

**Design and planning for a major building project in  
Astana**

**(Capstone Project II)**

**Bachelor of Engineering**

**(Civil Engineering)**



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**2017**

## DECLARATION

We hereby declare that this report entitled “Design and planning for a major building project in Astana” is the result of our own project work except for quotations and citations which have been duly acknowledged. We also declare that it has not been previously or concurrently submitted for any other degree at Nazarbayev University.

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## **Abstract**

The current work presents an architectural, structural and geotechnical review of a four-star Hotel and Convention Center “Premium”, construction of which is strategically chosen to be conducted on the left bank of Ishim River in Astana. The structure is designed to accommodate 153 top-quality comfortable guest rooms, fitness center, conference hall, auditorium, restaurant and many other provisions. The building is projected to answer the world class requirements in terms of service level and comfort, in the meantime offering democratic prices. The territory under the main 12-story building is 30 by 30 meters, with the vast first floor occupying a territory of 50 by 60 meters beneath the main building. The hotel territory includes secure parking places and attractively landscaped environment. Architectural drawings were developed in accordance with Construction Norms and Rules of the Republic of Kazakhstan. The final part of the paper estimates the cost and feasibility of the project, presents a thorough WBS and construction activities. The hotel is planned to recover all the investment costs in eleven and a half years.

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## **1. INTRODUCTION**

### **1.1. Project Description**

This paper reviews main procedures required to conduct a structural, geotechnical and architectural design of a structure. The report also provides project management description, and preliminary estimated costs. Thorough market and financial analysis has shown that construction of a Hotel and Convention Center facility is feasible solution for Astana, as the city is growing as an important commercial and business center. The city is predicted to have a growing demand in hotels offering high level services due to upcoming EXPO 2017. The location of the hotel is comfortable in the center of the city Orynbor street near the Triumph Arch and exposition itself and made easy for city guests to arrive from the airport. The Street parking is also available outside the building, which will be able to host around 30 cars.

Total estimated cost of the project is anticipated to be around \$30-40 mln, with financing to be provided by private investors. Project is expected to start in November 2016 and to be completed by March 2017.

### **1.2. Scope of the Project**

Structural part includes the summary of loads, and design and calculations of the main structural elements column, slab and beam. Geotechnical part of the project includes a selection of a foundation type with the account of regional weather conditions. Drainage system improvement was also considered due to high frequency of floods. Regarding the architecture, the building will represent an 11 story box-shaped structure, with exterior made of glazing and masonry.

### **1.3. Project Team Members**

Roles and Responsibilities were assigned to each group member based on members' abilities, interests, and preferences:

- Team Leader/Manager/Chief: **Aizada Abuova**

The team leader/manager/chief is responsible for organizational and management issues. The duties are (but not limited to) ensuring maximum team performance, planning the project schedule, checking the involvement of each individual, managing meetings. Here are some basic responsibilities for team leader:

- Maximize overall performance of the team
- Managing team meetings

- Schedule project milestones to achieve timely results
- Maintain team focus
- Ensure members perform their roles
- Keep everyone involved in the project

- Team Recorder: **Aiman Salmenbayeva**

The team recorder is responsible for documentation of the team. Specific responsibilities of team recorder

- Documenting team activities
- Communicate complex ideas
- Record information for permanent record
- Participate in the learning and problem solving process

- Team Reporter: **Ilyas Bakirov**

The team reporter is responsible for organizing and presenting information effectively. The duties are:

- Organize information
- Synthesizing ideas into presentations
- Communicate complex ideas
- Use visual graphics as presentation aids
- Participate in the learning and problem solving process

- Team Reflector: **Moldir Yeskalieva**

The team reflector is to develop the team's process skills. Specific responsibilities are:

- Observing group interactions and progress
- Provide feedback on the learning processes
- Form observations into constructive statements
- Improving team efficiency
- Participate in the learning and problem solving process

- Team Explorer: **Rollan Okpenov**

Rollan is responsible for generating new ideas and providing technical assistance.

Specific responsibilities are:

- Providing new opportunities and ideas
- Provide energy to motivate the team
- Checking feasibility of ideas
- Identifying resources that can be used
- Participate in the learning and problem solving process

#### **Work Distribution among team members:**

**Aizada:** Structural analysis of the main structural components, detailed design of beam, column and slab, Architectural analysis and literature review.

**Aiman:** Project Management, Cost Analysis, Risk Assessments, Time management technologies and processes, occupational safety, planning, and feasibility estimation.

**Ilyas:** Preliminary architectural design, technical drawings, literature review, floor plans, internal planning, overall layout.

**Moldir:** Geotechnical design, ground conditions analysis, Energy Analysis by Autodesk Revit.

**Rollan:** Landscape design, literature review.

#### **1.4. Literature Review**

EUROCODEs are reference design norms mainly used within the European Union (EU). They check if a proposed design complies with the requirements for strength, stability and safety; provide technical specifications for building materials; and serve as a basis for engineering and construction contracts. Special conditions including earthquakes, execution and temporary structures are also considered by the code. The EN EUROCODEs consist of 10 European Standards, EN 1990 – EN 1999:

- Eurocode: Basis of structural design (EN 1990)
- Eurocode 1: Actions on structures (EN 1991)
- Eurocode 2: Design of concrete structures (EN 1992)
- Eurocode 3: Design of steel structures (EN 1993)
- Eurocode 4: Design of composite steel and concrete structures (EN 1994)
- Eurocode 5: Design of timber structures (EN 1995)
- Eurocode 6: Design of masonry structures (EN 1996)
- Eurocode 7: Geotechnical design (EN 1997)

- Eurocode 8: Design of structures for earthquake resistance (EN 1998)
- Eurocode 9: Design of aluminium structures (EN 1999)

Construction Norms of Republic of Kazakhstan (CNaR RK ) is a series of construction standards applied in the territory of the country. These documents are enacted by the government and protect public health and social welfare through construction of safe buildings and structures. Unlike the EUROCODEs, which consider only structural and geotechnical designs, CNaR RK additionally provides norms for urban planning, site investigations and architectural design.

CNaR RK is used to perform architectural design, while EUROCODEs are used for structural and geotechnical design. For simplicity, four categories are defined according to the purpose of use during design and documents from the EUROCODEs and CNaR RK are listed as shown in the Table 1.

Table 1. 1. EUROCODEs and CNaR RK

	EUROCODE	CN RK
<b>Structural safety, serviceability and durability</b>	EN 1990	CNaR RK 1.01, CNaR RK 3.02
<b>Actions on structures</b>	EN 1991	CNaR RK 2.01
<b>Design and detailing</b>	EN 1992, EN 1993, EN 1994, EN 1995, EN 1996, EN 1999	CNaR RK 2.01-2.04, CNaR RK 5.02, CNaR RK 5.03, CNaR RK 5.04
<b>Geotechnical and Seismic design</b>	EN 1997, EN 1998	CNaR RK 5.01

## **2. ARCHITECTURAL DESIGN**

### **2.1. Design Statement**

#### **2.1.1. Main Function of the Building**

“Premium Hotel” is planned to be a hotel/ convention center facility for business and professional purposes. There are separate hotel and convention center components of the facility:

- The Hotel component includes 134 guestrooms and required service rooms.

The convention center consists of a 392m<sup>2</sup> auditorium, a 273m<sup>2</sup> conference/ meeting room, a 342m<sup>3</sup> restaurant and all necessary administrative and management offices

#### **2.1.2. Site Location**

The following criteria were considered during the site selection:

- At least 80x100m
- Close to the downtown where businesses are accumulated
- Convenient access to major highways and transport
- Easy and quick to drive-in and drive-out
- A harmonizing surrounding area with pleasant views

Moreover, EXPO construction is in progress in the city Astana. After the completion, that area will mainly attract visitors with professional and business purposes. Therefore, the building should preferably be located near the EXPO. Several locations along Turan avenue, Kabanbay batyr avenue and Orynbor street were in consideration. The locations along Turan avenue are excluded first due to the lack of surrounding buildings and undeveloped construction in that area. Two main location were analyzed along the remaining streets. Due frequent heavy traffic near the location along Kabanbay batyr avenue, the site along the Orynbor street is selected as the most appropriate.



a) Site on Kabanbay Batyr Avenue

b) Site on Orynbor Street

Figure 2. 1. Alternatives site location

### 2.1.3. Preliminary Design

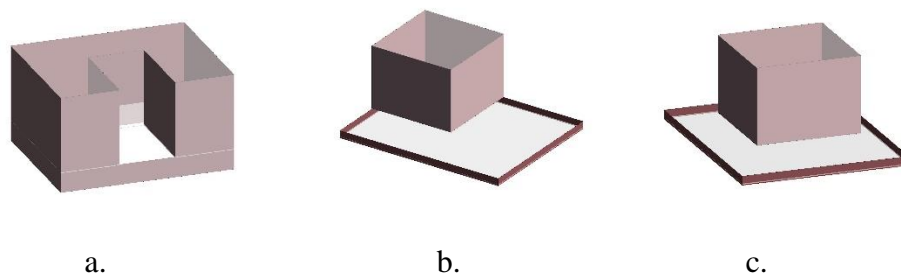


Figure 2. 2. (a, b, c.) Preliminary design models

During the development of preliminary design of a building surrounding structure designs were taken into account. Future location of “Premium Hotel” is surrounded by massive structures, mostly square and rectangular shaped. Therefore, rectangular and square shapes were used. “Premium Hotel” building is a composition of convention center and hotel itself. Convention center to be situated on the first floor with dimensions 60 m x 50 m. The first model which is shown in a Figure 2.2 (a) has a huge hotel component; while, models (b) and (c) relatively small. Convention center is a key component of a project, and it became crucial for building design decision. Convention center requires large spaces like conference hall and auditorium where view should not be obstructed. As our structure will be supported by columns, constructing model (a) would mean that spaces of the first floor will be filled with supporting columns. This will not allow us to properly distribute spaces for convention center. As a result, models (b) and (c) were considered further.

## **Choosing BIM**

One of the steps to start the project was choosing BIM software. BIM is an abbreviation of “Building information modeling”, it is a process where physical and functional characteristics of model can be generated. Both physical and functional characteristics are important for the project. Generating them with sketches will not only save time, but also provide better foundation for project management. To develop 3-D models SketchUp, ArchiCAD, AutoCAD, Vectorworks Architect and Revit software are commonly used. In terms of BIM software applications Revit and ArchiCAD are more advanced and mature in comparison to others. Both programs have their own advantages. Let’s start with Revit. Revit is highly demanded in the market, lots of companies use it all over the world. Also, a lot of add-ins are available for platform development. Another thing to mention is that Revit is widely supported, which means that variety of courses, books, tutorials and support are available in the internet. The last but not the least is that both architecture and MEP structures can be developed and supported with documentation. If we talk about ArchiCAD, it is oriented clearly towards architects. It has comfortable interface and layout, good rendering and visualization. However, extensions are not updated properly because it is not used as wide as Revit. For our major building project it is crucial to use both graphical design and documentation. Comparing stated before software, Revit was chosen, as it is widely used and supported.

### **2.2. Classification of building**

According to CNaR RK, building can be classified by purpose of use into the following types (CNaR 3.01-01-2008):

- Residential buildings
- Public buildings
- Industrial buildings
- Buildings for special purposes

The hotel belongs to the ‘Public buildings’ category and further architectural design will be developed according to the requirements on this category.

## 2.3. General Requirements

### 2.3.1. Building height and areas

The minimum floor-to-ceiling height in public and residential buildings is 3 meters (CNaR 3.02-02-2009), while typical height for living spaces in hotels is 3.3 meters (CNaR 3.02-13-2011). Ground level floor-to-floor height differs from the typical height by some factor: 2.0 for office buildings, 1.5 for residential/hotel buildings and 1.75 for other multi-purpose facilities. The first floor of the building is multi-use, therefore its floor-to-ceiling is calculated as  $3.3 \times 1.75 \approx 6$  meters. Additionally, presence of a mechanical floor is required to lay communications and to locate all engineering equipment, such heating and plumbing distribution manifolds, electrical transformers, elevator machinery, ventilation and air conditioning control equipment. The mechanical is possible to locate either underground, at the top or middle floor. Due to absence of a basement floor and allocation of a penthouse at the top, a middle floor is intended for the mechanical floor. According to the CNaR RK, height of such floor should be 1.8 meters.

The overall height of the building is  $H = 3.3 \times 10 + 1.8 + 6 = 40.8$  m excluding a roof. The calculated height should be now checked for compliance with the code. According to the CNaR RK 2.02-05-2009: Fire Safety of the Buildings and Facilities, buildings with bearing and enclosing structures made of natural or artificial stone materials, concrete or reinforced concrete are assigned to the 1<sup>st</sup> degree of fire resistance. Whereas, CNaR RK 3.02-02-2009: Public buildings and structures proposes not to exceed 16 floors or 50 meters limit for buildings of the 1<sup>st</sup> degree of fire resistance. This requirement  $H = 40.8 \text{ m} < 50 \text{ m}$  is then satisfied.

Regarding areas, site area is  $100 \times 80 = 8000 \text{ m}^2$  and the building occupies  $50 \text{ m} \times 60 \text{ m} = 3000 \text{ m}^2$  of the total area. Gross area of the ground floor is  $50 \text{ m} \times 60 \text{ m} = 3000 \text{ m}^2$ , while it is  $900 \text{ m}^2$  for the other floors. Therefore, the total gross area of the building is:

$$A = 3000 + 900 \times 10 = 12000 \text{ m}^2$$

Using the gross floor area of the building, occupancy load can be calculated as below:

$$\text{Occupancy load} = \frac{\text{Gross Area}}{\text{Floor Allowance per occupant}} = \frac{3000}{10} + \frac{9000}{20} = 750 \text{ occupants}$$

where the minimum floor allowance values are proposed by International Building Code (IBC) as  $100 \text{ ft}^2 = 9.29 \text{ m}^2$  for business areas and  $200 \text{ ft}^2 = 18.58 \text{ m}^2$  for hotels

(International Building Code, 2011). For calculation, the values were taken as  $10m^2$  and  $20m^2$  respectively. The calculated value means that the building can serve maximum 1500 occupants at the same time.

Additional to the gross area, usable area of the building can be calculated by the following formula:

$$\text{Gross Floor Area} = \text{Net Usable Area} + \text{Structural Space} \quad (\text{Eq. 2.1})$$

According to the CNaR RK, a net usable area in public buildings is a sum of areas of all space including balconies except areas of staircases and elevator shafts (CNaR 3.02-02-2009). Therefore, equation 1 can be rewritten as below:

$$\text{Net Usable Area} = \text{Gross Floor Area} - (\text{Area of elevator\&staircases}) \quad (\text{Eq. 2.2})$$

### 2.3.2. Means of egress

Means of egress is a way to travel from any point in a building to exit. These ways are important for safety purposes during fire and other emergencies. CNaR RK requires having at least two means of egress, specifically stairways at different sides of the public building (CNaR 3.02-02-2009). Design of the stairways is based on the following requirements:

- One stair flight should have at least 3 and no more than 16 steps. For double flight stairs, total number of steps should not exceed 18 (Sections 4.91).

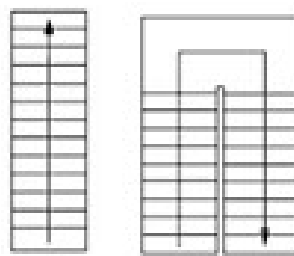


Figure 2. 3. Single and double flight staircases

- Every stair flight should be equipped with handrails. The standard handrail height is  $0.9m$  (Sections 4.92-93).
- Maximum slope of the stair flight suggested by the code is 1:2 (Section 4.95), while the preferable slope ranges between  $30 - 35^\circ$  (Figure 2.3). The majority of people considers this range as requiring the least effort to travel.

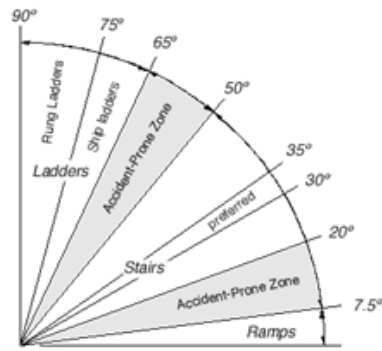


Figure 2. 4.Rule of thumb for stair dimensions (Griggs, 2001)

- Stair dimensions should be *width*  $\geq 1.35m$  (Section 4.97), *tread*  $\geq 0.3m$  and *rise*  $\leq 0.15m$  (Section 7.10).

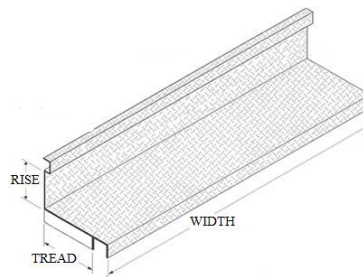


Figure 2. 5. Staircase step dimensions

From the given values, people have to climb  $\frac{3.3m}{0.15m/step} = 22 \text{ steps}$  to get to the next floor. If a double flight staircase is selected each flight will have  $\frac{22}{2} = 11 \text{ steps}$ . This selection satisfies the code requirement on the maximum number of steps. Total run for 11 steps is 3.3m.

- Distance between a stairway and the most distant room should be less than 60m (Section 110).
- In public buildings higher than 28 meters, one of the staircases should have a smokeproof enclosure of Type 1 that can be accessed only through balconies. The second staircase should be of Type 2 or 3 which blocks an access of smoke from the inner space and has continuous ventilation of fresh air. Distance between two means of egress should be at least 2.5m (Section 4.138).
- The width of the landing should be at least 1.2m.

These requirements enable to calculate the area occupied by two staircases using the staircase dimensions in Figure 2.6:

$$2 \times 2.7 \times 5.7 = 30.78 \text{m}^2$$

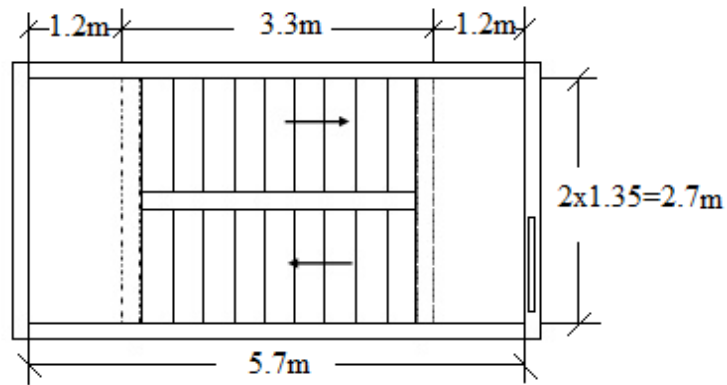


Figure 2. 6. Staircase dimensions

### 2.3.3. Elevators

CNaR RK suggests having minimum two elevators in public buildings, especially for hotels higher than 3 floors. Additionally, one of the elevators should have a cabin depth of at least 2.1m. Lechner (2011) claims that hotels need one passenger elevator for every 100 rooms or less and one additional service elevator for every 200 rooms. The Table 2.1 below shows capacity of an elevator and approximate shaft size for both passenger and service elevators (Lechner (011)):

Table 2. 1. Elevator shafts and sizes

	Capacity of Elevator		Shaft Size	
	in kg	in # of people	width (m)	depth (m)
Passenger elevator	910	12	2.4	2.1
Service elevator	1136	17	2.7	2.1

Conventional Control
Enter your planning information to get your required elevator solution

Metric | Imperial

Building information

Use of passenger elevator

Type i

Usage i

Zone information i

Number of Stops i

Travel for the zone (m) i

Population in the zone i

Applied parameters  Edit

Up peak handling capacity i (% of population/5 minutes)

Acceleration rate (m/s<sup>2</sup>) i

Interval (s) i

Travel time (s) i

System parameters

Acceleration i

Speed (m/s)

Estimated i 1.6

Actual i

Elevator size (persons)

Estimated i 6

Actual i

Required number of elevators	
Required by interval <span style="font-size: 0.8em;">i</span>	3.84
Required by handling capacity <span style="font-size: 0.8em;">i</span>	2.38
Actually required <span style="font-size: 0.8em;">i</span>	4

Figure 2. 7. Calculations of the number of elevators (Kone 2016)

Using the elevator traffic calculation tool KONE (2016), a hotel for business purposes requires 4 elevators as seen in the Figure 2.7. Accordingly, it is decided to locate a pair of passenger elevators at two sides of the building, whereas there will be an additional service elevator. So the approximate area occupied by the elevator shafts will be:

$$4 \times 2.1 \times 2.4 + 2.1 \times 2.7 = 20.16 + 5.67 = 25.83 \text{m}^2$$

### 2.3.4. Garbage Disposal and Dust Cleaning

In design of public buildings, garbage disposal and dust cleaning systems should be considered along with temporary garbage storage and its export from the building. Large public buildings might require a vacuum waste disposal system; while garbage chutes are enough for buildings with 3 floors and higher. Otherwise, garbage can be temporarily stored in collecting chambers with hard coating, preferably in a refrigerated space (Section 4.148-149).

Central dust cleaning is designed for public buildings under increased hygiene regulations. Household vacuum cleaners and/ or manual wet cleaning are sufficient for other buildings as well as hotels (Section 4.153).

### 2.3.5. Natural Lightening and Space Insolation

Design of natural and artificial lighting in public buildings is based on the combination of CNaR 2.04-05-2002: Natural and Artificial Lighting and CNaR RK 3.02-02-2009:

Public buildings and structures. The first code suggests that all spaces with human occupancy need natural lighting (Section 5.2.1). On the other hand, the second code makes exceptions to some rooms where artificial lighting is enough (Section 4.158). Those rooms include water closets, conference rooms and ballrooms. Allocation of the mentioned rooms is based on this norm. Moreover, spaces with natural lighting should be regularly ventilated through windows or by air conditioners (Section 4.161).

## **2.4. Requirements on main premises**

### **2.4.1. Corridors**

Width of a corridor depends on its length. The width should be at least 1.2m for the corridor whose length is less than 10m. If its length exceeds 10m the width should be more than 1.5m (CNaR RK 3.02-02-2009, Section 5.6). Additionally, corridors with a length of more than 60 meters should be separated by partitions with self-closing doors (Section 4.133).

### **2.4.2. Water closets**

CNaR RK 3.02-02-2009 for Public Buildings and Structures requires locating separate water closets for operating personnel, staff and visitors. Distance between a water closet and the most distant point of building should be less than 75 meters (Section 5.30). Amount of water closets and sanitary units varies depending on the type of the public buildings. There are the following requirements for public buildings:

Table 2. 2. General requirements on water closets

Male	<ul style="list-style-type: none"> <li>• 1 toilet for every 20-30 personnel and for every 50-60 visitor</li> <li>• 1 urinal for every 15-18 personnel and for every 50-80 visitor</li> <li>• 1 washbasin for every 4 toilets, but not less than 1 for a water closet</li> </ul>
Female	<ul style="list-style-type: none"> <li>• 1 toilet for every 15 staff member and for every 25-30 visitor</li> <li>• 1 washbasin for every 2 toilets, but not less than 1 for a water closet</li> </ul>

These requirements are applicable for the convention center part of the building, while for the hotel part there will be a separate sanitary facility for each hotel room.

Additional to the typical restrooms, it is required to locate a special toilet cabin for people with limited mobility. Its dimensions are  $1.65 \times 1.8m^2$  (Section 7.36).

### 2.4.3. Conference Hall

A conference hall in the convention center serves as a room for business meetings and conferences, as well as workshops and seminars. CNaR RK 3.02-02-2009 proposes to design conference halls based on its capacity. Minimum unit area is  $1.25m^2/seat$  in conference halls for less than 150 people and  $1.1m^2/seat$  in conference halls for more than 150 people (Section 5.19). The conference hall in the convention center is planned to accommodate approximately 100 people, therefore, minimum total area of the room should be  $1.25 * 100 = 125m^2$ . The designed conference hall will be small-scale and adaptable for different purposes as shown in the Figure 2.8.

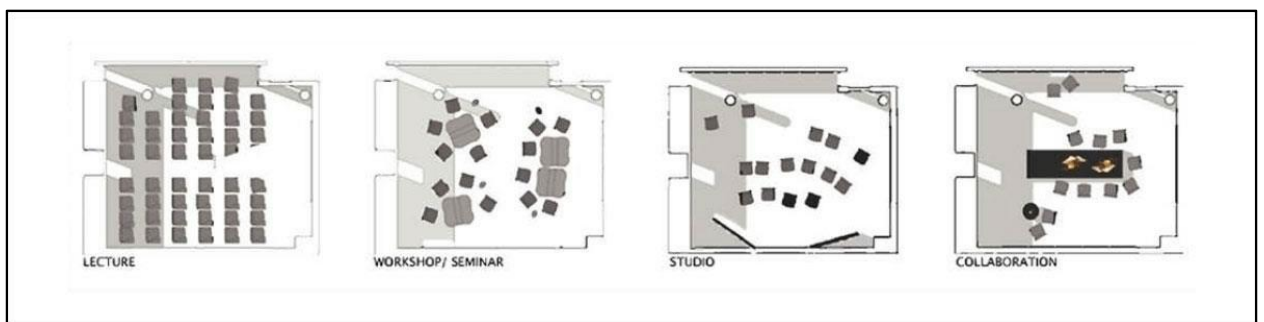


Figure 2. 8. Adaptable conference hall (Gee, 2006)

### 2.4.4. Auditorium

An auditorium is a space for large conferences, meetings, performances and presentations. In contrast to the conference hall, it can accommodate huge audiences. In our case, the auditorium can accommodate 180 people (15 rows and 12 seats per row). Initially, referring to the Figure 2.9, a shoebox shape of the auditorium is selected due to the shape simplicity. Moreover, the auditorium will be sloped to provide visibility of a screen from any point.

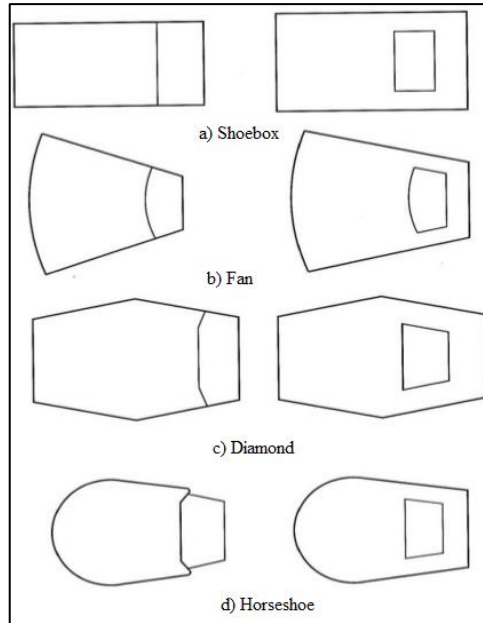


Figure 2. 9. Shapes of auditorium (Barron, 2010)

CNaR RK suggests a separate design procedure for calculation of auditorium dimensions (CNaR 3.02-02-2009, Appendix 6). The code requires that seats should be located within 45 degrees from both sides of the main axis as shown Figure 2.10. Next, distance from a screen to a backrest of the first row ( $d$ ) should be  $d = 0.36L$ , where  $L$  is distance from a screen to a backrest of the last row. Width of access routes should be at least 1.5m (Section 4.110). Using these requirements and typical values of the auditorium seating (Figure 2.11 and Table 2.3), auditorium dimensions can be calculated:

$$W = \text{Row Width} + \text{Width of Access Routes} = 12 \times 0.6 + 2 \times 1.5 = 10.2m$$

$$L = \text{Length of Seating Area} + \text{Width of Access Route} \\ + \text{Distance to Screen} = 13 \times 1 + 0.75 + 1.5 + 0.36 \times L$$

Solving the equation above, the length is  $L = 23.8m$ . Area of the auditorium is  $10.2 \times 23.8 \approx 243m^2$ . The code suggests the minimum unit area,  $1.1m^2/person$ . By multiplying to the capacity of the auditorium, minimum area can be determined as  $1.1 \times 180 = 198m^2 < 243m^2$ . This shows that the designed auditorium satisfies the code requirements.

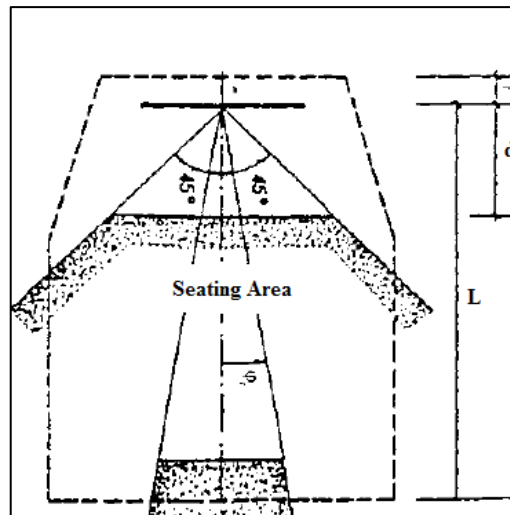


Figure 2. 10. Auditorium dimensions

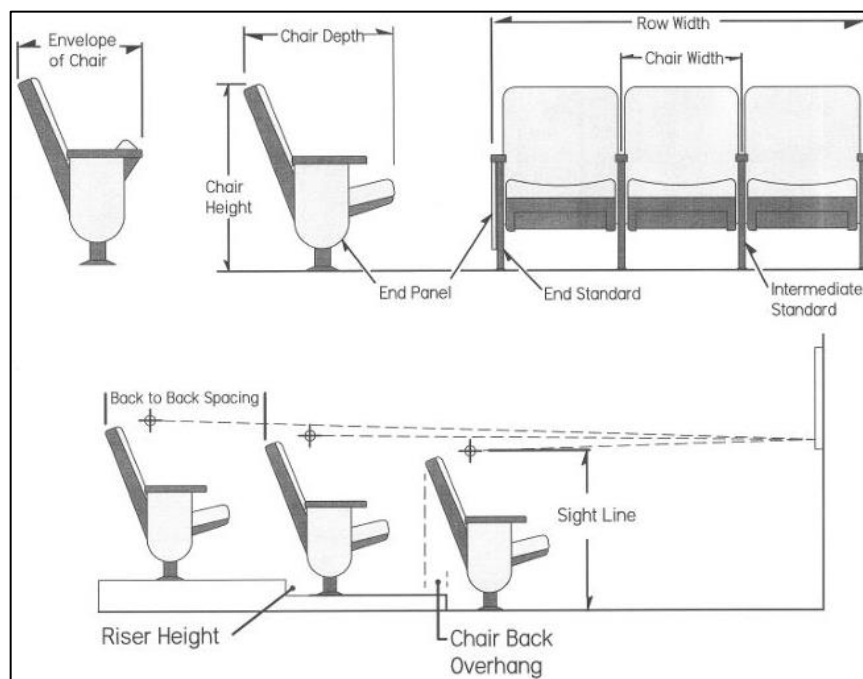


Figure 2. 11. Auditorium seating dimensions

Table 2. 3. Typical values for auditorium seating

Chair Width	600mm
Chair Depth	750mm
Back-to-back Spacing	1000mm
Riser Height	150mm

### 2.4.5. Restaurant

According to the CNaR RK 3.02-13-2011, capacity of the restaurant depends on the class of the hotel. For high-class hotels, it should be 90-95% of the hotel capacity (Section 4.3.3.3.4). Unit area of the restaurant is not less than  $1.8m^2/visitor$  (CNaR RK 3.02-02-2009, Section 5.29). If there are 133 hotel rooms, minimum total area of the hotel complying with the code will be  $1.8 \times 133 = 240m^2$ . Consequently, area of the restaurant can be set as  $457m^3$ .

### 2.4.6. Hotel Rooms

Minimum area of living spaces in the hotel should be  $12m^2$  (CNaR RK 3.02-02-2009, Section 5.16). Hotels are classified from 1\* to 5\* depending on its quality, the comfort level and the service provided. The designed hotel will be as 4\*(four star), because they have similar characteristics.

Table 2. 4. Areas of rooms and their distribution in 4\* hotels

Room type			% of total number of hotel rooms
Number of rooms	Number of people	Area, m <sup>2</sup>	
1	1	16	Not less than 20
1	2	20	Not less than 60
2	2	35	No more than 8
3-4	2(3)	50-65	No more than 8

Table 2. 5. Hotel Service Rooms

Room Type	Area, m <sup>2</sup>
Staff room with built-in cabinets for clean linen	16
Storage for dirty linen	6
Storage for cleaning equipment	4
Room of consumer service	6-8
Storage room for maid carts	12

WC for staff - toilet, sink, shower	4
-------------------------------------	---

Table 2. 6. Premises at reception-vestibule area of 4\* hotel

Name of premises	Minimum area, m <sup>2</sup>	Notes
Vestibule	100	
Reception desk	12	
Reservation office	8	
Bell service office	6	
Staff room	8	
Sanitary service room	10	
Room for administrator	12	

## 2.5. Non-structural materials

### 2.5.1. Flooring

Design of flooring is based on CNaR 2.03.13-88. Floor covering is selected as a parquet. Based on the code requirements, main floor layers are defined and demonstrated Table 2.7.

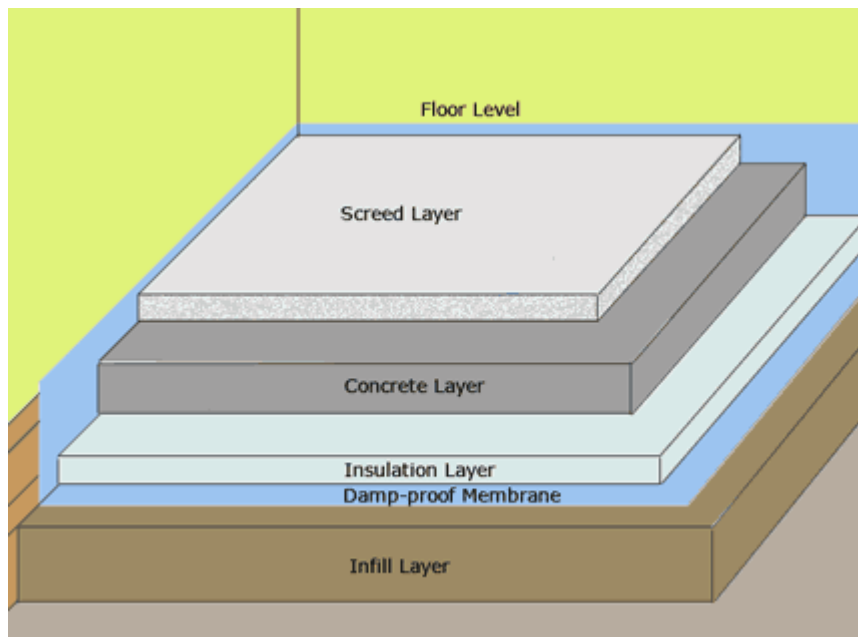


Figure 2. 12. Floor structure

Table 2. 7. Floor layers with thicknesses

Layer	Thickness, mm	Specific weight, kN/m <sup>3</sup>
Covering (parquet)	25	7.36 (750 kg/m <sup>3</sup> )
Screed layer (lightweight concrete)	50	9.81 (1000 kg/m <sup>3</sup> )
Concrete layer (cement-sand mortar)	40	17.66 (1800 kg/m <sup>3</sup> )
Insulation layer	50	1.96 (200 kg/m <sup>3</sup> )
Infill layer (gravel)	40	15.70 (1600 kg/m <sup>3</sup> )

### 2.5.2. Ceiling

CNAR 3.04.01-87 proposes a ceiling profile for different types of building. Soundproofing ceiling is selected so that the layer between a slab and a ceiling cover is filled with an insulation material. Moreover, the ceiling cover will be several layers of gypsum boards joint using green glue. The code suggests maximum ceiling thickness of 100mm. Overall ceiling structure is demonstrated in Figure 2.13 and thicknesses of layers are in Table 2.8.

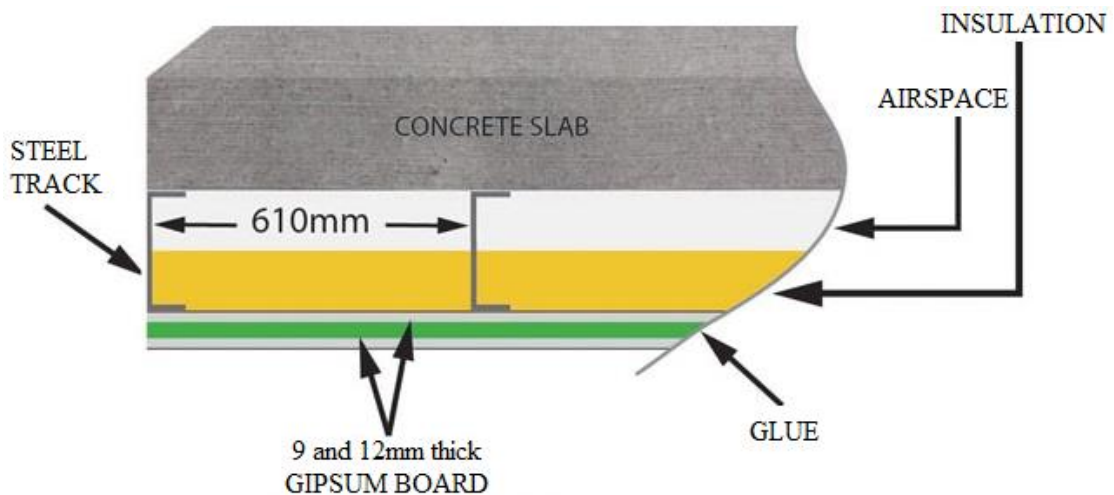


Figure 2. 13. Ceiling structure

Table 2. 8. Ceiling layers with thicknesses

Layer	Thickness, mm	Specific weight, kN/m <sup>3</sup>
Airspace	25	0
Insulation	50	1.96 (200 kg/m <sup>3</sup> )
Gypsum board	9+12=21	14.72 (1500 kg/m <sup>3</sup> )
Metal partitions	75	-

### 2.5.3. Roofing

Various roofing designs are suggested by СНиП РК 3.02-06-2009. According to the code, flat roof is designed for roofing of the building. It will be covered with several layers of bituminous asphalt paving to provide a waterproof surface. Slope of flat roofs should be at least 2<sup>0</sup> to comply with code requirements. Layers of the flat roof and their thicknesses are shown in Figure 2.14 and Table 2.9 respectively.

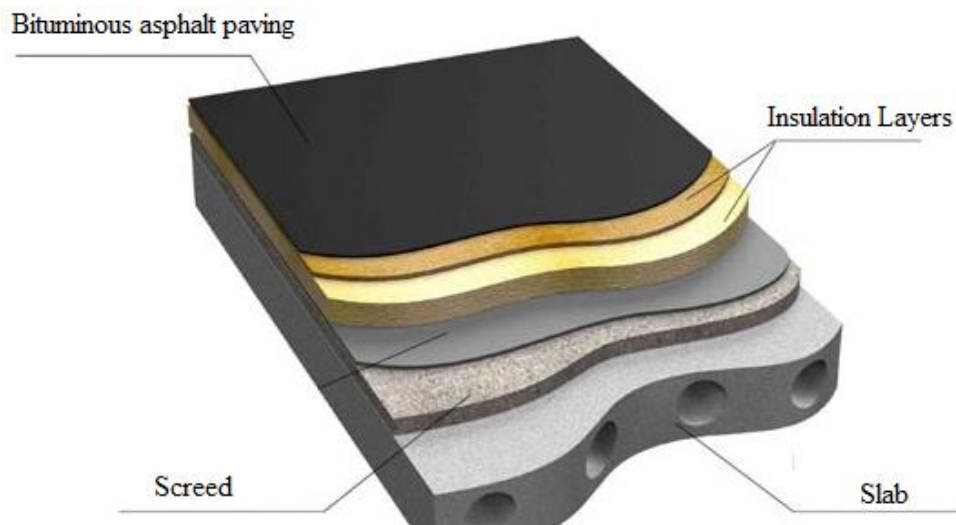


Figure 2. 14. Roof structure

Table 2. 9. Roof layers with thicknesses

Layer	Thickness, mm	Specific weight, kN/m <sup>3</sup>
Screed layer (lightweight concrete)	50	9.81 (1000 kg/m <sup>3</sup> )
Insulation Layer	50	1.96 (200 kg/m <sup>3</sup> )
Bituminous Asphalt Paving	3x5=15	5.89 (600 kg/m <sup>3</sup> )

### 3. STRUCTURAL DESIGN

#### 3.1. Building Frame

Concrete and steel are considered as the most widely used building material in the modern construction industry. Table 3.1 demonstrates a comparative study of these materials in terms of several parameters.

Table 3. 1. Comparison of structural materials

	Concrete	Steel
Strength	High compressive strength, low tensile strength	High strength
Ductility	Decreased ductility	High ductility
Safety	Fairly good fire and weather resistance	Low fireproofing property
Quality	No need for skilled personnel	Skilled workmanship
Maintenance	Easy maintenance	Hard maintenance
Construction time	Relatively slow construction	Rapid erection
Material Availability	Need to find a proper type of concrete	Limited material
Cost	Cost effective	More costly
Design possibilities	More space occupied Wide variety of forms	Less space occupied Repetitive use

\*Based on Emmitt and Gorse, 2014

Decreased cost, material availability in Astana and a wide variety of design possibilities are the main advantages of reinforced concrete buildings compared to steel frames. Moreover, construction time of reinforced concrete buildings can be decreased by using pre-cast structural elements. By analyzing the comparative study, reinforced concrete is selected as the main building material.

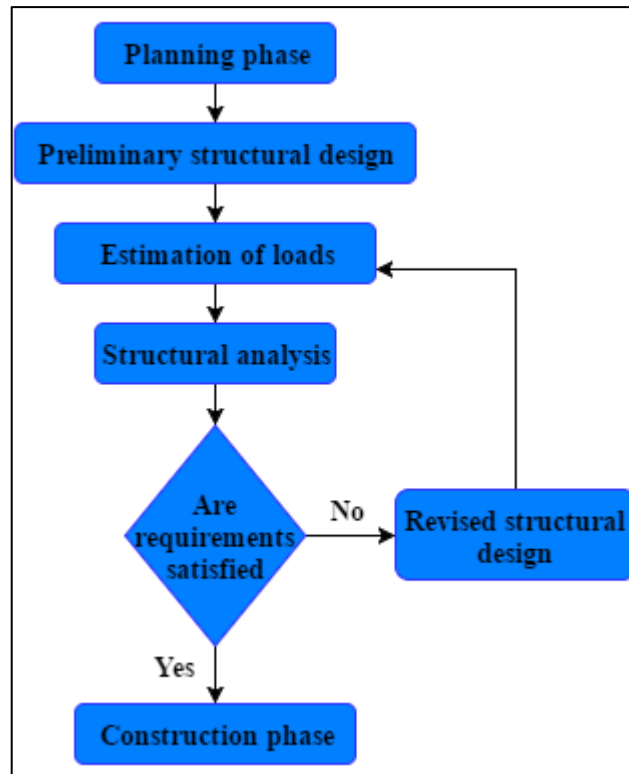


Figure 3. 1. Structural design process

According to the algorithm of structural design shown in the figure above, we have to develop preliminary structural design including all structural elements. The main structural elements are beams, columns and slab. In the EUROCODE, there are separate design procedure for each structural element. After that, structural analysis will be conducted to see if all Limit State requirements are satisfied. If the requirements are satisfied the design will be approved and be valid for construction. Otherwise, the design should be revised.

### 3.2. Structural Design Loads

Structural loads on buildings are classified as horizontal and vertical loads. Horizontal loads include dead and live loads, while vertical loads consist of wind and earthquake loads. Moreover, there are accidental loads including snow loads. Calculations of design loads are needed to analyze the whole structure and design structural members. This part of the report contains detailed description of design loads and provides their values for further structural design.

#### 3.2.1. Dead Load

Dead loads are the weight of all structural members and parts permanently attached to the structure. They include:

- Structural members: columns, beams and slabs
- Non-structural members: walls, roofing, ceiling, flooring, exterior and interior finishes
- Stairways, built-in partitions, plumbing and electrical fixtures

Dead loads due to non-structural members are calculated based on thickness of the material and its specific weight (Table 3.2).

Table 3. 2. Dead loads of non-structural members

<b>Flooring</b>	kN/m <sup>2</sup>
Covering	0.184
Screed Layer	0.491
Concrete Layer	0.706
Insulation Layer	0.098
Infill layer	0.628
<b>Total</b>	<b>2.107</b>

<b>Ceiling</b>	kN/m <sup>2</sup>
Insulation Layer	0.098
Gypsum Board	0.309
Partitions	0.192
<b>Total</b>	<b>0.599</b>

<b>Roofing</b>	kN/m <sup>2</sup>
Screed Layer	0.491
Insulation Layer	0.098
Bituminous Asphalt Paving	0.088
<b>Total</b>	<b>0.677</b>

### 3.2.2. Live Load

Live load is the sum of loads varying in magnitude and position. It can be calculated based on the use and occupancy of the building. EN 1991-1-1:2002 suggests values of live loads based on the category of the building. The hotel component of the building can be related to the Category A, whereas the convention center is in the Category C. Furthermore, NA to BS EN 1991-1-1:2002 constricts the categories to A3 and C3 for the hotel and

convention center respectively. Additionally, a roof is included to the separate category, H. Table 3.3 below shows live loads for the mentioned categories.

Table 3. 3. Live loads based on building category

Category	Live load, kN/m <sup>2</sup>
Category H	0,4
Category C3	4,0
Category A3	2,0

### 3.2.3. Wind Load

The kinetic energy of wind creates wind loading when it hits structures. Wind load depends the following parameters (Taranath, 2005):

- Wind speed
- Interval at which the design wind speed can occur
- Surrounding area of the building
- Height of the part under consideration
- Wind direction
- Shape and size of the building
- Wind incidence angle
- Structural properties of the exposed area
- Topographical features of the surrounding area

Figure 3.2 shows wind load directions on different surfaces (EN 1991-1-1:2002).

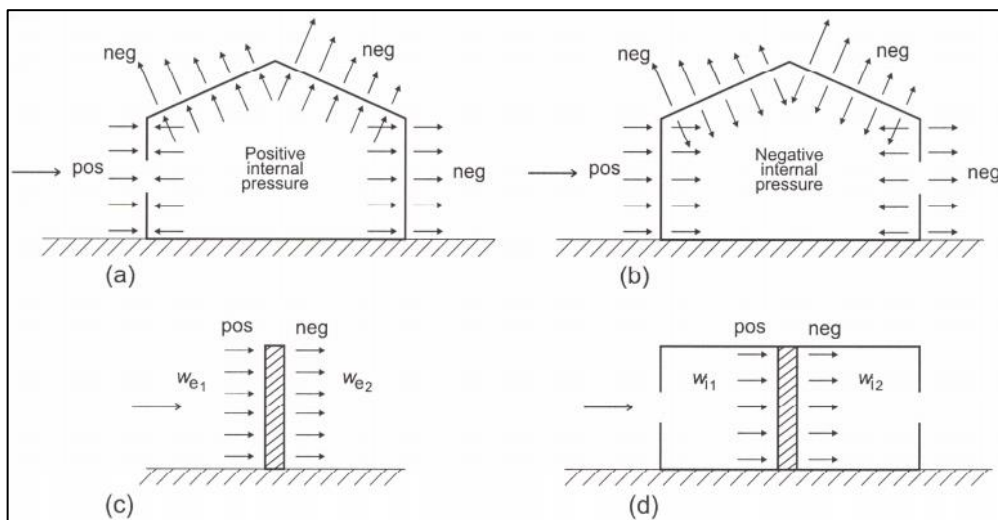


Figure 3. 2. Wind load on surfaces

According to the EUROCODE, calculation of wind load is possible using fundamental value of the basic wind velocity and terrain characteristics of the site. Basic wind velocity is determined by:

$$v_b = v_{b,0} \times c_{dir} \times c_{season} = 37.8 \times 1 \times 1 = 37.8\text{m/s}$$

where,  $v_b$  – basic wind velocity

$v_{b,0}$  – fundamental value of the basic wind velocity which defines 10-minute mean velocity measured 10m above the ground. It is 37.8m/s for Astana.

$c_{dir}$  – directional factor, conservatively taken as 1.0 for all directions

$c_{season}$  – seasonal factor, taken as 1.0

Terrain of the site is identified using Annex of EUROCODE (Appendix 1). As the building is located at the urban area terrain category is IV. For this terrain category, the following parameters are valid:

$$z_0 = 1.0\text{m}; z_{min} = 10\text{m and } z_{max} = 200\text{m}$$

where  $z_0$  – roughness length

$z_{min/max}$  – minimum/maximum height

Basic velocity pressure created by wind actions is:

$$q_b = \frac{1}{2} \times \rho_{air} \times v_b^2 = \frac{1}{2} \times 1.25 \times 37.8^2 = 893,025 \text{ N/m}^2$$

In order to find distributed wind load on the structure the following should be calculated first:

$$\text{Terrain factor } k_T = 0.19 \times \left(\frac{z_0}{z_{0,II}}\right)^{0.07} = 0.19 \times \left(\frac{1}{0.05}\right)^{0.07} = 0.234$$

$$\text{Roughness Factor } c_r(z) = k_T \times \ln\left(\frac{z}{z_0}\right)$$

$$\text{Turbulence intensity } I_v = \frac{k_1}{c_0(z) \times \ln\left(\frac{z}{z_0}\right)}$$

where  $z$  – height of the building and  $k_1$  – turbulence factor with recommended value of 1.0.

Important consideration in calculation of wind actions is width-height relationship. If height of the structure is greater than its width, distributed load will be different for the level that exceeds the width (Appendix 1). Moreover, calculations are made on one face of the building. Therefore, windward load at zone D and leeward load at zone E are considered.

Table 3.4. Distributed wind load

Elevation	Iv(z)	cr(z)	vm(z)	ce(z)	qp(z) (kN/m)	h/d	cpe, windward	we, windward	cpe, leeward	we, leeward
0-30	0,294	0,797	30,127	1,943	1,735	1	0,8	6,939	-0,5	-4,337
30-40,8	0,270	0,869	32,850	2,181	1,947	1,36	0,8	7,790	-0,7	-6,816

Table 3.5. Wind load at joints

Level	Altitude, m	Windward linear load, kN/m	Leeward linear load, kN/m	Distance, m	Point load, kN
1	6	6,939	-4,337	4,65	52,432
2	9,3	6,939	-4,337	3,3	37,210
3	12,6	6,939	-4,337	3,3	37,210
4	15,9	6,939	-4,337	3,3	37,210
5	19,2	6,939	-4,337	3,3	37,210
6	22,5	6,939	-4,337	2,55	28,753
7	24,3	6,939	-4,337	2,55	28,753
8	27,6	6,939	-4,337	3,3	37,210
9	30,9	7,790	-6,816	3,3	48,200
10	34,2	7,790	-6,816	3,3	48,200
11	37,5	7,790	-6,816	3,3	48,200
12	40,8	7,790	-6,816	1,65	24,100

### 3.2.4. Snow Load

Snow load is accidental load that depends on the building's location, shape, roofing type and its wind exposure. If snow is considerably severe snow load must be included in calculations of design loads in addition to the roof loading. EN 1991-1-1:2002 states that there is no need to consider snow load if the category H of roofs is selected.

EUROCODE suggest the formula to calculate snow load on roof of the structure:

$$s = \mu_1 \times C_e \times C_t \times s_k = 0.8 \times 0.8 \times 1.0 \times 1.5 = 0.96 \text{ kN/m}^2$$

Where  $\mu_1$  – snow load shape coefficient defined in Annex of EUROCODE (Appendix 1). Due to flat shape of the roof, this coefficient is 0.8 (Appendix 1).

$C_e$  – exposure coefficient. It is equal to 0.8 for Astana because considerable wind actions in the region (Appendix 1).

$C_t$  – thermal coefficient in general situations

$s_k$  – characteristic value of snow load on the ground. The value can be found in snow load maps provided in CN RK (Appendix 1) and it is 1.5 kN/m<sup>2</sup>.

### 3.3. Limit State Design

A limit state is a state at which a structure is no longer able to satisfy design criteria. A structure has to fulfill two main limit states (Mosley, Bungey and Hulse, 2012):

- Serviceability limit state (SLS): the building remains functional, but it can cause discomfort to occupants such as deflection, cracking, excessive vibration and durability.
- Ultimate limit state (ULS): exceeding the limit might cause collision of a structure and the structure is no longer safe and functional.

Partial factors of safety are applied to the actions in order to ensure safety of the structure at the limit states (Table 3.6).

Table 3. 6. Partial factors of safety for design loads at limit states

Limit state	Dead Load		Live Load	
SLS	1.0		1.0	
ULS	Unfavorable	Favorable	Unfavorable	Favorable
	1.35	1.15	1.50	0

\* EN1990:2002+A1

In order to be safe and functional, structural design has to satisfy the most unfavorable conditions.

### 3.4. Load Combinations

Structural design is based on different combinations of design loads. The general combination of loads is expressed as (EN 1991-1-1:2002):

$$\sum_{j \geq 1} \gamma_{G,j} G_{k,j} + \gamma_P P + \gamma_{Q,1} Q_{k,1} + \sum_{i > 1} \gamma_{Q,i} \psi_{0,i} Q_{k,i}$$

where,  $\gamma$  – Partial factor for corresponding actions;

$G_{k,j}$  – Dead load j;

$P$  – Pre-stressing action;

$Q_{k,i}$  – Live load i;

$\psi_{0,i}$  – load combination factor. Load combination factors can be specified for the building category under consideration (Table 3.7).

Table 3. 7. Load combination factors for building categories

Load	Combination, $\psi$
Live load	Category A: 0.7
	Category C: 0.7
	Category H: 0.7
Snow	0.7
Wind	0.5

\* EN1990:2002+A1

### 3.5. Structural Analysis

Structural analysis is a study of effects of loads on buildings and structures. The analysis includes verification of separate structural components if they can sustain various load combinations and check for overall safety, serviceability and stability of the structure as a whole. After conducting preliminary structural design, a structure should be analyzed for strength and rigidity requirements and check if the structure satisfies code provisions. Structural analysis of simple structures might be sufficiently accurate, while for complex structures it becomes complicated. Therefore, a set of assumptions has to be made on material properties, loading conditions, structure geometry, joint and support conditions of structural components.

Structural analysis methods can be classified based on the nature of applied loads and response of a structure to the actions (Zhang, 2015). Firstly, selection of the structural analysis method depends on whether actions on the structure static or dynamic. The major difference between these methods is that the dynamic loads have a time constraint and

accordingly, the structure will have a time-varying response to actions. Secondly, structures have elastic or inelastic response to applied loads. If a structure under consideration returns to its original form after application of loads the structure is called elastic. Otherwise, it is inelastic. The next criteria for the selection of the method of analysis is the degree on determinacy. When the structure is statically determinate, it can be analyzed by only static equilibrium equations; whereas for indeterminate structures they must satisfy both static equilibrium equations and compatibility conditions of internal forces. Due to complexity of calculations on statically indeterminate structures, numerical approximation methods are employed. Figure 3.3 below shows the classification of methods based on the mentioned criteria of selection.

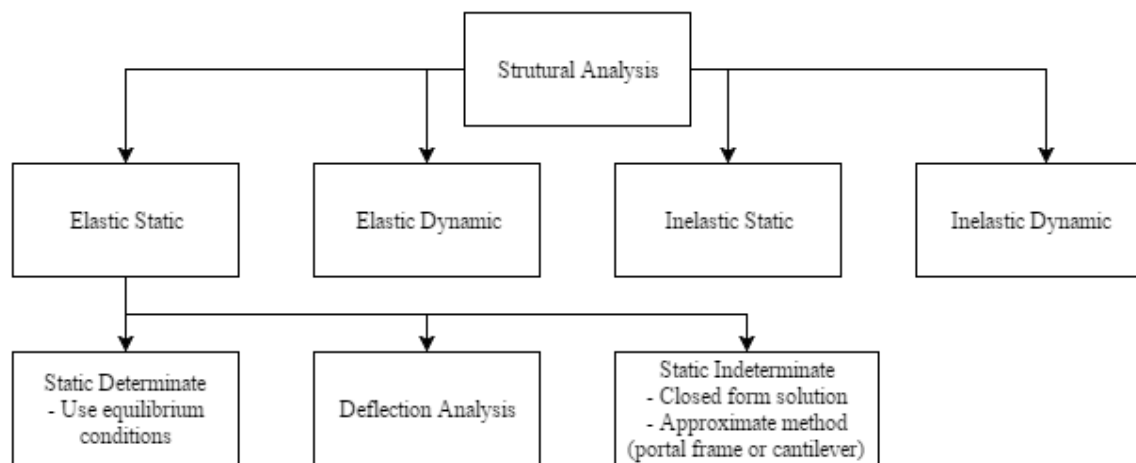


Figure 3. 3. Methods of structural analysis

Another method of structural analysis is use of a software, SAP2000. The software enables modeling complex structures using provided tools and simulates them according to different load conditions. Moreover, SAP2000 is able to design structural members considering not only structural aspects, but also economical one.

### 3.6. Structural Member Design

#### 3.6.1. Beam Design

There are three main parts of the design of reinforced concrete beams (Mosley, Bungey and Hulse, 2012):

- 1) Preliminary analysis of loads and their combinations; beam sizing;
- 2) Detailed structural analysis and design of steel reinforcements;
- 3) Check compliance with code requirements;

Practical considerations on beam design (Zhang 2015):

- Depth should be 8-10% of span to be make an economical beam.
- Typical ratio of width to depth is between 0.4-0.6.
- Single layer of steel is preferable due to cast considerations.
- Steel should be placed symmetrically.
- Beam width should be kept less than or equal to column width.

Notations:  $d$  – effective beam depth

$h$  – beam depth

$M$  – bending moment

$b$  – width of the section

$f_{ck}$  – characteristic cylinder strength of concrete

$\delta$  – moment redistribution factor

$f_{yk}$  – characteristic yield strength of concrete

$Z$  – lever arm

$A_s$  – cross sectional area of reinforcement

Basic design steps to design a rectangular beam (Zhang, 2015):

Step 1. Estimation of  $d = 8 - 10\%$  of  $L$

Step 2. Find  $h$  (50-70mm in total) including estimated bar diameter, link diameter and cover:  $h = d + (d_b + d_t + cover)$

Step 3. Assume  $b = (0.4 - 0.6)h$

Step 4. Calculate self-weight of concrete

Step 5. Calculate design moment based on design loads

Step 6. Find  $\lambda$ ,  $\delta$  and  $\eta$  for  $f_{ck}$

Step 7. Use  $k_{max}$  from the table proposed by EUROCODE, to determine  $d_{min} =$

$$\sqrt{\frac{M}{k_{max} b f_{ck}}}$$

Step 8. Adjust depth considering Step 7

Step 9. Check the self-weight with adjusted depth against initial assumption. Repeat Steps 2-6 until the difference is less than 5%

Step 10. Calculate  $k = \frac{M}{bd^2 f_{ck}}$

Step 11. Find  $\frac{z}{d} = 0.5[1 + (1 - 3k/\eta)^{1/2}]$

Step 12. Determine the required steel area  $A_s = \frac{\gamma_s M}{f_{yk} z}$

Step 13. Check the minimum and maximum steel ratio

Step 14. Size and arrange the reinforcing steel in the beam section

### 3.6.2. Slab Design

Slab is a flat structural member piece of reinforced concrete. There are horizontal slabs used as floors and roofs, and vertical slabs used as walls. They mainly act as a flexural member.

Notations:  $d$  – effective slab depth

$M$  – bending moment

$b$  – beam width

$f_{ck}$  – characteristic cylinder strength of concrete

$\delta$  – moment redistribution factor

$f_{yk}$  – characteristic yield strength of concrete

$Z$  – lever arm

$A_s$  – cross sectional area of reinforcement

Basic design steps:

Step 1. Find the bending moments

Step 2. Find  $K = \frac{M}{bd^2 f_{ck}}$

Step 3. Find  $K' = 0.60\delta - 0.18\delta^2 - 0.21$  ( $\delta \leq 1$ )

Step 4. Check  $K \leq K'$ : if  $K \leq K'$  compression reinforcement required

Step 5. Calculate  $Z = \frac{d}{2} [1 + \sqrt{1 - 3.353K}] \leq 0.95d$

$$\text{Then } A_s = \frac{M}{0.87f_{yk}Z}$$

Step 6. Check minimum and maximum reinforcement area

$$A_{s,min} = \frac{0.26f_{ctm}b_t d}{f_{yk}} \text{ where } f_{ck} \geq 25N/mm^2$$

$$A_{s,min} = 0.04A_c \text{ in tension or compression}$$

### 3.6.3. Column Design

Notations:  $b$  – column width

$h$  – column depth

$b$  – beam width

$f_{ck}$  – characteristic cylinder strength of concrete

$\alpha_{cc}$  – imperfection, 0.85 for UK practice

$f_{yk}$  – characteristic yield strength of concrete

$N_{Ed}$  – design ultimate axial load

$M_{Ed}$  – design ultimate moment

$A_s$  – cross sectional area of reinforcement

$A_g$  – gross area of reinforcement

$A_c$  – gross area of concrete

Zhang (2015) proposes the following procedure of designing axially loaded columns (only axial force is considered):

Step 1. Calculate axial force demands,  $N_{Ed}$

Step 2. Determine a column cross-section using

$$N_{Ed} \leq N_{Rd} = \alpha_{cc} * (\eta f_{ck} / \gamma_c * A_c + A_s f_y / \gamma_s) \text{ by assuming that } \frac{A_s}{A_g} = 1 \sim 3\%$$

Step 3. Solve the equation above to obtain  $A_g$

Step 4. Select section dimension and area of reinforcement

Step 5. Select links and check regulation

Design steps for the combination of axial force and moment differ from the procedure mentioned above. The procedure is based on column design charts (N-M interaction diagram) similar to Figure 3.4.

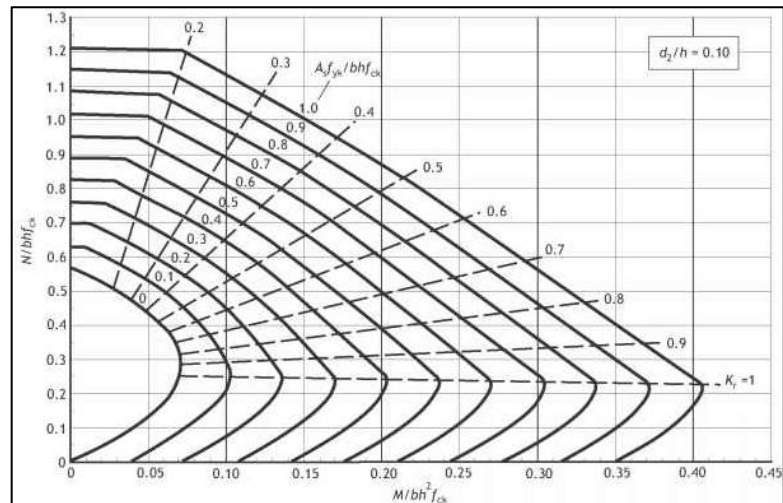
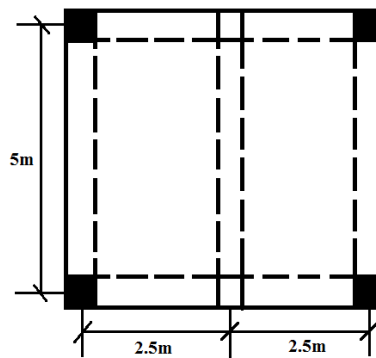


Figure 3. 4. Column design chart

### 3.7. Preliminary Structural Design

#### 3.7.1. Preliminary Slab Design:



$$\text{Ceiling} + \text{Flooring} = 2.706 \text{ kN/m}^2$$

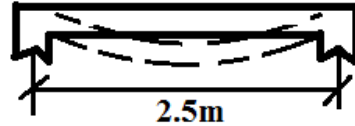
$$\text{Live load} = 2 \text{ kN/m}^2$$

$$f_{ck} = 25 \text{ MPa for C30 concrete}$$

$$f_{yk} = 500 \text{ MPa for Gr500}$$

For the simplicity of the design, one-way slab is made out of two-way slab by placing an additional slab. Therefore, the deflection is only in one direction and the slab can be considered as simply supported.

$$\frac{5000}{2500} = 2 \quad \underline{\text{OK}}$$



*Minimum effective depth*

$$= \frac{\text{Span}}{(\text{Basic span} - \text{effective depth ratio}) \times (\text{correction factor})}$$

From EC2, Table 7.4N: *basic span – effective depth ratio* = 20 for simply supported one-way slabs

*Correction factor (c. f.)* = 1.0

$$d_{min} = \frac{2500}{20} = 125mm$$

Assume the cover is 20mm and 10mm rebar:

$$\text{Overall depth of slab} = 125 + 20 + \frac{10}{2} = 150mm$$

$$\text{Self – weight of the slab} = 0.15 * 25 = 3.75kN/m^2$$

### **3.7.2. Preliminary Beam design:**

$$\text{Effective beam depth, } d = (8\sim 10\%)L = (0.08\sim 0.1) \times 5000 = (400\sim 500)mm$$

Assume  $d = 400mm$

$$\text{Beam depth, } h = 400 + 50 = 450mm$$

$$\text{Beam width, } b = (0.4\sim 0.6)h = 180\sim 270mm$$

Take  $b = 250mm$

### 3.7.3. Preliminary Column design:

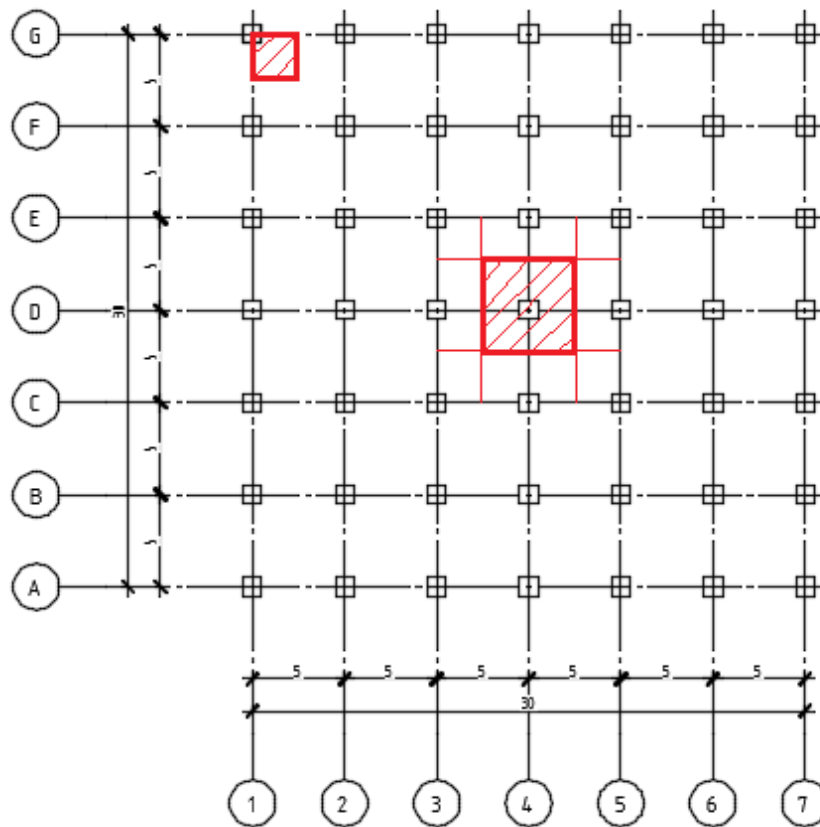


Figure 3. 5. Column grid

According to the column grid shown above (Figure 3.5), there are 49 columns. Tributary area method is can be used to determine ultimate axial force exerted by columns. Each column is responsible to carry loads on its tributary area. As an example, tributary areas of columns D4 and G1 are demonstrated in Figure 3.5. The column D4 is responsible for the largest area, so the load will be the highest. In structural design, analysis of the most critical area is sufficient. Therefore, the column D4 will be considered in column design. The procedure should be started from the top to bottom floor. For the top floor:

- 1) *Tributary area* =  $5 \times 5 = 25m^2$
- 2) *Dead Load* = *Slab* + *Beam* + *Roofing* + *Ceiling*  
*Live Load* = *Roof load*

Table 3. 8. Design loads

Dead Load		
Slab	3.75	kN/m <sup>2</sup>
Flooring	2.11	kN/m <sup>2</sup>
Roofing	0.68	kN/m <sup>2</sup>
Ceiling	0.60	kN/m <sup>2</sup>
Beam	3.38	kN/m
Live Load		
Live Load (floor)	4.00	kN/m <sup>2</sup>
Live load (roof)	1.36	kN/m <sup>2</sup>

$$Dead\ Load = (3.75 + 0.68 + 0.6) \times 25 + 3.38 \times 5 \times 3 = 176.3\text{kN}$$

$$Live\ Load = 1.36 \times 25 = 10\text{kN}$$

$$Ultimate\ Load = 1.35 \times 176.3 + 1.5 \times 34 = 289\text{kN}$$

$$3) N_{Ed} = 289\text{kN}$$

$$N_{Ed} \leq N_{Rd} = \alpha_{cc} * (\eta f_{ck} / \gamma_c * A_c + A_s f_y / \gamma_s)$$

where,  $\eta = 1.0$ ,  $\alpha_{cc} = 0.85$ ,  $f_{ck} = 25\text{MPa}$ ,  $f_y = 500\text{MPa}$ ,  $\gamma_s = 1.15$  and  $\gamma_c = 1.5$ .

Assuming  $A_s = 1\% \times A_g$

$$289 = 0.85 \times \left( \frac{1.0 \times 10^3 \times 25 \times 0.99 \times A_g}{1.5} + \frac{500 \times 10^3 \times 0.01 \times A_g}{1.15} \right)$$

$$A_g = 16307\text{mm}^2$$

If the section is square,  $b = w = \sqrt{14275} = 127.7\text{mm}$ . This value is minimum.

Set  $b = 300\text{mm}$ .

For the floor below, column self-weight and flooring are considered and Steps 1-3 are repeated. Results are represented in Table 3.9.

Table 3. 9. Column sizing by floor

Floor number	12	11	10	9	8	7	6	5	4	3	2	1
Ultimate Axial Force	288,97	735,23	1181,49	1627,74	2074,00	2528,06	2982,11	3436,17	3900,24	4364,32	4828,40	5287,19
Minimum Section Area, mm <sup>2</sup>	16306,98	41489,92	66672,86	91855,80	117038,75	142661,64	168284,54	193907,44	220095,98	246284,53	272473,08	298363,09
Minimum Depth, mm	127,70	203,69	258,21	303,08	342,11	377,71	410,22	440,35	469,14	496,27	521,99	546,23
Column size, mm	300,00	300,00	300,00	300,00	400,00	400,00	400,00	500,00	500,00	500,00	500,00	500,00
Column Section section area, m <sup>2</sup>	0,09	0,09	0,09	0,09	0,16	0,16	0,16	0,25	0,25	0,25	0,25	0,25
Column Volume, m <sup>3</sup>	0,30	0,30	0,30	0,30	0,53	0,53	0,53	0,83	0,83	0,83	0,83	0,83
Number of Columns per floor	49,00	49,00	49,00	49,00	49,00	49,00	49,00	49,00	49,00	49,00	49,00	49,00

### 3.8. Building frame analysis

As required two different types of loads are analyzed using hand calculations (Portal Method) and software (SAP2000). Dead and wind loads are demonstrated in Figure 3.6.

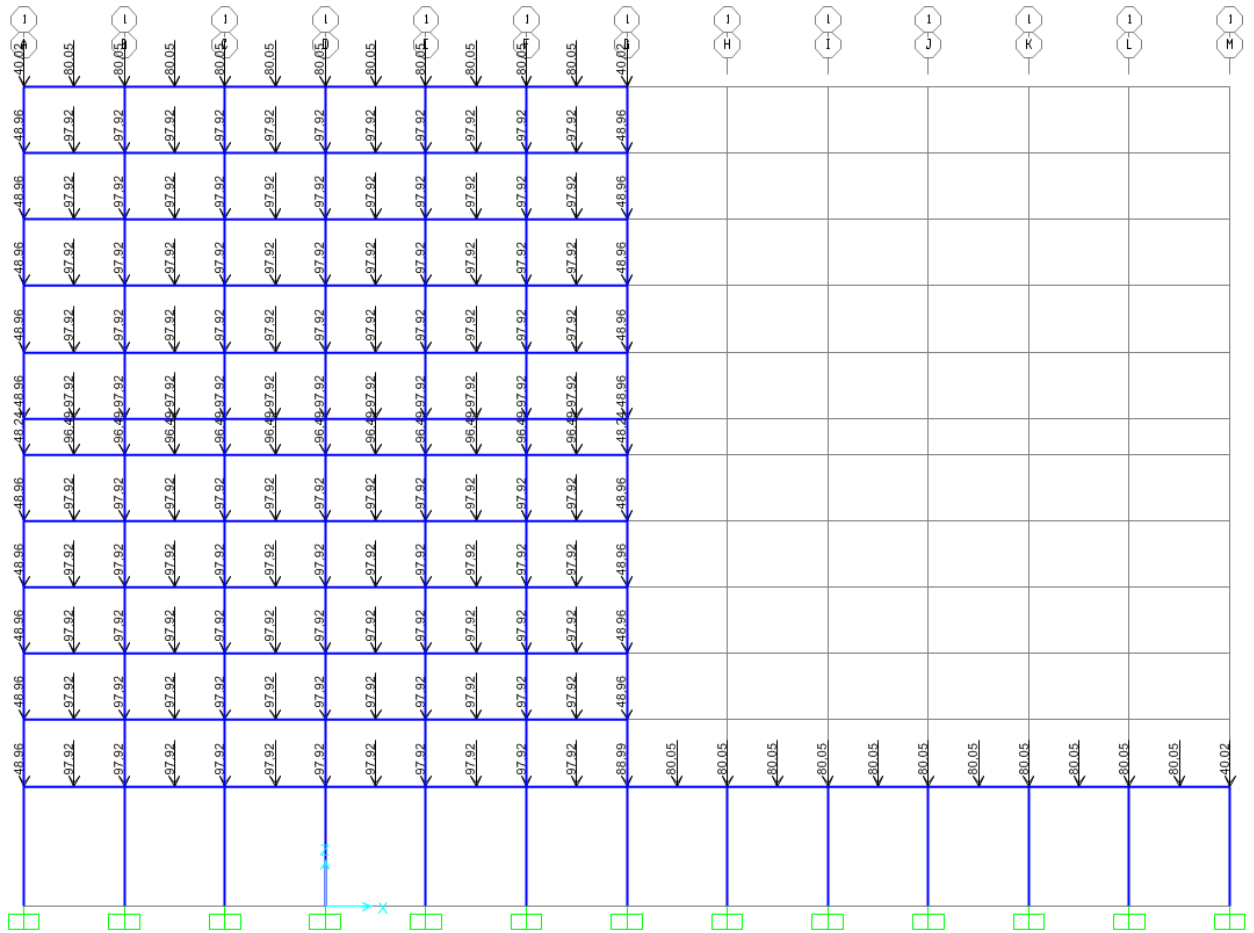


Figure 3.6. Dead Load applied to 2D frame

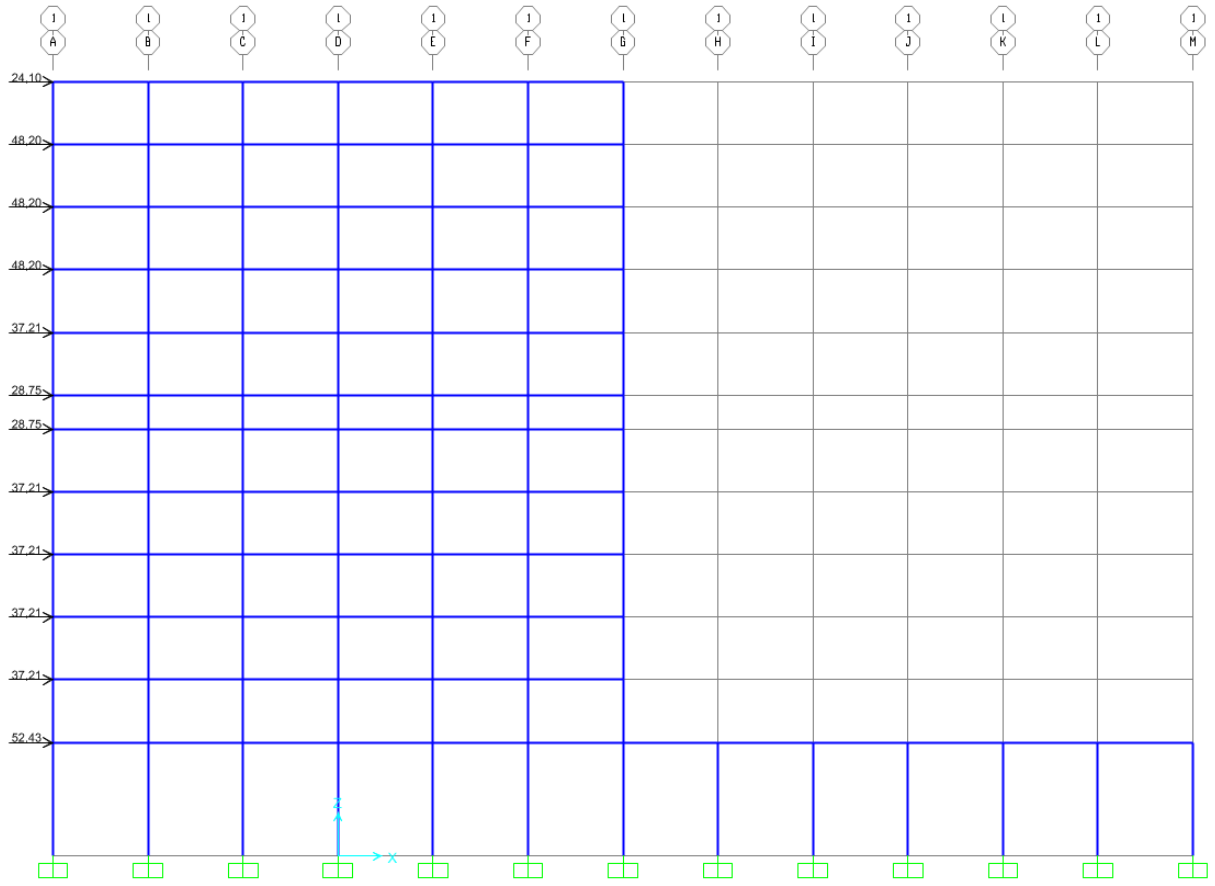


Figure 3. 7. Wind Load applied to 2D frame

### 3.8.1. Analysis under Wind Load

A structure subjected to any lateral loads should be analyzed for structural stability. In case of statically determinate structures, analysis are based on the equilibrium equations. Otherwise, approximate methods are applied that involve rather complex procedures.

Wind forces are calculated in the previous sections. Now, Portal Method are used to determine internal forces of frame members. Before the hand calculations, the following assumptions should be made in order to apply this method:

- A point of inflection occurs at the mid-height of each column.
- A point of inflection occurs at the mid-span of each beam.
- Shear force is distributed such that the interior column carries twice shear load of the exterior column at each floor.

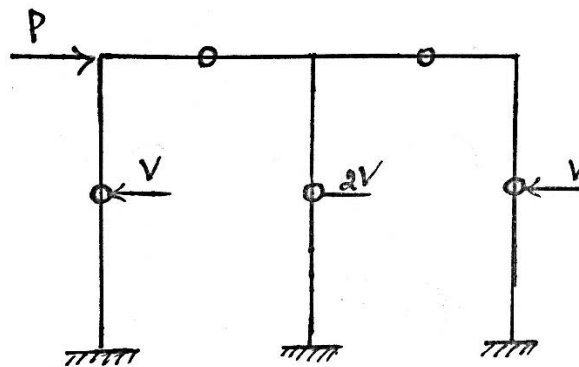
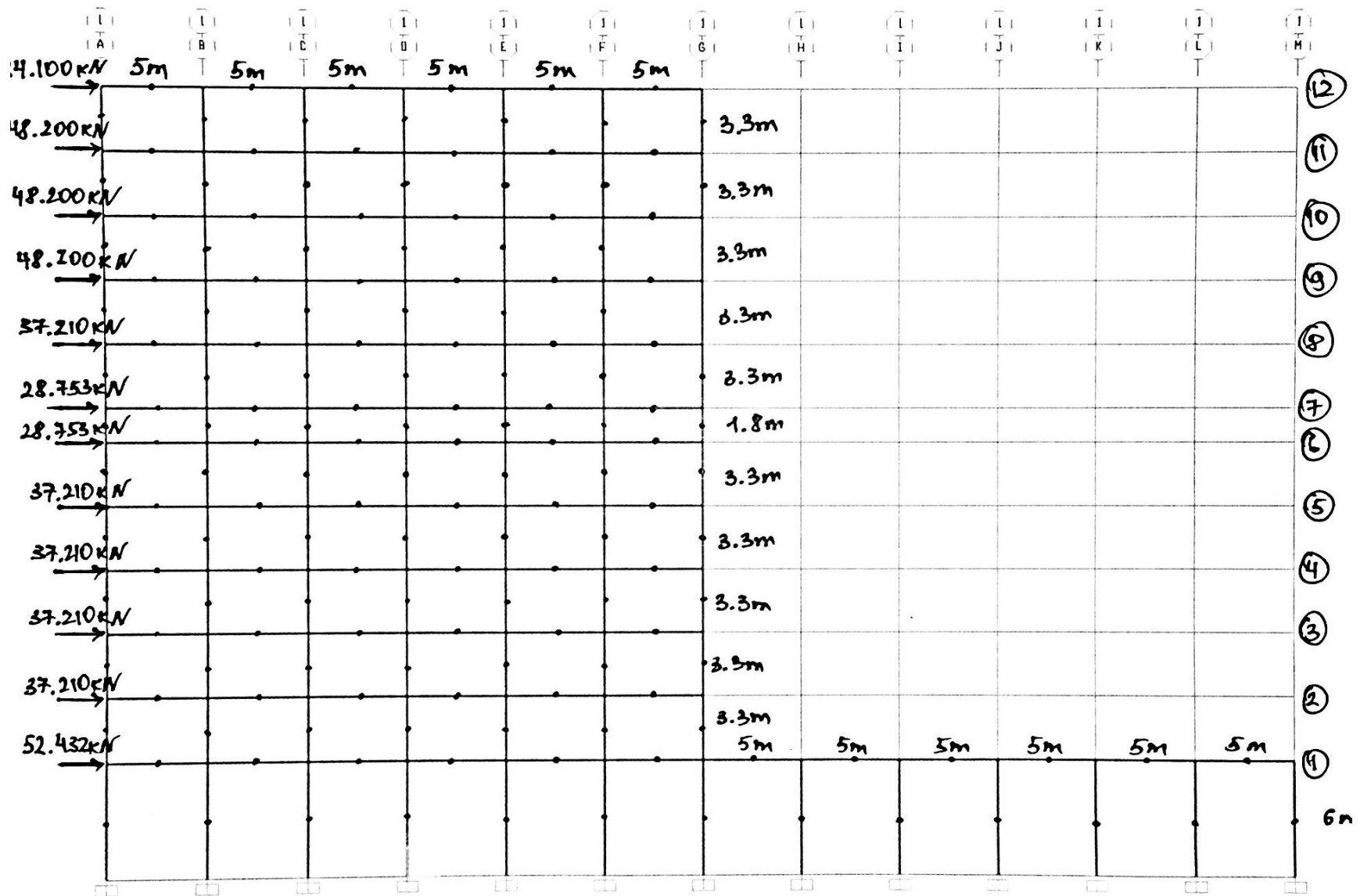


Figure 3. 8. Shear force distribution under horizontal loads

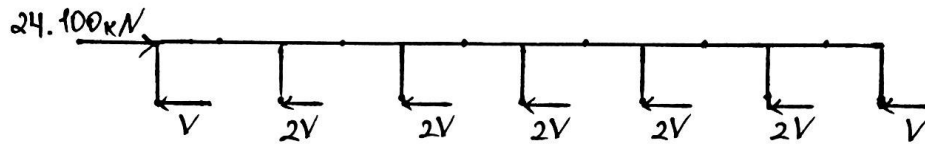
	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)
	1	2	3	4	5	6							
73	7 85	8 108	9 109	10 132	11 133	12 156							
74	13 86	14 107	15 110	16 131	17 134	18 155							
75	19 87	20 106	21 111	22 130	23 135	24 154							
76	25 88	26 105	27 112	28 129	29 136	30 153							
77	31 89	32 104	33 113	34 128	35 137	36 152							
78	37 90	38 103	39 114	40 127	41 138	42 151							
79	43 91	44 102	45 115	46 126	47 139	48 150							
80	49 92	50 101	51 116	52 125	53 140	54 149							
81	55 93	56 100	57 117	58 124	59 141	60 148							
82	61 94	62 99	63 118	64 123	65 142	66 147							
83	67 95	68 98	69 119	70 122	71 143	72 146	163	164	165	166	167	168	
84	96	97	120	121	144	145	157	158	159	160	161	162	



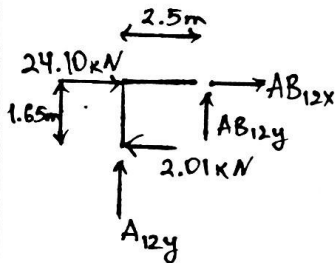
## Portal Method of Approximate Analysis

Assumptions:

- An inflection point occurs at the mid-height of each column
- An inflection point occurs at the mid-point of each beam
- The total horizontal shear at each floor is divided between the columns of that floor such that an interior column carries twice the shear of an exterior column.



Shear on 12<sup>th</sup> floor:  $12V = 24.100$   
 $V = 2.01 \text{ kN}$



$$\sum F_x = 0:$$

$$24.10 + AB_{12x} - 2.01 = 0$$

$$AB_{12x} = -22.09 \text{ kN}$$

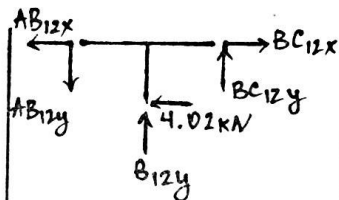
$$\sum M = 0:$$

$$-24.1 \times 1.65 - AB_{12x} \times 1.65 + AB_{12y} \times 2.5 = 0$$

$$AB_{12y} = 1.33 \text{ kN}$$

$$\sum F_y = 0: AB_{12y} + A_{12y} = 0$$

$$A_{12y} = -1.33 \text{ kN}$$



$$\sum F_x = 0:$$

$$AB_{12x} + 4.02 - BC_{12x} = 0$$

$$BC_{12x} = -18.07 \text{ kN}$$

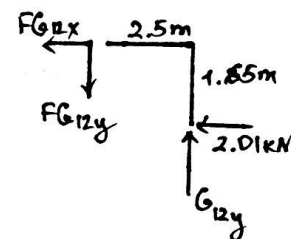
$$\sum M = 0:$$

$$1.65(AB_{12x} - BC_{12x}) + 2.5(BC_{12y} + AB_{12y}) = 0$$

$$BC_{12y} = 1.33 \text{ kN}$$

$$\sum F_y = 0: BC_{12y} + B_{12y} - AB_{12y} = 0$$

$$B_{12y} = 0$$



$$\sum F_x = 0: FG_{12x} + 2.01 = 0$$

$$FG_{12x} = -2.01 \text{ kN}$$

$$\sum M = 0: FG_{12x} \times 1.65 + FG_{12y} \times 2.5 = 0$$

$$FG_{12y} = 1.33 \text{ kN}$$

$$\sum F_y = 0: FG_{12y} = G_{12y}$$

$$G_{12y} = 1.33 \text{ kN}$$

The similar procedure is repeated for the other floors.  
 Calculations are continued in Excel spreadsheet.

Calculations made on the Excel spreadsheet are represented in Appendix 3. Comparing the results from two methods, it can be said that both methods output similar results with an acceptable error. Significant inconsistencies in shear forces and moments can be observed at some parts of the frame. However, these differences in internal forces can be explained by the third assumption stating that the internal column carries twice shear load of the exterior column. Nevertheless, the Portal method is still helpful in calculation of internal forces in the frame sections of the statically indeterminate structure and provides with similar results of the software.

### 3.8.2. Analysis under Dead Load

The second load pattern under consideration is dead loads on the building. Similar to the analysis under wind load, an approximate method of frame analysis are applied for hand calculations. Supports of a beam in a typical frame are neither fixed nor simply supported that makes the structure statically indeterminate. Therefore, beams can be divided into cantilever span and simply supported parts in order to create a statically determinate building. The divisions occur at zero-moment points. Theoretically, zero-moment points are located  $0.1L$  distance from supports. However, locations of those points practically differ from theoretical values, as it can be seen SAP2000 results. To eliminate errors due to wrong location of such points, software results are used in hand calculation.

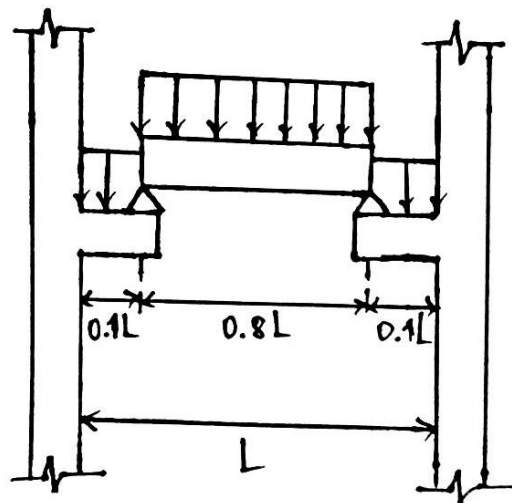
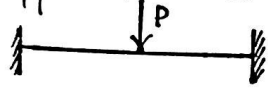


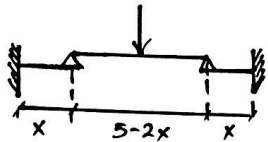
Figure 3. 9. Typical beam of frame

## Structural Analysis under Dead Load

Supports: neither fixed nor simply supported



Beams in y-direction will transfer distributed loads as a point load (P) to load-bearing beams in x-direction (shown left)



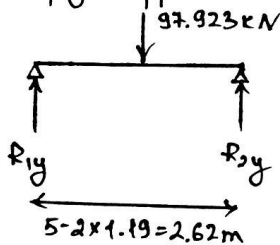
Supports are neither fixed nor simply supported which makes the structure statically indeterminate. Therefore, an approximate method should be used.

Beams are divided into simply-supported and cantilever span parts at points where moment is zero. Those spans can be considered separately

As an example, one beam can be analyzed

Take member 26, for which  $P = 97.923 \text{ kN}$   
 $x = 1.190 \text{ m}$

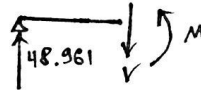
Simply supported span



$$\sum F_y = 0: R_{1y} + R_{2y} - 97.923 = 0$$

Applied load is equally distributed between supports.

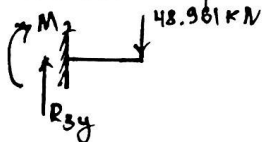
$$R_{1y} = R_{2y} = \frac{97.923}{2} = 48.961 \text{ kN}$$



At centre:  
 $V = 48.961 \text{ kN}$

$$M_1 = V \cdot \frac{2.62}{2} = 64.139 \text{ kNm}$$

Cantilever span



$$\sum F_y = 0: R_{3y} - 48.961 = 0$$

$$R_{3y} = 48.961 \text{ kN}$$

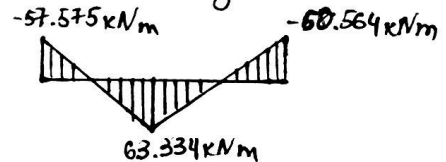
$$\sum M = 0: M_2 + 48.961 \times 1.19 = 0$$

$$M_2 = -58.264 \text{ kNm}$$

SAP2000 Results: Shear Diagram



Moment Diagram



Hand vs. SAP2000:

$$\text{Shear: Error} = \frac{|49.559 - 48.961|}{49.559} \times 100\% = 1.21\%$$

$$\text{Moment: Error} = \frac{|63.334 - 64.140|}{63.334} = 1.27\%$$

Error is in the acceptable range of  $\pm 5\%$ . Results are justified. Further calculation on the other frame section are performed in Excel spreadsheet.

### 3.9. Frame Design in SAP2000

Hand calculations on wind and dead loads should be compared with software output. Therefore, the most critical 2D frame is simulated in SAP2000. The software enables assigning appropriate section properties and loads as shown below.

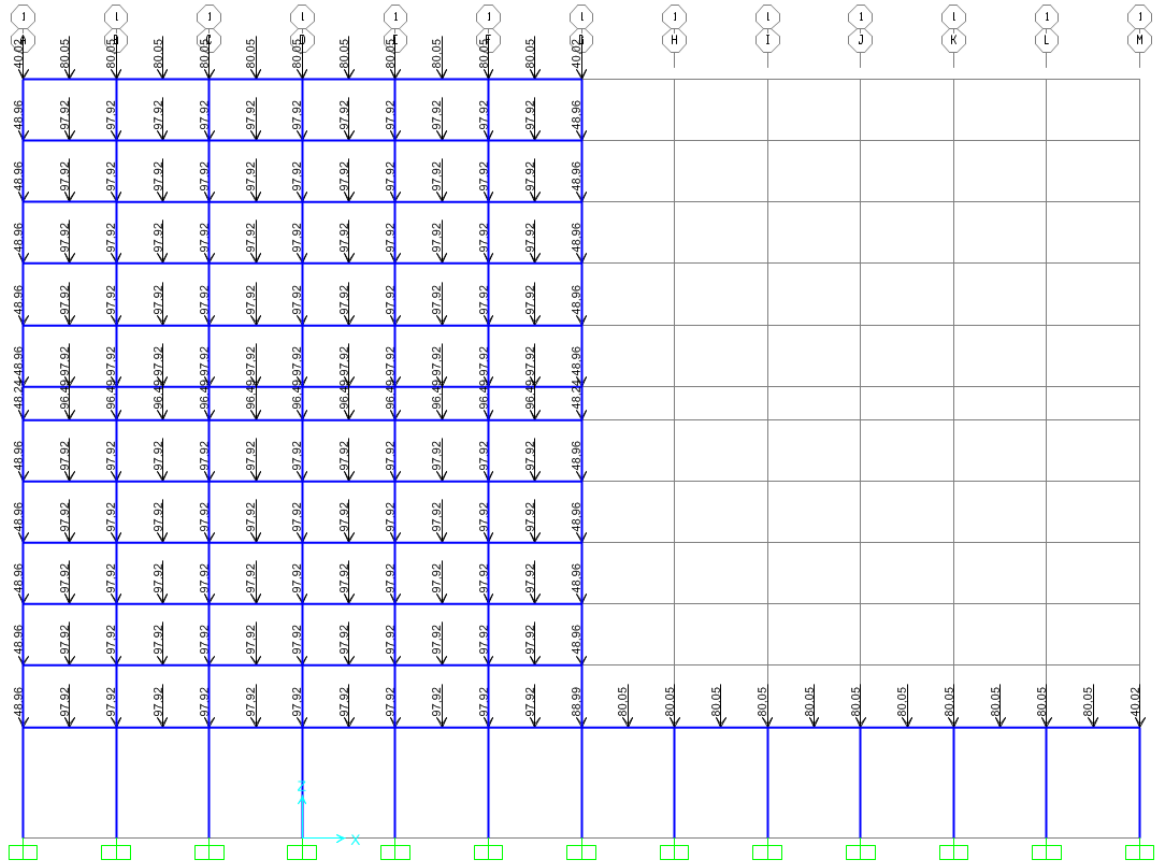


Figure 3. 10. Dead Load applied to 2D frame

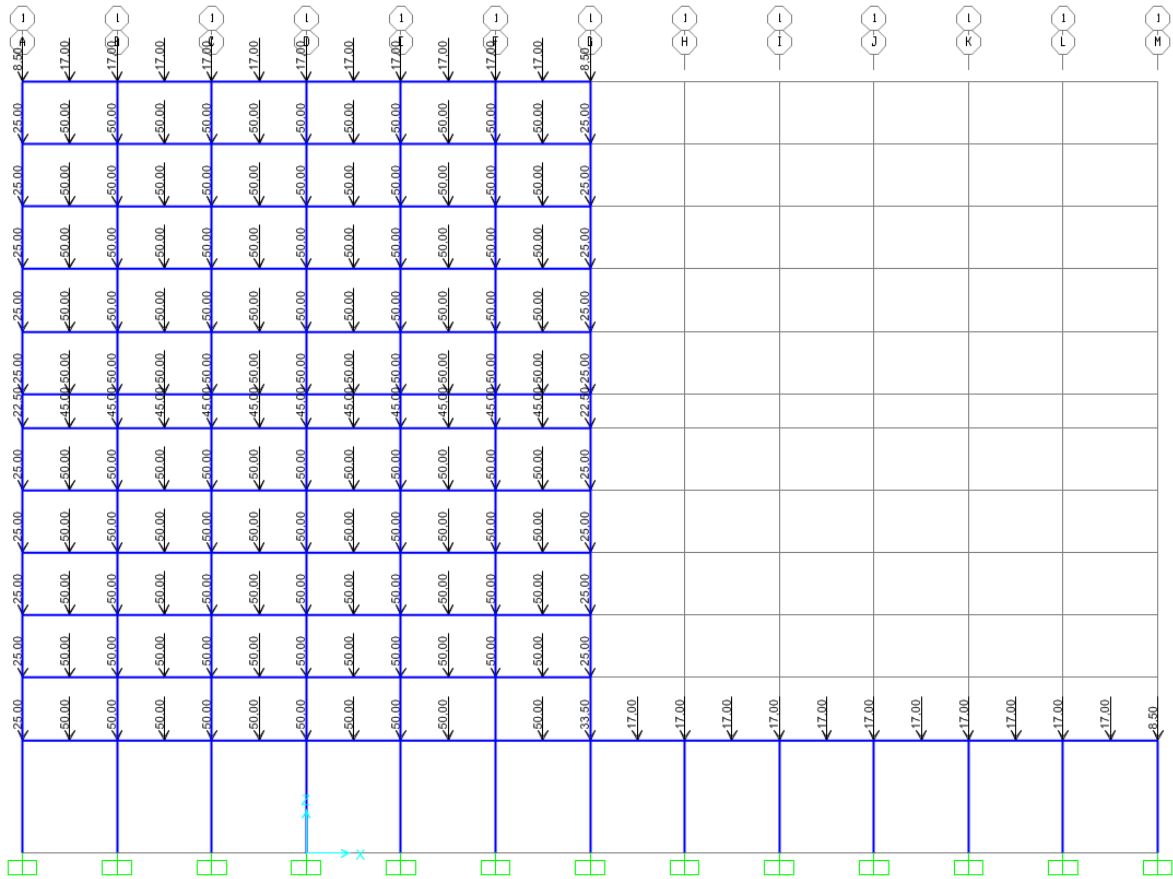


Figure 3. 11. Live Load applied to 2D frame

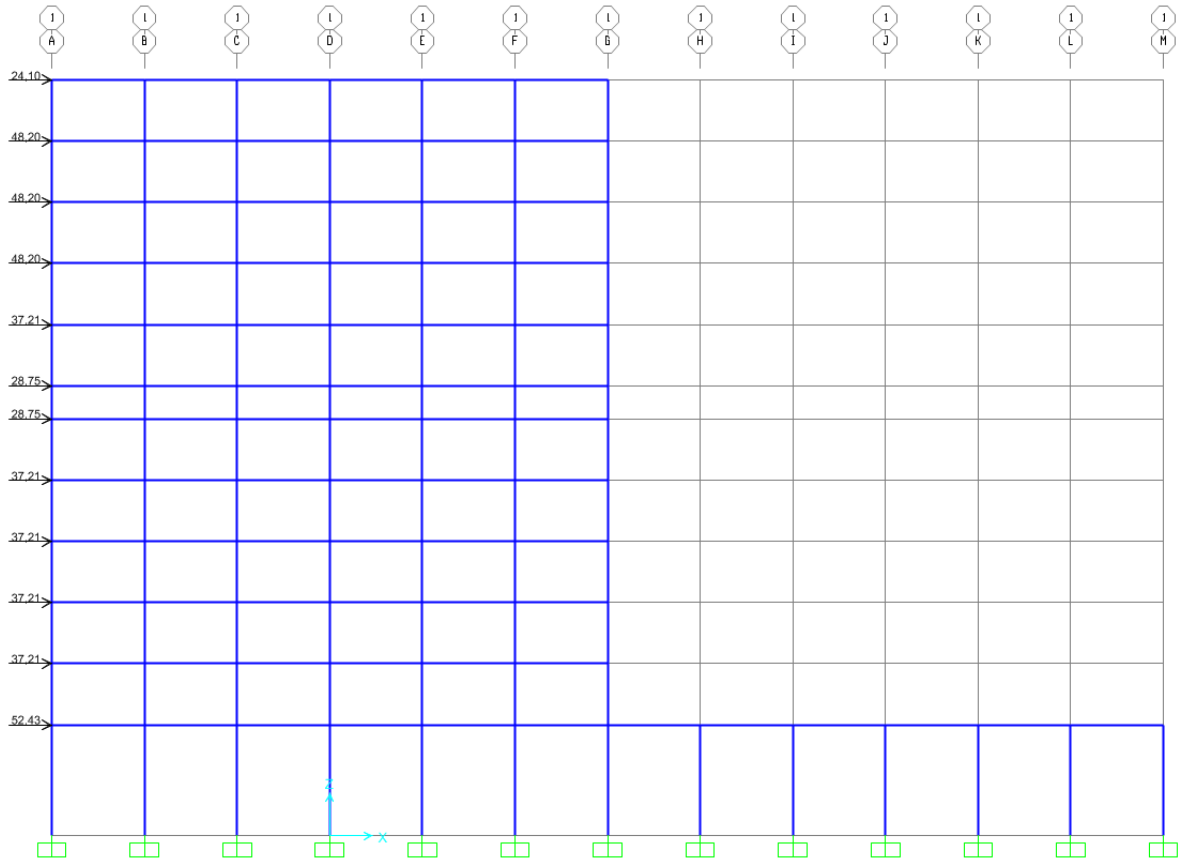


Figure 3. 12. Wind Loads applied to 2D frame

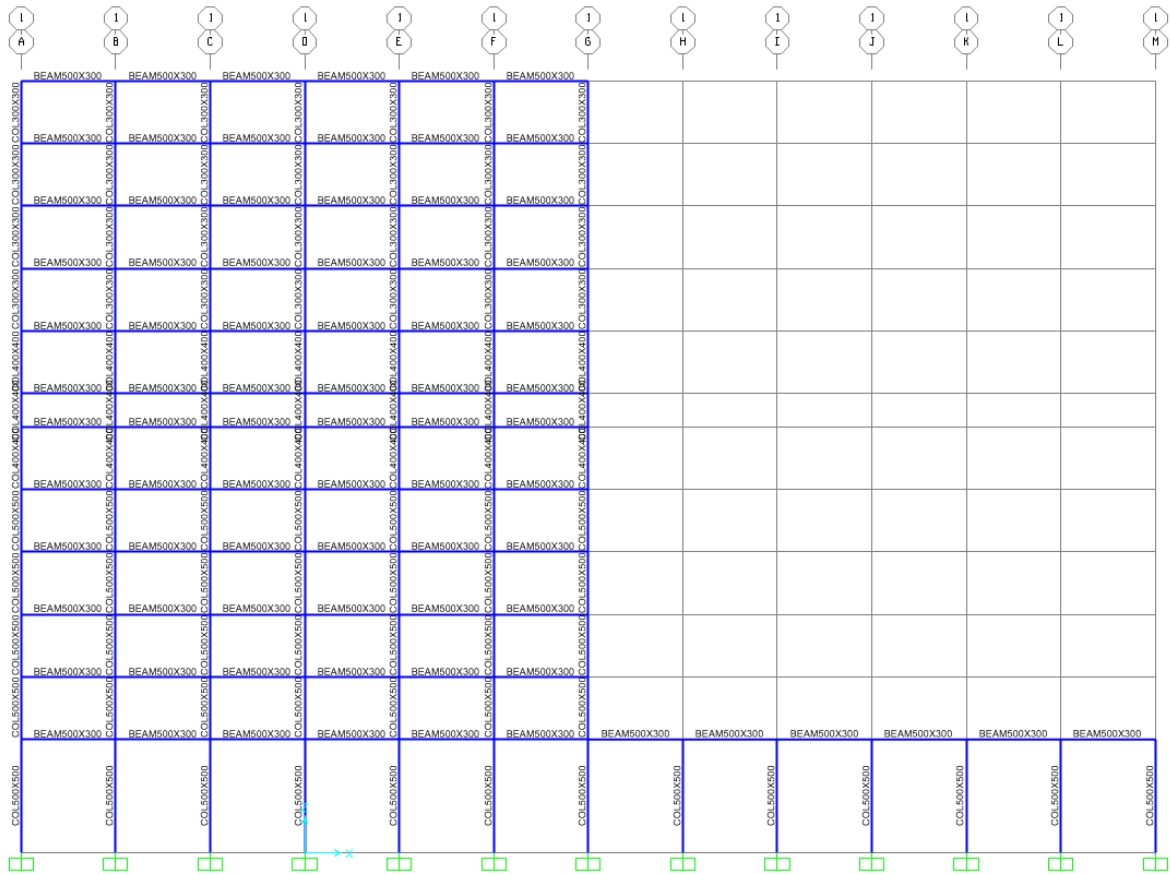
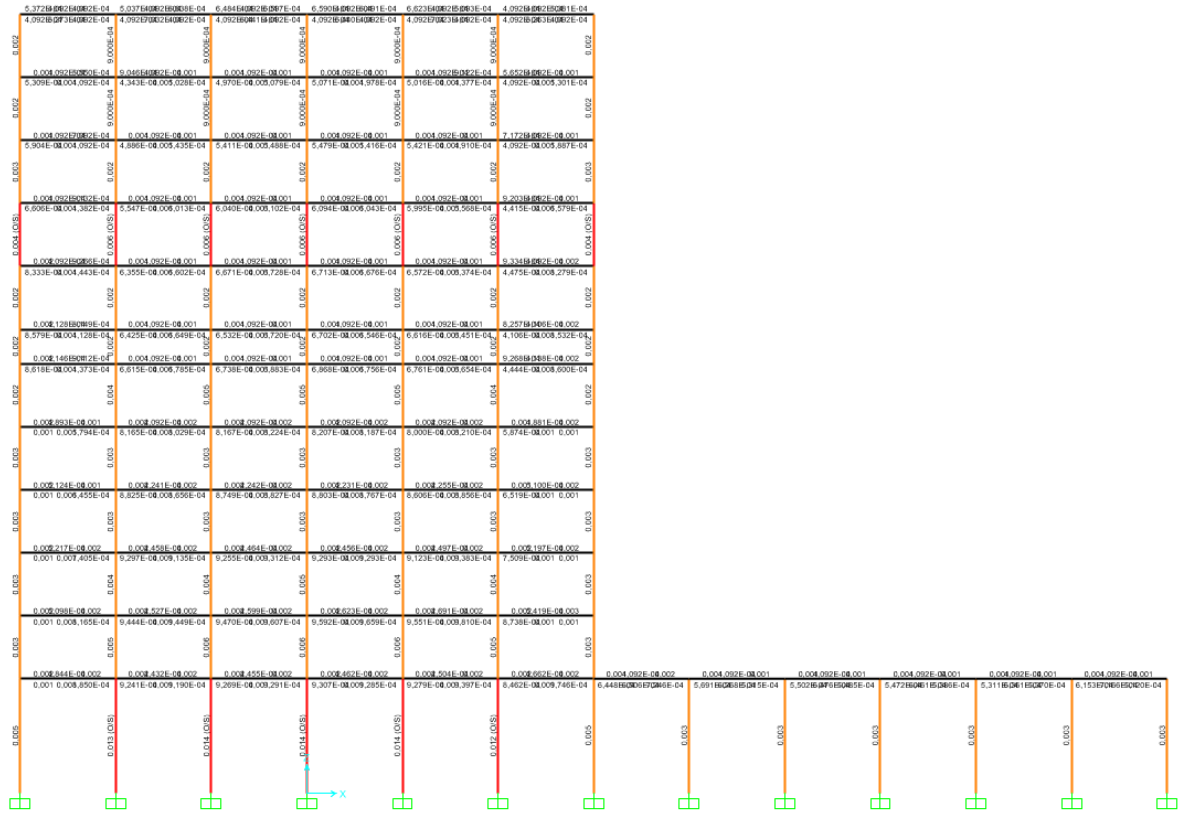


Figure 3. 13. Preliminary assigned frame sections

After all values are assigned, the model is ready to run. Moreover, SAP2000 is able to design sections and make structural detailing. The first run was unsuccessful due to failure in columns on the 1<sup>st</sup> and 9<sup>th</sup> levels (red members in Figure 3.14). An error message stated that required reinforcement exceeds maximum allowed. Therefore, the column sizes should be increased to provide enough space for reinforcing.



O/S #2 Reinforcing required exceeds maximum allowed

Figure 3. 14. Initial design output

500x500mm columns on the 1<sup>st</sup> floor and 300x300mm columns on the 9<sup>th</sup> floor are changed to 550x550mm and 400x400mm respectively. Afterwards, run is repeated. This trial was successful and the model all checks (Figure 3.15).



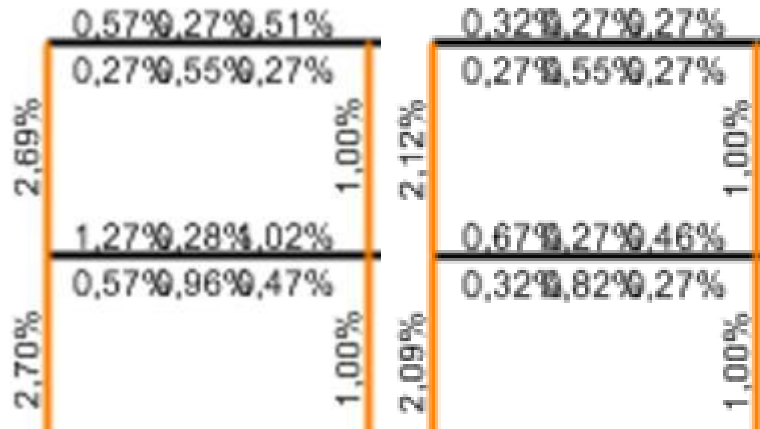


Figure 3. 16. Beam reinforcement in x-direction vs. y-direction

After the check, structural detailing of frame sections is printed.

### 3.10. Structural Detailing

#### 3.10.1. Beam Detailing

SAP2000 software suggests minimum required tension and compression reinforcements at different locations along the beam. Additionally, minimum shear reinforcement can be obtained. Detailing of tension, compression and shear reinforcements is made based on the software output and tabulated in Appendix 4. Rebars are arranged in a way that they satisfy the code requirements on minimum/ maximum reinforcement area, spacing and bar size. Software suggestion on the required steel area is then verified using hand calculation. Since the verification was successful, beam sections are drawn using the reinforcement detailing.

## Design of reinforcement for a beam

Take a beam on a typical floor: Beam #26

Ultimate moment on the beam is obtained from SAP2000.

$$M_u = 199.83 \text{ kN-m}$$

$$\text{Beam size: } h = 500 \text{ mm} \rightarrow d = 500 - 50 = 450 \text{ mm} \\ b = 300 \text{ mm}$$

<1> Check minimum depth of the beam

$$d_{\min} = \sqrt{\frac{M_u}{0.167 \times b \times f_{ck}}} = \sqrt{\frac{199.83 \times 10^6}{0.167 \times 300 \times 25}} = 399.43 \text{ mm} < 450 \text{ mm} \quad \underline{\text{OK}}$$

$$<2> K = \frac{M_u}{b \times d^2 \times f_{ck}} = \frac{199.83 \times 10^6}{300 \times 450^2 \times 25} = 0.132$$

$$\text{lever arm, } z = d \left[ 0.5 + \sqrt{0.25 - \frac{K}{1.134}} \right] = 450 \left[ 0.5 + \sqrt{0.25 - \frac{0.132}{1.134}} \right] = \\ = 389.71 \text{ mm}$$

$$<3> A_s = \frac{M_u}{0.87 f_y z} = \frac{199.83 \times 10^6}{0.87 \times 500 \times 389.71} = 1178.772 \text{ mm}^2$$

$$A_s = 1122.496 \text{ mm}^2 \text{ (Suggested by SAP2000)}$$

$$\text{Error} = \frac{1178.772 - 1122.496}{1178.772} \times 100\% = 4.77\% \text{ (within acceptable range of } \pm 5\%)$$

$$<5> A_{s, \min} = \begin{cases} 0.26 f_{ctm} b_t d / f_y = \frac{0.26 \times 2.6 \times 300 \times 450}{500} = 182.52 \text{ mm}^2 < 1178.772 \text{ mm}^2 \\ 0.0013 b_t d = 0.0013 \times 300 \times 450 = 175.5 \text{ mm}^2 \end{cases} \quad \underline{\text{OK}}$$

$$A_{s, \max} = 0.04 A_c = 0.04 \times 300 \times 500 = 6000 \text{ mm}^2 > 1178.772 \text{ mm}^2 \quad \underline{\text{OK}}$$

### 3.10.2. Column Detailing

The same procedure is repeated for column detailing and results are shown in Appendix 5.

#### Design of reinforcement for a column

Take column #84

$$N_{Ed} = 4641.34 \text{ kN} \quad (\text{SAP2000 values})$$

$$M_{Ed} = 255.41 \text{ kN}$$

<1> Trial section using  $N_{Ed}$  only

$$N_{Ed} \leq N_{Rd} = \alpha_{cc} \left( \eta \frac{f_{ck}}{f_c} A_c + A_s \cdot \frac{f_{yk}}{f_s} \right)$$

$$\text{Assume } A_s = 1\% A_g, \quad A_c = 99\% A_g$$

$$\alpha_{cc} = 0.85, \quad \eta = 1.0$$

$$4641.34 \times 10^3 = 0.85 \left( 1 \times \frac{25}{1.5} \times 0.99 A_g + 0.01 A_g \times \frac{500}{1.15} \right)$$

$$A_g \geq 261916.99 \text{ mm}^2 \quad h \geq \sqrt{A_g} = 511.78 \text{ mm} \quad \text{min required column size}$$

SAP2000 design: 550 x 550 mm column

<2> Normalized  $N_{Ed}$  and  $M_{Ed}$

$$\frac{N_{Ed}}{b h f_{ck}} = \frac{4641.34 \times 10^3}{550^2 \times 25} = 0.614$$

$$\text{Assume } d_2 = 50 \text{ mm} \Rightarrow \frac{d_2}{h} = \frac{50}{550} = 0.091$$

$$\frac{M_{Ed}}{b h^2 f_{ck}} = \frac{255.41 \times 10^6}{550^3 \times 25} = 0.061$$

$$\text{Use } \begin{cases} \frac{d_2}{h} = 0.05 \\ \frac{d_2}{h} = 0.10 \end{cases} \text{ graphs to interpolate}$$

<3> Apply N-M design charts

$$\frac{A_s f_y}{b h f_{ck}} = \begin{cases} 0.205 & x - 0.21 \\ 0.21 & 0.205 - 0.21 \end{cases} = \frac{0.091 - 0.05}{0.1 - 0.05} \quad x = 0.206$$

$$\frac{A_s f_y}{b h f_{ck}} = 0.206$$

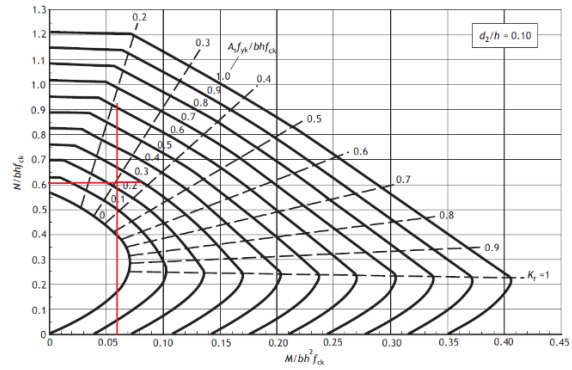
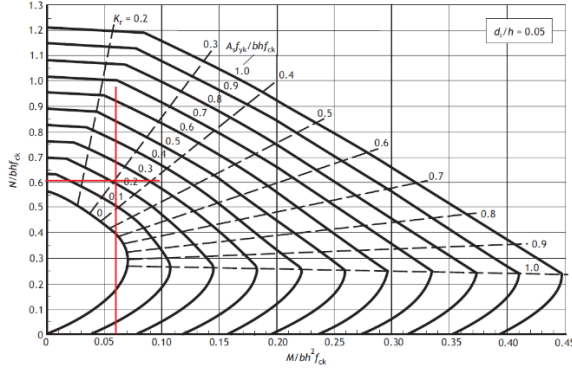
<3> Sizing longitudinal reinforcement

$$A_s = 0.206 \frac{550^2 \times 25}{500} = 3114.24 \text{ mm}^2 \quad (\text{hand})$$

$$\approx 3025.00 \text{ mm}^2 \quad (\text{SAP2000})$$

$$\text{Error} = \frac{|3025 - 3114.24|}{3025} \cdot 100\% = 2.95\%$$

Comparison of hand calculation and SAP2000 results shows error (2.95%) within the acceptable range of  $\pm 5\%$ .



<4> Check for maximum and minimum steel reinforcement

$$A_{s,min} = \begin{cases} 0.1 N_{Ed} f_s / f_y = 0.1 \times 4641.34 \times 1.15 / 500 \cdot 10^3 = 1067.5 \text{ mm}^2 \\ 0.002 A_c = 0.002 \times 550^2 = 605 \text{ mm}^2 \end{cases}$$

$A_s > A_{s,min}$  OK

$$A_{s,max} = 0.04 A_c = 0.04 \times 550^2 = 12100 \text{ mm}^2 > A_s \text{ OK}$$

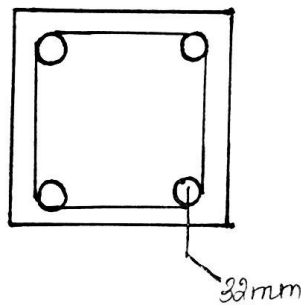
<5> design links

$$d_t = \begin{cases} 6 \text{ mm} \\ \frac{1}{4} d_b = \frac{1}{4} \cdot 32 = 8 \text{ mm} \end{cases} \leftarrow \text{(controlled)}$$

$$s_{max} = \begin{cases} 20 d_b = 20 \times 20 = 400 \text{ mm} \\ h = 550 \text{ mm} \\ 400 \text{ mm} \end{cases}$$

<6> Suggested reinforcement: 4@32

$$A_s = 3220 \text{ mm}^2$$



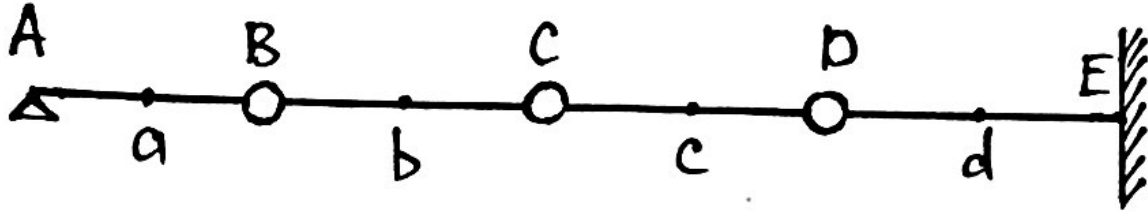
### 3.10.3. Slab Detailing

Slab detailing is made for the typical floor for which:

$$\text{Dead load, } w_d = \text{Self weight} + \text{Finishing} = 25 \times 0.150 + 2.706 = 6.456 \text{ kN/m}^2$$

$$\text{Live load, } w_L = 4 \text{ kN/m}^2$$

$$\text{Factored load, } w_u = 1.35 * w_d + 1.5 * w_L = 1.35 * 6.456 + 1.5 * 4 = 14.716 \text{ kN/m}^2$$



Location	Moment	Shear
End span (a)	$0.086Fl = 0.086$ $\times (14.716 \times 2.5)$ $\times 2.5$ $= 7.910 \text{ kNm/m}$	—
End support (E)	$-0.04Fl = 0.04$ $\times (14.716 \times 2.5)$ $\times 2.5$ $= -3.679 \text{ kNm/m}$	$0.46F$ $= 0.46 \times 14.716 \times 2.5$ $= 16.623 \text{ kN/m}$
First interior supports (B, D)	$-0.086Fl = -0.086$ $\times (14.716 \times 2.5)$ $\times 2.5$ $= -7.910 \text{ kNm/m}$	$0.6F$ $= 0.6 \times 14.716 \times 2.5$ $= 22.073 \text{ kN/m}$
Interior spans (b, c)	$0.063Fl = 0.063$ $\times (14.716 \times 2.5)$ $\times 2.5$ $= 5.794 \text{ kNm/m}$	—

Interior supports (C)	$-0.063Fl = -0.063$ $\times (14.716 \times 2.5)$ $\times 2.5$ $= -5.794 \text{ kNm/m}$	$0.5F$ $= 0.5 \times 14.716 \times 2.5$ $= 18.395 \text{ kN/m}$
-----------------------	---	---

Slab design is conducted for bending and transverse reinforcements. For bending reinforcement:

Middle of the end span (a)

$$M = 7.910 \text{ kNm}$$

d-effective depth

$$\text{Assume a 8mm rebar : } d = 150 - 20 - \frac{8}{2} = 126 \text{ mm}$$

$$\therefore K = \frac{M}{bd^2 f_{ck}} = \frac{7.910 \times 10^6}{1000 \times 126^2 \times 25} = 0.0199$$

$$\frac{z}{d} = 0.5 + \sqrt{0.25 - \frac{K}{1.134}} = 0.982$$

$$z = 0.982 \times 126 = 123.745 \text{ mm}$$

$$A_s = \frac{M}{0.87 f_{yk} z} = \frac{7.910 \times 10^6}{0.87 \times 500 \times 123.745} = 146.939 \text{ mm}^2$$

(2) Check for minimum reinforcement

$$A_{s, \min} = \begin{cases} 0.26 f_{ct} m b_t d / f_{yk} = 0.26 \times 2.6 \times 1000 \times 126 / 500 = 170.4 \text{ mm}^2 > A_s \\ 0.0013 b_t d = 0.0013 \times 1000 \times 126 = 163.8 \text{ mm}^2 \end{cases}$$

$$A_{s, \text{req}} = 170.4 \text{ mm}^2$$

$$\text{Provide } 8 \text{ mm} @ 275 \text{ mm} \Rightarrow A_s = 182.78 \text{ mm}^2$$

controlled  
by minimum  
reinforcement

(3) Transverse reinforcement

$$A_s = 0.0013 \times b_t \times d = 0.0013 \times 1000 \times 126 = 163.8 \text{ mm}^2$$

$$\text{Provide } 8 \text{ mm} @ 300 \text{ mm} \Rightarrow A_s = 167.55 \text{ mm}^2$$

Further detailing of slab is performed using Excel spreadsheet, which is presented in Appendix 6.

### 3.11. Serviceability Design

#### 3.11.1. Wind drift check

EUROCODE 8 on Seismic Design of Buildings sets limitations on deflection of the building due to horizontal loads. Serviceability of the building under wind load is evaluated in terms of interstorey drift. Interstorey drift ( $d_r$ ) is the difference of the average horizontal displacements at the top and bottom of the considered floor. According to the EC8, limits in interstorey drift depend on non-structural materials attached to the structure. For buildings with non-structural elements of:

- Brittle materials:  $d_r \leq 0.5\%h$
- Ductile materials:  $d_r \leq 0.75\%h$
- Without non-structural elements:  $d_r \leq 1.0\%h$

where  $h$  is the storey height.

The structure under consideration has non-structural brittle materials, so the first case is applicable. SAP2000 outputs absolute horizontal displacements of the storeys, while interstorey drift can be calculated by subtracting displacements of the adjacent floors (Table 3.10)

Table 3. 10. Interstorey drift due to wind load

Floor	Interstorey height	Absolute deflection (SAP2000)	Interstorey drift (SAP2000)	Interstorey drift (EUROCODE 8)
-	mm	mm	mm	mm
12	3300	51.86	1.10	16.5
11	3300	50.76	2.85	16.5
10	3300	47.91	4.60	16.5
9	3300	43.31	3.32	16.5
8	3300	39.98	3.71	16.5
7	1800	36.27	1.50	9
6	3300	34.77	4.77	16.5

5	3300	30.00	4.25	16.5
4	3300	25.76	4.72	16.5
3	3300	21.04	5.20	16.5
2	3300	15.84	5.78	16.5
1	6000	10.06	10.06	30

As seen from the table, interstorey drifts from the software comply with the code requirements. This suggests that serviceability of the structure under wind load is verified.

### 3.11.2. Deflection check

EUROCODE 2 on Design of Concrete Structures requires that the deflections harm neither the appearance nor the serviceability of the building during its lifetime. The final deflection of structural elements should be less than  $\frac{1}{250}$  or 0.4% of span. Before deflection calculation, maximum span-to-depth ratio ( $L/d$ ) can be checked. If design  $\frac{L}{d}$  of the structural member is less than the limit, deflection calculation is unnecessary. Maximum span-to-depth is given by the formula (EC2):

$$\frac{L}{d} = K \left[ 11 + \frac{1.5\sqrt{f_{ck}\rho_0}}{\rho} + 3.2\sqrt{f_{ck}} \left( \frac{\rho_0}{\rho} - 1 \right)^{1.5} \right] \text{ when } \rho \leq \rho_0$$

$$\frac{L}{d} = K \left[ 11 + \frac{1.5\sqrt{f_{ck}\rho_0}}{\rho - \rho'} + \frac{\sqrt{f_{ck}}}{12} \left( \frac{\rho'}{\rho_0} \right)^{0.5} \right] \text{ when } \rho > \rho_0$$

K is 1.0 for simply supported span, 1.5 for interior span, 1.3 for end span and 0.4 for cantilevers. Other values are  $\rho_0 = \frac{\sqrt{f_{ck}}}{1000}$ ,  $\rho = \frac{A_s}{bd}$  and  $\rho' = \frac{A_s'}{bd}$ , where  $A_s$  and  $A_s'$  are tension and compression reinforcement areas respectively.

*Slab deflection check*

$\rho_0 = \frac{\sqrt{25}}{1000} = 0.005$  and  $\rho = \frac{170.4}{1000 \times 126} = 0.00135$ . As  $\rho \leq \rho_0$ , the formula for the first case is applicable.

For interior span (K=1.5):

$$\text{Limit is } \frac{L}{d} = 1.5 \left[ 11 + \frac{1.5 \times \sqrt{25} \times 0.005}{0.00135} + 3.2 \times \sqrt{25} \left( \frac{0.005}{0.00135} - 1 \right)^{1.5} \right] = 164.86.$$

$$\text{Design value is } \frac{L}{d} = \frac{2500}{126} = 19.84.$$

For end span (K=1.3):

$$\text{Limit is } \frac{L}{d} = 1.5 \left[ 11 + \frac{1.5 \times \sqrt{25} \times 0.005}{0.00135} + 3.2 \times \sqrt{25} \left( \frac{0.005}{0.00135} - 1 \right)^{1.5} \right] = 142.89.$$

$$\text{Design value is } \frac{L}{d} = \frac{1000}{126} = 19.84.$$

In both spans, the design values do not exceed the limit. Therefore, deflection calculation is unnecessary.

#### *Beam deflection check*

Beam #26 is under consideration with  $L = 5000\text{mm}$  and  $d = 450\text{mm}$ . The provided tension and compression reinforcement areas are  $A_s = 1169\text{mm}^2$  and  $A'_s = 452\text{mm}^2$ .

$\rho_0 = \frac{\sqrt{25}}{1000} = 0.005$ ,  $\rho = \frac{1169}{300 \times 450} = 0.00866$  and  $\rho' = \frac{A'_s}{bd} = \frac{452}{300 \times 450} = 0.00335$ . Since  $\rho > \rho_0$ , the second formula should be applied:

$$\frac{L}{d} = 1.5 \times \left[ 11 + \frac{1.5 \times \sqrt{25} \times 0.005}{0.00866 - 0.00335} + \frac{\sqrt{25}}{12} \left( \frac{0.00335}{0.005} \right)^{0.5} \right] = 27.6$$

Design value is  $\frac{L}{d} = \frac{5000}{450} = 11.1$ . Calculation of beam deflection is not necessary because the design value is less than the limit.

### **3.11.3. Crack Check**

Flexural cracks occur along structural members under bending even at working loads. Uncontrolled cracks affect appearance and durability of the structure due to corrosion of reinforcement when the crack width exceeds the allowed limit. Rather than calculating the crack width, the code requires a minimum area of tension reinforcement, limiting bar spacings and sizes for crack control (Mosley, Bungey and Hulse, 2012).

- Check the spacing requirement by BS EN 1992: EUROCODE 2:

The code states that the spacing between rebars are  $s \leq \frac{70\,000}{f_y} \beta_b$  and  $s \leq \frac{47\,000}{f_s}$ , where  $\beta_b = \frac{A_{s,req}}{A_{s,prov}}$  and  $f_s = \frac{2}{3} f_y \beta_b$ .

Assume that the beam under consideration is beam #26 for which  $A_{s,req} = 1122.496\text{mm}^2$  and  $A_{s,prov} = 1169\text{mm}^2$ . Then,  $\beta_b = \frac{1122.496}{1169} = 0.96$  and  $f_s = \frac{2}{3} \times 500 \times 0.96 = 320\text{MPa}$ .

The provided reinforcement for the section is 5@16&2@10 located in two rows. Spacing can be calculated as  $s = \frac{300-2 \times 50-4 \times 16}{4} = 34\text{mm}$ .

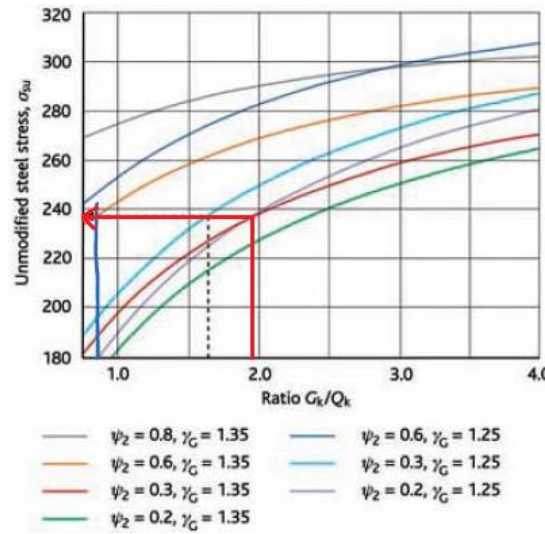
$$\frac{70\,000}{500} \times 0.96 = 134.4\text{mm} > 34\text{mm} \quad \text{OK}$$

$$\frac{47\,000}{320} = 146.9\text{mm} > 34\text{mm} \quad \text{OK}$$

- Check for a maximum size and spacing for the reinforcement (EC2):

Similar to the previous check, beam #26 is considered. As the beam is reinforced and located inside the building with low air humidity, the considered structural member is of XO exposure class (EC2 – Table 4.1). For this exposure class, a limiting crack width,  $\omega_{max}$  is 0.4mm (EC2 – Table 7.1N). Quasi-permanent value,  $\psi_2$  for domestic and residential areas is 0.3 (EC1).

The values  $\frac{G_k}{Q_k} = \frac{97.923}{50} = 1.96$ ,  $\psi_2 = 0.3$  and  $\gamma_G = 1.35$  are then used to unmodified steel stress ( $\sigma_{su}$ ) from the graph below:  $\sigma_{su} = 238\text{MPa}$



$$\text{Steel stress, } \sigma_s = \sigma_{su} \frac{A_{s,req}}{A_{s,prov}} = 238 \times \frac{1122.496}{1169} = 238 \times 0.96 = 228.5 \text{ MPa}$$

From the Tables 7.2N and 7.3N in EC2, maximum bar size and spacing for the corresponding steel stress are 20mm and 250mm respectively.

$$d_b = 16 \text{ mm} < 20 \text{ mm} \quad \underline{\text{OK}}$$

$$s = 34 \text{ mm} < 250 \text{ mm} \quad \underline{\text{OK}}$$

From the checks performed above, it can be said that cracks are controlled and no further calculation is needed.

## 4. GEOTECHNICAL DESIGN

### 4.1. Site Location

The multistory building is located on Orynbor sreet. near to EXPO city and “Mangilik El”. The location of the building is also close to Nazarbayev University; so, information of soil profile was taken from the survey which has been already done in the territory of the NOC “Nazarbayev University”. The area is not seismically active, so, it is not necessary to investigate liquefaction factors. However, the site is situated in Astana where the weather condition is considerably harsh.

The project is made for the construction of 12-storey residential building, where will be Hotel which can be beneficial during the EXPO opening period. It can be expected that weather condition is not favorable, so far the soil freezing has to be also considered.



Figure 4. 1. Location of Building

### 4.2. Climatic characterization of region

According to the site survey, the climate is sharply continental and arid. Winter is cold and long with a stable snow cover. Summer is relatively short, but hot. The territory of Astana on climatic zoning for the building belongs to the zone 1B. The area belongs to the zone of insufficient and unreliable moistening. Humidity Zone 3 (dry). This chapter provides a brief overview. Feature compiled by "the Scientific and Applied Climate Handbook. Series 3,

vyp.18. 1989", CNaR RK 2.04-01-2010 and CNaR RK 2.04-21-2004\* which is " Power consumption and heat protection of civil buildings ".

#### **4.2.1. Air temperature**

Annual variations of air temperature is characterized by persistent severe frosts in winter, the increase of the intense heat in the short spring season and the heat during the short summer. As the survey shows, the average monthly temperature of the coldest month of January is - 16.8 degrees, and the warmest - July 20.4 degrees Celsius. In some very severe winters, temperatures can drop to -49-52 degrees (the absolute minimum), but the probability of such a temperature of not more than 5%. On hot summer days the temperature can rise to 39-42 degrees, but such temperatures are observed not more than 1 time in 10 years. Settlement of the coldest five-day air temperature in Astana security 0.98 -36 degrees; Security 0.92 -33 degrees, the average temperature of the heating period - -8.4 degrees, the estimated duration of the heating period of 216-229 days.

#### **4.2.2. Depth of Ground Freezing**

The standard freezing depth for Astana according 5.01-102-2002 SMEs, p.p. 12.2.2-2.2.3 and CNaR RK 2.04-01-2010 is: 185cm for clay soils, 241cm for loam and sandy soils, 273cm for coarse soils. The average depth of penetration of "0" in the ground - 250 cm, the largest penetration is usually happened in March.

#### **4.3. Soil Profile**

Based on the description of the field output, and a result of static probing data and laboratory tests of soils, it has been determined that up to a depth of 17,0m in the geological structure of the site survey attended secondary alluvial deposits of sandy loam, sand medium size, gravelly sand, gravels and fluvial clay soils represented mainly clay and partly some loam. On the surface of these sediments can be overlaid by backfill which height is from 0.30 to 3.0m.

Alluvial gravelly and large sands throughout the section interbedded with each other, which have similar physical and mechanical properties, so united in one geotechnical element.

Fluvial loam and clay throughout the section are interlayered with each other have similar physical and mechanical properties, therefore, they are combined in one geotechnical element.

Each selected engineering-geological elements has particular values which describes their physical and mechanical properties as can be shown in Fig. xx below.

Table 4. 1. Soil Profile

Depth, m	Soil Layer	Unit weight, kN/m <sup>3</sup>	Density, g/cm <sup>3</sup>
3.0	Fill	18.30	1.87
4.6	Loam	19.13	1.97
5.5	Medium size sand	18.84	1.92
8.5	Gravelly sand	19.62	2.00
11.3	Gravel	20.11	2.05
14.3	Sandy clay	18.88	1.93

Filtration ratio of clay soil is determined on the compression-filtration device that allows testing under load at a variable pressure gradient, according to GOST 25584-90. Filtration coefficient  $C_p$  soil, m / day, reduced to filtering conditions at 10 ° C is calculated as follows:

$$K\Phi = \left[ \varphi * \frac{S}{H_0} \right] * \frac{A_{\Pi}}{A_k} * \frac{h}{T} \quad (\text{Eq. 4.1})$$

where:

S - the observed drop in water level in the piezometer, measured from the initial level, see;

H<sub>0</sub> - the initial pressure, see;

Φ - dimensionless coefficient;

t - time of the fall of the water level, s;

U<sub>p</sub> - piezometer sectional area, cm<sup>2</sup>;

A<sub>k</sub> - ring area, cm<sup>2</sup>;

h - height of the soil sample, which is equal to the height of the ring, see;

$T = (0.7 + 0,03T_f)$  - Amendment to bring the values of the hydraulic conductivity of the water filtration conditions at a temperature of 10 C, where  $T_f$  - the actual water temperature with experience 0C.

Groundwater feeding happens mainly due to infiltration of precipitation, as well as snowmelt and flood, as well as leakage of water communications. The scope of supply is the distribution area of the aquifer. The values of the filter coefficients for the soil taken from laboratory determinations and materials of study:

- Bulk soil - 0.06 - 0.15 m / day;

- For loam - 0.00001m / day;

for sand medium size:

- In the loose state – 6.60-9.95 m / d,

- The packed – 2.87-5.58 m / day;

for sand and gravel large:

- In the loose state - 8,05-16,34m / day, the mean value of 12.94m / day,

- The packed – 6.03-11.44m / day, mean 9.20m / day;

for gravel soils – 17.5-30.29m / day;

for eluvial clayey soils – 0.019-0.26m / day.

#### **4.4. Ground Water Condition**

In the research area, the depth of the groundwater is measured as between 1.50 – 2.30m which can be indicated according to the data of the drilling.

In the natural condition, the level of groundwater is not fixed and fluctuated by the season. The minimum level is noted in March, and the maximum one is recorded at the beginning of May. The amplitude of the fluctuated levels in the area of survey was around 1.0-1.5m.

In the spring, it can be expected the groundwater level rise at 0.30m above than given data at the time of research. The site survey of the project refers to the flooding areas.

Groundwater charging occurs mainly due to infiltration of precipitation, snowmelt and flood, as well as leakage of water communications. The scope of supply is the distribution area of the aquifer.

In the period of maximum standing groundwater level, water-bearing deposits could be all the ground which was revealed during drilling.

#### **4.5. Foundation design**

The main criteria to choose type of foundation is dependent on underground soil condition of the place and loads of the building. Common two types of foundation are well known in construction field, and they are shallow and deep foundations. These words describe the depth of foundation in soil; depth of shallow foundation is at least about 1m, while the depth of deep foundation is nearly 20-65m (<http://www.understandconstruction.com>).

##### **4.5.1. Foundation types: Shallow Foundation**

As can be mentioned before, shallow foundations are located near to the surface of the ground and the main function of it is to distribute the load from superstructure to subsoil layers. Two common types of shallow foundation are spread footing and mat (raft) foundation.

Spread footing foundation has a wider concrete bottom which supports the column that transfers the load of building to the bottom block. The wider block distributes the building weight over more area which leads to better stability. Generally, such type of foundation is used for medium or small size buildings, however, it is not be satisfactory for multistory building as in our case.

Mat foundation is a reinforced concrete cover which support superstructure part by distributing whole load of building across the entire area. Such foundation is constructed near the surface of the ground as typical shallow foundation. Generally, this type of foundation is used when underground basements are to be constructed and where soil is weak due to spreading the load over an entire area. In case of multistory buildings, the thick of mat foundation is to be increased.

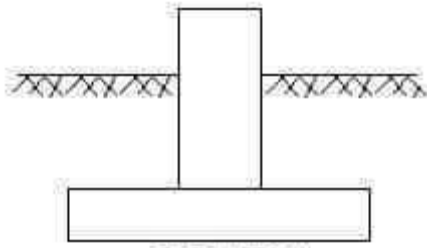


Figure 4. 2. Spread footing foundation

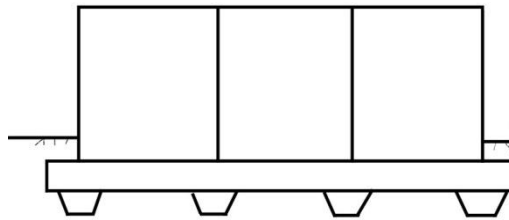


Figure 4. 3. Mat foundation

By taking into consideration the soil condition in the location of the major building, shallow foundation is not sufficient for this case. Firstly, spread footing foundation is mostly introduced for small or medium buildings. Though, the major building has 12 storeys that is enough high. In case of mat foundation, due to the large area of the building as 80m x 100m, the size of the mat foundation is to be sufficiently heavy. Thus, the applied load from the building is to be very large which in some cases can lead to instability of the structure. As in Astana the climate condition is quite hard, there are difficulties about freezing due to the cold weather. Underground water around the area of foundation can freeze and enlarge, therefore, the shallow foundation can be damaged. Accordingly, the foundation is needed to build below the frozen line. Otherwise, they should be shielded by insulation such as building heat which is penetrating into the ground and protect from freezing. Thereby, the shallow foundation is expunging from the choice list and another type of foundation is started to be analyzed.

#### **4.5.2. Foundation types: Deep Foundation**

Deep foundation is a long cylindrical material (concrete, steel and etc.) which distributes superstructure loads into the deep soil layers. This type of foundation is mostly utilized in

two conditions: when the soil is weak at the surface and when the weight of the superstructure is sufficiently heavy.






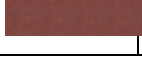
There are many types of deep foundation which can be classified by used material, loads carried, shape of cross section area, installation procedure and etc. First of all, the piles are made by three types of material: steel, concrete and timber. The shapes of steel piles are as H-section or pipe piles. Usually, steel piles are utilized when foundation has a high capacity and soil is sufficiently dense. Moreover, as steel has a high tensile strength, such piles are mostly used to withstand high tensile loads. However, there are three main disadvantages that lead to cancel steel piles from the list, firstly, the steel piles are relatively costly compared to other piles, secondly, high noise during the installation procedure, and finally, they are exposed to corrosion. Compared to steel piles which easily resist hard driving stress, the timber piles cannot. The main advantage of such piles is in the cost of it, however, they cannot be applied for such high loads of the building and are just cracked during the installation procedure. Furthermore, the third type of material that is used in deep foundation is a concrete. Concrete piles are separated into two main classes: cast-in-place and precast piles. Cast-in-place, or cast-in-situ, piles are installed by drilling a cylindrical hole and filling the prepared hole with concrete. These piles are separated into two classes: cased and uncased piles. Cased piles are built by putting steel casing into the soil and thereafter, filling the casing with concrete. Uncased piles are made by the same procedure, only difference is that the casing is gradually extracted by the end. This type of concrete pile is economical, however, there are some difficulties to join after filling with concrete and the steel casing can be spoiled during the driving process. The most familiar type of cast-in-place piles is drilled shafts. Another type of concrete piles is precast piles. They can be made by utilizing reinforcement and have any shape in cross section, mostly octagonal or square. Reinforced steel in the precast piles can help to withstand the bending moment caused by vertical and lateral loads and during transportation stage. The piles are poured and prepared to required length before transportation. Precast piles can be prestressed by high-strength steel usage, which means the maximum applied loads can be higher from 7500kN to 8500kN. The reason of being prestressed is to protect the piles from being broken during the driving procedure. The main advantages of such piles are resistant to corrosion, exposed to hard driving and additionally,

cheaper and can have larger load capacity compared with steel piles. Thus, the prestressed precast pile foundation is chosen as the best solution in our project.

#### 4.5.3. Design Procedure

In order to start the calculation, first of all, it can be needed to review the soil profile of the selected area that is shown in Table 4.2 below.

Table 4. 2. Soil Profile of the region, GW=2.0m below the ground surface

Color	Depth, m	Soil Layer	Unit weight, kN/m <sup>3</sup>	Density, g/cm <sup>3</sup>
	3.0	Fill	18.30	1.87
	1.6	Loam	19.13	1.97
	0.9	Medium size sand	18.84	1.92
	3.0	Gravelly sand	19.62	2.00
	2.8	Gravel	20.11	2.05
	3.0	Sandy clay	18.88	1.93

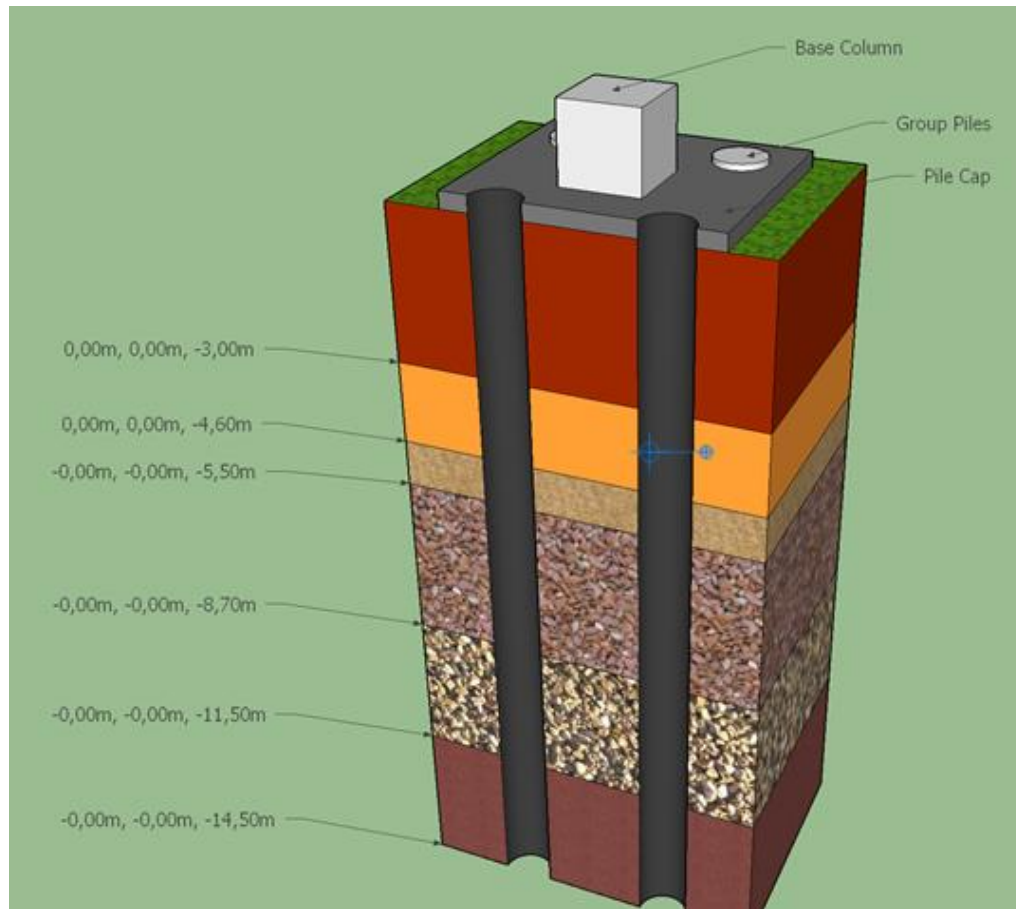


Figure 4. 4. Conceptual Design of Pile Foundation

Based on the soil profile, the presence of rock materials at the bottom of soil layers cannot be found. Moreover, as whole soil profile is sandy materials, it cannot be seen that there is strong soil layer at the bottom stratum (Das, 2006). Thus, there is almost no point bearing or compaction piles, most piles are friction piles due to the fact that the resistance of the reinforced concrete piles is mainly come from skin friction ( $Q_s$ ).

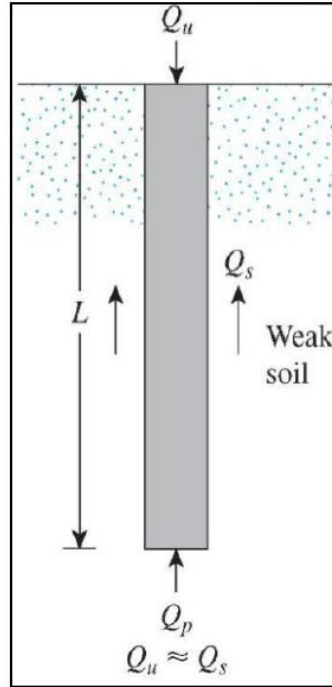


Figure 4. 5. Friction Pile (Das, 2006)

According to Braja Das (2006), the equation of the ultimate pile load is estimated as below.

$$Q_u = Q_p + Q_s \quad (4.4)$$

Where,  $Q_p$  - load at the pile end point,  $Q_s$  - load carrying by skin friction at the side of pile,  $Q_u$  - ultimate pile load.

The equation of the allowable load can be expressed as following.

$$Q_{all} = \frac{Q_u}{FS} \quad (4.5)$$

The range of the safety factor is between 2.5 and 4, it depends on the uncertainties extracted during the calculation of ultimate load.

The ultimate load-bearing capacity of group piles in sand can be expressed in the manner below.

Step 1. Define total ultimate load  $Q_u$  by using equation below.

$$\sum Q_u = n \ln 2 (Q_p + Q_s). \quad (4.6)$$

$$Q_p = A_p \sigma' N_{\sigma} \quad (4.7)$$

$$N\sigma = \frac{3Nq}{(1+2K_0)} \quad (4.8)$$

$$\sigma' = \left(\frac{1+2K_0}{3}\right) q' \quad (4.9)$$

Where,  $K_0 = 1 - \sin\phi'$ , and  $q' = \gamma L$ ,  $N\sigma$  - bearing capacity factor.

$$Q_s = (K \sigma' o \tan\delta') pL \quad (4.10)$$

Where,  $\delta' = 0.8 \phi'$ ,  $\sigma' o$  - average effective overburden pressure.

Step 2. Define ultimate load  $Q_u$  by suggesting as group piles, where dimensions are  $L_g$ ,  $B_g$  and  $L$ .

$$Q_p = A_p \sigma' o \quad N\sigma = (L_g B_g) \sigma' o \quad N\sigma \quad (4.11)$$

$$Q_s = (K \sigma' o \tan\delta') pL = (K \sigma' o \tan\delta') (L_g + B_g)L \quad (4.12)$$

$$\sum Q_u = n \ln 2 (Q_p + Q_s) = n \ln 2 [(L_g B_g) \sigma' o \quad N\sigma + (K \sigma' o \tan\delta') (L_g + B_g)L] \quad (4.13)$$

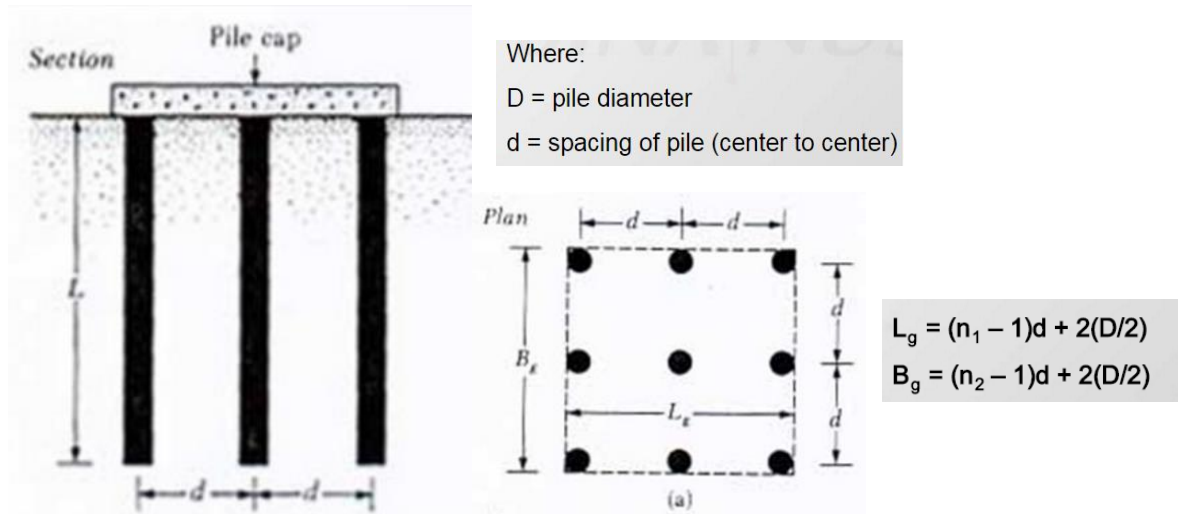


Figure 4. 6. Group Piles (Das, 2006)

Step 3. Thereafter, by finishing hand calculation, the lowest value is to be taken as  $Q_u$ .

#### 4.5.4. Load Applied

By the program SAP2000, the critical frames of super structural part are exposed to several load combinations. Thereafter, obtained results are illustrated in the table below. The table

shows the most critical three combinations, where axial, shear loads and moment are taken into account.

Table 4. 3. Loads on the Joints (under the high building)

Case	Axial (kN)	Shear (kN)	Moment (kN-m)	Maximum
DCON4	5389.576	53.51	197.97	Column 121 (Axial, N)
DCON6	4708.140	94.26	344.232	Column 96 (Moment, M and Shear, V)

Table 4. 4. Loads on the Joints (under bottom structure)

Case	Axial (kN)	Shear (kN)	Moment (kN-m)	Maximum
DCON4	336.783	8.45	24.71	Column 161 (Axial, N)
DCON6	150.030	16.07	45.56	Column 162 (Moment, M and Shear, V)

Thus, the values of moment, axial and shear forces were chosen from the most critical columns for the high 12 stories building with area  $30 \times 30 \text{ m}^2$ ,  $V=53.51 \text{ kN}$ ,  $N=5389.576 \text{ kN}$  and  $M=197.970 \text{ kN-m}$  for 1<sup>st</sup> case, and  $V=94.26 \text{ kN}$ ,  $N=4708.140 \text{ kN}$  and  $M=344.232 \text{ kN-m}$  for the 2nd case. Thereafter, the values for bottom structure of the building with area  $(50 \times 60 - 30 \times 30) \text{ m}^2$  were as it can be seen from the table above; case 1:  $V=8.45 \text{ kN}$ ,  $N=336.783 \text{ kN}$  and  $M=24.71 \text{ kN-m}$ , and additionally, case 2:  $V=16.07 \text{ kN}$ ,  $N=150.030 \text{ kN}$  and  $M=45.56 \text{ kN-m}$ . It can be clearly seen that axial load is more critical compared with shear and moment, hence, the design procedure will start from this load.

#### 4.5.5. Pile Group Design: Vertical Loads

In order to determine the ultimate capacity for group piles in saturated sand, the three steps calculations that are mentioned above will be used. The excel file has been started to define the sufficient group pile conjunction. Moreover, three pile sizes (where,  $B=0.40 \text{ m}$ ,  $B=0.45 \text{ m}$ ,  $B=0.60 \text{ m}$ ) were chosen for analysis. The US standard metric sizes for piles are illustrated in table below.

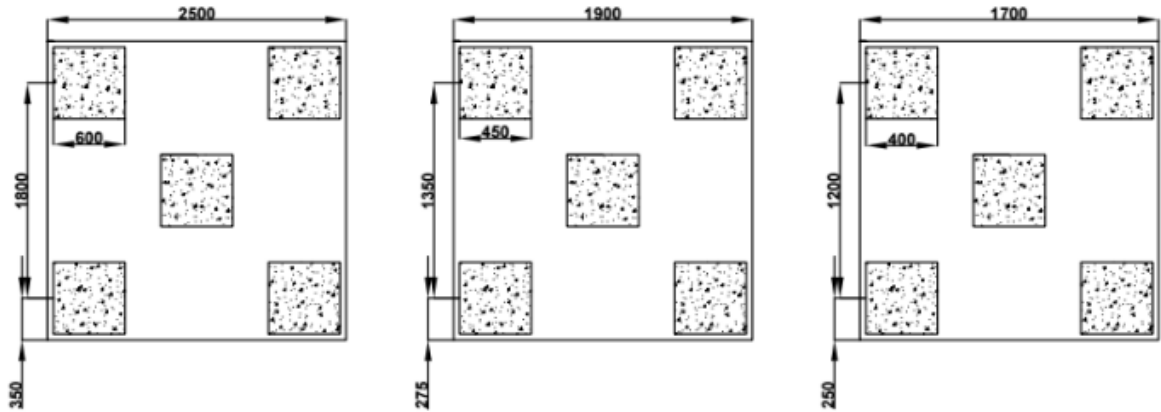


Figure 4. 7. (a) Pile cap dimensions for B=0.40m; (b) Pile cap dimensions for B=0.45m; (c) Pile cap dimensions for B=0.60m;

Table 4. 5. Standard metric pile sizes

Meters	Inches
0.35	14
0.40	16
0.45	18
0.60	24
0.75	30
1.00	42
1.20	48

The piles in a group can be located by several methods, and the most suitable one is by locating four piles in a group.

$$\text{Vertical Load on a pile} = \left(\frac{P}{R}\right) \pm \left(\frac{M_{xx} y}{I_{xx}}\right) \pm \left(\frac{M_{yy} x}{I_{yy}}\right) \quad (4.14)$$

R – amount of piles in a group, P – vertical load on a group pile cap;  $I_{xx} = \sum y^2$  about x-x direction,  $I_{yy} = \sum x^2$  about y-y direction; where, y is a spacing between the central axis and the pile in y-y direction, and x is spacing between the central axis and the pile in x-x direction.

Pile cap dimensions is to be determined for calculation of x and y dimensions. Thus,  $S \geq 3B$  and  $C \geq 0.5B$  are required for friction piles. From an economical view point, the lowest values were taken.

The obtained results by SAP2000 program are as following.

For 1<sup>st</sup> case: P=5389.576kN, M<sub>xx</sub>= 197.970kN -m, H<sub>xx</sub>=53.51kN. Furthermore, regarding to ACI code for y-y direction, it is required to account 30% of shear and moment values. So, M<sub>yy</sub>=0.3\*197.970=59.391kN-m, H<sub>yy</sub>=0.3\*53.51=16.053kN. By substituting these values, vertical loads for piles under high building with B=0.40m in compression and tension can be gained as following.

$$\text{Vertical Load on a pile} = \left(\frac{5389.576}{4}\right) + \left(\frac{197.970*y}{4y^2}\right) + \left(\frac{59.391*x}{4x^2}\right) = 1454.63\text{kN (C)}$$

$$\text{Vertical Load on a pile} = \left(\frac{5389.576}{4}\right) - \left(\frac{197.970*y}{4y^2}\right) - \left(\frac{59.391*x}{4x^2}\right) = 1240.16\text{kN (T)}$$

For 2<sup>nd</sup> case: P=4708.140kN, M<sub>xx</sub>= 344.232kN -m, H<sub>xx</sub>=94.26kN.

M<sub>yy</sub>=0.3\*344.232=103.270kN-m, H<sub>yy</sub>=0.3\*94.26=28.278kN.

For pile with B=0.40m.

$$\text{Vertical Load on a pile} = \left(\frac{4708.140}{4}\right) + \left(\frac{344.232*y}{4y^2}\right) + \left(\frac{103.270*x}{4x^2}\right) = 1363.494\text{kN (C)}$$

$$\text{Vertical Load on a pile} = \left(\frac{4708.140}{4}\right) - \left(\frac{344.232*y}{4y^2}\right) - \left(\frac{103.270*x}{4x^2}\right) = 990.576\text{kN (T)}$$

Total vertical is calculated as following  $V = 2*V_c + 2*V_t$ .

Table 4. 6. Vertical load on a pile both in compression and tension (under the high building)

			Case 1			Case 2		
B (m)	x (m)	y (m)	V <sub>c</sub> (kN)	V <sub>t</sub> (kN)	V (kN)	V <sub>c</sub> (kN)	V <sub>t</sub> (kN)	V (kN)
0.400	0.600	0.600	1454.63	1240.16	5389.58	1363.494	990.576	4708.14
0.450	0.675	0.675	1442.71	1252.08	5389.58	1342.776	1011.294	4708.14
0.600	0.900	0.900	1418.88	1275.91	5389.58	1301.341	1052.729	4708.14

In order to obtain values of the vertical loads for piles under bottom structure the results from SAP2000 are also utilized.

For 1<sup>st</sup> case: P=336.783kN, M<sub>xx</sub>= 24.71kN-m, H<sub>xx</sub>=8.45kN.

M<sub>yy</sub>=0.3\*24.71=7.413kN-m, H<sub>yy</sub>=0.3\*8.45=2.535kN, B=0.40m

$$\text{Vertical Load on a pile} = \left(\frac{336.783}{4}\right) + \left(\frac{24.71*y}{4y^2}\right) + \left(\frac{7.413*x}{4x^2}\right) = 97.58\text{kN (C)}$$

$$\text{Vertical Load on a pile} = \left(\frac{336.783}{4}\right) - \left(\frac{24.71 * y}{4y^2}\right) - \left(\frac{7.413 * x}{4x^2}\right) = 70.81 \text{ kN (T)}$$

For 2<sup>nd</sup> case: P=150.030kN, M<sub>xx</sub>= 45.56kN-m, H<sub>xx</sub>=16.07kN.

M<sub>yy</sub>=0.3\*45.56=13.668kN-m, H<sub>yy</sub>=0.3\*16.07=4.821kN, and B=0.40m.

$$\text{Vertical Load on a pile} = \left(\frac{150.030}{4}\right) + \left(\frac{45.56 * y}{4y^2}\right) + \left(\frac{13.668 * x}{4x^2}\right) = 62.19 \text{ kN (C)}$$

$$\text{Vertical Load on a pile} = \left(\frac{150.030}{4}\right) - \left(\frac{45.56 * y}{4y^2}\right) - \left(\frac{13.668 * x}{4x^2}\right) = 12.83 \text{ kN (T)}$$

Table 4. 7. Vertical load on a pile both in compression and tension (under bottom structure)

			Case 1			Case 2		
B (m)	x (m)	y (m)	V <sub>c</sub> (kN)	V <sub>t</sub> (kN)	V (kN)	V <sub>c</sub> (kN)	V <sub>t</sub> (kN)	V (kN)
0.400	0.600	0.600	97.58	70.81	336.78	62.190	12.830	150.040
0.450	0.675	0.675	96.09	72.30	336.78	59.444	15.571	150.030
0.600	0.900	0.900	93.12	75.27	336.78	53.960	21.055	150.030

Table 4. 8. Calculation results of  $Q_{\text{allowable}}$  for  $B=0.40\text{m}$

Depth	Soil	Thickness	$\gamma$	$c$	$\phi'$	$K_o$	$Nq$	eff.norm.groun.str	aver.eff.verb.press	$Q_s$	Cum. $Q_s$	$Q_p$	$Q_u$	$Q_{all}$
m		m	kN/m <sup>3</sup>	kN/m <sup>2</sup>	grades			kN/m <sup>2</sup>	kN/m <sup>2</sup>	kN	kN	kN	kN	kN
2	Fill	2	17	3	0	1,00	0	34,00	17,00	0,00	0,00	0,00	0,00	0,00
3	Fill	1	18,3	2,33	0	1,00	0	42,49	21,25	0,00	0,00	0,00	0,00	0,00
4	Loam	1	19,13	18,22	22,23	0,62	15,5	49,46	25,91	79,73	79,73	164,01	974,93	243,73
4,6	Loam	0,6	19,13	18,22	22,23	0,62	15,5	53,64	28,70	101,58	181,30	177,88	1436,72	359,18
5	Medium sand	0,4	18,84	1,33	32	0,47	81	55,98	30,51	175,30	356,60	1121,52	5912,50	1478,12
5,5	Medium sand	0,5	18,84	1,33	32	0,47	81	58,90	32,76	207,09	563,70	1180,04	6974,93	1743,73
6	Gravelly sand	0,5	19,62	1	34	0,44	115	61,98	35,22	260,47	824,17	1817,71	10567,53	2641,88
7	Gravelly sand	1	19,62	1	34	0,44	115	68,13	40,12	346,21	1170,38	1998,22	12674,38	3168,59
8	Gravelly sand	1	19,62	1	34	0,44	115	74,29	45,03	444,04	1614,42	2178,72	15172,55	3793,14
8,5	Gravelly sand	0,5	19,62	1	34	0,44	115	77,36	47,48	497,49	2111,91	2268,97	17523,51	4380,88
9	Gravel	0,5	20,11	0,67	32	0,47	81	80,69	50,05	517,71	2629,62	1616,69	16985,24	4246,31
10	Gravel	1	20,11	0,67	32	0,47	81	87,36	55,20	634,42	3264,04	1750,18	20056,87	5014,22
11	Gravel	1	20,11	0,67	32	0,47	81	94,02	60,35	762,97	4027,00	1883,67	23642,69	5910,67
11,3	Gravel	0,3	20,11	0,67	32	0,47	81	96,02	61,90	803,84	4830,84	1923,71	27018,22	6754,56
12	Sandy clay	0,7	18,88	33,78	20,59	0,65	12,4	100,88	65,07	553,85	5384,69	261,40	22584,39	5646,10
13	Sandy clay	1	18,88	33,78	20,59	0,65	12,4	107,83	69,61	641,82	6026,51	279,40	25223,64	6305,91
14	Sandy clay	1	18,88	33,78	20,59	0,65	12,4	114,77	74,14	736,22	6762,73	297,39	28240,50	7060,12
14,3	Sandy clay	0,3	18,88	33,78	20,59	0,65	12,4	116,85	75,50	765,79	7528,52	302,79	31325,27	6961,17

Table 4. 9. Calculation results of  $Q_{\text{allowable}}$  for  $B=0.45\text{m}$

Depth	Soil	Thickness	$\gamma$	c	$\phi'$	$K_o$	$Nq$	eff.norm.groun.str	aver.eff.overb.press	$Q_s$	Cum. $Q_s$	$Q_p$	$Q_u$	$Q_{all}$
m		m	kN/m <sup>3</sup>	kN/m <sup>2</sup>	grades			kN/m <sup>2</sup>	kN/m <sup>2</sup>	kN	kN	kN	kN	kN
2	Fill	2	17	3	0	1,00	0	34,00	17,00	0,00	0,00	0,00	0,00	0,00
3	Fill	1	18,3	2,33	0	1,00	0	42,49	21,25	0,00	0,00	0,00	0,00	0,00
4	Loam	1	19,13	18,22	22,23	0,62	15,5	49,46	25,91	89,69	89,69	207,57	1189,05	297,26
4,6	Loam	0,6	19,13	18,22	22,23	0,62	15,5	53,64	28,70	114,28	203,97	225,12	1716,37	429,09
5	Medium sand	0,4	18,84	1,33	32	0,47	81	55,98	30,51	197,21	401,18	1419,43	7282,42	1820,60
5,5	Medium sand	0,5	18,84	1,33	32	0,47	81	58,90	32,76	232,98	634,16	1493,48	8510,57	2127,64
6	Gravelly sand	0,5	19,62	1	34	0,44	115	61,98	35,22	293,03	927,19	2300,54	12910,93	3227,73
7	Gravelly sand	1	19,62	1	34	0,44	115	68,13	40,12	389,49	1316,67	2528,99	15382,67	3845,67
8	Gravelly sand	1	19,62	1	34	0,44	115	74,29	45,03	499,54	1816,22	2757,44	18294,65	4573,66
8,5	Gravelly sand	0,5	19,62	1	34	0,44	115	77,36	47,48	559,67	2375,89	2871,67	20990,25	5247,56
9	Gravel	0,5	20,11	0,67	32	0,47	81	80,69	50,05	582,43	2958,32	2046,12	20017,78	5004,44
10	Gravel	1	20,11	0,67	32	0,47	81	87,36	55,20	713,72	3672,04	2215,07	23548,45	5887,11
11	Gravel	1	20,11	0,67	32	0,47	81	94,02	60,35	858,34	4530,38	2384,02	27657,58	6914,40
11,3	Gravel	0,3	20,11	0,67	32	0,47	81	96,02	61,90	904,32	5434,70	2434,70	31477,59	7869,40
12	Sandy clay	0,7	18,88	33,78	20,59	0,65	12,4	100,88	65,07	623,08	6057,78	330,84	25554,47	6388,62
13	Sandy clay	1	18,88	33,78	20,59	0,65	12,4	107,83	69,61	722,05	6779,82	353,61	28533,75	7133,44
14	Sandy clay	1	18,88	33,78	20,59	0,65	12,4	114,77	74,14	828,25	7608,07	376,39	31937,84	7984,46
14,3	Sandy clay	0,3	18,88	33,78	20,59	0,65	12,4	116,85	75,50	861,52	8469,59	383,22	35411,25	7869,17

Table 4. 10. Calculation results of  $Q_{allowable}$  for  $B=0.60m$

Depth	Soil	Thickness	$\gamma$	$c$	$\phi'$	$K_o$	$N_q$	eff.norm.groun.str	aver.eff.verb.press	$Q_s$	Cum. $Q_s$	$Q_p$	$Q_u$	$Q_{all}$
m		m	kN/m <sup>3</sup>	kN/m <sup>2</sup>	grades			kN/m <sup>2</sup>	kN/m <sup>2</sup>	kN	kN	kN	kN	kN
2	Fill	2	17	3	0	1,00	0	34,00	17,00	0,00	0,00	0,00	0,00	0,00
3	Fill	1	18,3	2,33	0	1,00	0	42,49	21,25	0,00	0,00	0,00	0,00	0,00
4	Loam	1	19,13	18,22	22,23	0,62	15,5	49,46	25,91	119,59	119,59	369,02	1954,42	488,60
4,6	Loam	0,6	19,13	18,22	22,23	0,62	15,5	53,64	28,70	152,37	271,96	400,22	2688,71	672,18
5	Medium sand	0,4	18,84	1,33	32	0,47	81	55,98	30,51	262,94	534,90	2523,43	12233,31	3058,33
5,5	Medium sand	0,5	18,84	1,33	32	0,47	81	58,90	32,76	310,64	845,54	2655,08	14002,51	3500,63
6	Gravelly sand	0,5	19,62	1	34	0,44	115	61,98	35,22	390,71	1236,25	4089,85	21304,43	5326,11
7	Gravelly sand	1	19,62	1	34	0,44	115	68,13	40,12	519,31	1755,57	4495,99	25006,22	6251,56
8	Gravelly sand	1	19,62	1	34	0,44	115	74,29	45,03	666,06	2421,63	4902,12	29294,99	7323,75
8,5	Gravelly sand	0,5	19,62	1	34	0,44	115	77,36	47,48	746,23	3167,86	5105,19	33092,19	8273,05
9	Gravel	0,5	20,11	0,67	32	0,47	81	80,69	50,05	776,57	3944,43	3637,55	30327,93	7581,98
10	Gravel	1	20,11	0,67	32	0,47	81	87,36	55,20	951,63	4896,06	3937,90	35335,84	8833,96
11	Gravel	1	20,11	0,67	32	0,47	81	94,02	60,35	1144,45	6040,51	4238,25	41115,03	10278,76
11,3	Gravel	0,3	20,11	0,67	32	0,47	81	96,02	61,90	1205,76	7246,26	4328,36	46298,47	11574,62
12	Sandy clay	0,7	18,88	33,78	20,59	0,65	12,4	100,88	65,07	830,77	8077,04	588,16	34660,79	8665,20
13	Sandy clay	1	18,88	33,78	20,59	0,65	12,4	107,83	69,61	962,73	9039,77	628,65	38673,65	9668,41
14	Sandy clay	1	18,88	33,78	20,59	0,65	12,4	114,77	74,14	1104,33	10144,09	669,14	43252,93	10813,23
14,3	Sandy clay	0,3	18,88	33,78	20,59	0,65	12,4	116,85	75,50	1148,69	11292,79	681,28	47896,28	10643,62

#### 4.5.6. Pile Group Design: Lateral Loads

For the calculation of the horizontal load the equation below should be taken into consideration (Tomlinson, 2010).

$$\text{Horizontal Load on a pile} = \frac{(H_x^2 + H_y^2)^{1/2}}{R} \quad (4.15)$$

Where,  $H_x=94.26\text{kN}$ ,  $H_y=0.3*94.26=28.278\text{kN}$  in the case when the foundation is under the high building structure;  $H_x=16.07\text{kN}$ ,  $H_y=0.3*16.07=4.821\text{kN}$  values when the piles are under the bottom structure where the area is equal to  $(50 \times 60 - 30 \times 30) \text{ m}^2$ .

$$\text{Horizontal Load on a pile} = \frac{(94.26^2 + 28.278^2)^{1/2}}{4} = 24.603\text{kN} \quad (\text{main structure})$$

$$\text{Horizontal Load on a pile} = \frac{(16.07^2 + 4.821^2)^{1/2}}{4} = 4.194\text{kN} \quad (\text{bottom structure})$$

For analyzing of a single pile under lateral loading the Broms methods should be used for long, restrained pile in cohesionless soil that can be shown in Figure 4.8 below.

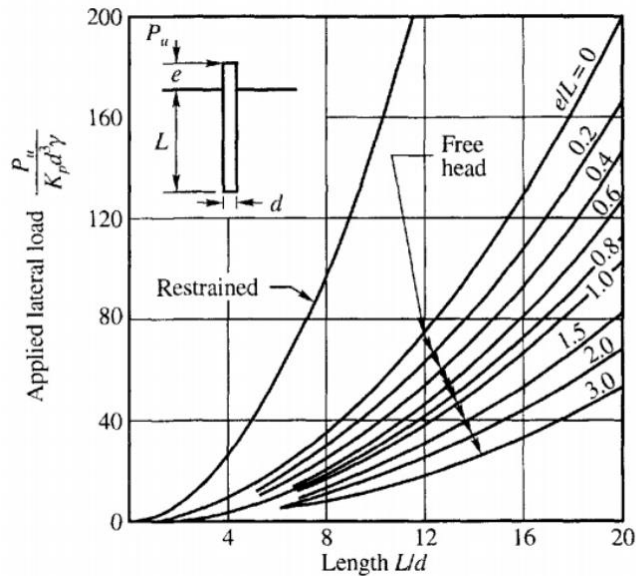


Figure 4. 8. Design of long piles under Lateral load in Cohesionless soil

So,  $\frac{L}{d} = \frac{8}{0.6} = 13.3$ . This value intersects with the vertical reading in point over 200, which is approximately between 250 and 300. Assume that  $\frac{P_{l,ult}}{K_p * d^3 * \gamma} = 250$ , where  $K_p = 4.0$  and  $\gamma = 20 \frac{\text{kN}}{\text{m}^3}$ ;

$$P_{l,ult} = 250 * K_p * d^3 * \gamma = 250 * 4.0 * 0.6^3 * 20 = 4320 \text{ kN} \quad (\text{main structure})$$

$$P_{t,ult} = 250 * K_p * d^3 * \gamma = 250 * 4.0 * 0.4^3 * 20 = 1280 \text{ kN} \quad (\text{bottom structure})$$

Thereafter, the load direction and spacing should be obtained for the group pile effect by Figure 4.9 below. When the spacing between piles in a group pile is 3B, for the first row the P-multiplier is equal to 0.4, for the second is 0.8. These factors are applied to  $P_{t,ult}$  value due to the fact that the group of piles in the first row are exposed to passive soil stress distribution correspond to the active soil stress in the second row of pile group.

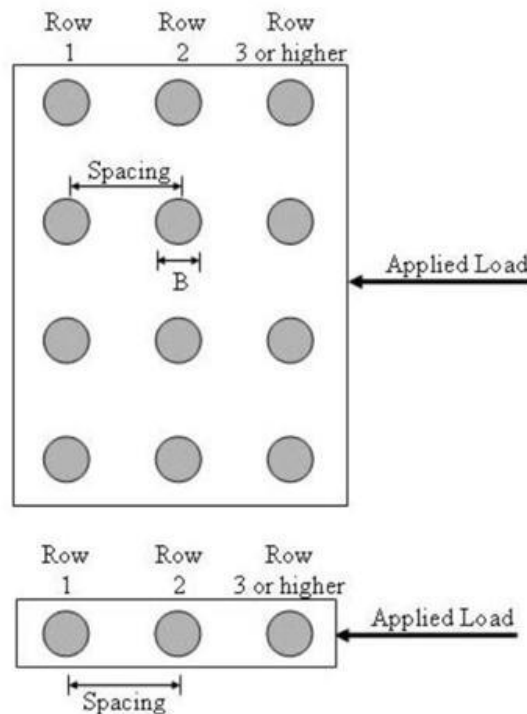


Figure 4. 9. Load direction and spacing for group piles

Table 4. 11. P-multiplier due to the row and spacing values

Pile CTC spacing (in the direction of loading)	P-Multipliers, $P_m$		
	Row 1	Row 2	Row 3 and higher
3B	0.8	0.4	0.3
5B	1.0	0.85	0.7

Eventually, the value of  $P_{t,ult}$  can be as following:

$$P_{t,ult}' = (0.8 * P_{t,ult}) * 2 + (0.8 * P_{t,ult}) * 2 = 2.4 * P_{t,ult} = 2.4 * 4320 = 10368 \text{ kN} \quad (\text{main structure})$$

$$P_{t,ult}' = (0.8 * P_{t,ult}) * 2 + (0.8 * P_{t,ult}) * 2 = 2.4 * P_{t,ult} = 2.4 * 1280 = 3072 \text{ kN} \quad (\text{bottom structure})$$

$$P = 4 * 24.603 = 98.412 \text{ kN} \quad (\text{main structure})$$

$$P = 4 * 4.194 = 16.776 \text{ kN} \quad (\text{main structure})$$

$P_{t,ult}$  is the ultimate lateral load that is factored by multipliers and can be resisted by a pile group.  $P$  is the ultimate lateral load which a pile group can resist. In both cases,  $P_{t,ult} > P$ , that means the pile group can be checked positively by lateral load also.

#### 4.5.7. Structural Failure of Pile Foundation during Installation

Structural failures of piles under working conditions are relatively rare. However, driven piles are subject to structural failure during the installation. Failures occur under various conditions, for example friction, bearing or combination of both. Different damages may happen along the shaft, toe or pile head. During the driving piles experience different stresses: compressive, flexural, tensile and torsional. Concrete piles can crush at the pile load. Causes of such pile damage can include not only very hard soils and obstructions, but also inappropriate hammer, insufficient cushion, tight pile cap and misalignment between pile and driving system. In the first two cases, when  $B=0.4$  and  $B=0.45$  lengths of piles have to be not less than 12 and 11 meters respectively (Tables 4.8-4.10). If the pile cross-section is taken as 0.6, length of 8 m is acceptable. The pile tip will rest in the gravelly sand layer, so the presence of large rock fragments is unlikely. In contrast, if pile of 11 meters will be chosen, the pile tip will rest in the gravel layer which might lead to the structural failure of piles.

#### 4.5.8. Pile Cap Design

Selected pile diameter  $B = 0.60 \text{ m}$ , Pile cap depth = 0.9m.

The Norwegian Code of Practice on Piling recommends a minimum pile spacing of  $3B$  for  $L < 12\text{m}$  in sand (or  $4B$  for  $L < 12$  in clay). Thus, spacing of piles = 2.0m, pile cap length =  $2.0 + 0.9 + 0.9 = 3.4\text{m}$ .

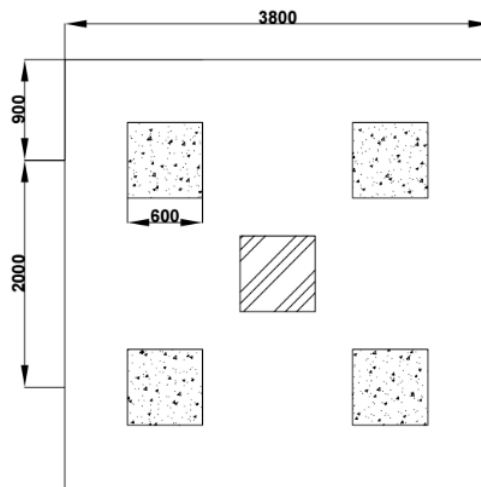


Figure 4. 10. Dimensions of Pile Cap

Size of cap is 3.8m x 3.8m x 0.9 m.

So, by assuming a pile cap as a rigid body with 650 mm backfill on top, the weight of the structure can be calculated.

W = weight of backfill + weight of slab + weight of pile cap

$$= 3.8\text{m} * 3.8\text{m} * 0.650\text{m} * 20 \frac{\text{kN}}{\text{m}^3} + 3.8\text{m} * 3.8\text{m} * 0.2\text{m} * 24 \frac{\text{kN}}{\text{m}^3} + 3.8\text{m} * 3.8\text{m} * 0.9\text{m} * 24 \frac{\text{kN}}{\text{m}^3} = 569.0 \text{ kN}$$

Bending moment and shear force in pile cap

Column size = 550mm x 550mm;

A-A and B-B - critical sections for calculation of bending moment;

$M_A'$  – bending moment due to dead load of pile cap on section A-A;

$M_B'$  – bending moment due to dead load of pile cap on section B-B;

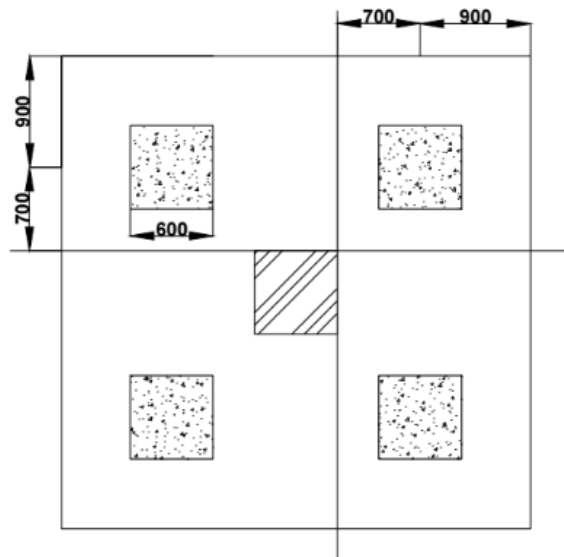


Figure 4. 11. Critical Section in pile cap for bending moment calculation

$$\text{Dead load of pile cap + slab + soil layer} = 0.9\text{m} * 24 \frac{\text{kN}}{\text{m}^3} + 0.2\text{m} * 24 \frac{\text{kN}}{\text{m}^3} + 0.650\text{m} * 20 \frac{\text{kN}}{\text{m}^3} = 39.4 \frac{\text{kN}}{\text{m}^2}$$

$$M_A' = M_B' = \frac{3.8 * 39.4 * 1.6}{2} = 120 \text{ kNm}$$

$$Q_1 = 1418.88\text{kN}, Q_3 = 1275.91\text{kN}, Q_2 = 1301.34\text{kN}, Q_4 = 1052.73\text{kN}.$$

$$M_A'' = 0.6 * (Q_2 + Q_3); M_B'' = 0.6 * (Q_1 + Q_2); V_A'' = Q_1 + Q_2; V_B'' = Q_2 + Q_3;$$

$Q_1, Q_2, Q_3$  and  $Q_4$  – pile reactions;

$M_A', M_B', V_A', V_B'$  – bending moments and shear forces in pile cap due to dead load of pile cap;

$M_A'', M_B'', V_A'', V_B''$  – bending moments and shear forces in pile cap due to reaction;

$M_A, M_B, V_A, V_B$  – combined bending moments and shear forces in pile cap.

By assuming reinforcement diameter = 20mm.

$$d_x = 900 - 90 (\text{cover}) - \frac{20}{2} (\text{bar dia.}) = 800\text{mm}; b = 3.8\text{m},$$

$$f_{cu} = 40 \frac{N}{mm^2} \text{ for concrete in pile cap, } f_y = 460 \frac{N}{mm^2} \text{ for reinforcement.}$$

$$K = \frac{M_A}{f_{cu} b d^2} = \frac{1546.35 * 10^6}{40 * 2990 * 800^2} = 0.0202$$

$$z = d * (0.5 + \sqrt{0.25 - \frac{K}{0.9}}) = 800 * (0.5 + \sqrt{0.25 - \frac{0.0202}{0.9}}) = 781.6\text{mm} \approx 782\text{mm}$$

$$A_{st} = \frac{M_A}{0.87 * f_y * z} = \frac{1546.35 * 10^6}{0.87 * 460 * 782} \approx 4941\text{mm}^2$$

Area of 20mm diameter bar = 314 mm<sup>2</sup>, and assume number is 35 for 20 mm diameter bars which are equally spaced in x-x direction and the same situation for opposite direction.

$$A = 35 * 314 \text{ mm}^2 = 10990 \text{ mm}^2 > 4941 \text{ mm}^2$$

$$\text{Maximum required } A_s = 0.4 * A_c = 0.4 * 3800 * 800 = 1216000 \text{ mm}^2$$

$$\text{Spacing rebar} = (3800\text{mm} - 35 * 20\text{mm} - 90\text{mm} - 90\text{mm} (\text{cover})) / 30 = 97.3\text{mm}$$

Minimum rebar spacing = 20mm or bar diameter (20mm), 95 mm > 20 mm (OK).

#### Checking punching shear stress in pile cap

$$\text{Perimeter of column} = U_1 = 2 (550 + 550) = 2200\text{mm}$$

Pile spacing = 3 \* pile diameter. Hence, the checking of punching shear stress has to be done.

$$\text{Perimeter on punching shear critical plane} = U_2 = 2 (385 + 510/2 + 1.5 * 800) = 3680 \text{ mm}$$

$$\text{Maximum ultimate load on column} = N = 5400 \text{ kN}$$

$$\text{Maximum ultimate load on pile} = Q = 1500 \text{ kN}$$

Punching shear stress on column =  $\frac{N}{U_1 d} = \frac{5400 * 10^3}{2200 * 800} = 3.07 \frac{N}{mm^2} < 5 \frac{N}{mm^2}$  or  $0.8 \sqrt{f_{cu}}$ , that is OK.

Punching shear stress at pile perimeter =  $\frac{Q}{\text{surface area of pile}} = \frac{1500 * 10^3}{510 * 4 * 800} = 0.92 \frac{N}{mm^2} < 5 \frac{N}{mm^2}$  or  $0.8 \sqrt{f_{cu}}$ , that is OK.

Punching shear stress of pile =  $\frac{Q}{U_2 d} = \frac{1500 * 10^3}{3680 * 800} = 0.51 \frac{N}{mm^2}$

Minimum value of vc for Grade 40  $\frac{N}{mm^2}$  concrete is  $0.4 \frac{N}{mm^2}$ , that is also OK.

#### 4.5.9. Elastic Settlement

Elastic Settlement of a pile under a vertical working load:

$$S_e = s_{e(1)} + s_{e(2)} + s_{e(3)}$$

Where:

$s_{e(1)}$  = elastic settlement of pile

$s_{e(2)}$  = settlement of pile caused by the load at the pile tip

$s_{e(3)}$  = settlement of pile caused by the load transmitted along the pile shaft

$$s_{e(1)} = \frac{(Q_{wp} + \xi Q_{ws})L}{A_p E_p}$$

$Q_{wp}$  = load carried at the pile point under working load condition

$Q_{ws}$  = load carried by frictional resistance under working load condition

$A_p$  = cross section area of pile

$L$  = pile length

$\xi = 0.6$

$$s_{e(2)} = \frac{q_{wp} D (1 - \mu^2) I_{wp}}{E_s}$$

$D$  = pile width

$q_{wp} = Q_{wp} / A_p$

$E_s$  = elastic modulus of soil below the pile point

$\mu$  = Poisson's ratio of soil

$I_{wp}$  = influence factor 0.85

$$s_{e(3)} = \left(\frac{Q_{ws}}{pL}\right)\left(\frac{D}{E_s}\right)(1 - \mu^2)I_{ws}$$

p=pile perimeter

L= embedded length of pile

$I_{ws}$ = influence factor,  $I_{ws} = 2 + 0.35\sqrt{\frac{L}{D}}$

Elastic settlement of group piles is given by Vesic:

$$s_{g(e)} = \sqrt{\frac{B_g}{D}} s_e$$

$s_e$ -elastic settlement of each pile at comparable working load

D-with of each pile

$B_g$ -width of group pile section

Table 4. 12. Calculated group pile elastic settlements for B=0.4;0.45; and 0.6 m.

$\mu$	0.3
$E_p$ , Pa	21000000
$I_{wp}$	0.85
$\xi$	0.6

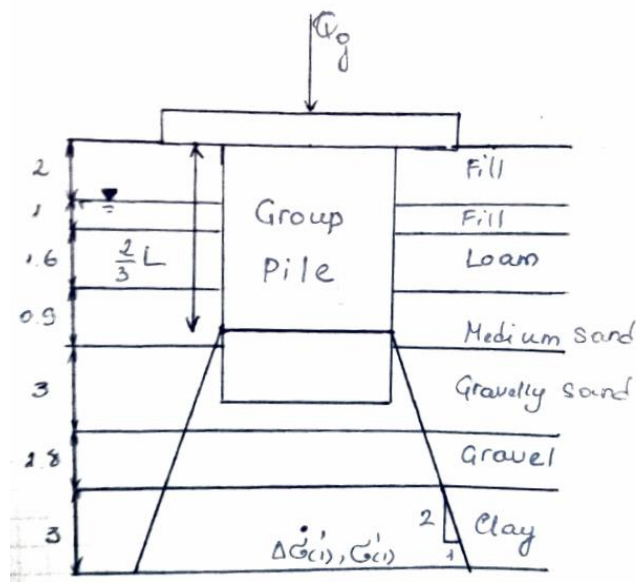
B	L	$A_p$	$E_s$	$B_g$	$Q_{wp}^1$	$Q_{ws}^2$	$I_{ws}$	$s_{e(1)}$	$s_{e(2)}$	$s_{e(3)}$	S (group)
m	m	mm <sup>2</sup>	kPa	m	kN	kN		mm	mm	mm	mm
0.60	8	0.36	21000	2.4	1124	439	3.28	1.47	69.00	1.95	145
0.45	11	0.20	23000	1.8	554	918	3.73	2.86	41.38	3.08	95
0.40	12	0.16	23000	1.6	471	1007	3.92	3.84	39.59	3.25	93

<sup>1,2</sup> - loads that a single pile can carry were obtained by dividing values from Tables 4.8-4.10 by four (four piles in a group)

It should be noted that the short-term settlement of 60X60 section piles is 50 mm more than two other types. Acceptability of this amount of settlement will be checked further.

#### 4.5.10. Consolidation settlement

For group piles, consolidation settlement is estimated by the 2:1 stress distribution method. In this method, the load  $Q_g$  is assumed to spread starting from a depth of  $2/3(L)$  of the pile. The layer that will notably consolidate is the clay layer at the depth of 11.3m - 14.3 m. Loam layer contains 20% of clay, therefore, it can consolidate, but since the layer is located above the stress distribution area, it will not make any notable difference.



Assume clay layer is normally consolidated. Then, settlement for layer is given by

$$s = \frac{CcHi}{1 + e_0} \log \frac{\sigma'_{(i)} + \Delta\sigma'_{(i)}}{\sigma'_{(i)}}$$

Where  $C_c$ -compression index,

$e_0$ -initial void ratio

$\Delta\sigma'_{(i)}$  – increase in effective stress at the middle of layer  $i$

$$\Delta\sigma'_{(1)} = \frac{5389.58kN}{(2.4 + 7.47)(2.4 + 7.47)} = \frac{55.32kN}{m^2}$$

$$\sigma'_{(1)} = 2 * 18.3 + 1 * (18.3 - 9.81) + 1.6 * (19.13 - 9.81) + 0.9 * (18.84 - 9.81) + 2.8 * (20.11 - 9.81) + 1.5(18.88 - 9.81) = \frac{110.57kN}{m^2}$$

$Cc = 0.009 * (LL - 10)$ , where  $LL = 40$  for this type of clay (According to « Engineering Survey Report » 2015).  $Cc=0.27$

Void ratio can be determined from  $Se = Gsw$ , where  $Gs=2.74$  and  $w = 85\%$  as stated in the technical report. Saturation ratio assumed 1 because clay layer fully below water table.  $E=2.329$

Thus, consolidation settlement for this layer:

$$s = \frac{0.27 * 3}{1 + 2.329} \log \frac{55.32 + 110.57}{55.32} = 116 \text{ mm}$$

Total settlement = elastic settlement + consolidation settlement. For the selected 0.6x0.6 width piles the value will be:

$145\text{mm} + 116\text{mm} = 261\text{mm}$ , which is acceptable.

## 5. PROJECT MANAGEMENT

### 5.1. Quantity Take-off

The table below presents a quantity takeoff of a project. It accounts labor, equipment and materials, and is based on the data obtained in the geotechnical and structural design results. The quantity takeoff is of a significant value for cost analysis, since it usually states the quantities and units of measure for the resources, equipment and cost of labor. These are direct costs. Indirect costs, or overhead include money spent on logistics, planning, supervision, loans, housing and feeding of project staff, costs of site utilities and etc. As it can be seen, the cost of main structural elements amounted to \$9,582,891. Indirect costs and expenses on minor structural details, as well as internal finishing, were not considered yet. However, overhead costs are estimated to be between 5% - 15% of project total direct cost. In addition, there is a general overhead. These are the costs that include the expenses of the head-office, engineers, directors and managers. They vary between 2% - 5% of the contract direct cost. The total cost of a project is defined as the sum of both direct and indirect expenses. Direct and indirect costs of activities are important to prepare the cash flow for a project.

Table 5. 1. Quantity take-off sheet

<b>Job: Hotel "Premium"</b>							
Activity type	Quantity	Unit	Calculations	Labor Cost	Equipment Cost	Material Cost	Total Cost
				direct			
<b>Excavation</b>	50*60*0.8 =2400	m <sup>3</sup>	<p><b>Labor</b> Foreman \$11/hr Operator 2 @ \$4.21/hr Laborers 6 x \$4.00/hr = \$24/hr Crew hourly rate = \$43.42</p> <p>Production rate = 50 m<sup>3</sup>/hr</p> <p><math>\frac{2400\text{m}^3}{50 \text{ m}^3/\text{hr}} * \\$43.42 = \\$2084.16</math></p> <p><b>Equipment</b> dozer <math>\frac{2400\text{m}^3}{50 \text{ m}^3/\text{hr}} * \frac{\\$19.7}{\text{hr}} = \\$945.6</math> backhoe <math>\frac{900\text{m}^3}{50 \text{ m}^3/\text{hr}} * \frac{\\$24.24}{\text{hr}} = \\$436.32</math></p>	\$2084.16	\$1382	\$0	\$3466
<b>Backfill</b>	50*60*0.6 60=1980	m <sup>3</sup>	<p><b>Labor</b> Labor unit cost = \$1.1 per m<sup>3</sup> <math>1980 * \frac{\\$1.1}{\text{m}^3} = \\$2178</math></p> <p><b>Equipment</b> Equipment unit cost = \$1.95 per m<sup>3</sup> <math>\frac{1980 * \\$0.9}{\text{m}^3} = \\$1782</math></p>	\$2178	\$1782	\$0	\$3960

<b>Piledriving rig (mobilize, demobilize)</b>			<b>Labor</b> Foreman \$11/hr Operator 2@\$4.21/hr Oiler 1@\$3.6 Piledriver 2@ \$8 Laborers 2@ \$4.00/hr Truck drivers 2@ \$3.6/hr  Crew hourly rate =\$38.22 <b>Two 8-hour days required:</b> $\$38.22 * 2 * 8 = \$611.52$	\$611.52	\$161.6	\$300	\$1073
			<b>Equipment</b> Crane, 50-ton \$25.7/hr Crane, 25-ton \$20.4/hr Lowboy \$16/hr Truck \$19/hr  <hr/> Equipment hourly rate =\$81.8 $\$81.8*2=161.6$				
			<b>Materials</b> General supplies \$300				
<b>Pile driving</b>	640	m	<b>Labor</b> Foreman \$11/hr Operator 2@\$4.21/hr Oiler 1@\$3.6 Piledriver 2@\$8 Laborers 2@\$4.00/hr Carpenter \$5/hr  Crew hourly rate =\$38.22	\$1165	\$1545	\$2848	\$5558

			Production rate = 21 m/hr $\frac{640}{21 \text{ m/hr}} * \$38.22 = \$1165$				
			<b>Equipment</b> Crane, 50-ton \$25.7/hr 450 cfm compressor \$6/hr Pile hammer & leads \$19/hr  Equipment hourly rate = \$50.7 $\frac{640}{21 \text{ m/hr}} * \$50.7 = \$1545$				
			<b>Materials</b> Concrete piling 640 m * \$3.7/m = <b>\$2368</b> Pile cushions 1 cushion per 8 m of pile $\frac{640}{8} * \$6 = \$480$				
<b>Footing forms (fabricate)</b>	600	M <sup>2</sup>	<b>Labor</b> Labor unit cost = \$1.6 per m <sup>2</sup> \$1.6 * 600 = \$960	\$960		\$390	\$1,350
			<b>Materials</b> <b>2 uses (50% salvage)</b> Plyform: \$0.8/m <sup>2</sup> * 600m * 0.5 = \$240 Lumber \$0.5/m <sup>2</sup> * 600m * 0.5 = \$150				
<b>Footing forms (place)</b>	1200	m <sup>2</sup>	<b>Labor</b> Labor unit cost = \$0.3/ m <sup>2</sup> \$0.3 * 1200 = \$360	\$67750	\$5420	\$6,233,000	\$6,306,170
			<b>Material</b> Nail, coatings, hardware \$0.2/m <sup>2</sup> 1200 * \$0.2 = \$240				

<b>Concrete, footings, place</b>	2400	m <sup>3</sup>	<b>Labor</b> Foreman \$11/hr Mason \$4.5/hr Operator \$4.21/hr Oiler \$3.6 Laborers 4@\$4.00/hr Carpenter \$5/hr <hr/> Crew hourly rate =\$44.31 <b>Production rate = 22 m3/hr</b> $\frac{2400}{22 \text{ m3/hr}} * 44.31 = \mathbf{\$4834}$	\$4834	\$3240	\$145,440	\$153,514
			<b>Equipment</b> Crane, 50-ton \$25.7/hr Vibrators 2@\$1/hr Buckets 2@\$1/hr Pile hammer & leads \$19/hr <hr/> Equipment hourly rate =\$29.7 $\frac{2400}{22 \text{ m3/hr}} * 29.7 = \mathbf{\$3240}$				
			<b>Materials</b> Concrete \$60.6 per m <sup>3</sup> $\$60.6 * 2400 = \mathbf{\$145,440}$				
<b>Steel, reinforcing place</b>	271 tons		<b>Labor</b> $271 * 1000\text{kg} * 0.25/\text{kg} = \mathbf{\$67750}$	\$67,750	\$5420	\$197,830	\$271,000
			<b>Equipment</b> Equipment unit cost = \$0.3/hr $271 * 1000 * 0.02 = \mathbf{\$5420}$				

			<b>Material</b> $\frac{\$730}{ton} * 271ton = \$197,830$				
<b>Exterior Glazing</b>	7776	M <sup>2</sup>	<b>Labor</b> $\frac{\$3}{m^2} * 7776m^2 = \$23328$ <b>Equipment</b> Equipment unit cost = \$0.2/m <sup>2</sup> $7776m^2 * \frac{\$0.2}{m^2} = \$1555.2$ <b>Material</b> $\$340 * 7776m^2 = \$2,643,840$	\$23,328	\$1555	\$2,643,840	2,668,723
<b>Total</b>							<b>\$9,414,814</b>

## 5.2. Economic Analysis of the Project

### 5.2.1. Calculation of revenue

The revenue to the hotel includes hotel rooms rent and income from additional hotel facilities (gym, restaurant, conference hall, and auditorium rent). The Tables 5.2 and 5.3 show revenue generated both from hotel rooms and hotel facilities.

Table 5. 2. Hotel rooms revenue for 100% occupancy.

Room Type	Number of rooms	Cost per night stay, \$	Annual Revenue, \$ (100% occupancy)
Standard	80	295	8614000
1-room			
Superior	60	330	7227000
1-room (extended)			
Suite	10	450	1642500
2-room, 2-bath			
Royal	3	500	547,500
4-room			
Total,\$			18,031,000

All prices were taken similar to 4\* star hotel in Astana (<http://www.diplomahotel.kz/>, 2016).

Table 5. 3. Revenue generated by additional hotel facilities

Facility Name	Cost of rent per day, \$	Annual Revenue, \$
Conference Hall	1500	547,500
Gym	Free	0
Meeting Room	600	219,000
Restaurant	980	357,700
Auditorium	1050	383,250
Total, \$		1,507,450

Hotel occupancy is never 100%, and according to the statistical data, average hotel occupancy can be taken as 45%. Thus, rough annual revenue is \$8,113,950

Hotel facilities are expected to be occupied 90% of the time. Annual revenue is \$1,356,705. Total expected annual revenue from the facility: \$9,470,655

### 5.2.2. Cash flow

Cash flow is simply defined as the difference between the project expenses and incomes. When considering the cash flow, it is important to know the actual time when expenditure happened.

$$\text{Cash flow} = \text{Income} - \text{Expense}$$

Expenses represent the payments, which a contractor makes for all the resources needed. Incomes are money the contractor receives from the owner after the work is accomplished. Forecasting the amount of expenses and incomes and timing them is crucial to ensure that sufficient amount of cash is available, when the maximum amount of cash will be requested by the contractor and serves as an indicator that cash resources are being utilized to the owner’s benefit. The table below shows calculated cash flow for the project duration period. Total cost of a project was derived from calculations in Capstone 1 which amounted to \$35,000,000. This sum was distributed very roughly by months very roughly in the “Estimated cost” row. The contractor makes an invoice at the end of the first month and receives payment at the end of the second month. Retention was taken into account, which was taken as the 10% of the first 50% of contract price or \$1,375,000 and given to the contractor at the end of the period. Overall, the profit of a contractor amounted to \$2,985,502.

Table 5. 4.Calculating Contract Cash Flow

Project Cost	\$35,000,000
Bid Price	\$38,500,000
Retainage	\$1,925,000
Mark up	10%
Project Duration	19 months

Month	1	2	3	4	5	6	7	8	9	10	11
Estimated cost	2000000	1880000	1820000	1820000	1820000	1820000	1820000	1820000	1820000	1820000	1820000
Acc cost	2000000	3880000	5700000	7520000	9340000	11160000	12980000	14800000	16620000	18440000	20260000
Invoice amount	0	2200000	2068000	2002000	2002000	2002000	2002000	2002000	2002000	2002000	2002000
Acc. Invoice	0	2200000	4268000	6270000	8272000	10274000	12276000	14278000	16280000	18282000	20284000
Retention	0	220000	206800	200200	200200	200200	200200	200200	200200	200200	96800
Amount Received	0	0	1980000	1861200	1801800	1801800	1801800	1801800	1801800	1801800	1801800
Cash required	2000000	1880000	-160000	-41200	18200	18200	18200	18200	18200	18200	18200
Acc. Cash required	2000000	3895000	3764213	3751244	3797578	3844260	3891292	3938677	3986417	4034515	4082974
Interest	15000	29213	28232	28134	28482	28832	29185	29540	29898	30259	30622

Month	12	13	14	15	16	17	18	19	20	21	Total
Estimated cost	1820000	1820000	1820000	1820000	1820000	1820000	1820000	2000000			35000000
Acc cost	22080000	23900000	25720000	27540000	29360000	31180000	33000000	35000000	35000000	35000000	
Invoice amount	2002000	2002000	2002000	2002000	2002000	2002000	2002000	2002000	2200000	0	38500000
Acc. Invoice	22286000	24288000	26290000	28292000	30294000	32296000	34298000	36300000	38500000	38500000	

Retention											1925000
Amount											
Received	1905200	2002000	2002000	2002000	2002000	2002000	2002000	2002000	2002000	4125000	38500000
Cash required	-85200	-182000	-182000	-182000	-182000	-182000	-182000	-2000	-2002000	-4125000	
Acc. Cash											profit of a
required	4028396	3876609	3723684	3569611	3414384	3257991	3100426	3121680	1143092	-2973335	contractor
Interest	30213	29075	27928	26772	25608	24435	23253	23413	8573		

Furthermore, S-curve was plotted based on the available data. The blue line represents the contractor's expenses and the orange line shows contractor's income – monthly disbursements, in other words, progress payments from the owner. At any time, the vertical distance between the lines represent the amount by which the contractor's project expense exceeds its receipts.

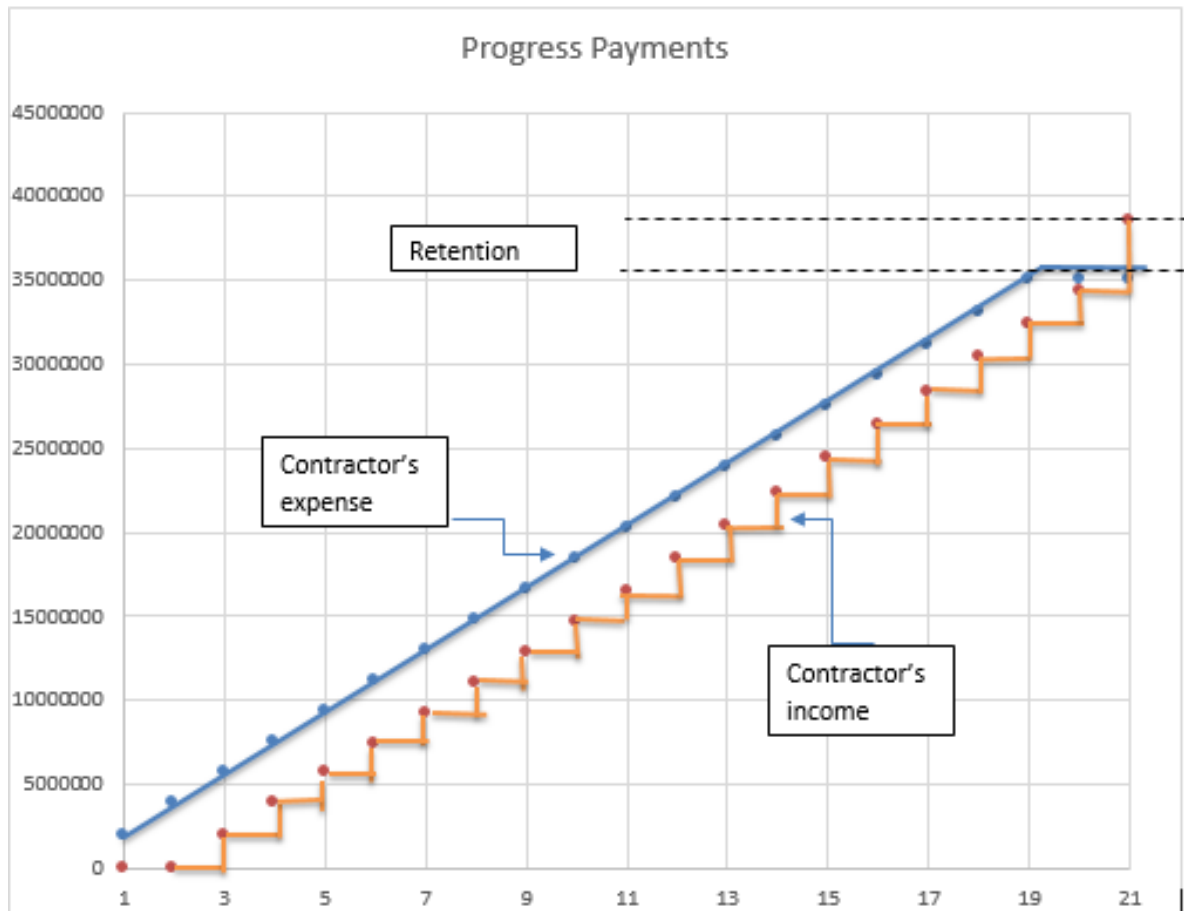


Figure 5. 1. Cash Flow

### 5.2.3. Present Worth method and Internal Rate of Return

NPV and IRR are two common ways of analyzing feasibility of a project. The economic feasibility of our project can be evaluated from either finding the NPV or determining the IRR.

Present Worth method is based on the concept of equivalent worth of all cash flows relative to the present. In other words, all the incomes and expenses are brought to the present point at an interest rate equal to the MARR (Minimum Acceptable Rate of Return). If the  $PW(i=MARR) > 0$ , then the project is acceptable.

$$\begin{aligned}
 PW(i = 20\%) &= -\$38,500,000 + \$9,350,655(P/A, 20\%, 11) \\
 &+ \$30,000,000(P/F, 20\%, 11)
 \end{aligned}$$

$= -\$38,500,000 + 40460846 + 4037640 > 0$ , which implies the project is feasible according to the PW decision rule.

If  $IRR \geq MARR$ , then project is economically feasible. In calculations, MARR was taken as 20%, capital investment is known from cash flow calculations, annual expenses on maintenance and the market value of a hotel after 10 years were assumed to be \$120,000 and \$30,000,000 respectively; annual revenues were calculated before. The table below shows resultant amount of cash accumulated in the end of each year from 1 to 11. (Study period is 11 years). Excel shows the  $IRR = 22\% > 20\%$ , thus the project is economically feasible according to the IRR decision rule.

Table 5. 5. IRR results

<b>MARR</b>	<b>20%</b>
<b>Capital Investment</b>	\$38,500,000
<b>Market Value</b>	\$30,000,000
<b>Annual Revenues</b>	9,470,655
<b>Annual Expenses</b>	\$120,000
<b>Study Period</b>	11 years
<b>EOY</b>	<b>Cash Flow</b>
<b>0</b>	-\$38,500,000
<b>1</b>	\$9,350,655
<b>2</b>	\$9,350,655
<b>3</b>	\$9,350,655
<b>4</b>	\$9,350,655
<b>5</b>	\$9,350,655
<b>6</b>	\$9,350,655
<b>7</b>	\$9,350,655
<b>8</b>	\$9,350,655
<b>9</b>	\$9,350,655
<b>10</b>	\$9,350,655

<b>11</b>	\$19,880,000
<b>IRR</b>	22%

### 5.3.Risk Management

Risk is a combination of likelihood and consequence. In other words, it is a function of probability of a given threat and the subsequent effect of that event on the project, and if that event happens, there will be either a positive or negative effect on the project objectives.

Wrong decisions can result in negative outcomes, such as budget overruns, late finish dates and project delays.

Risk assessment can be qualitative and quantitative. In the qualitative risk analysis, every hazard is characterized by its probability, impact, detection and mitigation. Quantitative method is more costly and time-consuming than qualitative risk assessment and should be carried out only when required.

#### 5.3.1.Failure Mode Failure Mode and Effects Analysis

In this risk assessment, most common hazards on the construction site have been identified in the first column of Table 5.5. The risk assessment is to be conducted using the Failure Mode and Effects Analysis technique, according to the procedure found in the study of Brahemzadih et al (2014). For this, first of all, after hazards have been identified, the severity, occurrence, and detection are assigned to each hazard (S1, O1, D1) based on the guidelines given on Figures A7-1 to A7-3 (Appendix 7). Further, Risk Priority Number (RPN) value has been calculated as follows:

$$RPN = S * O * D \quad \text{(Eq. 5.5)}$$

Where S – severity of a hazard,

O – probability of occurrence,

D – detection.

Risk Priority Number will help to determine acceptable and unacceptable risks.

Next, crisis grade of a threat is determined from the following criteria:

*Level 1:* Normal level, at which severity, probability and detection levels are less than 5.

In this case, no corrective action are needed (RPN<70)

*Level 2:* Semi-critical level at which at least one of three factors of RPN has a value greater than 5. In this case, mitigating action is needed ( $70 < \text{RPN} < 140$ ).

*Level 3:* Critical level at which at least two factors of the three-factor of RPN have high values. It is required to apply a preventive action in this case ( $\text{RPN} > 140$ )

It can be seen from the Table 5.6 that no RPN value is less than 70. Therefore, all hazards need mitigation. After the preventive action has been introduced, severity and probability S(2), O(2), and D(2) are assigned values again, taking into account the mitigation effect (See Table 5.5). Newly calculated RPN values are given in the last column. If crisis grade requirements are not satisfactory, further mitigation is needed.

Table 5. 6. Results of implementing FMEA technique.

Potential Failure Mode	Effect(s) of Failure	S(1)	O(1)	D(1)	RPN (1)	Mitigation	S(2)	O(2)	D(2)	RPN (2)
Fall from height (platform, scaffoldings, roofs)	From injury to death	10	2	6	120	Guardrails should be installed at the edges of roofs, scaffoldings; safety nets, personal fall arrest systems provided.	10	1	6	60
Caught in/between (malfunction of machinery)	From injury to death	8	3	6	162	Use machinery that is properly guarded;	8	1	6	48
Electrocution (contact with power tools/lines)	Range from mild discomfort to burns, neurological effects, death	9	5	4	180	Inspect extension cords regularly for signs of wear and tear, Don't overload cords or sockets.	9	1	4	36

Struck by (falling objects)	From injury to death	10	4	6	240	Wear safety helmets, Use tool lanyards to prevent tools from falling.  Keep all material at least 3 feet from a leading edge,	7	1	6	42
Hand-arm vibration	Can cause hand-arm vibration syndrome, permanent damage.	6	4	6	168	Try to opt for low-vibration tools	2	4	6	48
Inhaling dust, fumes, silica	Respiratory diseases	7	5	6	180	The use of respiratory mask	2	4	5	40
Noise	Hearing damage/losses	7	6	4	168	The use of ear plugs	3	6	3	30
Exposure to hazardous substances (wet	Skin diseases, dermatitis	8	5	6	240	Use protective gloves or coveralls	4	1	6	24

cement and solvents)										
Regular lifting, carrying, handling materials	Musculoskeletal disorders	6	8	6	288	Avoid manual handling operations as far as practicable	6	1	6	36
Asbestos	Death, cancer, lungs damage	10	4	7	280	Use PPE and RPE	8	1	7	56

As it can be seen from the Table of FMEA, after mitigation has been applied to each hazard, RPN values became less than 70. This means, they reached a crisis grade Level 1, and no further corrective action is needed.

In order to improve safety of the construction process and to prevent different accidents, regular safety management procedures are needed. FMEA risk assessment technique is one of the simplest ways of assessing the risks and mitigating them.

#### **5.4. Quality Management**

According to Project Management Body of Knowledge, quality represents the degree to which a list of proper features satisfy requirements. The purpose of quality management is to create a project with appropriate characteristics fulfilling customer expectations. Moreover, to eliminate any possible defects and make an improvement throughout the project construction. There are three main parts of quality management, which are quality planning, assurance and control. In order to succeed in quality management owner of the project must actively participate in its construction since owner has the highest interest in project success.

##### **5.4.1. Quality Planning**

Quality Planning is a process in which determination of organizational quality standards takes place. In this part, the participation of building owner is essential since it is important to determine the most reliable and at the same time allowable standards fulfilling all requirements. From the point of view of building owner it is better to engage independent specialists for this stage. Although it would probably take additional financial expenses, this stage requires specific knowledge and appropriate skills which is not given to all people. Quality Planning is a kind of process which requires to be done at the same time with project management plan, quality measures and acceptance criteria determination. All of this processes should be monitored by building owner. However, it is possible to argue that the most important one for building owner seems to be quality planning due to its significance for future result.

##### **5.4.2. Quality assurance**

Quality assurance represents a list of actions providing appropriate project plan realization and assessment of hotel performance. Quality assurance involves process analysis, quality audits and reviews. Quality audit is a kind of procedure which is used to compare the actual progress with planned one. This procedure might be planned and in

some cases unplanned. All results are reported to authority. Quality Review is another procedure which review all project outcomes comparing it with eligibility criteria. It is also helpful tool for information collection concerning the project. Moreover, this procedure is also useful for poor progress identification.

It is not a secret that most of contractors tries to avoid any misunderstanding with the owner such that in a case of any delay they prefer to create a view that everything goes according to plan. Therefore, it is better for owner to make some unplanned quality audit in order to see the actual progress of the project and what is more important is that this thing should be done by third party which have enough knowledge in construction to make the quality audit properly. Taking into account the size of project and the fact that the project is going to be located in Astana, which have problematic for construction weather, quality audit should be done once a month at least.

#### **5.4.3. Quality control**

Quality control is an approach applied to verify whether the project deliverables satisfy all standards, its capabilities and visitors expectations. There are different kinds of specific tools like control charts, statistical sampling, tests, process map and other similar processes.

Quality control should be done by owner and independent specialists who was engaged in quality planning process. Important moment here is that owner is the only person who actually know how the project should look like, but not always owner has enough knowledge in this specific area; therefore independent specialist might be needed. This process should be done frequently such that in a case of dissimilarity with the requirements, owner might take measures on time.

#### **5.5 Site Safety Management Plan**

Site Safety Management Plan is a significant part of project construction and the responsibility for this falls on contractor. The primary obligation of each contractor is to realize and enforce the safety procedures and policy to each employee; moreover, contractor must follow all those rules as well. Each worker on the site in a case of any hazard should report dangerous conditions and if possible mitigate it. Each contractor must provide appropriate safety measures and specific trainings related to safety management plan in order to decrease the risk of accident occurrence. (Site Specific Environmental, Health and Safety Plan, 2015)

To begin with contractor must construct the fence around the site in order to shield pedestrians; moreover, in places of pedestrian motion special visor must be constructed.

To provide appropriate safety measures General contractor must provide at first special uniform for all employee. Taking into account the fact that any construction site have hazard related to health of workers, it could be stated that uniform is an appropriate tool in decreasing the risk of any injury. The uniform should involve at least protective glasses, helmet, special gloves and in addition employee working on the elevated area should also be equipped with safety belts.

It could be argued that the most widespread hazards for employee and visitors are related to fire and elevated works. (Site Specific Environmental, Health and Safety Plan, 2015) For the elevated works there are some measures which must be provided by General contractor. Some of those measures are safety belts, special fences and hand rails.

There is an Emergency Action Plan which must be implemented in a case of fire or any other accidents required evacuation. In case of fire alarm every human involving employee must evacuate the site, despite the time and reason. Before the beginning of the project the General Contractor must divide all employees on groups such that each group would have own place for accountability. Moreover, there also must be person who would be responsible for visitor accountability. Each group must have a person who would be responsible for accounting of that group. Thus, in a case of fire, those responsible people must identify missing employee or visitors from their groups and immediately report their names to worker of fire department.

Actions required to perform in a case of fire:

1. It is required to close the door to the area of concern after all people would leave the room.
2. It is required to activate alarm in order to start the evacuation of building
3. It is required to phone fire department
4. It is required to evacuate the building and perform the accounting of each group or if a person was properly trained to mitigate the fire.

To sum above mentioned, it could be stated that site safety management requires separate exit for successful emergency; moreover, each floor must be provided by fire alarm switcher, fire protection measures like fire extinguisher, first aid kit and evacuation plan

description. Important thing is related to means of egress as was mentioned above. One should be able to exit the building without any dangerous for health obstacles. All combustible material must be minimized in places of emergency exit. (Site Specific Environmental, Health and Safety Plan, 2015)

The figures below represents location of fire alarm switchers, fire protection measures, first aid kit and evacuation plan description on the first and twelfth (typical) floors. According to CNaR RK, distance between Fire extinguishers or fire hoses should be located at lease 20m from the area of concern. As was mentioned before the size of the first floor of the building is 50x60m while the size of other floors is 30mx30m. Thus, it was decided to locate fire extinguishers on each corner of the first floor and two fire extinguishers on the other floors due to their smaller size. With respect to Evacuation Plan, it should be placed on visible place on each floor. Referring to first aid kit, it should be located on each floor as well. In addition, on each floor emergency phone must be placed.

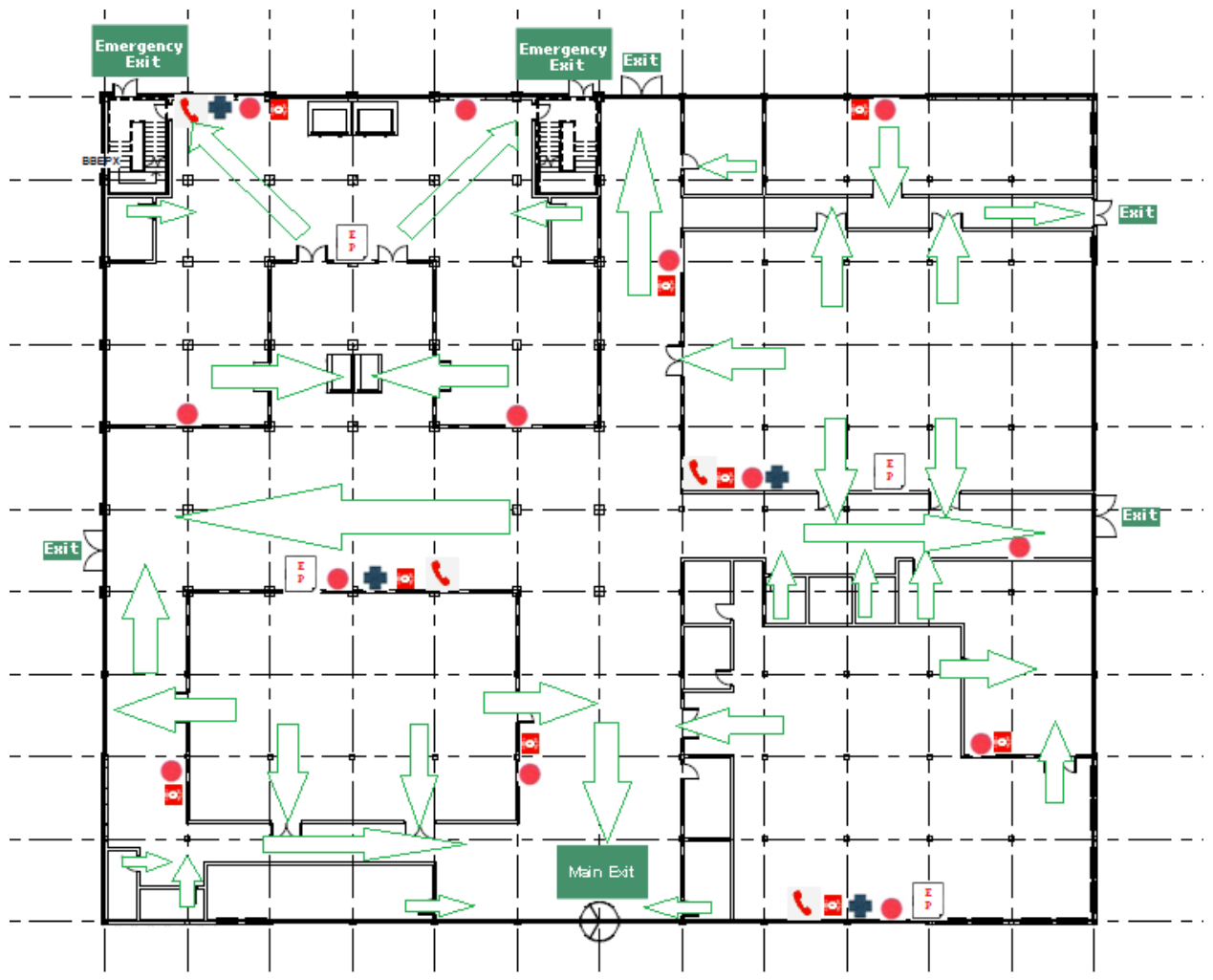


Figure 5. 2. First floor Evacuation Plan

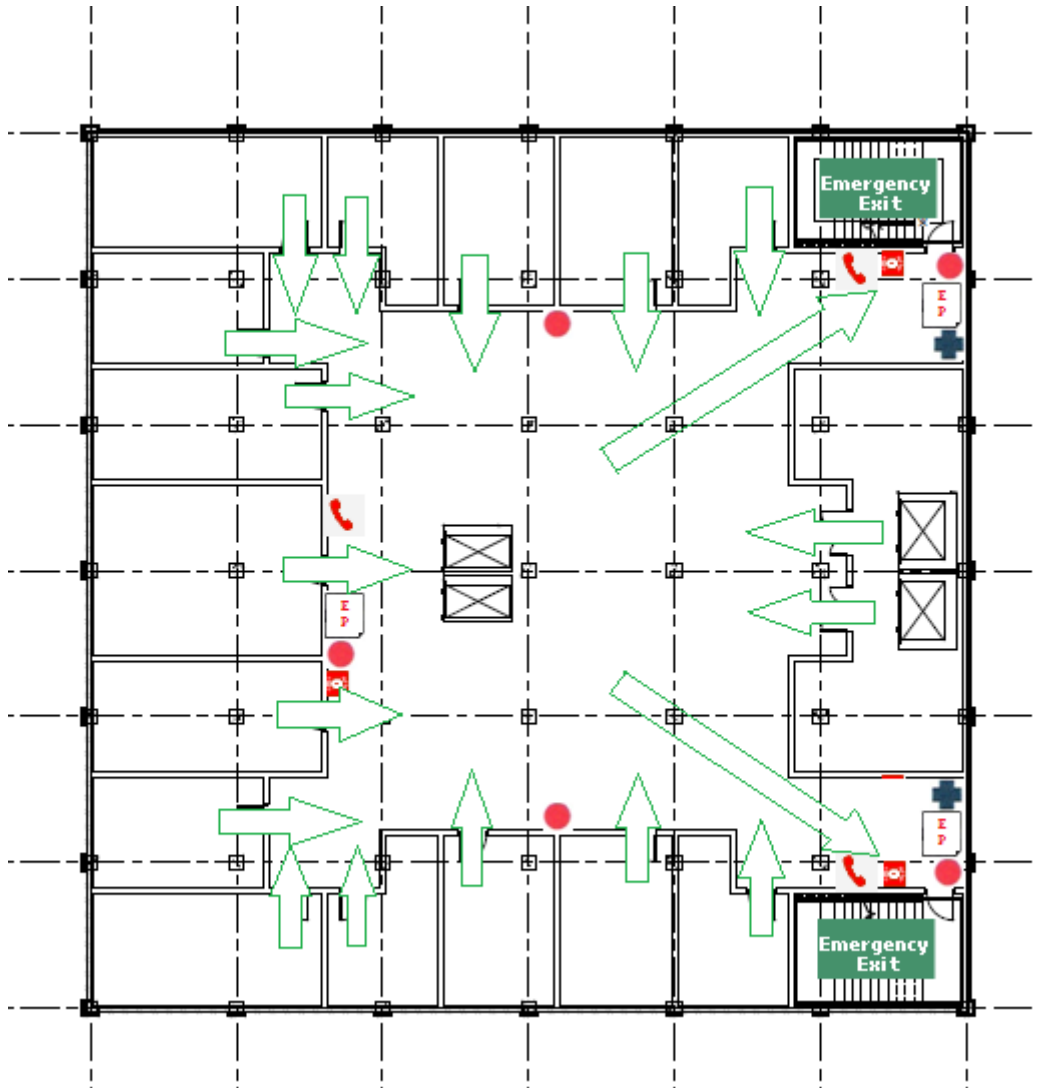


Figure 5. 3. Typical floor Evacuation Plan

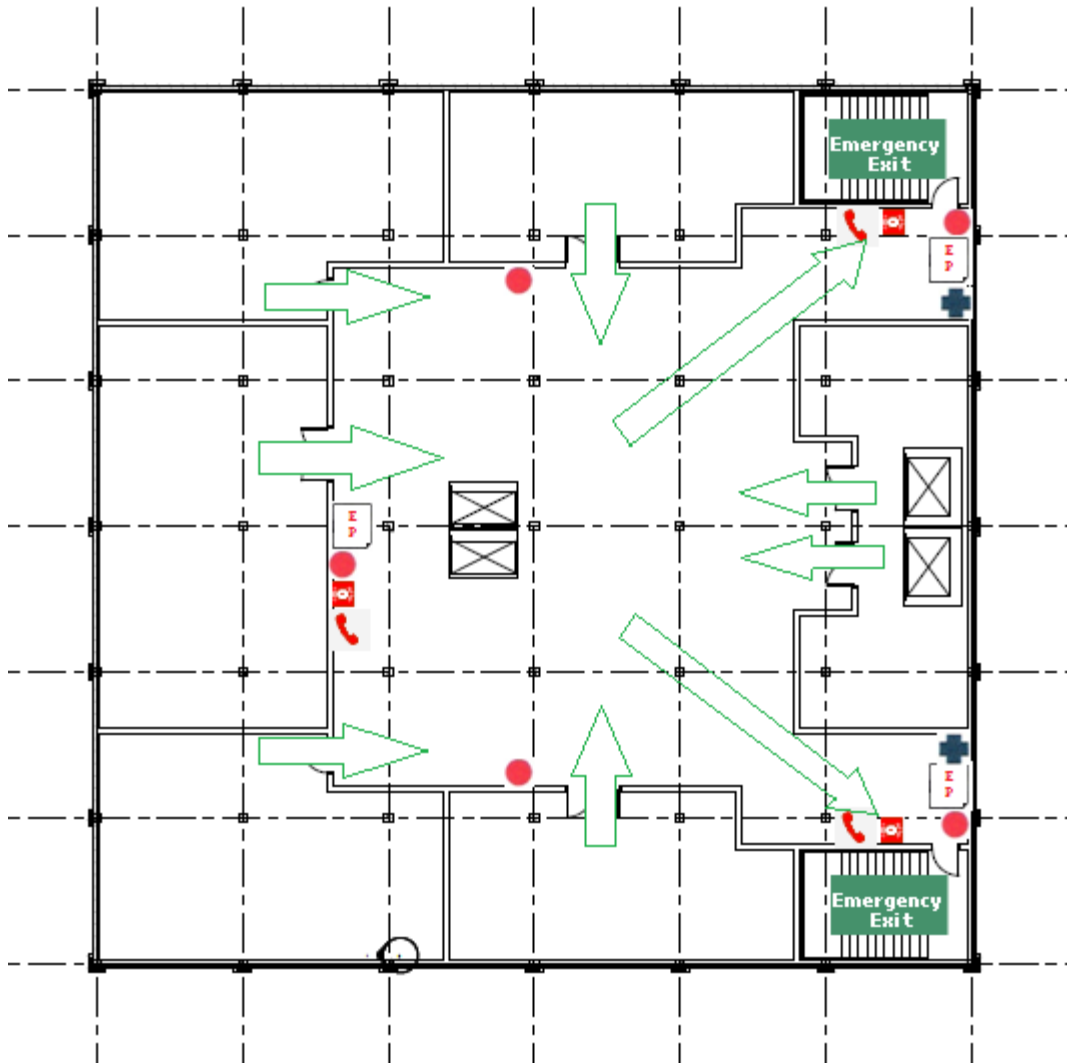







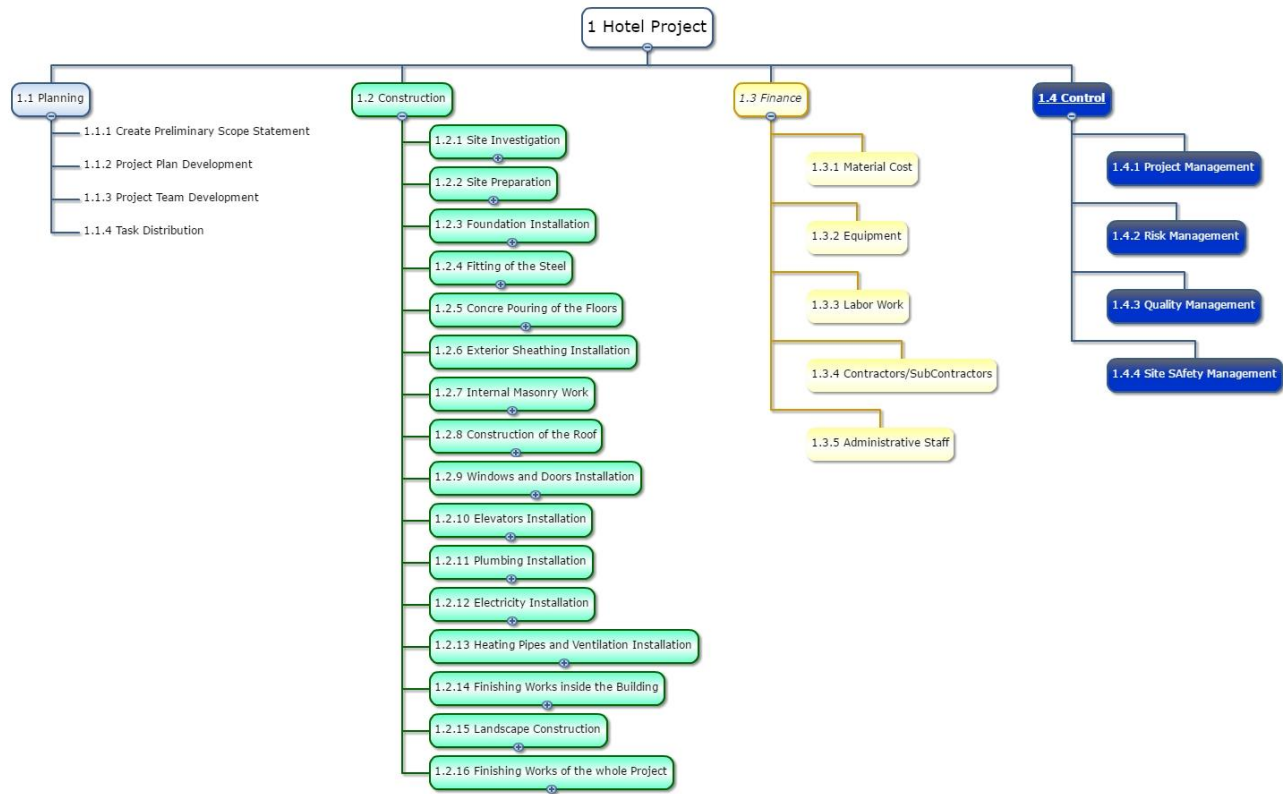
Figure 5. 4. 12<sup>th</sup> floor Evacuation Plan

	- Fire Extinguisher
	- First Aid Kit
	- Evacuation Plan
	- Fire Alarm Pull Station
	-Emergency Phone

## **5.6.Construction Schedule**

### **5.6.1.Work Breakdown Structure**

According to Md Hossain, Scheduling is an essential part of the project planning which helps to avoid undesirable situations like project delay. By the definition, scheduling is a logical sequence of all activities involving in the project. There are four main criteria influencing scheduling: time, source, scope and budget. Likewise scheduling represents the duration of the project fulfilling those requirements. In order to construct an appropriate schedule for the project it is better to construct first Work Breakdown Structure (WBS) in order to ensure that all activities are involved.



www.wbstool.com

Figure 5. 5. Work Breakdown Structure (WBS) for the project

More detailed WBS which shows extension of each part is demonstrated in Appendix 3.

### 5.6.2. Activity on Node Final Approach

Now with the usage of Work Breakdown Structure, it is possible to create the first view of project scheduling. The important thing here is that now it is required to find the golden middle among all requirements such that with the usage of reasonable amount of sources, budget and scope to finish the project on time without any delay.

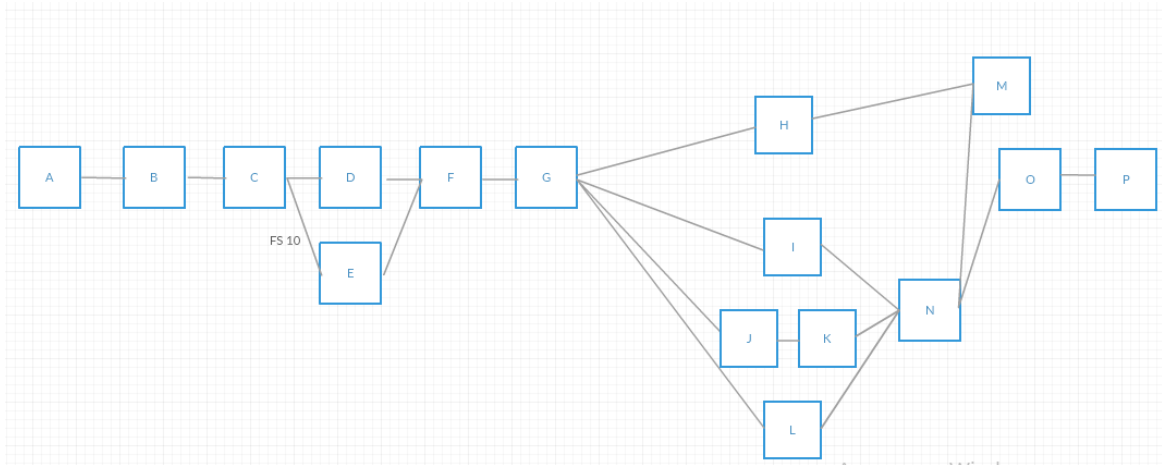


Figure 5. 6. Activity Diagram

- A-Site Investigation
- B-Site Preparation
- C-Foundation Installation
- D- Fitting of the Steel
- E- Concrete Pouring of the Floors
- F-Construction of the Roof
- G-Windows and Doors Installation
- H-Exterior Sheathing Installation
- I-Plumbing Installation
- J-Electricity Installation
- K-Elevator Installation
- L-Heating Pipes and Ventilation Installation
- M-Finishing Works inside the building
- N-Internal Masonry Work
- O-Landscape Construction
- P-Finishing of the Whole Project

According to our research and data taken during the interview with Leading Project Engineer from Highvill company, whose name is Temirhan Yerzhanov, we collected some information related to the duration of activities mentioned above. Thus, we have following data:

Table 5. 7. Durations of activities

<b>Activity</b>	<b>Duration</b>
<b>Site Investigation</b>	Total- 12 days
Surveying	5 days
Soil Analysis	7 days
<b>Site Preparation</b>	Total-22 days
Temporary Power Installation	2 days
Temporary Water Supply Installation	2 days
Temporary Fence Construction	2 days
Temporary PCC Construction	1 day
Site Cleaning and Grub	5 days
Rough Grading of the Site	10 days
Final Grading of the Site	5 days
Temporary Fire Protection System Installation	5 days
<b>Foundation Installation</b>	Total-63 days
Drilling of holes	10 days
Hole preparation	3 days
Driving of pile foundation	30 days
Formation of fence for Cap pouring	2 days
Pouring and Curing of the concrete	18 days
<b>Fitting of the Steel</b>	Total-65 days
Building of Columns and Beams for 1st,2nd,3rd floors	10 days
Building of Columns and Beams for 4th,5th,6th floors	15 days
Building of Columns and Beams for 7th,8th,9th floors	20days

Building of Columns and Beams for 10th,11th,12th floors	20 days
<b>Concrete Pouring of the Floors</b>	Total-188 days
<b>1. 1st,2nd,3rd floor Pouring</b>	Total-35 days
1.1 Formation of the fence for the 1st,2nd and 3rd floors	10 days
1.2 Rebar and utilities installation for the 1st,2nd and 3rd floors	10 days
1.3 Pouring and Curing of the 1st,2nd and 3rd floors	15 days
<b>2. 4th,5th,6th floor Pouring</b>	Total-40 days
2.1 Formation of the fence for the 4th,5th and 6th floors	10 days
2.2 Rebar and utilities installation for the 4th,5th and 6th floors	12 days
2.3 Pouring and Curing of the 4th,5th and 6th floors	18 days
<b>3 7th,8th,9th floor Pouring</b>	Total-45 days
3.1 Formation of the fence for the 7th,8th,9th floors	10 days
3.2 Rebar and utilities installation for the 7th,8th,9th floor	12 days
3.3 Pouring and Curing of the 7th,8th,9th floors	23 days
<b>4.10th,11th,12th floor Pouring</b>	Total-50 days
4.1 Formation of the fence for the 10th,11th,12th floors	10 days
4.2 Rebar and utilities installation for the 10th,11th,12th floors	15 days
4.3 Pouring and Curing of the 10th, 11th, 12th floors	25 days
5. Pouring and Curing of the Roof	18 days
<b>Exterior Sheathing Installation</b>	50 days
<b>Internal Mansonry Work</b>	Total- 60 days
Gesso of the Walls	50 days
Tiling of the restrooms, kitchen	25 days
Painting of the Walls	60 days
Floors and Ceilings Installation	60 days
<b>Construction of the Roof</b>	Total-31 days

Roof Drains Installation	4 days
Pouring and Curing of the roof fill	7 days
Finishing Work of the Roof	20 days
<b>Windows and Doors Installation</b>	30 days
Windows Installation	30 days
Interior Doors Installation	20 days
Main Entrance Installation	10 days
<b>Elevators Installation</b>	Total-30 days
Installation of the elevator equipment inside the pit	25 days
Installation of the elevator doors on each floor	10 days
Elevator Testing and Setting	5 days
<b>Plumbing Installation</b>	Total-65 days
Installation of the pipes and valves including seque and fire hoses	60 days
Plumbing Testing and Setting	5 days
<b>Electricity Installation</b>	Total-50 days
Setting of the wires and installation of transformers	30 days
Installation of sockets and lamps	20 days
Installation of electrical devices like air conditioning	30 days
<b>Heating Pipes and Ventilation Installation</b>	Total-55 days
Installation of the pipes	40 days
Construction of drywall walls covering the pipes	10 days
Setting of ventilation equipment	20 days
Testing and Fitting	5 days
<b>Finishing Works inside the Building</b>	Total-72 days
Finishing of residual trim work	20 days
Rough Cleaning of the Building	7 days
Final Cleaning of the Building	15 days
Furniture Installation	30 days

<b>Landscape Construction</b>	Total-56 days
1. Site Cleaning	5 days
2. Compaction of the Soil around the building	10 days
<b>3. Fence Construction</b>	Total-29 days
3.1 Remove of temporary Fence around the hotel area	1 day
3.2 Excavation of the Soil for Fence Fundament	1 day
3.3 Pouring and Curing of Fence Fundament	7 days
3.4 Construction of the fence from the brick	15 days
3.5 Gate Installation	5 days
4. PCC Installation, Special booth constructed on the factory	1 day
<b>5. Fountain Installation</b>	Total-12 days
5.1 Plumbing Installation	Total-1 day
5.1.1 Excavation of the Soil for Fence Fundament	1 day
5.1.2 Pipes Installation	
5.1.3 Pipes Burying	
5.2 Construction of the fountain structure	Total-11 days
5.2.1 Excavation of the Soil for Fence Fundament	1 day
5.2.2 Formation of fence for fountain walls pouring	1 day
5.2.3 Installation of rebar and pipes	1 day
5.2.4 Pouring and Curing of fountain	7 days
5.2.5 Sheathing of the fountain surface by decorative rock	1 day
5.3 Testing and Setting	1 day
<b>6. Pavers Path Construction</b>	Total-22 days
6.1 Construction of paths borders	Total-10 days
6.1.1 Excavation of Soil	1 day
6.1.2 Formation of fence for borders pouring	2 days
6.1.3 Pouring and Curing of Borders	7 days

6.2 Soil Grading	2 days
6.3 Construction of Pathways from the pavers	10 days
<b>7. Asphalt Covering</b>	<b>Total-12 days</b>
7.1 Soil Compaction, Accurate Grading	7 days
7.2 Pavement Construction	5 days
8. Barriers, Car Signs and Speed Bumps Installation	1 day
9. Drawing of Street Parking	1 day
<b>10. Lamp Posts Installation</b>	<b>Total-12 days</b>
10.1 Lamp Posts Electricity Installation	Total-1 day
10.1.1 Soil Excavation	1 day
10.1.2 Cables Installation	
10.1.3 Cables Burying	
10.2 Lamp Posts Construction	Total-11 days
10.2.1 Soil Excavation	1 day
10.2.2 Piers Installation	1 day
10.2.3 Pouring and Curing of Lamps Posts Fundament	7 days
10.2.4 Lamps Post fitting	2 days
<b>Finishing Works of the whole Project</b>	<b>Total-5 days</b>
Remove of Temporary Power Supply, Water Supply and PCC Construction	2 days
Outside Area Cleaning	5 days

Important to mention here is that Total durations of main activities were calculated in account of the fact that their sub-activities overlaps each other.

Figure 5. 7. AON diagram data

Activitiy	Duration	ES (Early Start)	EF (Early Finish)	LS (Late Start)	LF (Late Finish)	TF (Total Float)
A-Site Investigation	12 days	0	12	0	12	0

B-Site Preparation	22 days	12	34	12	34	0
C-Foundation Installation	63 days	34	97	34	97	0
D- Fitting of the Steel	65 days	97	162	230	295	133
E- Concrete Pouring of the Floors	188 days	107	295	107	295	0
F-Construction of the Roof	31 days	295	326	295	326	0
G-Windows and Doors Installation	30 days	326	356	326	356	0
H-Exterior Sheathing Installation	50 days	356	406	446	496	90
I-Plumbing Installation	65 days	356	421	371	436	15
J-Electricity Installation	50 days	356	406	356	406	0
K-Elevator Installation	30 days	406	436	406	436	0
L-Heating Pipes and Ventilation Installation	55 days	356	411	381	436	25
M-Finishing Works inside the building	72 days	496	568	496	568	0
N-Internal Masonry Work	60 days	436	496	436	496	0
O-Landscape Construction	56 days	496	552	507	563	11
P-Finishing of the Whole Project	5 day	552	557	563	568	11

Now with the proper data, we can find critical path of the project and calculate its duration. Thus, Critical Path of the Project is **A, B, C, E, F, G, J, K, N, M** and the duration of the project is **568** days.

### 5.6.3.Final Gantt Chart

With the usage of final AON diagram, now it is possible to construct following Gantt Chart of the project (Appendix 7).

The Table below represents ES and EF of each activity, sub-activity and work Packages.

Table 5. 8. ES and EF of all activities, sub-activities and work packages

<b>Activity</b>	<b>Duration</b>	<b>ES</b>	<b>EF</b>
<b>Site Investigation</b>	Total- 12 days	05/01/17	05/12/17
Surveying	5 days	05/01/17	05/05/17
Soil Analysis	7 days	05/06/17	05/12/17
<b>Site Preparation</b>	Total-22 days	05/13/17	06/01/17
Temporary Power Installation	2 days	05/13/17	05/14/17
Temporary Water Supply Installation	2 days	05/13/17	05/14/17
Temporary Fence Construction	2 days	05/13/17	05/14/17
Temporary PCC Construction	1 day	05/13/17	05/13/17
Site Cleaning and Grub	5 days	05/15/17	05/19/17
Rough Grading of the Site	10 days	05/18/17	05/27/17
Final Grading of the Site	5 days	05/28/17	06/01/17
Temporary Fire Protection System Installation	5 days	05/28/17	06/01/17
<b>Foundation Installation</b>	Total-63 days	06/02/17	08/03/17
Drilling of holes	10 days	06/02/17	06/11/17
Hole preparation	3 days	06/12/17	06/14/17
Driving of pile foundation	30 days	06/15/17	07/14/17
Formation of fence for Cap pouring	2 days	07/15/17	07/16/17
Pouring and Curing of the concrete	18 days	07/17/17	08/03/17
<b>Fitting of the Steel</b>	Total-65 days	08/04/17	10/07/17
Building of Columns and Beams for 1st,2nd,3rd floors	10 days	08/04/17	08/13/17
Building of Columns and Beams for 4th,5th,6th floors	15 days	08/14/17	08/28/17
Building of Columns and Beams for 7th,8th,9th floors	20days	08/29/17	09/18/17
Building of Columns and Beams for 10th,11th,12th floors	20 days	09/19/17	10/07/17
<b>Concrete Pouring of the Floors</b>	Total-188 days	08/14/17	02/17/18
1. 1st,2nd,3rd floor Pouring	Total-35 days	08/14/17	09/17/17

1.1 Formation of the fence for the 1st,2nd and 3rd floors	10 days	08/14/17	08/23/17
1.2 Rebar and utilities installation for the 1st,2nd and 3rd floors	10 days	08/24/17	09/02/17
1.3 Pouring and Curing of the 1st,2nd and 3rd floors	15 days	09/03/17	09/17/17
<b>2. 4th,5th,6th floor Pouring</b>	<b>Total-40 days</b>	09/18/17	10/27/17
2.1 Formation of the fence for the 4th,5th and 6th floors	10 days	09/18/17	09/27/17
2.2 Rebar and utilities installation for the 4th,5th and 6th floors	12 days	09/28/17	10/9/17
2.3 Pouring and Curing of the 4th,5th and 6th floors	18 days	10/10/17	10/27/17
<b>3 7th,8th,9th floor Pouring</b>	<b>Total-45 days</b>	10/28/17	12/11/17
3.1 Formation of the fence for the 7th,8th,9th floors	10 days	10/28/17	11/06/17
3.2 Rebar and utilities installation for the 7th,8th,9th floor	12 days	11/07/17	11/18/17
3.3 Pouring and Curing of the 7th,8th,9th floors	23 days	11/19/17	12/11/17
<b>4.10th,11th,12th floor Pouring</b>	<b>Total-50 days</b>	12/12/17	01/30/18
4.1 Formation of the fence for the 10th,11th,12th floors	10 days	12/12/17	12/21/17
4.2 Rebar and utilities installation for the 10th,11th,12th floors	15 days	12/22/17	01/05/18
4.3 Pouring and Curing of the 10th, 11th, 12th floors	25 days	01/06/18	01/30/18
5. Pouring and Curing of the Roof	18 days	01/31/18	02/17/18
<b>Exterior Sheathing Installation</b>	50 days	04/20/18	06/08/18
<b>Internal Masonry Work</b>	Total- 60 days	07/09/18	09/06/18
Gesso of the Walls	50 days	07/09/18	08/27/18
Tiling of the restrooms, kitchen	25 days	07/09/18	08/02/18
Painting of the Walls	60 days	07/09/18	09/06/18

Floors and Ceilings Installation	60 days	07/09/18	09/06/18
<b>Construction of the Roof</b>	Total-31 days	02/18/18	03/20/18
Roof Drains Installation	4 days	02/18/18	02/21/18
Pouring and Curing of the roof fill	7 days	02/22/18	02/28/18
Finishing Work of the Roof	20 days	03/01/18	03/20/18
<b>Windows and Doors Installation</b>	30 days	03/21/18	04/19/18
Windows Installation	30 days	03/21/18	04/19/18
Interior Doors Installation	20 days	03/31/18	04/19/18
Main Entrance Installation	10 days	03/21/18	03/30/18
<b>Elevators Installation</b>	Total-30 days	06/09/18	07/08/18
Installation of the elevator equipment inside the pit	25 days	06/09/18	07/03/18
Installation of the elevator doors on each floor	10 days	06/24/18	07/03/18
Elevator Testing and Setting	5 days	07/04/18	07/08/18
<b>Plumbing Installation</b>	Total-65 days	04/20/18	06/23/18
Installation of the pipes and valves including seqge and fire hoses	60 days	04/20/18	06/18/18
Plumbing Testing and Setting	5 days	06/19/18	06/23/18
<b>Electricity Installation</b>	Total-50 days	04/20/18	06/08/18
Setting of the wires and installation of transformers	30 days	04/20/18	05/19/18
Installation of sockets and lamps	20 days	05/20/18	06/08/18
Installation of electrical devices like air conditioning	30 days	05/10/18	06/08/18
<b>Heating Pipes and Ventilation Installation</b>	Total-55 days	04/20/18	06/13/18
Installation of the pipes	40 days	04/20/18	05/29/18
Construction of drywall walls covering the pipes	10 days	05/30/18	06/08/18
Setting of ventilation equipment	20 days	05/20/18	06/08/18
Testing and Fitting	5 days	06/09/18	06/13/18
<b>Finishing Works inside the Building</b>	Total-72 days	09/06/18	11/16/18
Finishing of residual trim work	20 days	09/06/18	09/25/18
Rough Cleaning of the Building	7 days	09/26/18	10/02/18

Final Cleaning of the Building	15 days	10/03/18	10/17/18
Furniture Installation	30 days	10/18/18	11/16/18
<b>Landscape Construction</b>	<b>Total-56 days</b>	<b>09/06/18</b>	<b>10/31/18</b>
1. Site Cleaning	5 days	09/06/18	09/10/18
2. Compaction of the Soil around the building	10 days	09/10/18	09/19/18
<b>3. Fence Construction</b>	<b>Total-29 days</b>	<b>09/10/18</b>	<b>10/08/18</b>
3.1 Remove of temporary Fence around the hotel area	1 day	09/10/18	09/10/18
3.2 Excavation of the Soil for Fence Fundament	1 day	09/11/18	09/11/18
3.3 Pouring and Curing of Fence Fundament	7 days	09/12/18	09/18/18
3.4 Construction of the fence from the brick	15 days	09/19/18	10/03/18
3.5 Gate Installation	5 days	10/04/18	10/08/18
4. PCC Installation, Special booth constructed on the factory	1 day	10/08/18	10/08/18
<b>5. Fountain Installation</b>	<b>Total-12 days</b>	<b>10/08/18</b>	<b>10/19/18</b>
5.1 Plumbing Installation	Total-1 day	10/08/18	10/08/18
5.1.1 Excavation of the Soil for Fence Fundament	1 day		
5.1.2 Pipes Installation			
5.1.3 Pipes Burying			
5.2 Construction of the fountain structure	Total-11 days	10/09/18	10/19/18
5.2.1 Excavation of the Soil for Fence Fundament	1 day		
5.2.2 Formation of fence for fountain walls pouring	1 day		
5.2.3 Installation of rebar and pipes	1 day		
5.2.4 Pouring and Curing of fountain	7 days		
5.2.5 Sheathing of the fountain surface by decorative rock	1 day		
5.3 Testing and Setting	1 day	10/19/18	10/19/18
<b>6. Pavers Path Construction</b>	<b>Total-22 days</b>	<b>10/08/18</b>	<b>10/29/18</b>
6.1 Construction of paths borders	Total-10days	10/08/18	10/17/18

6.1.1 Excavation of Soil	1 day		
6.1.2 Formation of fence for borders pouring	2 days		
6.1.3 Pouring and Curing of Borders	7 days		
6.2 Soil Grading	2 days	10/18/18	10/19/18
6.3 Construction of Pathways from the pavers	10 days	10/20/18	10/29/18
<b>7. Asphalt Covering</b>	<b>Total-12 days</b>	10/19/18	10/30/18
7.1 Soil Compaction, Accurate Grading	7 days	10/19/18	10/25/18
7.2 Pavement Construction	5 days	10/26/18	10/30/18
8. Barriers, Car Signs and Speed Bumps Installation	1 day	10/31/18	10/31/18
9. Drawing of Street Parking	1 day	10/31/18	10/31/18
<b>10. Lamp Posts Installation</b>	<b>Total-12 days</b>	10/08/18	10/19/18
10.1 Lamp Posts Electricity Installation	Total-1 day	10/08/18	10/08/18
10.1.1 Soil Excavation			
10.1.2 Cables Installation	1 day		
10.1.3 Cables Burying			
10.2 Lamp Posts Construction	Total-11 days	10/09/18	10/19/18
10.2.1 Soil Excavation	1 day		
10.2.2 Piers Installation	1 day		
10.2.3 Pouring and Curing of Lamps Posts Fundament	7 days		
10.2.4 Lamps Post fitting	2 days		
<b>Finishing Works of the whole Project</b>	<b>Total-5 days</b>	<b>11/01/18</b>	<b>11/05/18</b>
Remove of Temporary Power Supply, Water Supply and PCC Construction	2 days	11/01/18	11/02/18
Outside Area Cleaning	5 days	11/01/18	11/05/18

**This table and the Gantt Chart assumes that the start of project is 05.01.2018 (1<sup>st</sup> of May).**

## **5. LANDSCAPE DESIGN**

Landscape is an essential part of this project. Thus, it was decided to design it in most appropriate way such that to make the landscape as much convenient, for visitors, as

possible following all requirements and snips. To begin with, the whole area of the hotel might be divided in three main parts: main building, rest zone and the part involving infrastructure inside and outside the hotel zone.

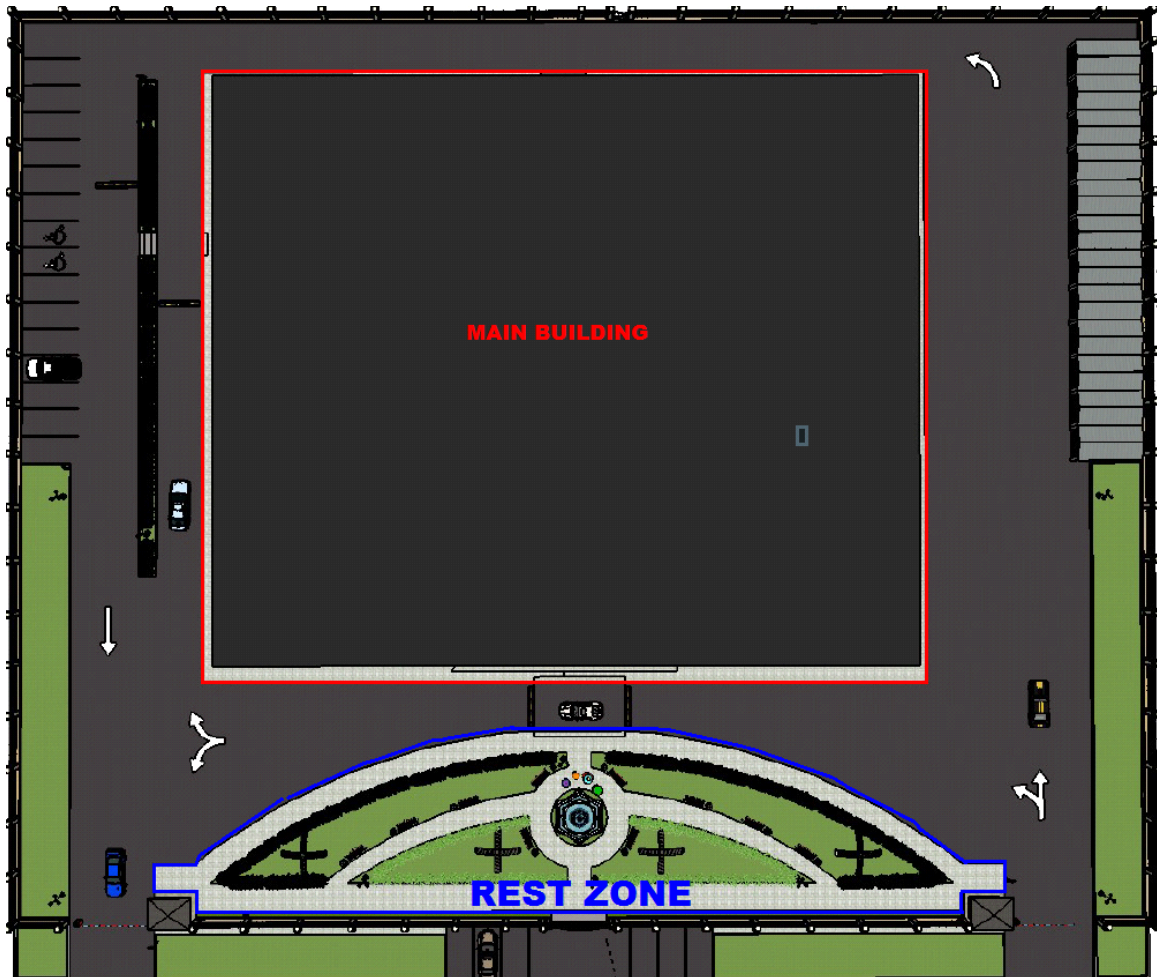


Figure 6. 1. Landscape. Top view

Starting from the general information, there would be fence around the hotel area in order to increase the security of visitors and create a sense of private. The whole territory is going to be lit due to lamp posts placed through the whole area. With the usage of appropriate snip the space between them should be from 35m to 50m. Thus, it was decided to locate them with the space length of 35m; however, in some places which requires more light, as rest zone, this length is shortened.

Referring to outside infrastructure, as was mentioned before the location of the hotel would be near the highway road on the "Orynbor" street, thus the main entrance to the hotel would be located near the road. There would be two PCC for visitors arrived on personal transport and gate for pedestrians. Referring to the PCC, they are divided on

entrance and exit one in order to simplify movement of cars as shown on the figures below:

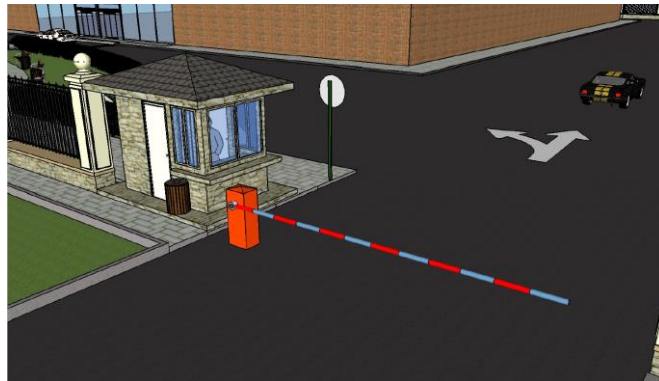


Figure 6. 2. PCC Car Entrance

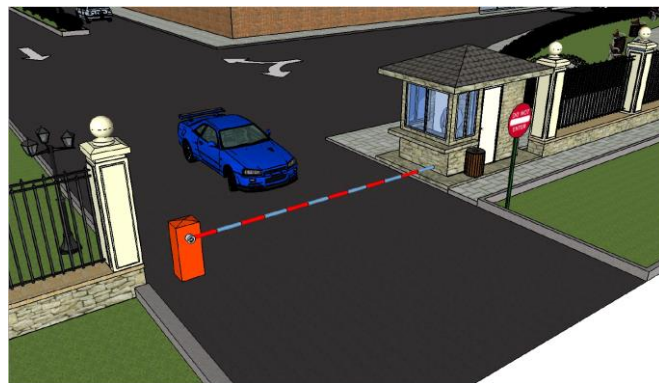


Figure 6. 3. PCC Car Exit



Figure 6. 4. Pedestrian Gate

According to the Figure 6.4, it is also might be seen that there would be outside parking in front of entrance/exit gate.

With respect to the infrastructure inside the hotel area, it was decided to use asphalt concrete for construction of roads. As it is shown the road is covered around the main building, creating convenient way for car movement from the PCC entrance to main entrance of the building or to the PCC exit going through both covered parking and street parking. Moreover, the road would also go through the staff entrance of the building in a case of delivery works. In order to avoid any misunderstanding there would be car signs showing the road direction through all area. It is important to mention that the hotel itself is going to be premium class and its visitors would likely to be from other cities or countries. This means that most of visitors would likely to be without own transport. Moreover, taking into account that car renting is not developed in Kazakhstan there is no need in big parking area. Nevertheless, it was decided to design both street and covered guest parking in order to avoid undesirable situations. However, the size of both parking is not big. As a result, there are 16 slots of 5mx2.3m and 12 boxes of 6mx3m for street and covered parking respectively. Finally, there would be speed bumps installed in areas of increased amount of pedestrians in order to minimize the risk of traffic accidents.



Figure 6. 5. Street Parking

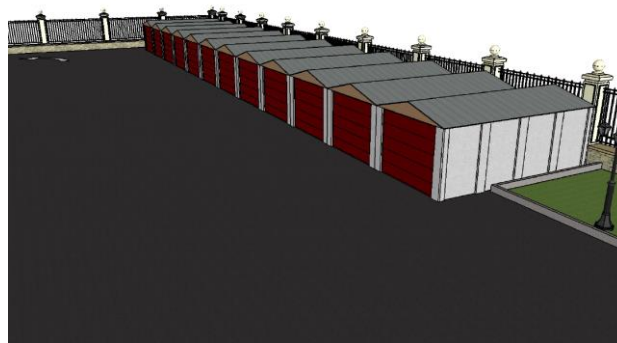


Figure 6. 6. Covered Parking

Next, referring to the rest zone, there would be kind of green area similar to park. This piece of hotel represents 2.5m radius and 1.4m in height hexagonal fountain located in the middle of the park, pathways around the green zone and installed benches. The pathways would be constructed from pavers. Moreover, this place would involve different kinds of flowers and plants in order to make it as much comfortable as possible. This piece of the project is going to lie between pedestrian entrance in the hotel area and main entrance of the building such that visitors might see all beauty of the hotel from the first steps.



Figure 6. 7. Rest Zone



Figure 6. 8. Rest Zone



Figure 6. 9. Rest Zone

Last, is the main building. It is not a secret that for landscape design it is essential to consider all entrances/exits of main building, but what is more important here is to definitely know their purposes. The Hotel is going to have two entrances/exits which have different purposes in the project. The first one is main entrance/exit of the building located in front of the construction. As it might be expected its purpose is to be used by visitors and guests; therefore most of facilities like green zone located in front of it. The second one is staff entrance/exit which is located in backside of the building. It is not acceptable for premium class hotel if staff would use the same entrance/exit with visitors; therefore, it is important to have an additional one. Moreover, in a case of delivery of foodstuffs or anything else it would be much more comfortable for staff to use backside entrance/exit due to its location which is near to destination place (staff room).



Figure 6. 10. Main Entrance/Exit

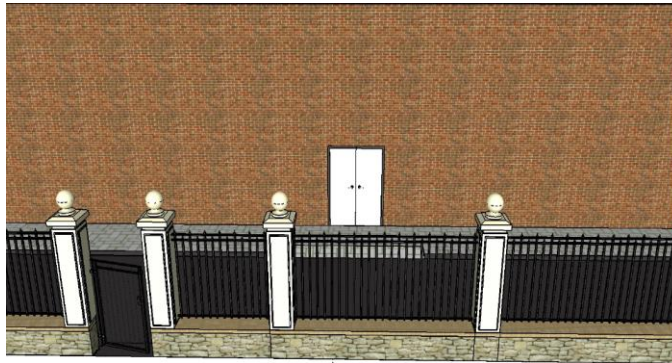


Figure 6. 11. Backside Entrance/Exit

In addition, there is pedestrian pathway constructed from pavers and lying around the whole building.

## 6. CONCLUSION AND RECOMMENDATIONS

To sum up, this report introduced the preliminary design of 12-story complex building with architectural, structural, geotechnical, project management analyses. Various literatures like articles, standards and handbooks were reviewed. Structural analysis part included structural loads calculations, analysis of 2D frames by SAP2000 software, as well as hand calculations. Beams, columns and slab details were calculated and drawn further. For the geotechnical design, allowed bearing capacities were calculated and based on the data obtained from SAP2000, optimal sizes of piles were found. Furthermore, pile cap design, and settlement calculations were performed. By means of the detailed quantity take-off analysis estimations of total project cost were determined. Economic analysis of the project included calculations of annual revenue and expenses. Contractor's cash flow was computed and the overall feasibility of the project were checked by NPV and IRR methods. Moreover, risk management, occupational safety and quality management review were performed in detail to meet all the specifications and client requirements.

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# APPENDICES

## Appendix 1

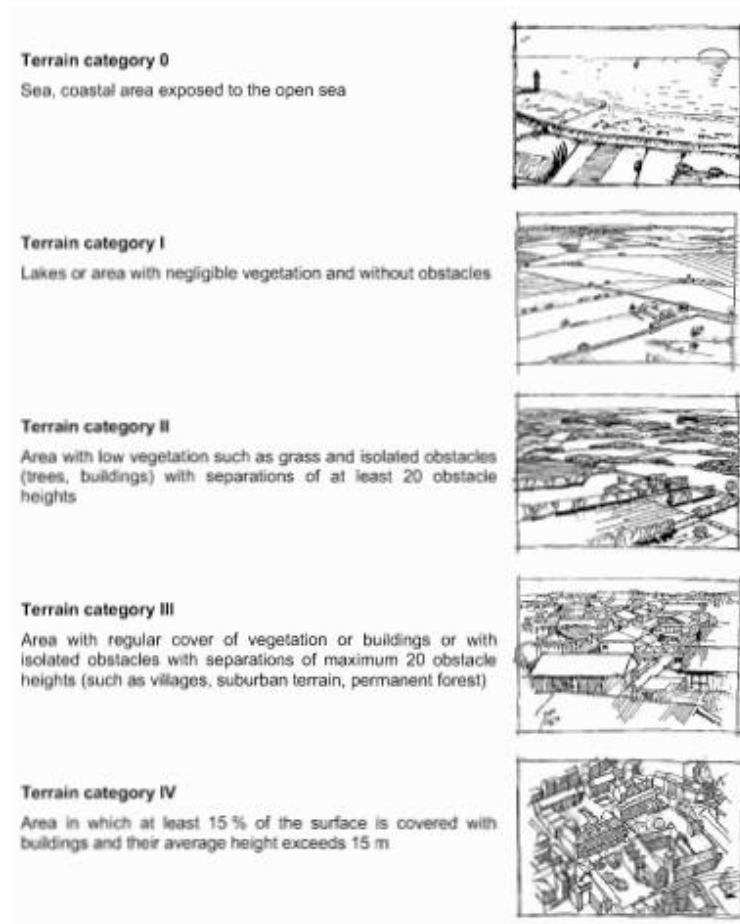


Figure A1. 1. Illustrations of terrain categories

Terrain category		$z_0$ m	$z_{min}$ m
0	Sea or coastal area exposed to the open sea	0,003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0,05	2
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0,3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1,0	10
NOTE: The terrain categories are illustrated in A. 1.			

Figure A1. 2. Parameters of terrain categories

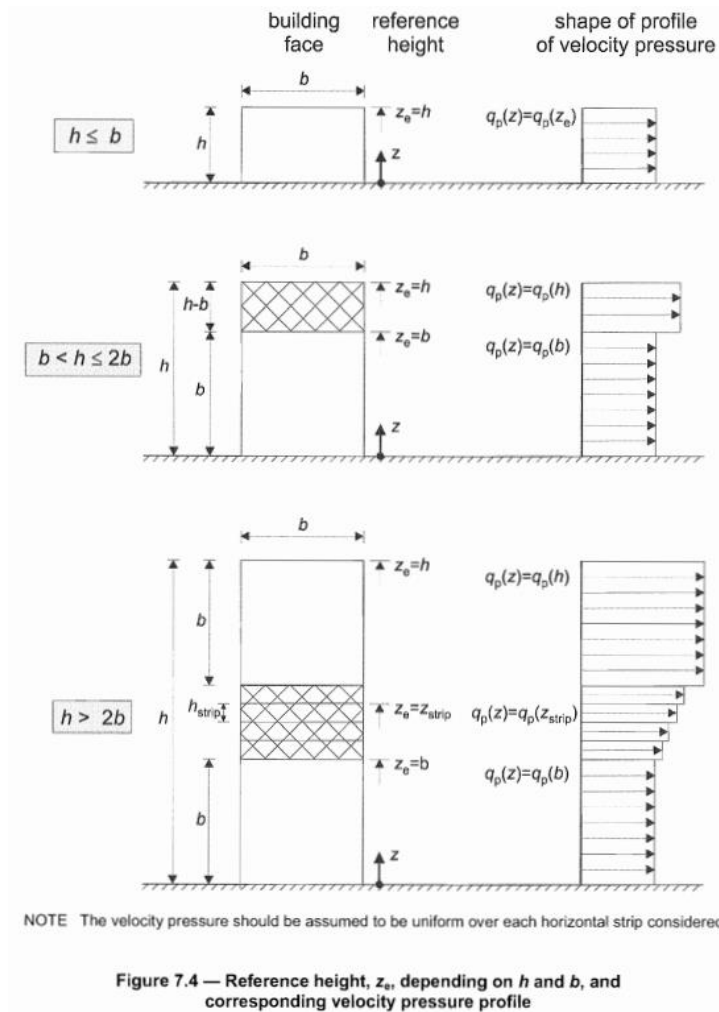


Figure A1. 3. Width-height effect on distribution of wind load

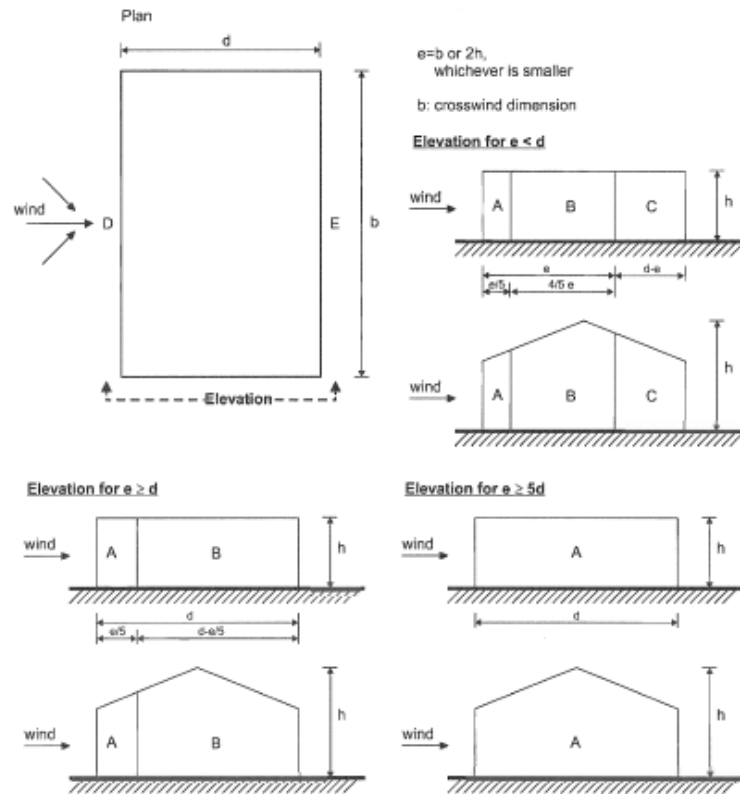


Figure A1. 4. Plan for vertical walls

Topography	$C_e$
Windswept <sup>a</sup>	0,8
Normal <sup>b</sup>	1,0
Sheltered <sup>c</sup>	1,2

<sup>a</sup> *Windswept topography*: flat unobstructed areas exposed on all sides without, or little shelter afforded by terrain, higher construction works or trees.

<sup>b</sup> *Normal topography*: areas where there is no significant removal of snow by wind on construction work, because of terrain, other construction works or trees.

<sup>c</sup> *Sheltered topography*: areas in which the construction work being considered is considerably lower than the surrounding terrain or surrounded by high trees and/or surrounded by higher construction works.

Figure A1. 5. Exposure coefficient for different topographies

Angle of pitch of roof $\alpha$	$0^\circ \leq \alpha \leq 30^\circ$	$30^\circ < \alpha < 60^\circ$	$\alpha \geq 60^\circ$
$\mu_1$	0,8	$0,8(60 - \alpha)/30$	0,0
$\mu_2$	$0,8 + 0,8 \alpha/30$	1,6	--

Figure A1. 6. Snow load shape coefficients

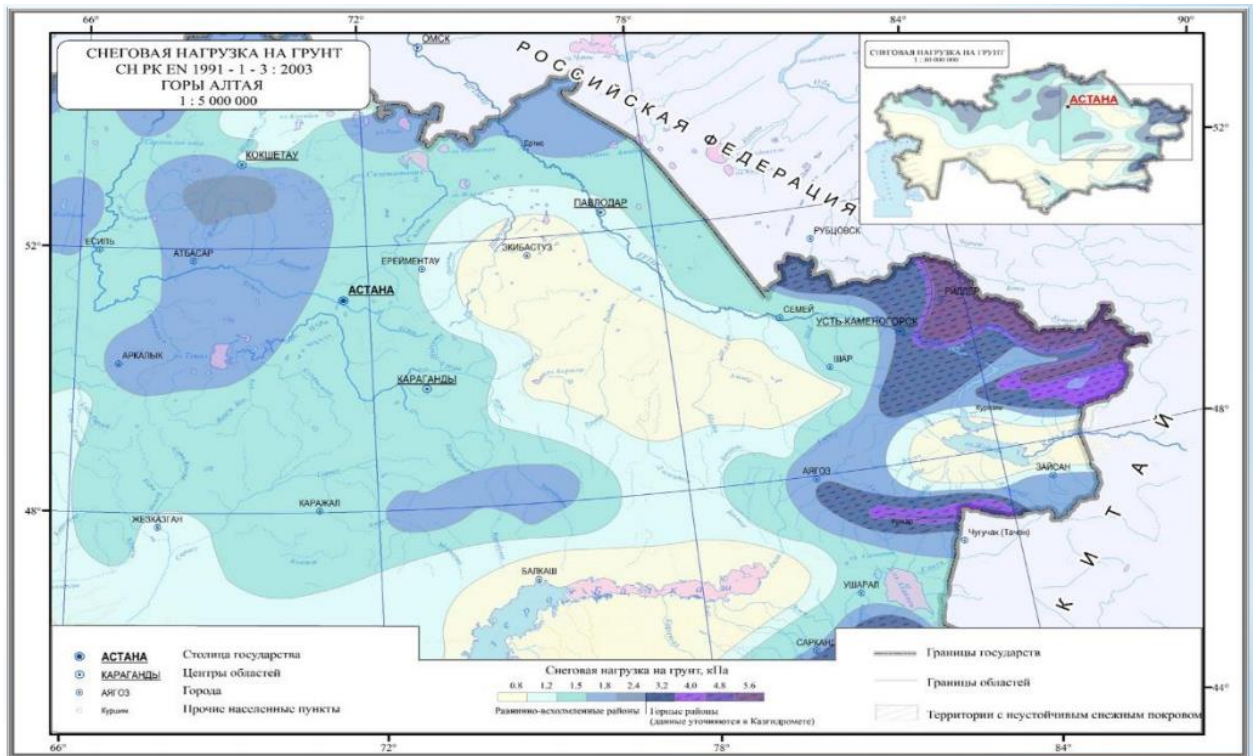


Figure A1. 7. Characteristic snow load on the ground

Appendix 2

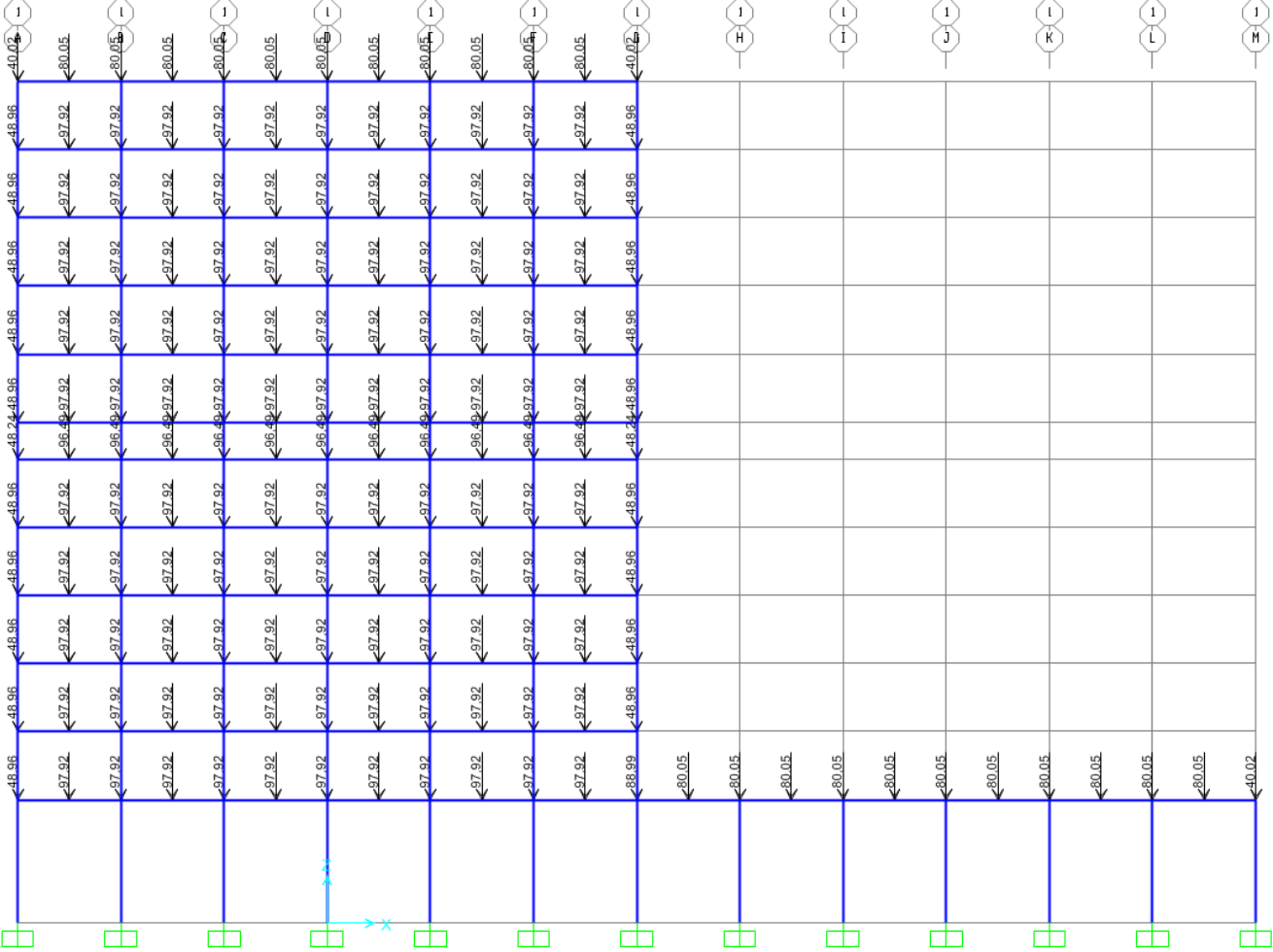


Figure A2. 1. Dead Load Assignments in x-direction

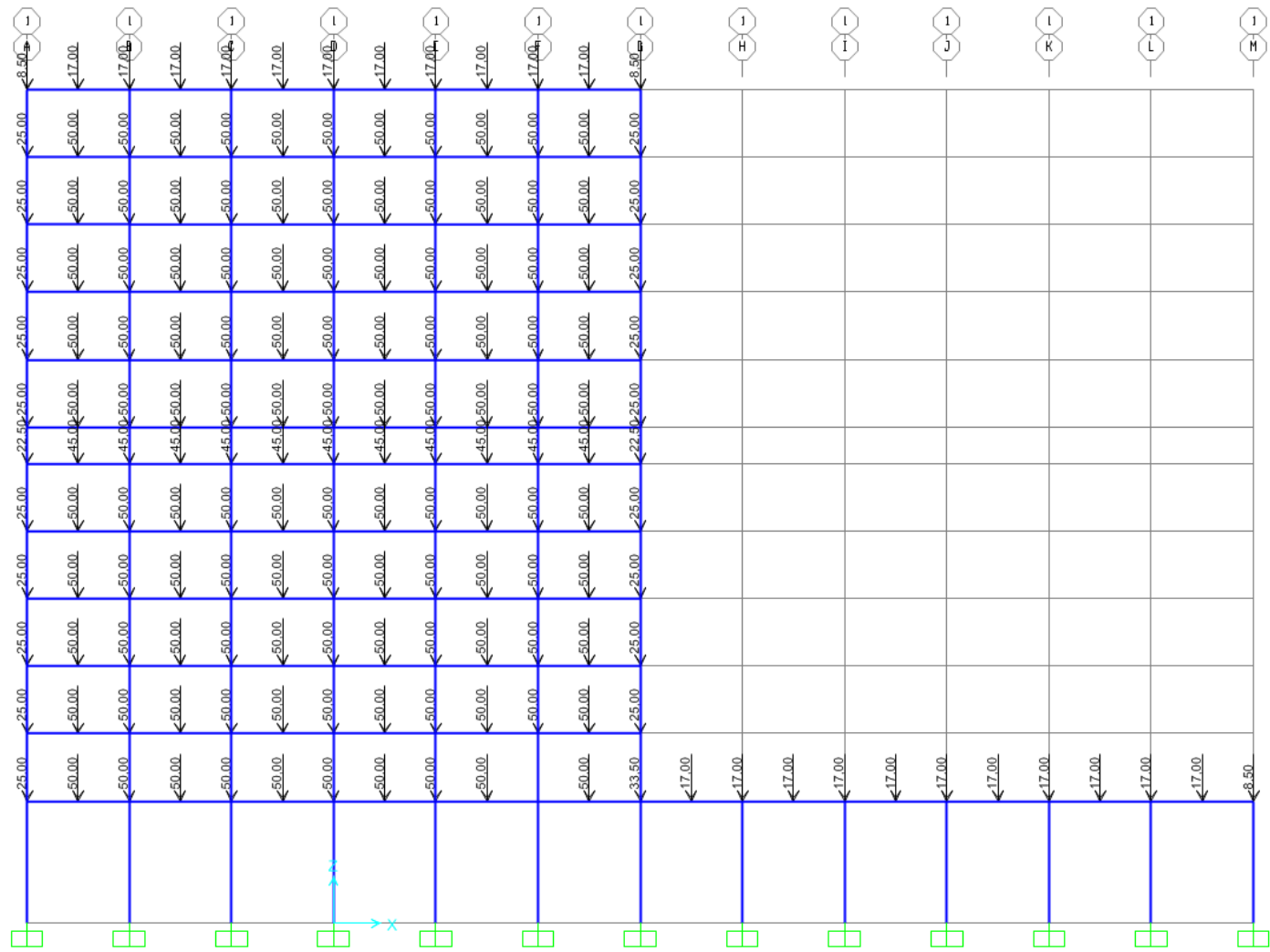


Figure A2. 2. Live Load Assignments in x-direction

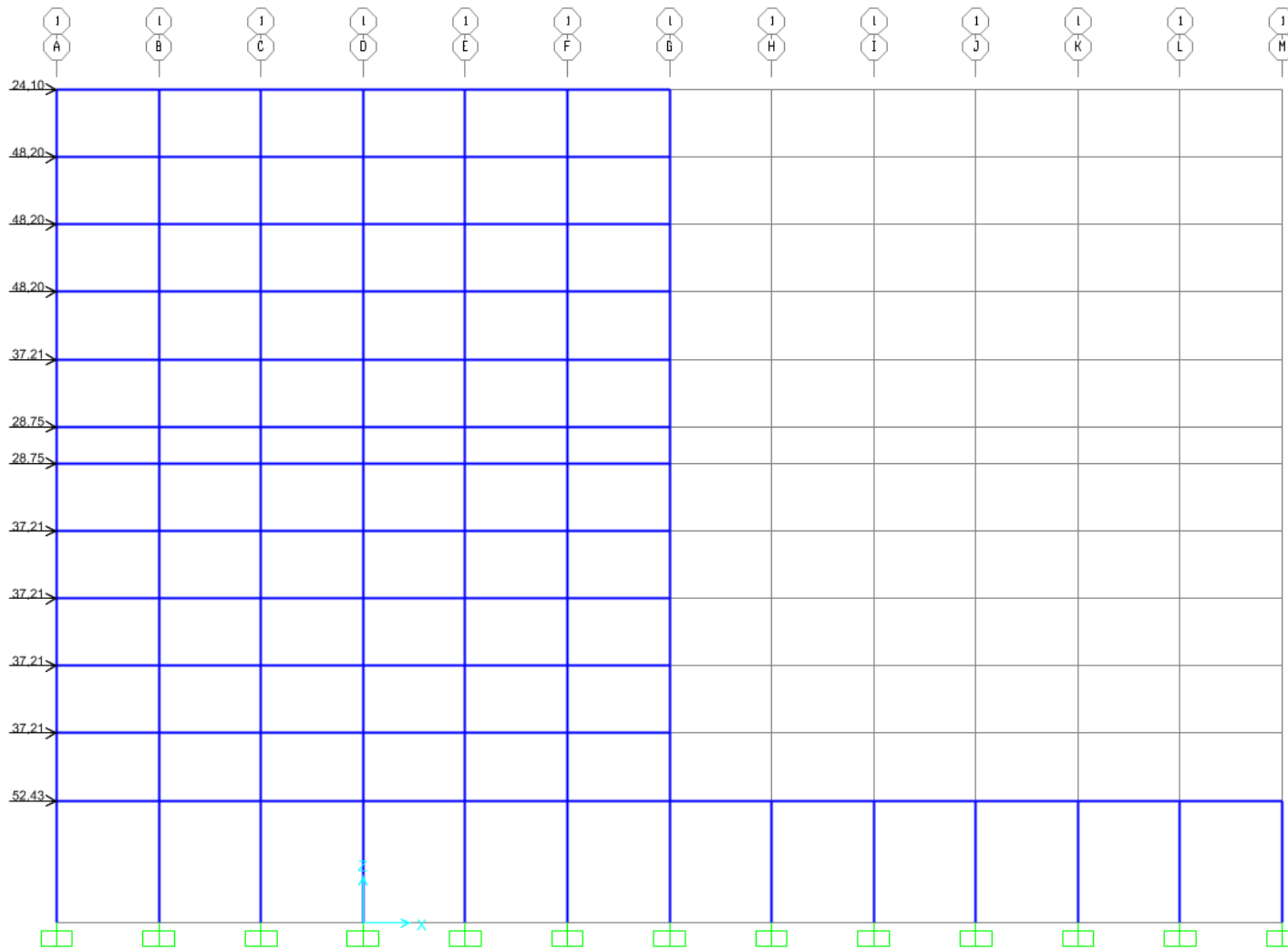


Figure A2. 3. Wind Load Assignments in x-direction

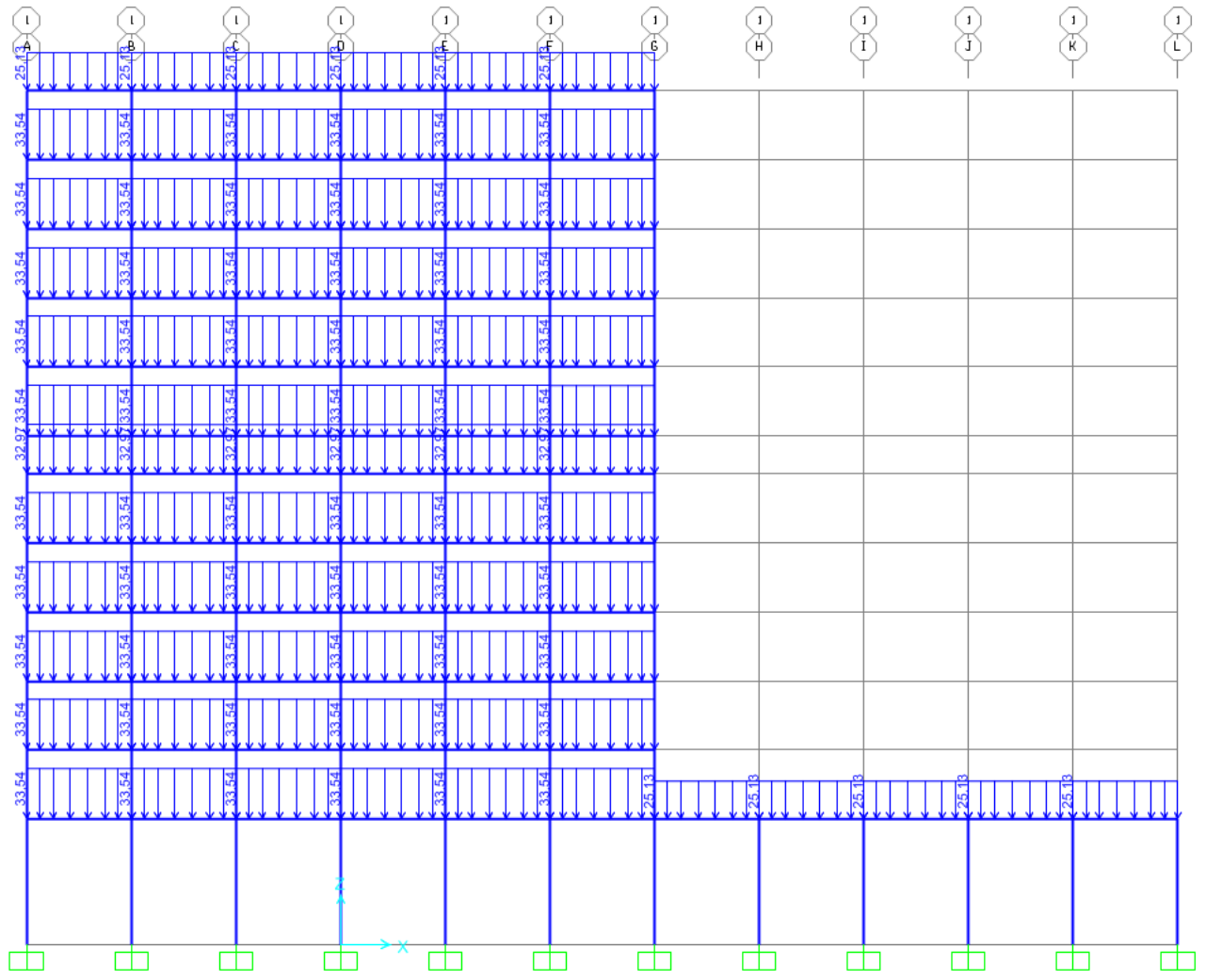


Figure A2. 4. Dead Load Assignments in y-direction

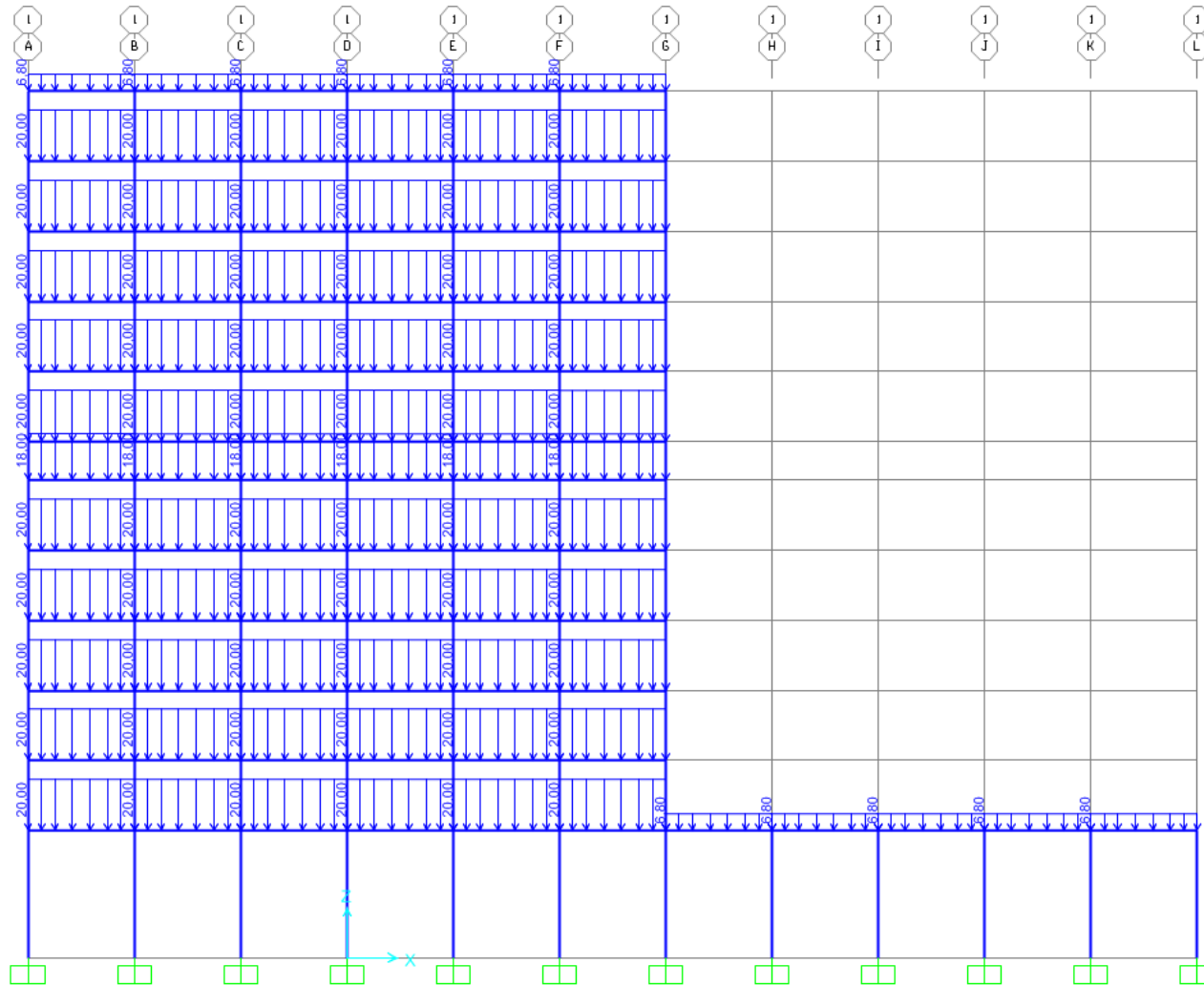


Figure A2. 5.Live Load Assignments in y-direction

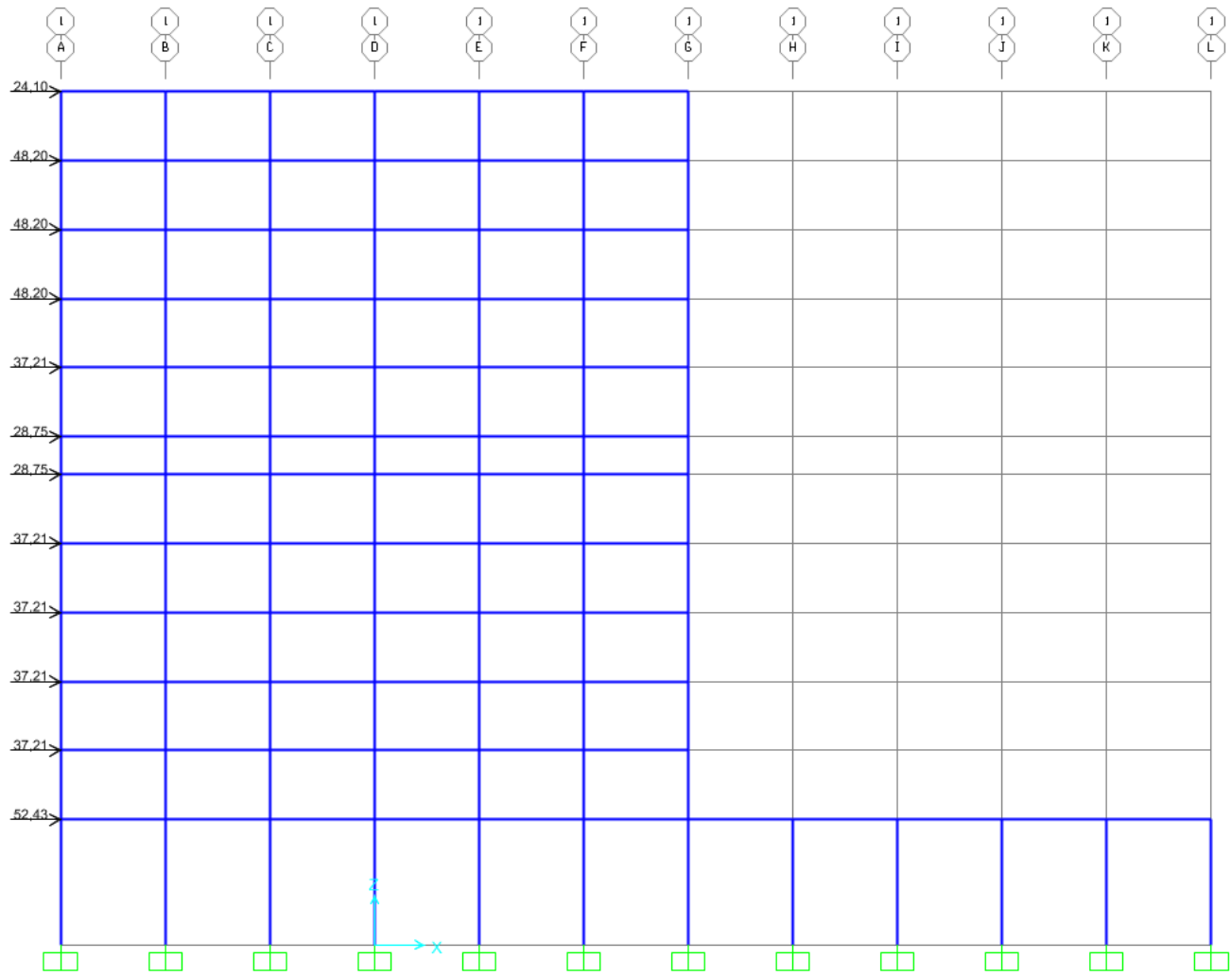


Figure A2. 6.Wind Load Assignments in y-direction

### Appendix 3

Table A3. 1. Comparison of SAP2000 and Portal Method results for structural analysis under wind load

Frame Number	Location	Axial Force (SAP2000)	Axial Force (hand)	Error	Shear Force (SAP2000)	Shear Force (hand)	Error	Moment (SAP2000)	Moment (hand)	Error
	m	kN	kN	%	kN	kN	%	kN-m	kN-m	%
1	0	-22,915	-22,092	3,593	0,486	1,326	172,737	2,703	3,314	22,595
1	5	-22,915	-22,092	3,593	0,486	1,326	172,737	0,271	-3,314	1321,884
2	0	-19,331	-18,075	6,497	2,245	1,326	40,958	6,626	3,314	49,987
2	5	-19,331	-18,075	6,497	2,245	1,326	40,958	-4,600	-3,314	27,964
3	0	-14,681	-14,058	4,242	1,528	1,326	13,253	3,629	3,314	8,682
3	5	-14,681	-14,058	4,242	1,528	1,326	13,253	-4,011	-3,314	17,375
4	0	-10,116	-10,042	0,734	1,549	1,326	14,429	4,043	3,314	18,033
4	5	-10,116	-10,042	0,734	1,549	1,326	14,429	-3,701	-3,314	10,466
5	5	-5,354	-6,025	12,533	2,283	1,326	41,940	-6,701	-3,314	50,548
6	0	-1,505	-2,083	38,425	0,664	1,326	99,623	0,091	3,314	3529,518
6	5	-1,505	-2,083	38,425	0,664	1,326	99,623	-3,227	-3,314	2,704
7	0	-42,256	-44,183	4,561	4,735	5,302	11,975	14,264	13,255	7,076
7	5	-42,256	-44,183	4,561	4,735	5,302	11,975	-9,410	-13,255	40,855

8	0	-34,538	-36,150	4,667	5,839	5,302	9,197	15,257	13,255	13,120
8	5	-34,538	-36,150	4,667	5,839	5,302	9,197	-13,940	-13,255	4,912
9	0	-27,358	-28,117	2,773	5,383	5,302	1,505	13,375	13,255	0,896
9	5	-27,358	-28,117	2,773	5,383	5,302	1,505	-13,540	-13,255	2,104
10	0	-20,140	-20,083	0,282	5,401	5,302	1,833	13,567	13,255	2,302
10	5	-20,140	-20,083	0,282	5,401	5,302	1,833	-13,437	-13,255	1,352
11	0	-13,079	-12,050	7,868	5,879	5,302	9,815	14,048	13,255	5,647
11	5	-13,079	-12,050	7,868	5,879	5,302	9,815	-15,345	-13,255	13,619
12	0	-5,610	-4,017	28,402	4,903	5,302	8,138	9,772	13,255	35,647
12	5	-5,610	-4,017	28,402	4,903	5,302	8,138	-14,746	-13,255	10,109
13	0	-41,995	-44,183	5,211	11,345	10,604	6,532	33,088	26,510	19,879
13	5	-41,995	-44,183	5,211	11,345	10,604	6,532	-23,638	-26,510	12,150
14	0	-34,745	-36,150	4,044	10,259	10,604	3,363	25,887	26,510	2,406
14	5	-34,745	-36,150	4,044	10,259	10,604	3,363	-25,406	-26,510	4,347
15	0	-27,697	-28,117	1,515	10,149	10,604	4,483	25,374	26,510	4,479
15	5	-27,697	-28,117	1,515	10,149	10,604	4,483	-25,371	-26,510	4,488
16	0	-20,599	-20,083	2,504	10,148	10,604	4,493	25,369	26,510	4,499
16	5	-20,599	-20,083	2,504	10,148	10,604	4,493	-25,374	-26,510	4,479
17	0	-13,541	-12,050	11,011	10,250	10,604	3,454	25,402	26,510	4,361
17	5	-13,541	-12,050	11,011	10,250	10,604	3,454	-25,849	-26,510	2,558

18	0	-6,278	-4,017	36,020	11,383	10,604	6,844	23,743	26,510	11,656
18	5	-6,278	-4,017	36,020	11,383	10,604	6,844	-33,173	-26,510	20,085
19	0	-47,651	-44,183	7,277	16,583	15,906	4,082	45,614	39,765	12,824
19	5	-47,651	-44,183	7,277	16,583	15,906	4,082	-37,302	-39,765	6,604
20	0	-38,295	-36,150	5,601	16,018	15,906	0,699	40,324	39,765	1,386
20	5	-38,295	-36,150	5,601	16,018	15,906	0,699	-39,767	-39,765	0,006
21	0	-28,594	-28,117	1,669	15,831	15,906	0,474	39,575	39,765	0,480
21	5	-28,594	-28,117	1,669	15,831	15,906	0,474	-39,580	-39,765	0,467
22	0	-19,026	-20,083	5,557	15,812	15,906	0,594	39,547	39,765	0,552
22	5	-19,026	-20,083	5,557	15,812	15,906	0,594	-39,512	-39,765	0,642
23	0	-9,445	-12,050	27,581	15,958	15,906	0,326	39,643	39,765	0,309
23	5	-9,445	-12,050	27,581	15,958	15,906	0,326	-40,145	-39,765	0,948
24	0	-0,313	-1,017	224,815	16,519	15,906	3,711	37,191	39,765	6,921
24	5	-0,313	-1,017	224,815	16,519	15,906	3,711	-45,405	-39,765	12,421
25	0	-30,367	-34,109	12,323	20,248	20,604	1,756	54,349	51,509	5,226
25	5	-30,367	-34,109	12,323	20,248	20,604	1,756	-46,892	-51,509	9,846
26	0	-25,933	-27,908	7,614	20,119	20,604	2,408	50,512	51,509	1,975
26	5	-25,933	-27,908	7,614	20,119	20,604	2,408	-50,083	-51,509	2,846
27	0	-21,135	-21,706	2,701	19,975	20,604	3,147	49,946	51,509	3,130
27	5	-21,135	-21,706	2,701	19,975	20,604	3,147	-49,931	-51,509	3,160

28	0	-16,221	-15,504	4,419	19,944	20,604	3,307	49,879	51,509	3,268
28	5	-16,221	-15,504	4,419	19,944	20,604	3,307	-49,843	-51,509	3,342
29	0	-11,393	-9,303	18,349	20,025	20,604	2,889	49,883	51,509	3,260
29	5	-11,393	-9,303	18,349	20,025	20,604	2,889	-50,244	-51,509	2,517
30	0	-6,901	-3,101	55,067	20,126	20,604	2,373	46,654	51,509	10,406
30	5	-6,901	-3,101	55,067	20,126	20,604	2,373	-53,973	-51,509	4,566
31	0	-37,864	-26,357	30,391	18,605	18,365	1,290	49,094	45,912	6,481
31	5	-37,864	-26,357	30,391	18,605	18,365	1,290	-43,930	-45,912	4,512
32	0	-28,718	-21,565	24,908	19,450	18,365	5,579	48,950	45,912	6,206
32	5	-28,718	-21,565	24,908	19,450	18,365	5,579	-48,299	-45,912	4,942
33	0	-19,173	-16,773	12,520	19,157	18,365	4,135	47,898	45,912	4,145
33	5	-19,173	-16,773	12,520	19,157	18,365	4,135	-47,887	-45,912	4,123
34	0	-10,098	-11,980	18,641	19,144	18,365	4,069	47,865	45,912	4,079
34	5	-10,098	-11,980	18,641	19,144	18,365	4,069	-47,856	-45,912	4,062
35	0	-0,482	-1,188	146,525	19,408	18,365	5,374	48,213	45,912	4,771
35	5	-0,482	-1,188	146,525	19,408	18,365	5,374	-48,826	-45,912	5,966
36	0	8,903	2,396	73,087	18,606	18,365	1,296	43,958	45,912	4,447
36	5	8,903	2,396	73,087	18,606	18,365	1,296	-49,071	-45,912	6,437
37	0	-12,493	-16,357	30,929	21,849	21,528	1,470	57,773	53,819	6,844
37	5	-12,493	-16,357	30,929	21,849	21,528	1,470	-51,469	-53,819	4,566

38	0	-13,101	-15,565	18,806	21,979	21,528	2,053	55,163	53,819	2,435
38	5	-13,101	-15,565	18,806	21,979	21,528	2,053	-54,731	-53,819	1,666
39	0	-14,317	-16,773	17,152	21,806	21,528	1,276	54,516	53,819	1,277
39	5	-14,317	-16,773	17,152	21,806	21,528	1,276	-54,517	-53,819	1,279
40	0	-14,902	-11,980	19,605	21,819	21,528	1,335	54,536	53,819	1,313
40	5	-14,902	-11,980	19,605	21,819	21,528	1,335	-54,557	-53,819	1,352
41	0	-16,007	-7,188	55,093	22,004	21,528	2,164	54,797	53,819	1,784
41	5	-16,007	-7,188	55,093	22,004	21,528	2,164	-55,223	-53,819	2,542
42	0	-16,480	-2,396	85,461	22,001	21,528	2,151	51,822	53,819	3,854
42	5	-16,480	-2,396	85,461	22,001	21,528	2,151	-58,181	-53,819	7,496
43	0	-41,718	-34,109	18,239	31,489	31,022	1,482	82,425	77,556	5,908
43	5	-41,718	-34,109	18,239	31,489	31,022	1,482	-75,020	-77,556	3,381
44	0	-32,100	-27,908	13,061	30,749	31,022	0,889	76,918	77,556	0,829
44	5	-32,100	-27,908	13,061	30,749	31,022	0,889	-76,828	-77,556	0,947
45	0	-22,828	-21,706	4,916	30,751	31,022	0,882	76,874	77,556	0,888
45	5	-22,828	-21,706	4,916	30,751	31,022	0,882	-76,881	-77,556	0,878
46	0	-13,797	-15,504	12,374	30,762	31,022	0,846	76,899	77,556	0,854
46	5	-13,797	-15,504	12,374	30,762	31,022	0,846	-76,913	-77,556	0,836
47	0	-4,632	-9,303	100,831	30,777	31,022	0,797	76,894	77,556	0,861
47	5	-4,632	-9,303	100,831	30,777	31,022	0,797	-76,991	-77,556	0,734

48	0	4,850	-3,101	163,935	31,639	31,022	1,949	75,382	77,556	2,883
48	5	4,850	-3,101	163,935	31,639	31,022	1,949	-82,812	-77,556	6,347
49	0	-30,895	-34,109	10,404	35,192	35,115	0,218	90,610	87,789	3,114
49	5	-30,895	-34,109	10,404	35,192	35,115	0,218	-85,353	-87,789	2,854
50	0	-25,953	-27,908	7,531	35,244	35,115	0,365	88,236	87,789	0,507
50	5	-25,953	-27,908	7,531	35,244	35,115	0,365	-87,983	-87,789	0,221
51	0	-20,970	-21,706	3,509	35,127	35,115	0,033	87,820	87,789	0,035
51	5	-20,970	-21,706	3,509	35,127	35,115	0,033	-87,817	-87,789	0,032
52	0	-15,945	-15,504	2,765	35,121	35,115	0,016	87,806	87,789	0,019
52	5	-15,945	-15,504	2,765	35,121	35,115	0,016	-87,798	-87,789	0,011
53	0	-11,081	-9,303	16,050	35,199	35,115	0,237	87,897	87,789	0,123
53	5	-11,081	-9,303	16,050	35,199	35,115	0,237	-88,099	-87,789	0,353
54	0	-6,592	-3,101	52,961	35,257	35,115	0,402	85,488	87,789	2,691
54	5	-6,592	-3,101	52,961	35,257	35,115	0,402	-90,795	-87,789	3,311
55	0	-33,255	-34,109	2,569	39,872	39,209	1,664	102,934	98,021	4,773
55	5	-33,255	-34,109	2,569	39,872	39,209	1,664	-96,425	-98,021	1,655
56	0	-27,088	-27,908	3,025	38,878	39,209	0,850	97,175	98,021	0,871
56	5	-27,088	-27,908	3,025	38,878	39,209	0,850	-97,213	-98,021	0,832
57	0	-21,134	-21,706	2,706	38,932	39,209	0,710	97,316	98,021	0,725
57	5	-21,134	-21,706	2,706	38,932	39,209	0,710	-97,345	-98,021	0,695

58	0	-14,988	-15,504	3,444	38,963	39,209	0,630	97,396	98,021	0,642
58	5	-14,988	-15,504	3,444	38,963	39,209	0,630	-97,421	-98,021	0,616
59	0	-8,670	-9,303	7,295	39,010	39,209	0,509	97,480	98,021	0,555
59	5	-8,670	-9,303	7,295	39,010	39,209	0,509	-97,570	-98,021	0,462
60	0	-1,131	-2,101	85,750	39,969	39,209	1,903	96,861	98,021	1,198
60	5	-1,131	-2,101	85,750	39,969	39,209	1,903	-102,985	-98,021	4,819
61	0	-40,769	-34,109	16,335	44,180	43,302	1,988	113,535	108,254	4,651
61	5	-40,769	-34,109	16,335	44,180	43,302	1,988	-107,367	-108,254	0,826
62	0	-35,265	-27,908	20,863	42,745	43,302	1,302	106,869	108,254	1,296
62	5	-35,265	-27,908	20,863	42,745	43,302	1,302	-106,857	-108,254	1,308
63	0	-31,045	-29,706	4,314	42,801	43,302	1,170	106,949	108,254	1,220
63	5	-31,045	-29,706	4,314	42,801	43,302	1,170	-107,054	-108,254	1,121
64	0	-26,552	-23,504	11,479	42,960	43,302	0,795	107,318	108,254	0,872
64	5	-26,552	-23,504	11,479	42,960	43,302	0,795	-107,485	-108,254	0,716
65	0	-21,555	-19,303	10,450	43,021	43,302	0,652	107,578	108,254	0,628
65	5	-21,555	-19,303	10,450	43,021	43,302	0,652	-107,529	-108,254	0,675
66	0	-15,871	-13,101	17,454	46,000	43,302	5,866	110,674	108,254	2,186
66	5	-15,871	-13,101	17,454	46,000	43,302	5,866	-119,328	-108,254	9,280
67	0	-30,968	-38,063	22,910	53,393	45,908	14,018	138,991	114,771	17,426
67	5	-30,968	-38,063	22,910	53,393	45,908	14,018	-127,976	-114,771	10,318

68	0	-35,893	-39,324	9,559	48,643	45,908	5,622	121,371	114,771	5,437
68	5	-35,893	-39,324	9,559	48,643	45,908	5,622	-121,844	-114,771	5,805
69	0	-40,710	-30,585	24,870	48,852	45,908	6,025	122,182	114,771	6,065
69	5	-40,710	-30,585	24,870	48,852	45,908	6,025	-122,081	-114,771	5,987
70	0	-46,295	-41,847	9,609	48,770	45,908	5,867	121,945	114,771	5,883
70	5	-46,295	-41,847	9,609	48,770	45,908	5,867	-121,904	-114,771	5,851
71	0	-52,946	-43,108	18,581	48,828	45,908	5,979	121,995	114,771	5,921
71	5	-52,946	-43,108	18,581	48,828	45,908	5,979	-122,143	-114,771	6,036
72	0	-61,499	-4,369	92,895	48,843	45,908	6,008	121,070	114,771	5,202
72	5	-61,499	-4,369	92,895	48,843	45,908	6,008	-123,145	-114,771	6,800
73	0	0,486	1,326	172,737	-1,185	-2,008	69,480	-2,703	-3,314	22,595
73	3,3	0,486	1,326	172,737	-1,185	-2,008	69,480	1,207	3,314	174,567
74	0	5,221	6,628	26,939	-7,129	-6,025	15,486	-13,057	-9,941	23,865
74	3,3	5,221	6,628	26,939	-7,129	-6,025	15,486	10,467	9,941	5,020
75	0	16,566	17,232	4,017	-13,334	-10,042	24,691	-22,621	-16,569	26,754
75	3,3	16,566	17,232	4,017	-13,334	-10,042	24,691	21,381	16,569	22,506
76	0	33,150	33,138	0,038	-13,883	-14,058	1,263	-24,234	-23,196	4,281
76	3,3	33,150	33,138	0,038	-13,883	-14,058	1,263	21,581	23,196	7,487
77	0	53,398	53,741	0,643	-20,726	-17,159	17,209	-32,769	-28,313	13,599
77	3,3	53,398	53,741	0,643	-20,726	-17,159	17,209	35,627	28,313	20,531

78	0	72,003	72,106	0,143	-17,615	-19,555	11,015	-13,467	-17,600	30,693
78	1,8	72,003	72,106	0,143	-17,615	-19,555	11,015	7,440	17,600	136,546
79	0	93,851	93,634	0,231	-22,875	-21,951	4,038	-50,333	-36,220	28,040
79	3,3	93,851	93,634	0,231	-22,875	-21,951	4,038	41,654	36,220	13,046
80	0	125,340	124,656	0,546	-23,366	-25,052	7,216	-40,772	-41,336	1,385
80	3,3	125,340	124,656	0,546	-23,366	-25,052	7,216	36,338	41,336	13,755
81	0	160,533	159,771	0,475	-29,682	-28,153	5,151	-54,272	-46,452	14,408
81	3,3	160,533	159,771	0,475	-29,682	-28,153	5,151	43,678	46,452	6,352
82	0	200,405	198,980	0,711	-33,637	-31,254	7,085	-59,256	-51,569	12,973
82	3,3	200,405	198,980	0,711	-33,637	-31,254	7,085	51,746	51,569	0,343
83	0	244,585	242,282	0,942	-30,079	-34,355	14,215	-61,789	-56,685	8,259
83	3,3	244,585	242,282	0,942	-30,079	-34,355	14,215	59,471	56,685	4,683
84	0	297,978	288,190	3,285	-41,542	-38,724	6,783	-101,521	-116,172	14,432
84	6	297,978	288,190	3,285	-41,542	-38,724	6,783	207,734	116,172	44,077
85	0	-	-	-	-3,584	-4,017	12,072	-6,355	-6,628	4,295
85	3,3	-	-	-	-3,584	-4,017	12,072	5,474	6,628	21,077
86	0	-	-	-	-11,303	-12,050	6,609	-19,193	-19,883	3,591
86	3,3	-	-	-	-11,303	-12,050	6,609	18,107	19,883	9,808
87	0	-	-	-	-18,553	-20,083	8,248	-31,419	-33,137	5,471
87	3,3	-	-	-	-18,553	-20,083	8,248	29,807	33,137	11,175

88	0	-	-	-	-27,909	-28,117	0,744	-47,819	-46,393	2,983
88	3,3	-	-	-	-27,909	-28,117	0,744	44,281	46,393	4,769
89	0	-	-	-	-32,343	-34,318	6,107	-53,123	-56,625	6,593
89	3,3	-	-	-	-32,343	-34,318	6,107	53,609	56,625	5,627
90	0	-	-	-	-41,489	-39,111	5,733	-39,272	-35,199	10,370
90	1,8	-	-	-	-41,489	-39,111	5,733	35,408	35,199	0,590
91	0	-	-	-	-40,881	-43,903	7,391	-71,224	-72,439	1,707
91	3,3	-	-	-	-40,881	-43,903	7,391	63,684	72,439	13,748
92	0	-	-	-	-50,500	-50,104	0,784	-88,254	-82,672	6,324
92	3,3	-	-	-	-50,500	-50,104	0,784	78,395	82,672	5,456
93	0	-	-	-	-55,441	-56,306	1,560	-95,194	-92,905	2,404
93	3,3	-	-	-	-55,441	-56,306	1,560	87,761	92,905	5,861
94	0	-	-	-	-61,607	-62,508	1,462	-105,839	-103,138	2,552
94	3,3	-	-	-	-61,607	-62,508	1,462	97,466	103,138	5,820
95	0	-	-	-	-67,111	-68,709	2,382	-116,771	-113,370	2,912
95	3,3	-	-	-	-67,111	-68,709	2,382	104,695	113,370	8,286
96	0	-	-	-	-62,186	-57,448	7,619	-144,651	-172,344	19,144
96	6	-	-	-	-62,186	-57,448	7,619	228,466	172,344	24,565
97	0	-	-	-	61,316	77,448	26,310	226,336	232,344	2,654
97	6	-	-	-	61,316	77,448	26,310	-141,558	-232,344	64,133

98	0	-	-	-	66,133	68,709	3,896	102,468	113,370	10,640
98	3,3	-	-	-	66,133	68,709	3,896	-115,772	-113,370	2,075
99	0	-	-	-	61,913	62,508	0,960	98,033	103,138	5,207
99	3,3	-	-	-	61,913	62,508	0,960	-106,279	-103,138	2,956
100	0	-	-	-	55,959	56,306	0,620	88,250	92,905	5,275
100	3,3	-	-	-	55,959	56,306	0,620	-96,416	-92,905	3,642
101	0	-	-	-	50,976	50,104	1,710	79,387	82,672	4,139
101	3,3	-	-	-	50,976	50,104	1,710	-88,835	-82,672	6,938
102	0	-	-	-	41,705	43,903	5,270	64,866	72,439	11,675
102	3,3	-	-	-	41,705	43,903	5,270	-72,759	-72,439	0,439
103	0	-	-	-	42,920	39,111	8,876	36,488	35,199	3,532
103	1,8	-	-	-	42,920	39,111	8,876	-40,768	-35,199	13,660
104	0	-	-	-	33,376	34,318	2,823	55,429	56,625	2,159
104	3,3	-	-	-	33,376	34,318	2,823	-54,712	-56,625	3,498
105	0	-	-	-	28,578	28,117	1,614	45,318	46,393	2,372
105	3,3	-	-	-	28,578	28,117	1,614	-48,989	-46,393	5,299
106	0	-	-	-	18,877	20,083	6,390	30,354	33,137	9,172
106	3,3	-	-	-	18,877	20,083	6,390	-31,941	-33,137	3,746
107	0	-	-	-	11,829	12,050	1,868	18,838	19,883	5,543
107	3,3	-	-	-	11,829	12,050	1,868	-20,198	-19,883	1,564

108	0	-	-	-	4,650	4,017	13,620	7,116	6,628	6,866
108	3,3	-	-	-	4,650	4,017	13,620	-8,229	-6,628	19,461
109	0	-	-	-	-4,565	-4,017	12,012	-8,053	-6,628	17,706
109	3,3	-	-	-	-4,565	-4,017	12,012	7,012	6,628	5,477
110	0	-	-	-	-11,784	-12,050	2,257	-20,096	-19,883	1,061
110	3,3	-	-	-	-11,784	-12,050	2,257	18,791	19,883	5,811
111	0	-	-	-	-18,882	-20,083	6,362	-31,950	-33,137	3,718
111	3,3	-	-	-	-18,882	-20,083	6,362	30,360	33,137	9,149
112	0	-	-	-	-28,450	-28,117	1,172	-48,767	-46,393	4,869
112	3,3	-	-	-	-28,450	-28,117	1,172	45,117	46,393	2,828
113	0	-	-	-	-33,363	-34,318	2,863	-54,693	-56,625	3,533
113	3,3	-	-	-	-33,363	-34,318	2,863	55,406	56,625	2,201
114	0	-	-	-	-42,439	-39,111	7,843	-40,346	-64,532	59,946
114	1,8	-	-	-	-42,439	-39,111	7,843	36,044	64,532	79,039
115	0	-	-	-	-41,854	-43,903	4,895	-73,008	-72,439	0,779
115	3,3	-	-	-	-41,854	-43,903	4,895	65,109	72,439	11,259
116	0	-	-	-	-50,885	-50,104	1,534	-88,671	-82,672	6,765
116	3,3	-	-	-	-50,885	-50,104	1,534	79,248	82,672	4,321
117	0	-	-	-	-55,910	-56,306	0,708	-96,374	-92,905	3,600
117	3,3	-	-	-	-55,910	-56,306	0,708	88,128	92,905	5,420

118	0	-	-	-	-62,057	-62,508	0,726	-106,613	-103,138	3,260
118	3,3	-	-	-	-62,057	-62,508	0,726	98,174	103,138	5,056
119	0	-	-	-	-66,550	-68,709	3,245	-116,198	-113,370	2,434
119	3,3	-	-	-	-66,550	-68,709	3,245	103,415	113,370	9,626
120	0	-	-	-	-60,965	-77,448	27,037	-140,610	-232,344	65,240
120	6	-	-	-	-60,965	-77,448	27,037	225,182	232,344	3,180
121	0	-	-	-	60,494	77,448	28,026	223,725	232,344	3,853
121	6	-	-	-	60,494	77,448	28,026	-139,237	-232,344	66,870
122	0	-	-	-	67,145	68,709	2,330	104,661	113,370	8,321
122	3,3	-	-	-	67,145	68,709	2,330	-116,918	-113,370	3,034
123	0	-	-	-	62,148	62,508	0,579	98,145	103,138	5,087
123	3,3	-	-	-	62,148	62,508	0,579	-106,944	-103,138	3,559
124	0	-	-	-	55,831	56,306	0,851	87,957	92,905	5,625
124	3,3	-	-	-	55,831	56,306	0,851	-96,285	-92,905	3,510
125	0	-	-	-	50,967	50,104	1,693	79,410	82,672	4,108
125	3,3	-	-	-	50,967	50,104	1,693	-88,780	-82,672	6,879
126	0	-	-	-	41,801	43,903	5,028	65,027	72,439	11,399
126	3,3	-	-	-	41,801	43,903	5,028	-72,918	-72,439	0,656
127	0	-	-	-	42,907	39,111	8,848	36,436	35,199	3,394
127	1,8	-	-	-	42,907	39,111	8,848	-40,796	-35,199	13,719

128	0	-	-	-	33,291	34,318	3,086	55,273	56,625	2,447
128	3,3	-	-	-	33,291	34,318	3,086	-54,588	-56,625	3,733
129	0	-	-	-	28,462	28,117	1,213	45,138	46,393	2,779
129	3,3	-	-	-	28,462	28,117	1,213	-48,788	-46,393	4,910
130	0	-	-	-	18,881	20,083	6,368	30,366	33,137	9,128
130	3,3	-	-	-	18,881	20,083	6,368	-31,942	-33,137	3,742
131	0	-	-	-	11,823	12,050	1,920	18,833	19,883	5,570
131	3,3	-	-	-	11,823	12,050	1,920	-20,183	-19,883	1,489
132	0	-	-	-	4,762	4,017	15,652	7,302	6,628	9,237
132	3,3	-	-	-	4,762	4,017	15,652	-8,413	-6,628	21,223
133	0	-	-	-	-3,848	-4,017	4,383	-6,792	-6,628	2,425
133	3,3	-	-	-	-3,848	-4,017	4,383	5,908	6,628	12,182
134	0	-	-	-	-11,317	-12,050	6,477	-19,209	-19,883	3,508
134	3,3	-	-	-	-11,317	-12,050	6,477	18,137	19,883	9,623
135	0	-	-	-	-18,580	-20,083	8,091	-31,454	-33,137	5,352
135	3,3	-	-	-	-18,580	-20,083	8,091	29,859	33,137	10,979
136	0	-	-	-	-27,712	-28,117	1,460	-47,477	-46,393	2,285
136	3,3	-	-	-	-27,712	-28,117	1,460	43,973	46,393	5,501
137	0	-	-	-	-32,204	-34,318	6,565	-52,925	-56,625	6,991
137	3,3	-	-	-	-32,204	-34,318	6,565	53,350	56,625	6,140

138	0	-	-	-	-41,590	-39,111	5,962	-39,434	-35,199	10,737
138	1,8	-	-	-	-41,590	-39,111	5,962	35,428	35,199	0,644
139	0	-	-	-	-41,117	-43,903	6,775	-71,618	-72,439	1,147
139	3,3	-	-	-	-41,117	-43,903	6,775	64,067	72,439	13,068
140	0	-	-	-	-50,599	-50,104	0,978	-88,306	-82,672	6,379
140	3,3	-	-	-	-50,599	-50,104	0,978	78,670	82,672	5,087
141	0	-	-	-	-55,088	-56,306	2,211	-94,917	-92,905	2,120
141	3,3	-	-	-	-55,088	-56,306	2,211	86,873	92,905	6,944
142	0	-	-	-	-62,627	-62,508	0,191	-107,559	-103,138	4,110
142	3,3	-	-	-	-62,627	-62,508	0,191	99,111	103,138	4,063
143	0	-	-	-	-68,311	-68,709	0,583	-119,091	-113,370	4,804
143	3,3	-	-	-	-68,311	-68,709	0,583	106,334	113,370	6,617
144	0	-	-	-	-59,758	-77,448	29,603	-136,879	-232,344	69,744
144	6	-	-	-	-59,758	-77,448	29,603	221,670	232,344	4,815
145	0	-272,738	-298,424	9,418	57,007	67,448	18,315	215,526	202,344	6,116
145	6	-272,738	-298,424	9,418	57,007	67,448	18,315	-126,516	-202,344	59,936
146	0	-247,066	-242,282	1,936	46,928	34,355	26,793	79,359	56,685	28,571
146	3,3	-247,066	-242,282	1,936	46,928	34,355	26,793	-75,503	-56,685	24,923
147	0	-201,066	-198,980	1,037	31,056	31,254	0,637	43,825	51,569	17,671
147	3,3	-201,066	-198,980	1,037	31,056	31,254	0,637	-58,661	-51,569	12,091

148	0	-161,096	-159,771	0,822	29,926	28,153	5,925	44,323	46,452	4,804
148	3,3	-161,096	-159,771	0,822	29,926	28,153	5,925	-54,431	-46,452	14,658
149	0	-125,840	-124,656	0,941	23,334	25,052	7,363	36,364	41,336	13,674
149	3,3	-125,840	-124,656	0,941	23,334	25,052	7,363	-40,638	-41,336	1,719
150	0	-94,201	-93,634	0,602	28,184	23,951	15,018	42,174	39,520	6,294
150	3,3	-94,201	-93,634	0,602	28,184	23,951	15,018	-50,832	-39,520	22,254
151	0	-72,200	-72,106	0,130	11,703	12,555	7,282	7,349	11,300	53,759
151	1,8	-72,200	-72,106	0,130	11,703	12,555	7,282	-13,717	-11,300	17,623
152	0	-53,595	-53,741	0,273	20,607	17,159	16,731	35,354	28,313	19,917
152	3,3	-53,595	-53,741	0,273	20,607	17,159	16,731	-32,648	-28,313	13,278
153	0	-33,469	-33,138	0,990	13,706	14,058	2,571	21,326	23,196	8,772
153	3,3	-33,469	-33,138	0,990	13,706	14,058	2,571	-23,904	-23,196	2,961
154	0	-16,950	-17,232	1,661	13,393	10,042	25,023	21,501	16,569	22,938
154	3,3	-16,950	-17,232	1,661	13,393	10,042	25,023	-22,697	-16,569	27,001
155	0	-5,567	-6,628	19,050	7,115	6,025	15,320	10,475	9,941	5,099
155	3,3	-5,567	-6,628	19,050	7,115	6,025	15,320	-13,005	-9,941	23,560
156	0	-0,664	-1,326	99,623	1,505	2,008	33,444	1,740	3,314	90,413
156	3,3	-0,664	-1,326	99,623	1,505	2,008	33,444	-3,227	-3,314	2,704

Table A3. 2. Comparison of SAP2000 and hand calculation results for structural analysis under dead load

Frame	Station	Zero- moment location	Axial Force (SAP2000)	Axial Force (hand)	Error	Shear Force (SAP2000)	Shear Force (hand)	Error	Moment (SAP2000)	Moment (hand)	Error
	m		kN	kN	%	kN	kN	%	kN-m	kN-m	%
1	0	0,846	-	-	-	-39,674	-40,025	0,885	-33,577	-33,861	0,845
1	2,5	0,846	-	-	-	40,373	40,025	0,862	65,608	66,201	0,905
1	5	0,846	-	-	-	40,373	40,025	0,862	-35,325	-33,861	4,143
2	0	1,093	-	-	-	-38,245	-40,025	4,654	-41,778	-43,727	4,665
2	2,5	1,093	-	-	-	41,802	40,025	4,251	53,833	56,335	4,647
2	5	1,093	-	-	-	41,802	40,025	4,251	-50,673	-43,727	13,706
3	0	1,255	-	-	-	-39,976	-40,025	0,123	-50,080	-50,231	0,303
3	2,5	1,255	-	-	-	40,071	40,025	0,115	49,861	49,831	0,059
3	5	1,255	-	-	-	40,071	40,025	0,115	-50,316	-50,231	0,169
4	0	1,255	-	-	-	-40,051	-40,025	0,065	-50,269	-50,231	0,075
4	2,5	1,255	-	-	-	39,996	40,025	0,073	49,860	49,831	0,057
4	5	1,255	-	-	-	39,996	40,025	0,073	-50,129	-50,231	0,203
5	0	1,212	-	-	-	-41,759	-40,025	4,152	-50,630	-48,510	4,187
5	2,5	1,212	-	-	-	38,288	40,025	4,537	53,766	51,552	4,118

5	5	1,212	-	-	-	38,288	40,025	4,537	-41,955	-48,510	15,625
6	0	0,878	-	-	-	-40,437	-40,025	1,019	-35,533	-35,142	1,099
6	2,5	0,878	-	-	-	39,610	40,025	1,048	65,560	64,921	0,975
6	5	0,878	-	-	-	39,610	40,025	1,048	-33,466	-35,142	5,008
7	0	1,130	-	-	-	-52,941	-48,962	7,517	-59,795	-55,302	7,514
7	2,5	1,130	-	-	-	44,982	48,962	8,847	72,558	67,102	7,519
7	5	1,130	-	-	-	44,982	48,962	8,847	-39,897	-55,302	38,612
8	0	1,123	-	-	-	-47,141	-48,962	3,862	-52,907	-54,984	3,926
8	2,5	1,123	-	-	-	50,782	48,962	3,585	64,947	67,420	3,808
8	5	1,123	-	-	-	50,782	48,962	3,585	-62,008	-54,984	11,328
9	0	1,251	-	-	-	-48,883	-48,962	0,161	-61,141	-61,251	0,180
9	2,5	1,251	-	-	-	49,040	48,962	0,160	61,066	61,153	0,143
9	5	1,251	-	-	-	49,040	48,962	0,160	-61,535	-61,251	0,462
10	0	1,254	-	-	-	48,919	48,962	0,087	61,063	61,398	0,548
10	2,5	1,254	-	-	-	48,919	48,962	0,087	61,063	61,006	0,093
10	5	1,254	-	-	-	48,919	48,962	0,087	-61,234	-61,398	0,267
11	0	1,221	-	-	-	-50,729	-48,962	3,484	-61,933	-59,782	3,474
11	2,5	1,221	-	-	-	47,194	48,962	3,745	64,888	62,622	3,493
11	5	1,221	-	-	-	47,194	48,962	3,745	-53,097	-59,782	12,589
12	0	0,891	-	-	-	-45,071	-48,962	8,632	-40,149	-43,625	8,656

12	2,5	0,891	-	-	-	52,852	48,962	7,361	72,527	78,779	8,620
12	5	0,891	-	-	-	52,852	48,962	7,361	-59,604	-43,625	26,808
13	0	1,079	-	-	-	-51,661	-48,962	5,225	-55,728	-52,829	5,200
13	2,5	1,079	-	-	-	46,262	48,962	5,835	73,425	69,574	5,244
13	5	1,079	-	-	-	46,262	48,962	5,835	-42,230	-52,829	25,099
14	0	1,147	-	-	-	-47,605	-48,962	2,849	-54,593	-56,159	2,868
14	2,5	1,147	-	-	-	50,318	48,962	2,696	64,419	66,245	2,835
14	5	1,147	-	-	-	50,318	48,962	2,696	-61,377	-56,159	8,502
15	0	1,250	-	-	-	-48,879	-48,962	0,169	-61,105	-61,202	0,158
15	2,5	1,250	-	-	-	49,044	48,962	0,168	61,093	61,202	0,178
15	5	1,250	-	-	-	49,044	48,962	0,168	-61,517	-61,202	0,512
16	0	1,254	-	-	-	-49,010	-48,962	0,099	-61,434	-61,398	0,058
16	2,5	1,254	-	-	-	48,913	48,962	0,099	61,092	61,006	0,140
16	5	1,254	-	-	-	48,913	48,962	0,099	-61,191	-61,398	0,338
17	0	1,220	-	-	-	-50,265	-48,962	2,593	-61,303	-59,733	2,561
17	2,5	1,220	-	-	-	47,658	48,962	2,735	64,359	62,671	2,624
17	5	1,220	-	-	-	47,658	48,962	2,735	-54,786	-59,733	9,029
18	0	0,917	-	-	-	-46,350	-48,962	5,634	-42,484	-44,898	5,681
18	2,5	0,917	-	-	-	51,573	48,962	5,064	73,390	77,506	5,608
18	5	0,917	-	-	-	51,573	48,962	5,064	-55,543	-44,898	19,166

19	0	1,129	-	-	-	-56,411	-48,962	13,206	-72,849	-55,282	24,114
19	2,5	1,129	-	-	-	41,512	48,962	17,945	68,178	67,121	1,550
19	5	1,129	-	-	-	41,512	48,962	17,945	-35,603	-55,282	55,276
20	0	1,161	-	-	-	-47,752	-48,962	2,533	-55,415	-56,844	2,580
20	2,5	1,161	-	-	-	50,171	48,962	2,411	63,965	65,559	2,492
20	5	1,161	-	-	-	50,171	48,962	2,411	-61,462	-56,844	7,513
21	0	1,246	-	-	-	-48,789	-48,962	0,354	-60,779	-61,006	0,374
21	2,5	1,246	-	-	-	49,134	48,962	0,351	61,194	61,398	0,333
21	5	1,246	-	-	-	49,134	48,962	0,351	-61,641	-61,006	1,030
22	0	1,253	-	-	-	-49,080	-48,962	0,241	-61,509	-61,349	0,261
22	2,5	1,253	-	-	-	48,843	48,962	0,243	61,192	61,055	0,224
22	5	1,253	-	-	-	48,843	48,962	0,243	-60,915	-61,349	0,713
23	0	1,224	-	-	-	-50,107	-48,962	2,286	-61,350	-59,929	2,316
23	2,5	1,224	-	-	-	47,816	48,962	2,396	63,919	62,475	2,259
23	5	1,224	-	-	-	47,816	48,962	2,396	-55,620	-59,929	7,747
24	0	0,863	-	-	-	-41,630	-48,962	17,611	-35,917	-42,254	17,642
24	2,5	0,863	-	-	-	56,293	48,962	13,024	68,156	80,150	17,597
24	5	0,863	-	-	-	56,293	48,962	13,024	-72,577	-42,254	41,781
25	0	1,396	-	-	-	-59,360	-48,962	17,518	-82,880	-68,350	17,531
25	2,5	1,396	-	-	-	38,563	48,962	26,965	65,520	54,053	17,500

25	5	1,396	-	-	-	38,563	48,962	26,965	-30,888	-68,350	121,283
26	0	1,190	-	-	-	-48,364	-48,962	1,235	-57,575	-58,264	1,197
26	2,5	1,190	-	-	-	49,559	48,962	1,206	63,334	64,140	1,271
26	5	1,190	-	-	-	49,559	48,962	1,206	-60,564	-58,264	3,797
27	0	1,246	-	-	-	-48,808	-48,962	0,314	-60,828	-61,006	0,292
27	2,5	1,246	-	-	-	49,115	48,962	0,313	61,192	61,398	0,336
27	5	1,246	-	-	-	49,115	48,962	0,313	-61,595	-61,006	0,955
28	0	1,252	-	-	-	-49,046	-48,962	0,172	-61,426	-61,300	0,205
28	2,5	1,252	-	-	-	48,877	48,962	0,173	61,190	61,104	0,141
28	5	1,252	-	-	-	48,877	48,962	0,173	-61,001	-61,300	0,490
29	0	1,221	-	-	-	-49,489	-48,962	1,066	-60,425	-59,782	1,064
29	2,5	1,221	-	-	-	48,434	48,962	1,089	63,297	62,622	1,067
29	5	1,221	-	-	-	48,434	48,962	1,089	-57,788	-59,782	3,451
30	0	0,807	-	-	-	-38,701	-48,962	26,512	-31,247	-39,512	26,449
30	2,5	0,807	-	-	-	59,222	48,962	17,325	65,505	82,892	26,542
30	5	0,807	-	-	-	59,222	48,962	17,325	-82,550	-39,512	52,135
31	0	1,388	-	-	-	-58,385	-48,962	16,140	-81,054	-67,959	16,157
31	2,5	1,388	-	-	-	39,538	48,962	23,834	64,909	54,445	16,121
31	5	1,388	-	-	-	39,538	48,962	23,834	-33,935	-67,959	100,260
32	0	1,191	-	-	-	-48,108	-48,962	1,774	-57,277	-58,313	1,809

32	2,5	1,191	-	-	-	49,815	48,962	1,713	62,992	64,091	1,744
32	5	1,191	-	-	-	49,815	48,962	1,713	-61,547	-58,313	5,254
33	0	1,237	-	-	-	-48,594	-48,962	0,756	-60,090	-60,565	0,791
33	2,5	1,237	-	-	-	49,329	48,962	0,745	61,395	61,838	0,723
33	5	1,237	-	-	-	49,329	48,962	0,745	-61,928	-60,565	2,200
34	0	1,254	-	-	-	-49,255	-48,962	0,596	-61,745	-61,398	0,562
34	2,5	1,254	-	-	-	48,668	48,962	0,603	61,393	61,006	0,630
34	5	1,254	-	-	-	48,668	48,962	0,603	-60,278	-61,398	1,858
35	0	1,234	-	-	-	-49,740	-48,962	1,565	-61,390	-60,418	1,582
35	2,5	1,234	-	-	-	48,183	48,962	1,616	62,960	61,985	1,547
35	5	1,234	-	-	-	48,183	48,962	1,616	-57,499	-60,418	5,078
36	0	0,865	-	-	-	-39,687	-48,962	23,369	-34,322	-42,352	23,396
36	2,5	0,865	-	-	-	58,236	48,962	15,926	64,896	80,052	23,355
36	5	0,865	-	-	-	58,236	48,962	15,926	-80,694	-42,352	47,516
37	0	1,365	-	-	-	-56,509	-48,243	14,628	-77,119	-65,852	14,611
37	2,5	1,365	-	-	-	39,977	48,243	20,677	64,153	54,756	14,648
37	5	1,365	-	-	-	39,977	48,243	20,677	-35,790	-65,852	83,996
38	0	1,194	-	-	-	-47,446	-48,243	1,680	-56,633	-57,602	1,711
38	2,5	1,194	-	-	-	49,040	48,243	1,625	61,982	63,005	1,651
38	5	1,194	-	-	-	49,040	48,243	1,625	-60,618	-57,602	4,975

39	0	1,238	-	-	-	-47,915	-48,243	0,685	-59,314	-59,725	0,693
39	2,5	1,238	-	-	-	48,571	48,243	0,675	60,475	60,883	0,675
39	5	1,238	-	-	-	48,571	48,243	0,675	-60,952	-59,725	2,014
40	0	1,253	-	-	-	-48,498	-48,243	0,526	-60,772	-60,448	0,532
40	2,5	1,253	-	-	-	47,988	48,243	0,531	60,473	60,159	0,519
40	5	1,253	-	-	-	47,988	48,243	0,531	-59,497	-60,448	1,599
41	0	1,235	-	-	-	-48,962	-48,243	1,468	-60,456	-59,580	1,449
41	2,5	1,235	-	-	-	47,524	48,243	1,513	61,948	61,027	1,486
41	5	1,235	-	-	-	47,524	48,243	1,513	-56,863	-59,580	4,778
42	0	0,902	-	-	-	-40,128	-48,243	20,223	-36,182	-43,515	20,269
42	2,5	0,902	-	-	-	56,358	48,243	14,399	64,139	77,092	20,195
42	5	0,902	-	-	-	56,358	48,243	14,399	-76,755	-43,515	43,306
43	0	1,381	-	-	-	-57,316	-48,962	14,576	-79,172	-67,616	14,596
43	2,5	1,381	-	-	-	40,607	48,962	20,574	64,117	54,788	14,550
43	5	1,381	-	-	-	40,607	48,962	20,574	-37,402	-67,616	80,782
44	0	1,228	-	-	-	-48,958	-48,962	0,007	-60,110	-60,125	0,025
44	2,5	1,228	-	-	-	48,965	48,962	0,007	62,285	62,279	0,009
44	5	1,228	-	-	-	48,965	48,962	0,007	-60,128	-60,125	0,006
45	0	1,247	-	-	-	-48,842	-48,962	0,245	-60,894	-61,055	0,264
45	2,5	1,247	-	-	-	49,081	48,962	0,243	61,211	61,349	0,225

45	5	1,247	-	-	-	49,081	48,962	0,243	-61,491	-61,055	0,709
46	0	1,251	-	-	-	-48,998	-48,962	0,074	-61,284	-61,251	0,055
46	2,5	1,251	-	-	-	48,925	48,962	0,075	61,210	61,153	0,094
46	5	1,251	-	-	-	48,925	48,962	0,075	-61,103	-61,251	0,243
47	0	1,226	-	-	-	-48,878	-48,962	0,171	-59,939	-60,027	0,147
47	2,5	1,226	-	-	-	49,045	48,962	0,170	62,257	62,377	0,192
47	5	1,226	-	-	-	49,045	48,962	0,170	-60,354	-60,027	0,543
48	0	0,928	-	-	-	-40,773	-48,962	20,083	-37,831	-45,436	20,104
48	2,5	0,928	-	-	-	57,150	48,962	14,328	64,102	76,967	20,070
48	5	0,928	-	-	-	57,150	48,962	14,328	-78,773	-45,436	42,320
49	0	1,398	-	-	-	-57,206	-48,962	14,412	-79,979	-68,448	14,417
49	2,5	1,398	-	-	-	40,717	48,962	20,248	63,036	53,956	14,406
49	5	1,398	-	-	-	40,717	48,962	20,248	-38,756	-68,448	76,614
50	0	1,236	-	-	-	-49,013	-48,962	0,105	-60,583	-60,516	0,110
50	2,5	1,236	-	-	-	48,910	48,962	0,105	61,949	61,887	0,100
50	5	1,236	-	-	-	48,910	48,962	0,105	-60,325	-60,516	0,317
51	0	1,244	-	-	-	-48,785	-48,962	0,362	-60,698	-60,908	0,347
51	2,5	1,244	-	-	-	49,138	48,962	0,359	61,264	61,496	0,378
51	5	1,244	-	-	-	49,138	48,962	0,359	-61,582	-60,908	1,094
52	0	1,251	-	-	-	-49,036	-48,962	0,152	-61,327	-61,251	0,124

52	2,5	1,251	-	-	-	48,887	48,962	0,152	61,264	61,153	0,181
52	5	1,251	-	-	-	48,887	48,962	0,152	-60,953	-61,251	0,489
53	0	1,231	-	-	-	-48,798	-48,962	0,335	-60,075	-60,272	0,327
53	2,5	1,231	-	-	-	49,125	48,962	0,333	61,921	62,132	0,341
53	5	1,231	-	-	-	49,125	48,962	0,333	-60,891	-60,272	1,017
54	0	0,958	-	-	-	-40,893	-48,962	19,731	-39,191	-46,905	19,684
54	2,5	0,958	-	-	-	57,030	48,962	14,148	63,042	75,499	19,759
54	5	0,958	-	-	-	57,030	48,962	14,148	-79,532	-46,905	41,024
55	0	1,354	-	-	-	-55,173	-48,962	11,258	-74,689	-66,294	11,240
55	2,5	1,354	-	-	-	42,750	48,962	14,530	63,243	56,110	11,278
55	5	1,354	-	-	-	42,750	48,962	14,530	-43,634	-66,294	51,933
56	0	1,241	-	-	-	-49,069	-48,962	0,219	-60,898	-60,761	0,224
56	2,5	1,241	-	-	-	48,854	48,962	0,220	61,774	61,643	0,213
56	5	1,241	-	-	-	48,854	48,962	0,220	-60,362	-60,761	0,661
57	0	1,246	-	-	-	-48,828	-48,962	0,273	-60,847	-61,006	0,261
57	2,5	1,246	-	-	-	49,095	48,962	0,272	61,224	61,398	0,284
57	5	1,246	-	-	-	49,095	48,962	0,272	-61,512	-61,006	0,823
58	0	1,249	-	-	-	-48,959	-48,962	0,005	-61,173	-61,153	0,033
58	2,5	1,249	-	-	-	48,964	48,962	0,005	61,223	61,251	0,045
58	5	1,249	-	-	-	48,964	48,962	0,005	-61,187	-61,153	0,056

59	0	1,233	-	-	-	-48,742	-48,962	0,450	-60,077	-60,370	0,487
59	2,5	1,233	-	-	-	49,181	48,962	0,446	61,779	62,034	0,413
59	5	1,233	-	-	-	49,181	48,962	0,446	-61,173	-60,370	1,313
60	0	1,027	-	-	-	-42,864	-48,962	14,225	-44,011	-50,283	14,252
60	2,5	1,027	-	-	-	55,059	48,962	11,074	63,149	72,120	14,207
60	5	1,027	-	-	-	55,059	48,962	11,074	-74,499	-50,283	32,504
61	0	1,303	-	-	-	-52,745	-48,962	7,173	-68,741	-63,797	7,192
61	2,5	1,303	-	-	-	45,178	48,962	8,375	63,122	58,607	7,152
61	5	1,303	-	-	-	45,178	48,962	8,375	-49,824	-63,797	28,046
62	0	1,232	-	-	-	-48,664	-48,962	0,611	-60,001	-60,321	0,533
62	2,5	1,232	-	-	-	49,259	48,962	0,604	61,659	62,083	0,689
62	5	1,232	-	-	-	49,259	48,962	0,604	-61,490	-60,321	1,901
63	0	1,239	-	-	-	-48,573	-48,962	0,800	-60,186	-60,663	0,794
63	2,5	1,239	-	-	-	49,350	48,962	0,787	61,246	61,740	0,808
63	5	1,239	-	-	-	49,350	48,962	0,787	-62,130	-60,663	2,361
64	0	1,243	-	-	-	-48,740	-48,962	0,454	-60,596	-60,859	0,435
64	2,5	1,243	-	-	-	49,183	48,962	0,450	61,254	61,545	0,474
64	5	1,243	-	-	-	49,183	48,962	0,450	-61,704	-60,859	1,369
65	0	1,232	-	-	-	-48,553	-48,962	0,841	-59,824	-60,321	0,830
65	2,5	1,232	-	-	-	49,370	48,962	0,827	61,559	62,083	0,852

65	5	1,232	-	-	-	49,370	48,962	0,827	-61,866	-60,321	2,498
66	0	1,095	-	-	-	-45,245	-48,962	8,214	-49,527	-53,613	8,249
66	2,5	1,095	-	-	-	52,678	48,962	7,055	63,585	68,791	8,187
66	5	1,095	-	-	-	52,678	48,962	7,055	-68,110	-53,613	21,285
67	0	1,211	-	-	-	-49,582	-48,962	1,251	-60,036	-59,292	1,239
67	2,5	1,211	-	-	-	48,341	48,962	1,284	63,919	63,111	1,263
67	5	1,211	-	-	-	48,341	48,962	1,284	-56,934	-59,292	4,142
68	0	1,239	-	-	-	-48,679	-48,962	0,580	-60,315	-60,663	0,578
68	2,5	1,239	-	-	-	49,244	48,962	0,574	61,383	61,740	0,582
68	5	1,239	-	-	-	49,244	48,962	0,574	-61,727	-60,663	1,723
69	0	1,238	-	-	-	-48,507	-48,962	0,937	-60,046	-60,614	0,947
69	2,5	1,238	-	-	-	49,416	48,962	0,920	61,222	61,789	0,926
69	5	1,238	-	-	-	49,416	48,962	0,920	-62,317	-60,614	2,732
70	0	1,240	-	-	-	-48,565	-48,962	0,816	-60,210	-60,712	0,834
70	2,5	1,240	-	-	-	49,358	48,962	0,803	61,203	61,691	0,798
70	5	1,240	-	-	-	49,358	48,962	0,803	-62,191	-60,712	2,378
71	0	1,233	-	-	-	-48,559	-48,962	0,829	-59,855	-60,370	0,859
71	2,5	1,233	-	-	-	49,364	48,962	0,815	61,541	62,034	0,801
71	5	1,233	-	-	-	49,364	48,962	0,815	-61,870	-60,370	2,425
72	0	1,144	-	-	-	-45,297	-48,962	8,090	-51,806	-56,012	8,119

72	2,5	1,144	-	-	-	52,626	48,962	6,963	61,436	66,392	8,067
72	5	1,144	-	-	-	52,626	48,962	6,963	-70,130	-56,012	20,131
73	0	-	-79,697	-80,047	0,439	-	-	-	33,577	33,861	0,845
73	3,3	-	-79,697	-80,047	0,439	-	-	-	-30,798	-33,861	9,946
74	0	-	-181,599	-177,970	1,998	-	-	-	28,997	25,934	10,563
74	3,3	-	-181,599	-177,970	1,998	-	-	-	-29,237	-25,934	11,297
75	0	-	-282,221	-275,893	2,242	-	-	-	26,491	26,896	1,529
75	3,3	-	-282,221	-275,893	2,242	-	-	-	-22,828	-26,896	17,817
76	0	-	-387,593	-373,816	3,555	-	-	-	50,021	45,954	8,131
76	3,3	-	-387,593	-373,816	3,555	-	-	-	-43,220	-45,954	6,326
77	0	-	-495,914	-471,739	4,875	-	-	-	39,661	36,927	6,894
77	3,3	-	-495,914	-471,739	4,875	-	-	-	-38,111	-36,927	3,108
78	0	-	-603,260	-569,662	5,569	-	-	-	42,943	44,128	2,758
78	1,8	-	-603,260	-569,662	5,569	-	-	-	-42,973	-44,128	2,686
79	0	-	-708,012	-667,585	5,710	-	-	-	34,146	32,992	3,380
79	3,3	-	-708,012	-667,585	5,710	-	-	-	-30,653	-32,992	7,631
80	0	-	-814,289	-764,431	6,123	-	-	-	48,520	46,181	4,821
80	3,3	-	-814,289	-764,431	6,123	-	-	-	-41,659	-46,181	10,854
81	0	-	-920,456	-862,354	6,312	-	-	-	38,320	33,798	11,799
81	3,3	-	-920,456	-862,354	6,312	-	-	-	-38,307	-33,798	11,770

82	0	-	-1024,589	-960,277	6,277	-	-	-	36,382	40,890	12,393
82	3,3	-	-1024,589	-960,277	6,277	-	-	-	-35,820	-40,890	14,155
83	0	-	-1126,295	-1058,200	6,046	-	-	-	32,921	27,850	15,402
83	3,3	-	-1126,295	-1058,200	6,046	-	-	-	-35,661	-27,850	21,902
84	0	-	-1224,838	-1156,123	5,610	-	-	-	24,375	32,186	32,043
84	6	-	-1224,838	-1156,123	5,610	-	-	-	-11,789	-32,186	173,023
85	0	-	-158,665	-160,094	0,901	-	-	-	6,453	6,453	0,002
85	3,3	-	-158,665	-160,094	0,901	-	-	-	-6,438	-6,453	0,242
86	0	-	-348,711	-355,940	2,073	-	-	-	6,572	6,556	0,236
86	3,3	-	-348,711	-355,940	2,073	-	-	-	-6,244	-6,556	5,002
87	0	-	-540,500	-551,786	2,088	-	-	-	6,120	5,807	5,105
87	3,3	-	-540,500	-551,786	2,088	-	-	-	-5,892	-5,807	1,434
88	0	-	-727,688	-747,632	2,741	-	-	-	13,920	14,005	0,607
88	3,3	-	-727,688	-747,632	2,741	-	-	-	-12,618	-14,005	10,989
89	0	-	-912,537	-943,478	3,391	-	-	-	14,069	12,682	9,856
89	3,3	-	-912,537	-943,478	3,391	-	-	-	-13,782	-12,682	7,981
90	0	-	-1098,106	-1139,324	3,754	-	-	-	9,560	10,660	11,506
90	1,8	-	-1098,106	-1139,324	3,754	-	-	-	-9,051	-10,660	17,774
91	0	-	-1282,015	-1335,170	4,146	-	-	-	11,792	10,184	13,642
91	3,3	-	-1282,015	-1335,170	4,146	-	-	-	-10,232	-10,184	0,472

92	0	-	-1469,503	-1528,862	4,039	-	-	-	12,476	12,524	0,387
92	3,3	-	-1469,503	-1528,862	4,039	-	-	-	-11,072	-12,524	13,120
93	0	-	-1657,156	-1724,708	4,076	-	-	-	10,756	9,303	13,505
93	3,3	-	-1657,156	-1724,708	4,076	-	-	-	-9,702	-9,303	4,108
94	0	-	-1846,898	-1920,554	3,988	-	-	-	7,562	7,961	5,271
94	3,3	-	-1846,898	-1920,554	3,988	-	-	-	-7,612	-7,961	4,582
95	0	-	-2038,663	-2116,400	3,813	-	-	-	2,566	2,217	13,595
95	3,3	-	-2038,663	-2116,400	3,813	-	-	-	-1,280	-2,217	73,201
96	0	-	-2233,606	-2312,246	3,521	-	-	-	2,101	1,164	44,595
96	6	-	-2233,606	-2312,246	3,521	-	-	-	-0,564	-1,164	106,529
97	0	-	-2317,863	-2312,246	0,242	-	-	-	0,666	0,601	9,788
97	6	-	-2317,863	-2312,246	0,242	-	-	-	0,135	-0,601	544,782
98	0	-	-2122,189	-2116,400	0,273	-	-	-	1,816	1,080	40,521
98	3,3	-	-2122,189	-2116,400	0,273	-	-	-	-1,922	-1,080	43,804
99	0	-	-1926,435	-1920,554	0,305	-	-	-	-0,618	0,224	136,218
99	3,3	-	-1926,435	-1920,554	0,305	-	-	-	-0,014	-0,224	1487,943
100	0	-	-1730,829	-1724,708	0,354	-	-	-	-0,499	-0,709	42,032
100	3,3	-	-1730,829	-1724,708	0,354	-	-	-	0,666	0,709	6,428
101	0	-	-1535,211	-1528,862	0,414	-	-	-	0,294	0,336	14,539
101	3,3	-	-1535,211	-1528,862	0,414	-	-	-	-0,584	-0,336	42,368

102	0	-	-1339,481	-1335,170	0,322	-	-	-	-1,350	-1,103	18,315
102	3,3	-	-1339,481	-1335,170	0,322	-	-	-	1,679	1,103	34,328
103	0	-	-1146,039	-1139,324	0,586	-	-	-	2,983	2,407	19,321
103	1,8	-	-1146,039	-1139,324	0,586	-	-	-	-2,899	-2,407	16,978
104	0	-	-949,707	-943,478	0,656	-	-	-	-1,443	-0,950	34,114
104	3,3	-	-949,707	-943,478	0,656	-	-	-	1,021	0,950	6,933
105	0	-	-753,417	-747,632	0,768	-	-	-	0,757	0,686	9,366
105	3,3	-	-753,417	-747,632	0,768	-	-	-	-0,761	-0,686	9,783
106	0	-	-556,533	-551,786	0,853	-	-	-	-0,077	-0,003	96,373
106	3,3	-	-556,533	-551,786	0,853	-	-	-	0,009	0,003	67,059
107	0	-	-359,413	-355,940	0,966	-	-	-	0,280	0,275	2,034
107	3,3	-	-359,413	-355,940	0,966	-	-	-	-0,298	-0,275	7,852
108	0	-	-161,826	-160,094	1,070	-	-	-	0,569	0,593	4,110
108	3,3	-	-161,826	-160,094	1,070	-	-	-	-0,594	-0,593	0,202
109	0	-	-160,169	-160,094	0,047	-	-	-	-0,048	-0,047	1,660
109	3,3	-	-160,169	-160,094	0,047	-	-	-	0,045	0,047	4,636
110	0	-	-356,137	-355,940	0,055	-	-	-	-0,043	-0,427	895,105
110	3,3	-	-356,137	-355,940	0,055	-	-	-	0,043	0,427	895,105
111	0	-	-552,114	-551,786	0,059	-	-	-	-0,041	-0,040	0,741
111	3,3	-	-552,114	-551,786	0,059	-	-	-	0,038	0,040	7,200

112	0	-	-748,251	-747,632	0,083	-	-	-	-0,094	-0,091	2,872
112	3,3	-	-748,251	-747,632	0,083	-	-	-	0,087	0,091	4,702
113	0	-	-944,335	-943,478	0,091	-	-	-	-0,082	-0,082	0,366
113	3,3	-	-944,335	-943,478	0,091	-	-	-	0,079	0,082	3,418
114	0	-	-1140,842	-1139,324	0,133	-	-	-	-0,104	-0,102	2,589
114	1,8	-	-1140,842	-1139,324	0,133	-	-	-	0,105	0,102	2,961
115	0	-	-1334,397	-1335,170	0,058	-	-	-	-0,076	-0,079	4,101
115	3,3	-	-1334,397	-1335,170	0,058	-	-	-	0,071	0,079	11,631
116	0	-	-1530,399	-1528,862	0,100	-	-	-	-0,136	-0,128	6,016
116	3,3	-	-1530,399	-1528,862	0,100	-	-	-	0,115	0,128	11,295
117	0	-	-1726,496	-1724,708	0,104	-	-	-	-0,140	-0,126	9,319
117	3,3	-	-1726,496	-1724,708	0,104	-	-	-	0,103	0,126	22,578
118	0	-	-1922,473	-1920,554	0,100	-	-	-	-0,236	-0,213	9,881
118	3,3	-	-1922,473	-1920,554	0,100	-	-	-	0,287	0,213	25,855
119	0	-	-2118,486	-2116,400	0,098	-	-	-	-1,821	-1,322	27,401
119	3,3	-	-2118,486	-2116,400	0,098	-	-	-	1,597	1,322	17,219
120	0	-	-2314,390	-2312,246	0,093	-	-	-	-0,510	-0,785	53,964
120	6	-	-2314,390	-2312,246	0,093	-	-	-	1,227	0,785	36,066
121	0	-	-2317,863	-2312,246	0,242	-	-	-	1,688	0,602	64,326
121	6	-	-2317,863	-2312,246	0,242	-	-	-	-0,976	-0,602	38,288

122	0	-	-2122,023	-2116,400	0,265	-	-	-	1,360	1,734	27,459
122	3,3	-	-2122,023	-2116,400	0,265	-	-	-	-1,841	-1,734	5,818
123	0	-	-1926,364	-1920,554	0,302	-	-	-	0,039	0,146	274,615
123	3,3	-	-1926,364	-1920,554	0,302	-	-	-	-0,407	-0,146	64,086
124	0	-	-1730,735	-1724,708	0,348	-	-	-	0,704	0,964	37,022
124	3,3	-	-1730,735	-1724,708	0,348	-	-	-	-0,945	-0,964	2,031
125	0	-	-1535,127	-1528,862	0,408	-	-	-	-0,068	-0,087	28,444
125	3,3	-	-1535,127	-1528,862	0,408	-	-	-	0,317	0,087	72,684
126	0	-	-1339,400	-1335,170	0,316	-	-	-	1,482	1,251	15,579
126	3,3	-	-1339,400	-1335,170	0,316	-	-	-	-1,819	-1,251	31,254
127	0	-	-1145,965	-1139,324	0,580	-	-	-	-2,778	-2,210	20,465
127	1,8	-	-1145,965	-1139,324	0,580	-	-	-	2,698	2,210	18,080
128	0	-	-949,634	-943,478	0,648	-	-	-	1,586	1,098	30,760
128	3,3	-	-949,634	-943,478	0,648	-	-	-	-1,170	-1,098	6,163
129	0	-	-753,346	-747,632	0,758	-	-	-	-0,594	-0,522	12,144
129	3,3	-	-753,346	-747,632	0,758	-	-	-	0,584	0,522	10,670
130	0	-	-556,472	-551,786	0,842	-	-	-	0,148	0,086	41,914
130	3,3	-	-556,472	-551,786	0,842	-	-	-	-0,086	-0,086	0,819
131	0	-	-359,372	-355,940	0,955	-	-	-	-0,198	-0,198	0,354
131	3,3	-	-359,372	-355,940	0,955	-	-	-	0,217	0,198	8,360

132	0	-	-161,801	-160,094	1,055	-	-	-	-0,483	-0,501	3,751
132	3,3	-	-161,801	-160,094	1,055	-	-	-	0,501	0,501	0,020
133	0	-	-158,772	-160,094	0,833	-	-	-	-6,423	-6,423	0,000
133	3,3	-	-158,772	-160,094	0,833	-	-	-	6,408	6,423	0,231
134	0	-	-348,960	-355,940	2,000	-	-	-	-6,540	-6,526	0,226
134	3,3	-	-348,960	-355,940	2,000	-	-	-	6,213	6,526	5,035
135	0	-	-540,891	-551,786	2,014	-	-	-	-6,089	-5,777	5,137
135	3,3	-	-540,891	-551,786	2,014	-	-	-	5,864	5,777	1,489
136	0	-	-728,259	-747,632	2,660	-	-	-	-13,839	-13,926	0,632
136	3,3	-	-728,259	-747,632	2,660	-	-	-	12,543	13,926	11,023
137	0	-	-913,317	-943,478	3,302	-	-	-	-13,997	-12,615	9,878
137	3,3	-	-913,317	-943,478	3,302	-	-	-	13,714	12,615	8,017
138	0	-	-1099,111	-1139,324	3,659	-	-	-	-9,463	-10,562	11,619
138	1,8	-	-1099,111	-1139,324	3,659	-	-	-	8,951	10,562	18,001
139	0	-	-1283,250	-1335,170	4,046	-	-	-	-11,731	-10,120	13,736
139	3,3	-	-1283,250	-1335,170	4,046	-	-	-	10,176	10,120	0,551
140	0	-	-1470,990	-1528,862	3,934	-	-	-	-12,348	-12,404	0,454
140	3,3	-	-1470,990	-1528,862	3,934	-	-	-	10,898	12,404	13,818
141	0	-	-1658,931	-1724,708	3,965	-	-	-	-10,802	-9,296	13,942
141	3,3	-	-1658,931	-1724,708	3,965	-	-	-	9,845	9,296	5,576

142	0	-	-1848,899	-1920,554	3,876	-	-	-	-7,317	-7,866	7,504
142	3,3	-	-1848,899	-1920,554	3,876	-	-	-	5,837	7,866	34,755
143	0	-	-2041,437	-2116,400	3,672	-	-	-	-6,502	-4,473	31,202
143	3,3	-	-2041,437	-2116,400	3,672	-	-	-	5,931	4,473	24,584
144	0	-	-2234,021	-2312,246	3,502	-	-	-	-4,133	-5,591	35,279
144	6	-	-2234,021	-2312,246	3,502	-	-	-	3,466	5,591	61,339
145	0	-	-1304,694	-1276,194	2,184	-	-	-	4,744	6,586	38,842
145	6	-	-1304,694	-1276,194	2,184	-	-	-	-6,362	-6,586	3,518
146	0	-	-1124,977	-1058,200	5,936	-	-	-	19,105	29,809	56,024
146	3,3	-	-1124,977	-1058,200	5,936	-	-	-	-30,532	-29,809	2,368
147	0	-	-1023,338	-960,277	6,162	-	-	-	37,578	38,301	1,924
147	3,3	-	-1023,338	-960,277	6,162	-	-	-	-36,853	-38,301	3,928
148	0	-	-919,318	-862,354	6,196	-	-	-	37,646	36,198	3,845
148	3,3	-	-919,318	-862,354	6,196	-	-	-	-38,065	-36,198	4,905
149	0	-	-813,327	-764,431	6,012	-	-	-	41,467	43,334	4,502
149	3,3	-	-813,327	-764,431	6,012	-	-	-	-48,269	-43,334	10,224
150	0	-	-707,216	-667,585	5,604	-	-	-	30,504	35,439	16,177
150	3,3	-	-707,216	-667,585	5,604	-	-	-	-33,994	-35,439	4,250
151	0	-	-602,615	-569,662	5,468	-	-	-	42,761	41,317	3,378
151	1,8	-	-602,615	-569,662	5,468	-	-	-	-42,736	-41,317	3,322

152	0	-	-495,418	-471,739	4,780	-	-	-	37,958	39,378	3,741
152	3,3	-	-495,418	-471,739	4,780	-	-	-	-39,502	-39,378	0,314
153	0	-	-387,235	-373,816	3,465	-	-	-	43,048	43,172	0,288
153	3,3	-	-387,235	-373,816	3,465	-	-	-	-49,828	-43,172	13,357
154	0	-	-281,981	-275,893	2,159	-	-	-	22,750	29,405	29,255
154	3,3	-	-281,981	-275,893	2,159	-	-	-	-26,401	-29,405	11,379
155	0	-	-181,446	-177,970	1,916	-	-	-	29,142	26,138	10,309
155	3,3	-	-181,446	-177,970	1,916	-	-	-	-28,905	-26,138	9,573
156	0	-	-79,633	-80,047	0,520	-	-	-	30,699	33,466	9,013
156	3,3	-	-79,633	-80,047	0,520	-	-	-	-33,466	-33,466	0,000
157	0	-	-162,831	-160,094	1,681	-	-	-	0,624	0,974	56,074
157	6	-	-162,831	-160,094	1,681	-	-	-	-0,974	-0,974	0,010
158	0	-	-158,937	-160,094	0,728	-	-	-	0,191	0,112	41,536
158	6	-	-158,937	-160,094	0,728	-	-	-	-0,112	-0,112	0,000
159	0	-	-160,882	-160,094	0,490	-	-	-	0,231	0,198	14,341
159	6	-	-160,882	-160,094	0,490	-	-	-	-0,198	-0,198	0,000
160	0	-	-157,445	-160,094	1,682	-	-	-	0,444	0,440	0,776
160	6	-	-157,445	-160,094	1,682	-	-	-	-0,632	-0,440	30,317
161	0	-	-172,479	-160,094	7,181	-	-	-	-0,675	-1,610	138,392
161	6	-	-172,479	-160,094	7,181	-	-	-	1,610	1,610	0,000

162	0	-	-69,859	-80,047	14,584	-	-	-	4,759	9,313	95,686
162	6	-	-69,859	-80,047	14,584	-	-	-	-9,313	-9,313	0,000
163	0	1,172	-	-	-	-38,106	-40,024	5,032	-44,663	-46,908	5,026
163	2,5	1,172	-	-	-	41,941	40,024	4,572	50,604	53,151	5,034
163	5	1,172	-	-	-	41,941	40,024	4,572	-54,248	-46,908	13,531
164	0	1,304	-	-	-	-40,844	-40,024	2,009	-53,274	-52,191	2,033
164	2,5	1,304	-	-	-	39,203	40,024	2,093	48,836	47,868	1,983
164	5	1,304	-	-	-	39,203	40,024	2,093	-49,171	-52,191	6,140
165	0	1,236	-	-	-	-39,687	-40,024	0,848	-49,059	-49,469	0,835
165	2,5	1,236	-	-	-	40,360	40,024	0,834	50,158	50,590	0,860
165	5	1,236	-	-	-	40,360	40,024	0,834	-50,741	-49,469	2,507
166	0	1,249	-	-	-	-40,475	-40,024	1,116	-50,544	-49,989	1,097
166	2,5	1,249	-	-	-	39,572	40,024	1,141	50,644	50,069	1,134
166	5	1,249	-	-	-	39,572	40,024	1,141	-48,286	-49,989	3,527
167	0	1,260	-	-	-	-37,826	-40,024	5,809	-47,655	-50,430	5,823
167	2,5	1,260	-	-	-	42,221	40,024	5,205	46,910	49,629	5,796
167	5	1,260	-	-	-	42,221	40,024	5,205	-58,642	-50,430	14,004
168	0	1,200	-	-	-	-50,211	-40,024	20,289	-60,252	-48,028	20,288
168	2,5	1,200	-	-	-	29,836	40,024	34,145	65,276	52,031	20,291
168	5	1,200	-	-	-	29,836	40,024	34,145	-9,313	-48,028	415,695

Appendix 4

Table A4. 1. Beam reinforcement detail

Level	Location	A-B											
		Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
12	TOP	473,831	3@12&2@10	496	4,68%	409,218	4@12	452	10,45%	409,218	4@12	452	10,45%
	BOTTOM	409,218	4@12	452	10,45%	818,077	4@12&5@10	845	3,29%	409,218	4@12	452	10,45%
11	TOP	997,934	2@20&5@10	1021	2,31%	409,218	2@20	628	53,46%	693,57	2@20&2@10	785	13,18%
	BOTTOM	476,848	2@20	628	31,70%	1232,225	4@20	1260	2,25%	409,218	2@20	628	53,46%
10	TOP	1130,717	2@12&3@20	1169	3,39%	409,218	4@12	452	10,45%	846,726	4@16&2@6	860,6	1,64%
	BOTTOM	536,639	5@12	566	5,47%	1243,108	3@12&3@20	1282	3,13%	409,218	4@12	452	10,45%
9	TOP	1564,837	5@20	1570	0,33%	409,218	2@20	628	53,46%	898,259	3@20	943	4,98%
	BOTTOM	725,332	2@20&2@8	729	0,51%	1180,416	3@20&5@8	1195	1,24%	431,359	2@20	628	45,59%
8	TOP	1859,409	5@20&3@12	1909	2,67%	409,218	2@20	628	53,46%	933,842	3@20	943	0,98%
	BOTTOM	847,029	3@16&4@10	914	7,91%	1148,982	5@16&2@10	1169	1,74%	447,657	3@16	603	34,70%
7	TOP	1756,476	4@20&5@12	1826	3,96%	409,218	2@20	628	53,46%	945,537	2@20&3@12	967	2,27%
	BOTTOM	805,116	4@16	804	-0,14%	1141,704	5@16&2@10	1169	2,39%	452,999	3@16	603	33,11%
6	TOP	1786,645	5@20&2@12	1796	0,52%	409,218	2@20	628	53,46%	1035,278	2@20&4@12	1080	4,32%
	BOTTOM	817,47	2@20&2@12	854	4,47%	1079,844	2@20&4@12	1080	0,01%	493,758	2@20	628	27,19%
5	TOP	2190,722	4@20&5@16	2270	3,62%	467,453	2@20	628	34,35%	1360,816	2@20&4@16	1432	5,23%
	BOTTOM	977,256	2@20&4@12	1080	10,51%	1132,406	3@20&2@12	1169	3,23%	637,986	2@20	628	-1,57%
4	TOP	2295,218	5@20&4@16	2374	3,43%	491,865	2@20	628	27,68%	1509,815	5@20	1570	3,99%
	BOTTOM	1031,089	4@20	1260	22,20%	1119,688	4@20	1260	12,53%	702,016	3@20	943	34,33%
3	TOP	2353,559	5@20&4@16	2374	0,87%	505,579	2@20	628	24,21%	1735,658	3@20&4@16	1747	0,65%
	BOTTOM	1061,481	4@20	1260	18,70%	1122,114	4@20	1260	12,29%	796,558	3@20	943	18,38%
2	TOP	2384,31	8@20	2510	5,27%	512,822	2@20	628	22,46%	1995,871	7@20	2200	10,23%
	BOTTOM	1077,575	4@20	1260	16,93%	1120,685	4@20	1260	12,43%	901,548	3@20	943	4,60%
1	TOP	2536,333	8@20	2510	-1,04%	548,764	2@20	628	14,44%	2372,189	8@20	2510	5,81%
	BOTTOM	1157,902	4@20	1260	8,82%	1130,077	4@20	1260	11,50%	1071,225	4@20	1260	17,62%

Level	Location	B-C											
		Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
12	TOP	538,032	2@12&4@10	540	0,37%	409,218	4@12	452	10,45%	669,487	4@12&3@10	688	2,77%
	BOTTOM	409,218	4@12	452	10,45%	683,905	4@12&3@10	688	0,60%	409,218	4@12	452	10,45%
11	TOP	936,264	3@20	943	0,72%	409,218	2@20	628	53,46%	1065,185	3@20&2@10	1100	3,27%
	BOTTOM	409,218	2@20	628	53,46%	1140,995	3@20&3@10	1179	3,33%	507,247	2@20	628	23,81%
10	TOP	1051,46	4@12&2@20	1080	2,71%	409,218	4@12	452	10,45%	1145,263	2@12&3@20	1169	2,07%
	BOTTOM	501,063	5@12	566	12,96%	1134,634	2@12&3@20	1169	3,03%	543,132	5@12	566	4,21%
9	TOP	1230,365	4@20	1260	2,41%	409,218	2@20	628	53,46%	1317,717	4@20&2@8	1361	3,28%
	BOTTOM	580,888	2@20	628	8,11%	1129,677	3@20&4@8	1144	1,27%	619,227	2@20	628	1,42%
8	TOP	1386,695	3@20&4@12	1395	0,60%	409,218	2@20	628	53,46%	1429,59	4@20&2@12	1486	3,95%
	BOTTOM	649,199	2@16&4@10	716	10,29%	1122,496	5@16&2@10	1169	4,14%	667,7	2@16&4@10	716	7,23%
7	TOP	1362,55	3@20&4@12	1395	2,38%	409,218	2@20	628	53,46%	1423,79	4@20&2@12	1486	4,37%
	BOTTOM	638,739	2@16&4@10	716	12,10%	1118,616	4@16&4@10	1118	-0,06%	665,205	2@16&4@10	716	7,64%
6	TOP	1405,348	4@20&2@12	1486	5,74%	409,218	2@20	628	53,46%	1466,148	4@20&2@12	1486	1,35%
	BOTTOM	657,258	2@20&2@12	854	29,93%	1053,975	2@20&4@12	1080	2,47%	683,384	2@20&2@12	854	24,97%
5	TOP	1766,507	4@20&3@16	1863	5,46%	409,218	2@20	628	53,46%	1765,268	4@20&3@16	1863	5,54%
	BOTTOM	809,23	2@20&2@12	854	5,53%	1110,474	3@20&2@12	1169	5,27%	808,722	2@20&2@12	854	5,60%
4	TOP	1928,188	5@20&2@16	1972	2,27%	420,514	2@20	628	49,34%	1920,32	5@20&2@16	1972	2,69%
	BOTTOM	874,659	3@20	943	7,81%	1106,671	4@20	1260	13,85%	871,514	3@20	943	8,20%
3	TOP	2060,386	4@20&4@16	2064	0,18%	444,481	2@20	628	41,29%	2050,036	4@20&4@16	2064	0,68%
	BOTTOM	926,898	3@20	943	1,74%	1104,64	4@20	1260	14,06%	922,85	3@20	943	2,18%
2	TOP	2184,85	7@20	2200	0,69%	470,947	2@20	628	33,35%	2205,962	7@20	2200	-0,27%
	BOTTOM	975,012	2@20&2@16	1030	5,64%	1103,336	4@20	1260	14,20%	984,941	2@20&2@16	1030	4,57%
1	TOP	2351,253	8@20	2510	6,75%	510,177	2@20	628	23,09%	2373,086	8@20	2510	5,77%
	BOTTOM	1060,276	4@20	1260	18,84%	1100,146	4@20	1260	14,53%	1071,694	4@20	1260	17,57%

Level	Location	C-D											
		Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
12	TOP	653,49	4@12&3@10	688	5,28%	409,218	4@12	452	10,45%	654,275	4@12&3@10	688	5,15%
	BOTTOM	409,218	4@12	452	10,45%	643,399	4@12&3@10	688	6,93%	409,218	4@12	452	10,45%
11	TOP	1047,958	3@20&2@10	1100	4,97%	409,218	2@20	628	53,46%	1058,882	3@20&2@10	1100	3,88%
	BOTTOM	499,483	2@20	628	25,73%	1096,478	3@20&2@10	1100	0,32%	504,408	2@20	628	24,50%
10	TOP	1141,339	2@12&3@20	1169	2,42%	409,218	4@12	452	10,45%	1148,224	2@12&3@20	1169	1,81%
	BOTTOM	541,382	5@12	566	4,55%	1096,848	2@12&3@20	1169	6,58%	544,453	5@12	566	3,96%
9	TOP	1304,886	4@20&2@8	1361	4,30%	409,218	2@20	628	53,46%	1318,594	4@20&2@8	1361	3,22%
	BOTTOM	613,623	2@28	628	2,34%	1097,995	3@20&4@8	1144	4,19%	619,61	2@20	628	1,35%
8	TOP	1432,515	4@20&2@12	1486	3,73%	409,218	2@20	628	53,46%	1444,439	4@20&2@12	1486	2,88%
	BOTTOM	668,958	2@16&4@10	716	7,03%	1097,979	4@16&4@10	1118	1,82%	674,08	2@16&4@10	716	6,22%
7	TOP	1395,118	3@20&4@12	1395	-0,01%	409,218	2@20	628	53,46%	1424,639	4@20&2@12	1486	4,31%
	BOTTOM	652,84	2@16&4@10	716	9,67%	1100,323	4@16&4@10	1118	1,61%	665,57	2@16&4@10	716	7,58%
6	TOP	1441,952	4@20&2@12	1486	3,05%	409,218	2@20	628	53,46%	1468,405	4@20&2@12	1486	1,20%
	BOTTOM	673,012	2@20&2@12	854	26,89%	1036,965	2@20&4@12	1080	4,15%	684,35	2@20&2@12	854	24,79%
5	TOP	1779,701	4@20&3@16	1863	4,68%	409,218	2@20	628	53,46%	1789,898	4@20&3@16	1863	4,08%
	BOTTOM	814,632	2@20&2@12	854	4,83%	1098,214	3@20&2@12	1169	6,45%	818,798	2@20&2@12	854	4,30%
4	TOP	1925,013	5@20&2@16	1970	2,34%	422,791	2@20	628	48,54%	1940,591	5@20&2@16	1970	1,52%
	BOTTOM	873,39	3@20	943	7,97%	1098,833	4@20	1260	14,67%	879,609	3@20	943	7,21%
3	TOP	2061,507	4@20&4@16	2064	0,12%	446,836	2@20	628	40,54%	2073,579	5@20&3@16	2173	4,79%
	BOTTOM	927,336	3@20	943	1,69%	1098,374	4@20	1260	14,72%	932,047	3@20	943	1,18%
2	TOP	2189,942	7@20	2200	0,46%	473,575	2@20	628	32,61%	2217,193	7@20	2200	-0,78%
	BOTTOM	976,958	2@20&2@16	1030	5,43%	1098,629	4@20	1260	14,69%	990,725	2@20&2@16	1030	3,96%
1	TOP	2356,157	8@20	2510	6,53%	512,798	2@20	628	22,47%	2384,209	8@20	2510	5,28%
	BOTTOM	1062,839	4@20	1260	18,55%	1098,363	4@20	1260	14,72%	1077,521	4@20	1260	16,94%

Level	Location	D-E											
		Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
12	TOP	653,813	4@12&3@10	688	5,23%	409,218	4@12	452	10,45%	653,822	4@12&3@10	688	5,23%
	BOTTOM	409,218	4@12	452	10,45%	643,388	4@12&3@10	688	6,93%	409,218	4@12	452	10,45%
11	TOP	1057,717	3@20&2@10	1100	4,00%	409,218	2@20	628	53,46%	1049,134	3@20&2@10	1100	4,85%
	BOTTOM	503,883	2@20	628	24,63%	1096,447	3@20&2@10	1100	0,32%	500,013	2@20	628	25,60%
10	TOP	1147,004	2@12&3@10	1169	1,92%	409,218	4@12	452	10,45%	1142,029	2@12&3@10	1169	2,36%
	BOTTOM	543,908	5@12	566	4,06%	1096,833	2@12&3@20	1169	6,58%	541,69	5@12	566	4,49%
9	TOP	1316,242	4@20&2@8	1361	3,40%	409,218	2@20	628	53,46%	1305,726	4@20&2@8	1361	4,23%
	BOTTOM	618,584	2@20	628	1,52%	1097,971	3@20&4@8	1144	4,19%	613,99	2@20	628	2,28%
8	TOP	1441,201	4@20&2@12	1486	3,11%	409,218	2@20	628	53,46%	1433,571	4@20&2@12	1486	3,66%
	BOTTOM	672,69	2@16&4@10	716	6,44%	1097,956	4@16&4@10	1118	1,83%	669,412	2@16&4@10	716	6,96%
7	TOP	1421,611	4@20&2@12	1486	4,53%	409,218	2@20	628	53,46%	1397,151	3@20&4@12	1395	-0,15%
	BOTTOM	664,267	2@16&4@10	716	7,79%	1100,298	4@16&4@10	1118	1,61%	653,719	2@16&4@10	716	9,53%
6	TOP	1465,93	4@20&2@12	1486	1,37%	409,218	2@20	628	53,46%	1444,916	4@20&2@12	1486	2,84%
	BOTTOM	683,291	2@20&2@12	854	24,98%	1036,948	2@20&4@12	1080	4,15%	674,285	2@20&2@12	854	26,65%
5	TOP	1786,811	4@20&3@16	1863	4,26%	409,218	2@20	628	53,46%	1783,278	4@20&3@16	1863	4,47%
	BOTTOM	817,538	2@20&2@12	854	4,46%	1098,205	3@20&2@12	1169	6,45%	816,094	2@20&2@12	854	4,64%
4	TOP	1936,205	5@20&2@16	1970	1,75%	421,986	2@20	628	48,82%	1928,724	5@20&2@16	1970	2,14%
	BOTTOM	877,859	3@20	943	7,42%	1098,83	4@20	1260	14,67%	874,873	3@20	943	7,79%
3	TOP	2068,597	5@20&3@16	2173	5,05%	445,948	2@20	628	40,82%	2068,463	5@20&3@16	2173	5,05%
	BOTTOM	930,104	3@20	943	1,39%	1098,367	4@20	1260	14,72%	930,052	3@20	943	1,39%
2	TOP	2200,494	7@20	2200	-0,02%	473,178	2@20		-100,00%	2215,499	7@20	2200	-0,70%
	BOTTOM	982,127	2@20&2@16	1030	4,87%	1098,726	4@20	1260	14,68%	989,852	2@20&2@16	1030	4,06%
1	TOP	2356,226	8@20	2510	6,53%	511,754	2@20	628	22,72%	2379,78	8@20	2510	5,47%
	BOTTOM	1062,875	4@20	1260	18,55%	1098,136	4@20	1260	14,74%	1075,201	4@20	1260	17,19%

Level	Location	E-F											
		Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
12	TOP	668,04	4@12&3@10	688	2,99%	409,218	4@12	452	10,45%	542,588	5@12	566	4,31%
	BOTTOM	409,218	4@12	452	10,45%	683,186	4@12&3@10	688	0,70%	409,218	4@12	452	10,45%
11	TOP	1062,692	3@20&2@10	1100	3,51%	409,218	2@20	628	53,46%	942,345	3@20	943	0,07%
	BOTTOM	506,125	2@20	628	24,08%	1140,317	3@20&3@10	1179	3,39%	451,542	2@20	628	39,08%
10	TOP	1142,653	2@12&3@20	1169	2,31%	409,218	4@12	452	10,45%	1055,657	4@12&2@20	1080	2,31%
	BOTTOM	541,968	5@12	566	4,43%	1133,941	2@12&3@20	1169	3,09%	502,955	5@12	566	12,53%
9	TOP	1312,596	4@20&2@8	1361	3,69%	409,218	2@20	628	53,46%	1233,523	4@20	1260	2,15%
	BOTTOM	616,992	2@30	628	1,78%	1129,133	3@20&4@8	1144	1,32%	582,282	2@20	628	7,85%
8	TOP	1422,725	4@20&2@12	1486	4,45%	409,218	2@20	628	53,46%	1389,181	3@20&4@12	1395	0,42%
	BOTTOM	664,746	2@16&4@10	716	7,71%	1122,065	5@16&2@10	1169	4,18%	650,274	2@16&4@10	716	10,11%
7	TOP	1417,852	4@20&2@12	1486	4,81%	409,218	2@20	628	53,46%	1367,074	3@20&4@12	1395	2,04%
	BOTTOM	662,648	2@16&4@10	716	8,05%	1118,237	4@16&4@10	1118	-0,02%	640,701	2@16&4@10	716	11,75%
6	TOP	1461,903	4@20&2@12	1486	1,65%	409,218	2@20	628	53,46%	1412,407	4@20&2@12	1486	5,21%
	BOTTOM	681,567	2@20&2@12	854	25,30%	1053,583	2@20&4@12	1080	2,51%	660,302	2@20&2@12	854	29,33%
5	TOP	1759,974	4@20&3@16	1863	5,85%	409,218	2@20	628	53,46%	1774,827	4@20&3@16	1863	4,97%
	BOTTOM	806,551	2@20&2@12	854	5,88%	1110,154	3@20&2@12	1169	5,30%	812,637	2@20&2@12	854	5,09%
4	TOP	1911,381	5@20&2@16	1970	3,07%	421,808	2@20	628	48,88%	1935,234	5@20&2@16	1970	1,80%
	BOTTOM	867,936	3@20	943	8,65%	1106,337	4@20	1260	13,89%	877,472	3@20	943	7,47%
3	TOP	2045,068	4@20&4@16	2064	0,93%	447,081	2@20	628	40,47%	2074,953	5@20&3@16	2173	4,73%
	BOTTOM	920,904	3@20	943	2,40%	1104,708	4@20	1260	14,06%	932,583	3@20	943	1,12%
2	TOP	2188,325	7@20	2200	0,53%	474,532	2@20	628	32,34%	2221,284	7@20	2200	-0,96%
	BOTTOM	976,34	2@20&2@16	1030	5,50%	1102,166	4@20	1260	14,32%	992,833	2@20&2@16	1030	3,74%
1	TOP	2347,7	8@20	2510	6,91%	512,51	2@20	628	22,53%	2382,986	8@20	2510	5,33%
	BOTTOM	1058,421	4@20	1260	19,05%	1102,02	4@20	1260	14,34%	1076,881	4@20	1260	17,00%

Level	Location	F-G											
		Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
12	TOP	409,218	4@12	452	10,45%	409,218	4@12	452	10,45%	474,68	3@12&2@10	496	4,49%
	BOTTOM	409,218	4@12	452	10,45%	817,55	4@12&5@10	845	3,36%	409,218	4@12	452	10,45%
11	TOP	701,801	2@20&2@10	785	11,86%	409,218	2@20	628	53,46%	996,718	2@20&5@10	1021	2,44%
	BOTTOM	409,218	2@20	628	53,46%	1231,864	4@20	1260	2,28%	476,296	2@20	628	31,85%
10	TOP	853,036	2@12&2@20	854	0,11%	409,218	4@12	452	10,45%	1127,952	2@12&3@20	1169	3,64%
	BOTTOM	410,553	4@12	452	10,10%	1242,694	3@12&3@20	1282	3,16%	535,404	5@12	566	5,71%
9	TOP	903,336	3@20	943	4,39%	409,218	2@20	628	53,46%	1556,129	5@20	1570	0,89%
	BOTTOM	433,688	2@20	628	44,80%	1180,163	3@20&5@8	1195	1,26%	721,654	2@20&2@8	729	1,02%
8	TOP	938,336	3@20	943	0,50%	409,218	2@20	628	53,46%	1846,463	5@20&3@12	1909	3,39%
	BOTTOM	449,71	3@16	603	34,09%	1148,817	5@16&4@10	1169	1,76%	841,795	3@16&4@10	914	8,58%
7	TOP	953,544	2@20&3@12	967	1,41%	409,218	2@20	628	53,46%	1747,816	4@20&5@12	1826	4,47%
	BOTTOM	456,653	3@16	603	32,05%	1141,55	5@16&&2@10	1169	2,40%	801,559	4@16	804	0,30%
6	TOP	1047,28	2@20&4@12	1080	3,12%	409,218	2@20	628	53,46%	1783,576	5@20&2@12	1796	0,70%
	BOTTOM	499,177	2@20	628	25,81%	1079,684	2@0&4@12	1080	0,03%	816,216	2@20&2@12	854	4,63%
5	TOP	1374,568	2@20&4@16	1432	4,18%	466,637	2@20	628	34,58%	2186,027	4@20&5@16	2270	3,84%
	BOTTOM	643,949	2@20	628	-2,48%	1132,233	3@20&2@12	1169	3,25%	975,462	2@20&4@12	1080	10,72%
4	TOP	1521,503	5@20	1570	3,19%	490,309	2@20	628	28,08%	2288,593	5@20&4@16	2374	3,73%
	BOTTOM	706,984	3@20		-100,00%	1119,76	4@20	1260	12,52%	1027,649	4@20	1260	22,61%
3	TOP	1751,23	3@20&4@16	1747	-0,24%	504,418	2@20	628	24,50%	2348,624	5@20&4@16	2374	1,08%
	BOTTOM	802,962	3@20	943	17,44%	1121,004	4@20	1260	12,40%	1058,904	4@20	1260	18,99%
2	TOP	2042,277	7@20	2200	7,72%	525,134	2@20	628	19,59%	2436,497	8@20	2510	3,02%
	BOTTOM	919,81	3@20	943	2,52%	1126,182	4@20	1260	11,88%	1105,004	4@20	1260	14,03%
1	TOP	2234,64	8@20	2510	12,32%	537,362	2@20	628	16,87%	2488,209	8@20	2510	0,88%
	BOTTOM	999,723	4@20	1260	26,03%	1100,697	4@20	1260	14,47%	1132,334	4@20	1260	11,27%

Level	Location	G-H											
		Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
1	TOP	1451,062	4@12&5@16	1462	0,75%	409,218	4@12	452	10,45%	1023,662	4@12&3@16	1055	3,06%
	BOTTOM	676,921	6@12	679	0,31%	825,61	8@12	905	9,62%	488,506	5@12	566	15,86%
Level	Location	H-I											
		Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
1	TOP	710,052	3@12&2@16	741	4,36%	409,218	4@12	452	10,45%	665,928	3@12&2@16	741	11,27%
	BOTTOM	409,218	4@12	452	10,45%	630,24	6@12	679	7,74%	409,218	4@12	452	10,45%
Level	Location	I-J											
		Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
1	TOP	750,17	3@12&2@16	741	-1,22%	409,218	4@12	452	10,45%	745,363	3@12&2@16	741	-0,59%
	BOTTOM	409,218	4@12	452	10,45%	646,872	6@12	679	4,97%	409,218	4@12	452	10,45%
Level	Location	J-K											
		Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
1	TOP	726,176	3@12&2@16	741	2,04%	409,218	4@12	452	10,45%	706,655	3@12&2@16	741	4,86%
	BOTTOM	409,218	4@12	452	10,45%	651,799	6@12	679	4,17%	409,218	4@12	452	10,45%
Level	Location	K-L											
		Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
1	TOP	690,573	3@12&2@16	741	7,30%	409,218	4@12	452	10,45%	812,77	4@12&2@16	854	5,07%
	BOTTOM	409,218	4@12	452	10,45%	610,703	6@12	679	11,18%	409,218	4@12	628	53,46%
Level	Location	L-M											
		Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
1	TOP	888,62	5@12&2@16	968	8,93%	409,218	4@12	452	10,45%	409,218	4@12	452	10,45%
	BOTTOM	426,932	4@12	452	5,87%	817,752	8@12	905	10,67%	409,218	4@12	452	10,45%

Table A4. 2. Beam shear reinforcement detail

A-B																
Level	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
12	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%
11	0,359	8mm@275mm	0,366	1,95%	0,338	8mm@275mm	0,366	8,28%	0,296	6mm@175mm	0,323	9,12%	0,318	6mm@175mm	0,323	1,57%
10	0,369	8mm@250mm	0,402	8,94%	0,348	8mm@275mm	0,366	5,17%	0,319	6mm@175mm	0,323	1,25%	0,341	8mm@275mm	0,366	7,33%
9	0,413	8mm@225mm	0,447	8,23%	0,392	8mm@250mm	0,402	2,55%	0,303	6mm@175mm	0,323	6,60%	0,324	8mm@300mm	0,335	3,40%
8	0,441	8mm@225mm	0,447	1,36%	0,42	8mm@225mm	0,447	6,43%	0,302	6mm@175mm	0,323	6,95%	0,323	6mm@175mm	0,323	0,00%
7	0,431	8mm@225mm	0,447	3,71%	0,409	8mm@225mm	0,447	9,29%	0,3	6mm@175mm	0,323	7,67%	0,321	8mm@300mm	0,335	4,36%
6	0,423	8mm@225mm	0,447	5,67%	0,402	8mm@250mm	0,402	0,00%	0,309	6mm@175mm	0,323	4,53%	0,331	8mm@300mm	0,335	1,21%
5	0,474	8mm@200mm	0,503	6,12%	0,452	8mm@200mm	0,503	11,28%	0,36	8mm@275mm	0,366	1,67%	0,381	8mm@250mm	0,402	5,51%
4	0,489	8mm@200mm	0,503	2,86%	0,468	8mm@200mm	0,503	7,48%	0,376	8mm@250mm	0,402	6,91%	0,397	8mm@250mm	0,402	1,26%
3	0,497	8mm@200mm	0,503	1,21%	0,476	8mm@200mm	0,503	5,67%	0,407	8mm@225mm	0,447	9,83%	0,428	8mm@225mm	0,447	4,44%
2	0,502	8mm@200mm	0,503	0,20%	0,481	8mm@200mm	0,503	4,57%	0,439	8mm@225mm	0,447	1,82%	0,46	8mm@200mm	0,503	9,35%
1	0,523	8mm@175mm	0,575	9,94%	0,502	8mm@200mm	0,503	0,20%	0,495	8mm@200mm	0,503	1,62%	0,516	8mm@175mm	0,575	11,43%
B-C																
Level	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
12	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%
11	0,331	8mm@300mm	0,335	1,21%	0,31	8mm@300mm	0,335	8,06%	0,323	8mm@300mm	0,335	3,72%	0,351	8mm@275	0,366	4,27%
10	0,344	8mm@275mm	0,366	6,40%	0,323	8mm@300mm	0,335	3,72%	0,339	8mm@275mm	0,366	7,96%	0,36	8mm@275mm	0,366	1,67%
9	0,36	8mm@275mm	0,366	1,67%	0,338	8mm@275mm	0,366	8,28%	0,346	8mm@275mm	0,366	5,78%	0,374	8mm@250mm	0,402	7,49%
8	0,376	8mm@250mm	0,402	6,91%	0,355	8mm@275mm	0,366	3,10%	0,362	8mm@275mm	0,366	1,10%	0,383	8mm@250mm	0,402	4,96%
7	0,372	8mm@250mm	0,402	8,06%	0,351	8mm@275mm	0,366	4,27%	0,36	8mm@275mm	0,366	1,67%	0,382	8mm@250mm	0,402	5,24%
6	0,373	8mm@250mm	0,402	7,77%	0,352	8mm@275mm	0,366	3,98%	0,36	8mm@275mm	0,366	1,67%	0,382	8mm@250mm	0,402	5,24%
5	0,424	8mm@225mm	0,447	5,42%	0,403	8mm@250mm	0,402	-0,25%	0,403	8mm@250mm	0,402	-0,25%	0,424	8mm@225mm	0,447	5,42%
4	0,444	8mm@225mm	0,447	0,68%	0,422	8mm@225mm	0,447	5,92%	0,422	8mm@225mm	0,447	5,92%	0,443	8mm@225mm	0,447	0,90%
3	0,459	8mm@200mm	0,503	9,59%	0,438	8mm@225mm	0,447	2,05%	0,437	8mm@225mm	0,447	2,29%	0,458	8mm@200mm	0,503	9,83%
2	0,473	8mm@200mm	0,503	6,34%	0,452	8mm@200mm	0,503	11,28%	0,455	8mm@200mm	0,503	10,55%	0,476	8mm@200mm	0,503	5,67%
1	0,498	8mm@200mm	0,503	1,00%	0,477	8mm@200mm	0,503	5,45%	0,48	8mm@200mm	0,503	4,79%	0,501	8mm@200mm	0,503	0,40%

C-D																
Level	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
12	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%
11	0,339	8mm@275	0,366	7,96%	0,318	8mm@300mm	0,335	5,35%	0,319	8mm@300mm	0,335	5,02%	0,341	8mm@275	0,366	7,33%
10	0,352	8mm@275mm	0,366	3,98%	0,33	8mm@300mm	0,335	1,52%	0,331	8mm@300mm	0,335	1,21%	0,353	8mm@275mm	0,366	3,68%
9	0,365	8mm@275mm	0,366	0,27%	0,344	8mm@275mm	0,366	6,40%	0,346	8mm@275mm	0,366	5,78%	0,367	8mm@275mm	0,366	-0,27%
8	0,378	8mm@250mm	0,402	6,35%	0,357	8mm@275mm	0,366	2,52%	0,358	8mm@275mm	0,366	2,23%	0,38	8mm@250mm	0,402	5,79%
7	0,373	8mm@250mm	0,402	7,77%	0,352	8mm@275mm	0,366	3,98%	0,356	8mm@275mm	0,366	2,81%	0,378	8mm@250mm	0,402	6,35%
6	0,375	8mm@250mm	0,402	7,20%	0,353	8mm@275mm	0,366	3,68%	0,357	8mm@275mm	0,366	2,52%	0,378	8mm@250mm	0,402	6,35%
5	0,424	8mm@225mm	0,447	5,42%	0,402	8mm@250mm	0,402	0,00%	0,404	8mm@225mm	0,447	10,64%	0,425	8mm@225mm	0,447	5,18%
4	0,442	8mm@225mm	0,447	1,13%	0,421	8mm@225mm	0,447	6,18%	0,422	8mm@225mm	0,447	5,92%	0,444	8mm@225mm	0,447	0,68%
3	0,458	8mm@200mm	0,503	9,83%	0,437	8mm@225mm	0,447	2,29%	0,438	8mm@225mm	0,447	2,05%	0,46	8mm@200mm	0,503	9,35%
2	0,473	8mm@200mm	0,503	6,34%	0,452	8mm@200mm	0,503	11,28%	0,456	8mm@200mm	0,503	10,31%	0,477	8mm@200mm	0,503	5,45%
1	0,498	8mm@200mm	0,503	1,00%	0,477	8mm@200mm	0,503	5,45%	0,482	8mm@200mm	0,503	4,36%	0,503	8mm@200mm	0,503	0,00%
D-E																
Level	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
12	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%
11	0,341	8mm@275mm	0,366	7,33%	0,319	8mm@300mm	0,335	5,02%	0,318	8mm@300mm	0,335	5,35%	0,34	8mm@275mm	0,366	7,65%
10	0,353	8mm@275mm	0,366	3,68%	0,331	8mm@300mm	0,335	1,21%	0,33	8mm@300mm	0,335	1,52%	0,352	8mm@275mm	0,366	3,98%
9	0,367	8mm@275mm	0,366	-0,27%	0,346	8mm@275mm	0,366	5,78%	0,344	8mm@275mm	0,366	6,40%	0,366	8mm@275mm	0,366	0,00%
8	0,379	8mm@250mm	0,402	6,07%	0,358	8mm@275mm	0,366	2,23%	0,357	8mm@275mm	0,366	2,52%	0,378	8mm@250mm	0,402	6,35%
7	0,377	8mm@250mm	0,402	6,63%	0,356	8mm@275mm	0,366	2,81%	0,352	8mm@275mm	0,366	3,98%	0,374	8mm@250mm	0,402	7,49%
6	0,378	8mm@250mm	0,402	6,35%	0,357	8mm@275mm	0,366	2,52%	0,354	8mm@275mm	0,366	3,39%	0,375	8mm@250mm	0,402	7,20%
5	0,425	8mm@225mm	0,447	5,18%	0,403	8mm@250mm	0,402	-0,25%	0,403	8mm@250mm	0,402	-0,25%	0,424	8mm@225mm	0,447	5,42%
4	0,443	8mm@225mm	0,447	0,90%	0,422	8mm@225mm	0,447	5,92%	0,421	8mm@225mm	0,447	6,18%	0,442	8mm@225mm	0,447	1,13%
3	0,459	8mm@200mm	0,503	9,59%	0,438	8mm@225mm	0,447	2,05%	0,438	8mm@225mm	0,447	2,05%	0,459	8mm@200mm	0,503	9,59%
2	0,475	8mm@200mm	0,503	5,89%	0,453	8mm@200mm	0,503	11,04%	0,455	8mm@200mm	0,503	10,55%	0,477	8mm@200mm	0,503	5,45%
1	0,498	8mm@200mm	0,503	1,00%	0,477	8mm@200mm	0,503	5,45%	0,481	8mm@200mm	0,503	4,57%	0,502	8mm@200mm	0,503	0,20%

E-F																
Level	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
12	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%
11	0,351	8mm@275	0,366	4,27%	0,33	8mm@300mm	0,335	1,52%	0,31	8mm@300mm	0,335	8,06%	0,332	8mm@300mm	0,335	0,90%
10	0,36	8mm@275mm	0,366	1,67%	0,338	8mm@275mm	0,366	8,28%	0,324	8mm@300mm	0,335	3,40%	0,345	8mm@275mm	0,366	6,09%
9	0,373	8mm@250mm	0,402	7,77%	0,352	8mm@275mm	0,366	3,98%	0,339	8mm@275mm	0,366	7,96%	0,36	8mm@275mm	0,366	1,67%
8	0,382	8mm@250mm	0,402	5,24%	0,36	8mm@275mm	0,366	1,67%	0,355	8mm@275mm	0,366	3,10%	0,377	8mm@250mm	0,402	6,63%
7	0,381	8mm@250mm	0,402	5,51%	0,359	8mm@275mm	0,366	1,95%	0,351	8mm@275mm	0,366	4,27%	0,373	8mm@250mm	0,402	7,77%
6	0,381	8mm@250mm	0,402	5,51%	0,36	8mm@275mm	0,366	1,67%	0,352	8mm@275mm	0,366	3,98%	0,374	8mm@250mm	0,402	7,49%
5	0,424	8mm@225mm	0,447	5,42%	0,402	8mm@250mm	0,402	0,00%	0,404	8mm@225mm	0,447	10,64%	0,425	8mm@225mm	0,447	5,18%
4	0,442	8mm@225mm	0,447	1,13%	0,42	8mm@225mm	0,447	6,43%	0,423	8mm@225mm	0,447	5,67%	0,444	8mm@225mm	0,447	0,68%
3	0,457	8mm@200mm	0,503	10,07%	0,436	8mm@225mm	0,447	2,52%	0,44	8mm@225mm	0,447	1,59%	0,461	8mm@200mm	0,503	9,11%
2	0,474	8mm@200mm	0,503	6,12%	0,452	8mm@200mm	0,503	11,28%	0,457	8mm@200mm	0,503	10,07%	0,479	8mm@200mm	0,503	5,01%
1	0,498	8mm@200mm	0,503	1,00%	0,477	8mm@200mm	0,503	5,45%	0,482	8mm@200mm	0,503	4,36%	0,503	8mm@200mm	0,503	0,00%
F-G																
Level	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %	Required	Detailing	Provided	Error, %
12	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%
11	0,319	8mm@300mm	0,335	5,02%	0,297	6mm@175mm	0,323	8,75%	0,338	8mm@275mm	0,366	8,28%	0,359	8mm@275mm	0,366	1,95%
10	0,342	8mm@275mm	0,366	7,02%	0,32	6mm@175mm	0,323	0,94%	0,347	8mm@275mm	0,366	5,48%	0,369	8mm@250mm	0,402	8,94%
9	0,325	8mm@300mm	0,335	3,08%	0,304	6mm@175mm	0,323	6,25%	0,39	8mm@250mm	0,402	3,08%	0,412	8mm@225mm	0,447	8,50%
8	0,323	8mm@300mm	0,335	3,72%	0,302	6mm@175mm	0,323	6,95%	0,418	8mm@225mm	0,447	6,94%	0,439	8mm@225mm	0,447	1,82%
7	0,323	8mm@300mm	0,335	3,72%	0,301	6mm@175mm	0,323	7,31%	0,408	8mm@225mm	0,447	9,56%	0,429	8mm@225mm	0,447	4,20%
6	0,332	8mm@300mm	0,335	0,90%	0,311	6mm@175mm	0,323	3,86%	0,401	8mm@250mm	0,402	0,25%	0,422	8mm@225mm	0,447	5,92%
5	0,383	8mm@250mm	0,402	4,96%	0,362	8mm@275mm	0,366	1,10%	0,452	8mm@200mm	0,503	11,28%	0,473	8mm@200mm	0,503	6,34%
4	0,399	8mm@250mm	0,402	0,75%	0,378	8mm@250mm	0,402	6,35%	0,466	8mm@200mm	0,503	7,94%	0,488	8mm@200mm	0,503	3,07%
3	0,43	8mm@225mm	0,447	3,95%	0,408	8mm@225mm	0,447	9,56%	0,475	8mm@200mm	0,503	5,89%	0,497	8mm@200mm	0,503	1,21%
2	0,468	8mm@200mm	0,503	7,48%	0,447	8mm@225mm	0,447	0,00%	0,487	8mm@200mm	0,503	3,29%	0,509	8mm@175mm	0,575	12,97%
1	0,483	8mm@200mm	0,503	4,14%	0,462	8mm@200mm	0,503	8,87%	0,497	8mm@200mm	0,503	1,21%	0,518	8mm@200mm	0,503	-2,90%

<b>G-H</b>																
<b>Level</b>	<b>Required</b>	<b>Detailing</b>	<b>Provided</b>	<b>Error, %</b>	<b>Required</b>	<b>Detailing</b>	<b>Provided</b>	<b>Error, %</b>	<b>Required</b>	<b>Detailing</b>	<b>Provided</b>	<b>Error, %</b>	<b>Required</b>	<b>Detailing</b>	<b>Provided</b>	<b>Error, %</b>
1	0,298	6mm@175mm	0,323	8,39%	0,29	6mm@175mm	0,323	11,38%	0,3	6mm@175mm	0,323	7,67%	0,321	6mm@175mm	0,323	0,62%
<b>H-I</b>																
1	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%
<b>I-J</b>																
1	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%
<b>J-K</b>																
1	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%
<b>K-L</b>																
1	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%
<b>L-M</b>																
1	0,296	6mm@175mm	0,323	9,12%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%	0,29	6mm@175mm	0,323	11,38%

Appendix 5

Table A5.1. Column reinforcement detail

A					B					C				
Level	Required	Detailing	Provided	Error, %	Level	Required	Detailing	Provided	Error, %	Level	Required	Detailing	Provided	Error, %
12	1909,173	4@25	1960	2,66%	12	900	8@12	905	0,56%	12	900	8@12	905	0,56%
11	1879,188	4@25	1960	4,30%	11	900	8@12	905	0,56%	11	900	8@12	905	0,56%
10	2497,921	8@20	2510	0,48%	10	2288,42	12@16	2414	5,49%	10	2474,869	8@20	2510	1,42%
9	1600	8@16	1610	0,63%	9	1600	8@16	1610	0,63%	9	1600	8@16	1610	0,63%
8	1600	8@16	1610	0,63%	8	1600	8@16	1610	0,63%	8	1600	8@16	1610	0,63%
7	1600	8@16	1610	0,63%	7	1921,042	4@25	1960	2,03%	7	2206,422	12@16	2414	9,41%
6	1911,007	4@25	1960	2,56%	6	4339,075	8@25&4@12	4382	0,99%	6	4646,028	4@32&6@16	4830	3,96%
5	2500	8@20	2510	0,40%	5	2500	8@20	2510	0,40%	5	2500	8@20	2510	0,40%
4	2500	8@20	2510	0,40%	4	2500	8@20	2510	0,40%	4	2768,165	4@25&8@12	2865	3,50%
3	2500	8@20	2510	0,40%	3	3938,59	4@32&8@12	4125	4,73%	3	4430,84	4@25&8@20	4470	0,88%
2	2500	8@20	2510	0,40%	2	5579,784	12@25	5890	5,56%	2	6232,881	8@32	6430	3,16%
1	3025	4@32	3220	6,45%	1	9162,987	12@32	9650	5,32%	1	10002,24	8@40	10100	0,98%
D					E					F				
Level	Required	Detailing	Provided	Error, %	Level	Required	Detailing	Provided	Error, %	Level	Required	Detailing	Provided	Error, %
12	900	8@12	905	0,56%	12	900	8@12	905	0,56%	12	900	8@12	905	0,56%
11	900	8@12	905	0,56%	11	900	8@12	905	0,56%	11	900	8@12	905	0,56%
10	1849,034	4@25	1960	6,00%	10	2475,129	8@20	2510	1,41%	10	2291,212	12@16	2414	5,36%
9	1600	8@16	1610	0,63%	9	1600	8@16	1610	0,63%	9	1600	8@16	1610	0,63%
8	1600	8@16	1610	0,63%	8	1600	8@16	1610	0,63%	8	1600	8@16	1610	0,63%
7	2103,283	4@20&8@12	2165	2,93%	7	2197,063	12@16	2414	9,87%	7	1933,722	4@25	1960	1,36%
6	4593,99	4@32&6@16	4830	5,14%	6	4645,146	4@32&6@16	4830	3,98%	6	4355,272	4@25&8@20	4470	2,63%
5	2500	8@20	2510	0,40%	5	2500	8@20	2510	0,40%	5	2500	8@20	2510	0,40%
4	2732,063	4@25&8@12	2865	4,87%	4	2765,045	4@25&8@12	2865	3,61%	4	2500	8@20	2510	0,40%
3	4581,184	4@32&6@16	4830	5,43%	3	4422,611	4@25&8@20	4470	1,07%	3	3965,604	4@32&8@12	4125	4,02%
2	6197,481	8@32	6430	3,75%	2	6215,243	8@32	6430	3,46%	2	5653,956	4@32&8@20	5730	1,34%
1	9961,897	8@40	10100	1,39%	1	9975,812	8@40	10100	1,24%	1	8889,828	4@40&8@25	8960	0,79%

G					H				
Level	Required	Detailing	Provided	Error, %	Level	Required	Detailing	Provided	Error, %
12	1915,38	4@25	1960	2,33%	1	978,892	4@16&8@6	1030	5,22%
11	1861,344	4@25	1960	5,30%	<b>I</b>				
10	2492,88	8@20	2510	0,69%	1	900	8@12	905	0,56%
9	1600	8@16	1610	0,63%	<b>J</b>				
8	1600	8@16	1610	0,63%	1	900	8@12	905	0,56%
7	1600	8@16	1610	0,63%	<b>K</b>				
6	1923,105	4@25	1960	1,92%	1	900	8@12	905	0,56%
5	2500	8@20	2510	0,40%	<b>L</b>				
4	2500	8@20	2510	0,40%	1	900	8@12	905	0,56%
3	2500	8@20	2510	0,40%	<b>M</b>				
2	2500	8@20	2510	0,40%	1	1235,193	4@20	1260	2,01%
1	3025	4@32	3220	6,45%					

## Appendix 6

Table A6. 1. One-way slab design

Floor	Dead Load	Live Load	Ultimate load	fck	fy	fctm	L	Slab depth	Slab width	Slab effective depth	Minimum reinforcement		Minimum reinforcement (controlled)
	kN/m <sup>2</sup>										kN/m <sup>2</sup>	kN/m <sup>2</sup>	
12	5,026	1,360	8,825	25	500	2,6	5	150	1000	126	170,4	163,8	170,4
11	6,456	4,000	14,716	25	500	2,6	5	150	1000	126	170,4	163,8	170,4
10	6,456	4,000	14,716	25	500	2,6	5	150	1000	126	170,4	163,8	170,4
9	6,456	4,000	14,716	25	500	2,6	5	150	1000	126	170,4	163,8	170,4
8	6,456	4,000	14,716	25	500	2,6	5	150	1000	126	170,4	163,8	170,4
7	6,456	4,000	14,716	25	500	2,6	5	150	1000	126	170,4	163,8	170,4
6	6,456	3,600	14,116	25	500	2,6	5	150	1000	126	170,4	163,8	170,4
5	6,456	4,000	14,716	25	500	2,6	5	150	1000	126	170,4	163,8	170,4
4	6,456	4,000	14,716	25	500	2,6	5	150	1000	126	170,4	163,8	170,4
3	6,456	4,000	14,716	25	500	2,6	5	150	1000	126	170,4	163,8	170,4
2	6,456	4,000	14,716	25	500	2,6	5	150	1000	126	170,4	163,8	170,4
1	6,456	4,000	14,716	25	500	2,6	5	150	1000	126	170,4	163,8	170,4

End Span															
	End support					Middle of end span					First interior support				
Floor	Moment	K	z/d	z	Required reinforcement	Moment (end span)	K	z/d	z	Required reinforcement	Moment (first interior support)	K	z/d	z	Required reinforcement
	kN-m			mm	mm <sup>2</sup>	kN-m			mm	mm <sup>2</sup>	kN-m			mm	mm <sup>2</sup>
12	-2,206	0,006	0,995	125,379	40,452	4,743	0,012	0,989	124,658	87,476	-4,743	0,012	0,989	124,658	87,476
11	-3,679	0,009	0,992	124,962	67,679	7,910	0,020	0,982	123,745	146,939	-7,910	0,020	0,982	123,745	146,939
10	-3,679	0,009	0,992	124,962	67,679	7,910	0,020	0,982	123,745	146,939	-7,910	0,020	0,982	123,745	146,939
9	-3,679	0,009	0,992	124,962	67,679	7,910	0,020	0,982	123,745	146,939	-7,910	0,020	0,982	123,745	146,939
8	-3,679	0,009	0,992	124,962	67,679	7,910	0,020	0,982	123,745	146,939	-7,910	0,020	0,982	123,745	146,939
7	-3,679	0,009	0,992	124,962	67,679	7,910	0,020	0,982	123,745	146,939	-7,910	0,020	0,982	123,745	146,939
6	-3,529	0,009	0,992	125,004	64,897	7,587	0,019	0,983	123,839	140,842	-7,587	0,019	0,983	123,839	140,842
5	-3,679	0,009	0,992	124,962	67,679	7,910	0,020	0,982	123,745	146,939	-7,910	0,020	0,982	123,745	146,939
4	-3,679	0,009	0,992	124,962	67,679	7,910	0,020	0,982	123,745	146,939	-7,910	0,020	0,982	123,745	146,939
3	-3,679	0,009	0,992	124,962	67,679	7,910	0,020	0,982	123,745	146,939	-7,910	0,020	0,982	123,745	146,939
2	-3,679	0,009	0,992	124,962	67,679	7,910	0,020	0,982	123,745	146,939	-7,910	0,020	0,982	123,745	146,939
1	-3,679	0,009	0,992	124,962	67,679	7,910	0,020	0,982	123,745	146,939	-7,910	0,020	0,982	123,745	146,939

Interior Span															
	First interior support					Middle of interior span					Interior support				
Floor	Moment	K	z/d	z	Required reinforcement	Moment	K	z/d	z	Required reinforcement	Moment (interior support)	K	z/d	z	Required reinforcement
	kN-m			mm	mm <sup>2</sup>	kN-m			mm	mm <sup>2</sup>	kN-m			mm	mm <sup>2</sup>
12	-4,743	0,012	0,989	124,658	87,476	3,475	0,009	0,992	125,020	63,896	-3,475	0,009	0,992	125,020	63,896
11	-7,910	0,020	0,982	123,745	146,939	5,794	0,015	0,987	124,356	107,113	-5,794	0,015	0,987	124,356	107,113
10	-7,910	0,020	0,982	123,745	146,939	5,794	0,015	0,987	124,356	107,113	-5,794	0,015	0,987	124,356	107,113
9	-7,910	0,020	0,982	123,745	146,939	5,794	0,015	0,987	124,356	107,113	-5,794	0,015	0,987	124,356	107,113
8	-7,910	0,020	0,982	123,745	146,939	5,794	0,015	0,987	124,356	107,113	-5,794	0,015	0,987	124,356	107,113
7	-7,910	0,020	0,982	123,745	146,939	5,794	0,015	0,987	124,356	107,113	-5,794	0,015	0,987	124,356	107,113
6	-7,587	0,019	0,983	123,839	140,842	5,558	0,014	0,987	124,424	102,689	-5,558	0,014	0,987	124,424	102,689
5	-7,910	0,020	0,982	123,745	146,939	5,794	0,015	0,987	124,356	107,113	-5,794	0,015	0,987	124,356	107,113
4	-7,910	0,020	0,982	123,745	146,939	5,794	0,015	0,987	124,356	107,113	-5,794	0,015	0,987	124,356	107,113
3	-7,910	0,020	0,982	123,745	146,939	5,794	0,015	0,987	124,356	107,113	-5,794	0,015	0,987	124,356	107,113
2	-7,910	0,020	0,982	123,745	146,939	5,794	0,015	0,987	124,356	107,113	-5,794	0,015	0,987	124,356	107,113
1	-7,910	0,020	0,982	123,745	146,939	5,794	0,015	0,987	124,356	107,113	-5,794	0,015	0,987	124,356	107,113

Table A6. 2. Slab reinforcement detail

End span												
Floor	End support				Middle of end span				First interior support			
	Required reinforcement	Detailing	Provided reinforcement	Error	Required reinforcement	Detailing	Provided reinforcement	Error	Required reinforcement	Detailing	Provided reinforcement	Error
	mm <sup>2</sup>		mm <sup>2</sup>	%	mm <sup>2</sup>		mm <sup>2</sup>	%	mm <sup>2</sup>		mm <sup>2</sup>	%
12	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
11	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
10	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
9	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
8	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
7	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
6	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
5	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
4	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
3	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
2	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
1	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%

Interior Span												
	First interior support				Middle of interior span				Interior support			
Floor	Required reinforcement	Detailing	Provided reinforcement	Error	Required reinforcement	Detailing	Provided reinforcement	Error	Required reinforcement	Detailing	Provided reinforcement	Error
	mm2		mm2	%	mm2		mm2	%	mm2		mm2	%
12	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
11	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
10	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
9	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
8	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
7	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
6	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
5	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
4	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
3	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
2	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%
1	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%	170,35	8mm@275mm	182,78	7,30%

## Appendix 7

Effect	Rank	Criteria
No	1	No effect
Very slight	2	Customer not annoyed
Slight	3	Customer slight annoyed
Minor	4	Customer experiences minor nuisance
Moderate	5	Customer experiences some dissatisfaction
Significant	6	Customer experiences discomfort
Major	7	Customer dissatisfied
Extreme	8	Customer very dissatisfied
Serious	9	Potential hazardous effect
Hazardous	10	Hazardous effect

Figure A7. 1. Severity guidelines for design

FMEA

Effect	Rank	Criteria
Almost never	1	Failure unlikely. History shows no failure
Remote	2	Rare number of failures likely
Very slight	3	Very few failures likely
Slight	4	Few failures likely
Low	5	Occasional number of failures likely
Medium	6	Medium number of failures likely
Moderately high	7	Moderately high number of failures likely
High	8	High number of failures likely
Very high	9	Very high number of failures likely
Almost certain	10	Failure almost certain

Figure A7. 2. Occurrence guidelines for design

FMEA

Effect	Rank	Criteria
Almost certain	1	Proven detection methods available in concept stage
Very high	2	Proven computer analysis available in early design stage
High	3	Simulation and/or modeling in early stage
Moderately high	4	Tests on early prototype system elements
Medium	5	Tests on preproduction system components
Low	6	Tests on similar system components
Slight	7	Tests on product with prototypes and system components installed
Very slight	8	Proving durability tests on products with system components installed
Remote	9	Only unproven or unreliable technique(s) available
Almost impossible	10	No known techniques available

Figure A7. 3. Detectability guidelines for design

FMEA