UNIVERSITY OF NAIROBI

MULTI STOREY CAR PARK DESIGN PROJECT

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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

April 2014
Dedications

To my family and to the cause of students
Abstract

University staff and students should quickly and easily find parking in order to prevent time wasting and to assist them in adhering to the lecturer time tables. There is a great need to relieve the stress on the currently available parking spaces or the current situation will inevitably worsen as the University Increases it’s capacity.

The objectives of this project were to carry out the structural design of a reinforced concrete multi-storey car park to Eurocode 2(EN 1992-1-1:2004), and to produce detailed drawings and specifications of the facility. The structure was designed for Ultimate Limit State and checked for Serviceability Limit State.

The multi-storey car park will attempt to ease pressure on the available parking space as the university streamlines itself towards vision 2030 by increasing its enrolment. The multi-storey car was designed to accommodate 300 vehicles compared to the 105 capacity of open ground at the proposed site next to the Hyslop building.
Acknowledgements

It is my pleasure to thank Engineer S.K. Mutua for accepting to supervise me for my project. It was my pleasure to work under his guidance.

Eng Mutua is very clear sighted and gave much needed direction in my undertaking. I remain ever grateful to him.
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## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access way</td>
<td>Carriageway not adjoining bays and used solely for the movement of vehicles.</td>
</tr>
<tr>
<td>Aisle</td>
<td>An access way serving adjoining bays.</td>
</tr>
<tr>
<td>Bay</td>
<td>The parking area, exclusive of aisle or other adjoining area, allocated to one car.</td>
</tr>
<tr>
<td>Bin</td>
<td>Two rows of bays with the access aisle running between them. A half-bin is one row of bays and the aisle serving them.</td>
</tr>
<tr>
<td>Deck</td>
<td>A slab at any level of the car park.</td>
</tr>
<tr>
<td>Parking angle</td>
<td>The angle between the longitudinal centreline of a bay and the aisle from which it is served.</td>
</tr>
<tr>
<td>Ramp</td>
<td>An accessway or aisle connecting parking areas at different levels. More usually, the term is applied to accessways only.</td>
</tr>
</tbody>
</table>
List of Symbols

A Cross sectional area
As Cross sectional area of reinforcement
As,min minimum cross sectional area of reinforcement
Ac Cross sectional area of concrete

EQU Static equilibrium
Fk Characteristic value of an action
Gk Characteristic permanent action
I Second moment of area of concrete section
L Length
M Bending moment
MEd Design value of the applied internal bending moment
N Axial force
NEd Design value of the applied axial force (tension or compression)
Qk Characteristic variable action
R Resistance
SLS Serviceability limit state
ULS Ultimate limit state
V Shear force
VEd Design value of the applied shear force

fc Compressive strength of concrete
fcd Design value of concrete compressive strength
fck Characteristic compressive cylinder strength of concrete at 28 days
fctk Characteristic axial tensile strength of concrete
fctm Mean value of axial tensile strength of concrete
ft Tensile strength of reinforcement
ftk Characteristic tensile strength of reinforcement
fy Yield strength of reinforcement
fyd Design yield strength of reinforcement
fyk Characteristic yield strength of reinforcement
1. INTRODUCTION

1.1 GENERAL

With the growing population in Kenya coupled with the high rural to urban migration, facilities, particularly parking space within the Nairobi CBD are inadequate. Using land as open ground parking doesn't fully utilize the land. Multi-storey car parks are common in highly populated cities and town centres. These car parks may be underground or above ground. Siting these car parks above ground economizes the cost of the structure and takes advantage of natural ventilation. The challenge with above ground multi-storey car parks in a scenic environment is how to blend the car park with the environment.

The University of Nairobi has been offering free parking to its lecturers and registered students. With the shortage of parking space within the CBD, a large number of people that have no immediate business in the university, park their cars in the university and head into town to undertake their business. This has caused a serious shortage in parking space within the University.

The provision of parking is a significant element of transport policy since its presence or absence has a major influence on the choice of transport mode. It can be argued that all parking is related to development; indeed, local authorities use parking policy to influence the demand for travel by private car within their areas. Such policies cover both parking provided by local government or the private sector and parking provided specifically in association with new development or redevelopment proposals.

The Nairobi County Government is implementing a plan to decongest Nairobi by promoting the use of public transport. This is being accomplished by exercising private car restraint by the significant increase in parking fees. The University of Nairobi will assist the plans of the Nairobi County Government by charging a subsidised fee for the parking facilities rather than offering them free of charge.
Plate 1: Proposed facility on existing open ground parking

Plate 2: A multi-storey car park in Nairobi Central Business District
1.2 PROBLEM STATEMENT

University staff and students should quickly and easily find parking in order to prevent time wasting and to assist them in adhering to the lecturer time tables.

The UON open ground parking located next to the Hyslop building can accommodate 105 vehicles. Parking space is in very high demand because of its closeness to the Central Business District. A large percentage of the parking space available is used by people who have no immediate business in the university, despite them having the university parking sticker.

The education and training goals of the government in the Vision 2030 social strategy include encouraging public and private universities to expand their enrolment and building 560 new secondary schools. A great increase in the number of university students and staff is imminent. Expansion of the university is already ongoing with the construction of the University Towers. There is a great need to relieve the stress on the currently available facilities particularly parking or the current situation will inevitably worsen.

The proposed multi-storey car park has a capacity of 300 vehicles.
1.3 OBJECTIVES

The objectives of this project were:

2. To provide detailed drawings.

1.4 PROJECT SIGNIFICANCE

The significance of the project was:

1. The multi-storey car park will attempt to ease pressure on the available parking space as the university streamlines itself towards vision 2030 by increasing its enrolment. The multi-storey car was designed to accommodate 300 vehicles compared to the 105 capacity of open ground at the proposed site next to the Hyslop building.
2. Once the construction costs are recovered, the university may explore possible ways to generate revenue from the multi-storey car park by considering charging the public for the facility.

1.5 METHODOLOGY

The methodology followed was:

1. The analysis and design was undertaken using computer software Autodesk Robot Structural Analysis 2014. The structure was modelled and analyzed in 3D. The software automatically generates the self weights. A manual definition of the loading was done to confirm the software results.
2. The detailing will be implemented using AutoCAD.
### 1.6 DESIGN INFORMATION SHEET

<table>
<thead>
<tr>
<th>Engineer: Harris Anyangu</th>
<th>Client: University of Nairobi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Codes</strong></td>
<td>Eurocode 1990:2002 Basis of Structural Design</td>
</tr>
<tr>
<td></td>
<td>Eurocode 1992:2004 Design of Concrete Structures</td>
</tr>
<tr>
<td></td>
<td>Eurocode 1997:2007 Geotechnical Design</td>
</tr>
<tr>
<td><strong>Intended Use</strong></td>
<td>Car Park</td>
</tr>
<tr>
<td></td>
<td>Minimum Cover 20mm</td>
</tr>
<tr>
<td><strong>Subsoil Conditions</strong></td>
<td>Gravel</td>
</tr>
<tr>
<td></td>
<td>Allowable Bearing Pressure=300KN/m²</td>
</tr>
<tr>
<td><strong>Accidental Loading</strong></td>
<td>150KN on columns</td>
</tr>
<tr>
<td><strong>Exposure Conditions</strong></td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Foundation Types</strong></td>
<td>RC footings to columns and walls</td>
</tr>
<tr>
<td><strong>Material data</strong></td>
<td>Grade 20 fₜₚ=20N/mm²; Max Aggregate size 20mm</td>
</tr>
<tr>
<td></td>
<td>fₚₚ=500N/mm² for longitudinal and transverse reinforcement</td>
</tr>
<tr>
<td><strong>Self Weight of Concrete</strong></td>
<td>25KN/m³</td>
</tr>
</tbody>
</table>
### 1.7 STRUCTURAL SUMMARY SHEET

<table>
<thead>
<tr>
<th>Component</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Beams</td>
<td>300x750mm</td>
</tr>
<tr>
<td>Staircase Beams</td>
<td>200x500mm</td>
</tr>
<tr>
<td>Slab</td>
<td>Waffle Slab</td>
</tr>
<tr>
<td></td>
<td>Topping: 150mm</td>
</tr>
<tr>
<td></td>
<td>Ribs: 150mm at 1000mm centres</td>
</tr>
<tr>
<td></td>
<td>Depth: 500mm</td>
</tr>
<tr>
<td>Columns</td>
<td>500x500mm</td>
</tr>
<tr>
<td></td>
<td>Internal columns at foundation level 600x600mm</td>
</tr>
<tr>
<td>RC Pad Foundations</td>
<td>Internal Foundations 5000x5000mmx1000mm</td>
</tr>
<tr>
<td></td>
<td>External Foundations 3200x3200x650mm</td>
</tr>
<tr>
<td>Cover</td>
<td>Slab: 20mm</td>
</tr>
<tr>
<td></td>
<td>Superstructure: 30mm</td>
</tr>
<tr>
<td></td>
<td>Substructure: 50mm</td>
</tr>
<tr>
<td>Retaining Wall</td>
<td>Wall 300mm thick; 4530mm Depth</td>
</tr>
<tr>
<td></td>
<td>Wall Foundation 400mm thick; 4400 mm Wide</td>
</tr>
<tr>
<td>Ramp</td>
<td>Depth 200mm</td>
</tr>
</tbody>
</table>
1.8 GENERAL ARRANGEMENT DRAWINGS

Figure 1-1: Plan
Figure 1-2: Section Along X-X
2. Literature Review

2.1 Design Geometry and Layout

2.1.1 Introduction

In the design of a car park, the designer should consider the full range of operational elements to achieve a comprehensive design solution that results in a safe, easy-to-use, high-quality car park.\[1\]

This design process is influenced by the parking purpose, how often users visit, payment and control systems, and relationship to the external highway network. Hence, for short-stay parking such as for shoppers – where higher dynamic and turnover capacities are required – wider bays are recommended. However, for office environments and long-stay parking where users are familiar with the parking procedures and turnover is a lot lower, narrower bays could be considered. Similarly, in a small car park, a low dynamic capacity may be acceptable, since at worst few drivers will be inconvenienced and then only for a short period. In a large car park, such a restraint is likely to be unacceptable because of the larger number of drivers affected and the greater delay that would be caused.\[1\]

For small private car parks, it is sometimes suggested that narrower bays may be used and headroom restricted, lack of circulation capacity being overcome by controlling the circulation and the parking of cars. However, for public car parks, this would give rise to a poor car-parking environment, which could impact on security fears and lead to low usage or crime. It is to be noted that the size of the car is a variable and the current market provides a full range of vehicles including sports, saloons, estates, four-wheel drive (4 × 4s) and multi-person vehicles (MPVs). The car market is not restrictive and so the flexibility of car dimensions has to be considered within the design with particular attention to widths and headroom requirements. The latter are most applicable to 4 × 4s and MPVs, which when fitted with roof bars or boxes can lead to a marked increase in clearance requirements. Any requirements for access for emergency vehicles will fundamentally affect all aspects of car-park design and therefore associated issues require early consideration, especially with respect to access routes.\[1\]
### Table 2.1: Comparison of typical vehicle dimensions

<table>
<thead>
<tr>
<th>Vehicle group</th>
<th>Proportion of vehicle group</th>
<th>Length (m)</th>
<th>Width (m) (Note 1)</th>
<th>Height (m) (Note 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small car</td>
<td>95%</td>
<td>3.95</td>
<td>1.75</td>
<td>1.75</td>
</tr>
<tr>
<td>Standard car</td>
<td>95%</td>
<td>4.75</td>
<td>2.06</td>
<td>1.85</td>
</tr>
<tr>
<td>Large car</td>
<td>100%</td>
<td>5.40</td>
<td>2.24</td>
<td>2.05</td>
</tr>
<tr>
<td>MPVs</td>
<td>100%</td>
<td>5.10</td>
<td>2.20</td>
<td>1.90</td>
</tr>
<tr>
<td>4 x 4</td>
<td>100%</td>
<td>5.05</td>
<td>2.25</td>
<td>2.05</td>
</tr>
</tbody>
</table>

Notes: 1. Width including wing mirrors. 2. Height excluding roof boxes, racks and roof bars

It is recommended that provisions be made for entrance and exit controls from the inception of planning of a car park. In many instances, for both public and private car parks, entrance and exit controls are required to restrict use to those authorised, to exclude cars when the car park is full, to prevent cars entering by an exit, and to ensure that payment for use is made. The design should also allow for flexibility in the type of controls to be installed since in time it may be necessary to install controls where none is required initially, or to alter those installed as a consequence of changing circumstances. If initial provision is not made for entrance and exit controls, it may later be difficult or impossible to make adequate provision within the site area. [1]

The car park has to provide good pedestrian links to external facilities. The links through the car park will require careful application of the design details with consideration given to footways, crossings, and standing areas adjacent to lifts and doorways. Good visibility with suitable clearances will enable people to move safely through the car park. [1]

Many factors influence whether a user will find the car park easy to use and be comfortable in the car park. The most important elements are outlined below:

- size of car park and ease of circulation
- layout in terms of column spacing, ability to find available spaces easily, aisle and ramp widths, headroom and ramp gradients
- safety and security
- level of visibility
This section examines the key elements that control design standards under three headings:

- the car
- geometric requirements
- layout. [1]

The recommendations apply to all classes of multi-storey and underground car park available for public and private use. Recommended dimensions in this section are net and allowances should be added for finishes and fittings and the sizes of columns where these protrude into the parking bays. For bays demarcated by lines on floors, dimensions are to the centres of lines. [1]

2.1.2 The Car

The design standards within this document are presented to accommodate the swept paths of the design cars. However, where the designer requires the geometry to be confirmed, computer-generated swept paths should be employed. Current programs include AUTOTRACK and AUTOTURN.

Turning circles can range from 10.2m for a typical small car to 12.62m for a Rolls-Royce; for larger limousines it could be up to 15.0m. These are minimum kerb-to-kerb turning circles and do not include body overhangs and driver ability. Hence, practical turning circle diameters for large cars could range from 13.4m to 15.0m. A simple template of a large car is shown in Fig. 2.1. [1]
The examination of new cars available in the UK shows that the height of 95% of standard cars fall below 1.85m, exclusive of roof racks/box. However, for MPVs and 4 × 4s, the 95 percentile increases to 2.05m. Adding a roof box increases the 95 percentile vehicle height to some 2.35m and 2.55m respectively. [1]

2.1.3 Geometric Requirements

Parking arrangements should be designed to allow drivers to manoeuvre easily and safely and, where appropriate, to segregate vehicles from pedestrian areas and routes. The manoeuvring ease is a function of aisle and bay widths, which also influence the dynamic capacity of the car park. This is of particular importance for short-stay car parks such as at retail centres where aisle capacities are critical to the operation car park. For longer-stay car parks, this is not so critical; therefore the bay dimensions could be reduced where customers are more familiar with the parking arrangements such as at office or station car parks. [1]
Bay width and length

Recommended practice is to design for normal use by the standard car and for occasional use by the large car. However, consideration needs to be given to the requirements of specialist car parks, and to increased vehicle dimensions. Typical bay dimensions for standard cars are shown in Table 2.1.3.\textsuperscript{[1]}

<table>
<thead>
<tr>
<th>Type of parking</th>
<th>Length (m) (Note 2)</th>
<th>Width (m)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed use</td>
<td>4.80</td>
<td>2.40</td>
<td>Mixed occupancy</td>
</tr>
<tr>
<td>Short stay</td>
<td>4.80</td>
<td>2.50</td>
<td>Typically less than 2 hours</td>
</tr>
<tr>
<td>Long stay</td>
<td>4.80</td>
<td>2.30</td>
<td>One movement per day e.g. business car park</td>
</tr>
<tr>
<td>Disabled user</td>
<td>4.80</td>
<td>3.60</td>
<td></td>
</tr>
</tbody>
</table>

Notes: 1. The dimensions are to be clear of any projections.
2. The preferred dimension is 4.80m for all bay lengths. However, with restricted space and appropriate signage, this can sometimes be reduced for small vehicles.

Table 2.2: Car bay dimensions

Column location

Clear-span construction is preferred, as it provides a safer environment for both drivers and pedestrians, but other design considerations often dictate the use of internal columns. The sizing of these columns and the spacing has to be carefully considered to maintain parking efficiency, bay access and sight lines. Columns at the front of the bays can reduce accessibility. Therefore, to improve parking manoeuvres, the recommended distances of columns from the aisle are shown in Fig. 2.3.\textsuperscript{[1]}

It is recommended that no fewer than three standard bays are provided between inter-bin columns adjacent to aisles and that bay widths be clear of finished column faces. However, a projection of 150mm to 200mm is acceptable if columns are within the recommended setback zone from the aisle (see Fig. 2.3).\textsuperscript{[1]}
Where larger columns are provided, as in mixed-use developments, special attention is required to maintain satisfactory clearances and operations. In such cases, the coordination of building and car park grids will need to be an iterative process. It is also to be noted that columns within the mid-third of the building...
of the bay will obstruct doors and should be considered carefully, especially where shear walls are being proposed. Additional side clearances will be required with shear walls.\textsuperscript{[1]}

**Headroom**

The recommended minimum clear height or headroom, measured normal to surfaces, for vehicles is 2.10m. This minimum is applied to entrances, exits, bays, aisles and ramps and so careful attention needs to be given to the various requirements applicable to each area. Additional clearances will be needed at changes in gradient such as at ramps and where traffic-calming measures are used.\textsuperscript{[1]}

To determine structural height, it is recommended that outline designs be prepared for signage, lighting, ventilation, barrier controls, sprinkler system and any other possible projections below structure such as conduits and drainage pipes. The downward projections of these various services should be estimated and added to the headroom to determine the clear structural height required. It is recommended that the headroom be checked at the bottom of ramps since cars will span from ramp to floor.\textsuperscript{[1]}

Traffic-calming measures such as speed humps and tables, must be carefully located. These measures are typically 75mm to 100mm high and so will restrict headroom locally. Where rising-step traffic control is proposed, pits 300mm to 600mm deep may be required. This local increase in depth must be taken into account when considering the available headroom on the floors below. Headroom allowances relating to structural depth and the depths for services and ‘sleeping policemen’ are shown in Fig. 2.4.\textsuperscript{[1]}
For safety, the headroom indicator board at the entrance to the car park is normally set some 50mm to 100mm below the actual headroom within the car park. Hence, the operational headroom could be set below the minimum clear floor height in the clients’ brief. This needs to be taken into account, discussed and clarified with the eventual operator. [1]

2.1.4 Car Park Layout

The car park design has to carefully consider the customer and provide a system that is easy and safe to use. Short-stay operations, such as facilities associated with retail centres, will have a greater turnover for a given level of static capacity and so will attract more two-way traffic throughout the day. Long-stay facilities associated with large office or business complexes and railway stations will produce high single-direction traffic flows in the mornings and evenings. Car parks expected to carry considerable traffic flows throughout the day or under tidal conditions should preferably have one-way-only systems, which give increased dynamic capacities. [1]

One- and two-way aisles

Drivers want to be able to find their way around the car park easily so that they can concentrate on looking for a vacant space. Cross movements should be avoided and aisle widths should be suitably sized. One-way circulatory systems and aisles, which normally have a higher dynamic capacity than two-way systems, can do much to reduce confusion and congestion. Drivers sometimes disregard one-way operations, leading to flow disruption and perhaps a safety hazard. This can be managed by good signing and lane markings. However, if two-way movements are considered likely, two-way
aisles should be introduced. This will require wider aisles and better visibility along with the correct markings and signing. Although this problem is more applicable to surface-level facilities, it should be borne in mind.\[1\]

**Parking angle**

Placing bays at an angle of less than 90° is a convenience for drivers since it facilitates entry and exit. This in turn improves the ‘dynamic and turnover capacity’ of the aisle. However, a disadvantage is that greater floor area per car is required. This reduction in 'static efficiency' – namely the ratio of area provided in bays to the total floor area – can significantly increase the cost per space. For standard bay dimensions and one-way aisle operations, reductions in the order of 3% can be expected for angles from 90° to 70°. For 45° parking, this reduction can be about 20%.[1]

Table 2.3: Recommended Aisle Widths

<table>
<thead>
<tr>
<th>Parking angle</th>
<th>Preferred aisle width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90° Two-way aisle</td>
<td>6.95</td>
</tr>
<tr>
<td>90° One-way aisle</td>
<td>6.00</td>
</tr>
<tr>
<td>60°</td>
<td>4.20</td>
</tr>
<tr>
<td>45°</td>
<td>3.60</td>
</tr>
</tbody>
</table>
2.2 Structural Performance and Characteristics of Car Park Structures

2.2.1 Unique Features

MSCP’s have a number of unique features that distinguish them from other buildings or structures. A lack of understanding and recognition of these distinct characteristics by designers and those responsible for inspection and maintenance is believed to be the major cause of many of the common problems identified in these structures. Some of the unique characteristics that make up car park structures are described below.

Car park structures have maximum spans and minimum supports in order to maximise vehicle parking space. The design module for clear span construction is 16m. This is a long span and the dead-load:live-load ratio is higher than for most other forms of normal concrete building structure. This fundamental design requirement leads inevitably to a far greater risk of cracking and long-term deflections than in other building structures.

A car park structure is subject to a substantial live load cycle from full to empty and also to substantial dynamic loadings associated with vehicles moving around the structure. The constant loading and unloading of the structure combined with the normal cyclical movement of the structure due to daily and seasonal thermal and moisture changes develops cracking and articulates joints which can open up pathways for salt and water ingress to accelerate deterioration.

Nearly all MSCP’s are open-sided structures with the concrete exposed to cycles of wetting and drying and differential temperatures within and between structural elements. This contrasts with the stable drying conditions in most buildings. The differential strains and movements need to be considered when selecting structural form in design and when appraising the effects of structural movements on strength and deterioration processes in car park structures. [2]

2.2.2 Conditions Causing Processes of Structural Deterioration

Structural deterioration and premature failures of car park structures occur as a result of a combination of adverse conditions taking place concurrently, rather than a single process acting alone. The following section represents recurring adverse conditions that have led to premature structural deterioration of existing car park structures over the last 50 years.
Chlorides

The case studies reviewed have shown that problem areas for reinforced concrete have developed most rapidly and severely where there is ponding of water, lack of concrete cover, poorly designed and leaking joints, honeycombing and/or other construction-related defects. The case studies have also highlighted the fact that problems associated with chloride attack on concrete are much less severe where movement and construction joints are correctly provided and good compaction of appropriately well designed concrete mixes is achieved.

Analysis of the case studies found that over 50% of structures (the vast majority of these constructed before 1975) had reinforced concrete contaminated with cast-in chlorides. These originate mainly from admixtures containing chlorides (i.e. calcium chloride accelerators) and in a few cases from chloride contaminated aggregates. Cast-in chlorides are a historic problem and in 1977 the maximum amount of chloride permitted by British Standards was substantially reduced.

However, vehicles continue to carry and deposit chloride-bearing de-icing salt into car park structures. Analysis of the areas in which chlorides build-up to initiate corrosion of the top reinforcement of typical un-surfaced car park deck slab after approximately 25 years shows that chlorides are concentrated along the traffic tracks and wheel positions in the most frequently used parking bays (see Fig 2-5). These areas of build-up also occur on ramps and within the first one or two levels of a car park structure. The lack of rain wash and the potential for evaporative concentration of ponded chloride-contaminated water in these areas increases the severity of exposure and build-up of chlorides.

![Figure 2-7: Areas of Chloride Concentration beneath tyres and tracks](image)

Defects associated with chlorides can range from aesthetic concerns (e.g. staining and deposits on soffits, walls, columns, etc.) to structural damage (e.g. localised corrosion and loss of bond strength...
of reinforcement and spalling concrete). Where chlorides have built up generally in a concrete slab, corrosion tends to develop in patches leading to spalling and delamination. Where the concrete is saturated and chloride ingress is localised, pitting corrosion (black rust) can develop leading to localised and rapid corrosion of reinforcement. [3]

Plate 3: Typical example of chloride-induced corrosion of reinforced concrete with subsequent dripping of salt water and calcium carbonate onto vehicles below

Carbonation
Concrete in car park structures is, like all concrete, subject to progressive loss of alkalinity in from the surface due to carbonation from atmospheric carbon dioxide (CO₂). Atmospheric CO₂ reacts with the cement hydrates to form calcium carbonate, which in turn results in a reduction of the alkalinity of the pore solution. The reduction in pH results in the depassivation of embedded steel and with an ample supply of oxygen and moisture, corrosion can take place rapidly. There are widespread instances of carbonation-induced corrosion developing prematurely in car park structures due to low cover to reinforcement, low quality concrete and/or construction defects. The environment in car park structures cycles between dry conditions, which speed carbonation, and wet conditions, which accelerate corrosion. Cars produce CO₂ from exhausts, but good ventilation generally limits the increase in carbonation rates. However, higher than average levels of carbonation have been observed in city centre car park structures, particularly where air circulation is poor, the ventilation is inadequate and vehicles stand for long periods with their engines running. [4]

Alkali-silica reaction
The damp conditions in car park structures concrete can encourage the development of alkali silica reaction when high alkali cement has been used with reactive aggregates. Current design
recommendation provide a basis for minimising the risk by limiting alkalis for this environment while IStructE guidance provides a method for assessing and managing structures with ASR. Waterproofing and improved drainage to minimise availability of moisture and promote drying can slow the reaction and rate of damage. [4]

Plate 4: Typical example of ASR damage of a reinforced concrete beam

Salt crystallisation
Concrete saturated with salt solutions – e.g. chlorides, sulfates, urea – can suffer from crystallisation pressure damage during periods of drying, particularly where salts are concentrated in an area where evaporation takes place. As water evaporates from within the concrete pore solutions they become increasingly concentrated until saturation is reached. Crystals will then begin to grow within the pore space of the concrete; the resultant stresses ultimately disrupt the matrix of the concrete causing cracking and in the worst cases spalling. Methods to reduce the risk of crystallisation include designing concrete to be dense and impermeable to salt ingress and removing the risk of chloride contaminated water reaching and ponding on the concrete by providing adequate drainage. [2]

Tyre abrasion
Tyre abrasion/erosion of slab decks is not uncommon in car park structures. The surfaces of concrete decks are subject to continuous movement of vehicles, braking and accelerating. This can cause dusting and wearing of the laitance on inadequate concrete surfaces.

Surface finishes
There are a range of textures applied to concrete intermediate decks, ranging from heavily tamped, inconsistent finishes to perfectly smooth, power floated finishes. In heavily textured decks there is a
greater risk of holding water and debris which not only reduces the aesthetic appearance of the car park and makes cleaning difficult it can also allow chloride-contaminated water to pond on the concrete surface and permeate through the deck. Heavy tamping may also reduce the cover to reinforcement if carried out badly. 

Smooth, power floated finishes on the other hand make cleaning easy and improve the visual appearance of the car park. However, they do promote “tyre squeal”, which is disconcerting for the car park user and surrounding properties. In the presence of water or oil such surfaces become slippery and hazardous for pedestrians and vehicles. A lightly brushed surface finish, carefully prepared to provide a consistent surface, has been found to provide a relatively easy cleaning regime and adequate skid resistance for intermediate decks.

In modern car parks skid resistant epoxy or polyurethane coatings have been used in intermediate decks. Some coatings available are not full elastomeric membranes and they often do not have the same crack bridging capabilities as the spray-applied or thin, poured epoxy membranes. Intermediate decks can therefore not be expected to be fully waterproof, unless specified to be so. It is however, important to ensure coatings are applied correctly. For example, membranes and coatings should be applied to dry surfaces to avoid blistering and/or delamination of the material in service. If properly specified and placed such materials can offer protection against ingress of chlorides and enhance the environment inside the car park.


**Car washing**

Car washing is sometimes carried out as an additional service in car park structures. It creates a more severe environment as it significantly increases the amount of salt (from the underside of vehicles) penetrating the parking decks. The associated wetting and drying accelerates chloride ingress and corrosion, once initiated. Special waterproofing and drainage provisions are needed in these areas. [2]

**Gypsum**

A few case studies showed that problems can arise through the misuse of gypsum-based substances used on car park decks for mopping up/removal of oil stains. Although not recommended by the manufacturers for use on concrete, it has been used and has resulted in sulfate attack. The cement paste is destroyed exposing the aggregate, which leads to high abrasion. It also breaks down the bond of some waterproof membranes. It is therefore prudent to test concrete decks for sulfates as part of any testing regime. [2]
3. Structural Analysis and Design

The Structure was loaded and analyzed in 3D. The structure automatically included the self weight.

Figure 3-8: 3D Model Showing Bending Moments
3.1 Slab Analysis and Design

Waffle Slab Arrangement

Plan

![Slab Arrangement Plan](image)

Figure 3-9: Slab Arrangement Plan

Section

![Slab Arrangement Section](image)

Figure 3-10: Slab Arrangement Section
Waffle Slab Loading

Flange Area = $7.7^2 = 59.29\text{m}^2$

Waffle = $7.7^2 - (0.85^2 \times 49) - (0.7^2 \times 16) = 16.05\text{m}^2$

Distributing the concrete weight over an area (7.7mx7.7m),

\[
Self\ Weight = \frac{(16.05 \times 0.35 \times 25) + (59.29 \times 0.15 \times 25)}{7.7 \times 7.7} = 6.12\text{KN/m}^2
\]

Finishes = $2.5\text{KN/m}^2$

\[f_{ck} = 25\text{N/mm}^2\]
\[f_{y_k} = 500\text{N/mm}^2\]

*Characteristic Permanent Load* = $8.62\text{KN/m}^2$

*Characteristic Variable Load* = $2.5\text{KN/m}^2$

Design Ultimate Load = $(1.35g_k + 1.5q_k)$
= $(1.35 \times 8.62 + 1.5 \times 2.5)$
= $15.39\text{KN/m}^2$
Figure 3-11: Panels
Figure 3.12: Slab Moments
Slab Shear Stress (Ultimate Limit State)

Figure 3-13: Slab Shear Stresses
Figure 3-14: Slab Displacements
**Multi-Storey Car Park Design**

<table>
<thead>
<tr>
<th>CLAUSE</th>
<th>SLAB DESIGN</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESIGN Panel 4</td>
<td>Midspan</td>
<td>Provide 2 H10 bars at the bottom of each rib (As=157mm²)</td>
</tr>
<tr>
<td><strong>Positive Moment at Midspan</strong></td>
<td>21.3KNm/m</td>
<td>Provide 3 H12 bars at the top of each rib (As=339mm²)</td>
</tr>
<tr>
<td>( M = \frac{21.3 \times 10^6}{1000 \times 440^2 \times 25} = 0.0044 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>From the lever arm curve, ( l_a = 0.95 ) and the neutral axis lies within the flange. and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( A_s = \frac{M}{0.87f_{yk}z} = \frac{21.3 \times 10^6}{0.87 \times 500 \times 0.95 \times 460} = 112 \text{ mm}^2 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Provide 2 H10 bars at the bottom of each rib. ( A_s = 157 \text{ mm}^2 ) (OK)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum ( A_s = 0.13bd% = 89.7 \text{ mm}^2 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Interior Support</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At interior support design as rectangular section for solid slab.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Negative Moment</strong></td>
<td>52.38KNm/m</td>
<td></td>
</tr>
<tr>
<td>( M = \frac{52.38 \times 10^6}{1000 \times 440^2 \times 25} = 0.0108 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>From the lever arm curve, ( l_a = 0.95 ) and the neutral axis lies within the flange. and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( A_s = \frac{M}{0.87f_{yk}z} = \frac{52.38 \times 10^6}{0.87 \times 500 \times 0.95 \times 460} = 275 \text{ mm}^2 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Provide 3 H12 bars at the top of each rib. ( A_s = 339 \text{ mm}^2 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Span-Effective Depth Ratio</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \rho = \frac{100A_{s,req}}{bd} = \frac{100 \times 157}{1000 \times 460} = 0.034 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hence, Concrete is lightly stressed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Span-Effective Depth Ratio for an end span 2 way spanning slab = ( 1.3 \times 30 = 39 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual Span-Effective Depth ratio = ( \frac{8000}{460} = 17.4 ) (OK)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.4N
3.2 Beam Analysis and Design

3.2.1 Beam 5(on Grid 5)

Geometry:

300 x 750 (mm)

Input:

- Cover: bottom c = 30 (mm)
  : side c1 = 30 (mm)
  : top c2 = 30 (mm)
- Coefficient $\beta_2 = 0.50$
- Method of shear calculations: strut inclination
- Redistribution of support moments by 20.0%

Calculation results:

The quantity of longitudinal reinforcement has been augmented due to perpendicular cracks

- **Internal forces in ULS**

<table>
<thead>
<tr>
<th>Span</th>
<th>$Mt_{max.}$</th>
<th>$Mt_{min.}$</th>
<th>$Ml$</th>
<th>$Mr$</th>
<th>$Ql$</th>
<th>$Qr$</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>190.93</td>
<td>-0.00</td>
<td>-267.28</td>
<td>-179.80</td>
<td>231.24</td>
<td>-226.43</td>
</tr>
<tr>
<td>P2</td>
<td>226.37</td>
<td>-0.00</td>
<td>-218.55</td>
<td>-202.18</td>
<td>245.05</td>
<td>-236.30</td>
</tr>
<tr>
<td>P3</td>
<td>226.26</td>
<td>-0.00</td>
<td>-224.43</td>
<td>-190.85</td>
<td>245.01</td>
<td>-232.73</td>
</tr>
<tr>
<td>P4</td>
<td>217.06</td>
<td>-0.00</td>
<td>-191.11</td>
<td>-174.76</td>
<td>240.92</td>
<td>-201.42</td>
</tr>
</tbody>
</table>

- **Internal forces in SLS**

<table>
<thead>
<tr>
<th>Span</th>
<th>$Mt_{max.}$</th>
<th>$Mt_{min.}$</th>
<th>$Ml$</th>
<th>$Mr$</th>
<th>$Ql$</th>
<th>$Qr$</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>116.38</td>
<td>0.00</td>
<td>-193.53</td>
<td>-170.77</td>
<td>167.22</td>
<td>-163.73</td>
</tr>
<tr>
<td>P2</td>
<td>118.89</td>
<td>0.00</td>
<td>-200.46</td>
<td>-192.95</td>
<td>177.41</td>
<td>-170.99</td>
</tr>
<tr>
<td>P3</td>
<td>117.47</td>
<td>0.00</td>
<td>-209.29</td>
<td>-182.78</td>
<td>177.36</td>
<td>-168.40</td>
</tr>
<tr>
<td>P4</td>
<td>134.26</td>
<td>0.00</td>
<td>-181.65</td>
<td>-126.16</td>
<td>174.37</td>
<td>-145.62</td>
</tr>
</tbody>
</table>

- **Required reinforcement area**

<table>
<thead>
<tr>
<th>Span</th>
<th>Span (mm²)</th>
<th>Left support (mm²)</th>
<th>Right support (mm²)</th>
</tr>
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<tbody>
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<td>top</td>
<td>bottom</td>
</tr>
<tr>
<td>P1</td>
<td>679</td>
<td>0</td>
<td>980</td>
</tr>
<tr>
<td>P2</td>
<td>816</td>
<td>0</td>
<td>827</td>
</tr>
<tr>
<td>P3</td>
<td>816</td>
<td>0</td>
<td>866</td>
</tr>
<tr>
<td>P4</td>
<td>780</td>
<td>0</td>
<td>745</td>
</tr>
</tbody>
</table>
Reinforcement:

**P1 : Span from 0.50 to 8.00 (m)**

**Longitudinal reinforcement:**
- **bottom** *(A500HW)*
  - 3 \( \varphi 20 \) \( l = 6.87 \) from 0.11 to 6.98
- **assembling (top)** *(A500HW)*
  - 3 \( \varphi 8 \) \( l = 4.30 \) from 2.10 to 6.40
- **support** *(A500HW)*
  - 3 \( \varphi 16 \) \( l = 2.94 \) from 0.11 to 6.98
  - 2 \( \varphi 16 \) \( l = 4.30 \) from 2.10 to 6.40
  - 2 \( \varphi 25 \) \( l = 5.84 \) from 5.33 to 11.17
  - 2 \( \varphi 8 \) \( l = 1.79 \) from 0.09 to 1.88
  - 3 \( \varphi 25 \) \( l = 5.84 \) from 5.33 to 11.17
  - 2 \( \varphi 16 \) \( l = 5.84 \) from 5.33 to 11.17
  - 2 \( \varphi 8 \) \( l = 1.79 \) from 0.09 to 1.88

**Transversal reinforcement:**
- **main** *(A500HW)*
  - stirrups
    - 52 \( \varphi 6 \) \( l = 0.76 \)
      - \( e = 1 \times 0.02 + 21 \times 0.08 + 3 \times 0.22 + 13 \times 0.28 + 14 \times 0.10 \) (m)
    - 52 \( \varphi 6 \) \( l = 1.83 \)
      - \( e = 1 \times 0.02 + 21 \times 0.08 + 3 \times 0.22 + 13 \times 0.28 + 14 \times 0.10 \) (m)
  - pins
    - 52 \( \varphi 6 \) \( l = 0.76 \)
      - \( e = 1 \times 0.02 + 21 \times 0.08 + 3 \times 0.22 + 13 \times 0.28 + 14 \times 0.10 \) (m)
    - 52 \( \varphi 6 \) \( l = 1.83 \)
      - \( e = 1 \times 0.02 + 21 \times 0.08 + 3 \times 0.22 + 13 \times 0.28 + 14 \times 0.10 \) (m)

**P2 : Span from 8.50 to 16.00 (m)**

**Longitudinal reinforcement:**
- **bottom** *(A500HW)*
  - 3 \( \varphi 20 \) \( l = 10.72 \) from 6.02 to 16.73
- **assembling (top)** *(A500HW)*
  - 3 \( \varphi 8 \) \( l = 4.30 \) from 10.10 to 14.40
- **support** *(A500HW)*
  - 3 \( \varphi 20 \) \( l = 5.63 \) from 13.44 to 19.06

**Transversal reinforcement:**
- **main** *(A500HW)*
  - stirrups
    - 57 \( \varphi 6 \) \( l = 0.76 \)
      - \( e = 1 \times 0.03 + 20 \times 0.08 + 3 \times 0.24 + 10 \times 0.28 + 3 \times 0.26 + 20 \times 0.08 \) (m)
    - 57 \( \varphi 6 \) \( l = 1.83 \)
      - \( e = 1 \times 0.03 + 20 \times 0.08 + 3 \times 0.24 + 10 \times 0.28 + 3 \times 0.26 + 20 \times 0.08 \) (m)
  - pins
    - 57 \( \varphi 6 \) \( l = 0.76 \)
      - \( e = 1 \times 0.03 + 20 \times 0.08 + 3 \times 0.24 + 10 \times 0.28 + 3 \times 0.26 + 20 \times 0.08 \) (m)
    - 57 \( \varphi 6 \) \( l = 1.83 \)
      - \( e = 1 \times 0.03 + 20 \times 0.08 + 3 \times 0.24 + 10 \times 0.28 + 3 \times 0.26 + 20 \times 0.08 \) (m)

**P3 : Span from 16.50 to 24.00 (m)**

**Longitudinal reinforcement:**
- **bottom** *(A500HW)*
  - 3 \( \varphi 20 \) \( l = 10.72 \) from 15.77 to 26.48
- **assembling (top)** *(A500HW)*
  - 3 \( \varphi 8 \) \( l = 4.30 \) from 18.10 to 22.40
- **support** *(A500HW)*
  - 2 \( \varphi 20 \) \( l = 3.05 \) from 14.87 to 17.92
  - 3 \( \varphi 25 \) \( l = 5.84 \) from 21.33 to 27.17

**Transversal reinforcement:**
- **main** *(A500HW)*
  - stirrups
    - 56 \( \varphi 6 \) \( l = 0.76 \)
      - \( e = 1 \times 0.01 + 19 \times 0.08 + 3 \times 0.24 + 10 \times 0.28 + 3 \times 0.26 + 20 \times 0.08 \) (m)
    - 56 \( \varphi 6 \) \( l = 1.83 \)
      - \( e = 1 \times 0.01 + 19 \times 0.08 + 3 \times 0.24 + 10 \times 0.28 + 3 \times 0.26 + 20 \times 0.08 \) (m)
  - pins
    - 56 \( \varphi 6 \) \( l = 0.76 \)
      - \( e = 1 \times 0.01 + 19 \times 0.08 + 3 \times 0.24 + 10 \times 0.28 + 3 \times 0.26 + 20 \times 0.08 \) (m)
    - 56 \( \varphi 6 \) \( l = 1.83 \)
      - \( e = 1 \times 0.01 + 19 \times 0.08 + 3 \times 0.24 + 10 \times 0.28 + 3 \times 0.26 + 20 \times 0.08 \) (m)
P4 : Span from 24.50 to 32.00 (m)

Longitudinal reinforcement:
- **bottom** (A500HW)
  - 3 ø20 \( l = 6.94 \) from 25.52 to 32.46
- **assembling (top)** (A500HW)
  - 3 ø8 \( l = 4.30 \) from 26.10 to 30.40
- **support** (A500HW)
  - 3 ø12 \( l = 2.86 \) from 29.60 to 32.46
  - 3 ø12 \( l = 1.91 \) from 30.50 to 32.41
  - 3 ø12 \( l = 3.41 \) from 32.45 to 32.45

Transversal reinforcement:
- **main** (A500HW)
  - stirrups
    - 50 ø6 \( l = 0.76 \)
      - \( e = 1*0.06 + 19*0.08 + 3*0.26 + 13*0.28 + 14*0.10 \) (m)
    - 50 ø6 \( l = 1.83 \)
      - \( e = 1*0.06 + 19*0.08 + 3*0.26 + 13*0.28 + 14*0.10 \) (m)
  - pins
    - 50 ø6 \( l = 0.76 \)
      - \( e = 1*0.06 + 19*0.08 + 3*0.26 + 13*0.28 + 14*0.10 \) (m)
    - 50 ø6 \( l = 1.83 \)
      - \( e = 1*0.06 + 19*0.08 + 3*0.26 + 13*0.28 + 14*0.10 \) (m)

![Figure 3-15: Beam 5 Analysis](image-url)
### Fire resistance

Calculations according to BS EN 1992-1-2:2004
Estimation in accordance with section 5. Tabulated data.
Number of sides exposed to fire: 3
Web type: WA
Beam type: freely supported

- **b_min** = 0.12(m)
- **a_min** = 0.03(m)

### Deflection and cracking

- **wt(QP)**: Total due to quasi-permanent combination
- **wt(QP)dop**: Allowable due to quasi-permanent combination
- **Dwt(QP)**: Deflection increment from the quasi-permanent load combination after erecting a structure.
- **Dwt(QP)dop**: Admissible deflection increment from the quasi-permanent load combination after erecting a structure.
- **wk**: Width of perpendicular cracks

<table>
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<tr>
<th>Span</th>
<th>wt(QP) (mm)</th>
<th>wt(QP)dop (mm)</th>
<th>Dwt(QP) (mm)</th>
<th>Dwt(QP)dop (mm)</th>
<th>wk (mm)</th>
</tr>
</thead>
<tbody>
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<td>9</td>
<td>32</td>
<td>3</td>
<td>0</td>
<td>0.3</td>
</tr>
<tr>
<td>P2</td>
<td>9</td>
<td>32</td>
<td>3</td>
<td>0</td>
<td>0.3</td>
</tr>
<tr>
<td>P3</td>
<td>9</td>
<td>32</td>
<td>3</td>
<td>0</td>
<td>0.3</td>
</tr>
<tr>
<td>P4</td>
<td>12</td>
<td>32</td>
<td>4</td>
<td>0</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Material survey:

- Concrete volume = 7.31 (m³)
- Formwork = 58.20 (m²)

- Steel A500HW
  - Total weight = 652.45 (kG)
  - Density = 89.22 (kG/m³)
  - Average diameter = 9.6 (mm)
  - Survey according to diameters:

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Length (m)</th>
<th>Weight (kG)</th>
<th>Number (No.)</th>
<th>Total weight (kG)</th>
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<tbody>
<tr>
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<td>0.76</td>
<td>0.17</td>
<td>215</td>
<td>36.40</td>
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<td>6</td>
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<td>0.41</td>
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<td>8</td>
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<td>12</td>
<td>1.91</td>
<td>1.69</td>
<td>3</td>
<td>5.08</td>
</tr>
<tr>
<td>12</td>
<td>2.86</td>
<td>2.54</td>
<td>3</td>
<td>7.62</td>
</tr>
<tr>
<td>12</td>
<td>3.41</td>
<td>3.03</td>
<td>3</td>
<td>9.08</td>
</tr>
<tr>
<td>16</td>
<td>1.79</td>
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<td>2</td>
<td>5.66</td>
</tr>
<tr>
<td>16</td>
<td>2.94</td>
<td>4.64</td>
<td>3</td>
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<td>134.96</td>
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</table>
### 3.2.2 Beam C (on Grid C)

**Geometry:**

300 x 750 (mm)

**Input:**

- **Cover**
  - bottom: $c = 30$ (mm)
  - side: $c_1 = 30$ (mm)
  - top: $c_2 = 30$ (mm)
- Coefficient $\beta_2 = 0.50$
- Method of shear calculations: long-term or cyclic load
- Redistribution of support moments by 20.0%

**Calculation results:**

The quantity of longitudinal reinforcement has been augmented due to perpendicular cracks

<table>
<thead>
<tr>
<th>Span</th>
<th>Mₜ max.</th>
<th>Mₜ min.</th>
<th>Mᵢ</th>
<th>Mᵣ</th>
<th>Qᵢ</th>
<th>Qᵣ</th>
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<th>Mₜ min.</th>
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<th>Mᵣ</th>
<th>Qᵢ</th>
<th>Qᵣ</th>
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<td>(kN*m)</td>
<td>(kN)</td>
<td>(kN)</td>
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</table>

**Required reinforcement area**

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<th>Span (mm²)</th>
<th>Left support (mm²)</th>
<th>Right support (mm²)</th>
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<td>top</td>
<td>bottom</td>
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<td>0</td>
</tr>
<tr>
<td>P2</td>
<td>76</td>
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<td>0</td>
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<td>0</td>
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<tr>
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<td>408</td>
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<td>0</td>
</tr>
<tr>
<td>P5</td>
<td>94</td>
<td>0</td>
<td>135</td>
</tr>
<tr>
<td>P6</td>
<td>118</td>
<td>0</td>
<td>43</td>
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<tr>
<td></td>
<td>208</td>
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<td></td>
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</table>
Reinforcement:

P1: Span from 0.50 to 4.00 (m)

Longitudinal reinforcement:
- bottom (A500HW)
  3 \( \phi 16 \) \( l = 3.42 \) from 0.27 to 3.69
- assembling (top) (A500HW)
  2 \( \phi 8 \) \( l = 2.70 \) from 1.30 to 4.00
- support (A500HW)
  3 \( \phi 12 \) \( l = 2.22 \) from 0.04 to 2.26

Transversal reinforcement:
- main (A500HW)
  stirrups 16 \( \phi 6 \) \( l = 1.83 \)
  \[ e = 1*0.15 + 6*0.18 + 2*0.26 + 7*0.24 \] (m)
  pins 16 \( \phi 6 \) \( l = 1.83 \)
  \[ e = 1*0.15 + 6*0.18 + 2*0.26 + 7*0.24 \] (m)

P2 : Span from 4.50 to 8.00 (m)

Longitudinal reinforcement:
- bottom (A500HW)
  3 \( \phi 16 \) \( l = 7.47 \) from 2.91 to 10.39
- support (A500HW)
  3 \( \phi 12 \) \( l = 7.78 \) from 3.20 to 10.90

Transversal reinforcement:
- main (A500HW)
  stirrups 19 \( \phi 6 \) \( l = 1.83 \)
  \[ e = 1*0.11 + 8*0.14 + 2*0.26 + 8*0.20 \] (m)
  pins 19 \( \phi 6 \) \( l = 1.83 \)
  \[ e = 1*0.11 + 8*0.14 + 2*0.26 + 8*0.20 \] (m)

P3 : Span from 8.50 to 16.00 (m)

Longitudinal reinforcement:
- bottom (A500HW)
  3 \( \phi 16 \) \( l = 7.02 \) from 9.61 to 16.64
- assembling (top) (A500HW)
  2 \( \phi 8 \) \( l = 3.50 \) from 10.10 to 13.60
- support (A500HW)
  2 \( \phi 12 \) \( l = 1.90 \) from 7.54 to 9.44
  3 \( \phi 16 \) \( l = 7.06 \) from 12.72 to 19.78
  3 \( \phi 16 \) \( l = 2.83 \) from 14.80 to 17.63

Transversal reinforcement:
- main (A500HW)
  stirrups 52 \( \phi 6 \) \( l = 1.83 \)
  \[ e = 15*0.10 + 14*0.26 + 4*0.20 + 19*0.08 \] (m)
  pins 52 \( \phi 6 \) \( l = 1.83 \)
  \[ e = 15*0.10 + 14*0.26 + 4*0.20 + 19*0.08 \] (m)

P4 : Span from 16.50 to 24.00 (m)

Longitudinal reinforcement:
- bottom (A500HW)
  3 \( \phi 16 \) \( l = 7.02 \) from 15.86 to 22.89
- assembling (top) (A500HW)
  2 \( \phi 8 \) \( l = 3.50 \) from 18.90 to 22.40
- support (A500HW)
  2 \( \phi 12 \) \( l = 1.91 \) from 23.05 to 24.96

Transversal reinforcement:
- main (A500HW)
  stirrups 52 \( \phi 6 \) \( l = 1.83 \)
$e = 1\times0.06 + 5\times0.08 + 15\times0.10 + 4\times0.20 + 11\times0.26 + 12\times0.12 + 4\times0.10$ (m)

pins $52 \phi 6$ $l = 1.83$
$e = 1\times0.06 + 5\times0.08 + 15\times0.10 + 4\times0.20 + 11\times0.26 + 12\times0.12 + 4\times0.10$ (m)

**P5 : Span from 24.50 to 28.00 (m)**

**Longitudinal reinforcement:**
- bottom (A500HW)
  3 $\phi 16$ $l = 7.47$ from 22.11 to 29.59
- support (A500HW)
  3 $\phi 12$ $l = 7.70$ from 21.60 to 29.30

**Transversal reinforcement:**
- main (A500HW)
  stirrups 19 $\phi 6$ $l = 1.83$
  
  $e = 1\times0.00 + 7\times0.20 + 2\times0.26 + 9\times0.16$ (m)
- pins 19 $\phi 6$ $l = 1.83$
  
  $e = 1\times0.00 + 7\times0.20 + 2\times0.26 + 9\times0.16$ (m)

**P6 : Span from 28.50 to 32.00 (m)**

**Longitudinal reinforcement:**
- bottom (A500HW)
  3 $\phi 16$ $l = 3.42$ from 28.81 to 32.23
- assembling (top) (A500HW)
  2 $\phi 8$ $l = 2.70$ from 28.50 to 31.20
- support (A500HW)
  3 $\phi 12$ $l = 2.22$ from 30.24 to 32.46

**Transversal reinforcement:**
- main (A500HW)
  stirrups 15 $\phi 6$ $l = 1.83$
  
  $e = 8\times0.26 + 7\times0.18$ (m)
- pins 15 $\phi 6$ $l = 1.83$
  
  $e = 8\times0.26 + 7\times0.18$ (m)
Multi-Storey Car Park Design

- **Fire resistance**

  Fire resistance: \( R_{60}(\text{BS EN 1992-1-2:2004}) \)
  Calculations according to: \( \text{BS EN 1992-1-2:2004} \)
  Estimation in accordance with section 5. Tabulated data.
  Number of sides exposed to fire: 3
  Web type: WA
  Beam type: freely supported
  \( b_{\text{min}} = 0.12(\text{m}) \)
  \( a_{\text{min}} = 0.03(\text{m}) \)

- **Deflection and cracking**

  \( \text{wt}(\text{QP}) \)  Total due to quasi-permanent combination
  \( \text{wt}(\text{QP})_{\text{dop}} \)  Allowable due to quasi-permanent combination
  \( \text{Dwt}(\text{QP}) \)  Deflection increment from the quasi-permanent load combination after erecting a structure.
  \( \text{Dwt}(\text{QP})_{\text{dop}} \)  Admissible deflection increment from the quasi-permanent load combination after erecting a structure.
  \( wk \)  - width of perpendicular cracks

<table>
<thead>
<tr>
<th>Span</th>
<th>( \text{wt}(\text{QP}) ) (mm)</th>
<th>( \text{wt}(\text{QP})_{\text{dop}} ) (mm)</th>
<th>( \text{Dwt}(\text{QP}) ) (mm)</th>
<th>( \text{Dwt}(\text{QP})_{\text{dop}} ) (mm)</th>
<th>( wk ) (mm)</th>
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<td>0.0</td>
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<tr>
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<td>0</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>P3</td>
<td>9</td>
<td>32</td>
<td>2</td>
<td>0</td>
<td>0.3</td>
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<tr>
<td>P4</td>
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<td>32</td>
<td>2</td>
<td>0</td>
<td>0.3</td>
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<tr>
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<td>0</td>
<td>0</td>
<td>0.0</td>
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<tr>
<td>P6</td>
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<td>16</td>
<td>0</td>
<td>0</td>
<td>0.0</td>
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</tbody>
</table>

**Material survey:**

- Concrete volume = 7.31 (m³)
- Formwork = 57.90 (m²)
- Steel A500HW
  - Total weight = 356.49 (kG)
  - Density = 48.75 (kG/m³)
  - Average diameter = 9.3 (mm)
  - Survey according to diameters:

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Length (m)</th>
<th>Weight (kG)</th>
<th>Number (No.)</th>
<th>Total weight (kG)</th>
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<td>6</td>
<td>11.85</td>
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</table>
3.3 Column Analysis and Design

3.3.1 Column D4 (Grid Position D4)

D4 3RD Floor

Input

Rectangular 500 x 500 (mm)
Height: L = 3.15 (m)
Slab thickness = 0.25 (m)
Beam height = 0.75 (m)
Cover = 40 (mm)

Loads:

<table>
<thead>
<tr>
<th>Case</th>
<th>Nature</th>
<th>Group</th>
<th>(\gamma_f)</th>
<th>N</th>
<th>My(s)</th>
<th>My(i)</th>
<th>Mz(s)</th>
<th>Mz(i)</th>
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<td>1.00</td>
<td>1204.44</td>
<td>22.77</td>
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<td>-20.70</td>
<td>16.96</td>
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<td>SLS Design SLS</td>
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<td>1.00</td>
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<td>-15.12</td>
<td>12.39</td>
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</tbody>
</table>

\(\gamma_f\) - load factor

Calculation results:

Safety factors \(R_d/E_d = 2.25 > 1.0\)

ULS Analysis

Design combination: ULS (B)

Internal forces:

\(N_{sd} = 1204.44 \text{ (kN)}\)
\(M_{sd} = -25.63 \text{ (kN*m)}\)
\(M_{sd} = 16.96 \text{ (kN*m)}\)

Design forces:

Lower node

\(N = 1204.44 \text{ (kN)}\)
\(N*_{etot} = -35.11 \text{ (kN*m)}\)
\(N*_{etot} = 24.09 \text{ (kN*m)}\)

Eccentricity:

\(e_{y} (My/N)\)
\(e_{z} (Mz/N)\)

Static

\(e_{Ed}: -21 \text{ (mm)}\)
14 \text{ (mm)}

Imperfection

\(e_{i}: 8 \text{ (mm)}\)
0 \text{ (mm)}

Initial

\(e_{0}: -13 \text{ (mm)}\)
14 \text{ (mm)}

Minimal

\(emin: 20 \text{ (mm)}\)
20 \text{ (mm)}

Total

\(etot: -29 \text{ (mm)}\)
20 \text{ (mm)}

Detailed analysis-Direction Y:

Slenderness analysis

Non-sway structure

\[ L (m) \quad Lo (m) \quad \lambda \quad \lambda_{lim} \]
\[ 3.15 \quad 3.15 \quad 21.82 \quad 55.20 \quad \text{Short column} \]

Buckling analysis

\(M_2 = 22.77 \text{ (kN*m)}\)
\(M_1 = -25.63 \text{ (kN*m)}\)

Case: Cross-section at the column end (Lower node), Slenderness not taken into account

\(M_0 = -25.63 \text{ (kN*m)}\)

\(ea = \theta_1 \times l_0/2 = 8 \text{ (mm)}\)

\(\theta_1 = \theta_0 + \alpha_1 + \alpha_m = 0.01\)
\(\theta_0 = 0.01\)
\(\alpha_h = 1.00\)
\(\alpha_m = (0.5(1+1/m))^0.5 = 1.00\)
\(m = 1.00\)
Ma = N*ea = 9.48 (kN*m)
ME\text{dmin} = 24.09 (kN*m)
M0Ed = \text{max}(ME\text{dmin},M0 + Ma) = -35.11 (kN*m)

**Detailed analysis-Direction Z:**

M2 = 16.96 (kN*m)  \hspace{1em} M1 = -20.70 (kN*m)

Case: Cross-section at the column end (Lower node), Slenderness not taken into account
M0 = 16.96 (kN*m)
e\text{a} = 0 (mm)
Ma = N*ea = 0.00 (kN*m)
ME\text{dmin} = 24.09 (kN*m)
M0Ed = \text{max}(ME\text{dmin},M0 + Ma) = 24.09 (kN*m)

**Reinforcement Area:**

Real (provided) area  \hspace{1em} Asr = 804 (mm2)
Ratio:  \hspace{1em} \rho = 0.32 \%

**Reinforcement:**

- Main bars (A500HW):
  - 4 \#16  \hspace{1em} l = 3.11 (m)

- Transversal reinforcement: (A500HW):
  - stirrups: 16 \#6  \hspace{1em} l = 1.73 (m)
  - 16 \#6  \hspace{1em} l = 0.48 (m)
  - pins 16 \#6  \hspace{1em} l = 1.73 (m)
  - 16 \#6  \hspace{1em} l = 0.48 (m)

**D4 2ND Floor**

**Input**

Rectangular 500 x 500 (mm)
Height: L = 3.15 (m)
Slab thickness = 0.25 (m)
Beam height = 0.75 (m)
Cover = 40 (mm)

**Loads:**

<table>
<thead>
<tr>
<th>Case</th>
<th>Nature</th>
<th>Group</th>
<th>( \gamma_f )</th>
<th>N</th>
<th>My(s)</th>
<th>My(i)</th>
<th>Mz(s)</th>
<th>Mz(i)</th>
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<tr>
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<td>Design SLS</td>
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<td>1728.58</td>
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<td>-19.33</td>
<td>-13.04</td>
<td>12.88</td>
</tr>
</tbody>
</table>

\( \gamma_f \) - load factor

**Calculation results:**

Safety factors Rd/Ed = 1.17 > 1.0

**ULS Analysis**

Design combination: ULS (B)
Internal forces:
\[ N_{sd} = 2384.00 \text{ (kN)} \]
\[ M_{sd} = -26.27 \text{ (kN*m)} \]
\[ M_{sdz} = 17.64 \text{ (kN*m)} \]

Design forces:
Lower node
\[ N = 2384.00 \text{ (kN)} \]
\[ N^{etotz} = -47.68 \text{ (kN*m)} \]
\[ N^{etoty} = 47.68 \text{ (kN*m)} \]

Eccentricity:
\[ e_{z} = \frac{M_y}{N} \]
\[ e_{y} = \frac{M_z}{N} \]

Static
\[ e_{Ed} = -11 \text{ (mm)} \]
\[ e_{y} = 8 \text{ (mm)} \]

Imperfection
\[ e_{i} = -3 \text{ (mm)} \]
\[ e_{o} = 15 \text{ (mm)} \]

Minimal
\[ e_{min} = 20 \text{ (mm)} \]

Total
\[ e_{tot} = -20 \text{ (mm)} \]

Detailed analysis - Direction Y:

Slenderness analysis

Non-sway structure

<table>
<thead>
<tr>
<th>L (m)</th>
<th>Lo (m)</th>
<th>( \lambda )</th>
<th>( \lambda_{lim} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.15</td>
<td>3.15</td>
<td>21.82</td>
<td>39.60</td>
</tr>
</tbody>
</table>

Short column

Buckling analysis
\[ M_2 = 28.80 \text{ (kN*m)} \]
\[ M_1 = -26.27 \text{ (kN*m)} \]

Case: Cross-section at the column end (Lower node), Slenderness not taken into account
\[ M_0 = -26.27 \text{ (kN*m)} \]
\[ e_{a} = \theta_{o} \alpha_{1} + \alpha_{m} = 0.01 \]
\[ \theta_{o} = 0.01 \]
\[ \alpha_{h} = 1.00 \]
\[ \alpha_{m} = (0.5(1+1/m)^0.5 = 1.00 \]
\[ m = 1.00 \]
\[ M_a = N^{e}e_a = 18.77 \text{ (kN*m)} \]
\[ M_{Edmin} = 47.68 \text{ (kN*m)} \]
\[ M_{0Ed} = \max(M_{Edmin},M_0 + M_a) = -47.68 \text{ (kN*m)} \]

Detailed analysis - Direction Z:

\[ M_2 = 17.64 \text{ (kN*m)} \]
\[ M_1 = -17.86 \text{ (kN*m)} \]

Case: Cross-section at the column end (Lower node), Slenderness not taken into account
\[ M_0 = 17.64 \text{ (kN*m)} \]
\[ e_{a} = \theta_{o} \alpha_{1} + \alpha_{m} = 0.01 \]
\[ \theta_{o} = 0.01 \]
\[ \alpha_{h} = 1.00 \]
\[ \alpha_{m} = (0.5(1+1/m)^0.5 = 1.00 \]
\[ m = 1.00 \]
\[ M_a = N^{e}e_a = 18.77 \text{ (kN*m)} \]
\[ M_{Edmin} = 47.68 \text{ (kN*m)} \]
\[ M_{0Ed} = \max(M_{Edmin},M_0 + M_a) = 47.68 \text{ (kN*m)} \]

Reinforcement Area:

Real (provided) area
\[ A_{sr} = 804 \text{ (mm2)} \]

Ratio:
\[ \rho = 0.32 \% \]

Reinforcement:

Main bars (A500HW):
- 4 \( \phi 16 \]
  \[ l = 3.11 \text{ (m)} \]

Transversal reinforcement: (A500HW):
- stirrups: 16 \( \phi 6 \]
  \[ l = 1.73 \text{ (m)} \]
- 16 \( \phi 6 \]
  \[ l = 0.48 \text{ (m)} \]
pins  
16 $\phi 6$  
I = 1.73 (m)  
16 $\phi 6$  
I = 0.48 (m)

D4 1ST Floor

**Input**

Rectangular 500 x 500 (mm)

Height: \( L = 3.15 \) (m)

Slab thickness = 0.25 (m)

Beam height = 0.75 (m)

Cover = 40 (mm)

** Loads:**

<table>
<thead>
<tr>
<th>Case</th>
<th>Nature</th>
<th>Group</th>
<th>( \gamma_f )</th>
<th>N (kN)</th>
<th>My(s) (kN*m)</th>
<th>Mz(s) (kN*m)</th>
<th>Mz(i) (kN*m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULS</td>
<td>Design</td>
<td>422</td>
<td>1.00</td>
<td>3569.80</td>
<td>22.94</td>
<td>-23.78</td>
<td>17.78</td>
</tr>
<tr>
<td>SLS</td>
<td>Design SLS</td>
<td>422</td>
<td>1.00</td>
<td>2588.37</td>
<td>16.91</td>
<td>-17.52</td>
<td>12.98</td>
</tr>
</tbody>
</table>

\( \gamma_f \) - load factor

**Calculation results:**

Safety factors \( R_d/E_d = 1.03 > 1.0 \)

**ULS Analysis**

Design combination: ULS (A)

Internal forces:

\( N_{sd} = 3569.80 \) (kN)  
\( M_{sy} = 22.94 \) (kN*m)  
\( M_{sz} = -17.78 \) (kN*m)

Design forces:

Upper node

\( N = 3569.80 \) (kN)  
\( N^{etotz} = 71.40 \) (kN*m)  
\( N^{etoty} = -71.40 \) (kN*m)

Eccentricity:

\( e_z (My/N) \)

\( e_y (Mz/N) \)

Static

\( e_{Ed} \) 6 (mm)

-5 (mm)

Imperfection

\( e_i \) 8 (mm)

8 (mm)

Initial

\( e_0 \) 14 (mm)

3 (mm)

Minimal

emin: 20 (mm)

20 (mm)

Total

etot: 20 (mm)

-20 (mm)

**Detailed analysis - Direction Y:**

**Slenderness analysis**

Non-sway structure

\( L (m) \) \( L_0 (m) \) \( \lambda \) \( \lambda_{lim} \) Short column

3.15 3.15 21.82 42.18 Short column

**Buckling analysis**

\( M_2 = 22.94 \) (kN*m)  
\( M_1 = -23.78 \) (kN*m)

Case: Cross-section at the column end (Upper node), Slenderness not taken into account

\( M_0 = 22.94 \) (kN*m)

\( e_a = 0.01 \lambda_0 / 2 = 8 \) (mm)

\( \theta_1 = \theta_0 \cdot \alpha_n \cdot \alpha_m = 0.01 \)

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\[ \theta_0 = 0.01 \]
\[ \alpha_h = 1.00 \]
\[ \alpha_m = (0.5(1+1/m))^{0.5} = 1.00 \]
\[ m = 1.00 \]
\[ M_a = N\epsilon_a = 28.11 \text{ (kN*m)} \]
\[ M_{\text{Ed,min}} = 71.40 \text{ (kN*m)} \]
\[ M_{0\text{Ed}} = \max(M_{\text{Ed,min}},M_0 + M_a) = 71.40 \text{ (kN*m)} \]

**Detailed analysis-Direction Z:**

\[ M_2 = 17.37 \text{ (kN*m)} \quad M_1 = -17.78 \text{ (kN*m)} \]

Case: Cross-section at the column end (Upper node), Slenderness not taken into account

\[ M_0 = -17.78 \text{ (kN*m)} \]
\[ \epsilon_a = \theta_1\ell_0/2 = 8 \text{ (mm)} \]
\[ \theta_1 = \theta_0 + \alpha_h \cdot \alpha_m = 0.01 \]
\[ \theta_0 = 0.01 \]
\[ \alpha_h = 1.00 \]
\[ \alpha_m = (0.5(1+1/m))^{0.5} = 1.00 \]
\[ m = 1.00 \]
\[ M_a = N\epsilon_a = 28.11 \text{ (kN*m)} \]
\[ M_{\text{Ed,min}} = 71.40 \text{ (kN*m)} \]
\[ M_{0\text{Ed}} = \max(M_{\text{Ed,min}},M_0 + M_a) = -71.40 \text{ (kN*m)} \]

**Reinforcement Area:**

Real (provided) area \( Asr = 3167 \text{ (mm2)} \)
Ratio: \( \rho = 1.28 \% \)

**Reinforcement:**

**Main bars (A500HW):**
- \( 4 \phi 32 \quad l = 3.11 \text{ (m)} \)

**Transversal reinforcement: (A500HW):**
- stirrups: \( 16 \phi 6 \quad l = 1.73 \text{ (m)} \)
  \( 192 \phi 6 \quad l = 0.48 \text{ (m)} \)
- pins \( 16 \phi 6 \quad l = 1.73 \text{ (m)} \)
  \( 192 \phi 6 \quad l = 0.48 \text{ (m)} \)

**D4 Ground Floor**

**Input**

Rectangular \( 500 \times 500 \text{ (mm)} \)
Height: \( L = 3.15 \text{ (m)} \)
Slab thickness = 0.25 \text{ (m)}
Beam height = 0.75 \text{ (m)}
Cover = 40 \text{ (mm)}

**Loads:**

<table>
<thead>
<tr>
<th>Case</th>
<th>Nature</th>
<th>Group</th>
<th>( \gamma_f )</th>
<th>N</th>
<th>My(s)</th>
<th>My(i)</th>
<th>My(s)</th>
<th>Mz(s)</th>
<th>Mz(i)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(kN)</td>
<td>(kN*m)</td>
<td>(kN*m)</td>
<td>(kN*m)</td>
<td>(kN*m)</td>
<td>(kN*m)</td>
</tr>
<tr>
<td>ULS</td>
<td>design</td>
<td>202</td>
<td>1.00</td>
<td>4759.84</td>
<td>14.25</td>
<td>-14.25</td>
<td>-18.98</td>
<td>19.77</td>
<td></td>
</tr>
<tr>
<td>SLS</td>
<td>Design SLS</td>
<td>202</td>
<td>1.00</td>
<td>3451.19</td>
<td>10.55</td>
<td>-10.59</td>
<td>-13.86</td>
<td>14.43</td>
<td></td>
</tr>
</tbody>
</table>

\( \gamma_f \) - load factor

**Calculation results:**
U.S. Analysis

Design combination: ULS (C)

Internal forces:
Nsd = 4759.84 (kN)  Msdy = -5.70 (kN*m)  Msdz = 7.91 (kN*m)

Design forces:
N = 4759.84 (kN)  N*etotz = -95.20 (kN*m)  N*etoty = 95.20 (kN*m)

Eccentricity:
ez (My/N)  ey (Mz/N)

Static eEd: -1 (mm)  2 (mm)
Imperfection ei: 8 (mm)  8 (mm)
Initial e0: 7 (mm)  10 (mm)
Minimal emin: 20 (mm)  20 (mm)
Total etot: -20 (mm)  20 (mm)

Detailed analysis - Direction Y:

Slenderness analysis

Non-sway structure

\[
\begin{array}{cccc}
L \,(m) & L_0 \,(m) & \lambda & \lambda_{lim} \\
3.15 & 3.15 & 21.82 & 45.10 \\
\end{array}
\]

Short column

Buckling analysis

M2 = 14.25 (kN*m)  M1 = -14.25 (kN*m)  Mmid = -5.70 (kN*m)

Case: Cross-section in the middle of the column, Slenderness not taken into account

M0 = M0e = 0.6*M02 + 0.4*M01 = -5.70 (kN*m)

M0emin = 0.4*M02

e = \theta_1 * \alpha_1 * \alpha_m = 0.01
\theta_0 = 0.01
\alpha_h = 1.00
\alpha_m = (0.5(1+1/m))^0.5 = 0.5
m = 1.00

Ma = N * e = 37.48 (kN*m)
MEdmin = 95.20 (kN*m)
M0Ed = max(MEdmin, M0 + Ma) = -95.20 (kN*m)

Detailed analysis - Direction Z:

M2 = 19.77 (kN*m)  M1 = -18.98 (kN*m)  Mmid = 7.91 (kN*m)

Case: Cross-section in the middle of the column, Slenderness not taken into account

M0 = M0e = 0.6*M02 + 0.4*M01 = 7.91 (kN*m)

M0emin = 0.4*M02

e = \theta_1 * \alpha_1 * \alpha_m = 0.01
\theta_0 = 0.01
\alpha_h = 1.00
\alpha_m = (0.5(1+1/m))^0.5 = 0.5
m = 1.00

Ma = N * e = 37.48 (kN*m)
MEdmin = 95.20 (kN*m)
M0Ed = max(MEdmin, M0 + Ma) = 95.20 (kN*m)

Reinforcement Area:

Real (provided) area  Asr = 6433 (mm2)
Ratio:  \rho = 2.57 %
Reinforcement:

**Main bars (A500HW):**
- 8 $\phi 32$ $l = 3.11$ (m)

**Transversal reinforcement: (A500HW):**
- Stirrups:
  - 10 $\phi 6$ $l = 1.73$ (m)
  - 80 $\phi 6$ $l = 0.49$ (m)
- Pins:
  - 10 $\phi 6$ $l = 1.73$ (m)
  - 80 $\phi 6$ $l = 0.49$ (m)

D4 Basement

Input

Rectangular $600 \times 600$ (mm)
- Height: $L = 5.03$ (m)
- Slab thickness = 0.25 (m)
- Beam height = 0.75 (m)
- Cover = 40 (mm)

Loads:

<table>
<thead>
<tr>
<th>Case</th>
<th>Nature</th>
<th>Group</th>
<th>$\gamma_f$</th>
<th>N (kN)</th>
<th>$M_y$ (kN*m)</th>
<th>$M_z$ (kN*m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULS</td>
<td>design</td>
<td>1023</td>
<td>1.00</td>
<td>6199.11</td>
<td>72.36</td>
<td>161.41</td>
</tr>
<tr>
<td>SLS</td>
<td>Design SLS</td>
<td>1023</td>
<td>1.00</td>
<td>4496.16</td>
<td>48.08</td>
<td>107.23</td>
</tr>
</tbody>
</table>

$\gamma_f$ - load factor

Calculation results:

Safety factors $R_d/E_d = 1.02 > 1.0$

ULS Analysis

Design combination: ULS (B)
- Internal forces:
  - $N_{sd} = 6199.11$ (kN)
  - $M_{sdy} = 161.41$ (kN*m)
  - $M_{sdz} = 13.83$ (kN*m)
- Design forces:
  - Lower node:
    - $N = 6199.11$ (kN)
    - $N^{etotz} = 228.25$ (kN*m)
    - $N^{etoty} = 123.98$ (kN*m)

Eccentricity:
- Static $e_{Ed}$: 26 (mm)
- Imperfection $e_i$: 11 (mm)
- Initial $e_0$: 37 (mm)
- Minimal $e_{min}$: 20 (mm)
- Total $e_{tot}$: 37 (mm)

Detailed analysis-Direction Y:

Slenderness analysis

Non-sway structure

<table>
<thead>
<tr>
<th>$L$ (m)</th>
<th>$L_0$ (m)</th>
<th>$\lambda$</th>
<th>$\lambda_{lim}$</th>
</tr>
</thead>
</table>
| 4.65    | 4.65      | 26.85    | 21.04            | Slender column

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Buckling analysis

\[ M_2 = 161.41 \text{ (kN}^\text{m}) \]
\[ M_1 = 72.36 \text{ (kN}^\text{m}) \]
Case: Cross-section at the column end (Lower node), Slenderness not taken into account
\[ M_0 = 161.41 \text{ (kN}^\text{m}) \]
\[ ea = \frac{1}{l_0} \times \frac{l_0}{2} = 11 \text{ (mm)} \]
\[ \theta_1 = \theta_0 + \alpha_1 + \alpha_2 \]
\[ \theta_0 = 0.01 \]
\[ \alpha_1 = 0.93 \]
\[ \alpha_2 = (0.5(1+1/m))^0.5 = 1.00 \]
\[ m = 1.00 \]
\[ M_a = N_ea = 66.84 \text{ (kN}^\text{m}) \]
\[ M_{Edmin} = 123.98 \text{ (kN}^\text{m}) \]
\[ M_{0Ed} = \max(M_{Edmin}, M_0 + M_a) = 228.25 \text{ (kN}^\text{m}) \]

Detailed analysis-Direction Z:

\[ M_2 = 13.83 \text{ (kN}^\text{m}) \]
\[ M_1 = -8.96 \text{ (kN}^\text{m}) \]
Case: Cross-section at the column end (Lower node), Slenderness not taken into account
\[ M_0 = 13.83 \text{ (kN}^\text{m}) \]
\[ ea = 0 \text{ (mm)} \]
\[ M_a = N_ea = 0.00 \text{ (kN}^\text{m}) \]
\[ M_{Edmin} = 123.98 \text{ (kN}^\text{m}) \]
\[ M_{0Ed} = \max(M_{Edmin}, M_0 + M_a) = 123.98 \text{ (kN}^\text{m}) \]

Reinforcement Area:

Real (provided) area \[ Asr = 8042 \text{ (mm}^2) \]
Ratio: \[ \rho = 2.23 \% \]

Reinforcement:

Main bars (A500HW):
- 10 \#32 \[ l = 4.99 \text{ (m)} \]

Transversal reinforcement: (A500HW):
  \begin{itemize}
  \item stirrups: 19 \#6 \[ l = 2.13 \text{ (m)} \]
    285 \#6 \[ l = 0.59 \text{ (m)} \]
  \item pins: 19 \#6 \[ l = 2.13 \text{ (m)} \]
    285 \#6 \[ l = 0.59 \text{ (m)} \]
  \end{itemize}
3.4 Foundation Analysis and Design

Figure 3-18: Reactions
3.4.1 Internal Pad Footing

Geometry:

![Diagram of Pad 1 and Pad 2 with dimensions]

Figure 3-19: Pad 1

A = 7.60 (m)  
B = 7.60 (m)  
h1 = 1.20 (m)  
h2 = 0.00 (m)  
h4 = 0.05 (m)

a = 0.60 (m)  
b = 0.60 (m)  
e_x = 0.00 (m)  
e_y = 0.00 (m)

Figure 3-20: Pad 2

a' = 250 (mm)  
b' = 250 (mm)  
c_{nom1} = 60 (mm)  
c_{nom2} = 60 (mm)

Loads:

<table>
<thead>
<tr>
<th>Foundation loads:</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Case</td>
<td>Nature</td>
<td>Group</td>
<td>N</td>
<td>Fx</td>
<td>Fy</td>
</tr>
<tr>
<td>DL1</td>
<td>dead load</td>
<td>1</td>
<td>3634.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>LL1</td>
<td>live load</td>
<td>1</td>
<td>862.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A1</td>
<td>accidental</td>
<td>1</td>
<td>0.00</td>
<td>150.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Backfill loads:

| Combination list |
|------------------|---|
| Case | Nature | Q1 (kN/m2) |
| DL1 | 1.00DL1+1.00LL1 |
| DL1 | 1.00DL1 |
| LL1 | 1.05DL1+0.80LL1 |
| ALS | 1.05DL1+0.35LL1+1.05A1 |
| ALS | 1.05DL1+1.05A1 |
| ALS | 1.05DL1 |
| ULS | 1.35DL1+1.50LL1 |
| ULS | 1.35DL1 |
| ULS | 1.00DL1+1.50LL1 |
| ULS | 1.00DL1 |
Multi-Storey Car Park Design

11. SLS : 1.00DL1+1.00LL1
12. SLS : 1.00DL1
13. SLS : 1.00DL1+0.50LL1
14. SLS : 1.00DL1+0.30LL1
15. ALS : 1.00DL1+0.50LL1+1.00A1
16. ALS : 1.00DL1+1.00A1
17. ALS : 1.00DL1
18. ALS : 1.00DL1+0.30LL1

Considerations

Foundation design for:
• Capacity
• Rotation
• Sliding
• Sliding with soil pressure considered: none
• Uplift
• Average settlement

Soil:
Soil level: \( N_1 = 2.18 \) (m)
Column pier level: \( N_a = 0.00 \) (m)

**well graded gravels**
• Soil level: 2.18 (m)
• Unit weight: 1700.00 (kG/m3)
• Unit weight of solid: 1700.00 (kG/m3)
• Internal friction angle: 42.0 (Deg)
• Cohesion: 0.00 (MPa)

Limit states

**Stress calculations**

Soil type under foundation: not layered
Design combination: **SLS : 1.00DL1+1.00LL1**
Load factors:
\[ 1.00 \times \text{Foundation weight} \]
\[ 1.00 \times \text{Soil weight} \]
Calculation results: On the foundation level
Weight of foundation and soil over it: \( G_r = 3786.34 \) (kN)
Design load:
\[ N_r = 8282.34 \) (kN)
\[ M_x = -0.00 \) (kN*m)
\[ M_y = 0.00 \) (kN*m)

Soil profile parameters:
\[ C = 0.00 \) (MPa)
\[ \phi = 0.00 \)
\[ \gamma = 0.00 \) (kG/m3)

Stress in soil: 0.14 (MPa)
Design soil pressure: 0.14 (MPa)
Safety factor: 1.011 > 1
Uplift

<table>
<thead>
<tr>
<th>Design combination:</th>
<th>SLS : 1.00DL1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load factors:</td>
<td>1.00 * Foundation weight</td>
</tr>
<tr>
<td></td>
<td>1.00 * Soil weight</td>
</tr>
<tr>
<td>Contact area:</td>
<td>s = 12.67</td>
</tr>
<tr>
<td></td>
<td>s\text{\text{lim}} = 1.00</td>
</tr>
</tbody>
</table>

Sliding

<table>
<thead>
<tr>
<th>Design combination</th>
<th>SLS : 1.00DL1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load factors:</td>
<td>1.00 * Foundation weight</td>
</tr>
<tr>
<td></td>
<td>1.00 * Soil weight</td>
</tr>
</tbody>
</table>

Weight of foundation and soil over it: \( G_r = 3786.34 \) (kN)

Design load:
- \( N_r = 7420.34 \) (kN)
- \( M_x = -0.00 \) (kN*m)
- \( M_y = 0.00 \) (kN*m)

Equivalent foundation dimensions: \( A_\text{\text{-}} = 7.60 \) (m)
\( B_\text{\text{-}} = 7.60 \) (m)

Sliding area: \( 57.76 \) (m²)

Foundation/soil friction coefficient: \( \text{tg}(\phi) = 0.90 \)

Cohesion: \( C = 0.00 \) (MPa)

Sliding force value: \( F = 0.00 \) (kN)

Value of force preventing foundation sliding:
- On the foundation level: \( F(\text{stab}) = 6681.30 \) (kN)

Stability for sliding: \( \infty \)

Average settlement

Soil type under foundation: not layered

Design combination: \( \text{SLS : 1.00DL1+1.00LL1} \)

Load factors:
- 1.00 * Foundation weight
- 1.00 * Soil weight

Weight of foundation and soil over it: \( G_r = 3786.34 \) (kN)

Average stress caused by design load: \( q = 0.14 \) (MPa)

Thickness of the actively settling soil: \( z = 5.00 \) (m)

Stress on the level \( z \):
- Additional: \( \sigma_z d = 0.04 \) (MPa)
- Caused by soil weight: \( \sigma_z \gamma = 0.14 \) (MPa)

Settlement:
- Original: \( s' = 1 \) (mm)
- Secondary: \( s'' = 0 \) (mm)
- TOTAL: \( S = 1 \) (mm) \(< S_{\text{adm}} = 50 \) (mm)

Safety factor: \( 34.4 > 1 \)

Settlement difference

Design combination: \( \text{SLS : 1.00DL1+0.80LL1} \)

Load factors:
- 1.00 * Foundation weight
- 1.00 * Soil weight

Settlement difference: \( S = 0 \) (mm) \(< S_{\text{adm}} = 50 \) (mm)

Safety factor: \( \infty \)
Rotation

About OX axis
Design combination: SLS : 1.00DL1
Load factors: 1.00 * Foundation weight
1.00 * Soil weight
Weight of foundation and soil over it: \( \text{Gr} = 3786.34 \text{ (kN)} \)
Design load:
\begin{align*}
&\text{Nr} = 7420.34 \text{ (kN)} \\
&M_x = -0.00 \text{ (kN}\cdot\text{m}) \\
&M_y = 0.00 \text{ (kN}\cdot\text{m})
\end{align*}
Stability moment: \( M_{\text{stab}} = 28197.28 \text{ (kN}\cdot\text{m}) \)
Rotation moment: \( M_{\text{renv}} = 0.00 \text{ (kN}\cdot\text{m}) \)
Stability for rotation: \( \infty \)

About OY axis
Design combination: SLS : 1.00DL1
Load factors: 1.00 * Foundation weight
1.00 * Soil weight
Weight of foundation and soil over it: \( \text{Gr} = 3786.34 \text{ (kN)} \)
Design load:
\begin{align*}
&\text{Nr} = 7420.34 \text{ (kN)} \\
&M_x = -0.00 \text{ (kN}\cdot\text{m}) \\
&M_y = 0.00 \text{ (kN}\cdot\text{m})
\end{align*}
Stability moment: \( M_{\text{stab}} = 28197.28 \text{ (kN}\cdot\text{m}) \)
Rotation moment: \( M_{\text{renv}} = 0.00 \text{ (kN}\cdot\text{m}) \)
Stability for rotation: \( \infty \)

RC design

Assumptions
\begin{itemize}
  \item Exposure : X0
  \item Structure class : S1
\end{itemize}

Analysis of punching and shear

Punching
Design combination: ULS : 1.35DL1+1.50LL1
Load factors: 1.35 * Foundation weight
1.35 * Soil weight
Design load:
\begin{align*}
&\text{Nr} = 11310.46 \text{ (kN)} \\
&M_x = -0.00 \text{ (kN}\cdot\text{m}) \\
&M_y = 0.00 \text{ (kN}\cdot\text{m})
\end{align*}
Length of critical circumference: \( 9.50 \text{ (m)} \)
Punching force: \( 5443.59 \text{ (kN)} \)
Section effective height: \( h_{\text{eff}} = 1.13 \text{ (m)} \)
Reinforcement ratio: \( \rho = 0.13 \% \)
Shear stress: \( 0.51 \text{ (MPa)} \)
Admissible shear stress: \( 0.53 \text{ (MPa)} \)
Safety factor: \( 1.045 > 1 \)

Required reinforcement

Spread footing:
bottom:
\begin{align*}
\text{ULS : 1.35DL1+1.50LL1} \\
&M_y = 5241.29 \text{ (kN}\cdot\text{m}) \\
&A_{\text{sx}} = 1469 \text{ (mm2/m)}
\end{align*}
Multi-Storey Car Park Design

ULS : 1.35DL1+1.50LL1
Mx = 5241.29 (kN*m) \( A_{sy} = 1469 \text{ (mm2/m)} \)

\( A_{s\min} \) = 1469 (mm2/m)

top:
\( A'_{sx} = 0 \text{ (mm2/m)} \)
\( A'_{sy} = 0 \text{ (mm2/m)} \)
\( A_{s\min} \) = 0 (mm2/m)

Provided reinforcement

Spread footing:
Bottom:
Along X axis:
57 A500HW 16 \( l = 7.48 \text{ (m)} \) \( e = 1^*\cdot-3.63 + 56^*0.13 \)
Along Y axis:
57 A500HW 16 \( l = 7.48 \text{ (m)} \) \( e = 1^*\cdot-3.63 + 56^*0.13 \)

Pier
Longitudinal reinforcement
Along X axis:
2 A500HW 12 \( l = 2.43 \text{ (m)} \) \( e = 1^*\cdot-0.18 + 1^*0.36 \)
Along Y axis:
2 A500HW 12 \( l = 2.43 \text{ (m)} \) \( e = 1^*\cdot-0.18 + 1^*0.36 \)

Transversal reinforcement
7 A500HW 16 \( l = 2.06 \text{ (m)} \) \( e = 1^*0.11 + 4^*0.20 + 2^*0.09 \)

Material survey:

- Concrete volume = 69.31 (m3)
- Formwork = 36.48 (m2)

- Steel A500HW
  - Total weight = 1379.97 (kG)
  - Density = 19.91 (kG/m3)
  - Average diameter = 15.9 (mm)
  - Survey according to diameters:

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Length (m)</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>3.05</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>3.09</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>2.06</td>
<td>7</td>
</tr>
<tr>
<td>16</td>
<td>7.48</td>
<td>114</td>
</tr>
</tbody>
</table>
3.4.1 Combined Pad Footing (Grid Position 3E,3F and 4E,4F)

Geometry:

![Diagram of Pad Footing](image)

**Figure 3-21: Pad 3**

\[
\begin{align*}
A &= 7.80 \text{ (m)} \\
B &= 7.70 \text{ (m)} \\
h_1 &= 1.10 \text{ (m)} \\
h_2 &= 0.00 \text{ (m)} \\
h_4 &= 0.05 \text{ (m)} \\
a_1 &= 0.50 \text{ (m)} \\
a_2 &= 0.50 \text{ (m)} \\
b_1 &= 0.50 \text{ (m)} \\
b_2 &= 0.50 \text{ (m)} \\
e_x &= 3.00 \text{ (m)} \\
e_y &= 0.15 \text{ (m)} \\
e_z &= 0.00 \text{ (m)} \\
\end{align*}
\]

**Figure 3-22: Pad 4**

\[
\begin{align*}
\text{a}_1' &= 500 \text{ (mm)} \\
\text{a}_2' &= 500 \text{ (mm)} \\
\text{b}_1' &= 500 \text{ (mm)} \\
\text{b}_2' &= 500 \text{ (mm)} \\
c_{nom1} &= 60 \text{ (mm)} \\
c_{nom2} &= 60 \text{ (mm)}
\end{align*}
\]

Loads:

**Foundation loads:**

<table>
<thead>
<tr>
<th>Case</th>
<th>Nature</th>
<th>Group</th>
<th>Pier</th>
<th>N</th>
<th>Fx</th>
<th>Fy</th>
<th>Mx</th>
<th>My</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(kN)</td>
<td>(kN)</td>
<td>(kN)</td>
<td>(kN*m)</td>
<td>(kN*m)</td>
</tr>
<tr>
<td>ULS</td>
<td>design</td>
<td>----</td>
<td>1</td>
<td>5282.78</td>
<td>21.84</td>
<td>-5.82</td>
<td>6.09</td>
<td>34.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>4142.49</td>
<td>0.82</td>
<td>-25.14</td>
<td>36.08</td>
<td>1.65</td>
</tr>
<tr>
<td>SLS</td>
<td>design</td>
<td>----</td>
<td>1</td>
<td>3847.79</td>
<td>15.54</td>
<td>-4.47</td>
<td>4.79</td>
<td>24.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>3020.30</td>
<td>0.46</td>
<td>-18.51</td>
<td>26.57</td>
<td>0.81</td>
</tr>
<tr>
<td>A1</td>
<td>accidental</td>
<td>1</td>
<td>1</td>
<td>0.00</td>
<td>150.00</td>
<td>0.00</td>
<td>0.00</td>
<td>180.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**Backfill loads:**

<table>
<thead>
<tr>
<th>Case</th>
<th>Nature</th>
<th>Q1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(kN/m2)</td>
</tr>
<tr>
<td>1/</td>
<td>ULS : ULS N=9425.27 Mx=42.17 My=1674.57 Fx=22.66 Fy=30.96</td>
<td></td>
</tr>
<tr>
<td>2/</td>
<td>SLS : SLS N=6868.72 Mx=31.36 My=1215.30 Fx=16.00 Fy=22.98</td>
<td></td>
</tr>
<tr>
<td>3/</td>
<td>ALS : 1.05A1</td>
<td></td>
</tr>
<tr>
<td>4/*</td>
<td>ULS : ULS N=9425.27 Mx=42.17 My=1674.57 Fx=22.66 Fy=30.96</td>
<td></td>
</tr>
<tr>
<td>5/*</td>
<td>SLS : SLS N=6868.72 Mx=31.36 My=1215.30 Fx=16.00 Fy=22.98</td>
<td></td>
</tr>
<tr>
<td>6/*</td>
<td>ALS : 1.00A1</td>
<td></td>
</tr>
</tbody>
</table>

Combination list

1/ ULS : ULS N=9425.27 Mx=42.17 My=1674.57 Fx=22.66 Fy=30.96
2/ SLS : SLS N=6868.72 Mx=31.36 My=1215.30 Fx=16.00 Fy=22.98
3/ ALS : 1.05A1
4/* ULS : ULS N=9425.27 Mx=42.17 My=1674.57 Fx=22.66 Fy=30.96
5/* SLS : SLS N=6868.72 Mx=31.36 My=1215.30 Fx=16.00 Fy=22.98
6/* ALS : 1.00A1
Considerations

Foundation design for:
- Capacity
- Rotation
- Sliding
- Sliding with soil pressure considered: none
- Uplift
- Average settlement

Soil:

Soil level: \( N_1 = 2.58 \) (m)
Column pier level: \( N_a = 0.00 \) (m)

well graded gravels
- Soil level: 2.18 (m)
- Unit weight: 1700.00 (kG/m3)
- Unit weight of solid: 1700.00 (kG/m3)
- Internal friction angle: 42.0 (Deg)
- Cohesion: 0.00 (MPa)

Limit states

Stress calculations

Soil type under foundation: not layered
Design combination: SLS : SLS N=6868.72 Mx=31.36 My=-1215.30 Fx=16.00 Fy=-22.98
Load factors:
1.00 * Foundation weight
1.00 * Soil weight
Calculation results: On the foundation level
Weight of foundation and soil over it: \( G_r = 1620.60 \) (kN)
Design load:
\( N_r = 8489.31 \) (kN)  \( M_x = 56.64 \) (kN*m)  \( M_y = -167.39 \) (kN*m)
Soil profile parameters:
\( C = 0.00 \) (MPa)
\( \phi = 0.00 \)
\( \gamma = 0.00 \) (kG/m3)
Stress in soil: 0.14 (MPa)
Design soil pressure 0.14 (MPa)
Safety factor: 1.005 > 1

Uplift

Design combination: SLS : SLS N=6868.72 Mx=31.36 My=-1215.30 Fx=16.00 Fy=-22.98
Load factors:
1.00 * Foundation weight
1.00 * Soil weight
Contact area:
\[ s = 2.22 \]
\[ s_{lim} = 1.00 \]
Sliding

Design combination: SLS : SLS N=6868.72 Mx=31.36 My=-1215.30 Fx=16.00 Fy=-22.98
Load factors:
1.00 * Foundation weight
1.00 * Soil weight
Weight of foundation and soil over it: Gr = 1620.60 (kN)
Equivalent foundation dimensions: A_ = 7.80 (m) B_ = 7.70 (m)
Sliding area: 60.06 (m2)
Foundation/soil friction coefficient: tg(\phi) = 0.90
Cohesion: C = 0.00 (MPa)
Value of force preventing foundation sliding:
- On the foundation level: F(stab) = 7643.81 (kN)
Stability for sliding: 272.9 > 1

Average settlement

Soil type under foundation: not layered
Design combination: SLS : SLS N=6868.72 Mx=31.36 My=-1215.30 Fx=16.00 Fy=-22.98
Load factors:
1.00 * Foundation weight
1.00 * Soil weight
Weight of foundation and soil over it: Gr = 1620.60 (kN)
Average stress caused by design load: q = 0.14 (MPa)
Thickness of the actively settling soil: z = 6.00 (m)
Stress on the level z:
- Additional: \sigma zd = 0.05 (MPa)
- Caused by soil weight: \sigma z\gamma = 0.16 (MPa)
Settlement:
- Original s' = 2 (mm)
- Secondary s'' = 0 (mm)
- TOTAL S = 2 (mm) < Sadm = 50 (mm)
Safety factor: 22.74 > 1

Settlement difference

Design combination: SLS : SLS N=6868.72 Mx=31.36 My=-1215.30 Fx=16.00 Fy=-22.98
Load factors:
1.00 * Foundation weight
1.00 * Soil weight
Settlement difference: S = 0 (mm) < Sadm = 50 (mm)
Safety factor: 621.2 > 1

Rotation

About OX axis
Design combination: SLS : SLS N=6868.72 Mx=31.36 My=-1215.30 Fx=16.00 Fy=-22.98
Load factors:
1.00 * Foundation weight
1.00 * Soil weight
Weight of foundation and soil over it: Gr = 1620.60 (kN)
Design load:
Nr = 8489.31 (kN) Mx = 56.64 (kN*m) My = -167.39 (kN*m)
Stability moment: Mstab = 32683.86 (kN*m)
Rotation moment: Mrenv = 56.64 (kN*m)
Stability for rotation: 577 > 1

About OY axis
Multi-Storey Car Park Design

Design combination: 

**SLS : SLS**

**Load factors:**
1.00 * Foundation weight
1.00 * Soil weight

Weight of foundation and soil over it: $Gr = 1620.60$ (kN)

Design load:
- $Nr = 8489.31$ (kN)
- $Mx = 56.64$ (kN*m)
- $My = -167.39$ (kN*m)

Stability moment: $M_{stab} = 34156.23$ (kN*m)

Rotation moment: $M_{renv} = 1215.30$ (kN*m)

Stability for rotation: $28.11 > 1$

**RC design**

**Assumptions**
- Exposure : $X0$
- Structure class : $S1$

**Analysis of punching and shear**

**Punching**

Fx=22.66 Fy=-30.96

Load factors:
- 1.35 * Foundation weight
- 1.35 * Soil weight

Design load:
- $Nr = 11613.08$ (kN)
- $Mx = 76.23$ (kN*m)
- $My = -235.85$ (kN*m)

Length of critical circumference: 7.18 (m)

Punching force: 4649.80 (kN)

Section effective height $h_{eff} = 1.03$ (m)

Reinforcement ratio: $\rho = 0.18\%$

Shear stress: 0.67 (MPa)

Admissible shear stress: 0.68 (MPa)

Safety factor: 1.003 > 1

**Required reinforcement**

**Spread footing:**

bottom:

ULS : ULS N=9425.27 Mx=42.17 My=-1674.57

Mx = 8301.47 (kN*m) $A_{sx} = 2492$ (mm2/m)

$A_{sy} = 2492$ (mm2/m)

$A_{min} = 1339$ (mm2/m)

top:

ALS : 1.00A1

My = -76.44 (kN*m) $A'_{sx} = 314$ (mm2/m)

$A'_{sy} = 0$ (mm2/m)

$A_{min} = 314$ (mm2/m)
Provided reinforcement

**Spread footing:**

**Bottom:**
- **Along X axis:**
  - 51 A500HW 16 \( l = 7.68 \) (m) \( e = 1 \times -3.49 + 50 \times 0.14 \)
- **Along Y axis:**
  - 64 A500HW 20 \( l = 7.58 \) (m) \( e = 1 \times -3.77 + 63 \times 0.12 \)

**Top:**
- **Along X axis:**
  - 51 A500HW 8 \( l = 7.68 \) (m) \( e = 1 \times -3.75 + 50 \times 0.15 \)

**Pier**

**Column pier: 1**

**Longitudinal reinforcement**
- **Along X axis:**
  - 2 A500HW 12 \( l = 2.64 \) (m) \( e = 1 \times -1.48 + 1 \times 0.26 \)
- **Along Y axis:**
  - 2 A500HW 12 \( l = 2.69 \) (m) \( e = 1 \times -0.13 + 1 \times 0.26 \)

**Transversal reinforcement**
- 6 A500HW 16 \( l = 1.66 \) (m) \( e = 1 \times 0.21 + 3 \times 0.20 + 2 \times 0.09 \)

**Column pier: 2**

**Longitudinal reinforcement**
- **Along X axis:**
  - 2 A500HW 12 \( l = 2.64 \) (m) \( e = 1 \times 1.52 + 1 \times 0.26 \)
- **Along Y axis:**
  - 2 A500HW 12 \( l = 2.69 \) (m) \( e = 1 \times -0.13 + 1 \times 0.26 \)

**Transversal reinforcement**
- 6 A500HW 16 \( l = 1.66 \) (m) \( e = 1 \times 0.21 + 3 \times 0.20 + 2 \times 0.09 \)

**Material survey:**

- Concrete volume = 66.07 (m³)
- Formwork = 34.10 (m²)
- Steel A500HW
  - Total weight = 2020.09 (kG)
  - Density = 30.58 (kG/m³)
  - Average diameter = 15.0 (mm)
  - Survey according to diameters:

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Length (m)</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>7.68</td>
<td>51</td>
</tr>
<tr>
<td>12</td>
<td>2.64</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>2.69</td>
<td>4</td>
</tr>
<tr>
<td>16</td>
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<td>16</td>
<td>7.68</td>
<td>51</td>
</tr>
<tr>
<td>20</td>
<td>7.58</td>
<td>64</td>
</tr>
</tbody>
</table>
3.5 Retaining Wall Analysis and Design

Geometry

Figure 3-23: Retaining Wall Geometry
Granular material saturated density $1700\text{kg/m}^2$
Coefficient of active pressure, $K_a = 0.33$
Surcharge: $10\text{ KN/m}^2$
Passive Pressure not considered

**HORIZONTAL LOADS,**

\[
\text{Earth Pressure, } p_a = K_a \rho g h = 0.33 \times 1.7 \times 9.81 \times 4.93 = 27.13 \text{ KN/m}^2
\]

\[
\text{Surcharge Pressure, } p_s = K_a \times 10 = 3.33 \text{ KN/m}^2
\]

Horizontal force on 1m length of wall,
\[
H_{k(\text{earth})} = 0.5 p_a h = 66.92 \text{ KN}
\]
\[
H_{k(\text{surch})} = p_s h = 16.27 \text{ KN}
\]

**VERTICAL LOADS,**

Permanent Loads,
\[
\text{Wall} = 0.3 \times 4.93 \times 25 = 37 \text{ KN}
\]
\[
\text{Base} = 0.4 \times 4.40 \times 25 = 44 \text{ KN}
\]
\[
\text{Earth} = 2.75 \times 4.93 \times 1.7 \times 9.81 = 226 \text{ KN}
\]
\[
\text{Total} = 307 \text{ KN}
\]

Variable Loads,
\[
\text{Surcharge} = 2.75 \times 10 = 27.5 \text{ KN}
\]

**OVERTURNING MOMENTS (EQU),**

Taking moments at A at the edge of the toe at the ultimate limit state, a factor of 1.1 is applied to the active earth pressure and 1.5 to the surcharge pressure,

\[
\text{Overturning Moment} = \gamma_f H_{k(\text{earth})} \frac{h}{3} + \gamma_f H_{k(\text{surch})} \frac{h}{2}
\]
\[
= (1.1 \times 66.9 \times 4.93/3) + (1.5 \times 16.2 \times 4.93/2)
\]
\[
= 181 \text{ KNm}
\]

For the restraining moment, a factor of 0.9 is applied to the permanent load and 0 to the variable surcharge load.

\[
\text{Resisting Moment} = \gamma_f (1.5 \times 37 + 2.2 \times 44 + 3.025 \times 226 + 0.8 \times 168)
\]
\[
= 873 \text{ KNm (>181)}
\]
Figure 3.24: Retaining Wall Active and Passive Pressures

Figure 3.25: Retaining Wall Forces
### 2.4.7.1 Sliding

A factor of 1.35 is applied to earth pressure and 1.5 to the surcharge pressure.

\[
\text{Sliding Force} = 1.35 \times 66.9 + 1.5 \times 16.3 \\
= 114.8\, \text{KN}
\]

Coefficient of friction \( \mu = 0.45 \)

\[
\text{Frictional Resisting Force} = 0.45 \times 1.0 \times 307 = 138\, \text{KN} (> 114.8)
\]

### Bearing Pressures, Ultimate Limit State (STR & GEO)

\[
p = \frac{N}{B} \pm \frac{6M}{B^2}
\]

\( M \) is the moment about the base centreline, Passive Pressure Ignored.

\[
M = \gamma_f (66.9 \times 1.643) + \gamma_f (16.3 \times 2.453) + \gamma_f (37 \times 0.7) \\
- \gamma_f (226 \times 0.8315) \\
= 1.35 \times 109.9 + 1.35 \times 25 + 1.5 \times 40 - 1 \times 188 \\
55\, \text{KNm}
\]

\[
p = \frac{(1.35 \times (37 + 44) + 1.0 \times 226 + 6 \times 55)}{4.4} \pm \frac{6 \times 55}{4.4^2}
\]

\[
= 76.2 \pm 17 \\
= 93.2, \ 59.2\, \text{KN/m}^2
\]

---

**Figure 3-26**: Retaining Wall Bearing Pressures
### RETAINING WALL

#### BENDING REINFORCEMENT,

For the wall,

Max Moment \( M_{Ed} = 90.3 \times \left( \frac{0.2 + 4.53}{3} \right) + 24.5 \times \left( \frac{0.2 + 4.53}{2} \right) \)

\[ = 214.8 \text{ KNm} \]

\[
\frac{M_{Ed}}{bd^2f_{ck}} = \frac{215 \times 10^6}{1000 \times 260^2 \times 20} = 0.159; \quad l_a = 0.83
\]

\[
A_s = \frac{215 \times 10^6}{0.83 \times 260 \times 0.87 \times 500} = 2290 \text{ mm}^2/m
\]

For the base,

Taking Moments for the vertical loads and the bearing pressures about the stem centre line,

\[
M_{Ed} = \gamma_f \times 44 \times \left( \frac{4.4}{2} − 1.5 \right) + \gamma_f \times 226 \times 1.525
\]

\[
- 59.2 \times 2.72 \times 1.525 − (80.45 − 59.2) \times \frac{2.75}{2}
\]

\[
\times \left( \frac{2.75}{3} + 0.15 \right)
\]

\[
= 1.35 \times 30.8 + 1.0 \times 344.7 - 245.6 - 31.12
\]

\[
= 108.9 \text{ KNm}
\]

\[
\frac{M_{Ed}}{bd^2f_{ck}} = \frac{109 \times 10^6}{1000 \times 360^2 \times 20} = 0.042; \quad l_a = 0.95
\]

\[
A_s = \frac{109 \times 10^6}{0.95 \times 360 \times 0.87 \times 500} = 733 \text{ mm}^2/m
\]
3.6 Ramp Analysis and Design

Geometry
Height: 3.15m
Internal Radius: 8m
External Radius: 12m
Width: 4m
Centreline Length: 31.6m
Slab thickness: 200mm
Turn Angle and direction: 180° Counter Clockwise
Gradient: 9.9%
You created this PDF from an application that is not licensed to print to novaPDF printer (http://www.novapdf.com)
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>STRUCTURAL DESIGN PROJECT</td>
<td>MULTI-STOREY PARKING BUILDING</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RAMP MOMENTS (MXX)</th>
<th>OUTPUT</th>
</tr>
</thead>
</table>

![Figure 3-28: Ramp Moments MXX](image.png)
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<tr>
<th></th>
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<tbody>
<tr>
<td>STRUCTURAL DESIGN PROJECT</td>
<td>MULTI-STOREY PARKING BUILDING</td>
</tr>
</tbody>
</table>

**RAMP MOMENTS(MYY)**

**Output**

![Figure 3-29: Ramp Moments MYY](image-url)

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### Positive Moment at Midspan

\[
M_{xx} = 18.69 \text{KNm/m} \quad M_{yy} = 21.83 \text{KNm/m}
\]

\[
\frac{M}{bd^2f_{ck}} = \frac{37.33 \times 10^6}{1000 \times 175^2 \times 25} = 0.029
\]

\[
\frac{z}{d} = (0.5 + \sqrt{0.25 - \frac{K}{1.134}})
\]

\[
K = \frac{M}{bd^2f_{ck}}
\]

<table>
<thead>
<tr>
<th>K</th>
<th>0.05</th>
<th>0.06</th>
<th>0.07</th>
<th>0.08</th>
<th>0.09</th>
</tr>
</thead>
<tbody>
<tr>
<td>(l_a = \frac{z}{d})</td>
<td>0.954</td>
<td>0.945</td>
<td>0.934</td>
<td>0.924</td>
<td>0.913</td>
</tr>
</tbody>
</table>

\(l_a = 0.95\) and the neutral axis lies within the flange. and

\[
A_s = \frac{M}{0.87f_{yk}z} = \frac{21.83 \times 10^6}{0.87 \times 500 \times 0.95 \times 175} = 301 \text{ mm}^2
\]

Minimum \(A_s = 0.13bd\% = 221 \text{ mm}^2\)

#### Interior Support

At interior support design as rectangular section for solid slab.

\[
M_{xx} = -27.53 \text{KNm/m}
\]

\[
\frac{M}{bd^2f_{ck}} = \frac{27.53 \times 10^6}{1000 \times 175^2 \times 25} = 0.036
\]

From the lever arm curve, \(l_a = 0.95\) and the neutral axis lies within the flange. and

\[
A_s = \frac{M}{0.87f_{yk}z} = \frac{27.53 \times 10^6}{0.87 \times 500 \times 0.95 \times 175} = 380 \text{ mm}^2
\]

#### Span-Effective Depth Ratio

\[
\rho = \frac{100A_{s,req}}{bd} = \frac{100 \times 301}{1000 \times 175} = 0.172
\]

Hence, Concrete is lightly stressed

Span-Effective Depth Ratio for an end span 2 way spanning slab = 1.5 \times 30 = 45

Actual Span-Effective Depth ratio = \(\frac{4000}{175} = 22.9\) (OK)
4. Discussion

The design of the car was limited due to the inadequate space at the proposed site. A 90 degree parking layout was infeasible under the available space. 90 degree layouts require larger aisle widths. The adopted 45 degree layout resulted in a 20% reduction of available parking spaces. This allowed for possible aisle widths of 3.3m. The floor space was also maximized by incorporating eternal ramps in the design.
5. Conclusion

The multi-storey car park was designed to Eurocode 2 (EN 1992-1-1:2004). The detailed drawings were provided. The proposed design has 300 bays to accommodate 300 vehicles.
6. References

1. "Design recommendations for multi-storey and underground car park", The Institution of Structural Engineers
2. "Enhancing the Whole Life Structural Performance of multi-storey car parks", Mott McDonald
4. "Alkali Silica Reactions in Concrete", BRE Digest 330, 1999