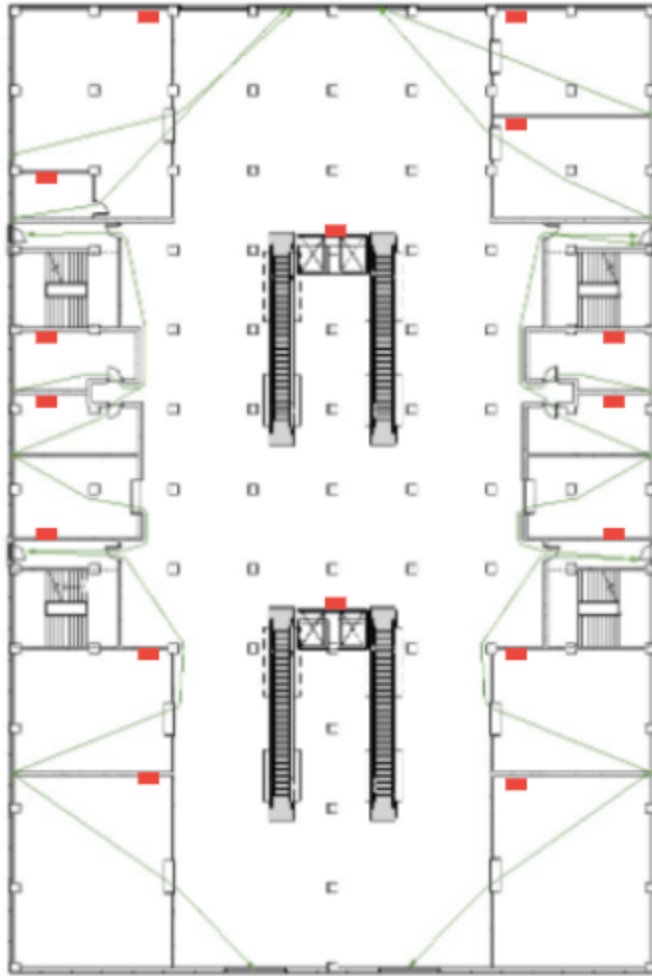
The hotel will implement a separated waste collection system to promote recycling efficiency and regulatory compliance. Guest rooms, offices, boutiques will be equipped with separated, color-coded **4 gallon** waste bins(Figure 5.9.1) to allow guests to distinguish between recyclables, organics and general waste.



**Figure 5.9.1** Coloured bins

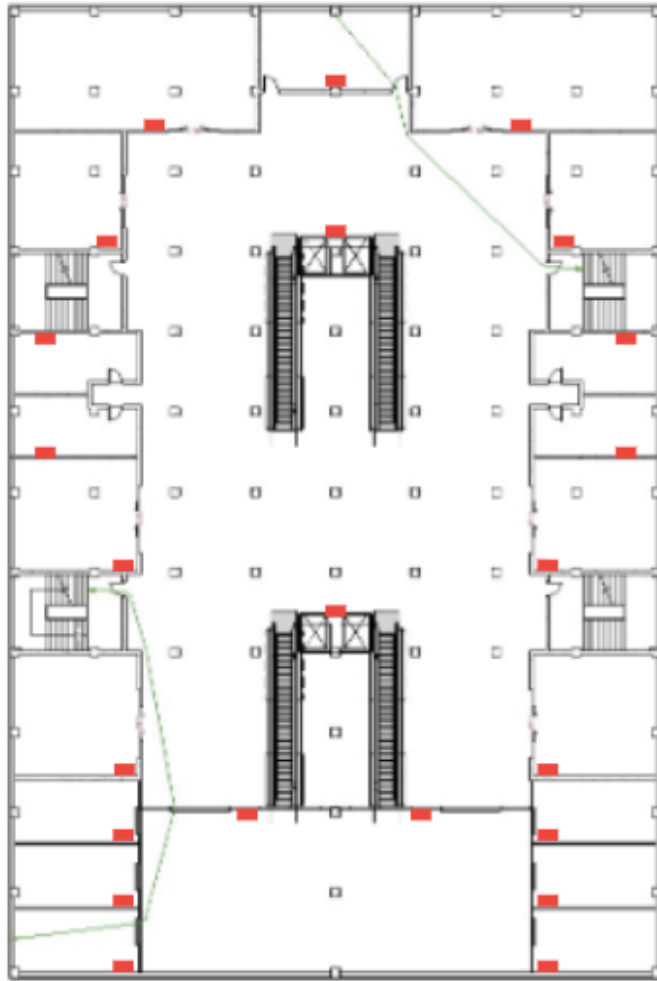
Public areas will contain larger, separated 12 gallon bins to accommodate higher waste volumes of waste in high-traffic zones such as zones beside elevators and escalators.

All waste bins will be placed in accordance with the 2022 NYC Fire Code, NYC Building Code, and regulations of the New York City Department of Sanitation (DSNY). The main requirement is to keep emergency paths available. The Figures 5.9.2 - 5.9.4 demonstrate the layout of the hotel's floors with green lines showing emergency paths. Red boxes represent the combination of three separated coloured bins.



**Figure 5.9.2** Waste Collection Points Layout 1st floor





**Figure 5.9.3** Waste Collection Points Layout 2nd floor



**Figure 5.9.4** Waste Collection Points Layout 3-5 floors



**Figure 5.9.4** Waste Collection Points Layout 6-9 floors

Garbage will be collected twice a day, at 12AM and 9PM to be transported to the waste collection area in the rear yard, where waste is stored in larger separated containers. Recyclables and general waste is collected by private carter to be transported to recycling and incineration plants respectively according to the schedule.

Internal waste collection and transportation to the storage area will be managed by 2 designated waste managers per shift, while guest room, boutiques and offices waste removal will be integrated into routine housekeeping operations.

**Table 5.9** Summary of waste collection plan

| Floor | Type of waste | Color of bin | Number of 4 gal bin | Number of 12 gal bin | Collection time | Storage container |
|-------|---------------|--------------|---------------------|----------------------|-----------------|-------------------|
| 1     | Recyclable    | blue         | 13                  | 3                    | 12 AM/ 9 PM     | 1 cy              |
|       | Composting    | brown        | 13                  | 3                    | 12 AM/ 9 PM     | 95 gal            |
|       | Incineration  | black        | 13                  | 3                    | 12 AM/ 9 PM     | 1 cy              |
| 2     | Recyclable    | blue         | 21                  | 2                    | 12 AM/ 9 PM     | 1 cy              |
|       | Composting    | brown        | 21                  | 2                    | 12 AM/ 9 PM     | 95 gal            |
|       | Incineration  | black        | 21                  | 2                    | 12 AM/ 9 PM     | 1 cy              |
| 3-5   | Recyclable    | blue         | 18                  | 2                    | 12 AM/ 9 PM     | 1 cy              |
|       | Composting    | brown        | 18                  | 2                    | 12 AM/ 9 PM     | 95 gal            |
|       | Incineration  | black        | 18                  | 2                    | 12 AM/ 9 PM     | 1 cy              |
| 6-9   | Recyclable    | blue         | 8                   | 1                    | 12 AM/ 9 PM     | 1 cy              |
|       | Composting    | brown        | 8                   | 1                    | 12 AM/ 9 PM     | 95 gal            |
|       | Incineration  | black        | 8                   | 1                    | 12 AM/ 9 PM     | 1 cy              |

### 5.10 Integrated solid waste management plan

The goal of our integrated solid waste management plan is to maximize the composting of food waste by increasing the composting rate from 77% to 90%. Several reasons support the feasibility of achieving this goal. Firstly, the hotel guests and restaurant generate large quantities of food waste on a daily basis, making composting a highly relevant and impactful strategy. Secondly, the installed composting machine in the rear yard can allow processing of increased volumes of organic waste, without purchasing additional equipment. Thirdly, the presence of a

rooftop garden creates a direct use for the produced compost, establishing a closed-loop system in which waste is converted into a valuable resource.

In order to achieve the composting rate of 90%, several measures will be implemented. For example: improving source separation of organic waste through staff training, reducing contamination from non-compostable materials, and optimizing the operation of the composting system. Moreover, awareness programs for hotel guests will be launched to encourage proper waste segregation.

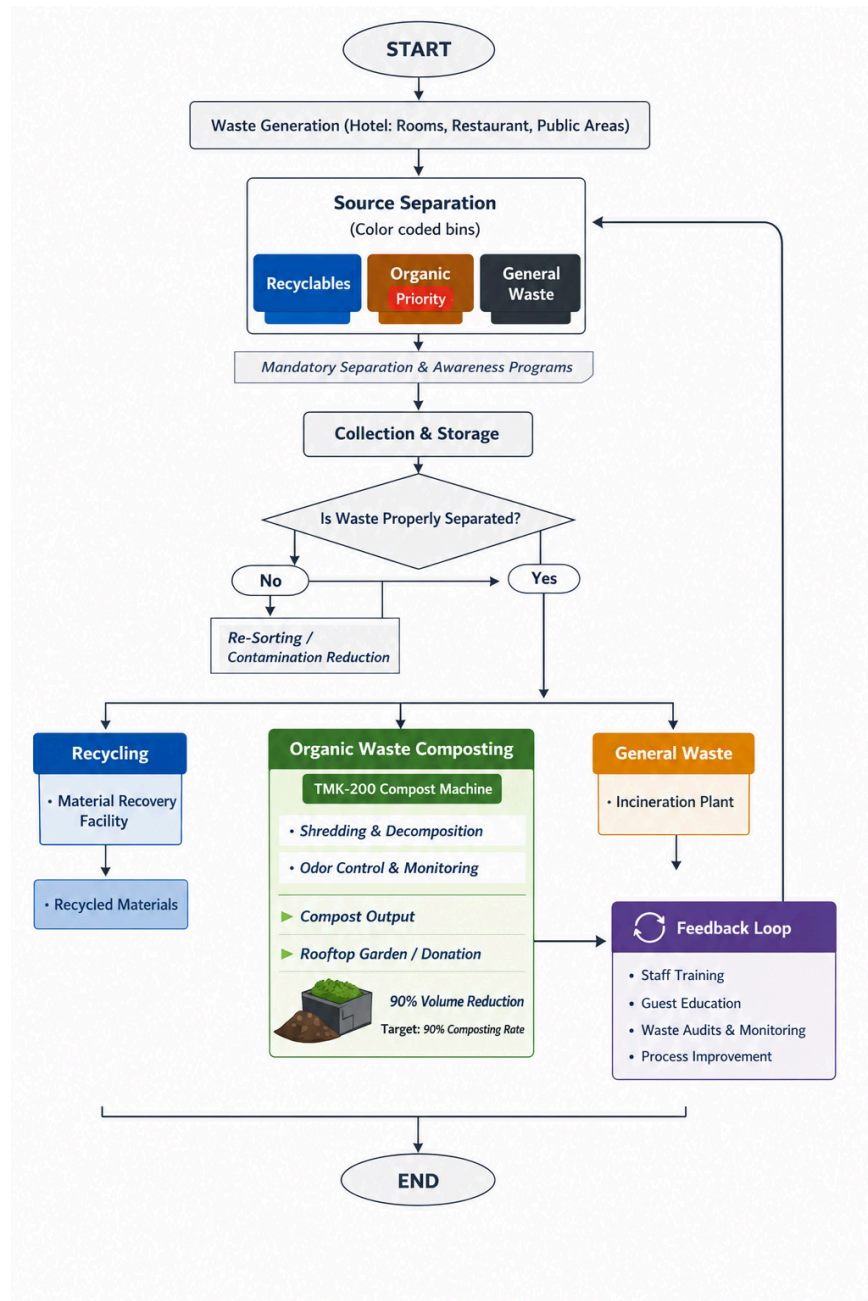
The summary of rules to be implemented for maximizing composting rate:

- Conduct mandatory staff training on proper separation of organic waste, especially for kitchen personnel..
- Increase the number and accessibility of organic waste bins in all waste generation areas.
- Ensure full capture of food waste by prohibiting its disposal in general waste bins.
- Utilize the full processing capacity of the on-site composting machine.
- Monitor composting performance through regular waste audits and data tracking.
- Maintain contamination levels below target thresholds (e.g., <5%) to ensure compost quality.
- Implement monthly evaluation of composting rates and system performance.
- Introduce awareness programs and signage to guide staff and guests in proper waste sorting

A real-world example of successful composting prioritizing waste management can be observed in hotel systems in San Diego (Carvalho, 2014). Several large hotels in San Diego applied a city-supported food waste composting program, where organic waste from kitchens and restaurants was separately collected and sent to composting facilities. The program required strict source separation, staff training, and contamination control (typically below 1%). As a result, hotels increased their waste diversion rates, even achieving over 80% diversion from landfill .

This example proves that with proper waste separation, staff training, and dedicated collection systems, hotels can successfully prioritize composting and thus reduce landfill dependency.

The whole process of the waste management plan, with the goal of maximizing composting, is shown on the following flowchart on Figure 5.10.



**Figure 5.10** Waste Management Flowchart

### 5.11 Operational finances of waste management plan

In order to evaluate the economic feasibility of our waste management plan, it is necessary to estimate both capital expenditures (CAPEX) and operational expenditures (OPEX). These two components will provide an understanding of the total cost associated with the waste management system in the hotel. Capital expenditures correspond to the initial investments,

whereas operational expenditures represent the ongoing annual costs that are necessary for continuous operation of the system.

### **5.11.1 Capital expenditures**

Capital expenditures include all initial one-time costs associated with the purchase, installation, and implementation of the waste management system components. These costs occur at the start of the project and then are later distributed over time through depreciation.

#### *Bins and Containers*

As it was mentioned earlier, bins and containers of different sizes and color are needed to be purchased to enable effective waste separation by both staff members and guests.

For our hotel, plastic containers were selected instead of metal alternatives due to several practical and economic advantages. Firstly, plastic containers are much more economical, making them suitable for mass use throughout the hotel. Secondly, plastic bins are resistant to corrosion, which is particularly important in the environment containing liquids or organic material from waste. In addition, plastic containers are lighter than metal ones, making them easier to use and reducing the physical strain on staff during daily work. Thus, despite the lower cost, modern plastic containers are quite practical and durable, making them suitable for their intended use.

Unit prices shown on Table 5.11.1 for all container types were obtained from major US retail platforms such as Amazon, Walmart and others. These sources provide a reliable representation of current market prices and ensure that cost estimates are realistic and verifiable.

#### *Composting System*

To support the project's objective of maximizing composting amounts of waste, an on-site composting system needs to be purchased. According to Green Planet Solutions the price of composting machines depends on the country (e.g 18000-55000\$ in Canada) and the processing capacity, which can vary from 50 to 2000 kg/day. On the grounds that we are using a TMK-200 Kitchen Waste Compost Machine with the capacity 200 kg/day, which is considered to be small-scale commercial composting equipment, it would be reasonable to take 22500\$ as unit price. Retailer informs that the price includes: equipment purchase, installation and basic operational training.

#### *Awareness Program*

Since the effectiveness of the waste management system strongly depends on user participation, it is important to make sure that both guests and staff follow waste separation rules. Therefore,

an awareness program is introduced as part of the system design. This program includes: informational posters placed in guest rooms and common areas, along with an awareness video displayed on in-room televisions and staff communication systems.

These measures are designed to provide clear waste sorting instructions, reduce contamination of recyclable materials, and contribute to the goal of maximizing composting. The use of both visual and digital communication tools ensures information is accessible and consistently reinforced.

### *Staff Training*

In addition to general awareness, specialized training is required for waste management personnel. Waste managers are responsible for controlling the system, monitoring waste streams, and ensuring compliance with established procedures.

Training is assumed to be conducted through online professional courses, which offer a cost-effective and flexible solution. For example, Solid Waste Association of North America(SWANA) offers "Managing Integrated Solid Waste Management Systems" online courses for the price of 400\$ per person. This approach allows staff to acquire the necessary knowledge for efficient management of the system.

The summary of all capital expenses is summarized in Table 5.11.1.

**Table 5.11.1.** CAPEX summary

| Item                                     | Quantity | Unit Cost (\$)                       | Total Cost (\$) |
|------------------------------------------|----------|--------------------------------------|-----------------|
| 4-gallon bins                            | 360      | 11(Amazon, n.d.)                     | 3960            |
| 12-gallon bins                           | 45       | 26(Walmart, n.d.)                    | 1170            |
| 1 cubic yard containers                  | 2        | 1259(WebstaurantStore, n.d.)         | 2518            |
| 95-gallon container                      | 1        | 286(Amazon, n.d.)                    | 286             |
| Composting system(installation included) | 1        | 22500(Green Planet Solutions, 2025)  | 22500           |
| Awareness posters                        | 86       | 10                                   | 860             |
| Awareness video                          | 1        | 1000(Vidico, 2026)                   | 1000            |
| Staff training                           | 2        | 400(Solid Waste Association of North | 800             |

|             |  |                        |       |
|-------------|--|------------------------|-------|
|             |  | America [SWANA], n.d.) |       |
| Total CAPEX |  |                        | 33094 |

### 5.11.2 Operational expenditures

Operating expenses represent the annual costs associated with the operation and maintenance of a waste management system. In this analysis, operating expenses also include depreciation, allowing capital investments to be expressed as equivalent annual costs. Thus, such an approach provides a more accurate representation of the system's overall annual financial burden.

#### *Waste Collection Costs*

Waste collection and transportation are handled by a private hauler, who enters into a contract that specifies the cost of services. These costs are typically expressed per ton, a standard approach in waste management analysis. Based on industry data and typical values in the US, the following waste disposal prices can be estimated: household waste is valued at \$100 per ton; recyclables are valued at \$30 per ton. The higher cost for general waste occurs due to the fact that the waste has no economic value and requires paid disposal. In contrast, recyclable materials have a recoverable value and thus it can offset part of the treatment cost. As a result, the net cost associated with recyclables is typically lower and may include only collection and transportation charges in service contracts.

#### *Maintenance Costs*

Maintenance costs are associated with the composting system, which requires periodic servicing to operate properly. These include: replacement of consumable components, routine inspection, minor repairs. Based on Green Planet Solutions data, maintenance costs are estimated as 3% of the capital cost of the composting machines. This percentage reflects typical values for small-scale equipment.

#### *Utilities*

Utility costs also must be included in operational expenses calculations, which typically include expenses associated with the consumption of water and electricity. Water and electricity are required for cleaning of bins, operation of composting equipment, and other supporting functions. Given the relatively small scale of the system, these costs are assumed to be \$300 per year.

#### *Labor Costs*



Labor costs correspond to the salary of designated waste management personnel. The average salary of a waste manager in New York City is reported to be 103634\$ per year (Indeed, n.d.).

### *Depreciation*

Depreciation is used to represent the gradual reduction in value of capital assets over time.

The straight-line depreciation method is applied:

$$\text{Annual Depreciation Expense} = \frac{\text{Purchase Cost} - \text{Salvage value}}{\text{Estimated Useful Life}}$$

Here, a zero salvage value is assumed for all components, as they are expected to have no residual value at the end of their useful life due to wearing off and technological obsolescence.

Bins and containers:

$$\text{Annual Depreciation Expense} = \frac{7934 - 0}{10} = 793\$$$

Composting system:

$$\text{Annual Depreciation Expense} = \frac{22500 - 0}{10} = 2250\$$$

Awareness program:

$$\text{Annual Depreciation Expense} = \frac{1860 - 0}{10} = 186\$$$

The results of OPEX calculations are summarized in the Table 5.11.2.

**Table 5.11.2.** OPEX summary

| Category                     | Calculation                             | Annual Cost (\$) |
|------------------------------|-----------------------------------------|------------------|
| General waste collection     | $56.2 \times 100\$/\text{ton}$          | 5620             |
| Recyclables collection       | $25.6 \times 30\$/\text{ton}$           | 768              |
| Maintenance(compost system)  | 3% of CAPEX Cost                        | 675              |
| Utilities(water+electricity) | Assumed                                 | 300              |
| Labor(wages)                 | Staff number (2) $\times$ 103433\$/year | 206866           |
| Bins & containers            | Depreciation formula                    | 793              |

|                                                 |                      |        |
|-------------------------------------------------|----------------------|--------|
| Depreciation                                    |                      |        |
| Composter Depreciation                          | Depreciation formula | 2250   |
| Awareness programme Depreciation(video+posters) | Depreciation formula | 186    |
| Miscellaneous(unforeseen costs)                 | Assumed              | 200    |
| TOTAL OPEX                                      |                      | 217658 |

### 5.11.3 Revenue

To offset operational costs, potential revenue streams are considered. In this case, the sources of income are the sale of recyclable materials and the sale of compost. Revenue from recyclables has been calculated in a previous section and is equal to 944\$ per year. In case of revenue from compost, the current composting rate of 77% produces approximately 35.5 tons of compost per year. It is assumed that 70% of this compost( 24.85 tons per year), can be sold, while the remaining 30% (10.65 tons per year) is utilized on-site for rooftop gardening purposes. A price of \$40 per ton is assumed, which lies within typical market ranges for bulk compost products. Thus, total revenue from compost equals 994\$ per year. Thus, the total revenue is 1938\$ per year.

### 5.11.4 Total annual cost

The overall financial performance of the system is evaluated by calculating the total annual cost:

$$\text{Total Annual Cost} = \text{Total OPEX} - \text{Revenue}$$

$$\text{Total Annual Cost} = 217658 - 1938 = 215720\$$$

This value represents the net cost required to operate the system on an annual basis, taking into account both expenses and income streams.

## 6. Construction Management

### 6.1 Project Charter

The Project Charter is presented in the form of a table to show all essential information about our project, outlining its key dates and major characteristics.

**Table 6.1.1.** Project Charter

| Project Overview   |                                                                                                                                                                                                                                                                                                                                                                                                       |                    |               |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|---------------|
| <b>Title</b>       | Design of the Multi-story Hotel Building in a Strong Wind Zone in New York City, New York, USA                                                                                                                                                                                                                                                                                                        |                    |               |
| <b>Description</b> | The project is a multi-story hotel building in a strong wind zone. The hotel is named “Adzharat” and it has 9 floors, 1-storey basement. The exact address of the hotel is 135-17 140 <sup>th</sup> St, New York City, NY 11436, USA. The site is located near JFK International Airport. There is a Baisley Pond Park, several restaurants, shops, ship centers, and banks near the chosen location. |                    |               |
| <b>Start Date</b>  | August 2025                                                                                                                                                                                                                                                                                                                                                                                           | <b>Finish Date</b> | December 2027 |
| <b>Purpose</b>     | The main goal of this project is to design and construct a 9-storey hotel in a strong wind zone. The project has to comply with the standards and regulations of the New-York City. Additionally, energy-efficient and environmentally-friendly systems should be considered during construction process to reduce long-term operational costs and maintain high guest comfort in the building.       |                    |               |

|                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                   |                 |
|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|-----------------|
| <b>Key Features</b>   | <ul style="list-style-type: none"> <li>• Number of floors: 9</li> <li>• 74 rooms</li> <li>• 1 storey basement</li> <li>• Fitness center, restaurant, kids' area, Lobby, Walmart, SPA included</li> <li>• Parking</li> </ul>                                                                                                                                                                                                                                                                                                                               |                   |                 |
| <b>Assumptions</b>    | <ul style="list-style-type: none"> <li>• It is not anticipated that environmental factors or regulations will change suddenly.</li> <li>• New York State labour and safety regulations will be adhered to during construction.</li> <li>• Weather-sensitive work will be scheduled for the best seasons, and major delays are not anticipated due to typical NYC weather.</li> <li>• It is assumed that skilled labour will be available for the duration of the project, so significant shortages impacting productivity are not anticipated.</li> </ul> |                   |                 |
| <b>Estimated Cost</b> | \$81,200,000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                   |                 |
| <b>Key Dates</b>      | <b>Stage</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <b>Start Date</b> | <b>End Date</b> |
|                       | Planning                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 25.08.2025        | 11.12.2025      |
|                       | Site Preparation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 12.12.2025        | 09.03.2026      |
|                       | Structural Work                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 10.03.2026        | 22.04.2027      |
|                       | Finishing                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 23.04.2027        | 23.11.2027      |
|                       | Project Finalization                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 24.11.2027        | 21.12.2027      |

|                         |                     |
|-------------------------|---------------------|
| <b>Team<br/>Members</b> | Tasmin Khairullina  |
|                         | Rassul Kaden        |
|                         | Adelina Muratova    |
|                         | Diana Mirtayeva     |
|                         | Zhangir Azhimuratov |
|                         | Akzhol Seitkhaliyev |
|                         | Akezhan Bolat       |

## 6.2 Feasibility Study

A feasibility study was carried out in the early phase of the project to evaluate its viability in terms of initial investment and expected benefits after completion. To determine it, site analysis, environment analysis, economic analysis, and risk assessment were conducted.

### 1. Site Analysis

The hotel is at 135-17 140th St, New York City, NY 11436, USA. It is close to JFK International Airport and has restaurants, shops, and services nearby. It is expected that both tourists and business travellers will be well served because major transportation options like the AirTrain and underground connect Manhattan and other boroughs. The hotel also includes a large parking area, its own restaurant, shops, coworking areas, and a library inside. Business travelers who might not have much time to go outside benefit from this as they will have the opportunity to conveniently work and live in the hotel area. The building gives an easy access for everything necessary to all of our tourists.

### 2. Environment

The New York City structures should be designed to resist large lateral forces and prolonged weather conditions since the city is located at the coast and therefore the buildings are exposed to high winds, heavy rain and storms. The project is in compliance with the Building Code of NYC requirements, such as the facade durability requirements and wind-load provisions.

The compliance with the regulations of the NYC Department of Buildings (DOB) guarantees stormwater management, erosion control, and construction pollution prevention. Other recommendations of the NYC Mayor Office of Climate and Environmental Justice back the idea of sustainable material choice and climate-resilient design. Besides, the rest of local regulations will be taken into account and followed corresponding to the NYC standards.

### 3. Economic

The project is expected to be funded by the use of private equity, bank loans or government incentives on the development of the project being green. Financial plan involves the amount of money that has been saved to take care of unforeseen expenses such as climatic change. Operating costs are sustainable efforts to reduce costs and comprise staffing, maintenance and utilities. Energy efficient technologies in the building should reduce the electricity bill by 1015 percent over the lifespan of the building.

The modern features and the location of the hotel close to JFK International Airport are set to maintain the occupancy rates of the hotel to be between 75-85 percent which is the normal occupancy rate in New York City. Room prices ought to be comparable to those of the nearby hotels. The ROI would be realized in a period of nine years, based on the business performance and industry performance.

### 4. Risk Assessment

New York City has stringent wind loads that should be considered in the building design. The building must be reinforced, wind braced and aerodynamic to ensure safety and compliance of codes.

Occupancy rates can be impacted when the economy is going down or when the amount of tourists and business travelers increase or decrease. A sober financial strategy is under consideration and then there are contingency plans that will be resorted to in case the money will not flow in.

Unstable weather, difficulty in acquiring materials, or the unavailability of skilled workers may be factors that may delay construction projects. An elaborate project management plan must encompass the means of addressing the risks, additional time schedule, and contract provisions that will contribute to the reduction of the risks and the time schedule keeping of the project within the planned timeline.

### 6.3 Cost Estimation

The preliminary costs were calculated using RS Means software.

|                                         |                          |                       |                         |
|-----------------------------------------|--------------------------|-----------------------|-------------------------|
| <b>\$48,900,555.45</b><br>Building Cost | NEW YORK, NY<br>Location | 9<br>Stories (Ea.)    | Yes<br>Basement         |
| \$336.02<br>Cost per S.F.               | 145,527<br>Floor Area    | 11.50<br>Story Height | \$0.00<br>Additive Cost |

**Figure 6.3.1.** Preliminary Cost Estimation using RS Means

**Table 6.3.1.** Cost Estimation

| Detailed Cost Estimation |               |
|--------------------------|---------------|
| Subtotal                 | \$ 35,000,000 |
| Substructure             | \$2,200,000   |
| Shell                    | \$16,800,000  |

|                                               |                     |
|-----------------------------------------------|---------------------|
| Interiors                                     | \$8,300,000         |
| Services                                      | \$14,600,000        |
| <b>Contractor Fees (GC, Overhead, Profit)</b> | <b>\$ 8,190,000</b> |
| <b>Architectural Fees</b>                     | <b>\$ 3,500,000</b> |
| <b>User Fees</b>                              | <b>\$ 1,400,000</b> |
| <b>Land Cost</b>                              | <b>\$3,370,000</b>  |
| <b>Total Building Cost</b>                    | <b>\$58,000,000</b> |
| <b>Inflation Rate</b>                         | <b>40%</b>          |
| <b>Total Building Cost with IR</b>            | <b>\$81,200,000</b> |

The cost of land was calculated using the nearest land on sale (<https://www.loopnet.com/>). It is located ~2.5 km from the chosen location for our project. The closest location on sale is 220-12 147th Ave, Springfield Gardens, NY 11413. It costs \$2,500,000, which is \$78.6 per square foot. Our chosen location is 42920 sq ft., which makes our cost of land equal to \$3,373,354.8

RS Means Software uses pricing data from 2018. Thus, when estimating construction costs, we should account for inflation. Since the inflation rate from 2018-2025 was around 40-45%, we used 40% as the inflation rate. Considering this, the final preliminary total building cost was  $48,471,682.10 * 1.40 = \$72,583,051.70$ .



**Table 6.3.2.** Payback Period Estimation

| <b>Year</b> | <b>ADR<br/>(\$/night)</b> | <b>Room<br/>Revenue<br/>(\$M)</b> | <b>Non-Room<br/>Revenue<br/>(\$M)</b> | <b>Operating<br/>Expenses<br/>(\$M)</b> | <b>Cumulative<br/>Revenue<br/>(\$M)</b> | <b>Remaining<br/>Cost Balance<br/>(\$M)</b> |
|-------------|---------------------------|-----------------------------------|---------------------------------------|-----------------------------------------|-----------------------------------------|---------------------------------------------|
| <b>1</b>    | 314                       | 7.15                              | 1.43                                  | 1.72                                    | 6.86                                    | –65.1                                       |
| <b>2</b>    | 339                       | 7.72                              | 1.54                                  | 1.85                                    | 14.27                                   | –57.7                                       |
| <b>3</b>    | 366                       | 8.33                              | 1.67                                  | 2.00                                    | 22.27                                   | –49.7                                       |
| <b>4</b>    | 396                       | 9.02                              | 1.80                                  | 2.16                                    | 30.93                                   | –41.1                                       |
| <b>5</b>    | 427                       | 9.72                              | 1.94                                  | 2.33                                    | 40.26                                   | –31.7                                       |
| <b>6</b>    | 448                       | 10.20                             | 2.04                                  | 2.45                                    | 50.06                                   | –21.9                                       |
| <b>7</b>    | 471                       | 10.72                             | 2.14                                  | 2.57                                    | 60.35                                   | –11.6                                       |
| <b>8</b>    | 495                       | 11.27                             | 2.25                                  | 2.71                                    | 71.17                                   | –0.83                                       |
| <b>9</b>    | 519                       | 11.82                             | 2.36                                  | 2.84                                    | 82.52                                   | <b>+10.5</b>                                |

As can be seen from the table 5.3.2, the payback period estimation was calculated considering several factors, such as ADR, room and non-room revenues and operating expenses. ADR reflects the cost of the room per one night, and it is expected to grow by 8% annually. The Non-Room Revenue includes the profit from restaurant, shops, SPA, and other non-room related services of our hotel. The payback period was estimated to be 9 years.

## 6.4 Schedule

### 6.4.1 Work Breakdown Structure

A Work Breakdown Structure (WBS) was developed for this project, as illustrated in Figure 5.3.1.2. It is organized into five main sections: Planning, Site Preparation, Structural Work, Finishing, and Project Finalization. Each section is further divided into subcomponents that outline the key tasks required throughout the project workflow.

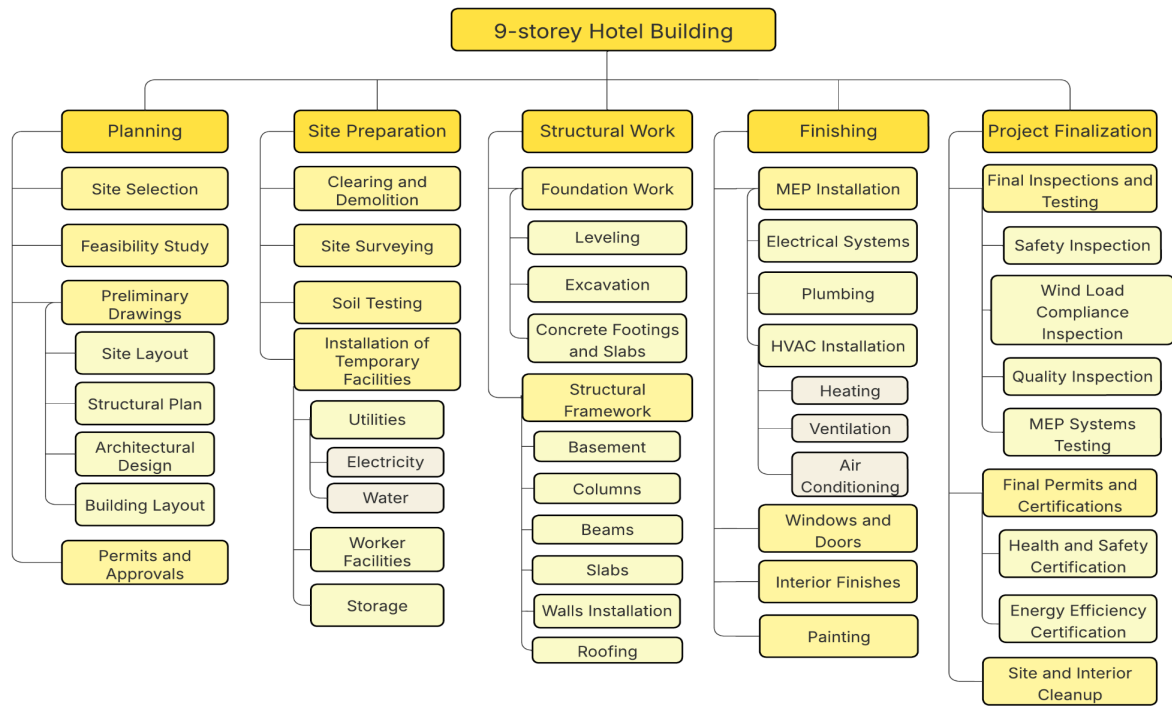


Figure 6.4.1.1. Work Breakdown Structure

## 6.4.2 Scheduling

The preliminary schedule was created using Microsoft Project.

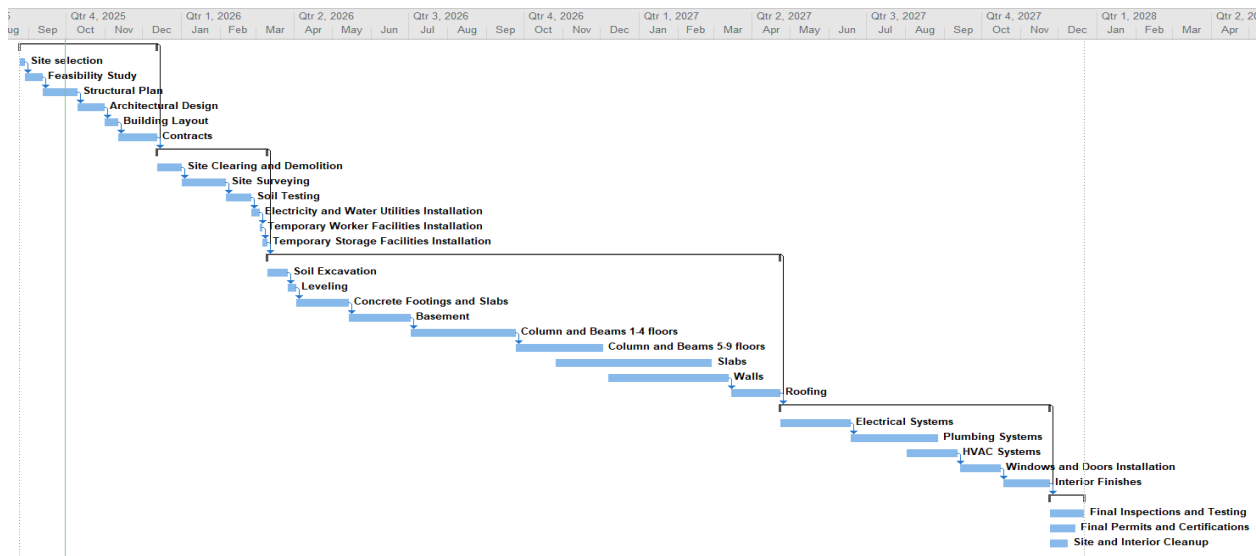


Figure 6.4.2.1. Schedule in Microsoft Project

| Название задачи                              | Duration        | Start               | Finish              |
|----------------------------------------------|-----------------|---------------------|---------------------|
| <b>Planning</b>                              | <b>79 days</b>  | <b>Mon 8/25/25</b>  | <b>Thu 12/11/25</b> |
| Site selection                               | 4 days          | Mon 8/25/25         | Thu 8/28/25         |
| Feasibility Study                            | 10 days         | Fri 8/29/25         | Thu 9/11/25         |
| Structural Plan                              | 20 days         | Fri 9/12/25         | Thu 10/9/25         |
| Architectural Design                         | 15 days         | Fri 10/10/25        | Thu 10/30/25        |
| Building Layout                              | 7 days          | Fri 10/31/25        | Mon 11/10/25        |
| Contracts                                    | 23 days         | Tue 11/11/25        | Thu 12/11/25        |
| <b>Site Preparation</b>                      | <b>62 days</b>  | <b>Fri 12/12/25</b> | <b>Mon 3/9/26</b>   |
| Site Clearing and Demolition                 | 14 days         | Fri 12/12/25        | Wed 12/31/25        |
| Site Surveying                               | 25 days         | Thu 1/1/26          | Wed 2/4/26          |
| Soil Testing                                 | 14 days         | Thu 2/5/26          | Tue 2/24/26         |
| Electricity and Water Utilities Installation | 5 days          | Wed 2/25/26         | Tue 3/3/26          |
| Temporary Worker Facilities Installation     | 2 days          | Wed 3/4/26          | Thu 3/5/26          |
| Temporary Storage Facilities Installation    | 2 days          | Fri 3/6/26          | Mon 3/9/26          |
| <b>Structural</b>                            | <b>293 days</b> | <b>Tue 3/10/26</b>  | <b>Thu 4/22/27</b>  |
| Soil Excavation                              | 12 days         | Tue 3/10/26         | Wed 3/25/26         |
| Leveling                                     | 5 days          | Thu 3/26/26         | Wed 4/1/26          |
| Concrete Footings and Slabs                  | 30 days         | Thu 4/2/26          | Wed 5/13/26         |
| Basement                                     | 35 days         | Thu 5/14/26         | Wed 7/1/26          |
| Column and Beams 1-4 floors                  | 60 days         | Thu 7/2/26          | Wed 9/23/26         |
| Column and Beams 5-9 floors                  | 50 days         | Thu 9/24/26         | Wed 12/2/26         |
| Slabs                                        | 90 days         | Mon 10/26/26        | Fri 2/26/27         |
| Walls                                        | 70 days         | Mon 12/7/26         | Fri 3/12/27         |
| Roofing                                      | 29 days         | Mon 3/15/27         | Thu 4/22/27         |
| <b>Finishing</b>                             | <b>153 days</b> | <b>Fri 4/23/27</b>  | <b>Tue 11/23/27</b> |
| Electrical Systems                           | 40 days         | Fri 4/23/27         | Thu 6/17/27         |
| Plumbing Systems                             | 50 days         | Fri 6/18/27         | Thu 8/26/27         |
| HVAC Systems                                 | 30 days         | Mon 8/2/27          | Fri 9/10/27         |
| Windows and Doors Installation               | 25 days         | Mon 9/13/27         | Fri 10/15/27        |
| Interior Finishes                            | 27 days         | Mon 10/18/27        | Tue 11/23/27        |
| <b>Project Finalization</b>                  | <b>20 days</b>  | <b>Wed 11/24/27</b> | <b>Tue 12/21/27</b> |
| Final Inspections and Testing                | 20 days         | Wed 11/24/27        | Tue 12/21/27        |
| Final Permits and Certifications             | 14 days         | Wed 11/24/27        | Mon 12/13/27        |
| Site and Interior Cleanup                    | 10 days         | Wed 11/24/27        | Tue 12/7/27         |

**Figure 6.4.2.2. Project Dates in Microsoft Project**

Project scheduling was done using the Microsoft Project as indicated in Figures 5.4.2.1 and 5.4.2.2. The most critical dates, time to be spent on the task, and dependencies associated with the project stage were identified and inputted into the scheduling software in a systematic manner. All the key construction stages such as Planning, Site Preparation, Structural Work, Finishing and Project Finalization were broken down into distinct activities with particular date of start and finish.

It was also indicated that some tasks would not start before they had their predecessor activities completed; an example being that Structural Work could not start before Site Preparation had

been completed. Meanwhile, overlapping of compatible activities was permitted like during the Finishing phase to save time and decrease the length of time of the whole project. This is used to maximize resource use and reduce potential economic losses from schedule delays. The gantt chart shows the logical flow of the work and interdependences between the tasks.

## 6.5 Risk Management

The risk management of the 9-story “Adzharat” business hotel in New York City included risk evaluation using the Modified Risk Matrix (MRM) method developed by Guo et al. (2021). In this method, the overall risk level is calculated using the formula:

$$R = L \times S$$

Where,

R - risk level;

L - likelihood of the risk;

S - severity of the consequence.

The Risk Assessment Table is shown below:

**Table 6.5.1.** Risk Assessment

| Category               |    | Risk                                                                                    | Likelihood<br>(1-5) | Severity<br>(1-5) | Risk<br>Level | Mitigation Strategy                                                                                                                                                |
|------------------------|----|-----------------------------------------------------------------------------------------|---------------------|-------------------|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Site and Environmental | E1 | Strong wind events causing structural or façade damage during construction or operation | 3                   | 5                 | 15            | Build the building according to the ASCE 7 wind loads requirements; apply the aerodynamic shaping, wind bracing and on-site wind measurements during construction. |
|                        | E2 | Soil instability or weak                                                                | 3                   | 4                 | 12            | Carry out extensive geotechnical surveys and                                                                                                                       |

|           |    |                                                                         |   |   |    |                                                                                                                                                                                                                                 |
|-----------|----|-------------------------------------------------------------------------|---|---|----|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|           |    | subgrade conditions affecting foundation performance                    |   |   |    | apply proper foundation designs (e.g. deep pile foundation, soil stabilization). Providing continuous observation during excavation is going to make sure that any settlement issues are early revealed.                        |
|           | E3 | Flooding or drainage issues                                             | 2 | 5 | 10 | Install adequate site grading, stormwater controls and waterproofing. Construct drainage systems to suit the specifications of NYC DEP and capacity to manage extreme weather runoff.                                           |
|           | E4 | Construction delays due to severe weather conditions (wind, rain, snow) | 4 | 3 | 12 | Establish a weather sensitive constructions schedule that contains built in float and temporary protective structures. Real-time weather-checks can be used to adapt the activities and ensure safety of workers and materials. |
| Financial | F1 | Cost overrun due to material                                            | 3 | 4 | 12 | Add a 10-15 percent contingency to the budget;                                                                                                                                                                                  |

|                    |    |                                                                                                        |   |   |    |                                                                                                                                                                   |
|--------------------|----|--------------------------------------------------------------------------------------------------------|---|---|----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                    |    | price escalation or regulatory changes                                                                 |   |   |    | use fixed-price contracts; and monitor the regulation and material markets regularly.                                                                             |
|                    | F2 | Funding Shortfalls                                                                                     | 2 | 5 | 10 | Create financial contingency fund and find varied sources of funds. Review cash-flow on a regular basis to readjust expenses before they get to a critical point. |
|                    | F3 | Reduced occupancy rates due to tourism fluctuations or economic downturn                               | 2 | 4 | 8  | Flexible pricing strategy, revenue mix (restaurant, spa, retail) and reinforced marketing partnerships and loyalty programs to stabilize occupancy.               |
| Design and Quality | D1 | Structural or façade design not adequately addressing wind loads, leading to redesign or safety issues | 2 | 5 | 10 | Conduct wind tunnel or CFD testing; have certified engineers peer review; make sure that NYC Building Code is adhered to.                                         |
|                    | D2 | Use of substandard or non-compliant                                                                    | 2 | 4 | 8  | Implement strict procurement controls, an approved vendor list, and                                                                                               |

|  |    |                                                                                 |   |   |   |                                                                                                                                           |
|--|----|---------------------------------------------------------------------------------|---|---|---|-------------------------------------------------------------------------------------------------------------------------------------------|
|  |    | materials due to supply issues or poor supervision                              |   |   |   | material inspection. To ensure compliance, demand documentation (certifications, test reports) and conduct random on-site quality audits. |
|  | D3 | Poor coordination among design disciplines leading to rework or schedule delays | 3 | 3 | 9 | Use Building Information Modeling (BIM); conduct multidisciplinary coordination meetings; conduct design audits periodically.             |

After completing the risk assessment table, the modified risk matrix was created.

|                      |                       | Severity Level    |              |                 |                |                 |
|----------------------|-----------------------|-------------------|--------------|-----------------|----------------|-----------------|
|                      |                       | 1<br>(Negligible) | 2<br>(Minor) | 3<br>(Moderate) | 4<br>(Serious) | 5<br>(Critical) |
| Level of Probability | 1<br>(Remote)         |                   |              | E4              |                |                 |
|                      | 2<br>(Unlikely)       |                   |              |                 | F3, D2         | E3, F2, D1      |
|                      | 3<br>(Likely)         |                   |              | D3              | E2, F1         | E1              |
|                      | 4<br>(Highly Likely)  |                   |              | E4              |                |                 |
|                      | 5<br>(Near Certainty) |                   |              |                 |                |                 |

**Figure 6.5.1** The Modified Risk Matrix

The risks were identified and divided into three general categories: Environmental, Financial, Design and Quality. Furthermore, to make risks specific, they were divided into subcategories such as E1, E2, E3, E4, F1, F2, F3, D1, D2, and D3. For each of them, appropriate mitigation strategies were identified to prevent serious consequences. The risks with higher probability and severity levels must be addressed immediately, and the prevention measures must be strictly followed. However, this does not necessarily mean that low levels of probability and severity should not be considered; each risk should be treated with the appropriate resource level based on its urgency and severity.

## 6.6 Quality Management

The 9 story New York hotel will adopt a systematic approach from design to construction. The Quality Management Plan will specify procedures and checklists, performance measures and other means of meeting industry and regulatory standards. Our quality management approach aims to achieve the best possible construction quality with as few defects as possible that could affect safety. The plan has been developed using the ISO 9001:2015, ASTM, ANSI and OSHA standards, and meets the SBC regulations.



## **6.6.1 Quality Control Measures**

### **1. Inspection and Testing of Materials**

Inspection and testing aim to ensure that all materials used in construction meet the construction specifications and generally accepted standards. Once the materials are delivered to the site, they should comply with relevant ASTM standards and meet minimum ANSI standards. Building materials, including steel, concrete, and wood, are tested in laboratories to ensure appropriate strength, lifespan and moisture content. They are also subject to quality control certificates from the supplier. If any materials do not meet the standards, they are either replaced or rejected to avoid construction flaws. This helps ensure the longevity and safety of the structure.

### **2. Workmanship Assessment**

Periodic workmanship assessments are made to ensure that construction activities comply with design specifications and other industry standards. Workmanship guidelines are in compliance with SBC and IBC. Non-conformance issues are reported and resolved in a timely manner. Third-party consultants may be employed to review critical stages of the construction, such as foundations and seismic bracing, for further quality control.

### **3. Non-Conformance Reporting (NCR)**

If quality criteria is not achieved, a Non-Conformance Report (NCR) is raised. Issues must be resolved within a specified period and checked by subsequent inspections. The project will also use continuous improvement methods by recording lessons learned from the NCRs and addressing them in future projects.

### **4. Subcontractor Quality Management**

So as to ensure a high level of quality on the project, subcontractors are required to provide their Quality Control Plans (QCPs) prior to starting work. Their work is reviewed on a weekly and monthly basis. Subcontractors who do not comply with quality standards must develop corrective action plans or be replaced.

### **5. Document Control**

Thorough and timely documentation is critical. An online document management system will be employed to store material test reports, inspection checklists, suppliers' certificates, and NCRs.

Document control procedures will be based on the ISO 9001:2015 framework to ensure that all documents are maintained and are available for audits or inspections.

6.6.2 Quality Metrics

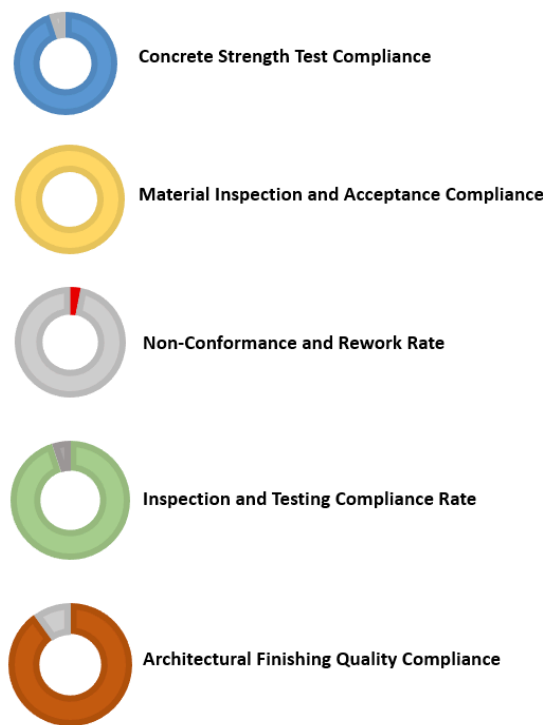


Figure 6.6.2 Quality Metrics

Table 6.6.2. Quality Metrics Description

| Metric Category                               | Description                                                                                                                 | Target          |
|-----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|-----------------|
| Material Inspection and Acceptance Compliance | Verifies that all construction materials conform to project specifications through site inspections and laboratory testing. | 100% compliance |
| Concrete Strength Test Compliance             | Confirms that structural elements such as concrete meet required strength,                                                  | 95% compliance  |

|                                            |                                                                                                                              |                                        |
|--------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|
|                                            | stability, and safety standards.                                                                                             |                                        |
| Inspection and Testing Compliance Rate     | Measures whether construction activities are completed according to the project schedule during quality control inspections. | $\geq 95\%$ of tasks completed on time |
| Architectural Finishing Quality Compliance | Ensures finishing works such as tiling, painting, and ceilings meet hotel quality standards                                  | $\geq 90\%$ compliance                 |
| Non-Conformance and Rework Rate            | Monitors the amount of work that must be redone due to errors or defects.                                                    | $\leq 3\%$ of total work               |

### 6.6.3. Quality Control Checklist

The checklist was developed based on the project's quality control requirements to ensure that the construction work is being performed in accordance with the design, material, and safety requirements. The checklist is shown in Figure 5.6.3 and matches the construction activities of the project. There are four phases to this checklist: pre-construction, structural construction, architectural and MEP, and final inspection. This is aligned with the construction process and ensures that key elements, particularly reinforced concrete structural elements, are inspected and verified.

## Hotel Construction Quality Control Checklist

### Project Information:

Project Name: Design of a 9-story “Adzharat” business hotel in New York City, USA  
Location: 135-17 140th St, New York City, NY 11436, USA  
Project Manager: Akzhol Seitkhaliyev  
Inspection Team: Tasmin Khairullina, Rassul Kaden, Adelina Muratova  
Inspection Date: 02.03.2026

#### Phase 1: Pre-Construction Quality Control Site Preparation

- Verify site clearing, demolition, and removal of debris
  - Confirm site leveling according to approved grading plan
  - Check soil conditions match geotechnical investigation report
  - Verify site access for construction equipment
- #### Structural Preparation
- Review structural drawings and specifications
  - Confirm material specifications for concrete and reinforcement
  - Verify contractor qualifications and approvals
  - Check layout marking matches structural plans

#### Phase 2: Structural Construction Quality Control Foundation Works

- Verify excavation depth and dimensions
- Inspect reinforcement placement according to structural drawings
- Check formwork stability and alignment
- Verify concrete mix design and strength grade
- Inspect concrete pouring and compaction
- Confirm proper curing procedures

#### Columns, Beams, and Slabs

- Verify reinforcement size, spacing, and placement
- Inspect formwork alignment and verticality of columns
- Check beam and slab thickness according to structural design
- Monitor concrete pouring process
- Confirm curing time before removing formwork

#### Structural Stability and Alignment

- Check vertical alignment of columns
- Verify slab levelness
- Inspect structural connections
- Confirm no cracks or structural defects

#### Phase 3: Architectural and MEP Quality Control Walls and Exterior

- Inspect wall installation and alignment
- Check waterproofing installation
- Verify roofing installation quality

#### Mechanical, Electrical, Plumbing (MEP)

- Inspect HVAC system installation
- Verify plumbing installation and leakage testing
- Check electrical wiring installation
- Confirm compliance with safety standards

#### Interior Finishes

- Check drywall and partitions
- Inspect painting quality
- Verify flooring installation
- Inspect doors and windows installation

#### Phase 4: Final Inspection and Commissioning System Testing

- Test HVAC systems
- Verify plumbing system operation
- Test electrical systems
- Check fire safety systems

#### Final Quality Verification

- Inspect overall structural condition
- Ensure building meets design specifications

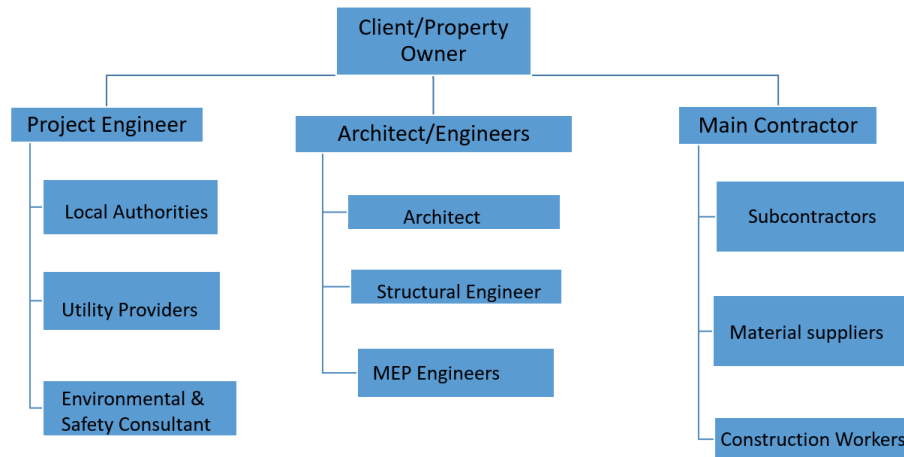
Figure 6.6.3 Quality Control Checklist

## 6.7. Procurement planning

### 6.7.1. Stakeholders Analysis

The stakeholder analysis has been undertaken to understand the relationships and hierarchy between all the stakeholders in the construction process. It facilitates the coordination and communication of all parties involved in the project, and helps to prevent problems and delays.

The pyramid structure has all the key players involved in the project from the property owner, project engineer and project management team down to the main contractor and subcontractors, as shown in the figure below.



**Figure 6.7.1 Stakeholders Hierarchy**

The owner of the project is the client/property owner, who is the primary financier, decision maker and ensures the project is delivered in accordance with the project objectives. The project engineer, architects and engineers, and main contractor are at the second level in the hierarchy. These stakeholders play a role in project planning, design, coordination and implementation of the construction works, and supervision of the stakeholders at the third level. The third level includes the supporting stakeholders such as local government, utilities, environmental and safety consultants, subcontractors, suppliers and workers who are involved in specific technical, regulatory and construction activities.

This hierarchy is used to create the stakeholder analysis table to classify stakeholders based on their roles, and levels of interest and influence. Interest defines the level of concern stakeholders have for the project outcome, while influence defines stakeholders' ability to influence project decisions and final outcomes. In general, stakeholders with greater interest and influence are involved with the project. The stakeholder analysis table is shown below.

**Table 6.7.1.** Stakeholders Analysis

| <b>Position of Stakeholder</b> | <b>Role in the Project</b>                                  | <b>Interest</b> | <b>Influence</b> |
|--------------------------------|-------------------------------------------------------------|-----------------|------------------|
| Client / Property Owner        | Project initiation, funding, decision-making                | High            | High             |
| Architect & Engineers          | Design of systems and structure                             | High            | Moderate         |
| Project Manager                | Manages communication, scope, and execution                 | High            | High             |
| Regulatory Authorities         | Permits granting, codes enforcement, safety compliance      | Moderate        | High             |
| Design Consultants             | Assistance with specialist aspects (interior, facade, etc)  | Moderate        | Moderate         |
| Main Contractor                | Responsible for overall construction works                  | High            | High             |
| Subcontractors                 | Performance of specific trades (plumbing, electrical, etc.) | Moderate        | Moderate         |
| Suppliers                      | Materials and equipment supply                              | Moderate        | Low              |
| Utility Providers              | Delivers electricity, water, gas, etc.                      | Low             | Moderate         |

|                            |                                                     |          |          |
|----------------------------|-----------------------------------------------------|----------|----------|
| Environmental Consultants  | Ensures that environmental regulations are followed | Moderate | Low      |
| Site Workers / Technicians | Execution of physical construction tasks            | Moderate | Low      |
| Legal Advisors             | Contracts and legal compliance management           | Moderate | Low      |
| Financial Advisors         | Budget monitoring and cost control                  | Moderate | Moderate |

## 6.8. Construction Safety

To maintain a safe construction environment, a construction safety risk register was prepared for this project. This register aims to identify the primary risks that may arise during the different stages of the project and the potential consequences for people, equipment and the site. Using this information, preventive and mitigation measures can be put into place to minimise the risk of accidents and enhance safety on the site. The table below shows the key construction safety risks identified for this project:

**Table 6.8.** Safety Risk Register

| Hazard type             | Likelihood (1-5) | Severity (1-5) | Risk Level | Control Measures                                         |
|-------------------------|------------------|----------------|------------|----------------------------------------------------------|
| Work at Elevated Levels | 4                | 5              | 20         | Safety training, full-body harnesses, secure scaffolding |

|                                                   |   |   |    |                                                          |
|---------------------------------------------------|---|---|----|----------------------------------------------------------|
| Slip and Fall Incidents                           | 3 | 3 | 9  | Clean walkways, warning signs, anti-slip surfaces        |
| Manual and Mechanical Material Handling Risks     | 3 | 4 | 12 | Lifting equipment, safe handling training                |
| Fire and Combustible Material Hazards             | 2 | 5 | 10 | Fire extinguishers, safe storage, smoking restrictions   |
| Structural or Foundation Instability              | 2 | 5 | 10 | Soil checks, reinforcement inspection, design compliance |
| Insufficient Use of Personal Protective Equipment | 3 | 4 | 12 | Mandatory PPE, regular site safety inspections           |
| Adverse Weather Conditions                        | 3 | 3 | 9  | Weather monitoring, hydration breaks, shaded rest areas  |
| Electrical Installation Hazards                   | 3 | 4 | 12 | Insulated tools, routine electrical checks               |
| Excessive Noise Exposure                          | 2 | 3 | 6  | Ear protection, noise control barriers                   |
| Caught-In / Caught-Between Hazards                | 4 | 4 | 16 | Restricted work zones, machine guarding, supervision     |
| Exposure to Harmful                               | 3 | 4 | 12 | Ventilation, protective                                  |



|                                       |   |   |    |                                                       |
|---------------------------------------|---|---|----|-------------------------------------------------------|
| Construction Substances               |   |   |    | masks, material handling guidance                     |
| Falling Tools or Materials            | 4 | 4 | 16 | Safety helmets, toe boards, secured storage           |
| Formwork or Temporary Support Failure | 3 | 5 | 15 | Formwork inspection, proper installation, supervision |

The risks identified were assessed using two criteria: likelihood and severity. Both criteria were scored from 1-5 and the overall risk score was obtained by multiplying these two values. As a result of this analysis, the following risks are judged to be the most critical for this project: work at heights, caught-in or caught-between, falling tools or materials, and formwork collapse. These need to be more closely controlled and monitored during construction.



**Figure 6.7.1** Hierarchy of Controls

In the context of this project, the hierarchy of controls has been used as a tool to guide the selection of effective control measures to address the identified risks. This hierarchy promotes the use of more effective and proactive strategies, like eliminating the hazard if possible or

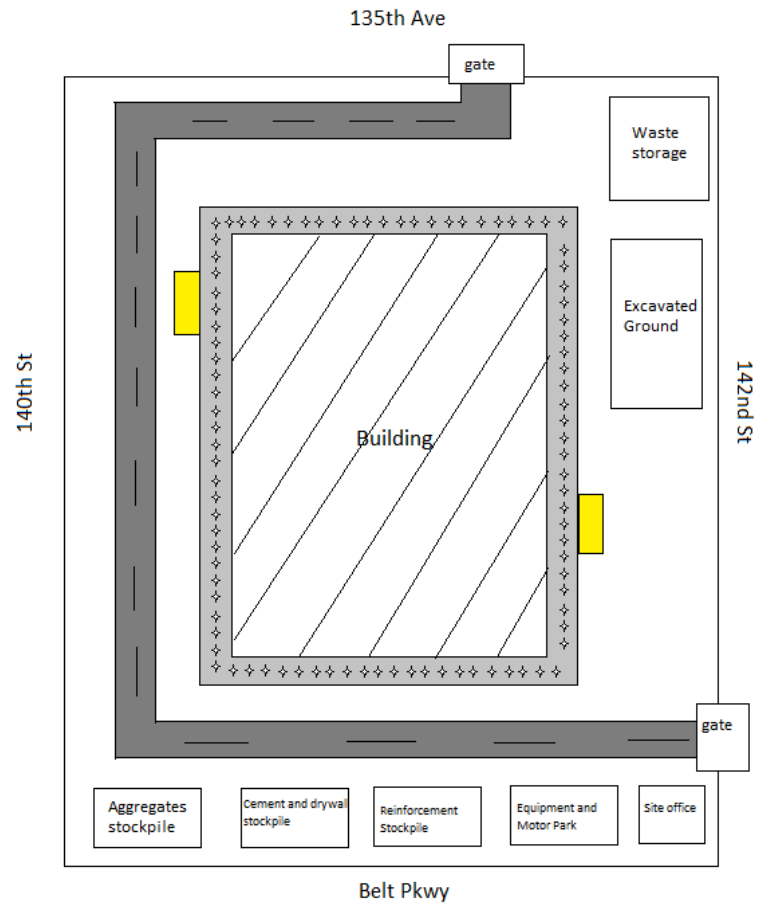
minimising the risk through engineering controls, over administrative controls or personal protective equipment (PPE). For this project, the work at height and mechanical operations, which involved higher risks, were managed through a combination of engineering controls (e.g., safe scaffolding, guard systems) and rigorous procedures, with PPE used as an additional precaution. This approach to the application of controls enables a more organised and effective control of risks in the construction site.

## **6.9. Construction Site Planning**

The construction site layout was created considering the real project site in Jamaica, New York, including the existing buildings, street access, and the site's construction space. Given the urban location, the site is densely populated and the plan was designed to provide safe and efficient circulation of workers, materials, and construction equipment.

The primary access to the site is planned from 142nd Street to enable convenient access for construction vehicles and deliveries. The site is internally organised around the building footprint to facilitate continuous traffic flow and minimise traffic congestion at various phases of construction. Specific zones are allocated for material stockpiles (reinforcement, cement and finishing materials) and site equipment and machinery to facilitate site works.

The site plan also includes the excavation zone which is positioned based on the building footprint and foundation works, with an adequate area around it for material storage and safe passage during the early phases of the project. Furthermore, the site office, worker amenities, and waste management area are set apart to ensure site management and enhance safety. In sum, the construction site plan was designed to increase efficiency of work flow, ensure safety and coordination of construction activities within the urban site constraints..



**Figure 6.9.1** Site Plan

## 7. Appendix

**Table 3.5.6** Column dimension iterative calculations

| 9-STORY, INTERIOR COLUMNS |           |           |               |        |         |      |                         |                         |              |            |                        |
|---------------------------|-----------|-----------|---------------|--------|---------|------|-------------------------|-------------------------|--------------|------------|------------------------|
| Column 0                  |           |           |               |        |         |      |                         |                         |              |            |                        |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f <sub>c</sub><br>(MPa) | f <sub>y</sub><br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                         | 800       | 3500      | 23,56         | 63,34  | 6932,33 | 0,65 | 35                      | 420                     | 396149       | 629        | 650                    |
| 2                         | 629       | 3500      | 23,56         | 39,20  | 6908,20 | 0,65 | 35                      | 420                     | 394770       | 628        |                        |
| 3                         | 628       | 3500      | 23,56         | 39,07  | 6908,06 | 0,65 | 35                      | 420                     | 394762       | 628        |                        |
| Column 1                  |           |           |               |        |         |      |                         |                         |              |            |                        |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f <sub>c</sub><br>(MPa) | f <sub>y</sub><br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                         | 800       | 7000      | 23,56         | 126,68 | 6287,98 | 0,65 | 35                      | 420                     | 359328       | 599        | 600                    |
| 2                         | 599       | 7000      | 23,56         | 71,12  | 6232,43 | 0,65 | 35                      | 420                     | 356153       | 597        |                        |
| 3                         | 597       | 7000      | 23,56         | 70,49  | 6231,80 | 0,65 | 35                      | 420                     | 356117       | 597        |                        |
| Column 2-4                |           |           |               |        |         |      |                         |                         |              |            |                        |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f <sub>c</sub><br>(MPa) | f <sub>y</sub><br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                         | 800       | 3500      | 23,56         | 63,34  | 5542,33 | 0,65 | 35                      | 420                     | 316717       | 553        | 550                    |
| 2                         | 553       | 3500      | 23,56         | 30,24  | 5509,23 | 0,65 | 35                      | 420                     | 314826       | 551        |                        |
| 3                         | 551       | 3500      | 23,56         | 30,06  | 5509,04 | 0,65 | 35                      | 420                     | 314815       | 549        |                        |
| Column 5-7                |           |           |               |        |         |      |                         |                         |              |            |                        |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f <sub>c</sub><br>(MPa) | f <sub>y</sub><br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                         | 700       | 3500      | 23,56         | 48,49  | 3357,72 | 0,65 | 35                      | 420                     | 191877       | 438        | 450                    |

|                           |           |           |               |        |         |      |              |             |              |            |                        |
|---------------------------|-----------|-----------|---------------|--------|---------|------|--------------|-------------|--------------|------------|------------------------|
| 2                         | 438       | 3500      | 23,56         | 18,99  | 3328,22 | 0,65 | 35           | 420         | 190191       | 436        |                        |
| 3                         | 436       | 3500      | 23,56         | 18,82  | 3328,05 | 0,65 | 35           | 420         | 190182       | 436        |                        |
| Column 8-9                |           |           |               |        |         |      |              |             |              |            |                        |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f'c<br>(MPa) | fy<br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                         | 500       | 3500      | 23,56         | 24,74  | 1169,17 | 0,65 | 35           | 420         | 66812        | 258        | 400                    |
| 2                         | 258       | 3500      | 23,56         | 6,61   | 1151,04 | 0,65 | 35           | 420         | 65777        | 256        |                        |
| 3                         | 256       | 3500      | 23,56         | 6,51   | 1150,94 | 0,65 | 35           | 420         | 65771        | 256        |                        |
| 9-STORY, EXTERIOR COLUMNS |           |           |               |        |         |      |              |             |              |            |                        |
| Column 0                  |           |           |               |        |         |      |              |             |              |            |                        |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f'c<br>(MPa) | fy<br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                         | 800       | 3500      | 23,56         | 63,34  | 4485,40 | 0,65 | 35           | 420         | 256319       | 506        | 500                    |
| 2                         | 506       | 3500      | 23,56         | 25,37  | 4447,43 | 0,65 | 35           | 420         | 254149       | 504        |                        |
| 3                         | 504       | 3500      | 23,56         | 25,15  | 4447,21 | 0,65 | 35           | 420         | 254137       | 499        |                        |
| Column 1                  |           |           |               |        |         |      |              |             |              |            |                        |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f'c<br>(MPa) | fy<br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                         | 800       | 7000      | 23,56         | 126,68 | 4084,45 | 0,65 | 35           | 420         | 233406       | 483        | 500                    |
| 2                         | 483       | 7000      | 23,56         | 46,20  | 4003,97 | 0,65 | 35           | 420         | 228807       | 478        |                        |
| 3                         | 478       | 7000      | 23,56         | 45,29  | 4003,06 | 0,65 | 35           | 420         | 228755       | 478        |                        |
| Column 2-4                |           |           |               |        |         |      |              |             |              |            |                        |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f'c<br>(MPa) | fy<br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                         | 800       | 3500      | 23,56         | 63,34  | 3581,46 | 0,65 | 35           | 420         | 204663       | 452        |                        |

450

|                       |           |           |               |        |         |      |              |             |              |            |                         |
|-----------------------|-----------|-----------|---------------|--------|---------|------|--------------|-------------|--------------|------------|-------------------------|
| 2                     | 452       | 3500      | 23,56         | 20,25  | 3538,38 | 0,65 | 35           | 420         | 202201       | 450        |                         |
| 3                     | 450       | 3500      | 23,56         | 20,01  | 3538,13 | 0,65 | 35           | 420         | 202187       | 450        |                         |
| Column 5-7            |           |           |               |        |         |      |              |             |              |            |                         |
| Iteration             | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f'c<br>(MPa) | fy<br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimention<br>(mm) |
| 1                     | 700       | 3500      | 23,56         | 48,49  | 2170,91 | 0,65 | 35           | 420         | 124057       | 352        | 400                     |
| 2                     | 352       | 3500      | 23,56         | 12,28  | 2134,69 | 0,65 | 35           | 420         | 121987       | 349        |                         |
| 3                     | 349       | 3500      | 23,56         | 12,07  | 2134,49 | 0,65 | 35           | 420         | 121976       | 349        |                         |
| Column 8-9            |           |           |               |        |         |      |              |             |              |            |                         |
| Iteration             | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f'c<br>(MPa) | fy<br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimention<br>(mm) |
| 1                     | 500       | 3500      | 23,56         | 24,74  | 754,55  | 0,65 | 35           | 420         | 43119        | 208        | 400                     |
| 2                     | 208       | 3500      | 23,56         | 4,27   | 734,08  | 0,65 | 35           | 420         | 41949        | 205        |                         |
| 3                     | 205       | 3500      | 23,56         | 4,15   | 733,96  | 0,65 | 35           | 420         | 41942        | 205        |                         |
| 9-STORY, EDGE COLUMNS |           |           |               |        |         |      |              |             |              |            |                         |
| Column 0              |           |           |               |        |         |      |              |             |              |            |                         |
| Iteration             | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f'c<br>(MPa) | fy<br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimention<br>(mm) |
| 1                     | 800       | 3500      | 23,56         | 63,34  | 2768,15 | 0,65 | 35           | 420         | 158186       | 398        | 400                     |
| 2                     | 398       | 3500      | 23,56         | 15,65  | 2720,47 | 0,65 | 35           | 420         | 155461       | 394        |                         |
| 3                     | 394       | 3500      | 23,56         | 15,39  | 2720,20 | 0,65 | 35           | 420         | 155446       | 394        |                         |
| Column 1              |           |           |               |        |         |      |              |             |              |            |                         |
| Iteration             | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f'c<br>(MPa) | fy<br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimention<br>(mm) |
| 1                     | 800       | 7000      | 23,56         | 126,68 | 2544,12 | 0,65 | 35           | 420         | 145384       | 381        |                         |

400

|                           |           |           |               |        |         |      |                         |                         |              |            |                        |
|---------------------------|-----------|-----------|---------------|--------|---------|------|-------------------------|-------------------------|--------------|------------|------------------------|
| 2                         | 381       | 7000      | 23,56         | 28,78  | 2446,22 | 0,65 | 35                      | 420                     | 139790       | 374        |                        |
| 3                         | 374       | 7000      | 23,56         | 27,67  | 2445,11 | 0,65 | 35                      | 420                     | 139726       | 374        |                        |
| Column 2-4                |           |           |               |        |         |      |                         |                         |              |            |                        |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f <sub>c</sub><br>(MPa) | f <sub>y</sub><br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                         | 800       | 3500      | 23,56         | 63,34  | 2211,71 | 0,65 | 35                      | 420                     | 126389       | 356        | 400                    |
| 2                         | 356       | 3500      | 23,56         | 12,51  | 2160,88 | 0,65 | 35                      | 420                     | 123484       | 351        |                        |
| 3                         | 351       | 3500      | 23,56         | 12,22  | 2160,59 | 0,65 | 35                      | 420                     | 123467       | 351        |                        |
| Column 5-7                |           |           |               |        |         |      |                         |                         |              |            |                        |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f <sub>c</sub><br>(MPa) | f <sub>y</sub><br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                         | 700       | 3500      | 23,56         | 48,49  | 1343,60 | 0,65 | 35                      | 420                     | 76780        | 277        | 400                    |
| 2                         | 277       | 3500      | 23,56         | 7,60   | 1302,71 | 0,65 | 35                      | 420                     | 74443        | 273        |                        |
| 3                         | 273       | 3500      | 23,56         | 7,37   | 1302,48 | 0,65 | 35                      | 420                     | 74430        | 273        |                        |
| Column 8-9                |           |           |               |        |         |      |                         |                         |              |            |                        |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f <sub>c</sub><br>(MPa) | f <sub>y</sub><br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                         | 500       | 3500      | 23,56         | 24,74  | 468,45  | 0,65 | 35                      | 420                     | 26769        | 164        | 400                    |
| 2                         | 164       | 3500      | 23,56         | 2,65   | 446,35  | 0,65 | 35                      | 420                     | 25507        | 160        |                        |
| 3                         | 160       | 3500      | 23,56         | 2,52   | 446,23  | 0,65 | 35                      | 420                     | 25500        | 160        |                        |
| 5-STORY, INTERIOR COLUMNS |           |           |               |        |         |      |                         |                         |              |            |                        |
| Column 0                  |           |           |               |        |         |      |                         |                         |              |            |                        |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f <sub>c</sub><br>(MPa) | f <sub>y</sub><br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                         | 800       | 3500      | 23,56         | 63,34  | 4045,93 | 0,65 | 35                      | 420                     | 231205       | 481        |                        |

500

|                           |           |           |               |        |         |      |              |             |              |            |                         |
|---------------------------|-----------|-----------|---------------|--------|---------|------|--------------|-------------|--------------|------------|-------------------------|
| 2                         | 481       | 3500      | 23,56         | 22,88  | 4005,48 | 0,65 | 35           | 420         | 228893       | 478        |                         |
| 3                         | 478       | 3500      | 23,56         | 22,65  | 4005,25 | 0,65 | 35           | 420         | 228880       | 478        |                         |
| Column 1                  |           |           |               |        |         |      |              |             |              |            |                         |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f'c<br>(MPa) | fy<br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimention<br>(mm) |
| 1                         | 800       | 7000      | 23,56         | 126,68 | 3401,59 | 0,65 | 35           | 420         | 194384       | 441        | 450                     |
| 2                         | 441       | 7000      | 23,56         | 38,47  | 3313,39 | 0,65 | 35           | 420         | 189344       | 435        |                         |
| 3                         | 435       | 7000      | 23,56         | 37,48  | 3312,39 | 0,65 | 35           | 420         | 189287       | 435        |                         |
| Column 2-5                |           |           |               |        |         |      |              |             |              |            |                         |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f'c<br>(MPa) | fy<br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimention<br>(mm) |
| 1                         | 800       | 3500      | 23,56         | 63,34  | 2655,93 | 0,65 | 35           | 420         | 151773       | 390        | 400                     |
| 2                         | 390       | 3500      | 23,56         | 15,02  | 2607,61 | 0,65 | 35           | 420         | 149012       | 386        |                         |
| 3                         | 386       | 3500      | 23,56         | 14,75  | 2607,34 | 0,65 | 35           | 420         | 148997       | 386        |                         |
| 5-STORY, EXTERIOR COLUMNS |           |           |               |        |         |      |              |             |              |            |                         |
| Column 0                  |           |           |               |        |         |      |              |             |              |            |                         |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f'c<br>(MPa) | fy<br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimention<br>(mm) |
| 1                         | 800       | 3500      | 23,56         | 63,34  | 2628,59 | 0,65 | 35           | 420         | 150211       | 388        | 400                     |
| 2                         | 388       | 3500      | 23,56         | 14,87  | 2580,12 | 0,65 | 35           | 420         | 147441       | 384        |                         |
| 3                         | 384       | 3500      | 23,56         | 14,59  | 2579,85 | 0,65 | 35           | 420         | 147426       | 384        |                         |
| Column 1                  |           |           |               |        |         |      |              |             |              |            |                         |
| Iteration                 | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f'c<br>(MPa) | fy<br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimention<br>(mm) |
| 1                         | 800       | 7000      | 23,56         | 126,68 | 2227,64 | 0,65 | 35           | 420         | 127299       | 357        |                         |

400



|                       |           |           |               |        |         |      |                         |                         |              |            |                        |
|-----------------------|-----------|-----------|---------------|--------|---------|------|-------------------------|-------------------------|--------------|------------|------------------------|
| 2                     | 357       | 7000      | 23,56         | 25,20  | 2126,16 | 0,65 | 35                      | 420                     | 121500       | 349        |                        |
| 3                     | 349       | 7000      | 23,56         | 24,05  | 2125,02 | 0,65 | 35                      | 420                     | 121434       | 348        |                        |
|                       |           |           |               |        |         |      |                         |                         |              |            |                        |
| Column 2-5            |           |           |               |        |         |      |                         |                         |              |            |                        |
| Iteration             | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f <sub>c</sub><br>(MPa) | f <sub>y</sub><br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                     | 800       | 3500      | 23,56         | 63,34  | 1724,65 | 0,65 | 35                      | 420                     | 98556        | 314        | 400                    |
| 2                     | 314       | 3500      | 23,56         | 9,75   | 1671,07 | 0,65 | 35                      | 420                     | 95493        | 309        |                        |
| 3                     | 309       | 3500      | 23,56         | 9,45   | 1670,77 | 0,65 | 35                      | 420                     | 95476        | 309        |                        |
| 5-STORY, EDGE COLUMNS |           |           |               |        |         |      |                         |                         |              |            |                        |
| Column 0              |           |           |               |        |         |      |                         |                         |              |            |                        |
| Iteration             | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f <sub>c</sub><br>(MPa) | f <sub>y</sub><br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                     | 800       | 3500      | 23,56         | 63,34  | 1632,94 | 0,65 | 35                      | 420                     | 93315        | 305        | 400                    |
| 2                     | 305       | 3500      | 23,56         | 9,23   | 1578,84 | 0,65 | 35                      | 420                     | 90223        | 300        |                        |
| 3                     | 300       | 3500      | 23,56         | 8,93   | 1578,54 | 0,65 | 35                      | 420                     | 90206        | 300        |                        |
| Column 1              |           |           |               |        |         |      |                         |                         |              |            |                        |
| Iteration             | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f <sub>c</sub><br>(MPa) | f <sub>y</sub><br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |
| 1                     | 800       | 7000      | 23,56         | 126,68 | 1408,92 | 0,65 | 35                      | 420                     | 80513        | 284        | 400                    |
| 2                     | 284       | 7000      | 23,56         | 15,94  | 1298,18 | 0,65 | 35                      | 420                     | 74184        | 272        |                        |
| 3                     | 272       | 7000      | 23,56         | 14,68  | 1296,92 | 0,65 | 35                      | 420                     | 74113        | 272        |                        |
| Column 2-5            |           |           |               |        |         |      |                         |                         |              |            |                        |
| Iteration             | b<br>(mm) | H<br>(mm) | p<br>(kN/m^3) | R (kN) | R+axial | φ    | f <sub>c</sub><br>(MPa) | f <sub>y</sub><br>(MPa) | Ag<br>(mm^2) | b'<br>(mm) | Final dimation<br>(mm) |

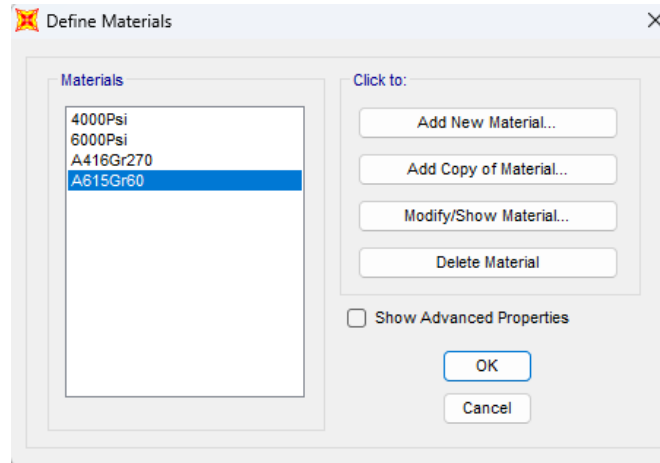
|   |     |      |       |      |         |      |    |     |       |     |     |
|---|-----|------|-------|------|---------|------|----|-----|-------|-----|-----|
| 1 | 300 | 3500 | 23,56 | 8,91 | 1022,07 | 0,65 | 35 | 420 | 58407 | 242 | 400 |
| 2 | 242 | 3500 | 23,56 | 5,78 | 1018,95 | 0,65 | 35 | 420 | 58228 | 241 |     |
| 3 | 241 | 3500 | 23,56 | 5,76 | 1018,93 | 0,65 | 35 | 420 | 58227 | 241 |     |

**Table 3.5.7** Column dimensions for 9 and 5 story parts

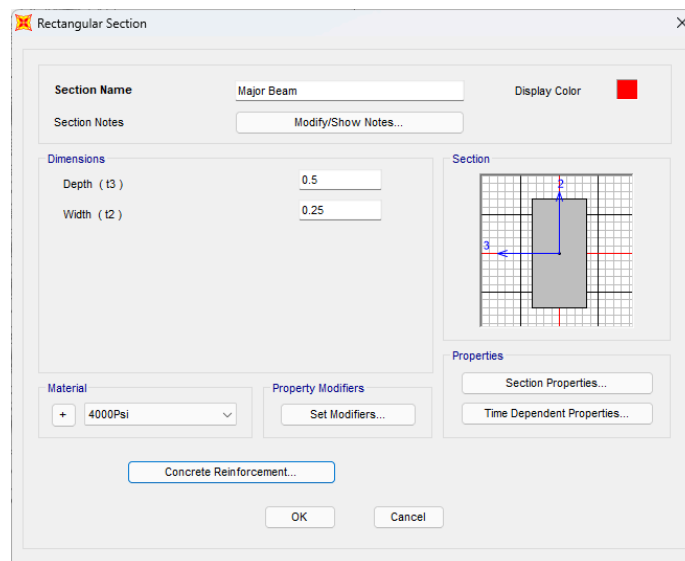
| Column # | 9 story         |                 |             | 5 story         |                 |             |
|----------|-----------------|-----------------|-------------|-----------------|-----------------|-------------|
|          | Interior Column | Exterior Column | Edge Column | Interior Column | Exterior Column | Edge Column |
| Column 0 | 650             | 500             | 400         | 500             | 400             | 400         |
| Column 1 | 600             | 500             | 400         | 450             | 400             | 400         |
| Column 2 | 550             | 450             | 400         | 400             | 400             | 400         |
| Column 3 | 550             | 450             | 400         | 400             | 400             | 400         |
| Column 4 | 550             | 400             | 400         | 400             | 400             | 400         |
| Column 5 | 450             | 400             | 400         | 400             | 400             | 400         |
| Column 6 | 450             | 400             | 400         |                 |                 |             |
| Column 7 | 450             | 400             | 400         |                 |                 |             |
| Column 8 | 400             | 400             | 400         |                 |                 |             |
| Column 9 | 400             | 400             | 400         |                 |                 |             |

**Table 3.6.1** Large Span Slab super imposed service load

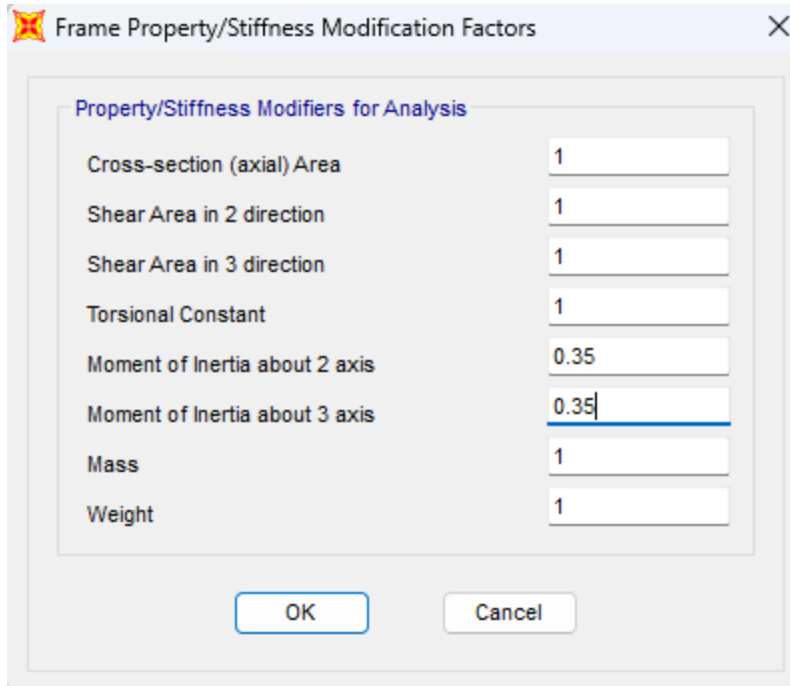
| Slab level | Super imposed Dead Load (kPa) | Live Load (kPa) | Roof Live load (kPa) | Snow Load (kPa) | Load Combinations (kPa) | Load Combinations (psf) |
|------------|-------------------------------|-----------------|----------------------|-----------------|-------------------------|-------------------------|
| 0,00       | 4,76                          | 0,89            | 0,00                 | 0,00            | 7,13                    | 148.91                  |
| 1,00       | 4,34                          | 0,89            | 0,00                 | 0,00            | 6,62                    | 138,26                  |
| Roof       | 0,88                          | 0,00            | 0,89                 | 1,58            | 3,58                    | 74.77                   |



**Figure 3.7.1** Material Properties



**Figure 3.7.2** Major Beam section



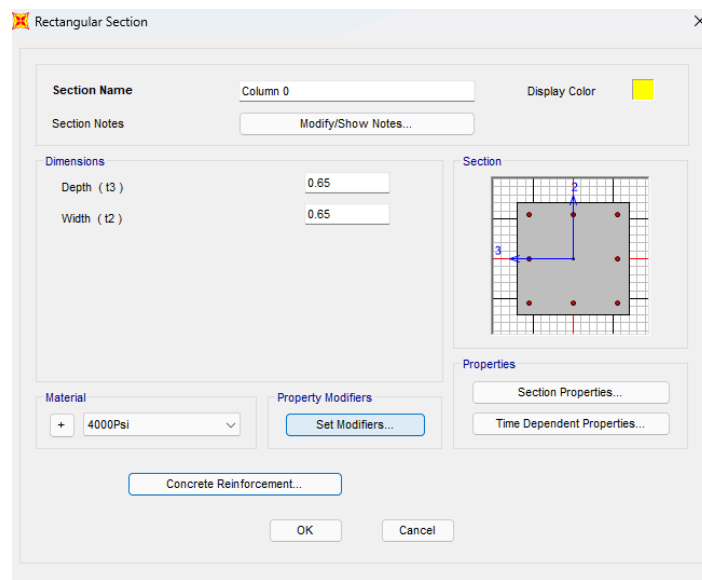
Frame Property/Stiffness Modification Factors

Property/Stiffness Modifiers for Analysis

|                                |      |
|--------------------------------|------|
| Cross-section (axial) Area     | 1    |
| Shear Area in 2 direction      | 1    |
| Shear Area in 3 direction      | 1    |
| Torsional Constant             | 1    |
| Moment of Inertia about 2 axis | 0.35 |
| Moment of Inertia about 3 axis | 0.35 |
| Mass                           | 1    |
| Weight                         | 1    |

OK Cancel

**Figure 3.7.3** Beam Modifiers



Rectangular Section

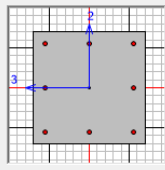
Section Name: Column 0 Display Color:

Section Notes: Modify/Show Notes...

Dimensions

|            |      |
|------------|------|
| Depth (t3) | 0.65 |
| Width (t2) | 0.65 |

Section



Properties

Section Properties...

Time Dependent Properties...

Material: + 4000Psi ▼

Property Modifiers: Set Modifiers...

Concrete Reinforcement...

OK Cancel

**Figure 3.7.4** Basement column section

**Rectangular Section**

**Section Name**  **Display Color** ■

**Section Notes**

---

**Dimensions**

Depth (t3)

Width (t2)

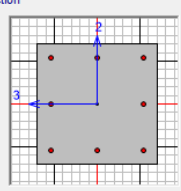
---

**Material**  4000Psi

**Property Modifiers**

---

**Section**



**Properties**

**Figure 3.7.5** 1 floor column section

**Rectangular Section**

**Section Name**  **Display Color** ■

**Section Notes**

---

**Dimensions**

Depth (t3)

Width (t2)

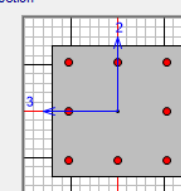
---

**Material**  4000Psi

**Property Modifiers**

---

**Section**



**Properties**

**Figure 3.7.6** 2-4 floor column section

**Rectangular Section**

Section Name:  Display Color: ■

Section Notes:

**Dimensions**

Depth (t3):

Width (t2):

**Material**

**Property Modifiers**

**Section**

**Properties**

**Figure 3.7.7** 5-7 floor column section

**Rectangular Section**

Section Name:  Display Color: ■

Section Notes:

**Dimensions**

Depth (t3):

Width (t2):

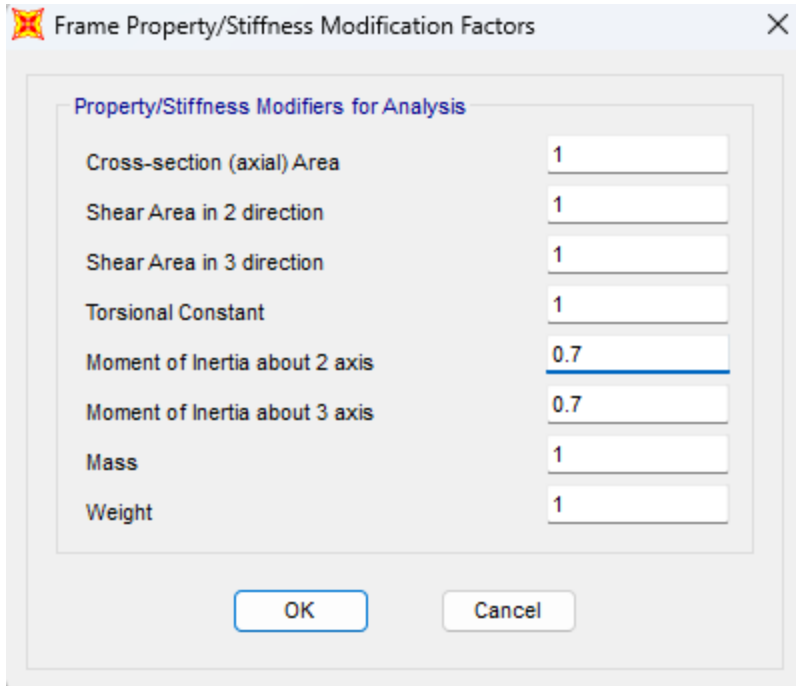
**Material**

**Property Modifiers**

**Section**

**Properties**

**Figure 3.7.8** 8-9 floor column section



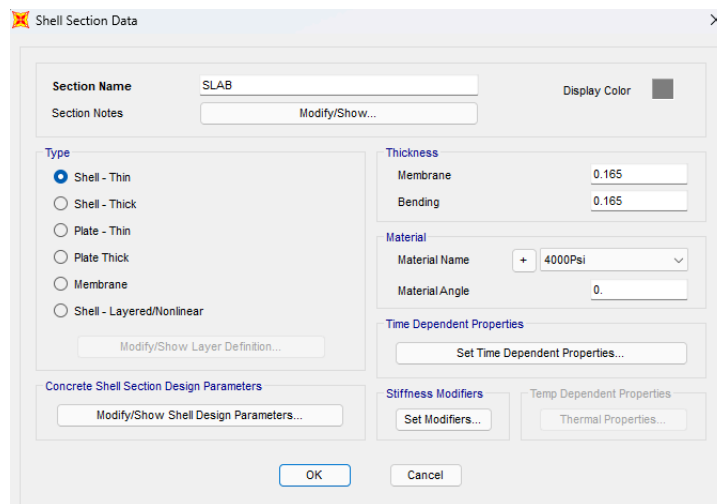
**Frame Property/Stiffness Modification Factors**

**Property/Stiffness Modifiers for Analysis**

|                                |     |
|--------------------------------|-----|
| Cross-section (axial) Area     | 1   |
| Shear Area in 2 direction      | 1   |
| Shear Area in 3 direction      | 1   |
| Torsional Constant             | 1   |
| Moment of Inertia about 2 axis | 0.7 |
| Moment of Inertia about 3 axis | 0.7 |
| Mass                           | 1   |
| Weight                         | 1   |

OK Cancel

**Figure 3.7.9** Column modifiers



**Shell Section Data**

Section Name: SLAB Display Color: ☐

Section Notes:

**Type**

- ☒ Shell - Thin
- ☐ Shell - Thick
- ☐ Plate - Thin
- ☐ Plate Thick
- ☐ Membrane
- ☐ Shell - Layered/Nonlinear

**Thickness**

Membrane: 0.165

Bending: 0.165

**Material**

Material Name: + 4000Psi

Material Angle: 0.

**Time Dependent Properties**

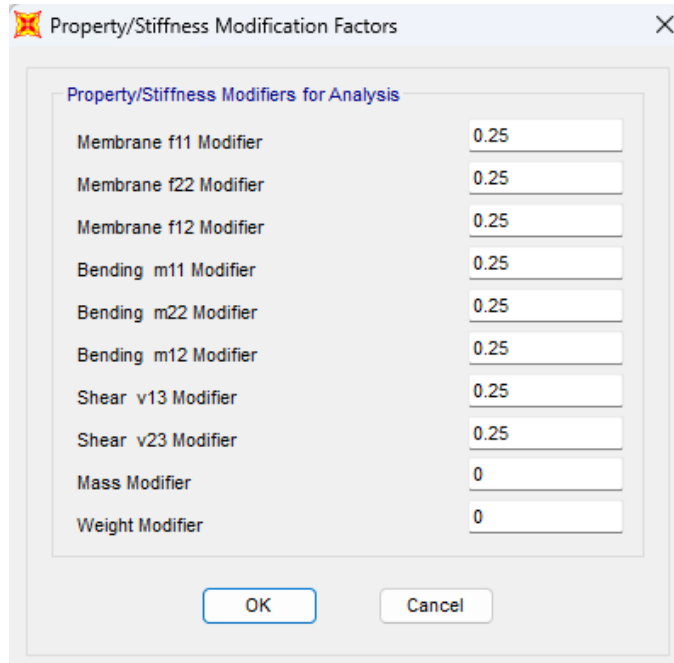
**Concrete Shell Section Design Parameters**

**Stiffness Modifiers**

**Temp Dependent Properties**

OK Cancel

**Figure 3.7.10** Slab section data



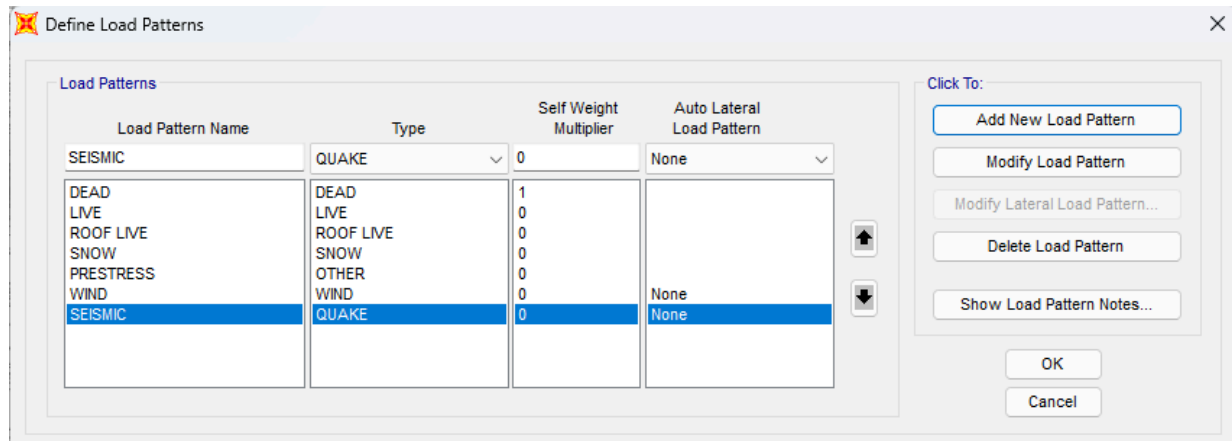
Property/Stiffness Modification Factors

Property/Stiffness Modifiers for Analysis

|                       |      |
|-----------------------|------|
| Membrane f11 Modifier | 0.25 |
| Membrane f22 Modifier | 0.25 |
| Membrane f12 Modifier | 0.25 |
| Bending m11 Modifier  | 0.25 |
| Bending m22 Modifier  | 0.25 |
| Bending m12 Modifier  | 0.25 |
| Shear v13 Modifier    | 0.25 |
| Shear v23 Modifier    | 0.25 |
| Mass Modifier         | 0    |
| Weight Modifier       | 0    |

OK Cancel

**Figure 3.7.11** Slab section modifiers according to the code



Define Load Patterns

Load Patterns

| Load Pattern Name | Type      | Self Weight Multiplier | Auto Lateral Load Pattern |
|-------------------|-----------|------------------------|---------------------------|
| SEISMIC           | QUAKE     | 0                      | None                      |
| DEAD              | DEAD      | 1                      |                           |
| LIVE              | LIVE      | 0                      |                           |
| ROOF LIVE         | ROOF LIVE | 0                      |                           |
| SNOW              | SNOW      | 0                      |                           |
| PRESTRESS         | OTHER     | 0                      |                           |
| WIND              | WIND      | 0                      | None                      |
| SEISMIC           | QUAKE     | 0                      | None                      |

Click To:

Add New Load Pattern

Modify Load Pattern

Modify Lateral Load Pattern...

Delete Load Pattern

Show Load Pattern Notes...

OK

Cancel

**Figure 3.7.12** Load Patterns



**Load Combination Data**

Load Combination Name (User-Generated) Serviceability loads

Notes Modify/Show Notes...

Load Combination Type Linear Add

**Options**

Convert to User Load Combo Create Nonlinear Load Case from Load Combo

**Define Combination of Load Case Results**

| Load Case Name | Load Case Type | Scale Factor |
|----------------|----------------|--------------|
| SNOW           | Linear Static  | 1            |
| DEAD           | Linear Static  | 1            |
| LIVE           | Linear Static  | 1            |
| PRESTRESS      | Linear Static  | 1            |
| ROOF LIVE      | Linear Static  | 1            |
| SNOW           | Linear Static  | 1            |

Add Modify Delete

OK Cancel

**Figure 3.7.13** Serviceability load combination

**Load Combination Data**

Load Combination Name (User-Generated) 1.2DL+1.6LL+0.5SL

Notes Modify/Show Notes...

Load Combination Type Linear Add

**Options**

Convert to User Load Combo Create Nonlinear Load Case from Load Combo

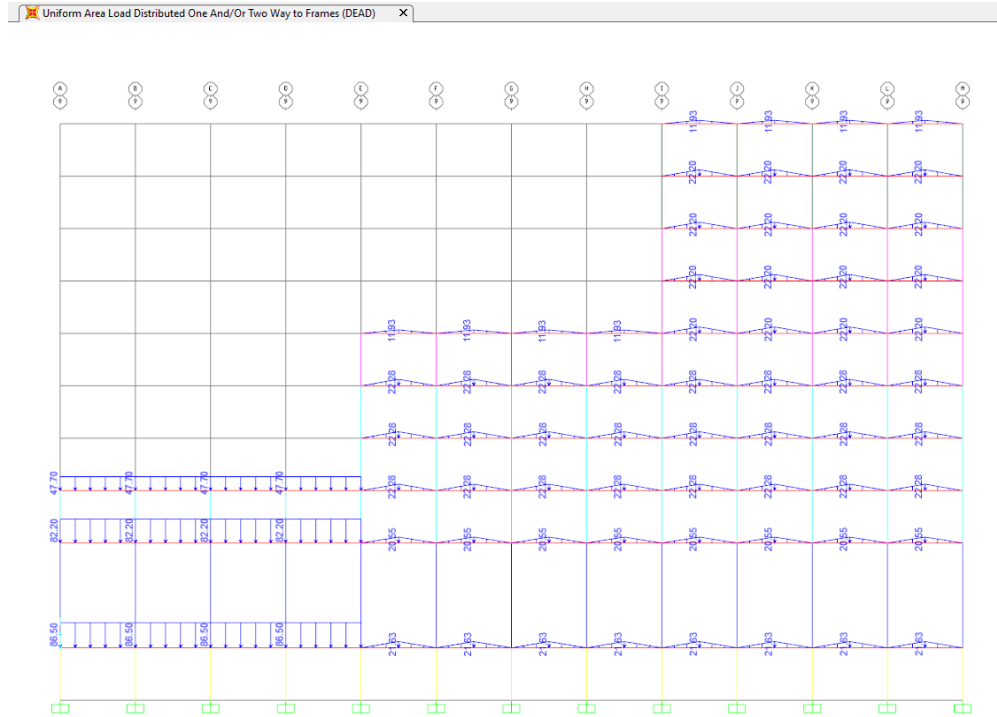
**Define Combination of Load Case Results**

| Load Case Name | Load Case Type | Scale Factor |
|----------------|----------------|--------------|
| PRESTRESS      | Linear Static  | 1            |
| DEAD           | Linear Static  | 1.2          |
| LIVE           | Linear Static  | 1.6          |
| SNOW           | Linear Static  | 0.5          |
| PRESTRESS      | Linear Static  | 1            |

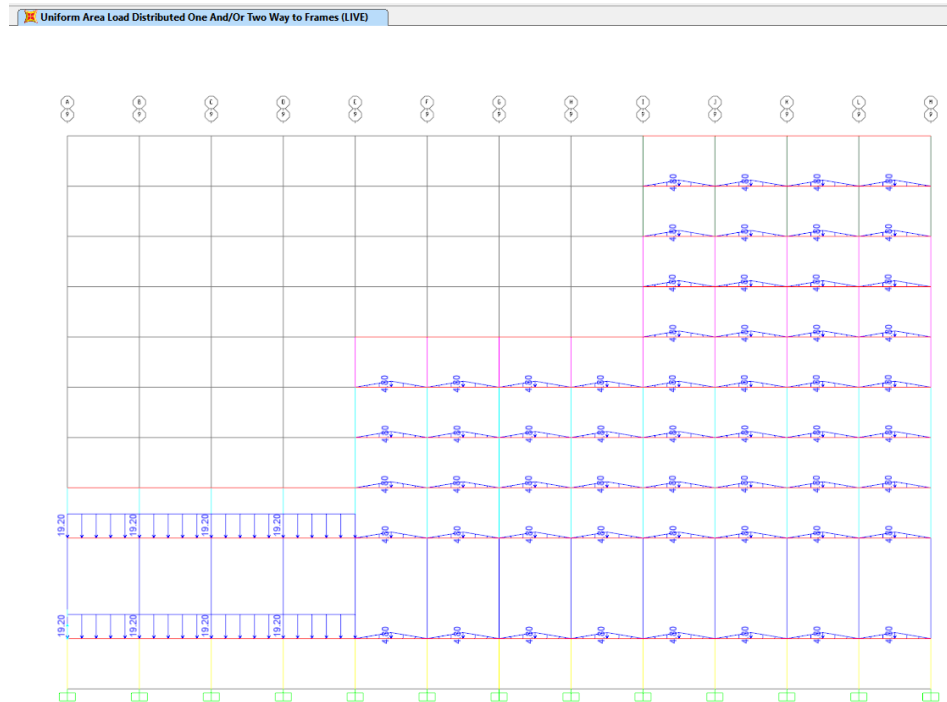
Add Modify Delete

OK Cancel

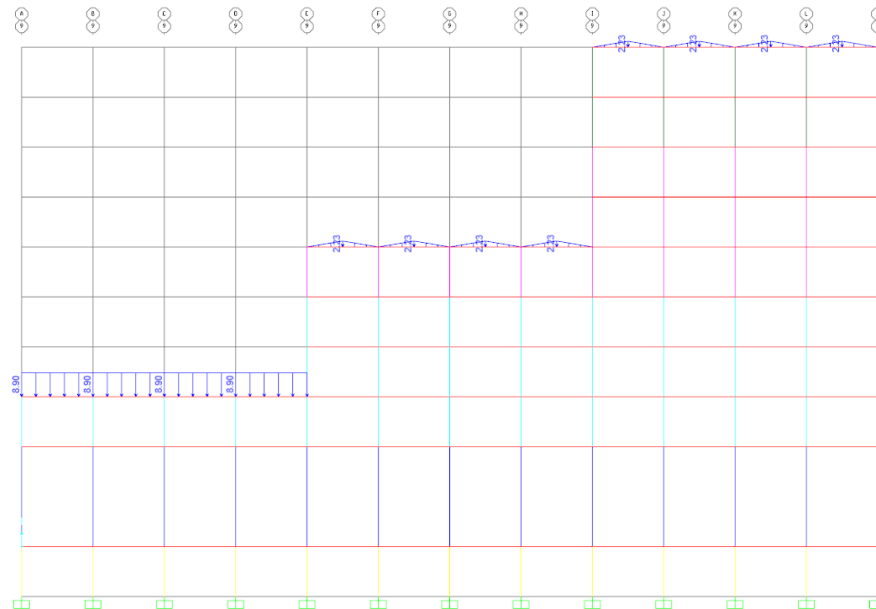
**Figure 3.7.14** Most critical load combination



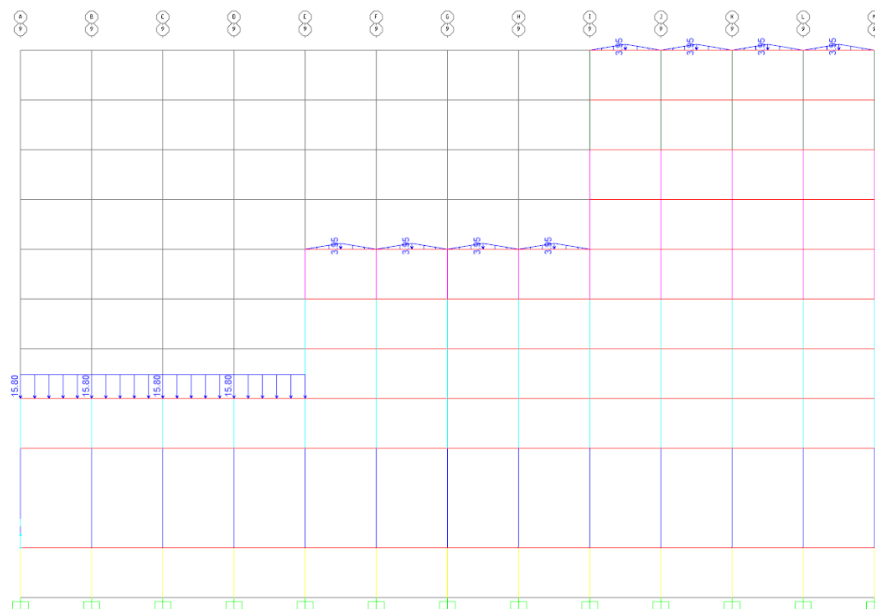
**Figure 3.7.15** Dead Load Assign



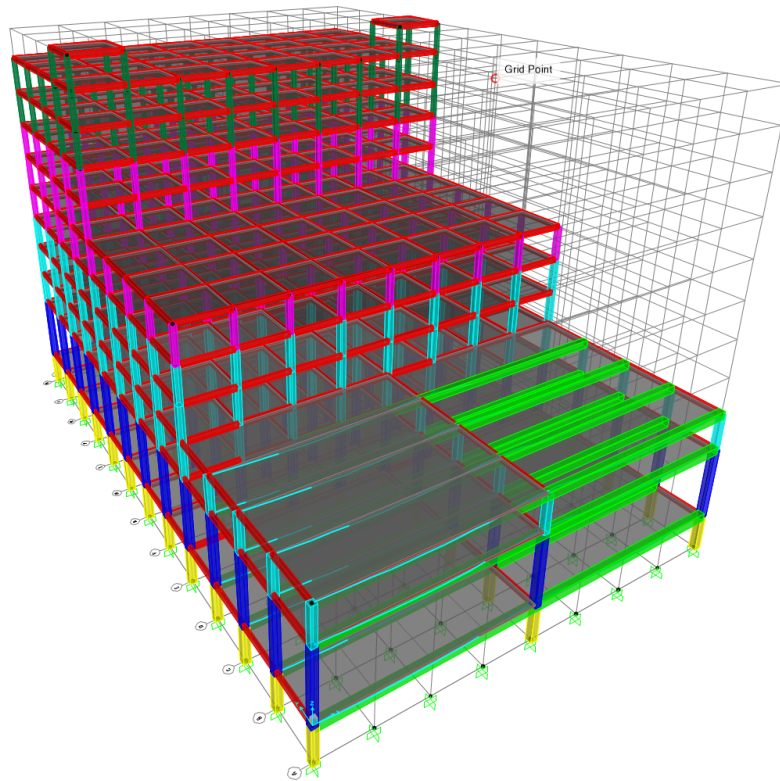
**Figure 3.7.16** Live Load Assign



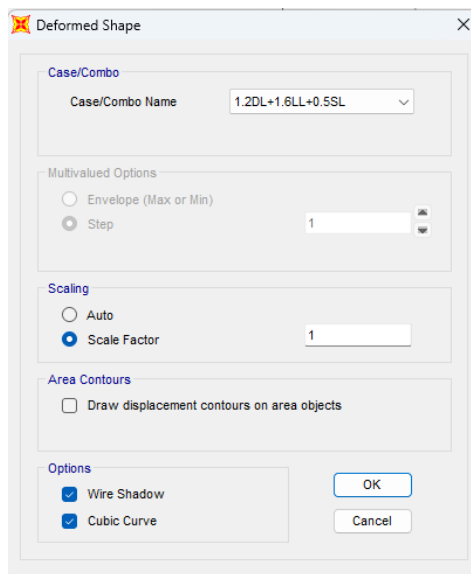
**Figure 3.7.17** Roof Live Load Assign



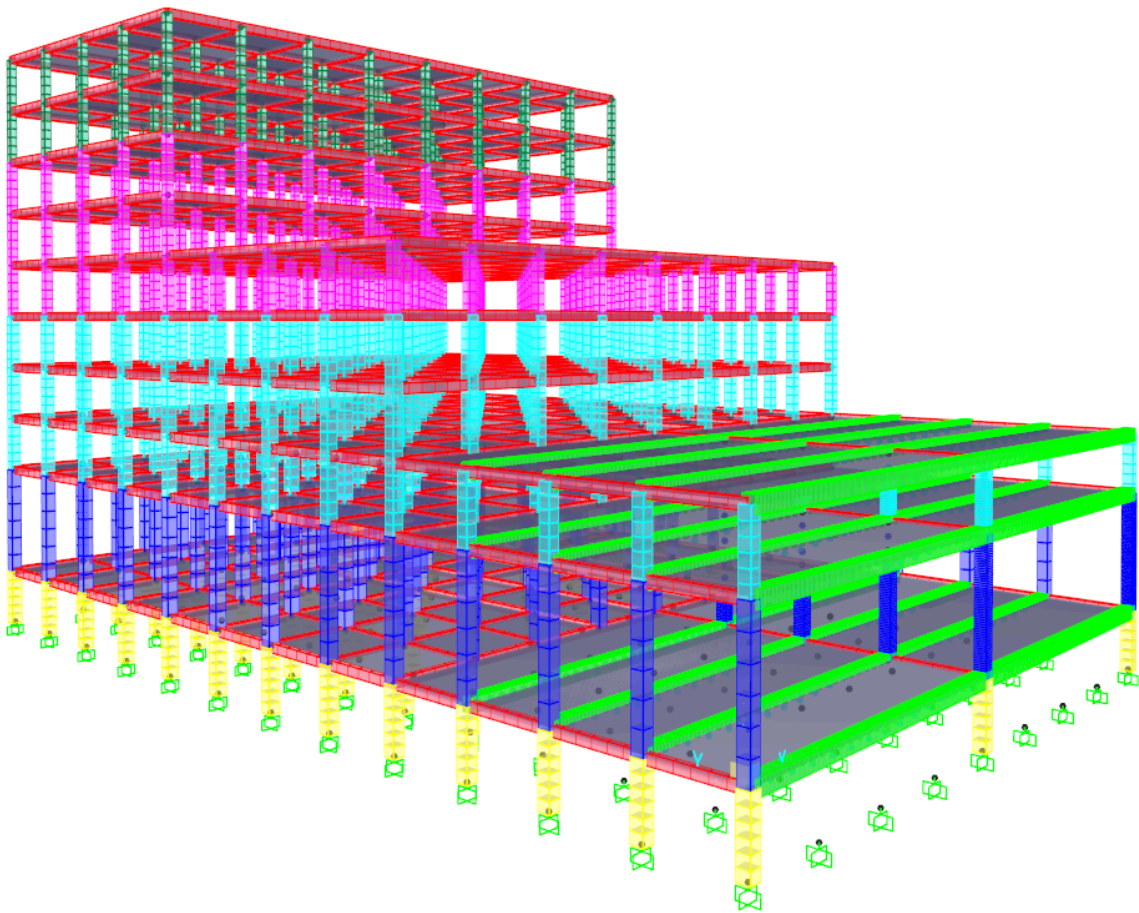
**Figure 3.7.18** Snow Load Assign



**Figure 3.7.19 3D model**



**Figure 3.7.20 Deformed Shape settings**



**Figure 3.7.21** 3D deformed shape

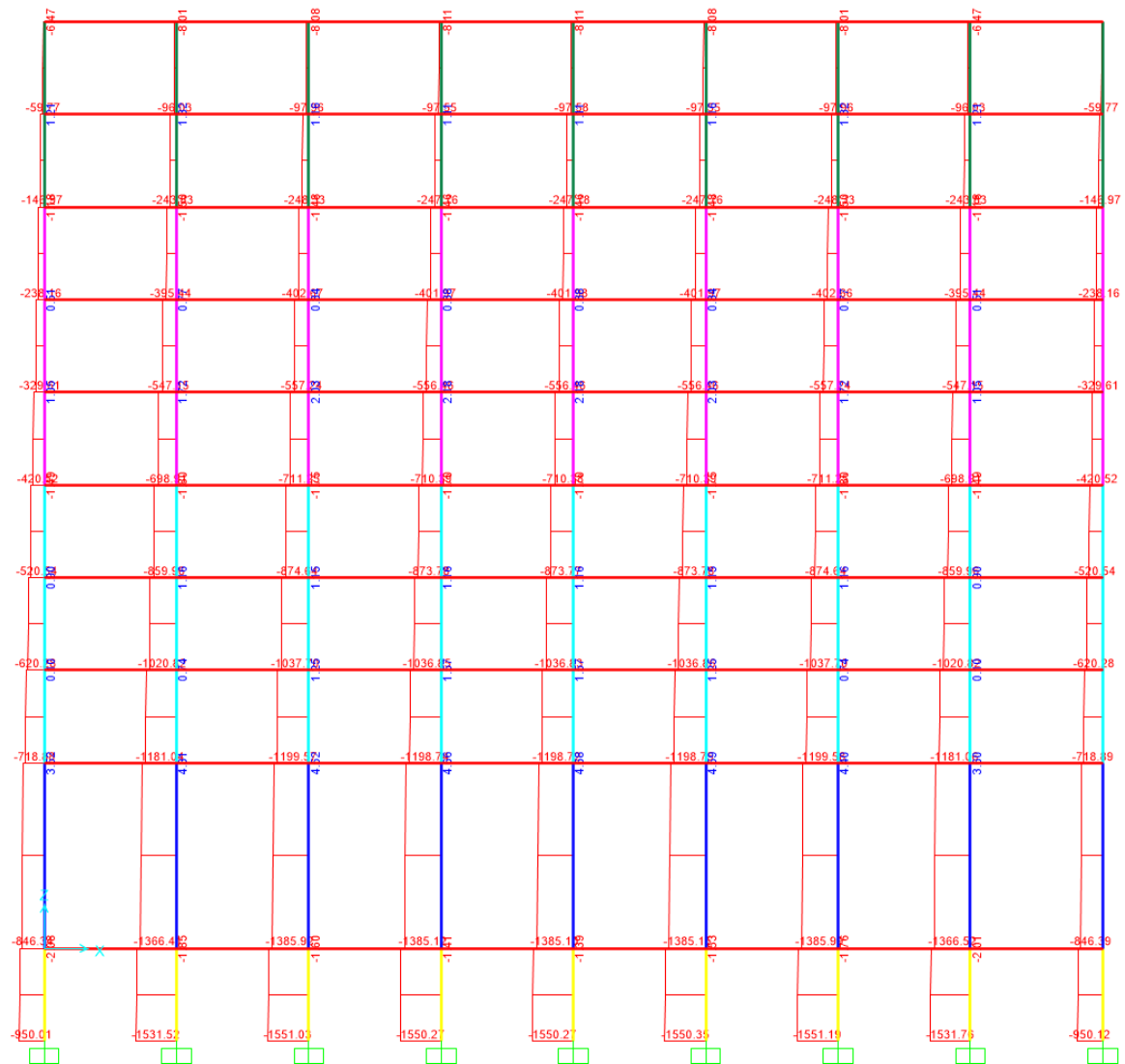


Figure 3.7.22 Axial Force diagram due to Dead Load (frame M)

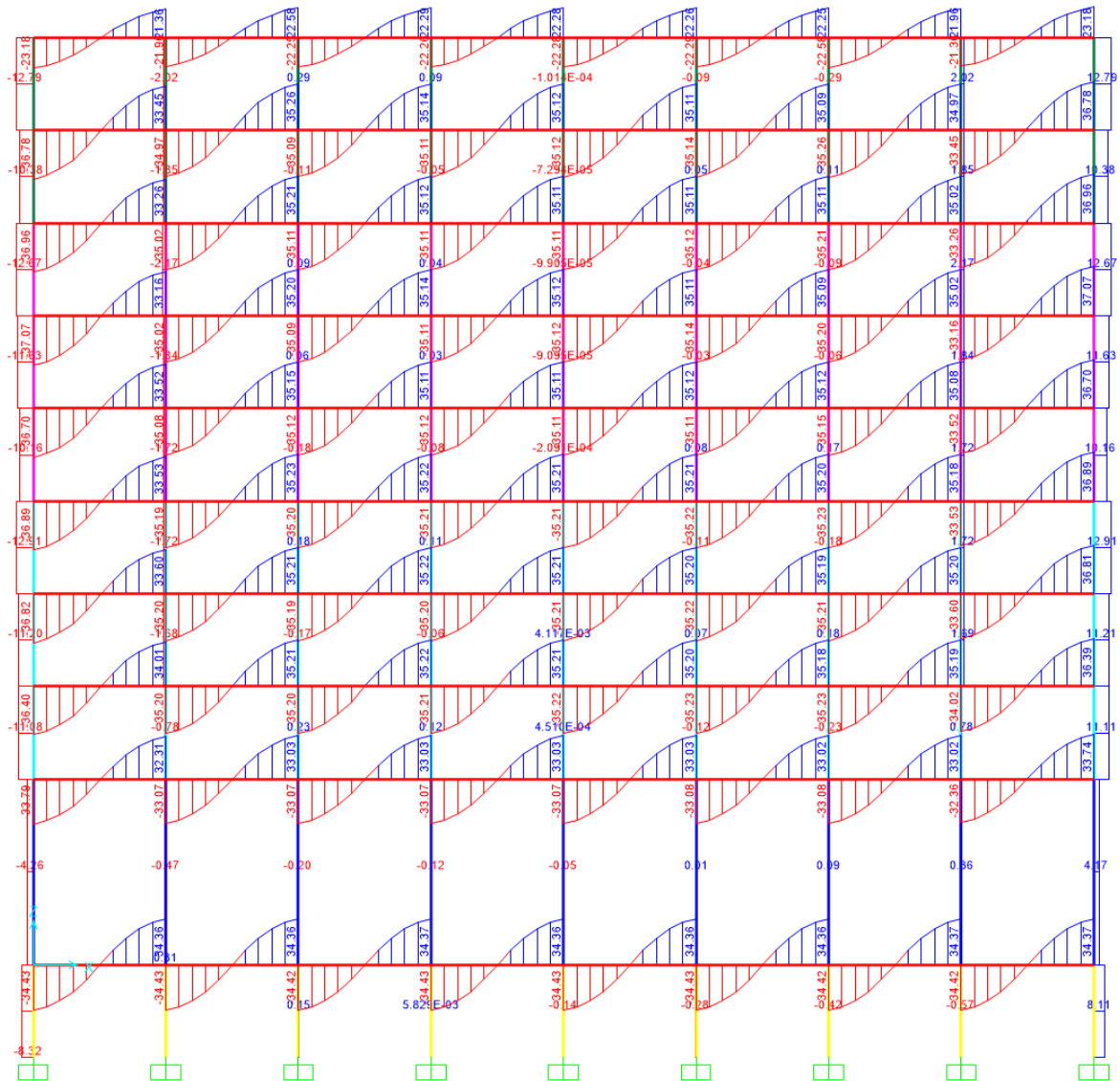


Figure 3.7.23 Shear Force diagram due to Dead Load (frame M)

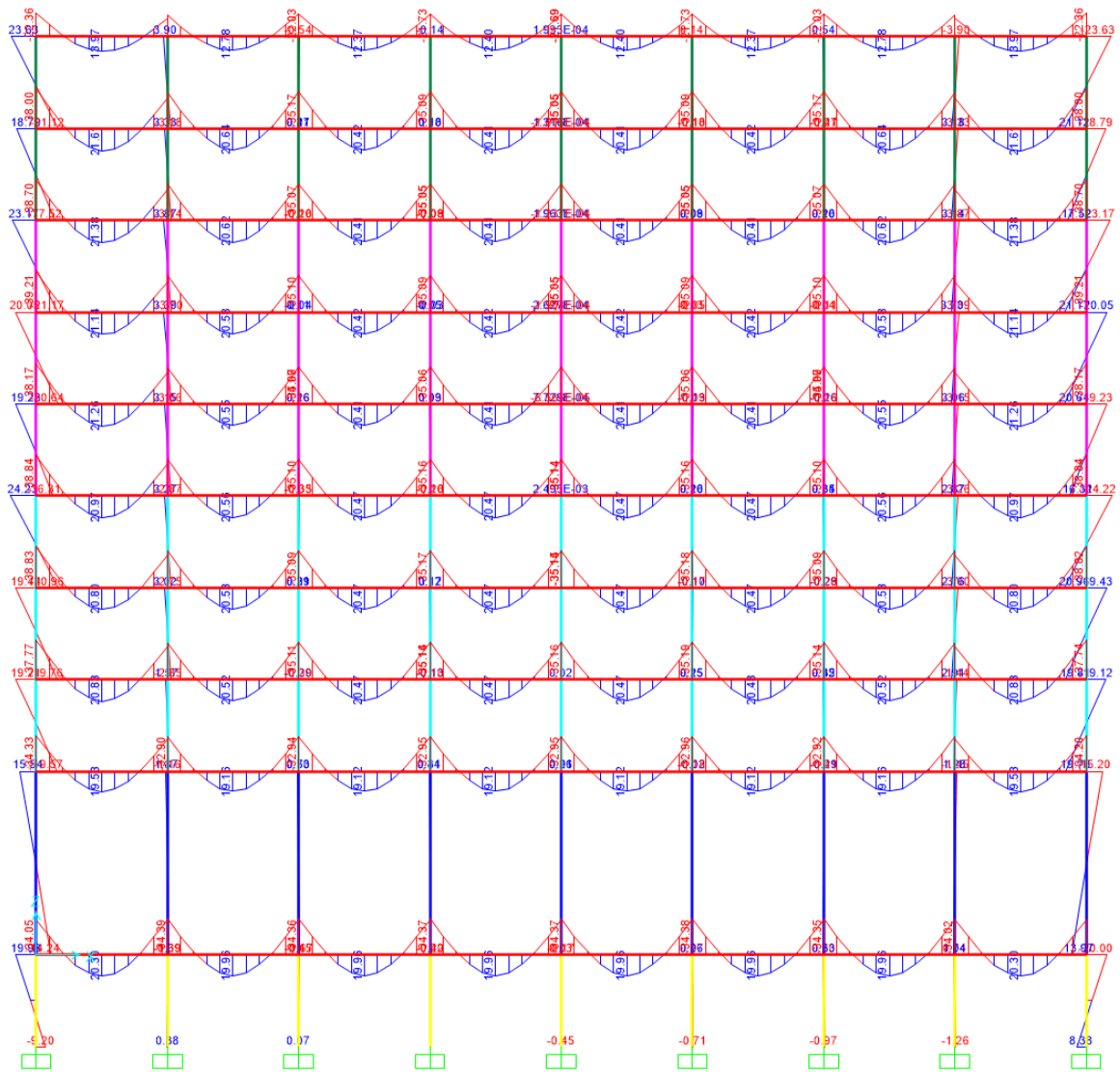
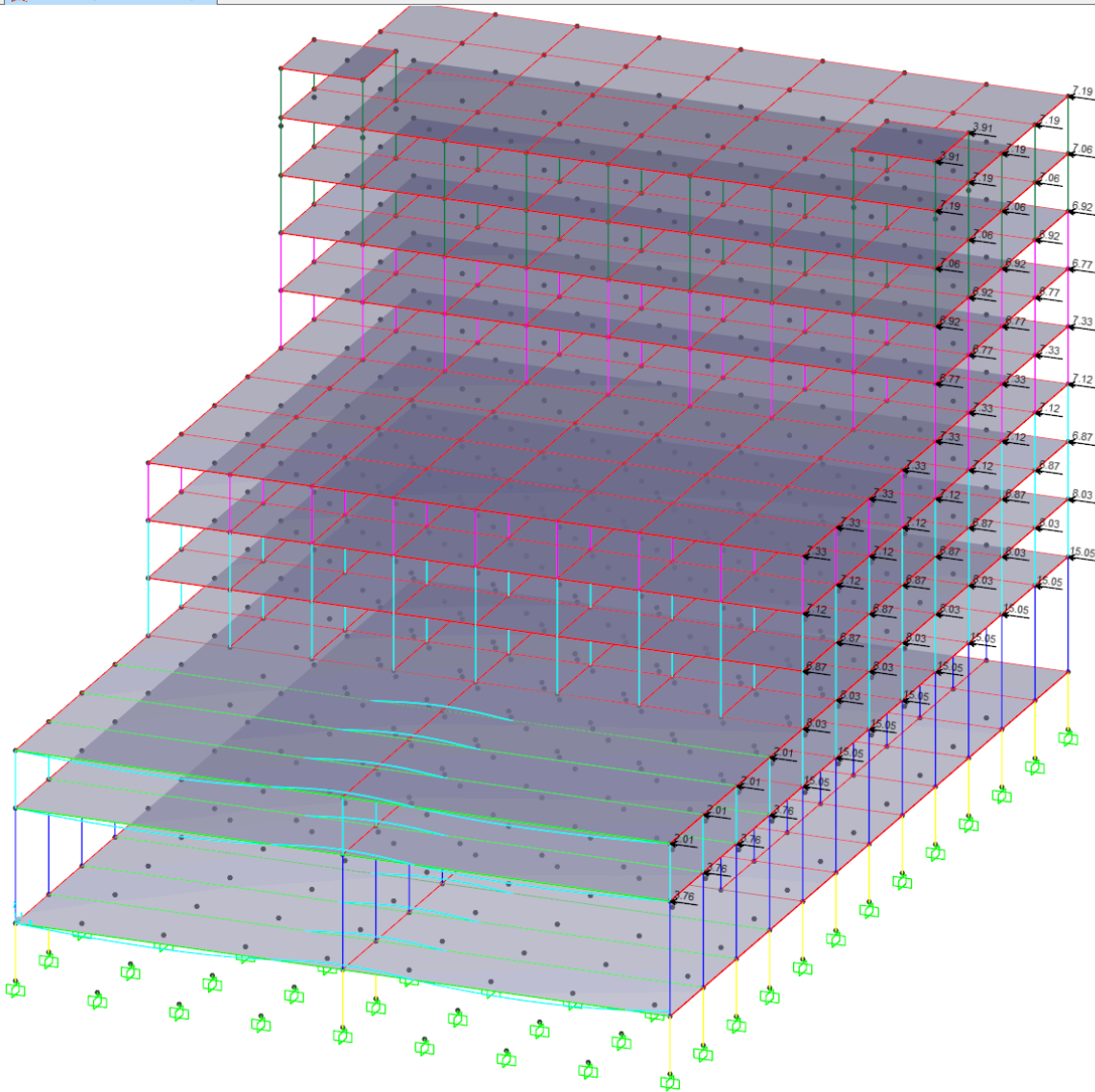
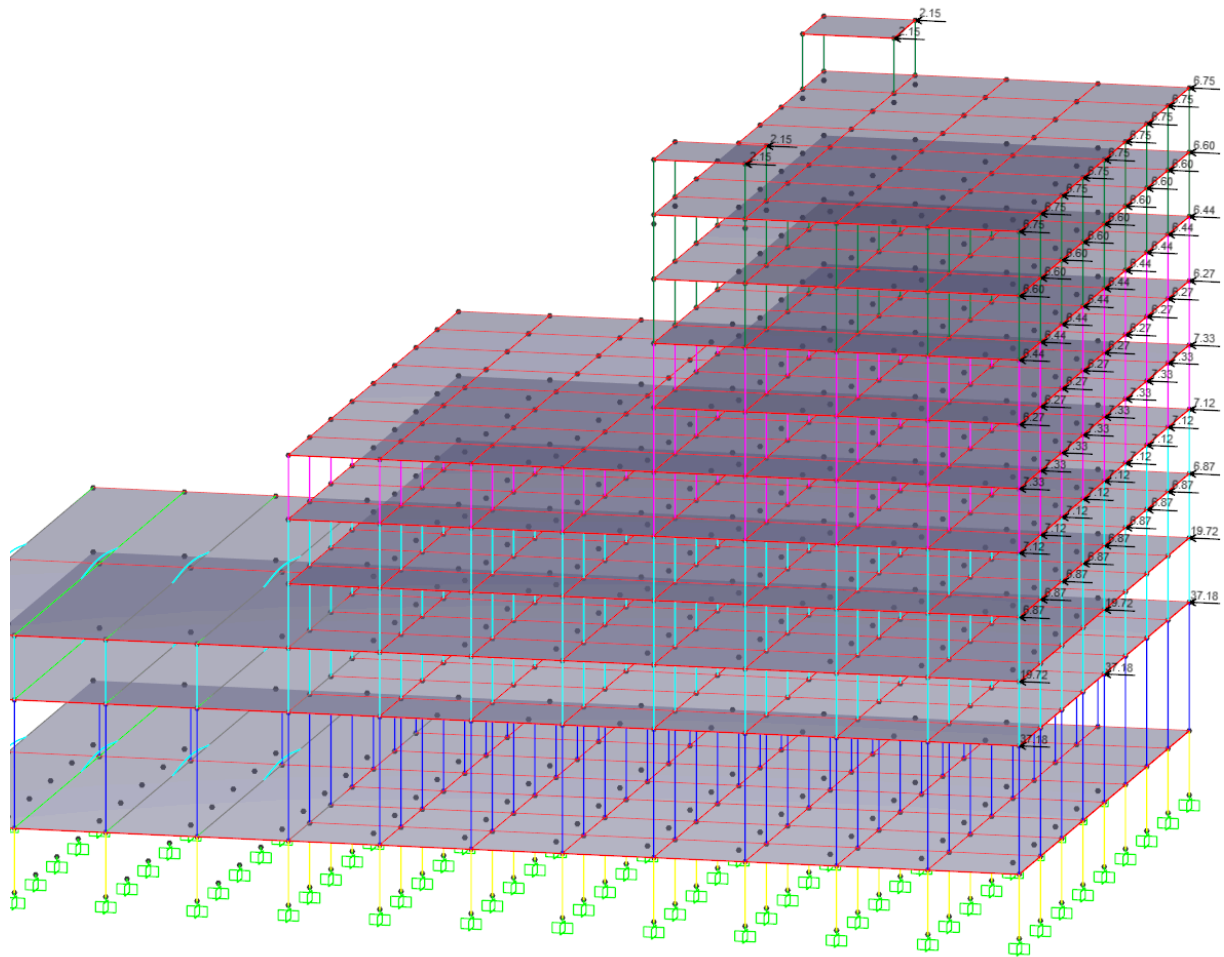


Figure 3.7.24 Moment diagram due to Dead Load (frame M)

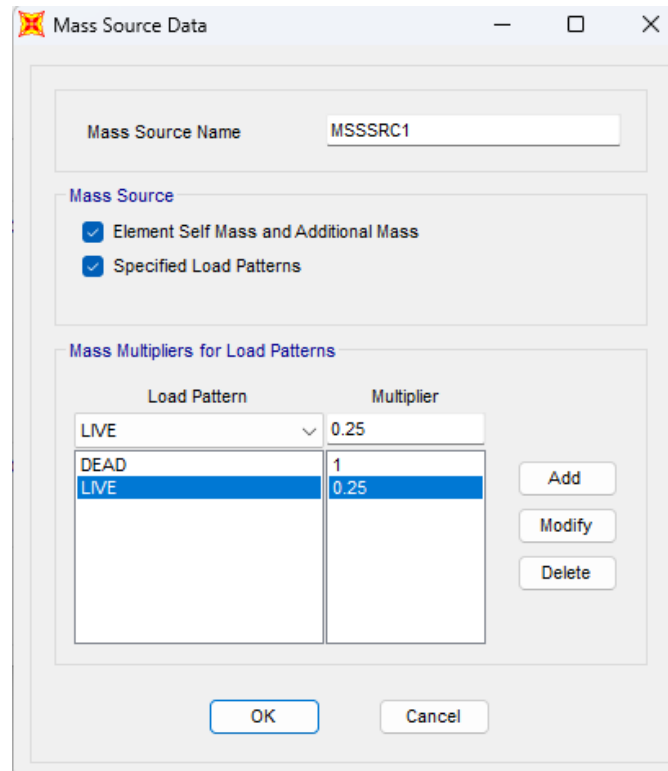




**Figure 3.9.6** Wind Load in X-direction assign



**Figure 3.9.7** Wind Load in Y-direction assign



Mass Source Data

Mass Source Name: MSSSRC1

Mass Source

- ☒ Element Self Mass and Additional Mass
- ☒ Specified Load Patterns

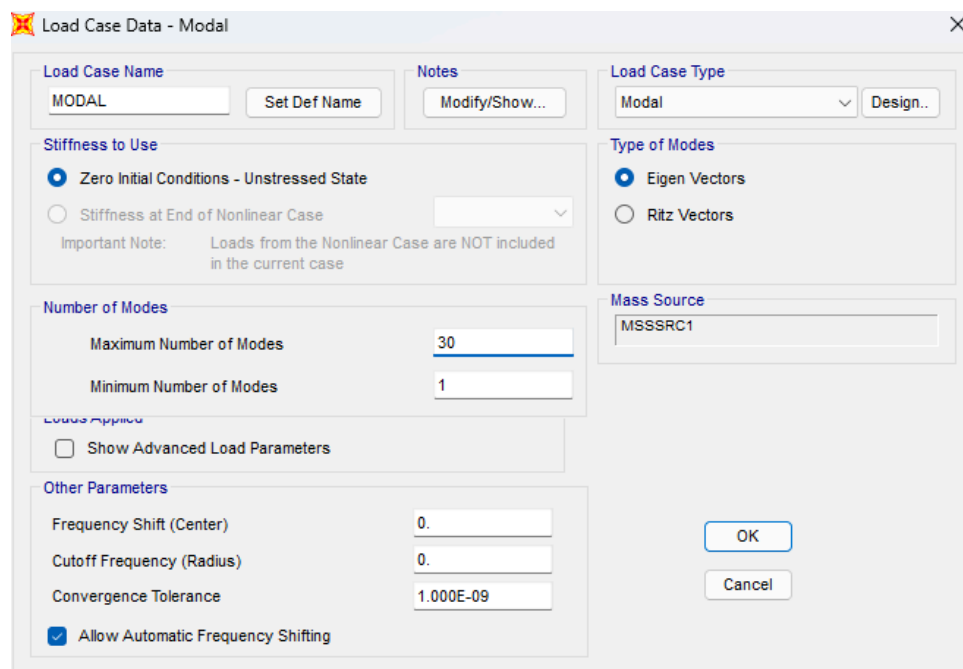
Mass Multipliers for Load Patterns

| Load Pattern | Multiplier |
|--------------|------------|
| LIVE         | 0.25       |
| DEAD         | 1          |
| LIVE         | 0.25       |

Buttons: Add, Modify, Delete

Buttons: OK, Cancel

**Figure 3.9.8.** Mass Source Data



Load Case Data - Modal

Load Case Name: MODAL Set Def Name Modify/Show...

Load Case Type: Modal Design..

Stiffness to Use

- ☒ Zero Initial Conditions - Unstressed State
- ☐ Stiffness at End of Nonlinear Case

Important Note: Loads from the Nonlinear Case are NOT included in the current case

Number of Modes

Maximum Number of Modes: 30

Minimum Number of Modes: 1

Loads Apply

- ☐ Show Advanced Load Parameters

Other Parameters

Frequency Shift (Center): 0.

Cutoff Frequency (Radius): 0.

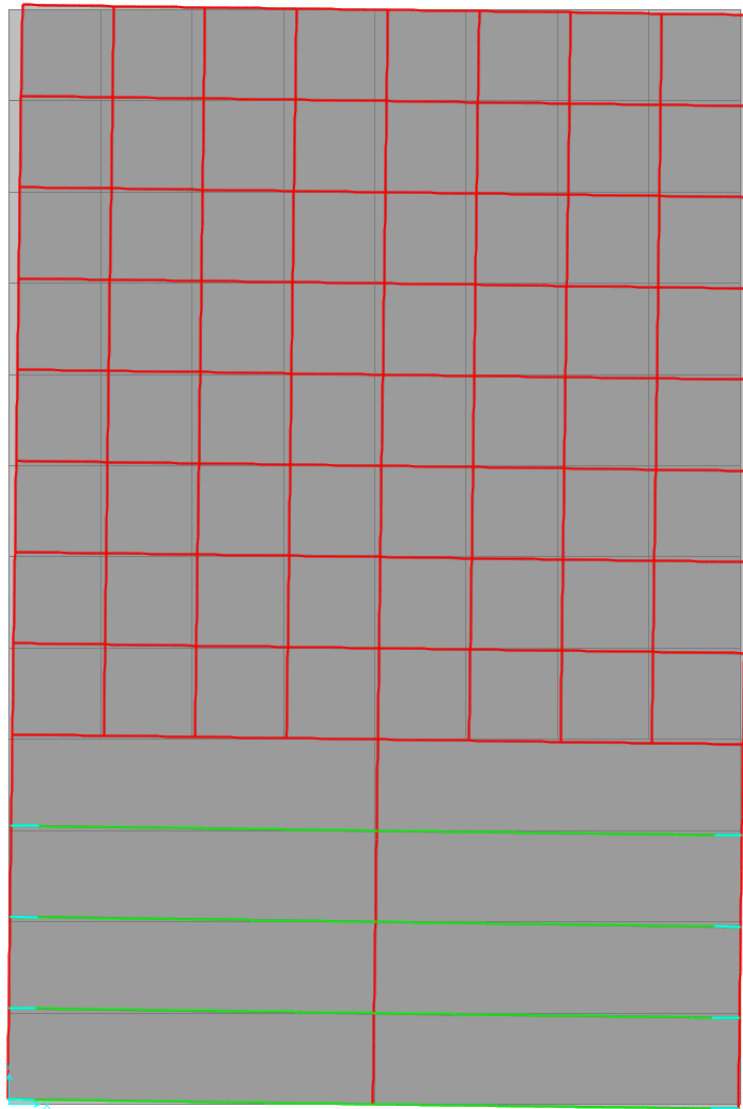
Convergence Tolerance: 1.000E-09

- ☒ Allow Automatic Frequency Shifting

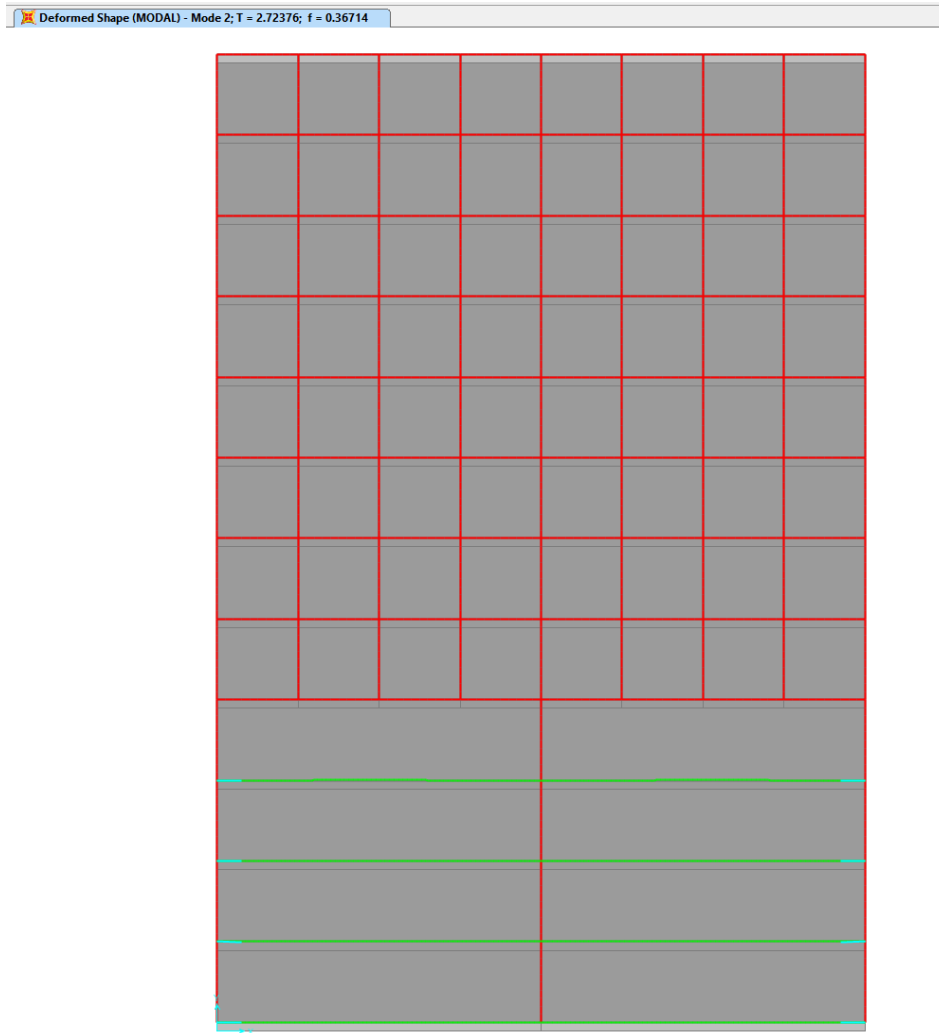
Buttons: OK, Cancel

Mass Source: MSSSRC1

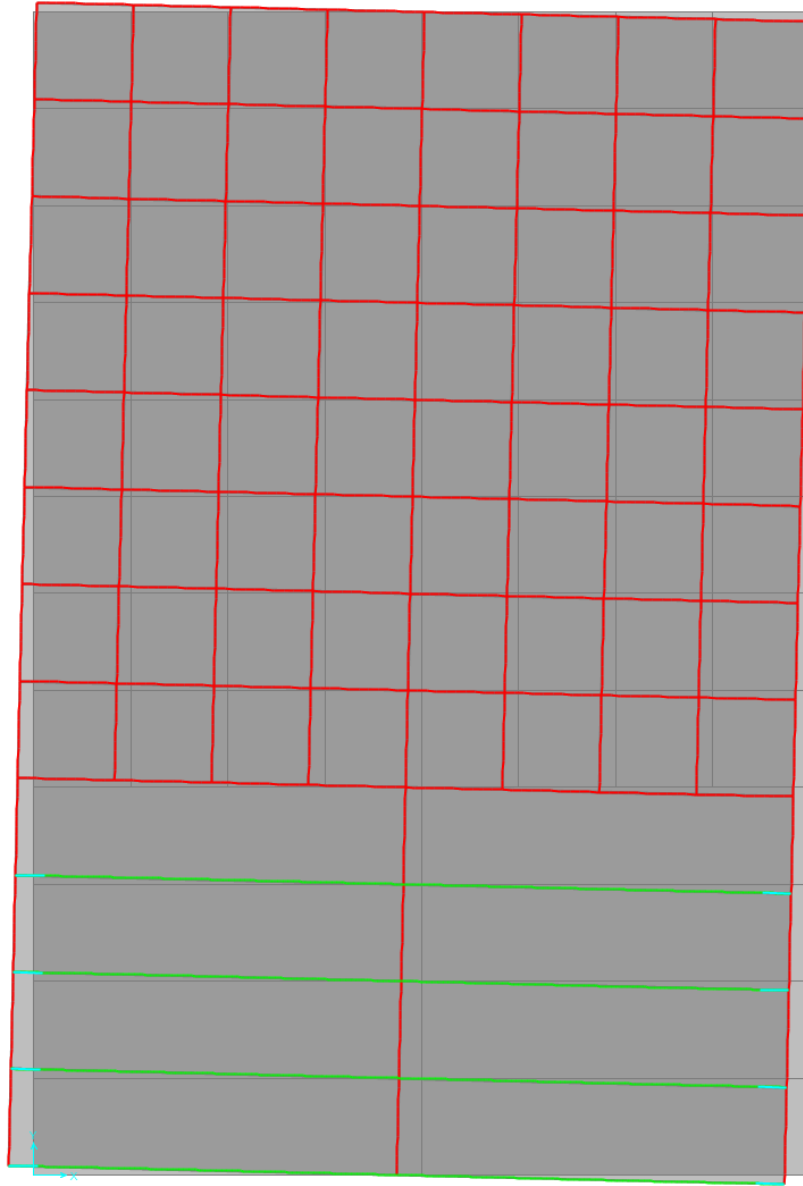
**Figure 3.9.9** Modal Case Data



**Figure 3.9.10.** Modal Analysis, mode 1,  $T^*=3.0451$



**Figure 3.9.11** Modal Analysis, mode 2,  $T^*=2.72376$



**Figure 3.9.12** Modal Analysis, mode 3,  $T^*=2.05735$

## 8. References

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