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THE UNIVERSITY OF NAIROBI

**DEPARTMENT OF CIVIL AND CONSTRUCTION ENGINEERING**

**A REVIEW OF HOLY FAMILY BASILICA, NAIROBI UNDERGROUND PARKING SILO**

**BY**

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A project submitted as a partial fulfilment for the requirement for the award of the degree of

BACHELOR OF SCIENCE IN CIVIL ENGINEERING 2022

# DECLARATION

This project is my original work and has not been presented for the award of a degree in any other University or Publication.

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# DEDICATION

This project is dedicated to the people I hold dear

My father Bernard Mweu

My mother Mabel Kadenyi Galo

My sister Cynthia Mbelete Mweu

They have shown their love and support throughout my educational pursuit this far.

A special thanks to my friends, colleagues, mentors and project supervisor Prof. Mumenya who offered me much-needed advice and inspiration.

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# TABLE OF CONTENTS

[DECLARATION ii](#_Toc135040378)

[DEDICATION iii](#_Toc135040379)

[ACKNOWLEDGEMENTS iv](#_Toc135040380)

[TABLE OF CONTENTS v](#_Toc135040381)

[List of Figures ix](#_Toc135040382)

[List of Abbreviations x](#_Toc135040383)

[Glossary xi](#_Toc135040384)

[List of Symbols xii](#_Toc135040385)

[Abstract xiv](#_Toc135040386)

[Chapter 1 Introduction 12](#_Toc135040387)

[1.1 General 12](#_Toc135040388)

[1.2 Advantages of underground parking facilities versus conventional parking 12](#_Toc135040389)

[1.3 Scope and Purpose of this project 13](#_Toc135040390)

[1.4 Subject matter development 13](#_Toc135040391)

[1.5 Value to the reader 13](#_Toc135040392)

[1.6 Objectives of the Project 13](#_Toc135040393)

[1.7 Methodology 13](#_Toc135040394)

[Chapter 2 Literature Review 14](#_Toc135040395)

[2.1 Introduction 14](#_Toc135040396)

[2.2 Number of Parking spaces required 15](#_Toc135040397)

[2.2.1 Design Day and Hour 15](#_Toc135040398)

[2.3 Cost of Parking 16](#_Toc135040399)

[2.4 Ideal Design Vehicle Characteristic 16](#_Toc135040400)

[2.5 Factors determining the usability of a carpark 16](#_Toc135040401)

[2.5.1 Size of car park 16](#_Toc135040402)

[2.5.2 Ease of circulation 16](#_Toc135040403)

[2.5.3 Column spacing 16](#_Toc135040404)

[2.5.4 Ease of finding parking spaces 17](#_Toc135040405)

[2.5.5 Aisle and ramp widths 17](#_Toc135040406)

[2.5.6 Headroom and ramp gradients 17](#_Toc135040407)

[2.5.7 Safety and security 17](#_Toc135040408)

[2.5.8 Level of visibility 18](#_Toc135040409)

[2.5.9 Lighting 18](#_Toc135040410)

[2.5.10 Quality and style of internal surface finishes 18](#_Toc135040411)

[2.5.11 Proper user information and signage. 18](#_Toc135040412)

[2.6 Geometrical and Layout Considerations 18](#_Toc135040413)

[2.6.1 Parking lot capacity 18](#_Toc135040414)

[2.6.2 Parking aisle capacity 18](#_Toc135040415)

[2.6.3 Bay width and length 19](#_Toc135040416)

[2.6.4 Aisle width and bin width 19](#_Toc135040417)

[2.6.5 Column placement 19](#_Toc135040418)

[2.6.6 Headroom 19](#_Toc135040419)

[2.6.7 Floor, ramp, and access way gradients 19](#_Toc135040420)

[2.6.8 Ramp and Access way curvature, widths, and clearance on structure 19](#_Toc135040421)

[2.7 Pedestrian and Vehicular Safety 20](#_Toc135040422)

[2.8 Speed Considerations 20](#_Toc135040423)

[2.9 Design Considerations 20](#_Toc135040424)

[2.9.1 Permissible Stress design 20](#_Toc135040425)

[2.9.2 Load factors design 20](#_Toc135040426)

[2.9.3 Limit State Design 22](#_Toc135040427)

[2.10 Codes of Practice 24](#_Toc135040428)

[2.10.1 British Standards (BS) 24](#_Toc135040429)

[2.10.2 Eurocodes (EN) 26](#_Toc135040430)

[2.11 Analysis of Structure at Ultimate Limit State (ULS) 27](#_Toc135040431)

[2.11.1 Introduction 27](#_Toc135040432)

[2.11.2 Loads 27](#_Toc135040433)

[2.12 Frame Analysis 28](#_Toc135040434)

[2.13 Factors influencing the Durability of Parking Structures 28](#_Toc135040435)

[2.13.1 Cracking 28](#_Toc135040436)

[2.13.2 Leaking 29](#_Toc135040437)

[2.13.3 Corrosion 29](#_Toc135040438)

[2.13.4 Concrete quality 30](#_Toc135040439)

[2.14 Green Earth Considerations 31](#_Toc135040440)

[2.14.1 Dust 31](#_Toc135040441)

[2.14.2 Vehicular Emissions 31](#_Toc135040442)

[2.14.3 Noise 32](#_Toc135040443)

[2.14.4 Waste 32](#_Toc135040444)

[2.15 Building Information Modelling (BIM) 32](#_Toc135040445)

[2.15.1 Introduction 32](#_Toc135040446)

[2.15.2 Tekla TEDDS Student Version 32](#_Toc135040447)

[2.15.3 Autodesk Revit Student Version 32](#_Toc135040448)

[2.15.3 Microsoft Excel 33](#_Toc135040449)

[Chapter 3 Analysis and Design 34](#_Toc135040450)

[3.1 Introduction 34](#_Toc135040451)

[3.2 Design Information Sheet 34](#_Toc135040452)

[3.3 Construction levels definition 35](#_Toc135040453)

[3.4 Design Sheets 35](#_Toc135040454)

[3.5 Structural Drawings 35](#_Toc135040455)

[Chapter 4 Discussion 36](#_Toc135040456)

[4.1 General 36](#_Toc135040457)

[4.2 Elements of design 36](#_Toc135040458)

[4.2.1 Foundations 36](#_Toc135040459)

[4.2.3 Slabs 37](#_Toc135040460)

[4.2.4 Beams 38](#_Toc135040461)

[4.2.5 Columns 39](#_Toc135040462)

[4.2.6 Walls 40](#_Toc135040463)

[4.2.7 Lift Core 40](#_Toc135040464)

[4.2.8 Staircase 41](#_Toc135040465)

[4.2.9 Ramp 41](#_Toc135040466)

[4.3 Structural Design 41](#_Toc135040467)

[4.3.1 Subframe analysis spreadsheets 41](#_Toc135040468)

[4.4 Python Programming. 42](#_Toc135040469)

[4.4.1 Python Program Summary 42](#_Toc135040470)

[Chapter 5 44](#_Toc135040471)

[5.1 Conclusion 44](#_Toc135040472)

[5.2 Challenges faced in the project 44](#_Toc135040473)

[5.3 Recommendations 44](#_Toc135040474)

[BIBLIOGRAPHY 45](#_Toc135040475)

[APPENDIX 46](#_Toc135040476)

[Location of the Holy Family Basilica parking lot 46](#_Toc135040477)

# List of Figures

# List of Abbreviations

BIM- Building Information Modelling

BRC – British Reinforcement Company Ltd

DPM – Damp Proof Membrane

EWEF- Each Way Each Face

FEA – Finite Element Analysis

IFC – International Foundation Class

PDF – Portable Device Format

TOF - Top of Footing

TOS – Top of Steel/Slab

TOW – Top of Wall

SSL – Structural Slab Level

SFL – Structural Floor Level

UUS-Urban Underground Space

# Glossary

Accessway Carriageway not adjoining bays and used solely for the movement of vehicles.

Aisle An accessway serving adjoining bays.

Bay The parking area, exclusive of aisle or other adjoining area, allocated to one car.

Bin Two rows of bays with the access aisle running between them.

A half-bin one row of bays and the aisle serving them.

BRC A steel reinforcement material in concrete

Clearway ramp Aramp system that does not include an aisle in its circulation and which provides unencumbered access between the parking floors and an entrance or exit.

Deck Aslab at any level of the car park.

Dynamic capacity May be applied in reference to either to the individual parts of a car park or to a car park as a whole. It is the maximum flow per hour of cars, or where appropriate, people, which the part of the car park or the car park as a whole, as the case may be, can accommodate.

Parking angle The angle between the longitudinal centreline of a bay and the aisle from which it is served.

Ramp An accessway or aisle connecting parking areas at different levels. More usually, the term is applied to accessways only.

Reservoir An accessway where cars may queue without obstructing movements in other parts of a car park or the external road system. A reservoir may also be described as a vehicle reservoir.

Static capacity The total number of bays in a car park.

# List of Symbols

A – Cross sectional area

Ac – Concrete Cross Sectional Area

As – Reinforcement Cross Sectional Area

Asc – Area of Steel in Compression (BS)

As,min – Minimum Cross Sectional Area of reinforcement allowed.

Ast –Area of tension steel (BS)

Asv – Area of Shear reinforcement (BS)

Asw – Cross sectional area of shear reinforcement (EC)

BS – British Standards

BSI – British Standards Institute

c/c – Centre to Centre

EC – Eurocodes

Fc – Concrete Compressive Strength

Fck – Characteristic compressive cylinder strength of concrete at 28 days

Fcu – characteristic strength of concrete (BS)

Ft – Tensile strength of reinforcement

Fy – Yield strength of reinforcement

Gk – Characteristic permanent action

L/l – Length or Span dimension.

M – Bending Moment in a specified direction.

N - Axial Force

Qk – Characteristic variable action

SLS - Serviceability Limit State

ULS – Ultimate Limit State

V – Shear force

VEd – Design Shear force value

Wk – Characteristic wind load (BS)

Wk – Crack width (EC)

b – Overall width of a cross-section or actual flange width in a T or L beam

bw – Width of the web on T, I , or L beams.

d – Diameter; depth

dg – Largest nominal maximum aggregate size

h – Height, Overall Cross-sectional depth.

m - Mass

t – Member thickness

φ – Diameter of a reinforcing bar

# Abstract

Over the last several years, there has been an influx of motor vehicles within urban areas around the world. This influx could be attributed to the increased individualism of people and the eternal human search for comfort in life. Having many cars to service a few people (mostly lone drivers or single passenger carrying) is putting a strain on existing transportation infrastructure facilities.

Imagine, maneuvering through the city traffic in the morning, owing to the increased number of vehicles within the country. This journey to one’s destination, most likely their work takes longer than necessary since the world over is conditioned to work during the daytime adding to the already existing problem. Well, assuming you have maneuvered traffic and arrived at your destination, it is now upon you to find suitable and safe parking for the vehicle. A single passenger carrying vehicle consumes an average of 4.5m2 of parking space. For every 10 vehicles, 50m2 of limited parking space is needed.

The problem at hand is expected to be exacerbate by population increase and increased construction of buildings within towns and their environs. The possible solutions to this would be to reduce the number of vehicles within the country or create much needed parking space. Realistically, the latter option is the only viable one. Creating parking space from existing construction land requires creativity and innovation in engineering. Both underground and aboveground space need to be utilized to do this. Either, incorporate parking floors within the higher levels, or sink the building foundations lower to create below ground parking levels.

With more time, mass concentration in mega cities is going to be a nightmare for urban planners and policy makers. This is where we, as engineers come in to find suitable and sustainable solutions to create livable cities for all these people using the existing limited resources at hand.

# Chapter 1 Introduction

## 1.1 General

The Holy family Basilica underground parking is situated in the Central Business District of Nairobi at the intersection between City Hall way and Parliament rd. The geo-coordinates of the parking structure are (-1.2878381475370102, 36.81995400214215). Initially, the cathedral housed a ground level parking lot which over time proved too small a space. Plans for the construction of the underground parking facility began in 2012 and the project was officially launched in 2020. This project is expected to review the design efficiency of the underground parking facility since it was commissioned up to date.

Vehicle parking is a major land consumer in projects and if not planned for well, it has a relatively low Return on Investment in a development. Underground parking facilities try to solve this problem as much as possible while at the same time preserving the general aesthetic of the area in question. On the flipside, underground parking structures require specialized care in design to account for challenges in ventilation (of vehicle exhaust and breathable air) and heat buildup dissipation.

The parking facility at the church has a capacity to serve a total of 512 parking slots as it tries to tackle the parking lot deficit hitting the capital every other day. The state of the art facility boasts 2 lifts, a stairwell, intelligent parking guidance system and 24/7 CCTV surveillance.

## 1.2 Advantages of underground parking facilities versus conventional parking

* Conserves useful development space as the structure can fit many vehicles in a limited space.
* Has a higher capacity for storage
* Shelters vehicles from harsh weather elements
* Increased security for vehicles while parking
* Improves the aesthetic appearance of the city
* Reduces illegal vehicle parking on streets

## 1.3 Scope and Purpose of this project

The scope of this project is limited to the structural review and analysis of various members and design elements within the Holy Family Basilica Underground Parking Structure in Nairobi, Kenya.

This project purposes to accomplish an in-depth understanding of the working of various loads and factors acting on the four storey underground parking structure.

## 1.4 Subject matter development

A literature review will be done encompassing the different factors of design analysis to be done. The actual analysis of members and elements will also be done. Digital design of the members will also be undertaken and a program built to do the proposed calculations.

## 1.5 Value to the reader

This project aims to explore the feasibility and usefulness of underground parking as a solution for city centers space utilization. The reader will gain an insight into the planning and design of the construction of underground structures.

## 1.6 Objectives of the Project

1. To do a design review analysis of Holy Family Basilica underground parking facility
2. To design members and elements of the parking structure using specialized BIM software such as Revit 2023 and Tekla TEDDS.
3. To build a Python Program that outputs the calculations of the project in question.

## 1.7 Methodology

The method followed in carrying out this project was as follows

* Visual analysis of the already built structure by taking photographs and videos
* Preparation of floorplans and elevations using Revit 2023(student license)
* Structural analysis and design using Tekla TEDDS software
* Structural detailing using Tekla TEDDS software
* Create a python program coded using vscode and relevant python libraries.

# Chapter 2 Literature Review

## 2.1 Introduction

Underground space refers to the area created for development below the natural ground level in a certain location (Goel et al., 2013). In contemporary construction, underground space could refer to space above ground but created under an existing building/structure to be utilized in other purposes. Car parks are an integral part of a development, often forming the first impression a visitor has of a town or specific development (p. 9).It may either be created by open excavation of soil or hard rock and strata or burrowing through the sides of raised hills or canyons. Technological advancements have allowed for 3D designs to be carried out by BIM software.

The phenomenon of underground engineering has been in existence since time immemorial but the more urbanized the world becomes, the more this type of construction method poses challenges for engineers. The use of underground space has become increasingly popular worldwide as a means of meeting the growing demand for infrastructure, while minimizing the impact on the environment and urban areas (Singh et al., 2012, p. 2). In this day and age, the world is gearing towards engineering for sustainability meaning that engineers will need to move beyond traditional practice and consider their projects as part of a far larger physical and social system (National Research Council et al., 2013).

Urban Underground Space (UUS) is quickly becoming a key indicator of growth of many global cities otherwise termed as urbanization. It is a metric being used to measure how much percentage of development activities in these cities/towns is being done below the ground. UUS is a driver of urban sustainability, urban cohesiveness, aesthetic improvement and renewable energy development (Bobylev, 2016)

It therefore makes sense to take an in-depth look at the utilization of underground space within the Kenyan capital and relate it to the field of construction. Structural design and underground construction is relatively new in the country and poses an engineering. This project will do a comprehensive review of the structure by using both Eurocode and British Standard codes of design and analysis. The considerations will cut across slabs, columns, beams, and foundations.

## 2.2 Number of Parking spaces required

According to (Chrest et al., 2001), parking generation is the peak accumulation of parked vehicles generated by the land uses present under predetermined conditions. Parking demand is the number of spaces that should be provided for a building(s), typically including a small cushion of extra spaces over and above the expected peak accumulation of vehicles on a design day. Parking spaces required are normally measured as x spaces per unit y of land use. The units employed in this study are sq.m.

The maximum number of parking spaces can be determined manually by estimations and measuring or by applying a specific formula that follows:

Wherer:

N = spaces

S = area of the parking area (m2).

n = number of aisles.

𝑳𝒊 = length of aisle (m)

𝒍𝒊 = width of aisle (m)

a = average area, occupied by a parked car (m2).

Λ= necessary space around the vehicle for parking maneuvers

The average values used for a and a + λ in this study are 21 m2 and 25 m2

### 2.2.1 Design Day and Hour

The parking should be designed with 24/7 considerations in mind. Assuming it is open for use throughout as is in our case, it should be designed to be effectively used every single hour of every single day for a total of 8760 hours in the year. Efficient use-design ensures that the end user can utilize the facility with as much ease as possible.

## 2.3 Cost of Parking

Generally, parking structure construction is an investment of extremes with a low Return on Investment especially in cases where parking is offered free of charge. In the Holy Family Basilica Underground parking, the Intelligent Parking System manages fees paid by the vehicle owners which is prorated according to time spent at the facility.

## 2.4 Ideal Design Vehicle Characteristic

In the design and analysis of the parking silo, a vehicle expected to be the largest in size and weight out of those expected to be using the facility is considered. This is known as the Ideal Design Vehicle which may vary with time and technological improvements of vehicles in future.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Comparison of typical vehicle dimensions.** | | | | |
| Vehicle class | Vehicle Group Proporttion (%) | Length | Width (m)  including wing mirrors | Height (m)  Excluding roof boxes, racks, and bars |
| Small car | 95 | 3.95 | 1.75 | 1.75 |
| Standard Car | 95 | 4.75 | 2.06 | 1.85 |
| Large Car | 100 | 5.40 | 2.24 | 2.05 |
| MPVs | 100 | 5.10 | 2.20 | 1.90 |
| 4\*4 drives | 100 | 5.05 | 2.25 | 2.05 |

## 2.5 Factors determining the usability of a carpark

### 2.5.1 Size of car park

The size of the parking lot is crucial since it must be able to handle the demand for spaces. If a parking lot is too small, it could fill up too soon and create traffic. On the other side, if it's too big, it might not be used effectively and might take up too much room.

### 2.5.2 Ease of circulation

The ease of circulation within the carpark is also important. This may include the width of the aisles and ramps, as well as the spacing between columns. Aisles and ramps that are too narrow can create bottlenecks and make it difficult for drivers to maneuver, while wide aisles and ramps can help to improve the flow of traffic.

### 2.5.3 Column spacing

Column spacing in a parking facility affects usability by determining the size of parking spaces. Narrow column spacing can make it difficult to maneuver and create dark areas while wide spacing can waste space. Appropriate spacing is essential for providing safe and efficient parking, as it affects visibility, lighting conditions, and overall design. Balancing the needs for safety, accessibility, and space efficiency is crucial in determining column spacing.

### 2.5.4 Ease of finding parking spaces

It should be simple for drivers to find available parking spots. In addition to using clear and simple signage, this may entail using electronic signs or other technology to display the availability of parking spaces.

### 2.5.5 Aisle and ramp widths

Aisle width refers to the width of the lanes that run between rows of parked cars. To ensure that cars can travel through the parking area securely and easily, adequate aisle width is required. It may be challenging for vehicles to pass one another or for drivers to maneuver their vehicles into confined parking places if the aisle width is too narrow. Drivers may have a tougher time finding a parking space as a result of delays and bottlenecks caused by this. Also, it could be challenging for emergency vehicles to enter the parking area if the aisle width is too small.

Ramp width, on the other hand, refers to the width of the lanes that connect different levels of a multi-level parking facility. Enough ramp width is required, much as suitable aisle widths, to guarantee that cars may move through the parking facility securely and easily. The ability of drivers to maneuver through the parking facility may be hampered if the ramp width is too narrow. Also, it could be challenging for emergency vehicles to enter the parking facility if the ramp width is too small.

Inadequate widths of Aisle and Ramps can also create an inconvenience for people with disabilities, as well as for people with strollers or carts, which can make the parking facility less accessible to them.

### 2.5.6 Headroom and ramp gradients

The headroom within a carpark should be sufficient to accommodate the height of most vehicles. Low headroom can be a problem for drivers of taller vehicles, such as SUVs or pickup trucks, as they may struggle to clear the ceiling. This can lead to damage to the vehicle or the carpark infrastructure. The gradient of ramps within the carpark should be designed to be easily navigable by drivers. Ramps that are too steep can be difficult to drive up or down, especially for drivers of larger or heavier vehicles. This can lead to accidents or damage to the vehicles. On the other hand, ramps with a more gradual gradient can be easier for drivers to navigate and may be less likely to cause accidents or damage.

### 2.5.7 Safety and security

The safety and security of the carpark is important for the peace of mind of users. This may involve the use of surveillance cameras, security personnel, or other measures to deter crime and ensure the safety of drivers and their vehicles.

### 2.5.8 Level of visibility

The level of visibility within the carpark can also impact usability. Poor visibility can make it difficult for drivers to see other vehicles and pedestrians, increasing the risk of accidents.

### 2.5.9 Lighting

Adequate lighting is important for the safety and security of carpark users. Poor lighting can make it difficult for drivers to find their way around the carpark and may increase the risk of accidents or crime.

### 2.5.10 Quality and style of internal surface finishes

The quality and style of the internal surface finishes of the carpark can also impact usability. A well-maintained carpark with high-quality finishes can create a more pleasant and welcoming environment for users.

### 2.5.11 Proper user information and signage.

Clear and easy-to-follow signage and user information can help drivers to find their way around the carpark and locate their vehicle. It can also help to ensure that users are aware of any rules or regulations that apply within the carpark.

## 2.6 Geometrical and Layout Considerations

The parking area was designed in such a way as to increase maneuverability and overall end user usability as well as safety. In addition to this, the designers put into consideration different types of users that are vehicles and pedestrians who should be fitted to effectively utilize the facilities simultaneously and with ease.

### 2.6.1 Parking lot capacity

Parking lot capacity may be subdivided into two mainly Static capacity and Dynamic capacity. Static capacity refers to the designed and already existing parking lot infrastructure available for use and as such, it cannot be easily changed. Dynamic capacity refers to the normalized maximum in and out flow of vehicles within the facility.

### 2.6.2 Parking aisle capacity

The aisle is the space allocated for the movement of vehicles into and out of the parking structure. In the parking aisle, only dynamic parking capacity is usually considered and this is dependent on the aisle dimensions, car size proportions and expected vehicle circulation at any given time during use.

### 2.6.3 Bay width and length

The bay is the actual space intended for parking by a single vehicle. The dimensions allotted for this space are supposed to be standardized to accommodate normal use by a regular sized vehicle as well as large vehicle occasional use.

### 2.6.4 Aisle width and bin width

Over the years, the have been proposed standards for the widths of the aisle and bins in different regions of the world.

### 2.6.5 Column placement

In the planning for the structure, columns need to be placed with efficiency and end-user safety in mind. This requires the engineer to consider bay accessibility as well as sight lines in the parking area. Columns need to be placed such that parking maneuvers are made easier and the column size recommended is 150mm to 200mm is acceptable.

### 2.6.6 Headroom

The column sizing needs to account for the height clearance required in the parking area while considering overhead gutters, smoke alarms, lighting, and security systems. The recommended headroom measured from slab to slab normally is 2.10m for entrances and exits, bays and bins, aisles and ramps

### 2.6.7 Floor, ramp, and access way gradients

Design recommendations stipulate that floors should be constructed with a gradient fall of 1:60 to allow for proper drainage. Steep ramps such as those greater than 1:10, a transition length is provided for at the top and bottom to prevent vehicle grounding.

### 2.6.8 Ramp and Access way curvature, widths, and clearance on structure

Ramp curvature refers to the degree to which a ramp bends or curves as it travels through the parking facility. To guarantee that cars may go through the parking facility securely and easily, an adequate ramp curvature is required. Cars may find it challenging to maneuver and perform turns if the ramp's curve is too tight, especially at higher speeds. Drivers may have a tougher time finding a parking space as a result of delays and bottlenecks caused by this. Emergency vehicles may also have trouble getting to the parking facility due to the tight curves.

Ramp width and clearance on structure, are closely related. The width of the ramp should be adequate to allow vehicles to pass through comfortably, and provide enough space for safety clearance on both sides, avoiding the risk of scratching or damaging vehicles or the structure. Additionally, the ramp should have a clearance on the structure that's high enough to allow vehicles to pass through safely, without hitting the ceiling or any other structures that might be in the way. If the clearance on the structure is too low, it can be dangerous for vehicles, as it may cause damage to the vehicle or the structure.

Access way curvature, width, and clearance are similar to the ramp's width. The access way is a path that provides entry and exit to the parking facility, and should have a comfortable width and an adequate curvature. Also, it should be designed with a suitable clearance on the structure, to ensure that the vehicles that enter and exit the parking facility can do so safely and without causing any damage to the vehicle or the structure.

## 2.7 Pedestrian and Vehicular Safety

Security and the safety of all users of the parking structure takes center stage in the design, construction and operation of the facility. The structure should be strong and robust enough to withstand the different loads applied to it in design.

In operation, parking structures are notorious for criminal activities such as mugging, rape and stabbings and these need to be taken care of.

Underground parking structures need to prioritize pedestrian and vehicular safety. Adequate lighting, clear signage, and designated pedestrian pathways can improve visibility and reduce the risk of collisions. Additionally, speed limits, speed bumps, and mirrors can be implemented to encourage safe driving. Proper ventilation and fire suppression systems are also important for emergency situations. Overall, ensuring the safety of both pedestrians and vehicles is crucial for a successful and functional underground parking structure.

## 2.8 Speed Considerations

The parking structure designers have a speed consideration during inception that is typically displayed on signage at different intervals within the facility. The safe pace at which cars should be driven inside a parking structure is referred to as the "speed consideration" in subterranean parking facilities. To guarantee that automobiles may safely navigate the parking area without getting into accidents or endangering pedestrians, speed limits are often set and enforced. The layout, lane widths, and column placement of the parking facility can all have an impact on the safe operating speed for automobiles. It is crucial to make sure that the speed restriction is suitable for the parking facility's design and that it is clearly communicated to cars through markings and signage. The risk of accidents, the safety of pedestrians, and the chance of damage to the facilities themselves can all be decreased by reducing the speed of vehicles in subterranean parking structures.

## 2.9 Design Considerations

The structural design considerations taken into account during the design of a structure need to ensure that the structure’s operation is suitable throughout its expected lifetime.

### 2.9.1 Permissible Stress design

Permissible stress design when used in designing accounts for failure such that no member of the structure is allowed to go past its elastic limit. The values for permissible stress design are obtained as a ratio of failure stress to factor of safety appropriate to the design.

### 2.9.2 Load factors design

Load factors design takes into account the failure of a structure by the effect of collapse loads

#### Live Loads

Accidental Loadings

Accidental loads in a structure can occur when there is a sudden and unexpected influx of weight on the structure, such as from a heavy vehicle driving over the slab or from an earth movement (landslide).

#### Earthquake Loading

The seismic characteristics of an underground structure need to be considered in the design and analysis stage. According to (Wood, 2007), since underground constructions are restricted by the soil or rock around them and are unable to move on their own, they often do not experience significant dynamic amplification effects. They are impacted by the ground's displacement around them rather than the structure's inertia forces.

Earthquake loads in underground buildings occur when the structure is subjected to the ground shaking and shaking forces associated with an earthquake. This can cause the building to experience lateral and vertical movements, as well as rotational forces, which can lead to structural damage. To prevent or mitigate the effects of earthquake loads, underground buildings are often designed using specialized earthquake-resistant materials and construction techniques, such as base isolation or energy dissipation systems. These methods can help to reduce the amount of earthquake-induced movement and forces on the building.

Geological and geotechnical investigations are important components of the planning and design of underground infrastructures. These investigations enable the identification of potential hazards, such as geological faults, groundwater, and soil instability, and the selection of appropriate construction methods (Singh et al., 2012, p. 51).

The car park's structure may be vulnerable to both horizontal and vertical forces during an earthquake because the ground directly beneath it may tremble and move erratically. These forces may cause the parking lot's structure to sag or possibly collapse, which could harm the cars parked there and endanger the lives of anybody inside.

A parking garage that is underground must be built to fulfill particular seismic loading standards if it is to resist the pressures that an earthquake can produce. Usually, a seismic hazard analysis is conducted to ascertain the anticipated earthquake forces that the structure will experience. This research can be used to design the structure of the parking lot so that it can withstand these stresses.

Using a seismic base isolation system, where the structure is physically separated from the ground using flexible bearings, is one method of designing for seismic load. These bearings allow the structure to move independently from the ground, minimizing the forces communicated to the structure during an earthquake.

Another strategy is to build the structure utilizing seismic-resistant methods, like using steel or reinforced concrete frames with energy-dissipating components. This will increase the building's flexibility and ability to endure seismic forces without collapsing.

In all situations, the design must adhere to regional building rules and ordinances that specify the specifications for seismic design, including the minimum required strength and stiffness of the structure and the permitted amounts of deformation.

Overall, creating an underground parking lot to withstand earthquake forces is a challenging task that calls for thorough evaluation of structural design possibilities, careful consideration of seismic hazard, and adherence to all applicable standards and regulations.

### 2.9.3 Limit State Design

Limit state designs are divided into:

#### Serviceability limit state

Serviceability limit state (SLS) design is a type of design methodology that is used to ensure that a structure is safe, stable, and functional throughout its intended service life. It is one of the two limit states that structures are designed for, the other being the ultimate limit state (ULS) which is about safety against collapse.

The main goal of SLS design is to prevent a structure from significantly deforming or deteriorating over time while it performs its intended purpose. The structure must be able to sustain the loads it will encounter throughout its service life and must not suffer from severe deflections, vibrations, cracking, or other types of deterioration that would impair its operation or the safety of the surrounding area.

A thorough examination of the loads that the structure will be subjected to over the course of its service life must be done in order to design a structure for SLS. Both the dead loads (the weight of the structure and its own parts) and the live loads are included in this (such as people, snow, wind, etc). Once the loads are determined, the structure can be built so that it can sustain them without deflecting or deteriorating excessively.

Building regulations and standards typically use parameters like as maximum permitted deflections, crack widths, vibrational requirements, etc. to define the serviceability limit state. To guarantee that a structure is secure, sturdy, and useful, designers must make sure it complies with certain codes and standards.

Examples of serviceability limit state criteria are:

* **Durability**

Durability describes a structure's capacity to tolerate the effects of environmental conditions over the course of its intended service life, including moisture, temperature variations, and chemical exposure. A structure must be built with materials and construction techniques that can withstand these environmental influences without degrading too quickly in order to be durable.

* **Stability**

Stability is the ability of the structure to maintain its overall shape and integrity under the loads that it will be subjected to during its service life. Both horizontal and vertical stability are referred to here. The subject of horizontal stability is how a structure reacts to lateral forces like wind and earthquake. The ability of a structure to maintain both itself and the loads it is intended to carry without buckling or collapsing is known as vertical stability.

* **Fire resistance**

Fire resistance is the ability of a structure to maintain its structural integrity and perform its intended function in case of a fire. Building codes and regulations specify the minimum fire resistance requirements for different types of structures and materials.

* **Deflection**

Deflection is the amount of bending or deformation in a structural member, caused by the loads that it is subjected to. The deflection should not exceed certain limits as established by codes and standards to avoid discomfort to the occupants or damage to the non-structural elements such as partitions or finishes.

* **Cracking**

Cracking refers to the formation of cracks in a structure, and it's usually an indicator of excessive deformation or deterioration. Codes and standards specify the maximum allowable crack widths, which if exceeded, may lead to structural damage, leakage or a reduction in durability

* **Excessive vibration**

Excessive vibration is the excessive movement or shaking of a structure, and it can cause discomfort to the occupants, damage to non-structural elements, or even instability. Vibration criteria will depend on the type of structure and its intended use, but codes and standards will establish limits on the levels of vibration that a structure can experience

#### Ultimate limit state

Ultimate limit state (ULS) design is used to make sure that a structure is secure and resistant to collapsing over the duration of its specified service life. One of the two limit states for which structures are intended is the serviceability limit state (SLS), which is concerned with usability and user comfort.The main objective of ULS design is to make sure that a structure can bear the highest expected loads during its service life without collapsing. This means that the building must be able to withstand the heaviest loads it may experience, such as those resulting from severe weather conditions or natural disasters.

* **Loss of static equilibrium of the structure (EQU):**

The loss of stability or balance of the structure can happen when a structure is subjected to excessive loads and the internal forces inside the structure are unable to keep the structure in an equilibrium. The structure can then collapse or lose its stability as a result of this. Designers must make sure the structure is built to withstand the anticipated loads and that the structural components are appropriately sized and placed to preserve stability in order to avoid this scenario.

* **Internal failure or excessive deformation of the structure (STR):**

This ULS scenario refers to the failure of a structural element or excessive deformation of the structure itself. It can happen when the structure deforms beyond what is acceptable or when the loads and strains on the structural components are greater than their capacities. To avoid this situation, designers must make sure that the building's materials are robust enough to withstand the anticipated stresses and that the structural elements are scaled and organized correctly to prevent excessive deformation.

* **Failure or excessive deformation of the ground (GEO):**

The ground on which the structure is built fails or deforms excessively in this ULS scenario. It can happen if the rock or soil beneath the structure is unable to support the structure's weight or if the rock or soil is unstable as a result of moisture fluctuations or other reasons. The foundation of the structure must be adequately built to disperse the structure's weight and to withstand forces that could cause the ground to break or deform in order to avoid this scenario.

* **Fatigue failure of the structure (FAT):**

In this ULS scenario, a structural part fails as a result of continuous loading and unloading. It can happen when cyclic loading is applied to the structural element, which leads to the development of microscopic cracks that eventually spread until the element fails. Designers must make sure that the structural part is adequately constructed to resist fatigue and that the anticipated loads and number of load cycles are taken into account during the design phase in order to avoid this situation.

## 2.10 Codes of Practice

The codes of practice are a set of rules outlining how professionals in the industry are supposed to undertake their design work for maximum efficiency and safety. They are a mirror of the design recommendations aforementioned in addition to others specific to materials used. The material characteristics considered are: stress-strain relationships, modulus of elasticity, Poisson’s ratio and inherent variability within material manufacture and construction processes.

### 2.10.1 British Standards (BS)

The British Standards are a specification of recommended procedure, quality of output, terminology, and other details, in a particular field, drawn up and published by the British Standards Institution

The BS will be used and referred to while designing for loads, concrete, and RC detailing as follows:

* BS 6399-part 1-1996 Loading for Buildings.
* BS 8110-1-1997 Concrete analysis.
* BS 8666-2005 RC detailing.
* BS 2655 Loads due to Lifts

#### BS 6399 part 1-1996 Loadings for Buildings

BS 6399 provides stipulations for the code of practice for dead and imposed loads.

Dead load refers to the load due to the weight of all walls, permanent partitions, floors, roofs, finishes and all other permanent construction including services of a permanent nature.

Imposed loads refers to the load assumed to be produced by the intended occupancy or use, including the weight of movable partitions, distributed, concentrated, impact and inertia, loads, but excluding wind loads.

According to Table 1, the minimum imposed floor loads in a car parking with vehicles not exceeding 2500 are 2.5 kN/m2 for uniformly distributed loads and 9.0kN for concentrated loads.

Clause 11 gives loading conditions for vehicle barriers in a carpark as F = 0.5mv2 / (dc + db) where m is the gross mass of the vehicle in kg, v is the velocity of the vehicle in m/s normal to the barrier, dc is the deformation of the vehicle in mm and db is the deformation of the barrier in mm. In the case where the vehicles using it do not exceed a mass of 2500kg, the unknowns may assume the following values: m=1500kg, v=4.5m/s and dc=100mm. In a special case where db is zero such as in a rigid barrier, the force F for vehicles up to 2500kg is 150kN.

The British Standards provide for accidental loads on key or protected elements as 34kN/m2.

For classes F and G of vehicular use, specifically pedestrian areas in car parks, the minimum horizontal imposed loads for parapets, barriers and balustrades, etc. is taken as 1.5 for the following:

* Horizontally uniformly distributed line load (kN/m)
* A uniformly distributed load applied to the infill (kN/m2)
* A point load applied to part of the infill (kN)

#### BS 8110-1-1997 Concrete analysis.

BS 8110 is a British Standard that provides guidance on the design and construction of reinforced and prestressed concrete structures, including underground parking silos. The standard covers the analysis, design, and construction of concrete elements and structures and it's intended to be used in conjunction with other relevant standards and codes. When designing an underground parking silo, the standard requires the calculation of loads and stresses that the structure will be subjected to. This includes the weight of the structure, the weight of the parked cars, and the live loads such as the weight of people, snow, and wind. The standard also provides rules for detailing the reinforcement of concrete elements such as columns, beams, and walls to withstand these loads.

Safety is one of the main tenets of the standard. The underground parking silo can maintain its structural integrity even in the case of an earthquake or other natural disaster thanks to the safety measures included in the design. Assuring that the structure is safe and stable against collapse for the duration of its planned service life as well as being useful and comfortable to use, it also includes provisions for the design of the structure for both the serviceability limit state (SLS) and ultimate limit state (ULS).

The standard also offers guidelines for the installation and curing of concrete, as well as specifications for quality control and testing, all of which are essential for guaranteeing the strength and lifespan of the underground parking silo. It also discusses the rules for designing prestressed concrete components, which can increase the structure's overall stability.

In conclusion, BS 8110 is a thorough standard that offers recommendations for the analysis, design, and building of reinforced and prestressed concrete buildings, including subterranean parking silos. It is meant to be used in conjunction with other pertinent standards and norms and emphasizes safety and functionality throughout the design and building process.

#### BS 8666-2005 RC detailing.

BS 8666:2005 provides guidance on the detailing of reinforcement in reinforced concrete structures. When applied to an underground building, this standard is aimed to ensure the safety, strength, and durability of the structure, and it covers the design, fabrication and installation of reinforcement in reinforced concrete. The standard provides detailed guidelines on the layout and spacing of reinforcement, as well as the size and type of reinforcement required. It also covers the requirements for the distribution of reinforcement, including the minimum and maximum amounts of reinforcement that are required in different parts of the structure.

The standards for fire resistance when applied to a subterranean construction are one of the important parts of the standard. The standard contains guidelines for designing reinforcement to offer enough fire resistance to guarantee building occupant safety and structural integrity in the event of a fire. The detailing of reinforcement for toughness and resistance to environmental conditions is likewise covered by BS 8666. In underground structures where the environment can be more hostile than in aboveground buildings, the standard contains standards for the design of reinforcement to withstand corrosion and the effects of moisture.

In conclusion, the British standard BS 8666:2005 offers instructions on the detailing of reinforcement in reinforced concrete structures. It is intended to provide detailed guidelines for the design, fabrication, and installation of reinforcement, including fire resistance, corrosion resistance, and other environmental factors, when applied to an underground building. This is done in order to ensure the safety, strength, and durability of the structure.

### 2.10.2 Eurocodes (EN)

The Eurocodes are the 10 structural design standards put forward to be followed while doing structural design within the European Union.

The EN will be used and referred to while designing for loads, concrete, and RC detailing as follows:

* EN 1990(2002) Eurocode: Basis of Structural Design
* EN 1991-1-1(2002) Eurocode 1: Actions on Structures
* EN 1992-1-1(2004) Eurocode 2: Design of Concrete Structures
* EN 1998 Eurocode 8: Design of Structures for Earthquake Resistance

#### EN 1990 (2002) Eurocode: Basis of Structural Design

This code provides the principles and requirements for the structural design of all types of buildings, including underground buildings. It lays down the basic principles and assumptions to be used in the design process and provides guidance on how to assess the safety and reliability of the structure. It also covers the determination of design loads, such as gravity loads and environmental loads, which are relevant for the design of underground buildings. It stipulates the safety, serviceability and durability of structures basing on both the limit state concept and partial factors method.

#### EN 1991-1-1 (2002) Eurocode 1: Actions on Structures

This code covers the actions that are likely to act on a structure, including the loads imposed by the surrounding ground and water, as well as the loads imposed by the structures and equipment above the underground building. Part 1-1 of this Eurocode deals with general actions which are Material Densities, self-weight and imposed loads for buildings. For underground buildings, the code provides guidance on how to assess the impact of soil and groundwater on the structure and how to design the structure to withstand these loads.

#### EN 1992-1-1 (2004) Eurocode 2: Design of Concrete Structures

This code provides guidance on the design of concrete structures, including underground buildings. It covers the design of reinforced and prestressed concrete structures, as well as the design of foundations and retaining walls. For underground buildings, the code provides guidance on the use of reinforced and prestressed concrete, the design of retaining walls, and the design of foundations that take into account the soil and groundwater conditions. Part 1-1 of this Eurocode deals with general rules and regulations for buildings constructed using concrete.

#### EN 1998 Eurocode 8: Design of Structures for Earthquake Resistance

This code covers the design of structures for earthquake resistance, including underground buildings. It provides guidance on the seismic design of structures, taking into account the soil conditions, the characteristics of the earthquake, and the building's response to the earthquake. For underground buildings, the code provides guidance on how to design the structure to withstand the ground movements caused by an earthquake.

## 2.11 Analysis of Structure at Ultimate Limit State (ULS)

### 2.11.1 Introduction

The RC structure (reinforced concrete), implements several elements such as beams, columns, slabs, and walls joined together to form a single unit

### 2.11.2 Loads

The loads determined in the analysis of an RC structure will be divided as follows:

#### Vertical loads

Permanent or dead loads

This is the weight of the permanent structure and other fixed elements that make up a building or structure. It does not change over time. Permanent loads in this vehicle silo will be the building self weight including all members in the construction, fittings, finishing, toll booths, payment points, as well as circulation elements such as the lift core.

Imposed or live loads

Live load refers to the weight of movable objects that may occupy or move through a structure, such as people, furniture, equipment, or vehicles. It can vary in magnitude and location over time.

In this underground parking silo, the variable loads include but are not limited to: human beings, vehicular loads, appliances, furniture, etc.

#### Lateral loads

These are the loads that act on a building from the sides. Normally, lateral loads are earthquake loads and wind loads. In this project however, wind loads will not be considered owing to the location of the building underground. On the other hand, earthquake loads in this building will be of major concern for the structural designer. Faults, epicenters, foci, magnitude, probabilities and wavelength of earthquakes will be considered for analysis by the engineer.

## 2.12 Frame Analysis

The RC structures are normally analyzed as rigid frames where slabs are analyzed as continuous members supported by beams and columns.

Plane frame analysis is done for the columns and beams in a building as well as the overall frame layout of the building.

## 2.13 Factors influencing the Durability of Parking Structures

### 2.13.1 Cracking

Cracks in a structure can be classified into two, namely Structural cracks and Non Structural cracks. Structural cracks come about due to flaws in design, construction and/or improper use. Non-Structural cracks occur due to internal building stresses in building materials for example in plastering and finishing. These cracks do not impact the overall functioning of the building but may create the impression of structural failures. Cracks pose a risk in the usability and structural integrity of a building in that they may lead to weakening of the members and the building itself.

#### Preventing Cracking

Proper design and construction: Proper design and construction of underground structures is the first line of defense against cracking. The design and construction should take into account the soil and groundwater conditions, the anticipated loads on the structure, and the materials used. The design should also consider the differential settlement and movement of the ground to prevent any excessive deformation of the structure.

Proper waterproofing: One of the primary reasons for cracking in underground structures is the infiltration of water into the structure. Proper waterproofing of the foundation walls and floors can prevent water from entering the building and causing cracks. A waterproofing membrane can be installed on the exterior or interior of the structure to create a barrier against water infiltration.

Proper drainage: Proper drainage is essential for preventing water from pooling around the foundation and causing cracks. A proper drainage system should be installed to divert water away from the building's foundation and prevent water from accumulating in the soil around the building.

Proper maintenance: Regular inspection and maintenance of the building's foundation and structure can help identify any cracks early and prevent them from becoming more significant problems. Any cracks that are detected should be repaired promptly before they can cause any further damage.

Proper ventilation: Proper ventilation of underground structures can help prevent the buildup of moisture and humidity that can cause cracking in concrete structures. A proper ventilation system should be installed to ensure adequate air circulation within the building.

### 2.13.2 Leaking

Leaking is a common problem in underground structures, including underground parking facilities. Water can enter the structure through cracks in the walls or floors, faulty joints or seals, or inadequate waterproofing measures. This can cause several problems to the structure. First of all, it has the potential to impair the parking facility's structural soundness over time by weakening the concrete and causing corrosion to steel reinforcing. This can create dangerous safety risks for people utilizing the facilities in cars and on foot. Second, water leaks inside the building can harm parked cars, leading to corrosion, mildew, and possible electrical and mechanical issues. Last but not least, water leaks can make surfaces slick, raising the possibility of slips and falls for people as well as diminishing the traction of vehicles passing through the facility, possibly resulting in accidents.

#### Preventing leaking.

Proper site selection: Choosing a site with suitable soil conditions and groundwater level is critical to prevent leaking.

Waterproofing: Installing waterproofing materials on the exterior of the structure, such as membranes or coatings, can prevent water from infiltrating the structure.

Drainage systems: Proper drainage systems, including perimeter drains, interior drains, and sump pumps, can effectively remove any water that enters the structure.

Construction techniques: Ensuring proper compaction of backfill material around the structure during construction can prevent the formation of voids that can lead to leaking. Regular maintenance: Regular inspections and maintenance of drainage systems, waterproofing materials, and other components can help identify and address potential issues before they become major problems.

### 2.13.3 Corrosion

Corrosion is a common problem in underground parking structures, especially those constructed using reinforced concrete. Corrosion occurs when the reinforcing steel in the concrete begins to rust due to exposure to water, oxygen, and chloride ions. This can cause the concrete to crack and spall, reducing the strength of the structure and compromising its safety.

#### Preventing corrosion.

Use of high-quality materials, such as stainless steel or epoxy-coated rebar, which are more resistant to corrosion than regular steel. Proper surface preparation and coating application during construction can also help to prevent corrosion.

Regular maintenance and inspection of the structure can help to identify and address any corrosion issues before they become severe. This can include regular cleaning, repairs to damaged or cracked concrete, and the application of protective coatings or sealants.

Proper drainage systems can also help to prevent corrosion by minimizing the amount of water that comes into contact with the structure. This can include the use of drainage channels, sump pumps, and other systems designed to divert water away from the structure.

Overall, preventing corrosion in underground parking structures requires a combination of proper design, construction, and maintenance practices. By taking proactive steps to prevent corrosion, building owners can ensure that their parking structures remain safe, durable, and long-lasting

### 2.13.4 Concrete quality

Concrete quality is critical to the durability and longevity of underground structures, including parking garages. Poor-quality concrete can lead to cracking, spalling, and other forms of deterioration that can compromise the structural integrity of the facility and shorten its service life. To ensure high-quality concrete, it is essential to use the right mix of ingredients, including aggregates, cement, water, and admixtures. The use of low-quality or contaminated aggregates can lead to concrete that is prone to cracking and deteriorating prematurely. The water-to-cement ratio is also crucial, as too much water can weaken the concrete and make it more susceptible to cracking.

Another important factor in ensuring concrete quality is proper curing. Adequate curing allows the concrete to gain strength and durability over time. If curing is insufficient or not done correctly, the concrete can be weaker and more prone to cracking and other forms of deterioration. It is pragmatic for the site engineer and material engineer to perform tests on the quality of concrete being used to ensure that it achieves the strength needed in design.

On-site tests of concrete are conducted to assess the quality, strength, and performance of concrete at the construction site. These tests provide valuable information about the concrete's characteristics and help ensure that it meets the required specifications. Some common on-site tests conducted on concrete:

* Slump Test: As mentioned earlier, the slump test is performed on fresh concrete to measure its workability and consistency. It is a quick and simple test that can be conducted at the construction site.
* Concrete Cube or Cylinder Testing: Concrete cubes or cylinders are cast on-site and cured under controlled conditions. These specimens are then tested for compressive strength in a laboratory to verify whether the concrete meets the specified strength requirements.
* Rebound Hammer Test: The rebound hammer test, also known as the Schmidt hammer test, is a non-destructive test that provides an estimate of the concrete's compressive strength. It involves striking the concrete surface with a spring-loaded hammer and measuring the rebound value.
* Pull-off Test: The pull-off test is conducted to assess the bond strength between concrete and other materials such as coatings or adhesives. A specialized instrument is used to apply a tensile force to a bonded area, and the force required to pull off the material is measured.
* Carbonation Depth Test: Carbonation depth test is performed to determine the depth to which carbon dioxide has penetrated into the concrete. It helps assess the level of carbonation and the potential risk of reinforcement corrosion.
* Chloride Content Test: This test measures the chloride ion content in concrete, which is crucial for assessing the risk of corrosion for reinforcing steel. It involves extracting concrete samples and analyzing them in a laboratory.
* In-situ Density Test: The in-situ density test measures the density or unit weight of hardened concrete at the construction site. It provides an indication of the concrete's quality and compaction level.
* Temperature Monitoring: Temperature monitoring involves measuring and recording the internal temperature of freshly placed concrete during curing. It helps ensure that the concrete is properly cured and avoids excessive temperature differentials that could lead to cracking or other issues.

#### Ensuring proper concrete quality

To prevent issues related to concrete quality in underground structures, it is essential to ensure that the mix design is appropriate for the application and that high-quality materials are used. Additionally, the concrete should be properly placed, finished, and cured to ensure that it achieves the desired strength and durability. Regular inspection and maintenance can also help detect any signs of deterioration early, allowing for timely repairs to prevent more significant problems down the road

## 2.14 Green Earth Considerations

Today’s engineers and construction stake-holders are tasked with the daunting task of building a greener future and greener cities. In the design and planning of an underground parking structure, considerations for the general wellbeing of the surroundings in the operation life of the facility. The major considerations taken into account are: Dust, vehicular emissions, noise, and waste.

### 2.14.1 Dust

It is expected that a lot of dust could be tracked in by the movement of vehicles and pedestrians into the underground parking. The buildup of dust in the underground parking could impede breathing and/or affect the moving components of the vehicles during storage. It is necessary to have proper ventilation in the building in the form of regularly cleaned ventilation ducts and airways.

### 2.14.2 Vehicular Emissions

Vehicles produce emissions in form of exhaust fumes during operation. These fumes contain, to a large extent, nitrogen (N2), water vapor (H2O) (except with pure-carbon fuels), and carbon dioxide (CO2) which are harmful to human beings. A high amount of fumes lowers the concentration of breathable oxygen in the structure rendering it unsafe.

### 2.14.3 Noise

Vehicle engines in operation produce a lot of noise and this could be further amplified by the closed nature of the underground parking. The building should have proper acoustic specifications to absorb the sound or noise produced by the vehicles. This may be in the form of insulation and reverb cancelling installations by a sound engineer.

### 2.14.4 Waste

Due to the little space and lack of natural light, waste management in subterranean parking garages can present some special difficulties. To keep the parking garage clean and safe and to lessen the negative effects on the environment, proper trash management is crucial. A recycling program ought to be implemented in the facility to sort out, plastics, cardboard, glass and paper at the source. The trash bins should be placed strategically and conveniently for effective waste collection.

Proper Environmental considerations will improve the overall use experience of the building and help to move the world a step closer to being Green

## 2.15 Building Information Modelling (BIM)

### 2.15.1 Introduction

Building Information Modeling (BIM) programs is a type of software that is used to create digital representations of buildings, infrastructure, and other built assets. Computer-aided design and modeling tools are powerful tools for optimizing the performance of underground infrastructures. These tools enable engineers to simulate and analyze different construction scenarios, evaluate the impact of design decisions, and optimize the use of resources (Singh et al., 2012, p. 344).

### 2.15.2 Tekla TEDDS Student Version

The Design Analysis of the building were done using Tekla software and output into docx (MS-Word) executable files. Tekla Tedds is a software application for automating repetitive structural and civil engineering calculations. The software integrates with other software tools such as Autodesk Revit, AutoCAD and Tekla Structures, and it can export to a variety of file formats, including Excel, IFC, Word, and PDF. The software can also be utilized for creating, checking and sharing calculations with other people.

### 2.15.3 Autodesk Revit Student Version

The underground parking 2D and 3D visual layout designs were created using Autodesk Revit software and exported to Tekla for design analysis. Autodesk Revit is a Building Information Modeling (BIM) software application for architects, structural engineers, MEP engineers, designers and contractors. It is used for the creation of 3D architectural designs, as well as for the documentation and management of building projects. The software allows users to design and document building systems in 3D, perform analyses, create construction documentation and create visualization of the building. It is widely used for creating detailed, accurate, and accurate building models, for creating accurate construction documents, for collaboration and coordination between different disciplines, and for simulating the building performance before it is built.

### 2.15.3 Microsoft Excel

Microsoft excel is a spreadsheet software normally used for calculation in a broad range of fields. In this project, the engineer uses it for earthquake analysis and subframe analysis. It is a versatile software and can be used to create macros and checks in analysis to automate simple tasks in design.

# Chapter 3 Analysis and Design

## 3.1 Introduction

The review of the structural analysis and design of the parking structure is done using both the Eurocode EN standards and the British Standards as well. The structural elements considered in the design of the Reinforced Concrete RC structure will be:

* Slabs
* Beams
* Columns
* Foundation

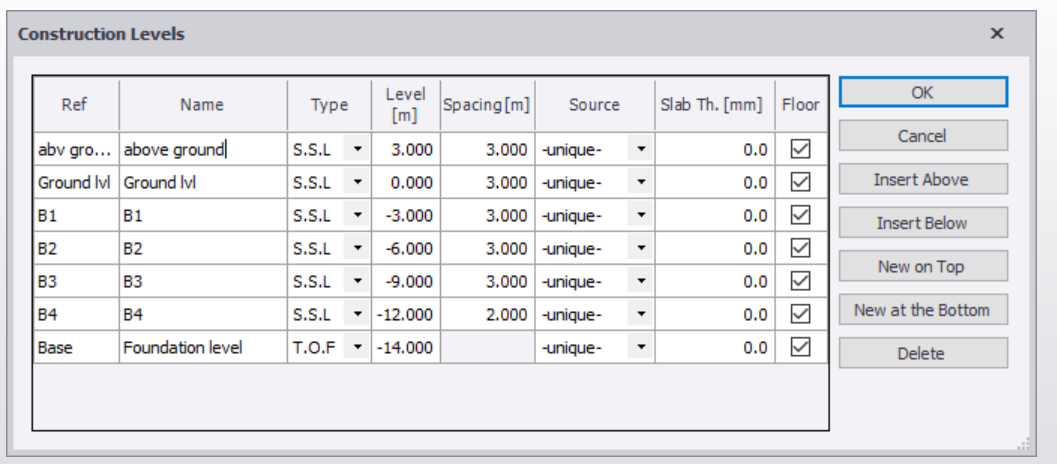
## 3.2 Design Information Sheet

A Design information sheet is prepared to show the general conditions taken into account during the design of the structure. It also gives useful information as to the relevant parties involved in the design and managerial work going in to the work.

|  |  |
| --- | --- |
| **Analysis of HFB underground parking silo** | |
| Architect | John Doe |
| Engineer in Charge | Mr. Kelly Mweu Changilwa |
| Building registration Authority | National Construction Authority |
| Date of Submission | 1/6/2019 |
| Intended use of structure | Multi-storey parking silo |
| Relevant building regulations | BS  BS  EN  EN |
| Fire Resistance Requirements | 60 minutes |
| General Loading Conditions |  |
| Earthquake Loading Conditions |  |
| Wind Loading conditions | N/A it is an underground structure |
| Subsoil Conditions | Alluvium, clays, swamp soils  Safe Bearing Pressure: 150kPa |
| Foundation type | RC footings to walls and columns  Foundation cover to reinforcement=50mm |
| Material data | Concrete Grade 40 with 20mm maximum aggregate size  Characteristic strength of steel used fy=460N/mm2 |
| Other relevant information | Concrete self weight-24.0 kN/m3  Dimensions in drawings are in millimetres. |

## 3.3 Construction levels definition

The design of the building takes up the levels defined below. The building has only 1 level above the natural ground surface. Therefore the level (m) dimensions from B1 (Basement 1) to the foundation are denoted as negative numbers to imply depth below ground. Structural Slab levels are used for all the levels except the foundation, which is defined using the Top of Footing.



## 3.4 Design Sheets

BS stands for british standards while EN stands for Eurocodes

## 3.5 Structural Drawings

# Chapter 4 Discussion

## 4.1 General

Structural analysis plays a crucial role in the design and construction of underground car parks, ensuring the safety and stability of the structure. In this project, we have conducted a review and analysis of an underground car park to assess its structural performance under different loading conditions. Our analysis includes a detailed examination of the structural elements, such as the columns, beams, and slabs, as well as the foundation and support systems. Through our analysis, we aim to identify any potential structural issues and propose solutions to improve the overall performance and safety of the car park. In this discussion, we will present and discuss our findings, including any limitations or challenges encountered during the analysis.

## 4.2 Elements of design

### 4.2.1 Foundations

The building foundations utilize square pad footings for the columns at a depth of 2000mm

Any construction project must take into account a foundation's integrity since it assures the stability and safety of the structure that is built upon it. To examine a foundation's integrity, a number of checks can be made, including the following:

1. Visual inspection: Examining the surface of the foundation for any visible cracks, damage, or other abnormalities.

2. Structural load testing: This involves applying simulated loads to the foundation to see how it holds up and to identify any weaknesses or deficiencies.

3. Soil testing: This involves analyzing the soil upon which the foundation is built to ensure it has the necessary strength and stability to support the structure.

4. Rebar inspection: If the foundation includes reinforced concrete, it is important to check the integrity of the rebar (reinforcing bars) to ensure they are properly placed and not corroded.

5. Settlement measurement: This involves measuring the amount of settlement (sinking) that has occurred in the foundation over time to ensure it is within acceptable limits.

A number of things need to be taken into account, such as the hardpacking procedure, the use of a damp proof membrane (DPM), the addition of reinforcing concrete (BRC), and the appropriate mixing of concrete. In order to reduce settlement and boost stability, the earth beneath the foundation is compacted through a process known as hardpacking. Using a DPM helps stop moisture from getting inside the structure and potentially harming the foundation. Steel mesh known as BRC is used to strengthen concrete and increase its strength and stability. Concrete must be properly mixed in order for it to have the necessary consistency and strength to support the construction. All of these elements can contribute to ensuring that the foundation is stable and capable of supporting the building.

### 4.2.3 Slabs

When reviewing a 2-way slab, the following factors are considered:

* Material

The type of material used for the slab should be chosen based on its strength, durability, and cost. Common materials for slabs include reinforced concrete and steel.

* Thickness

The thickness of the slab should be chosen based on its ability to support the expected loads and span the desired distance. The slab should be thick enough to provide sufficient strength, but not so thick as to be unnecessarily heavy or costly.

* Loads

The types and magnitudes of the loads that the slab will be subjected to should be considered, including both the dead load (the weight of the structure itself) and the live load (the weight of the vehicles and people using the structure). It is important to ensure that the slab is able to support the expected loads without failing or becoming damaged.

* Span/Length

The span of the slab, or the distance between supports, should be chosen based on the ability of the slab to span the distance without excessive deflections or cracking. The span should be appropriate for the material and thickness of the slab.

* Support conditions

The support conditions of the slab, including the type and spacing of the supports, should be reviewed to ensure that they are adequate to transfer the loads to the underlying structure.

* Deflections

The deflections of the slab, or how much it bends under load, should be considered to ensure that they do not exceed acceptable limits and cause damage to the structure or the occupants. The slab should be designed to have sufficient stiffness to prevent excessive deflections.

* Damage

Any damage to the slab, such as cracks or corrosion, should be identified and repaired in order to ensure the structural integrity of the structure.

* Maintenance

The maintenance needs of the slab, including any necessary repairs or replacements, should be considered in order to ensure the long-term stability and safety of the structure. It is important to regularly inspect the slab for signs of wear or damage, and to address any issues as they arise.

In the project, the structural engineer recommends the use of 16mm diameter bars in the reinforcement of slabs in both the x and y directions and top and bottom areas of the slab to make a ‘bed’ type structure. These are spaced at 250mm both in the top and the bottom ie, Each Way Each Face (EWEF). These would apply for all floors of the structure including the topmost slab cover at the level above ground. In the actual construction, a damp proof membrane DPM is necessary to be used in the slab constructions.

Several factors were considered in this decision and these are:

* 16mm is the highest value of reinforcement obtained while performing both the Eurocode and British Standards analysis of the slab panels
* It is easily available in the country Kenya as 16 is a normal design diameter for steel fabricators
* Provides for over reinforcement of the structure because some of the slab panels require just 12 mm in diameter.
* A bed type of reinforcement for slabs provides extra strength and take in dynamic moments owing to vehicular loads very well

### 4.2.4 Beams

Beam design requires that the structural engineer take the following into account while

* Material

The material used for the beams should be chosen based on its strength and durability. Common materials for car park beams include reinforced concrete and steel.

* Cross-sectional shape

The cross-sectional shape of the beams should be chosen based on its ability to distribute the loads placed on it. Rectangular and circular shapes are commonly used for car park beams.

* Size

The size of the beams, including their width and depth, should be chosen based on their ability to support the loads placed on them. The beams should be designed to withstand the weight of the vehicles and people using the car park, as well as any other loads that may be imposed on them, such as the weight of snow or ice.

* Loads

The types and magnitude of the loads that the beams will be subjected to should be considered, including both the dead load (the weight of the structure itself) and the live load (the weight of the vehicles and people using the structure). It is important to ensure that the beams are able to support the expected loads without failing or becoming damaged.

* Spacing

The spacing of the beams should be chosen based on their ability to distribute the loads placed on them. The beams should be spaced close enough together to provide sufficient support, but not so close as to be unnecessary or inefficient.

* Connections

The connections between the beams and other structural elements, such as columns and walls, should be reviewed to ensure that they are adequate to transfer the loads between the components. Any weaknesses or deficiencies in the connections should be addressed.

* Deflections

The deflections of the beams, or how much they bend under load, should be considered to ensure that they do not exceed acceptable limits and cause damage to the structure or the occupants. The beams should be designed to have sufficient stiffness to prevent excessive deflections.

* Damage

Any damage to the beams, such as cracks or corrosion, should be identified and repaired in order to ensure the structural integrity of the structure.

* Maintenance

The maintenance needs of the beams, including any necessary repairs or replacements, should be considered in order to ensure the long-term stability and safety of the structure. It is important to regularly inspect the beams for signs of wear or damage, and to address any issues as they arise.

The beam selected for the construction of the structure is a Reinforced Concrete RC type, rectangular in shape. A rectangular beam provides easy workability in construction and easy placement of reinforcement.

The beam dimensions selected is 500mm by 300mm. The beam requires only bottom reinforcement As but nominal reinforcement As,min was provided at the top of the beam to hold the link in place as well. Bottom reinforcement provided was 3, 16mm diameter bars while top reinforcement is 2, 12mm diameter bars. In addition to this, 2, 12 mm diameter bars may be placed at the mid section of the beam to ensure that sagging does not occur due to the length of the beam although these are not structural requirements but rather, a contingency in case of movement as the building is situated underground.

### 4.2.5 Columns

Columns in a building may be designed as either being circular or rectangular, depending on the architectural specifications. In this project, the designer preferred a rectangular column 550mm by 350mm and a height of 3 meters each. Columns give the building vertical structure and provide support for beams which in turn provide support for slabs.

The column chosen was unbraced and reinforced concrete column.

Considerations regarding columns in the structural design of an underground building:

Load bearing capacity

Weight of members and supports

Nature of the pad footing in the design

Location of the building as underground.

### 4.2.6 Walls

The underground car park utilized normal style walls, albeit a bit thicker than usual since the area of construction is fairly level and there are pre-existing constructions in the area. Retaining walls could have been considered if there was a slope to be taken care of in the area.

Structural walls are those that provide support to the overall structure and are essential for maintaining the stability of the parking structure. These walls are usually made of reinforced concrete and are designed to withstand the weight of the soil and the vehicles above. Structural walls are also important in preventing the collapse of the parking structure in case of an earthquake or other natural disasters.

Non-structural walls, on the other hand, are not designed to provide support to the structure but are important for separating different areas within the parking structure. These walls can be made of materials such as drywall, glass, or metal and are used to create separate parking bays, storage areas, and other partitions within the parking structure. Unlike structural walls, non-structural walls can be removed or modified without affecting the overall stability of the structure.

### 4.2.7 Lift Core

A lift core is a mechanical device that provides vertical transportation within a building. One of its key components is a shear wall, which is a structural element that helps to support the weight of the building and provides resistance to lateral loads such as wind or earthquakes. The shear wall in a lift core typically runs the height of the building and acts as a backbone, providing a stable core for the lift and other building systems. This core is essential for the safe and efficient movement of people and goods throughout the building.

The shear wall is made up of reinforced concrete or steel and is designed to resist horizontal loads. When a lateral force is applied to the building, the shear wall absorbs the force and distributes it evenly across the building, reducing the impact of the force on any one area. This helps to prevent the building from collapsing or toppling over. In a lift core, the shear wall also serves to anchor the lift rails, which guide the car up and down the building. The rails are attached to the shear wall, providing additional stability and support for the lift.

The design of the shear wall in a lift core is critical to the safety and efficiency of the lift. The wall must be strong enough to withstand the lateral loads and vibrations caused by the movement of the lift. It must also be designed to prevent damage from any potential impact or collision with the lift car.

### 4.2.8 Staircase

When designing a staircase, it's important to consider the length of the treads and risers. Treads are the horizontal steps, and risers are the vertical elements that support the treads. The length of the treads and risers affects the comfort and safety of those using the staircase. The length of the treads should be sufficient to provide adequate foot space, allowing for comfortable use. The risers should be uniform in height to prevent tripping hazards. Building codes often specify the maximum and minimum tread depth and riser height to ensure the safety of occupants.

When designing a staircase, it's also important to consider the surrounding space and the overall aesthetic of the building. The design of the staircase can greatly impact the building's visual appeal and should be designed to complement the building's architecture and interior design. The length of treads and risers is an important consideration in the design of a safe and comfortable staircase. As a structural engineer, it's essential to ensure that the design meets building codes and regulations while also providing the necessary comfort and safety for the building's occupants. The staircase design follows both Eurocodes and British Standards in design.

### 4.2.9 Ramp

Designing a vehicle ramp in a building requires careful consideration to ensure that it is safe, stable, and able to withstand the loads imposed on it over time. The ramp must be designed to accommodate the size and weight of the vehicles that will be using it, and it must be able to handle any additional loads, such as people and equipment. The design of the ramp's structural components must account for the loads that will be imposed on them, including the weight of the vehicles, the weight of people and equipment, and any lateral loads, such as wind or seismic forces. The ramp must also meet building codes and regulations to ensure the safety of occupants.

In addition to the structural design, the ramp must also be designed with proper drainage to prevent water from pooling and creating a hazard. It must also provide adequate lighting and signage for the safety of drivers and pedestrians. Overall, the design of a vehicle ramp in a building requires careful consideration of all its components to ensure that it is safe, stable, and meets all building codes and regulations. As a structural engineer, it's essential to ensure that the design provides the necessary support and safety for the building's occupants and their vehicles.

## 4.3 Structural Design

### 4.3.1 Subframe analysis spreadsheets

Subframe analysis is a type of structural analysis that is commonly used in civil engineering design to analyze the behavior of complex structures such as underground parking structures. An underground parking structure is typically constructed with multiple levels and is designed to support the weight of vehicles and pedestrians. Subframe analysis is used to analyze the structure of each level and to ensure that it can safely support the intended loads.

In subframe analysis, the structure is divided into smaller subframes, each of which is analyzed individually. The analysis considers the properties of the materials used in the structure, the geometry of the subframe, and the loads that are applied to it. The loads that are applied to each subframe can include the weight of the vehicles and pedestrians, as well as any other external loads that the structure may experience, such as wind or earthquakes.

Once the analysis is complete, the engineer can determine whether the subframe is strong enough to support the intended loads or whether additional reinforcement is needed. This analysis can also help the engineer to identify any weak points in the structure and to develop strategies to address them. For example, if a particular subframe is found to be weaker than the others, the engineer may recommend additional reinforcement or changes to the design to ensure that it can safely support the intended loads.

#### 4.3.1.1 TCC 21 Subframe Analysis

#### 4.3.1.2 TCC 41 Continous Beams

#### 4.3.1.3 TCC 53 Column Design

#### 4.3.1.4 TCC 81 Foundation Pads

#### 4.3.1.5 TCC 94 Two-Way Slabs

## 4.4 Python Programming.

Programming software calculators for this project was done using python programming language. This program has its strengths in scientific data analysis and its application in the engineering field is well received and respected. It is also a relatively simple language to learn hence the researcher found it suitable for use.

In programming the following were used:

* Python version 3.11 64-bit installed in the laptop computer.
* Jupyter Notebooks to allow for modular cell based calculations of analysis equations
* Plotly packages to aid in the visualization of Free Body Diagrams, Shear Force Diagrams and Bending Moment Diagrams
* Math package to allow the fast calculation and execution of equations
* Numpy package to allow storage of array data (vectors) for example forces having 3-Dimensional data eg. Magnitude, Location and Direction.
* Vscode IDE to work with python within Jupyter Notebooks.

The notebooks created are able to perform checks and analysis of the following:

* Beams (statically determinate beams)

Due to the scope of this project, these programs are to be used for educational research only.

### 4.4.1 Python Program Summary

The program created is supposed to perform the following calculations basing on :

Beam Design for statically determinate beams. It is capable of taking in inputs, calculating the relevant analysis based on design codes, giving output in form of shear force diagrams and bending moment diagrams. The language of choice is python as it has a very deep background in mathematical and scientific works.

The notebook of choice is jupyter which allows for easy manipulation of the code in form of cells and to run the code small modules at a time.

# Chapter 5

## 5.1 Conclusion

The objectives of the project were all achieved. A design review analysis of Holy Family Basilica underground parking facility was done and the members and elements of the parking structure modelled using specialized BIM software. Finally, a Python Program that outputs the calculations of the analysis was built.

## 5.2 Challenges faced in the project

The research was successful but the engineer encountered several hiccups during the project which were as follows:

1. The actual Holy Family Basilica designs were out of reach, hence the researcher had to improvise on BIM software.
2. Harmonizing between different analysis software was a bit of a technical challenge owing to the nature of the computer used in this research.

## 5.3 Recommendations

After carefully reviewing the project, the researcher made the following recommendations:

1. Towns and city planners should encourage and champion the construction of underground parking structures owing to the numerous advantages they offer the owners and users.
2. The underground vehicle parking should implement reinforced retaining walls in its structure to ensure that differential earth settlement does not compromise its integrity
3. Structural engineers should implement different BIM software in the design and analysis of complex underground structures such as this.
4. Proper onsite and offsite tests should be done on the materials to ensure suitable quality of approvals and disapprovals of the ongoing works in the site.
5. Developers need to do proper price benchmarking to make sure the projects do not go over budgets and ensure the profit margins are easily achievable.

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# APPENDIX

## Location of the Holy Family Basilica parking lot

<https://goo.gl/maps/fhj8QRDev9zGw1DV7>



Google maps street view of Holy Family Basilica