

**DESIGN OF “KENSEMAX BUSINESS CENTER” MULTI-STORY
COMMERCIAL BUILDING IN SAN-FRANCISCO, USA**

Capstone Project II

**Bachelor of Engineering
(Civil & Environmental Engineering)**



Group 2:

Ali Yessengeldin (201997989)

Amirzhan Zhunisbek (201836882)

Arulan Bauyrzhanov (201849048)

Baryskhan Zhumabek (201924725)

Bernar Kakabay (201993150)

Kuanysh Mukhamedkhan (201874161)

Serikbolsyn Maulembayev (201857925)

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Abstract

The main objective of this project is to design a multi-story commercial building located in San Francisco, California, USA. The address of the construction site is located at 2555 Irving St., Sunset District of San Francisco city. This project aims at increasing the commercial activity in the neighborhood by providing office spaces for companies of various sizes. The design is done by implementing previously obtained knowledge from courses in different disciplines of civil engineering, including architectural, structural, geotechnical, environmental design, and construction management.

The design of the structure and foundations was done according to the local building codes, mainly ASCE-7 by American Society of Civil Engineers and International Building Code (IBC). The design process involved performing hand calculations the results of which were then compared with the simulation results of software such as SAP2000, GEO5, and PLAXIS 3D.

The architectural and structural parts of the project focus on designing a structure that will be able to withstand the conditions from the surrounding environment, including seismic activity, corrosion, dead, live, and wind loads. The geotechnical part involves designing a proper foundation that will act as a support for transferring the structural loads from the building to the soil. Environmental design focuses on developing a strategy that will help to efficiently manage the waste produced by the daily activities of customers that rent the office spaces of the building. The purpose of construction management is to create a strategy for a more efficient allocation of resources, organizing the construction process into smaller tasks, reviewing various risks that may occur during the construction project.

Declaration

We hereby declare that this report entitled “*Design of “KenseMax Business Center” multi-story commercial building in San-Francisco, USA*” is the result of our own project work except for quotations and citations which have been duly acknowledged. We also declare that it has not been previously or concurrently submitted for any other degree at Nazarbayev University.

Ali Yessengeldin



Amirzhan Zhunisbek



Arulan Bauyrzhanov



Baryskhan Zhumabek



Bernar Kakabay



Kuanysh Mukhamedkhan



Serikbolsyn Maulembayev



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Introduction

The main goal of our Capstone Project is to design a 5-story high commercial building located at 2555 Irving St., Sunset District neighborhood of San Francisco, California, USA. The project is divided into several civil engineering disciplines, the workload for each section is distributed as follows:

- Architectural/Structural Design - 15%
- Geotechnical Design - 30%
- Environmental Design - 35%
- Construction Management - 20%

The name for the commercial building that needs to be designed for our project is “KenseMax Business Center”, which originates from a Kazakh word “kense”, meaning “office”. The reason behind this is because the main purpose of the construction project is to create a building meant for providing office space for companies of small to medium sizes.

The construction site is located at the northwestern part of San Francisco city. The reason why this location was chosen is because the main challenges of this region are related to high seismic activity coming from San Andreas fault, air salinity due to the proximity of the city to the Pacific Ocean, and high wind activity from meteorological conditions. The average annual level of humidity of 75% in San Francisco is due to the city being located near the ocean (Weather-and-climate.com, 2024). San Francisco is highly vulnerable to seismic activity from nearby faults, such as the San Andreas fault, Hayward fault, and Calaveras fault. One of the most devastating earthquakes in San Francisco with a magnitude of 7.9 took place on April 18, 1906, causing 3,000 casualties, injuring around 225,000 people, and leading to a loss of \$400 million USD due to property damage (California Earthquake Authority, 2020). Nowadays, the construction companies in the San Francisco Bay Area comply with the modified version of the International Building Code. For the design process, the local building codes will also be reviewed.

1. Architectural Design

1.1. Site Selection

San Francisco's significant seismic activity is largely due to its proximity to the San Andreas Fault. This fault is the source of major earthquakes in the area, including the catastrophic 1906 quake. Given the ongoing tectonic activity, the city enforces strict building codes and earthquake readiness strategies to reduce damage and ensure safety. Consequently, construction projects in San Francisco must adhere to both the International Building Code (IBC) and local regulations tailored to manage seismic risks. Additionally, continuous research helps enhance earthquake prediction and response.

1.2. Functionality of the building

The project involves constructing a five-story commercial building in San Francisco, California, designed to offer office spaces and parking facilities for lease to various business owners. Tenants will have the flexibility to customize their leased spaces to suit their specific business needs. All necessary technical communications and safety protocols will be thoroughly addressed prior to finalizing any lease agreements.

1.3. Site Analysis

The site for the new commercial building is located at 2555 Irving Street in the Sunset District of San Francisco, California. This area boasts proximity to parks, subway lines, and schools, as per Google Earth. The Sunset District is San Francisco's largest residential zone and is bordered by Golden Gate Park to the north and the Pacific Ocean along Ocean Beach to the west. The Parkside neighborhood marks the southeastern corner of the district. Originally covered with sand dunes, this area was known as the "Outside Lands" in the 19th century.

Development in the Sunset District began in earnest in the late 19th century following the creation of Golden Gate Park and accelerated after the 1906 earthquake. This led to the construction of row houses and tract homes on what were once sand dunes, replacing the small settlement of Carville. Carville was unique for its homes made from discarded cable cars and horse-drawn trolleys. By the 1930s, the Sunset had evolved into a streetcar suburb, and post-World War II growth saw the leveling of dunes for the construction of more residential buildings, many designed by Henry Doelger, featuring similar layouts and minimal spacing between them.

The district has historically been a hub for Irish and Italian communities, but since the late 1960s, there has been a significant increase in Asian, particularly Chinese, immigrants. This shift was spurred by the 1965 Immigration and Nationality Act and furthered by the Handover of Hong Kong, leading to political and economic uncertainties that drove immigration. By 1999, Chinese homeowners represented about 60% of the population in both the Sunset and Richmond districts.

San Francisco's climate features a wet season from November to April, with relatively consistent rainfall and occasional heavy downpours, and drier conditions prevail from late spring through early fall. Summer temperatures average in the mid-60s to low 70s Fahrenheit (18-24°C), while winter temperatures are usually in the mid-50s to low 60s Fahrenheit (12-17°C). The city is also known for its windy conditions, particularly near the coastal areas, which can make it feel cooler than actual temperatures suggest.

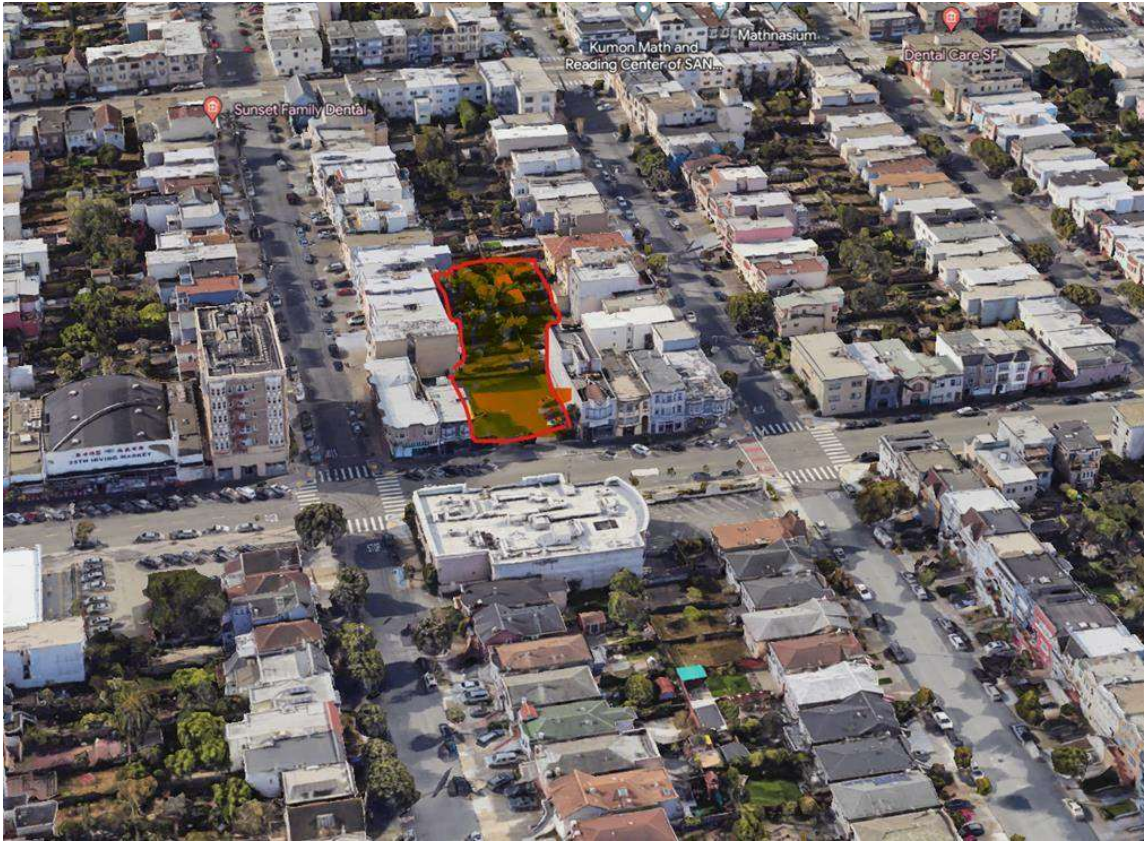


Figure 1.1. The site territory location (Google Earth)

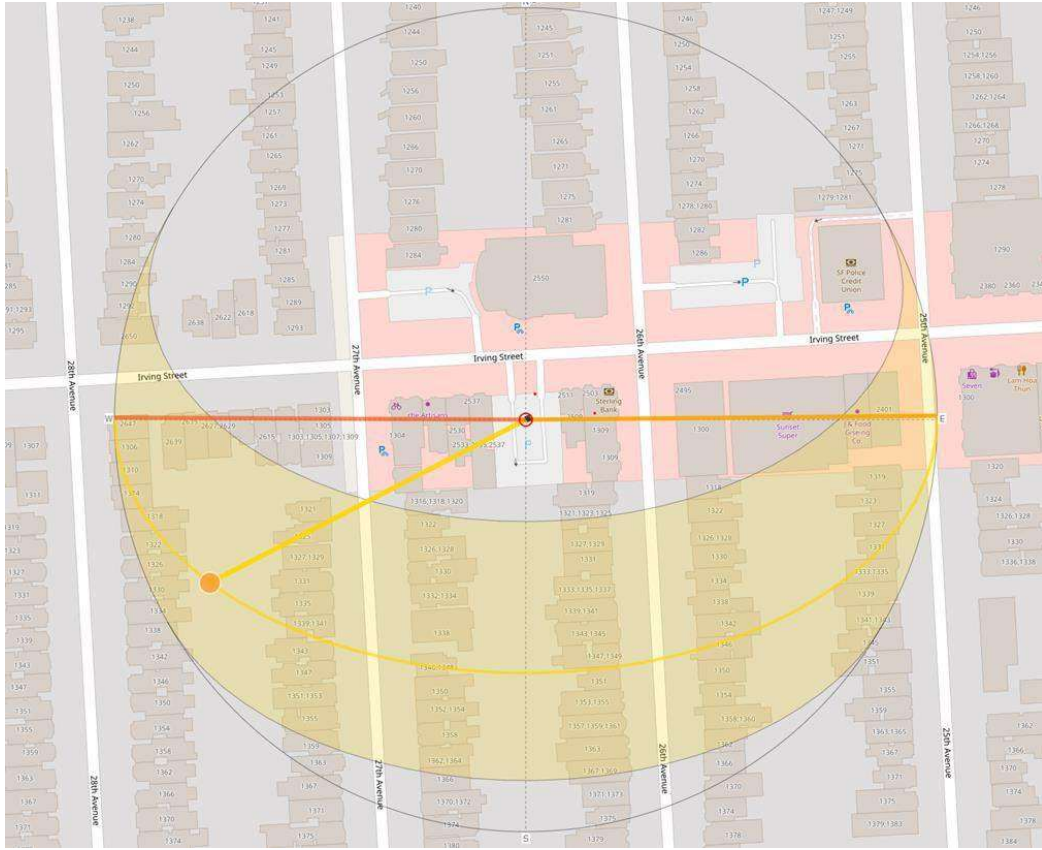


Figure 1.2. Sun path map on the site (*SunCalc sun position- und sun phases calculator, n.d.*)



Figure 1.3 San Francisco transit map (Belov, 2023)

1.4. Architectural Drawings

According to the International Building Code (IBC), our commercial building is classified under the B occupancy category, with specific requirements detailed in Chapter 4 of the IBC. The building is constructed under type 1A conditions, which involve the use of concrete and noncombustible main structural elements. The fire resistance of building assemblies can be selected based on ASTM E119 standards, while the fire resistance classification for finishes is guided by ASTM E84. To enhance safety, the building is equipped with automatic water sprinklers designed to facilitate the safe evacuation of occupants. The emergency exit routes are determined

by the building's occupancy type, construction type, height, and area. Given the relatively low building height and floor area, coupled with the high standards of fire safety, our facility is deemed safe for use.

Figure 1.3 presents a 3D model of the building, created using Autodesk Revit software, while Figure 1.4 illustrates the plan for the underground parking located beneath the first floor. Notably, the building features two elevator shafts with bulkheads on the roof and two staircases that provide access across all floors.

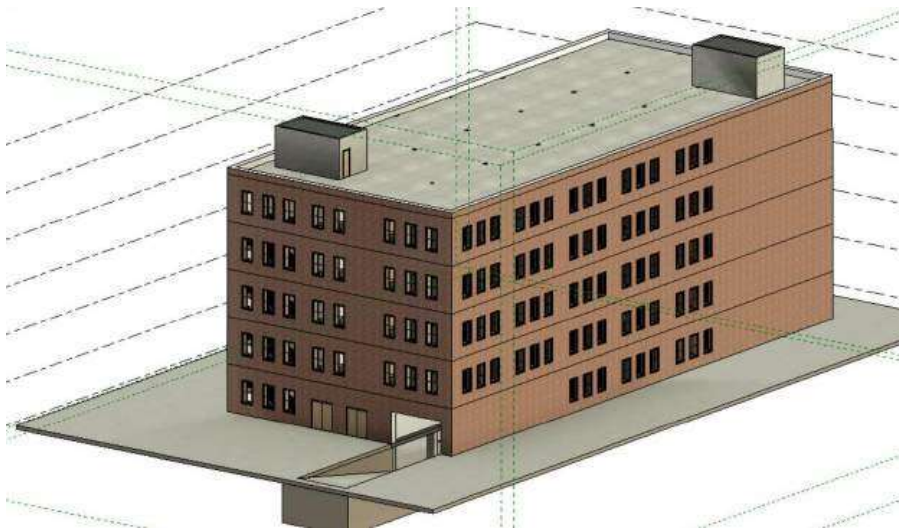


Figure 1.3 Architectural design of the building

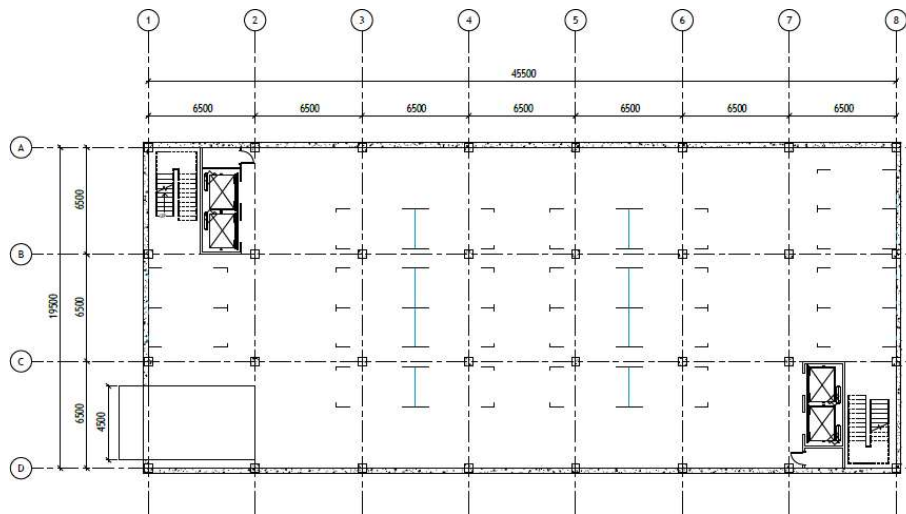


Figure 1.4 Underground parking lot (Floor 0) plan

1.5. LEED v4 for Neighborhood Development

Leads for neighborhood development (ND) can be applied for neighborhood-scale projects that are currently planning, designing or being constructed up to 75 percent of readiness. Our project is located in the Neighborhood District of San Francisco making it suitable for ND LEED certification.

ND certification has 5 main blocks of credits, which are Smart Location and Linkage (SLL), Neighborhood Pattern and Design (NPD), Green Infrastructure and Building (GIB), Innovation (IN), Regional Priority (RP). Special conditions of prerequisite should be satisfied for the SLL, NPD and GIB.

Prerequisite for Smart Location and Linkage (SLL)

- (1) Smart Location Required: Our project is located in the developed areas of San Francisco and can be served by existing water infrastructures. Project is also located instead of the current parking lot, making it infill development, therefore satisfying the Option 1 requirement of infill sites.

- (2) Imperiled Species and Ecological Communities Conservation: Site location satisfies requirement of Case 1. Sites without Affected Species or Ecological Community as there are no threatened or endangered animals in the neighborhood district.
- (3) Wetland and Water Body Conservation: Site has no sensitive areas such as wetlands and water bodies within 30 meters.
- (4) Agricultural Land Conservation: Project is located on an infill site, meets option 1.
- (5) Floodplain Avoidance: According to the San Francisco flood hazard map, our project location is entirely outside of any flood area().

Prerequisites for Neighborhood Pattern and Design (NPD) and Green Infrastructure and Building (GIB) require profound knowledge of city planning and implementation of construction technologies. For this capstone project it is assumed that the project will meet all prerequisite requirements. Calculation of LEED credits scores will be provided as an excel spreadsheet. Overall our project gained 51 points ranking it as Silver certification.

Smart Location & Linkage		15
Prereq	Smart Location	Required
Prereq	Imperiled Species and Ecological Communities	Required
Prereq	Wetland and Water Body Conservation	Required
Prereq	Agricultural Land Conservation	Required
Prereq	Floodplain Avoidance	Required
Credit	Preferred Locations	7
Credit	Brownfield Remediation	0
Credit	Access to Quality Transit	3
Credit	Bicycle Facilities	0
Credit	Housing and Jobs Proximity	1
Credit	Steep Slope Protection	1
Credit	Site Design for Habitat or Wetland and Water Body Conservation	1
Credit	Restoration of Habitat or Wetlands and Water Bodies	1
Credit	Long-Term Conservation Management of Habitat or Wetlands and Water Bodies	1

Figure 1.3 Credits for Smart Location and Linkage

Neighborhood Pattern & Design		19
Prereq	Walkable Streets	Required
Prereq	Compact Development	Required
Prereq	Connected and Open Community	Required
Credit	Walkable Streets	5
Credit	Compact Development	3
Credit	Mixed-Use Neighborhoods	3
Credit	Housing Types and Affordability	2
Credit	Reduced Parking Footprint	1
Credit	Connected and Open Community	1
Credit	Transit Facilities	0
Credit	Transportation Demand Management	0
Credit	Access to Civic & Public Space	1
Credit	Access to Recreation Facilities	1
Credit	Visibility and Universal Design	0
Credit	Community Outreach and Involvement	2
Credit	Local Food Production	0
Credit	Tree-Lined and Shaded Streetscapes	0
Credit	Neighborhood Schools	0

Figure 1.4 Credits for Neighborhood Pattern and Design

Green Infrastructure & Buildings		15
Prereq	Certified Green Building	Required
Prereq	Minimum Building Energy Performance	Required
Prereq	Indoor Water Use Reduction	Required
Prereq	Construction Activity Pollution Prevention	Required
Credit	Certified Green Buildings	1
Credit	Optimize Building Energy Performance	1
Credit	Indoor Water Use Reduction	1
Credit	Outdoor Water Use Reduction	2
Credit	Building Reuse	1
Credit	Historic Resource Preservation and Adaptive	0
Credit	Minimized Site Disturbance	1
Credit	Rainwater Management	1
Credit	Heat Island Reduction	0
Credit	Solar Orientation	0
Credit	Renewable Energy Production	0
Credit	District Heating and Cooling	2
Credit	Infrastructure Energy Efficiency	1
Credit	Wastewater Management	2
Credit	Recycled and Reused Infrastructure	1
Credit	Solid Waste Management	1
Credit	Light Pollution Reduction	0

Figure 1.5 Credits for Green Infrastructure and Buildings

Innovation & Design Process		0
Credit	Innovation	0
Credit	LEED® Accredited Professional	0

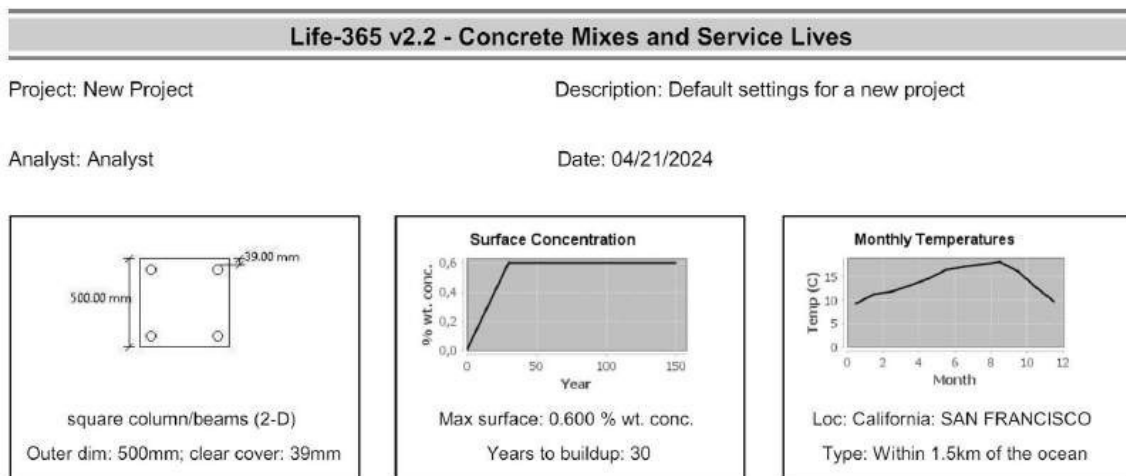
Figure 1.6 Credits for Innovation and Design Process

Regional Priority Credits			2
Credit	Regional Priority Credit: Region Defined		0
Credit	Regional Priority Credit: Region Defined		0
Credit	Regional Priority Credit: Region Defined		1
Credit	Regional Priority Credit: Region Defined		1

Figure 1.7 Credits for Regional Priority

1.6. Life-365 Software

In the software two different designs were compared. First was base design with 0.42 w/c ratio, alternative case was designed to have less w/c ratio in order to decrease the porosity and 50% of cementitious material was replaced with blast furnace slag. Results have shown that the concrete mixture that is selected for our construction project is suitable and cost effective in the resistance to chloride action.



Concrete Mixes

Alt name	User?	w/cm	SCMs	Inhib.	Barrier	Reinf.
Base case		0.42				Black Steel
Alternative 1		0.3	Slag (50%);			Black Steel

"n/a" indicates that, since the user is specifying the diffusion properties of this mix, this value is not specified.

Diffusion Properties and Service Lives

Alt name	D28	m	Ct	Init.	Prop.	Service life
Base case	8,87E-12 m ² /m/sec	0.2	0.05 % wt. conc.	8.6 yrs	6 yrs	14.6 yrs
Alternative 1	4,57E-12 m ² /m/sec	0.49	0.05 % wt. conc.	34.7 yrs	6 yrs	40.7 yrs

"->" indicates that the user has directly specified this value; "+" indicates the service life exceeds the study period.

Figure 1.8 Results of Life-365 Concrete Mixes and Service Lives

Life-365 v2.2 - Life-Cycle Costs				
Project: New Project	Description: Default settings for a new project			
Analyst: Analyst	Date: 04/21/2024			
Life-Cycle Costs				
Name	Construction Cost	Barrier Cost	Repair Cost	Life-Cycle Cost
Base case	\$48.31 per m	\$0.00 per m	\$962.14 per m	\$1,010.45 per m
Alternative 1	\$48.31 per m	\$0.00 per m	\$738.93 per m	\$787.24 per m

Graphs

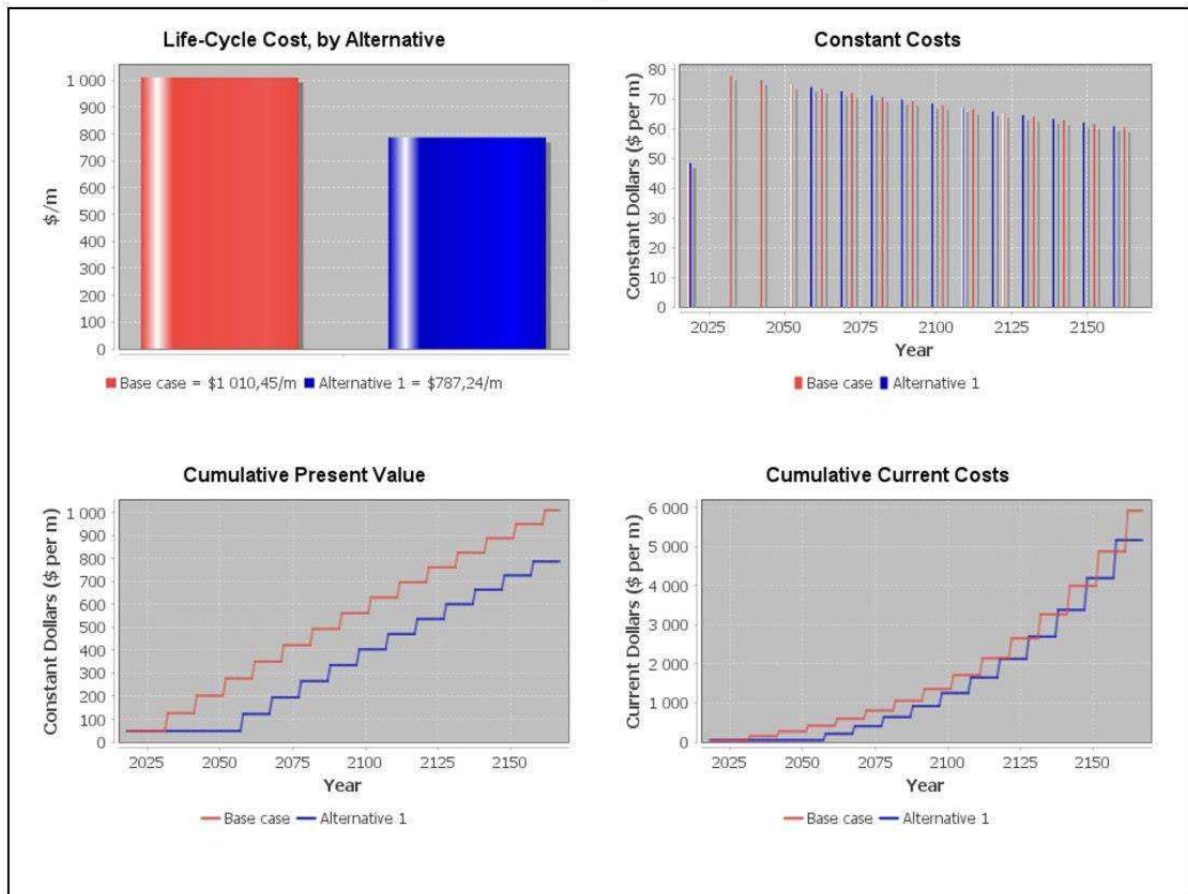


Figure 1.9 Results of Life-365 Life-Cycle Cost

2. Structural Design

2.1. Review of codes and standards

The ACI-318 code, officially known as the "ACI 318 Building Code Requirements for Structural Concrete," is a comprehensive standard issued by the American Concrete Institute (ACI) for designing and constructing concrete structures. It's widely used in the construction industry, particularly for projects involving concrete structures. The code includes guidelines on load calculations, strength design, and serviceability requirements. It also addresses the design of various structural elements like beams, columns, slabs, and foundations.

ACI-318 is used as a primary standard to meet the safety and regulatory requirements of the local building code of San Francisco. While ensuring the safe and quality design of structural members, code also helps to make cost effective decisions.

Incorporating the ACI-318 code in a construction capstone project not only ensures compliance with industry standards but also provides a robust framework for designing and executing a concrete structure project. Therefore ACI-318 code is the most suitable standard code to design the structural members of this capstone project.

The International Building Code (IBC) is a model building code developed by the International Code Council (ICC). It is widely adopted throughout the United States and in several other countries as a primary source for building design and construction regulations.

The IBC code provides comprehensive regulations for almost all aspects of building design and construction, including structural, fire protection, accessibility, and energy efficiency requirements. The code has extensive provisions for fire safety, including fire-resistance ratings, fire protection systems, and means of egress. It also incorporates standards for accessibility in buildings, ensuring that they are usable by people with disabilities.

Using the IBC code as the primary regulatory framework to ensure that the capstone project complies with the latest building standards. This is crucial for legal approvals and safety

certifications. Incorporating the IBC code in a construction capstone project provides a comprehensive and compliant approach to building design and construction. It ensures that the project adheres to the highest standards of safety, functionality, and sustainability.

The ASCE code, developed by the American Society of Civil Engineers, refers to a set of standards and guidelines that are crucial for civil engineering practices. While ASCE produces multiple standards, the most notable is ASCE 7, which focuses on minimum design loads for buildings and other structures.

ASCE 7 provides comprehensive guidelines for determining the design loads on buildings and other structures. It covers various load types, including dead, live, soil, flood, wind, snow, rain, earthquake, and other environmental loads. Performing a comprehensive analysis of the site, considering factors like wind speed, seismic activity, and snow loads as outlined in ASCE 7, informs critical decisions in the pre-design phase.

Integrating ASCE standards, especially ASCE 7, into a construction capstone project provides a solid foundation for designing and constructing structures that are safe, reliable, and compliant with industry standards. It ensures that our building design structure will withstand various environmental and load conditions.

Underwriters Laboratories (UL) is a global safety certification company that provides a broad range of safety-related certification, validation, testing, inspection, auditing, advising, and training services. UL standards focus on product safety and performance, and are highly regarded in various industries.

UL conducts tests to assess whether products comply with specific safety standards. This includes testing for electrical safety, fire resistance, material quality, and environmental impact. The UL fire-rated solutions for walls, roofings, ceilings are based on various ASTM testing methods. Assemblies that are designed to 1 hour fire-resistance are taken from USG corporation which

offers assemblies presented by UL solutions. Materials that are commercially offered by USG corporation are mentioned in the design of assemblies, and properties of materials can be found on USG site to ensure the compliance with the ASTM standards. Most of the weight properties of materials were taken from documentations presented in the USG corporate website.

Incorporating UL standards and certifications into a construction capstone project adds significant value in terms of safety, compliance, and quality. It demonstrates a commitment to building safely and responsibly, while also providing an educational opportunity to understand the importance of safety standards in the construction industry.

2.2. Design of non-structural members

Non-structural members were designed to meet the requirements of IBC chapter 6 table 601 fire-resistance rating requirements for building elements, where it is required to provide 1-hour fire protection rating for Type II A building for structural and non-structural elements. Leading design solutions were taken from the United States Gypsum Corporation (USG). Testing per ASTM standards can be provided for every design and material used commercially available at usg.com. This section provides design solutions for roofing, ceilings, flooring, interior partitions, and exterior walls.

The flooring design is not tested following ASTM. However, the concrete cover for reinforcement in the slab will provide primary fire protection. Fire protection for reinforcement steel in concrete will be provided by concrete cover by IBC chapter 7, table 721.1, minimum protection of structural parts based on periods.

Table 2.1 *Roofing Design for 1 Hour resistance Top to bottom*

Material	Weight
Mechanically attached, hot-mopped single-ply membrane	0.02943 kPa

Material	Weight
Polyisocyanurate insulation board 2" [50.8 mm], mechanically fastened to the gypsum sheathing	0.144 kPa
1/2" [12.7 mm] loosely laid gypsum board, mechanically attached to structural cement-fiber unit (Fiberock® Brand interior panels)	0.149 kPa
3/4" [19.1 mm] Structural cement-fiber unit (Structo Crete® Brand structural panels)	0.239 kPa
Steel joists 10" [254 mm] deep, 16ga. Spaced 20" o.c.	0.52 kPa
Insulation 3-1/2" [88.9 mm] glass fiber batt insulation	0.184 kPa
5/8" [15.9 mm] gypsum panel (Sheetrock® Brand Ecosmart panels Firecode X)	0.086 kPa
Sum:	1.352 kPa

Table 2.2 Floor Ceiling 1.5-hour fire-rated construction UL Des L527

Material	Weight
Two layers of 5/8" [15.9 mm] Sheetrock® Firecode C core gypsum panels (Comply with ASTM C1396)	0.21 kPa
RC-1 channel 1/2" [12.7 mm]	0.047 kPa

9-3/8" [238.1 mm] 16 gauge steel joists 24" o.c.	0.51 kPa
3/4" [19.1 mm] T&G plywood floor	0.09 kPa
Finishing (Beadex® Brand Silver Set 90 joint compound)	0.0025 kPa
Sum:	0.8595 kPa

Table 2.3 Floor Finishing Materials

Material	Weight
Ceramic tile [19 mm] on 13-mm mortar bed	0.77 kPa
Lightweight concrete screed [40 mm]	0.6 kPa
Single-ply sheet	0.03 kPa
Mineral wool for slab [40 mm]	0.051 kPa
Sum:	1.451 kPa

Table 2.4 Interior Partition 0.5 Hours Fire-Rated

Materials	Weight
Gypsum panel 5/8" [15.9 mm] (Sheetrock® Gypsum Panel)	0.106 kPa
Wood Studs 1 layer 2" x 4" [38 x 89 mm], 16" [406 mm] O.C.	0.192 kPa
Fiberglass insulation 3-1/2" [89 mm]	0.168 kPa

Gypsum panel 5/8" [15.9 mm] (Sheetrock® Gypsum Panel)	0.106 kPa
Sum:	0.572 kPa

Table 2.5 Exterior Walls 1 hour Fire-Rated

Materials	Weight
Gypsum panel 5/8" [15.9 mm] (Sheetrock® Gypsum Panel)	0.106 kPa
Wood Studs 1 layer 2" x 6" [38 x 140 mm], 16" [406 mm] O.C.	0.287 kPa
Fiberglass insulation 6-1/4" [159 mm]	0.299 kPa
Gypsum panel 5/8" [15.9 mm] (Sheetrock® Gypsum Panel)	0.106 kPa
Gypsum panel 5/8" [15.9 mm] (Sheetrock® Gypsum Panel)	0.106 kPa
Sum:	0.904 kPa

2.3. Design of Structural Members

Slab Design Direct Design Method The Minimum thickness of the two-way slab system was calculated per ACI-318 Table 8.3.1.2. The yield strength of the steel used in slabs and beams is required to calculate the modulus of elasticity. According to ACI-318, 8.2.6 steel yield strength should be selected per chapter 20, and concrete design properties should be chosen in accordance with chapter 19. 30 Mpa yield strength concrete and grade 60 steel with 420 Mpa yield strength are chosen for this building. According to ACI-318 table 6.6.3.1.1 to perform elastic analysis moments of inertia were multiplied by reduction factor of 0.35 for beams and 0.25 for slabs

$\alpha_f m$	Minimum h , in.	
$\alpha_f m \leq 0.2$	8.3.1.1 applies	
$0.2 < \alpha_f m \leq 2.0$	Greater of:	$\frac{l_n(0.8 + \frac{f_y}{200,000})}{36 + 5\beta(\alpha_{fm} - 0.2)}$
		5.0
$\alpha_f m > 2.0$	Greater of:	$\frac{l_n(0.8 + \frac{f_y}{200,000})}{36 + 9\beta}$
		3.5

Table 2.6 (ACI-318 Table 8.3.1.2)

$$\alpha_f = \frac{E_{cb} * I_b * 0.35}{E_{cs} * I_s * 0.25}$$

$$\alpha_{fm} = \frac{a}{f} + \frac{a}{f^2} + \frac{a}{f^3} + \frac{a}{f^4}$$

α_f - stiffness ratio

α_{fm} - average stiffness ratio

E_{cb} - Young's modulus of elasticity of beam concrete

E_{cs} - Young's modulus of elasticity of slab concrete

I_b - moment of inertia for beam

I_s - moment of inertia for slab

Iteration	Assumed Height (mm)	I_b (mm ⁴)	I_s (mm ⁴)	α_{fm}	Calculated Height (mm)
#1	250	$7.4377 \cdot 10^9$	$8.4635 \cdot 10^9$	1.2303	174
#2	200	$7.4377 \cdot 10^9$	$4.3334 \cdot 10^9$	2.4029	159

Table 2.7 Summarization of Iterations

Further iterations would create the same calculated value for height, therefore it was estimated to take 170 mm as a thickness of slab.

Limitations for Direct Design Method

Limitation	Check
There must be a minimum of three continuous spans in each direction.	Pass
The panels must be square or rectangular; the ratio of the longer to the shorter span within a panel must not exceed 2.0.	Pass
Adjacent spans in each direction must not differ by more than one-third of the longer span	Pass
Columns must not be offset by a maximum of	Pass

10% of the span length, in the direction of offset, from either axis between centerlines of successive columns.	
All loads shall be due to gravity only. All loads must be uniform, and the ratio of the unfactored live to unfactored dead load must not exceed 2.0.	Pass
If beams are present along all sides, the ratio of the relative stiffness of beams in two perpendicular directions, $\alpha_{f1}l_2^2/\alpha_{f2}l_1^2$ must not be less than 0.2 nor greater than 5.0.	Pass

Table 2.8 Limitation Check for Direct Design Method

Interior Slab

$$q_D = 7.86 + 0.170 * 23.6 = 11.872 \text{ kN/m}^2$$

$$q_u = 11.872 * 1.2 + 2.88 * 1.6 = 18.85 \text{ kN/m}^2$$

$$M_o = \frac{18.85 * 6.5^2 * 6.5}{8} = 647 \text{ kNm}$$

$$\text{Negative Moment}(M_n) = 0.65 * 647 = 421 \text{ kNm}$$

$$\text{Positive Moment}(M_p) = 0.35 * 647 = 227 \text{ kNm}$$

$$\underline{y} = \frac{1240 * 170 * 170/2 + 300^2 * 320}{1240 * 170 + 300^2} = 155.3 \text{ mm}$$

$$I_s = \frac{6500 * 170^3}{12} = 2.66 * 10^9 \text{ mm}^4$$

$$I_b = \frac{1240 * 170^3}{12} + 1240 * 170 * 70.3^2 + \frac{300^4}{12} + 300^2 * 164.7^2 = 4.666 * 10^9 \text{ mm}^4$$

$$\alpha_{f1} = \frac{EI_b}{EI_s} = 1.754$$

$$\alpha_{fm} = 1.754$$

$$\beta = \frac{l_2}{l_1} = 1$$

$$h = \frac{6 * (0.8 + 420/1400)}{36 + 5 * 1 * (1.754 - 0.2)} = 0.151 \geq 0.127 \text{ assumed } 170 \text{ is greater}$$

$$\alpha_{f1} l_2 / l_1 = 1.754 * 1 = 1.754 \geq 1$$

Negative Moment Distribution

$$\text{Beam} = 0.85 * 0.75 * 421 = 315.75 \text{ kNm}$$

$$\text{Column Strip} = 0.15 * 0.75 * 421 = 47.36 \text{ kNm}$$

$$\text{Middle Strip} = 0.25 * 421 = 105.25 \text{ kNm}$$

Positive Moment Distribution

$$\text{Beam} = 0.85 * 0.75 * 227 = 144.7 \text{ kNm}$$

$$\text{Column Strip} = 0.15 * 0.75 * 227 = 25.54 \text{ kNm}$$

$$\text{Middle Strip} = 0.25 * 227 = 56.75 \text{ kNm}$$

Interior Slab				
DDM	Column Strip		Middle Strip	
	Negative	Positive	Negative	Positive
Mu	47.36	25.54	105.25	56.75
Width of strip (m)	3.25	3.25	3.25	3.25
Effective depth (m)	0.1446	0.1446	0.1446	0.1446
Ru	774.3712799	417.5980255	1720.915904	927.9047748
Steel Ratio	0.001495	0.000801	0.003378	0.001796
As	702.3577942	376.4484525	1587.38136	843.866109

Min As	994.5	994.5	994.5	994.5
Selected Bars	6 #16 (1194)	6 #16 (1194)	8 #16 (1592)	6 #16 (1194)

Table 2.9 Calculation of Reinforcement of Interior Slab

Edge Slab

$$y = \frac{770 * 170 * 170/2 + 300^2 * 320}{\frac{770 * 170 + 300^2}{170^3 * (3.25 + 0.5)}} = 180.74mm$$

$$I_{ss} = \frac{770 * 170^3}{12} + 770 * 170 * 95.74^2 + \frac{300^4}{12} + 300^2 * 139.26^2 = 3.936 * 10^9 mm^4$$

$$\alpha_{f1} = \frac{EI_b}{E_{ss}} = 2.56$$

$$\alpha_{f2;f3;f4} = \frac{EI_b}{E_s} = 1.754$$

$$\alpha_{fm} = \frac{2.56 + 1.754 * 3}{4} = 1.955$$

$$h = \frac{6 * (0.8 + 420/1400)}{36 + 5 * 1 * (1.955 - 0.2)} = 0.147 \geq 0.127 \text{ assumed } 170 \text{ is greater}$$

$$\text{Interior Negative Moment}(M_n) = 0.7 * 647 = 453kNm \text{ Positive Moment}(M_p)$$

$$= 0.57 * 647 = 369kNm$$

$$\text{Exterior Negative Moment}(M_n) = 0.16 * 647 = 104kNm$$

$$\alpha_{f1} l_2 / l_1 = 2.56 \geq 1$$

$$C = \sum \left(1 - 0.63 \frac{x}{y}\right) \frac{xy}{3} = \left(1 - 0.63 \frac{170}{470}\right) \frac{170^3 * 170}{3} + \left(1 - 0.63 \frac{300}{470}\right) \frac{300^3 * 170}{3}$$

$$= 3.123 * 10^9 mm^4$$

$$\beta_t = \frac{E_{cb} * C}{2 * E_{cs} * I} = 1.014$$

Interior Negative Moment Distribution

$$\begin{aligned} \text{Beam} &= 0.85 * 0.75 * 453 = 289kNm \\ \text{Column Strip} &= 0.15 * 0.75 * 453 = 51kNm \\ \text{Middle Strip} &= 0.25 * 453 = 113.3kNm \end{aligned}$$

Positive Moment Distribution

$$\begin{aligned} \text{Beam} &= 0.85 * 0.75 * 369 = 235kNm \\ \text{Column Strip} &= 0.15 * 0.75 * 369 = 42kNm \\ \text{Middle Strip} &= 0.25 * 369 = 92.2kNm \end{aligned}$$

Exterior Slab						
DDM	Column Strip			Middle Strip		
	Internal Negative	Positive	External Negative	Internal Negative	Positive	External Negative
Mu	51	42	14.01	113.3	92.2	10.61
Width of strip (m)	3.25	3.25	3.25	3.25	3.25	3.25
Effective depth (m)	0.1446	0.1446	0.1446	0.1446	0.1446	0.1446
Ru	833.8879915	686.73128 71	229.0739365	1852.539401	1507.53868 3	173.4814037
Steel Ratio	0.001611	0.001323	0.000438	0.003645	0.002948	0.000331
As	757.1219167	621.92424 59	205.8428086	1712.91715	1385.18759 5	155.7422554
Min As	994.5	994.5	994.5	994.5	994.5	994.5
Selected Bars	6 #16 (1194)	6 #16 (1194)	6 #16 (1194)	9 #16 (1791)	7 #16 (1393)	6 #16 (1194)

Table 2.10 Calculation of Reinforcement of Exterior Slab

Corner Slab

$$\alpha_{f1;f2} = \frac{EI_b}{E_{ss}} = 2.56$$

$$\alpha_{f3;f4} = \frac{EI_b}{EI_s} = 1.754$$

$$\alpha_{fm} = \frac{2.56 * 2 + 1.754 * 2}{4} = 2.16$$

$$h = \frac{6 * (0.8 + 420/1400)}{36 + 9 * 1} = 0.146 \geq 0.089 \text{ assumed } 170 \text{ is greater}$$

Corner beam will have the same C value and will generate the same values as calculations for edge slabs.

Corner Slab						
DDM	Column Strip			Middle Strip		
	Internal Negative	Positive	External Negative	Internal Negative	Positive	External Negative
Mu	51	42	14.01	113.3	92.2	10.61
Width of strip (m)	3.25	3.25	3.25	3.25	3.25	3.25
Effective depth (m)	0.1446	0.1446	0.1446	0.1446	0.1446	0.1446
Ru	833.8879915	686.73128 71	229.0739365	1852.539401	1507.53868 3	173.4814037
Steel Ratio	0.001611	0.001323	0.000438	0.003645	0.002948	0.000331
As	757.1219167	621.92424 59	205.8428086	1712.91715	1385.18759 5	155.7422554
Min As	994.5	994.5	994.5	994.5	994.5	994.5
Selected Bars	6 #16 (1194)	6 #16	6 #16 (1194)	9 #16 (1791)	7 #16	6 #16 (1194)

		(1194)			(1393)	
--	--	--------	--	--	--------	--

Table 2.11 Calculation of Reinforcement of Corner Slab

Interior Slab Shear Design

$$V_u = 18.85 * (3.25 - 0.15 - 0.1446) = 2.733 \text{ lb/in}^2 * 116.35 = 0.318K$$

Assume $A_v \leq A_{v,min}$, convert values to inch (300mm to 11.81 inch, 144.6mm to 5.69 inch,

$$\rho = \frac{A_{s,max}}{bd} = \frac{1587.4}{300 * 144.6} = 0.0365$$

$$\lambda_s = \sqrt{\frac{5.69}{1 + \frac{5.69}{10}}} = 1.13 \geq 1$$

$$\phi V_c = 0.75 * [8 * 1 * 1 * 0.0365^{1/3} * \sqrt{4351}] * 11.81 * 5.69 = 8.82K$$

$$\phi V_c \geq V_u$$

Column Design

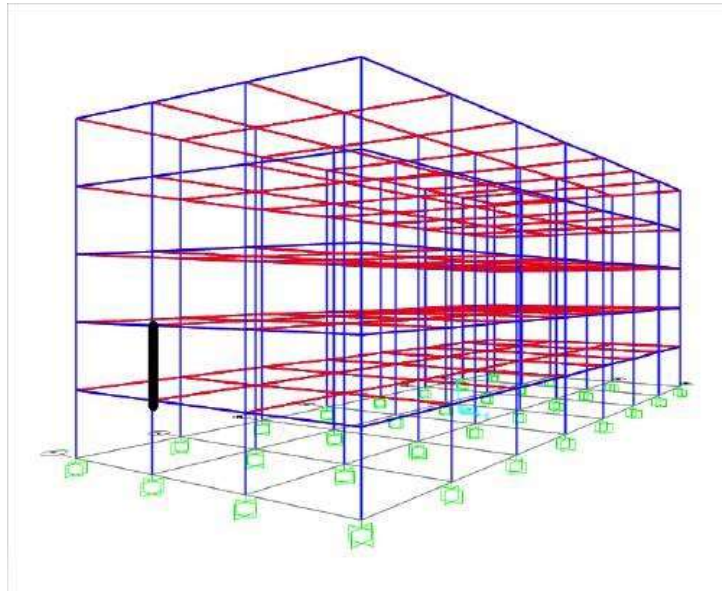


Figure 2.1 Designed Column

$$I_{cb} = \frac{450^4}{12} = 3.42 * 10^9 \text{mm}^4 = 8209 \text{in}^4 \quad I_{ca} = \frac{500^4}{12} = 5.208 * 10^9 \text{mm}^4$$

$$I_b = \frac{300 * 470^3}{12} = 2.59 * 10^9 mm^4 = 6223 in^4$$

$$\psi_a = \frac{0.7 * 5.208}{\frac{3130}{0.35 * 2.59 * 3}} = 2.78 \quad \psi_b = \frac{\frac{0.7 * 3.42}{3130}}{\frac{0.35 * 2.5}{9 * 3}} = 1.83$$

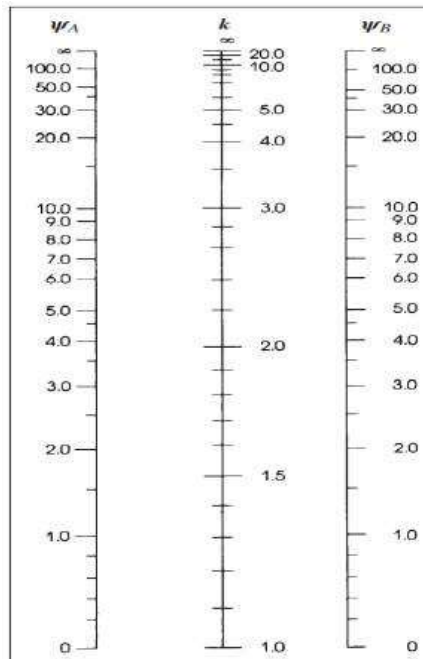


Figure 2.2 Identifying K value from beam to slab stiffness retain for Sway frames

$$K = 1.65$$

$$\frac{K * l_n}{h} = \frac{1.65 * 3130}{0.288 * 450} = 39.84 \geq 22$$

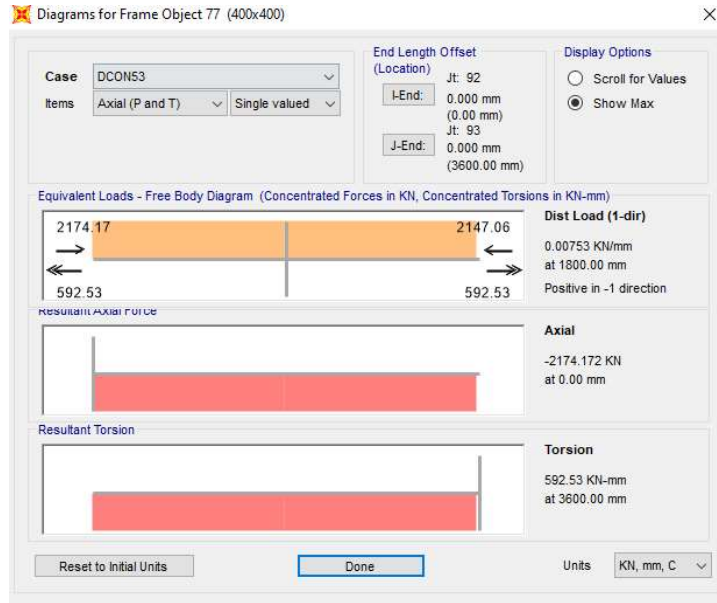


Figure 2.3 Axial Load From SAP 2000 for combination DCON53 (1.24D+1L+1E)

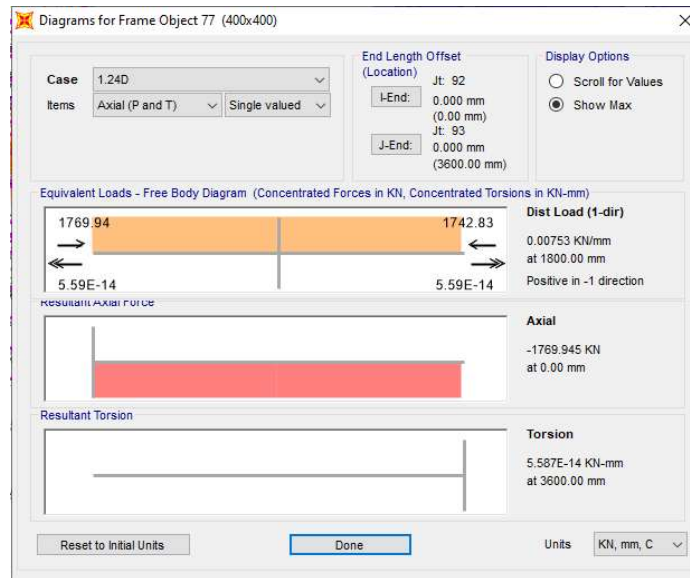


Figure 2.4 Axial Load From SAP 2000 for combination 1.24D

$$\beta_{dns} = \frac{1742}{2147} = 0.811$$

$$EI = \frac{0.4EcI_g}{1 + \beta_{dns}} = \frac{0.4 * 57000 * \sqrt{4351} * 8209in^2}{1 + 0.811} = 6.817 * 10^6 Kin^2$$

$$P_c = \frac{\pi^2 EI}{(Kl_n)^2} = \frac{\pi^2 * 6.817 * 10^6 Kin^2}{(1.65 * 123.22)^2} = 1627K = 7237kN$$

$$\Sigma P_u = 12 * 2147 + 16 * \left(\frac{2}{3} * 2147\right) + 4\left(\frac{1}{3} * 2147\right) = 51528kN$$

$$\Sigma P_c = 7237 * 32 = 231584kN$$

$$\delta_s = \frac{1}{1 - \frac{51528}{231584}} = 1.422 \geq 1$$

$$M_c = M_{u,bns} + \delta_s M_{u,bs} = 99.3kNm + 1.422 * 76.84kNm = 208.6kNm$$

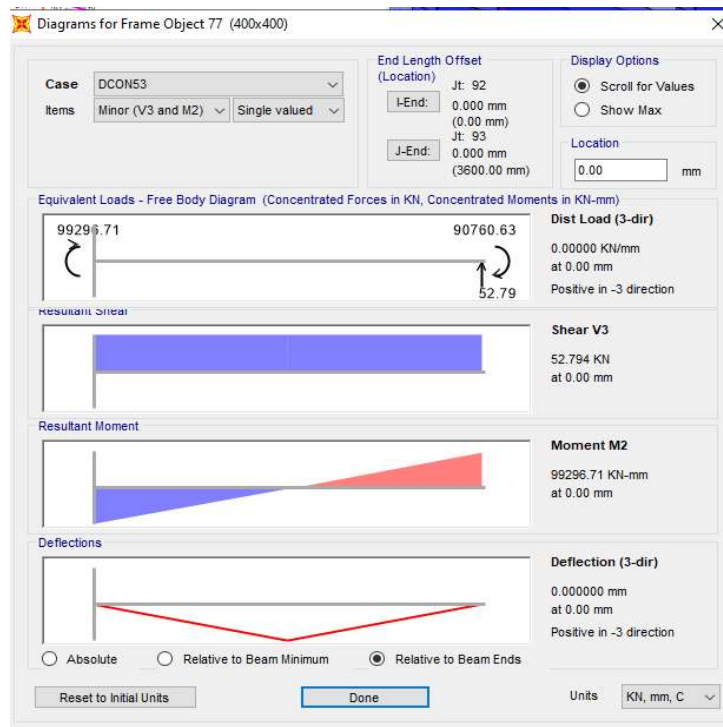


Figure 2.5 $M_{u,bns}$ values from SAP 2000 for combination DCON53 (1.24D+1L+1E)

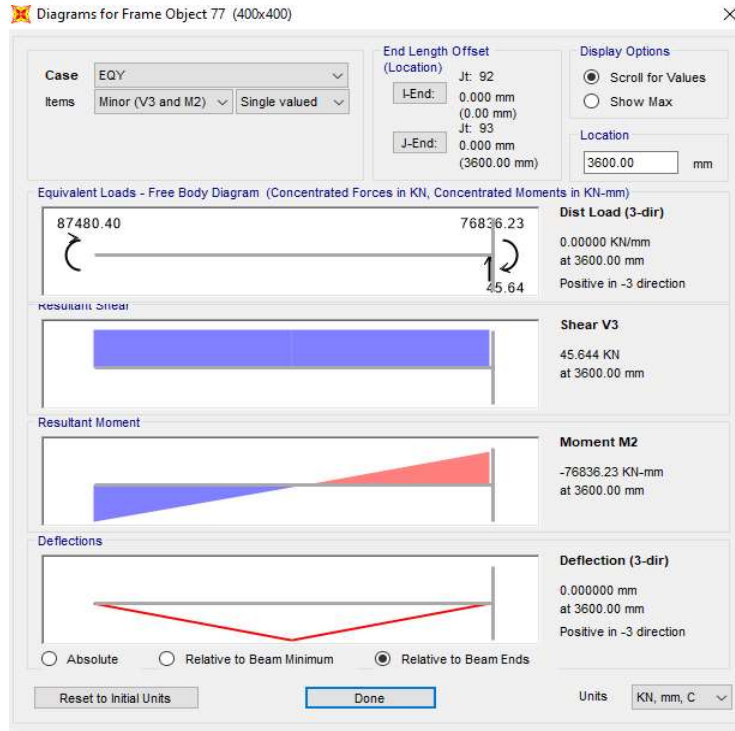


Figure 2.6 $M_{u,bs}$ values from SAP 2000 for combination EQY (earthquake case)

$$\gamma = \frac{450 - 2 * 38.1 - 16}{450} \approx 0.8$$

$$e = \frac{M_c}{P_u} = \frac{208.6}{2147} = 0.0972$$

$$P_n = \frac{P_u}{\phi} = \frac{2147}{0.65} = 3303.1 \text{ kN}$$

$$K_n = \frac{P_n}{f_c * A_g} = \frac{3303.1 \text{ kN}}{30000 \text{ kPa} * 0.45^2} = 0.543$$

$$R_n = \frac{K_n * e}{h} = \frac{0.543 * 0.0972}{0.45} = 0.117$$

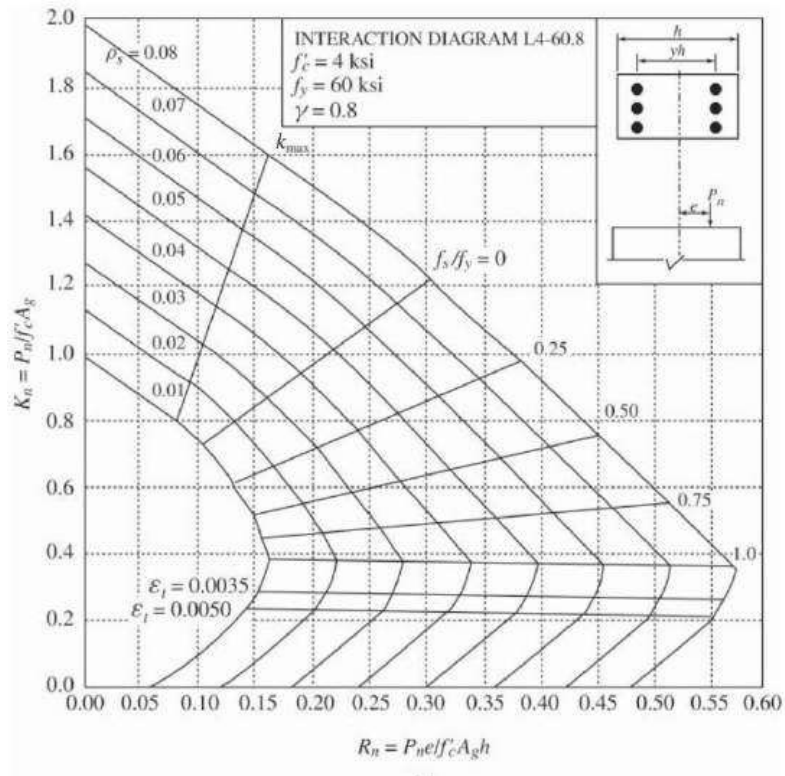


Figure 2.7 Interaction Diagram

$$\rho = 0.01$$

$$A_s = 0.45^2 * 0.01 = 2025 \text{mm}^2$$

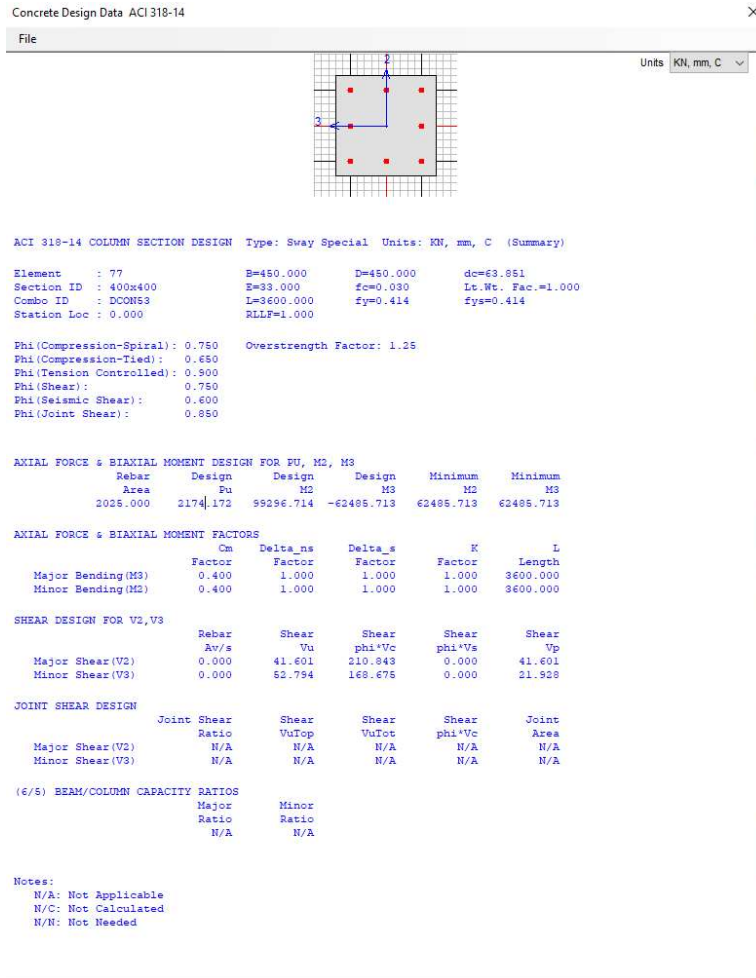


Figure 2.8 Rebar Area Comparison From SAP 2000

Beam Design

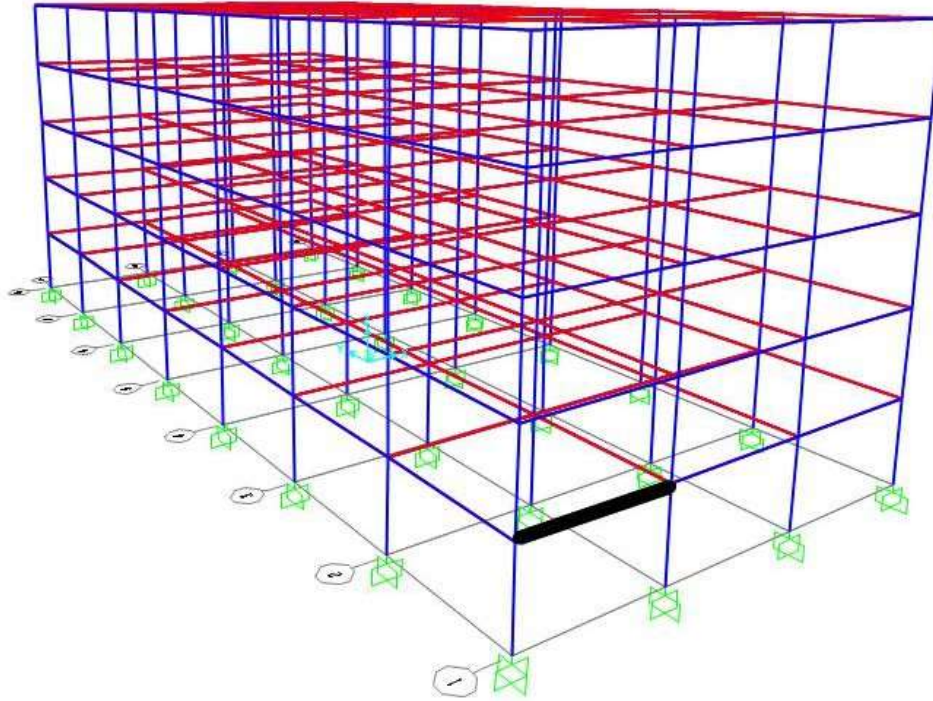


Figure 2.9 Designed Beam

	Beam Design		
	Positive	Middle	Negative
Mu	21.81	6.51	42.8
Width of strip (m)	0.3	0.3	0.3
Effective depth (m)	0.243	0.243	0.243
Ru	1367.97876	408.3237838	2684.52503
Steel Ratio	0.002668	0.000783	0.005365
As (mm ²)	194.4940103	57.08987384	391.1273446
Min As	240.57	241.56	241.56

Selected Bars	2 #13 (258)	2 #13 (258)	4 #13 (516)
SAP2000 As (mm ²)	246	240	508

Table 2.12 Beam Design Calculation

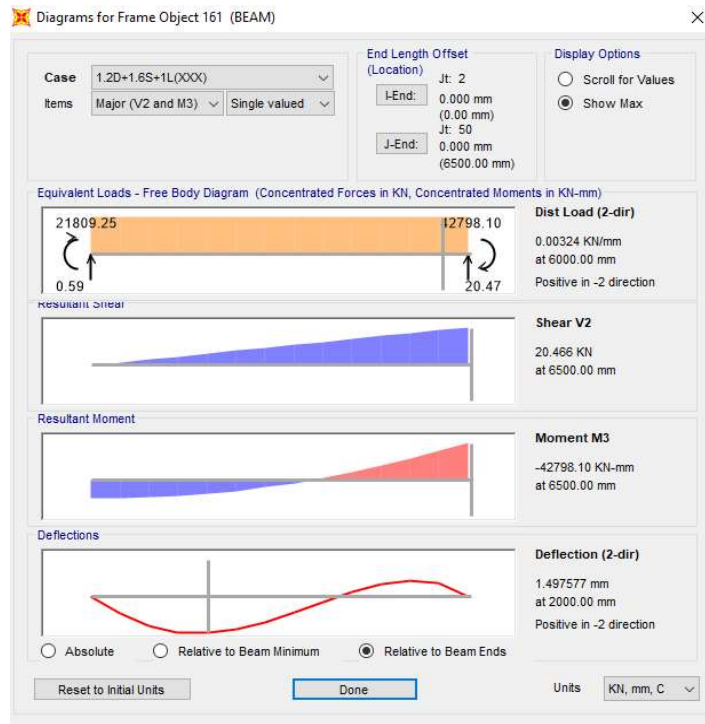


Figure 2.10 Negative Moment From SAP2000

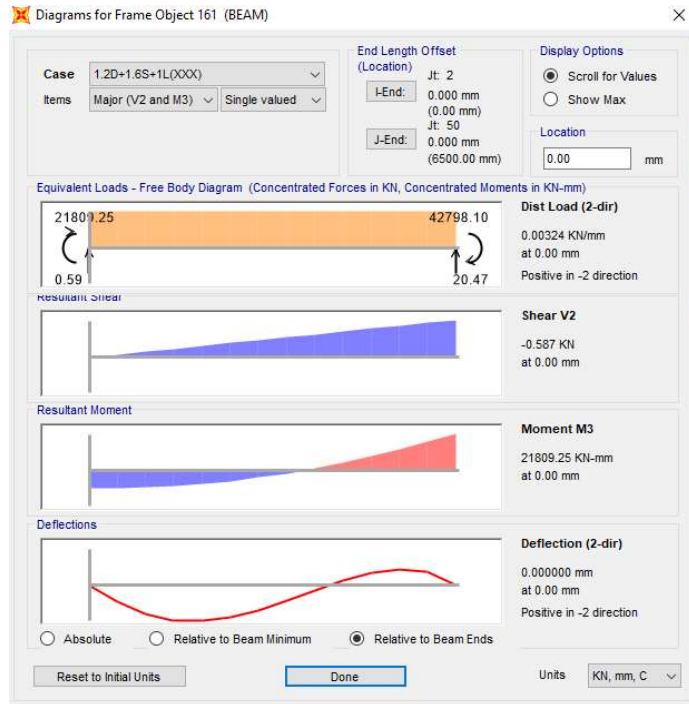


Figure 2.11 Positive Moment From SAP 2000

2.4 Wind Load Calculation

ASCE-7 Chapter 26 provides general requirements for wind loads, where values for basic wind speed are taken from wind hazard maps. Wind loads are calculated using procedures in ASCE-7 Chapter 27.

The building has three occupancy categories. From ASCE-7 figure 26.5-1B, the basic wind speed is 52 m/s. No hill is under construction, meaning the topographical factor equals 1. The directionality factor equals 0.85 by ASCE-7 table 26.6-1 for main wind force resisting systems. Our facility is considered low-rise by section 26.2; buildings that are less than 18 m are considered low-rise. Additionally, calculations for approximate natural frequency from section 26.9.3 for concrete moment-resisting structures resulted in 1.11 Hz. Therefore, the building is deemed rigid by two parameters, and the gust effect can be taken as 0.85 according to section 26.9.1. Velocity pressure exposure for exposure category B is taken from Table 27.3-1.

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

q_z - design velocity pressure at height z

K_z - velocity pressure exposure coefficient at height z

K_{zt} - topographical factor

K_d - wind directionality factor

V - basic wind speed

Main wind force resisting system of our building is similar for case 1 of figure 27.4-8 ASCE-7.

We assumed the building is fully enclosed for the wind force calculation, and no internal pressure affects the wind force. Therefore, net design pressure:

$$P = P_{W,i} - P_L$$

$$P_{W,i} = q_z G C_p$$

$$P_L = q_h G C_p$$

P - net design pressure

$P_{W,i}$ - net design pressure for windward direction

P_L - net design pressure for leeward direction

C_p - external pressure coefficient from ASCE-7 figure 27.4-1

G - gust-effect coefficient

External pressure for windward direction is 0.8 for all values of $L/B = 2.3$, and by interpolation external pressure for leeward direction is -0.285.

Direction	Story	h (ft)	z (ft)	K_z	K_{zt}	K_d	V^2	qz (pa)	$P_{W,i}$ or P_L (Pa)	P (Pa)	F (kN)
Windward	5	11.8	59.1	0.85	1	0.85	2704	1197.8	814.5	1104.7	6.5
	4	11.8	47.2	0.80	1	0.85	2704	1123.8	764.2	1054.4	12.5
	3	11.8	35.4	0.73	1	0.85	2704	1035.2	703.9	994.1	11.7
	2	11.8	23.6	0.65	1	0.85	2704	921.9	626.9	917.1	10.8
	1	11.8	11.8	0.57	1	0.85	2704	809.7	550.6	840.8	9.9
Leeward			59.1	0.85	1	0.85	2704	1197.8	-290.2	0.0	

Table 2.13 Wind Load Forces Calculation

2.5 Seismic Load Calculation

Seismic load calculator was calculated per ASCE-7 16 Chapters 1, 11, 12, 21, 22. ELF analytical procedure will be used to calculate seismic loads. Following Table 12.6-1, the ELF

analysis method is permitted for a building that does not have structural irregularities and is not higher than 48.8 meters.

Design Code	ASCE-7 16
Site Class	D
Occupancy Category	III
S_S ASCE Hazard Tool	1.748g
S_1 ASCE Hazard Tool	0.713g
$S_{MS} = S_S F_a = 1.735 * 1.0$	1.748g
$S_{M1} = S_1 F_v = 0.707 * 1.7$	1.212g
$S_{DS} = \frac{2}{3} S_{MS}$	1.165g
$S_{D1} = \frac{2}{3} S_{M1}$	0.808g
Seismic Design Category Table 11.6-1	D
Long Period T_L	12 sec

Table 2.14 Calculation of Main Components for Seismic Load

Section 12.8 Provides the procedure to calculate equivalent lateral force.

$$V = C_s W$$

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

$$T_a = C_t h_n^x$$

V - shear at a base of a structure

W - effective seismic weight section 12.7.2

C_s - the seismic response coefficient

R - response modification constant table 12.2-1 for special reinforced concrete

I_e - seismic importance factor from table 1.5-2

T_a - approximate fundamental period section 12.8.2.1

$C_t h_n^x$ - values from table 12.8-2 for C_t and x (0.0466 and 0.9 respectively)

The value of C_s should not exceed the following:

For $T_a \leq T_L$

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

R	8
I_e	1.25
C_s	0.181
T_a	0.628 s
$C_{s,max}$	0.199
W	43800.64 kN
V	7919.16 kN

Table 2.15 Base Shear Calculation

Vertical distribution of seismic forces is calculated in accordance with section 12.8.3

$$F_x = C_{vx}V$$

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

C_{vx} - vertical distribution factor

w_x, w_i - effective seismic weight at story x or i (section 12.7.2)

h_x, h_i - height from base to level x or i

k - For structure with $0.5 < T < 2.5$, a linear interpolation should be done between $k=1$ and $k=2$

Floor	Mass of Floor (kN)	Height (m)	WiHi ^k	Cvx	Fvx (kN)
5	8436.16	18	182759.63	0.3325	2633.03
4	8718.88	14.4	148961.57	0.2710	2146.10
3	8718.88	10.8	109679.87	0.1995	1580.16
2	8963.36	7.2	73241.69	0.1332	1055.20
1	8963.36	3.6	35029.37	0.0637	504.67
Total	43800.64		549672.13	1	7919.16

Table 2.16 Distributed Seismic Loads

2.6. SAP 2000

To develop SAP 2000 model design of column, beams and slabs were recreated in the program. ASTM A615 was assigned as material for reinforcement in columns, and Eurocode standard concrete material C30/37 was set for the material of concrete of structural members. Dead load, live load, and wind load combinations were created to assess a model's loads. The wind load was perpendicularly applied to the short section, as there is no wind load on the side of the building due to its being closely constructed. Values for shear forces were compared for the outer section where wind load was applied. Axial forces were compared for internal columns.

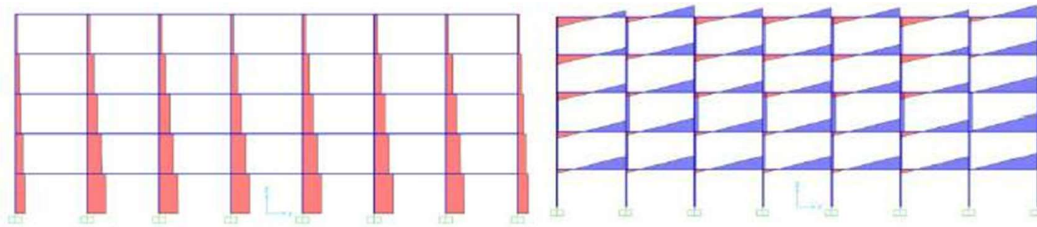


Figure 2.12 SAP 2000 3D Long Section Axial and Shear Force Analysis Results

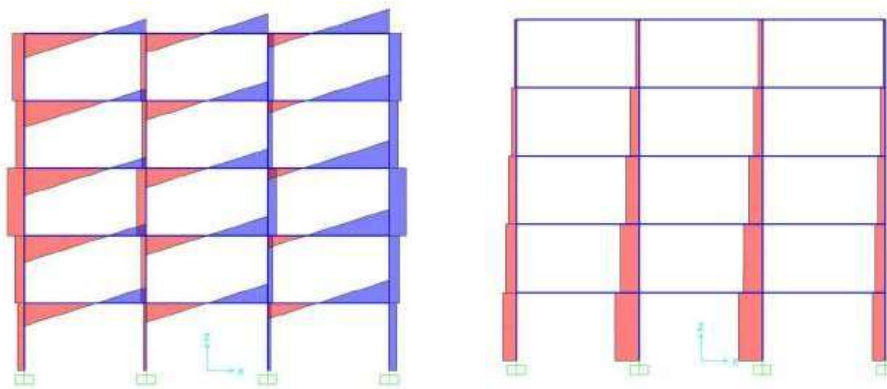


Figure 2.13 SAP 2000 3D Short Section Axial and Shear Force Analysis Results

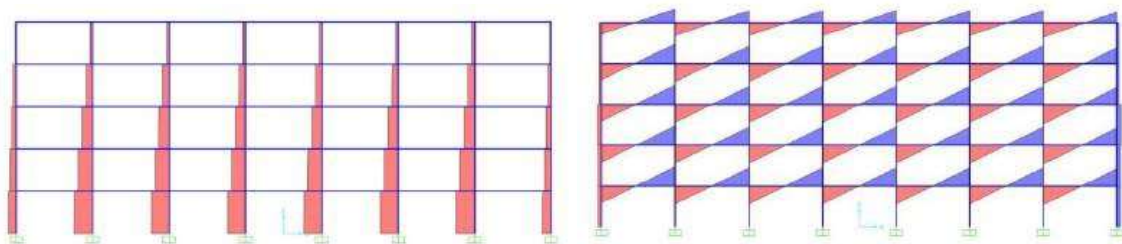


Figure 2.14 SAP 2000 2D Long Section Axial and Shear Force Analysis Results

Floor	Calculated Shear (kN)	SAP 2000 Shear 3D (kN)	SAP 2000 Shear 2D (kN)
5	4.33	5.86	41.56
4	5.97	4.84	39.44
3	9.94	9.57	89.14
2	14.44	5.03	64.3
1	18.58	3.14	66.4

Table 2.17 Shear Force Values Comparison

Floor	Calculated Axial force (kN)	SAP 2000 Axial force 3D (kN)	SAP 2000 Axial force 2D (kN)
5	446.6	682.4	478.8
4	1046.7	1555	1157.6
3	1650.8	2504.3	1833.3
2	2258.9	3308.6	2502.1
1	2871.1	4317.6	3184.3

Table 2.18 Axial Force Values Comparison

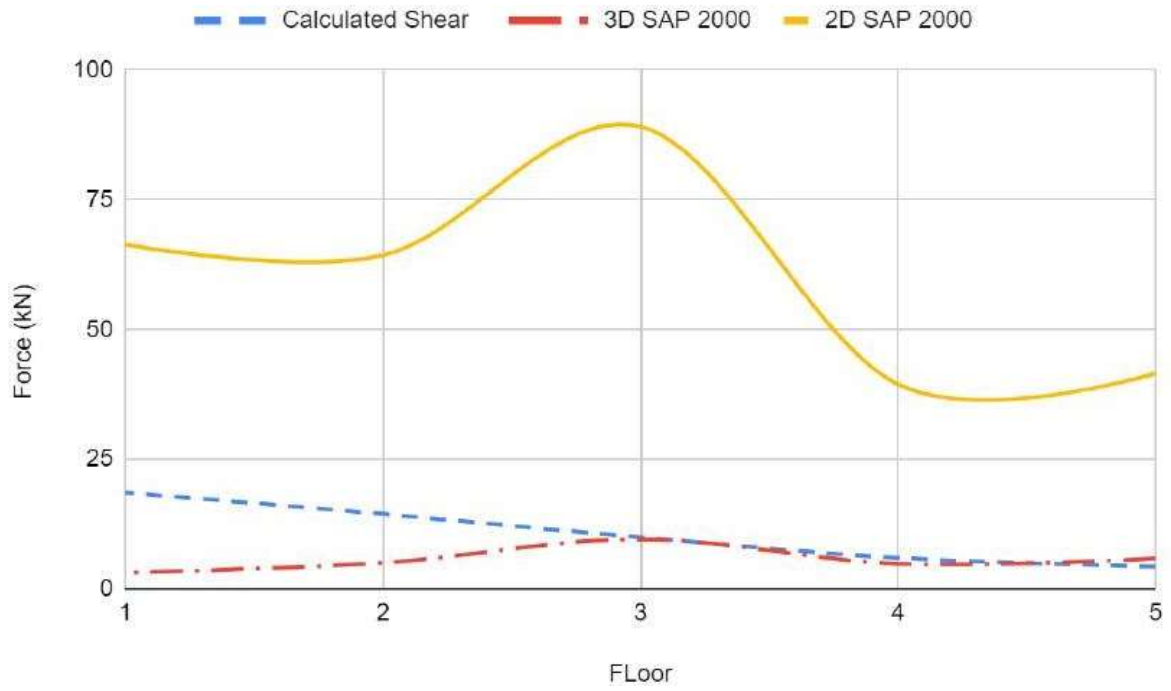


Figure 2.15 Graphical Comparison of Shear Force

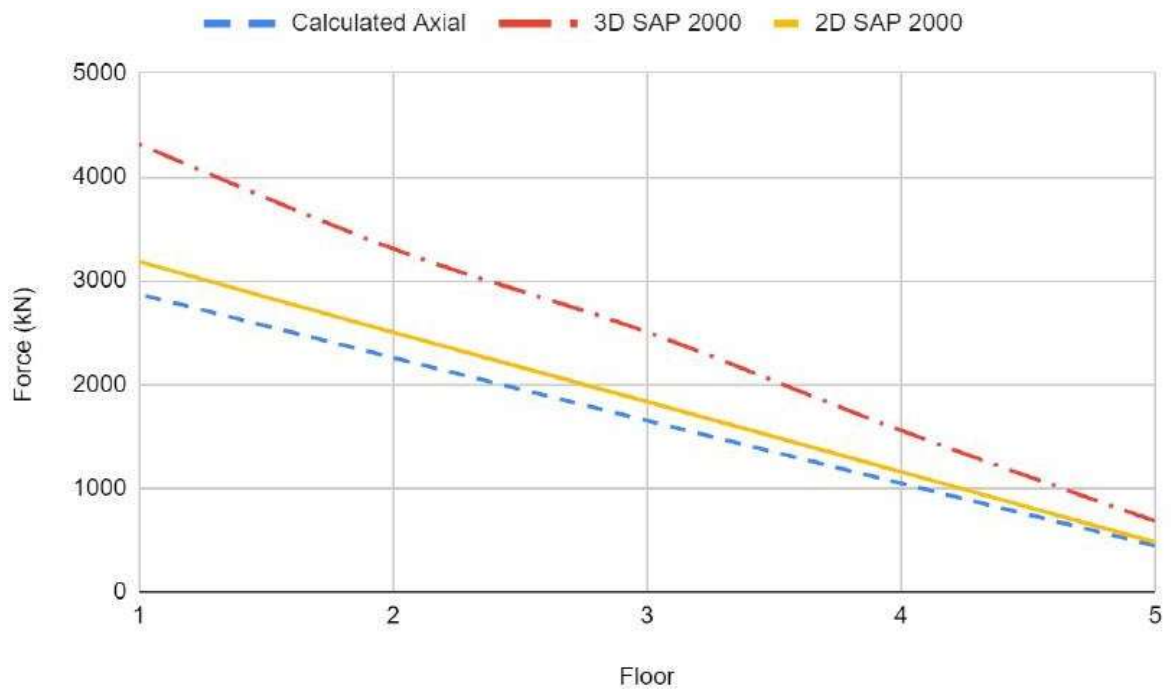


Figure 2.16 Graphical Comparison of Axial Force

Performing a comparative evaluation between hand-calculated results and those obtained from software like SAP2000 can provide valuable insights into the accuracy and reliability of the analysis. However, it's important to note that the accuracy of the results depends on various factors, including the complexity of the structure, input parameters, and the precision of the hand calculations. While performing analysis and checking for the design of structural members, it was identified that 48 columns with a tributary area of 42.25 m^2 did not pass the loading conditions. It is important to note that all internal columns passed the test. When designing for columns, internal members were chosen for calculation. Column design did not include the design for a moment, shear, and torsion resistance, which might be the reason for such failure in performing analysis.

3. Geotechnical Design

Soil is one of the most important factors that need to be considered during the design process of the construction project since it affects the type and dimensions of foundation that acts as a support for loads exerted by the structure. Geotechnical design part focuses on the analysis of soil characteristics based on the borehole data obtained from the geotechnical investigation of the construction site, after which the analysis results are then used for the design of foundation and retaining walls. In Capstone I, an overall analysis of the soil profile from the investigation report and preliminary design of foundation and retaining wall has been performed. For Capstone II, the focus of the geotechnical design was primarily on more detailed design of foundation, analysis of retaining wall for stability, and software simulations. For this section, the calculations were made using equations from the 9th edition of Principles of Foundation Engineering by Braja M. Das (2019).

3.1. Site Description

A geotechnical investigation report provided by A3Geo, Inc. that was published on June 22, 2022 has been used to obtain the soil characteristics data for geotechnical design calculations. This report contains information from site tests that were performed at 2550 Irving St., San Francisco, California, USA. The plan of the geotechnical investigation can be seen in Figure 3.1. The report includes information from:

- 3 cone penetrometer test (CPT) soundings
- 3 borehole logs with standard penetration test (SPT) data
- 2 hand-auger borings
- Multi-channel analysis of surface waves (MASW) test

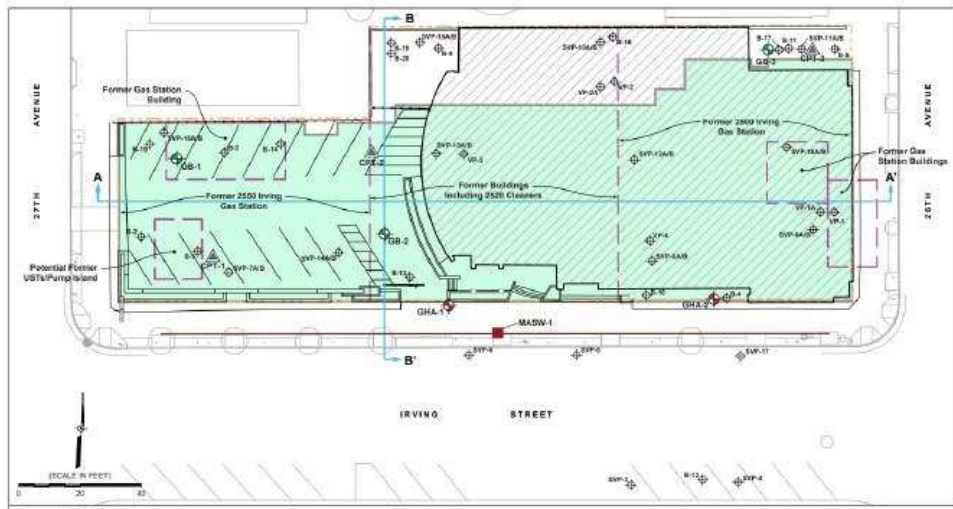


Figure 3.1. Site plan of the geotechnical investigation on 2550 Irving St. (A3GEO, 2022)

According to the report, the seismicity on the construction site comes from the seismic activity of San Andreas fault and the location of the groundwater table is around 77 feet (23.47 meters) below ground surface (A3GEO, 2022). The construction site is located in the northwestern part of San Francisco which is labeled as yellow, meaning that the level of liquefaction risk is medium, as shown in Figure 3.2 (Western Geographic Science Center, 2021).

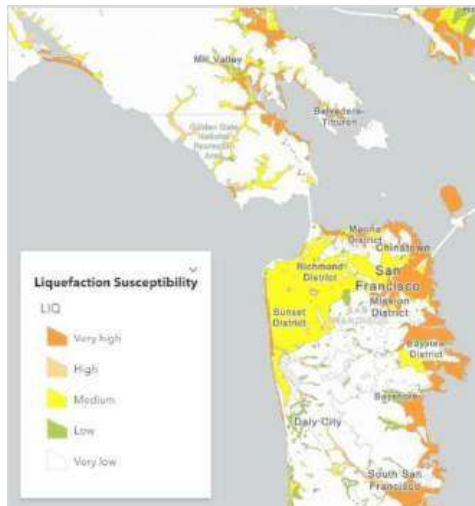


Figure 3.2. Liquefaction susceptibility map of San Francisco (Western Geographic Science Center, 2021)

The geotechnical report also provides a shear wave velocity profile of the construction site that was obtained from MASW testing, shown in Figure 3.3. According to ASCE-7, the site classification is based on the average value of shear wave velocity for the depth of 100 feet. The average shear wave velocity value for upper depth of 100 feet (30 meters) has been calculated using the following equation:

$$V_{s,100} = \frac{\sum V_i h_i}{100}$$

Where,

$V_{s,100}$ - average shear wave velocity for 100 ft, ft/s

V_i - shear wave velocity of i-th layer, ft/s

h_i - thickness of i-th layer, ft

The calculated average shear wave velocity for 100 feet is equal to 995.6 ft/s (303.5 m/s), meaning that the construction site can be classified as Site Class D since the $V_{s,100}$ value lies within the range between 600 to 1200 ft/s, as specified in Figure 3.4 (ASCE, 2022).

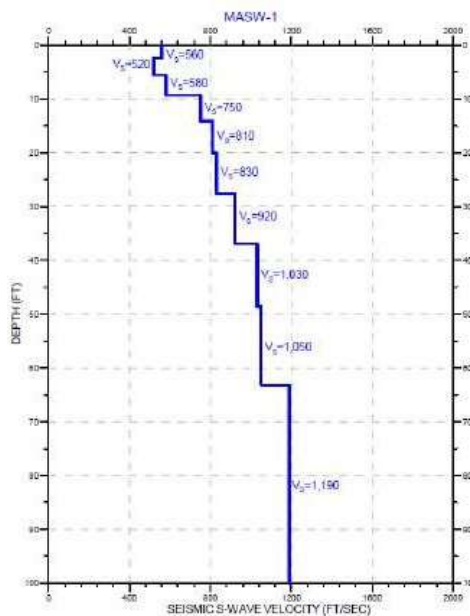


Figure 3.3. Seismic shear wave velocity profile at 2550 Irving St. (A3GEO, 2022)

Site Class	\bar{v}_s	\bar{N} or \bar{N}_{ch}	\bar{s}_u
A Hard rock	>5000 ft/s (>1500 m/s)	not applicable	not applicable
B Rock	2500 to 5000 ft/s (760 to 1500 m/s)	not applicable	not applicable
C Very dense soil and soft rock	1200 to 2500 ft/s (370 to 760 m/s)	> 50	> 2000 psf (> 100 kPa)
D Stiff soil	600 to 1200 ft/s (180 to 370 m/s)	15 to 50	1000 to 2000 psf (50 to 100 kPa)
E Soil	<600 ft/s (<180 m/s)	<15	<1000 psf (<50 kPa)
	Any profile with more than 10 ft of soil having the following characteristics: —Plasticity index $PI > 20$, —Moisture content $w \geq 40\%$, and —Undrained shear strength $\bar{s}_u < 500$ psf		
F Soils requiring site-specific evaluation		1. Soils vulnerable to potential failure or collapse 2. Peats and/or highly organic clays 3. Very high plasticity clays 4. Very thick soft/medium clays	

Figure 3.4. ASCE site classification table (ASCE, 2022)

3.2. Soil Profile

Soil characteristics data were taken from borehole log GB-2 due to its close proximity to the location of construction site of the project and its greater depth compared to other boreholes. From Table 3.1 it can be seen that the soil profile consists mainly of layers of granular cohesionless soil, namely poorly graded sand (SP). From the geotechnical investigation report, the values are given in imperial units, which were then converted to SI units for further calculations.

Table 3.1. Soil profile from GB-2 borehole log

Depth, ft	Soil type	SPT N_{60} values	Dry unit weight, pcf	Moisture content, %
0 - 5.5	Poorly graded sand (SP)	11	99.0	3.0
5.5 - 15.0	Poorly graded sand (SP)	2	99.0	3.0
15.0 - 25.0	Poorly graded sand (SP)	14	99.0	3.0

25.0 - 30.0	Poorly graded sand (SP)	22	107.0	3.0
30.0 - 35.0	Poorly graded sand (SP)	24	107.0	3.0
35.0 - 62.34	Poorly graded sand (SP)	40	107.0	3.0

The N_{60} values obtained from standard penetration testing (SPT) field tests in granular soils should be adjusted due to the influence from effective overburden pressure σ'_o , which can be done using the following equation:

$$(N_1)_{60} = C_N N_{60}$$

Where,

$(N_1)_{60}$ - adjusted N_{60} value

C_N - correction factor

N_{60} - SPT N-value from in-situ investigation

The correction factor C_N can be calculated using the following equation that was proposed by Liao and Whitman (1986):

$$C_N = \sqrt{\frac{1}{(\frac{\sigma'_o}{p_a})}}$$

Where,

C_N - correction factor

σ'_o - effective overburden pressure, kPa

p_a - atmospheric pressure, ~100 kPa

Table 3.2 summarizes the calculation results for $(N_1)_{60}$ values:

Table 3.2. $(N_1)_{60}$ calculation results

Depth, m	σ'_o/p_a	$(N_1)_{60}$
----------	-----------------	--------------

0 - 1.68	0.2691	21
1.68 - 4.57	0.7320	2
4.57 - 7.62	1.2205	13
7.62 - 9.14	1.4836	18
9.14 - 10.67	1.7485	18
10.67 - 19.00	1.8282	30

Since the values of friction angles were not given in the borehole log from the investigation report, several methods can be used to correlate the SPT values with friction angle in granular soils. Methods proposed by Peck et al. (1974), Schmertmann (1975), and Hatanaka and Uchida (1996) were used to calculate friction angle values using N_{60} or $(N_1)_{60}$, after which the average values of the results were determined, as shown in Table 3.3.

Peck et. al (1974):

$$\phi' (\text{°}) = 27.1 + 0.3(N_1)_{60} - 0.00054[(N_1)]^2$$

Schmertmann (1975):

$$\phi' = \tan^{-1} \left[\frac{N_{60}}{12.2 + 20.3(\sigma'_o/p_a)} \right]^{0.34}$$

Hatanaka and Uchida (1996):

$$\phi' = \sqrt{15.4(N_1)_{60} + 20}$$

Table 3.3. Friction angle calculation results

Depth, m	Peck et. al (1974), °	Schmertmann (1975), °	Hatanaka and Uchida (1996), °	Average friction angle ϕ' , °
0 - 1.68	33.2	40.4	38.1	37.2

1.68 - 4.57	27.8	22.4	26.0	25.4
4.57 - 7.62	30.8	35.7	34.0	33.5
7.62 - 9.14	32.3	38.7	36.7	35.9
9.14 - 10.67	32.4	38.4	36.7	35.8
10.67 - 19.00	35.5	43.0	41.3	39.9

Given and calculated soil characteristics are summarized in Table 3.4 with SI units. The values from this table will be used for the foundation and retaining wall design process calculations. An AutoCAD drawing of soil profile can be seen in Figure 3.5.

Table 3.4. Summarized soil characteristics for borehole GB-2

Depth, m	Soil type	SPT N ₆₀ values	Dry unit weight, kN/m ³	Moistur e content, %	(N ₁) ₆₀	Unit weight, kN/m ³	Friction angle, °
0 - 1.68	Poorly graded sand (SP)	11	15.55	3.0	21	16.02	37.2
1.68 - 4.57	Poorly graded sand (SP)	2	15.55	3.0	2	16.02	25.4
4.57 - 7.62	Poorly graded sand (SP)	14	15.55	3.0	13	16.02	33.5
7.62 - 9.14	Poorly graded sand (SP)	22	16.81	3.0	18	17.31	35.9

9.14 - 10.67	Poorly graded sand (SP)	24	16.81	3.0	18	17.31	35.8
10.67 – 19.00	Poorly graded sand (SP)	40	16.81	3.0	30	17.31	39.9

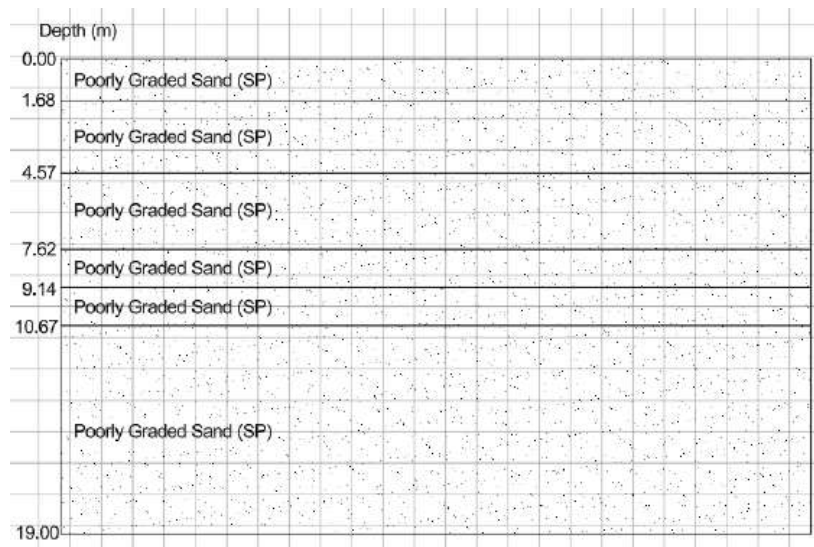


Figure 3.5. Soil profile drawing

3.3. Liquefaction Analysis

We have to check the construction site for liquefaction hazard since it is located in a seismic zone and the soil profile mostly consists of granular soil. The increase of sea level and precipitation may also cause the groundwater level to rise, saturating the soil in the area with moisture. The loss of resistance in saturated granular soils can be caused by an earthquake which leads to liquefaction, meaning that the soil behaves as a liquid (Law and Ling, 1992).

The values of peak ground acceleration a_{max} of 0.71 g and earthquake magnitude M_w of 8.00 from geotechnical investigation report were used in calculating the Liquefaction Potential Index (LPI). Based on the calculated value of LPI, the degree of liquefaction hazard can be assessed based on the table by Sonmez (2003), shown in Figure 3.6.

Liquefaction potential index (LI)	Liquefaction potential
0	Non-liquefiable
$0 < LI \leq 2$	Low liquefiable
$2 < LI \leq 5$	Moderate liquefiable
$5 < LI \leq 15$	High liquefiable
$15 < LI$	Very high liquefiable

Figure 3.6. Degrees of liquefaction potential (Sonmez, 2003)

The formulas used for the calculation of LPI were taken from Geostru.eu (2020) and Novotechsoftware.com (n.d.). The first step is to calculate the stress reduction factor r_d using the values of depth in meters and following equation:

$$r_d = \frac{1.0 - 0.4113z^{0.5} + 0.04052z + 0.001753z^{1.5}}{1 + 0.4177z^{0.5} + 0.05729z - 0.006205z^{1.5} + 0.001210z^2}$$

Next, we need to determine Cyclic Stress Ratio (CSR) using the following formula:

$$CSR = 0.65 \frac{\sigma_v a_{max}}{\sigma_v' g} r_d$$

Where,

CSR - Cyclic Stress Ratio

σ_v/σ_v' - total overburden stress to effective overburden stress ratio

a_{max} - peak ground acceleration, m/s^2

g - acceleration due to Earth's gravity, $9.81 m/s^2$

Then, we need to determine the Cyclic Resistance Ratio with 7.5 magnitude ($CRR_{7.5}$) using the adjusted N_{60} values and following equation:

$$CRR_{7.5} = \frac{1}{34 - \left(\frac{N_1}{6}\right)} + \frac{(N_1)_{60}}{135} + \frac{50}{\left(10\left(\frac{N_1}{6}\right) + 45\right)^2} - \frac{1}{200}$$

After that, Magnitude Scaling Factor (MSF) is calculated based on the value of earthquake magnitude M_w and following formula:

$$MSF = \frac{10^{2.24}}{M_w^{2.56}}$$

To calculate the Factor of Safety (FS) values, we need to use the previously calculated values for $CRR_{7.5}$, CSR, and MSF in the following equation:

$$FS = \frac{CRR_{7.5}}{CSR} MSF$$

If the FS values are greater than 1, it means that the soil is non-liquefiable. If the FS values are less than 1, $F(z)$ and $W(z)$ need to be determined to calculate LPI:

$$F(z) = 1 - FS$$

$$W(z) = 10 - 0.5z$$

$$LPI = F(z)W(z)$$

The calculation results for LPI are summarized in Table 3.5. According to the calculation results, the LPI values lie within the range of moderate and high risk of liquefaction based on the classification by Sonmez (2003).

Table 3.5. Liquefaction potential index calculation results

Depth, m	$(N_1)_{60}$	r_d	CSR	$CRR_{7.5}$	MSF	FS	$F(z)$	$W(z)$	LPI
0 – 1.68	21	0.9891	0.4564	0.2282	0.8474	0.4237	0.5763	9.160	5.2785
1.68 – 4.57	2	0.9686	0.4470	0.0529		0.1003	0.8997	7.715	6.9413
4.57 – 7.62	13	0.9418	0.4347	0.1405		0.2740	0.7260	6.190	4.4939
7.62 – 9.14	18	0.9206	0.4249	0.1918		0.3826	0.6174	5.430	3.3526
9.14 – 10.67	18	0.8906	0.4110	0.1918		0.3955	0.6045	4.665	2.8200
10.67 – 19.00	30	0.6410	0.2958	0.4676		1.3396	-	-	0

3.4. Foundation Design

The foundation design section of the geotechnical part of the project focuses on choosing an appropriate type of foundation that will be used to transfer the loads from the structure taken from the structural part based on calculations of bearing capacity that use several iterations. Our goal for Capstone II is to review the results of the preliminary geotechnical design and use software such as GEO5 and PLAXIS to run simulations and compare the results obtained from hand calculations.

The following table shows the results obtained from SAP2000 software used in the structural analysis:

Table 3.6. SAP2000 structural loads summary

Internal columns	Dead	Live	Seismic	Total
Vertical load (kN)	3545	772	-	5025
Moment (kNm)	-	-	156	251
Shear (kN)	-	-	76	122
Edge columns	Dead	Live	Seismic	Total
Vertical load (kN)	1077	209	-	1747
Moment (kNm)	-	-	136	227
Shear (kN)	-	-	56	97
Corner columns	Dead	Live	Seismic	Total
Vertical load (kN)	1970	401	-	2762

Moment (kNm)	-	-	160	256
Shear (kN)	-	-	76	122

3.4.1. Shallow Foundation

Shallow foundation is a type of foundation that transfers the structural loads on the soil layers located near the ground surface, rather than layers of rock or soil located in greater depths. This type of foundation is often used for buildings of smaller size. Since shallow foundations require less resources for construction and excavation, they are a more affordable option compared to deep foundations. However, using shallow foundation may not be appropriate in case if soil has poor physical characteristics (civiltoday.com, n.d.).

To calculate the bearing capacity of square footing, the following three iterations of dimensions will be used:

- 1st iteration: B = L = 2.0 m, D_f = 1.5 m
- 2nd iteration: B = L = 2.5 m, D_f = 1.5 m
- 3rd iteration: B = L = 3.0 m, D_f = 1.5 m

A factor of safety equal to 2.0 will be taken for calculations since it is a minimum factor of safety specified in 2019 San Francisco Building Code (Department of Building Inspection, 2020).

Two methods will be used to calculate the bearing capacity of shallow foundations which are the General Bearing Capacity method and Terzaghi's Bearing Capacity method.

General Bearing Capacity method

The General Bearing Capacity method uses the following equation:

$$q_u = c'N_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + \frac{1}{2}\gamma BN_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i}$$

The bearing capacity factors for this equation were taken based on the friction angle on which the bottom of the shallow foundation is located. Since all three iterations are located at the same depth, the factors for friction angle of 25° will be used for calculations: N_c = 20.72, N_q =

10.66, $N_\gamma = 10.88$. The soil layer is classified as poorly graded sand (SP) with a very small fines content, meaning that the cohesion value is taken as 0.

The following equations are used to calculate the shape, depth, and inclination factors:

Shape factors:

$$F_{cs} = 1 + \left(\frac{B}{L}\right) \left(\frac{N_q}{N_c}\right)$$

$$F_{qs} = 1 + \left(\frac{B}{L}\right) \tan\phi'$$

$$F_{\gamma s} = 1 - 0.4 \left(\frac{B}{L}\right)$$

Depth factors:

Since $D_f/B \leq 1$ and $\phi' > 0$:

$$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N \tan\phi'}$$

$$F_{qd} = 1 + 2 \tan\phi' (1 - \sin\phi')^2 \left(\frac{D_f}{B}\right)$$

$$F_{\gamma d} = 1$$

Inclination factors:

Due to no inclination, $F_{ci} = F_{qi} = F_{\gamma i} = 1$

1st iteration:

$$q = (16.02)(1.5) = 24.03$$

$$F_{qs} = 1 + \left(\frac{2.0}{2.0}\right) \tan 25.4^\circ = 1.4750$$

$$F_{\gamma s} = 1 - 0.4 \left(\frac{2.0}{2.0}\right) = 0.6$$

$$F_{qd} = 1 + 2 \tan 25.4^\circ (1 - \sin 25.4^\circ) \left(\frac{1.5}{2.0}\right) = 1.2323$$

$$F_{\gamma d} = 1$$

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

$$\begin{aligned}
q_u &= (24.03)(10.66)(1.4750)(1.2323)(1) + \frac{1}{2}(16.02)(2.0)(10.88)(0.6)(1)(1) \\
&= 570.18 \text{ kN/m}^2 \\
Q_{all} &= q_{all} B^2 = \frac{q_u}{FS} B^2 = \frac{570.19}{2} \times 2.0^2 = 1140.38 \text{ kN}
\end{aligned}$$

2nd iteration:

$$\begin{aligned}
q &= (16.02)(1.5) = 24.03 \\
F_{qs} &= 1 + \left(\frac{2.5}{2.5}\right) \tan 25.4^\circ = 1.4750 \\
F_{\gamma s} &= 1 - 0.4\left(\frac{2.5}{2.5}\right) = 0.6 \\
F_{qd} &= 1 + 2 \tan 25.4^\circ (1 - \sin 25.4^\circ) \left(\frac{1.5}{2.5}\right) = 1.1858 \\
F_{\gamma d} &= 1 \\
F_{qi} &= F_{\gamma i} = 1
\end{aligned}$$

$$\begin{aligned}
q_u &= (24.03)(10.66)(1.4750)(1.1858)(1) + \frac{1}{2}(16.02)(2.5)(10.88)(0.6)(1)(1) \\
&= 578.76 \text{ kN/m}^2 \\
Q_{all} &= q_{all} B^2 = \frac{q_u}{FS} B^2 = \frac{578.76}{2} \times 2.5^2 = 1808.63 \text{ kN}
\end{aligned}$$

3rd iteration:

$$\begin{aligned}
q &= (16.02)(1.5) = 24.03 \\
F_{qs} &= 1 + \left(\frac{3}{3}\right) \tan 25.4^\circ = 1.4750 \\
F_{\gamma s} &= 1 - 0.4\left(\frac{3}{3}\right) = 0.6 \\
F_{qd} &= 1 + 2 \tan 25.4^\circ (1 - \sin 25.4^\circ)^2 \left(\frac{1.5}{3}\right) = 1.1548 \\
F_{\gamma d} &= 1 \\
F_{qi} &= F_{\gamma i} = 1
\end{aligned}$$

$$\begin{aligned}
q_u &= (24.03)(10.66)(1.4750)(1.1548)(1) + \frac{1}{2} (16.02)(3)(10.88)(0.6)(1)(1) \\
&= 593.21 \text{ kN/m}^2 \\
Q_{all} &= \frac{593.21}{2} \times 3^2 = 2669.43 \text{ kN}
\end{aligned}$$

Terzaghi's Bearing Capacity method

The following formula is proposed by Terzaghi to calculate the bearing capacity of shallow foundation:

$$q_u = 1.3c'N_c + qN_q + 0.4\gamma BN_\gamma$$

This method uses different bearing capacity factors than the General Bearing Capacity method. The factors for the friction angle of 25° are as follows: $N_c = 25.13$, $N_q = 12.72$, $N_\gamma = 8.34$.

1st iteration:

$$\begin{aligned}
q_u &= (24.03)(12.72) + (0.4)(16.02)(2.0)(8.34) = 412.55 \text{ kN/m}^2 \\
Q_{all} &= \frac{412.55}{2} \times 2.0^2 = 825.09 \text{ kN}
\end{aligned}$$

2nd iteration:

$$\begin{aligned}
q_u &= (24.03)(12.72) + (0.4)(16.02)(2.5)(8.34) = 439.27 \text{ kN/m}^2 \\
Q_{all} &= \frac{439.27}{2} \times 2.5^2 = 1372.71 \text{ kN}
\end{aligned}$$

3rd iteration:

$$\begin{aligned}
q_u &= (24.03)(12.72) + (0.4)(16.02)(3)(8.34) = 465.99 \text{ kN/m}^2 \\
Q_{all} &= \frac{465.99}{2} \times 3^2 = 2096.95 \text{ kN}
\end{aligned}$$

Table 3.7 summarizes the calculation results for all three iterations of shallow foundation bearing capacity. The final value of bearing capacity is taken as an average of General and Terzaghi's method. GEO5 software was used to create a model of shallow foundation to run simulations to compare the bearing capacity results. An example of the GEO5 model of shallow

foundation based on the second iteration can be seen in Figure 3.7. Table 3.7 shows that the values from hand calculations and software simulations are close.

Table 3.7. Shallow foundation bearing capacity results

Iteration	B, m	L, m	D _f , m	General Bearing Capacity, kN	Terzaghi's Bearing Capacity, kN	Average Q _{all} , kN	GEO5 Calculation	Comparison of hand calculation vs GEO5
1	2.0	2.0	1.5	1140.37	825.09	982.73	1508.67	Close
2	2.5	2.5	1.5	1808.63	1372.71	1590.67	1900.13	Close
3	3.0	3.0	1.5	2669.43	2096.95	2383.19	2299.76	Close

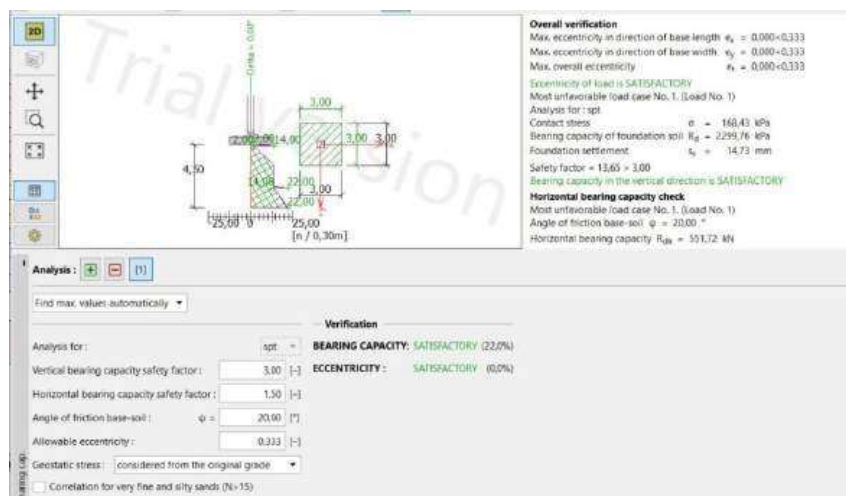


Figure 3.7. Shallow foundation model and simulation results in GEO5

Shallow foundation settlement

The settlement of shallow foundation was calculated using Schmertmann's method (1978) shown in the following equation:

$$S_e = C_1 C_2 (\bar{q} - q) \sum_0^{z_2} \frac{I_z \Delta z}{E_s}$$

Where

C_1 - correction factor of depth of embedment of shallow foundation

C_2 - the creep correction factor in the soil

\bar{q} - stress at the level of foundation, kN/m^2

q - effective stress at the basement level of the foundation, kN/m^2

I_z - strain influence factor

E_s - is the modulus of elasticity of the soil

Following equations were used to calculate correction factors:

$$C_1 = 1 - 0.5 \left(\frac{q}{\bar{q} - q} \right)$$

$$C_2 = 1 + 0.2 \log \left(\frac{t}{0.1} \right)$$

Where,

t - time during settlement occurs due to applied load, assumed to be 50 years

To calculate the strain influence factor, values for square foundations of $z_1 = 0.5B$ and $z_2 = 2B$ were taken according to Schmertmann (1978). By taking the chosen shallow foundation of 3 meters into account, z_1 is equal to 1.5 and z_2 is equal to 6 meters. The iteration with $B = L = 3$ meters is taken since it is able to withstand minimum vertical structural load of 1747 kN from edge columns.

Below are the calculations for shallow foundation settlement:

$$I_{z(m)} = 0.5 + 0.1 \sqrt{\frac{\bar{q} - q}{q_{z(1)}}}$$

$$I_{z(m)} = 0.5 + 0.1 \sqrt{\frac{194.11 - 24.03}{(1.5 + 1.5) * 16.02}} = 0.688$$

$$q = 1.5 \times 16.02 = 24.03 \text{ kN/m}^2$$

$$\bar{q} = 1747/3.0^2 = 194.11 \text{ kN/m}^2$$

$$C_1 = 1 - 0.5 \left(\frac{24.03}{194.11 - 24.03} \right) = 0.929$$

$$C_2 = 1 + 0.2 \log \left(\frac{50}{0.1} \right) = 1.54$$

The results of the calculation of $\frac{I_z * \Delta z}{E_s}$ are shown in Table 3.8.

Table 3.8. Results of calculations for $\frac{I_z * \Delta z}{E_s}$

Layer	Δz , m	E_s , kN/m ²	I_z at the middle of layer	$\frac{I_z * \Delta z}{E_s}$
1	1.5	35000	0.294	$1.26 * 10^{-5}$
2	4.5	35000	0.344	$4.42 * 10^{-5}$
Sum				$5.68 * 10^{-5}$

The final value of elastic settlement of shallow foundation was calculated to be 13.8 mm.

$$S_e = C_1 C_2 (\bar{q} - q) \sum_0^{z^2} \frac{I_z \Delta z}{E_s} = 0.929 * 1.54 * (194.11 - 24.03) * 5.68 * 10^{-5} =$$

$$= 0.0138 \text{ m} = 13.8 \text{ mm}$$

GEO5 software was also used to compare the hand calculation results of shallow foundation settlement, which can be seen in Table 3.9. GEO5 results turned out to be close to hand calculations with slight differences.

Table 3.9. Comparison of hand calculation and GEO5 simulation of settlement of shallow foundation

Shallow foundation settlement hand calculation, mm	GEO5 simulation settlement, mm
13.8	14.73

3.4.2. Mat Foundation

Mat foundation, which is also known as raft foundation, is a slab of reinforced concrete that is placed underneath a large area to transfer the structural loads to the soil. Mat foundation is often used in areas with poor soil conditions at shallow depths for commercial or residential buildings. This type of foundation is simpler and more effective to work with since it requires less resources for excavation and construction. Mat foundations are used to distribute the loads from the structure over a large area. However, mat foundations are vulnerable to edge erosion and require special calculations if concentrated loads need to be supported (civiltoday, n.d.).

The following formula is used to calculate the net allowable bearing capacity for mat foundations:

$$q_{net} = \frac{N_{60}}{0.08} \left(\frac{B+0.3}{B} \right)^2 F_d \left(\frac{S_e}{25} \right)$$

Where,

N_{60} - standard penetration resistance

B - width of foundation, m

$F_d = 1 + 0.33(D_f/B) \leq 1.33$

S_e - allowable settlement, mm

The allowable settlement value for mat foundation is taken as 50 mm based on the recommendations by Terzaghi and Peck (1948). The net pressure applied by the structure to mat foundation is determined using the equation below:

$$q = \frac{Q}{A} - \gamma D_f$$

Where,

q - net pressure applied on foundation, kN/m²

Q - load exerted by the building, kN

A - area of the mat foundation, m²

γ - unit weight of the soil, kN/m³

D_f - depth of mat foundation, m

Table 3.10 summarizes the calculation results for two iterations used for mat foundation bearing capacity calculation:

Table 3.10. Mat foundation net allowable bearing capacity calculation results

Iteration	B, m	L, m	D_f , m	N_{60}	Allowable settlement S_e	Net allowable bearing pressure q_{net} , kN/m^2	Net pressure applied on foundation q , kN/m^2
1	48	22	1	2	50	50.98	21.48
2	50	24	1	2		50.94	16.98

3.4.3. Deep Foundation

Deep foundation can be described as the type of foundation often made in a cylindrical form or a column that uses shaft and point resistance to support structural loads. This type of foundation is used for large structures in case the soil layers located near the ground surface are not suitable for supporting the loads and are prone to excessive settlement. Deep foundations are known for their higher bearing capacity, ability to withstand lateral forces, versatility, and lesser usage of horizontal space. However, the process of installing piles is expensive and requires specialized labor and equipment (civiltoday, n.d.).

Three iterations of pile foundation dimensions were used to calculate the bearing capacity of a single pile. The cross-section of piles was taken as circular for calculations:

- 1st iteration: $D = 0.60$ m, $L = 10$ m
- 2nd iteration: $D = 0.65$ m, $L = 10$ m
- 3rd iteration: $D = 0.70$ m, $L = 10$ m

The calculation of end-bearing capacity and shaft resistance for pile foundation was done using various methods.

End-bearing capacity Q_p

The end-bearing capacity Q_p of piles was calculated using three methods, including Meyerhof (1976), Vesic (1977), and Coyle and Castello (1981). The equations used for these methods are shown below:

Meyerhof (1976):

$$Q_p = q' N_q^* A_p \leq A_p q_l$$

$$q_l = 0.5 p_a N_q^* \tan \phi'$$

Where,

Q_p - end-bearing capacity, kN

A_p - cross-section area of pile, m²

q_l - limiting point resistance, kN/m²

N_q^* - bearing capacity factor

Vesic (1977):

$$Q_p = A_p \sigma'_{\underline{a}} N_{\sigma}^*$$

$$\sigma'_{\underline{a}} = \left(\frac{1 + 2K_o}{3} \right) q'$$

$$K_o = 1 - \frac{\sin \phi'}{E_s}$$

$$I_r = \frac{2(1 + \mu_s) q' \tan \phi'}{I_r}$$

$$I_{rr} = \frac{1}{1 + I_r \Delta}$$

$$\mu_s = 0.1 + 0.3 \left(\frac{\phi' - 25}{20} \right)$$

$$\Delta = 0.005 \left(1 - \frac{\phi' - 25}{20} \right) \frac{q'}{p_a}$$

Where,

$\sigma'_{\underline{a}}$ - mean effective normal ground stress at pile point level, kN/m²

N_{σ}^* - bearing capacity factor

K_o - at-rest earth pressure coefficient

I_r - rigidity index of soil

I_{rr} - reduced rigidity index of soil

E_s - elastic modulus of soil, MPa

μ_s - Poisson's ratio of soil

Δ - average plastic zone volumetric strain under the pile point

Coyle and Castello (1981):

$$Q_p = q' N^* A_p$$

Frictional resistance of soil Q_s

To calculate the frictional resistance of soil Q_s , unit frictional resistance and Coyle and Castello (1981) methods were used, shown in the following formulas:

Unit frictional resistance:

$$Q_s = \Sigma p \Delta L f$$

$$L' = 15D$$

$$f = K \sigma_o' \tan \delta'$$

Where,

p - pile perimeter, m

K - effective earth pressure coefficient, taken as 1.5 for precast concrete piles

σ_o' - effective vertical stress, kN/m²

δ' - soil-pile friction angle, assumed to be $0.8\phi'$

Coyle and Castello (1981):

$$Q_s = f_{av} p L = (K \sigma_o \tan \delta') p L$$

The average values for Q_p and Q_s from different methods were taken for further calculations. The following equation is then used to calculate the allowable bearing capacity of pile:

$$Q_{all} = \frac{Q_p + Q_s}{FS}$$

The calculation results for pile foundation are summarized in Table 3.11:

Table 3.11. Pile foundation bearing capacity calculation results

Iteration	D, m	L, m	Q _p , kN				Q _s , kN			Q _{all} , kN
			Meyerh of (1976)	Vesic (1977)	Coyle and Castello (1981)	Final Q _p	Unit friction al resistan ce	Coyle and Castello (1981)	Final Q _s	
1	0.60	10.0	4102.3	4422.1	4723.3	4415.9	1455.2	2951.5	2203.3	2647.7
2	0.65	10.0	4814.6	5189.8	5543.4	5182.6	1596.3	3197.5	2396.9	3031.8
3	0.70	10.0	5583.7	6018.9	6429.0	6010.6	1720.3	3443.4	2581.9	3437.0

Pile foundation settlement

Since the soil profile mostly consists of poorly graded sand (SP) and no clay is present, the pile foundation settlement was calculated using the elastic settlement rather than consolidation settlement. The calculations were done for the first iteration of deep foundation calculations since it is able to withstand the minimum vertical load of 1747 kN from edge columns. The pile elastic settlement was determined based on Vesic's method (1977). In this method, the elastic settlement is calculated from three components which include:

- Elastic shortening of the pile $s_{e(1)}$
- Settlement of the pile under working load at the pile point $s_{e(2)}$
- Settlement of the pile under working load across the pile shaft $s_{e(3)}$

The equation for calculating the first component of the elastic settlement is shown below:

$$S_{e(1)} = \frac{(Q_{wp} + \varepsilon Q_{ws})L}{AE_p}$$

Where,

- Q_{wp} - working load at the pile point, kN
- Q_{ws} - is working load across the pile shaft, kN
- A - cross-sectional area of the pile point, m^2
- L - length of the pile, m
- E_p - modulus of elasticity of the material of the pile, GPa
- ε - constant dependent on the skin friction distribution, 0.5-0.67

Since skin friction mostly increases with more depth, the value for ε is taken as 0.67 for calculations. According to the Civil Wale website, the value of elastic modulus for concrete lies within a range between 30 to 50 GPa, so the average value of 40 GPa was taken (CivilWale, n.d.). Q_{wp} and Q_{ws} were taken from pile capacity calculations in Table 3.X. The pile is of circular shape with a diameter equal to 0.60 m and 10 m length from the first iteration shown in Table 3.X.

Elastic shortening of the pile $s_{e(1)}$ is calculated as shown below:

$$s_{e(1)} = \frac{(1766.36 + 0.67 \times 881.32) \times 10}{\pi \times 0.30^2 \times 40 \times 10^6} = 0.00208m = 2.08 \text{ mm}$$

The following equation was used to calculate the second component of the pile settlement due to working load at pile point $s_{e(2)}$:

$$s_{e(2)} = \frac{Q_{wp} C_p}{D q_p}$$

Where,

- C_p - empirical coefficient, taken as 0.02 for driven pile in sand
- q_p - ultimate point resistance of pile, kN/m^2
- D - width (diameter) of the pile, m

The second part of the settlement was calculated as shown below:

$$s_{e(2)} = \frac{(1766.36)(0.02)}{(0.6) \left(\frac{4415.9}{\pi \times 0.30} \right)} = 0.00565 \text{ m} = 5.65 \text{ mm}$$

For the third part of the elastic settlement calculation, the Poisson's ratio was taken as 0.41. Since the soil layer on which the pile tip is located is classified as poorly graded sand (SP), according to Kumar and Madhusudhan, the Poisson's ratio for that type of soil is equal to 0.41 (Kumar and Madhusudhan, 2012).

The modulus of elasticity of the soil was approximated based on the following equation proposed by Chen and Kulhawy (1994):

$$E_s = m p_a$$

Where,

p_a - atmospheric pressure, 100 kN/m²

m - coefficient which varies between 500 and 1000 for dense soil, so the average value of 750 was used for further calculation:

$$E_s = m \times p_a = 750 \times 100 = 75000 \text{ kN/m}^2$$

The third part of the pile elastic settlement which is under the working load across the pile shaft was calculated by the equation below:

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

Where,

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

The calculation of the third component of elastic settlement is described below:

$$s_{e(3)} = \frac{(881.32)(0.60)}{(\pi)(0.60)(10)(7500)} (1 - 0.41^2) (2 + 0.35 \sqrt{\frac{10}{0.60}}) = 0.00107 \text{ m} = 1.07 \text{ mm}$$

The value of the total elastic settlement was calculated as the sum of the results of all components of elastic settlement of the pile:

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

$$s_{e(t)} = 2.08 + 5.65 + 1.07 = 8.80 \text{ mm}$$

The calculation results show that the value of total elastic settlement is equal to 8.80 millimeters, which is within an acceptable range for pile foundation.

3.4.4. Foundation Type Selection

By comparing the bearing capacity calculation results for both shallow and deep foundations, we have decided that using pile foundation would be more suitable compared to shallow foundation. Despite the third iteration for shallow foundation being able to support the minimum vertical load shown in Table 3.6, which is 1747 kN from edge columns, and the shallow foundation being a more affordable option, using pile foundation would be more suitable for our project since piles can be placed in groups to withstand greater loads. For our case, shallow foundations cannot withstand loads from internal and corner columns. Single piles can be used to support the minimum load which is exerted by edge columns, while a group pile with a configuration of 2x1 and 2x2 can be used to support loads from corner and internal columns, respectively. Based on the structural loads given in Table 3.6, a layout of deep foundations was made in AutoCAD shown in Figure 3.8. The type of pile that will be used for this project is a driven pile. Driven piles are known for their high bearing capacity and are suitable for group piles. They can also be installed in a wide variety of soils and do not require any excavation. However, the installation of driven piles is expensive and causes noise which can be distracting to nearby residents (Structuralguide.com, 2023).

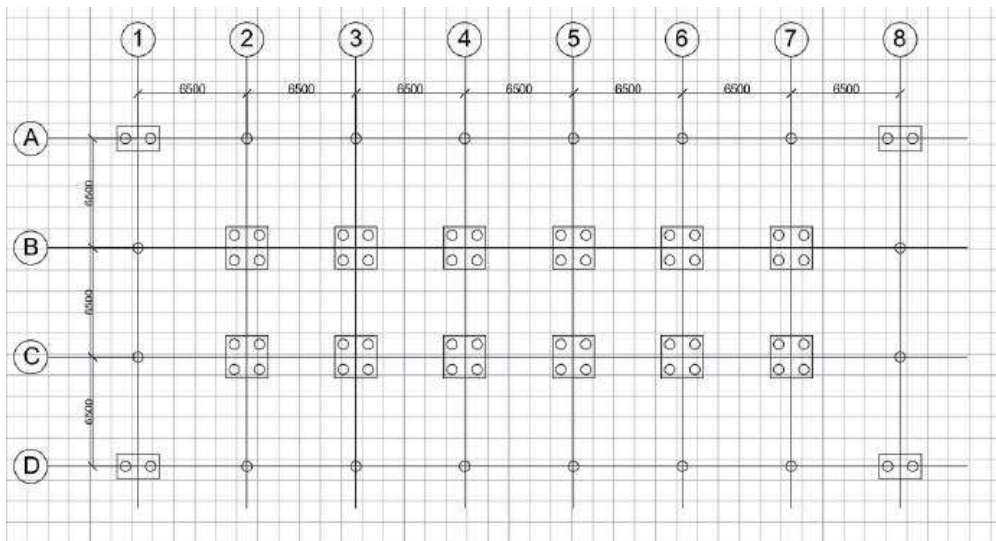


Figure 3.8. Layout of single and group piles

GEO5 software was used to create the model of a single pile with a 0.60 meter diameter and length of 10 meters, shown in Figure 3.9. GEO5 calculation shows similar results regarding the bearing capacity of a single pile, with slight differences, as seen in Figure 3.10.

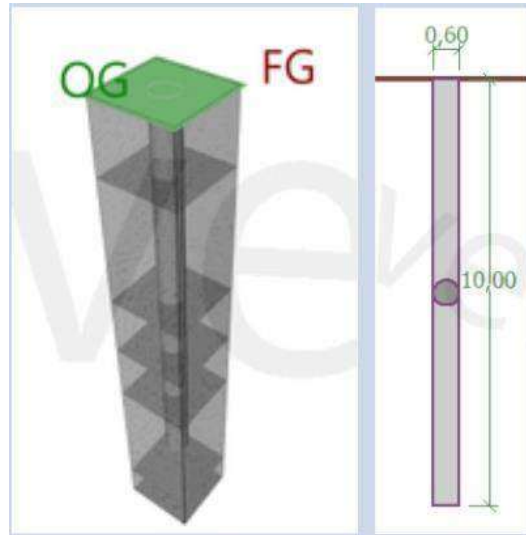


Figure 3.9. 3D and 2D view of the GEO5 single pile model

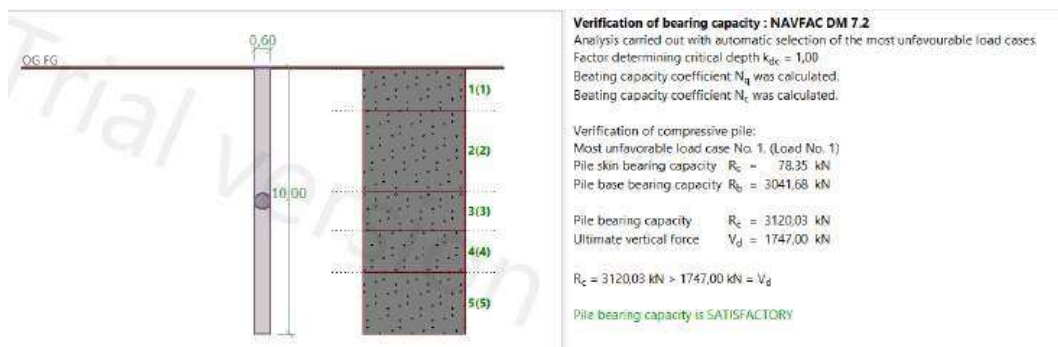


Figure 3.10. GEO5 single pile simulation results

GEO5 software also calculates the displacement, shear force, and bending moment experienced by piles and compiles the results in the form of graphs, shown in Figure 3.11. Figure 3.12 shows the reinforcement layout required for a single layout based on GEO5 software calculations.

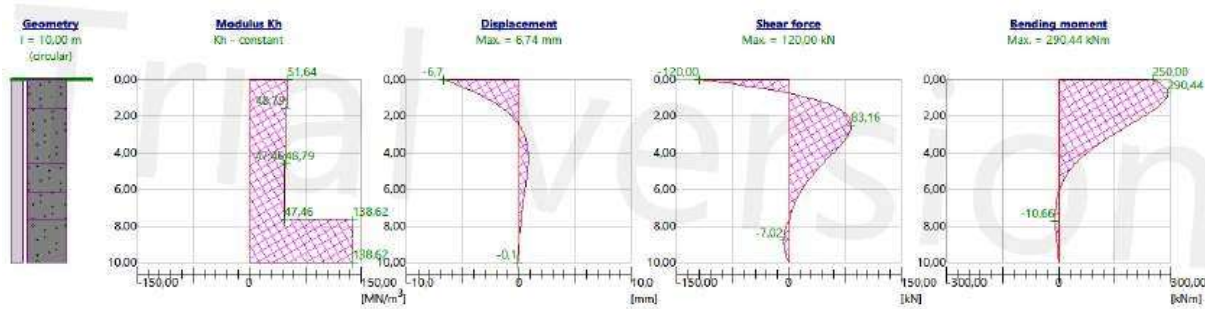


Figure 3.11. GEO5 results for displacement, shear force, and bending moment for a single pile

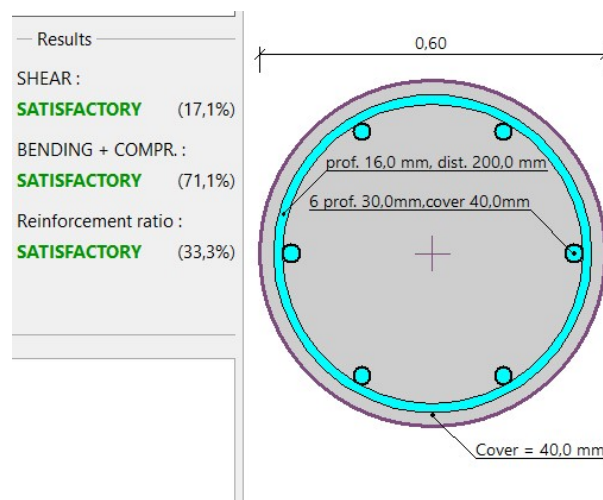


Figure 3.12. GEO5 single pile reinforcement calculation results

3.4.5. Group Piles

Piles are often used in groups to transfer the loads exerted by structures to the soil. After groups have been placed, a slab called pile cap is placed on top. The minimum center-to-center spacing for group piles d is usually taken as $2.5D$, which is equal to 1.5 meters in our case. The first iteration for single piles was used for group piles, with a diameter of 0.60 meters and 10 meter length in 2x2 and 2x1 configurations.

The length L_g and width B_g of group piles are determined using the following formula:

$$L_g = (n_1 - 1)d + 2(D/2)$$

$$B_g = (n_2 - 1)d + 2(D/2)$$

Where,

n_1, n_2 - number of piles

d - center-to-center spacing of piles, m

D - pile width (diameter), m

The load bearing efficiency of group piles is determined using the equation below:

$$\eta = \frac{2(n_1 + n_2 - 2)d + 4D}{pn_1n_2}$$

If the value of η is greater than or equal to 1, the piles behave as individual piles, therefore:

$$Q_{g(u)} = \Sigma Q_u$$

In other case when $\eta < 1$, then:

$$Q_{g(u)} = \eta \Sigma Q_u$$

Calculations for 2x1 group pile configuration:

$$L_g = (2 - 1) \times 1.5 + 2(0.6/2) = 2.1 \text{ m}$$

$$B_g = (2 - 1) \times 1.5 + 2(0.6/2) = 2.1 \text{ m}$$

$$\eta = \frac{2(n_1 + n_2 - 2)d + \Phi}{pn_1n_2} = \frac{2(2 + 2 - 2) \times 1.5 + 4 \times 0.6}{1.884 \times 2 \times 2} = 1.115$$

Calculations for 2x2 group pile configuration:

$$L_g = (1 - 1) \times 1.5 + 2(0.6/2) = 0 \text{ m}$$

$$B_g = (2 - 1) \times 1.5 + 2(0.6/2) = 2.1 \text{ m}$$

$$\eta = \frac{2(n_1 + n_2 - 2)d + \Phi}{pn_1n_2} = \frac{2(1 + 2 - 2) \times 1.5 + 4 \times 0.6}{1.884 \times 2 \times 2} = 1.433$$

The group pile efficiency for both 2x2 and 2x1 group piles are greater than 1, meaning that the piles behave as individual piles, meaning that the bearing capacity of group piles is equal to the sum of bearing capacities of each pile.

Group pile settlement

The following formula was used to calculate the settlement of the pile group:

$$S_{e(g)} = \sqrt{\frac{B_g}{D}} \times S_e$$

Where,

$s_{(e)}$ - total elastic settlement of a single pile, m

B_g - width of a pile group, m

2x2 group pile:

Center-to-center spacing between the piles is taken as $d = 2.5D = (2.5)(0.6) = 1.5$ m. B_g is determined using the following formula:

$$B_g = (n_1 - 1)d + 2(D/2) = (2 - 1) \times 1.5 + 2(0.6/2) = 2.1 \text{ m}$$

$$S_{e(g)} = \sqrt{\frac{2.1}{0.6}} \times 8.80 = 16.46 \text{ mm}$$

2x1 group pile:

$$B_g = (2 - 1) \times 1.5 + 2(0.6/2) = 2.1 \text{ m}$$

$$S_{e(g)} = \sqrt{\frac{2.1}{0.6}} \times 8.80 = 16.46 \text{ mm}$$

GEO5 software simulation

GEO5 software was used to create the models for group piles for simulations to calculate bearing capacity, which can be seen in Figures 3.13 and 3.14. The models also include the top view of group piles with pile cap dimensions. The thickness of the pile cap was taken as 1.0 meters. The results from hand calculations and GEO5 simulations for group and single piles are summarized in Table 3.12.

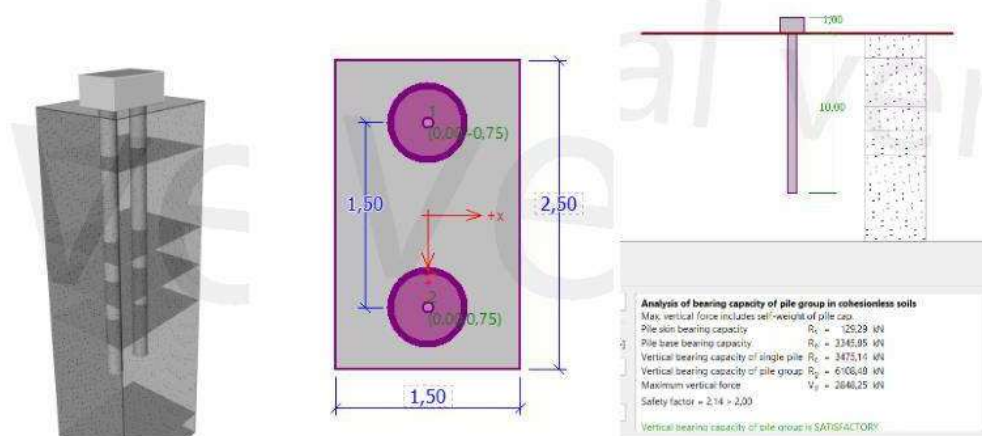


Figure 3.13. 2x1 group pile 3D model, top view, and 2D model in GEO5

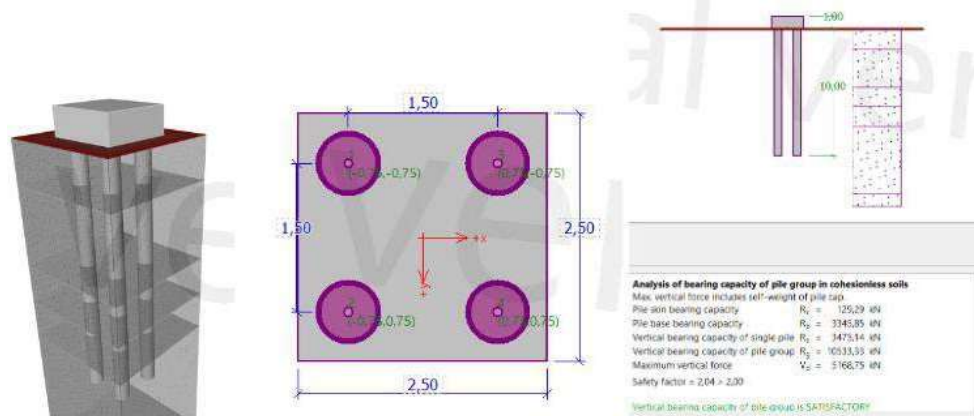


Figure 3.14. 2x2 group pile 3D model, top view, and 2D model in GEO5

Table 3.12. Single and group pile hand calculations and GEO5 simulation results

Foundation type	Bearing capacity, kN		Settlement, mm	
	Hand calculation	GEO5	Hand calculation	GEO5
Single Pile (edge)	2647.7	3475.14	8.80	1.4
2x1 Group Pile (corner)	5295.4	6108.48	16.46	31.5

2x2 Group Pile (interior)	10590.8	10533.33	16.46	14.7
------------------------------	---------	----------	-------	------

By comparing the hand calculation and GEO5 simulation results for deep foundation, it can be seen that the bearing capacity values have slight differences. On the other hand, the hand calculation results for settlement of a single pile is greater than GEO5, whereas the result for a 2x1 group pile is smaller. The settlement results for the 2x2 group pile have minor differences. Overall, the calculation results are satisfactory since the settlement of deep foundations is within the acceptable range of below 50 mm and the bearing capacity is sufficient to withstand the structural loads. GEO5 also provides the results for the bending moment and shear force experienced by group piles from loads, as shown in Figures 3.15 and 3.16.

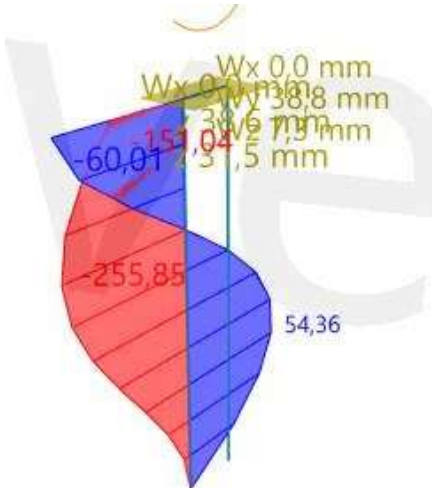


Figure 3.15. GEO5 bending moment (red) and shear force (blue) diagram for 2x1 group pile

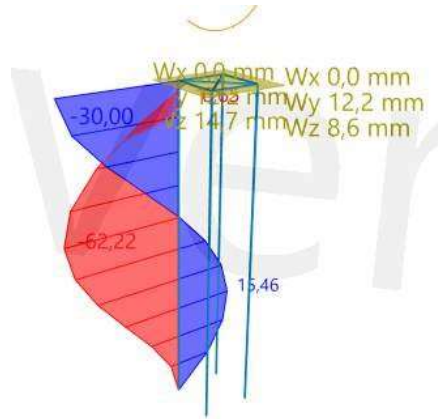


Figure 3.16. GEO5 bending moment (red) and shear force (blue) diagram for 2x2 group pile

3.4.6. PLAXIS 3D Simulations

PLAXIS 3D software was used to create a 3D model of the basement with a deep foundation to evaluate the performance of the geotechnical design of the project. By running a simulation on a PLAXIS 3D model, we can determine the settlement experienced by the group piles from exerted structural loads. The 3D model of the basement is shown in Figures 3.17 and 3.18. The basement walls and pile caps for group piles were modeled as plate elements and piles were modeled as embedded beam elements. Point loads were placed on top of the group pile models.

The borehole data for the 3D soil model was based on the information from soil profile from Table 3.4. Each layer was assigned as a Mohr-Coulomb model soil material using the physical characteristics such as unit weight, friction angle, Poisson's ratio, and stiffness modulus. The groundwater level was input as 24.0 meters based on data from the investigation report.

After creating the soil model and structures, a mesh was generated for further simulation-based model analysis. For better performance, the mesh was generated in Coarse mode. 4 stages were used during the staged construction section, including:

- Initial phase (No changes)
- Excavation (Upper layers of soil were removed for the basement construction)
- Construction (Structures such as walls, pile caps, and piles were activated)
- Loading (Structural loads were applied)

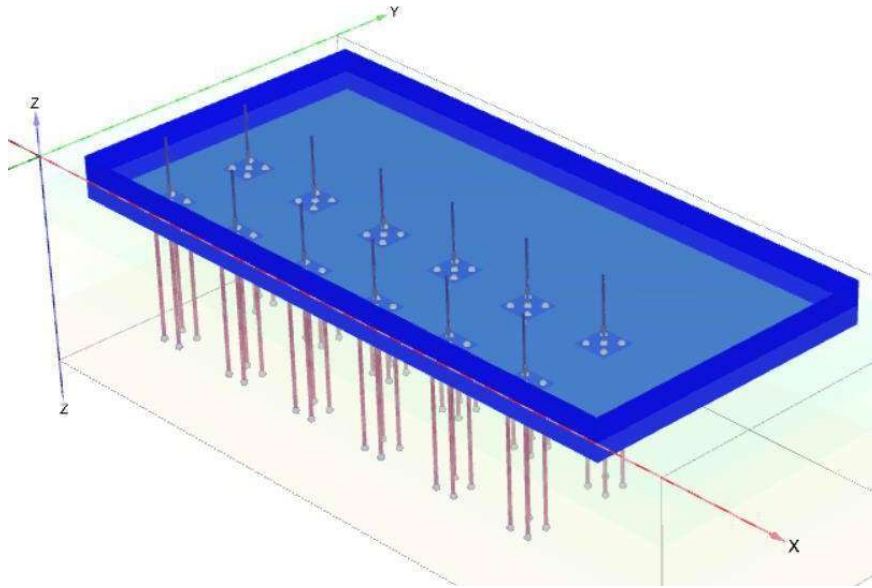


Figure 3.17. PLAXIS 3D basement model

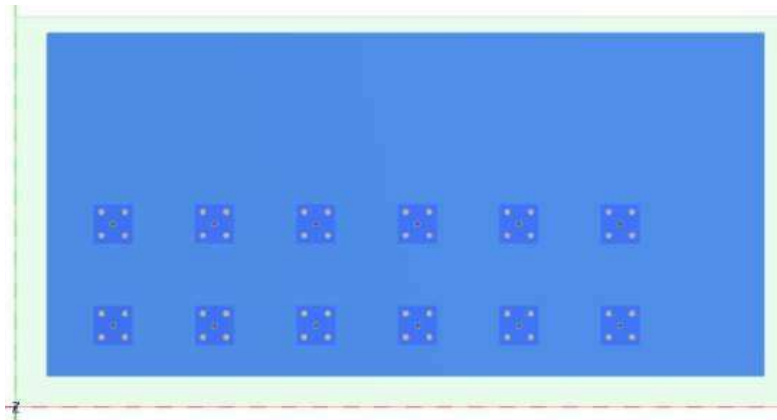


Figure 3.18. Top view of the pile foundation layout in PLAXIS 3D

After creating four phases in a staged construction section, a simulation must be run by pressing the “Calculate” button. After the calculations for simulation have been completed, the results can be viewed by pressing the “Output” button which opens a separate window showing the displacements and stresses in a diagram. The simulation results for our PLAXIS 3D model can be seen in Figure 3.19 and 3.20.

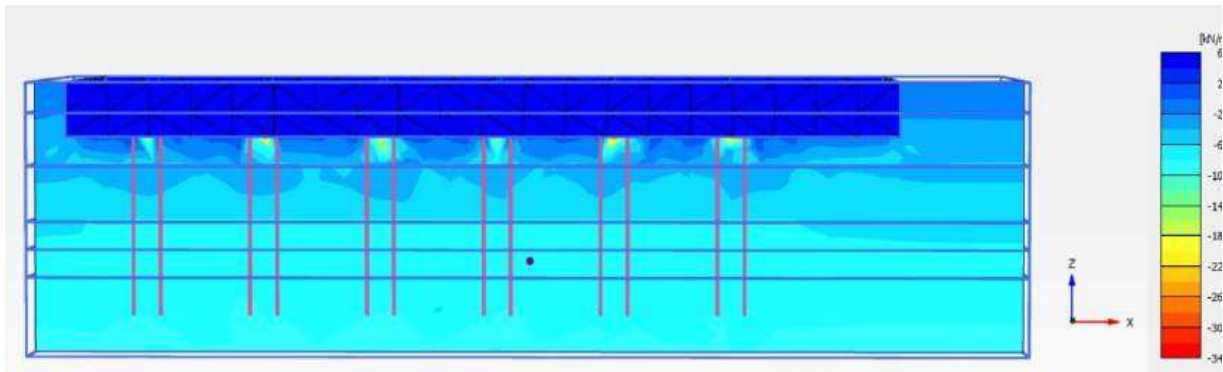


Figure 3.19. Cross sectional diagram of total stresses in vertical direction in PLAXIS 3D

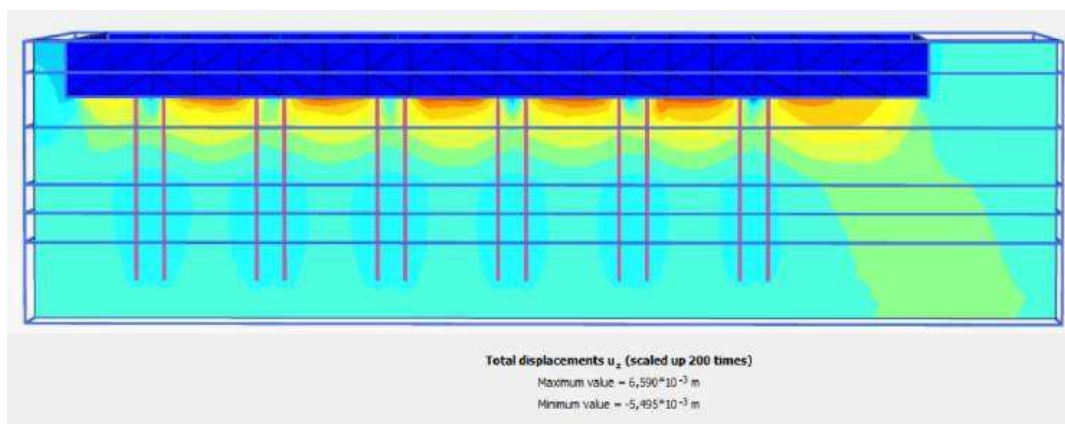


Figure 3.20. Cross sectional diagram of vertical displacements in PLAXIS 3D

3.5. Retaining Wall Design

One of the main considerations for the geotechnical section of the project is the presence of an underground level basement for parking, for which a retaining wall needs to be designed to resist forces from the soil. Due to the groundwater table being located 23.47 meters below ground surface, the pore water pressure values were taken as 0 for calculations, which means that the value of A_4 is also equal to 0. The lateral force exerted per unit length of wall by soil was calculated using the Rankine active pressure equation. The cohesion values were also taken as 0 since the soil layers are cohesionless poorly graded sand (SP). The type of retaining wall that will be used for the basement is a cantilever wall made from concrete. The overall height of the retaining wall is 4.5 meters, with 3.0 meters open for the basement and 1.5 meters underground.

3.5.1. Rankine Active Case Calculations

The following formula was used to determine the lateral earth pressure:

$$\sigma_a' = \sigma_o' K_a$$

Where,

σ_a' - lateral earth pressure, kN/m²

σ_o' - overburden pressure, kN/m²

K_a - Rankine active earth pressure coefficient

The following equation was used to calculate the values for Rankine active earth pressure coefficient:

$$K_a = \tan^2\left(45 - \frac{\phi'}{2}\right)$$

Where,

ϕ' - the friction angle of the soil layer, °

Figure 3.21 shows the pressure distribution diagram that is used to calculate the active force per unit length by summing the areas:

$$P_a = A_1 + A_2 + A_3 + A_4$$

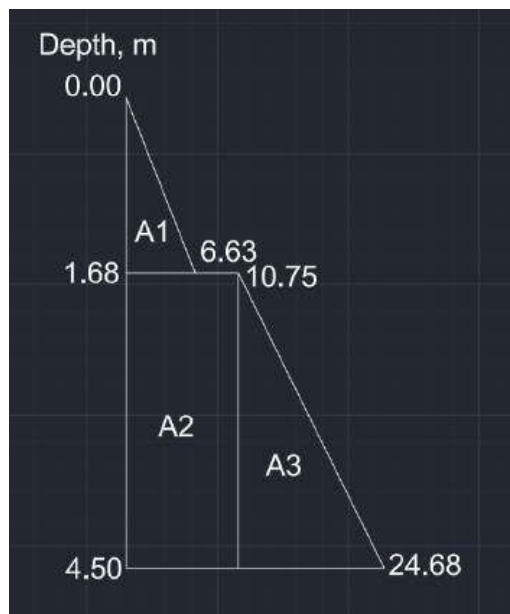


Figure 3.21. Pressure distribution diagram for calculation of active pressure value P_a

First soil layer calculations:

$$K_{a(1)} = \tan^2\left(45 - \frac{37.2}{2}\right) = 0.2464$$

$$\sigma_o' = (16.02)(1.68) = 26.91 \text{ kN/m}^2$$

$$\sigma_a' = (26.91)(0.2464) = 6.63 \text{ kN/m}^2$$

Second soil layer calculations:

$$K_{a(2)} = \tan^2\left(45 - \frac{25.4}{2}\right) = 0.3996$$

$$\sigma_o' = (16.02)(4.5) = 72.09 \text{ kN/m}^2$$

$$\sigma_a' = (26.91)(0.2464) + (16.02)(2.82)(0.3996) = 24.68 \text{ kN/m}^2$$

Rankine active force per unit length and line of action distance calculations:

$$P_a = (0.5)(1.68)(6.63) + (2.82)(10.67) + (0.5)(2.82)(24.68 - 10.67) = 55.41 \text{ kN/m}$$

$$\bar{z} = \frac{(A_1)\left(2.82 + \frac{1.68}{3}\right) + (A_2)\left(\frac{2.82}{2}\right) + (A_3)\left(\frac{2.82}{3}\right)}{P_a}$$

$$= \frac{(5.57)\left(2.82 + \frac{1.68}{3}\right) + (30.09)\left(\frac{2.82}{2}\right) + (19.75)\left(\frac{2.82}{3}\right)}{55.41} = 1.4405 \text{ m}$$

Calculation results are summarized below in Table 3.K:

Table 3.13. Rankine active case calculation results

Depth, m	Unit weight, kN/m ³	Friction angle, °	Overburden pressure σ_o' , kN/m ²	Rankine active pressure coefficient K_a	Lateral earth pressure σ_a' , kN/m ²	Rankine active force per unit length P_a , kN/m	Line of action distance, m	Line of action distance from GEO5, m
0	16.02	37.2	0	0.2464	0	55.41	1.4405	1.42
1.68	16.02	37.2	26.91	0.2464	6.63			

1.68 ⁺	16.02	25.4	26.91	0.3996	10.75			
4.5	16.02	25.4	72.09	0.3996	24.68			

3.5.2. Cantilever Wall Design and Stability Check

The next step is to create the dimensions for the cantilever wall using the proportioning method shown in Figure 3.22. The final result of the cantilever wall dimensioning is shown in Figure 3.23.

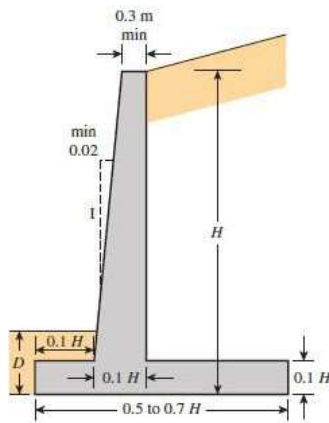


Figure 3.22. Cantilever wall dimensioning (Das, 2019)

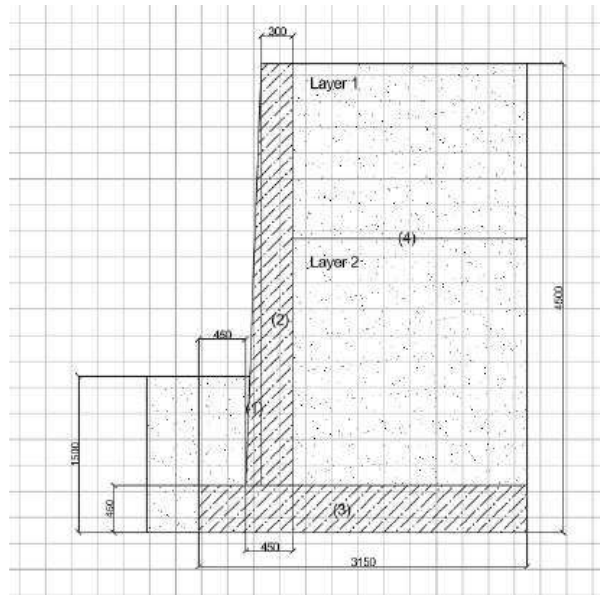


Figure 3.23. AutoCAD drawing of cantilever wall with dimensions

Before calculating the factor of safety against overturning, sliding, and bearing capacity failure, the vertical load from cantilever wall and soil ΣV and resisting moment ΣM_R must be calculated. This is done in Table 3.14 where the unit weight of soil is taken as 16.02 kN/m^3 for the first and second soil layers, the unit weight of concrete is assumed to be 24.0 kN/m^3 . Soil layers were combined into Section 4 since they have the same unit weight.

Table 3.14. Vertical load per unit length and resisting moment calculation

Section	Area, m^2	Weight/Unit Length, kN/m	Moment arm from point C, m	Moment, $\text{kN}\cdot\text{m/m}$
1	$(0.15)(4.05)(0.5) = 0.30$	$(0.3)(24.0) = 7.20$	0.550	$(7.20)(0.550) = 3.96$
2	$(0.30)(4.05) = 1.21$	$(1.21)(24.0) = 29.04$	0.750	$(29.04)(0.750) = 21.78$
3	$(3.15)(0.45) = 1.42$	$(1.42)(24.0) = 34.08$	1.575	$(34.08)(1.575) = 53.68$

4	(2.25)(4.05) = 9.11	(9.11)(16.02) =145.94	2.025	(145.94)(2.025) = 295.53
	ΣV =	216.26	ΣM _R =	374.95

To check for overturning, we must first calculate the overturning moment using the previously calculated active force P_a and following formula:

$$M_o = P_a \left(\frac{H}{3} \right) = 55.41 \times \frac{4.5}{3} = 83.12 \text{ kN} \cdot \text{m/m}$$

After that, the following equation is used to calculate the factor of safety against overturning:

$$FS_{\text{overturning}} = \frac{\Sigma M_R}{M_o} = \frac{374.95}{83.12} = 4.51 > 1.5 \text{ (ok)}$$

To check for sliding along the base, we must first determine the Rankine passive pressure coefficient K_p and Rankine passive pressure P_p using the following equations:

$$K_p = \tan^2 \left(45 + \frac{\phi'_2}{2} \right) = \tan^2 \left(45 + \frac{25.4}{2} \right) = 2.502$$

$$P_p = \frac{1}{2} K_p \gamma_2 D^2 + 2c'_2 \sqrt{K_p D} = 0.5 \times 2.502 \times 16.02 \times 1.5^2 = 45.09 \text{ kN/m}$$

After that, the factor of safety against sliding is determined using the following formula (k_1 and k_2 values are assumed to be 2/3):

$$FS_{\text{sliding}} = \frac{(\Sigma V) \tan(k_1 \phi'_2) + B k_2 c'_2 + P_p}{P_a \cos \alpha} = \frac{216.26 \times \tan\left(\frac{2}{3} \times 25.4\right) + 45.09}{55.41} = 2.00 > 1.5 \text{ (ok)}$$

To check for bearing capacity failure, we must first determine the eccentricity e , after which the maximum and minimum pressures that occur at toe (q_{toe}) and heel (q_{heel}), respectively, must be calculated. The eccentricity must not exceed the width of cantilever wall B divided by 6:

$$e = \frac{B}{2} - \frac{\Sigma M_R - \Sigma M_o}{\Sigma V} = \frac{3.1}{2} - \frac{374.95 - 83.12}{216.26} = 0.2256 \text{ m} < \frac{B}{6} = \frac{3.1}{6} = 0.525 \text{ m}$$

$$q_{\text{heel}}^{\text{heel}} = \frac{\Sigma V}{B} \left(1 \pm \frac{6e}{B} \right) = \frac{216.26}{3.15} \times \left(1 \pm \frac{6 \times 0.2256}{3.15} \right)$$

$$q_{toe} = 98.16 \text{ kN/m}^2$$

$$q_{heel} = 39.15 \text{ kN/m}^2$$

After that, the ultimate bearing capacity of soil (q_u) underneath the cantilever wall must be calculated using the following formula:

$$q_u = c'N_cF_{cd}F_{ci} + qN_qF_{qd}F_{qi} + \frac{1}{2}\gamma B'N_\gamma F_{\gamma d}F_{\gamma i}$$

The value of friction angle of the soil layer underneath the retaining wall is equal to 25.4° , meaning that the bearing capacity factors are:

- $N_c = 20.72$
- $N_q = 10.66$
- $N_\gamma = 10.88$

$$B' = B - 2e = 3.15 - 2 \times 0.2256 = 2.6988 \text{ m}$$

$$q = \gamma D = 16.02 \times 1.5 = 24.03 \text{ kN/m}^2$$

$$F_{qd} = 1 + 2\tan\phi'(1 - \sin\phi')^2 \left(\frac{D}{B}\right) = 1 + 2\tan 25.4(1 - \sin 25.4)^2 \left(\frac{1.5}{3.15}\right) = 1.1475$$

$$F_{cd} = F_{qd} - \frac{1 - F_{qd}}{N_c \tan\phi'} = 1.1475 - \frac{1 - 1.1475}{20.72 \tan 25.4} = 1.1625$$

$$F_{\gamma d} = 1$$

$$\psi = \tan^{-1} \left(\frac{P_a \cos\alpha}{\Sigma V} \right) = \tan^{-1} \left(\frac{55.41}{216.26} \right) = 14.37$$

$$F_{ci} = F_{qi} = \left(1 - \frac{\psi}{90}\right)^2 = \left(1 - \frac{14.37}{90}\right)^2 = 0.706$$

$$F_{\gamma i} = \left(1 - \frac{\psi}{\phi'}\right)^2 = \left(1 - \frac{14.37}{25.4}\right)^2 = 0.189$$

$$q_u = (24.03)(10.66)(1.1625)(0.706) + \frac{1}{2}(16.02)(2.6988)(10.88)(1)(0.189)$$

$$= 254.689 \text{ kN/m}^2$$

The factor of safety against bearing capacity failure is calculated using the following equation:

$$FS_{\text{bearing capacity}} = \frac{q_u}{q_{toe}} = \frac{254.689}{98.16} = 2.60 > 2.0 \text{ (ok)}$$

The calculation results for checks against overturning and sliding failure are successful since the factor of safety values are over 1.5. The factor of safety for bearing capacity failure is also successful since its value is over 2.0.

GEO5 cantilever wall simulation

GEO5 software was used to create a model of cantilever wall (Figure 3.24) to run simulations, the results of which are shown in Figures 3.25 and 3.26.

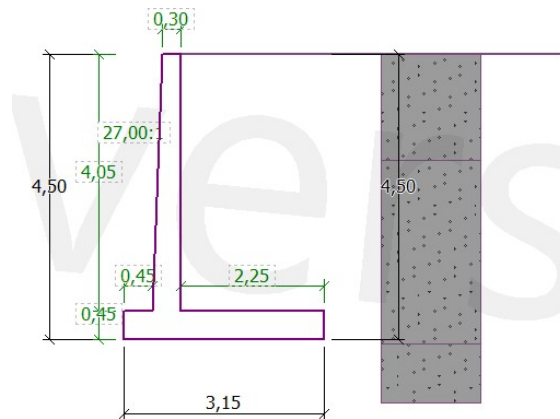


Figure 3.24. GEO5 cantilever wall model

Verification : [1]						
No.	Force	F _x [kN/m]	F _z [kN/m]	Applic. point		Coeff.
				x [m]	z [m]	[-]
1	Weight - wall	0,00	67,53	1,13	-1,32	1,000
2	Weight - earth wedge	0,00	70,42	1,65	-1,75	1,000
3	Active pressure	-59,86	78,10	2,40	-1,42	1,000

— Verification —

OVERTURNING: SATISFACTORY (33,6%)

SLIP: SATISFACTORY (87,5%)

Figure 3.25. GEO5 simulation results for overturning and sliding failure check

Verification	
ECCENTRICITY:	SATISFACTORY (20,2%)
FOUNDATION SOIL:	SATISFACTORY (56,8%)

Figure 3.26. GEO5 simulation results for bearing capacity failure check

As shown in Figures 3.25 and 3.26, the simulation results are satisfying, meaning that our cantilever wall is suitable for retaining the forces exerted by soil. GEO5 simulation results in

Figure 3.27 also show the results for bending moment and shear force calculations with reinforcement that should be used for the cantilever wall.

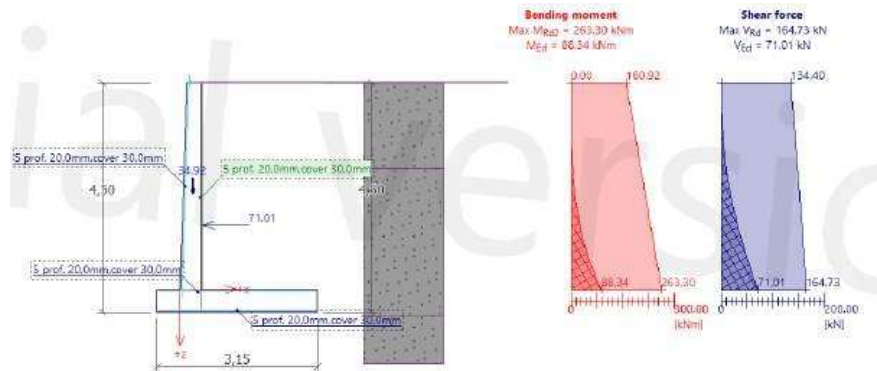


Figure 3.27. GEO5 cantilever wall reinforcement, bending moment, and shear force calculations

3.6. Excavation and Foundation Construction Procedure

3.6.1. Excavation procedure

The building of basements for buildings has become popular with the development of cities and the increase of population of the cities. The numbers of vehicles are increasing due to higher population and development of the car production industry. The buildings could be categorized as infrastructural facilities, and they need to adapt to the modern realities. Therefore, the basements are built in order to create additional useful space and to build parkings (Thapa, 2022). There are several problems related to the construction of the basement, such as loose soil that may cause sliding of the land, danger to nearby constructions such as pavement and buildings. In order to avoid the damage to nearby buildings and make the excavation process safe, the support of excavation is needed. An excavation more than 4.5 meters is considered as deep excavation, but in our case the excavation is only 3 meters deep. However, the location of our building and excavation is close to other buildings, so the land should be retained during the excavation procedure.

The 4.5 meter deep sheet piles could be used as a temporary support for the excavation, as they could be easily driven to the soil and does not require difficult procedures to build it. It may also be designed in different dimensions, so they could perfectly fit the excavation depth. It has low buckling under heavy driving, economically viable due to reusability as a temporary

support. Another advantage of using steel sheet piles is the fact that it does not cause excessive soil displacement during driving.

Before the driving of sheet piles, the partial excavation should be done, in order to protect the sheet piles from the effects of the dense sand. After that the vibratory driving could be accomplished using the ICE-815 driver based on vibration principles. The interlocks of the sheet piles should be initially lubricated in order to avoid damage due to excess friction with the soil (Athanasopoulos, 2011). The driving should be vertical, so the inclinometers could be placed in order to check the verticality of the placement, the inclinometers could be placed near the sheet piles. The vibrations of the ground caused by the driving process should be checked systematically during the driving. Seismometers such as 2 Hz Mark Products could be placed on the ground. The attenuation of ground vibrations should be recorded at different distances from the 4 driven sheet piles from 4 sides of the excavation. During all the procedures the vibration levels should be lower than the allowable limit. The vibrations during start and end of vibrations could be higher by 20 percent compared to vibration levels during the steady procedure, but these vibrations are short-term, so the nearby building should be considered as safe if the limits are not exceeded. The driven sheet piles should be braced to each other using the horizontally placed struts. They should support the walls located opposite and the corners by bracing. The braced structure could look as in the example shown in Figure 3.28.



Figure 3.28. Braced steel sheet piles example (Athanasopoulos, 2011).

After the end of excavation procedure and following the cantilever retaining walls installation the temporary retaining structure should be removed. The removal would be done using the vibrating driver that was used for its installation. The additional 1.5 meters excavation should be made near the temporary support, and the thin concrete layer should be casted. The reinforcement of the cantilever should be placed on the concrete layer and cased by formwork. The concrete should be poured to make a 4.5 meters deep cantilever wall and after curing the mold should be removed. The coarse gravel could be placed between the backfill and outer side of the retaining wall for better drainage. The pvc tube could be placed at the bottom of coarse material for the drainage system. The backfill material should be placed on top of the heel of the retaining wall.

3.6.2. Group Piles Installation

The group piles should be prefabricated in factory conditions, in which they could be tested for bearing capacity. The use of prefabricated concrete structures reduces the amount of waste created by 55 percent (Jaillon, 2009). According to studies by Lachimpadi, the construction process in which materials casted on the construction location produces three times more waste than non-conventional construction types such as Industrialized Building Systems in which the prefabricated materials are used which are assembled in the factories (Lachimpadi, 2012). The prefabricated materials are not only more effective in terms of performance and sustainability, but also could be time saving.

The deep piles are fabricated using the right proportion of steel reinforcement, cement, aggregates, water and additional mixtures. The concrete mix should be put on the steel reinforcement cage consisting of 6 steel bars in the molds to achieve the required dimensions. The main reinforcement bars should be tied with lateral ties made of steel. The width of the inner side of the molds should be 0.6 meters and the depth should be 10 meters to match the desired dimensions. The distance between rebars and the mold should be 40 millimeters to provide required cover. The reinforcement should be longer than the depth of mold, as it is required for further interlock with the pile cap. The concreting should be made quite higher than the mold depth for placement of pile cap reinforcement. Piles should be cured in the optimal conditions to achieve the goal of strength and durability. The test should be accomplished on the piles to check

the parameters such as bearing capacity, strength and the impurities should be identified before the transportation to the construction site.

The thin layer of concrete should be placed to connect the piles; and the reinforcement of the pile cap should be placed above the reinforcements of piles and they should be integrated with each other. First of all, the shear reinforcement of the pile cap should be placed on the center, then horizontal ties are put inside the shear reinforcement. The additional shear reinforcement should be put above the horizontal ties. After that, bottom reinforcement could be placed on the bottom part of shear reinforcement of the pile cap. Then, the main reinforcement of the pedestal should be placed and connected with lateral ties. In the end, the top reinforcement of the pile cap would be integrated and the pile cap should be concreted and cured in proper conditions. In order to achieve uniform temperature during curing the formwork could be covered with plastic (Benmokrane, 2021). During all concreting procedures the electrical vibrators should be applied in order to avoid concrete segregation and excess air voids.

The individual piles and group piles would be driven to the soil on the excavated area using the vibratory driver. The hard drive is not compatible with the precast concrete. The vibration may result in less friction between the soil and deep piles. The correct placement of piles should be checked during the installation. The driving force should be adjusted correctly to avoid the damage of piles. The 2x2 group piles should be driven first. Then followed by 2x1 pile groups as shown in Figure 3.29. The piles should be installed using the square pattern proposed by in order to provide even displacement of soil. The single piles should be placed one by one at the end in the linear order, as their impact is assumed to be not significant, and the linear placement one by one may help to save time and resources due to effectiveness in terms of scheduling and construction management.

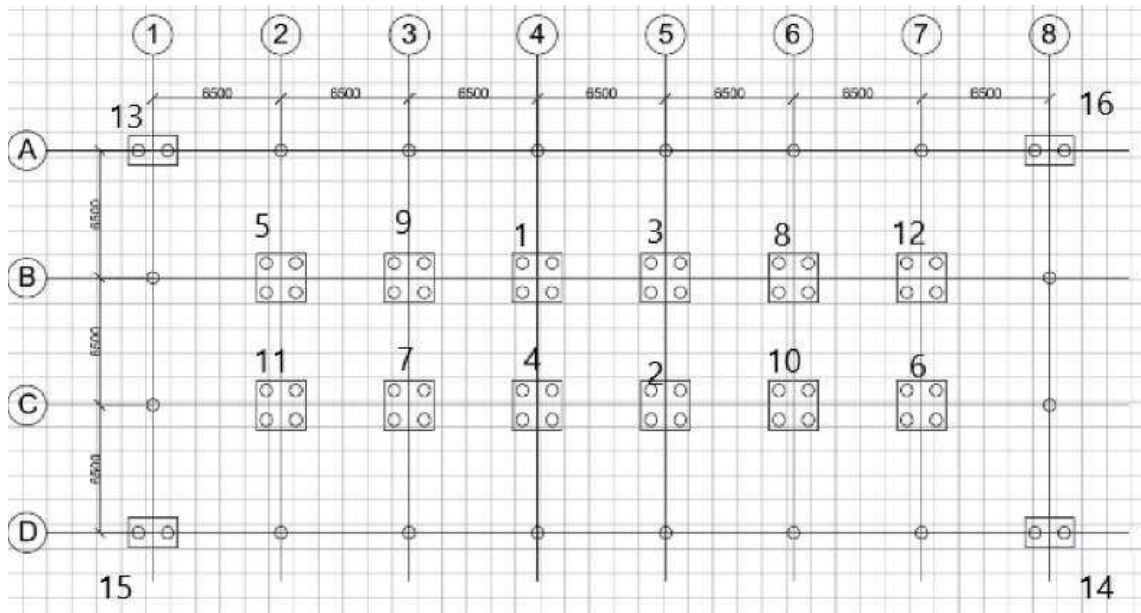


Figure 3.29. Group piles placement order

4. Environmental Design

4.1 Waste Management options

There are three waste management potentials, that is recyclable, composting and incineration. In order to find how many kilograms from each of these options and how much energy could be recovered, the simple formulas were used which commonly include the amount of waste generated. Recycling materials include papers, plastics, glass and metals, whereas composting generally consists of organic materials such as food. Regarding incineration, there are non-recyclable materials which are not suitable for recycling or composting, that is why they are incinerated in exchange for energy.

The formulas for the waste that can be realistically recycled and composted are shown below, respectively:

$$\begin{aligned} \text{Expected Recyclable Waste} &= (\text{Total Waste Generated} \times \text{Percentage of Recyclables}/100) \times \\ &\times (1 - \text{Contamination Rate}/100) \end{aligned}$$

$$\begin{aligned} \text{Expected Compostable Waste} &= (\text{Total Waste Generated} \times \text{Percentage of Compostables}/100) \times \\ &\times (1 - \text{Contamination Rate}/100) \end{aligned}$$

where Total Waste Generated is the annual total solid waste generation in our commercial building and Percentage of Recyclables/Compostables is the percentage of recyclable/organic materials from the total solid waste. These values were already calculated in the previous Capstone Project report. The contamination rate is the percentage of recyclables that are contaminated and cannot be recycled. According to *Zero Waste Design Guidelines*, 10-15% of recyclable and organic materials can be contaminated, therefore undergo incineration. The rate was taken as 10% as considering a minimum of contamination.

Thus, the calculated results are represented below:

- Recycling Potential

$$\begin{aligned} \text{Estimated Recyclable Waste} &= (65\,865.71 \text{ kg/year} \times 52/100) \times (1 - 10/100) \\ &= 30\,825.15 \text{ kg/year} \end{aligned}$$

$$\text{Contaminated Waste} = (65\,865.71 \text{ kg/year} \times 52/100) \times (10/100) = 3\,425 \text{ kg/year}$$

- Composting Potential

$$\begin{aligned} \text{Estimated Compostable Waste} &= (65\,865.71 \text{ kg/year} \times 20/100) \times (1 - 10/100) \\ &= 11\,855.83 \text{ kg/year} \end{aligned}$$

$$\text{Contaminated Waste} = (65\,865.71 \text{ kg/year} \times 20/100) \times (10/100) = 1\,317.3 \text{ kg/year}$$

- Incineration Potential

Formula for calculating recovered energy from the incinerated waste follows as:

$$\begin{aligned} \text{Energy Recovery (kJ)} \\ &= \text{Waste Mass (kg)} \times \text{Calorific Value (kJ/kg)} \times \text{Incineration Efficiency} \end{aligned}$$

where Waste Mass is non-recyclable materials in addition with the contaminated waste of recyclable and organic materials, as contaminated recyclable and compostable waste are now only suitable for incineration. Calorific value is the calorific value of the waste, representing the energy

content per unit mass. This value varies depending on the composition of the waste, however according to Zaman, the average person in San Francisco produces about 1417 kilowatt hours of energy annually (Zaman, 2013). Therefore, this value can be taken as an average for calorific value by dividing it to the annual solid waste generation of an average San Francisco citizen, which results in kilowatt per kilogram. Incineration Efficiency is the efficiency of the incineration process in converting the calorific value into usable energy.

$$\text{Waste Mass} = (65\,865.71 \text{ kg/year} \times 28/100) + 3\,425 + 1\,317.3 = 23\,184.7 \text{ kg/year}$$

$$\text{Calorific Value (kWh/kg)} = 1417 \text{ kWh/year} \div (1.5 \text{ kg/day} \times 365 \text{ days/year}) = 2.59 \text{ kWh/kg}$$

$$\text{Calorific Value (kJ/kg)} = 2.59 \text{ kWh/kg} \times 3\,600 \text{ J/Wh} = 9\,317.3 \text{ kJ/kg}$$

$$\begin{aligned} \text{Energy Recovery (kWh)} &= 23\,184.7 \text{ kg/year} \times 9\,317.3 \text{ kJ/kg} \times 93\% = 200\,897\,489 \text{ kJ} \\ &= 200\,897.5 \text{ MJ/year} \end{aligned}$$

- Methane recovery potential

Anaerobic microbiological decomposition is a process where microorganisms obtain energy and grow by breaking down organic material in an environment without oxygen, resulting in the production of methane (CH₄). The process of anaerobic digestion can be split into four stages, each characterized by its unique set of microorganisms:

1. Hydrolysis: This phase involves converting non-soluble biopolymers into soluble organic compounds.
2. Acidogenesis: During this phase, soluble organic compounds are converted into volatile fatty acids (VFA) and CO₂.
3. Acetogenesis: In this phase, volatile fatty acids are transformed into acetate and H₂.

4. Methanogenesis: The final phase involves the conversion of acetate, CO₂, and H₂ into methane gas

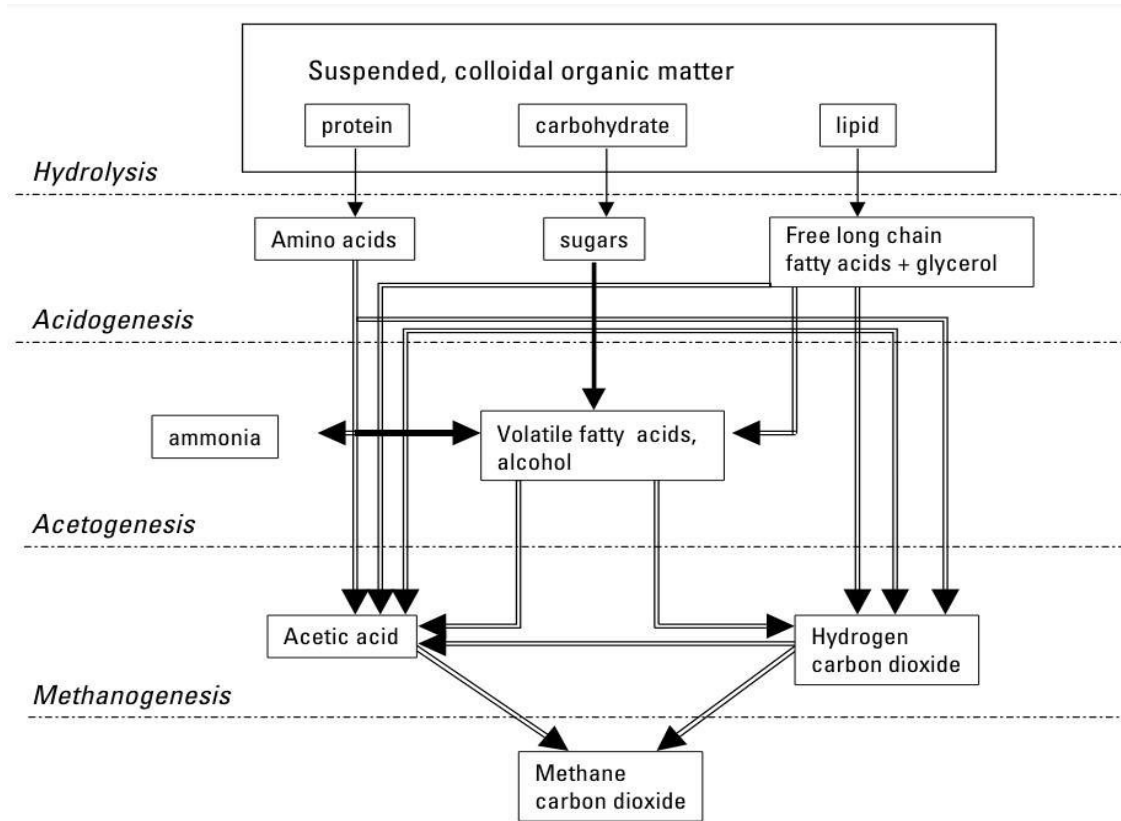
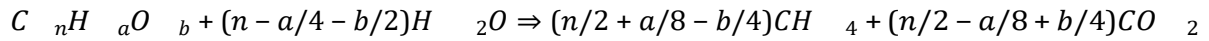


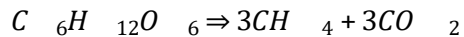
Figure 4.1. Simplified schematic representation of the anaerobic degradation process (Reith et al., 2003)

The measurement known as Chemical Oxygen Demand (COD) is utilized to assess the quantity of organic matter within waste streams and anticipate the potential for generating biogas. To determine the oxygen equivalent of oxidizable organic matter, a potent chemical oxidizing agent is employed in an acidic environment. During the process of anaerobic digestion, the biodegradable COD found in organic material is retained in the final byproducts, namely methane and newly formed bacterial mass. If an organic compound ($C_nH_aO_b$) is completely biodegradable and would be entirely converted by anaerobic organisms (assuming sludge yield is zero) into CH₄, CO₂, the theoretical amount of gases generated can be calculated using the Buswell equation (1):



By checking several compounds such as glucose ($C_6H_{12}O_6$), acetic acid ($C_2H_4O_2$), pyruvate ($C_3H_3O_3$) and other organic compounds, biogas yield equals approximately $750 m^3$ per tonne.

Example 1:



1 mol of glucose = 180 g

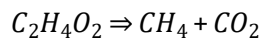
1 mol of glucose produces 3 mole of methane and 3 mole of carbon dioxide

Then, 180 g of glucose produces $(6 \times 22.4) L = 134.4 L$ or $0.1344 m^3$ of biogas

Therefore, 1 000 000 grams (1 tonne) of glucose will produce:

$$\frac{0.1344 \times 1\,000\,000}{180} = 747 m^3/ton\ of\ biogas$$

Example 2:



1 mol of acetic acid = 60 g

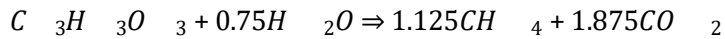
1 mol of acetic acid produces 1 mole of methane and 1 mole of carbon dioxide

Then, 60 g of acetic acid produces $(2 \times 22.4) L = 44.8 L$ or $0.0448 m^3$ of biogas

Therefore, 1 000 000 grams (1 tonne) of acetic acid will produce:

$$\frac{0.0448 \times 1\,000\,000}{60} = 747 m^3/ton\ of\ biogas$$

Example 3:



1 mol of pyruvate = 87 g

1 mol of pyruvate produces 1.125 mole of methane and 1.875 mole of carbon dioxide

Then, 87 g of pyruvate produces (3×22.4) L = 67.2 L or 0.0672 m³ of biogas

Therefore, 1 000 000 grams (1 tonne) of pyruvate will produce:

$$\frac{0.0672 \times 1\,000\,000}{87} = 772 \text{ m}^3/\text{ton of biogas}$$

- This value was rounded up to 750 m³/ton

The biogas volume can also be calculated by using Ideal gas law formula:

$$V = \frac{n \times R \times T}{P}$$

where P is the atmospheric pressure

T is the temperature

n is the number of moles

and R is gas constant

Next, the waste sector is the primary contributor to methane emissions, as it undergoes anaerobic decomposition of organic waste, resulting in the production of landfill gases (LFGs). These LFGs contain approximately 50-60% methane (CH₄) and 30-40% carbon dioxide (CO₂) (Yasim et al., 2023). Thus, it can be assumed that methane constitutes about 50% of the total biogas.

$$750 \text{ m}^3/\text{ton} \times 50\% = 375 \text{ m}^3/\text{ton of biochemical methane potential}$$

4.2 Selection of suitable waste management options

Another careful balance is struck among their environmental impact, cost-effectiveness, regulatory compliance, and practical applicability in selecting appropriate options for waste management. Therefore, in developing a strategic approach, more preference can be given to the hierarchy of waste that lays more emphasis on the prevention of the generation of wastes. A solid waste management system, more so in a city like San Francisco, where waste reduction goals are aggressive, would start with evaluating the quantity and kinds of waste produced. This includes a comprehensive waste audit that shall inform the selection of tailored waste management strategies. Source reduction of waste is one of the preferred alternatives.

Once reduction is addressed, reuse of materials gains attention. This may involve the facility repurposing items or donating items from the facility no longer needed. Recycling follows, and San Francisco has long been a leader in curbside recycling programs. All these can become maximally efficient with due and proper segregation at source. That means clear labeling of bins, staff training, and regular audits to minimize contamination. Most often, the recovery occurs in the form of composting or energy recovery.

Organic waste composting is very timely for San Francisco in its pursuit of zero waste. This organic matter may be converted into a rich compost that may be put into a helpful purpose in city parks or marketed to farm businesses. Finally, any remaining waste that cannot be prevented, reused, recycled, or recovered is disposed of environmentally in the best way possible. In managing the waste in landfills, this shows that some quantities of waste will be handled in San Francisco. This should be done in compliance with all the environmental regulations and with an eye to future opportunities to bring this final fraction even lower.

In all these, it is imperative that continuous education and involvement of personnel and the public carry on. Ultimately, regular training and awareness programs will help inculcate a sense of community that owns up to its environmental footprint. Being adaptable and looking forward, a waste management plan will be growing together with new technologies and practices to reduce waste and the impacts connected to it even more.

According to the first part of the Capstone Project, each enterprise is producing 31.1 kg/week. In “KenseMax” business center there would be around 50 enterprises, so weekly production would be:

$$31.1 \text{ kg/enterprise/week} * 50 \text{ enterprises} = 1555 \text{ kg/week}$$

The indoor trash cans are 42 gallons on average, which is approximately 159 liters in volume. According to the waste conversion table, the kg/liters value is 0.24 (Wellington City Council, 2022).

$$1555 \text{ kg/week} \div 0.33 \text{ kg/liter} = 4712.12 \text{ liters/week}$$

For recycling:

$$4712.12 \text{ liters/week} * 0.52 = 2450.30 \text{ liters/week}$$

For organic:

$$4712.12 \text{ liters/week} * 0.20 = 942.42 \text{ liters/week}$$

For other garbage:

$$4712.12 \text{ liters/week} * 0.28 = 1319.40 \text{ liters/week}$$

The 4-wheeled commercial bin's volume is 1100 liters (Gaskells, n.d.). Hence, to deal with all waste there should be 3 bins for recycling, 1 bin for organic, and 2 bins for other garbage. However, organic waste almost fills the bin, so it would be safer if we get 2 bins for organic waste.

4.3 Waste collection plan

According to the first Capstone report, the total waste composition is 52% of recycling materials (glass, plastic, paper, and etc.), 20% organic waste (food wastes), 28% landfill. Hence, in an effort to uphold environmental stewardship and cleanliness using five containers would be the most suitable option. Each container's volume is 1100 liters (1.5 yd), to facilitate the management of generated waste. Out of these, two have been allotted for recycling purposes, two for general non-recyclable waste, and one solely for organic food waste. Each has been designated

to streamline segregation and enhance our efforts in recycling. These containers are collected from waste every week, done with one of our licensed waste management service providers, in this case, to maintain uniformity and reliability in our operations.

Perhaps the most critical aspect of our waste management mechanism is the strict training schedule of our personnel. This started with in-depth induction training of recruits on the subject of waste segregation issues, judicious use of containers, and how to handle the material meticulously. This training is specifically designed to focus on reducing contamination, particularly for the recycling and organic waste streams. Monthly newsletters complement these ongoing education programs, so the staff is attuned to the latest practices in waste management and regulations. Our staff is also familiar with emergency procedures and can deal with situations such as spillage and overflow that can cause unpleasant repercussions. This is part and parcel of our operations, and therefore, we need to be vigilant about the state of the waste containers. Containers are subjected to frequent inspections to clean out all unnecessary material, over-spilling, and unnecessary contamination. The containers are also cleaned and disinfected just after the collection of waste in them regularly.

We readily inform our contracted waste management service provider of any abnormality, such as needed collections. Where necessary, a damaged container or the need for further collection is adequately informed to our appointed waste management service provider promptly for the quick redress and maintenance of hygienic standards. Compliance with environmental guidelines by the City of San Francisco is a commitment embedded in our operational ethos. We document rigorously all actions being developed under the waste management process: quantities of waste, frequency of collection, and incident reports for compliance and strategic reviews. By these means, rigorous implementation of this plan, which shall synergize our organized waste collection approach with proactive training and sensitization of our human resources.

4.4 Integrated solid waste management plan

Making sure our trash avoids landfills is hard. Many groups handle waste. Tenants, managers, cleaners, brokers, and haulers all play roles. This makes it tough to know who's responsible. Waste deals usually charge a set fee each month. So, cutting waste may not save cash. Thus, we lack a big reason to reduce waste. New rules about recycling for firms started on August 1, 2016. A year after, on August 1, 2017, they began to check that people follow the rules. Now, there must be different bins for trash and items that can be reused. Things like metal, glass, plastic, and paper can go into one bin together. Also, all the bins need clear signs to show which is for trash and which is for recycling. On August 1, 2016, updated commercial recycling regulations were introduced, while enforcement began one year later, on August 1, 2017. These include requirements to offer containers for the trash and recycled material that can also be merged into a stream containing metal, glass, plastic, and paper. Additionally, all containers must be clearly marked so as not to be mistaken for one another (Zero Waste, n.d.).

Signs indicating the right placement of the designated materials and separation of the items should be real or posted in all areas of disposal such as storage, maintenance, public space, and the staff working space. Transparent bags should be used to set up the recyclable materials to quickly identify the room's contents and verify if it is handled as required. The process ensures that only the recyclable materials are collected and treated in the right way. In the existing construction regulations, there is an evident lack of guidelines pertaining to waste management within commercial structures. This shortfall frequently leads to inadequate provisioning for waste handling by the majority of contractors during the building process. Improving waste management involves creating well-ventilated storage spaces specifically designed for bio containers. This will encourage janitorial staff to consistently maintain the containers, reducing potential odor problems. The absence of clear regulations for waste storage has resulted in several issues, such as waste being left on sidewalks for extended periods and loading zones at docks being taken over, forcing loading activities onto the streets. To address this issue, it is crucial to establish designated storage areas with adequate capacity. This complexity presents a range of challenges that require effective solutions. In general, management can be categorized into four key areas (Zero Waste, n.d.).

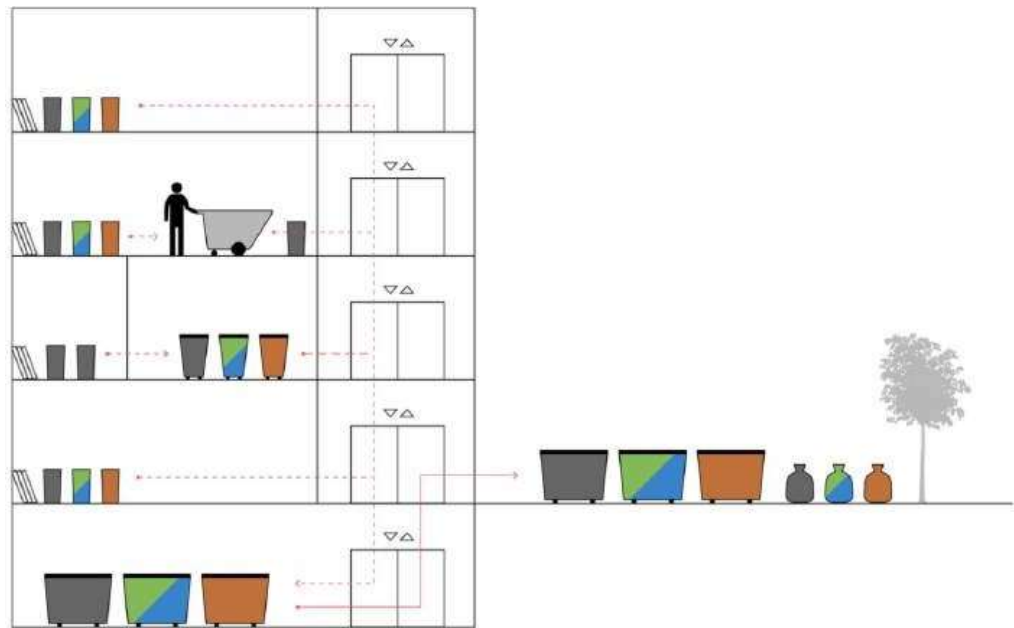


Figure 4.2. Typology 3: Elevator to shared storage (Zero Waste, n.d.)

Any attempts to put tenant convenience first could unintentionally result in higher labor expenses for the building management. In addition, the implementation of specialist equipment has the potential to save labor or transportation costs; yet, this could include increased capital expenditure and upkeep requirements. The garbage of the tenants is collected and brought to the common area with possible balers in bins by elevators. Waste is moved to the storage area by employees or tenants, who have the option of disposing of it in 1-2 cubic yard containers. There are various advantages to having a common storage space. It improves convenience by eliminating the need to schedule building-wide waste pickup with individual tenant waste collection. It also makes pickup less frequent. But there are certain disadvantages as well. The use of priceless space for a special storage room is one major drawback. It is also necessary to consider the additional work needed to move waste from the storage facility to the curb for disposal. Several waste management best practices are implemented at the shared storage facility. First, it encourages volume reduction by using cardboard balers and other compacting equipment to reduce waste volume and improve trash processing efficiency. Furthermore, the area makes it easier to deploy diversion tactics. Last but not least, although it is not frequently utilized, the common storage space

enables waste metering and open pricing by stream. Renters may incur fees based on how much rubbish they produce, frequently on a per-bag basis (Zero Waste, n.d.).



Fig. 2 Baled cardboard

In order to attain efficacy, a plan necessitates the estimation of waste quantities derived from incoming goods, the design of efficient waste transportation paths, the identification of the resources and employee procedures required for waste handling, the creation of well-planned and arranged storage area, and the establishment of guidelines concerning waste collection times, and container types. Users may quickly learn how to sort and dispose of waste products in the appropriate containers by implementing an easy-to-use system that makes use of uniform visuals and signs across the facility. Furthermore, integrating waste data input into the design promotes responsible waste management techniques and helps increase public awareness. Convenience is crucial, too, since it may be difficult to sustain high levels of involvement in waste separation initiatives if it is simpler to dispose of garbage than it is to properly separate recyclables and organics. One of the most important ways to minimize waste output is to reduce consumption. Encouraging choices to reduce the amount of goods purchased may make a big difference. For example, sharing furniture and equipment in an office setting cuts down on the need for extra

resources, and using reusable dishes instead of disposable ones. Compaction of waste materials results in a reduction in storage and setout area needed, which enhances a facility's overall space efficiency. Furthermore, less trash volumes might mean fewer garbage collection trips, which means fewer truck miles and related transportation emissions. Another technique that lowers the weight and amount of garbage is organic waste preparation. When used properly, equipment expenditures may greatly improve waste management procedures, even if they may also result in increased expenses and operational considerations. But in our case, we will not use it (Zero Waste, n.d.).

Best practice strategies for building design

Organizing the material flow of garbage
Identify the types and amounts of garbage.
<p>Make a route plan.</p> <ul style="list-style-type: none"> • Think of storage and transportation containers.
Create a storage area that is designed.
Make a collecting plan.
Take staff protocols into consideration.
Make arrangements to return delivery materials.
Taking into account multi-tenant buildings
Strategies for Waste Diversion
<p>Ensure equal disposal of convenience</p> <ul style="list-style-type: none"> • Establish central garbage stations in offices.

<ul style="list-style-type: none"> ● Sites for storing waste and loading docks: Place suitable-sized containers at every site where waste is managed.
<p>Provide obvious signage and visual clues.</p> <ul style="list-style-type: none"> ● Make use of the standard signs. ● Create apertures in containers that alert users to appropriate contents.
<p>Give everyone a chance to provide input.</p> <ul style="list-style-type: none"> ● Present waste facts to influence decisions. ● Virtual feedback
<p>Create programs for education and awareness</p>
<p>Arrangement for Use in Occupancy</p>
<p>Waste Reduction Strategies</p>
<p>Cut back on the number of materials used</p> <ul style="list-style-type: none"> ● Create with less packaging and throwaway dinnerware in mind. ● Provide biodegradable cutlery and plates. ● Create with less paper usage in mind.
<p>Reduce food waste generation</p> <ul style="list-style-type: none"> ● Reduce waste in food storage design.
<p>Encourage recycling and donation</p> <ul style="list-style-type: none"> ● Plan storage for large quantities of goods.

Streamline the design to provide transparent pricing.
<ul style="list-style-type: none"> • Designed to track and report on individual business waste.
Strategies for Reducing Volume
Equipment for volume reduction: crushers, grinders, balers, and commercial compactors

Organizing the material flow of garbage

Planning is essential for creating waste disposal routes. This includes considering workforce, transportation options, and any potential obstructions from elevators, service corridors, lifts. The use of safe vertical transfer techniques, taking into account transfer methods that accommodate elevation changes or manual lifting, minimizing staff travel distances and handling points to reduce contamination risks, and accounting for time constraints on elevator usage, common space movement, staff availability. Carefully choosing trash containers is essential. This involves taking into account things like staff safety, storage, mobility, and cleaning needs. We need to make sure there is enough room for cleaning containers if necessary, and that containers can be transported across the allocated waste disposal area with ease, taking turning circles and clearance into consideration. We need to make sure there is enough room set out for storing transport containers, and give staff safety first priority when choosing containers by choosing those with low weight and handling hazards. According to research, effective waste storage spaces are essential for encouraging trash diversion. Waste frequently builds up on loading docks and hallways due to inadequate storage, which may force loading operations into the street. The required area for storage and container movement clearances, as well as mechanical elements like ventilation, temperature control, lighting, and measures for cleaning containers, should all be taken into account. Make sure there is also simple access to the building's outside for collection and disposal. Choosing to store garbage at ground level or utilizing bigger waste containers rather than bags can help reduce the risk of flooding (Zero Waste, n.d.).

Garbage management procedures can be optimized by incorporating design solutions, such as using rear-load containers that can be easily moved out at collection time or setting up shared

compactor containers in loading docks. Consider the manpower needed to move containers back inside and clean them in facilities that use wheeled containers. Management initiatives will also be streamlined by making sure that collection places are easily accessible and by synchronizing with features like planting zones, street furniture, sidewalk design, loading zones, and curb cuts. Install enclosures and screens for appeal if there is sidewalk storage available. Staffing and maintenance requirements must be considered. We should work together to create standard operating procedures (SOPs) that may be strengthened after occupancy. It is critical to assess how labor hours and upfront expenses balance out because leasing waste management equipment rather than buying it can lower upfront costs and provide maintenance assistance. We may improve staff motivation and responsibility by following up with staff education, training, and support (Zero Waste, n.d.).

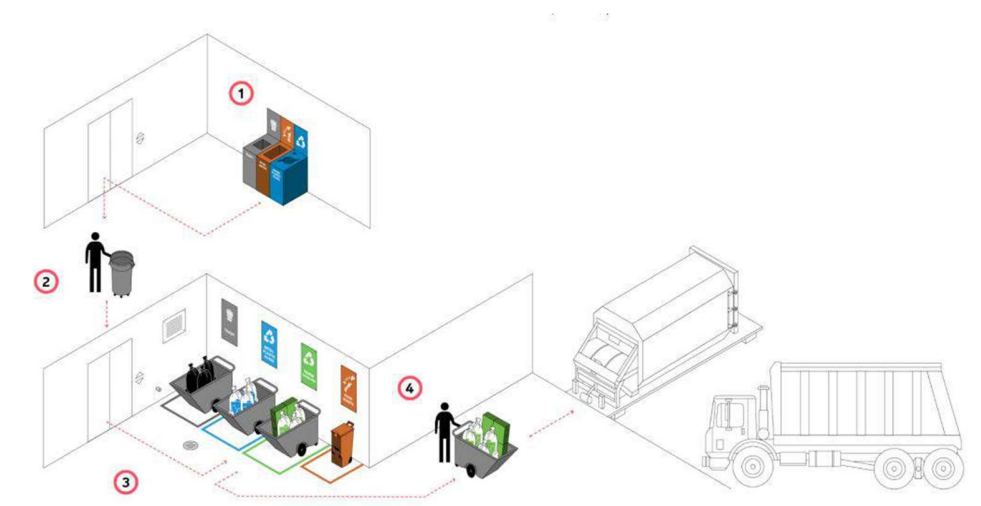


Figure 4.3. Waste transportation scheme (Zero Waste, n.d.)

By decreasing volume, shared equipment may significantly reduce expenses. The cost of hiring a worker to manage shared equipment can be recovered. Tenants might be charged differently for the use of the space. We need to think about using a single carter for building-wide collecting setups. We make sure the contract stipulates that individual tenants must utilize the common equipment and storage or, in the event that the shared area is not available or accessible at all times, they must provide a place for the storage of garbage and follow guidelines. Clear communication is essential in order to guarantee that people can dispose of their garbage in a

timely manner. The use of standardized signs and visual signals may lower contamination and increase capture rates. Visual communication is more efficient than textual signs. Individuals usually need only a few seconds to decide where to put their waste, especially in multilingual situations (Zero Waste, n.d.).



Figure 4.4. Station for separating waste (Zero Waste, n.d.)

Use internationally recognized color coding, standardized signage with instantly recognizable graphics, and uniform design elements throughout the facility. We encourage tenants to use the offered standard signs. When choosing signage language, we take into account local waste management regulations. We make use of the free, multilingual signs provided by the local trash management agency. To help consumers dispose of garbage properly, we provide apertures in the design of the waste receptacles. Form-fitting apertures can act as visible indicators for particular categories. To prevent user annoyance and encourage the best possible waste diversion, it is crucial to make sure that holes can handle different items. Empirical studies have indicated that visual cues, including energy meters and dashboards, can significantly impact human behavior

(Hermesen et al., 2016). By incorporating this idea into waste management systems, rates of trash diversion may be increased. To do this, we have to think about putting information about garbage creation and diversion into visual representations at strategic locations where waste is produced. This will enable people to see the results of their actions up close. Virtual feedback systems can be included into a facility to improve communication and promote positive behavioral changes. Examples of these mechanisms include building-wide digital platforms. Tenants may be better informed about their part by being given access to real-time information. Digital displays and smartboards are a viable substitute for conventional paper-based communication tools including file cabinets, printers, copiers, and easels. We make sure there is enough room when organizing bulk item storage for things that are ready to be picked up. Maintenance personnel can record trash data by using hampers that have integrated scales and entry displays. Making use of free tools, like Etsy's Divertsy, may expedite the tracking procedure and provide insightful data on waste management effectiveness (Zero Waste, n.d.).

Volume-reducing technology for waste streams installed may drastically reduce the amount of space needed for storage and set-up, personnel expenses, and the number of vehicles required for garbage collection. In the end, this results in less of an impact on the environment and more operational efficiency. Since organic waste contains up to 90% water, it may be very expensive and heavy to transport. However, by using on-site waste pretreatment techniques, waste volume and weight can be significantly reduced. We may promote sustainability while improving overall operational efficiency through the use of equipment and procedures. Prior to selecting equipment, numerous elements must be properly evaluated to guarantee that the solutions chosen are acceptable. Compactors, balers, crushers, shredders, grinders, and organic waste treatment systems are all designed to handle different forms of garbage. When evaluating waste management equipment options, we consider cost and maintenance requirements, waste stream compatibility, compaction ratio, labor and training requirements, dimensions and clearance requirements, power consumption, waste generation capability. Compactors, with capacities ranging from 10 to 40 cubic yards, can handle both wet and dry waste. The compactor is an integral component of a self-contained unit that, when full, is removed by a roll-off truck and returned empty for reuse (Zero Waste, n.d.).

Self-contained compactors are often installed on a loading dock with a raised platform to facilitate the operation of dumping debris straight into the compactor. When a dock platform is

lacking, side-loading compactors or cart tippers can be used. To handle different waste streams, compactors can be separated into separate sections, enabling garbage and recyclables to be compacted simultaneously. Customized compactors can also be created to meet the specific size requirements of a loading dock. Sharing compactor containers among tenants may be a practical and cost-effective strategy. Access to compactor containers can be controlled via electronic tags, which ensure that each tenant's garbage is weighed before being fed to the compactor. This allows prices to be directly related to the amount of garbage created by each tenant, encouraging responsibility and waste minimization measures. Sensors connected into the compactor system may also automate service notifications, telling the garbage collection provider when the compactor is full and needs to be emptied. When installing interior compactors, several factors must be considered, including available headroom for servicing and truck access during removal, appropriate methods for filling the compactor (e.g., using a loading dock platform to tip waste from a tilt truck), weight requirements, and adherence to safety best practices established by the American National Standards Institute (ANSI) and the Occupational Safety and Health Administration. Stationary or breakaway compactors are typically used for cardboard and other dry waste compaction. These ground-mounted compactors compress waste materials into big containers with capacities ranging from 10 to 40 cubic yards each. When these containers are filled, a roll-off truck collects them and transports them to a processing facility (Zero Waste, n.d.).

Hand-fed compactors are stand-alone trash management devices that allow personnel to manually fill waste bags or containers with capacities ranging from 1 to 2 cubic yards. Vertical compactors are commonly used for wet waste applications in areas where bigger compactor containers are unfeasible. They generally crush garbage into containers ranging from 3 to 8 cubic yards. Compacting receptacles, which are suited for both trash and recycling, can be put indoors or outdoors and are intended for safe public usage. These technologically equipped receptacles notify maintenance personnel when they need to be emptied, making garbage collection more efficient and decreasing overflow. Balers, which are usually used for cardboard recycling, may also process metal, plastic, and plastic film waste streams. To maintain the value of each recycled item, bale them individually. When contemplating on-site balers, make sure you have enough room and clearance to service the equipment, store bales, and transport them to the set-out place. Balers for cardboard recycling take more manpower than a huge compactor, but they are less labor-

intensive than human bundling. Compaction rates can vary, reaching 8:1 for cardboard and 5:1 for plastic and metal recycling (Zero Waste, n.d.).

Crushers and shredders fulfill a variety of waste management functions. Glass crushers, for example, are especially useful for companies that produce large quantities of non-returnable glass bottles. These machines can reach a compaction ratio of around 5:1, which considerably reduces storage space needs. Paper shredders serve a role in the secure disposal of confidential documents, frequently eliminating a significant amount of paper trash from haulers' waste streams because they are generally maintained by independent organizations. Shredding consoles require adequate storage, such as secured containers. Food waste pulpers and shredders can assist reduce waste volume and simplify disposal operations (Zero Waste, n.d.).

4.6 Waste collection plan (second, conservative plan for peak)

First of all, daily, weekly, and monthly amounts of the waste were calculated for the regular days. Then the values are multiplied to the peak factors, which were taken from the lecture slides.

	Daily	Weekly	Monthly
Average (kg)	222.14	1555.00	6664.20
Peak (kg)	555.35	3498.75	11662.35

Figure 1. Daily, weekly, monthly waste amounts listed in kilograms.

The peak values are mostly for holidays such as International Women's day, Independence Day and other holidays during which the crowded people tend to visit the commercial center. High-traffic holidays, therefore, demand very flexible and proactive waste management during these periods to assure efficiency and cleanness of the environment. In order to manage waste during peak seasons the following solutions are provided:

- using a waste spot on each floor or cutting down travel for people. This will also encourage proper waste disposal and contribute toward a clean environment, minimizing the probability of throwing litter in other areas.
- picking up waste at least twice as often, specifically at noon and after lunch. Collection around peak hours is likely to reap more productivity, in the sense that the bins are not allowed to overflow, and further waste management is carried out in a more befitting manner.
- analyzing peak sessions and making adjustments to the day plan. Sometimes, when that standard amount of trash proves insufficient, there remains no other way except to get waste collecting services and transfer the additional waste to landfill sites to make the commercial center free of clutter.
- if waste cans are full, hire additional services to collect and move waste to landfills
- hiring more staff, for example, volunteers during peak times. Recruiting volunteers or temporary staff who shall ensure that the pace of the operations of waste management is maintained. Such will involve monitoring the level of waste bins, visitor guides about waste separation, and ensuring cleanliness for high traffic-required areas. Offering them incentives like bonuses for diligent waste management would ensure that they carry out their duties properly - collect all waste and ensure it is segregated and stored in the right order.
- collection of organic waste should be done daily while on holidays since food wastes are usually smelly and a source of attraction for pests. This practice is critical to make everything healthier and cleaner.
- and, staff sensitization and education are very critical. The workforce should, through adequate information, be able to retrain on the practical storage and separation of waste, therefore being in a position to inculcate a culture of environmental responsibility. This should be done by a few employees chosen to head such a training section, especially those who will ensure that protocols in waste management are adhered to. Such champions of waste need to be incentivized to allow the commercial center to realize the highest standards of cleanliness and efficiency even in peak months of the year.

4.6 Operational finances of waste management plan (project costs/revenues)

A critical aspect of the project is the assessment of the financial implications of implementing a system. After careful consideration, Recology proves to be the optimal choice for waste collection needs. Recology provides a full range of solutions, from regular waste collection to specialized recycling and composting programs.

Recology's services come with fixed rates for Trash, Recycling, and Composting collection containers as per initiative ordinance, ensuring consistent and predictable waste management costs. Volume rate charges equally across collections, ensuring fairness and consistency. In addition to fixed rates and volume-based charges, the landfill diversion discount presents an opportunity for further cost savings. The landfill diversion discount is a policy aimed to reduce the amount of waste sent to landfills. This discount is calculated based on the percentage of waste diverted from the landfill. To determine this percentage, the total volume of waste recycled and composted is divided by the total volume of waste generated. However, to ensure the discount is applied fairly, 25% is subtracted from this percentage. It is important to demonstrate proper sorting of waste, separating recyclable materials from non-recyclables and compostable materials, to qualify for the discount. This emphasis on proper sorting not only increases diversion rates but also maximizes the recovery of valuable materials from the waste stream. Containers situated at an elevation of 4 feet or higher or lower than ground level incur a 25% premium charge, reflecting the additional pay. Similarly, the distance from the curb impacts pricing: if a container is within 100 feet of the curb, a 10% premium is applied, recognizing the relative ease of access. Conversely, containers located beyond this range face a 25% premium, reflecting the increased logistical challenges and time. These pricing adjustments aim to accurately reflect the varying demands. Materials for composting and recycling need to be kept apart properly. If this isn't done, recyclables and compostable materials can end up in the wrong trash can, which could raise the cost of disposal. Bins that have an excessive number of recyclables or compostable materials in them may lose any diversion incentives and be charged a 100% contamination fee. All waste must be disposed of in containers with tightly fitting lids, according to a local regulation. Penalties could result from breaking this rule. The ordinance's goal is to keep the environment clean and to stop littering by making sure that garbage is appropriately contained. Customers are required to deposit cardboard in paper bags, cardboard boxes, or recycling bins with closed lids, as long as the cardboard does not exceed two feet in any dimension (8 cubic feet). Any extra cardboard stacked next to the bin

will cost \$16.39 for every 8 cubic feet. We will need to arrange appropriate posters to encourage people to follow the rules. Reactivating an account after a service suspension or creating a new service account both cost \$20. If bins and containers receive damage beyond normal wear and tear, we are responsible for paying for repairs. If we encounter frequent misplaced containers, we must report it, sign the appropriate documentation, and accept financial responsibility if the cart is stolen. Container cleaning services are also available at an additional cost (*Explanation of Possible Charges on Your Commercial Bill* (Ref: <https://Sf.gov/Refuse-Rates-Administration-Office-Controller>), n.d.).

New trash collection and disposal charges for the years 2023 and 2024 were approved by the Refuse Rate Board in August of 2023 in San Francisco. The Refuse Rate Board is essential to monitoring the expenses and activities of the city's garbage haulers. Maintaining rate stability and accountability is the board's principal goal, which it accomplishes through a rigorous review procedure (*San Francisco Refuse Rates (January - September 2024)* | *San Francisco*, n.d.-b).

Uniform commercial rates that go into effect on January 1, 2024 through September 30, 2024 (*San Francisco Refuse Rates (January - September 2024)* | *San Francisco*, n.d.-b).

Uniform commercial rates that go into effect on January 1, 2024 through September 30, 2024.	
Size, Collections per week	2 per week
32 - gal cart	53.30 \$
64 - gal cart	106.60 \$
96 - gal cart	159.91 \$
1.0 - yd bin	311.76 \$
1.5 - yd bin	467.64 \$
2.0 - yd bin	555.12 \$

2.5 - yd bin	694.23 \$
3.0 - yd bin	774.26 \$
4.0 - yd bin	967.95 \$
6.0 - yd bin	1,374.66 \$
7.0 - yd bin	1,603.49 \$

- The prices apply to **32-gallon carts** with a **45-pound** weight restriction. There will be an extra charge of **\$0.1205 per pound** if the contents of the cart weigh more than 45 pounds.
- The prices apply to **64-gallon carts** with a **90-pound** weight restriction. There will be an extra charge of **\$0.1205 per pound** if the contents of the cart weigh more than 90 pounds.
- The prices apply to **96-gallon carts** with a **135-pound** weight restriction. There will be an extra charge of **\$0.1205 per pound** if the contents of the cart weigh more than 135 pounds.
- The uncompacted weight: the weight of the waste material before it is compacted or compressed in the collection process. In this context, the given rate is applicable to a standard volume of one yard of waste with a weight of **300 pounds**. If the waste's weight exceeds 300 pounds, an additional charge of \$12.05 per 100 pounds (or **\$0.1205 per pound**) will be applied.
- The compacted weight: the weight of the waste material before it is compacted or compressed in the collection process. In this context, the given rate is applicable to a standard volume of one yard of waste with a weight of **450 pounds**. If the waste's weight exceeds 450 pounds, an additional charge of \$12.05 per 100 pounds (or **\$0.1205 per pound**) will be applied (*San Francisco Refuse Rates (January - September 2024) | San Francisco, n.d.-b*).

This pricing structure helps account for the additional resources and effort required to handle waste that is heavier than the standard weight for a given volume. To calculate the total annual cost we will use garbage collection once a week which is \$467.64 for 1.5 - yd bin. There

will be several such containers at the central station. 3 containers for general waste, 2 for recycling and 2 for organics. The total quantity is 7 containers. Multiplying 467.64 dollars by 7 containers, we get the cost of the service at 3273.5 dollars for one month. Multiplying this number by 12 we get a sum of 39281.8. Our recycling rate is 52 percent. If we take into account the discount of minus 25 percent from the recology service, our discount will be.

$$52 - 25 = 27\%$$

Using the 27 percent discount, the annual payment of \$39281.8 after the discount is \$28,675.7. The garbage collection service costs us \$28,675.7 a year.

Calculating the number of trash cans for the entire building, the number is 18 bins. Three bins cost \$658.96 (*Three Stream Connectable Recycling Trash Can Combo (3 Sizes, 29 Colors)*, n.d.). Multiplying \$658.96 by 6 gives the capital cost of all bins at \$3953.76. We need to determine the number of workers we need to employ to collect waste from bins and transport it to the central shared storage. We need to determine the number of workers we need to hire to collect waste from containers and transport it to a central general storage facility. Let's say we need to collect waste twice a day. Let's say each collection trip takes 1 hour. So, in general, according to the assumptions, garbage collection will take 2 hours each day. If the average hourly wage for a worker is \$15/hour, then the cost per day for a worker is \$30 (Salary.com, n.d.). On average, if we include 25 days of holidays, then 365 days we subtract 25 and get 340 days. We will have one employee working for 340 days. 25 days for two workers. We multiply 340 by 30 dollars and we get \$10,200. We multiply the remaining 25 days by 60 dollars since there will be two workers. Calculations show that this will be equal to \$1500. Adding the two sums we get:

$$\$10,200 + \$1500 = \$11700$$

To transport waste between floors, we purchase two carts. Heavy Duty 2-Wheeled Trash Can with Attached Lid costs \$26.57. We are purchasing two pieces. The amount is:

$$\$26.57 * 2 = \$53,14$$

Adding everything together, the initial annual fee is equal to:

$$\$28,675.7 + \$3953.76 + \$11,700 + \$53,14 = \$44,382.6$$

Additionally, we can calculate the depreciation of transport bins and regular ones. We can refer to a service life of 10 years. We need to divide the cost by 10:

$$\$28,675.7 + \$3953.76/10 + \$11,700 + \$53,14/10 = \$40,776.4$$

5. Construction Management

5.1. Project Charter

Table 5.1. Project Charter

Project Charter	
Project Title:	“KENSEMAX BUSINESS CENTER” MULTI-STORY COMMERCIAL BUILDING IN SAN-FRANCISCO, USA
Project Background:	The design of a 5-story business center with underground parking and Integrated Waste Management System (IWMS). The building is designed to offer high-quality corporate office space for enterprises, with an environmental emphasis. The IWMS will allow to collect, store and send waste for processing.
Project Manager:	Serikbolsyn Maulembayev
Project Sponsor:	Stakeholders
Project Start Date:	September 15, 2023

Project End Date:	November 14, 2024
Duration:	425 days
Project Scope:	<p>Building Design and Construction: Operate with engineers and architects to create a contemporary, useful commercial building. Build a five-story building with an open parking lot and an underground parking level.</p> <p>Corrosion Management: Evaluate the corrosive environment in complete detail. For structural components and finishes, use materials that are resistant to corrosion. Put maintenance plans into action to stop corrosion.</p> <p>Measures for Seismic Resilience: Consult with professionals in seismic engineering to assess and plan the structure for seismic resilience. When necessary, use seismic retrofitting procedures. Evaluate and upgrade earthquake resilience strategies on a regular basis.</p> <p>Integrated Waste Management: To build and implement an integrated waste management system, work with waste management experts. Incorporate places for composting, recycling, and waste sorting. Inform building residents on safe disposal techniques for waste.</p>
Project Objectives:	<p>Develop the design for sustainable multi story commercial building. Develop the IWMS. Meet all local construction and environmental codes.</p> <p>Develop an economically efficient object.</p>
Risks and Assumptions:	<ul style="list-style-type: none"> •Seismic activity •Fire •Shortage of labor •Safety risks during the construction that may lead to injuries of workers •Shortage of construction materials •Issues with subcontractors and suppliers •Delay •Budget overrun •Low demand on office tenants
Financials	\$17 million

5.2. Work Breakdown Structure

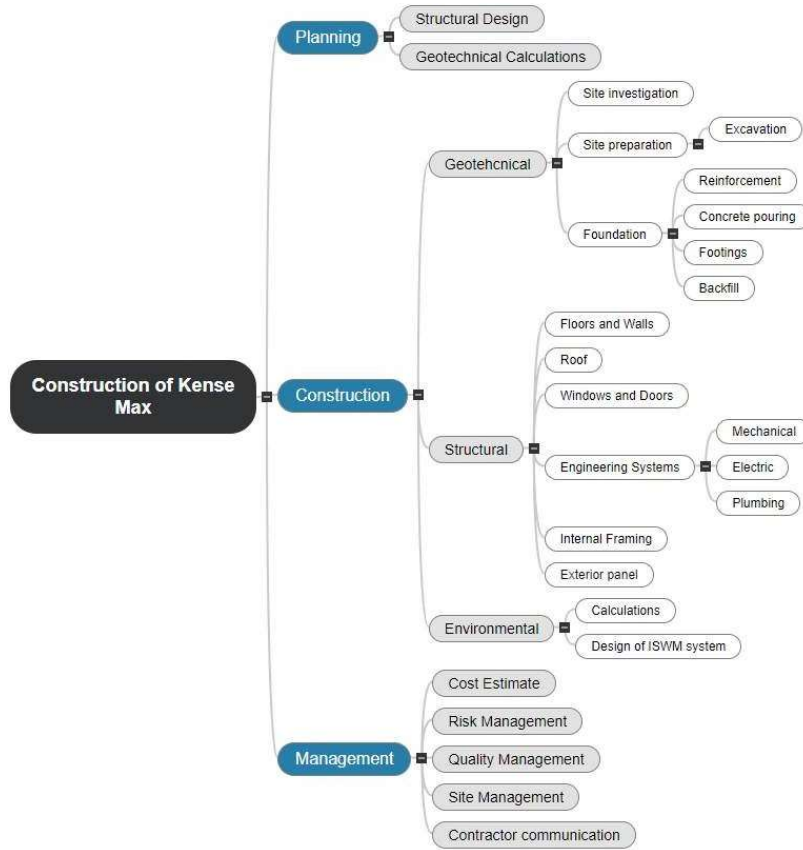


Figure 5.1. Work Breakdown Structure

5.3. Schedule and Gantt Chart

Table 5.2. Schedule

Task Name	Duration	Start	Finish	Predecessors	Resource Names
Phase 1 - Design and Preparation	80 days	Fri 9/15/23	Thu 1/4/24		
Site selection	5 days	Fri 9/15/23	Thu 9/21/23		Project Manager, Site Engineer

Site investigation	15 days	Fri 9/22/23	Thu 10/12/23	2	Site Engineer
Develop the design	60 days	Fri 10/13/23	Thu 1/4/24	3	Project Manager,Site Engineer
Phase 2 - Bids and contracts	20 days	Fri 1/5/24	Thu 2/1/24		
Research contractors	5 days	Fri 1/5/24	Thu 1/11/24	4	Project Manager
Receive bids	10 days	Fri 1/12/24	Thu 1/25/24	6	Project Manager
Award	5 days	Fri 1/26/24	Thu 2/1/24	7	Project Manager
Phase 3 - Foundation	38 days	Fri 2/2/24	Tue 3/26/24		
Site preparation	7 days	Fri 2/2/24	Mon 2/12/24	8	Excavator ,Project Manager,Site Engineer,Foreman
Excavation	5 days	Tue 2/13/24	Mon 2/19/24	10	Excavator ,Foreman
Footings	10 days	Tue 2/20/24	Mon 3/4/24	11	Crane,Site Engineer,Foreman
Reinforcement	7 days	Tue 3/5/24	Wed 3/13/24	12	Crane,Site Engineer,Foreman
Concrete pouring	7 days	Thu 3/14/24	Fri 3/22/24	13	Site Engineer,Foreman
Backfill	2 days	Mon 3/25/24	Tue 3/26/24	14	Excavator ,Foreman
Phase 4 - Superstructure	75 days	Wed 3/27/24	Tue 7/9/24		
Floors and Walls	45 days	Wed 3/27/24	Tue 5/28/24	15	Crane,Site Engineer,Foreman
Roof	15 days	Wed	Tue	17	Crane,Foreman

		5/29/24	6/18/24		
Internal Framing	15 days	Wed 6/19/24	Tue 7/9/24	18	Crane,Foreman
Phase 5 - Exterior	60 days	Wed 7/10/24	Tue 10/1/24		
Doors and Windows	25 days	Wed 7/10/24	Tue 8/13/24	19,14	Foreman
Exterior panel	20 days	Wed 8/14/24	Tue 9/10/24	21,14	Crane,Foreman
Paving	15 days	Wed 9/11/24	Tue 10/1/24	22	Excavator ,Foreman
Phase 6 - Internal	85 days	Wed 7/10/24	Tue 11/5/24		
Escalators and Elevators	30 days	Wed 7/10/24	Tue 8/20/24	19	Foreman
Drywall	20 days	Wed 8/21/24	Tue 9/17/24	19,25	Foreman
Painting	15 days	Wed 9/18/24	Tue 10/8/24	26	Foreman
Flooring	20 days	Wed 10/9/24	Tue 11/5/24	27	Foreman
Phase 7 - MEP	40 days	Wed 7/10/24	Tue 9/3/24		
HVAC	15 days	Wed 7/10/24	Tue 7/30/24	19	Site Engineer
Electrical	10 days	Wed 7/31/24	Tue 8/13/24	30	Site Engineer
Plumbing	10 days	Wed 8/14/24	Tue 8/27/24	31	Site Engineer
Waste management	5 days	Wed	Tue 9/3/24	32	Project Manager

system		8/28/24			
Phase 8 - Finishing	7 days	Wed 11/6/24	Thu 11/14/24		
Cleaning and Finalizing	3 days	Wed 11/6/24	Fri 11/8/24	33,28,23	Excavator ,Project Manager,Foreman
Inspections	2 days	Mon 11/11/24	Tue 11/12/24	35	Project Manager,Site Engineer
Closeout	2 days	Wed 11/13/24	Thu 11/14/24	36	Project Manager

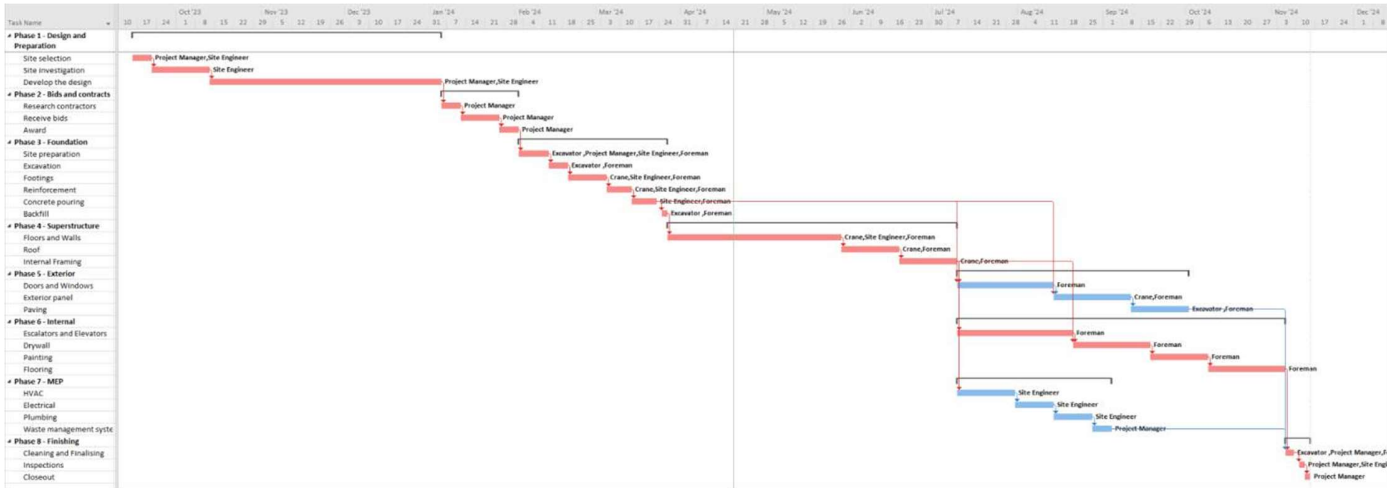


Figure 5.2. Work Breakdown Structure

5.4. Cost/Benefit Analysis

Cost

The detailed cost of the construction is provided in Appendix (Table 5.1.1). The calculations were performed using RS Means software, with implementation of our structural and architectural design.. Total cost of construction including contractor fee can be estimated at approximately \$15 million. The summary is shown in the following table:

Table 5.3. Cost summary

ID	Name	Cost per S.F.	Cost
A	Substructure	\$10.91	\$540,247.23
B	Shell	\$71.28	\$3,529,322.17
C	Interiors	\$29.53	\$1,462,038.25
D	Services	\$83.48	\$4,133,563.70
E	Equipment & Furnishings	\$33.45	\$1,656,265.00
	SubTotal	\$228.65	\$11,321,436.35
	Contractor Fees (GC ,Overhead ,Profit)	\$57.16	\$2,830,359.09
	Architectural Fees	\$17.15	\$849,107.73
	Total Building Cost	\$302.96	\$15,000,903.16

Land costs

The land costs around the construction site were found using the Zillow online resource. Prices can be seen on the screenshot. The land costs are in the range of 1.4 - 2.0 million dollars, with the average of \$1.7 million. So, we assumed this price.



Figure 5.3. Costs of the land in San-Francisco, Irving street (Zillow, 2024)

Revenue

The revenue from the project will be generated through the renting out commercial office space from 4 stories, and Food & Beverage facilities on the first floor. Rentable area was calculated to be around 40,000 square feet.

Several commercial buildings have been analyzed in the San Francisco Bay area which are approximately the same value as ours (in terms of building quality), in the radius of 15 miles surrounding our building location, and their renting price per square feet, to compare and offer competitive pricing for our office spaces.

Table 5.4. Rent price analysis (Data from LoopNet)

Building Name	Cost of renting
California Tower	\$40.00 /sf/yr
Bayshore Business Center	\$65.96 /sf/yr
2435-2445 16th Street	\$54.00 /sf/yr
Redstone 2940 16th St	\$59.60 /sf/yr
Merchants Exchange Building	\$46.00 /sf/yr

Based on the information above, and considering the eco-advantage of our building we chose our pricing - \$60 per square feet per year.

Table 5.5. Income from rent

Land cost	\$1.7 M
Construction cost	\$303/sq.ft.
Total cost with land	\$16.7 M
Rentable area	40.000 sq.ft.
Rent price	\$60/sf/yr
Annual income from renting	\$2.4 M

Since financing of the project is fully done by owners, there is no loan payment and interest rate. A summary of inflows and outflows is below :

Table 5.6. Cash flow and Payback

Item	Cost/Benefit
Land	-1.7 million
Construction (including GC overhead and profit)	-15 million
Operating (staff, maintenance)	-0.3 million (yearly)
Tax (property, income) and Insurance	-0.5 million (yearly)
Rent profit	+ 2.4 million (yearly)
Cash Flow	+ 1.6 million (yearly)
Payback	11 years

Net Present Value Calculation

To estimate the feasibility of our project, we are conducting a NPV calculation on the 20-year period. This is a common way to determine whether the advantages of constructing the building and running it as a business will outweigh the costs. We are assuming the discount factor of 8 per cent. Below, you can see the calculations :

Table 5.7. Net Present Value of a project

Time period	Cash flow	Present Value
0	\$1,600,000	\$1,600,000
1	\$1,600,000	\$1,481,481
2	\$1,600,000	\$1,371,742
3	\$1,600,000	\$1,270,132
4	\$1,600,000	\$1,176,048
5	\$1,600,000	\$1,088,933
6	\$1,600,000	\$1,008,271
7	\$1,600,000	\$933,585

8	\$1,600,000	\$864,430
9	\$1,600,000	\$800,398
10	\$1,600,000	\$741,110
11	\$1,600,000	\$686,213
12	\$1,600,000	\$635,382
13	\$1,600,000	\$588,317
14	\$1,600,000	\$544,738
15	\$1,600,000	\$504,387
16	\$1,600,000	\$467,025
17	\$1,600,000	\$432,430
18	\$1,600,000	\$400,398
19	\$1,600,000	\$370,739
20	\$1,600,000	\$343,277
Total		\$17,309,036
Initial Investment		\$16,700,000
Net present Value		\$609,036

As you can see, the NPV value is positive, which is an indicator of profitability of the project over the 20-year period which we studied.

Stakeholder chart

Project’s financing is carried out by two main parties - Appolo Projects construction investment company which plays the role of the main owner, and our Capstone team, which is the designing company. General contractor has no share in the project, and only receives its profit margin. Appolo Projects has experience in investing in commercial projects all over the USA. Our Capstone Team is interested in timely completion of the project with high quality, and we also have interest in maximizing the profitability of the Business Center. Appolo Projects, in turn, are interested in their return on investment. Our team coordinates all aspects needed for the project, resolves issues as they appear and makes sure that everything is going according to the schedule. Unlike us, Appolo Projects are not involved in the daily activities of the project but they still have

authority to influence financial decisions. The relationship between our Capstone Team and our investor is collaborative meaning that we support open communication and align our interests.

Stakeholder chart

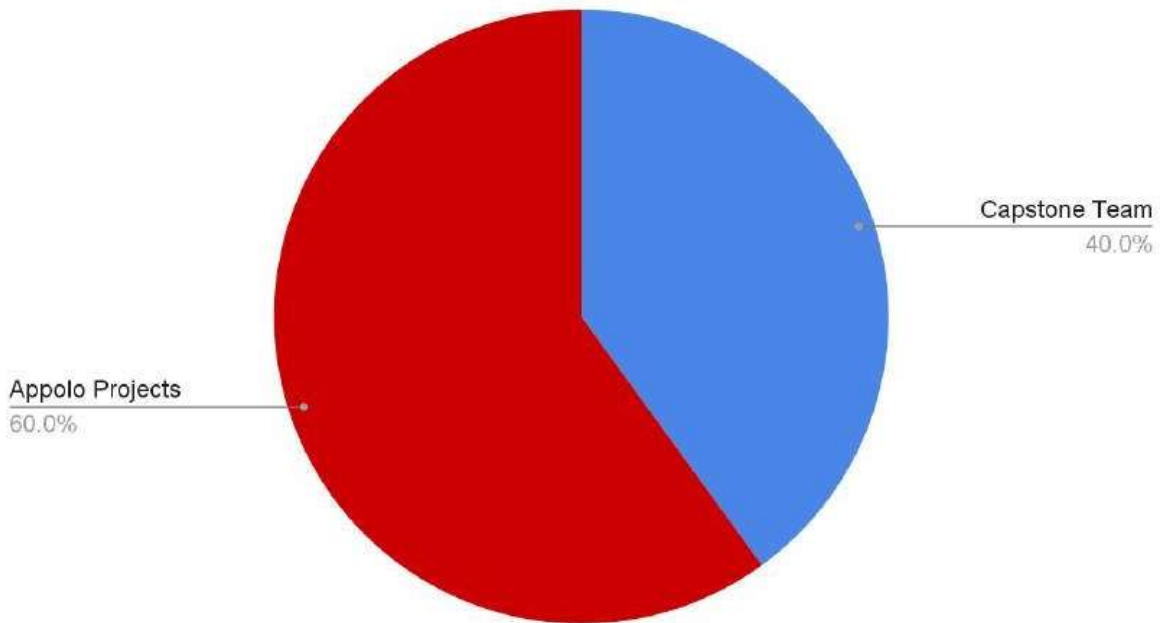


Figure 5.4. Stakeholder chart

5.5. Quality Management

Quality assurance must be performed by an independent specialist, engineering supervisor. Project managers must conduct quality control, or assure control by an independent engineer where corresponding expertise is needed. They must assure compliance with codes and requirements at each stage.

Below is the quality control checklist for each stage and aspect of construction :

Table 5.8. Quality control measures

Quality Control		
Type of Work	Engineering Checklist	Project Manager Checklist
Design		<ul style="list-style-type: none"> - Assure supervision of design from independent engineers - Assure supervision by independent engineers for each stage of construction for accordance to design and requirements
Foundation and Structure	<ul style="list-style-type: none"> - Compressive strength testing of concrete samples - Monitor curing of concrete - Alignment of beams and columns 	
MEP Systems	<ul style="list-style-type: none"> - Pressure testing of plumbing lines - Test electrical indicators - Grounding 	
Interior	<ul style="list-style-type: none"> - Test functionality of doors, windows - Check smoothness of walls, floors 	
Safety		<ul style="list-style-type: none"> - Organising safety controls according to regulations
Schedule		<ul style="list-style-type: none"> - Compare planned and actual progress - Analyze critical path to prioritize

5.6. Procurement

Procurement process :

Procurement process involves several stages needed for the flow of the project. Process begins with finding how much goods and what kind of services are needed for the project. All available resources are analyzed and the demand is forecasted. Then, purchase requisition is made indicating the amount of goods and services. All details of the needed goods and services are described. Based on this information, the procurement team analyses if all of the requested

products are really needed, based on factors such as budget available, analysis of suppliers, procedures and policies, the decision is made. Upon approval of the request, the budget approval is obtained after the document where the need for goods and benefit of these goods is submitted.

Afterwards, quotation requests to several suppliers are sent and suppliers reply with their quotations where their proposals are given. Therefore, negotiations take place where price, schedule, terms and conditions of payment, and other factors are discussed with the supplier. As the final part of negotiations, a contract should be made and signed by both parties. Afterwards, suppliers prepare goods and services and move on to their delivery and provision. Next stage is a three-way-matching that involves checking purchase order, invoices and receipts provided by the supplier. In case if all documents are correct and there are no disagreements, invoice is approved. Payment is done in accordance with the ways stated in the contract and all of the required documents are kept in archive for future reference.

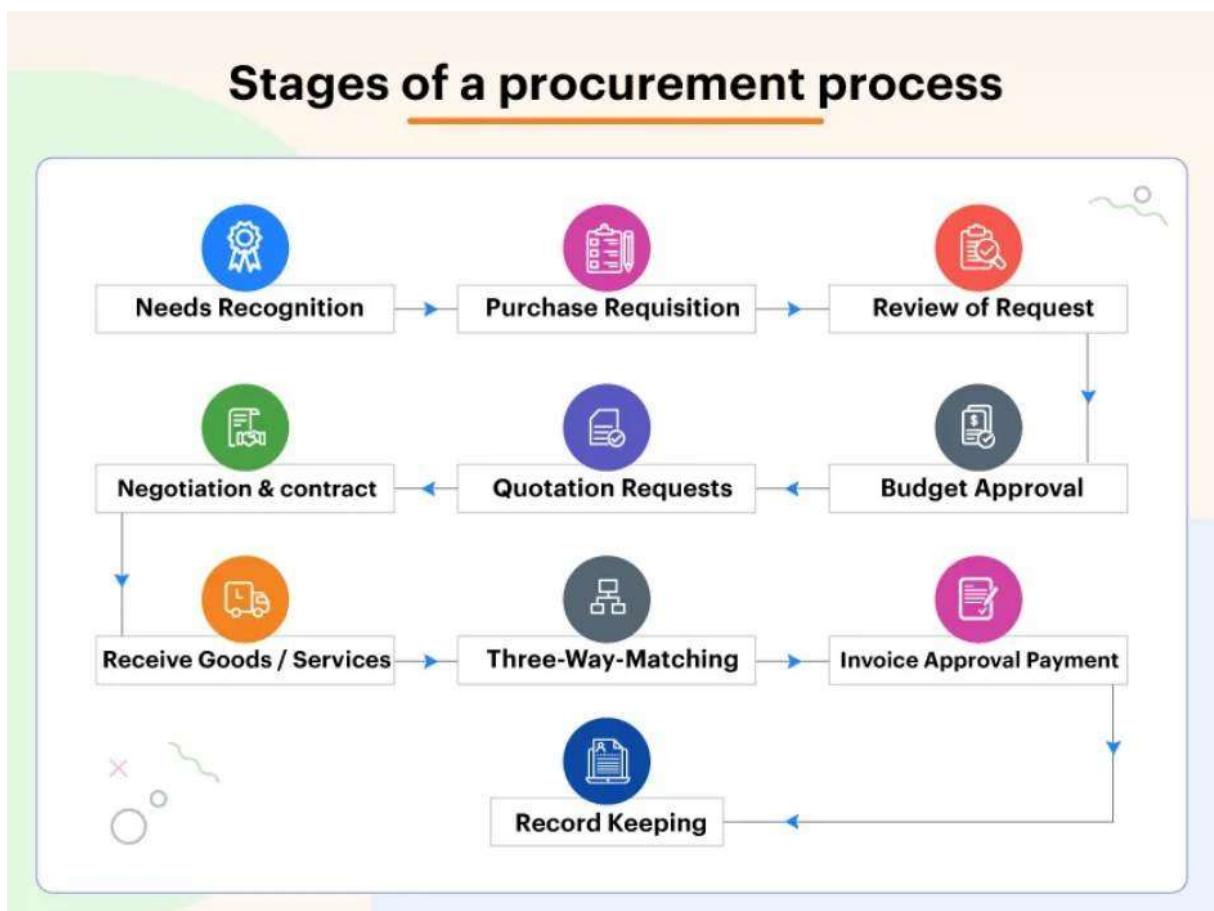


Figure 5.5. Procurement process (Kissflow, 2024)

Source selection criteria

It is essential to consider factors as price-cost, quality, experience and reputation and schedule when selecting a source. In order to keep the building profitable, it is important to make sure that costs are not too high. However, at the same time the quality of the business center should not be damaged because of the low cost. So, it is important to find a balance.

When choosing a supplier, different sources were evaluated based on their pricing and their competitive advantages. We asked the suppliers to provide detailed information regarding the cost of different components such as workers, materials, equipment and other expenses. We chose suppliers who had transparent pricing and who were ready to cut some costs without damaging the quality.

The second criteria was quality. Market research was conducted and a source that has a strong reputation for the quality of its products and services was chosen. Apart from that, verification of adherence to standards were checked as well as the presence of needed certifications.

Another selection criteria was the experience and the reputation of the supplier. Since our project is big and requires responsibility, commitment and a strong team, we couldn't choose suppliers who have no relevant experience. So, preference was given to those who have completed several successful projects. We tried to choose those who have experience in working with construction in the San Francisco area particularly since they have to understand the local market, as well as regulatory terms and practices that work best there. Portfolios of projects provided by several suppliers were carefully analyzed and sources that have complete projects with the scope similar to KENSEMAX Business Center were chosen.

Final criteria was a schedule. It is essential for any project to be completed on time since prolonged delays imply increased costs and other consequences. So, we carefully analyzed if the chosen source has a history of completing the projects on time. Careful analysis of the resources and capacity was done to ensure that they do not delay the project. Also, preference was given to sources that were flexible and adaptable. Since constructing the business center requires quite a lot of time, unexpected issues could occur, therefore, our suppliers had to be flexible in order to respond to these changes.

Vendor list :

Table 5.9. List of suppliers

Vendor List	Supply
Hathaway Dinwiddie Construction Company	General Contractor
Allied Concrete Ready Mix Services Inc.	Concrete
Bay Metals	Steel
L&W Supply	Masonry
Stained Glass Garden	Glass and Windows
Duct Pros.	HVAC
BV Electric.	Electrical
Excel Plumbing	Plumbing
Drywall & Painting SF	Drywall
Cal-Wood Flooring Supply, Inc.	Flooring
Noz Design	Interior Design
Bay Area Recycling Co.	Waste Management

5.7. Risk Management

		Consequences				
		Insignificant (1) No injuries / minimal financial loss	Minor (2) First aid treatment / medium financial loss	Moderate (3) Medical treatment / high financial loss	Major (4) Hospitalizable / large financial loss	Catastrophic (5) Death / massive financial loss
Likelihood	Almost Certain (5) Often occurs / once a week	Moderate (5)	High (10)	High (15)	Catastrophic (20)	Catastrophic (25)
	Likely (4) Could easily happen / once a month	Moderate (4)	Moderate (8)	High (12)	Catastrophic (16)	Catastrophic (20)
	Possible (3) Could happen or known it to happen / once a year	Low (3)	Moderate (6)	Moderate (9)	High (12)	High (15)
	Unlikely (2) Hasn't happened yet but could / once every 10 years	Low (2)	Moderate (4)	Moderate (6)	Moderate (8)	High (10)
	Rare (1) Conceivable but only on extreme circumstances / once in 100 years	Low (1)	Low (2)	Low (3)	Moderate (4)	Moderate (5)

Figure 5.6. Risk Matrix

Main strategies to deal with risk:

1. Avoid - remove the risk
2. Mitigate - make risk's consequences lowest
3. Transfer - to other parties
4. Accept - if the risk is very unlikely or unmanageable

Below is the table with risks, their likelihood and consequences scores, overall score according to the risk matrix above, and strategies:

Table 5.10. Risks and their strategies

Risk	Likelihood Value	Consequence Value	Overall Value and Level	Strategy
Natural and environmental disasters				
Seismic activity	3 California is a state with high seismic activity	5	15 High	Ensure compliance with the latest codes. Hire experienced structural engineers and design structure that can resist earthquake
Fire	3 Fire happens every year in California	5	15 High	Monitor the fire situation. Ensure compliance with the latest codes. Hire experienced structural engineers and design fire-resistant structure
Construction				
Shortage of labor	1 High availability of labor in California	3 Will lead to financial losses	3 Low	Hire and build relationships with experienced contractors
Safety risks during the construction that may lead to injuries of workers	2 Relatively low story building	5	10 High	Conduct construction according to safety standards and requirements. Provide all necessary equipment, safety uniform.

	No severely hazard chemicals used			Have an insurance strategy
Shortage of construction materials	1 High availability of materials in California	3 Will lead to financial losses	3 Low	Find and build relationships with stable suppliers. Monitor the situation
Quality issues	2 Quite high level of competence of workers, but could happen	4 May lead to loss of profit and need to repair	8 Moderate	Quality control, measures, checklists
Management				
Issues with subcontractors and suppliers	3 Could happen	4	12 High	Choose reliable contractors with reputation and experience. Consider all needed project details in the contract
Delay	3 Could happen	3	9 Moderate	Develop comprehensive schedule with realistic dates. Have effective communication with contractors. Monitor regularly.
Budget overrun	3 Could happen	4	12 High	Conduct detailed feasibility study. Monitor costs during the whole project. Negotiate and choose best pricing type with contractors
Low demand on office tenants	2 High demand on commercial space in San-Francisco	5 Total economic fail of the project in case of lack of tenants	10 High	Develop and maintain proper marketing strategy. Offer a range of high quality services and a high quality building

Risks which received a high value of risk level are marked with red and the strategies to deal with them are shown.

5.8. Safety Management

Managing and assuring safety on the construction site is crucial. Safety specialists must work on the site and assure safety measures on each stage of construction.

General contractors must assure safety equipment for all workers : helmets, glasses, gloves and elevation belts. GC must also provide helmets for all visitors, such as engineers, designers, managers.

Another important factor is fire safety. Fire safety measures list, as well as evacuation plans, fire alarm system, protection equipment and first aid set must be present on each floor. Project managers and engineers must assure compliance with fire safety codes and inspection by the official San-Francisco state organization. Also, regular training on evacuation and checking of fire alarm systems must be conducted.

5.9. Site planning

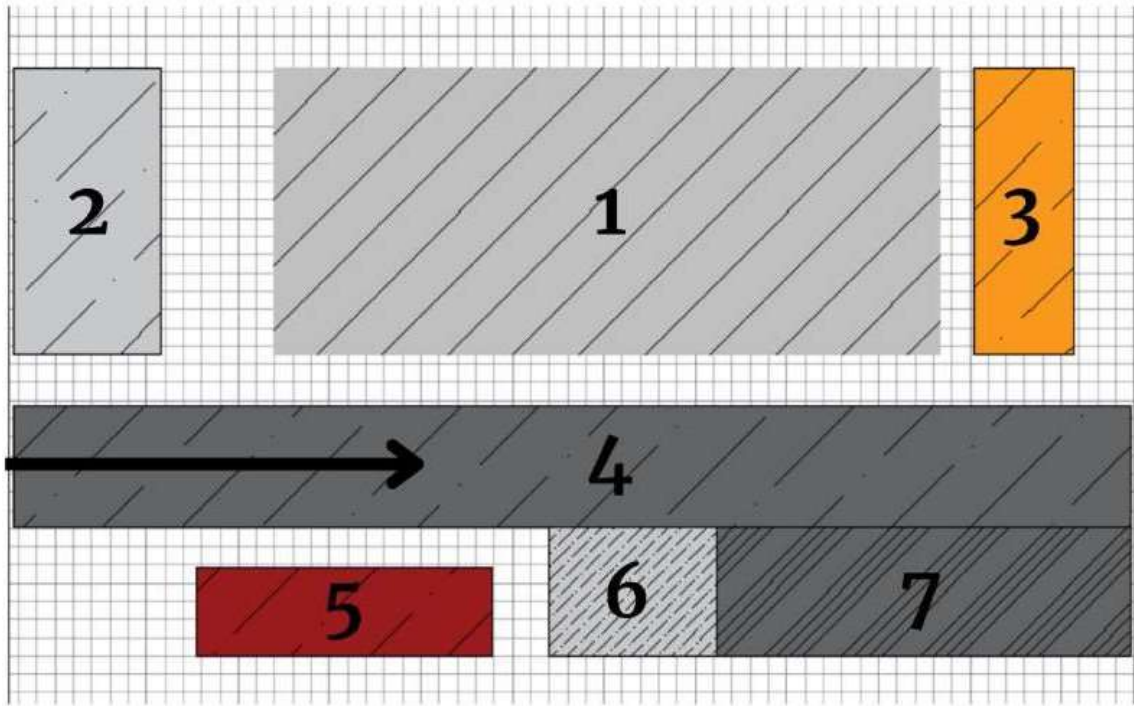


Figure 5.6. Site Plan

- 1 - Main building
- 2 - Parking for construction vehicles
- 3 - Crane
- 4 - Road
- 5 - Site office
- 6 - Concrete mixing zone
- 7 - Material stockpile

Conclusion

In conclusion, our group was able to design a viable construction project based on the knowledge from various disciplines of civil engineering and literature review of local standards. By taking the challenges coming from the location that we have chosen for our project, we were able to take those factors into consideration during the architectural, structural, and geotechnical design process.

During the first part of the Capstone project from the previous semester, we have reviewed the literature regarding the standards for construction and made preliminary designs of the structure and foundation. In this semester, we have evaluated the previous results for structural and geotechnical parts by running simulations using various types of software, including SAP2000, GEO5, and PLAXIS 3D.

For the environmental part, a more detailed strategy for managing the waste developed for the second part of our capstone project, with robust potential in recycling, composting, and incineration, all fitting with sustainable practice and energy recovery. We have successfully identified and classified the types of waste, estimated the potential for recyclable and compostable quantities, and assessed recoverable energy from incineration, considering practical and theoretical standpoints. This technique also underlines our use of anaerobic digestion, reflecting our commitment to innovation in environmentally friendly solutions by tapping the most out of organic wastes for producing methane.

On the other hand, the constraints also put more emphasis on the next step in research that makes our waste management process improved and refined, and further research into the project aims to make the project achieve greater efficiency and environmental standard compliance, as it contributes more towards the sustainable development goals.

References

- A3GEO (2022). Geotechnical Investigation Report, Project No. 1146-4B, p. 108. Available at: <https://sfmohcd.org/sites/default/files/Attachment%20G%20-%20Geotechnical%20Investigation%20Report.pdf>.
- Amazon.com. (2024). Toter 025548-R1GRS Residential Heavy Duty 2-Wheeled Trash Can with Attached Lid, 48-Gallon, Greenstone. Retrieved April 20, 2024, from <https://www.amazon.com/Toter-025548-R1GRS-Residential-2-Wheeled-Greenstone/dp/B004YKCDUW?th=1>
- ASCE (2022). *ASCE 7-22: Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. American Society of Civil Engineers.
- Athanasopoulos, G. A., Vlachakis, V. S., & Pelekis, P. C. (2011). Installation and performance of a steel sheet pile wall for supporting an excavation in urban environment. In *Geo-Frontiers 2011: Advances in Geotechnical Engineering* (pp. 3370-3380).
- Benmokrane, B., Mohamed, H. M., Mousa, S., Elsafty, A., & Nolan, S. (2021). Design, construction, testing, and behavior of driven precast concrete piles reinforced with GFRP bars and spirals. *Journal of Bridge Engineering*, 26(8), 04021050.
- California Earthquake Authority (2020). *CEA - Earthquake Risk in San Francisco*. [online] Earthquakeauthority.com. Available at: <https://www.earthquakeauthority.com/Blog/2020/san-francisco-bay-area-earthquake-prediction-risk>.
- civiltoday.com. (n.d.). *Advantages and Disadvantages of Pile Foundation - Civil Engineering*. [online] Available at: <https://civiltoday.com/geotechnical-engineering/foundation-engineering/deep-foundation/449-advantages-and-disadvantages-of-pile-foundation>.
- civiltoday.com. (n.d.). *Advantages and Disadvantages of Raft Foundation - Civil Engineering*. [online] Available at: <https://civiltoday.com/geotechnical-engineering/foundation-engineering/raft-foundation/449-advantages-and-disadvantages-of-raft-foundation>.

engineering/foundation-engineering/168-advantages-and-disadvantages-of-raft-foundation.

civiltoday.com. (n.d.). *What is a Shallow Foundation? Types of Shallow Foundation - Civil Engineering*. [online] Available at: <https://civiltoday.com/geotechnical-engineering/foundation-engineering/404-what-is-shallow-foundations-types>.

Civil Wale. (n.d.). MODULUS OF ELASTICITY OF CONCRETE. Available at: <https://civilwale.com/modulus-of-elasticity-of-concrete/#:~:text=Modulus%20of%20elasticity%20of%20concrete%20is%20the%20measurement%20of%20the,of%2030%20to%2050%20GPa>.

Das, B.M. (2019). *Principles of foundation engineering*. Boston, Massachusetts: Cengage Learning.

Department of Building Inspection. (2020). Guidelines for Preparation of Geotechnical and Earthquake Ground. Available at: <https://sf.gov/sites/default/files/2022-08/AB-111.pdf>.

Gaskells. (n.d.). Commercial waste bins | Sizes suitable for any business. Gaskells Waste. Retrieved April 20, 2024, from <https://gaskellswaste.co.uk/containers/>

Geostru.eu. (2020). *Liquefaction resistance of soil with Liquiter*. [online] Available at: <https://www.geostru.eu/en/blog/2020/05/01/liquefaction-resistance-of-soil-with-liquiter/> [Accessed 19 Apr. 2024].

Jaillon, L., Poon, C. S., & Chiang, Y. H. (2009). Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong. *Waste management*, 29(1), 309-320.

Kumar, J., & Madhusudhan, B. N. (2012). Dynamic properties of sand from dry to fully saturated states. *Géotechnique*, 62(1), 45-54.

Lachimjadi, S. K., Pereira, J. J., Taha, M. R., & Mokhtar, M. (2012). Construction waste minimisation comparing conventional and precast construction (Mixed System and IBS)

- methods in high-rise buildings: A Malaysia case study. *Resources, Conservation and Recycling*, 68, 96-103.
- Law, K.T. and Ling, Y.H. (1992). Liquefaction of granular soils with non-cohesive and cohesive fines. *Proc., 10th World Conf. on Earthquake Engineering*, 3, pp.1491–1496.
- Novotechsoftware.com. (n.d.). *Stress Reduction Factor (rd)*. [online] Available at: <https://novotechsoftware.com/help/en/novoliq/StressReductionFactorrd.html> [Accessed 19 Apr. 2024].
- Office of the Refuse Rates Administrator | San Francisco*. (n.d.). <https://www.sf.gov/departments/office-refuse-rates-administrator>
- Reith, J. H., & Wijffels, R. H. (2003). *Bio-methane & bio-hydrogen: Status and perspectives of biological methane and hydrogen production*. Dutch Biological Hydrogen Foundation.
- Salary.com. (n.d.-b). *Hourly wage for Trash Collector | Salary.com*. <https://www.salary.com/research/salary/posting/trash-collector-hourly-wages>
- Sonmez, H. (2003). Modification of the liquefaction potential index and liquefaction susceptibility mapping for a liquefaction-prone area (Inegol, Turkey). *Environmental Geology*, 44(7), pp.862–871. doi:<https://doi.org/10.1007/s00254-003-0831-0>.
- Structuralguide.com. (2023). *Driven Piles Advantages and Disadvantages*. [online] Available at: <https://www.structuralguide.com/driven-piles-advantages-and-disadvantages/> [Accessed 20 Apr. 2024].
- San Francisco Refuse rates (January - September 2024) | San Francisco*. (n.d.-b). <https://www.sf.gov/reports/december-2023/san-francisco-refuse-rates-january-september-2024#commercial-refuse-compactor-and-debris-box-rates>
- Thapa, M., Neupane, N. R., & Chhetri, P. (2022). Identifying and Evaluating the Criteria in Planning the Excavation Support System in Basement Construction using Analytical Hierarchy Process.

- Three Stream connectable Recycling Trash Can Combo (3 sizes, 29 colors)*. (n.d.-b). Trash Cans Unlimited. <https://trashcansunlimited.com/three-stream-connectable-recycling-trash-can-combo-3-sizes-29-colors/>
- Weather-and-climate.com. (2024). *Average humidity in San Francisco (CA)*. [online] Available at: https://weather-and-climate.com/average-monthly-Humidity-perc,San-Francisco,United-States-of-America#google_vignette [Accessed 20 Apr. 2024].
- Wellington City Council. (2022). Event waste conversion table: Litres to kilograms [PDF file]. Wellington City Council. Retrieved April 20, 2024, from <https://wellington.govt.nz/-/media/rubbish-recycling-and-waste/reducing-your-waste/events/files/event-waste-conversion-table-litres-to-kilograms.pdf?la=en&hash=3787D172E68832F4A5EF90B6956F1FBED87A076C>
- Western Geographic Science Center (2021). *A liquefaction susceptibility map of the San Francisco/Oakland area | U.S. Geological Survey*. [online] Usgs.gov. Available at: <https://www.usgs.gov/media/images/liquefaction-susceptibility-map-san-franciscooakland-area> [Accessed 20 Apr. 2024].
- Yasim, N. S., & Buyong, F. (2023). Comparative of experimental and theoretical biochemical methane potential generated by municipal solid waste. *Environmental Advances*, 11, 100345. <https://doi.org/10.1016/j.envadv.2023.100345>
- Zaman, A. U., & Lehmann, S. (2013). The Zero waste index: A performance measurement tool for waste management systems in a ‘zero waste city.’ *Journal of Cleaner Production*, 50, 123–132. <https://doi.org/10.1016/j.jclepro.2012.11.041>
- Zero waste*. (n.d.-b). <https://www.zerowastedesign.org/>

Appendices

Table 5.1.1 Detailed Construction Cost using RSMMeans software

		Quantity	% of Total	Cost per S.F.	Cost
A	Substructure		4.77%	\$10.91	\$540,247.23
A1010	Standard Foundations			\$5.36	\$265,618.70
	Strip footing, concrete, reinforced, load 14.8 KLF, soil bearing capacity 6 KSF, 12" deep X 32" wide	433		\$0.56	\$27,631.46
	Spread footings, 3000 PSI concrete, load 500K, soil bearing capacity 6 KSF, 9' 6" square X 30" deep	65.30		\$4.81	\$237,987.24
A1030	Slab on Grade			\$1.26	\$62,597.91
	Slab on grade, 4" thick, non industrial, reinforced	8252.33		\$1.26	\$62,597.91
A2010	Basement Excavation			\$0.89	\$43,965.13
	Excavate and fill, 10,000 SF, 8' deep, sand, gravel, or common earth, on site storage	8252.33		\$0.89	\$43,965.13
A2020	Basement Walls			\$3.39	\$168,065.49
	Foundation wall, CIP, 12' wall height, pumped, .52 CY/LF, 24.29 PLF, 14" thick	433		\$3.39	\$168,065.49
B	Shell		31.17%	\$71.28	\$3,529,322.17
B1010	Floor Construction			\$35.21	\$1,743,303.25
	Cast -in -place concrete column ,20"square ,tied ,500Kload ,12' story height ,394 lbs /LF ,4000 PSI	783.64		\$2.99	\$147,892.71
	Cast -in -place concrete column ,12",square ,tied ,minimum reinforcing ,150Kload ,10'-14' story height	866		\$1.59	\$78,583.61
	Cast -in -place concrete column ,16",square ,tied ,minimum reinforcing ,300Kload ,10'-14' story height	866		\$2.16	\$107,083.50
	Cast -in -place concrete column ,20",square ,tied ,minimum reinforcing ,500Kload ,10'-14' story height	1732		\$6.16	\$305,198.32
	Cast -in -place concrete beam and slab ,7.5"slab ,two way ,12"column ,25x25'bay ,40 PSF superimposed	41261.66		\$19.18	\$949,750.73

	Flat slab ,concrete ,with drop panels ,6"slab /2.5"panel ,12"column ,15x15'bay ,75PSF superimposed l	8252.33		\$3.13	\$154,794.38
B1020	Roof Construction			\$3.46	\$171,379.10
	Roof ,concrete ,beam and slab ,25x25'bay ,40 PSF superimposed load ,20"deep beam ,9"slab ,152PSF tota	8252.33		\$3.46	\$171,379.10
B2010	Exterior Walls			\$23.94	\$1,185,176.84
	Metal facing pnl ,textured al ,4'x 8'x 5/16"plywd backing ,sgl face ,8"x 16"x 8"CMU partition ,R -15	24940.8		\$23.94	\$1,185,176.84
B2020	Exterior Windows			\$6.30	\$311,930.43
	Windows ,aluminum ,sliding ,insulated glass ,5'x 3'	415.68		\$6.30	\$311,930.43
B2030	Exterior Doors			\$0.48	\$23,573.61
	Door ,aluminum & glass ,with transom ,narrow stile ,double door ,hardware ,6'-0"x 10'-0"opening	1.85		\$0.35	\$17,177.21
	Door ,steel 18 gauge ,hollow metal ,1 door with frame ,no label ,3'-0"x 7'-0"opening	1.85		\$0.13	\$6,396.40
B3010	Roof Coverings			\$1.67	\$82,750.39
	Roofing ,single ply membrane ,EPDM ,60 mils ,loosely laid ,stone ballast	8252.33		\$0.34	\$17,069.95
	Insulation ,rigid ,roof deck ,extruded polystyrene ,40 PSI compressive strength ,4"thick ,R20	8252.33		\$0.80	\$39,588.51
	Roof edges ,aluminum ,duranodic ,.050"thick ,6"face	433		\$0.31	\$15,476.07
	Flashing ,aluminum ,no backing sides ,.019"	433		\$0.07	\$3,457.29
	Gravel stop ,aluminum ,extruded ,4" ,duranodic ,.050"thick	433		\$0.14	\$7,158.57
B3020	Roof Openings			\$0.23	\$11,208.55
	Roof hatch ,with curb ,1" fiberglass insulation ,2'-6"x 3'-0" ,galvanized steel ,165 lbs	3.71		\$0.10	\$5,061.53
	Smoke hatch ,unlabeled ,galvanized ,2'-6"x 3' ,not incl hand winch operator	3.71		\$0.12	\$6,147.02
c	Interiors		12.9 1%	\$29.53	\$1,462,038.25
C1010	Partitions			\$5.26	\$260,401.41
	Concrete block (CMU) partition ,light weight ,hollow ,6"thick ,no finish ,foamed in insulation	4951.4		\$1.74	\$86,284.04
	Metal partition ,5/8 fire rated gypsum board face ,no base ,3-5/8"@24"OC framing ,same opposite face	6601.86		\$0.88	\$43,716.31

	Metal partition ,5/8"fire rated gypsum board face ,no base ,3-5/8"@24"OC framing ,same opposite face	4951.4		\$0.84	\$41,695.15
	Furring 1 side only ,steel channels ,3/4",24"OC	4951.4		\$0.30	\$14,655.45
	Gypsum board ,1face only ,exterior sheathing ,fire resistant ,5/8"	4951.4		\$0.14	\$7,034.95
	Gypsum board ,1face only ,exterior sheathing ,fire resistant ,5/8"	24940.8		\$0.72	\$35,435.89
	Add for the following :taping and finishing	4951.4		\$0.11	\$5,230.91
	Add for the following :taping and finishing	24940.8		\$0.53	\$26,348.71
C1020	Interior Doors			\$4.00	\$198,086.86
	Door ,single leaf ,kd steel frame ,hollow metal ,commercial quality ,flush ,3'-0"x 7'-0"x 1-3/8"	140.26		\$4.00	\$198,086.86
C1030	Fittings			\$0.24	\$11,910.65
	Toilet partitions ,cubicles ,ceiling hung ,plastic laminate	10.52		\$0.24	\$11,910.65
C2010	Stair Construction			\$4.60	\$227,844.12
	Stairs ,steel ,pan tread for conc in -fill ,picket rail ,12 risers w /landing	16.09		\$4.60	\$227,844.12
3010	Wall Finishes			\$1.54	\$76,170.82
	Painting ,interior on plaster and drywall ,walls & ceilings ,roller work ,primer & 2coats	24940.8		\$0.66	\$32,782.69
	Painting ,interior on plaster and drywall ,walls & ceilings ,roller work ,primer & 2coats	33009.33		\$0.88	\$43,388.13
C3020	Floor Finishes			\$6.23	\$308,713.06
	Carpet tile ,nylon ,fusion bonded ,18"x 18"or 24"x 24",35oz	29708.4		\$3.52	\$174,371.67
	Vinyl ,composition tile ,maximum	14854.2		\$1.15	\$56,864.11
	Tile ,ceramic natural clay	4951.4		\$1.56	\$77,477.28
C3030	Ceiling Finishes			\$7.65	\$378,911.33
	Acoustic ceilings ,3/4"fiberglass board ,24"x 48"tile ,tee grid ,suspended support	49514		\$7.65	\$378,911.33
D	Services		36.5	1%	\$4,133,563.70
D1010	Elevators and Lifts			\$17.53	\$868,150.01
	Traction ,geared passenger ,3500lb ,8 floors ,12' story height ,2 car group ,200 FPM	2.47		\$17.53	\$868,150.01
D2010	Plumbing Fixtures			\$2.12	\$104,908.37
	Water closet ,vitreous china ,bowl only with flush valve ,wall hung	10.52		\$0.89	\$44,268.05

	Urinal ,vitreous china ,wall hung	3.71		\$0.17	\$8,460.69
	Lavatory w /trim ,vanity top ,PE on CI ,20"x 18"	6.80		\$0.29	\$14,318.38
	Service sink w /trim ,PE on CI ,wall hung w /rim guard ,24"x 20"	4.95		\$0.50	\$24,960.50
	Water cooler ,electric ,wall hung ,wheelchair type ,7.5GPH	4.95		\$0.26	\$12,900.75
D2020	Domestic Water Distribution			\$0.73	\$36,340.75
	Gas fired water heater ,commercial ,100<F rise ,200MBH input ,192 GPH	1.98		\$0.73	\$36,340.75
D2040	Rain Water Drainage			\$0.50	\$24,554.59
	Roof drain ,CI ,soil ,single hub ,5"diam ,10' high	3.71		\$0.30	\$14,628.70
	Roof drain ,CI ,soil ,single hub ,5"diam ,for each additional foot add	99.59		\$0.20	\$9,925.89
D3050	Terminal & Package Units			\$26.61	\$1,317,701.23
	Rooftop ,multizone ,air conditioner ,offices ,25,000SF ,79.16ton	49514		\$26.61	\$1,317,701.23
D4010	Sprinklers			\$4.84	\$239,717.52
	Wet pipe sprinkler systems ,steel ,light hazard ,1floor ,10,000SF	6189.25		\$0.71	\$35,115.95
	Wet pipe sprinkler systems ,steel ,light hazard ,each additional floor ,10,000SF	43324.75		\$3.95	\$195,491.67
	Standard High Rise Accessory Package 8story	0.61		\$0.18	\$9,109.90
D4020	Standpipes			\$1.83	\$90,709.71
	Wet standpipe risers ,class III ,steel ,black ,sch 40,4"diam pipe ,1floor	1.48		\$0.39	\$19,078.59
	Wet standpipe risers ,class III ,steel ,black ,sch 40,4"diam pipe ,additional floors	10.39		\$0.64	\$31,673.37
	Fire pump ,electric ,with controller ,5"pump ,100HP ,1000 GPM	1		\$0.72	\$35,574.70
	Fire pump ,electric ,for jockey pump system ,add	1		\$0.09	\$4,383.05
D5010	Electrical Service /Distribution			\$2.35	\$116,212.99
	Underground service installation ,includes excavation ,backfill ,and compaction ,100' length ,4' depth	1.25		\$0.85	\$42,056.25
	Feeder installation 600V ,including RGS conduit and XHHW wire ,60A	100		\$0.06	\$2,958.94
	Feeder installation 600V ,including RGS conduit and XHHW wire ,200A	100		\$0.13	\$6,658.00
	Feeder installation 600V ,including RGS conduit and XHHW wire ,800A	100		\$0.54	\$26,515.10
	Switchgear installation ,incl switchboard ,panels & circuit breaker ,277/480V ,800A	1.2		\$0.77	\$38,024.70
D5020	Lighting and Branch Wiring			\$19.64	\$972,633.32

	Receptacles incl plate ,box ,conduit ,wire ,16.5per 1000 SF ,2.0W per SF ,with transformer	49514		\$7.81	\$386,806.34
	Miscellaneous power ,1.2watts	49514		\$0.56	\$27,748.64
	Central air conditioning power ,4 watts	49514		\$0.98	\$48,720.29
	Motor installation ,three phase ,460V ,15HP motor size	4		\$0.31	\$15,407.14
	Motor feeder systems ,three phase ,feed to 200V 5HP ,230V 7.5HP ,460V 15HP ,575V 20HP	200		\$0.07	\$3,634.42
	Motor connections ,three phase ,200/230/460/575V ,up to 5HP	1			\$227.47
	Motor connections ,three phase ,200/230/460/575V ,up to 100HP	1		\$0.02	\$927.39
	Fluorescent fixtures recess mounted in ceiling ,1.6watt per SF ,40FC ,10fixtures @32wattper 1000SF	56941.1		\$9.88	\$489,161.63
D5030	Communications and Security			\$7.32	\$362,610.20
	Telephone wiring for offices laboratories ,8jacks /MSF	37135.5		\$2.80	\$138,548.84
	Communication and alarm systems ,fire detection ,addressable ,100 detectors ,includes outlets ,boxes	0.61		\$1.41	\$69,655.86
	Fire alarm command center ,addressable with voice ,excl .wire & conduit	0.61		\$0.18	\$8,697.12
	Internet wiring ,8 data /voice outlets per 1000S.F.	37.13		\$2.94	\$145,708.38
D5090	Other Electrical Systems				\$25.01
	Uninterruptible power supply with standard battery pack ,15kVA /12.75kW	15.47			\$25.01
E	Equipment & Furnishings		14.6	3%	\$33.45
E1090	Other Equipment				\$33.45
E1090D10	10.00-Moving stairs ,escalator type ,10 FTht ,32" width ,glass balustrade	10.00			\$33.45
F	Special Construction		0%		
G	Building Sitework		0%		
	SubTotal		100	%	\$228.65
	Contractor Fees (GC ,Overhead ,Profit)		25.0	%	\$57.16

	Architectural Fees		6.0 %	\$17.15	\$849,107.73
	User Fees		0.0 %	\$0.00	\$0.00
	Total Building Cost			\$302.96	\$15,000,903.16

Biweekly Reports (Spring 2024)

Week 3

Minutes of Group Project Log Form
Capstone 2: Nazarbayev University

Acad Week	3
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Project Title	KenseMax Business Center
Group's number and Student's name	Group 2 Ali Yessengeldin (201997989) Amirzhan Zhunisbek (201836882) Arulan Bauyrzhanov (201849048) Bernar Kakabay (201993150) Kuanysh Mukhamedkhan (201874161) Serikbolsyn Maulembayev (201857925) Baryskhan Zhumabek (201924725)

6) So what have you done for 1st week

Achievement until the writing of this project log report (print in bullet form and give specific achievements) – If necessary, you can attach supporting document (word, excel, pdf, etc)

After presenting the final poster and submitting our report and technical drawings for Capstone Project I, we have received feedback in the email from the professors that were responsible for project evaluation. During the group meeting, we have discussed what we should change and what should be added further in our project, such as the software that will be used for the geotechnical analysis part. During the lecture, the professors showed us the options that we could use for calculations, such as Plaxis and GEO5. The work scope for all project sections have been shared on the Moodle platform.

2nd week
3rd week

Subsequent plan of works (print in bullet form and give specific achievements)

- Recalculate two-way slab system for interior and exterior slabs with beams
- Design reinforcement detailing for a two-way slab system
- Recreate SAP 2000 model to calculate the fundamental period of building
- Use GEO5 or Plaxis to evaluate the foundation and retaining wall design
- Confirm the shear wave velocity value from the soil investigation report by actual calculations as it was suggested in feedback from professors.
- Find information about reinforcement of foundation and discuss the technique that would be used with team members.

(1) Need to be more specific
 (2) Describe future plan based on 4th

Course Leader's Comments

Signature	sth
NAME: Ali Yessengeldin	6th
DATE: 24.01.2024	

Don't forget that this is practice board for your work

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Convenor	Date Received

Plan for mid-term
 (3) Any poster?
 9.0

Minutes of Group Project Log Form
Capstone 2: Nazarbayev University

Acad Week	6
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Project Title	KenseMax Business Center
Group's number and Student's name	Group 2 Ali Yessengeldin (201997989) Amirzhan Zhunisbek (201836882) Arulan Bauyrzhanov (201849048) Bernar Kakabay (201993150) Kuanysh Mukhamedkhan (201874161) Serikbolsyn Maulembayev (201857925) Baryskhan Zhumabek (201924725)

Achievement until the writing of this project log report (*print in bullet form and give specific achievements*) – If necessary, you can attach supporting document (word, excel, pdf, etc)

Week 4:

- After the guest lecture by Prof. Dichuan Zhang, Sung-Woo Moon, and Alfredo Satyanaga, our group has decided to focus on the structural and geotechnical parts of the Capstone Project.
- GEO5 software has been installed for the geotechnical part.

Week 5:

- For the structural part, SAP2000 calculations for members have been performed.
- For the geotechnical part, GEO5 software has been used to calculate the bearing capacity of each foundation type and elastic settlement.
- Liquefaction potential has been calculated according to the feedback from the previous semester.

Week 6:

- Group meeting has been conducted regarding the preparation for the midterm presentation for Capstone Project 2.
- GEO5 software calculations have been compared to hand calculations from the previous semester.

Subsequent plan of works (*print in bullet form and give specific achievements*)

- Complete the poster for Capstone Project 2 midterm presentation and present it to evaluators.
- Improve the Capstone Project sections based on the feedback by each evaluator.
- Recalculate two-way slab system for interior and exterior slabs with beams.
- Design reinforcement detailing for a two-way slab system
- Recreate SAP 2000 model to calculate the fundamental period of building
- Confirm the shear wave velocity value from the soil investigation report by actual calculations as it was suggested in feedback from professors.
- Find information about reinforcement of foundation and discuss the technique that would be used with team members.

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Convenor		Date Received	

**Minutes of Group Project Log Form
Capstone 2: Nazarbayev University**

Acad Week	9
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Project Title	KenseMax Business Center
Group's number and Student's name	Group 2 Ali Yessengeldin (201997989) Amirzhan Zhunisbek (201836882) Arulan Bauyrzhanov (201849048) Bernar Kakabay (201993150) Kuanysh Mukhamedkhan (201874161) Serikbolsyn Maulembayev (201857925) Baryskhan Zhumabek (201924725)

Achievement until the writing of this project log report (<i>print in bullet form and give specific achievements</i>) – if necessary, you can attach supporting document (word, excel, pdf, etc)	
Week 7:	<ul style="list-style-type: none"> Midterm poster for Capstone Project 2 has been presented to evaluating professors.
Week 8:	<ul style="list-style-type: none"> PLAXIS 3D software has been reviewed for further simulations required for the geotechnical part. For the geotechnical part, making calculations retaining wall design and foundation design with taking seismic activity into account was discussed.
Week 9:	<ul style="list-style-type: none"> Midterm poster feedback from the evaluating professors has been received. The type of reinforcement for foundation was chosen. The number and area of reinforcement of foundation was calculated using the knowledge from foundation engineering elective. Calculations of two-way slab reinforcement and beam torsional and shear reinforcement are being reconsidered.

ok

Subsequent plan of works (<i>print in bullet form and give specific achievements</i>)	
<ul style="list-style-type: none"> Redo hand calculations for the bearing capacity analysis of foundations. Compare the new results from hand calculations with GEO5 simulations. Recalculation of column reinforcement with consideration of buckling and moment 	

Course Leader's Comments	
Signature	<p>Is that all?</p> <p>week #</p> <p>9.0</p>
NAME: Ali Yessengeldin	
DATE: 16.02.2024	

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Convener		Date Received	