CED
ARCHITECTURAL ENGINEERING
DEPARTMENT

SUPERVISED BY: Dr. HAMOUD DEHWAH

MOHAMMED QAID AL-ZIYADI
ID: 200793030
Abstract

This project is aimed to design a structure for commercial residential apartments. The building is under construction located in Al-Khubar city. The original plans were obtained from Dr. Dehwah but the original plan has been modified and replaced with a new design. The building has a large built-up area with 6 stories height which as a result makes the project challenging. An intensive literature review has been done to find the best choices to obtain a better structural design.

A manual calculation for some elements of the building was carried out to determine the understanding of the basic and minimum knowledge that any structural engineer should have. Also, placing the columns and beams was an important task and has a great effect on the quality of the structural design to the whole project and it will impact greatly on the results that STAAD Pro is going to provide after modeling.

After drawing the model in STAAD Pro, the design process was just a matter of choosing the correct design parameter and the building code that the designer wants the program to design based on. After getting the intensive data and information from STAAD Pro, the reading and extracting of this data plays a major rule on the structural design. After reading the data and taking from it what will help in the design, a structural drawings and cross sections were provided to complete the substructure design cycle.

In addition, in order to finish any structural design project the structural engineer should design the foundation that the substructure is going to rest on without any failure and that what has been done in this project.
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Chapter 1: Introduction

There are two choices for the ARE students. They either choose the summer training program (ARE400) and that course take place on the summer for 8 weeks training at a certified company. Or they could choose the Cooperative Training Program and that take place on the summer and one semester (28 weeks of training at IC Company in my case). In my case my choice was COOP program for terms 103 & 111 at IC Company. In 28 weeks of continuous training that gave me a great experience in different fields I mentioned them in my COOP report. The other part attached to the training is to choose one of building system or more than one of building systems so we achieve both field experience and solving problems and working in the design division. The structural of the building always fascinates me and always make me wonder about the secrets of designing it and the techniques behind building these great structures that we see nowadays. I won't waste time to describe the importance of building structure it is just enough that the beauty of the buildings that we see every day there are structural designer behind those great buildings. So, my choice was to design the structure of a building. In addition, I choose Dr. Hamoud Dehwah to advise me and supervise me during the whole project.
1. **Objectives**

1.1. **Course objectives**

- To be able to apply knowledge of mathematics, science and engineering.
- To be able to design and conduct experiments, as well as analyze and interpret data.
- To be able to design a system, component, or process to meet desired needs within constraints.
- To have knowledge of contemporary issues.
- To be able to identify, formulate, and solve engineering problems.
- To understand professional and ethical responsibility.
- To be able to communicate effectively.
- To use techniques, skills, and modern engineering tools necessary for engineering practice.
- To be able to communicate in writing and oral presentation and discuss engineering issues.
1.2. **Structural Design Objectives**

“Structural design can be defined as admixture of art and Science, combining the engineer’s feeling for the behavior of a structure with a sound knowledge of a structure with a sound knowledge of the principles of statics, dynamics, mechanics of materials, and structural mechanics of materials, and structural analysis, to produce a safe economic structure that will serve its intended purpose.” (Salmon and Johnson 1990).

Structure design is the application of structural theory to ensure that buildings and other structures are built to support all loads and resist all constraining forces that may be reasonably expected to be imposed on them during their expected service life, without hazard to occupants or users and preferably without dangerous deformations, excessive sideways (drift), or annoying vibrations. In addition, good design requires that this objective be achieved economically. Structural members are selected by the load or weight they must support; therefore, the architectural engineer must begin with the roofing materials and work downward to the foundation to determine the sizes of support members.

Any engineering structure should satisfy the functional and structural, have a sufficient degree of performance, a reasonable cost and should be aesthetically attractive. The purpose of structural analysis and design is to enable the designer to design the structure with adequate strength, stiffness and stability. The general procedure is as follows.

1. Based on space requirements and shape, suitable structural frame works are selected.
2. Based on preliminary analysis and experience approximate dimensions of various structural members are fixed.
3. Detailed analysis is performed to determine the bending moments, shear force, axial forces etc. at the required section.
4. Using the result of analysis the various members are designed ensuring adequate factor of safety (FS).

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1Introduction to structural design, [http://www.assakkaf.com/courses/ence355/lectures/part1/chapter0b.pdf](http://www.assakkaf.com/courses/ence355/lectures/part1/chapter0b.pdf)
2. **Structural Design Process and Detailed Procedure**

The entire process of structural planning and design requires not only imagination and conceptual thinking but also sound knowledge of practical aspects, such as recent design codes and bye-laws, backed up by ample experience, institution and judgment.

It is emphasized that any structure to be constructed must satisfy the need efficiency for which it is intended and shall be durable for its desired life span. Thus, the design of any structure is categorized into following two main types:

a) Functional design  
b) Structural design

2.1. **FUNCTIONAL DESIGN:**

The structure to be constructed should primarily serve the basic purpose for which it is to be used and must have a pleasing look.

The building should provide happy environment inside as well as outside. Therefore, the functional planning of a building must take into account the proper arrangements of room/halls to satisfy the need of the client, good ventilation, lighting, acoustics, unobstructed view in the case of community halls, cinema theatres, etc.

2.2. **STRUCTURAL DESIGN:**

Once the form of the structure is selected, the structural design process starts. Structural design is an art and science of understanding the behavior of structural members subjected to loads and designing them with economy and elegance to give a safe, serviceable and durable structure.

2.2.1. **STAGES IN STRUCTURAL DESIGN:**

The process of structural design involves the following stages.

A. Structural planning.  
B. Action of forces and computation of loads.  
C. Methods of analysis.  
D. Member design.  
E. Detailing, Drawing and Preparation of schedules.
2.2.1.1. **STRUCTURAL PLANNING:**

After getting an architectural plan of the buildings, the structural planning of the building frame is done. This involves determination of the following.

1. **Position and orientation of columns.**
2. **Positioning of beams.**
3. **Spanning of slabs.**
4. **Layouts of stairs.**
5. **Selecting proper type of footing.**

2.2.1.1.1. **Positioning and orientation of columns:**

**A. Positioning columns**

Following are some of the building principles, which help in deciding the columns positions.

1. Columns should preferably be located at (or) near the corners of a building, and at the intersection of beams/walls.
2. Select the position of columns so as to reduce bending moments in beams.
3. Avoid larger spans of beams.
4. Avoid larger center-to-center distance between columns.
5. Columns on property line.

**B. Orientation of columns:**

1. **Avoid projection of columns:**

The projection of columns outside the wall in the room should be avoided as they not only give bad appearance but also obstruct the use of floor space, creating problems in placing furniture flush with the wall. The width of the column is required to be kept not less than 200mm to prevent the column from being slender. The spacing of the column should be considerably reduced so that the load on column on each floor is less and the necessity of large sections for columns does not arise.
ii. Orient the column so that the depth of the column is contained in the major plane of bending or is perpendicular to the major axis of bending.

This is provided to increase moment of inertia and hence greater moment resisting capacity. It will also reduce Leff/d ratio resulting in increase in the load carrying capacity of the column.

2.2.1.2. POSITIONING OF BEAMS:

A. Beams shall normally be provided under the walls or below a heavy concentrated load to avoid these loads directly coming on slabs.

B. Avoid larger spacing of beams from deflection and cracking criteria. (The deflection varies directly with the cube of the span and inversely with the cube of the depth i.e. \( L^3/D^3 \). Consequently, increase in span L which results in greater deflection for larger span).

2.2.1.3. SPANNING OF SLABS:

This is decided by supporting arrangements. When the supports are only on opposite edges or only in one direction, then the slab acts as a one way supported slab. When the rectangular slab is supported along its four edges it acts as a one way slab when \( Ly/Lx < 2 \).

The two way action of slab not only depends on the aspect ratio but also on the ratio of reinforcement on the directions. In one way slab, main steel is provided along with short span only and the load is transferred to two opposite supports. The steel along the long span just acts as the distribution steel and is not designed for transferring the load but to distribute the load and to resist shrinkage and temperature stresses.

A slab is made to act as a one way slab spanning across the short span by providing main steel along the short span and only distribution steel along the long span. The provision of more steel in one direction increases the stiffness of the slab in that direction.

According to elastic theory, the distribution of load being proportional to stiffness in two orthogonal directions, major load is transferred along the stiffer short span and the slab behaves as one way. Since, the slab is also supported over the short edge there is a tendency of the load on the slab by the side of support to get transferred to the nearer support causing tension at top across this short supporting edge. Since, there does not exist any steel at top across this short edge in a one way slab interconnecting the slab and the side beam, cracks develop at the top along that edge. The cracks may run through the depth of the slab due to differential deflection between the slab and the supporting short edge beam/wall. Therefore, care should be taken to provide minimum steel at top across the short edge support to avoid this cracking.

A two way slab is generally economical compare to one way slab because steel along both the spans acts as main steel and transfers the load to all its four supports. The two way action is advantageous essentially for large spans (>3m) and for live loads (>3kN/m2). For short spans and light loads, steel required for two way slabs does not differ appreciably as compared to steel for two way slab because of the requirements of minimum steel.
2.2.1.4. FOOTING:

The type of footing depends upon the load carried by the column and the bearing capacity of the supporting soil. The soil under the foundation is more susceptible to large variations. Even under one small building the soil may vary from soft clay to a hard murmur. The nature and properties of soil may change with season and weather, like swelling in wet weather. Increase in moisture content results in substantial loss of bearing capacity in case of certain soils which may lead to differential settlements. It is necessary to conduct the survey in the areas for soil properties. For framed structure, isolated column footings are normally preferred except in case of exists for great depths, pile foundations can be an appropriate choice. If columns are very closely spaced and bearing capacity of the soil is low, raft foundation can be an alternative solution. For a column on the boundary line, a combined footing or a raft footing may be provided.\(^4\)

\(^4\)Structural design process, http://theconstructor.org/structural-engg/analysis/structural-design-process/1673/
3. Reinforced Concrete Structure

3.1. Concrete:

Concrete is a stone like substance obtained by permitting a carefully proportioned mixture of cement, sand and gravel or other aggregate and water to harden in forms of the shape and of dimensions of the desired structure.

3.2. Reinforced cement concrete:

Since concrete is a brittle material and is strong in compression. It is weak in tension, so steel is used inside concrete for strengthening and reinforcing the tensile strength of concrete. The steel must have appropriate deformations to provide strong bonds and interlocking of both materials. When completely surrounded by the hardened concrete mass it forms an integral part of the two materials, known as "Reinforced Concrete". Reinforced Concrete is a structural material, is widely used in many types of structures. It is competitive with steel if economically designed and executed.

3.2.1. Advantages of reinforced concrete

- It has relatively high compressive strength
- It has better resistance to fire than steel
- It has long service life with low maintenance cost
- In some types of structures, such as dams, piers and footings, it is most economical structural material
- It can be cast to take the shape required, making it widely used in pre-cast structural components
- It yields rigid members with minimum apparent deflection
- Yield strength of steel is about 15 times the compressive strength of structural concrete and well over 100 times its tensile strength
- By using steel, cross sectional dimensions of structural members can be reduced e.g. in lower floor columns.

3.2.2. Disadvantages of reinforced concrete

- It needs mixing, casting and curing, all of which affect the final strength of concrete
- The cost of the forms used to cast concrete is relatively high
- It has low compressive strength as compared to steel (the ratio is about 1:10 depending on material) which leads to large sections in columns/beams of multistory buildings
- Cracks develop in concrete due to shrinkage and the application of live loads.
Chapter 2: Building Characteristics & Description

1.1. Site location

The site is located in Al-Khubar City, Saudi Arabia, near Al-Rashid mall.

![Site Location](image)

1.2. Building Description

- The building is designed to have 6 stories each story with 3.5 m height.
- The site area = 34.8 m (north & south) × 24 m (east & west) = 835.2 m²
- The building built-up area = 29.8 m (north & south) × 19 m (east & west)
  = 566.2 m²
- The structure of the building will be using reinforced concrete.
- I will use solid slabs for floors and roofs.
- Reinforced concrete structural farming system (column & beam).
- The design is based on ACI code.
Chapter 3: literature review

All the information in this literature review are a paper research and a study that had been done in Riyadh city by Abdulaziz I. Al-Negheimish1, Ahmad B. Shuraim1 and Abdullah S. Al-Tayyar2

1: Assistant professor, Civil Engineering Department, King Saud University
2: Structural Engineer, The Municipality of Riyadh
E-mail: negaimsh@ksu.edu.sa

1. Literature review methodology

Data and design documents including architectural and structural design drawings, design assumptions and calculation sheets were collected for 41 residential building projects in Riyadh. Additional information relating to the design engineer background, code of practice used (if any), and the general philosophy regarding analysis and design were collected using simple questionnaire prepared for this purpose. In addition, copies of codes, handbooks and other data used by the designer were obtained for most projects. The data were collected with the cooperation of the Municipality of Riyadh and involves actual projects submitted to the Municipality approval. The selected projects are limited to villas, duplexes and low-rise apartment buildings and represent typical practice in Riyadh.

All the data and design documents collected were reviewed and studied for structural design assumptions and adequacy of the overall design features. In depth check of the structural design was performed on a selected number of cases covering typical layout and design. However, due to space limitation, the results of the in-depth check are not given here but can be found elsewhere [Al-Tayyar, 1998].
2. Results

2.1. General Characteristics Of Buildings

2.1.1. Buildings types

Modern residential buildings in the Kingdom can be classified as either single-family housing (villas) or multi-family housings such as apartment buildings and duplexes. The villas are detached dwellings with a privacy fence on the property line constructed normally using masonry walls. Duplexes are semi-detached dwellings with more compact floor plan compared to villas. Most buildings are constructed using reinforced concrete framed structures with reinforced concrete flat roof deck slabs. Curtain walls and partitions are normally constructed using no-load bearing masonry walls. According to this classification, 26 out of the 41 buildings in the study sample are villas, 9 are apartment buildings and 6 are duplexes or multiplexes. Two of the apartment buildings were designed for residential use only and the remaining 7 were for dual commercial and residential use.

![Building Types chart](image-url)

*Figure 2 Building Types chart*
2.1.2. Plot area and built-up area

Zoning regulations in Riyadh limit the percentage of built-up area to 60% of the plot area over most part of the city. The results of these zoning regulations were reflected in built-up areas for the three building types in the study sample. The percentages of built-up area in apartment buildings were the highest, with duplexes ranking second and villas third with mean values of 57%, 52%, and 40%, respectively. It was also clear from the data that the mean floor area is highest for villas with duplexes having the most compact floor area. These results were expected in view of the commercial aspects involved. The plan layouts for most buildings were irregular. The irregularity included spans, loads, and dimensions of structural members (joists, beams, columns and footings). This complicates both the structural design and construction of the building.

2.1.3. Number of stories and story-height

Most of the buildings in Riyadh are two stories high due to zoning regulations. The construction permit for buildings with more than two stories is issued by the central permit office in the Municipality. In all the studied projects, the buildings were two-story high, with only 5 of them with basements. Some of the buildings had upstairs annex, which were about 10% of the first floor area. The heights of the ground and first floors were 3.0 m in all the projects except for the commercial apartment buildings where a height of 3.5 m was specified. The height of parapet wall was 1.8 m in all projects.

2.1.4. Characteristics of Structural Members

Typically, residential buildings in Riyadh are built as reinforced concrete (RC) frames supported by isolated footings. All walls of the ground floor are supported by grade beams. The slab system is either solid slab supported on beams or joist slab with block filler known locally as “Hordi slab”. In this section, data and information relating to the structural design of members such as types, frequencies, dimensions, thickness, and other aspects of the design are given.

2.1.5. Choice of slab systems

The slab system used is limited to Hordi slabs and solid slabs on beams. The percentage use of these two types is illustrated graphically in Figure 3. As can be seen from this figure, 37% of the projects used only Hordi slabs, 7% used solid slabs, and 56% used both in the same building. These data show the wide use of Hordi slabs as they were utilized fully or partially in 38 out of the 41 projects or 93% of the total. The wide use of Hordi slab attributed to many factors the most important of which are:

1. They provide more flexibility for floor layout and future modifications
2. They are perceived to possess superior thermal and sound insulations
3. Ease of construction.
Among the 38 projects using Hordi slabs, 39% used Hordi slabs in both floor and roof, 50% in first floor only, and 11% used Hordi slabs in selective areas only. **It should be noted here that it is a common practice to use solid slabs** in bathrooms even with Hordi slab construction. For Hordi slabs, the range of the slab thicknesses were 250-380 mm with the thickness 320 mm being the most common as it comprised 84% of the total. The 320 mm thickness for Hordi slabs is a result of using 250 x 400 x 200mm Hordi blocks and top slab of 70 mm thickness. Among the 26 projects using solid slabs (fully or partially), 12% used solid slabs in both floors and roofs, 69% in roof only, and 19% used solid slabs in selective areas only. The range of the solid slab thickness used was 100-200 mm with the **120 mm and 150 mm thicknesses being the most common.**
2.1.6. Beams
Typical types of beams used in buildings are grade beams, drop beams and Hordi beams (flat hidden beams). Widths of grade beams and drop beams depend on widths of the walls; however, the depths of these beams are variable. The range of depth used for grade beams was (300 mm - 800 mm) with common depth of 600 mm. For drop beams, the depths used were in the range of (400 mm - 800 mm) with 700 mm as a common depth. The number of groupings used for grade beams in each building was between 3 to 7, while it was 2 to 6 for drop beams. Hordi beam widths depend on design requirements, and Hordi beam depths depend on type of filler block used for Hordi slabs. The most common depth used for Hordi beam was 320 mm. The range of Hordi beam widths was (400 mm - 1600 mm), the number of groupings used for Hordi beams was between 2 to 4.

2.1.7. Columns
Columns are critical elements in RC design. They carry loads from beams and transfer it to footings. The general characteristics of columns used in buildings in Riyadh can be inferred from the data collected. Due to the common practice of having the columns hidden in walls, the widths of most columns are the same as that of walls, while depths of columns depend on design requirements. The column depths were in the range of (400 mm - 1150 mm), with 600 mm being the common depth. The number of groupings used for columns in each building was between 4 to 7. The total number of columns used for each building was (16 to 72) columns, with mean value equal to 35 columns. The range of area carried by each column was (7.8 m²) with a mean value of 11.0 m². The number of interior columns used in each building was (2 to 40) columns, with a mean value of 14 columns. The range of floor area carried by interior columns was (10.7 m² to 40.5 m²) per column with a mean value of 17.6 m² exterior columns used in each building was (12 to 32), with a mean value of 21. The range of floor area carried by exterior columns was (4.2 m² to 18.0 m² to 26.3 m²). The number of) with a mean value of 7.2 m. These data show the use of a large number of columns per building with each supporting only small area. Rationalization of design should reduce the number of columns and simplify the structural layout.

2.1.8. Footings
Footings transfer loads from columns into the ground below. The most common types of footings used in the foundations of residential building are the isolated footings. The minimum size of footings used is (1000 mm x 900 mm x 400 mm) while the maximum size is (2800 mm x 2800 mm x 600 mm). The number of groupings used for footings in each building ranges between 3 to 6.

2.2. Design Code
In most countries, the design engineer is guided by specifications called codes of practice. Engineering specifications are set up by various organizations to represent the minimum requirements necessary for the safety of the public. The codes specify design loads, allowable stresses, material quality, construction types, and other requirements related to building construction. In the USA, reinforced concrete design follows Building Code Requirements for Reinforced Concrete, widely known as the ACI code [ACI-318, 1995]. In Saudi Arabia, all the universities have adopted the ACI code in teaching courses dealing with design of concrete structures. If the use of specific code is not mandated by law, structural engineers would be expected to employ the code which they are familiar with. This is most likely to be their native country code or the one they used during their university education. This clearly is reflected in the data shown in Figure 2. From this figure, 8 engineers out of the total reported using ACI
Code, another 6 Arab (Syrian) Code and 3 used British Code. However, the majority reported basing their design on references other than code. References cited include handbooks by Albhaeri and Helal, both from Egypt\(^5\).

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2.3. **Structural Design Using STAAD Pro**

2.3.1. **Computer-Aided Analysis & Design**

Computers have recently been brought in to aid structural designers. These machines are as effective as the available software (i.e., computer programs). Programs are available for design of slabs, simply supported and continuous beams. Columns under biaxial bending isolated footings, combined footings and rafts. There are also available 2-D plane frame programs, grids, retaining walls, etc. not only all the available programs may be to the liking of a designer. The assumptions made in the development of some programs may not be acceptable to the structural designer and in one case, it was found that the column program purchased was valid only for short columns and not for long columns, although at the time of purchase, it was claimed to be valid for both short and long columns.

In practice, continuous beams, frame analysis under horizontal loads are almost always solved by a computer. Sometimes, a building is divided into frames in both the principal directions. All the frames with the vertical and the horizontal loads are put in the computer a nether solution is got which includes the complete design of beams at all the floor levels. Column loads are then assembled manually. Column design under biaxial bending at all levels is done by a computer program.

A very powerful program STAAD Pro is also available in the market which can be used for 3-D analysis of a building as a whole. It is useful for analysis and design of multi-storied buildings. We may consider the followings methods of approach in order to tap the full capacity of STAAD Pro software.

2.3.2. **Structural Design Using STAAD - PRO**

- Concurrent Engineering* based user environment for development, analysis, design, visualization and verification.

- Full range of analysis including static, P-delta, pushover, response spectrum, time history, cable (liner and non-linear), buckling and steel-concrete and timber design.

2.3.3. **Comparison**

2.3.3.1. **Limitations of Hand Computation Methods**

- Applicable for small problems
- Tedious for even medium sized problems
- 3-D analysis is almost impossible
2.3.3.2. Advantage for Invention of Computer

- Matrix methods of structural analysis
- Development of numerical techniques
- Finite element method
- Programming languages developed

2.3.3.3. In STAAD Pro you can do

- Object-oriented intuitive 2D/3D graphical model generation.
- Pull down menus, floating tool bars, and tool tip help.
- Quick data input through property sheets and spreadsheets.
- Customizable structural templates for creating a model.
- Complete support of VBA macros for customization (integrate with Match CDA or Excel).
- Supports truss and beam members, plates, solids, linear and non-linear cables and curvilinear beams.
- Advance automatic load generation facilities for wind, snow, area, floor and moving loads.
- Flexible zoom, pan and multiple views.
- Isometric and perspective view and 3D shapes.
- Toggle display of loads, supports, properties, joints, members, etc. Built-in command file editor for text editing.
- State-of-the-art graphical pre and post processors.
- Rectangular/cylindrical coordinate systems with mix and match capabilities.
- Joint, member/element, mesh generation with flexible user-controlled numbering scheme.
- Import/Export DSF, DWG, VRML, C IS/2 and Excel files.
- Efficient algorithm minimizes disk space requirements.
- FPS, metric or SI units.
- Presentation quality printer plots of geometry and results as part of run output.

2.3.3.4. Graphics Environment Model Generation

- Easy auto mesh and auto refinement of user-defined polygonal element boundary by simple mouse clicks, including openings and column/wall lines.
- Unlimited Undo and Redo.
- More structure wizard models including user-defined parametric structures to create any structural template.
- 2D and 3D graphic generation using rectangular, cylindrical and reverse cylindrical coordinates systems.
- Segments of repetitive geometry may be used to generate complex structural models.
- Generate, copy, repeat, mirror, pivot, etc. for quick and easy geometry generation.
- Comprehensive graphics editing.
- Library of commonly used structures can be picked and display of properties, loadings, supports, orientations etc.
- Graphical specification and display of properties, loadings, supports, orientations etc.
- Import/Export Auto Cad 2D/3D/ DXF or C IS/2 files to start your model.
- Access to text editor to modify model quickly through command syntax.
- User-controlled scale factors for deflected or mode shapes.
- Intelligent objects (beams, plates, columns) to report geometry.
- Structure Wizard to create parametric templates, meshes with holes and curved surfaces.
- Easy “snap-to” construction grid for laying out beams and columns on irregular grids.
- Step-by-hand calculations including all formulae, intermediate results, and code clauses for steel and concrete design.

- Graphically displaying built-up sections and customized shapes in 3D within the STAAD. Pro environment.

- New customizable node/member renumbering scheme.\(^6\)

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Chapter 4: Project Description

Design is not just a computational analysis, creativity should also be included. Art is skill acquired as the result of knowledge and practice. Design of structures as thought courses tends to consist of guessing the size of members required in a given structure and analyzing them in order to check the resulting stresses and deflection against limits set out in codes of practice. Structural Design can be seen as the process of disposing material in three dimensional spaces so as to satisfy some defined purpose in the most efficient possible manner. Engineer might see purpose of the structural system as being to carry imposed loads to foundation in the most direct manner possible. It should interfere with function of structure intended.

The project has been divided in seven main phases:

✓ Phase A: Develop the architectural drawings for the 6 stories building (using REVIT).
✓ Phase B: Position and Dimension of columns and structural floor plans.
✓ Phase C: Manual calculation for slab & beam.
✓ Phase D: Design Building Structural using STAAD Pro.
✓ Phase E: Design the foundation using STAAD Foundation.

To get the most benefit from this project I tried to make the project as comprehensive as possible on most of the structural design fields. The project has been divided into phases to get familiar with all Structural design aspects. The project includes:

✓ Structural Analysis & Design.
✓ Concrete Structure.
✓ Foundation, Slab, Beams & Columns Design.

1. Codes & Standards

Design should be based on certified codes and standards to insure safety. Following the codes and standers used:

1.1. American Concrete Institute (ACI), The ACI has published many references and journals. Building Code Requirement for Structural Concrete (ACI318-08 Code) is a widely recognized reinforced concrete design and construction guide. Although the ACI Code does not have official power of enforcement, it is generally adapted as authorized code by jurisdictions not only in United States but also many countries as Saudi Arabia.

1.2. The Saudi Building Code (SBC)
2. **Computer Software**

Design should be based on certified codes and standards to insure safety. Following the codes and standards used:

- ✓ AutoCAD 2011: Graphical Presentation of Building Drawings & Details.
- ✓ STAAD Pro V8i: Structural Analysis & Design (For the Structure Frame).
- ✓ STAAD Foundation V4i: foundation design.
- ✓ Rivet Architecture 2012: Graphical Presentation of Building Drawings & details and 3D modeling.
Chapter 5: Phase A: Develop the architectural drawings

1. Design Description and Limitations

The site was provided with the site area = 34.8 m (north & south) × 24 m (east & west) = 835.2 m². I used hard copy of initial plans and drawings to the building was provided to me by Dr. Dehwah and I design the building using Rivet 2012 to design the architectural floor plans for the building and I modified the original plans ( The original plans are provided in Appendix A ). The building has 6 stories with height of 3.5m each. In each floor I designed to be 4 apartments with main staircase & elevator in the center of the building near the entrance. The roof are used in my case and I designed there to be 2 apartments only because of the Saudi Regulation in commercial residential building that any extra used space on the roof will be only 50% of the roof space only. The site is exposed to main two streets from south (25m width) and west (15 m width). That will result in 5 m setback on the south elevation and 3 m in the west elevation. The north and east elevations are exposed to neighbors buildings. The setback is minimum 1 m according to the Saudi Regulations.
2. Architectural Floor Plans

Figure 5 First Floor Architectural Plan
Figure 6 Repeated Architectural Floor Plan (2nd, 3rd, 4th and 5th Floor)
Figure 7 Last Floor Architectural Plan
Chapter 6: Phase B: Position and Dimension of columns and structural floor plans

1. **Placing columns guidelines, dimension and limitations**

I mentioned in my introduction the process and the procedure of structural building design guidelines that I used to place the columns in my building. Furthermore, the dimension of the columns originally I started with (0.2 m × 0.6 m) then I revised this as I am going to mention in the next chapters. In addition, the direction of the column isn't random I mentioned that in my introduction. Also, there are other limitations that are related to the direction of the column that there are ratios of the columns direction (6:4 or 5:5) in the whole project. It is kind of thump rule that has been used in designing the building structural. Also, because I used solid slab flooring system the maximum spanning between two columns are 5 m.

2. **Visiting Al-Ansari consulting office**

- For one whole day I sit-down with Eng. Tareq and discuss several things about the structure of the building generally and about my project specially.
- I showed him my layout of the structural plans and he was impressed with my design and didn't have any changes in the layout.
- He suggested that I change my slab choice from solid slab to Hordi slab system but after discussion I convinced him with my choice of solid slab system.
- He taught me some thump rules related the beam and foundation design.
3. **Structural Floor Plans**

![Figure 8 First Floor Structural Plan](image-url)
Figure 9 Repeated Structural Floor Plan
Chapter 7: Phase C: Manual calculation of slab & beam

1. Reinforced cement concrete Design philosophy and concepts

The design of a structure may be regarded as the process of selecting proper materials and proportioned elements of the structure, according to the art, engineering science and technology. In order to fulfill its purpose, the structure must meet its conditions of safety, serviceability, economy and functionality.

A. Strength design method

It is based on the ultimate strength of the structural members assuming a failure condition, whether due to the crushing of concrete or due to the yield of reinforced steel bars. Although there is additional strength in the bar after yielding (due to Strain Hardening), this additional strength in the bar is not considered in the analysis or design of the reinforced concrete members. In the strength design method, actual loads or working loads are multiplied by load factor to obtain the ultimate design loads. The load factor represents a high percentage of factor for safety required in the design. The ACI code emphasizes this method of design. This method is what is going to be used in the manual calculation.

B. Working stress design

This design concept is based on elastic theory, assuming a straight line stress distribution along the depth of the concrete. The actual loads or working loads acting on the structure are estimated and members are proportioned on the basis of certain allowable stresses in concrete and steel. The allowable stresses are fractions of the crushing strength of concrete (fc’) and the yield strength (fy). Because of the differences in realism and reliability over the past several decades, the strength design method has displaced the older stress design method.

1.1. Limit state design

It is a further step in the strength design method. It indicates the state of the member in which it ceases to meet the service requirements, such as, losing its ability to withstand external loads or local damage. According to limit state design, reinforced concrete members have to be analyzed with regard to three limit states:

A. Load carrying capacity (involves safety, stability and durability)
B. Deformation (deflection, vibrations, and impact)
C. The formation of cracks

The aim of this analysis is to ensure that no limiting state will appear in the structural member during its service life.
1.2. Loads

Structural members must be designed to support specific loads. Loads are those forces for which a structure should be proportioned. Loads that act on structure can be divided into three categories.

A. Dead loads
B. Live loads
C. Environmental loads

1.2.1. Dead Loads:

Dead loads are those that are constant in magnitude and fixed in location throughout the lifetime of the structure. It includes the weight of the structure and any permanent material placed on the structure, such as roofing, tiles, walls etc. They can be determined with a high degree of accuracy from the dimensions of the elements and the unit weight of the material.

1.2.2. Live loads:

Live loads are those that may vary in magnitude and may also change in location. Live loads consists chiefly occupancy loads in buildings and traffic loads in bridges. Live loads at any given time are uncertain, both in magnitude and distribution.


Structural members must always be proportioned to resist loads greater than service or actual loads, in order to provide proper safety against failure. In the strength design method, the member is designed to resist the factored loads which are obtained by multiplying the factored loads with live loads.

Different factors are used for different loadings. As dead loads can be estimated quite accurately, their load factors are smaller than those of live loads, which have a high degree of uncertainty. Several load factor conditions must be considered in the design to compute the maximum and minimum design forces. Reduction factors are used for some combinations of loads to reflect the low probability of their simultaneous occurrences. Now if the ultimate load is denoted by \( U \), the according to the ACI code, the ultimate required strength \( U \), shall be the most critical of the following

**Basic Equation**

\[ U = 1.2D + 1.6L \]

In addition to the load factors, the ACI code specifies another factor to allow an additional reserve in the capacity of the structural member. The nominal strength is generally calculated using accepted, analytical procedures based on statistics and equilibrium. However, in order to account for the degree of accuracy within which the nominal strength can be calculated and for adverse variations in materials and dimensions, a strength reduction factor (\( \phi \)) should be used in the strength design method. Values of the strength reduction factor \( \phi \) (Phi) are:

For flexure of tension controlled sections \( \phi = 0.9 \)
For shear and torsion $\varnothing = 0.75$

For compression members with spiral reinforcement $\varnothing = 0.70$

For compression members with lateral ties $\varnothing = 0.65$

### 1.3.1. Minimum reinforcement ratio ($\rho_{\text{min}}$)

If the external moment applied on the beam is very small and the dimensions of sections are specified (as is sometimes required architecturally) and are large than needed to resist the external ultimate moment, the calculations may show that very small or no steel reinforcement is required. In this case the maximum tensile stress due to bending moment may be equal to or less than the modulus of rupture of concrete.

If no reinforcement is provided, sudden failure will be expected when the first crack occurs, thus giving no warning. ACI code specifies a minimum steel area.\(^7\)

2. **Specifications**

- Foundation design is based on soil bearing capacity of 250 KPa, soil type is Sabkha soil (see Appendix B).
- Reinforced concrete has a Compressive strength ($f'_c$) of 28 MPa (4000 psi).
- Steel rebar have yield strength ($f_y$) of 420 MPa (60000 psi).
- All reinforcing bars, ties, and spirals require 4 cm. cover.
- Soil have an allowable pressure of 5.2 ksf
- Overall Live Load= 1.92KN/m² (see Appendix B, Live Load Tables, Private rooms and corridors serving them).
- Dead Load is combined of:
  - Ceramic or quarry tile (20 mm) on 13 mm mortar bed= 0.8 (kN/m²), (see Appendix B).
  - Plaster on tile or concrete= 0.25 (kN/m²), (see Appendix B).
- Load combination: $TL = 1.2 \ (DD + SW ) + 1.6 \ LL$
- Unit weight of concrete = 24 KN/m³ (150 pcf ), (see Appendix B).
- Unit weight of soil = 16 kN/m³ (100 pcf )
- Story Height = 4 m
3. **Slab Design**

3.1. **The Slab Selection In Plan**

- This is the slab I have selected to design it manually.
- I choose the slab with the greatest spans so my design will be for the maximum.

*Figure 10 Second Structural Floor Plan (slab selection)*
**Slab Design**

The design would be according to the Load Distribution Method using ACI codes.

\[
\begin{align*}
 f_c^1 &= 28 \text{ MPa} \\
 f_y &= 280 \text{ MPa}
\end{align*}
\]

Unit weight of concrete \( \varphi_{\text{conc}} = 24 \text{ KN/m}^3 \)

Cement finish (25 mm) on stone – concrete \( f_{i\lambda} = 1.55 \text{ KN/m}^2 \)

Plaster on concrete = 0.25 \text{ KN/m}^2

Live load for slabs = 1.92 \text{ KN/m}^2

- **Material**:
  - \( f_c' = 28 \text{ MPa} \), \( f_y = 280 \text{ MPa} \)
  - \( L_a = 4.2 \text{ m} \), \( L_b = 5.7 \text{ m} \)
  - \( \frac{L_a}{L_b} = 0.74 < 2 \) (2 way slab)

- **Design of slab \( S_1 \)**:

  o **Clear span**:
    - \( L_1 = L_a - 20 \text{ cm} = 4.0 \text{ m} \)
    - \( L_2 = L_b - 20 \text{ cm} = 5.5 \text{ m} \)

  o **Minimum thickness of two-way slabs**:
    - \( \text{Perimeter} = (L_1 + L_2) \times 2 = 19 \text{ m} \)
    - \( t_{\text{min}} = \frac{\text{Perimeter}}{180} \times 100 = 10.55 \text{ cm} = 105.5 \text{ mm} \)

  o **Actual thickness of slab**:
    \( t = 140 \text{ mm} \)
- Loads on slab:

- Dead Loads:

\[ DL = 1.55 + 0.25 + (0.14) \times (24) \text{ KN/m}^3 = 5.16 \text{ KN/m}^3 \]

- Live Load:

\[ LL = 1.92 \text{ KN/m}^2 \]

- Combining Loads:

\[ w^4 = 1.2(DL) + 1.6(LL) = 1.2(5.16) + 1.6(1.92) = 9.26 \text{ KN/m}^2 \]

- Distribution of Load:

\[ \lambda = \frac{L_1}{L_2} = 0.73 \]

\[ w_1 = w_u \frac{1}{1 + \lambda^4} = 5.35 \text{ KN/m}^2 , \quad \frac{w_1}{w_u} = 58\% \]

\[ w_2 = w_u \frac{\lambda^4}{1 + \lambda^4} = 3.91 \text{ KN/m}^2 , \quad \frac{w_2}{w_u} = 42\% \]
- Bending moment:

\[ M_{1 \text{ neg}} = \frac{1}{11} w_1 \ L_1^2 = 7.78 \text{ KN} \text{ m/m} \]

\[ M_{2 \text{ neg}} = \frac{1}{11} w_2 \ L_2^2 = 8.88 \text{ KN} \text{ m/m} \]

\[ M_{1 \text{ pos}} = \frac{1}{16} w_1 \ L_1^2 = 5.35 \text{ KN} \text{ m/m} \]

\[ M_{2 \text{ pos}} = \frac{1}{16} w_2 \ L_2^2 = 6.10 \text{ KN} \text{ m/m} \]

- Top reinforcements in short direction:

\[ b = 1 \text{ m} , \ d = t - \left( 20 \text{ mm} + \frac{10 \text{ mm}}{2} \right) = 115 \text{ mm} \]

\[ M_u = M_{1 \text{ neg}} \cdot b = 7.78 \text{ KN} \cdot \text{m} \]

\[ \Rightarrow M_n = \frac{M_u}{\phi} = \frac{M_u}{0.9} = 8.64 \text{ KN} \cdot \text{m} \]

\[ \mathcal{R} = \frac{M_n}{b \cdot d^2} = 0.654 \text{ MPa} \]

\[ \mathcal{P} = 0.85 \cdot \frac{f'_c}{f_y} \cdot \left( 1 - \sqrt{1 - 2 \times \frac{R}{0.85 \cdot f'_c}} \right) = 0.00236 \]

\[ \mathcal{P}_{\text{max}} = 0.85 \cdot \frac{f'_c}{f_y} \cdot \frac{0.003}{0.003 + 0.004} = 0.0364 \]

\[ \Rightarrow \mathcal{P} \leq \mathcal{P}_{\text{max}} = 1 \]

\[ A_s = p \cdot b \cdot d = 2.714 \text{ cm}^2 \]

\[ A_{s_{\text{min}}} = \begin{cases} 0.002 \cdot b \cdot t & \text{if } f_y \leq 40 \text{ ksi} \Rightarrow A_{s_{\text{min}}} = 2.8 \text{ cm}^2 \\ 0.0018 \cdot b \cdot t & \text{if } f_y = 60 \text{ ksi} \\ \frac{0.0018 \cdot f_y}{60 \text{ ksi}} \cdot b \cdot t & \text{otherwise} \end{cases} \]

\[ A_{\text{req}} = \max \left( A_s, A_{s_{\text{min}}} \right) = 2.8499 \text{ cm}^2 \]
\[ S = \frac{TT (10 \text{ mm})^2}{4 As_{req}}, \text{ } b = 280 \text{ mm} \]

\[ S_{\text{max}} = \min(2t, 450 \text{ mm}) = 280 \text{ mm} \]

\[ As_{\text{req}} = \frac{b}{s} \cdot \frac{TT (10 \text{ mm})^2}{4} = 2.8499 \text{ cm}^2 \]

- Actual spacing:

\[ S_{\text{top}} = \text{Floor} (\min(s, s_{\text{max}}), 10 \text{ mm}) = 280 \text{ mm} \]

- Bottom reinforcements in short direction:

\[ M_u = M_{1 \text{ pos}} \cdot b = 5.35 \text{ KN.m} \]

\[ \Rightarrow M_n = \frac{M_u}{0.9} = 5.944 \text{ KN.m} \]

\[ R = \frac{M_n}{b \cdot d^2} = 0.449 \text{ MPa} \]

\[ \mathcal{P} = 0.85 \frac{f_y^1}{f_y} \left( 1 - \sqrt{1 - 2 \frac{R}{0.85 \cdot f_y^1}} \right) = 0.00162 \quad \mathcal{P} \leq \mathcal{P}_{\text{max}} = 1 \]

\[ As = \mathcal{P} \cdot b \cdot d = 1.86 \text{ cm}^2 \]

\[ As_{\text{req}} = \max(As, As_{\text{min}}) = 2.8499 \text{ cm}^2 \]

\[ S = \frac{\pi (10 \text{ mm})^2}{4 As_{\text{req}}}, \text{ } b = 275.6 \text{ mm} \]

\[ As_{\text{pro}} = \frac{b}{s} \cdot \frac{TT (10 \text{ mm})^2}{4} = 2.8499 \text{ cm}^2 \]
- Actual spacing:

\[
S_{bt} = \text{Floor} \left( \min \left( s, s_{\text{max}} \right), 10 \text{ mm} \right) = 275.6 \text{ mm}
\]

- Top reinforcements in long direction:

\[
M_u = M_{2\text{ neg}} \cdot b = 8.88 \text{ KN.m}
\]

\[
M_n = \frac{M_u}{0.9} = 9.867 \text{ KN.m}
\]

\[
R = \frac{M_n}{b \cdot d^2} = 0.746 \text{ MPa}
\]

\[
\mathcal{P} = 0.85 \frac{f_c^1}{f_y} \cdot \left( 1 - \sqrt{1 - 2 \cdot \frac{R}{0.85 \cdot f_c^1}} \right) = 0.00271
\]

\[
As = g \cdot b \cdot d = 3.117 \text{ cm}^2
\]

\[
As_{\text{req}} = \max( As, As_{\text{min}} ) = 3.117 \text{ cm}^2
\]

\[
S = \frac{\pi (10 \text{ mm})^2}{4 As_{\text{req}}} \cdot b = 251.97 \text{ mm}
\]

\[
As_{\text{pro}} = \frac{b}{s} \cdot \frac{TT (10 \text{ mm})^2}{4} = 3.117 \text{ cm}^2
\]

- Actual spacing:

\[
S_{\text{top}} = \text{Floor} \left( \min \left( s, s_{\text{max}} \right), 10 \text{ mm} \right) = 251.97 \text{ mm}
\]
- Bottom reinforcements in long direction:

\[ M_u = M_{2_{\text{pos}}} \cdot b = 6.1 \text{ KN.m} \]

\[ M_n = \frac{M_u}{0.9} = 6.778 \text{ KN.m} \]

\[ \mathcal{R} = \frac{M_n}{b \cdot d^2} = 0.5125 \text{ MPa} \]

\[ \mathcal{P} = 0.85 \frac{f'_{c}}{f'y} \cdot \left( 1 - \sqrt{1 - 2 \cdot \frac{\mathcal{R}}{0.85f'_{c}}} \right) = 0.00185 \quad \mathcal{P} \leq \mathcal{P}_{\text{max}} = 1 \]

\[ A_s = \rho \cdot b \cdot d = 2.13 \text{ cm}^2 \]

\[ A_{s_{\text{req}}} = \max(A_s, A_{s_{\text{min}}}) = 2.8 \text{ cm}^2 \]

\[ S = \frac{\pi (10 \text{ mm})^2}{4 A_{s_{\text{req}}} \cdot b} = 280.499 \text{ mm} \]

\[ A_{s_{\text{pro}}} = \frac{b}{s} \cdot \frac{TT (10 \text{ mm})^2}{4} = 2.8 \text{ cm}^2 \]

- Actual spacing:

\[ S_{\text{bot}} = \text{Floor} (\min (s, s_{\text{max}}), 10 \text{ mm}) = 280 \text{ mm} \]
4. **Beam Design**

1.4. **The Beam Selection In the Plan**

- I have selected this beam to design it manually.
- I selected the beam that will carry the greatest loads so that I am designing the maximum case.
- The building is shown in the next figure.
Design of Beams

- Loads on \((B_1)\):
  1) Own weight:
      Assume \(h = \frac{L}{10} \rightarrow \frac{L}{15} \Rightarrow \frac{480}{13} = 36.9 \approx 40 \text{ cm}\)
      Try \(h\) overall depth of the beam = 40 cm
      \(-b = 20 \text{ cm (width of wall)}\).
      \(\therefore\) own weight of \(B_1 = (0.2 \times 0.26 \times 24) \times 1.2 = 1.5 \text{ KN/m}\)

  2) Loads from slab \((S_1)\):
      \(w_{4t} = 9.26 \text{ KN/m}^2\)
      \(\therefore w - bend = \alpha \left(\frac{WS}{2}\right)\)
      \(\therefore w - shear = \beta \left(\frac{WS}{2}\right)\)

      \(\alpha = \left[1 - \frac{1}{3} \left(\frac{S}{L}\right)^2\right] = \left[1 - \frac{1}{3} \left(\frac{4.2}{4.7}\right)^2\right]
      = 0.73\)

      \(\beta = \left[1 - \frac{1}{2} \left(\frac{S}{L}\right)\right] = \left[1 - \frac{1}{2} \left(\frac{4.2}{4.7}\right)\right] = 0.55\)

      \(\therefore w - bend = \alpha \left(\frac{WS}{2}\right)
      = \frac{0.73 \times 9.26 \times 4.2}{2}
      = 14.2 \text{ KN/m}\)

      \(\therefore w - shear = \beta \left(\frac{WS}{2}\right)
      = \frac{0.55 \times 9.26 \times 4.2}{2}
      = 10.7 \text{ KN/m}\)

  3) Loads from \((S_2)\):
      \(\alpha = \left[1 - \frac{1}{3} \left(\frac{S}{L}\right)^2\right] = \left[1 - \frac{1}{3} \left(\frac{3.6}{4.7}\right)^2\right] = 0.80\)

      \(\beta = \left[1 - \frac{1}{2} \left(\frac{S}{L}\right)\right] = \left[1 - \frac{1}{2} \left(\frac{3.6}{4.7}\right)\right] = 0.62\)

      \(\therefore w - bend = \alpha \left(\frac{WS}{2}\right)
      = \frac{0.8 \times 9.26 \times 3.6}{2}
      = 13.3 \text{ KN/m}\)

      \(\therefore w - shear = \beta \left(\frac{WS}{2}\right)
      = \frac{0.62 \times 9.26 \times 8.6}{2}
      = 10.33 \text{ KN/m}\)
- Total loads on \((B_1)\) for bending = \(w_{bt}\)
  \[w_{bt} = \text{own weight} + \text{loads from slabs } (S_1, S_2)\]
  \[w_{bt} = 1.5 + 14.2 + 13.33 = 29 \text{ KN/m}\]

- Total loads on \((B_1)\) for shear = \(W_{sh}\)
  \[w_{sh} = 1.5 + 10.7 + 10.33 = 22.53 \text{ KN/m}\]

- Loads on \((B_2)\):
  1) Own weight:
     \[\therefore \text{own weight} = 1.5 \text{ KN/m}\]
  2) Loads from \((S_4)\):
     - First we need to find \((y)\):
       \[1.65 = \frac{1}{2} y \implies y = 3.3 \text{ m}\]
       \[x_2 = \frac{1}{2}(3.3)\sqrt{3} = 2.86 \text{ m}\]
     - Now using interpolation:
       \[y_1 = x_1 \frac{y_2}{x_2} = (1.4) \frac{9.26}{2.86}\]
       \[\Rightarrow y_1 = w_{at(1.4m)} = 4.5 \text{ KN/m}\]
       \[\text{Area of } \triangle = \text{load on } B_2\]
       \[= \frac{1}{2} (1.4)(4.5)\]
       \[= 3.15 \text{ KN}\]
       \[\Rightarrow w_{bt} = 1.5 \text{ KN/m}\]
       \[w_{sh} = 1.5 \text{ KN/m}\]
- **Loads on** $(B_3)$:
  1) **Own weight:**
     
     $= 1.5 \text{ KN/m}$
  
  2) **Loads from** $(S_4)$ on $(B_3)$:
     
     $\alpha = 0.76$
     
     $\beta = 0.57$
     
     $\therefore w - \text{bend} = \alpha \left( \frac{WS}{2} \right) = \frac{0.76 \times 9.26 \times 3.3}{2} = 11.6 \text{ KN/m}$
     
     $\therefore w - \text{shear} = \beta \left( \frac{WS}{2} \right) = \frac{0.57 \times 9.26 \times 3.3}{2} = 8.71 \text{ KN/m}$
  
  3) **Loads on** $(B_{13})$ from $(S_4)$ and $(S_6)$:
     
     - **From** $(S_4)$:
       
       $w - \text{bend} = \frac{2}{3} \left( \frac{WS}{2} \right) = \frac{9.26 \times 3.3}{3} = 10.2 \text{ KN/m}$
       
       $w - \text{shear} = \frac{1}{2} \left( \frac{WS}{2} \right) = \frac{9.26 \times 3.3}{4} = 7.64 \text{ KN/m}$

     - **From** $(S_6)$:
       
       $\alpha = 0.85$
       
       $\beta = 0.67$
       
       $w - \text{bend} = \frac{2}{3} \left( \frac{0.85 \times 9.26 \times 2.2}{2} \right) = 8.65 \text{ KN/m}$
       
       $w - \text{shear} = \frac{2}{3} \left( \frac{0.67 \times 9.26 \times 2.2}{2} \right) = 6.82 \text{ KN/m}$

     - $(B_{13})$ won weight $= 1.5 \text{ KN/m}$

- **Total loads on** $(B_{13})$ for bending:

  $w_{bt} = 1.5 + 8.65 + 10.2 = 20.35 \text{ KN/m}$

  Total loads on $(B_{13})$ for shear:

  $w_{bsh} = 1.5 + 7.64 + 6.82 = 15.96 \text{ KN/m}$
- Loads from \((S_6)\) on \((B_3)\):
  
  \[
  w - \text{bend} = \frac{2}{3} \left(\frac{WS}{2}\right) = \frac{9.26 \times 2.2}{3} = 6.8 \text{KN/m}
  \]
  
  \[
  w - \text{shear} = \frac{1}{2} \left(\frac{WS}{2}\right) = \frac{9.26 \times 2.2}{4} = 5.1 \text{KN/m}
  \]

1) Loads from \((S_5)\) and \((S_7)\) on \((B_{14})\):

\[
\alpha = 0.68
\]

\[
\beta = 0.51
\]

\[
w - \text{bend} = \alpha \left(\frac{WS}{2}\right) \times 2 = 0.68 \times 9.26 \times 3.55 = 22.35 \text{KN/m}
\]

\[
w - \text{shear} = \beta \left(\frac{WS}{2}\right) \times 2 = 0.51 \times 9.26 \times 3.55 = 16.76 \text{KN/m}
\]

- Won weight = 1.5 KN/m

- Total loads on \((B_{14})\) for bending:
  \[
w_{b,t} = 1.5 + 22.35 = 23.85 \text{KN/m}
  \]

- Total loads on \((B_{14})\) for shear:
  \[
w_{sh,t} = 1.5 + 16.76 = 18.26 \text{KN/m}
  \]

2) Loads from slab \((S_5)\) and \((S_7)\) on \((B_3)\):

\[
w - \text{bend} = \frac{2}{3} \left(\frac{WS}{2}\right) = \frac{9.26 \times 3.55}{3} \times 2 = 21.9 \text{KN/m}
\]

\[
w - \text{shear} = \frac{1}{2} \left(\frac{WS}{2}\right) = \frac{9.26 \times 3.55}{4} \times 2 = 16.4 \text{KN/m}
\]

- Total loads on \((B_3)\):
  \[
w_{b,t} = 1.5 + 11.6 + 21.9 + 6.8 = 35 \text{KN/m}
  \]
  
  \[
w_{sh,t} = 1.5 + 8.71 + 16.4 + 5.1 = 31.7 \text{KN/m}
  \]

- Concentrated loads:
  \[
p_1 = \frac{20.4}{2} \times 3.3 = 33.66 \text{KN}
  \]
  
  \[
p_2 = \frac{23.8}{2} \times 3.6 = 42.84 \text{KN}
  \]
- Loads on (B₄):

1) Own weight = 1.5 KN/m

2) Loads from (S₈):
   \[ w – bend = 10.95 KN/m \]
   \[ w – shear = 8.2 KN/m \]

   - Loads from (S₇) on (B₁₅):
     \[ w – bend = 11.2 KN/m \]
     \[ w – shear = 8.38 KN/m \]

   - Loads from (S₉) on (B₁₅):
     \[ w_b = 1.2 \times 9.26 = 11.1 KN/m \]

   ∴ won weight = 1.5 KN/m
   \[ \Rightarrow w_t = 22.3 + 1.5 = 24.8 KN/m \]

- Total loads on (B₄) for bending:
  \[ w_{b_t} = 22.65 KN/m \]

- Total loads on (B₄) for shear:
  \[ w_{sh_t} = 17.3 KN/m \]

- Concentrated loads:
  \[ p_3 = \frac{23.8}{2} \times 3.6 = 42.84 KN/m \]

- B₅ = B₁
  \[ \Rightarrow w_{b_t} = 29 KN/m \]
  \[ w_{sh_t} = 22.53 KN/m \]


\[ p_1 = 3.15\, KN \]
\[ p_2 = 33.66\, KN \]
\[ p_3 = 42.84\, KN \]
\[ p_4 = 42.84\, KN \]
Moment of Inertia

- For (AB):
  - \( b_f = \text{the smallest of} \):
    1) \( L/4 = \frac{17 \times 100}{4} = 118 \text{ cm} \leftarrow \text{control (smallest)} \)
    2) \( 16t + b_w = 16(14) + 20 = 244 \text{ cm} \)
    3) \( S_{aw} = \frac{420}{2} + \frac{125}{2} = 273 \text{ cm} \)

\[ \Rightarrow b_f = 118 \text{ cm} \]
\[ b_w = 20 \text{ cm} \]
\[ y = \frac{\sum AY}{\sum A} = \frac{14 \times 118 \times 7 + 20 \times 26 \times 27}{14 \times 118 + 20 \times 26} = \frac{25604}{2172} \]

\[ \Rightarrow y = 11.78 \text{ cm from the top} \]
\[ I_{AB} = \Sigma I_0 + Ad^2 = \frac{118 \times 14^3}{12} + 118 \times 14(11.78 - 7)^2 + \frac{20 \times 26^3}{12} + 20 \times 26(27 - 11.78)^2 \]

\[ I_{AB} = 2.15 \times 10^5 \text{cm}^4 \]
• For (BC):
  \( b_f = \text{the least of} : \)
  1) \( L/4 = \frac{14 \times 100}{4} = 35 \text{ cm} \leftarrow \text{control (smallest)} \)
  2) \( S_{av} = \frac{360 + 420}{2} = 390 \text{ cm} \)

16t + \( b_w = 244 \text{ cm} \)
  \( \Rightarrow b_f = 35 \text{ cm}, \quad b_w = 20 \text{ cm} \)

\[
\bar{y} = \frac{\sum AY}{\sum A} = \frac{35 \times 14 \times 7 + 20 \times 26 \times 27}{14 \times 35 + 20 \times 26} = \frac{17470}{1010} = 17.3 \text{ cm from the top}
\]

\[
l_{BC} = \Sigma l_0 + Ad^2 = \frac{35 \times 14^3}{12} + 35 \times 14 (17.3 - 7)^2
\]
\[
+ \frac{20 \times 26^3}{12} + 20 \times 26 (27 - 17.3)^2
\]

\( l_{BC} = 1.38 \times 10^5 \text{cm}^4 \)

• For (CD):
  \( b_f = \text{the least of} : \)
  1) \( L/4 = \frac{465}{4} = 116.25 \text{ cm} \leftarrow \text{(control – smallest)} \)
  2) \( S_{av} = \frac{360 + 420}{2} = 390 \text{ cm} \)
  3) \( 16t + b_w = 244 \text{ cm} \)
  \( \Rightarrow b_f = 116.25 \text{ cm}, \quad b_w = 20 \text{ cm} \)

\[
\bar{y} = \frac{\sum AY}{\sum A} = \frac{116.25 \times 14 \times 7 + 20 \times 26 \times 27}{14 \times 116.25 + 20 \times 26} = \frac{25432.5}{2147.5} = 11.84 \text{ cm}
\]

\[
l_{CD} = \Sigma l_0 + Ad^2 = \frac{116.25 \times 14^3}{12} + 116.25 \times 14 (11.84 - 7)^2
\]
\[
+ \frac{20 \times 26^3}{12} + 20 \times 26 (27 - 11.84)^2 = 2.135 \times 10^5 \text{cm}^4
\]

\( l_{CD} = 2.135 \times 10^5 \text{cm}^4 \)
• For (DE):
  o \( b_f = \text{the smallest of} \):
    1) \( L/4 = \frac{385}{4} = 96.25 \text{ cm} \approx 97 \text{ cm} \)
    2) \( S_{\text{av}} = \frac{360+420}{2} = 390 \text{ cm} \)
  16t + \( b_w = 244 \text{ cm} \)
  \( \Rightarrow b_f = 97 \text{ cm}, \quad b_w = 20 \text{ cm} \)

  \[ \bar{y} = \frac{\Sigma AY}{\Sigma A} = \frac{97 \times 14 \times 7 + 20 \times 26 \times 27}{14 \times 97 + 20 \times 26} = 12.5 \text{ cm} \]

  \[ I_{DE} = \Sigma I_0 + Ad^2 = \frac{97 \times 14^3}{12} + 97 \times (12.5 - 7)^2 \]

  \[ + \frac{20 \times 26^3}{12} + 20 \times 26 (27 - 12.5)^2 \]

  \[ I_{DE} = 2.02 \times 10^5 \text{ cm}^4 \]

• For (EF):
  o \( b_f = \text{the least of} \):
    1) \( L/4 = \frac{320}{4} = 80 \text{ cm} \)
    2) \( S_{\text{av}} = \frac{360+420}{2} = 390 \text{ cm} \)
    3) \( 16t + b_w = 244 \text{ cm} \)
  \( \Rightarrow b_f = 80 \text{ cm}, \quad b_w = 20 \text{ cm} \)

  \[ \bar{y} = \frac{\Sigma AY}{\Sigma A} = \frac{80 \times 14 \times 7 + 20 \times 26 \times 27}{14 \times 80 + 20 \times 26} = 13.4 \text{ cm} \]

  \[ I_{EF} = \Sigma I_0 + Ad^2 = \frac{80 \times 14^3}{12} + 80 \times 14 (13.4 - 7)^2 \]

  \[ + \frac{20 \times 26^3}{12} + 20 \times 26 (27 - 13.4)^2 \]

  \[ I_{EF} = 1.90 \times 10^5 \text{ cm}^4 \]
The Stiffness

<table>
<thead>
<tr>
<th>Member</th>
<th>I/L</th>
<th>Relative (K)</th>
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<tbody>
<tr>
<td>AB</td>
<td>457.5</td>
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</tr>
<tr>
<td>BC</td>
<td>985.7</td>
<td>4.31</td>
</tr>
<tr>
<td>CD</td>
<td>459.1</td>
<td>2</td>
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<tr>
<td>DE</td>
<td>524.7</td>
<td>2.3</td>
</tr>
<tr>
<td>EF</td>
<td>593.8</td>
<td>2.6</td>
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</table>
Distribution Factor

\[ D_{AB} = D_{FE} = 1 \]

\[ D_{BA} = \frac{2}{2 + 4.31} = 0.32 \]

\[ D_{BC} = \frac{4.31}{2 + 4.31} = 0.68 \]

\[ D_{CB} = \frac{4.31}{2 + 4.31} = 0.68 \]

\[ D_{CD} = \frac{2}{2 + 4.31} = 0.32 \]

\[ D_{DC} = \frac{2}{2 + 2.3} = 0.47 \]

\[ D_{DE} = \frac{2.3}{2 + 2.3} = 0.53 \]

\[ D_{ED} = \frac{2.3}{2.6 + 2.3} = 0.47 \]

\[ D_{EF} = \frac{2.6}{2.6 + 2.3} = 0.53 \]
Fixed End Moment

\[
M_{AB} = + \frac{wl^2}{12} = \frac{29 \times 4.7^2}{12} = +53.4 \text{ KN.m}
\]

\[
M_{BA} = - \frac{wl^2}{12} = - 53.4 \text{ KN.m}
\]

\[
M_{BC} = + \frac{wl^2}{12} + \frac{P_1 ab^2}{L^2} = + \frac{1.5 \times 1.4^2}{12} + \frac{3.15 \times 0.93 \times 0.47^2}{1.4^2} = 0.58 \text{ KN.m} \approx 0.6 \text{ KN.m}
\]

\[
M_{CB} = - \frac{wl^2}{12} - \frac{P_1 a^2 b}{L^2} = - \frac{1.5 \times 1.4^2}{12} - \frac{3.15 \times 0.93 \times 0.47}{1.4^2} = - 0.9 \text{ KN.m}
\]

\[
M_{CD} = + \frac{wl^2}{12} + \frac{P_2 ab^2}{L^2} + \frac{P_3 ab^2}{L^2}
\]

\[
= + \frac{35 \times 4.65^2}{12} + \frac{33.66 \times 2.45 \times 2.2^2}{4.65^2} + \frac{42.84 \times 3.55 \times 1.1^2}{4.64^2}
\]

\[
= + 90 \text{ KN.m}
\]

\[
M_{DC} = - \frac{wl^2}{12} - \frac{P_2 a^2 b}{L^2} - \frac{P_3 a^2 b}{L^2} = - 111.2 \text{ KN.m} \approx -111 \text{ KN.m}
\]

\[
M_{DE} = + \frac{wl^2}{12} + \frac{P_4 ab^2}{L^2} = + \frac{22.65 \times 3.95^2}{12} + \frac{42.84 \times 2.45 \times 1.4^2}{3.85^2} = + 42 \text{ KN.m} M_{ED} = - \frac{wl^2}{12} - \frac{P_4 a^2 b}{L^2} = - 52 \text{ KN.m}
\]

\[
M_{EF} = + \frac{wl^2}{12} = + \frac{29 \times 3.2^2}{12} = + 25 \text{ KN.m}
\]

Cantilever Beam (FG)

\[
M_{FG} = -M_{FG} = - \frac{PL^2}{2} = - \frac{43.5 \times 1.5^2}{2} = - 33 \text{ KN.m}
\]
<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
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<tr>
<td>D.F</td>
<td>1</td>
<td>0.32</td>
<td>0.68</td>
<td>0.68</td>
<td>0.32</td>
<td>0.47</td>
<td>0.53</td>
<td>0.47</td>
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<td>-90</td>
<td>111</td>
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<td>F.E.M</td>
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<td>-25.4</td>
<td>54.1</td>
<td>68.6</td>
<td>28.512</td>
<td>31.7</td>
<td>-35.7</td>
<td>-27.4</td>
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<tr>
<td>C.O.</td>
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<td>-20.6</td>
<td>29.2</td>
<td>13.7</td>
<td>-0.25</td>
<td>-0.29</td>
<td>8.4</td>
<td>9.4</td>
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<td>Distribution</td>
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<tr>
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<td>-6.9</td>
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<td>-5.2</td>
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<td>-3.45</td>
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<tr>
<td>C.O.</td>
<td>1.1</td>
<td>2.35</td>
<td>5.13</td>
<td>2.42</td>
<td>0.75</td>
<td>0.85</td>
<td>1.4</td>
<td>1.6</td>
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<td>Distribution</td>
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<td>2.6</td>
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<tr>
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<td>-1.8</td>
<td>-1.1</td>
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<td>-0.9</td>
<td>-1</td>
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<td>-0.23</td>
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<td>67.3</td>
<td>-67.3</td>
<td>94.4</td>
<td>-94.5</td>
<td>28.5</td>
<td>-28.5</td>
</tr>
</tbody>
</table>

- If we assume support A and F is hinge
- \( M = 0 \) around them both
- All moments are in KN.m
STRUCTURAL DESIGN PROJECT

M O H A M M E D  Q A I D A L - Z I Y A D I
Design for Max. negative moment: at support D:

\[ M_u = -94.5 \text{ KN.m} \]

The section is considered a rectangular section with:

\[ b = b_w, \text{let } (h = 0.6m, b_w = 0.2m) \]

\[ \Rightarrow R_u = \frac{M_u}{\theta bd^2} = \frac{94.5}{0.9 \times 0.2 \times 0.56} = 938 \text{ KN/m}^2 \]

- From (ACI 318.08) tables:

\[ P = 0.75 P_b = (0.75)(0.02) = 0.015 \]

\[ d = 60 - 4 = 56 \text{ cm} \]

\[ \Rightarrow A_s (\text{Required}) = P \cdot b \cdot d = 0.015 \times 200 \times 560 \]

\[ A_s = 1680 \text{ mm}^2 \quad \text{use } 9 \varnothing 16 \]

\[ A_s = 1809 \text{ mm}^2 \]

- Check provided \( \phi M_n \):

\[ a = \frac{A_s f_y}{0.85 b f_c} = \frac{(18.09)(420)}{0.85 (20 \times 28)} = 15.96 \text{ cm} \]

\[ \phi M_n = \phi f_y A_s (d \cdot \frac{a}{2}) \]

\[ = (0.9)(420) \times 1000 \times (18.09 \times 10 - 4) \left(0.56 - \frac{0.1596}{2}\right) \]

\[ \phi M_n = 328 \text{ KN.m} > M_u = 94.5 \text{ KN.m} \]
Design for Max. positive moment beam (D.E):

\[ M_u = 114.9 \text{ KN.m} \]

- The minimum of: (in inches):
  1) \[ \frac{L}{4} = 96.25 \text{ cm} \leftarrow \text{min} \]
  2) \[ b_{\text{min}} 16t = 244 \text{ cm} \]
  3) \[ \phi \cdot \phi = 385 \text{ cm} \]

\[ b_e = 96.25 = 0.9625 \text{m} \]

\[ \phi M_n = 0.85 \phi f'_c \cdot b_e \cdot t \cdot (d - t/2) \]

\[ = 0.85 \cdot (0.9) \cdot (28000) \cdot (0.9625) \cdot (0.14) \cdot (0.56 - 0.14/2) \]

\[ \phi M_n = 1414 \text{ KN.m} > M_u = 114.9 \text{ KN.m} \]

\[ R_n = \frac{M_u}{\phi bd^2} = \frac{114.9}{(0.9)(0.2)(0.56)^2} = 2036 \text{ KN/m}^2 \]

\[ m = \frac{f_y}{0.85f_c} = \frac{420}{(0.85)(28)} = 17.65 \]

\[ \phi = \frac{1}{m} \left( 1 - \sqrt{1 - \frac{2mR_n}{f_y}} \right) = 0.00507 \]

\[ A_s = \phi db = 0.00507 \times 0.2 \times 0.56 = 568 \text{ mm}^2 \]

choose 3 \( \phi 16 \), \[ A_s = 603 \text{ mm}^2 \]
Shear Reinforcement:

\[ V_u = 137.6 \text{ KN} \]

\[ V_c = 0.17 \sqrt{f'_c} \quad bw \times d = 0.17 \times \sqrt{28} \times 0.2 \times 0.56 \times 1000 \]

\[ V_c = 100.75 \text{ KN} \]

\[ V_s = \frac{1}{\phi} (V_u - \phi V_c) = \frac{1}{0.75} (137.6 - 0.75 (100.75)) \]

\[ V_s = 82.7 \text{ KN} \]

\[ V_{s_{max}} = 2V_c = 2 \times 100.75 = 201.5 \text{ KN} > V_s = 82.7 \text{ KN} \]

\[ S = \frac{d}{2} = \frac{56}{2} = 28 \text{ cm} \]

*use 8mm @ 14 cm*
Chapter 8: Phase D: Design Building Structural using STAAD Pro.

1. Design methodology:

- Draw the model of the building in STAAD Pro.
- Chose ACI code in the design.
- Get the steel area for each column.
- Compare the steel area of each column with the other columns & try to end up with few numbers of columns to ease the construction process.
- Draw the cross section for each type of columns showing the steel bars.
- Get the steel area for each beam.
- Compare the steel area of each beam with the other beams & try to end up with few numbers of beams to ease the construction process.
- Draw the cross section for each type of beams showing the steel bars.
2. *Modeling the building using STAAD Pro:*

*Figure 11 Load Distribution in all floors*

*Figure 12 The Building in STAAD Pro just beams & columns*
Figure 14 The Load Distribution in the First Floor

Figure 13 3-D Model for the Structure of the Building
3. Column Design For The First Floor:

3.1. Extract and read the results from STAAD Pro:

- There were 1500 pages full of information as shown in Figure 15.
- It was hard and lengthy process to get the information about every column then try to illustrates them in a nice way to show the steel area for each column.
- Then compare the results to have only few types of columns.
- All structural drawings will be provided in Appendix A with proper scale.

Figure 16 Example #1 of Data extracted from STAAD Pro

<table>
<thead>
<tr>
<th>Load No.</th>
<th>Load</th>
<th>Design Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3</td>
<td>Fy(Mpa) 420</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fc(Mpa) 28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>As Reqd(mm²) 1200.000000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aₜ (%) 1.047000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bar Size 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bar No. 4</td>
</tr>
</tbody>
</table>

Figure 15 Example #2 of the results from STAAD Pro
After extracting all the Data needed from STAAD Pro the results are shown below was written on the first floor plan after trying different cross sectional area for columns so the design will have no failures. (Plan with proper scale will be provided in Appendix A). additionally, at the first trial I ended up with 7 different columns each with its own area of steel:
The second trial I changed the cross sectional areas of the columns to a better design and to take more loads and I ended up with this structural plans for columns (a plan with proper scale will be provided in Appendix A):
<table>
<thead>
<tr>
<th>COLUMN NUMBER</th>
<th>AREA OF COLUMN</th>
<th>REINFORCEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>C#1</td>
<td>0.2 * 0.6 M</td>
<td>8 #16</td>
</tr>
<tr>
<td>C#2</td>
<td>0.2 * 0.7 M</td>
<td>10 #16</td>
</tr>
<tr>
<td>C#3</td>
<td>0.2 * 0.8 M</td>
<td>14 #16</td>
</tr>
<tr>
<td>C#4</td>
<td>0.2 * 0.9 M</td>
<td>16 #16</td>
</tr>
<tr>
<td>C#5</td>
<td>0.5 * 0.5 M</td>
<td>14 #16</td>
</tr>
</tbody>
</table>

Figure 17: Column reinforcement
4. Beam Design:

4.1. Extract and read the results from STAAD Pro:

- There was 1500 pages full information as shown in Figure 18.
- It was hard and lengthy process to get the information about every beam then try to illustrates them in a nice way to show the steel area for each beam.
- Then compare the results to have only few types of beams.
- All structural drawings will be provided in Appendix A with proper scale.

Figure 18 Example #1 on Beam design and information from STAAD Pro on beams
**BEAM NO. 1 DESIGN RESULTS - FLEXURE PER CODE ACI 318-05**

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>HEIGHT (MM)</th>
<th>BAR INFO</th>
<th>FROM (MM)</th>
<th>TO (MM)</th>
<th>ANCHOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>61</td>
<td>2 - 20MM</td>
<td>0</td>
<td>4872</td>
<td>YES NO</td>
</tr>
<tr>
<td>2</td>
<td>543</td>
<td>2 - 12MM</td>
<td>0</td>
<td>447</td>
<td>YES NO</td>
</tr>
<tr>
<td>3</td>
<td>539</td>
<td>2 - 20MM</td>
<td>3652</td>
<td>5700</td>
<td>NO YES</td>
</tr>
</tbody>
</table>

**BEAM NO. 1 DESIGN RESULTS - SHEAR**

AT START SUPPORT - $V_U = 77.16$ KNS $V_C = 104.94$ KNS $V_S = 0.00$ KNS

$T_U = 4.16$ KN-MET $T_C = 3.0$ KN-MET $T_S = 5.6$ KN-MET LOAD 3

STIRRUPS ARE REQUIRED FOR TORSION.

REINFORCEMENT FOR SHEAR IS PER CL.11.5.5.1.

PROVIDE 12 MM 2-LEGGED STIRRUPS AT 156. MM C/C FOR 2313. MM

ADDITIONAL LONGITUDINAL STEEL REQD. FOR TORSIONAL RESISTANCE = 1.69 SQ.CM.

AT END SUPPORT - $V_U = 107.63$ KNS $V_C = 103.60$ KNS $V_S = 39.92$ KNS

$T_U = 4.16$ KN-MET $T_C = 3.0$ KN-MET $T_S = 5.6$ KN-MET LOAD 3

STIRRUPS ARE REQUIRED FOR SHEAR AND TORSION.

PROVIDE 12 MM 2-LEGGED STIRRUPS AT 156. MM C/C FOR 2313. MM

ADDITIONAL LONGITUDINAL STEEL REQD. FOR TORSIONAL RESISTANCE = 1.69 SQ.CM.

---

*Figure 19 Example #2 the results got from STAAD Pro for beams*
There are 137 beams in the second floor plan (As shown in Appendix A in proper scale) as shown below and after studying all the results and comparing them with each other, there were just 6 different types of beams which are:

![Figure 20 Beams Types across the second floor plan](image)
As shown in Appendix D, the results were combined to form just 6 types of beams which are:

Table 1 Beam Types

<table>
<thead>
<tr>
<th>Beam #</th>
<th>Dimension</th>
<th>Bottom R. #</th>
<th>Top right R. #</th>
<th>Top left R. #</th>
<th>Stirrups # 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>B₁</td>
<td>200*600</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>@ 272 c/c</td>
</tr>
<tr>
<td>B₂</td>
<td>200*600</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>@ 272 c/c</td>
</tr>
<tr>
<td>B₃</td>
<td>200*600</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>@ 270 c/c</td>
</tr>
<tr>
<td>B₄</td>
<td>200*600</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>@ 270 c/c</td>
</tr>
<tr>
<td>B₅</td>
<td>200*600</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>@ 270 c/c</td>
</tr>
<tr>
<td>B₆</td>
<td>200*600</td>
<td>3</td>
<td>6</td>
<td>6</td>
<td>@ 156 c/c</td>
</tr>
</tbody>
</table>
Chapter 9: Phase E: Design the foundation using STAAD Foundation

- After getting all the information needed from STAAD Pro, the STAAD Pro file was imported to STAAD Foundation.
- All the inputs were blogged then the design process started.
- After taken the results and studying them I compared them with each other.
- Then, I design the foundation system for the building.
- All the results and the foundation plan are in Appendix A.
- Example of the manual calculation of the footing are included in Appendix D.
Structural Engineering Ethics

Fundamental Purpose

This Code of Ethics is provided as guidance for individual structural engineers, and applies to the responsible individual who provides professional services in the analysis, assessment, design, construction, or repair of buildings, bridges, and other structures.

All of the Fundamental Principles, Tenets and Guidelines should be applied in accordance with the standards of skill and care generally exercised by other structural engineers in the same locale acting under similar circumstances and conditions.

Fundamental Principles

To uphold and advance the integrity, honor and dignity of the structural engineering profession by:

1. using their knowledge and skill for the enhancement of human welfare;
2. being honest and impartial in serving with fidelity the public, their employers and clients; and
3. striving to increase the competence of practitioners and the prestige of the structural engineering profession.

Fundamental Tenets

Structural engineers:

1. use their knowledge and skill in the performance of their professional duties to make decisions in the interest of the safety, health, and welfare of the public.
2. perform services only in areas of their competence.
3. issue public statements in an objective and honest manner.
4. act for each employer or client as faithful agents or trustees, and avoid conflicts of interest.
5. build their professional reputation on merit and compete fairly with others.
6. act in such a manner as to uphold and enhance the honor, integrity, and dignity of the structural engineering profession, without tolerance for corruption.
7. continue their professional development throughout their careers, and provide opportunities for the professional development of others.

NCSEA (National Council of Structural Engineers Associations) wishes to acknowledge and thank the American Society of Civil Engineers (ASCE), whose Code of Ethics was used as the basis for this document.
Appendix A
Figure 21 bending moment diagram in 3-D
Appendix B
Table 2: Allowable Bearing Pressures

<table>
<thead>
<tr>
<th>CLASS OF MATERIALS</th>
<th>MAXIMUM ALLOWABLE FOUNDATION PRESSURE (TSF)</th>
<th>MAXIMUM ALLOWABLE FOUNDATION PRESSURE (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bedrock (Notes 2 and 7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1a Hard sound rock—gneiss, diabase, schist</td>
<td>60</td>
<td>5,746</td>
</tr>
<tr>
<td>1b Medium hard rock—marble, serpentine</td>
<td>40</td>
<td>3,830</td>
</tr>
<tr>
<td>1c Intermediate rock—shale, sandstone</td>
<td>20</td>
<td>1,915</td>
</tr>
<tr>
<td>1d Soft rock—weathered rock</td>
<td>8</td>
<td>766</td>
</tr>
<tr>
<td>2. Sandy gravel and gravel (GW, GP) (Notes 3, 4, 8, and 9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2a Dense</td>
<td>10</td>
<td>958</td>
</tr>
<tr>
<td>2b Medium</td>
<td>6</td>
<td>575</td>
</tr>
<tr>
<td>3. Granular soils (GC, GM, SW, SP,SM, and SC) (Notes 4, 5, 8, and 9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3a Dense</td>
<td>6</td>
<td>575</td>
</tr>
<tr>
<td>3b Medium</td>
<td>3</td>
<td>287</td>
</tr>
<tr>
<td>4. Clays (SC, CL, and CH) (Notes 4, 6, 8, and 9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4a Hard</td>
<td>5</td>
<td>479</td>
</tr>
<tr>
<td>4b Stiff</td>
<td>3</td>
<td>287</td>
</tr>
<tr>
<td>4c Medium</td>
<td>2</td>
<td>192</td>
</tr>
<tr>
<td>5. Silts and silty soils (ML and MH) (Notes 4, 8, and 9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5a Dense</td>
<td>3</td>
<td>287</td>
</tr>
<tr>
<td>5b Medium</td>
<td>1.5</td>
<td>144</td>
</tr>
<tr>
<td>6. Organic silts, organic clays, peats, soft clays, loose granular soils and varved silts</td>
<td>See 1804.2.1</td>
<td>See 1804.2.1</td>
</tr>
<tr>
<td>7. Controlled and uncontrolled fills</td>
<td>See 1804.2.2 or 1804.2.3</td>
<td>See 1804.2.2 or 1804.2.3</td>
</tr>
</tbody>
</table>

(Tables)
### Table 3 Minimum uniformly distributed live loads

<table>
<thead>
<tr>
<th>Occupancy or Use</th>
<th>Uniform psf (kN/m²)</th>
<th>Conc. lbs (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grandstands (see stadium and arena bleachers)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gymnasiums, main floors, and balconies</td>
<td>100 (4.79) Note (4)</td>
<td></td>
</tr>
<tr>
<td>Handrails, guardrails, and grab bars</td>
<td>See Section 4.4</td>
<td></td>
</tr>
<tr>
<td>Hospitals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating rooms, laboratories</td>
<td>60 (2.87)</td>
<td>1000 (4.45)</td>
</tr>
<tr>
<td>Private rooms</td>
<td>40 (1.92)</td>
<td>1000 (4.45)</td>
</tr>
<tr>
<td>Wards</td>
<td>40 (1.92)</td>
<td>1000 (4.45)</td>
</tr>
<tr>
<td>Corridors above first floor</td>
<td>80 (3.83)</td>
<td>1000 (4.45)</td>
</tr>
<tr>
<td>Hotels (see residential)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Libraries</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reading rooms</td>
<td>60 (2.87)</td>
<td>1000 (4.45)</td>
</tr>
<tr>
<td>Stack rooms</td>
<td>150 (7.18) Note (3)</td>
<td>1000 (4.45)</td>
</tr>
<tr>
<td>Corridors above first floor</td>
<td>80 (3.83)</td>
<td>1000 (4.45)</td>
</tr>
<tr>
<td>Penal institutions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cell blocks</td>
<td>40 (1.92)</td>
<td></td>
</tr>
<tr>
<td>Corridors</td>
<td>100 (4.79)</td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dwellings (one- and two-family)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uninhabitable attics without storage</td>
<td>10 (0.48)</td>
<td></td>
</tr>
<tr>
<td>Uninhabitable attics with storage</td>
<td>20 (0.96)</td>
<td></td>
</tr>
<tr>
<td>Habitable attics and sleeping areas</td>
<td>30 (1.44)</td>
<td></td>
</tr>
<tr>
<td>All other areas except stairs and balconies</td>
<td>40 (1.92)</td>
<td></td>
</tr>
<tr>
<td>Hotels and multifamily houses</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Private rooms and corridors serving them</strong></td>
<td>40 (1.92)</td>
<td></td>
</tr>
<tr>
<td><strong>Public rooms and corridors serving them</strong></td>
<td>100 (4.79)</td>
<td></td>
</tr>
</tbody>
</table>

ACI 318-08
Table 4: Minimum Densities for design loads from materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (kN/m³)</th>
<th>Material</th>
<th>Density (kN/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>26.5</td>
<td>Earth (submerged)</td>
<td>12.5</td>
</tr>
<tr>
<td>Bituminous products</td>
<td></td>
<td>Clay</td>
<td>11.0</td>
</tr>
<tr>
<td>Asphaltum</td>
<td>13.0</td>
<td>Soil</td>
<td>11.0</td>
</tr>
<tr>
<td>Graphite</td>
<td>21.0</td>
<td>River mud</td>
<td>14.0</td>
</tr>
<tr>
<td>Paraffin</td>
<td>9.0</td>
<td>Sand or gravel</td>
<td>9.5</td>
</tr>
<tr>
<td>Petroleum, crude</td>
<td>8.5</td>
<td>Sand or gravel and clay</td>
<td>10.0</td>
</tr>
<tr>
<td>Petroleum, refined</td>
<td>8.0</td>
<td>Glass</td>
<td>25.0</td>
</tr>
<tr>
<td>Petroleum, benzine</td>
<td>7.0</td>
<td>Gravel, dry</td>
<td>16.5</td>
</tr>
<tr>
<td>Petroleum, gasoline</td>
<td>6.5</td>
<td>Gypsum, loose</td>
<td>11.0</td>
</tr>
<tr>
<td>Pitch</td>
<td>11.0</td>
<td>Gypsum, wallboard</td>
<td>8.0</td>
</tr>
<tr>
<td>Tar</td>
<td>12.0</td>
<td>Ice</td>
<td>9.0</td>
</tr>
<tr>
<td>Brass</td>
<td>82.5</td>
<td>Iron</td>
<td>71.0</td>
</tr>
<tr>
<td>Bronze</td>
<td>87.0</td>
<td>Cast</td>
<td>75.5</td>
</tr>
<tr>
<td>Cast-stone masonry (cement, stone, sand)</td>
<td>23.0</td>
<td>Wrought</td>
<td>111.5</td>
</tr>
<tr>
<td>Cement, portland, loose</td>
<td>14.0</td>
<td>Lead</td>
<td></td>
</tr>
<tr>
<td>Ceramic tile</td>
<td>23.5</td>
<td>Lime</td>
<td></td>
</tr>
<tr>
<td>Charcoal</td>
<td>2.0</td>
<td>Hydrated, loose</td>
<td>5.0</td>
</tr>
<tr>
<td>Cinder fill</td>
<td>9.0</td>
<td>Hydrated, compacted</td>
<td>7.0</td>
</tr>
<tr>
<td>Cinders, dry, in bulk</td>
<td>7.0</td>
<td>Masonry, Ashlar stone</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td></td>
<td>Granite</td>
<td>26.0</td>
</tr>
<tr>
<td>Anthracite, piled</td>
<td>8.0</td>
<td>Limestone, crystalline</td>
<td>26.0</td>
</tr>
<tr>
<td>Bituminous, piled</td>
<td>7.5</td>
<td>Limestone, oolithic</td>
<td>21.0</td>
</tr>
<tr>
<td>Lignite, piled</td>
<td>7.5</td>
<td>Marble</td>
<td>27.0</td>
</tr>
<tr>
<td>Peat, dry, piled</td>
<td>3.5</td>
<td>Sandstone</td>
<td>23.0</td>
</tr>
<tr>
<td>Concrete, plain</td>
<td></td>
<td>Masonry, brick</td>
<td></td>
</tr>
<tr>
<td>Cinder</td>
<td>17.0</td>
<td>Hard (low absorption)</td>
<td>20.5</td>
</tr>
<tr>
<td>Expanded-slag aggregate</td>
<td>16.0</td>
<td>Medium (medium absorption)</td>
<td>18.0</td>
</tr>
<tr>
<td>Haydite (burned-clay aggregate)</td>
<td>14.0</td>
<td>Soft (high absorption)</td>
<td>16.0</td>
</tr>
<tr>
<td>Slag</td>
<td>21.0</td>
<td>Masonry, concrete*</td>
<td></td>
</tr>
<tr>
<td>Stone (including gravel)</td>
<td>23.0</td>
<td>Lightweight units</td>
<td>16.5</td>
</tr>
<tr>
<td>Vermiculite and perlite aggregate, non-load-bearing</td>
<td>4.0-8.0</td>
<td>Medium weight units</td>
<td>19.5</td>
</tr>
<tr>
<td>Other light aggregate, load-bearing</td>
<td>11.0-16.5</td>
<td>Normal weight units</td>
<td>21.0</td>
</tr>
<tr>
<td>Concrete, reinforced</td>
<td></td>
<td>Masonry grout</td>
<td>22.0</td>
</tr>
<tr>
<td>Cinder</td>
<td>17.5</td>
<td>Masonry, rubble stone</td>
<td>24.0</td>
</tr>
<tr>
<td>Slag</td>
<td>22.0</td>
<td>Granite</td>
<td></td>
</tr>
<tr>
<td>Stone (including gravel)</td>
<td>24.0</td>
<td>Limestone, crystalline</td>
<td>23.0</td>
</tr>
<tr>
<td>Copper</td>
<td>87.5</td>
<td>Limestone, oolithic</td>
<td>22.0</td>
</tr>
<tr>
<td>Cork, compressed</td>
<td>2.0</td>
<td>Marble</td>
<td>24.5</td>
</tr>
<tr>
<td>Earth (not submerged)</td>
<td>10.0</td>
<td>Sandstone</td>
<td>21.5</td>
</tr>
<tr>
<td>Clay, dry</td>
<td>17.5</td>
<td>Mortar, cement or lime</td>
<td>20.5</td>
</tr>
<tr>
<td>Clay, damp</td>
<td></td>
<td>Particleboard</td>
<td>7.0</td>
</tr>
</tbody>
</table>

12 Saudi Building Code (SBC)
### Table 3-1: Minimum Design Dead Loads

<table>
<thead>
<tr>
<th>Component</th>
<th>Load (kN/m²)</th>
<th>Component</th>
<th>Load (kN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COVERINGS, ROOF, AND WALL</strong></td>
<td></td>
<td><strong>FLOORS AND FLOOR FINISHES</strong></td>
<td></td>
</tr>
<tr>
<td>Asbestos-cement shingles</td>
<td>0.20</td>
<td>Asphalt block (50 mm), 13 mm mortar</td>
<td>1.45</td>
</tr>
<tr>
<td>Asphalt shingles</td>
<td>0.10</td>
<td>Cement finish (25 mm) on stone-concrete fill</td>
<td>1.55</td>
</tr>
<tr>
<td>Cement tile</td>
<td>0.80</td>
<td>Ceramic or quarry tile (20 mm) on 13 mm mortar bed</td>
<td>0.80</td>
</tr>
<tr>
<td>Clay tile (for mortar add 0.50 kN/m²)</td>
<td>0.60</td>
<td>Ceramic or quarry tile (20 mm) on 25 mm mortar bed</td>
<td>0.023</td>
</tr>
<tr>
<td>Book tile, 50 mm</td>
<td>1.00</td>
<td>Concrete fill finish (per mm thickness)</td>
<td>0.20</td>
</tr>
<tr>
<td>Book tile, 75 mm</td>
<td>1.00</td>
<td>Hardwood flooring, 20 mm</td>
<td>0.20</td>
</tr>
<tr>
<td>Ludowici</td>
<td>0.50</td>
<td>Linoleum or asphalt tile, 6 mm</td>
<td>0.05</td>
</tr>
<tr>
<td>Roman</td>
<td>0.60</td>
<td>Marble and mortar on stone-concrete fill</td>
<td>1.60</td>
</tr>
<tr>
<td>Spanish</td>
<td>0.90</td>
<td>Slate (per mm thickness)</td>
<td>0.03</td>
</tr>
<tr>
<td>Composition:</td>
<td></td>
<td>Solid flat tile on 25 mm mortar base</td>
<td>1.10</td>
</tr>
<tr>
<td>Three-ply ready roofing</td>
<td>0.05</td>
<td>Subflooring, 20 mm</td>
<td>0.15</td>
</tr>
<tr>
<td>Four-ply felt and gravel</td>
<td>0.25</td>
<td>Terrazzo (38 mm) directly on slab</td>
<td>0.90</td>
</tr>
<tr>
<td>Five-ply felt and gravel</td>
<td>0.30</td>
<td>Terrazzo (25 mm) on stone-concrete fill</td>
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<td>Copper or tin</td>
<td>0.05</td>
<td>Terrazzo (25 mm), on 50 mm stone concrete</td>
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<tr>
<td>Corrugated asbestos-cement roofing</td>
<td>0.20</td>
<td>Wood block (75 mm) on mastic, no fill</td>
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<tr>
<td>Deck, metal, 20 gage</td>
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<td>Wood block (75 mm) on 13 mm mortar base</td>
<td>0.80</td>
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<tr>
<td>Deck, metal, 18 gage</td>
<td>0.15</td>
<td></td>
<td></td>
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<tr>
<td>Decking, 50 mm wood (Douglas fir)</td>
<td>0.25</td>
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<td></td>
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<tr>
<td>Decking, 75 mm wood (Douglas fir)</td>
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<tr>
<td>Fiberboard, 13 mm</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Gypsum sheathing, 13 mm</td>
<td>0.10</td>
<td><strong>FRAME PARTITIONS</strong></td>
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<tr>
<td>Insulation, roof boards (per mm thickness)</td>
<td>0.0015</td>
<td>Movable steel partitions</td>
<td>0.20</td>
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<tr>
<td>Cellular glass</td>
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<tr>
<td>Fibrous glass</td>
<td>0.002</td>
<td>each side</td>
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<tr>
<td>Fiberboard</td>
<td>0.003</td>
<td>Wood studs, 50 x 100, unplastered</td>
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<tr>
<td>Perlite</td>
<td>0.0015</td>
<td>Wood studs, 50 x 100, plastered one side</td>
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<td>Polystyrene foam</td>
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<td>Urethane foam with skin</td>
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<tr>
<td>Plywood (per mm thickness)</td>
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<td>Rigid insulation, 13 mm</td>
<td>0.05</td>
<td>Exterior stud walls with brick vencer</td>
<td>2.30</td>
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<td>Skylight, metal frame, 10 mm wire glass</td>
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<td>Windows, glass, frame and sash</td>
<td>0.40</td>
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<tr>
<td>Slate, 5 mm</td>
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<td>Clay brick wythes:</td>
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<td>Slate, 6 mm</td>
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<td>100 mm</td>
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<td>Waterproofing membranes:</td>
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<td>Bituminous, gravel-covered</td>
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<td>Bituminous, smooth surface</td>
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<td>Single-ply, sheet</td>
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<td>Wood sheathing (per mm thickness)</td>
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<td><strong>CEILINGS</strong></td>
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<td>Wood shingles</td>
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<td>Acoustical fiberboard</td>
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<tr>
<td>FLOOR FILL</td>
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<td>Lightweight concrete, per mm</td>
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<td>Plaster on tile or concrete</td>
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<tr>
<td>Sand, per mm</td>
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<td>Plaster on wood lath</td>
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<tr>
<td>Stone concrete, per mm</td>
<td>0.023</td>
<td>Suspended steel channel system</td>
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<td></td>
<td></td>
<td>Suspended metal lath and cement plaster</td>
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<tr>
<td></td>
<td></td>
<td>Suspended metal lath and gypsum plaster</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wood furring suspension system</td>
<td>0.15</td>
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</table>

---

13 Saudi Building Code (SBC)
Table 6 cross sectional steel areas of groups of bars (metric)

### Bar Area Tables:

#### Cross Sectional areas of groups of bars (mm²)

<table>
<thead>
<tr>
<th>Bar Size (mm)</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>16</th>
<th>20</th>
<th>25</th>
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<th>40</th>
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<td>157</td>
<td>226</td>
<td>402</td>
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<td>982</td>
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<td>2011</td>
<td>3142</td>
<td>4909</td>
<td>8042</td>
<td>12566</td>
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</tbody>
</table>

| Circumference | 18.8| 25.1| 31.4| 37.7| 50.3| 62.8| 78.5|100.5|125.7|

#### Cross Sectional areas of bars per metre width (mm²)

<table>
<thead>
<tr>
<th>Bar Size (mm)</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>16</th>
<th>20</th>
<th>25</th>
<th>32</th>
<th>40</th>
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<td>1142</td>
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<td>1636</td>
<td>2681</td>
<td>4189</td>
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</tbody>
</table>
Appendix C
STRUCTURAL DESIGN PROJECT

(Continued)

FIGURE 2.3 Elastic-curve equations for prismatic beams. (m) Simple beam—load increasing uniformly to one end.

FIGURE 2.4 Any span of a continuous beam (a) can be treated as a simple beam, as shown in (b) and (c). In (c), the moment diagram is decomposed into basic components.

<table>
<thead>
<tr>
<th>Section</th>
<th>Moment of inertia</th>
<th>Section modulus</th>
<th>Radius of gyration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equilateral polygon</td>
<td>$I = \frac{A}{24} (6R^2 - a^2)$</td>
<td>$I = \frac{L}{r}$</td>
<td>$\sqrt{\frac{6R^2 - a^2}{24}} = R$</td>
</tr>
<tr>
<td>Area $A$</td>
<td>$I = \frac{A}{48} (12r^2 + a^2)$</td>
<td>$I = \frac{L}{R \cos 180^\circ/n}$</td>
<td>$\sqrt{\frac{12r^2 + a^2}{48}}$</td>
</tr>
<tr>
<td>Rad inscribed circle $r$</td>
<td>$I = \frac{AR^2}{4}$ (approx)</td>
<td>$I = \frac{L}{AR}$ (approx)</td>
<td>$\sqrt{\frac{12b^2 + 12bb_1 + b_1^2}{6(2b + b_1)}}$</td>
</tr>
<tr>
<td>No. of sides $n$</td>
<td></td>
<td></td>
<td>$h = \frac{\sqrt{12b^2 + 12bb_1 + b_1^2}}{6(2b + b_1)}$</td>
</tr>
<tr>
<td>Length of side $a$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axis as in preceding section of octagon</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

FIGURE 2.1 Geometric properties of sections.

FIGURE 2.6 Fixed-end moments for a prismatic beam. (a) For a concentrated load. (b) For a uniform load. (c) For two equal concentrated loads. (d) For three equal concentrated loads.
CASE 2. Beam Supported Both Ends—Concentrated Load at Any Point

\[ \begin{align*} 
R &= \frac{W}{L} \\
M_{max} &= \frac{Wb}{L} \\
V_{max} &= \frac{W}{L} \\
\end{align*} \]

At point of load:
\[ M = \frac{Wb}{L} \]
\[ V = \frac{W}{L} \]
\[ V_{max} = \frac{W}{L} \]

CASE 3. Beam Supported Both Ends—Two Unequal Concentrated Loads, Unequally Distributed

\[ \begin{align*} 
R &= \frac{W}{L} \\
M_{max} &= \frac{Wb}{L} \\
\end{align*} \]

At point of load:
\[ M = \frac{Wb}{L} \]
\[ V = \frac{W}{L} \]
\[ V_{max} = \frac{W}{L} \]

CASE 4. Beam Supported Both Ends—Three Unequal Concentrated Loads, Unequally Distributed

\[ \begin{align*} 
R &= \frac{W}{L} \\
M_{max} &= \frac{Wb}{L} \\
\end{align*} \]

\[ \begin{align*} 
M_{max} &= \frac{Wb}{L} \\
V_{max} &= \frac{W}{L} \\
\end{align*} \]

At point of load:
\[ M = \frac{Wb}{L} \]
\[ V = \frac{W}{L} \]
\[ V_{max} = \frac{W}{L} \]

CASE 5. Beam Fixed Both Ends—Continuous Load, Uniformly Distributed

\[ \begin{align*} 
R &= \frac{W}{L} \\
M_{max} &= \frac{Wb}{L} \\
\end{align*} \]

At point of load:
\[ M = \frac{Wb}{L} \]
\[ V = \frac{W}{L} \]
\[ V_{max} = \frac{W}{L} \]

CASE 6. Beam Fixed Both Ends—Concentrated Load at Any Point

\[ \begin{align*} 
R &= \frac{W}{L} \\
M_{max} &= \frac{Wb}{L} \\
V_{max} &= \frac{W}{L} \\
\end{align*} \]

At point of load:
\[ M = \frac{Wb}{L} \]
\[ V = \frac{W}{L} \]
\[ V_{max} = \frac{W}{L} \]

CASE 7. Beam Fixed at One End (Cantilever)—Continuous Load, Uniformly Distributed

\[ \begin{align*} 
R &= \frac{W}{L} \\
M_{max} &= \frac{Wb}{L} \\
\end{align*} \]

At point of load:
\[ M = \frac{Wb}{L} \]
\[ V = \frac{W}{L} \]
\[ V_{max} = \frac{W}{L} \]

CASE 8. Beam Fixed at One End (Cantilever)—Concentrated Load at Any Point

\[ \begin{align*} 
R &= \frac{W}{L} \\
M_{max} &= \frac{Wb}{L} \\
\end{align*} \]

At point of load:
\[ M = \frac{Wb}{L} \]
\[ V = \frac{W}{L} \]
\[ V_{max} = \frac{W}{L} \]

CASE 9. Beam Fixed at One End, Supported at Other—Concentrated Load at Any Point

\[ \begin{align*} 
R &= \frac{W}{L} \\
M_{max} &= \frac{Wb}{L} \\
\end{align*} \]

At point of load:
\[ M = \frac{Wb}{L} \]
\[ V = \frac{W}{L} \]
\[ V_{max} = \frac{W}{L} \]

FIGURE 2.2 (Continued)
CASE 10. Beam Fixed at One End, Supported at Other—Continuous Load, Uniformly Distributed

\[ R = \frac{3}{8} W \]
\[ R_1 = V_{(\text{max})} = \frac{5}{8} W \]

At \( x \):
\[ V = \frac{3}{8} W - \frac{Wx}{L} \]

At \( x \) when \( x = \frac{3}{2} L \)
\[ M_{(\text{max})} = \frac{9}{128} WL \]
At fixed ends:
\[ M_1 = \frac{1}{4} WL \]
At \( x \):
\[ M = \frac{Wx}{L} \left( \frac{3}{8} L - \frac{1}{2} x \right) \]

\[ A_t: \text{when } x = 0.4215L \]
\[ D_{(\text{max})} = 0.0054 \frac{WL^3}{EI} \]
At \( x \):
\[ D = \frac{Wx}{48EI} \left[ -3Lx^2 + 2x^3 + L^3 \right] \]

FIGURE 2.2 (Continued)

CASE 11. Beam Overhanging Both Supported Unsymmetrically Placed—Continuous Load, Uniformly Distributed

\[ \frac{W}{a + L + b} = W = \text{load per unit of length} \]
\[ R = w \left[ \frac{2L}{(a + L)^2 + b^2} \right] \]
\[ R_1 = w \left[ \frac{b}{(b + L)^2 + a^2} \right] \]
\[ V_{(\text{max})} = wa \text{ or } R - wa \]

At \( x \) when \( x < a \)
\[ V = w(a - x) \]
At \( x_1 \) when \( x_1 < L \)
\[ V = R - w(a + x_1) \]
At \( x_2 \) when \( x_2 < b \)
\[ V = w(b - x_2) \]

At \( x_1 \) when \( x_1 = \frac{R}{w} - a \)
\[ M_{(\text{max})} = R \left( \frac{R}{2w} - a \right) \]
At \( R \):
\[ M_1 = \frac{1}{2} w a^2 \]
At \( R_1 \):
\[ M_1 = \frac{1}{2} w b^2 \]
At \( x \) when \( x < a \)
\[ M = \frac{1}{2} w (a - x)^2 \]
At \( x_1 \) when \( x_1 < L \)
\[ M = \frac{1}{2} w (a + x_1)^2 - R_1 \]
At \( x_2 \) when \( x_2 < b \)
\[ M = \frac{1}{2} w (b - x_2)^2 \]

FIGURE 2.2 (Continued)

CASE 12. Beam Overhanging Both Supports, Symmetrically Placed—Two Equal Concentrated Loads at Ends

\[ R = R_1 = V_{(\text{max})} = \frac{W}{2} \]

At \( x \) when \( x < a \)
\[ V = \frac{W}{2} \]
At \( x_1 \) when \( x_1 < L \)
\[ M_{(\text{max})} = \frac{Wz_1}{2} \]
At free ends:
\[ D = \frac{Wz_1^2 (3L + 2a)}{12EI} \]
At center:
\[ D = \frac{Wz_1^2}{16EI} \]

FIGURE 2.2 (Continued)
STRUCTURAL DESIGN PROJECT

FIGURE 2.2 Elastice-curve equations for prismatic beams: (p) Cantilever beam—concentrated load at free end. (Continued)

FIGURE 2.3 Elastice-curve equations for prismatic beams: (e) Beam fixed at both ends—concentrated load at center (Continued)

FIGURE 2.3 Elastic-curve equations for prismatic beams: (a) Shears, moments, and deflections for full uniform load on a simply supported prismatic beam. (b) Shears and moments for uniform load over part of a simply supported prismatic beam. (c) Shears, moments, and deflections for a concentrated load at any point of a simply supported prismatic beam.
FIGURE 2.3 Elastic-curve equations for prismatic beams: (j) Shears, moments, and deflections for uniform load over the full length of a cantilever. (k) Shears, moments, and deflections for uniform load on a beam overhang. (l) Shears, moments, and deflections for triangular loading on a prismatic cantilever. (Continued)

FIGURE 2.3 Elastic-curve equations for prismatic beams: (g) Shears, moments, and deflections for a concentrated load on a beam overhang. (h) Shears, moments, and deflections for a concentrated load on the end of a prismatic cantilever. (i) Shears, moments, and deflections for a uniform load over the full length of a beam with overhang. (Continued)

FIGURE 2.3 Elastic-curve equations for prismatic beams: (d) Shears, moments, and deflections for a concentrated load at midspan of a simply supported prismatic beam. (e) Shears, moments, and deflections for two equal concentrated loads on a simply supported prismatic beam. (f) Shears, moments, and deflections for several equal loads equally spaced on a simply supported prismatic beam. (Continued)
FIGURE 2.5  Reactions of continuous beam (a) found by making the beam statically determinate. (b) Deflections computed with interior supports removed. (c), (d), and (e) Deflections calculated for unit load over each removed support, to obtain equations for each redundant.
FIGURE 2.27  Fixed-end moments in beams. (Brockenbrough and Merritt-Structural Designer’s Handbook, McGraw-Hill.)
Appendix D
### Table 7: Beam Reinforcement Table

<table>
<thead>
<tr>
<th>Beam #</th>
<th>Dimension</th>
<th>Bottom R. # 16</th>
<th>Top right R. # 16</th>
<th>Top left R. # 16</th>
<th>Stirrups # 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
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<td>2</td>
<td>2</td>
<td>@ 272 c/c</td>
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<tr>
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<td>200*600</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>@ 272 c/c</td>
</tr>
<tr>
<td>B3</td>
<td>200*600</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>@ 270 c/c</td>
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### Table 8: Detailed Beam Results from STAAD Pro and # of Steel Bars

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**MOHAMMED QAID AL-ZIYADI**
Manual Calculation for Foundation Design

Footing #1

**Isolated Footing 1**

*Input Values*

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<th>Concrete and Rebar Properties</th>
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<tr>
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<tr>
<td>Yield Strength of Steel : 415.000 MPa</td>
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<td>Maximum Bar Size : # 18</td>
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<td>Minimum Bar Spacing : 2.00 in</td>
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<th>Concrete Covers</th>
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</table>
Soil Properties

- Unit Weight: 16.00 kN/m³
- Soil Bearing Capacity: 160.00 kN/m²
- Soil Surcharge: 0.00 kip/ft²
- Depth of Soil above Footing: 0.00 in

**Geometry**

Initial Footing Dimensions

- Thickness (Ft): 10.00 in
- Length - X (Ft): 10.00 in
- Width - Z (Ft): 10.00 in
- Eccentricity along X (Oxd): 0.00 in
- Eccentricity along Z (Ozd): 0.00 in

**Pedestal**

Include Pedestal? No

**Footing Design Calculations**

**Footing Size**

- Initial Length ($L_o$): 10.00 in
- Initial Width ($W_o$): 10.00 in

Min. area required from bearing pressure, $A_{min} = \frac{P}{q_{max}} = 21139.602 \text{ in}^2$

Area from initial length and width, $A_o = L_o \times W_o = 100.00 \text{ in}^2$

Final dimensions for design.

- Length ($L_2$): 150.00 in
- Width ($W_2$): 150.00 in
- Area ($A_2$): 22500.00 in²

Governing Load Case: # 3

Calculated pressures at 4 corners.

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Pressure at corner 1 ($q_1$) (kip/lin²)</th>
<th>Pressure at corner 2 ($q_2$) (kip/lin²)</th>
<th>Pressure at corner 3 ($q_3$) (kip/lin²)</th>
<th>Pressure at corner 4 ($q_4$) (kip/lin²)</th>
<th>Area of footing in uplift ($A_{up}$) (in²)</th>
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<td>0.02</td>
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</table>
If $A_y$ is zero, there is no uplift and no pressure adjustment is necessary. Otherwise, to account for uplift, areas of negative pressure will be set to zero and the pressure will be redistributed to remaining corners.

Summary of adjusted pressures at 4 corners.

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Pressure at corner 1 ($q_1$) (kip/in²)</th>
<th>Pressure at corner 2 ($q_2$) (kip/in²)</th>
<th>Pressure at corner 3 ($q_3$) (kip/in²)</th>
<th>Pressure at corner 4 ($q_4$) (kip/in²)</th>
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</table>

Adjust footing size if necessary.

Check for stability against overturning and sliding:

<table>
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<tr>
<th>Load Case No.</th>
<th>Factor of safety against sliding Along X-Direction</th>
<th>Factor of safety against overturning About X-Direction</th>
<th>About Z-Direction</th>
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</thead>
<tbody>
<tr>
<td>3</td>
<td>222.765</td>
<td>379.911</td>
<td>1028.635</td>
</tr>
</tbody>
</table>

Critical load case and the governing factor of safety for overturning and sliding:

Critical Load Case for Sliding along X-Direction: 3
Governing Disturbing Force: -1.146 kip
Governing Restoring Force: 255.158 kip
Minimum Sliding Ratio for the Critical Load Case: 222.765

Critical Load Case for Overturning about X-Direction: 3
Governing Overturning Moment: -100.755 kip-in
Governing Resisting Moment: 3827.791 kip-in
Minimum Overturning Ratio for the Critical Load Case: 379.911

Critical load case and the governing factor of safety for overturning and sliding:

Critical Load Case for Sliding along Z-Direction: 3
Governing Disturbing Force: -1.129 kip
Governing Restoring Force: 255.158 kip
Minimum Sliding Ratio for the Critical Load Case: 226.108

Critical Load Case for Overturning about Z-Direction: 3
Governing Overturning Moment: 37.212 kip-in
Governing Resisting Moment: 3827.791 kip-in
Minimum Overturning Ratio for the Critical Load Case: 1028.635

Check Trial Depth against Punching Shear strength, $V_c$
Calculated Effective Depth, \( d_{ef} = \) \( D - C_{outer} \times 1.0 = \) 20.00 in
For rectangular column, \( \bar{D} = \frac{B_{col}}{D_{col}} = \) 4.50

Effective depth, \( d_{eff} \) increased until 0.75\% \( V_u \) ≥ Punching Shear Force

Punching Shear Force, \( P_u = 456.36 \text{ kip, Load Case} \# 3 \)

From ACI Cl.11.2.2.1, \( \bar{D} \) for column = \[ 2 \times (B_{col} + D_{col} + 2 \times d_{eff}) = 166.61 \text{ in} \]
Equation 11-33, \( V_{col} = \left( \frac{2b}{D} \right) \times \beta_0 \times d_{eff} \times \sqrt{1000 \times F_{ci}} = 613.47 \text{ kip} \]
Equation 11-34, \( V_{col} = \left( \frac{2 + 4.0 \times \frac{d_{eff}}{D}}{\frac{b}{D}} \right) \times \beta_0 \times d_{eff} \times \sqrt{1000 \times F_{ci}} = 1444.33 \text{ kip} \]
Equation 11-35, \( V_{col} = \frac{4 \times \beta_0 \times d_{eff} \times \sqrt{1000 \times F_{ci}}}{\frac{b}{D}} = 849.42 \text{ kip} \]
Punching shear strength, \( V_u = 0.75 \times \text{minimum of} \ (V_{ct}, V_{cf}, V_{cd}) = 400.10 \text{ kip} \)
0.75 \% \( V_u \) ≥ \( V_u \) hence, OK

Check Trial Depth against One-Way Shear strength, \( V_c \)

Shear along the Z-Z axis.

From ACI Cl.11.3.1.1, \( V_c = \)
\[ 2W \times d_{eff} \times \sqrt{1000 \times F_{ci}} = 382.36 \text{ kip} \]
Distance along Z to design shear, \( D_z = 0.5S + 0.5D + \text{def} + \text{Cz} = 112.72 \text{ in} \)

Check that 0.75 \% \( V_u \) ≥ \( V_{im} \) where \( V_{im} \) is the shear force for the critical load cases at a distance \( d_{eff} \) from the face of the column caused by bending about the X axis.

From above calculations, \( 0.75 \times V_c = 286.77 \text{ kip} \)
Critical load case for \( V_{im} \) is \# 3
\[ \frac{V_{im}}{V_{im,\text{cr}}} = 122.77 \text{ kip} \]
0.75 \% \( V_c \) ≥ \( V_{im} \) hence, OK

Shear along the X-X axis.

From ACI Cl.11.3.1.1, \( V_c = \)
\[ 2W \times d_{eff} \times \sqrt{1000 \times F_{ci}} = 382.36 \text{ kip} \]
Distance along X to design shear, \( D_x = 0.5S + 0.5D - \text{def} + \text{Cz} = 51.06 \text{ in} \)

Check that 0.75 \% \( V_u \) ≥ \( V_{im} \) where \( V_{im} \) is the shear force for the critical load cases at a distance \( d_{eff} \) from the face of the column caused by bending about the Z axis.

From above calculations, \( 0.75 \times V_c = 286.77 \text{ kip} \)
Critical load case for \( V_{im} \) is \# 3
\[ \frac{V_{im}}{V_{im,\text{cr}}} = 167.44 \text{ kip} \]
0.75 \% \( V_c \) ≥ \( V_{im} \) hence, OK

Design for Flexure about Z axis

Calculate the flexural reinforcement along the X direction of the footing. Find the area of steel required, \( A \), as per Section 3.9 of Reinforced Concrete Design (5th ed.) by Salmon and Wang (Ref. 1)

Critical Load Case # 3

The strength values of steel and concrete used in the formulae are in ksi
Factor $\bar{P}_1$, from ACI Cl.10.2.7.3

For $F_c \leq 4$ ksi, 0.85

From ACI Cl. 10.3.2, $P_{mil} = 0.85 \times \bar{P}_1 \times \overline{F_o} \times \frac{87}{[F_p \times (87 + F_p)]}$ 0.0207

From ACI Cl. 10.3.3, $P_{min} = 0.75 \times P_{mil}$ 0.0215

From ACI Cl. 7.12.2, $P_{min}$ = 0.00180

From Ref. 1, Eq. 3.8.4a, constant $m = \frac{F_p}{[0.85 \times \overline{F_o}]}$ 17.44

Calculate reinforcement ratio $\bar{P}$ for critical load case

Design for flexure about Z axis is performed at the face of the column at a distance, $d_x = 0.5x + 0.5x_{Ddol} + O_{x}d = 71.66$ in

Ultimate moment, $M_{u,dol} = 8209.29$ kip-in

Nominal moment capacity, $M_n = \frac{M_u}{\Phi}$ 9200.32 kip-in

Required $\bar{P} = \frac{1}{m} \left(1 - \frac{1 - 2 \times m \times \frac{M_n}{[F_p \times W \times d_{max}]}}{M_u}ight) = 0.00261$

Since $P_{max} \leq P \leq P_{min}$ OK

Area of Steel Required, $A_y = \frac{P \times W \times d_{max}}{\bar{P}}$ 7.82 sq.in

Find suitable bar arrangement between minimum and maximum rebar sizes

Available development length for bars, $D_{L} = 0.5 \times [L - D_{dol}] - C_{dolw} = 69.00$ in

Try bar size #8, Area of one bar = 0.79 sq.in

Number of bars required, $N_{bar} = \frac{A_y}{A_{bar}} = 10$

Because the number of bars is rounded up, make sure new reinforcement ratio $\leq P_{max}$

Total reinforcement area, $A_{tot, max} = N_{bar} \times \text{(Area of one bar)} = 7.90$ sq.in

d_{eff} = D - C_{dolw} - 0.5 \times (\text{diam. of one bar}) = 20.50 in

Reinforcement ratio, $\bar{P} = \frac{A_{tot, max}}{d_{eff} \times W} = 0.00267$

From ACI Cl. 7.6.1, minimum required clear distance between bars, $C_g = \max (\text{Diameter of one bar}, 1.0, \text{Min. User Spacing}) = 16.11$ in

Check to see if width is sufficient to accommodate bars

Design for Flexure about X axis

Calculate the flexural reinforcement along the Z direction of the footing. Find the area of steel required, $A_y$, as per Section 3.8 of Reinforced Concrete Design (5th ed.) by Salmon and Wang (Ref. 1)

Critical Load Case #3

The strength values of steel and concrete used in the formulae are in ksi

Factor $\bar{P}_1$, from ACI Cl.10.2.7.3

For $F_c < 4$ ksi, 0.85
From ACI Cl. 10.3.2, \( P_{\text{min}} = \frac{0.85 \times \beta_1 \times F_t \times 27}{(F_y \times (87 + F_u))} \) = 0.02871
\[ \text{From ACI Cl. 10.3.3, } P_{\text{max}} = 0.75 \times \rho_{\text{tot}} \text{max} = 0.02153 \]
\[ \text{From ACI Cl.7.12.2, } P_{\text{min}} = 0.00180 \]
\[ \text{From Eq. 3.8.4a, constant } m = \frac{F_y}{(0.85 \times F_t)} = 17.44 \]

Calculate reinforcement ratio \( \rho \) for critical load case

Design for flexure about X axis is performed at the face of the column at a distance, \( D_x \) = 0.5 \( x \) + 0.5 \( x \) = 92.72 in

Ultimate moment,
\[ M_u = \frac{6402.53}{6} = 1067.12 \text{ kip-in} \]

Nominal moment capacity, \( M_n = \frac{M_u}{1.2} \)
\[ M_n = \frac{6002.02}{1.2} = 5001.68 \text{ kip-in} \]

Required \( \rho = \frac{1}{m} \left( 1 - \frac{1}{2} \times \frac{M_u}{M_n} \right) \times \Phi \)
\[ \rho = \frac{1}{5} \left( 1 - \frac{1}{2} \times \frac{6002.02}{6002.02} \right) \times \Phi = 0.00187 \]

Since \( \rho_{\text{min}} \leq \rho \leq \rho_{\text{max}} \) OK

Area of Steel Required, \( A_s = \frac{\rho \times W \times d_{\text{eff}}}{5.34} \) sq.in

Find suitable bar arrangement between minimum and maximum rebar sizes

Available development length for bars, \( D_L = 0.5 \times (L - D_{\text{min}}) - C_{\text{cover}} \)
\[ D_L = 0.5 \times (98 - 10) - 3.5 = 55.28 \text{ in} \]

Try bar size \# 7

Area of one bar = 0.60 sq.in

Number of bars required, \( N_{\text{bar}} = \frac{A_s}{A_{\text{bar}}} = 9 \)

Because the number of bars is rounded up, make sure new reinforcement ratio \( \rho_{\text{max}} \)

Total reinforcement area, \( A_{\text{total}} = N_{\text{bar}} \times (\text{Area of one bar}) = 5.40 \text{ sq.in} \)

\[ d_{\text{eff}} = D - C_{\text{cover}} - 9.5 \times \text{(dist. of one bar)} = 18.67 \text{ in} \]

Reinforcement ratio, \( \bar{\rho} = \frac{A_{\text{total}}}{d_{\text{eff}} \times W} = 0.00191 \)

From ACI Cl.7.6.1, minimum rect'd clear distance between bars, \( C_y = \max (\text{Diameter of one bar}, 1.0, \text{Min. User Spacing}) = 18.14 \text{ in} \)

Check to see if width is sufficient to accommodate bars
References

1. ACI 318-08

2. Civil Engineering Formulas.

3. PCA notes on ACI codes 2008
4. **Saudi Building Code**


