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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL LAYOUT OPTIMIZATION FOR HOUSING PROJECT 40/60

A Thesis in Structural Engineering

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled '**Structural Layout Optimization for Housing Project 40/60**' presented by **BEZANEH HABTEMARIAM KETSELA**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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I certify that research work titled "Structural Layout Optimization for Housing Project 40/60" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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ABSTRACT

The increasing complexity of homes, the use of innovative materials and technologies, and the increased population in urban areas of Ethiopia have introduced many challenges to the building industry and design profession as a whole. These challenges call for the development and continual improvement of efficient engineering methods for housing applications.

The origin of this thesis lies in the minimization of cost by changing the structural layout configuration for housing project 40/60. In doing so, it compliments current design practices and building code requirements.

The typical floor slab system is divided into panels that are bounded by beams in all sides having a definite length and width. Each panel is divided into smaller segments. These smaller segments are added on each side of the spans in x and y directions. Hence, a number of rectangular panels can be formed and used as a variable.

A C++ program is written to analyze and select the optimal panel dimensions. These optimal panels are rearranged and used as a floor slab. After conducting an analysis, design and cost comparison, it is able to design a building which is more cost effective.

The knowledge gained from investigation and diagnosis benefits the wider community through economy.

This thesis proposes a basis for minimizing the cost of housing project 40/60. Hence, it mainly focuses on programming, analytical and theoretical problem formulation.

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CHAPTER 1 INTRODUCTION

1.1 Background of the Problem

Experiences and judgments play an important role in designing structural elements concerning in its safety, serviceability and cost effectiveness. But these kinds of knowledge cannot be easily gained or obtained. Hence, some literatures tried to put these things through different mechanisms. The one is that through structural layout configuration or rearranging the structural elements (size, shape and proportion of the 3-D form of the structure).

Our country Ethiopia is now in a renaissance. And this brings up a lot of construction in the country. Some of which include large scale projects like the great renaissance dam, urban and sub-urban metro trains and housing projects for Addis. So, when a large scale project is undergoing, ineffectiveness in design may cause a great deal of consumption of time during construction and loss of money.

The aim of this housing project was to enable low-income urban dwellers acquire homes of their own, changing the image of the city so as to meet international standards, transfer of knowledge and skill to the construction industry and promoting cost efficient housing construction technology [5]. At present, the scope of this housing project has been widened to include low income dwellers and middle class Ethiopians. The G+4 building initially designed couldn't meet the space constraint so; the project has been extended to G+12 living condos. In addition, to meet the ever increasing housing demand 40,000 houses per year and 200,000 houses in the first five years was intended to be completed[8].

During the design of this structure the engineer should consider the safety, serviceability, time and high quality requirements. But most of all, the structural layout is the important one, because all these (safety, serviceability, time and high quality requirements) are based on the structural layout configuration of the building.

The advantage of arranging our structural layout (selection of proper system configuration for the structure) is that it will have a uniform and continuous distribution of mass, stiffness, strength and ductility, well separated non-structural components and simple behavior for analysis [1] Structural simplicity, characterized by the existence of clear and direct paths for the transmission of the seismic forces, is an important objective to be pursued, since the modeling, analysis, dimensioning, detailing and construction of simple structures are subject to much less uncertainty and thus the prediction of its seismic behavior is much more reliable [2].

So, structural layout (selection of proper system configuration for the structure) for the housing project generally will help improve in the reduction of the total cost of the building.

1.2 Statement of the problem

Housing project 40/60 is an Ethiopian government project to make the urban dwellers a home owner. The “owner” will pay the first down payment within five years which is 40% of the total cost of the house. The rest 60% is going to be paid after the “Owner” received the home. The name 40/60 comes from the payment method. There are also different housing projects like 20/80 and 10/90.

Generally it is a well-known fact that the cost of materials is getting higher and higher around the world with their quality compromised. This might be due to the scarcity of resources we are having now. So, using these materials effectively will help us to optimize our budget.

Optimization is an excellent tool that helps a lot not only in using materials effectively but also in minimizing the cost. Most of the costs in building constructions are not only from material costs. There is also workmanship, labor and machine costs. The decrement in material cost is an effective one because the other costs i.e. workmanship, labor and machine costs are based on material cost.

As the cost of materials are getting higher and higher and resources are becoming scarce with a high finance to buy products and people are striving for getting money and yet unable to fulfill their needs, the government offers housing projects for low-in-come urban dwellers. But it is a well-known fact that people are still unable to afford. This is due to the cost of the buildings (materials that the building is using) and the demand of the house. So, if engineers are able to decrease the cost of the buildings and if they are able to construct more houses with less cost, people will be able to afford one.

1.3 Research Objective and Scope

This thesis is about structural layout optimization for housing projects 40/60 with an aim of minimizing its structural cost. The previously adopted structural layout is not cost effective. Thus, the study of layout optimization is important.

The optimum column layout design for these buildings are going to be studied first and the optimum location of columns for these structures will be investigated. The layouts are then going to be optimized, including the locations of columns and then the rectilinear shapes for the plan layout will be studied, optimized and proposed. But there will be certain limitations to achieve this, one is that architects' constraint and the need to convince them to make changes so that an optimum column layout can be accommodated in the proposed architectural plan. In most cases the engineer must follow the architectural plan, and architects always place the columns in their desired locations by hiding them in the intersection of walls, regardless of whether or not these are their optimum locations. And the other is that minor changes in the plan layout such as the location of walls and columns are quite acceptable for architects' in order to meet the engineering requirements. The outcome of this methodology shows that even minor changes in the column layout may have a considerable effect on the costs. Therefore, instead of globally optimum column layout, a local optimum column layout can be selected that meets the architects' requirement.

Only rectilinear layouts and line shapes were studied. This means that the lines and shapes that are investigated are in the form of straight lines and sharp edges. A line other than straight lines i.e. curves, circles, ellipses or any other irregular shapes that don't have a sharp edge are not included in this research. Other structural systems such as steel or composite are beyond the scope of this thesis.

To sum up, in most published studies the cost optimization functions deal only with cross-sectional variables and functions of the design action effects which are not determinate and vary as the shape changes. Therefore, in an iterative procedure to solve an optimization problem, each step includes dealing with the structural analysis and structural design variables, although in cases such as these, unless alternative design variables are selected, for the cost function, the optimization procedure might be too complex.

Finally, the structural analysis and design optimization of the building model is accomplished by using structural analysis and design software. During analysis of the building, different load combinations are used according to the Ethiopian building code of standards but the one that is selected will be based on the structural software analysis output results that cause maximum bending or torsional moment, shear or deflection.

1.4 Application of Results

A successful completion of this research will play a major role in showing how a simple adjustment in layout will affect the total structural cost of the building, how one is able to minimize the structural cost by selecting the appropriate layout, improving the integration of architects with engineers in architectural design stage hence enabling advancement in architectural design which can help improve the global image of Ethiopia, creating awareness of layout and how it affects on structural design and finally, it will assist the housing project to achieve its goal in minimum cost.

1.5 Structure of the Report

This research contains six chapters and each chapter is divided into sub sections. On the first chapter an introduction is provided with the inclusion of the problem background, research motivation and objectives and limitations of the study and finally application of the results. In general, this chapter tries to see the overall problem and the solution mechanisms.

Chapter two is about literature review that mainly concerns about the fundamentals of layout optimization and its constituents. Different types of layout techniques, advantages and limitations and their development are also included in this chapter.

The third chapter deals with the introduction of knapsack problem and their use. It also tries to systematically state and formulate the housing project problem in accordance with the need defined by the knapsack problem.

After the formulation and selection of the knapsacks, the analysis and design is taking care of in the fourth chapter. In this chapter, structural arrangements are set up followed by modeling the structure, material and load properties are defined and final analysis is done.

The fifth chapter concerns with the comparison of costs. Bill of quantity from the final analysis is made and compared with that of the “old” or “un-optimized” structure. This chapter highlights the discussion and economic analysis based on both material and labor cost.

On the sixth chapter, conclusion and recommendation is made. The significance and contribution of structural layout optimization for housing projects will be explained. Finally, a list of reference material used to assist this research will be listed together with annexes.

CHAPTER 2 LITEREATURE REVIEW

2.1 Introduction

Inadequate proportioning and detailing of structural elements, connections and supports are well known in bringing uncertainties while estimating the demands and strengths in earthquake resistant design and hence, leading to an over estimated higher cross-sections (beams, slabs, columns, shear walls and any other structural members) of the building which in turn leads to higher cost. The best way to overcome these uncertainties by proper selection of building configuration, its structural layout, proper proportioning and detailing of their structural elements, connections and supports.

In such a process, achieving an economical structural layout with a minimized cost is one of the primary objectives. Mostly, the structural layout design of buildings are offered based on architectural requirements, without paying enough attention to the cost components and the economic effects that a layout design might have on the total cost of the building. Some small modifications in the layout plan of the building may lead to a significant cost saving. The layout design of a structure influences the entire design process and consequently, the total cost.

Structural optimization is an application of *optimization methods* to structural design. The typical structural optimization problem is formally formulated to minimize an objective function representing the structural cost under constraints on mechanical properties of the structure [9].

Structural layout optimization is a technique which enables automatic identification of optimal arrangements of structural elements. The application of technique is considered through “technical” and “visual” aspects of design i.e. it incorporates both architects and engineers throughout problem formulation and design process.

Over the past few decades, optimizing the cost of structures has been developed using a variety of methods, although one limiting feature of existing methods is that the representation is limited to either single structure or structures with predefined shapes. This implies that the effect of layout design on costs has not been studied adequately enough.

The literature of geometric layout and topological optimization are vast. The topics are also diverse. Different literatures defined about layout and topology optimizations. But it is so difficult to make a clear boundary between the two because one overlaps the other. Usually and in most literatures, topology optimization is a subset of layout optimizations.

In some literatures, the layout problem is defined as an arrangement of materials that play a major role in the design of structural elements [17]. During the design process, the manner in which material is distributed is significant for engineers to develop a supporting system or create a conceptual design for structural members.

In order to distribute evenly, one of the most important things for buildings is that columns should preferably be arranged in rectangular grids [7]. This is not to say that other arrangements are not used or important, but regular rectangular grids tend to be easier and more economical to construct and provide a flexible layout that can be readily adapted during the life of the structure.

Layout optimization is so difficult to formulate and it is probably the most difficult class of problems in structural optimization. On the other hand it is also a very important one, because it results in much higher material savings than cross-section optimization [10]. Having the difficulties in formulation, there are different kinds of techniques that will help us to formulate the problem. Although there are many possible formulations for structural optimization, e.g., *minimum weight design* and *maximum stiffness design*, the term *structural optimization* or *optimum design* is usually used for representing all types of optimization problems corresponding to structural design [9].

Most of the problem formulation methods are dynamic and lie in the category of genetic algorithms. This method is one of bio-inspired optimization method and it is playing an increasingly important role in the studies of complex systems.

In the process of designing structures in various fields of engineering, the designer and engineer make their best decisions at every step in view of structural and non-structural aspects such as stiffness, strength, serviceability, constructability and aesthetic property. In other words, they make their *optimal* decisions to realize their best designs; hence, the process of structural design may be regarded as an *optimum design* even though *optimality* is not explicitly pursued [9].

2.2 Development of Layout Optimization

The origin of structural optimization is sometimes credited to Galileo Galilee, who investigated the optimal shape of a beam subjected to a static load. However, his approach was rather intuitive, and he didn't establish any theoretical foundation of structural optimization [9].

Starting from the period of Galilee, scholars get awareness and started writing books about structural layout optimization. During this period, structural layout technique was used.

The first developed structural layout optimization technique was in 1960s in order to automatically identify the optimal arrangement of members in either 2-D or 3-D structural works, satisfying predefined constraints and a predefined optimality criteria [13]. During this time, theories were also started to develop.

The theories developed in early stages lack practicality and it was only in the later part of the last century that the optimal layout theory was developed. This theory was developed by Prager and Rozvany and it was one of the earliest to provide a more general treatment of the optimal theory [12]. In the optimal layout theory, an arrangement of structural members is sought leading to minimum load of the structure for a specified loads and materials.

During the last 20 years, structural optimization has become one of the most important topics of engineering applications. Design optimization of structure has been an interesting area of research in the field of engineering design for its ability to short the design cycle and to enhance product quality. Significant research activity has occurred in the area of structural optimization in the last decade. Especially for topology optimization of structure, many new theoretical, algorithmic and computational contributions have resulted by researchers and engineers [11].

2.3 Types of Layout Optimization

Optimization of structures can be classified into three categories: sizing, shaping and topology optimization. Topology optimization is concerned with the structure members and connectivity between members. In general it is easily represented by discrete variables rather than by those used for continuous optimization problems. Topology optimization is the most difficult and complex among the three categories and it is especially useful in developing innovative conceptual designs. Structural optimization, in particular the topology optimization, has been identified as one of the most challenging tasks in structural design. Topology optimization usually referred as layout optimization or general shape optimization [15].

Size optimization is commonly used for finding the optimal cross-sectional area of beam elements in a frame or calculating the optimal thickness of plate elements while satisfying design criteria. In this method, the shape or connectivity of members may not change but they may be removed during the process.

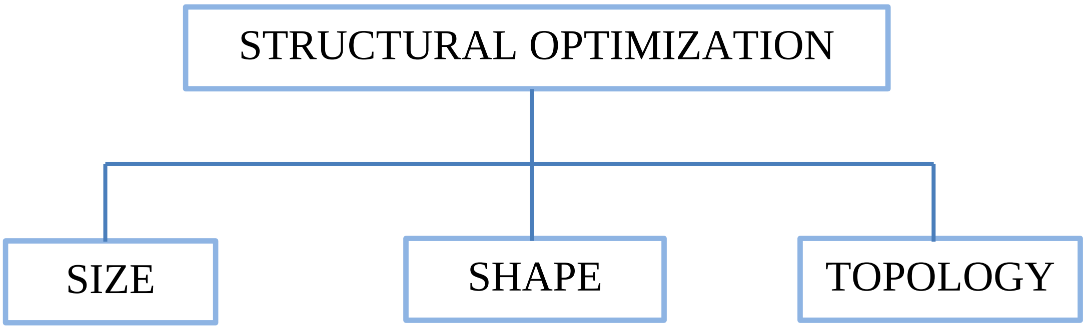

Figure 2-3-1: classification of optimization

In order to achieve the efficiency in global optimization search, many heuristic algorithms have been developed such as evolutionary algorithm, genetic algorithm, ant algorithm and simulated annealing algorithm. In recent years, many biologically inspired methods come to use in topology optimization of structure [15].

2.4 Advantages and Disadvantage of Layout Optimization

One advantage of structural layout optimization is that it has a potential to provide the architects and the engineers with the ability to rapidly communicate and give solutions to designs that are structurally sound. Since, the process is dynamic and modifications can be done easily especially if a dynamic programming is set. It also results in much higher material savings than any other optimization techniques. However, the complication in mathematical formulation and the difficulties in solving it, structural layout optimization is considered as one of the most challenging research field.

It should be noted that application of optimization technology in design is by no means new; it is widely used in the automotive and aerospace industries, though it is found comparatively little application in the construction industry. Recently, some buildings have been designed with the help of this technology with tools such as the 'EifForm' design software developed by shea [14] has attracted significant interest.

2.5 Knapsack problem

Knapsacks are basic problems in combinatorial optimization. As a basic combinatorial optimization, knapsack problems arise when we want to select an optimum subset of bounded weight from a set of items each of which has a weight and a profit. Each item consumes a known amount of resource and contributes a known benefit. Items are to be selected in a way which maximizes the total benefit without exceeding a given amount of resources and contributes a known benefit [16]. In knapsack problems, it is typically assumed that the weights and profits are positive.

Knap sack problems have been intensively studied in the past few decades [16] because of its immediate application in the industry and management sectors. Furthermore, knapsack problems arise in many practical situations and frequently occur by relaxing the various integer-programming problems. A variety of complex optimization problems can be solved through a serious of knapsack-type problems [6].

The knapsack problem is one of the fundamental NP-complete (nondeterministic polynomial time) combinatorial optimization problems which mean it's method for computing the solutions using a reasonable amount of time remains undiscovered. So, these kinds of problems are often addressed using approximation algorithms. The knapsack problem (KP) and its multidimensional version (MKP) are basic problems in combinatorial optimization.

Common applications of knapsack problems are in resource allocation with financial constraints, construction and heterogeneous test and selection of capital investments.

CHAPTER 3 MODELING THE PROBLEM

3.1 Introduction

With increased population and land requirement for residential and commercial purposes in urban areas, multistoried buildings are becoming common in construction industry. When compared to low-rise buildings, apartments and multi-story buildings accommodate more people per unit of area of land and also decrease the cost per unit area of the construction. The quantity of steel and concrete for footings, beams, columns and slabs contribute mostly to the overall cost of the structure. Further these quantities are variable while cost of finishing's and building services is assumed constant for a constant built up area. Hence, from the financial point of view, it is important to reduce the quantities of both steel and concrete without compromising on quality and design requirements.

A challenging problem facing designers in the preliminary layout design phase is how to efficiently represent the layouts of the structure. An ideal system for the preliminary layout design of buildings is one which results in an economic design and in parallel, fully considers all aspects of the process and the imposed constraints. To achieve such an ideal system, one will require major advances in multi-objective decision. Therefore, a practical preliminary layout design, in addition to satisfying the architectural constraint must consider the achieved profit as well [17]. The original plan layout for housing project 40-60 is given in fig. 3-1-1.

Figure 3-1-1: original plan layout

In order to describe the column layout of the buildings of rectangular floor plan, it is practical to divide the floor plan by smaller rectangular areas. That is, a column layout can be described as an arrangement of rectangular areas that completely fill the entire rectangular floor area. In other words, a column layout can be created by subdividing the entire floor area into several rectangular areas with no gaps as shown in the fig. 3-1-2. Any variation in the buildings column layout is equivalent to the variation of rectangles' dimensions. Various arrangement of any set of rectangular sub areas that fill the floor plan and satisfy the geometric constraints is feasible solutions. Each feasible solution represents both a column layout design and a rectilinear pattern for floor plan. Therefore, selecting the optimum set of rectangles and their optimum arrangement among the set of feasible solutions result in an optimum layout design.

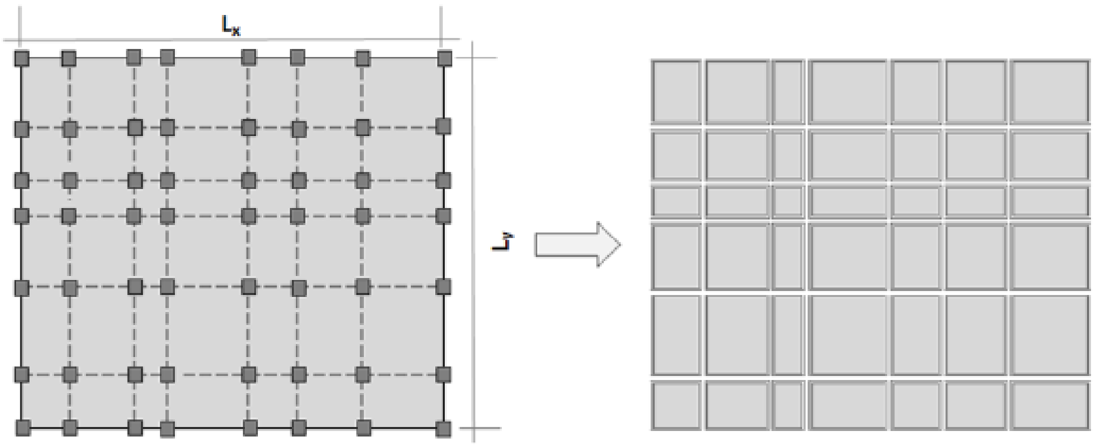

Figure 3-1-2: Sub-divided Rectangular Plan

3.2 Formulation of the Problem

Consider the typical floor plan layout for 40/60 housing project shown on fig. 3-1-1 with a definite and predetermined plan length, L_x width, L_y and area *A*. The Floor areas are subjected to live load (Qk) and dead load (Gk). The aim is to find the optimum grid layout with maximum profit (minimum cost). This optimized grid layout is modeled for analysis and design of the structure. Finally a cost comparison between the old (the previous or original) layout and the new (the optimized layout) is done.

For the knapsack optimization technique, only the grid layout for typical floor area is selected. This is because, the typical floor areas are many in number as shown in fig. 3-2-

1 and it is assumed to result much higher cost reduction than considering the other floor plans.

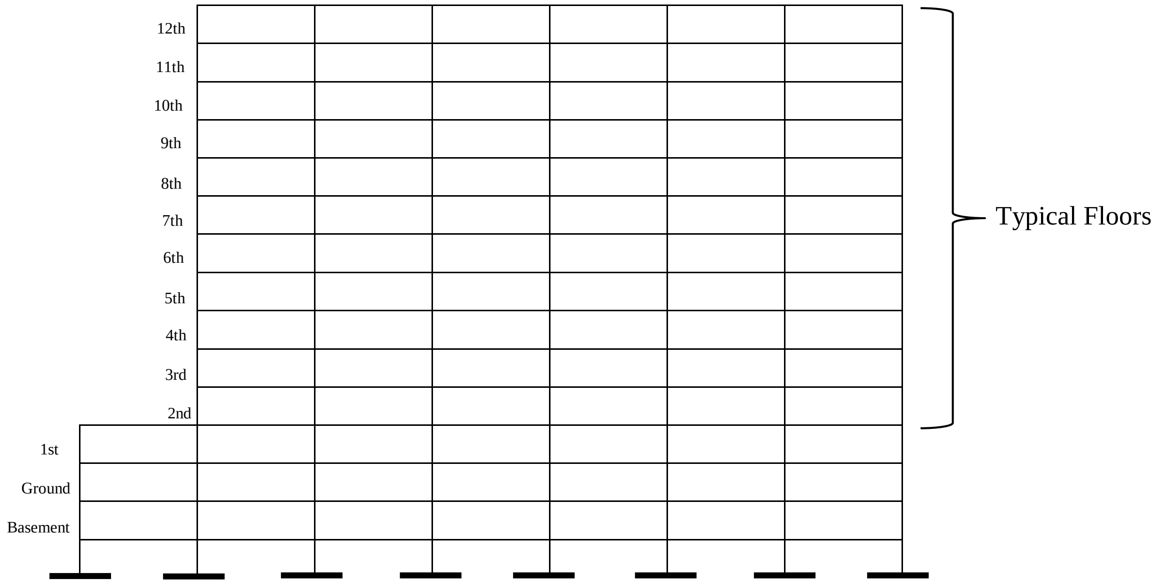

Figure 3-2-1: Section view of typical floors

The initial grid layout that is given by the architect is considered to be the starting point. Assume that there is a set of rectangles of various lengths and widths which meet the geometric requirement, such as maximum and minimum span lengths and their corresponding areas. Since the aim is to optimize the structure, the maximum and minimum spans are also obtained from the architectural layout. These rectangles represent the relative locations of columns on their corners and the floor (slab) surrounded by them. The rectangles are used to cover a floor plan of area *A*. The problem changes to selecting an appropriately arranged set of rectangles of total area *A* that maximizes the profit (objective function) and meet the constraints. And some constraints must be set to turn the optimum layout problem into a knapsack problem. The rectangles are placed on the floor plan with their four sides parallel to the *x* and *y* axes. That is, the edge of a rectangle is parallel to an edge of the enclosing rectangle. There is also no overlap for any two rectangles. To have all the columns on a grid pattern, the edges shared by any two adjacent rectangles have the same length. This will help the layout from off center columns and places all the columns on a grid pattern as shown on fig. 3-1-2 above. Furthermore, there can be no column on the rectangles' edges. Columns are only allowed to be located on corners.

As mentioned above the aim is to determine the number and lengths of spans for each direction. This problem can be treated as a simple knapsack problem as follows:

Given a set of items i ε I= {1, 2, 3,…, n} and a knapsack with limited capacity of *a* with associated vector of weights r_i and a profit b_i, the knapsack problem is the problem of selecting a subset of items from I so that the total profit of the selected items are maximum and they can fit into a knapsack of limited capacity *a*. The general knapsack problem can be formulated as:-

$$Maximize\ f = \sum_{i=1}^{n} b_i y_i \quad (1)$$

$$\sum_{i=1}^{n} r_i y_i \le a \quad (2)$$

y_i =1 if item i is chosen

y_i =0 if item i is not chosen

Where: - y_i is a variable associated with item i.

b_i and r_i respectively indicate the profit and the weight of Item i ε I = {1, 2 … n} and assumed they are positive.

Frist lets select the total length of spans from the architectural drawing in both X and Y directions. We can obtain Lx=34.90m and Ly=36.50m and the maximum and minimum length of spans in X & Y direction l_{minx}=2.95m, l_{maxx}=6.50m & l_{miny}=4.20, l_{maxy}=6.70m. From this we can see that the spans are bounded [2.95m, 6.50m] in X-direction and [4.20m, 6.70m] in Y-direction.

From the bounded spans we can form a set of rectangles by discretizing the domain for each span. But when discretizing, we have to define a desirable accuracy or interval accuracy, ε. The smaller accuracy the more accurate result will be and the more running time the algorithm needs. Since we have two different spans, we have two different desirable accuracy or interval accuracy ε_1 and ε_2 in both X & Y directions. Each span length rests in the set of {l_{imin}, l_{imin}+ε, +2ε… , l_{imax}-ε, l_{imax}}. So, let's select that the spans are discretized into 10 equal parts. Hence,

$$\varepsilon_1 = \frac{6.50 - 2.95}{10} = 0.355 \quad \text{In the X-direction} \tag{3}$$

$$\varepsilon_2 = \frac{6.70 - 4.20}{10} = 0.25 \quad \text{In the Y-direction} \tag{4}$$

Again from the bounded spans, we can obtain the maximum and minimum possible number of spans both in X and Y directions.

$$N_{sx\max} = \frac{L_x}{l_{\min x}} = \frac{34.90}{2.95} = 11.83 \tag{5}$$

$$N_{sx\min} = \frac{L_x}{l_{\max x}} = \frac{34.90}{6.50} = 5.37 \tag{6}$$

$$N_{sy\max} = \frac{L_y}{l_{\min y}} = \frac{36.50}{4.20} = 8.69 \tag{7}$$

$$N_{sy\min} = \frac{L_y}{l_{\max y}} = \frac{36.50}{6.70} = 5.45 \tag{8}$$

Every two intersecting spans, in the X and Y directions, can potentially identify a rectangle that can be used to form a rectilinear shape. Now, the number of spans in each direction is fixed and the aim is to determine the length of spans. Maximum possible numbers of spans are selected in both directions.

Consider the building with a rectangular plan and maximum possible number of spans in X and Y directions as shown in Fig. 3-2-2. There are N and M spans in X and Y-directions respectively (N and M) are known.

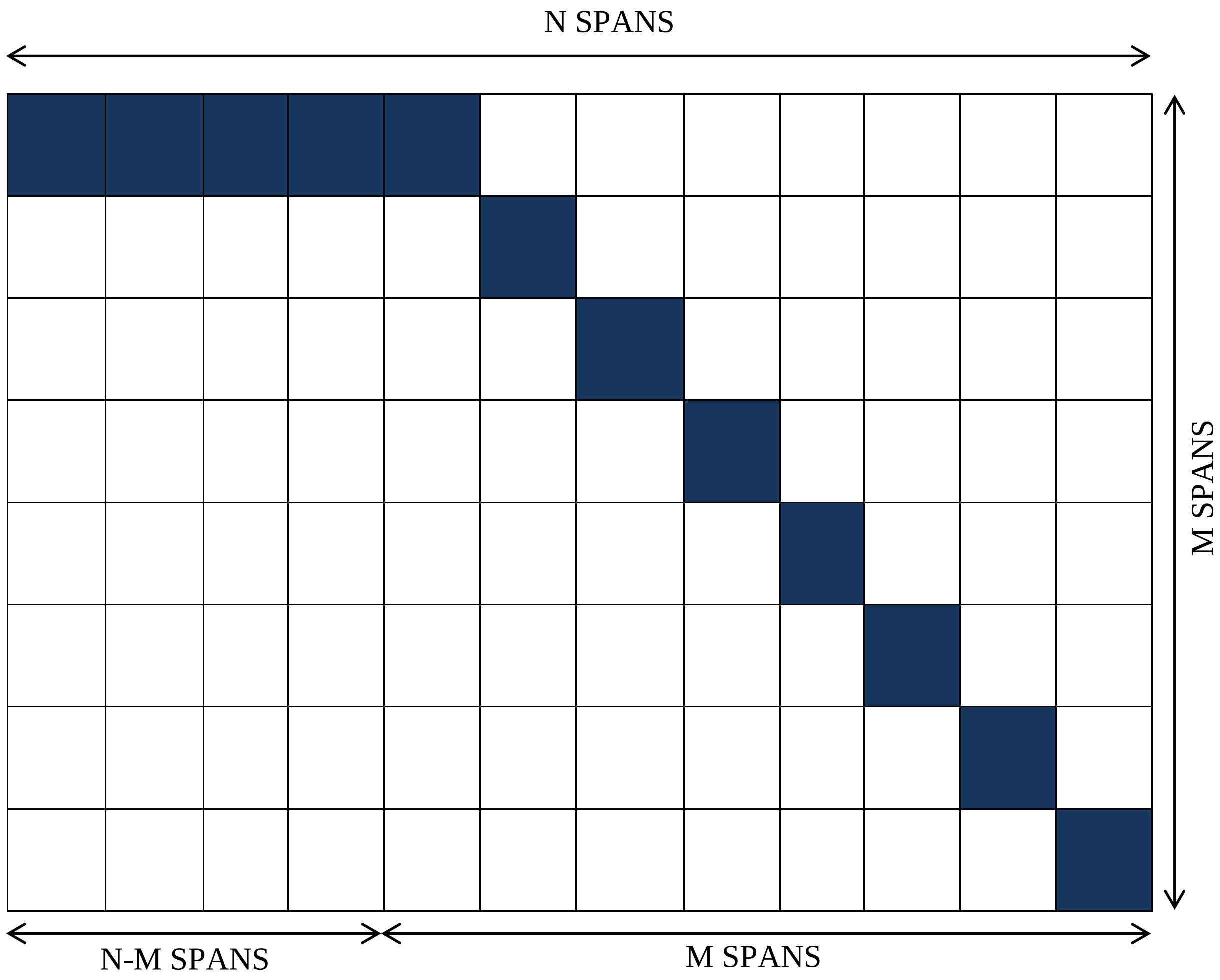

Figure 3-2-2: Knapsack Model for Layout Optimization

Now, the numbers of knapsack are set to the maximum number of spans in the longest edge of the enclosing rectangle. So, there is a knapsack with a capacity of 12 items each with a size of length (2.95, 4.20). This means that there is a total knapsack area of $12*2.95*4.20=148.68m^2$.

The reason why the maximum possible numbers of spans for the longest edge is assumed to be the number of knapsacks is that it leads to the lower number of feasible solutions and consequently lower computation time, compared to the shortest edge.

From architectural drawing, we can obtain the corresponding area with its desirable function and loading condition. This implies we can have our benefit for that corresponding area.

For live load the corresponding load is taken from European standard, Eurocode 2: Design of concrete structures-part 1: General rules and rules for buildings, prEN 1995-1-1, November 2001.

For dead loads it's taken according to their floor finish materials and imposed loads.

For a total of 121 elements, the benefits are loadings and the weights are span areas. These benefits and weights are tabulated as follows.

Table 3-2-1: Weights, items and benefits

Items	Areas,m^2	Gk, KN/m^2	Qk, KN/m^2	Load, KN
1	2.950x4.20=12.390	1.40	2.00	42.126
2	2.950x4.45=13.128	1.40	2.00	44.635
3	2.950x4.70=13.865	1.40	2.00	47.141
4	2.950x4.95=14.603	1.40	2.00	49.650
5	2.950x5.20=15.340	1.40	2.00	52.156
6	2.950x5.45=16.078	1.40	2.00	54.665
7	2.950x5.70=16.815	1.40	2.00	57.171
8	2.950x5.95=17.553	1.40	2.00	59.680
9	2.950x6.20=18.290	1.40	2.00	62.186
10	2.950x6.45=19.028	1.40	2.00	64.695
11	2.950x6.70=19.765	1.40	2.00	67.201
12	3.305x4.20=13.881	1.40	2.00	47.195
13	3.305x4.45=14.707	1.40	2.00	50.004
14	3.305x4.70=15.534	1.40	2.00	52.816
15	3.305x4.95=16.360	1.40	2.00	55.624
16	3.305x5.20=17.186	1.40	2.00	58.432
17	3.305x5.45=18.012	1.40	2.00	61.241
18	3.305x5.70=18.839	1.40	2.00	64.053

19	3.305x5.95=19.665	1.40	2.00	66.850
20	3.305x6.20=20.491	1.40	2.00	69.669
21	3.305x6.45=21.317	1.40	2.00	72.478
22	3.305x6.70=22.144	1.40	2.00	75.290
23	3.660x4.20=15.372	1.40	2.00	52.265
24	3.660x4.45=16.287	1.40	2.00	55.376
25	3.660x4.70=17.202	1.40	2.00	58.487
26	3.660x4.95=18.117	1.40	2.00	61.598
27	3.660x5.20=19.032	1.40	2.00	64.709
28	3.660x5.45=19.947	1.40	2.00	67.820
29	3.660x5.70=20.862	1.40	2.00	70.931
30	3.660x5.95=21.777	1.40	2.00	74.042
31	3.660x6.20=22.692	1.40	2.00	77.153
32	3.660x6.45=23.607	1.40	2.00	80.264
33	3.660x6.70=24.522	1.40	2.00	83.375
34	4.015x4.20=16.863	1.40	2.00	57.334
35	4.015x4.45=17.867	1.40	2.00	60.748
36	4.015x4.70=18.871	1.40	2.00	64.161
37	4.015x4.95=19.874	1.40	2.00	67.572
38	4.015x5.20=20.878	1.40	2.00	70.985
39	4.015x5.45=21.882	1.40	2.00	74.399
40	4.015x5.70=22.886	1.40	2.00	77.812
41	4.015x5.95=23.889	1.40	2.00	81.223
42	4.015x6.20=24.893	1.40	2.00	84.636
43	4.015x6.45=25.897	1.40	2.00	88.050
44	4.015x6.70=26.901	1.40	2.00	91.463

45	4.370x4.20=18.354	1.40	2.00	62.400
46	4.370x4.45=19.447	1.40	2.00	66.120
47	4.370x4.70=20.539	1.40	2.00	69.833
48	4.370x4.95=21.632	1.40	2.00	73.549
49	4.370x5.20=22.724	1.40	2.00	77.262
50	4.370x5.45=23.817	1.40	2.00	80.978
51	4.370x5.70=24.909	1.40	2.00	84.691
52	4.370x5.95=26.002	1.40	2.00	88.405
53	4.370x6.20=27.094	1.40	2.00	92.120
54	4.370x6.45=28.187	1.40	2.00	95.836
55	4.370x6.70=29.279	1.40	2.00	99.549
56	4.725x4.20=19.845	1.40	2.00	67.473
57	4.725x4.45=21.026	1.40	2.00	71.488
58	4.725x4.70=22.208	1.40	2.00	75.507
59	4.725x4.95=23.389	1.40	2.00	79.523
60	4.725x5.20=24.570	1.40	2.00	83.538
61	4.725x5.45=25.751	1.40	2.00	87.553
62	4.725x5.70=26.933	1.40	2.00	91.572
63	4.725x5.95=28.114	1.40	2.00	98.588
64	4.725x6.20=29.30	1.40	2.00	99.620
65	4.725x6.45=30.476	1.40	3.00	134.094
66	4.725x6.70=31.658	1.40	3.00	139.295
67	5.080x4.20=21.336	1.40	2.00	72.542
68	5.080x4.45=22.606	1.40	2.00	76.860
69	5.080x4.70=23.876	1.40	2.00	81.178
70	5.080x4.95=25.146	1.40	2.00	85.496
71	5.080x5.20=26.416	1.40	2.00	89.814
72	5.080x5.45=27.686	1.40	2.00	94.132

73	5.080x5.70=28.956	1.40	2.00	98.450
74	5.080x5.95=30.226	1.40	3.00	132.994
75	5.080x6.20=31.496	1.40	3.00	138.582
76	5.080x6.45=32.766	1.40	3.00	144.170
77	5.080x6.70=34.036	1.43	2.00	116.743
78	5.435x4.20=22.827	1.40	2.00	77.612
79	5.435x4.45=24.186	1.41	2.00	82.474
80	5.435x4.70=25.545	1.45	2.00	88.130
81	5.435x4.95=26.903	1.40	2.00	91.470
82	5.435x5.20=28.262	1.40	2.00	96.091
83	5.435x5.45=29.621	1.40	2.00	100.711
84	5.435x5.70=27.447	1.40	3.00	120.767
85	5.435x5.95=32.338	1.42	2.10	113.830
86	5.435x6.20=33.697	1.42	2.10	118.613
87	5.435x6.45=35.056	1.43	2.00	120.242
88	5.435x6.70=36.415	1.00	1.00	72.830
89	5.790x4.20=24.318	1.41	2.00	82.924
90	5.790x4.45=25.766	1.45	2.00	88.893
91	5.790x4.70=27.213	1.40	2.00	92.524
92	5.790x4.95=28.661	1.40	2.00	97.447
93	5.790x5.20=30.108	1.40	3.00	132.480
94	5.790x5.45=31.556	1.40	3.00	138.846
95	5.790x5.70=33.003	1.42	2.10	116.171
96	5.790x5.95=34.451	1.43	2.00	118.167
97	5.790x6.20=35.898	1.43	2.00	123.130
98	5.790x6.45=37.346	1.00	1.00	74.692
99	5.790x6.70=38.793	1.00	1.00	77.586
100	6.145x4.20=25.809	1.45	2.00	89.041

101	6.145x4.45=27.345	1.40	2.00	92.970
102	6.145x4.70=28.882	1.42	2.00	98.770
103	6.145x4.95=30.418	1.40	3.00	133.840
104	6.145x5.20=31.954	1.40	3.00	140.600
105	6.145x5.45=33.490	1.40	3.00	147.360
106	6.145x5.70=35.027	1.43	2.00	120.140
107	6.145x5.95=36.563	1.00	1.00	73.130
108	6.145x6.20=38.099	1.00	1.00	76.200
109	6.145x6.45=39.635	1.00	1.00	79.270
110	6.145x6.70=41.172	1.00	1.00	82.340
111	6.500x4.20=27.300	1.40	2.00	92.820
112	6.500x4.45=28.925	1.40	2.00	98.350
113	6.500x4.70=30.550	1.40	3.00	134.420
114	6.500x4.95=32.175	1.40	3.00	141.570
115	6.500x5.20=33.800	1.42	2.10	118.980
116	6.500x5.45=35.425	1.43	2.00	121.510
117	6.500x5.70=37.050	1.00	1.00	74.100
118	6.500x5.95=38.675	1.00	1.00	77.350
119	6.500x6.20=40.300	1.00	1.00	80.600
120	6.500x6.45=41.925	1.00	1.00	83.500
121	6.500x6.70=43.550	1.00	1.00	87.100

Now, from the table 3-2-1 there are lists for the items, weights and benefit so, the next process will be solving for the optimum layout by using knapsack principle. But in this case, the benefits that are going to be selected are the inverse (1/w). This is because the benefits are actually the load and if these benefits are taken directly, it will maximize the load but the result needed is to minimize it. So, it is necessary to take the inverse during optimizing the structure.

Now, the general equation for the knapsack problem is as follows:-

$$Maximize\ f(y) = \sum_{i=1}^{121} b_i y_i \tag{9}$$

Subjected to:

$$\sum_{i=1}^{121} r_i y_i \le 148.68$$
$$0 \le y_i <= 1 \tag{10}$$
$$b_i \ge 0, \quad r_i \ge 0, \quad 0 \le i \le 121$$

As it is seen, the weights and benefits for this specific condition are too much in number. So, a certain mechanism or a program should be developed to do the iteration process. A flowchart that shows the iteration process is shown on fig.3-2-3. This iteration process can also be done using MS excel because the problem is a linear programming problem. Hence, the problem is formulated on MS excel and a program is written on C++ for this specific problem. Then a comparison is made to obtain optimal layout of plans. The code for C++ is presented in appendix A and the formulation for MS excel is presented in appendix F.

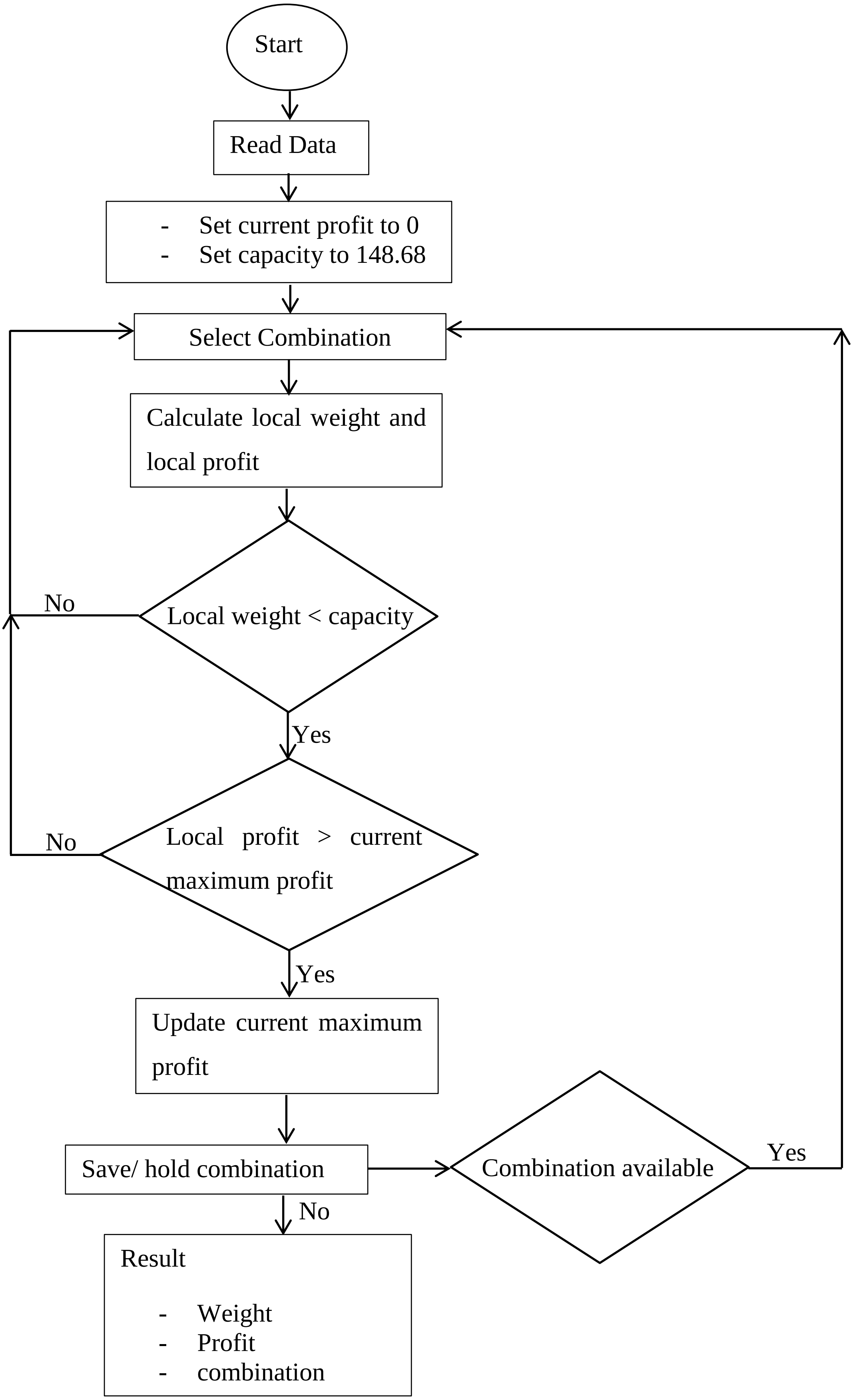

Figure 3-2-3: Flowchart for C++ program

Now we can easily see the selected optimal layout of plans.

Table 3-2-2: Selected elements from C++ program

Items	Areas,m^2	Gk, KN/m^2	Qk, KN/m^2	Load, KN
1	2.950x4.20=12.390	1.40	2.00	42.130
2	2.950x4.45=13.128	1.40	2.00	44.630
3	2.950x4.70=13.865	1.40	2.00	47.140
4	2.950x4.95=14.603	1.40	2.00	49.650
5	2.950x5.20=15.340	1.40	2.00	52.160
6	3.305x4.20=13.881	1.40	2.00	47.200
7	6.145x5.20=31.954	1.40	2.00	140.60
8	6.145x5.45=33.490	1.40	2.00	147.360
	Total Area= 148.651			

Table 3-2-3: Selected elements from MS excel

Items	Areas,m^2	Gk, KN/m^2	Qk, KN/m^2	Load, KN
1	2.950x4.20=12.390	1.40	2.00	42.130
2	2.950x4.45=13.128	1.40	2.00	44.630
3	2.950x4.70=13.865	1.40	2.00	47.195
4	2.950x4.95 =14.603	1.40	2.00	49.650
5	3.305x4.20 =13.881	1.40	2.00	47.200
6	3.305x4.45 =14.707	1.40	2.00	50.000
7	6.145x5.45=33.490	1.40	3.00	147.360
8	6.500x4.95=32.175	1.40	3.00	141.57
	Total Area= 148.239			

Table 3-2-4: Comparison of Selected elements by C++ and MS excel

Items	Selected elements form MS excel	Selected elements form C++
1	2.950x4.20=12.390 m^2	2.950x4.20=12.390 m^2
2	2.950x4.45=13.128 m^2	2.950x4.45=13.128 m^2
3	2.950x4.70=13.865 m^2	2.950x4.70=13.865 m^2
4	2.950x4.95 =14.603 m^2	2.950x4.95=14.603 m^2
5	3.305x4.20 =13.881 m^2	2.950x5.20=15.340 m^2
6	3.305x4.45 =14.707 m^2	3.305x4.20=13.881 m^2
7	6.145x5.45=33.490 m^2	6.145x5.20=31.954 m^2
8	6.500x4.95=32.175 m^2	6.145x5.45=33.490 m^2
	Total Area= 148.239 m^2	Total Area= 148.651 m^2

For the next subsequent chapters i.e. for the analysis and design of the new optimized structure, we are going to use the panels on Table 3-2-2. This is because the results obtained from C++ is much accurate than the results obtained from MS excel. The items 1 up-to 4 above on Table 3-2-4 are the elements selected for both programs. The MS excel avoid selecting the elements from 4 up-to 8 on Table 3-2-4. These elements are the reason to get different optimized areas. The panels on Table 3-2-2 are put in plan and the optimized structure is presented in Fig. 3-2-5. From the optimized structure one can observe the change in dimensions. Take for example Axis 2-2' that was 2.45m on the original plan layout is now changed into 2.95m on Axis 1-2 on the optimized plan layout. These are shown in Fig. 3-2-4.

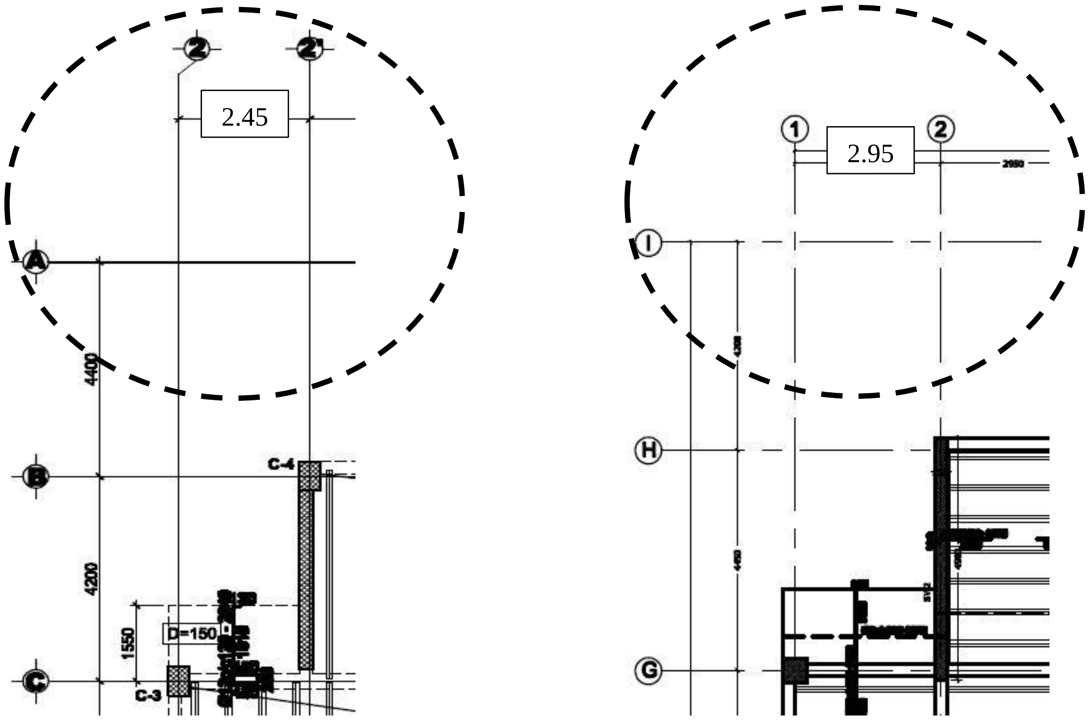

Figure 3-2-4: Sample comparison of Original and Optimized structural plan layout

Figure 3-2-5: Optimized structural plan layout

CHAPTER 4 ANALYSIS AND DESIGN OF OPTIMIZED STRUCTURE USING CONVENSIONAL REINFORCED CONCRETE SYSTEM

4.1 Introduction

A representative architectural drawing, shown on fig 3-1-1, that was previously adopted for the 40/60 housing project is changed to the "optimized" architectural layout shown in fig 3-2-5. This architectural layout is modeled and analyzed on ETABS version 9.7.4 to compare the economical aspect of the previous structural layout and the "optimized" layout.

The structure represents a divided "H" shape that makes the structure irregular in plan. To avoid this plan irregularity, expansion joints are introduced and divided the building into three parts.

4.2 Dimensioning and setting up structural arrangement

With the help of the new optimized structure, the dimensioning and the arrangements are shown in **drawing A annex** of this research. Shear wall locations and sizes might or might not be varied in shape and size. This is decided when the analysis of the structure is finished. Hence, the design and analysis of the optimized structure is finally carried out.

4.3 Material properties, loading and load combinations

Since our aim is to optimize the structure, the material property is taken as the same as the previously done structure. These material properties are also defined according to Ethiopian Building code of standards as well as Eurocode (European standard).

The loads and loading combinations are set in due consideration of the self-weight of the structure, imposed dead loads, live loads and earthquake loads. The material properties, load cases and load combinations are summarized in table 4-3-1, table 4-3-2 and table 4-3-3 respectively.

Table 4-3-1: Material properties of concrete and steel

Concrete Grade	**C-30**	**C-25**
Material type	isotropic	isotropic
Cylindrical strength (f_{ck}) [MPa]	24	20
Modulus of elasticity [GPa]	32	29
Mass per unit volume	2.4465	2.4465
Weight per unit volume	25	25
Poisons ratio	0.2	0.2
Coefficient of thermal expansion [℃]	$9.9*10^{-6}$	$9.9*10^{-6}$
Shear modulus[Gpa]	13.33	12.08
Steel grade	**S-400**	**S-300**
Material type	isotropic	isotropic
Minimum yield strength [Mpa]	400	300
Modulus of elasticity [GPa]	200	200
Mass per unit volume [kg/m^3]	2.548	2.548
Weight per unit volume [KN/m^3]	78.54	78.54
Poisons ratio	0.3	0.3
Coefficient of thermal expansion [℃]	$1.17*10^{-5}$	$1.17*10^{-5}$
Shear modulus[Gpa]	76.88	76.88

Table 4-3-2: Load cases

Case	Type	Self-weight multiplier	Auto load
SELFW	DEAD	1	
LIVE	LIVE	0	
OTHERDL	SUPER DEAD	0	
EQXP	QUAKE	0	UBC97
EQXN	QUAKE	0	UBC97
EQYP	QUAKE	0	UBC97
EQYN	QUAKE	0	UBC97

Table 4-3-3: Load combinations

Combinations	Type	Case	Factor	Case Type
COMB1	ADD	SELFW	1	Static
		OTHERDL	1	Static
		LIVE	1	Static
COMB2	ADD	SELFW	1.3	Static
		OTHERDL	1.3	Static
		LIVE	1.6	Static
COMB3	ADD	COMB2	0.75	Combo
		EQXP	1	Static
COMB4	ADD	COMB2	0.75	Combo
		EQXP	-1	Static
COMB5	ADD	COMB2	0.75	Combo
		EQXN	1	Static
COMB6	ADD	COMB2	0.75	Combo
		EQXN	-1	Static

COMB7	ADD	COMB2	0.75	Combo
		EQYP	1	Static
COMB8	ADD	COMB2	0.75	Combo
		EQYP	-1	Static
COMB9	ADD	COMB2	0.75	Combo
		EQYN	1	Static
COMB10	ADD	COMB2	0.75	Combo
		EQYN	-1	Static
ENVELOPE	ENVE	COMB1	1	Combo
		COMB2		Combo
		COMB3		Combo
		COMB4		Combo
		COMB5		Combo
		COMB6		Combo
		COMB7		Combo
		COMB8		Combo
		COMB9		Combo
		COMB10		Combo
ENVX	ENVE	COMB3	1	Combo
		COMB4		Combo
		COMB5		Combo
		COMB6		Combo
ENVY	ENVE	COMB7	1	Combo
		COMB8		Combo
		COMB9		Combo
		COMB10		Combo

4.4 Modeling and design aspects

As per Euro-code 1 part 1, 1 a reduction factor is employed according to floor categories of loaded areas. The recommended value for the reduction factor α_A for categories A to E is determined as follows:

$$\alpha_A = \frac{5}{7}\psi_o + \frac{A_o}{A} \leq 1 \quad (9)$$

With restrictions for category C and D: $\alpha_A \geq 0.6$

The recommended values for α_n is given below.

$$\alpha_n = \frac{2+(n-2)\psi_o}{n} \quad (10)$$

Table 4-4-1: Live load reduction factors

Number of stories supported	Reduction factor
3	0.9
4	0.85
5	0.82
6	0.8
7	0.786
8	0.775
9	0.76667
10	0.760
11	0.75454
12	0.75
13	0.74615
14	0.74286
15	0.74

Drift and stability index values are given according to table 4-4-2.

Table 4-4-2: Drift and stability values

Story	P [KN]	Story shear Vx [KN]	Story shear Vy [KN]	Drift, X	Drift, Y	Stability Index, ϴx	Stability Index, ϴy
TTB	8975.62	1504.58	1504.58	0.0011	0.005	0.0066	0.0292
12th	20872.37	2674.93	2674.93	0.0012	0.005	0.0090	0.0398
11^{th}	32769.12	3764.06	3764.06	0.0012	0.005	0.0104	0.0453
10^{th}	44665.87	4769.41	4769.41	0.0012	0.005	0.0117	0.0487
9^{th}	56562.62	5690.98	5690.98	0.0013	0.005	0.0128	0.0527
8^{th}	68459.37	6528.77	6528.77	0.0013	0.005	0.0139	0.0556
7^{th}	80356.12	7282.78	7282.78	0.0013	0.005	0.0148	0.0574
6^{th}	92252.86	7953.01	7953.01	0.0013	0.005	0.0154	0.0592
5^{th}	104149.61	8539.46	8539.46	0.0013	0.005	0.0158	0.0585
4^{th}	116046.36	9042.14	9042.14	0.0012	0.005	0.0156	0.0578
3^{rd}	127943.11	9461.03	9461.03	0.0011	0.004	0.0149	0.0541
2^{nd}	142409.43	9850.40	9850.40	0.0009	0.003	0.0134	0.0477
1^{st}	157127.8	10151.09	10151.09	0.0007	0.003	0.0104	0.0402
Ground	173894.97	10378	10378	0.0004	0.002	0.0068	0.0302
Basement	179293.87	10416.25	10416.25	0.0002	0.001	0.0034	0.0138

Based on the table 4-4-2, second order effect(P-Δ effect) and inter story drifts are checked and fulfilled according to the conditions on euro code 8 section 4.4.2.2 and 4.4.3.2 as well as EBCS-8 1995 section 2.4.2.2 and 2.4.3.2 respectively.

Stiffness modification factors are used according to table 4-4-3

Table 4-4-3: Stiffness modification factors

	Modification factor
Beams	0.35
Slabs	0.35
Columns	0.7
Cracked walls	0.35
Un-cracked walls	0.7

CHAPTER 5 COST COMPARISON

Now that the analysis and the design have been done using structural analysis software, the remaining part is to compare the cost of the “optimized structure” with that of the “old” one. For the purpose of cost evaluation, different tasks are carried out which includes, optimization of the 40/60 housing project using knapsack method as a method for the layout optimization and performing the analysis and design using structural analysis software called ETABS V.9.7.4. For manual calculations for specific members, different excel sheets are used for design purposes as well as for calculations of the bill of quantities. An excel sheet for the design of cantilever solid slab is attached in Appendix B. For designing the stairs, an excel sheet is attached in Appendix C.

Quantity for the ribbed slab using the conventional reinforced concrete system is calculated and compared with the price for the ribbed slab using the optimization technique.

Quantity for the columns using the conventional reinforced concrete system is calculated and compared with the price for the columns using the optimization technique.

Finally, comparison is done based on the quantity and current unit rates for the materials.

These cost comparisons exclude maintenance costs of both systems & time delay costs. The cost due to quality is assumed to be equal for both systems because we are assumed using the same materials with the same quality levels.

5.1 Material cost for slabs

Material cost for the two systems can be compared by taking the quantity values tabulated in the tables. The concrete grades used for both systems is C25 (It is a concrete strength having 25MPa of cube strength)

Table 5-1-1: Cost summary for reinforced concrete system slab

Item	Description	Unit	Quantity	Unit Price [Birr/m^3]	Amount [Birr]
1	Ground floor slab				
1.1	170mm thick Ground floor Slab	m^3	122.07	2500.00	305,175.00

1.2	180mm thick Ground floor Slab	m^3	31.66	2500.00	79,150.00
1.3	Formwork				
1.4	Formwork to 170mm thick Slab	m^2	1,047.62	147.00	154,000.10
1.5	Formwork to 180mm thick Slab	m^2	893.92	147.00	131,406.24
1.6	Rebar				
1.7	Dia. 10mm deformed bar	kg	35,174.14	35.00	1,231,094.90
1.8	Dia. 12mm deformed bar	kg	68,559.99	35.00	2,399,599.65
2	Frist floor Slab up-to 12th floor Slab				
	Ribbed slab for suspended floor slab made of 60mm thick concrete slab in C-25 60x120mm one way concrete girder with c/c spacing of 600mm 220x520mm hallow concrete ribbed block and all according to the detail structural drawing	m^3	532.09	3,966.66	2,110,620.12
2.1	mesh				
	Dia. 8mm	kg	61,601.04	35	2,156,036.40
2.2	Support reinforcements				
	Dia. 14mm	kg	26,571.16	35	929,990.60
3	Pre-cast elements (PB-1) to the size of 5500x120x80mm made of 0.0528m3 concrete in C-25/ beam. Price includes beam erecting, bending and placing in position, welding of reinforcement bar and mold according to structural detail drawing	Pcs	1,860.00	1,800.00	3,348,000.00
	a) Dia. 6mm plain bar (5.544kg)				
	b) Dia. 12mm deformed bar (5.2332kg)				
	c) Dia. 14mm deformed bar (20.038kg)				
4	Pre-cast elements (PB-2) to the size of 4400x120x80mm made of 0.042m3 of concrete in C-25/ beam Price includes beam erecting, bending and placing in position, welding of reinforcement bar and mold according to structural detail drawing	Pcs	1,754.00	1,700.00	2,981,800.00
	a) Dia. 6mm plain bar (5.28kg)				
	b) Dia. 12mm deformed bar (10.68kg)				
5	Pre-cast elements (PB-3) to the size of 4200x120x80mm made of 0.042m3 of concrete in C-25/ beam Price includes beam erecting, bending and placing in position, welding of reinforcement bar and mold according to structural detail	Pcs	468	1,650.00	772,200.00

	drawing				
	a) Dia. 6mm plain bar (5.28kg)				
	b) Dia. 12mm deformed bar (10.68kg)				
	Total				**16,293,898.01**

Table 5-1-2: Cost summary for optimized reinforced concrete system slab

Item	Description	Unit	Quantity	Unit Price [Birr/m^3]	Amount [Birr]
1	Floor slabs				
	150mm thick Ground floor Slab	m^3	122.74	2500.00	306,850.00
	150mm thick First floor Slab	m^3	114.32	2500.00	285,800.00
	150mm thick Second floor Slab	m^3	109.97	2500.00	274,925.00
	Formwork				
	Formwork to 150mm thick Slab	m^2	2313.53	147.00	340,088.91
	Rebar				
	150mm thick Ground floor Slab				
	Dia. 8mm deformed bar	kg	3,642.65	35.00	127,492.75
	Dia. 10mm deformed bar	kg	3,823.34	35.00	133,816.9
	Dia. 12mm deformed bar	kg	3,830.01	35.00	134,050.35
	Dia. 14mm deformed bar	kg	267.67	35.00	9,368.45
	150mm thick First floor Slab				
	Dia. 8mm deformed bar	kg	3,106.61	35.00	108,731.35
	Dia. 10mm deformed bar	kg	3,600.03	35.00	126,001.05
	Dia. 12mm deformed bar	kg	3,082.53	35.00	107,888.55
	Dia. 14mm deformed bar	kg	151.50	35.00	5,302.50
	150mm thick Second floor Slab				
	Dia. 8mm deformed bar	kg	3,110.70	35.00	108,874.50
	Dia. 10mm deformed bar	kg	3600.03	35.00	126,001.05
	Dia. 12mm deformed bar	kg	3082.53	35.00	107,888.55
	Dia. 14mm deformed bar	kg	151.50	35.00	5,302.50
2	3rd up-to 12th floor Slab				
	Pre-cast elements (PB-1) to the size of 3450x120x80mm made of 0.03m3 concrete in C-25/ beam. Price includes beam erecting, bending and placing in position, welding of reinforcement bar and mold according to structural detail drawing	Pcs	1,870	1,650.00	3,085,500.00
	a) Dia. 6mm plain bar (5.28kg)				
	b) Dia. 12mm deformed bar (10.68kg)				

	Pre-cast elements (PB-2) to the size of 6400x120x80mm made of 0.061m3 of concrete in C-25/ beam Price includes beam erecting, bending and placing in position, welding of reinforcement bar and mold according to structural detail drawing	Pcs	800	1,800.00	1,440,000.00
	a) Dia. 6mm plain bar (5.753kg)				
	b) Dia. 12mm plain bar (10.68kg)				
	c) Dia. 14mm plain bar (20.038kg)				
	Rebar				
	3^{rd} up-to 12^{th} floor Slab				
	Dia. 8mm deformed bar	kg	13,693.61	35.00	479,276.35
	Dia. 10mm deformed bar	kg	4,726.47	35.00	165,426.45
	Dia. 12mm deformed bar	kg	7,301.26	35.00	255,544.10
	Dia. 16mm deformed bar	kg	48,456.51	35.00	1,695,977.85
	Dia. 20mm deformed bar	kg	86,392.83	35.00	3,023,749.05
	Total				**12,453,856.21**

5.2 Material cost for column

The concrete grade used for both systems is C30 (It is a concrete strength having 30MPa of cube strength). Table 5-2-1 and Table 5-2-2 below show the costs for steel and concrete respectively.

Table 5-2-1: Cost summary for the steel used in columns

	Total mass [kg]	Price per kg [Birr]	Total cost [Birr]
For Reinforced Concrete system	145,797.14	35.00	5,102,899.90
For optimized Reinforced Concrete system	183,527.23	35.00	6,423,453.05

Table 5-2-2: Cost summary for the concrete used in columns

	Total volume of concrete [m^3]	Price per m^3 [Birr]	Total cost [Birr]
For Reinforced Concrete system	715.36	2,700.00	1,931,472.00
For optimized Reinforced Concrete system	594.11	2,700.00	1,604,097.00

5.3 Material cost for beam

Material cost for the two systems can be compared by taking the quantity values computed in appendix E of this research. The concrete grade used for both systems is C25 (It is a concrete strength having 25MPa of cube strength). Table 5-3-1 and Table 5-3-2 below show the costs for steel and concrete respectively.

Table 5-3-1: Cost summary for the steel used in beams

	Total mass [kg]	Price per kg [Birr]	Total cost [Birr]
For Reinforced Concrete system	238,806.36	35.00	8,358,222.60
For optimized Reinforced Concrete system	154,327.90	35.00	5,401,476.50

Table 5-3-2: Cost summary for the concrete used in beams

	Total volume of concrete [m^3]	Price per m^3 [Birr]	Total cost [Birr]
For Reinforced Concrete system	801.27	2,500.00	2,003,175.00
For optimized Reinforced Concrete system	731.89	2,500.00	1,829,725.00

5.4 Material cost for shear wall

Material cost for the two systems can be compared by taking the quantity values computed in appendix E of this research. The concrete grade used for both systems is C25 (It is a concrete strength having 25MPa of cube strength). Table 5-4-1 and Table 5-4-2 below show the costs for steel and concrete respectively.

Table 5-4-1: Cost summary for the steel used in shear walls & lift duct

	Total mass [kg]	Price per kg [Birr]	Total cost [Birr]
For Reinforced Concrete system	45,979.14	35.00	1,609,269.90
For optimized Reinforced Concrete system	55,155.59	35.00	1,930,445.65

Table 5-4-2: Cost summary for the concrete used in shear walls & lift duct

	Total volume of concrete [m^3]	Price per m^3 [Birr]	Total cost [Birr]
For Reinforced Concrete system	439.88	2,500.00	1,099,700.00
For optimized Reinforced Concrete system	389.00	2,500.00	972,500.00

5.5 Discussion

The total cost for the slab, beams, column and shear wall can be summarized in figure 5-5-1 below. As it represents, the total cost of the optimized structure as compared to the old original structure is lower. So, the application of structural layout optimization method for housing project 40/60 can be so helpful in reduction of its cost. This method can also be used prior to architectural designs. In doing so, the structural engineer first lays the structural outlines and then based on this outlines the architect functionalize the area. The layouts can be further outlined and iterated for a better output solutions and cost optimization.

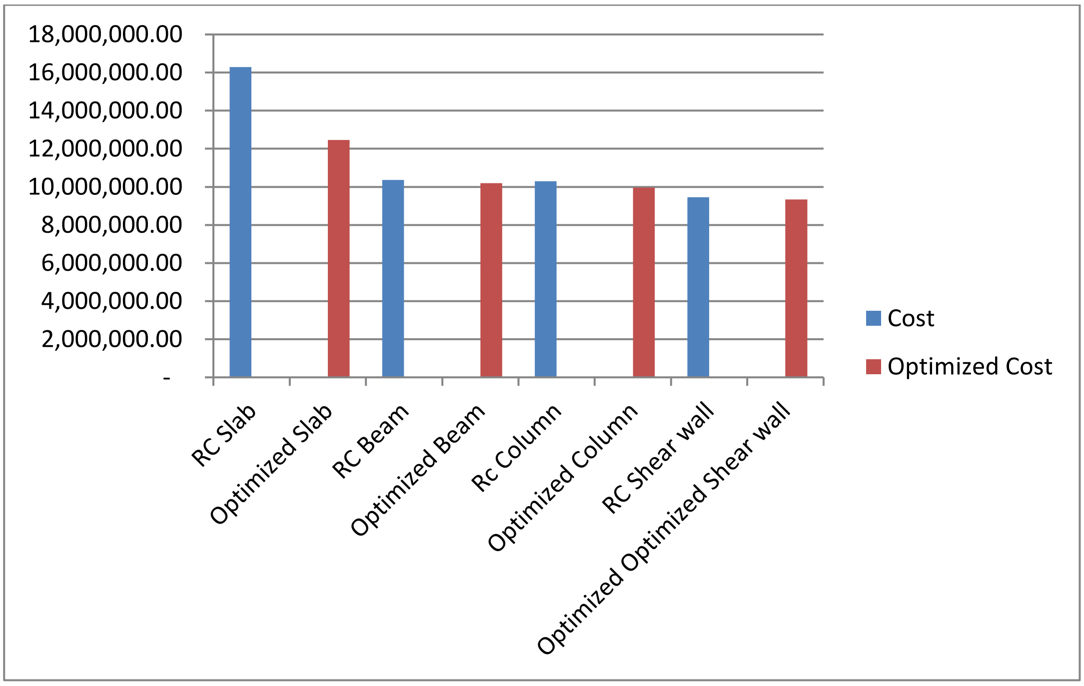

Figure 5-5-1: Cost summary

CHAPTER 6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Two alternative designs for the housing project 40/60 have been presented: the original one, a design that didn't adopt the layout optimization technique, and a second one, that adopts the structural layout optimization technique using knapsack problem. Each design features the same material and the same design standards. However, the design that adopts structural layout optimization technique is recommended as it was found to be more economical in terms of the overall structural cost of the building.

In chapter five, the cost comparison between the two systems i.e. between the optimized structure and the previously designed structure was clearly depicted. As it was shown in fig 5-5-1, layout optimization has a tremendous effect on the cost of the slab because it is directly related to the layout of slabs. The others (beams, columns and shear walls) are indirectly affected by the layout optimization process.

Architectural design systems should be done in collaboration with the structural engineer. This will aid to obtain an optimum layout that can help to achieve a minimum cost in the intended project and limits the scopes of the architect and also reduces the time required on design stage. Since the two professionals are doing together or in collaboration, there will not be an elapsed time due to the effect of design flexibility.

Finally, the overall structural drawings are presented in appendix F. From these it is clearly shown the application of Structural Layout Optimization must be used in the 40/60 housing projects. Because these structures are going to be built many in number and in different areas, a small minimization in cost will be able to help us save a due amount of money.

6.2 Recommendation

Structural Layout Optimization should be considered to improve the construction industry and specifically the beauty, quality and production time of the housing project.

The C++ program adopted for this research doesn't work to optimize for all kinds of structural layout types. This can be considered as a drawback. So, it is better to try formulating a universally adoptable program for structural layout optimization technique.

This research didn't address all of the problems the housing project faces. It tries to solve a problem related to cost. But problems with regard to quality and production time are not addressed. So, it is recommended to include quality and time in future studies with the inclusion of cost.

It would have been better if this research considers all the needs of the user and the architect. But it lacks addressing questions like mentioned above.

In this research, the economics in cost reduction is achieved only by optimizing the structural members through the loads on the slab panels but one can also try to reduce the cost by using different materials (may be steel, composite or any other relevant structural material) and different grades of structural materials as a primary option.

Design and cost comparison of column and shear wall with that of lateral wall systems shall also be investigated. This will help to compare the cost with that of the columns.

Design and cost comparison of ribbed (cast-in-situ), solid and that of flat slabs shall also be investigated not only with the cost of the structure but also with that of quality and construction period.

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APPENDIX A Computer program for solving knapsack problem

```
#include <stdio.h>

const double capacity = 148.68;

const int number_of_elements = 121;

double weight[] = {};

double profit[] = {};

double resultWeightCombination [121];

double resultProfitCombination [121];

int numberOfPickedElements = 0;

double totalWeightSum = 0;

double maxProfit = 0;

void combinationUtil(double arr[], double data[], double data_p[], int start, int end,

                    int index, int r);

 // The main function that prints all combinations of size r

// in arr[] of size n. This function mainly uses combinationUtil()

void printCombination(double arr[], int n, int r)

{

    // A temporary array to store all combination one by one

    double data[r];

    double data_p[r];

     // Print all combination using temprary array 'data[]'
```

```
    combinationUtil(arr, data, data_p, 0, n-1, 0, r);
}
 /* arr[]  ---> Input Array
   data[] ---> Temporary array to store current combination
   start & end ---> Staring and Ending indexes in arr[]
   index  ---> Current index in data[]
   r ---> Size of a combination to be printed */
void combinationUtil(double arr[], double data[], double data_p[], int start, int end,
                     int index, int r)
{
    // Current combination is ready to be printed, print it
    if (index == r)
    {
        double weightSum = 0;
        double localProfitMax = 0;
        int combinationSize = r;
                        int j;
        for (j=0; j<r; j++) {
            weightSum += data[j];
            localProfitMax += data_p[j];
            //comment this line
```

```
        printf("%f ", data[j]);
    }
        //comment this line
    printf("\n");
    // valid sack!
    if(weightSum <= capacity) {
        if(localProfitMax >= maxProfit) {
            // replace local profit
            maxProfit = localProfitMax;
            totalWeightSum = weightSum;
            numberOfPickedElements = combinationSize;
             // copy result
            int k;
            for(k=0; k<combinationSize; k++) {
                resultWeightCombination[k] = data[k];
                resultProfitCombination[k] = data_p[k];
            }
            //printf("\nWeight Sum -> %d Profit Sum --> %d\n", weightSum,
localProfitMax);
        }
    }
```

```
      return;
    }
    // replace index with all possible elements. The condition
    // "end-i+1 >= r-index" makes sure that including one element
    // at index will make a combination with remaining elements
    // at remaining positions
    int i;
    for (i=start; i<=end && end-i+1 >= r-index; i++)
    {
        data[index] = arr[i];
        data_p[index] = profit[i];
        combinationUtil(arr, data, data_p, i+1, end, index+1, r);
    }
}
 // Driver program to test above functions
int main()
{
            int p;
    for(p=number_of_elements; p>0; p--) {
        //totalWeightSum = 0;
        //int i = 4;
```

```
        int n = sizeof(weight)/sizeof(weight[0]);
        printCombination(weight, n, p);
    }
    printf("Maximum Weight = %f, Maximum profit %f \n\n", totalWeightSum, maxProfit);
    printf("Weight Combination\n");
    int k;
    for(k=0; k<numberOfPickedElements; k++) {
        printf("%f, ", resultWeightCombination[k]);
    }
    printf("\n");
    printf("Profit Combination\n");
    for(k=0; k<numberOfPickedElements; k++) {
        printf("%f, ", resultProfitCombination[k]);
    }
    printf("\n");
}
```

APPENDIX B DESIGN OF TYPICAL CANTILEVER SLAB

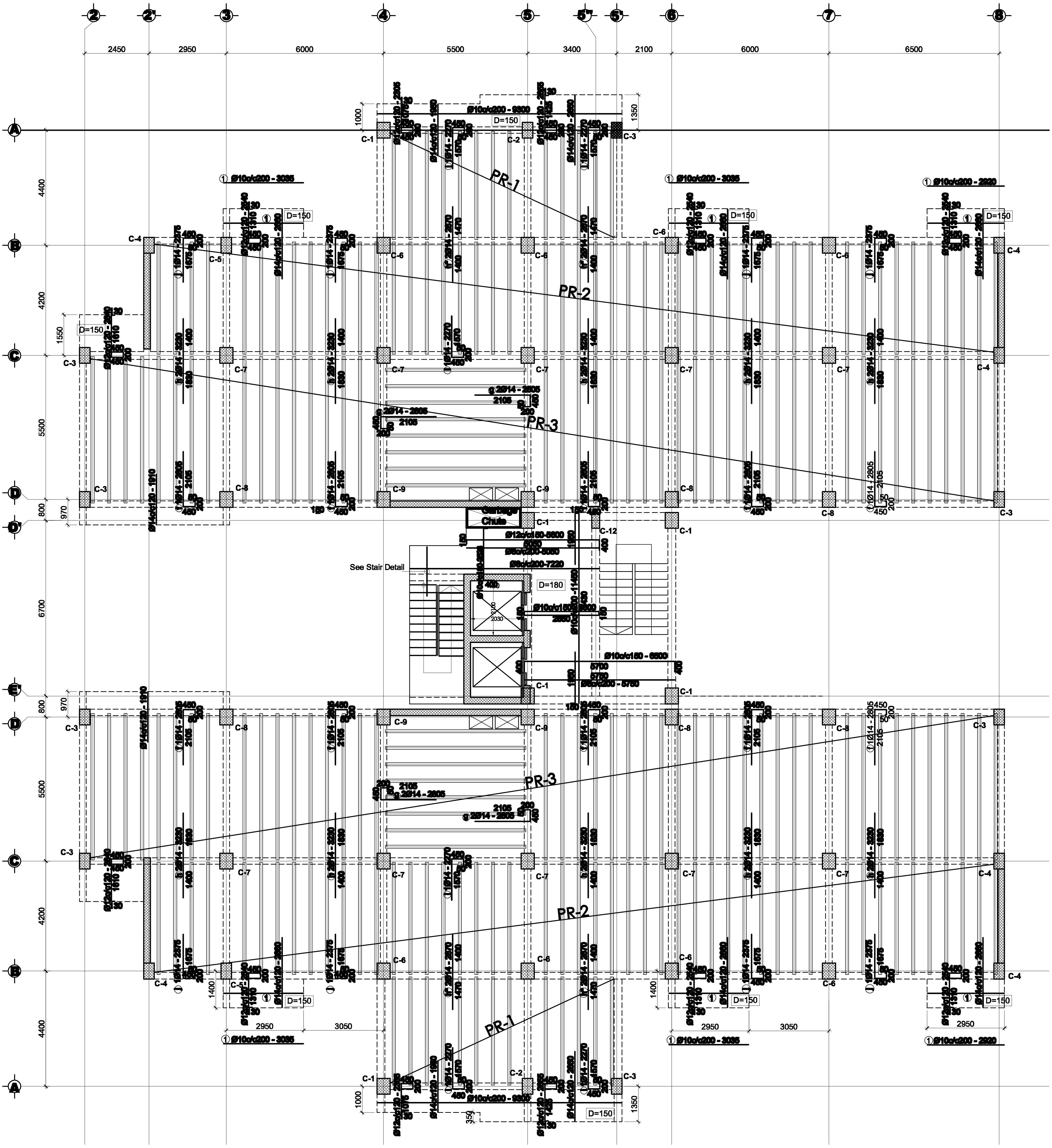
APPENDIX C STAIR DESIGN

APPENDIX D WALL LOAD CALCULATION

APPENDIX E SLAB DESIGN

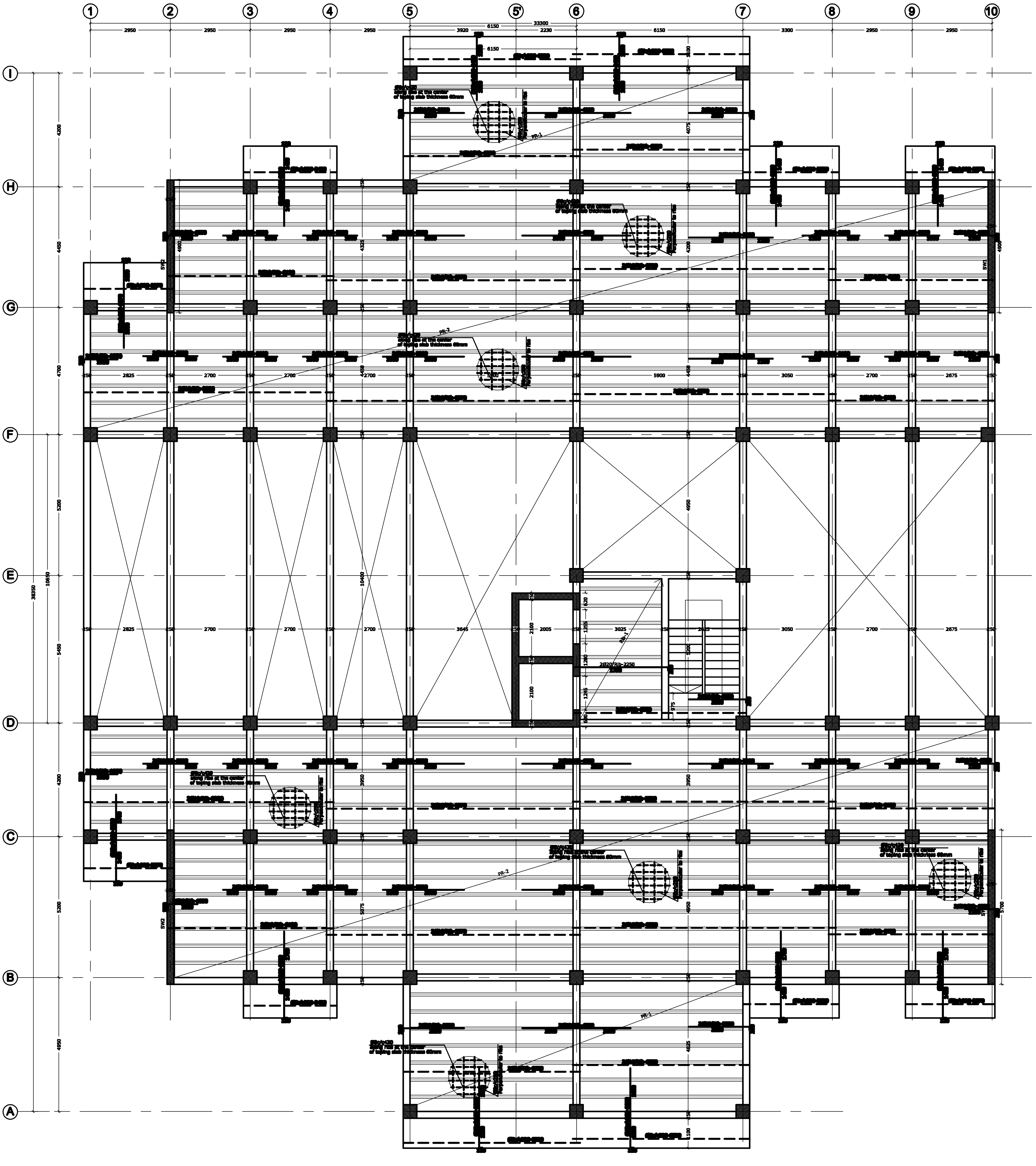
APPENDIX F FORMULATION OF KNAPSACK ON MS EXCEL

APPENDIX G DRAWINGS



TYPICAL FLOOR SLAB REINFORCEMENT & BEAM LAYOUT

SC 1:100

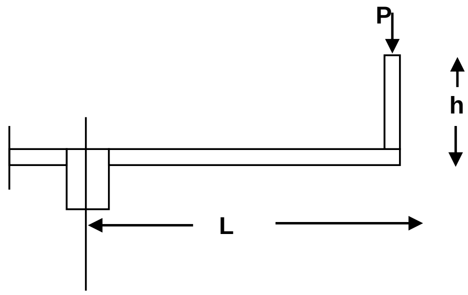


TYPICAL 3rd to 12th FLOOR SLAB REINFORCEMENT LAYOUT +10.80 to +38.80

scale 1:50

APPENDIX B

DESIGN OF TYPICAL CANTILEVER SLAB Axis C & G….1-2



D_{used}=	150mm	Bar diameter used=	12mm
d=	129mm	Cantilever length, L=	1.50m

LOADING

DEAD LOAD

	thickness(m)	unit wt.(kN/m^3)	load(kN/m^2)
RC slab	0.150	25	3.75
floor finish	0.030	27	0.81
plastering	0.020	23	0.46
screed	0.020	23	0.46
		Total=	5.48

LIVE LOAD

For balcony, live load= **q_k= 4 KN/m^2** **(EBCS-1,Table 2.10)**

Q_k= 2 KN

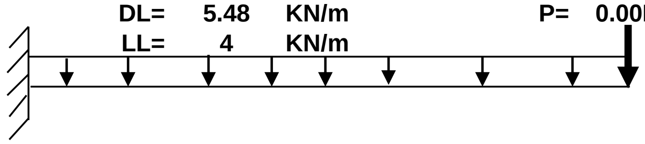
Weight of the wall at the edge of slab:

Wall used= **15** cm thick HCB wall of height h= **0.00m**

Then, **P= 0 KN/m**

DL= 5.48 KN/m **P= 0.00KN**

LL= 4 KN/m



Load transfer to supprting beam: **DL=** 8.22KN/m

LL= 6.00KN/m

Maximum design moment at the support= **15.21 KN.m/m**

μ= **M/(f_{cd}bd^2)= 0.081**

From the general design chart in design aid for EBCS-2,**K_z= 0.95**

A_s=M_{sd}/(zf_{yd})=M_{sd}/(K_zdf_{yd})= 476.97 mm^2 **$A_{s,min}$= 258** mm^2

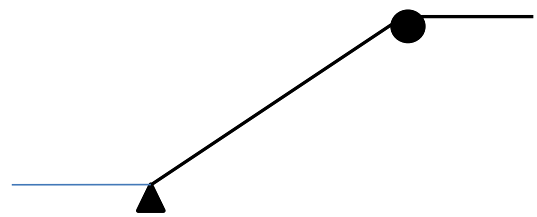
There fore use dia. **12mm** bar c/c **200mm**

APPENDIX C

STAIR DESIGN

TYPICAL STAIR

f_{ck}=	25MPa	f_{cd}=	11.33MPa
f_{yk}=	400MPa	f_{yd}=	347.83MPa
cover=	15mm	ф=	14mm
le=	5.20m	lx=	6.15m



Slab depth Determination

β_a for 2:1	β_a for 1:1	Ratio calc.	β_a calc
25	35	0.85	36.54

d= 168mm use D= 200mm

D= 190mm d= 178mm

Riser= 16.00cm

Tread= 30.00cm

slab weight = 5.67KN/m

weight of steps = 0.60KN/m

thickness of finish = 30mm

unit wt. of finish = 27KN/m3

thickness of mortar = 20mm

unit wt. of mortar = 23KN/m3

Live load = 3.00KN/m

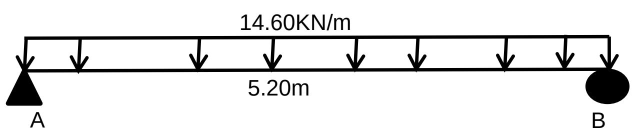
Dead load(DL)= 7.54KN/m

Total live load(LL)= 3.00KN/m

design load(P_d)= 1.3DL+1.6LL

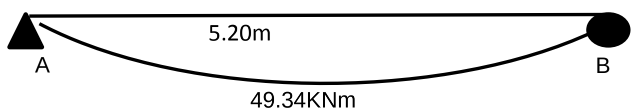
design load(P_d)= 14.60KN/m

wall load= 0.00KN



	Factored	Unfactored G_k	Unfactored Q_k
Moment at A-B=	49.34KN-m		
Shear at A & B=	37.95KN	25.47KN	10.14KN
Load transfer to A & B=	6.17KN/m	4.14KN/m	1.65KN/m

Assigned on SAP



$\rho_{calc}=(1-\sqrt{(1-2M/f_{cd}*b*d^2)})(f_{cd}/f_{yd})$

ρ_{calc}= 0.004835989

$A_{s\ req}$= ρ*b*d= 860.81 mm^2

spacing= ab*b/$A_{s\ req}$

spacing= 170mm

$A_{s\ min}$= ρ*b*d= 222.50 mm^2

use ϕ 14 C/C 170 at A

use ϕ 14 C/C 170 at B

$\rho_{calc}=(1-\sqrt{(1-2M/f_{cd}*b*d^2)})(f_{cd}/f_{yd})$

ρ_{calc}= 0.004836

$A_{s\ req}$= ρ*b*d= 860.81 mm^2

spacing= ab*b/$A_{s\ req}$

spacing= 170mm

APPENDIX D

Wall Load Calculation

Basement Floor Beams Level -2.80						
Axis	γ(KN/m^3)	Size (m)	Plastering(m)	γ(KN/m^3)	Wall ht(m)	Total load(KN/m)
Axis I..5-6-7	25	0.20	0.03	23	1.90	12.12
Axis H..1-2-3-4-5	25	0.20	0.03	23	1.90	12.12
Axis H..7-8-9-10	25	0.20	0.03	23	1.90	12.12
Axis B..1-2-3-4-5	25	0.20	0.03	23	1.90	12.12
Axis B..7-8-9-10	25	0.20	0.03	23	1.90	12.12
Axis A..5-6-7	25	0.20	0.03	23	1.90	12.12
Axis 1..B-C-D-E-F-G-H	25	0.20	0.03	23	1.90	12.12
Axis 10..B-C-D-E-F-G-H	25	0.20	0.03	23	1.90	12.12
Axis 5..H-I & A-B	25	0.20	0.03	23	1.90	12.12
Axis 7..H-I & A-B	25	0.20	0.03	23	1.90	12.12

Ground Floor Beams Level +0.4						
Axis	γ(KN/m^3)	Size (m)	Plastering(m)	γ(KN/m^3)	Wall ht(m)	Total load(KN/m)
Axis H..2-3-4-5	14	0.20	0.03	23	2.70	11.29
Axis H..9-10	14	0.20	0.03	23	2.70	11.29
Axis 1..G-F & D-C	14	0.20	0.03	23	2.70	11.29
Axis 5..G-H-F	14	0.10	0.03	23	2.70	7.51
Axis 5..C-D	14	0.20	0.03	23	2.70	11.29
Axis 7..G-H-F	14	0.10	0.03	23	2.70	7.51
Axis 7..B-C-D	14	0.10	0.03	23	2.70	7.51
Axis 8..G-F	14	0.20	0.03	23	2.70	11.29
Axis 8..C-B	14	0.10	0.03	23	2.70	7.51
Axis 10..G-F & C-D	14	0.20	0.03	23	2.70	11.29

Frist Floor Beams Level +3.60						
Axis	γ(KN/m^3)	Size (m)	Plastering(m)	γ(KN/m^3)	Wall ht(m)	Total load(KN/m)
Axis H..4-5 & 7-8	14	0.20	0.03	23	2.70	11.29
Axis H..8-9-10	14	0.20	0.03	23	2.70	11.29
Axis G..1-2	14	0.20	0.03	23	2.70	11.29
Axis G..8-9-10	14	0.20	0.03	23	2.70	11.29
Axis F..8-9-10	14	0.20	0.03	23	2.70	11.29
Axis B..4-5	14	0.20	0.03	23	2.70	11.29
Axis 1..G-F	14	0.20	0.03	23	2.70	11.29
Axis 5..H-I	14	0.20	0.03	23	2.70	11.29
Axis 5..F-G-H	14	0.10	0.03	23	2.70	7.51
Axis 5..B-C-D	14	0.10	0.03	23	2.70	7.51
Axis 5..A-B	14	0.20	0.03	23	2.70	11.29
Axis 7..H-I	14	0.20	0.03	23	2.70	11.29
Axis 7..F-G-H	14	0.10	0.03	23	2.70	7.51
Axis 7..B-C-D	14	0.10	0.03	23	2.70	7.51
Axis 7..A-B	14	0.20	0.03	23	2.70	11.29

APPENDIX F

Weight	Benefit		Weight1	Benefit1	Knapsack Capacity
12.39	42.13	1	12.39	42.13	148.68
13.128	44.63	1	13.128	44.63	
13.865	47.14	1	13.865	47.14	
14.603	49.65	1	14.603	49.65	
15.34	52.16	0	0	0	
16.078	54.66	0	0	0	
16.815	57.17	0	0	0	
17.553	59.68	0	0	0	
18.29	62.19	0	0	0	
19.028	64.69	0	0	0	
19.765	67.2	0	0	0	
13.881	47.2	1	13.881	47.2	
14.707	50	1	14.707	50	
15.534	52.81	0	0	0	
16.36	55.62	0	0	0	
17.186	58.43	0	0	0	
18.012	61.24	0	0	0	
18.839	64.05	0	0	0	
19.665	66.86	0	0	0	
20.491	69.67	0	0	0	
21.317	72.48	0	0	0	
22.144	75.29	0	0	0	
15.372	52.26	0	0	0	
16.287	55.38	0	0	0	
17.202	58.49	0	0	0	
18.117	61.6	0	0	0	
19.032	64.71	0	0	0	
19.947	67.82	0	0	0	
20.862	70.93	0	0	0	
21.777	74.04	0	0	0	
22.692	77.15	0	0	0	
23.607	80.26	0	0	0	
24.552	83.37	0	0	0	
16.863	57.33	0	0	0	
17.867	60.75	0	0	0	
18.871	64.16	0	0	0	
19.874	67.57	0	0	0	
20.878	70.99	0	0	0	
21.882	74.4	0	0	0	
22.886	77.81	0	0	0	

23.889	81.22	0	0	0
24.893	84.64	0	0	0

25.897	88.05	0	0	0
26.901	91.46	0	0	0
18.354	62.4	0	0	0
19.447	66.12	0	0	0
20.539	69.83	0	0	0
21.632	73.55	0	0	0
22.724	77.26	0	0	0
23.817	80.98	0	0	0
24.909	84.69	0	0	0
26.002	88.41	0	0	0
27.094	92.12	0	0	0
28.187	95.83	0	0	0
29.279	99.55	0	0	0
19.845	67.47	0	0	0
21.026	71.49	0	0	0
22.208	75.51	0	0	0
23.389	79.52	0	0	0
24.57	83.54	0	0	0
25.751	87.55	0	0	0
26.933	91.57	0	0	0
28.114	95.59	0	0	0
29.295	99.6	0	0	0
30.476	134.1	0	0	0
31.658	139.29	0	0	0
21.336	72.54	0	0	0
22.606	76.86	0	0	0
23.876	81.18	0	0	0
25.146	86.75	0	0	0
26.416	89.81	0	0	0
27.686	94.13	0	0	0
28.956	98.45	0	0	0
30.226	132.99	0	0	0
31.496	138.58	0	0	0
32.766	144.17	0	0	0
34.036	116.74	0	0	0
22.827	77.61	0	0	0
24.186	82.47	0	0	0
25.545	88.13	0	0	0
26.903	91.47	0	0	0
28.262	96.09	0	0	0
29.621	100.71	0	0	0
30.98	136.31	0	0	0
32.338	113.83	0	0	0

33.697	118.61	0	0	0
35.056	120.24	0	0	0
36.415	72.83	0	0	0
24.318	82.92	0	0	0
25.766	88.89	0	0	0
27.213	92.52	0	0	0
28.661	97.45	0	0	0
30.108	132.48	0	0	0
31.556	138.84	0	0	0
33.003	116.17	0	0	0
34.451	118.17	0	0	0
35.898	123.13	0	0	0
37.346	74.69	0	0	0
38.793	77.59	0	0	0
25.809	89.04	0	0	0
27.345	92.97	0	0	0
28.882	98.77	0	0	0
30.418	133.84	0	0	0
31.954	140.6	0	0	0
33.49	147.36	1	33.49	147.36
35.027	120.14	0	0	0
36.563	73.13	0	0	0
38.099	76.2	0	0	0
39.635	79.27	0	0	0
41.172	82.34	0	0	0
27.3	92.82	0	0	0
28.925	98.35	0	0	0
30.55	134.42	0	0	0
32.175	141.57	1	32.175	141.57
33.8	118.98	0	0	0
35.425	121.51	0	0	0
37.05	74.1	0	0	0
38.675	77.35	0	0	0
40.3	80.6	0	0	0
41.925	83.85	0	0	0
43.55	87.1	0	0	0
		2	65.665	288.93

Second Floor Beams Level +6.80						
Axis	γ(KN/m^3)	Size (m)	Plastering(m	γ(KN/m^3)	Wall ht(m)	Total load(KN/m)
Axis H..4-5 & 7-8	14	0.20	0.03	23	2.70	11.29
Axis H..8-9-10	14	0.20	0.03	23	2.70	11.29
Axis G..1-2	14	0.20	0.03	23	2.70	11.29
Axis G..8-9-10	14	0.20	0.03	23	2.70	11.29
Axis 1..G-F & C-D	14	0.20	0.03	23	2.70	11.29
Axis 5..H-I	14	0.20	0.03	23	2.70	11.29
Axis 5..F-G-H	14	0.10	0.03	23	2.70	7.51
Axis 5..B-C-D	14	0.10	0.03	23	2.70	7.51
Axis 5..A-B	14	0.20	0.03	23	2.70	11.29
Axis 7..H-I	14	0.20	0.03	23	2.70	11.29
Axis 7..F-G-H	14	0.10	0.03	23	2.70	7.51
Axis 7..B-C-D	14	0.10	0.03	23	2.70	7.51
Axis 10..F-G & C-D	14	0.20	0.03	23	2.70	11.29

Third & Typical Floor Beams Level +10.00 to +38.80						
Axis	γ(KN/m^3)	Size (m)	Plastering(m	γ(KN/m^3)	Wall ht(m)	Total load(KN/m)
Axis H..2-3-4-5 & 7-8-9-10	14	0.20	0.03	23	2.70	11.29
Axis G..3-4-5-6-7	14	0.20	0.03	23	2.70	11.29
Axis F..1-2-3-4-5	14	0.20	0.03	23	2.70	11.29
Axis F..7-8-9-10	14	0.20	0.03	23	2.70	11.29
Axis D..1-2-3-4-5	14	0.20	0.03	23	2.70	11.29
Axis D..7-8-9-10	14	0.20	0.03	23	2.70	11.29
Axis C..3-4-5-6-7	14	0.20	0.03	23	2.70	11.29
Axis B..2-3-4-5 & 7-8-9-10	14	0.20	0.03	23	2.70	11.29
Axis 1..G-F	14	0.20	0.03	23	2.70	11.29
Axis 3..G-H	14	0.10	0.03	23	2.70	7.51
Axis 5..H-I	14	0.20	0.03	23	2.70	11.29
Axis 6..H-I	14	0.10	0.03	23	2.70	7.51
Axis 7..G-H-I	14	0.20	0.03	23	2.70	11.29
Axis 1..D-C	14	0.20	0.03	23	2.70	11.29
Axis 3..B-C	14	0.20	0.03	23	2.70	11.29
Axis 5..A-B	14	0.20	0.03	23	2.70	11.29
Axis 6..A-B	14	0.10	0.03	23	2.70	7.51

Roof Beams Level +42.00						
Axis	γ(KN/m^3)	Size (m)	Plastering(m	γ(KN/m^3)	Wall ht(m)	Total load(KN/m)
Parapet wall at the edge	14	0.20	0.03	23	1.20	5.02

	Area load for Solid Slabs		
	Thickness(	Unit wt.(kN/m3)	Load(kN/m2)
floor finish	0.03	27	0.81
plastering	0.02	23	0.46
screed	0.03	23	0.69
Partition Load			0.5
		Total dead load=	2.46KN/m2
		Live load=	2.0KN/m2

* changes according to the function of the area in use

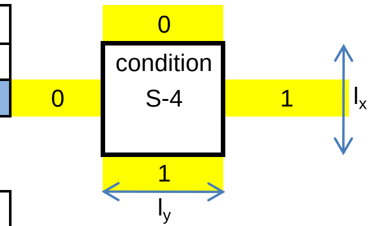
Refer to Ebcs-1, 1995 Table 2.10

APPENDIX E

SLAB DESIGN

Axis 5-6….H-I

f_{ck}=	25MPa	f_{cd}=	11.33MPa
f_{yk}=	300MPa	f_{yd}=	260.87MPa
cover=	15mm	ϕ=	10mm
l_y=	6.15m		
l_x=	4.20m		
β_a for 2:1	β_a for 1:1	Ratio calc.	β_a calc
30	40	1.46	35.36



d=	101mm	use D=	150mm
D=	120mm	d=	130mm

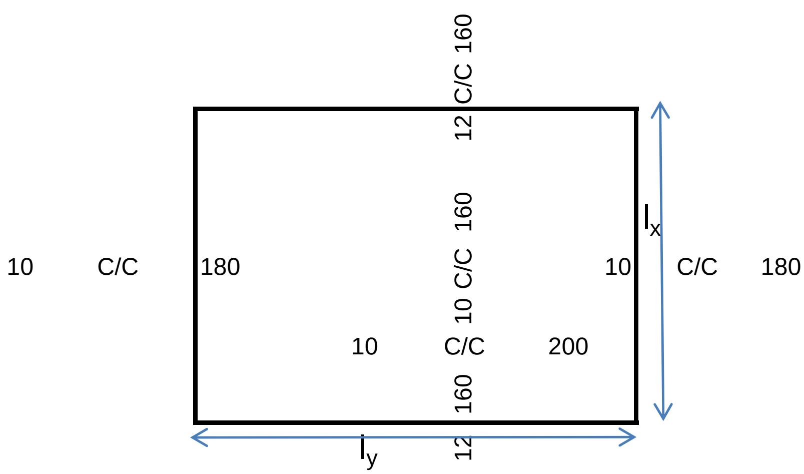
	Thickness	Unit wt.(kN/m³)	Load(kN/m²)
Dead Load	0.15m	25	3.75
Floor Finish	0.03m	27	0.81
Plastering	0.02m	23	0.46
Screed	0.03m	23	0.69
Wall Load	0.20m	14	
	Length	0.00m	
	Height	0.00m	0.00

Total dead load	5.71	KN/m²
Live Load	5	KN/m²
Total design load(Pd)	15.42	KN/m (taking 1m strip width)

α_{xs}=	0.075	α_{ys}=	0.048	m_{xs}=	20.32
α_{xf}=	0.056	α_{yf}=	0.036	m_{xf}=	15.24
k_{zxs}=	0.89	k_{zys}=	0.93	m_{ys}=	13.06
k_{zxf}=	0.92	k_{zyf}=	0.95	m_{yf}=	9.79

μ_{xs}=	$M_{xs}/f_{cd}bd^2$=	0.1759	$A_s=M_{sd}/K_z d f_{yd}$=	671.36
μ_{xf}=	$M_{xf}/f_{cd}bd^2$=	0.1319	$A_s=M_{sd}/K_z d f_{yd}$=	489.04
μ_{ys}=	$M_{ys}/f_{cd}bd^2$=	0.1130	$A_s=M_{sd}/K_z d f_{yd}$=	414.112
μ_{yf}=	$M_{yf}/f_{cd}bd^2$=	0.0848	$A_s=M_{sd}/K_z d f_{yd}$=	393.21

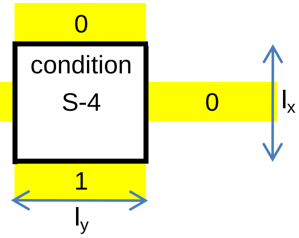
	mm²	ϕ,mm	spacing,mm	ϕ used	C/C
A_{sxs}=	671.36	12	168.46	12	160
A_{sxf}=	489.04	10	160.60	10	160
A_{sys}=	414.11	10	189.66	10	180
A_{syf}=	393.21	10	199.74	10	200



SLAB DESIGN

Axis 6-7….H-I

f_{ck}=	25MPa	f_{cd}=	11.33MPa
f_{yk}=	300MPa	f_{yd}=	260.87MPa
cover=	15mm	ϕ=	10mm
l_y=	6.15m		
l_x=	4.20m		
β_a for 2:1	β_a for 1:1	Ratio calc.	β_a calc
30	40	1.46	35.36



d=	101mm	use D=	150mm
D=	120mm	d=	130mm

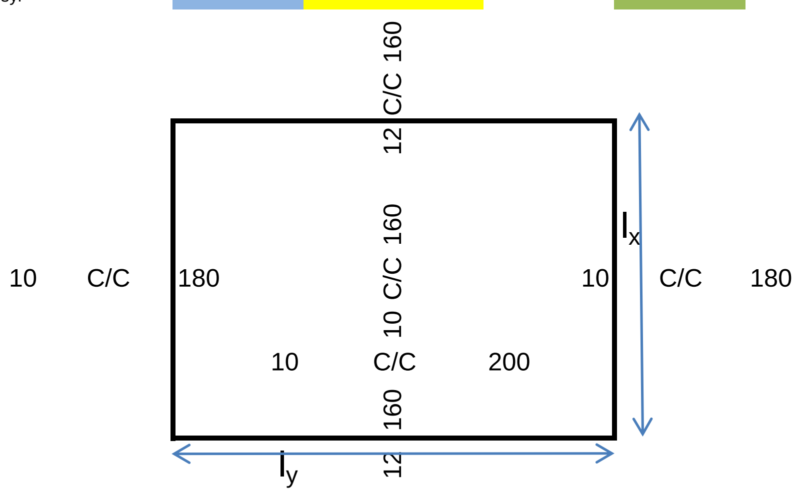
	Thickness	nit wt.(kN/m	Load(kN/m^2)
Dead Load	0.15m	25	3.75
Floor Finish	0.03m	27	0.81
Plastering	0.02m	23	0.46
Screed	0.03m	23	0.69
Wall Load	0.20m	14	
	Length	0.00m	
	Height	0.00m	0.00

Total dead load	5.71	KN/m^2
Live Load	5	KN/m^2
Total design load(Pd)	15.42	KN/m (taking 1m strip width)

α_{xs}=	0.075	α_{ys}=	0.048	m_{xs}=	20.32
α_{xf}=	0.056	α_{yf}=	0.036	m_{xf}=	15.24
k_{zxs}=	0.89	k_{zys}=	0.93	m_{ys}=	13.06
k_{zxf}=	0.92	k_{zyf}=	0.95	m_{yf}=	9.79

μ_{xs}=	Mxs/fcdbd^2	0.1759	$As=M_{sd}/K_z d f_{yd}$=	671.36
μ_{xf}=	Mxf/fcdbd^2=	0.1319	$As=M_{sd}/K_z d f_{yd}$=	489.04
μ_{ys}=	Mys/fcdbd^2	0.1130	$As=M_{sd}/K_z d f_{yd}$=	414.112
μ_{yf}=	Myf/fcdbd^2=	0.0848	$As=M_{sd}/K_z d f_{yd}$=	393.21

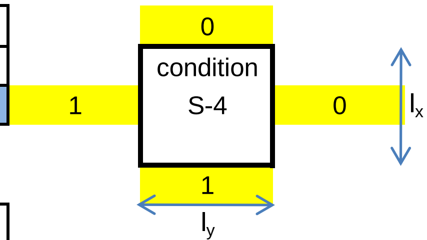
	mm^2	ϕ,mm	spacing,mm	ϕ used	C/C
A_{sxs}=	671.36	12	168.46	12	160
A_{sxf}=	489.04	10	160.60	10	160
A_{sys}=	414.11	10	189.66	10	180
A_{syf}=	393.21	10	199.74	10	200



SLAB DESIGN

Axis G-H....1-2

f_{ck}=	25MPa	f_{cd}=	11.33MPa
f_{yk}=	300MPa	f_{yd}=	260.87MPa
cover=	15mm	ϕ=	10mm
l_y=	4.45m		
l_x=	2.95m		
β_a for 2:1	β_a for 1:1	Ratio calc.	β_a calc
30	40	1.51	34.92



d=	72mm	use D=	150mm
D=	90mm	d=	130mm

	Thickness	nit wt.(kN/m	Load(kN/m^2)
Dead Load	0.15m	25	3.75
Floor Finish	0.03m	27	0.81
Plastering	0.02m	23	0.46
Screed	0.03m	23	0.69
Wall Load	0.20m	14	
	Length	0.00m	
	Height	0.00m	0.00

Total dead load 5.71 KN/m^2

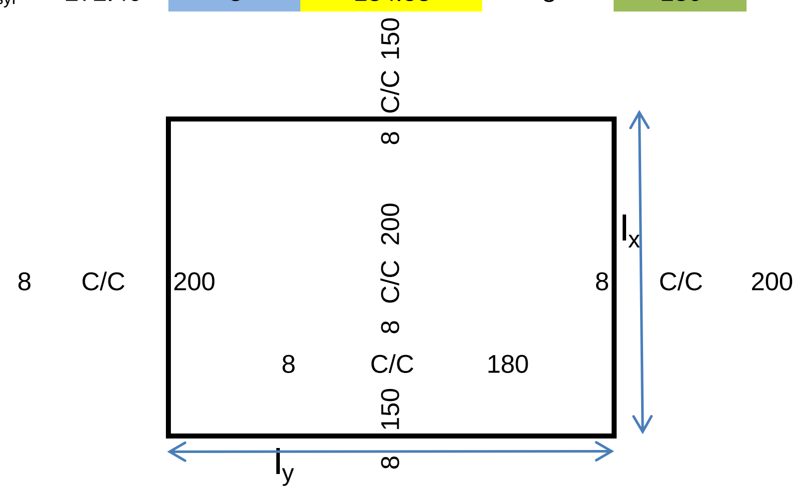
Live Load 5 KN/m^2

Total design load(Pd) 15.42 KN/m (taking 1m strip width)

α_{xs}=	0.077	α_{ys}=	0.048	m_{xs}=	10.28
α_{xf}=	0.057	α_{yf}=	0.036	m_{xf}=	7.71
k_{zxs}=	0.89	k_{zys}=	0.93	m_{ys}=	6.44
k_{zxf}=	0.92	k_{zyf}=	0.95	m_{yf}=	4.83

μ_{xs}=	$Mxs/fcdbd^2$	0.1758	$As=M_{sd}/K_z df_{yd}$=	339.57
μ_{xf}=	$Mxf/fcdbd^2$	0.1319	$As=M_{sd}/K_z df_{yd}$=	247.35
μ_{ys}=	$Mys/fcdbd^2$	0.1102	$As=M_{sd}/K_z df_{yd}$=	203.948
μ_{yf}=	$Myf/fcdbd^2$	0.0827	$As=M_{sd}/K_z df_{yd}$=	272.40

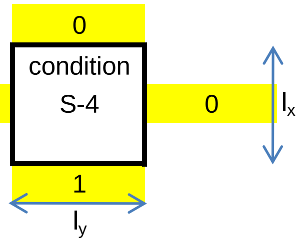
	mm^2	ϕ,mm	spacing,mm	ϕ used	C/C
A_{sxs}=	339.57	8	148.03	8	150
A_{sxf}=	247.35	8	203.21	8	200
A_{sys}=	216.67	8	231.99	8	200
A_{syf}=	272.40	8	184.53	8	180



SLAB DESIGN

Axis G-H….2-3

f_{ck}=	25MPa	f_{cd}=	11.33MPa
f_{yk}=	300MPa	f_{yd}=	260.87MPa
cover=	15mm	ϕ=	10mm
l_y=	4.45m		
l_x=	2.95m		
β_a for 2:1	β_a for 1:1	Ratio calc.	β_a calc
30	40	1.51	34.92



d=	72mm	use D=	150mm
D=	90mm	d=	130mm

	Thickness	nit wt.(kN/m	Load(kN/m^2)
Dead Load	0.15m	25	3.75
Floor Finish	0.03m	27	0.81
Plastering	0.02m	23	0.46
Screed	0.03m	23	0.69
Wall Load	0.20m	14	
	Length	0.00m	
	Height	0.00m	0.00

Total dead load 5.71 KN/m^2

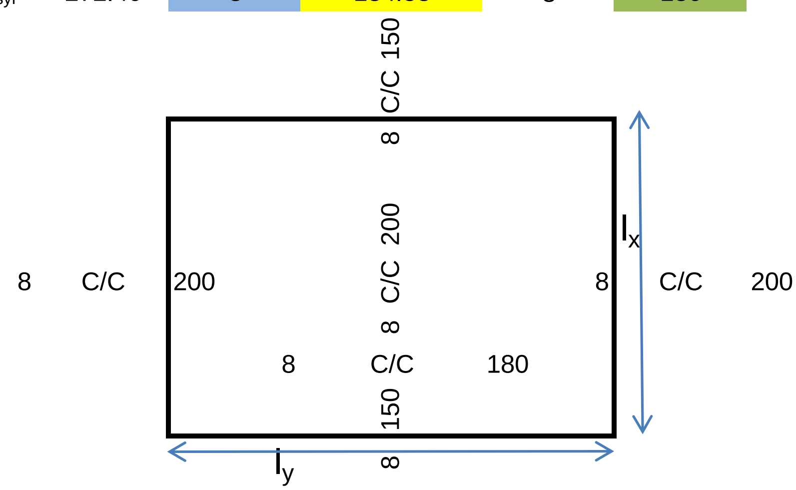
Live Load 5 KN/m^2

Total design load(Pd) 15.42 KN/m (taking 1m strip width)

α_{xs}= 0.077	α_{ys}= 0.048	m_{xs}= 10.28
α_{xf}= 0.057	α_{yf}= 0.036	m_{xf}= 7.71
k_{zxs}= 0.89	k_{zys}= 0.93	m_{ys}= 6.44
k_{zxf}= 0.92	k_{zyf}= 0.95	m_{yf}= 4.83

μ_{xs}= Mxs/fcdbd^2	0.1758	$As=M_{sd}/K_z df_{yd}$=	339.57
μ_{xf}= Mxf/fcdbd^2=	0.1319	$As=M_{sd}/K_z df_{yd}$=	247.35
μ_{ys}= Mys/fcdbd^2	0.1102	$As=M_{sd}/K_z df_{yd}$=	203.948
μ_{yf}= Myf/fcdbd^2=	0.0827	$As=M_{sd}/K_z df_{yd}$=	272.40

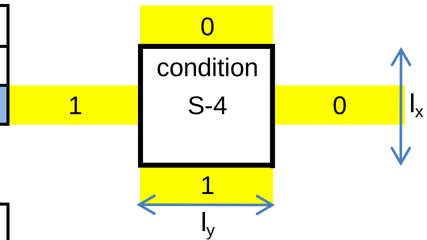
	mm^2	ϕ,mm	spacing,mm	ϕ used	C/C
A_{sxs}=	339.57	8	148.03	8	150
A_{sxf}=	247.35	8	203.21	8	200
A_{sys}=	216.67	8	231.99	8	200
A_{syf}=	272.40	8	184.53	8	180



SLAB DESIGN

Axis G-H….3-4

f_{ck}=	25MPa	f_{cd}=	11.33MPa
f_{yk}=	300MPa	f_{yd}=	260.87MPa
cover=	15mm	ϕ=	10mm
l_y=	4.45m		
l_x=	2.95m		
β_a for 2:1	β_a for 1:1	Ratio calc.	β_a calc
30	40	1.51	34.92
d=	72mm	use D=	150mm
D=	90mm	d=	130mm



	Thickness	nit wt.(kN/m	Load(kN/m^2)
Dead Load	0.15m	25	3.75
Floor Finish	0.03m	27	0.81
Plastering	0.02m	23	0.46
Screed	0.03m	23	0.69
Wall Load	0.20m	14	
	Length	0.00m	
	Height	0.00m	0.00

Total dead load 5.71 KN/m^2

Live Load 5 KN/m^2

Total design load(Pd) 15.42 KN/m (taking 1m strip width)

α_{xs}=	0.077	α_{ys}=	0.048	m_{xs}=	10.28
α_{xf}=	0.057	α_{yf}=	0.036	m_{xf}=	7.71
k_{zxs}=	0.89	k_{zys}=	0.93	m_{ys}=	6.44
k_{zxf}=	0.92	k_{zyf}=	0.95	m_{yf}=	4.83

μ_{xs}=	Mxs/fcdbd^2	0.1758	$As=M_{sd}/K_z df_{yd}$=	339.57
μ_{xf}=	Mxf/fcdbd^2=	0.1319	$As=M_{sd}/K_z df_{yd}$=	247.35
μ_{ys}=	Mys/fcdbd^2	0.1102	$As=M_{sd}/K_z df_{yd}$=	203.948
μ_{yf}=	Myf/fcdbd^2=	0.0827	$As=M_{sd}/K_z df_{yd}$=	272.40

	mm^2	ϕ,mm	spacing,mm	ϕ used	C/C
A_{sxs}=	339.57	8	148.03	8	150
A_{sxf}=	247.35	8	203.21	8	200
A_{sys}=	216.67	8	231.99	8	200
A_{syf}=	272.40	8	184.53	8	180