Jimma University

Jimma Institute of Technology

School of Civil and Environmental Engineering

Structural Engineering Stream

Optimum Design of Reinforced Concrete Flat Slab using Simplified Method

A thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Masters of Science in Structural Engineering

By: Birhanu Haile Woldemichael

October 15, 2016

Jimma, Ethiopia

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Main Advisor: Dr. Abrham Gebre (PhD)

Co Advisor: Mr. Aklilu Tadesse (MSc)

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THESIS EXAMINING BOARD

As member of the examining board of the final MSc open defense, we certify that we have read and evaluated the thesis prepared by **Birhanu Haile Woldemichael** entitled: "Optimum Design of Reinforced Concrete Flat Slab using Simplified Method." and recommended that it would be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Structural Engineering.

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DECLARATION

I, the undersigned, declare that this thesis entitled **"Optimum Design of Reinforced Concrete Flat Slab using Simplified Method''** is my original work, has not been presented by any other person for the award of a degree in this or any other university, and all source of material used for this thesis have been duly acknowledged.

Candidate:

Mr. Birhanu Haile Woldemichael

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As Master research advisors, we hereby certify that we have read and evaluate this M.Sc. research prepared under our guidance, by Mr. Birhanu Haile Woldemichael entitled: **"Optimum Design of Reinforced Concrete Flat Slab using Simplified Method''**

We recommend that it can be submitted as fulfilling the M.Sc. thesis requirements.

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NOTATIONS

Symbols	General	Units
Dx	Drop panel size in shorter direction	mm
Dy	Drop panel size in longer direction	mm
dt	Thickness or depth of drop	mm
dd	Over all effective depth of drop from the top of slab	mm
dsl	Effective depth of slab in the longer direction	mm
dss	Effective depth of slab in the shorter direction	mm
dtl	Effective depth of drop in the longer direction	mm
dts	Effective depth of drop in the shorter direction	mm
Est	Equivalent slab thickness	mm
f_{cd}	Design comprehensive strength of concrete	Mpa
f_{ctk}	Characteristic tensile strength of concrete	Mpa
f_{ctd}	Design tensile strength of concrete	Mpa
f_y	Yield stress of steel	Mpa
f_{yk}	The characteristic strength of the reinforcement	Mpa
G	Constraints	
L_{ny}	Effective Span in the longer direction	mm
L_{nx}	Effective Span in the shorter direction	mm
Nx	Total length of slab in shorter direction	mm
Ny	Total length of slab in longer direction	mm
Q_k	Total live load	KN/m^2
G_k	Total dead load	KN/m^2
S	Grade of steel	
V_c	The shear force carried by concrete	KN

Symbols	General	Units
V_{cp}	Punching shear resistance	
X1	Effective depth of slab	mm
X1d	Thickness to limit deflection	mm
X2	Overall depth of drop from top of slab	mm
X3	No.of span required in the longer direction	no
X4	No.of span required in the shorter direction	no
Xumax	Depth of neutral axis	mm
ρ	Reinforcement ratio	
U	Perimeter of critical section	mm
Z	Moment arm	mm
Ly	Length of slab in longer direction	mm
Lx	Length of slab in shorter direction	mm
Pd	Design load	
St	Overall depth or thickness of slab	mm

ABBREVATIONS

Ccost	Cost of concrete
Scost	Cost of steel
DFP	Davidon-Fletcher-Powell
BM	Bending Moment
ERA	Ethiopian Road Authority
EBCS	Ethiopian Building Code Standard
LLMS	Length Middle Strip in longer direction
LLCS	Length Column Strip in longer direction
LSCS	Length Column Strip in shorter direction
LSMS	Length Middle Strip in shorter direction
Mnegmax	Maximum negative bending moment in all bending moment
Mdrop	The ultimate moment in the drop
Mposmax	Maximum positive bending moment in all bending moment
Mslab	The ultimate moment in the slab
NLPP	Nonlinear Programming Problem
Qconcrete	Total quantity of concrete
Qsteel	Total quantity of steel
COSTtotal	Total cost of material
SUMT	Sequential Unconstrained Minimization Technique

ABSTRACT

Reinforced Concrete flat slabs are commonly chosen for its architectural convenience in construction of reinforced concrete frame Buildings. More over this slab type is economical compared with other types of conventional reinforced concrete slabs. The code requirement is generally concerned on safety and alternative designs, apart from the code requirement; the design should be economically chosen. For a given design, there are alternatives that satisfy the requirement imposed by the codes. The designer must be in a position to choose an optimal design against constrain measure of optimality.

The main objective function is to minimize the total cost in the design process of the reinforced concrete flat slab. The structure is modeled and analyzed by using Ethiopian Building Code Standard for concrete structures. The optimization processes is done for different grades of concrete, different grades of steel, different number of panels in a given total span length and different total span length.

Design constraints for the optimization are hence considered according to Ethiopian Building Code Standard 2, 1995, structural use of concrete. The analysis and design for an optimization is done by using MATLAB software. Optimization is formulated in nonlinear programming problem (NLPP) by using sequential unconstrained minimization technique (SUMT).Minimum depth constraints and punching shear stress constraints are very active constraints in the optimization procedures.

The total cost of reinforced concrete flat slab decreases as the number of panels increases in a given slab size of flat slab and the total cost increases as the grade of concrete and the grade of steel increases for a given slab size of reinforced concrete flat slab. The reduction of weight for reinforced concrete flat slab is directly proportional to the number of panel increment in a given slab size.

Key Words: *Flat Slab, Reinforced concrete, Slab size, Panels, Structural optimization.*

CHAPTER ONE: INTRODUCTION

1.1 General

A reinforced concrete flat slab floor is a reinforced concrete slab supported directly by concrete columns without the use of intermediate beams. The slab may be of constant thickness throughout or, in the area of column it may be thickened as a drop panel. The column may also have a constant section or it may be flared to form a column head or capital[1].

The drop panels are effective in reducing the shearing stresses where the column is liable to punch through the slab, and they also provide an increased moment resistance where the negative moments are greatest [2].

A flat–plate floor is a uniform thickness slab that rests directly on columns and does not have beam or column heads or drop panel. In this case the column tends to punch through the slab, producing diagonal tensile stresses. Therefore, a general increase in the slab thickness is required or special reinforcement is used [2].

Optimization is the act of obtaining the best results under certain circumstances .Optimum design is a structural synthesis which collects all important engineering aspects to develop structural versions not only safe but also economic[3].

Any system can be described by a set of quantities, some or all of which are viewed as variables during the optimization processes. The solution of the system is defined as finding the values of these variables which are called design variables [3].

In many problems the choice of variables is not entirely free but is subjected to restrictions arising from the nature of the problem and variables. In many practical problems, the variables cannot be chosen arbitrarily, rather they have to satisfy certain specified functions and other requirements called constraints[4].

There usually exist an alternative number of feasible solutions that satisfy the constraints. In order to find the best one; it is necessary to form a function, called an objective function, of the variables to use for comparison of feasible solutions. The objective function is the function whose extreme value is required in an optimization problem. Any vector (a column matrix) that satisfies all constraints is called feasible point or vector [3].

Nonlinear programing deals with the problem of optimizing an objective function in the presence of equality and inequality constraints. If all the functions are linear, we obviously have a linear program. Otherwise the problem is a nonlinear program[5].

Sequential unconstrained minimization (SUMT) is iterative algorithms that find a solution to the constrained minimization problem as the limit of a sequence of vectors. In SUMT the constraint minimum problem is converted into unconstrained one by introducing penalty function [6].

MATLAB is a very popular high level programing language for computation. It is used extensively both in industry and in universities worldwide. It is much easier to use than other popular programing languages such as Fortran or C.MALAB is an excellent choice to perform computational optimization. Two or more lines of C or C+ programing language is equal one line of MATLAB programing language [7], [8].

1.2 Statement of the problem

Acceptable standards and manuals put criterion in the design of reinforced concrete flat slab, these standard focuses on the safety issues and alternatives of materials in design but not in the choosing of the best from alternatives that fulfills the principle of design. Ethiopian Building Code standard for concrete structure permitted grade of concrete C25, C30, C40, C50 and C60 for load bearing structures and similarly grade of steel for practice in reinforced concrete structures are valid for yield strength range from 400Mpa to 600Mpa.Which combination of the given alternatives of material is the most economical and give less weight in the construction is not point out in the code.

Reinforced concrete flat slab frame buildings are chosen in the high rise building and have been constructing in Ethiopia especially in the capital of the country and reinforced concrete is commonly used as construction material in Ethiopian Building construction industry. As the number of reinforced concrete buildings that are constructing in Ethiopia is in considerable number the cost that is not saved will be bigger in cumulative if the structure is not optimized.

The search for further improvement is not over and optimizations for cheaper and less weight reinforced concrete flat slab frame buildings for all times have to come. The design of economical and structurally safe reinforced concrete flat slab is a complex task due to many relevant parameters, conditions and possibilities; it is difficult to select the most economical solution for every situation. Therefore this study focuses on finding optimization methods in design of reinforced concrete flat slab.

This research is conducted so as to choose the alternatives designs that can be done under the design principles proposed by Ethiopian Building code standard.

1.3 Research Questions

1. What are the different causes that make optimum design of reinforced concrete flat slab difficult?

2. What is the extent of the cost saving between the design of reinforced concrete flat slab optimizing and in the normal design without optimizing?

3. What is the best optimization method that can be used in the optimum design of reinforced concrete flat slab?

1.4 Objective

1.4.1 General Objective

- To develop a standard method to aid engineers in the design and optimization of structurally safe, cost and weight improved reinforcement concrete flat slab and prepare a tool to carryout similar activities.

1.4.2 Specific Objectives

- To prepare computer aided design program and make optimum design of reinforced concrete flat slab efficient.

- To search the optimum values of the various design variables and understand the trained of change of price and weight for different design vector variable variations.

- To study the total cost and total weight change in the design of reinforced concrete flat slab with variation of different design variables.

1.5 The study Design and Methodology

The methodology for carrying out the research work has focused on the survey of available literature by different authors. The main topics are: Reinforced concrete flat slab, Structural optimization and on using of MATLAB software for the objective of the study. The study is on how to design reinforced concrete flat slab optimizing using MATLAB software.

To do so, first the analysis and design of reinforced concrete flat slab is stated in terms of symbols and variables. Then a computer program is written in terms of symbols using MATLAB software language to formulate the problem and perform the structural analysis and design. Optimization is formulated in nonlinear programming problem (NLPP) in which the objective function as well as the constraint equation is nonlinear. Sequential unconstrained minimization technique (SUMT) is used to optimize the cost function which represents the cost of concrete and reinforcement steel. In sequential unconstrained minimization techniques the constraint minimization problem is converted into unconstrained one by introducing penalty function. MATLAB solution for unconstrained optimization problem is done by using the solver of the software searching the optimum slab depth iteratively. The normalized constraints are used as barriers in staying in the feasible region. A different grade of concrete, different grades of reinforcing steel, different number of panels in the longer and shorter direction and different depths of slab and drop depth is used as design variables. More over the mentioned variables were verified for different total length of a given span. During the final stage of the study total cost difference and total weight difference for different design variables are studied in order to see cost and weight change for different variable.

1.6 Application of the study

The document is use full to ministry of construction and design, and private construction, design and consulting organizations. It can be applied in minimizing the overall budget incurring in the construction of reinforced concrete buildings with flat slab frame structures and generally on optimization of reinforced concrete flat slab frame structures.

1.7 Scope of the study

The scope of the study has been limited to the design and optimization of reinforced concrete flat slabs through the following variables: different grades of concrete, different grades of steel, different number of panels in the longer and shorter direction and different depths of slab and drop. Ethiopian Building Code Standard 1995 of simplified method in the design of reinforced concrete flat slab is used in the analysis and design of Reinforced concrete fat slab.

1.8 Organization of the thesis

This thesis is concerned on optimum design of reinforced concrete flat slab by means of MATLAB software. In the light of these the thesis is organized as follows.

Chapter one: is introduction it addresses around overall about of the study, statement of the problem, objective of the thesis, the study design and methodology, application of the study and its scope.

Chapter two: deals with literature survey around the study. The main topics are reinforced concrete flat slab, optimum design of reinforced concrete structure and on use of MATLAB in optimization of structures.

Chapter three: presents about structural optimization and methods of optimization in detail, the design vectors, Constraints, Objective function and methods of optimization are elaborated.

Chapter four: Describes modeling and problem formulation. The design variables, constraints and objective function in the study of reinforced concrete flat slab are identifies and problems are formulated so as to write in MATLAB language, and solve it using penalty function method.

Chapter five: presents the design steps written in MATLAB programing language. In here each design steps and the normalized constraints are written in MATLAB language. The variables identified can be varied for different cases of the design and the prepared programing language aids in doing so.

Chapter six: is about finding active constraints at optimum. This chapter presents: constraint values, values of total cost of normal design and values of total cost of optimum design. Different three starting points are taken in order to be sure of that the minimum is not local minimum rather it is global minimum.

Chapter seven: presents the comparative results for different grade of steel, grade of concrete and length of span. Total quantities of steel, total quantities of concrete and total cost of flat slab are compared for the mentioned variables and it is presented.

Chapter eight: presents results and discussion.

Finally chapter nine addresses conclusions and recommendation.

CHAPTER TWO: LITERATURE SURVEY

2.1 Reinforced Concrete Flat Slab

2.1.1 Introduction

The flat slab is beamless slab directly supported by column without beam, originated in USA by Turner in 1906. The flat slab is often thickened close to the supporting columns to provide adequate strength in shear. This thickened portion is called drop. In some cases, the top section of the column where it meets the floor slab or drop panel is enlarged which is known as column capital. Column capital increases the perimeter of the critical section, for shear and hence increases the capacity of the slab for resisting two-way shear and to reduce negative bending moment at the support. For high rise building flat slab can be used with drop panels or column capital[9].

Common practice of design and construction is to support the slabs by beams and support the beams by columns. This may be called as beam slab construction. The beams reduce the available net clear ceiling height. Hence in ware houses, offices and public halls sometimes beams are avoided and slabs are directly supported by columns. Flat slabs are highly versatile elements widely used in construction, providing minimum depth, fast construction and allowing flexible column grids. A flat slab may be solid slab or may have recesses formed on the soffit so that the soffit comprises a series of ribs in two directions [10].

2.1.2 Types of Reinforced Concrete Flat Slab

Flat slab can be classified in to following types according to demand of structure [11].

a) Flat slab with drop panel and without column capital.

b) Flat slab with column capital and without drop panel.

c) Flat slab with drop panel and column capital.

d) Flat slab without drop panel and column capital

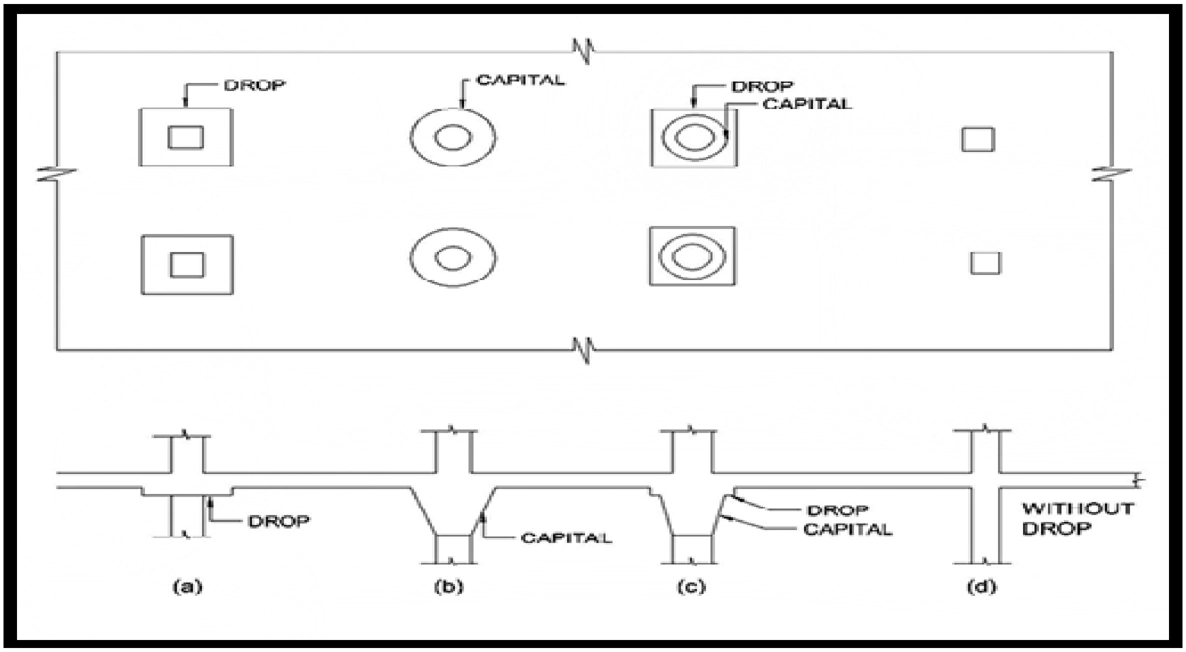


Figure 2.1 Classification of Flat Slab adopted from Sayali A.Baitule International journal 2016

Flat slab construction shown in figure 2.1 (a) and (b) are also beamless but incorporates a thickened slab region in the vicinity tops. Both are devices to reduce the stress due to shear and negative bending around the column. They are referred as drop panels and column capitals. The drop panels are effective in reducing the shearing stresses where the column is liable to punch through the slab, and they also provide an increased moment resistance where the negative moments are greatest[12].

The drop panels are rectangular (may be square) and influence the distribution of moments in the slab. The smaller dimension of the drop is at least one third of the smaller dimension of the surrounding panels, Lx/3 and the drop may be 25 to 50 percent thicker than the rest of the slab. The size of drop is taken into account when assessing the resistance to punching shear[13].

Uses of Drop Panel

- Increases shear strength of slab.
- Increase negative moment capacity of slab.
- Stiffen the slab and hence reduce deflection

2.1.3 Advantages of Reinforced Concrete Flat Slab

Reinforced concrete flat slab has advantages of the conventional beam supported reinforced concrete slab .The Flat slab system is a special structural form of reinforced concrete construction that possesses major advantage over the conventional moment-resisting frames. Flat Slab system provides architectural flexibility, unobstructed space, lower building height, easier form work and shorter construction time.

The advantages of using reinforced concrete flat slab constructions are[14]:

- Downward beam protrusion is elimination, reducing ceiling congestion, and probably reducing floor-to-floor height.
- Simplified formwork and construction generally.
- Windows can extend up to the underside of the slab, and there are no beams to obstruct the light and the circulation of air.
- The absence of sharp corners gives greater fire resistance as there is less danger of the concrete sapling and exposing the reinforcement

There are however, some serious issues that require examination with the reinforced concrete flat slab construction system. Among the issues which were observed are[15].

- potentially large transverse displacement because of the absence of deep beams and/or shear walls, resulting in low transverse stiffness. This induces excessive deformations which in turn causes damage of nonstructural members even when subjected to earthquakes of moderate intensity.

- Another issue is brittle punching failure due to transfer of shear forces and unbalance moments between slabs and columns.

- Flat slab systems are also susceptible to significant reduction in stiffness resulting from cracking that occurs from construction load, service gravity loads, temperature and shrinkage effects and lateral loads.

- Although, there are some concerns of flat slab and flat plate that can be stated as: Thicker slab is needed, heavier overall structure is obtained, serious attention required to deflection control. Very serious attention required to punching shear problem at slab to column connection.

- The reinforced concrete flat slab system's structural efficiency is often hindered by occasionally poor performance of under earthquake loading due to inherent insufficient lateral resistance. This undesirable behavior is mainly due to the absence of deep beams and/or shear walls in the flat slab system which generally give rise to excessive lateral deformation[14]

2.2 Analysis and Design of Reinforced Concrete Flat Slab

2.2.1 Analysis of Reinforced concrete Flat slab

The term flat slabs or plate means a reinforced concrete slab with or without drops and supported generally without beams, by columns with or without flared column heads. The force acting in the middle plane of a plate can be determined on the basis of any of linear analysis, Plastic analysis or nonlinear analysis. The provision given in the appendix A of Ethiopian Building code standard 2, 1995 are for the design of flat slabs supported by generally rectangular arrangement of columns and where the ratio of longer to the shorter span does not exceed two. A flat slab including columns or walls may be analyzed using the equivalent frame method or, where applicable, the simplified method. The minimum thickness adopted in slab on point support is 150mm [13].

2.2.2 Components of Flat Slab

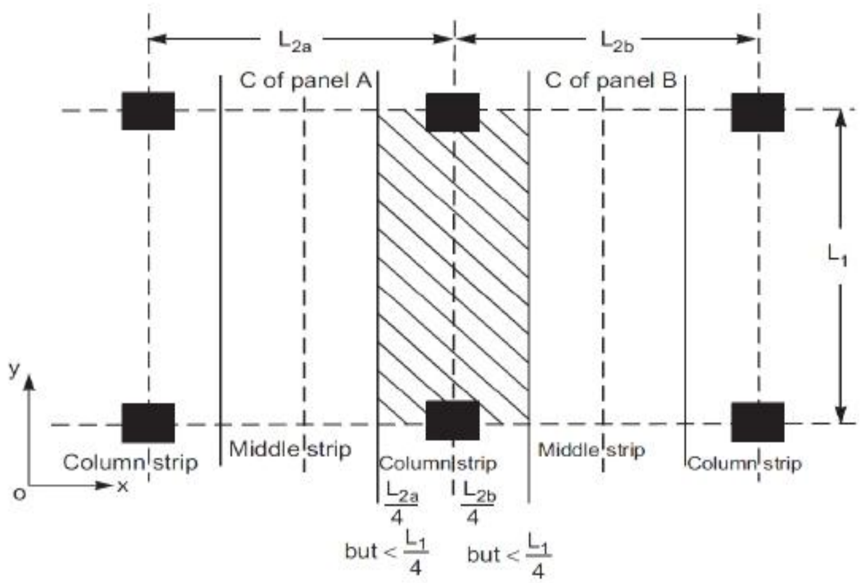


Fig 2.2 Panels, column strips and middle strips in y-direction adopted from Advanced R.C.C Design

Panel: Panel means that part of a slab bounded on-each of its four sides by the center -line of a Column or center-lines of adjacent-spans.

Column strip: Column strip means a design strip having a width of 0.25 L_2, but not greater than 0.25 L_1, on each side of the column center-line, where L_1 is the span in the direction moments are being determined, measured center to center of supports and L_2 is the span transverse to L_1 measured center to center of Supports. If drops with dimensions not less than $L_2/3$ are used, a width equal to the drop dimension is used.

Middle strip: Middle strip means a design strip bounded on each of its opposite sides by the column strip.

Drop: The drops when provided shall be rectangular in plan, and have a length in each direction not less than one- third of the panel length in that direction. Smaller drops may, however, still be taken in to account when assessing the resistance of punching shear.

For exterior panels, the width of drops at right angles to the non- continuous edge and measured from the center–line of the columns shall be equal to one –half the width of drop for interior panels. Since the span is large it is desirable to provide drop.

2.2.3 Thickness of Flat Slab from Serviceability Requirement

Minimum depth for deflection requirement enables the designer to avoid extremely complex deflection calculations in routine designs. Deflections of two-way slab systems need not be computed if the overall slab thickness meets the minimum requirements. The following minimum effective depth shall be provided unless computation of deflection indicates that smaller thickness may be used without exceeding the limits on deflections [13].

$$d \geq (0.4 + 0.6\frac{f_{yk}}{400})\frac{L_e}{\beta_a}$$

Where: f_{yk} is the characteristic strength of the reinforcement (MPA)

L_e is the effective span; and for two way slabs, the shorter span

β_a is the appropriate constant from the following table and for slabs carrying partitions walls likely to crack, shall be taken as $\beta_a \leq \frac{150}{L_o}$

L_o is the distance in m between points of zero moments; and for a cantilever, twice the length to the face of the support.

Table 2.1 Values of β_a

Member	Simply Supported	End Spans	Interior Spans	Cantilevers
Beams	20	24	28	10
Slabs				
(a) Span ratio = 2:1	25	30	35	12
(b) Span ratio = 1:1	35	40	45	10
Flat slabs (based on longer span)	24			-

Source: EBCS-2, 1995

It is also specified that in no case, the thickness of flat slab shall be less than 150 mm [13].

2.2.4 Determination of Bending Moment and Shear Force

Direct design method and equivalent frame methods are used in the design of flat slab. Direct design method is called 'the direct analysis method 'because this method essentially prescribes values for moments various parts of the slab panel without the need for structural analysis. For design, the slab is considered to be a series of frames in two directions. The direct design method is applicable when the proposed structures satisfy the restrictions on geometry and loading. If the structure does not satisfy the criteria, the more general method of elastic analysis is the equivalent frame method. In the equivalent frame method, the structure is divided in to continuous frames centered on the column lines on either side of the columns, extending both longitudinally and transversely. Each frame is composed of abroad continuous beam and a row of columns.

2.2.5 The Simplified Method

This method has the limitation that it can be used only if the following conditions are full filed. Direct Design Method as per EBCS 2, 1995: According to the EBCS 2 specification, the direct design method of analysis is subjected to the following restrictions.

- Design is based on the single load case of all spans loaded with the maximum design ultimate load.
- There are at least three rows of panels of approximately equal spans in the direction being considered.

- Successive span length in each direction shall not differ by more than one-third of the longer span
- Maximum offsets of columns from either axis between center lines of successive columns shall not exceed 10% of the span (in the direction of the offset)

2.2.6 Distribution of B.M.in to -ve and +ve moment

Longitudinal Distribution: The distribution of design span and support moments depends on the relative stiffness of the different sections which in turn depends on the restraint provided for the slab by the supports. Accordingly, the distribution factors are given in the following table[13].

Table 2.2 Bending Moment and Shear Force Coefficients for Flat slabs of Three or More Equal Spans.

	Outer support		Near center of first span	First interior support	Center of interior span	Interior support
	Column	Wall				
Moment	-0.040FL	-0.020FL	0.083FL	-0.063FL	0.071FL	-0.055FL
Shear	0.45F	0.40F	-	0.60F	-	0.50F
Total Column moments	0.040FL	-	-	0.022FL	-	0.022FL

Source: EBCS-2, 1995

NOTE:

1. F is the total design ultimate load on the strip of slab between adjacent columns considered.
2. L is the effective span = L_1-2h_c/3
3. The limitations of Section A.4.3.1(2) of EBCS 2, need not be checked
4. The moments shall not be redistributed

2.2.7 Distribution of bending Moment across the panel width

Lateral Distribution: The design moment obtained from the above (or equivalent frame analysis) shall be divided between the column and middle strips according to the following table.

Table 2.3 Distribution of Design Moments in Panels of Flat Slabs

	Apportionment been column and middle strip expressed as percentages of the total negative or positive design moment	
	Column strip (%)	Middle. Strip (%)
Negative	75	25
Positive	55	45

Source: EBCS-2, 1995

NOTE: For the case where the width of the column strip is taken as equal to that of the drop and the middle strip is thereby increased in width, the design moments to be resisted by the middle strip shall be increased in proportion to its increased width. The design moments to be resisted by the column strip may be decreased by an amount such that the total positive and the total negative design moments resisted by the column strip and middle strip together are unchanged.

2.2.8 Shear in Flat Slabs, as per EBCS 2

The concrete section (thickness of the slab) must be adequate to sustain the shear force, since stirrups are not convenient. Two types of shear are considered

i) **Beam type Shear**: Diagonal tension Failure and critical section is considered at **d** distance from the face of the column or capital and V_c is given below as.

i.e. $V_c = 0.25 f_{ctd} k_1 k_2 b_w d$

ii) **Punching Shear**: perimeter shear which occurs in slabs without beams around columns. It is characterized by formation of a truncated punching cone or pyramid around concentrated loads or reactions. The outline of the critical section is shown in Fig. below.

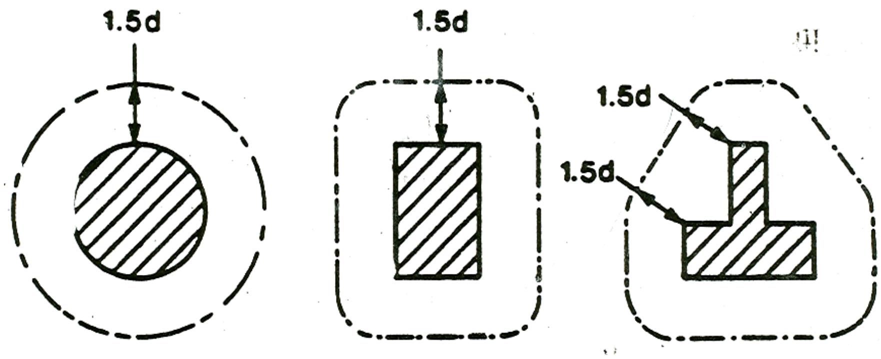


Fig. 2.3 Critical section remote from a free edge adopted from EBCS-2, 1995

The shear force to be resisted can be calculated as the total design load on the area bounded by the panel centerlines around the column less the load applied with in the area defined by the critical shear perimeter. The punching shear resistance without shear reinforcement is[13]:

$V_{cp} = 0.25\ f_{ctd}\ k_1\ k_2\ u\ d$(EBCS 1995)

$V_{cp} = 0.5\ f_{ctd}\ k_1\ k_2\ Ud$ (ESCP 1983)

$K_1 = (1+50\rho) \leq 2.0$

$K_2=1.6-d>1$

$\rho_e= (\rho_{ex+}\ \rho_{ey})^{1/2} \leq 0.015$

u = perimeter of critical section

d = ½(d_x+d_y), average effective depth

2.2.9 Equivalent frame method

Equivalent Frame Method as per EBCS 2, 1995: According to the EBCS 2 specification, Equivalent Frame Method of analysis is treated as follows:

(1) The width of slab used to define the effective stiffness of the slab will depend upon the aspect ratio of the panels and the type of loading, but the following provisions may be applied in the absence of more accurate methods:

- In the case of vertical loading, the full width of the Panel, and
- For lateral loading, half the width of the panel may be used to calculate the stiffness of the slab.

(2) The moment of inertia of any section of slab or column used in calculating the relative stiffness of members may be assumed to be that of the cross section of the concrete alone.

(3) Moments and forces within a system of flat slab panels may be obtained from analysis of the structure under the single load case of maximum design load on all spans or panels simultaneously, provided:

- The ratio of the characteristic imposed load to the characteristic dead load does not exceed 1.25.
- The characteristic imposed load does not exceed 5.0 kN/m2 excluding partitions.

(4) Where it is not appropriate to analyze for the single load case of maximum design load on all spans, it will be sufficient to consider following arrangement of vertical loads:

- All spans loaded with the maximum design ultimate load, and
- Alternate spans with the maximum design ultimate load and all other spans loaded with the minimum design ultimate load ($1.0G_k$).

(5) Each frame may be analyzed in its entirety by any elastic method. Alternatively, for vertical loads only, each strip of floor and roof may be analyzed as a separate frame with the columns above and below fixed in position and direction at their extremities. In either case, the analysis shall be carried out for the "appropriate design ultimate loads on each span calculated for a strip of slab of width equal to the distance between center lines of the panels on each side of the columns[13]

Reinforced concrete Flat slab Detailing: The spacing in a flat slab shall not exceed two times the slab thickness or 350mm.The spacing between secondary bar shall not exceed 400mm.The ratio of secondary reinforcement to the main reinforcement shall be at least equal to 0.2.The geometrical ratio of main reinforcement in a slab shall not be less than $0.5/f_{yk}$ .Minimum area of tension reinforcement should be greater than 0.0013. The minimum length of reinforcement is as per appendix A , at least 50 percent of bottom bars should be from support to support[13], [16].

2.3 Reinforced concrete column design

In the optimum design of reinforced concrete flat slab consideration of column is mandatory. One of the variables in this study is the number of panels in the shorter and longer direction as the number of panels increases the number of columns. Account of reinforced concrete flat slab is directly supported on columns and if we say panels it means center to center distance of columns it is mandatory to consider the column in the optimum design of reinforced concrete flat sab.

Design of columns, EBSC 2

The internal forces and moments may generally be determined by elastic global analysis using either first order theory or second order theory.

First-order theory, using the initial geometry of the structure, may be used in the following cases

Non-sway frames

Braced frames

Design methods which make indirect allowances for second-order effects.

Second-order theory, taking into account the influence of the deformation of the structure, may be used in all cases.

Design of None sways Frames

Individual non-sway compression members shall be considered to be isolated elements and be designed accordingly.

Design of Isolated Columns

For buildings, a design method may be used which assumes the compression members to be isolated. The additional eccentricity induced in the column by its deflection is then calculated as a function of slenderness ratio and curvature at the critical section

Total eccentricity

- The total eccentricity to be used for the design of columns of constant cross-section at the critical section is given by:

$$e_a = e_e + e_a + e_2$$

Where: e_e is equivalent constant first-order eccentricity of the design axial load

ea is the additional eccentricity allowance for imperfections. For isolated columns:

$$e_a = \frac{L_e}{300} \geq 20\,\text{mm}$$

e_2 is the second-order eccentricity

First order equivalent eccentricity

1. For first-order eccentricity e_0 is equal at both ends of a column

   $e_e = e_o$

2. For first-order moments varying linearly along the length, the equivalent eccentricity is the higher of the following two values:

   $e_e = 0.6e_{02} + 0.4e_{o1}$

$e_e = 0.4e_0$

where e_{01} and e_{02} are the first-order eccentricities at the ends, e_{02} being positive and greater in magnitude than e_{01}.

e_{01} is positive if the column bents in single curvature and negative if the column bends in double curvature.

3. For different eccentrics at the ends, (2) above, the critical end section shall be checked for first order moments:

$e_{tot} = e_{02} + e_a$

Short and Slender column

Columns may be divided into broad categories: Short columns, for which the strength is governed by the strength of materials and the geometry of the cross section, and slender columns for which the strength may be significantly reduced by lateral deflection[2].

Detailing

Size: The minimum lateral dimension of a column shall be at least 150 mm.

Longitudinal Reinforcement:

a) The area of longitudinal reinforcement shall neither be less than $0.008A_c$ nor more than $0.08A_C$. The upper limit shall be observed even where bars overlap.
b) For columns with a larger cross-section than required by considerations of loading, a reduced effective area not less than one-half die total area may be used to determine minimum reinforcement and design strength
c) The minimum number of longitudinal reinforcing bars shall be 6 for bars in a circular arrangement and 4 for bars in a rectangular arrangement
d) The diameter of longitudinal bars shall not be less than 12 mm

Lateral Reinforcement

a) The diameter of ties or spirals shall not be less than 6 mm or one quarter of the diameter of the longitudinal bars.
b) The center-to-center spacing of lateral reinforcement shall not exceed:
    - 12 times the minimum diameter of longitudinal bars.
    - least dimension of column
    - 300 mm

c) Ties shall be arranged such that every bar or group of bars placed in a corner and alternate longitudinal bar shall have lateral support provided by the corner of a tie with an included angle of not more than 135^0 and no bar shall be further than 150 mm clear on each side along the tie from such a laterally supported bar.

d) Up to five longitudinal bars in each corner may be secured against lateral buckling by means of the main ties. The center-to-center distance between the outermost of these bars and the corner bar shall not exceed 15 times the diameter of the tie.

$$s_{max} = 350 \text{ mm}$$

e) Spirals or circular ties may be used for longitudinal bars located around the perimeter of a circle. The pitch of spirals shall not exceed 100 mm.

2.4 Grades of Steel and Concrete

Grades of Concrete: Concrete grade is measured in terms of its characteristic compressive cube strength, for class I the followings are permissible grade of concrete that are recommended for load bearing structures.C25,C30,C40,C50 and C60[13]. Methods of specification of Concrete as per EBCS 2, 1995 concrete may be specified in one of three ways:

1. Design Mixes: With this method the required compressive strength is specified, together with any other limits that may be required, such that as maximum aggregate size, minimum cement content, and workability.
2. Prescribed mixes: With this method, the designer assumes responsibility for designing the mix and stipulates to the producer the mix proportions and the materials which shall be employed.
3. Standard (or Normal) mixes: The mix proportions which are appropriate for grade C5 to C30 may be taken from Table 2.4,taken from EBCS 2 .These standard mixes which are rich in cement ,and are intended for use where the cost of trial mixes or of acceptance cure testing is not justified, may be used without verification of compressive strength

Grades of Steel: The application rules for design and detailing in Ethiopian building code standard two for practice in reinforced concrete are valid for a specified yield strength range from 400MPa to 600MPa[13].

Table 2.4: Standard Mixes for ordinary Structural Concrete per 50kg Bag of Cement

Concrete Grade	Normal Max.Size of Aggregate (mm)	40		20		14		10	
	Workability	Medium	High	Medium	High	Medium	High	Medium	High
	Limits of slump that may be expected (mm)	30 to 60	60 to 120	20 to 50	50 to 100	10 to 30	30 to 60	10 to 25	25 to 50
C20	Total aggregate (kg)	305	270	280	480	250	220	240	200
	Fine aggregate (%)	30-35	30-40	30-40	35-50	35-45	40-50	40-50	45-55
	Vol.of finished concrete (m3)	0.165	0.155	0.156	0.252	0.143	0.13	0.137	0.121
C25	Total aggregate (kg)	265	240	240	280	250	195	210	175
	Fine aggregate (%)	30-35	30-40	30-40	35-45	35-45	40-50	40-50	45-55
	Vol.of finished concrete (m3)	0.147	0.137	0.137	0.127	0.143	0.118	0.124	0.11
C30	Total aggregate (kg)	235	215	210	190	305	170	180	150
	Fine aggregate (%)	30-35	30-40	30-40	35-45	30-35	40-50	40-50	45-55
	Vol.of finished concrete (m3)	0.134	0.127	0.124	0.115	0.165	0.106	0.109	0.097

Source: EBCS-2, 1995

2.5 Reinforced Concrete Cost analysis

The reinforced concrete costs are estimated based on: concrete volume, reinforcement mass and formwork area. The costs of each of these parameters depend on material costs, work load and repetition. Input information, especially material and labor costs are depending on the local economy and requires updates.

While estimating the costs of a certain reinforced concrete structure, several uncertainties must be kept in mind. Major parameters in costs estimation are repetition, location of the structure or structural behavior. Contractors may choose for different (more expensive) solutions to avoid or minimize risks or for many other reasons.

The analysis of reinforced concrete costs is quite straightforward. Basically, it is all about determining the material types, the amount of work and volumes of all parts of the given structure[17].

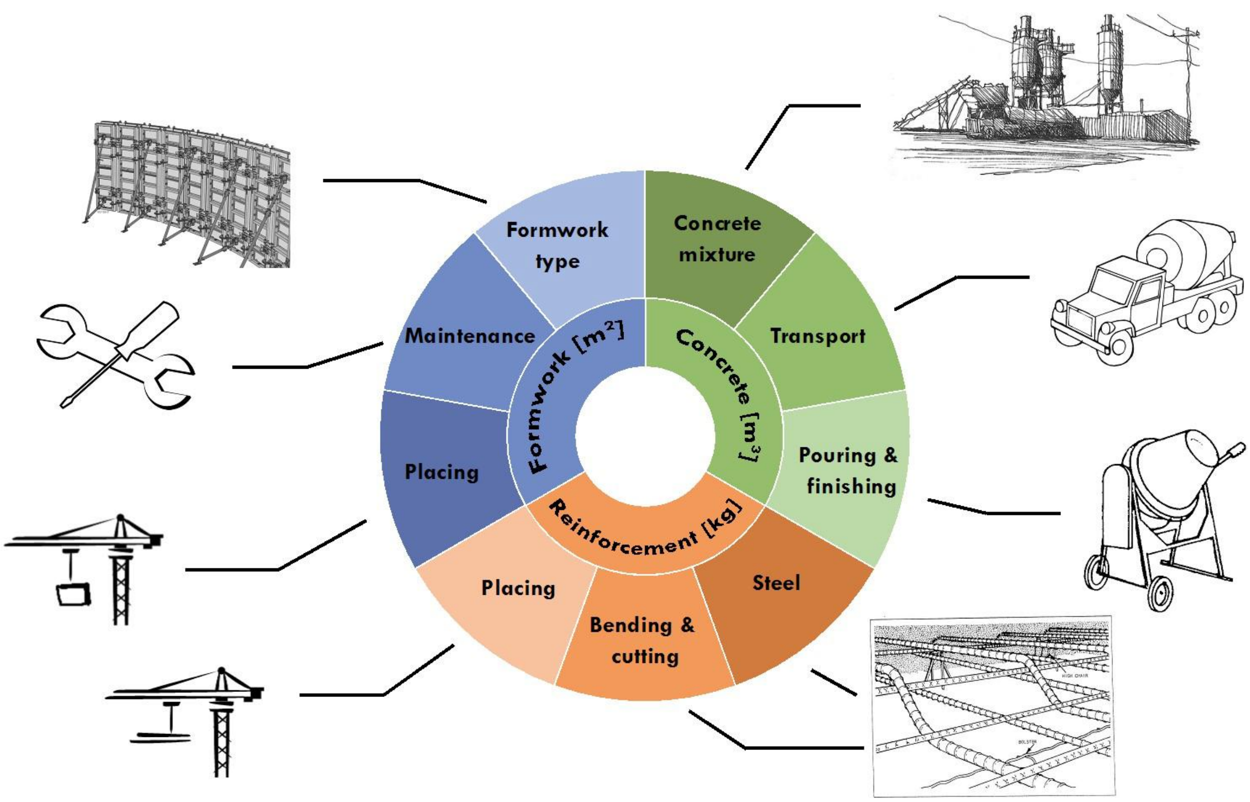


Fig 2.4 Cost analysis of reinforced concrete adopted from Report of Slobbe, 2015

Concrete Costs

The estimated costs of the concrete volume depend on several factors. The major ones are the costs for the material, the required work to pour and finish the concrete and the transportation costs. Since the costs of all of these components depend on economic factors, their values change over time and with the location. This can be explained by different travelling distances from concrete plant to sight (or transportation of materials to the concrete plant), differences in labor costs or the constantly changing costs of resources. To keep the costs estimation reliable, it is required to keep the economy related data up to date.

$$C_{cost} = V_c * (C_{material} + C_{transport} + L_{distance} * C_{transportation,km} + H_{workload} * C_{manpower})$$

where

Ccost = are the estimated costs of the concrete per m^3

Vc= is the volume of concrete in [m3]

$C_{material}$= are the material costs, depending on the concrete type

$C_{transport}$= are some basic costs for transportation,

$L_{distance}$ = the travelling distance concrete plant - site in [km]

$C_{transportation,km}$= are the costs per travelled km,

$H_{workload}$= is the workload required for pouring and finishing,

$C_{manpower}$= are the costs of a worked hour, usually

Table 2.5 Concrete cost for 1m^3 of concrete (C-20)

WORK ITEM: Reinforced Concrete (C-20) — **LABOUR HOURLY OUTPUT:** 0.500 m3 / hr

TOTAL QTY.: 1 m^3 — **EQUIPMENT:** 0.920 m3 / hr

(A) Material Cost					(B) Labour					(C) Equipment Cost				
Type of Material	Unit	Qty.	* Rate	Cost per Unit	Labour by Trade	Unit	UF	** Indexed Hour. Cost	Hourly Cost	Type of Equipment	No	UF	Hourly Rental	Hourly Cost
Cement	Qt	3.20	300.00	960.00	Forman	1	0.10	16.67	1.67	Tools	4	1	0.15	0.60
Sand	m^3	0.500	1250.00	625.00	G.Leader	1	0.25	6.25	1.56	Mixer	1	1	37.50	37.50
Aggregate	m^3	0.750	1250.00	937.50	DL	4	1.00	5.00	20.00	Vibrator	2	1	10.00	20.00
Water	m^3	0.24	6.25	1.50	Mason	1	1.00	12.50	12.50					
					Helper	1	1.00	7.50	7.50					
					Mixer Opr.	1	1.00	6.25	6.25					
					Vibrator Op	2	1	6.25	12.5					
	Total =			2524.00			Total =		61.98			Total =		58.10

A = Material unit cost		B = Manpower Unit Cost		C = Equipment Unit Cost	
Total of	2524.00	= Total of 61.98	123.96	= Total of 58.10	63.15
		Hourly output 0.5		Hourly output 0.92	

DIRECT COST OF WORK ITEM = **A + B + C** = 2711.11

Remarks: 20% Add for overhead and profit = 3253.33 = **3253.40** Birr Per m3

UF: UTILIZATION FACTOR

*: Inclusive of Waste, Transporting, Handling, etc.

**: Inclusive of Benefits, trade subsidies and cost of overtime related output.

Table 2.6 Concrete cost for 1m^3 of concrete (C-25)

WORK ITEM:	**Reinforced Concrete (C-25)**							**LABOUR HOURLY OUTPUT:**			**0.500**	**m3 / hr**		
TOTAL QTY.:	**1**		**m^3**					**EQUIPMENT:**		**0.920**	**m3 / hr**			
(A) Material Cost					**(B) Labour**					**(C) Equipment Cost**				
Type of Material	**Unit**	**Qty.**	*** Rate**	**Cost per Unit**	**Labour by Trade**	**Unit**	**UF**	**** Indexed Hour. Cost**	**Hourly Cost**	**Type of Equipment**	**No**	**UF**	**Hourly Rental**	**Hourly Cost**
Cement	Qt	3.64	300.00	1092.00	Forman	1	0.10			Tools	4	1	0.15	0.60
Sand	m^3	0.52	1250.00	650.00	G.Leader	1	0.25	33.23	8.31	Mixer	1	1	37.50	37.50
Aggregate	m^3	0.78	1250.00	975.00	DL	4	1.00	0.85	3.40	Vibrator	2	1	10.00	20.00
Water	m^3	0.21	6.25	1.33	Mason	1	1.00							
					Helper	1	1.00							
					Mixer Opr.	1	1.00							
					Vibrator Op	2	1							
	Total =			2718.33			Total =		11.71			Total =		58.10

A = Material unit cost — Total of (1:01) 2718.33

B = Manpower Unit Cost — = Total of (1:02) 11.71 — 23.41; Hourly output 0.5

C = Equipment Unit Cost — = Total of (1:03) 58.10 — 63.15; Hourly output 0.92

DIRECT COST OF WORK ITEM = **A + B + C** = 2804.90

Remarks: 20% = 3365.88 = **3365.90** Birr Per m3

UF: UTILIZATION FACTOR

*: Inclusive of Waste, Transporting, Handling, etc.

**: Inclusive of Benefits, trade subsidies and cost of overtime related output.

Table 2.7 Concrete cost for 1m^3 of concrete (C-30)

WORK ITEM:	**Reinforced Concrete (C-30)**							**LABOUR HOURLY OUTPUT:**			**0.500**	**m3 / hr**		
TOTAL QTY.:	**1**		**m^3**					**EQUIPMENT:**		**0.920**	**m3 / hr**			
(A) Material Cost					**(B) Labour**					**(C) Equipment Cost**				
Type of Material	**Unit**	**Qty.**	*** Rate**	**Cost per Unit**	**Labour by Trade**	**Unit**	**UF**	**** Indexed Hour. Cost**	**Hourly Cost**	**Type of Equipment**	**No**	**UF**	**Hourly Rental**	**Hourly Cost**
Cement	Qt	4.03	300.00	1209.00	Forman	1	0.10			Tools	4	1	0.15	0.60
Sand	m^3	0.510	1250.00	637.50	G.Leader	1	0.25			Mixer	1	1	37.50	37.50
Aggregate	m^3	0.770	1250.00	962.50	DL	4	1.00			Vibrator	2	1	10.00	20.00
Water	m^3	0.19	6.25	1.19	Mason	1	1.00							
					Helper	1	1.00							
					Mixer Opr.	1	1.00							
					Vibrator Op	2	1							
	Total =			2810.19			Total =					Total =		58.10

A = Material unit cost — Total of (1:01) 2810.19

B = Manpower Unit Cost — = Total of (1:02); Hourly output 0.5

C = Equipment Unit Cost — = Total of (1:03) 58.10 — 63.15; Hourly output 0.92

DIRECT COST OF WORK ITEM = **A + B + C** = 2873.34

Remarks: 20% Add for overhead and profit = 3448.01 = **3448.10** Birr Per m3

UF: UTILIZATION FACTOR

*: Inclusive of Waste, Transporting, Handling, etc.

**: Inclusive of Benefits, trade subsidies and cost of overtime related output.

Formwork Costs

The following formula hold for the design of formwork

$Costs/m^2 = I_{investment} / N_{repettition} + manhours/m^2$

Where

$I_{investment}$= the investment to buy and maintain the formwork times the amount of times it should be replaced or maintained when operational.

$N_{repettition}$= The amount of times the system is used during construction.

$manhours/m^2$= The workload for a square meter times the salary of the worker.

This formula states that the costs for a m^2] of formwork are determined by the investment for the initial formwork system (purchase), the amount of work required to place and maintain the formwork and the repetition (reuse) of the formwork. The results of this formula may change with the chosen type of formwork.

Summary of cost per meter cube (As per SNPPR Design, construction and supervision Office)

- f_{ck}=Characteristic cylinder strength of concrete

= C 20,C 25 ,C30 (Different grades of Concrete)

- Ccost=Cost of concrete including formwork and labor cost

✓ 3253.33+113.76=3367.09 birr/m3 for C20/25 of f_{ck}=20 Mpa

✓ 3365.88+ 113.76 =3479.64 birr/m3 for C25/30 of f_{ck}=25 Mpa

✓ 3448.01+113.76= 3561.77 birr/m3 for C30/37 of f_{ck}=30 Mpa

Reinforcement Costs

The costs for reinforcement are, like concrete, depending on several parameters. The main parameters in case of reinforcement are the material costs and processing (transporting, cutting, bending and placing). The material costs depend on the bar diameter and the amount of reinforcement in a project (mass production).the processing costs depend on the required amount of work. The estimation of the reinforcement costs is described as the summation of all the sets of reinforcements. Note that the parameters of the equation are (among others) depending on the diameter. This might result in the requirement to use this equation for several reinforcement diameters.

$Scost = \sum (C_{material} + workload * C_{manhour})$

Where:

Scost=reinforcement cost per kg

$C_{material}$= is material costs (depending on diameter and amount of steel)

$C_{manhour}$ =are the costs of a worked hour

Cost of reinforcement bar per kg for different grades of steel as per SNPPR Design, construction and supervision office.

- F_y=Characteristic strength of steel

=S 400, S 500 (Different grades of Steel)

- Scost=Cost of steel including labour cost
- ✓ 30.7+2.28=32.96 birr/kg for S 400 of f_y=400Mpa
- ✓ 38.68+2.28=38.94 birr/kg for S 500 of f_y=500Mpa

2.6 Optimum Design of Reinforced Concrete Structures

In the ideal case, optimization should consider the structure as a whole and take into account its initial cost, maintenance cost and functional benefits. However, in most designs such an approach is too complicated to be of practical use. Hence optimization of individual structural components is commonly adopted. The basis of optimization is minimum weight or minimum cost. The former is better for high rise buildings in which the same component is repeated story after story. For low rise buildings the minimum cost is a better criterion for the optimum design of components. The main factors to be considered are the costs of steel, concrete and shuttering. The problem is considerably simplified by neglecting the latter and treating the cost ratio of steel to concrete as a variable to obtain the optimum designs[18].

2.7 MATLAB Software

MATLAB is an acronym for MATrix LABoratory and it is a very large computer application which is divided to several special application fields referred to as toolboxes. MATLAB which is capable of performing advanced mathematical and engineering computations[19].It is a powerful software program specialized in numerical computation of matrices. Due to the nature of optimization algorithms and the proposed structural optimizations, this program is suited for the optimization part of the processes[17].

It has inbuilt optimization Toolbox functions among which ‘fmincon’is the function for the purpose of constrained nonlinear minimization and ‘fminunc’ is for unconstrained optimization program.The optimization Toolbox is a collection of the MATLAB numeric computing power.The tool box includes routines for many types of optimization including unconstrained nonlinear minimization and constrained nonlinear minimization[20].

CHAPTER THREE: STRUCTURAL OPTIMIZATION

3.1 Introduction

People optimize. Airline companies schedule crews and aircraft to minimize cost. Investors seek to create portfolios that avoid excessive risks while achieving a high rate of return. Manufacturers aim for maximum efficiency in the design and operation of their production processes.

Nature optimizes. Physical systems tend to a state of minimum energy. The molecules in an isolated chemical system react with each other until the total potential energy of their electrons is minimized. Rays of light follow paths that minimize their travel time[21].

Engineering design relies heavily on optimization as economy and keeps safety. Optimization is the act of obtaining the best result under given circumstances. In the design of any structure a designer has to take many technological and managerial decisions at several stages. The ultimate goal of all such decisions is to obtain solution which gives the best results, namely either minimum or maximum with respect to criterion and satisfying certain conditions[22].

Optimization means making things the best. Thus, structural optimization is the subject of making an assemblage of materials sustains loads in the best way. However, to make any sense out of that objective it is necessary to specify the term "best". The first such specification that comes to mind may be to make the structure as light as possible, i.e., to minimize weight. Another idea of "best" could be to make the structure as less costly as possible. Clearly such maximizations or minimizations cannot be performed without any constraints. For instance, if there is no limitation on the amount of material that can be used, the structure can be made stiff without limit and this lead to an optimization problem without a well-defined solution. Quantities that are usually constrained in structural optimization problems are stresses, displacements and/or the geometry. Structural optimization problem is formulated by an objective function that should be maximized or minimized and using some of the other measures as constraints [3].

3.2 Engineering Applications of Optimization

Optimization, in its broadest sense, can be applied to solve any engineering problem. To indicate the wide scope of the subject, some typical applications from different engineering disciplines are given below:[23].

- Design of aircraft and aerospace structures for minimum weight.

- Finding the optimal trajectories of space vehicles.
- Design of civil engineering structures like frames, foundations, bridges, towers, chimneys and dams for minimum cost.
- Minimum weight design of structures for earthquake, wind and other types of random loading.
- Design of water resources systems for maximum benefit.
- Optimal plastic design of structures.
- Optimum design of linkages, cams, gears, machine tools and other mechanical components.
- Selection of machining conditions in metal gutting processes for minimum production cost.
- Design of pumps, turbines and heat transfer equipment for maximum efficiency.
- Design of pumps, turbines and heat transfer equipment for maximum efficiency.
- Optimum design of electrical machinery like motors, generators and transformers
- Optimum design of electrical networks.
- Shortest route taken by a salesman visiting different cities during one tour.
- Optimal production planning, controlling and scheduling.
- Analysis of statistical and building empirical models from experimental results to obtain the most accurate representation of the physical phenomenon.
- Optimum design of chemical processing, equipment and plants.
- Design of optimum pipe line networks for process industries.
- Selection of site for an industry.
- Planning of maintenance and replacement of equipment to reduce operating costs.
- Allocation of resources or services among several activities to maximize the benefit.

3.3 Formulation of the Optimization Problem

An optimization or a mathematical programming problem can be stated as follows [3].

$$\text{Find } X = \begin{Bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{Bmatrix} \text{ which minimizes } f(X)$$

Subjected to the constraints

$$g_j(X) \leq 0, \; j = 1,2,.....,m$$

$$l_j(X) = 0, \; j = 1,2,....., p$$

Where X is a $n-$dimensional vector called the design vector, $f(X)$ is termed the objective function, and $g_j(X)$ and $l_j(X)$ are known as inequality and equality constraints, respectively. The number of variables (n) and the number of constraints (m) and/or (p) need not be related in any way. This problem is called a constrained optimization problem. Some optimization problems do not involve any constraints and can be stated as:

$$\text{Find } X = \begin{Bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{Bmatrix} \text{ which minimizes } f(X)$$

Such problems are called unconstrained optimization problems.

3.4 Design Vector

Any engineering system is defined by a set of quantities some of which are viewed as variables during the design process. In general, certain quantities are usually fixed at the outset and these are called pre assigned parameters. All the other quantities are treated as variables in the design process and are called design or decision variables. The design variables are collectively represented as a design vector (X)[4].

3.5 Constraints

Any design which meets all the requirements placed on it, is called a feasible design. The restrictions that must be satisfied, in order to produce a feasible design, are called constraints. From a physical point of view, two kinds of constraints might be identified. These are [23].

- Design Constraints (side constraints):

These are specified limitations (upper or lower bound) on a design variable, or a relationship that fixes the relative value of a group of design variables. Examples of such constraints include minimum slope of a roof structure, minimum thickness of slab, or maximum depth of a beam.

- Behavior Constraints:

These derived from behavior requirements. Limitations on the maximum stresses, displacements, or buckling strength are typical examples of behavior constraints.

3.6 Constraint Surface

For illustration, consider an optimization problem with only inequality constraints $g_j(X) \le 0$. The set of values of x that satisfy the equation $g_j(X) = 0$, forms a hyper surface in the design space and is called a constraints surface. Note that this is an (n-1) dimensional subspace, where n is the number of design variables. The constraints surface divides the design into two regions; one in which $g_j(X) < 0$ and the other in which $g_j(X) > 0$.Thus the point lying on the hyper surface will satisfy the constraint $g_j(X)$ critically, whereas the points lying in the region where $g_j(X) > 0$ are infeasible or unacceptable, and the points lying in the region where $g_j(X) < 0$ are feasible or acceptable. The collection of all the constraint surfaces (x) = 0, *j* = 1, 2 …m, which separates the acceptable region is called the composite constraint surface [23].

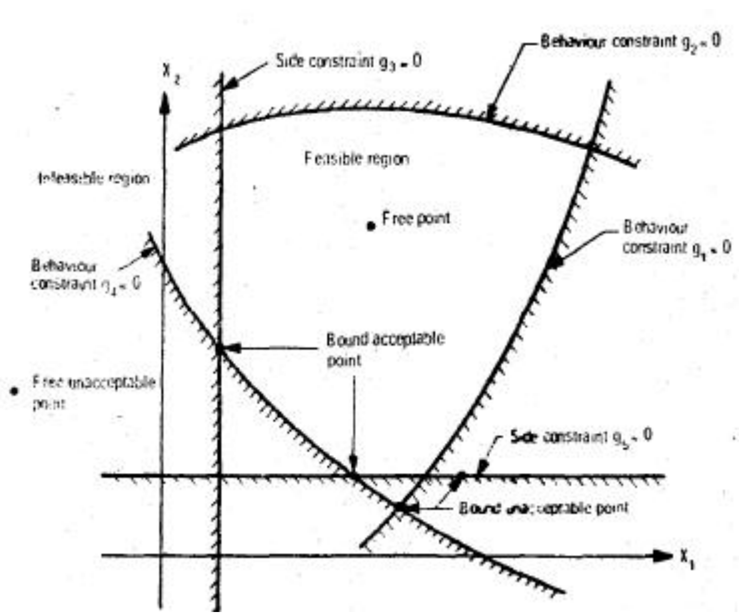


Fig 3.1 Constraint Surface in a Hypothetical two dimensional Design Space adopted from S.Rao 2009

Fig. 3.1 shows a hypothetical two-dimensional design space where the infeasible region is indicated by hatched lines. A design point lies on one or more than one constraint surface is called a bound point, and the associated constraint is called an active constraint. The design points which do not lie on any constraint surface are known as free points. Depending on whether a particular design point belongs to the acceptable or unacceptable region, it can be identified as one of the following four types:

1. Free and acceptable point.
2. Free and unacceptable point.
3. Bound and acceptable point.
4. Bound and unacceptable point.

All these four types of points are shown in Fig 3.1.above

3.7 Objective Function

In a structural design problem, there should be well defined criterion by which the performance or cost of the structure can be judged under different combination of design Fig 3.2 Constraint Surface in a hypothetical two dimensional Design variables. This index is generally referred to as the objective cost or a merit function. The conventional design procedures aim an acceptable or adequate design which merely satisfies the functional and other requirements of the problem. In general, there will be more than one acceptable design, and the purpose of optimization is to choose best one out of many acceptable design available. Thus a criterion has to be chosen for comparing the different alternative acceptable design and for selecting the best one. The criterion, with respect to which the design is optimized, when expressed as a function of the design variables, is known as criterion or merit or objective function. The choice of objective function is governed by the nature of problem. In civil engineering structural design, the objective is usually taken as the minimization of cost. Thus the selection of the objective function can be one of the most important decisions in the whole optimum design process. In some situations, there may be more than one criterion to be satisfied simultaneously. An optimization problem involving, multiple objective functions known as a multi objective programming problem. With multiple objectives there arise a possibility of conflict, and one simple way to handle the problem is to construct an overall objective function as a liner combination of the conflicting multiple objective functions. Thus, if $f1(X)$ and $f2(X)$ denote two objective functions, construct a new (overall) objective function for optimization as $f(x) = \alpha1f1(x) + \alpha2f2(x)$.Where $\alpha1$ and $\alpha2$ are constants whose values indicate the relative important of one objective relative to the other[23].

3.8 Objective Function Surfaces

The locus of all points satisfying f(x) = c= constant forms a hyper surface in the design space, and for each value of c there corresponds a different member of a family of surfaces. These surfaces, called the objective function surfaces, are shown in a hypothetical two dimensional design space in Fig 3.2.Once the objective function surfaces are drawn along with the constraint surfaces, the optimum point can be determine without much difficulty. But the main problem is that as the number of design variables exceeds two or three, the constraint and objective function surface surfaces become complex even for visualization and the problem has to be solved purely as a mathematical problem[23].

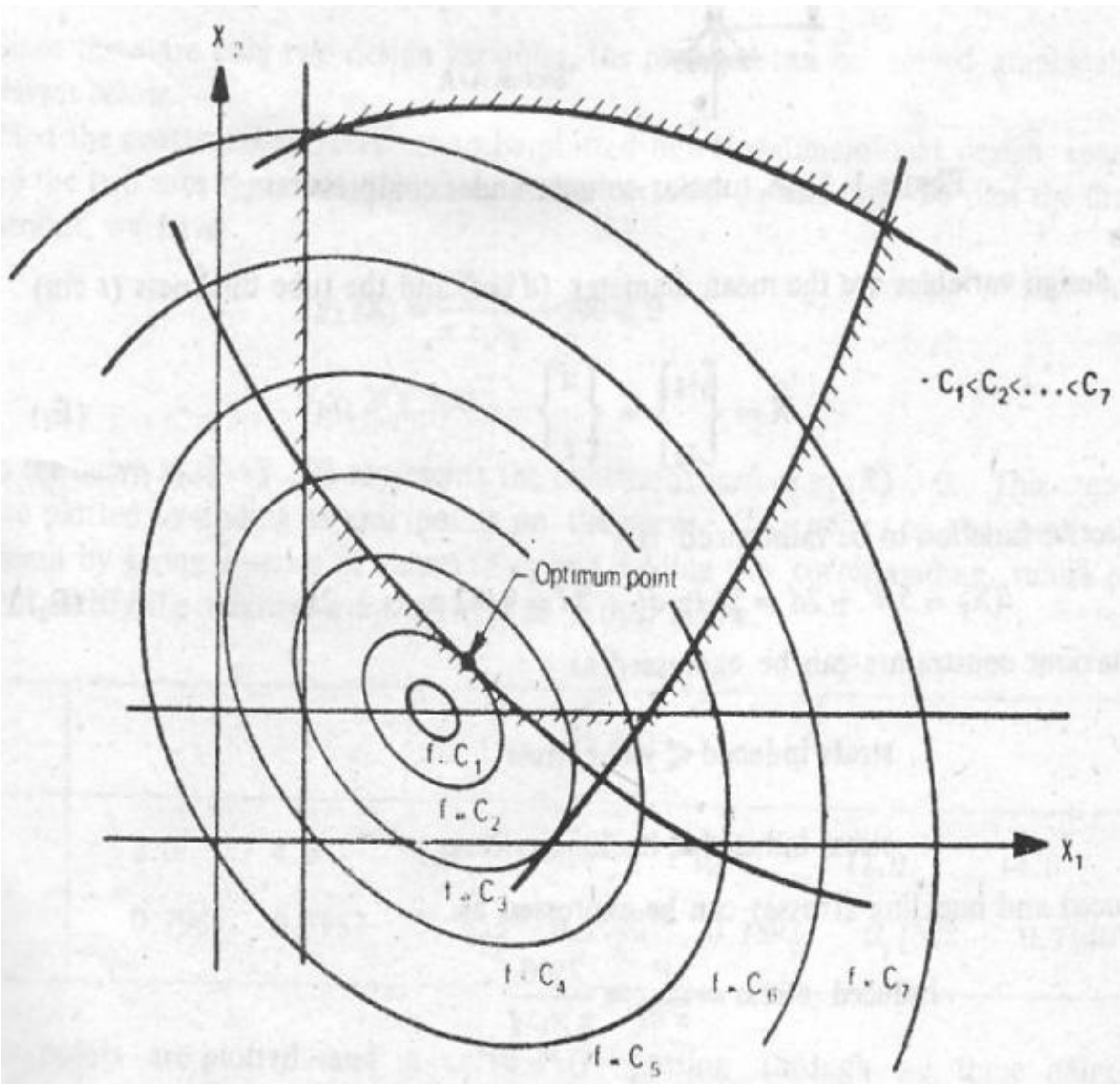


Fig 3.2 The contours of the objective function adopted from S.Rao 2009

3.9 Optimization Steeps

The design for reinforced concrete flat slab is written in MATLAB programing language and the written program helps to design reinforced concrete flat slab easily again and again.in the design of the reinforced concrete flat slab the penalty function method is used to formulate the design principles in constraints. The optimization steps are shown in the flow chart below.

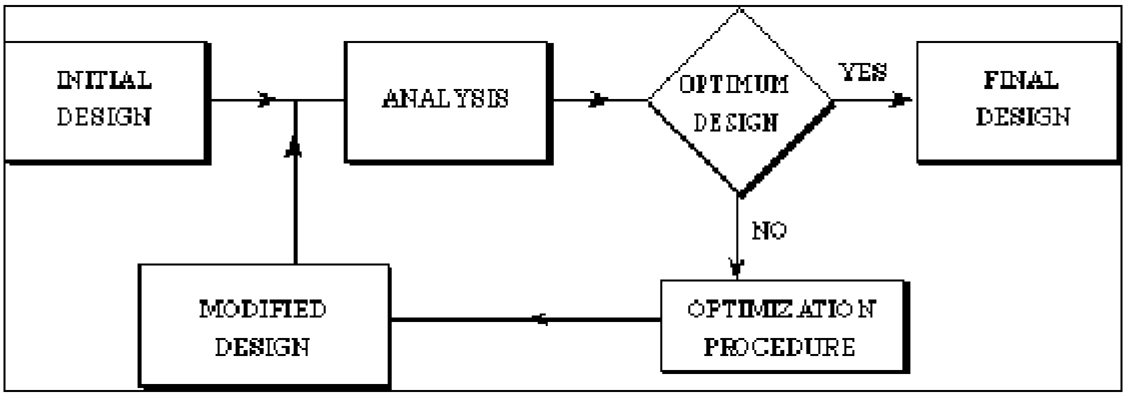


Fig.3.3 Structural optimization flow chart adopted from kiran S.Patil International Journal, 2013

3.10 Methods for the Solution of the NLPP

The problem is called a nonlinear programming problem (NLP) if the objective function is nonlinear and/or the feasible region is determined by nonlinear constraints. Nonlinearities is the form of either nonlinear objective functions or nonlinear constraints are crucial for representing an application properly as a mathematical program problem[24].

There are several methods for the solution of constrained NLPP. All these methods can be classified into two broad categories, namely [23].

1) Direct method

2) Indirect method

In the direct method, the constraints are handled in an explicit manner.In most of the indirect methods, the constrained problem is solved as a sequence of unconstrained minimization problem of the direct method.

An indirect method which is widely adopted is the penalty function methods. The penalty function method developed by Fiacco and Mc-cormic converts the constrained minimization problem to a sequential unconstrained minimization Technique (SUMT).Penalty function method transform the basic optimization problem into alternative formulation such that numerical solutions are sought by solving a sequence of unconstrained minimization problem.

Penalty function methods are able to solve constrained optimization problems transferring the constrained optimization problem in to unconstrained problem There are two type of penalty function methods[25]. The exterior penalty function method and the interior penalty function method. In the exterior penalty function method starting point is chosen in the infeasible region and the optimum is sought from the infeasible region with a of sequence minimization. This method is useful when it is difficult to get a feasible starting point. But In most of the practical Structural Optimization problem it is easy to get a starting feasible point, so interior penalty function method can be used in which the Starling Point is chosen in the feasible region and Optimum is sought from within the feasible region.

3.11 The Sequential Unconstrained Minimization Technique (SUMT)

The interior penalty that is embedded in the analysis and design equation of reinforced concrete flat slab converts the constraints into unconstrained optimization problem. The constraints are normalized between -1 and zero so as to follow the design at minimum depth dimensions satisfying the design principles controlled by the normalized constraints. The design is done for initial proportioned depths in the feasible region keeping the constraints and then redesigned for negative value of constraints of depth and punching shear approaching zero from the left. In doing so, we can get the minimum costs and weight.

In designing again and again to get the minimum cost the constraints are the one that controls the design in the feasible region .S.S.Rao in his book says the penalty function methods are barrier method account of the designs are controlled by the normalized constraints.

3.12 MATLAB Solution of Unconstrained Optimization Problems

The optimization problem that is converted into unconstrained by interior function method and that is written in MATLAB programing language should be minimized in minimizing numerical methods of DFP and cubic interpolation methods can be used and again the value is checked for constraints since it is treated as unconstrained optimization problem. For DFP methods the gradients for each iteration and again on should search the bounders in the negative and positive values at the first derivative in minimization using cubic interpolation. In all of the methods we need to check for values of the constraints.

The MATLAB solution of unconstrained optimization can easily calculate each value of iteration variables of depth of slab and iterative values take us to the optimum value. The initial depth proportioned is minimized using the program below. In doing we can get iterative values of depth of slab and we need to approximate the overall depth we can start by adding 110mm in the depth of slab to start for the drop panel depth that is in the overall depth of the slab. Again here we need to check each value of variables to be in the feasible region by inspecting the values of constraints.

The following steps can be used in getting the depths in each iteration that depths are the depths at which the design is minimum it can be iterated again and again as the constraints in each value is in the feasible region. The overall depth is proportioned starting from the depth of slab taking the punching shear force and the punching shear stress into account.

The MATLAB solution steps are given below[23].

Step 1: Write an M-file objfun.m for the objective function.

Step 2: Invoke unconstrained optimization program (write this in new MATLAB file).

clc

clear all

warning off

x0 = [X1,X2,X3,X4]; % Starting guess

fprintf ('The values of function value at starting pointn');

f=objfun(x0)

options = optimset('LargeScale', 'off');

[x, fval] = fminunc (@objfun,x0,options)

This produces the solution or ouput as follows:

The values of function value at starting point and

Optimization terminated: relative infinity-norm of gradient less than options TolFun.

To demonstrate for starting point of X1=300,X2=400,X3=4,X4=4

```
f= COSTtotal
clc
clear all
warning off
x0 = [300;400;4;4]; % Starting guess
fprintf ('The values of function value at starting pointn');
f=objfun(x0)
options = optimset('LargeScale', 'off');
[x, fval] = fminunc (@objfun,x0,options)
```

3.13 Termination Criteria in subsequent design

The design is terminated for which the constraint values of minimum depth and shear constraints approaches zero from the left and the values of minimum depth and over all depth of the reinforced concrete flat slab be in a position that more deduction of the depths cause the design to fail or the constraints to become positive The designs for different variables are seen in the table 6.1 to 6.49 there the design fail for 5mm reduction of depth of slab and overall depth at constraint values of minimum depth and punching approaching zero from the left.

CHAPTER FOUR: MODELING AND PROBLEM FORMULATION

4.1 Introduction

The modeling process is concerned with the construction of a mathematical generalization of a given problem that can be analyzed to produce meaningful answers that guide the decisions to be implemented. Central to this process is the identification or the formulation of the problem[21].In this study the design variables, constraints and objective function are identifies and problems are formulated so as to solve it using penalty function methods. The constraints are used as the barriers in the design of reinforced concrete flat slab that the normalized constraints are allowed to be between zero and negative one. The total cost function it the final out put result, which is the cost function of concrete and steel are used .The cost of concrete and steel includes the labor cost.

4.1.1 Design Variables

In general, certain quantities are usually fixed at the outset and these are called pre assigned parameters. All the other quantities are treated as variables in the design process and are called design or decision variables. The design variables that are considered in the optimization processes of reinforced concrete flat slab in this study are: grade of concrete, grade of steel, effective depth of slab, overall depth of drop from the top of slab number of spans required in the longer direction and shorter direction.

X1= Effective depth of slab.

X2=Overall depth of drop from top of slab.

X3=No. of span required in longer direction.

X4=No. of span required in shorter direction.

4.1.2 Constraint Equation

The constraints are normalized to vary between -1 and 0.The constraints helps to lay the points generated to be in the feasible domains since the constraints act as barriers during the minimization processes. That is why penalty function method is known as barrier methods[23]. The constraints in the design process as per Ethiopian Building Code Standard 2, 1995, simplified method, are listed below:

No of span constraint in x direction

There are at least three rows of panels of approximately of approximately equal spans in the direction being considered.

X3=Minimum three no. of span required in longer direction

G1= (2/X3)-1 < 1

No of span constraint in y direction

There are at least three rows of panels of approximately of approximately equal spans in the direction being considered.

X4=Minimum three no. of span required in shorter direction

G2= (2/X4)-1 < 1

Length constraint

For two way reinforced concrete slab the length of longer span is less than the length of two times the sorter span.

Ly=length of slab in longer direction.

Lx=length of slab in shorter direction.

G3=(Ly/ (2*Lx))-1 < 1

Minimum depth constraint

Thickness of flat slab from serviceability requirement is given by: $d \geq (0.4 + 0.6\frac{f_{yk}}{400})\frac{L_e}{\beta_a}$

Ly=length of slab in longer direction.

G4= $(((0.4 + 0.6\frac{f_{yk}}{400})\frac{Ly}{24}) / X1)-1<1$

Depth constraint

The minimum depth for the point support reinforced concrete flat slab is 150mm

St=overall depth or thickness of slab = X1+cover

G5= (150/St)-1 < 1

Load constraint

The ratio of live load to dead load is taken as not to exceed 1.25.

Qk=live load

Gk=Total dead lod

G6=(Qk/ (1.25*Gk))-1 < 1

Calculation of Maximum Bending Moment

The ultimate moment from stress strain requirement is calculated as follow:

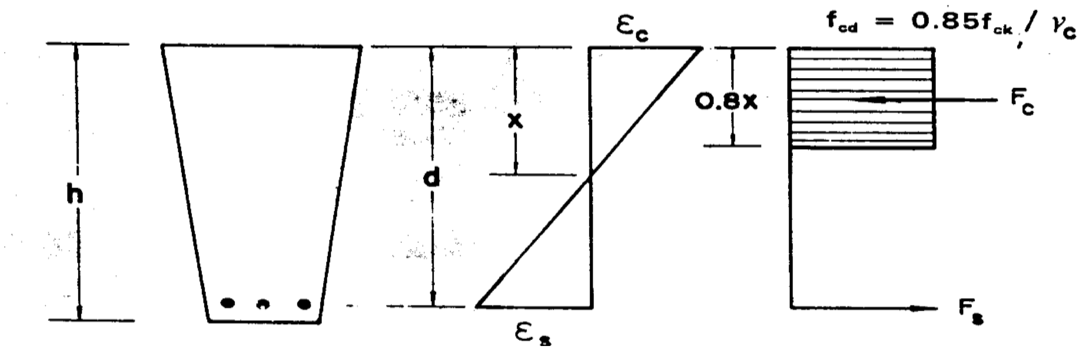


Figure 4.1. Rectangular Stress diagram as per EBCS 2

Steel grades S400.S460, S500 have characteristic yield strength of f_{yk}=400,460 and 500Mpa respectively[26].

ε_{s1}=S/E=400/200000=0.002

ε_{s2}=S/E=460/200000=0.0023

ε_{s3}=S/E=500/200000=0.0025

Applying similarity of stress strain diagram, the depth of neutral axis Xumax=X is given below:

- Xumax=X=0.64*X1 fore S=400
- Xumax=X=0.60*X1 fore S=460
- Xumax=X=0.58*X1 fore S=500

M=F_c*z=F_s*z

Moment constraint in slab

Mposmax=Maximum positive bending moment in all bending moment.

Mslab=The ultimate moment capacity of slab

Mslab=0.45*fck* LSMS*Xumax*(X1-0.4*Xumax)

Xumax =Effective depth of neutral axis.

G7= (Mposmax/Mslab)-1 < 1

Moment constraint in drop

Mnegmax=Maximum negative bending moment in all bending moment.

Mdrop =The ultimate moment capacity of drop

Mdrop=0.45*fck*LSCS*Xumax*(dd-0.40*Xumax)

Xumax =Effective depth of neutral axis.

G8= (Mnegmax/Mdrop)-1 < 1

Constraint of beam type shear force

Diagonal tension shear force failure where the critical section is considered at a distance of 'd' from the face of the column or capital should not be greater than the shear force carried by concrete.

Vcr= Diagonal tension shear force

Vcb= Shear force carried by concrete

G9= (Vcr/Vcb)-1 < 1

Constraint of check of punching in slab

Punching shear stress resistance should be greater than the punching shear stress around column. The punching shear resistance Vcp is given by $0.5*f_{ctd}*K_1*K_2$.

Vcdc= Punching shear stress around column

Vcp= Punching shear stress resistance

G10= (Vcdc/Vcp)-1 < 1

Constraint of check of punching in drop

Punching shear stress resistance should be greater than the punching shear stress around drop. The punching shear resistance Vcp is given by $0.5*f_{ctd}*K_1*K_2$.

Vcdd= Punching shear stress around drop

Vcp= Punching shear stress resistance

G11= (Vcdd/Vcp)-1 < 1

4.1.3 Formulation of the Objective Function

The total cost of materials (concrete and steel reinforcement) is considered as the objective function which should be minimized. The total cost of the slab can be stated as:

COSTtotal= Qconcrete*Ccost+ Qsteel*Scost

COSTtotal=Total cost of slab

Qconcrete= Total quantity of concrete

Qsteel= Total quantity of steel

Ccost=Cost of concrete per meter cube

Scost=Cost of reinforcement per kg

4.1.4 Different parameters and Conditions for comparative study

For comparative study the following parameters are considered for the different result out puts

f_{ck}=Characteristic strength of concrete

= C 20,C 25 ,C 30

F_y=Characteristic strength of steel

=S 400, S 500

Ccost=Cost of concrete including formwork and labour cost

=3367.09 birr/m3 for C20/25 of f_{ck}=20 Mpa

=3479.64 birr/m3 for C25/30 of f_{ck}=25 Mpa

=3561.77 birr/m3 for C30/37 of f_{ck}=30 Mpa

Scost=Cost of steel including labor cost

=32.96 birr/kg for S 400 of f_y=400Mpa

=38.94 birr/kg for S 500 of f_y=500Mpa

Different total spans taken: 20mX20m , 25mX25m ,30 X30m

4.2 Design Step for Conventional Reinforced Concrete Flat Slab Design

(Simplified Method)

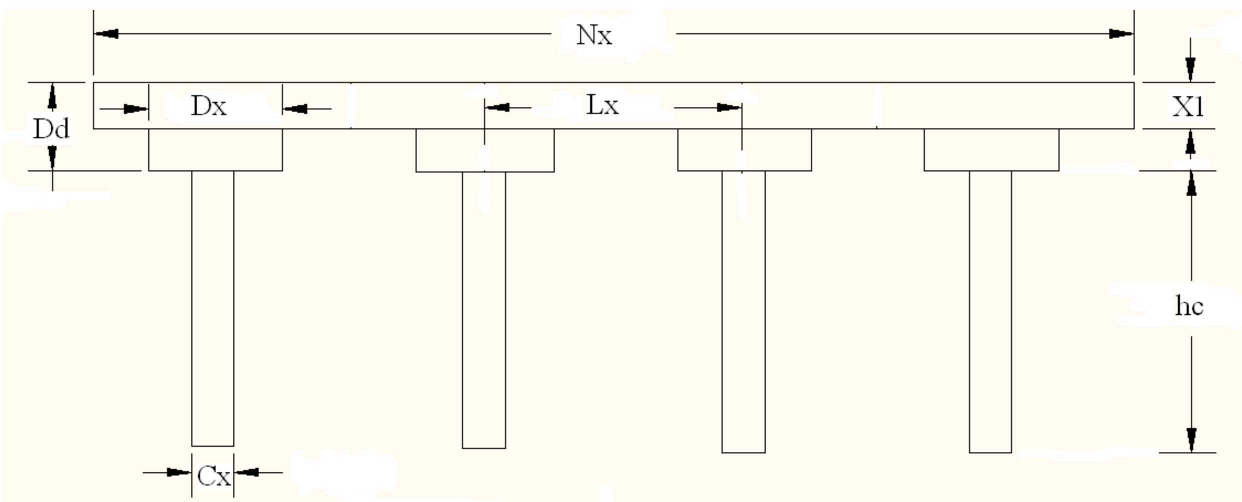


Fig.4.2. Typical shape of flat slab with drop panel (in X-direction)

4.2.1 Problem Formulation

The design is carried in terms of variables so that it is convenient to program in MATLAB and the variables perioral defined and then formulated. Variables should be defined first to program in MATLAB and to use the output for further calculation. The design included the design of column so that the effect of dead load and increment in panels are to be taken in to account. Since flat slab is supported by column as we increase the panels intern we increase the number of columns. In optimization of reinforced concrete flat slab the panel increment means the increment of columns owing to flat slab is supported by column. In this study the column is included to consider the effect of slab dead load and slab panel increment.

4.2.2 Design Steps

The design steps are done in terms of variables so that it is convent to write in MATLAB programing .The assigned variables should be first declared above so that the MATLAB can understand and use in the preceding computations.

- **Variables**

F_{ck}=Characteristic strength of concrete.

F_{yk}=Characteristic strength of steel.

X1= Effective depth of slab

X2=Overall depth of drop from top of slab.

X3=No. of span required in first direction

X4=No. of span required in second direction

Nx=Total length of slab in shorter direction.

Ny=Total length of slab in longer direction.

Lx=length of slab in shorter direction.

Lx= Nx/X3

Ly=length of slab in longer direction.

Ly= Ny/X4

Ccost=Cost of concrete.

Scost=Cost of steel.

- **Finding Clear Length of Slab**

Cx=overall depth of column in shorter direction.

Cx=Lx/10

Cy=overall depth of column in longer direction.

Cy=Ly/10

Lcx= clear length of slab in shorter direction.

Lcx=Lx-Cx

Lcy= clear length of slab in longer direction.

Lcy=Ly-Cy

- **Select Slab Thickness to limit Deflection**

X1= $(0.4+0.6\frac{f_{yk}}{400})\frac{Ly}{24}$

St= Over all depth or thickness of Slab

Cover=15

St= X1+Cover

- **Finding Length of Column Strip and Middle Strip**

LLMS=Length Middle Strip in longer direction.

LLMS=Ly- LLCS

LLCS= Length Column Strip in longer direction.

LLCS =2*Lx/4

LSMS = Length Middle Strip in shorter direction.

LSMS=Lx- LSCS

LSCS= Length Column Strip in shorter direction.

LSCS =2*Lx/4

Dx= drop panel size in shorter direction.

Dx=Lx/3

Dy= drop panel sizes in longer direction.

Dy=Ly/3

dt=Thickness or depth of drop

dt= X2-St

dd=Over all effective depth of drop from the top of slab

dd=X2-Cover

Effective Depth of Slab and Drop in longer and shorter direction

d_{barb} =Bar diameter to the bottom of slab and drop

d_{barb} =12

dsl=Effective depth of slab in the longer direction

dsl=St-Cover- d_{barb} /2

dss=Effective depth of slab in the shorter direction

dss=St-Cover - 1.5* d_{barb}

Drop

dtl=Effective depth of drop in the longer direction

dtl= dt-cover -d_{barb} /2

dts=Effective depth of drop in the shorter direction

dts= dt- 1.5* d_{barb}

- **Finding Equivalent Slab Thickness**

Dx= drop panel size in shorter direction.

Dx=Lx/3

Dy= drop panel sizes in longer direction.

Dy=Ly/3

Est= Equivalent Slab Thickness.

Est= ((Lx*Ly*St) + (Dx*Dy*(X2-St)))/ (Lx*Ly)

- **Loading**

Dead load and live loads that are used for design are taken according to Ethiopian building code standards[13], [27].

G_{ks1}=Dead load from slab

G_{ks1}= Est*24/10^3

G_{ks2} =Dead load from finishing + Partition =(0.05*23)+2=3.15

G_k = Total Dead load

$G_k = G_{ks1} + G_{ks2}$

Q_k =5

Pd=Design load

Pd=1.3*Gk+1.6*Q_k

- **Design strength of materials**

$F_{cd} = 0.85 * F_{ck} / 8_c$ $\quad\quad$ $8_c = 1.5$

$F_{ctk} = 0.21*(F_{ck})^{2/3}$

$F_{ctd} = F_{ctk} / 8_c$

$F_{yd} = F_{yk} / 8_s$ $\quad\quad$ $8_s = 1.15$

$\rho = \rho_{,min} = 0.5/ F_{yk}$

K1=1+50*ρ

K2=1.6-(dtl+dts)/(2*10^3)

- **Check for Shear**

Beam Type Shear

F=Pd*Lx*Ly

Vmax=0.5*F

Dave= Effective depth of average Slab Thickness.

Dave=(St+dt)/2

Daved = Dave-Cover-1.5* d_{barb}

Vcr = (4-(0.5*Cy +10^{-3}* Daved))/4* Vmax

Vcb=0.25* F_{ctd} *K_1*K_2*Lx* Daved

Punching Shear

Punching shear is critical because the depth is governed by it. Consider critical section to be 1.5d from face of support.

Punching Shear perimeter

- Perimeter Around Column:Ud
  ddav =Average effective depth of drop in the longer and shorter direction
  dtav=(dtl+dts)/2
  Ud=3*(Cx+dtav)*4
- Perimeter Around drop: Us
  dsav =Average effective depthof slab in the longer and shorter direction
  dsav=(dsl+dss)/2
  Us=3*(Dx+dtav)*4

Punching shear stress around Column

Vdvc =Punching Shear Force around column

Vdvc =(Lx*Ly-$(Cy+3*dtav)^2$)*Pd

Punching Shear Stress around

Vcdc=(Vdv*1000)/ (Ud *dtav)

Punching shear stress around Drop

Vdvd =Punching Shear Force around drop

Vdvd =(Lx*Ly-(Dy+3*dsav)$)^2$*Pd

Punching Shear Stress around drop

Vcdd=(Vdv*1000)/ (Us *dsav)

Punching Shear stress resistance

Vcp=0.5* F_{ctd} *K_1*K_2

- **Design for Flexure**

BM = Bending Moment

L=Effective Span

C=Bending and Shear force coefficient (EBCS 2, Table A-14)

F=Pd*Lx*Ly

M=CFL

Effective Span, Moment at the support and Moment at field for the longer span

L_{ny}=Effective Span in the longer direction

Cy=depth of column in the longer direction

h_{cy} = sqrt(4*C_y^2/pi)

L_{ny}=Ly-2* h_{cy} /3

M_s=Moment at the support

M_s = C *F* L_{ny}

M_f =Moment at the field

M_f =C *F* L_{ny}

Effective Span, Moment at the support and Moment at field for the shorter span

L_{nx}=Effective Span in the longer direction

Cx=depth of column in the longer direction

$h_{cx} = sqrt(4*C_x^2/pi)$

$L_{nx}=Ly-2* h_{cx} /3$

M_s=Moment at the support

$M_s = C *F* L_{nx}$

M_f =Moment at the field

$M_f = C *F* L_{nx}$

- **Distribution of Moment**

For Longer Span

Bending moment for exterior panel

ML1 =Interior negative moment in longer direction for exterior panel.

ML1= $M_f = -0.063 *F* L_{ny}$

ML2=Positive moment in longer direction for exterior panel.

ML2= $M_s = 0.083 *F* L_{ny}$

ML3=Exterior negative moment in longer direction for exterior panel.

ML3= $M_s = -0.040 *F* L_{ny}$

Bending moment for exterior panel-column strip

MLc1= Interior negative design moment in column strip in longer direction for exterior panel.

MLc1 =0.75 *ML1

MLc2_ Positive design moment in column strip in longer direction for exterior panel.

MLc2 =0.55* ML2

MLc3 =Exterior negative design moment in column strip in longer direction for exterior panel.

MLc3 =0.75 *ML3

Bending moment for exterior panel-middle strip

MLm1= Interior negative design moment in middle strip in longer direction for exterior panel.

MLm1 =0.25 *ML1

MLm2 =Positive design moment in middle strip in longer direction for exterior panel.

MLm2 =0.45 *ML2

MLm3= Exterior negative design moment in middle strip in longer direction for exterior panel.

MLm3 =0.25

Bending moment for interior panel

ML4 =Interior negative moment in longer direction for interior panel.

ML4= M_s = -0.055 *F* L_{ny}

ML5=Positive moment in longer direction for interior panel.

ML5= M_s = 0.071 *F* L_{ny}

Bending moment for interior panel-column strip

MLc4= Interior negative design moment in column strip in longer direction for interior panel.

MLc4 =0.75* ML4

MLc5 =Positive design moment in column strip in longer direction for interior panel.

MLc5 =0.55 *ML5

MLc6= Exterior negative design moment in column strip in longer direction for interior panel.

MLc6 =0.75 *ML4

Bending moment for interior panel-middle strip

MLm4= Interior negative design moment in middle strip in longer direction for interior panel.

MLm4 =0.25* ML4

MLm5 =Positive design moment in middle strip in longer direction for interior panel.

MLm5 =0.45* ML5

MLm6= Exterior negative design moment in middle strip in longer direction for interior panel.

MLm6 =0.25 *ML4

For Shorter Span

BM = Bending Moment

L=Effective Span

C=Bending and Shear force coefficient (EBCS 2, Table A-14)

F=Pd*Lx*Ly

M=CFL

Moment along the longer span of the interior panel

L_{ny}=Effective Span in the Shorter direction

Cx=depth of column in the Shorter direction

h_{cx}= sqrt(d*C_x^2/pi)

L_{nx}=Ly-2* h_{cx} /3

M_s=Moment at the support

M_s = -0.055 *F* L_{nx}

M_f =Moment at the field

M_f = +0.071 *F* L_{nx}

Bending moment for exterior panel

Ms1 =Interior negative moment in shorter direction for exterior panel.

MS1= M_f = -0.063 *F* L_{nx}

Ms2=Positive moment in shorter direction for exterior panel.

MS2= M_s = 0.083 *F* L_{nx}

Ms3=Exterior negative moment in shorter direction for exterior panel.

MS3= M_s = -0.040 *F* L_{nx}

Bending moment for exterior panel-column strip

Msc1= Interior negative design moment in column strip in shorter direction for exterior panel.

MSc1 =0.75 *MS1

Msc2_ Positive design moment in column strip in shorter direction for exterior panel.

MSc2 =0.55* MS2

Msc3= Exterior negative design moment in column strip in shorter direction for exterior panel.

MSc3 =0.75 *MS3

Bending moment for exterior panel-middle strip

Msm1= Interior negative design moment in middle strip in shorter direction for exterior panel.

MSm1 =0.25 *MS1

Msm2_ Positive design moment in middle strip in shorter direction for exterior panel.

MSm2 =0.45 *MS2

Msm3= Exterior negative design moment in middle strip in shorter direction for exterior panel.

MSm3 =0.25

Bending moment for interior panel

Ms4 =Interior negative moment in shorter direction for interior panel.

MS4= M_s = -0.055 *F* L_{nx}

Ms5=Positive moment in shorter direction for interior panel.

MS5=M_s = 0.071 *F* L_{nx}

Bending moment for interior panel-column strip

Msc4= Interior negative design moment in column strip in shorter direction for interior panel.

MSc4 =0.75*MS4

Msc5 =Positive design moment in column strip in shorter direction for interior panel.

MSc5 =0.55 *MS5

Msc6= Exterior negative design moment in column strip in shorter direction for interior panel.

MSc6 =0.75 *MS4

Bending moment for interior panel-middle strip

Msm4= Interior negative design moment in middle strip in shorter direction for interior panel.

MSm4 =0.25* MS4

Msm5_ Positive design moment in middle strip in shorter direction for interior panel.

MSm5 =0.45* MS5

Msm6= Exterior negative design moment in middle strip in shorter direction for interior panel.

MSm6 =0.25 *MS4

- **Check for Maximum Moment in Slab**

Thickness of slab from consideration of maximum positive moment any where in slab.

Xumax =Effective depth of neutral axis.

Mslab=0.45*fck* LSMS*Xumax*(X1-0.4*Xumax)

- **Check for Maximum Moment in Drop**

Thickness of drop from consideration of maximum negative moment in column strip.

dd = Effective depth of drop from top of slab.

Mdrop=0.45*fck*LSCS*Xumax*(dd-0.4*Xumax)

- **Calculation of Reinforcement**

In Longer Direction

For column strip top reinforcement at support

ρsteel = Density of steel=7850 kg/m^3.

McsnegLmax= Maximum negative bending moment at support from column strip

AstcstL=Area of column strip top reinforcement in longer direction.

$\rho=\{1-\sqrt{[1-2M/bd^2f_{cd}]}\}f_{cd}/f_{yd}$

AstcstL= ρ*LLCS* dtl

dcsbL= Diameter of reinforcing bar in longer direction.

ScstL= Spacing of column strip top reinforcement in longer direction.

ScstL= (pi/4)*((dcstL) ^{2}/AstcstL)*LLCS

LbcstL=Total reinforcing bar length in longer direction.

$LbcstL_1$=2*0.33*Lny+Cy

QcstL=Quantity of column strip top reinforcement in Kg in longer direction.

$QcstL_1$=AstcstL*LbcstL*7850/10^9

$LbcstL_2$=2*0.2*Lny+Cy

QcstL=Quantity of column strip top reinforcement in Kg in longer direction.

$QcstL_2$=AstcstL*LbcstL*7850/10^9

For column strip bottom reinforcement at mid

ρsteel = Density of steel=7850 kg/m^3.

McsposLmax= Maximum positive bending moment at mid from column strip

AstcsbL= Area of column strip bottom reinforcement in longer direction.

$\rho=\{1-\sqrt{[1-2M/bd^2f_{cd}]}\}f_{cd}/f_{yd}$

AstcstL= ρ*LLCS* dsl

dcsbL= Diameter of reinforcing bar in longer direction.

ScsbL=Spacing of column strip bottom reinforcement in longer direction.

ScsbL= (pi/4)*((dcsbL)^2/AstcsbL)*LLCS

LbcstL= Total reinforcing bar length in longer direction.

LbcstL= Ly-2*0.125Lny

QcsbL=Quantity of column strip bottom reinforcement in Kg in longer direction.

QcsbL=AstcsbL*LbcstL*7850/109

For middle strip top reinforcement at support

ρsteel = Density of steel=7850 kg/m3.

MmsnegLmax=Maximum negative bending moment inline of support in middle strip in longer direction

AstmstL= Area of middle strip top reinforcement in longer direction.

$\rho=\{1-\sqrt{[1-2M/bd^2f_{cd}]}\}f_{cd}/f_{yd}$

AstcstL= ρ*LLCS* dtl

dmstL = Diameter of reinforcing bar in longer direction
SmstL. = Spacing of middle strip top reinforcement in longer direction.

SmstL=(pi/4)*((dmstL)2/AstmstL)*LLMS

LbmstL= Total reinforcing bar length in longer direction.

LbmstL=2*0.33*Lnx+Cx

QmstL=Quantity of middle strip top reinforcement in Kg in longer direction.

QmstL=AstmstL*LbmstL*7850/10^9

For middle strip bottom reinforcement at mid

ρsteel = Density of steel=7850 kg/m^3.

MmsposL= Maximum positive bending moment at mid in middle strip in longer direction

AstmsbL= Area of middle strip bottom reinforcement in longer direction.

ρ=$\{1-\sqrt{[1-2M/bd^2f_{cd}]}\}f_{cd}/f_{yd}$

AstcstL= **ρ***LLCS* dsl

dmsbL= Diameter of reinforcing bar in longer direction.

SmsbL= provided spacing of middle strip bottom reinforcement in longer direction.

SmsbL= (pi/4)*($(dmsbL)^2$/AstmsbL)*LLMS

$LbcstL_1$= Total reinforcing bar length in longer direction.

$LbcstL_1$=Lx-2*75

$QmsbL_1$=Quantity of column strip bottom reinforcement in Kg in longer direction.

$QmsbL_1$=AstmsbL*LbcstL*7850/10^9

$LbcstL_2$= Total reinforcing bar length in longer direction.

$LbcstL_2$=Ly-2*0.15*Lny

$QmsbL_2$=Quantity of column strip bottom reinforcement in Kg in longer direction.

$QmsbL_2$=AstmsbL*LbcstL*7850/10^9

In Shorter Direction

For column strip top reinforcement at support

ρsteel = Density of steel=7850 kg/m^3.

McsnegLmax= Maximum negative bending moment at support from column strip

AstcstL=Area of column strip top reinforcement in shorter direction.

$\rho=\{1-\sqrt{[1-2M/bd^2f_{cd}]}\}f_{cd}/f_{yd}$

AstcstS= ρ*LLCS* dtl

dcsbS= Diameter of reinforcing bar in shorter direction.

ScstL= Spacing of column strip top reinforcement in shorter direction.

ScstS= (pi/4)*((dcstL) ^{2}/AstcstL)*LLCS

LbcstS=Total reinforcing bar shorter in longer direction.

$LbcstS_1$=2*0.33*Lny+Cy

QcstS=Quantity of column strip top reinforcement in Kg in longer direction.

$QcstS_1$=AstcstL*LbcstL*7850/10^9

$LbcstS_2$=2*0.2*Lny+Cy

QcstS=Quantity of column strip top reinforcement in Kg in longer direction.

$QcstS_2$=AstcstL*LbcstL*7850/10^9

For column strip bottom reinforcement at mid

ρsteel = Density of steel=7850 kg/m^3.

McsposSmax= Maximum positive bending moment at mid from column strip
AstcsbS= Area of column strip bottom reinforcement in Songer direction.

$\rho=\{1-\sqrt{[1-2M/bd^2f_{cd}]}\}f_{cd}/f_{yd}$

AstcstS= ρ*LLCS* dsl

dcsbS= Diameter of reinforcing bar in shorter direction.

ScsbS=Spacing of column strip bottom reinforcement in shorter direction.

ScsbS= (pi/4)*((dcsbS)^2/AstcsbS)*LSCS

LbcstS= Total reinforcing bar in shorter direction.

LbcstS= Lx-2*0.125Lnx

QcsbS=Quantity of column strip bottom reinforcement in Kg in shorter direction.

QcsbS=AstcsbS*LbcstS*7850/109

For middle strip top reinforcement at support

ρsteel = Density of steel=7850 kg/m^3.

MmsnegSmax=Maximum negative bending moment inline of support in middle strip in shorter direction

AstmstS= Area of middle strip top reinforcement in shorter direction.

$\rho=\{1-\sqrt{[1-2M/bd^2f_{cd}]}\}f_{cd}/f_{yd}$

AstcstS= ρ*LSCS* dtl

dmstS = Diameter of reinforcing bar in shorter direction
SmstS. = Spacing of middle strip top reinforcement in shorter direction.

SmstS=(pi/4)*((dmstS)2/AstmstS)*LSMS

SbmstS= Total reinforcing bar length in shorter direction.

LbmstS=2*0.33*Lnx+Cx

QmstS=Quantity of middle strip top reinforcement in Kg in shorter direction.

$QmstS=AstmstS*LbmstS*7850/10^9$

For middle strip bottom reinforcement at mid

ρsteel = Density of steel=7850 kg/m^3.

MmsposS= Maximum positive bending moment at mid in middle strip in shorter direction

AstmsbS= Area of middle strip bottom reinforcement in shorter direction.

$\rho=\{1-\sqrt{[1-2M/bd^2f_{cd}]}\}f_{cd}/f_{yd}$

AstcstL= ρ*LSCS* dsl

dmsbS= Diameter of reinforcing bar in longer direction.

SmsbS= provided spacing of middle strip bottom reinforcement in shorter direction.

SmsbS= (pi/4)*((dmsbS)^2/AstmsbS)*LLMS

LbcstS$_1$= Total reinforcing bar length in shorter direction.

LbcstS$_1$=Lx-2*75

QmsbL$_1$=Quantity of column strip bottom reinforcement in Kg in shorter direction.

QmsbS$_1$=AstmsbS*LbcstS$_1$*7850/10^9

LbcstL$_2$= Total reinforcing bar length in shorter direction.

LbcstL$_2$=Lx-2*0.15*Lnx

QmsbS$_2$=Quantity of column strip bottom reinforcement in Kg in shorter direction.

QmsbS$_2$=AstmsbS*LbcstS*7850/10^9

- **Column Strip Top Reinforcement**

Column strip top reinforcement in longer direction

Pt=0.13% [Assume] = percentage of steel in longer direction.

ρsteel = Density of steel=7850 kg/m^3

AstdistL= Area of top side distribution reinforcement in longer direction.

AstdistL=(0.13/100)* LLCS*St

SdistL=Spacing of top side distribution reinforcement in longer direction.

SdistL=(pi/4)*((ddistL)2/AstdistL)*LLCS

LbdistL=Total top side distribution reinforcing bar length in longer direction.

LbdistL=(Ly-0.6*Ly) +Cy

QdistL=Quantity of top side distribution reinforcement in Kg in longer direction.

QdistL=AstdistL*LbdistL*7850/10^9

Column strip top reinforcement in shorter direction

Pt=0.13% [Assume] = percentage of steel in shorter direction.

ρsteel = Density of steel=7850 kg/m^3

AstdistS= Area of top side distribution reinforcement in shorter direction.

AstdistS=(0.13/100)* LSCS*St

SdistS=Spacing of top side distribution reinforcement in shorter direction.

SdistS=(pi/4)*((ddistS)2/AstdistS)*LSCS

LbdistS=Total top side distribution reinforcing bar length in shorter direction.

LbdistS=(Lx-0.6*Lx)+Cx

QdistS=Quantity of top side distribution reinforcement in Kg in shorter direction.

QdistS=AstdistS*LbdistS*7850/109

- **Calculation of Drop Panel Bottom Steel**

Drop panel bottom reinforcement in longer direction

Pt. = 0.13% [Assume] = percentage of steel in longer direction.

AstdropL= Area of bottom side drop reinforcement in longer direction.

AstdropL=(0.13/100)* Dx*X2

SdropL=Spacing of bottom side drop reinforcement in longer direction.

SdropL=(pi/4)*((ddropL)2/AstdropL)*Dx

LbdropL=Total bottom side drop reinforcing bar length in longer direction.

LbdropL=Dy+(X2-2*cover) +2*300

QdropL=Quantity of bottom side drop reinforcement in Kg in longer direction.

QdropL=AstdropL*LbdropL*7850/10^9

Drop panel bottom reinforcement in shorter direction

Pt. = 0.13% [Assume] = percentage of steel in shorter direction.

ρsteel = Density of steel=7850 kg/m3.

AstdropS= Area of bottom side drop reinforcement in shorter direction.

AstdropS=(0.13/100)* Dy*X2

SdropS=Spacing of bottom side drop reinforcement in shorter direction.

SdropS=(pi/4)*((ddropS)2/AstdropS)*Dy

LbdropS=Total bottom side drop reinforcing bar length in shorter direction.

LbdropS=Dx+(X2-2*cover) +2*300

QdropS=Quantity of bottom side drop reinforcement in Kg in shorter direction.

QdropS=AstdropS*LbdropS*7850/10^9

Design of Reinforced Concrete Column

Load Applied On Column

WT=Total load on whole surface

WT=Pd*Nx*Ny*10^{-6}

Wte=Load on each column

WT=Wte/ ((X4+1)*(X3+1))

Dead load from column

DL=Cx*Cy*hf*24*1.3*10^-9;

Design load

Nu= Wte+ DL

Total eccentricity

$$e_a = e_e + e_a + e_2$$

$$e_a = \frac{L_e}{300} \geq 20\,\text{mm}$$

e_2=Mnegmax*1000/Nu;

Design of main steel: For the regular column arrangement of reinforced concrete column uniaxial column design chart is used and the chart is programed in MATLAB programing language.

For $\frac{d'}{h}$ ==0.05 the range of υ and μ are as follows

υ = 0.2 , 0.4 ,0.6 , 0.8 , 1.0 , 1.2 , 1.4 , 1.6 , 1.8 , 2.0 , 2.2

μ =0.0, 0.1 , 0.2 , 0.3 , 0.4 , 0.5 , 0.6 , 0.7

Fot each combination in each range we can read 'w'and program it

Normal force ratio:

$$\upsilon = \frac{N_u}{f_{cd} bh}$$

Moment ratios

$$\mu = \frac{M_u}{f_{cd} b h^2}$$

Select suitable chart which satisfy $\frac{d'}{h}$ ratio:

Area of steel after reading of mechanical steel ratio

$$\text{Asc} = \frac{\omega A_c f_{cd}}{f_{yd}}$$

Asc=Area of steel in column

Pt.=0.8%= minimum percent of steel

Pt.=8%= maximum percent of steel

dcol=Diameter of column bar

dcol=2*(Cy*0.05-15) for $\frac{d'}{h}$=0.05

Nbc=Total no. of bar in column.

Nbc=Asc/((pi/4)*dcol2)

Nb=Number of bar

a_b=area of one bar

Nb=Asc/a_b

Total area in one column

Asc=Nb*(pi/4)*(dcol^2);

Ties calculation

dties=Diameter of ties=8mm

Sties=Spacing of ties minimum of the following according to EBCS

Sties1=Minimum Spacing=300mm

Sties2=12*dcol

Sties3=Cx

Calculation of Column Reinforcement

Qcolm= quantity of main steel.

$Qcolm=Asc*hf*7850/10^9$

Lties =Length of ties.

Lties=2*((Cx-30)+(Cy-30))

Nties=No. of ties in one column.

Nties=(hf/Stiesmin)

Aties=Area of ties.

$Aties=(pi/4*8^2)*Nties$

Qcolt=quantity of ties

$Qcolt=Lties*Aties*7850/10^9$

Qcol=Total quantity of steel in column.

Qcol= (Qcolm+Qcolt)

- **Constraint Equation**

Span constraint in x direction

G1= (2/X3)-1

Span constraint in y direction

G2= (2/X4)-1

Length constraint

G3=(Ly/ (2*Lx))-1

Minimum depth constraint

$$G4= (((0.4+0.6\frac{f_{yk}}{400})\frac{Ly}{24}) / X1)-1$$

Slab depth constraint

G5= (150/St)-1

Load constraint

G6=(Qk/ (1.25*Gk))-1

Moment constraint in slab

G7= (Mposmax/Mslab)-1

Moment constraint in drop

G8= (Mnegmax/Mdrop)-1

Constraint of beam type shear

G9= (Vcr/Vc)-1

Constraint of check of punching in slab

G10= (Vcdc/Vcp)-1

Constraint of check of punching in drop

G11= (Vcdd/Vcp)-1 < 1

- **Quantity Concrete**

Qcslab=Quantity of concrete in slab.

Qcslab=((X3*Lx*X4*Ly)*St/10^9)

Qcdrop= Quantity of concrete in drop/capital.

Qcdrop=((X3+1)*(X4+1)*Dx*Dy*(X2-St)/10^9)

Qccolumn= Quantity of concrete in column.

Qccolumn=(Cx*Cy*hf/10^9)

Qconcrete=Total quantity of concrete.

Qconcrete= Qcslab +Qcdrop + Qccolumn

- **Quantity of Steel**

Qsslab=Quantity of steel in slab.

Qsslab=X4*(QcstL+ QcsbL+ QmstL+ QmsbL+ QdistL) + X3*(QcstS+ QcsbS+ QmstS+ QmsbS+ QdistS)

Qsdrop= Quantity of steel in drop/capital.

Qsdrop=(X4+1)*(X3+1)*(QdropL + QdropS)

Qscolumn= Quantity of steel in column.

Qscolumn=(X4+1)*(X3+1)*Qcol

Qsteel=Total quantity of steel.

Qsteel= Qsslab + Qsdrop + Qcolumn

COSTtotal= Total cost of material

COSTtotal= Qconcrete*Ccost+ Qsteel*Scost

CHAPTER FIVE: THE DESIGN STEPS WRITTEN IN MATLAB PROGRAMING LANGUAGE

```
% Optimum Design of Reinforced Concrete of flat slab
% The user is expected to enter the variables and
% The user is expected to Check the constraints to be b/n -1 & 0
% X1= Effective depth of slab
% X2=Overall depth of drop from top of slab
% X3=No.of span required in longer direction
% X4=No.of span required in shorter direction
X1=input('Enter Effective depth of slab in mm:');
X2= input('Enter Overall depth of slab mm:');
X3= input('Enter No.of span required in longer direction in no.:');
X4=input('Enter No.of span required in shorter direction in no.:');
Nx=input('Enter total length of slab in shorter direction in mm:');
Ny= input('Enter total length of slab in longer direction in mm:');
hf=4000;
L1= Nx/X3;
L2= Ny/X4;
% Ly=length of slab in longer direction.
Ly=max(L1 ,L2);
% Lx=length of slab in shorter direction.
Lx=min(L1 ,L2);
S= input('Enter yield stress steel for required grade in Mpa :');
fck= input('Enter the caracteristic comprehensive cylinder strength of concrete in
Mpa:');
if S==400;
Scost=30.7+2.28;
else if S==500;
Scost=38.68+2.28;
end
end
if fck==20;
Ccost=3253.33+113.76;
else if fck==25;
Ccost=3365.88+113.76;
else if fck==30;
Ccost=3448.01+113.76;
end
end
end
% Clear Length of Slab
Cx=Lx/10;
Cy=Ly/10;
Lcx=Lx-Cx;
Lcy=Ly-Cy;
% Select Slab Thickness to Limit Deflection
fyk=S;
X1d=(0.4+0.6*fyk/400)*Ly/24;
if X1>=X1d;
   X1==X1;
end
cover=15;
St=X1+cover;
% finding Length of column and middle strip
LLCS =2*Lx/4;
LLMS=Ly- LLCS;
LSCS =2*[Lx/4];
LSMS=Lx- LSCS;
```

```
% Drop Panel Dimentions
Dx=Lx/3;
Dy=Ly/3;
dt=X2-X1d;
dd=X2-cover;
% Effective Depth of Slab and Drop in the short and long direction
% dbar=bar diameter to the bottom of slab and drop
dbarb=12;
dsl=St-cover-dbarb/2;
dss=St-cover-1.5*dbarb;
dtl=dt-cover-dbarb/2;
dts=dt-cover-1.5*dbarb;
% Finding Equivalent Slab Thickness
Est=((Lx  * Ly * St)+ (Dx* Dy*( X2- St) ))/(Lx  * Ly);
Est=ceil(Est);
% Loading
% Gks1=dead load from slab
Gks1= Est*24/10^3;
% Gks2=Dead load from finishing + Partition =(0.05*23)+2
Gks2=3.15;
% Gk  = Total Dead load
Gk=Gks1+Gks2;
% Qk=live load
Qk=5;
% Pd=Design load
Pd=1.3*Gk+1.6*Qk;
% Design strength of materials
fcd=0.85*fck/1.5;
fctk=0.21*fck^(2/3);
fctd=fctk/1.5;
fyd=fyk/1.15;
p=0.5/fyk;
K1=1+50*p;
K2=1.6-((dtl+dts)/(2*10^3));
% Check for Shear
% Beam Type Shear
F=Pd*Lx*Ly*10^-6;
Vmax=0.5*F;
% Average effective depth of slab and drop
Dave=(St+dt)/2;
Daved=Dave-cover-1.5*dbarb;
Vcr=((Ly*10^-3)/2-((Cy*10^-3)/2-(Daved*10^-3)))*Vmax*2/(Ly*10^-3);
% Shear force carried by concrete
Vcb=0.25*fctd*K1*K2*Lx*10^-3*Daved;
% Punching Shear
dtav=(dtl+dts)/2;
Ud=3*(Cx+dtav)*4;
dsav=(dsl+dss)/2;
Us=3*(Dx+dtav)*4;
% Punching shear stress around Column
Vdvc=((Lx*Ly*10^-6)-((Cy*10^-3)+(dtav*10^-3))^2)*Pd;
Vcdc=(Vdvc*1000)/(Ud*dtav);
% Punching shear stress around Drop
Vdvd=((Lx*Ly*10^-6)-(Dy*10^-3+3*dsav*10^-3)^2)*Pd;
Vcdd=(Vdvd*1000)/(Us*dtav);
% Punching shear stress resistance
Vcp=0.5*fctd*K1*K2;
% Design for Flexure
% Effective Span calculation
```

```
hcy=sqrt(4*Cy^2/pi);
hcx=sqrt(4*Cx^2/pi);
% Lny=Effective span in the longer direction.
Lny=(Ly-2*hcy/3)*10^-3;
% Lny=Effective span in the shorer direction.
Lnx=(Lx-2*hcx/3)*10^-3;
% Disribution of moment
%for longer span
% Bending moment for exterior panel
ML1=0.063*F*Lny;
ML2=0.083*F*Lny;
ML3=0.040*F*Lny;
%Bending moment for exterior panel-column strip:
MLc1 =0.75 *ML1;
MLc2 =0.55* ML2;
MLc3 =0.75 *ML3;
%Bending moment for exterior panel-middle strip:
MLm1 =0.25 *ML1;
MLm2 =0.45 *ML2;
MLm3 =0.25 *ML1;
%Bending moment for interior panel
ML4=0.055*F*Lny;
ML5=0.071*F*Lny;
%Bending moment for interior panel-column strip
MLc4 =0.75* ML4;
MLc5 =0.55 *ML5;
MLc6 =0.75 *ML4;
%Bending moment for interior panel-middle strip
MLm4 =0.25* ML4;
MLm5 =0.45* ML5;
MLm6 =0.25 *ML4;
%for shorter span
% Bending moment for exterior panel
MS1=0.063*F*Lnx;
MS2=0.083*F*Lnx;
MS3=0.040*F*Lnx;
%Bending moment for exterior panel-column strip:
MSc1 =0.75 *MS1;
MSc2 =0.55* MS2;
MSc3 =0.75 *MS3;
%Bending moment for exterior panel-middle strip:
MSm1 =0.25 *MS1;
MSm2 =0.45 *MS2;
MSm3 =0.25 *MS1;
%Bending moment for interior panel
MS4=0.055*F*Lnx;
MS5=0.071*F*Lnx;
%Bending moment for interior panel-column strip
MSc4 =0.75* MS4;
MSc5 =0.55 *MS5;
MSc6 =0.75 *MS4;
%Bending moment for interior panel-middle strip
MSm4 =0.25* MS4;
MSm5 =0.45* MS5;
MSm6 =0.25 *MS4;
%check for maximum bending moment
Mneg=[ MLc1, MLc3, MLm1, MLm3, MLc4, MLc6, MLm4, MLm6, MSc1, MSc3, MSm1, MSm3,
MSc4, MSc6, MSm4, MSm6];
Mnegmax=max(Mneg);
```

```
Mpos=[ MLc2, MLm2, MLc5, MLm5, MSc2, MSm2, MSc5, MSm5];
Mposmax=max(Mpos);
%finding effective depth of slab
if (fyk==400)
Xumax=0.64*X1;
else if (fyk==460)
Xumax=0.60*X1;
else if (fyk==500)
Xumax=0.58*X1;
end
end
end
Mslab=0.45*fck* LSMS*Xumax*(X1-0.4*Xumax)*10^-6;
%finding effective depth of drop
if (fyk==400)
Xumax=0.64*dd;
else if (fyk==460)
Xumax=0.60*dd;
else if (fyk==500)
Xumax=0.58*dd;
end
end
end
Mdrop=0.45*fck*LSCS*Xumax*(dd-0.40*Xumax)*10^-6;
%Calculation of reinforcement
%In longer  direction
% 1 For column strip top reinforcement at support
%McsnegL= Maximum negative bending moment at support from column strip
McsnegL=[ MLc1, MLc3, MLc4, MLc6];
McsnegLmax=max(McsnegL);
p1=(1-sqrt(1-((2*McsnegLmax*10^6)/(fcd*LLCS*dtl^2))))*fcd/fyd;
if p1>=0.5/fyk;
p1=p1;
else if p1<=0.5/fyk;
p1=0.5/fyk;
end
end
AstcstL= p1*LLCS*dtl;
dcstL=32;
ScstL=(pi/4)*(( dcstL ^2)/AstcstL)*LLCS;
if ((ScstL>100)&&(ScstL<=300))
ScstL=ceil(ScstL-1);
else if ((ScstL<100)||(ScstL>300))
dcstL =25;
ScstL=(pi/4)*(( dcstL ^2)/AstcstL)*LLCS;
else if ((ScstL>100)&&(ScstL<=300))
ScstL=ceil(ScstL-1);
else if ((ScstL<100)||(ScstL>300))
dcstL =20;
ScstL=(pi/4)*((dcstL^2)/AstcstL)*LLCS;
else if ((ScstL>100)&&(ScstL<=300))
ScstL=ceil(ScstL-1);
else if ((ScstL<100)||(ScstL>300))
dcstL=16;
ScstL=(pi/4)*((dcstL^2)/AstcstL)*LLCS;
else if ((ScstL>100)&&(ScstL<=300))
ScstL=ceil(ScstL-1);
else if ((ScstL<100)||(ScstL>300))
dcstL=12
```

```
ScstL=(pi/4)*((dcstL^2)/AstcstL)*LLCS
else if ((ScstL>100)&&(ScstL<=300))
ScstL=ceil(ScstL-1)
else if ((ScstL<100)||(ScstL>300))
dcstL=8;
ScstL=(pi/4)*((dcstL^2)/AstcstL)*LLCS;
else if ((ScstL>100)&&(ScstL<=300))
ScstL=ceil(ScstL-1);
end
end
end
end
end
end
end
end
end
end
end
LbcstL1=2*0.33*Lny+Cy;
LbcstL2=2*0.2*Lny+Cy;
LbcstL=LbcstL1+LbcstL2;
QcstL=AstcstL*(LbcstL1+LbcstL2)*7850/10^9;
QcstL=ceil(QcstL);
%Calculation of reinforcement
%In longer  direction
% 2 For column strip bottom reinforcement at mid
%McsposL= Maximum positive bending moment at mid from column strip
McsposL=[ MLc2, MLc5];
McsposLmax=max(McsposL);
p2=(1-sqrt(1-((2*McsposLmax*10^6)/(fcd*LLCS*dsl^2))))*fcd/fyd;
if p2>=0.5/fyk;
p2=p2;
else if p2<=0.5/fyk;
p2=0.5/fyk;
end
end
AstcsbL= p2*LLCS*dsl;
dcsbL=32;
ScsbL=(pi/4)*(( dcsbL ^2)/AstcsbL)*LLCS;
if (ScsbL>100)&&(ScsbL<=300)
ScsbL=ceil(ScsbL-1);
else if (ScsbL<100)||(ScsbL>300)
dcsbL =25;
ScsbL=(pi/4)*(( dcsbL ^2)/AstcsbL)*LLCS;
if (ScsbL>100)&&(ScsbL<=300);
ScsbL=ceil(ScsbL-1);
else if (ScsbL<100)||(ScsbL>300)
dcsbL =20;
ScsbL=(pi/4)*((dcsbL^2)/AstcsbL)*LLCS;
if (ScsbL>100)&&(ScsbL<=300)
ScsbL=ceil(ScsbL-1);
else if (ScsbL<100)||(ScsbL>300)
dcsbL=16;
ScsbL=(pi/4)*((dcsbL^2)/AstcsbL)*LLCS;
if (ScsbL>100)&&(ScsbL<=300)
ScsbL=ceil(ScsbL-1);
else if (ScsbL<100)||(ScsbL>300)
dcsbL=12;
```

```
ScsbL=(pi/4)*((dcsbL^2)/AstcsbL)*LLCS;
if (ScsbL>100)&&(ScsbL<=300);
ScsbL=ceil(ScsbL-1);
else if (ScsbL<100)||(ScsbL>300)
dcsbL=8;
ScsbL=(pi/4)*((dcsbL^2)/AstcsbL)*LLCS;
if (ScsbL>100)&&(ScsbL<=300)
ScsbL=ceil(ScsbL-1);
end
end
end
end
end
end
end
end
end
end
end
end
LbcstL=Ly-2*0.125*Lny;
QcsbL=AstcsbL*LbcstL*7850/10^9;
QcsbL=ceil(QcsbL);
%Calculation of reinforcement
%In longer  direction
% 3 For middle strip top reinforcement at support
%MmsnegL= Maximum negative bending moment at support from column strip
MmsnegL=[ MLm1, MLm3, MLm4, MLm6];
MmsnegLmax=max(MmsnegL);
p3=(1-sqrt(1-((2*MmsnegLmax*10^6)/(fcd*LLCS*dsl^2))))*fcd/fyd;
if p3>=0.5/fyk;
p3=p3;
else if p3<=0.5/fyk;
p3=0.5/fyk;
end
end
AstmstL= p3*LLCS*dts;
dmstL=32;
SmstL=(pi/4)*(( dmstL ^2)/AstmstL)*LLMS;
if (SmstL>100)&&(SmstL<=300)
SmstL=ceil(SmstL-1);
else if (SmstL<100)||(SmstL>300)
dmstL =25;
SmstL=(pi/4)*(( dmstL ^2)/AstmstL)*LLMS;
if (SmstL>100)&&(SmstL<=300);
SmstL=ceil(SmstL-1);
else if (SmstL<100)||(SmstL>300)
dmstL =20;
SmstL=(pi/4)*((dmstL^2)/AstmstL)*LLMS;
if (SmstL>100)&&(SmstL<=300)
SmstL=ceil(SmstL-1);
else if (SmstL<100)||(SmstL>300)
dmstL=16;
SmstL=(pi/4)*((dmstL^2)/AstmstL)*LLMS;
if (SmstL>100)&&(SmstL<=300)
SmstL=ceil(SmstL-1);
else if (SmstL<100)||(SmstL>300)
dmstL=12;
SmstL=(pi/4)*((dmstL^2)/AstmstL)*LLMS;
if (SmstL>100)&&(SmstL<=300)
```

```
SmstL=ceil(SmstL-1);
else if (SmstL<100)||(SmstL>300)
dmstL=8;
SmstL=(pi/4)*((dmstL^2)/AstmstL)*LLMS;
if (SmstL>100)&&(SmstL<=300)
SmstL=ceil(SmstL-1);
end
end
end
end
end
end
end
end
end
end
end
LbmstL=0.22*2*Lx+Cx;
QmstL=AstmstL*LbmstL*7850/10^9;
QmstL=ceil(QmstL);
%Calculation of reinforcement
%In longer  direction
% 4 For middle strip bottom reinforcement at mid
%MmsposL= Maximum positive bending moment at mid from column strip
MmsposL=[ MLm2, MLm5];
MmsposLmax=max(MmsposL);
p4=(1-sqrt(1-((2*MmsposLmax*10^6)/(fcd*LLMS*dsl^2))))*fcd/fyd;
if p4>=0.5/fyk;
p4=p4;
else if p4<=0.5/fyk;
p4=0.5/fyk;
end
end
AstmsbL= p4*LLMS*dsl;
dmsbL=32;
SmsbL=(pi/4)*(( dmsbL ^2)/AstmsbL)*LLMS;
if (SmsbL>100)&&(SmsbL<=300)
SmsbL=ceil(SmsbL-1);
else if (SmsbL<100)||(SmsbL>300)
dmsbL =25;
SmsbL=(pi/4)*(( dmsbL ^2)/AstmsbL)*LLMS;
if (SmsbL>100)&&(SmsbL<=300);
SmsbL=ceil(SmsbL-1);
else if (SmsbL<100)||(SmsbL>300)
dmsbL =20;
SmsbL=(pi/4)*((dmsbL^2)/AstmsbL)*LLMS;
if (SmsbL>100)&&(SmsbL<=300)
SmsbL=ceil(SmsbL-1);
else if (SmsbL<100)||(SmsbL>300)
dmsbL=16;
SmsbL=(pi/4)*((dmsbL^2)/AstmsbL)*LLMS;
if (SmsbL>100)&&(SmsbL<=300)
SmsbL=ceil(SmsbL-1);
else if (SmsbL<100)||(SmsbL>300)
dmsbL=12;
SmsbL=(pi/4)*((dmsbL^2)/AstmsbL)*LLMS;
if (SmsbL>100)&&(SmsbL<=300)
SmsbL=ceil(SmsbL-1);
else if (SmsbL<100)||(SmsbL>300)
```

```
dmsbL=8;
SmsbL=(pi/4)*((dmsbL^2)/AstmsbL)*LLMS;
if (SmsbL>100)&&(SmsbL<=300)
SmsbL=ceil(SmsbL-1);
end
end
end
end
end
end
end
end
end
end
end
LbcstL1=Ly-2*75;
LbcstL2=Ly-2*0.15*Lny;
LbcstL=LbcstL1+LbcstL2;
QmsbL=AstmsbL*(LbcstL1+LbcstL2)*7850/10^9;
QmsbL=ceil(QmsbL);
%Calculation of reinforcement
%In shorter  direction
% 1 For column strip top reinforcement at support
%McsnegS= Maximum negative bending moment at support from column strip
McsnegS=[ MSc1, MSc3, MSc4, MSc6];
McsnegSmax=max(McsnegS);
p5=(1-sqrt(1-((2*McsnegLmax*10^6)/(fcd*LLCS*dtl^2))))*fcd/fyd;
if p5>=0.5/fyk;
p5=p5;
else if p5<=0.5/fyk;
p5=0.5/fyk;
end
end
AstcstS= p5*LSCS*dtl;
dcstS=32;
ScstS=(pi/4)*(( dcstS ^2)/AstcstS)*LSCS;
if (ScstS>100)&&(ScstS<=300)
ScstS=ceil(ScstS-1);
else if (ScstS<100)||(ScstS>300)
dcstS =25;
ScstS=(pi/4)*(( dcstS ^2)/AstcstS)*LSCS;
else if (ScstS>100)&&(ScstS<=300);
ScstS=ceil(ScstS-1);
else if (ScstS<100)||(ScstS>300)
dcstS =20;
ScstS=(pi/4)*((dcstS^2)/AstcstS)*LSCS;
else if (ScstS>100)&&(ScstS<=300)
ScstS=ceil(ScstS-1);
else if (ScstS<100)||(ScstS>300)
dcstS=16;
ScstS=(pi/4)*((dcstS^2)/AstcstS)*LSCS;
else if (ScstS>100)&&(ScstS<=300)
ScstS=ceil(ScstS-1);
else if (ScstS<100)||(ScstS>300)
dcstS=12;
ScstS=(pi/4)*((dcstS^2)/AstcstS)*LSCS;
else if (ScstS>100)&&(ScstS<=300)
ScstS=ceil(ScstS-1);
else if (ScstS<100)||(ScstS>300)
```

```
dcstS=8;
ScstS=(pi/4)*((dcstS^2)/AstcstS)*LSCS;
else if (ScstS>100)&&(ScstS<=300)
ScstS=ceil(ScstS-1);
end
end
end
end
end
end
end
end
end
end
end
LbcstS1=2*0.33*Lnx+Cx;
LbcstS2=2*0.2*Lnx+Cx;
LbcstS=LbcstS1+LbcstS2;
QcstS=AstcstS*(LbcstS1+LbcstS2)*7850/10^9;
QcstS=ceil(QcstS);
%Calculation of reinforcement
%In shorter  direction
% 2 For column strip bottom reinforcement at mid
%McsposS= Maximum positive bending moment at mid from column strip
McsposS=[ MSc2, MSc5];
McsposSmax=max(McsposS);
p6=(1-sqrt(1-((2*McsposLmax*10^6)/(fcd*LSCS*dsl^2))))*fcd/fyd;
if p6>=0.5/fyk;
p6=p6;
else if p6<=0.5/fyk;
p6=0.5/fyk;
end
end
AstcsbS= p6*LSCS*dsl;
dcsbS=32;
ScsbS=(pi/4)*(( dcsbS ^2)/AstcsbS)*LSCS;
if (ScsbS>100)&&(ScsbS<=300)
ScsbS=ceil(ScsbS-1);
else if (ScsbS<100)||(ScsbS>300)
dcsbS =25;
ScsbS=(pi/4)*(( dcsbS ^2)/AstcsbS)*LSCS;
if (ScsbS>100)&&(ScsbS<=300);
ScsbS=ceil(ScsbS-1);
else if (ScsbS<100)||(ScsbS>300)
dcsbS =20;
ScsbS=(pi/4)*((dcsbS^2)/AstcsbS)*LSCS;
if (ScsbS>100)&&(ScsbS<=300)
ScsbS=ceil(ScsbS-1);
else if (ScsbS<100)||(ScsbS>300)
dcsbS=16;
ScsbS=(pi/4)*((dcsbS^2)/AstcsbS)*LSCS;
if (ScsbS>100)&&(ScsbS<=300)
ScsbS=ceil(ScsbS-1);
else if (ScsbS<100)||(ScsbS>300)
dcsbS=12;
ScsbS=(pi/4)*((dcsbS^2)/AstcsbS)*LSCS;
if (ScsbS>100)&&(ScsbS<=300)
ScsbS=ceil(ScsbS-1);
else if (ScsbS<100)||(ScsbS>300)
```

```
dcsbS=8;
ScsbS=(pi/4)*((dcsbS^2)/AstcsbS)*LSCS;
if (ScsbS>100)&&(ScsbS<=300)
ScsbS=ceil(ScsbS-1);
end
end
end
end
end
end
end
end
end
end
end
LbcstS=(2/3)*Lx+600;
QcsbS=AstcsbS*LbcstS*7850/10^9;
QcsbS=ceil(QcsbS);
%Calculation of reinforcement
%In shorter  direction
% 3 For middle strip top reinforcement at support
%MmsnegS= Maximum negative bending moment at support from column strip
MmsnegS=[ MSm1, MSm3, MSm4, MSm6];
MmsnegSmax=max(MmsnegS);
p7=(1-sqrt(1-((2*MmsnegSmax*10^6)/(fcd*LSMS*dsl^2))))*fcd/fyd;
if p7>=0.5/fyk;
p7=p7;
else if p7<=0.5/fyk;
p7=0.5/fyk;
end
end
AstmstS= p7*LSCS*dtl;
dmstS=32;
SmstS=(pi/4)*(( dmstS ^2)/AstmstS)*LSMS;
if (SmstS>100)&&(SmstS<=300)
SmstS=ceil(SmstS-1);
else if (SmstS<100)||(SmstS>300)
dmstS =25;
SmstS=(pi/4)*(( dmstS ^2)/AstmstS)*LSMS;
if (SmstS>100)&&(SmstS<=300);
SmstS=ceil(SmstS-1);
else if (SmstS<100)||(SmstS>300)
dmstS =20;
SmstS=(pi/4)*((dmstS^2)/AstmstS)*LSMS;
if (SmstS>100)&&(SmstS<=300)
SmstS=ceil(SmstS-1);
else if (SmstS<100)||(SmstS>300)
dmstS=16;
SmstS=(pi/4)*((dmstS^2)/AstmstS)*LSMS;
if (SmstS>100)&&(SmstS<=300)
SmstS=ceil(SmstS-1);
else if (SmstS<100)||(SmstS>300)
dmstS=12;
SmstS=(pi/4)*((dmstS^2)/AstmstS)*LSMS;
if (SmstS>100)&&(SmstS<=300)
SmstS=ceil(SmstS-1);
else if (SmstS<100)||(SmstS>300)
dmstS=8;
SmstS=(pi/4)*((dmstS^2)/AstmstS)*LSMS;
```

```
if (SmstS>100)&&(SmstS<=300)
SmstS=ceil(SmstS-1);
end
end
end
end
end
end
end
end
end
end
end
LbmstS=0.22*2*Lx+Cx;
QmstS=AstmstS*LbmstS*7850/10^9;
QmstS=ceil(QmstS);
% Calculation of reinforcement
% In Shorter direction
% 4 For middle strip bottom reinforcement at mid
% MmsposS= Maximum positive bending moment at mid from column strip
MmsposS=[ MSm2, MSm5];
MmsposSmax=max(MmsposS);
p8=(1-sqrt(1-((2*MmsposSmax*10^6)/(fcd*LSMS*dsl^2))))*fcd/fyd;
if p8>=0.5/fyk;
p8=p8;
else if p8<=0.5/fyk;
p8=0.5/fyk;
end
end
AstmsbS= p8*LSMS*dsl;
dmsbS=32;
SmsbS=(pi/4)*(( dmsbS ^2)/AstmsbS)*LSMS;
if (SmsbS>100)&&(SmsbS<=300)
SmsbS=ceil(SmsbS-1);
else if (SmsbS<100)||(SmsbS>300)
dmsbS =25;
SmsbS=(pi/4)*(( dmsbS ^2)/AstmsbS)*LSMS;
if (SmsbS>100)&&(SmsbS<=300);
SmsbS=ceil(SmsbS-1);
else if (SmsbS<100)||(SmsbS>300)
dmsbS =20;
SmsbS=(pi/4)*((dmsbS^2)/AstmsbS)*LSMS;
if (SmsbS>100)&&(SmsbS<=300)
SmsbS=ceil(SmsbS-1);
else if (SmsbS<100)||(SmsbS>300)
dmsbS=16;
SmsbS=(pi/4)*((dmsbS^2)/AstmsbS)*LSMS;
if (SmsbS>100)&&(SmsbS<=300)
SmsbS=ceil(SmsbS-1);
else if (SmsbS<100)||(SmsbS>300)
dmsbS=12;
SmsbS=(pi/4)*((dmsbS^2)/AstmsbS)*LSMS;
if (SmsbS>100)&&(SmsbS<=300)
SmsbS=ceil(SmsbS-1);
else if (SmsbS<100)||(SmsbS>300)
dmsbS=8;
SmsbS=(pi/4)*((dmsbS^2)/AstmsbS)*LSMS;
if (SmsbS>100)&&(SmsbS<=300)
SmsbS=ceil(SmsbS-1);
```

```
end
end
end
end
end
end
end
end
end
end
end
LbcstS1=Lx-2*75;
LbcstS2=Lx-2*0.15*Lnx;
LbcstS=LbcstS1+LbcstS2;
QmsbS=AstmsbS*(LbcstS1+LbcstS2)*7850/10^9;
QmsbS=ceil(QmsbS);
% CS top reinforcement in longer direction
% Pt= [Assume] 0.13%
AstdistL=(0.13/100)* LLCS*St;
ddistL=8;
SdistL=(pi/4)*(( ddistL ^2)/AstdistL)*LLCS;
if (SdistL>100)&&(SdistL<=300)
SdistL=ceil(SdistL-1);
else if (SdistL<100)||(SdistL>300)
ddistL =12;
SdistL=(pi/4)*(( ddistL ^2)/AstdistL)*LLCS;
if (SdistL>100)&&(SdistL<=300);
SdistL=ceil(SdistL-1);
else if (SdistL<100)||(SdistL>300)
ddistL =16;
SdistL=(pi/4)*((ddistL^2)/AstdistL)*LLCS;
if (SdistL>100)&&(SdistL<=300)
SdistL=ceil(SdistL-1);
else if (SdistL<100)||(SdistL>300)
ddistL=20;
SdistL=(pi/4)*((ddistL^2)/AstdistL)*LLCS;
if (SdistL>100)&&(SdistL<=300)
SdistL=ceil(SdistL-1);
else if (SdistL<100)||(SdistL>300)
ddistL=25;
SdistL=(pi/4)*((ddistL^2)/AstdistL)*LLCS;
if (SdistL>100)&&(SdistL<=300)
SdistL=ceil(SdistL-1);
else if (SdistL<100)||(SdistL>300)
ddistL=32;
SdistL=(pi/4)*((ddistL^2)/AstdistL)*LLCS;
if (SdistL>100)&&(SdistL<=300)
SdistL=ceil(SdistL-1);
end
end
end
end
end
end
end
end
end
end
end
```

```
LbdistL=(Ly-0.6*Ly)+Cy;
QdistL=AstdistL*LbdistL*7850/10^9;
QdistL=ceil(QdistL);
% CS top reinforcement in shorter direction
% Pt= [Assume] 0.13%
AstdistS=(0.13/100)* LSCS*St;
ddistS=8;
SdistS=(pi/4)*(( ddistS ^2)/AstdistS)*LSCS;
if (SdistS>100)&&(SdistS<=300)
SdistS=ceil(SdistS-1);
else if (SdistS<100)||(SdistS>300)
ddistS =12;
SdistS=(pi/4)*(( ddistS ^2)/AstdistS)*LSCS;
if (SdistS>100)&&(SdistS<=300);
SdistS=ceil(SdistS-1);
else if (SdistS<100)||(SdistS>300)
ddistS =16;
SdistS=(pi/4)*((ddistS^2)/AstdistS)*LSCS;
if (SdistS>100)&&(SdistS<=300)
SdistS=ceil(SdistS-1);
else if (SdistS<100)||(SdistS>300)
ddistS=20;
SdistS=(pi/4)*((ddistS^2)/AstdistS)*LSCS;
if (SdistS>100)&&(SdistS<=300)
SdistS=ceil(SdistS-1);
else if (SdistS<100)||(SdistS>300)
ddistS=25;
SdistS=(pi/4)*((ddistS^2)/AstdistS)*LSCS;
if (SdistS>100)&&(SdistS<=300)
SdistS=ceil(SdistS-1);
else if (SdistS<100)||(SdistS>300)
ddistS=32;
SdistS=(pi/4)*((ddistS^2)/AstdistS)*LSCS;
if (SdistS>100)&&(SdistS<=300)
SdistS=ceil(SdistS-1);
end
end
end
end
end
end
end
end
end
end
end
LbdistS=(Lx-0.6*Lx)+Cx;
QdistS=AstdistS*LbdistS*7850/10^9;
QdistS=ceil(QdistS);
% Reinforcement for drop panel bottom steel longer direction
% Pt= [Assume] 0.13%
AstdropL=(0.13/100)* Dx*X2;
ddropL=8;
SdropL=(pi/4)*(( ddropL ^2)/AstdropL)*Dx;
if (SdropL>100)&&(SdropL<=300)
SdropL=ceil(SdropL-1);
else if (SdropL<100)||(SdropL>300)
ddropL =12;
SdropL=(pi/4)*(( ddropL ^2)/AstdropL)*Dx;
```

```
if (SdropL>100)&&(SdropL<=300);
SdropL=ceil(SdropL-1);
else if (SdropL<100)||(SdropL>300)
ddropL =16;
SdropL=(pi/4)*((ddropL^2)/AstdropL)*Dx;
if (SdropL>100)&&(SdropL<=300)
SdropL=ceil(SdropL-1);
else if (SdropL<100)||(SdropL>300)
ddropL=20;
SdropL=(pi/4)*((ddropL^2)/AstdropL)*Dx;
if (SdropL>100)&&(SdropL<=300)
SdropL=ceil(SdropL-1);
else if (SdropL<100)||(SdropL>300)
ddropL=25;
SdropL=(pi/4)*((ddropL^2)/AstdropL)*Dx;
if (SdropL>100)&&(SdropL<=300)
SdropL=ceil(SdropL-1);
else if (SdropL<100)||(SdropL>300)
ddropL=32;
SdropL=(pi/4)*((ddropL^2)/AstdropL)*Dx;
if (SdropL>100)&&(SdropL<=300)
SdropL=ceil(SdropL-1);
end
end
end
end
end
end
end
end
end
end
end
LbdropL=Dy+(X2-2*cover)+2*300;
QdropL=AstdropL*LbdropL*7850/10^9;
QdropL=ceil(QdropL);
% Reinforcement for drop panel bottom steel shorter direction
% Pt= [Assume] 0.13%
AstdropS=(0.13/100)* Dy*X2;
ddropS=8;
SdropS=(pi/4)*(( ddropS ^2)/AstdropS)*Dy;
if (SdropS>100)&&(SdropS<=300)
SdropS=ceil(SdropS-1);
else if (SdropS<100)||(SdropS>300)
ddropS =12;
SdropS=(pi/4)*(( ddropS ^2)/AstdropS)*Dy;
if (SdropS>100)&&(SdropS<=300);
SdropS=ceil(SdropS-1);
else if (SdropS<100)||(SdropS>300)
ddropS =16;
SdropS=(pi/4)*((ddropS^2)/AstdropS)*Dy;
if (SdropS>100)&&(SdropS<=300)
SdropS=ceil(SdropS-1);
else if (SdropS<100)||(SdropS>300)
ddropS=20;
SdropS=(pi/4)*((ddropS^2)/AstdropS)*Dy;
if (SdropS>100)&&(SdropS<=300)
SdropS=ceil(SdropS-1);
else if (SdropS<100)||(SdropS>300)
```

```
ddropS=25;
SdropS=(pi/4)*((ddropS^2)/AstdropS)*Dy;
if (SdropS>100)&&(SdropS<=300)
SdropS=ceil(SdropS-1);
else if (SdropS<100)||(SdropS>300)
ddropS=32;
SdropS=(pi/4)*((ddropS^2)/AstdropS)*Dy;
if (SdropS>100)&&(SdropS<=300)
SdropS=ceil(SdropS-1);
end
end
end
end
end
end
end
end
end
end
end
LbdropS=Dx+(X2-2*cover)+2*300;
QdropS=AstdropS*LbdropS*7850/10^9;
QdropS=ceil(QdropS);
%  Load applied on column
% WT=Total load on whole surface
% Ncy=no of column in y direction.
% Ncx=no of column in x direction.
%Wte=Load on each column
WT=Pd*Nx*Ny*10^-6;
Ncy=X4+1;
Ncx=X3+1;
Wte=WT/((X4+1)*(X3+1));
% design of column
% Assume column dimention
% Dead load from column
DL=Cx*Cy*hf*24*1.3*10^-9;
Nu=Wte+DL;
% Total eccentricity
e1=max((hf/300),20);
e1=20;
e2=Mnegmax*1000/Nu;
if(hf/Cy)<(12);
e3=0;
end
e=e1+e2+e3;
Mu=Nu*e*10^-3;
% Calculation of normal force ratio
% Calculation of moment ratio
v=(Nu*10^3)/(fcd*Cx*Cy);
u=(Mu*10^6)/(fcd*Cx*Cy^2);
% Mechanical steel reinforcement ratio
 if (0.2>=v>=0) && (0.1<=v<=0.2);
w=0.3;
else if (0.2>=v>=0) && (0.2<=v<=0.3);
w=0.5;
else if (0.2>=v>=0) && (0.3<=v<=0.4);
w=0.7;
else if (0.2>=v>=0) && (0.4<=v<=0.5);
w=0.9;
```

```
else (0.2>=v>=0) && (0.5<=v<=0.6);
w=1.1;
    end
    end
    end
    end
if (0.4>=v>=0.2) && (0.1<=v<=0.2);
w=0.27;
else if (0.4>=v>=0.2)&& (0.2<=v<=0.3);
w=0.37;
else if (0.4>=v>=0.2)&&(0.3<=v<=0.4);
w=0.65;
else if (0.4>=v>=0.2)&&(0.4<=v<=0.5);
w=0.85;
else (0.4>=v>=0.2)&& (0.5<=v<=0.6);
w=1.08;
    end
    end
    end
    end
if (0.6>=v>=0.4)&& (0.1<=v<=0.2);
w=0.18;
else if (0.6>=v>=0.4)&& (0.2<=v<=0.3);
w=0.47;
else if (0.6>=v>=0.4)&& (0.3<=v<=0.4);
w=0.68;
else if (0.6>=v>=0.4)&&(0.4<=v<=0.5);
w=0.87;
else (0.6>=v>=0.4)&& (0.5<=v<=0.6);
w=1.1;
    end
    end
    end
end
if (0.7>=v>=0.6)&&(0.1<=v<=0.2);
w=0.33;
else if (0.8>=v>=0.6)&& (0.2<=v<=0.3);
w=0.57;
else if (0.8>=v>=0.6)&& (0.3<=v<=0.4);
w=0.78;
else if (0.8>=v>=0.6)&& (0.4<=v<=0.5);
w=0.95;
else   (0.8>=v>=0.6)&& (0.5<=v<=0.6);
w=1.05;
    end
    end
    end
end
if (1>=v>=0.8)&&(0.1<=v<=0.2);
w=0.42;
else if (1>=v>=0.8)&& (0.2<=v<=0.3);
w=0.75;
else if (1>=v>=0.8)&& (0.3<=v<=0.4);
w=0.95;
else  (1>=v>=0.8)&& (0.4<=v<=0.5);
 w=1.05;
    end
    end
end
```

```
if (1.2>=v>=1)&&(0.1<=v<=0.2);
   w=0.72;
else if (1.2>=v>=1)&& (0.2<=v<=0.3);
   w=0.92;
else  (1.2>=v>=1)&& (0.3<=v<=0.4);
   w=1;
    end
end
if (1.4>=v>=1.2)&&(0<=v<=0.1);
  w=0.52;
else if (1.4>=v>=1.2)&&(0.1<=v<=0.2);
  w=0.92;
else  (1.4>=v>=1.2)&&(0.2<=v<=0.3);
  w=1.1;
    end
    end
 if (1.6>=v>=1.4)&&(0<=v<=0.1);
  w=1;
else  (1.6>=v>=1.4)&&(0.1<=v<=0.2);
  w=1.1;
    end
 if (1.8>=v>=1.6)&&(0<=v<=0.1);
   w=0.85;
else (1.8>=v>=1.6)&&(0.1<=v<=0.2);
   w=0.85;
    end
 if (2>=v>=1.8)&&(0<=v<=0.1);
    w=1.1;
 end
 % reinforcement ratio
 % area reinforcement
Pw=w*fcd/fyd;
if 0.08>=Pw>=0.008;
 Pw=Pw;
else if Pw <=0.008
   Pw=0.008;
 else Pw>=0.08;
    Pw=0.08;
    end
end
Asc=Pw*Cy*Cx;
dcol=2*(Cy*0.05-15);
ceil(dcol);
ab=(pi/4)*(dcol^2);
Nb=Asc/ab;
ceil(Nb);
Asc=Nb*(pi/4)*(dcol^2);
%ties calculation
dties=8;
Sties1=300;
Sties2=12*dcol;
Sties3=Cx;
Sties= [Sties1, Sties2, Sties3];
Stiesmin=min(Sties);
%calculatin of column reinforcement
% Qcolm= quantity of main steel
Qcolm=Asc*hf*7850/10^9;
Lties=2*((Cx-30)+(Cy-30));
Nties=ceil(hf/Stiesmin);
```

```
Aties=(pi/4*8^2)*Nties;
%Qcolt=quantity of ties
Qcolt=Lties*Aties*7850/10^9;
Qcol=ceil(Qcolm+Qcolt);
% Constraint equation
% No of span constraint in x direction
G1=(2/X3)-1
% No of span constraint in y direction
G2=(2/X4)-1
% Length constraint
G3=(Ly/(2*Lx))-1
% Minimum depth contraint
G4=(((0.4+0.6*fyk/400)*Ly/24)/X1)-1
% Depth constraint
G5=(150/St)-1
% Load constraint
G6=Qk/(1.25*Gk)-1
% moment constraint in slab
G7=(Mposmax/Mslab)-1
% moment constraint in drop
G8=(Mnegmax/Mdrop)-1
% constraint of beam type shear
G9=(Vcr/Vcb)-1
% constraint of Check of punching in slab
G10=(Vcdc/Vcp)-1
% Constraint of check of punching in drop
G11= (Vcdd/Vcp)-1
%Quantity of material
%Concrete
Qcslab=ceil((X3*Lx*X4*Ly)*St/10^9);
Qcdrop=ceil((X3+1)*(X4+1)*Dx*Dy*(X2-St)/10^9);
Qccolumn=ceil(Cx*Cy*hf/10^9);
Qconcrete= Qcslab  +Qcdrop + Qccolumn;
%Steel
Qsslab=X4*(QcstL+ QcsbL+ QmstL+ QmsbL+ QdistL)+ X3*(QcstS+ QcsbS+ QmstS+ QmsbS+
QdistS);
Qsdrop=(X4+1)*(X3+1)*( QdropL + QdropS);
Qcolumn=(X4+1)*(X3+1)*Qcol;
Qsteel= Qsslab + Qsdrop + Qcolumn;
% Total cost of material
COSTtotal= Qconcrete*Ccost+ Qsteel*Scost;
fprintf('X1= %g mm.\n',X1)
fprintf('X2= %g mm.\n',X2)
fprintf('X3= %g no.\n',X3)
fprintf('X4= %g no.\n',X4)
fprintf('COSTtotal= %g Birr.\n',COSTtotal)
```

CHAPTER SIX: ACTIVE CONSTRAINTS AT MINIMUM

1.Active Constraints at Minimum

Span	=	20mx20m
Grade of Concrete	=	20
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	3

Table 6.1 Constraints Value at (20x20, 20, 400, 3)

Design variables	SP1	OP1	SP2	OP2	SP3	OP3
X1	280	210	300	210	350	210
X2	430	320	450	320	500	320
X3	3	4	3	4	3	4
X4	3	4	3	4	3	4
COST(Birr)	**792820**	**599718**	814645	**599718**	8.78E+05	**599718**
Constraints Value						
G1	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G2	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0079**	-0.0741	**-0.0079**	-0.2063	**-0.0079**
G5	-0.4915	-0.3333	-0.5238	-0.3333	-0.589	-0.3333
G6	-0.6223	-0.5462	-0.6387	-0.5462	-0.674	-0.5462
G7	-0.7569	-0.7827	-0.7821	-0.7827	-0.8288	-0.7827
G8	-0.8855	-0.8934	-0.8928	-0.8934	-0.9077	-0.8934
G9	-0.0983	-0.174	-0.1437	-0.174	-0.2215	-0.174
G10	**-0.0082**	-0.0273	-0.1308	-0.0273	-0.3266	-0.0273
G11	-0.7306	-0.7381	-0.7623	-0.7381	-0.8134	-0.7381

Minimum cost flat slab **599718** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 792820
Optimum design= 599718
Cost saving over the normal design= **24.36** %

2.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	20
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.2 Constraints Value at (20x20,20,400,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	210	170	250	170	300	170
X2	320	255	350	255	400	255
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	**599718**	**512430**	6.45E+05	**512430**	712158	**512430**
Constraints Value						
G1	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G2	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0196**	-0.1667	**-0.0196**	-0.3056	**-0.0196**
G5	-0.3333	-0.1892	-0.434	-0.1892	-0.5238	-0.1892
G6	-0.5462	-0.486	-0.5897	-0.486	-0.6347	-0.486
G7	-0.7827	-0.8024	-0.8371	-0.8024	-0.8783	-0.8024
G8	-0.8934	-0.8974	-0.9061	-0.8974	-0.9235	-0.8974
G9	-0.174	-0.2109	-0.2782	-0.2109	-0.3661	-0.2109
G10	**-0.0273**	**-0.001**	-0.2605	**-0.001**	-0.4714	**-0.001**
G11	-0.7381	-0.7335	-0.7997	-0.7335	-0.8547	-0.7335

Minimum cost flat slab **512430** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 599718
Optimum design= 512430
Cost saving over the normal design= **14.55** %

3.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	20
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.3 Constraints Value at (20x20,20,400,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	200	170	190	170	180	170
X2	280	255	270	255	260	255
X3	5	5	5	5	5	5
X4	5	5	5	5	5	5
COST(Birr)	549273	**512430**	6.27E+05	**512430**	614488	**512430**
constraints Value						
G1	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G2	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.1667	**-0.0196**	-0.1228	**-0.0196**	-0.0741	**-0.0196**
G5	-0.3023	-0.1892	-0.2683	-0.1892	-0.2308	-0.1892
G6	-0.5295	-0.486	-0.5159	-0.486	-0.5014	-0.486
G7	-0.8498	-0.8024	-0.8364	-0.8024	-0.8207	-0.8024
G8	-0.9115	-0.8974	-0.906	-0.8974	-0.8998	-0.8974
G9	-0.3237	-0.2109	-0.2883	-0.2109	-0.2461	-0.2109
G10	-0.2814	**-0.001**	-0.1886	**-0.001**	-0.0677	**-0.001**
G11	-0.8063	-0.7335	-0.7825	-0.7335	-0.7515	-0.7335

Minimum cost flat slab **512430** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

4.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	20
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	3

Table 6.4 Constraints Value (20x20, 20, 500 ,3)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	320	240	350	240	400	240
X2	485	355	500	355	550	355
X3	3	4	3	4	3	4
X4	3	4	3	4	3	4
COST(Birr.)	**8.59E+05**	**6.48E+05**	8.93E+05	**6.48E+05**	9.59E+05	**6.48E+05**
constraints Value						
G1	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G2	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0017**	**-0.0017**	-0.0873	**-0.0017**	-0.2014	**-0.0017**
G5	-0.5522	-0.4118	-0.589	-0.4118	-0.6386	-0.4118
G6	-0.6551	-0.5815	-0.674	-0.5815	-0.7036	-0.5815
G7	-7.89E-01	-0.8133	-0.817	-0.8133	-0.8506	-0.8133
G8	-8.99E-01	-0.9037	-0.9014	-0.9037	-0.9135	-0.9037
G9	-0.1365	-0.2124	-0.1737	-0.2124	-0.9135	-0.2124
G10	**-0.0462**	**-0.0147**	-0.1145	**-0.0147**	-0.2331	**-0.0147**
G11	-0.7434	-0.7391	-0.7627	-0.7391	-0.812	-0.7391

Minimum cost flat slab **648212** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 8.59E+05
Optimum design= 6.48E+05
Cost saving over the normal design= **24.54** %

5.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	20
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.5 Constraints Value(20x20,20,500,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	350	195	300	195	240	195
X2	450	285	400	285	355	285
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	7.98E+05	**557400**	7.22E+05	**557400**	**6.48E+05**	**557400**
constraints Value						
G1	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G2	-0.6	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.3155	**-0.0171**	-0.2014	**-0.0171**	**-0.0017**	**-0.0171**
G5	-0.589	-0.2857	-0.5238	-0.2857	-0.4118	-0.2857
G6	-0.6708	-0.5241	-0.6347	-0.5241	-0.5815	-0.5241
G7	-0.8977	-0.8323	-0.8699	-0.8323	-0.8133	-0.8323
G8	-0.9315	-0.9094	-0.9182	-0.9094	-0.9037	-0.9094
G9	-0.39	-0.2631	-0.3286	-0.2631	-0.2124	-0.2631
G10	-0.4941	**-0.0311**	-0.3209	**-0.0311**	**-0.0147**	**-0.0311**
G11	-0.8643	-0.7452	-0.8194	-0.7452	-0.7391	-0.7452

Minimum cost flat slab **557400** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 6.48E+05
Optimum design= 557400
Cost saving over the normal design= **14.01** %

6.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	20
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.6 Constraints Value(20x20, 20, 500, 5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	300	195	250	195	200	195
X2	400	285	350	285	300	285
X3	5	5	5	5	5	5
X4	5	5	5	5	5	5
COST(Birr)	7.14E+05	**557400**	6.36E+05	**557400**	5.64E+05	**557400**
constraints Value						
G1	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G2	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.3611	**-0.0171**	-0.2333	**-0.0171**	-0.0417	**-0.0171**
G5	-0.5238	-0.2857	-0.434	-0.2857	-0.3023	-0.2857
G6	-0.6347	-0.5241	-0.5897	-0.5241	-0.3023	-0.5241
G7	-0.9167	-0.8323	-0.8885	-0.8323	-0.839	-0.8323
G8	-0.9477	-0.9094	-0.9357	-0.9094	-0.9179	-0.9094
G9	-0.4865	-0.2631	-0.4242	-0.2631	-0.3032	-0.2631
G10	-0.6417	**-0.0311**	-0.5121	**-0.0311**	-0.2199	**-0.0311**
G11	-0.9019	-0.7452	-0.867	-0.7452	-0.7913	-0.7452

Minimum cost flat slab **557400** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

7.Active Constraints at Minimum

Span	=	20mx20m
Grade of Concrete	=	25
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	3

Table 6.7 Constraints Value(20x20,25,400,3)

Design variables	SP1	OP1	SP2	OP2	SP3	OP3
X1	280	210	300	210	350	210
X2	420	310	450	310	500	310
X3	3	4	3	4	3	4
X4	3	4	3	4	3	4
COST(Birr)	**8.53E+05**	**652451**	8.80E+05	**652451**	9.46E+05	**652451**
constraints Value						
G1	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G2	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0079**	-0.0741	**-0.0079**	-0.2063	**-0.0079**
G5	-0.4915	-0.3333	-0.5238	-0.3333	-0.589	-0.3333
G6	-0.6214	-0.5449	-0.6387	-0.5449	-0.674	-0.5449
G7	-0.8058	-0.8264	-0.8257	-0.8264	-0.863	-0.8264
G8	-0.9039	-0.909	-0.9142	-0.909	-0.9262	-0.909
G9	-0.2098	-0.2684	-0.2621	-0.2684	-0.3291	-0.2684
G10	**-0.0666**	**-0.0404**	-0.251	**-0.0404**	-0.4197	**-0.0404**
G11	-0.7487	-0.7447	-0.7951	-0.7447	-0.8392	-0.7447

Minimum cost flat slab **652451** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 8.53E+05
Optimum design= 652451
Cost saving over the normal design= **23.54** %

8.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	25
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.8 Constraints Value(20x20,25,400,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	210	170	250	170	300	170
X2	310	250	350	250	400	250
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	**652451**	**562494**	7.02E+05	**562494**	771254	**562494**
constraints Value						
G1	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G2	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0196**	-0.1667	**-0.0196**	-0.3056	**-0.0196**
G5	-0.3333	-0.1892	-0.434	-0.1892	-0.5238	-0.1892
G6	-0.5449	-0.486	-0.5897	-0.486	-0.6347	-0.486
G7	-0.8264	-0.8419	-0.8697	-0.8419	-0.9027	-0.8419
G8	-0.909	-0.9144	-0.9249	-0.9144	-0.9388	-0.9144
G9	-0.2684	-0.3063	-0.3779	-0.3063	-0.4537	-0.3063
G10	**-0.0404**	**-0.0552**	-0.3628	**-0.0552**	-0.5445	**-0.0552**
G11	-0.7447	-0.7498	-0.8274	-0.7498	-0.8748	-0.7498

Minimum cost flat slab **562494** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 652451
Optimum design= 562494
Cost saving over the normal design= **13.79** %

9.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	25
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.9 Constraints Value(20x20,25,400,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	300	170	250	170	200	170
X2	400	250	350	250	300	250
X3	5	5	5	5	5	5
X4	5	5	5	5	5	5
COST(Birr)	771254	**562494**	6.77E+05	**562494**	604002	**562494**
constraints Value						
G1	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G2	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.4444	**-0.0196**	-0.3333	**-0.0196**	-0.1667	**-0.0196**
G5	-0.5238	-0.1892	-0.434	-0.1892	-0.3023	-0.1892
G6	-0.6347	-0.486	-0.5897	-0.486	-0.5322	-0.486
G7	-0.9377	-0.8419	-0.9166	-0.8419	-0.8795	-0.8419
G8	-0.9608	-0.9144	-0.9519	-0.9144	-0.9386	-0.9144
G9	-0.5753	-0.3063	-0.5308	-0.3063	-0.4465	-0.3063
G10	-0.7388	**-0.0552**	-0.6614	**-0.0552**	-0.5096	**-0.0552**
G11	-0.9265	-0.7498	-0.9048	-0.7498	-0.8642	-0.7498

Minimum cost flat slab **562494** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

10.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	25
Grade of Steel	=	500
initially Span Divided in no. of small span in x and y Directions	=	3

Table 6.10 Constraints Value(20x20,25,500,3)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	320	240	350	240	400	240
X2	465	345	500	345	550	345
X3	3	4	3	4	3	4
X4	3	4	3	4	3	4
COST(Birr)	**922172**	**706140**	9.60E+05	**706140**	1.03E+06	**706140**
constraints Value						
G1	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G2	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0017**	**-0.0017**	-0.0873	**-0.0017**	-0.2014	**-0.0017**
G5	-0.4118	-0.4118	-0.589	-0.4118	-0.6386	-0.4118
G6	-0.6537	-0.5794	-0.674	-0.5794	-0.7036	-0.5794
G7	-0.8317	-0.8511	-0.8536	-0.8511	-0.8805	-0.8511
G8	-0.9119	-0.9185	-0.9211	-0.9185	-0.9308	-0.9185
G9	-0.2349	-0.3064	-0.2879	-0.3064	-0.3391	-0.3064
G10	**-0.0301**	**-0.0349**	-0.2369	**-0.0349**	-0.4018	**-0.0349**
G11	-0.7435	-0.7474	-0.7955	-0.7474	-0.838	-0.7474

Minimum cost flat slab **706140** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 922172
Optimum design= 706140
Cost saving over the normal design= **23.43** %

11.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	25
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.11 Constraints Value(20x20,25,500,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	300	195	250	195	240	195
X2	400	275	350	275	345	275
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	781911	**608366**	7.14E+05	**608366**	**706140**	**608366**
constraints Value						
G1	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G2	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.2014	**-0.0171**	-0.0417	**-0.0171**	**-0.0017**	**-0.0171**
G5	-0.5238	-0.2857	-0.434	-0.2857	-0.4118	-0.2857
G6	-0.6347	-0.5228	-0.5897	-0.5228	-0.5794	-0.5228
G7	-0.8959	-0.866	-0.8607	-0.866	-0.8511	-0.866
G8	-0.9346	-0.922	-0.9197	-0.922	-0.9185	-0.922
G9	-0.4214	-0.3441	-0.3256	-0.3441	-0.3064	-0.3441
G10	**-0.4148**	**-0.0028**	-0.084	**-0.0028**	**-0.0349**	**-0.0028**
G11	-0.8443	-0.7417	-0.7606	-0.7417	-0.7474	-0.7417

Minimum cost flat slab **608366** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 706140
Optimum design= 608366
Cost saving over the normal design= **13.85** %

12.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	25
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.12 Constraints Value(20x20,25,500,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	300	195	250	195	200	195
X2	400	275	350	275	300	275
X3	5	5	5	5	5	5
X4	5	5	5	5	5	5
COST(Birr)	767944	**608366**	6.89E+05	**608366**	614709	**608366**
constraints Value						
G1	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G2	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.3611	**-0.0171**	-0.2333	**-0.0171**	-0.0417	**-0.0171**
G5	-0.5238	-0.2857	-0.434	-0.2857	-0.3023	-0.2857
G6	-0.6347	-0.5228	-0.5897	-0.5228	-0.5322	-0.5228
G7	-0.9334	-0.866	-0.9108	-0.866	-0.8712	-0.866
G8	-0.9581	-0.922	-0.9486	-0.922	-0.9343	-0.922
G9	-0.5575	-0.3441	-0.5038	-0.3441	-0.3995	-0.3441
G10	-0.6912	**-0.0028**	-0.5795	**-0.0028**	-0.3277	**-0.0028**
G11	-0.9155	-0.7417	-0.8854	-0.7417	-0.8201	-0.7417

Minimum cost flat slab **608366** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

13.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	30
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	3

Table 6.13 Constraints Value(20x20,30,400,3)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	280	210	300	210	350	210
X2	405	300	450	300	500	300
X3	3	4	3	4	3	4
X4	3	4	3	4	3	4
COST(Birr)	**9.13E+05**	**707645**	9.41E+05	**707645**	1.01E+06	**707645**
constraints Value						
G1	-0.3333	-0.5	-0.5	-0.5	-0.3333	-0.5
G2	-0.3333	-0.5	-0.5	-0.5	-0.3333	-0.5
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0079**	-0.3056	**-0.0079**	-0.2063	**-0.0079**
G5	-0.4915	-0.3333	-0.5238	-0.3333	-0.589	-0.3333
G6	-0.6206	-0.5437	-0.6387	-0.5437	-0.674	-0.5437
G7	-0.8384	-0.8556	-0.9183	-0.8556	-0.8859	-0.8556
G8	-0.9138	-0.9188	-0.9598	-0.9188	-0.9385	-0.9188
G9	-0.2808	-0.3332	-0.5421	-0.3332	-0.4059	-0.3332
G10	**-0.0417**	**-0.0091**	-0.7006	**-0.0091**	-0.4861	**-0.0091**
G11	-0.7454	-0.7396	-0.9136	-0.7396	-0.8576	-0.7396

Minimum cost flat slab **707645** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 9.13E+05
Optimum design= 707645
Cost saving over the normal design= **22.52** %

14.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	30
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.14 Constraints Value(20x20,30,400,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	210	170	250	170	300	170
X2	300	245	350	245	400	245
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	**707645**	**607222**	7.55E+05	**607222**	826700	**607222**
constraints Value						
G1	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G2	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0196**	-0.1667	**-0.0196**	-0.3056	**-0.0196**
G5	-0.3333	-0.1892	-0.434	-0.1892	-0.5238	-0.1892
G6	-0.5437	-0.4844	-0.5897	-0.4844	-0.6347	-0.4844
G7	-0.8556	-0.8685	-0.8914	-0.8685	-0.9189	-0.8685
G8	-0.9188	-0.9256	-0.9374	-0.9256	-0.949	-0.9256
G9	-0.3332	-0.3741	-0.4491	-0.3741	-0.5163	-0.3741
G10	**-0.0091**	**-0.076**	-0.4357	**-0.076**	-0.5966	**-0.076**
G11	-0.7396	-0.7572	-0.8471	-0.7572	-0.8891	-0.7572

Minimum cost flat slab **607222** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 707645
Optimum design= 607222
Cost saving over the normal design= **14.19** %

15.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	30
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.15 Constraints Value(20x20,30,400,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	200	170	190	170	180	170
X2	270	245	260	245	250	245
X3	5	5	5	5	5	5
X4	5	5	5	5	5	5
COST(Birr)	644357	**607222**	6.31E+05	**607222**	619326	**607222**
constraints Value						
G1	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G2	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.1667	**-0.0196**	-0.1228	**-0.0196**	-0.0741	**-0.0196**
G5	-0.3023	-0.1892	-0.2683	-0.1892	-0.2308	-0.1892
G6	-0.5282	-0.4844	-0.5144	-0.4844	-0.4999	-0.4844
G7	-0.9001	-0.8685	-0.8911	-0.8685	-0.8807	-0.8685
G8	-0.9364	-0.9256	-0.9322	-0.9256	-0.9275	-0.9256
G9	-0.4692	-0.3741	-0.4396	-0.3741	-0.404	-0.3741
G10	-0.3715	**-0.076**	-0.2777	**-0.076**	-0.1504	**-0.076**
G11	-0.833	-0.7572	-0.8092	-0.7572	-0.777	-0.7572

Minimum cost flat slab **607222** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

16.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	30
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	3

Table 6.16 Constraints Value(20x20,30,500,3)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	320	240	350	240	400	240
X2	450	345	500	345	550	345
X3	3	4	3	4	3	4
X4	3	4	3	4	3	4
COST(Birr)	**9.83E+05**	**757895**	1.02E+06	**757895**	1.09E+06	**757895**
constraints Value						
G1	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G2	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0017**	**-0.0017**	-0.0873	**-0.0017**	-0.2014	**-0.0017**
G5	-0.5522	-0.4118	-0.589	-0.4118	-0.6386	-0.4118
G6	-0.6522	-0.5783	-0.674	-0.5783	-0.7036	-0.5783
G7	-0.8601	-0.8759	-0.878	-0.8759	-0.9004	-0.8759
G8	-0.9217	-0.9279	-0.9342	-0.9279	-0.9424	-0.9279
G9	-0.3076	-0.3706	-0.3694	-0.3706	-0.4148	-0.3706
G10	**-0.0097**	**-0.0108**	-0.3242	**-0.0108**	-0.4703	**-0.0108**
G11	-0.7417	-0.7443	-0.8189	-0.7443	-0.8565	-0.7443

Minimum cost flat slab **757895** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 9.83E+05
Optimum design= 757895
Cost saving over the normal design= **22.89** %

17.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	30
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.17 Constraints Value(20x20,30,500,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	300	195	250	195	240	195
X2	400	270	350	270	345	270
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	836539	**650535**	7.67E+05	**650535**	**757895**	**650535**
constraints Value						
G1	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G2	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.2014	**-0.0171**	-0.0417	**-0.0171**	**-0.0017**	**-0.0171**
G5	-0.5238	-0.2857	-0.434	-0.2857	-0.4118	-0.2857
G6	-0.6347	-0.5214	-0.8839	-0.5214	-0.5783	-0.5214
G7	-0.9133	-0.8885	-0.8839	-0.8885	-0.8759	-0.8885
G8	-0.9455	-0.9325	-0.5897	-0.9325	-0.9279	-0.9325
G9	-0.4876	-0.4098	-0.4028	-0.4098	-0.3706	-0.4098
G10	-0.4818	**-0.0247**	-0.1888	**-0.0247**	**-0.0108**	**-0.0247**
G11	-0.8621	-0.7493	-0.788	-0.7493	-0.7443	-0.7493

Minimum cost flat slab **650535** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 757895
Optimum design= 650535
Cost saving over the normal design= **14.17** %

18.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	30
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.18 Constraints Value(20x20,30,500,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	220	195	210	195	200	195
X2	300	270	290	270	280	270
X3	5	5	5	5	5	5
X4	5	5	5	5	5	5
COST(Birr)	687543	**650535**	6.75E+05	**650535**	661302	**650535**
constraints Value						
G1	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G2	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.1288	**-0.0171**	-0.0873	**-0.0171**	-0.0417	**-0.0171**
G5	-0.3617	-0.2857	-0.3333	-0.2857	-0.3023	-0.2857
G6	-0.5547	-0.5214	-0.5424	-0.5214	-0.5295	-0.5214
G7	-0.9087	-0.8885	-0.9014	-0.8885	-0.893	-0.8885
G8	-0.9437	-0.9325	-0.9405	-0.9325	-0.9369	-0.9325
G9	-0.4465	-0.4098	-0.4648	-0.4098	-0.4357	-0.4098
G10	-0.3872	**-0.0247**	-0.3019	**-0.0247**	-0.1887	**-0.0247**
G11	-0.8391	-0.7493	-0.8176	-0.7493	-0.7892	-0.7493

Minimum cost flat slab **650535** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

19.Active Constraints at Minimum

Span	=	25mx25m
Grade of Concrete	=	20
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	3

Table 6.19 Constraints Value at (25x25, 20, 400, 3)

Design variables	SP1	OP1	SP2	OP2	SP3	OP3
X1	350	265	360	265	370	265
X2	550	405	560	405	570	405
X3	3	4	3	4	3	4
X4	3	4	3	4	3	4
COST(Birr)	**1.47E+06**	**1.09E+06**	1.49E+06	**1.09E+06**	1.50E+06	**1.09E+06**
constraints Value						
G1	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G2	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0173**	-0.0355	**-0.0173**	-0.0616	**-0.0173**
G5	-0.589	-0.4643	-0.6	-0.4643	-0.6104	-0.4643
G6	-0.6778	-0.6081	-0.6839	-0.6081	-0.6898	-0.6081
G7	-0.7304	-0.7669	-0.7419	-0.7669	-0.7525	-0.7669
G8	-0.8806	-0.8886	-0.8834	-0.8886	-0.8862	-0.8886
G9	-0.0136	-0.1263	-0.0299	-0.1263	-0.0447	-0.1263
G10	**-0.0058**	**-0.0378**	-0.0501	**-0.0378**	-0.0898	**-0.0378**
G11	-0.7266	-0.7388	-0.7381	-0.7388	-0.7485	-0.7388

Minimum cost flat slab **1091480** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1472330
Optimum design= 1091480
Cost saving over the normal design= **25.87** %

20.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	20
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.20 Constraints Value at (25x25,20,400,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	265	210	300	210	350	210
X2	405	320	450	320	500	320
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	**1.09E+06**	**8.90E+05**	1.16E+06	**8.90E+05**	1.27E+06	**8.90E+05**
constraints Value						
G1	-0.5	-6.00E-01	-0.5	-0.6	-0.5	-6.00E-01
G2	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0173**	**-0.0079**	-0.1319	**-0.0079**	-0.256	**-0.0079**
G5	-0.4643	-0.3333	-0.5238	-0.3333	-0.589	-0.3333
G6	-0.6081	-0.5462	-0.6387	-0.5462	-0.674	-0.5462
G7	-0.7669	-0.7827	-0.8085	-0.7827	-0.8495	-0.7827
G8	-0.8886	-0.8934	-0.9057	-0.8934	-0.9189	-0.8934
G9	-0.1263	-0.174	-0.214	-0.174	-0.279	-0.174
G10	**-0.0378**	**-0.0273**	-0.2888	**-0.0273**	-0.4344	**-0.0273**
G11	-0.7388	-0.7381	-0.8029	-0.7381	-0.8415	-0.7381

Minimum cost flat slab **889551** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1091480
Optimum design= 889551
Cost saving over the normal design= **18.50** %

21.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	20
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.21 Constraints Value at (25x25,20,400,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	240	210	230	210	220	210
X2	350	320	340	320	330	320
X3	5	5	5	5	5	5
X4	5	5	5	5	5	5
COST(Birr)	9.49E+05	**8.90E+05**	9.28E+05	**8.90E+05**	9.07E+05	**8.90E+05**
constraints Value						
G1	-0.6	-6.00E-01	-0.6	-6.00E-01	-0.6	-6.00E-01
G2	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.1319	**-0.0079**	-0.0942	**-0.0079**	-0.053	**-0.0079**
G5	-0.4118	-0.3333	-0.3878	-0.3333	-0.3617	-0.3333
G6	-0.5804	-0.5462	-0.5696	-0.5462	-0.5582	-0.5462
G7	-0.8256	-0.7827	-0.813	-0.7827	-0.7988	-0.7827
G8	-0.9074	-0.8934	-0.9031	-0.8934	-0.8984	-0.8934
G9	-0.2679	-0.174	-0.241	-0.174	-0.21	-0.174
G10	-0.2706	**-0.0273**	-0.2051	**-0.0273**	-0.1256	**-0.0273**
G11	-0.8009	-0.7381	-0.7839	-0.7381	-0.7634	-0.7381

Minimum cost flat slab **889551** **Birr**

Note: SP = Starting Point.

OP = Optimum Point.

22.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	20
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	3

Table 6.22 Constraints Value (25x25, 20, 500 ,3)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	400	300	405	300	410	300
X2	615	450	620	450	625	450
X3	3	4	3	4	3	4
X4	3	4	3	4	3	4
COST(Birr.)	**1.60E+06**	**1.18E+06**	1.61E+06	**1.18E+06**	1.62E+06	**1.18E+06**
constraints Value						
G1	-0.3333	-0.5	-0.3333	-0.5	**-0.3333**	-0.5
G2	-0.3333	-0.5	-0.3333	-0.5	**-0.3333**	-0.5
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0017**	**-0.0017**	-0.0141	**-0.0017**	-0.0261	**-0.0017**
G5	-0.6386	-0.5238	-0.6429	-0.5238	-0.6471	-0.5238
G6	-0.7072	-0.6387	-0.7098	-0.6387	-0.7123	-0.6387
G7	-7.65E-01	-0.7953	-0.7689	-0.7953	-0.7732	-0.7953
G8	-8.92E-01	-0.8992	-0.8928	-0.8992	-0.8939	-0.8992
G9	-0.0373	-0.1555	-0.0437	-0.1555	-0.0499	-0.1555
G10	**-0.0038**	**-0.0282**	-0.0251	**-0.0282**	-0.0453	**-0.0282**
G11	-0.7295	-0.74	-0.735	-0.74	-0.0453	-0.74

Minimum cost flat slab **1182140** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1.60E+06
Optimum design= 1.18E+06
Cost saving over the normal design= **26.16** %

23.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	20
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 9.23 Constraints Value(25x25,20,500,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	320	240	310	240	300	240
X2	470	355	460	355	450	355
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr.)	**1.22E+06**	**9.66E+05**	1.20E+06	**9.66E+05**	**1.18E+06**	**9.66E+05**
constraints Value						
G1	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G2	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.0641	**-0.0017**	-0.0339	**-0.0017**	**-0.0017**	**-0.0017**
G5	-0.5522	-0.4118	-0.5385	-0.4118	-0.5238	-0.4118
G6	-0.6537	-0.5815	-0.6463	-0.5815	-0.6387	-0.5815
G7	-0.8151	-0.8133	-0.8056	-0.8133	-0.7953	-0.8133
G8	-0.9053	-0.9037	-0.9024	-0.9037	-0.8992	-0.9037
G9	-0.1948	-0.2124	-0.1762	-0.2124	-0.1555	-0.2124
G10	-0.1519	**-0.0147**	-0.0947	**-0.0147**	**-0.0282**	**-0.0147**
G11	-0.7716	-0.7391	-0.757	-0.7391	-0.74	-0.7391

Minimum cost flat slab **965671** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1.18E+06
Optimum design= 965671
Cost saving over the normal design= **18.31** %

24.Active Constraints at Minima

Span	=	20mx20m
Grade of Concrete	=	20
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.24 Constraints Value(25x25, 20, 500, 5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	270	240	260	240	250	240
X2	420	355	410	355	400	355
X3	5	5	5	5	5	5
X4	5	5	5	5	5	5
COST(Birr.)	1.04E+06	**9.66E+05**	1.02E+06	**9.66E+05**	9.99E+05	**9.66E+05**
Constraints Value						
G1	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G2	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.1127	**-0.0017**	-0.0785	**-0.0017**	-0.0417	**-0.0017**
G5	-0.4737	-0.4118	-0.4545	-0.4118	-0.434	-0.4118
G6	-0.6135	-0.5815	-0.6044	-0.5815	-0.5947	-0.5815
G7	-0.845	-0.8133	-0.8353	-0.8133	-0.8245	-0.8133
G8	-0.9287	-0.9037	-0.9262	-0.9037	-0.9234	-0.9037
G9	-0.3281	-0.2124	-0.3106	-0.2124	-0.2908	-0.2124
G10	-0.4406	**-0.0147**	-0.4049	**-0.0147**	-0.3638	**-0.0147**
G11	-0.8444	-0.7391	-0.8349	-0.7391	-0.8241	-0.7391

Minimum cost flat slab **965671** **Birr**

Note: SP = Starting Point.

OP = Optimum Point.

25.Active Constraints at Minimum

Span	=	25mx25m
Grade of Concrete	=	25
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	3

Table 6.25 Constraints Value(25x25,25,400,3)

Design variables	SP1	OP1	SP2	OP2	SP3	OP3
X1	350	265	360	265	370	265
X2	530	390	540	390	550	390
X3	3	4	3	4	3	4
X4	3	4	3	4	3	4
COST(Birr)	**1.57E+06**	**1.18E+06**	**1.59E+06**	**1.18E+06**	**1.61E+06**	**1.18E+06**
constraints Value						
G1	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G2	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0173**	-0.0355	**-0.0173**	-0.0616	**-0.0173**
G5	-0.589	-0.4643	-0.6	-0.4643	-0.6104	-0.4643
G6	-0.6765	-0.6071	-0.6827	-0.6071	-0.6886	-0.6071
G7	-0.7849	-0.8138	-0.794	-0.8138	-0.8025	-0.8138
G8	-0.8972	-0.9038	-0.8998	-0.9038	-0.9022	-0.9038
G9	-0.1314	-0.2251	-0.1471	-0.2251	-0.1614	-0.2251
G10	**-0.0293**	**-0.0405**	-0.0791	**-0.0405**	-0.1233	**-0.0405**
G11	-0.7367	-0.7432	-0.7496	-0.7432	-0.7609	-0.7432

Minimum cost flat slab **1176300** **Birr**

Note: SP = Starting Point.

OP = Optimum Point.

Normal design = 1.57E+06

Optimum design= 1176300

Cost saving over the normal design= **25.21** %

26.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	25
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.26 Constraints Value(25x25,25,400,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	265	210	300	210	350	210
X2	390	310	400	310	450	310
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	**1.18E+06**	**9.68E+05**	1.24E+06	**9.68E+05**	1.34E+06	**9.68E+05**
constraints Value						
G1	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G2	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0173**	**-0.0079**	-0.1319	**-0.0079**	-0.256	**-0.0079**
G5	-0.4643	-0.3333	-0.5238	-0.3333	-0.589	-0.3333
G6	-0.6071	-0.5449	-0.6347	-0.5449	-0.6708	-0.5449
G7	-0.8138	-0.8264	-0.8479	-0.8264	-0.8804	-0.8264
G8	-0.9038	-0.909	-0.9044	-0.909	-0.9199	-0.909
G9	-0.2251	-0.2684	-0.2724	-0.2684	-0.3485	-0.2684
G10	**-0.0405**	**-0.0404**	-0.0913	**-0.0404**	-0.3487	**-0.0404**
G11	-0.7432	-0.7447	-0.7593	-0.7447	-0.8249	-0.7447

Minimum cost flat slab **968116** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1176300
Optimum design= 968116
Cost saving over the normal design= **17.70** %

27.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	25
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.27 Constraints Value(25x25,25,400,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	240	210	230	210	220	210
X2	340	310	330	310	320	310
X3	5	5	5	5	5	5
X4	5	5	5	5	5	5
COST(Birr)	1.03E+06	**9.68E+05**	1.01E+06	**9.68E+05**	9.84E+05	**9.68E+05**
constraints Value						
G1	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G2	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.1319	**-0.0079**	-0.0942	**-0.0079**	-0.053	**-0.0079**
G5	-0.4118	-0.3333	-0.3878	-0.3333	-0.3617	-0.3333
G6	-0.5794	-0.5449	-0.5685	-0.5449	-0.557	-0.5449
G7	-0.8607	-0.8264	-0.8506	-0.8264	-0.8393	-0.8264
G8	-0.9214	-0.909	-0.9176	-0.909	-0.9135	-0.909
G9	-0.3561	-0.2684	-0.3311	-0.2684	-0.3022	-0.2684
G10	-0.3054	**-0.0404**	-0.2358	**-0.0404**	-0.1497	**-0.0404**
G11	-0.8125	-0.7447	-0.7947	-0.7447	-0.7726	-0.7447

Minimum cost flat slab **968116** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

28.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	25
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	3

Table 6.28 Constraints Value(25x25,25,500,3)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	400	300	410	240	420	240
X2	590	435	600	345	610	345
X3	3	4	3	4	3	4
X4	3	4	3	4	3	4
COST(Birr)	**1.70E+06**	**1.27E+06**	1.72E+06	**1.37E+06**	1.74E+06	**1.37E+06**
constraints Value						
G1	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G2	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0017**	**-0.0017**	-0.0261	**-0.0017**	-0.0493	**-0.0017**
G5	-0.6386	-0.5238	-0.6471	-0.5238	-0.6552	-0.5238
G6	-0.7057	-0.6379	-0.7108	-0.6379	-0.7157	-0.6379
G7	-0.8123	-0.8365	-0.8192	-0.8365	-0.8256	-0.8365
G8	-0.906	-0.9137	-0.9081	-0.9137	-0.9101	-0.9137
G9	-0.1528	-0.2543	-0.1652	-0.2543	-0.1766	-0.2543
G10	**-0.0061**	**-0.0379**	-0.0551	**-0.0379**	-0.0986	**-0.0379**
G11	-0.7347	-0.7461	-0.7471	-0.7461	-0.7582	-0.7461

Minimum cost flat slab **1272290** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1699900
Optimum design= 1272290
Cost saving over the normal design= **25.16** %

29.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	25
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.29 Constraints Value(20x20,25,500,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	400	240	350	240	300	240
X2	450	345	440	345	435	345
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	1.45E+06	**1.05E+06**	1.36E+06	**1.05E+06**	**1.27E+06**	**1.05E+06**
constraints Value						
G1	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G2	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	-0.6386	**-0.0171**	-0.1443	**-0.0171**	**-0.0017**	**-0.0171**
G5	-0.6386	-0.4118	-0.589	-0.4118	-0.5238	-0.4118
G6	-0.6971	-0.5794	-0.6701	-0.5794	-0.6379	-0.5794
G7	-0.8965	-0.8511	-0.8723	-0.8511	-0.8365	-0.8511
G8	-0.9094	-0.9185	-0.9104	-0.9185	-0.9137	-0.9185
G9	-0.3349	-0.3064	-0.298	-0.3064	-0.2543	-0.3064
G10	-0.3349	**-0.0349**	-0.026	**-0.0349**	**-0.0379**	**-0.0349**
G11	-0.0587	-0.7474	-0.7495	-0.7474	-0.7461	-0.7474

Minimum cost flat slab **1046930** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1272290
Optimum design= 1046930
Cost saving over the normal design= **17.71** %

30.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	25
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.30 Constraints Value(25x25,25,500,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	240	200	250	200	300	200
X2	345	290	350	290	400	290
X3	5	6	5	6	5	6
X4	5	6	5	6	5	6
COST(Birr)	**1.05E+06**	**9.25E+05**	1.07E+06	**9.25E+05**	1.26E+06	**9.25E+05**
constraints Value						
G1	-0.6	-0.6667	-0.6	-0.6667	-0.6	-0.6667
G2	-0.6	-0.6667	-0.6	-0.6667	-0.6	-0.6667
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0171**	**-0.0017**	-0.0417	**-0.0017**	-0.2014	**-0.0017**
G5	-0.2857	-0.3023	-0.434	-0.3023	-0.5238	-0.3023
G6	-0.5228	-0.5308	-0.5783	-0.5308	-0.6347	-0.5308
G7	-0.866	-0.8604	-0.863	-0.8604	-0.8959	-0.8604
G8	-0.922	-0.9236	-0.8395	-0.9236	-0.9346	-0.9236
G9	-0.3441	-0.3412	-0.0998	-0.3412	-0.4214	-0.3412
G10	**-0.0028**	**-0.0722**	-6.1525	**-0.0722**	-0.4148	**-0.0722**
G11	-0.7417	-0.7575	-2.1783	-0.7575	-0.8443	-0.7575

Minimum cost flat slab **925373** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1.05E+06
Optimum design= 925373
Cost saving over the normal design= **11.61** %

31.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	30
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	3

Table 6.31 Constraints Value(25x25,30,400,3)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	350	265	360	265	370	265
X2	515	380	520	380	530	380
X3	3	4	3	4	3	4
X4	3	4	3	4	3	4
COST(Birr)	**1.67E+06**	**1.26E+06**	1.68E+06	**1.26E+06**	1.70E+06	**1.26E+06**
constraints Value						
G1	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G2	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0173**	-0.0355	**-0.0173**	-0.0616	**-0.0173**
G5	-0.589	-0.4643	-0.6	-0.4643	-0.6104	-0.4643
G6	-0.6753	-0.6062	-0.6815	-0.6062	-0.6875	-0.6062
G7	-0.8212	-0.8451	-0.8288	-0.8451	-0.8358	-0.8451
G8	-0.9093	-0.9155	-0.9099	-0.9155	-0.9123	-0.9155
G9	-0.2177	-0.3001	-0.2281	-0.3001	-0.2423	-0.3001
G10	**-0.0461**	**-0.0528**	-0.0686	**-0.0528**	-0.1203	**-0.0528**
G11	-0.744	-0.7489	-0.7502	-0.7489	-0.7634	-0.7489

Minimum cost flat slab **1258540** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1.67E+06
Optimum design= 1258540
Cost saving over the normal design= **24.45** %

32.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	30
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.32 Constraints Value(25x25,30,400,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	280	210	270	210	265	210
X2	400	310	390	310	380	310
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	1.29E+06	**1.04E+06**	1.27E+06	**1.04E+06**	**1.26E+06**	**1.04E+06**
constraints Value						
G1	-0.5	-0.6667	-0.5	-0.6667	-0.5	-0.6667
G2	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.4	-0.5	-0.4	-0.5	-0.4
G4	-0.0699	**-0.0079**	-0.0355	**-0.0079**	**-0.0173**	**-0.0079**
G5	-0.4915	-0.3333	-0.4737	-0.3333	-0.4643	-0.3333
G6	-0.6197	-0.5449	-0.6108	-0.5449	-0.6062	-0.5449
G7	-0.8582	-0.8553	-0.8497	-0.8553	-0.8451	-0.8553
G8	-0.9223	-0.9241	-0.9193	-0.9241	-0.9155	-0.9241
G9	-0.3401	-0.3521	-0.3191	-0.3521	-0.3001	-0.3521
G10	-0.2156	**-0.174**	-0.1453	**-0.174**	**-0.0528**	**-0.174**
G11	-0.7898	-0.7873	-0.7719	-0.7873	-0.7489	-0.7396

Minimum cost flat slab **1044140** **Birr**

Note: SP = Starting Point.

OP = Optimum Point.

Normal design = 1.26E+06

Optimum design= 1044140

Cost saving over the normal design= **17.04** %

33.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	30
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.33 Constraints Value(25x25,30,400,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	210	175	250	175	300	175
X2	310	255	350	255	400	255
X3	5	6	5	6	5	6
X4	5	6	5	6	5	6
COST(Birr)	**1.04E+06**	**9.25E+05**	1.13E+06	**9.25E+05**	1.24E+06	**9.25E+05**
constraints Value						
G1	-0.6	-0.6667	-0.6	-0.6667	-0.6	-0.6667
G2	-0.6	-0.6667	-0.6	-0.6667	-0.6	-0.6667
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0079**	-0.1667	**-0.0079**	-0.3056	**-0.0079**
G5	-0.3333	-0.2105	-0.434	-0.2105	-0.5238	-0.2105
G6	-0.5437	-0.4938	-0.5897	-0.4938	-0.6347	-0.4938
G7	-0.8556	-0.8639	-0.8914	-0.8639	-0.9189	-0.8639
G8	-0.9188	-0.9251	-0.9374	-0.9251	-0.949	-0.9251
G9	-0.3332	-0.3659	-0.4491	-0.3659	-0.5163	-0.3659
G10	**-0.0091**	**-0.0822**	-0.4357	**-0.0822**	-0.5966	**-0.0822**
G11	-0.7396	-0.7582	-0.8471	-0.7582	-0.8891	-0.7582

Minimum cost flat slab **925245** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1.04E+06
Optimum design= 9.25E+05
Cost saving over the normal design= **11.39** %

34.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	30
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	3

Table 6.34 Constraints Value(25x25,30,500,3)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	400	300	410	300	420	300
X2	575	420	580	420	590	420
X3	3	4	3	4	3	4
X4	3	4	3	4	3	4
COST(Birr)	**1.79E+06**	**1.35E+06**	1.81E+06	**1.46E+06**	1.83E+06	**1.46E+06**
constraints Value						
G1	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G2	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0017**	**-0.0017**	-0.0261	**-0.0017**	-0.0493	**-0.0017**
G5	-0.6386	-0.5238	-0.6471	-0.5238	-0.6552	-0.5238
G6	-0.7046	-0.6363	-0.7098	-0.6363	-0.7147	-0.6363
G7	-0.844	-0.8641	-0.8497	-0.8641	-0.855	-0.8641
G8	-0.9176	-0.9228	-0.9181	-0.9228	-0.9199	-0.9228
G9	-0.2395	-0.3233	-0.2477	-0.3233	-0.2589	-0.3233
G10	**-0.0284**	**-0.003**	-0.0502	**-0.003**	-0.1006	**-0.003**
G11	-0.7433	-0.7407	-0.7493	-0.7407	-0.762	-0.7407

Minimum cost flat slab **1354670** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1.79E+06
Optimum design= 1354670
Cost saving over the normal design= **24.52** %

35.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	30
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.35 Constraints Value(25x25,30,500,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	320	240	310	240	300	240
X2	440	335	430	335	420	335
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	1.39E+06	**1.12E+06**	1.38E+06	**1.12E+06**	**1.35E+06**	**1.12E+06**
constraints Value						
G1	-0.5	-0.6667	-0.5	-0.6667	-0.5	-0.6667
G2	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.4	-0.5	-0.4	-0.5	-0.4
G4	-0.0641	**-0.0171**	-0.0339	**-0.0171**	**-0.0017**	**-0.0171**
G5	-0.5522	-0.4118	-0.5385	-0.4118	-0.5238	-0.4118
G6	-0.6515	-0.5783	-0.6441	-0.5783	-0.6363	-0.5783
G7	-0.8772	-0.8761	-0.871	-0.8761	-0.8641	-0.8761
G8	-0.928	-0.9279	-0.9255	-0.9279	-0.9228	-0.9279
G9	-0.3596	-0.3706	-0.3425	-0.3706	-0.3233	-0.3706
G10	-0.1681	**-0.0366**	-0.0935	**-0.0366**	**-0.003**	**-0.0366**
G11	-0.782	-0.7607	-0.7633	-0.7607	-0.7407	-0.7607

Minimum cost flat slab **1120860** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1354670
Optimum design= 1120860
Cost saving over the normal design= **17.26** %

36.Active Constraints at Minima

Span	=	25mx25m
Grade of Concrete	=	30
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.36 Constraints Value(25x25,30,500,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	240	200	250	200	300	200
X2	335	280	350	280	400	280
X3	5	6	5	6	5	6
X4	5	6	5	6	5	6
COST(Birr)	**1.12E+06**	**9.93E+05**	1.14E+06	**9.93E+05**	1.25E+06	**9.93E+05**
constraints Value						
G1	-0.6	-0.6667	-0.6	-0.6667	-0.6	-0.6667
G2	-0.6	-0.6667	-0.6	-0.6667	-0.6	-0.6667
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0017**	**-0.0017**	-0.0417	**-0.0017**	-0.2014	**-0.0017**
G5	-0.4118	-0.3023	-0.434	-0.3023	-0.5238	-0.3023
G6	-0.5794	-0.5295	-0.5897	-0.5295	-0.6347	-0.5295
G7	-0.8759	-0.8839	-0.8839	-0.8839	-0.9133	-0.8839
G8	-0.93	-0.9315	-0.9331	-0.9315	-0.9455	-0.9315
G9	-0.3779	-0.3976	-0.4028	-0.3976	-0.4876	-0.3976
G10	**-0.082**	**-0.0111**	-0.1888	**-0.0111**	-0.4818	**-0.0111**
G11	-0.7612	-0.7453	-0.788	-0.7453	-0.8621	-0.7453

Minimum cost flat slab **992538** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1.12E+06
Optimum design= 992538
Cost saving over the normal design= **11.45** %

37.Active Constraints at Minimum

Span	=	30mx30m
Grade of Concrete	=	20
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	3

Table 6.37 Constraints Value at (30x30, 20, 400, 3)

Design variables	SP1	OP1	SP2	OP2	SP3	OP3
X1	420	315	425	315	430	315
X2	680	490	685	490	690	490
X3	3	4	3	4	3	4
X4	3	4	3	4	3	4
COST(Birr)	**2.47E+06**	**1.79E+06**	2.48E+06	**1.79E+06**	2.50E+06	**1.79E+06**
constraints Value						
G1	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G2	-0.3333	-0.5	-0.3333	-0.5	-0.3333	-0.5
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0079**	-0.0196	**-0.0079**	-0.031	**-0.0079**
G5	-0.6552	-0.5455	-0.6591	-0.5455	-0.6629	-0.5455
G6	-0.7195	-0.6522	-0.7219	-0.6522	-0.7242	-0.6522
G7	-0.7036	-0.7436	-0.7088	-0.7436	-0.7139	-0.7436
G8	-0.8776	-0.8833	-0.8787	-0.8833	-0.8798	-0.8833
G9	-0.0026	-0.0586	-0.5977	-0.0586	0.0712	-0.0586
G10	**-0.0026**	**-0.015**	-0.018	**-0.015**	-0.0327	**-0.015**
G11	-0.722	-0.7306	-0.7261	-0.7306	-0.7299	-0.7306

Minimum cost flat slab **1793350** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 2473660
Optimum design= 1793350
Cost saving over the normal design= **27.50** %

38.Active Constraints at Minima

Span	=	30mx30m
Grade of Concrete	=	20
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.38 Constraints Value at (30x30,20,400,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	315	255	320	255	325	255
X2	490	385	550	385	555	385
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	**1.79E+06**	**1.45E+06**	1.84E+06	**1.45E+06**	1.85E+06	**1.45E+06**
constraints Value						
G1	-0.5	-6.00E-01	-0.5	-6.00E-01	-0.5	-6.00E-01
G2	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0196**	-0.1319	**-0.0196**	-0.256	**-0.0196**
G5	-0.5455	-0.4444	-0.5238	-0.4444	-0.589	-0.4444
G6	-0.6522	-0.5986	-0.6387	-0.5986	-0.674	-0.5986
G7	-0.7436	-0.7714	-0.8085	-0.7714	-0.8495	-0.7714
G8	-0.8833	-0.8906	-0.9057	-0.8906	-0.9189	-0.8906
G9	-0.0586	-0.1412	-0.214	-0.1412	-0.279	-0.1412
G10	**-0.015**	**-0.0099**	-0.2888	**-0.0099**	-0.4344	**-0.0099**
G11	-0.7306	-0.7437	-0.8029	-0.7437	-0.8415	-0.7437

Minimum cost flat slab **1451210** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1793350
Optimum design= 1451210
Cost saving over the normal design= **19.08** %

39.Active Constraints at Minima

Span	=	30mx30m
Grade of Concrete	=	20
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.39 Constraints Value at (25x25,20,400,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	255	210	260	210	270	210
X2	385	320	400	320	410	320
X3	5	6	5	6	5	6
X4	5	6	5	6	5	6
COST(Birr)	**1.45E+06**	**1.23E+06**	1.47E+06	**1.23E+06**	1.49E+06	**1.23E+06**
constraints Value						
G1	-6.00E-01	-7.14E-01	-0.6	-7.14E-01	-0.6	-7.14E-01
G2	-0.6	-0.6667	-0.6	-0.6667	-0.6	-0.6667
G3	-0.5	-0.4167	-0.5	-0.4167	-0.5	-0.4167
G4	**-0.0196**	**-0.0079**	-0.0942	**-0.0079**	-0.053	**-0.0079**
G5	-0.4444	-0.3333	-0.3878	-0.3333	-0.3617	-0.3333
G6	-0.5986	-0.5462	-0.5696	-0.5462	-0.5582	-0.5462
G7	-0.7714	-0.7827	-0.813	-0.7827	-0.7988	-0.7827
G8	-0.8906	-0.8934	-0.9031	-0.8934	-0.8984	-0.8934
G9	-0.1412	-0.174	-0.241	-0.174	-0.21	-0.174
G10	**-0.0099**	**-0.0273**	-0.2051	**-0.0273**	-0.1256	**-0.0273**
G11	-0.7437	-0.0524	-0.7839	-0.0524	-0.7634	-0.0524

Minimum cost flat slab **1233500** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1451210
Optimum design= 1233500
Cost saving over the normal design= **15.00** %

40.Active Constraints at Minima

Span	=	30mx30m
Grade of Concrete	=	20
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.40 Constraints Value (30x30, 20, 500 ,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	360	290	370	290	380	290
X2	550	430	560	430	570	430
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr.)	**1.96E+06**	**1.58E+06**	1.99E+06	**1.58E+06**	2.02E+06	**1.58E+06**
constraints Value						
G1	-0.5	-0.6	-0.3333	-0.6	-0.3333	-0.6
G2	-0.5	-0.6	-0.3333	-0.6	-0.3333	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0017**	**-0.0086**	-0.0141	**-0.0086**	-0.0261	**-0.0086**
G5	-0.6	-0.5082	-0.6429	-0.5082	-0.6471	-0.5082
G6	-0.7768	-0.6347	-0.7098	-0.6347	-0.7123	-0.6347
G7	-0.78	-0.7995	-0.7689	-0.7995	-0.7732	-0.7995
G8	-8.95E-01	-0.8012	-0.8928	-0.8012	-0.8939	-0.8012
G9	-0.089	-0.1688	-0.0437	-0.1688	-0.0499	-0.1688
G10	**-0.0303**	**-0.0186**	-0.0251	**-0.0186**	-0.0453	**-0.0186**
G11	-0.7378	-0.7384	-0.735	-0.7384	-0.0453	-0.7384

Minimum cost flat slab **1581190** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1.96E+06
Optimum design= 1.58E+06
Cost saving over the normal design= **19.41** %

41.Active Constraints at Minima

Span	=	30mx30m
Grade of Concrete	=	20
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 9.41 Constraints Value(25x25,20,500,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	290	240	300	240	310	240
X2	430	355	440	355	450	355
X3	5	6	5	6	5	6
X4	5	6	5	6	5	6
COST(Birr.)	**1.58E+06**	**1.34E+06**	1.61E+06	**1.34E+06**	1.64E+06	**1.34E+06**
constraints Value						
G1	-0.6	-0.6667	-0.5	-0.6667	-0.5	-0.6667
G2	-0.6	-0.7143	-0.5	-0.7143	-0.5	-0.7143
G3	-0.5	-0.4167	-0.5	-0.4167	-0.5	-0.4167
G4	**-0.0086**	**-0.0017**	-0.0339	**-0.0017**	-0.0726	**-0.0017**
G5	-0.5082	-0.4118	-0.5385	-0.4118	-0.5238	-0.4118
G6	-0.6347	-0.5815	-0.6463	-0.5815	-0.6387	-0.5815
G7	-0.7995	-0.8133	-0.8056	-0.8133	-0.7953	-0.8133
G8	-0.8012	-0.8056	-0.9024	-0.8056	-0.8992	-0.8056
G9	-0.1688	-0.2124	-0.1762	-0.2124	-0.1555	-0.2124
G10	**-0.0186**	**-0.041**	-0.0947	**-0.041**	-0.1524	**-0.041**
G11	-0.7384	-0.7535	-0.757	-0.7535	-0.7726	-0.7535

Minimum cost flat slab **1344840** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1.58E+06
Optimum design= 1.34E+06
Cost saving over the normal design= **14.95** %

42.Active Constraints at Minimum

Span	=	30mx30m
Grade of Concrete	=	25
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.42 Constraints Value(30x30,25,400,4)

Design variables	SP1	OP1	SP2	OP2	SP3	OP3
X1	315	255	320	255	330	255
X2	475	375	480	375	490	375
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	**1.92E+06**	**1.57E+06**	1.94E+06	**1.57E+06**	1.96E+06	**1.57E+06**
constraints Value						
G1	-0.5	-0.6	-0.3333	-0.6	-0.3333	-0.6
G2	-0.5	-0.6	-0.3333	-0.6	-0.3333	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0196**	-0.0355	**-0.0196**	-0.0616	**-0.0196**
G5	-0.5455	-0.4444	-0.6	-0.4444	-0.6104	-0.4444
G6	-0.6515	-0.5967	-0.6827	-0.5967	-0.6886	-0.5967
G7	-0.7952	-0.8177	-0.794	-0.8177	-0.8025	-0.8177
G8	-0.9006	-0.9053	-0.8998	-0.9053	-0.9022	-0.9053
G9	-0.1717	-0.2382	-0.1471	-0.2382	-0.1614	-0.2382
G10	**-0.0518**	**-0.0536**	-0.0791	**-0.0536**	-0.1233	**-0.0536**
G11	-0.7437	-0.7468	-0.7496	-0.7468	-0.7609	-0.7468

Minimum cost flat slab **1567130** **Birr**

Note: SP = Starting Point.

OP = Optimum Point.

Normal design = 1.92E+06

Optimum design= 1567130

Cost saving over the normal design= **18.41** %

43.Active Constraints at Minima

Span	=	30mx30m
Grade of Concrete	=	25
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.43 Constraints Value(30x30,25,400,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	255	210	260	210	300	210
X2	375	310	380	310	400	310
X3	5	6	5	6	5	6
X4	5	6	5	6	5	6
COST(Birr)	**1.57E+06**	**1.34E+06**	1.58E+06	**1.34E+06**	1.69E+06	**1.34E+06**
constraints Value						
G1	-0.6	-0.6667	-0.6	-0.6	-0.6	-0.6
G2	-0.6	-0.6667	-0.6	-0.6	-0.6	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0196**	**-0.0079**	-0.0942	**-0.0079**	-0.053	**-0.0079**
G5	-0.4444	-0.3333	-0.3878	-0.3333	-0.3617	-0.3333
G6	-0.5967	-0.5449	-0.5685	-0.5449	-0.557	-0.5449
G7	-0.8177	-0.8264	-0.8506	-0.8264	-0.8393	-0.8264
G8	-0.9053	-0.909	-0.9176	-0.909	-0.9135	-0.909
G9	-0.2382	-0.2684	-0.3311	-0.2684	-0.3022	-0.2684
G10	**-0.0536**	**-0.0404**	-0.2358	**-0.0404**	-0.1497	**-0.0404**
G11	-0.7468	-0.7447	-0.7947	-0.7447	-0.7726	-0.7447

Minimum cost flat slab **1342700** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1.57E+06
Optimum design= 1.34E+06
Cost saving over the normal design= **14.32** %

44.Active Constraints at Minima

Span	=	30mx30m
Grade of Concrete	=	25
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.44 Constraints Value(30x30,25,500,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	360	290	365	290	370	290
X2	530	415	535	415	540	415
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	**2.09E+06**	**1.70E+06**	2.11E+06	**1.70E+06**	2.12E+06	**1.70E+06**
constraints Value						
G1	-0.5	-0.6	-0.3333	-0.6	-0.3333	-0.6
G2	-0.5	-0.6	-0.3333	-0.6	-0.3333	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0017**	**-0.0086**	-0.0261	**-0.0086**	-0.0493	**-0.0086**
G5	-0.6	-0.5082	-0.6471	-0.5082	-0.6552	-0.5082
G6	-0.6821	-0.6282	-0.7108	-0.6282	-0.7157	-0.6282
G7	-0.8219	-0.8414	-0.8192	-0.8414	-0.8256	-0.8414
G8	-0.9099	-0.9093	-0.9081	-0.9093	-0.9101	-0.9093
G9	-0.1977	-0.2515	-0.1652	-0.2515	-0.1766	-0.2515
G10	**-0.0418**	**-0.0179**	-0.0551	**-0.0179**	-0.0986	**-0.0179**
G11	-0.7448	-0.7145	-0.7471	-0.7145	-0.7582	-0.7145

Minimum cost flat slab **1698360** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 2091600
Optimum design= 1698360
Cost saving over the normal design= **18.80** %

45.Active Constraints at Minima

Span	=	30mx30m
Grade of Concrete	=	25
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.45 Constraints Value(30x30,25,500,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	290	240	350	240	400	240
X2	415	350	450	350	500	350
X3	5	6	5	6	5	6
X4	5	6	5	6	5	6
COST(Birr)	**1.70E+06**	**1.46E+06**	1.87E+06	**1.46E+06**	**2.03E+06**	**1.46E+06**
constraints Value						
G1	-0.6	-0.6667	-0.5	-0.6667	-0.5	-0.6667
G2	-0.6	-0.6667	-0.5	-0.6667	-0.5	-0.6667
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0086**	**-0.0017**	-0.1443	**-0.0017**	-0.401	**-0.0017**
G5	-0.5082	-0.4118	-0.589	-0.4118	-0.5238	-0.4118
G6	-0.6282	-0.5804	-0.6701	-0.5804	-0.6379	-0.5804
G7	-0.8414	-0.8509	-0.8723	-0.8509	-0.8365	-0.8509
G8	-0.9093	-0.9208	-0.9104	-0.9208	-0.9137	-0.9208
G9	-0.2515	-0.314	-0.298	-0.314	-0.2543	-0.314
G10	**-0.0179**	**-0.0964**	-0.026	**-0.0964**	-0.6484	**-0.0964**
G11	-0.7145	-0.7621	-0.7495	-0.7621	-0.7461	-0.7621

Minimum cost flat slab **1455770** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1.70E+06
Optimum design= 1.46E+06
Cost saving over the normal design= **14.28** %

46.Active Constraints at Minima

Span	=	30mx30m
Grade of Concrete	=	30
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.46 Constraints Value(30x30,30,400,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	315	255	350	255	400	255
X2	455	365	500	365	550	365
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	**2.04E+06**	**1.68E+06**	2.15E+06	**1.68E+06**	2.30E+06	**1.68E+06**
constraints Value						
G1	-0.5	-0.6	-0.3333	-0.6	-0.3333	-0.6
G2	-0.5	-0.6	-0.3333	-0.6	-0.3333	-0.6
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0079**	**-0.0196**	-0.0355	**-0.0196**	-0.0616	**-0.0196**
G5	-0.5455	-0.4444	-0.6	-0.4444	-0.6104	-0.4444
G6	-0.6493	-0.5957	-0.6815	-0.5957	-0.6875	-0.5957
G7	-0.83	-0.8556	-0.8483	-0.8556	-0.8358	-0.8556
G8	-0.9098	-0.9188	-0.9166	-0.9188	-0.9123	-0.9188
G9	-0.246	-0.311	-0.2281	-0.311	-0.2423	-0.311
G10	**-0.0092**	**-0.0604**	-0.0686	**-0.0604**	-0.1203	**-0.0604**
G11	-0.7364	-0.7512	-0.7502	-0.7512	-0.7634	-0.7512

Minimum cost flat slab **1675170** **Birr**

Note: SP = Starting Point.

OP = Optimum Point.

Normal design = 2.04E+06

Optimum design= 1675170

Cost saving over the normal design= **17.95** %

47.Active Constraints at Minima

Span	=	30mx30m
Grade of Concrete	=	30
Grade of Steel	=	400
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.47 Constraints Value(30x30,30,400,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	255	210	300	210	350	210
X2	365	310	400	310	450	310
X3	5	6	5	6	5	6
X4	5	6	5	6	5	6
COST(Birr)	**1.68E+06**	**1.44E+06**	1.81E+06	**1.44E+06**	**1.97E+06**	**1.44E+06**
constraints Value						
G1	-0.6	-0.6667	-0.5	-0.6667	-0.5	-0.6667
G2	-0.6	-0.6667	-0.5	-0.6667	-0.5	-0.6667
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0196**	**-0.0079**	-0.0355	**-0.0079**	-0.2857	**-0.0079**
G5	-0.4444	-0.3333	-0.4737	-0.3333	-0.4643	-0.3333
G6	-0.5957	-0.5449	-0.6108	-0.5449	-0.6062	-0.5449
G7	-0.8556	-0.8553	-0.8497	-0.8553	-0.8451	-0.8553
G8	-0.9188	-0.9241	-0.9193	-0.9241	-0.9155	-0.9241
G9	-0.311	-0.3521	-0.3191	-0.3521	-0.3001	-0.3521
G10	**-0.0604**	**-0.1502**	-0.1453	**-0.1502**	-0.451	**-0.1502**
G11	-0.7512	-0.7739	-0.7719	-0.7739	-0.7489	-0.7739

Minimum cost flat slab **1444740** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1.68E+06
Optimum design= 1.44E+06
Cost saving over the normal design= **13.76** %

48.Active Constraints at Minima

Span	=	30mx30m
Grade of Concrete	=	30
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	4

Table 6.48 Constraints Value(30x30,30,500,4)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	360	290	370	290	380	290
X2	515	405	520	405	530	405
X3	4	5	4	5	4	5
X4	4	5	4	5	4	5
COST(Birr)	**2.21E+06**	**1.81E+06**	2.24E+06	**1.81E+06**	2.27E+06	**1.81E+06**
constraints Value						
G1	-0.5	-0.6	-0.5	-0.6667	-0.5	-0.6667
G2	-0.5	-0.6	-0.5	-0.6	-0.5	-0.6
G3	-0.5	-0.5	-0.5	-0.4	-0.5	-0.4
G4	**-0.0017**	**-0.0086**	-0.0339	**-0.0171**	-0.0017	**-0.0171**
G5	-0.6	-0.5082	-0.5385	-0.4118	-0.5238	-0.4118
G6	-0.6809	-0.6282	-0.6441	-0.5783	-0.6363	-0.5783
G7	-0.8772	-0.8679	-0.871	-0.8761	-0.8641	-0.8761
G8	-0.9206	-0.9244	-0.9255	-0.9279	-0.9228	-0.9279
G9	-0.3596	-0.3706	-0.3425	-0.3706	-0.3233	-0.3706
G10	**-0.0482**	**-0.0277**	-0.0935	**-0.0366**	-0.003	**-0.0366**
G11	-0.7495	-0.7472	-0.7633	-0.7607	-0.7407	-0.7607

Minimum cost flat slab **1811680** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 2.21E+06
Optimum design= 1.81E+06
Cost saving over the normal design= **18.06** %

49.Active Constraints at Minima

Span	=	30mx30m
Grade of Concrete	=	30
Grade of Steel	=	500
Initially Span Divided in no. of small span in x and y Directions	=	5

Table 6.49 Constraints Value(30x30,30,500,5)

Design variables	SP1	**OP1**	SP2	OP2	SP3	OP3
X1	290	240	300	240	350	240
X2	405	340	450	340	500	340
X3	5	6	5	6	5	6
X4	5	6	5	6	5	6
COST(Birr)	**1.81E+06**	**1.56E+06**	1.86E+06	**1.56E+06**	2.02E+06	**1.56E+06**
constraints Value						
G1	-0.6	-0.6667	-0.6	-0.6667	-0.6	-0.6667
G2	-0.6	-0.6667	-0.6	-0.6667	-0.6	-0.6667
G3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
G4	**-0.0086**	**-0.0017**	-0.0417	**-0.0017**	-0.1786	**-0.0017**
G5	-0.5082	-0.4118	-0.434	-0.4118	-0.5238	-0.4118
G6	-0.6282	-0.5794	-0.5897	-0.5794	-0.6347	-0.5794
G7	-0.8679	-0.8759	-0.8839	-0.8759	-0.9133	-0.8759
G8	-0.9244	-0.93	-0.9331	-0.93	-0.9455	-0.93
G9	-0.3706	-0.3779	-0.4028	-0.3779	-0.4876	-0.3779
G10	**-0.0277**	**-0.082**	-0.3612	**-0.082**	-0.5172	**-0.082**
G11	-0.7472	-0.7612	-0.788	-0.7612	-0.8621	-0.7612

Minimum cost flat slab **1556750** **Birr**

Note: SP = Starting Point.
OP = Optimum Point.

Normal design = 1.81E+06
Optimum design= 1556750
Cost saving over the normal design= **14.07** %

CHAPTER SEVEN: COMPARATIVE RESULTS FOR DIFFERENT GRADE OF STEEL, CONCRETE AND LENGTH OF SPAN

1. CASE: C20 S 400

Grade of Concrete	=	20.00	
Grade of Steel	=	400.00	
Cost of Concrete	=	3367.09	Birr/m³
Cost of Steel	=	32.98	Birr/Kg

Table 7.1.1 Quantity of concrete in m³ (20 ,400)

C20 S400		Quantity of concrete in m³		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	**131.00**	**98.00**	**80.00**
25mX25m		**255.00**	**191.00**	**152.00**
Span		**4X4**	**5X5**	**6X6**
30mX30m		**325.00**	**262.00**	**217.00**

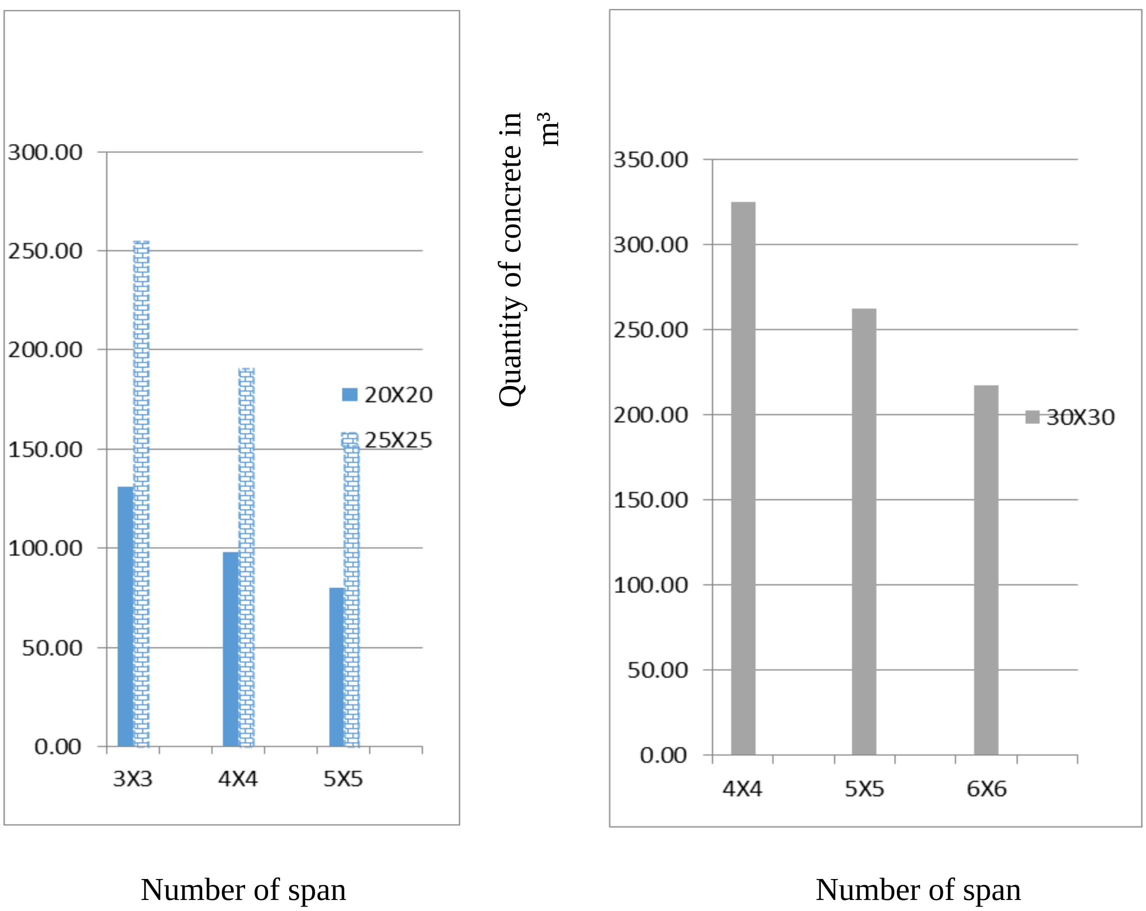


Fig.7.1 Quantity of concrete in m³ for different spans and number of panels (C20 S 400)

1. CASE: C20 S 400

Grade of Concrete = 20.00

Grade of Steel = 400.00

Cost of Concrete = 3367.09 Birr/m³

Cost of Steel = 32.98 Birr/Kg

Table 7.1.2 Quantity of steel in kg (20 ,400)

C20 S400		Quantity of steel in kg		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	**10665.00**	**8179.00**	**7370.00**
25mX25m		**18609.00**	**13595.00**	**11454.00**
Span		**4X4**	**5X5**	**6X6**
30mX30m		**21196.00**	**17254.00**	**15247.00**

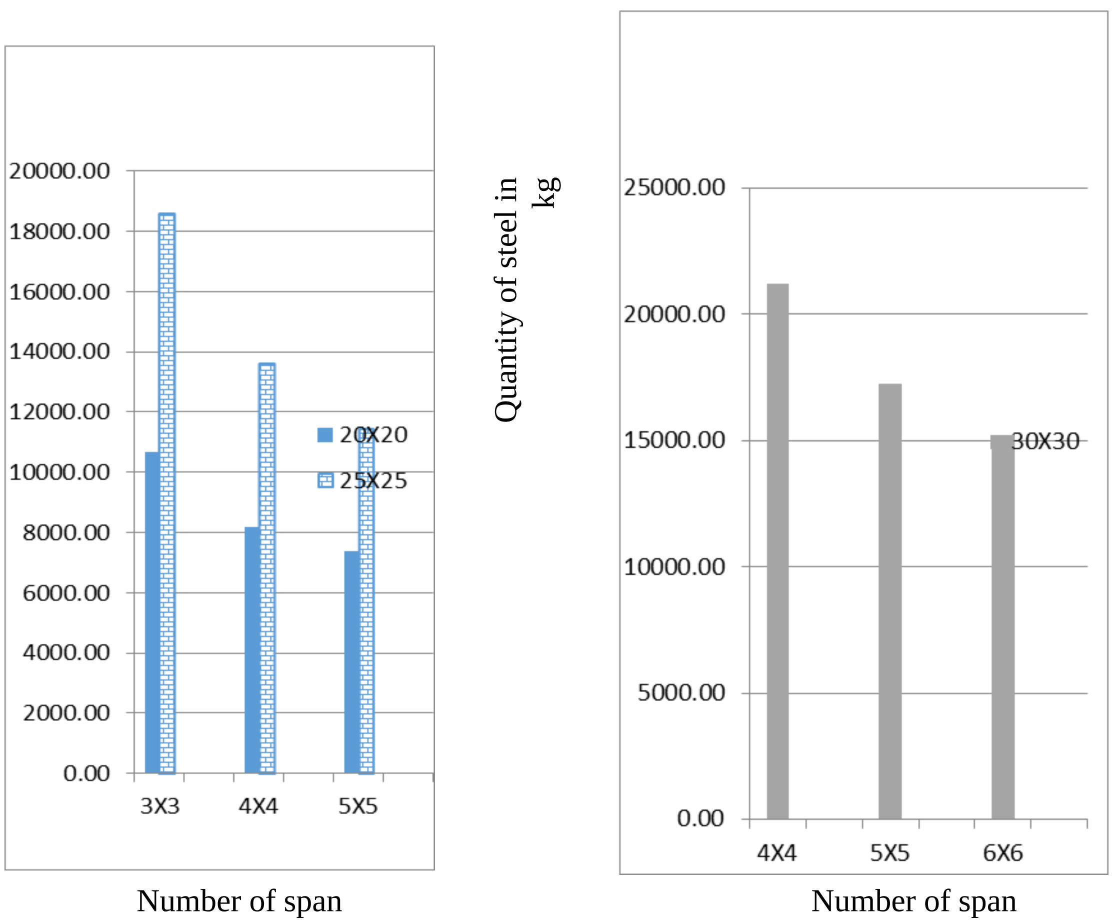


Fig.7.2 Quantity of steel in kg for different spans and number of panels (C20 S 400)

1. CASE: C20 S 400

Grade of Concrete	=	20.00	
Grade of Steel	=	400.00	
Cost of Concrete	=	3367.09	Birr/m³
Cost of Steel	=	32.98	Birr./Kg

Table 7.1.3 Cost of Flat Slab per m² (20 ,400)

C20 S400		Cost of Flat Slab per m²		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	**1982.05**	**1499.30**	**1281.08**
25mX25m		**2352.00**	**1744.00**	**1424.00**
Span		**4X4**	**5X5**	**5X5**
30mX30m		**1992.61**	**1612.46**	**1370.56**

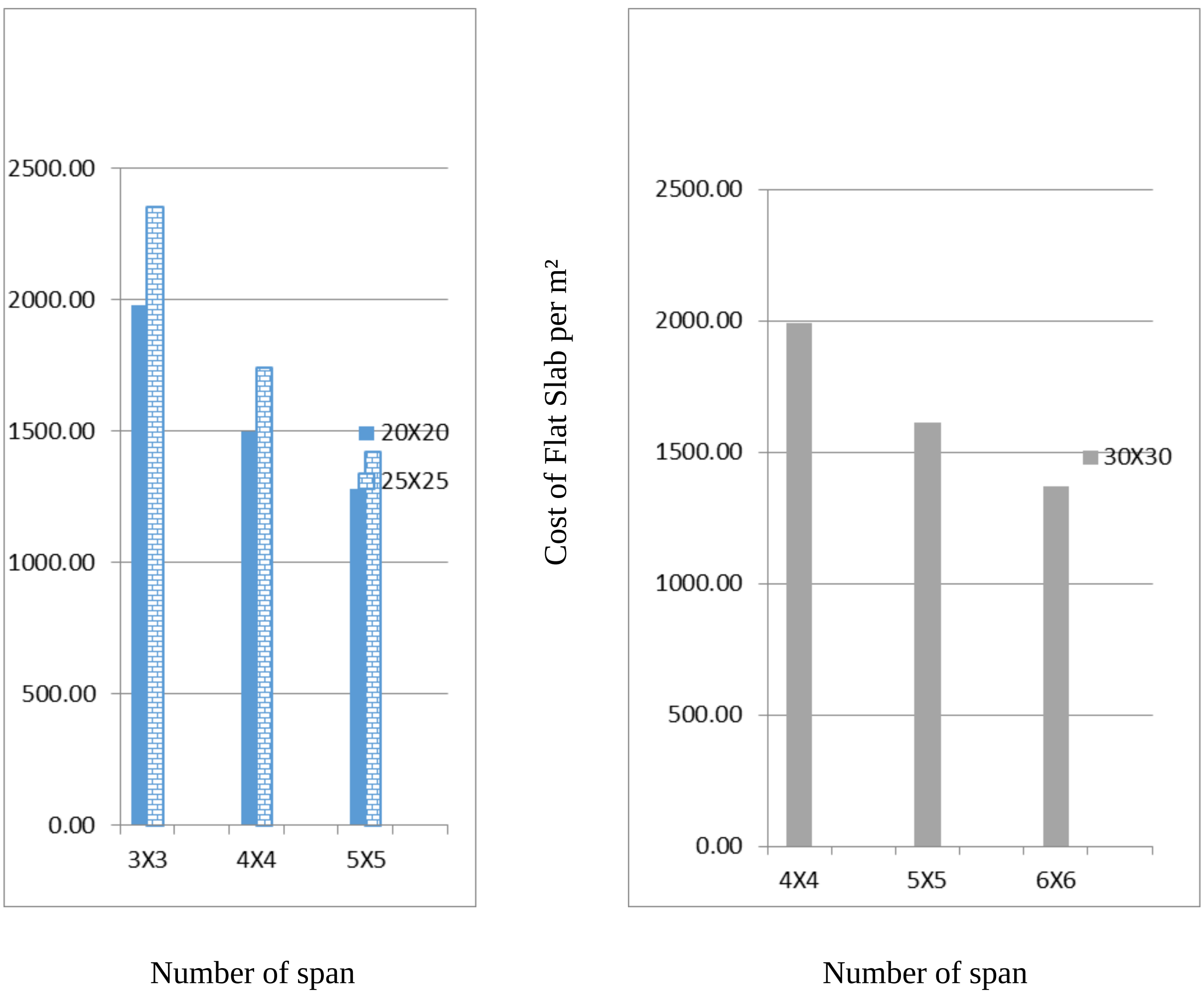


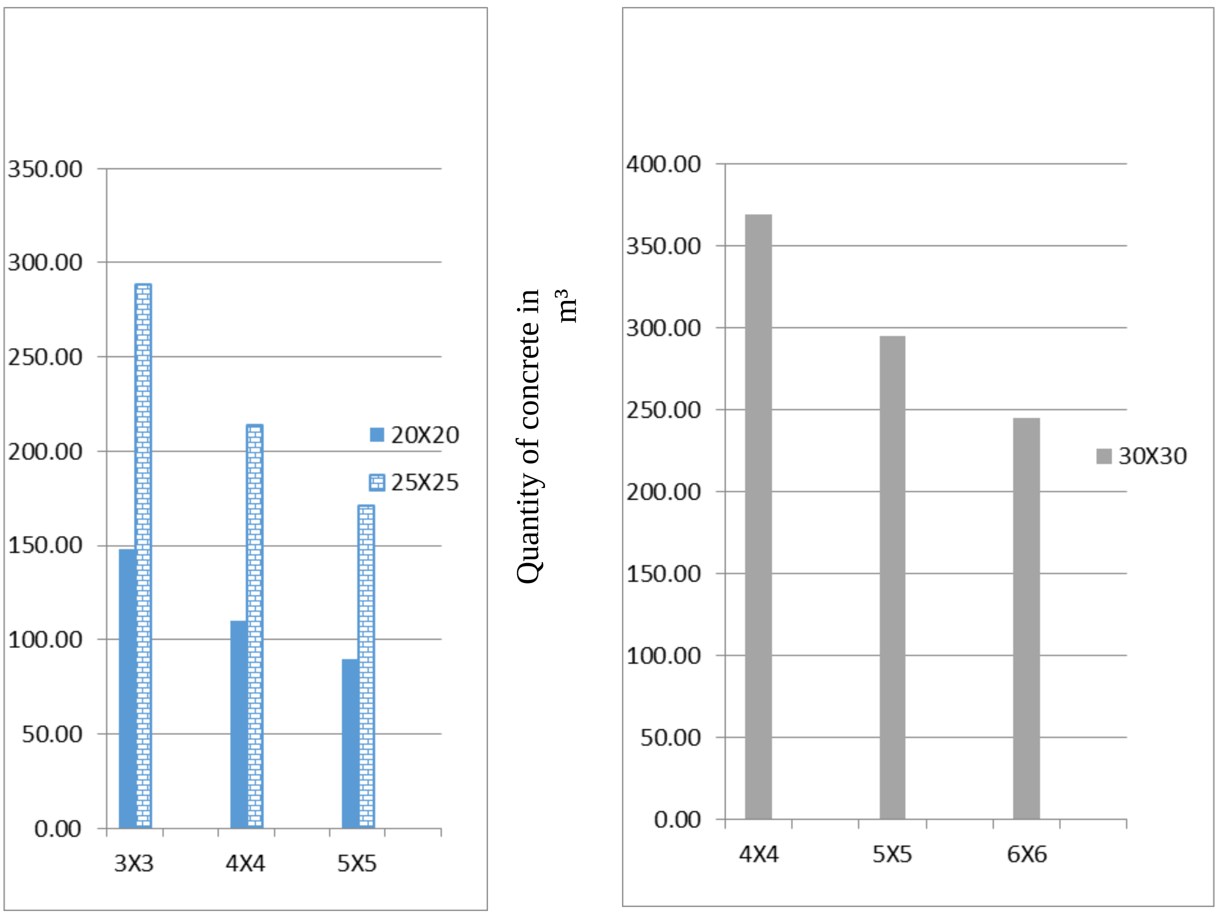
Fig.7.3 Cost of Flat Slab per m²for different spans and number of panels (C20 S 400)

2. CASE: C20 S 500

Grade of Concrete	=	20.00	
Grade of Steel	=	500.00	
Cost of Concrete	=	33677.09	Birr/m³
Cost of Steel	=	40.96	Birr/.Kg

Table 7.2.1 Quantity of concrete in m³ (20 ,500)

C20 S500		Quantity of concrete in m³		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	**148.00**	**110.00**	**90.00**
25mX25m		**288.00**	**214.00**	**171.00**
Span		**4X4**	**5X5**	**6X6**
30mX30m		**369.00**	**295.00**	**245.00**



Number of span Number of span

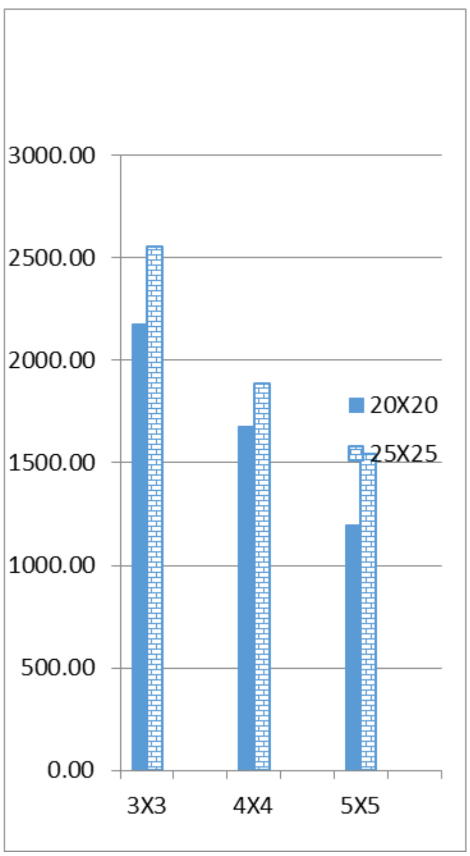
Fig.7.4 Quantity of concrete in m³ for different spans and number of panels (C20 S 500)

2. CASE: C20 S 500

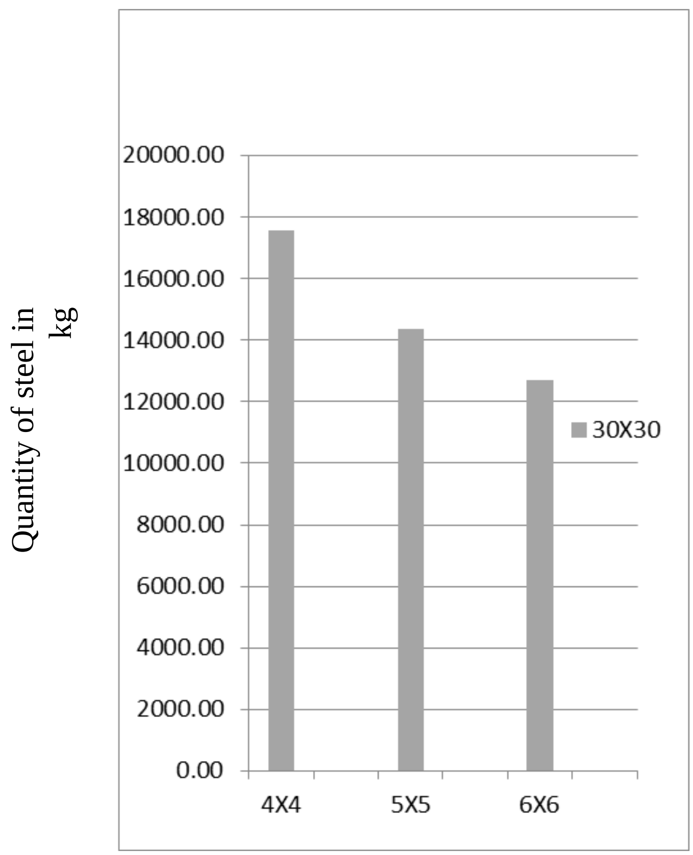
Grade of Concrete	=	20.00	
Grade of Steel	=	500.00	
Cost of Concrete	=	3367.09	Birr/m³
Cost of Steel	=	40.96	Birr/.Kg

Table 7.2.2 Quantity of steel in kg (20 ,500)

C20 S500		Quantity of steel in kg		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	**2180.00**	**1678.00**	**1198.00**
25mX25m		**2560.00**	**1888.00**	**1545.60**
Span		**4X4**	**5X5**	**6X6**
30mX30m		17566.00	**14353.00**	**12693.00**



Number of span



Number of span

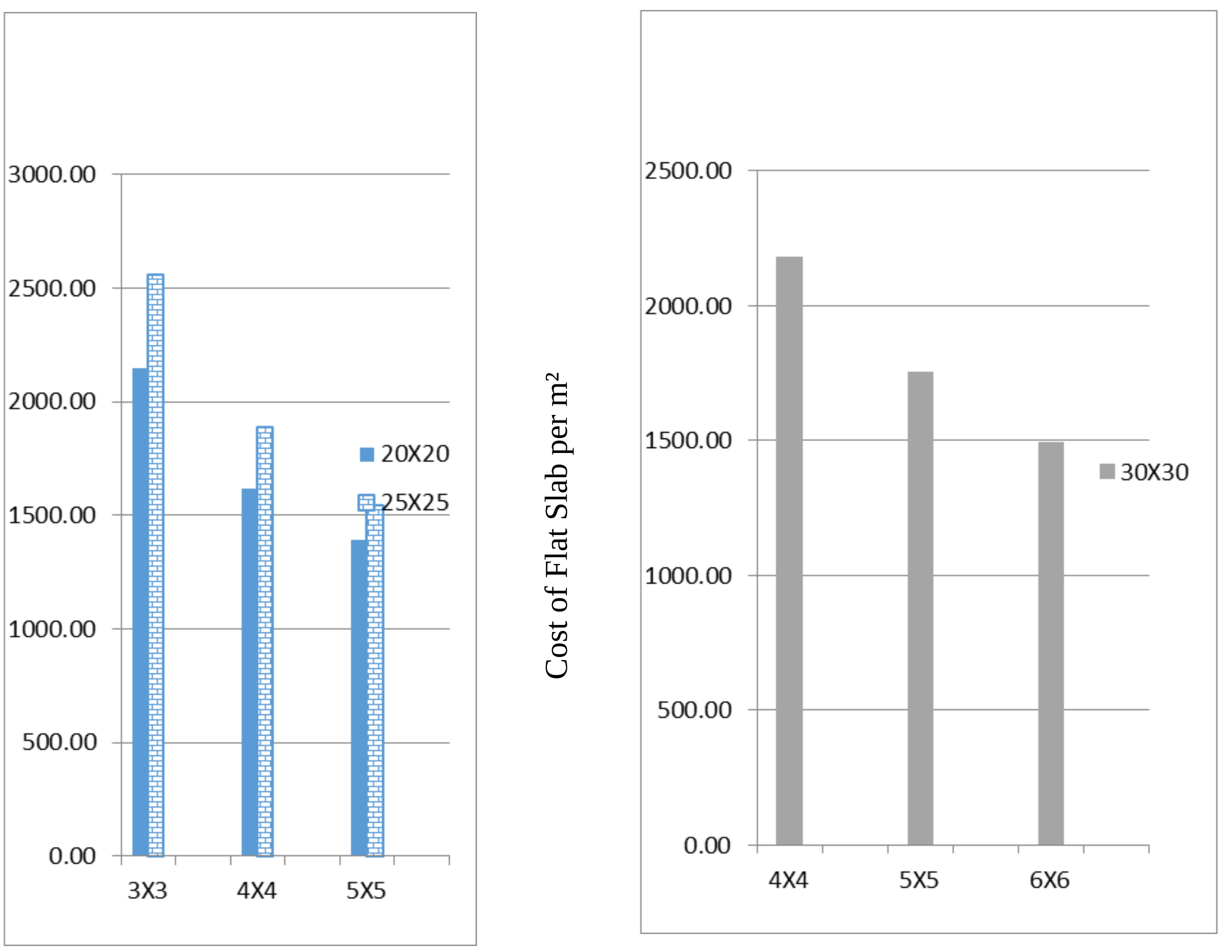
Fig.7.5 Quantity of steel in kg for different spans and number of panels (C20 S 500)

2. CASE: C20 S 500

Grade of Concrete	=	20.00	
Grade of Steel	=	500.00	
Cost of Concrete	=	3367.09	Birr/m³
Cost of Steel	=	40.09	Birr/.Kg

Table 7.3.3 Cost of Flat Slab per m² (20 ,500)

C20 S500		Cost of Flat Slab per m²		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	**2147.66**	**1620.00**	**1393.50**
25mX25m		**2560.00**	**1888.00**	**1545.60**
Span		**4X4**	**5X5**	**6X6**
30mX30m		**2179.96**	**1756.88**	**1494.27**



Number of span   Number of span

Fig.7.6 Cost of Flat Slab per m² for different spans and number of panels (C20 S 500)

3. CASE: C25 S 400

Grade of Concrete	=	25.00	
Grade of Steel	=	400.00	
Cost of Concrete	=	3479.64	Birr/m³
Cost of Steel	=	32.98	Birr./Kg

Table 7.3.1 Quantity of concrete in m³ (25 ,400)

C25 S400		Quantity of concrete in m³		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	**130.00**	**97.00**	**80.00**
25mX25m		**253.00**	**189.00**	**151.00**
Span		**4X4**	**5X5**	**6X6**
30mX30m		**323.00**	**261.00**	**216.00**

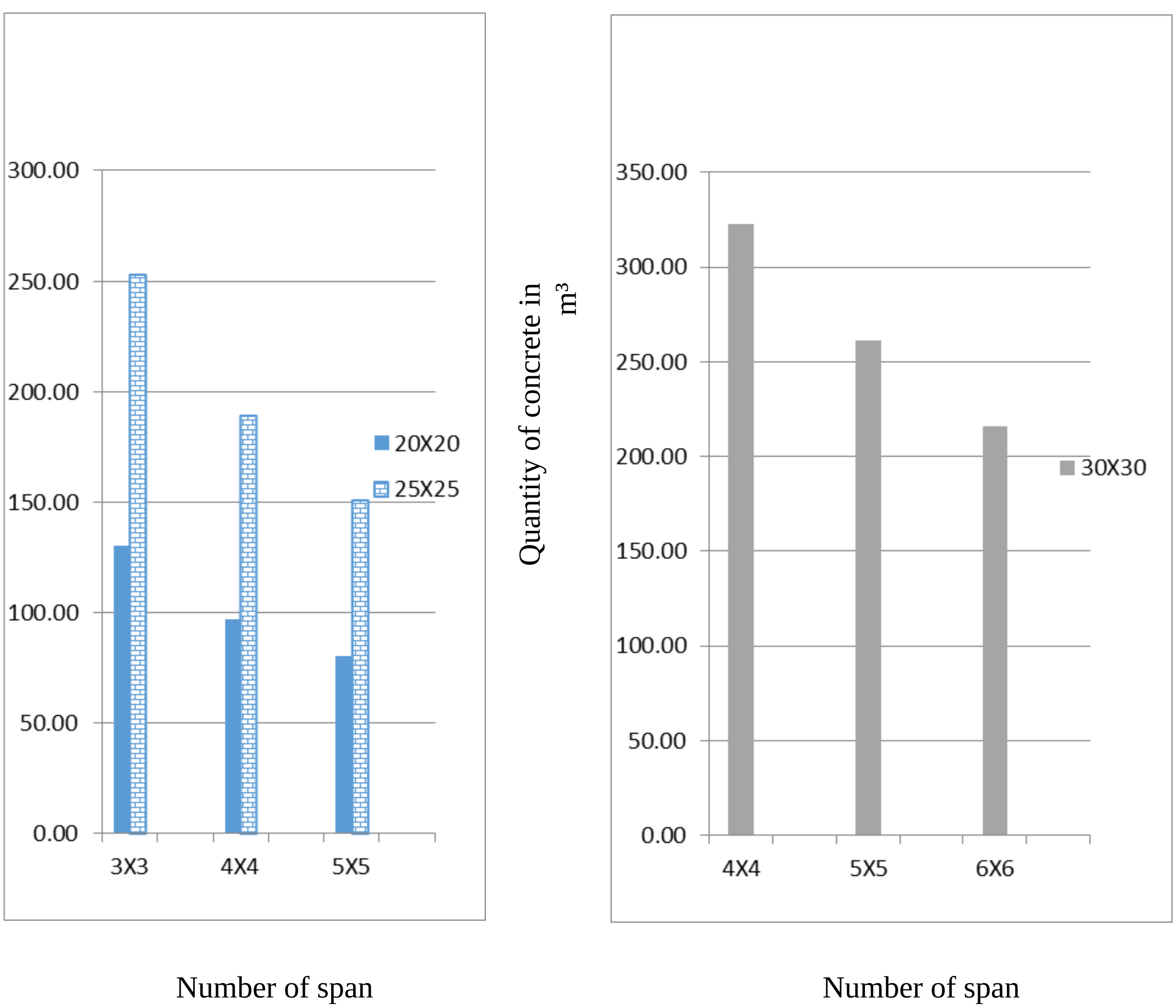


Fig.7.7 Quantity of concrete in m³ for different spans and number of panels (C25 S 400)

3. CASE: C25 S 400

Grade of Concrete	=	25.00	
Grade of Steel	=	400.00	
Cost of Concrete	=	3579.64	Birr/m³
Cost of Steel	=	32.98	Birr/.Kg

Table 7.3.2 Quantity of steel in kg (25 ,400)

C25 S400		Quantity of steel in kg		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	**12158.00**	**9549.00**	**8615.00**
25mX25m		**20994.00**	**15726.00**	**13423.00**
Span		**4X4**	**5X5**	**6X6**
30mX30m		**24158.00**	**19980.00**	**17923.00**

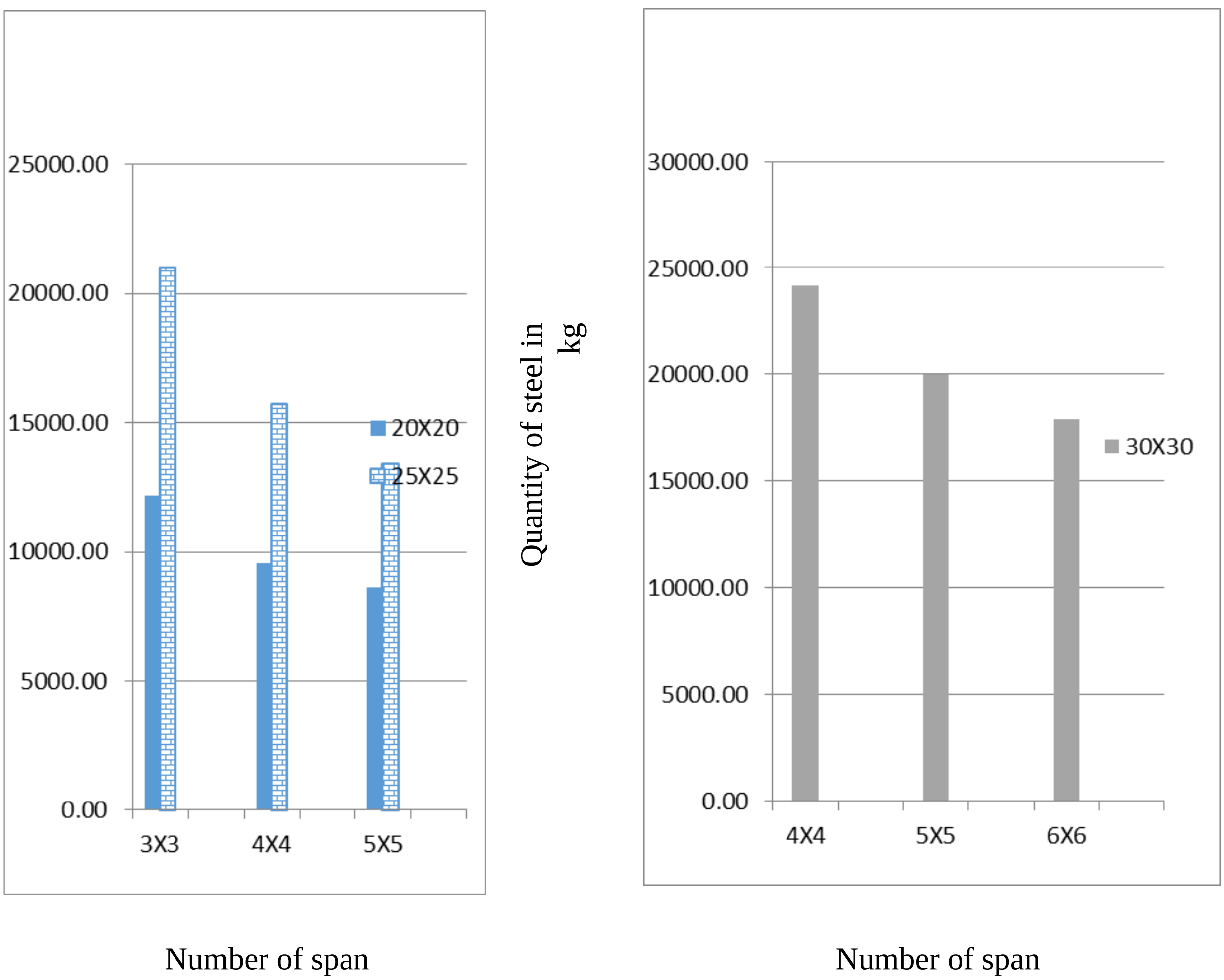


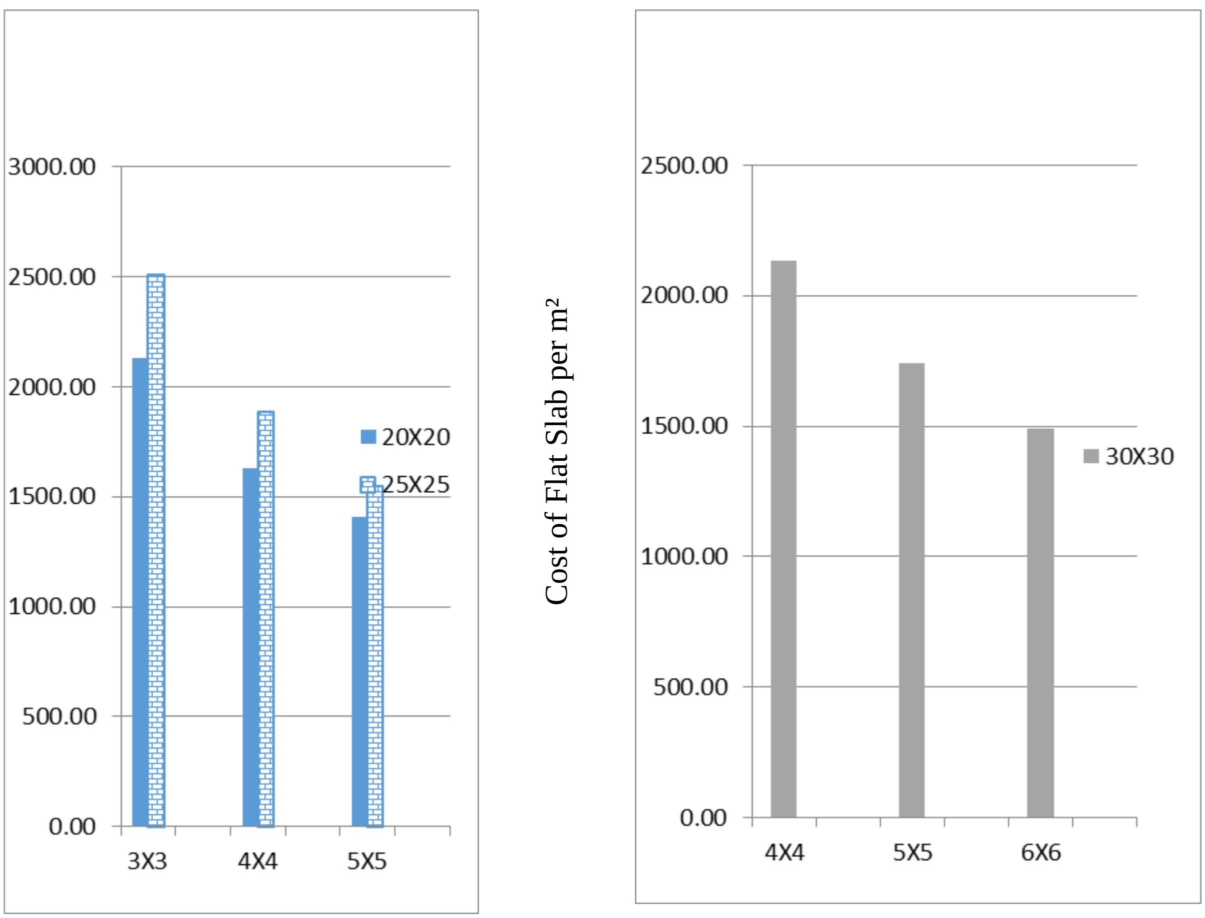
Fig.7.8 Quantity of steel in kg for different spans and number of panels (C25 S 400)

3. CASE: C25 S 400

Grade of Concrete	=	25.00	
Grade of Steel	=	400.00	
Cost of Concrete	=	3479.64	Birr/m³
Cost of Steel	=	32.98	Birr/.Kg

Table 7.3.3 Cost of Flat Slab per m² (25 ,400)

C25 S400		Cost of Flat Slab per m²		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	**2133.31**	**1631.13**	**1406.24**
25mX25m		**2512.00**	**1888.00**	**1548.80**
Span		**4X4**	**5X5**	**6X6**
30mX30m		**2134.06**	**1741.26**	**1491.89**



Number of span Number of span

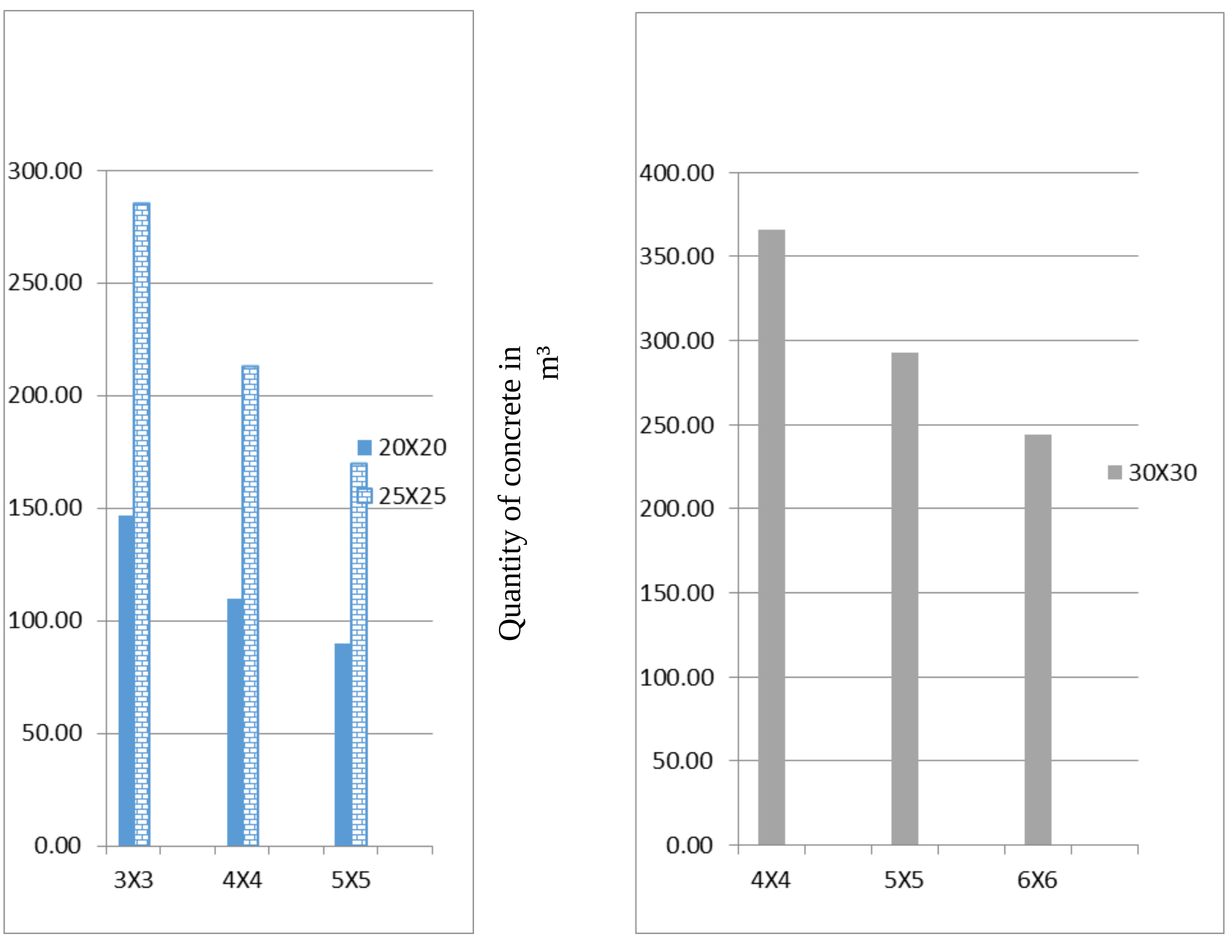
Fig.7.9 Cost of Flat Slab per m²for different spans and number of panels (C25 S 400)

4. CASE: C25 S 500

Grade of Concrete	=	25.00	
Grade of Steel	=	500.00	
Cost of Concrete	=	3479.64	Birr/m³
Cost of Steel	=	40.96	Birr/.Kg

Table 7.4.1 Quantity of concrete in m³ (25 ,500)

C25 500		Quantity of concrete in m³		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	**147.00**	**110.00**	**90.00**
25mX25m		**285.00**	**213.00**	**170.00**
Span		**4X4**	**5X5**	**6X6**
30mX30m		**366.00**	**293.00**	**244.00**



Number of span Number of span

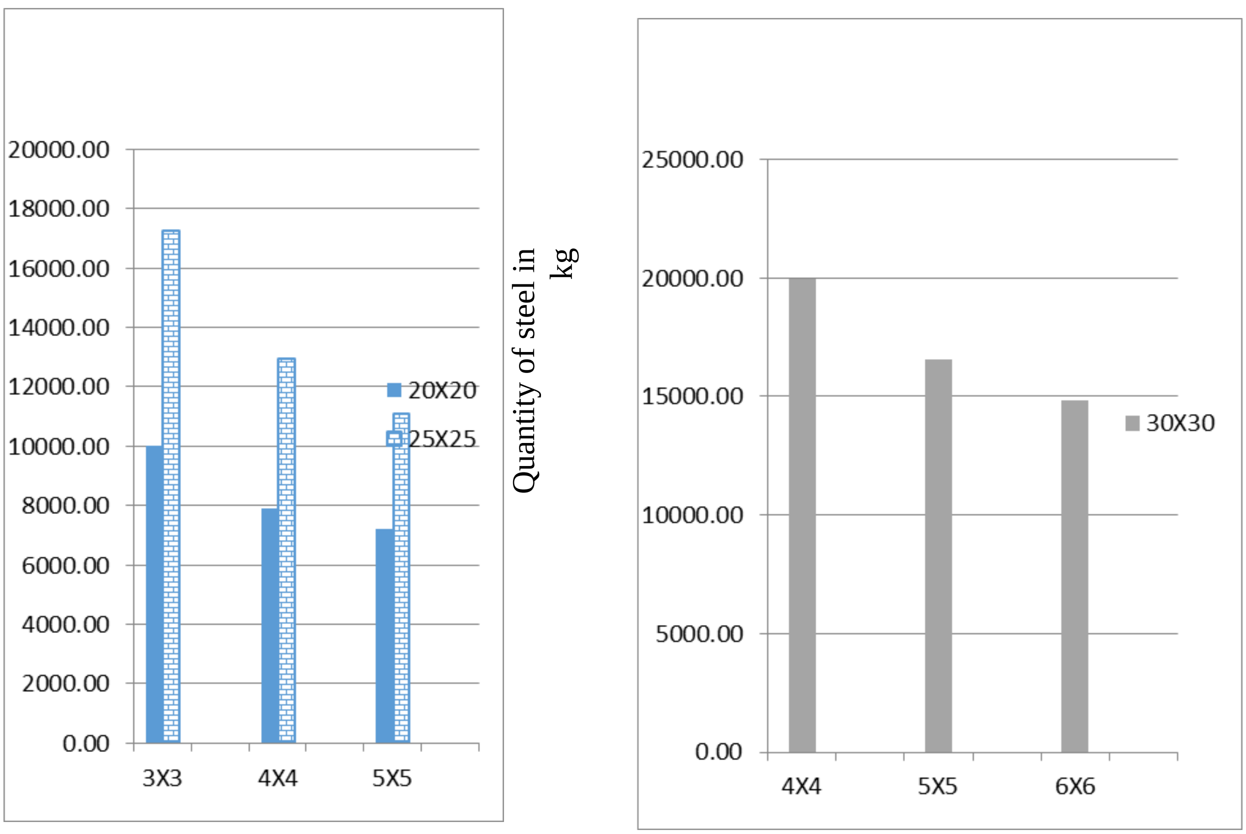
Fig.7.10 Quantity of concrete in m³ for different spans and number of panels (C25 S 500)

4. CASE: C25 S 500

Grade of Concrete	=	25.00	
Grade of Steel	=	500.00	
Cost of Concrete	=	3479.64	Birr/m³
Cost of Steel	=	40.96	Birr/.Kg

Table 7.4.2 Quantity of steel in kg (25 ,500)

C25 S500		Quantity of steel in kg		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	**10026.00**	**7895.00**	**7207.00**
25mX25m		**17290.00**	**12967.00**	**11118.00**
Span		**4X4**	**5X5**	**6X6**
30mX30m		**19972.00**	**16573.00**	**14813.00**



Number of span Number of span

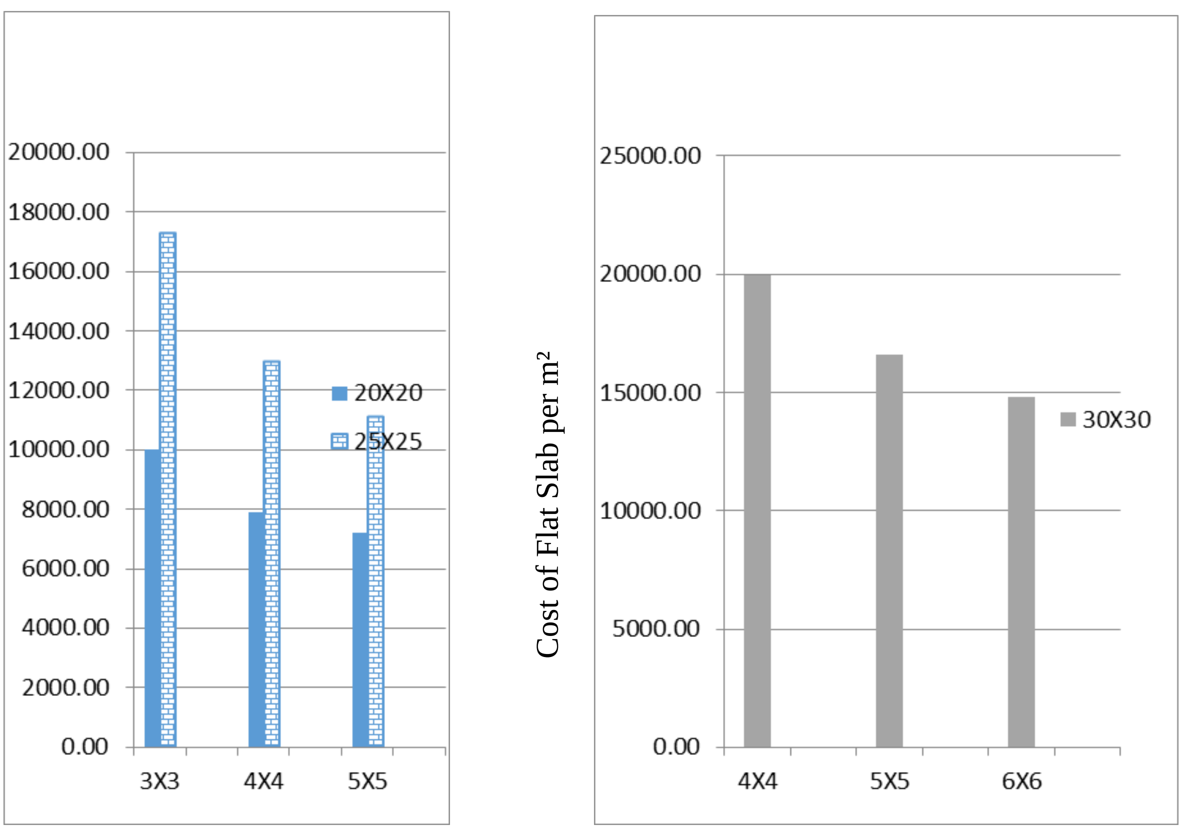
Fig.7.11 Quantity of steel in kg for different spans and number of panels (C25 S 500)

4. CASE: C25 S 500

Grade of Concrete	=	25.00	
Grade of Steel	=	500.00	
Cost of Concrete	=	3479.64	Birr/m³
Cost of Steel	=	40.96	Birr/.Kg

Table 7.4.3 Cost of Flat Slab per m² (25 ,500)

C25 S500		Cost of Flat Slab per m²		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	**2305.43**	**1765.35**	**1520.92**
25mX25m		**2720.00**	**2032.00**	**1680.00**
Span		**4X4**	**5X5**	**6X6**
30mX30m		**2324.00**	**1887.07**	**1617.52**



Number of span　　　　　Number of span

Fig.7.12 Cost of Flat Slab per m²for different spans and number of panels (C25 S 500)

5. CASE: C30 S 400

Grade of Concrete	=	30.00	
Grade of Steel	=	400.00	
Cost of Concrete	=	3561.77	Birr/m³
Cost of Steel	=	32.98	Birr./Kg

Table 7.5.1 Quantity of concrete in m³ (30 ,400)

C30 400		Quantity of concrete in m³		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	**129.00**	**97.00**	**79.00**
25mX25m		**251.00**	**188.00**	**151.00**
Span		**4X4**	**5X5**	**6X6**
30mX30m		**320.00**	**259.00**	**216.00**

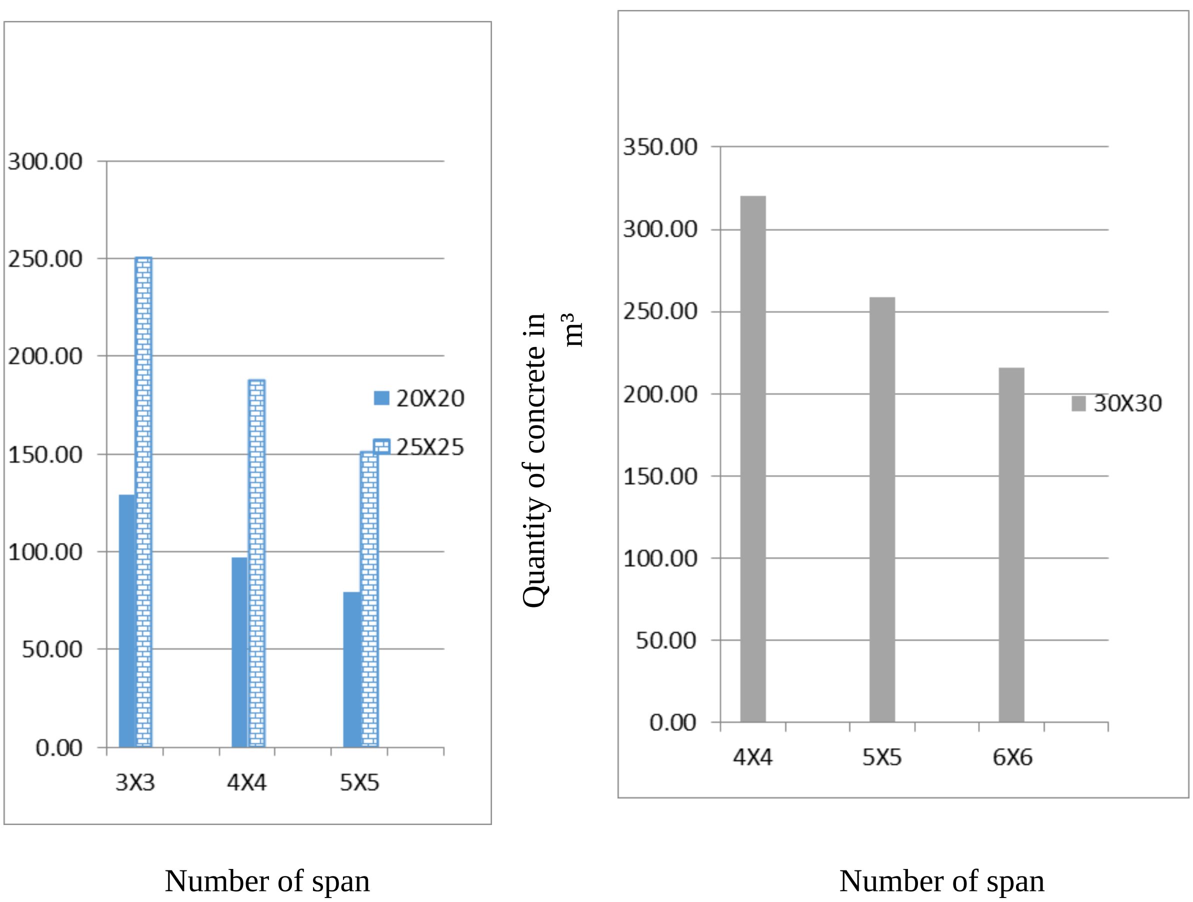


Fig.7.13 Quantity of concrete in m³ for different spans and number of panels (C30 S 400)

5. CASE: C30 S 400

Grade of Concrete	=	30.00	
Grade of Steel	=	400.00	
Cost of Concrete	=	3561.77	Birr/m³
Cost of Steel	=	32.98	Birr/Kg

Table 7.5.2 Quantity of steel in kg (30 ,400)

C30 S400		Quantity of steel in kg		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	13761.00	10981.00	9880.00
25mX25m		23406.00	17857.00	15292.00
Span		**4X4**	**5X5**	**6X6**
30mX30m		27344.00	22822.00	**20479.00**

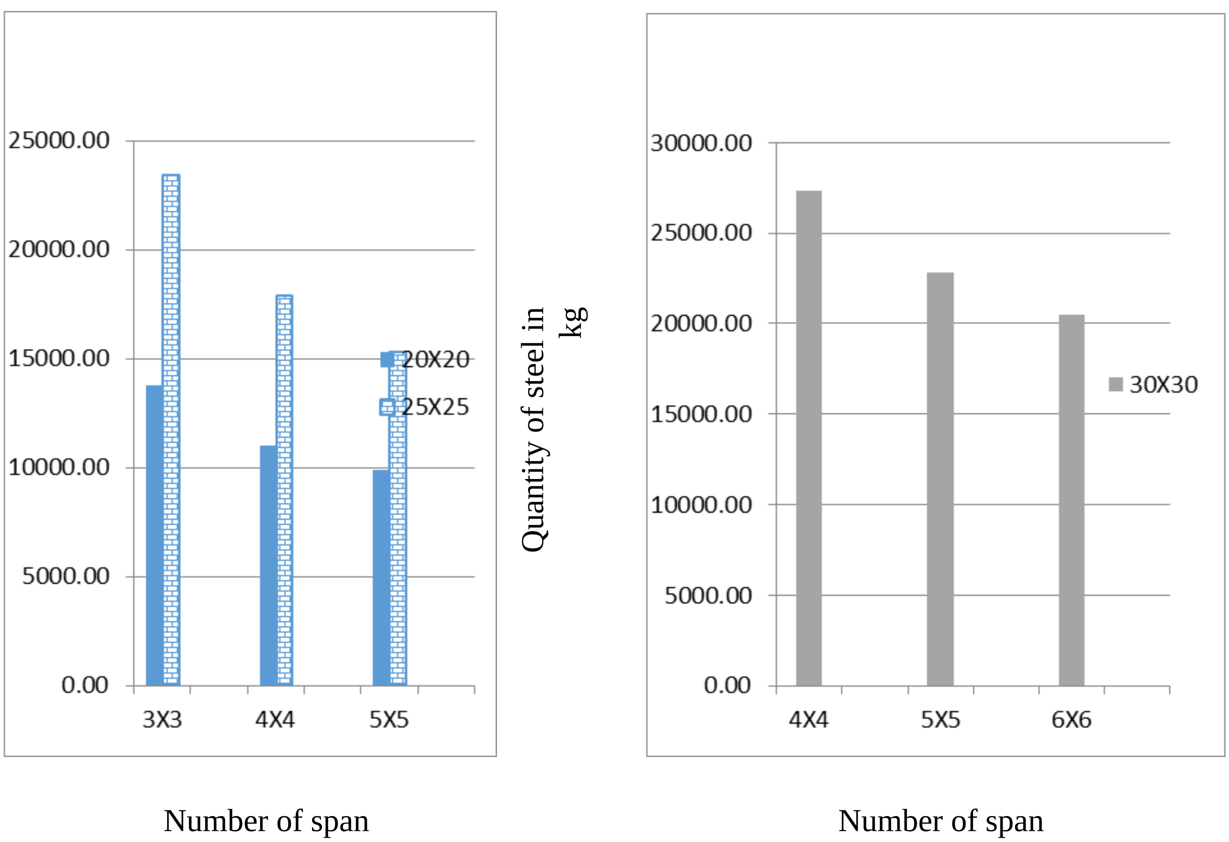


Fig.7.14 Quantity of steel in kg for different spans and number of panels (C30 S 400)

5. CASE: C30 S 400

Grade of Concrete	=	30.00	
Grade of Steel	=	400.00	
Cost of Concrete	=	3561.77	Birr/m³
Cost of Steel	=	32.96	Birr/Kg

Table C.5.3 Cost of Flat Slab per m² (30 ,400)

C30 S400		Cost of Flat Slab per m²		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	2283.27	1769.11	1518.06
25mX25m		2672.00	2016.00	1664.00
Span		**4X4**	**5X5**	**6X6**
30mX30m		2268.41	1861.30	**1605.27**

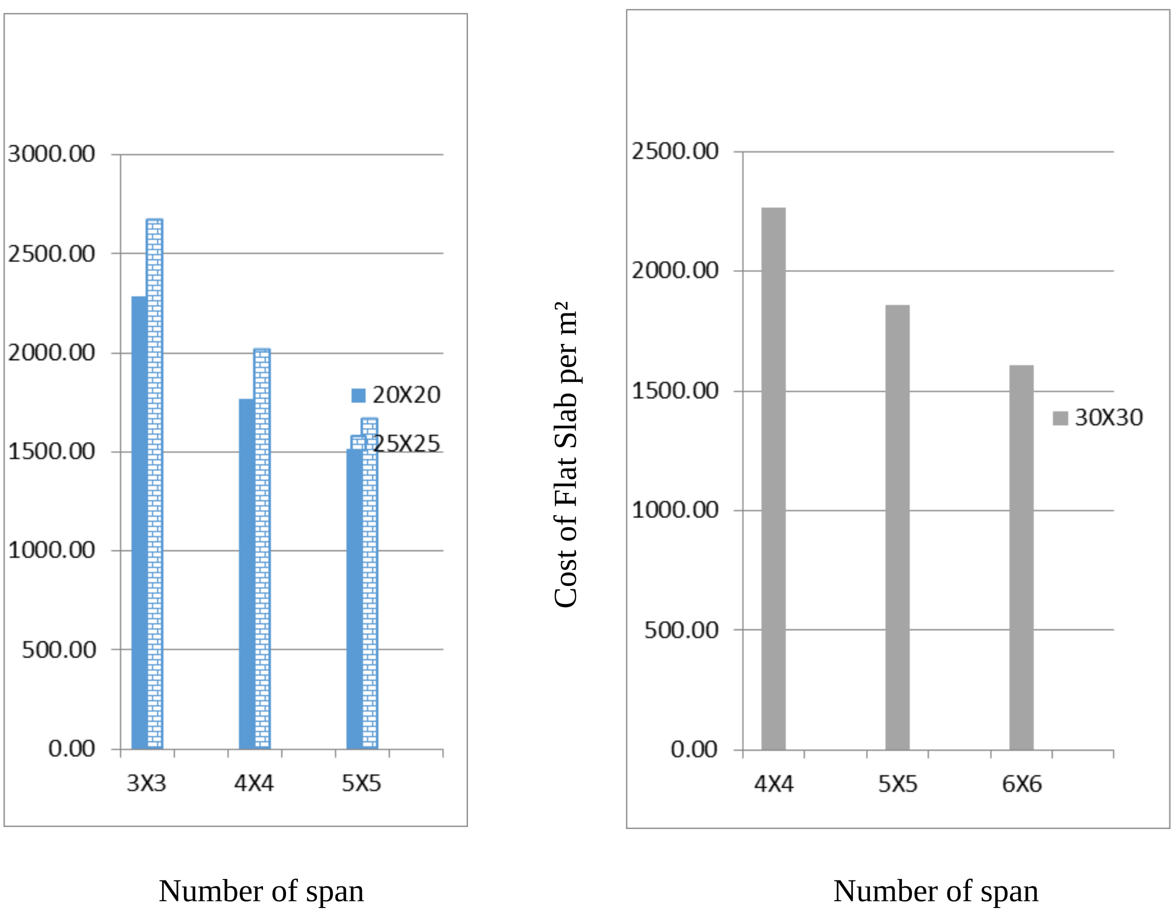


Fig.7.15 Cost of Flat Slab per m²for different spans and number of panels (C30 S 400)

6. CASE: C30 S 500

Grade of Concrete	=	30.00	
Grade of Steel	=	500.00	
Cost of Concrete	=	3561.77	Birr/m³
Cost of Steel	=	40.96	Birr/Kg

Table 7.6.1 Quantity of concrete in m³ (30 ,500)

C30 500		Quantity of concrete in m³		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	146.00	75.00	89.00
25mX25m		283.00	211.00	169.00
Span		**4X4**	**5X5**	**6X6**
30mX30m		**363.00**	292.00	**243.00**

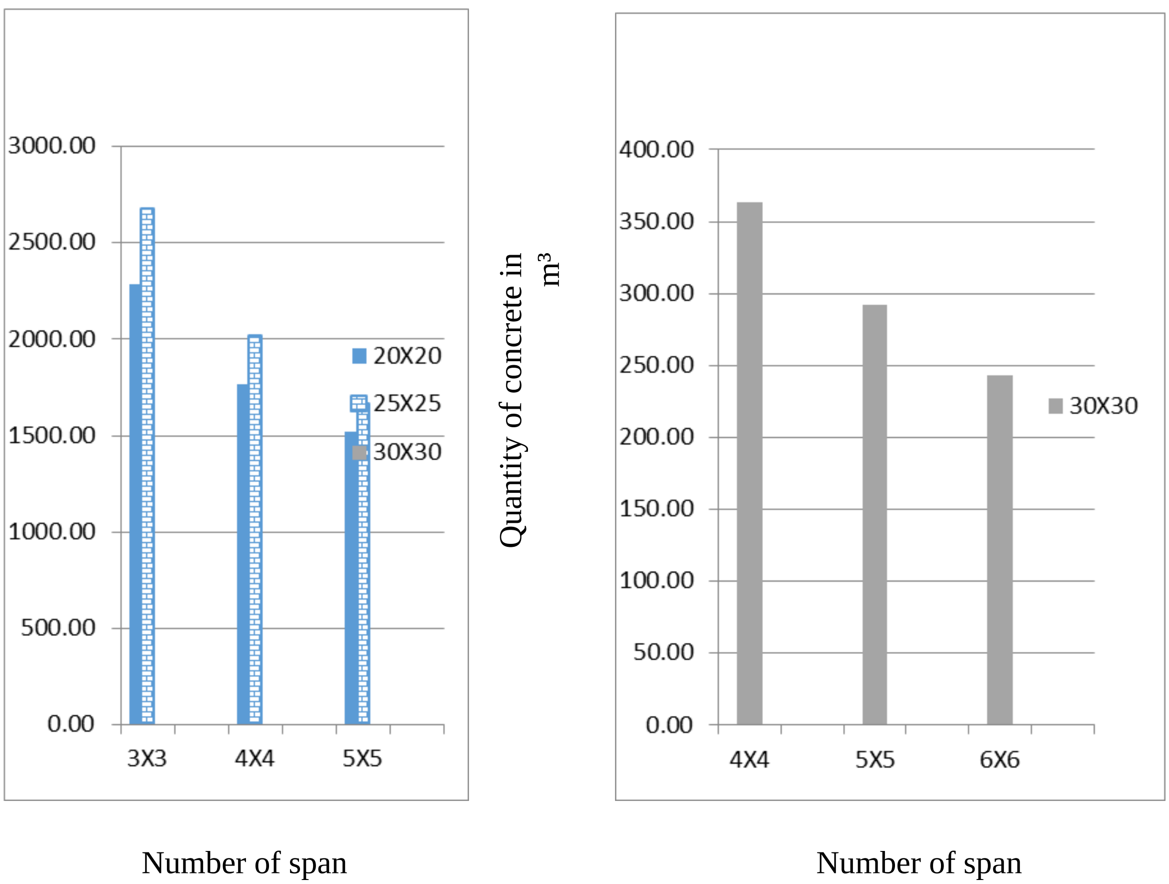


Fig.7.16 Quantity of concrete in m³ for different spans and number of panels (C30 S 500)

6. CASE: C30 S 500

Grade of Concrete = 30.00

Grade of Steel = 500.00

Cost of Concrete = 3561.77 Birr/m³

Cost of Steel = 40.96 Birr/Kg

Table 7.6.2 Quantity of steel in kg (30 ,500)

C30 S500		Quantity of steel in kg		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	11301.00	8938.00	8143.00
25mX25m		19210.00	14725.00	12669.00
Span		**4X4**	**5X5**	**6X6**
30mX30m		22415.00	18839.00	**16876.00**

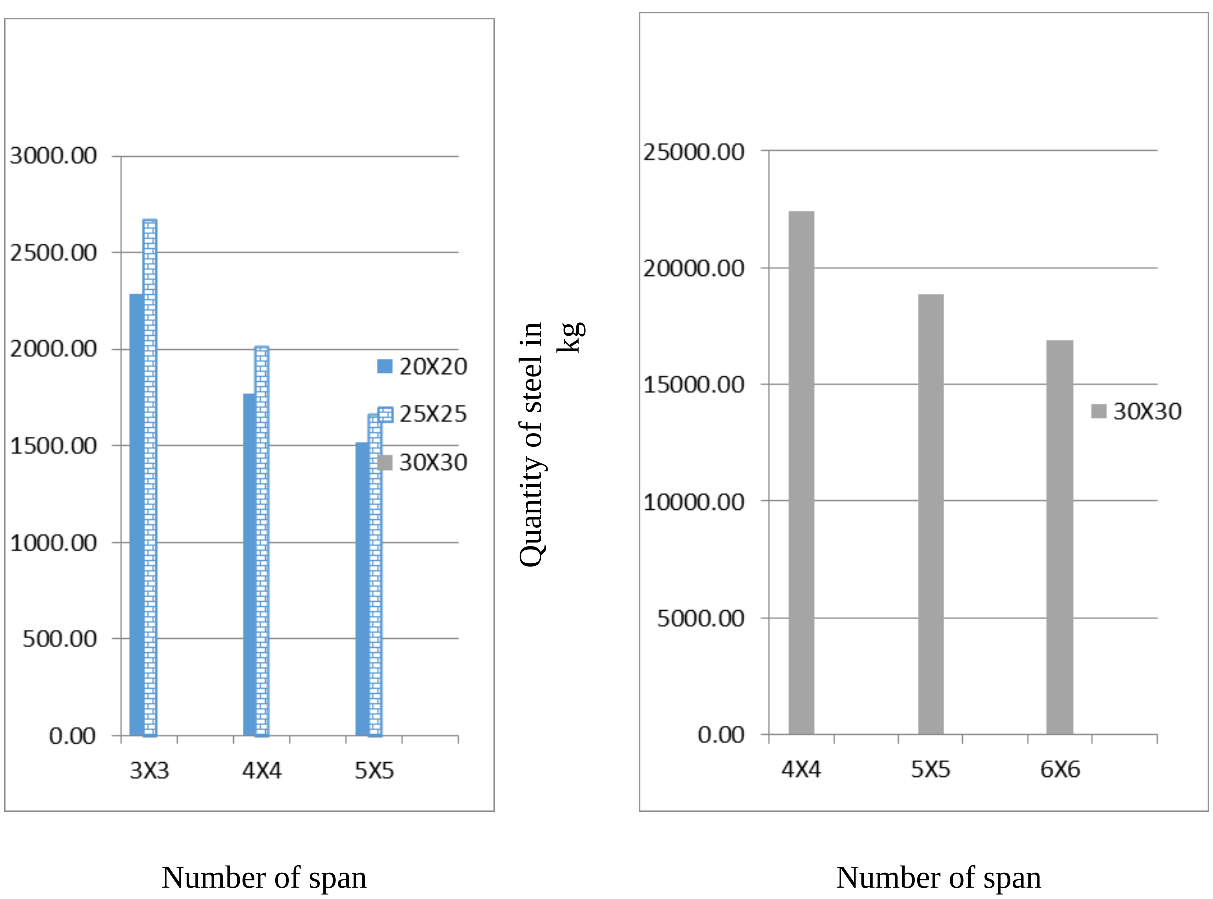


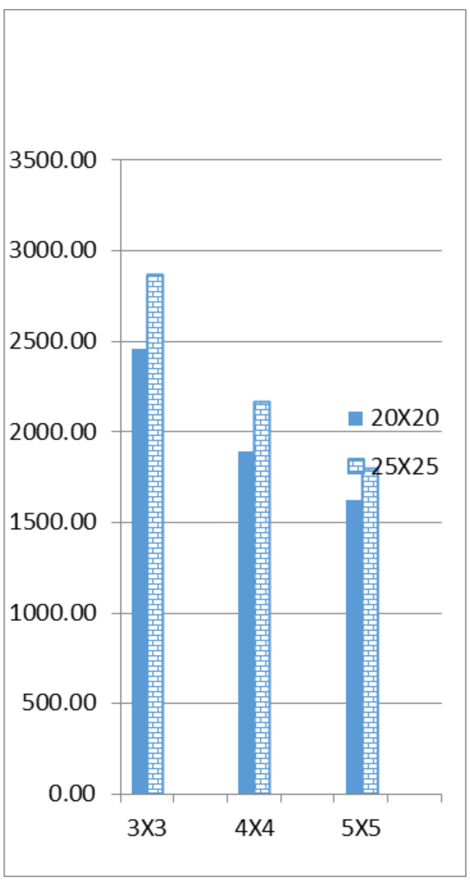
Fig.7.17 Quantity of steel in kg for different spans and number of panels (C30 S 500)

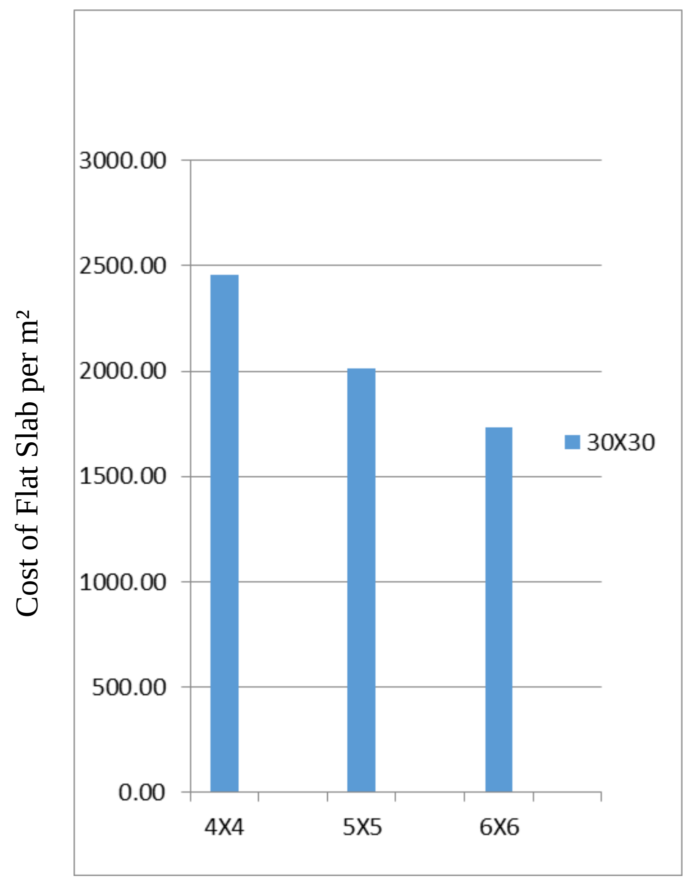
6. CASE: C30 S 500

Grade of Concrete	=	30.00	
Grade of Steel	=	500.00	
Cost of Concrete	=	3561.77	Birr/m³
Cost of Steel	=	40.96	Birr/Kg

Table 7.6.3 Cost of Flat Slab per m² (30 ,500)

C30 S500		Cost of Flat Slab per m²		
Span	**S.P.(NO.SPAN)**	**3X3**	**4X4**	**5X5**
20mX20m	**S.P.(NO.SPAN)**	2457.27	1894.74	1626.34
25mX25m		2864.00	2160.00	1792.00
Span		**4X4**	**5X5**	**6X6**
30mX30m		**2456.71**	2012.98	**1729.72**





Number of span Number of span

Fig.7.18 Cost of Flat Slab per m²for different spans and number of panels (C30 S 500)

CHAPTER EIGHT: RESULTS AND DISCUSSION

8.1 Results

8.1.1 Design and analysis written in MATLAB language

The design and analysis program written in MATLAB language helps a designer to analyses and design efficiently and easily changing the design variables and the proportioning of span. The constraints are normalized between -1 and 0. In the design processes the normalized constraints helps the designer to be in the feasible region of the design.The constraints help the designer to revise his design variables being in the safe side of the design.

8.1.2 Experience with the method of optimum

Most of the optimization method will enables us to find a local minimum only and not necessarily a global minimum. In order to ascertain whether minimum cost of the flat slab obtained for any particular parameter is local minimum or a global on the optimization of different types of span and grade of concrete is carried out with three different starting points designated as SP1, SP2 and SP3.The design vector at optimum, the value of penalty function as well as objective function and the value of constraints are tabulated in tables. From this point it is clear that optimum design starting from three different points is the same. Therefore it can be concluded that the optimum design corresponds to global minimum.

8.1.3 Active Constraints at the optimum

The value of constraints at the optimum design of flat slab for various span and grade combinations are shown in the table 6.1 to 6.49 it can be shown from this table that constraints are active at optimum namely G4 and G10 for optimum point with each of starting point SP1, SP2 and SP3 and other constraints are active in various spans and grade according to the design requirement. In the optimum design the among the design variables the minimum depth and the overall depth of the slab is optimum in 5mm range i.e. deduction of 5mm from the depth of the slab or the overall depth cause the deign to fail or the most active constraints the minimum depth constraints and punching constraints to be out of the range of -1 and zero.

8.1.4 Comparison of Optimum design and normal design

In table 6.1 to 6.49 shows that the comparison of costs of normal design and optimum designs for various spans and grade of concrete. It can be seen from this table that the percentage of saving obtained for optimum dependent also various with the different spans and grade of concrete. Maximum cost saving of 25 % over the normal design is achieved in case of flat slab. The saving achieved thorough optimization can thus be significant.

8.1.5 Variation of Optimum Cost for Different Number of Panels of Slab Units

Illustrative table 7.1.1 to table 7.6.3 and fig 7.1 to 7.18 shows the cost of optimum design of reinforced concrete flat slab unit with various spans. From the table it can be seen that as the total span of flat slab divided into more number of panels the total cost will be decreased and in turn there is saving in cost.

8.1.6 Variation of Cost Optimum Designs for Different Grade of Concrete and Steel

Illustrative table 7.1.1 to table 7.6.3 and fig 7.1 to 7.18 shows the cost of optimum design of flat slab with various grade of concrete for different combination of spans. From table it can be seen that the cost of structure is minimum for concrete grade C 20 but if we use C 25 there is rise in price of structure and if we use C 30 grade instead of C 25 then it can be seen that there is rise in price. Hence it will be economical and suitable to use C 25 instead of C 30 but if we consider overall economy the C 20 will be most suitable.

Similarly for steel S400 is more economical than S 500.There for reinforced concrete flat slab C 20 and S 400 is more economical and suitable for construction.

8.2 Discussion

The developed nonlinear programing problem, all the analysis and design steps and the introduction of the penalty function embedding the constraints and writing all by the MATLAB programing language helps for the optimum design of reinforced concrete flat slab. The written analysis and design nonlinear programing problem can be used as a standard method to aid engineers in the design and optimization of structurally safe cost and weight improved reinforcement concrete flat slab. The constrained optimization problem is converted to unconstrained optimization problem by embedding the normalized constraints and hence the problem can be iterated by solution methods of unconstrained minimization by MATLAB in order to take the vectors to the optimum values. The prepared MATLAB program can be used us a tool to carry out similar activities varying design variables as required.

The analysis and design, as well as the nonlinear programing problem that are written in MATLAB programing language helps the designer to carry out the activity of design of reinforced concrete flat slab efficiently in short time inserting the required inputs. More over the MATLAB solution for unconstrained optimization helps to iterate the design vectors easily as it is reaches to optimum iteratively. Hence, optimum design of reinforced concrete flat slab design is efficient by means of computer program.

As the number of panels increases for a given total span length the total cost of the reinforced concrete flat slab reduces and hence there is saving. As the slab depth and the overall depth, decreases being in the feasible region of design (the constraints are in the range of -1 and zero) the total cost decreases for a given span length of reinforced concrete flat slab. Moreover the total weight reduces as the number of panels increases for a given total span. Lower grades of steel and lower grades of concrete gives least total cost in the design of reinforced concrete flat slab.

The depth of slab and over all depth is reduced iteratively until reduction of 5mm makes the design fail(constraints become positive).At it is showed in the tables of chapter six until 25 percent of cost save is seen as difference between normal design and optimum design.

CHAPTER NINE: CONCLUSION AND RECOMMENDATION

9.1 Content Summary

The problem of optimization of flat slab has been formulated as a mathematical programing problem. The resulting optimum design problem is constrained nonlinear problem and has been solved by sequential unconstrained minimization technique. Parametric study with respect to different types of spans and grade of concrete combination of reinforced concrete flat slab section has been carried out. The result of optimum design of reinforced concrete flat slab has been compared and conclusions are forwarded. For the optimum design of reinforced concrete flat slab the design variables used are Effective depth of slab, Overall depth of drop from top of slab, Number of span required in the longer direction and Number of span required in the shorter direction. The above variables are studied for different grades of concrete, steel, number of panels and different span length.

The cost of reinforced concrete flat slab unit for various spans and grade of concrete is taken as objective function. The cost has two components i.e. concrete cost and steel cost. The concrete cost includes cost of concrete, cost of formwork, labor cost whereas steel cost includes cost of reinforcing steel and steel labor cost.

The constraints for the safe design of reinforced concrete flat slab are the following

- Number of span constraint in X direction
- Number of span constraint in Y direction
- Length constraint
- Minimum depth constraint
- Depth Constraint
- Load constraint
- Moment constraint in slab
- Moment constraint in drop
- Constraint of beam type shear
- Constraint of punching in slab
- Constraint check of punching in drop

Taking all this things into account the behavior constraints equation are formulated. The constrained optimization problem resulting from the mathematical programming problems of optimum design of reinforced concrete flat slab has been solved by SUMT. The constrained optimization problem has been converted into unconstrained, one by penalty function method embedding the normalized constraints with the programing problem.

The normalized constraints are used as barriers to stay in the feasible region of the design i.e safe design satisfying all the constraints. As the constraints are normalized the designer is expected to follow the constraints to be between -1 and 0 in all of the change of vectors in the design processes to find the optimum values.

Moreover since the constrained optimization problem is converted into unconstrained, the MATLAB solution can be used to get the iteration of depths in order to reach to the optimum values being in the feasible region.

9.2 Conclusions

The thesis shows that it is possible to formulate and obtain solution for the optimum design of reinforced concrete flat slab. Several number of variables and constraints are the are the one that make optimum design of reinforced concrete flat slab difficult and this is managed by MATLAB software that works several manipulations at the same time.

The following points have been summarized as conclusions for the research work:

1. It is observed that, the time required for manual deign is much greater than in case of MATLAB which gives the result in microseconds.

2. As the grade of concrete increases in the design of a given total span of reinforced concrete flat slab at the optimum the total cost increases.

3. As the grade of steel increases in the design of a given total span of reinforced concrete flat slab at the optimum the total cost decreases

4. The percentage reduction in optimum weight for reinforced concrete flat slab is directly proportional to number of panel divisions in a given total span.

5. The optimum cost for reinforced concrete flat slab is attained at C 20 and S 400.

6. The maximum cost saving of 25 percent over the normal design is achieved in the optimum design processes of reinforced concrete fat slab.

9.3 Recommendations

1. The designer can use the prepared user friendly computer program and save the time required for manual deign which is much greater than in case of MATLAB which gives the result in microseconds.
2. The designers in design and consultation office are advised to use lower grades of concrete so as to get optimized design.
3. Similarly to attain the optimum design of reinforced concrete flat slab the designers should use lower grade of concrete.
4. Designers should proportion the number of panels in the design of reinforced concrete flat slab in a way that the panel division increases so as to get least weight.
5. The structural designer should use lower grade of concrete / C 20 / and lower grade of steel / S 400 / to attain the optimum design of reinforced concrete flat slab.
6. The 25% cost saving over the normal design is significant so the ministry of construction should work put criterion on optimization of reinforced concrete flat slab.

9.4 Future Research

Further studies on the optimum design of reinforced concrete flat slabs can be done. These include the following:

1. Considering other cases of flat slab such as a reinforced concrete slab with column heads and combination of drop with column head.

2. Using other methods of structural analysis as finite element method

3. Considering relevant additional constraints

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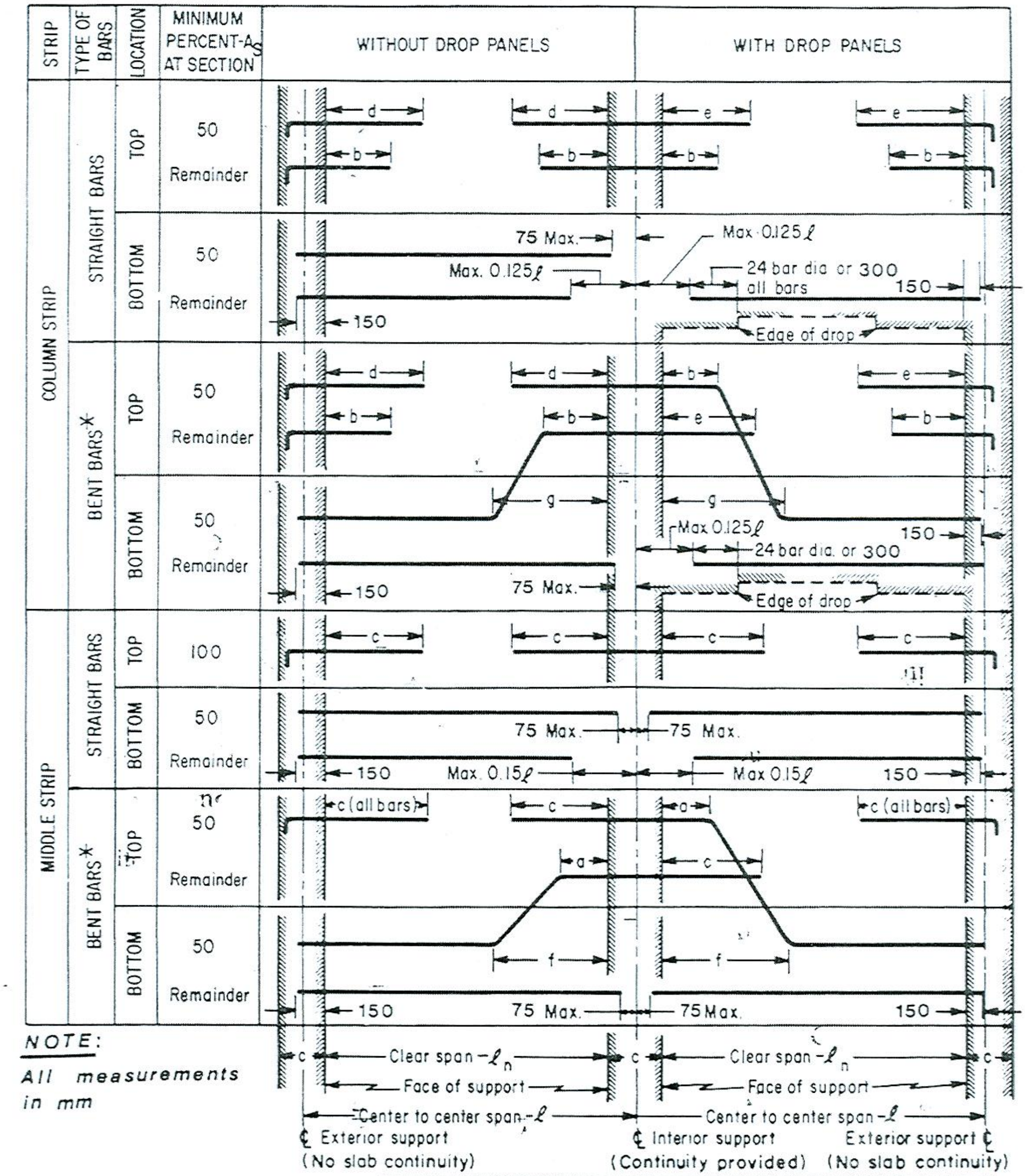
APPENDIX A: Minimum Bend Point Locations and Extensions for reinforcement

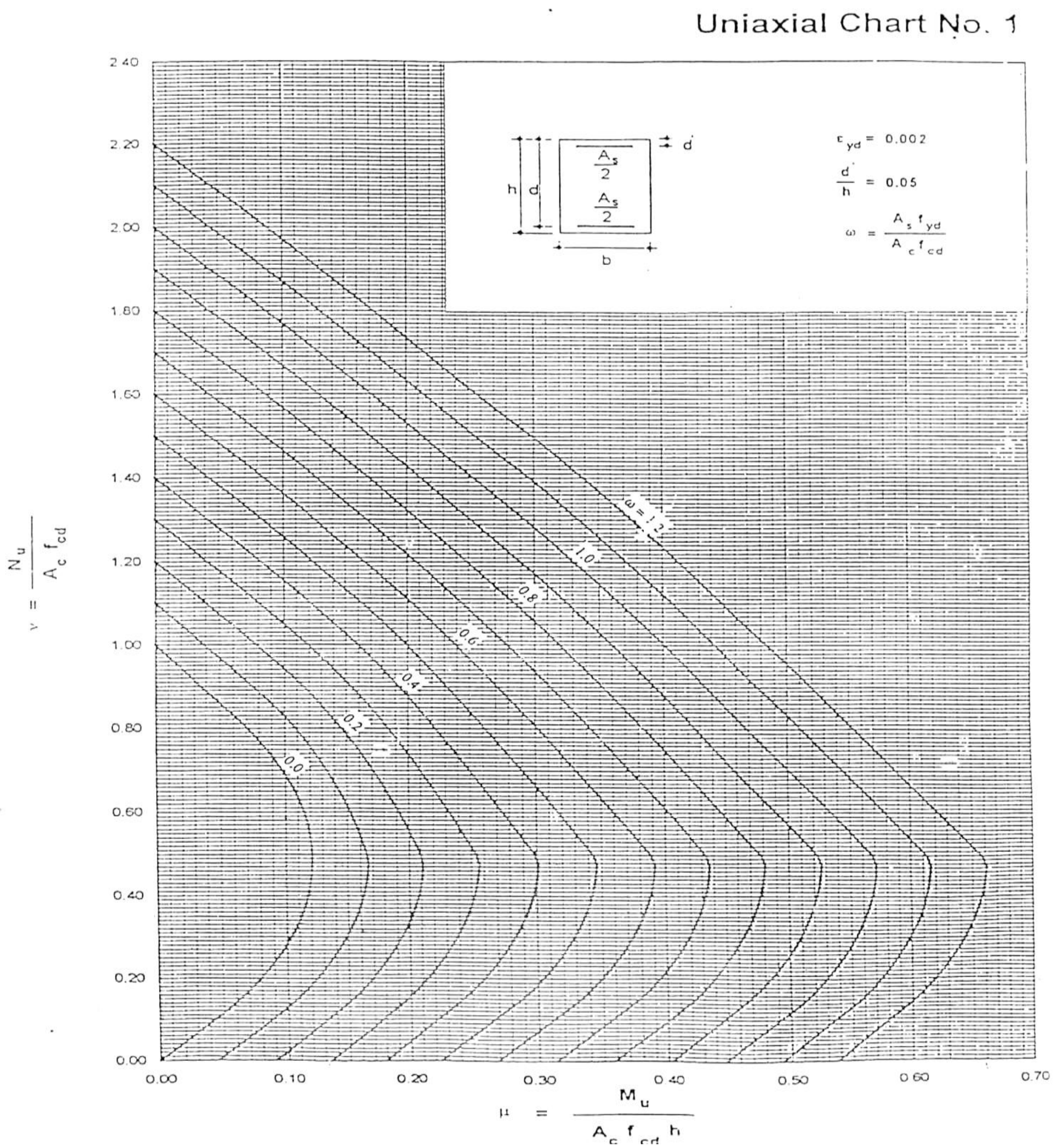


* Bent bars at exterior supports may be used if a general analysis is made

	BAR LENGTH FROM FACE OF SUPPORT						
	MINIMUM LENGTH					MAXIMUM LENGTH	
MARK	a	b	c	d	e	f	g
LENGTH	$0.14\ell_n$	$0.20\ell_n$	$0.22\ell_n$	$0.30\ell_n$	$0.33\ell_n$	$0.20\ell_n$	$0.24\ell_n$

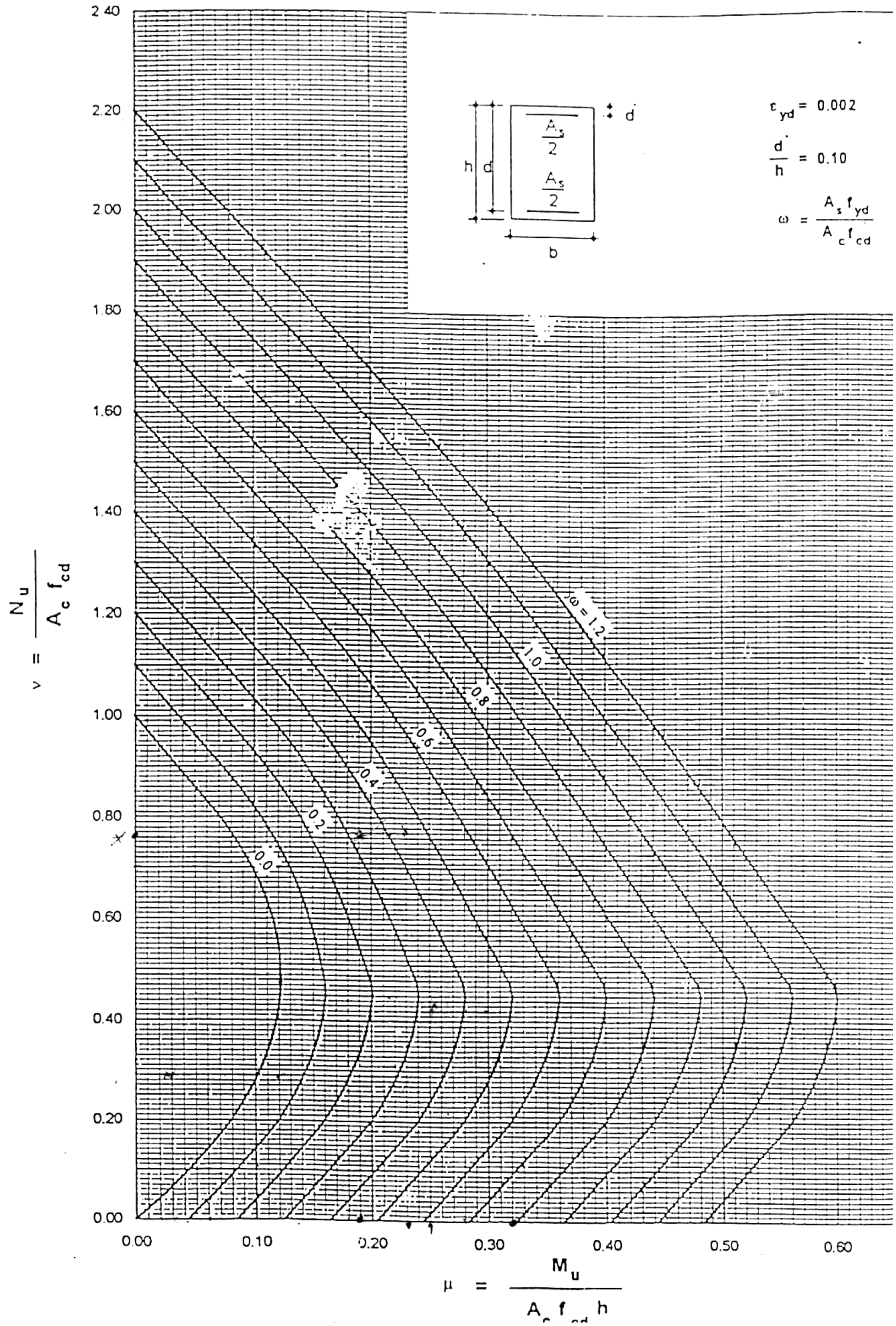
Source EBCS 2, 1995

APPENDIX B: Design Charts Reinforced Concrete Column



Source ESCP-2

Uniaxial Chart No. 2



Source ESCP-2

APPENDIX C: Comparison of Hand Calculation and MATLAB Calculation

Values		Manual Calculation	Matlab Calculation	Unit
Variables				
X1	=	210	210	mm
X2	=	340	340	mm
X3	=	4	4	no's
X4	=	4	4	no's
Nx	=	20000	20000	mm
Ny	=	20000	20000	mm
hf	=	4000	4000	mm
Ly	=	5000	5000	mm
Lx	=	5000	5000	mm
S	=	400	400	N/mm2
Fck	=	20	20	N/mm2
Scost	=	44	44	Birr/Kg
Ccost	=	3502	3502	Birr/m3
Cx	=	500	500	mm
Cy	=	500	500	mm
Lcx	=	4500	4500	mm
Lcy	=	4500	4500	mm
Select slab thickness to limit difflection				
Fyk	=	400	400	N/mm2
X1d	=	208.333333	208.3333	mm
X1	=	210	210	mm
Cover	=	15	15	mm
St	=	225	225	mm
Finding length of column strip and middle strip				
LLCS	=	2500	2500	mm
LLMS	=	2500	2500	mm
LSCS	=	2500	2500	mm
LSMS	=	2500	2500	mm
Drop Panel Dimension				
Dx	=	1666.6666	1666.6666	
Dy	=	1666.6666	1666.6666	
dt	=	131.6667	131.6667	
dd	=	325	325	
Effective depths of slab and drop in the longer and shorter directions				
dsl	=	204	204	mm
dss	=	192	192	mm
dtl	=	110.6667	110.6667	mm
dts	=	98.6667	98.6667	mm

Finding equvalent slab thickness				
Est	=	238	238	mm
Loading				
Gks1	=	5.7876	5.712	KN/m2
Gks2	=	3.15	3.15	KN/m2
Gk	=	9.0376		KN/m2
Qk	=	5	5	KN/m2
Pd	=	19.74888	195206	KN/m2
Design Strength of Materials				
fcd	=	11.3333	11.3333	N/mm2
fctk	=	1.5473	1.543	
fctd	=	1.0315	1.0315	
fyd	=	374.826	347.8261	
p	=	0.00125	0.0013	
K1	=	1.0625	1.0625	
K2	=	1.514	1.514	
Check for Shear				
Beam type Shear				
F	=	488.015	488.015	KN
Vmax	=	244.007	244.007	KN
Dave	=	170	170	mm
Daved	=	134	134	mm
Vcr	=	232.6856	232.6856	KN
Vcb	=	277.94	277.94	KN
Punching Shear				
dtav	=	86	86	mm
Ud	=	7032	7032	mm
dsav	=	196	196	mm
Us	=	21032	21032	mm
Vdvc	=	476.7992	476.7992	KN
Vcdc	=	0.7884	0.7884	
Vdvd	=	388.7816	388.7816	KN
Vcdd	=	0.2149	0.2149	
Vcp	=	0.8297	0.8297	

Values	Manual Calculation		Matlab Calculation	Unit
Design For Flexure				
Effective Span Calculation				
hcy	=	564.1896	564.1896	mm
hcx	=	564.1896	564.1896	mm
Lny	=	4.6239	4.6239	m
Lnx	=	4.6239	4.6239	m
Distribution of Moment				
FOR LONG SPAN				
Bending moment for exterior panel				
ML1	=	142.16077	142.16077	KNm
ML2	=	187.2911	187.2911	KNm
ML3	=	90.2608	90.2608	KNm
Bending moment for exterior panel-column strip				
MLc1	=	106.6206	106.6206	KNm
MLc2	=	103.0101	103.0101	KNm
MLc3	=	67.6956	67.6956	KNm
Bending moment for exterior panel-middle strip				
Mlm1	=	35.5402	35.5402	KNm
Mlm2	=	84.281	84.281	KNm
Mlm3	=	35.5402	35.5402	KNm
Bending moment for interior panel				
ML4	=	124.1086	124.1086	KNm
ML5	=	160.2129	160.2129	KNm
Bending moment for interior panel-column strip				
MLc4	=	93.0814	93.0814	KNm
MLc5	=	88.1171	88.1171	KNm
MLc6	=	93.0814	93.0814	KNm
Bending moment for interior panel-middle strip				
MLm4	=	31.0271	31.0271	KNm
MLm5	=	72.0958	72.0958	KNm
MLm6	=	31.0371	31.0371	KNm
FOR SHORTER SPAN				
Bending moment for exterior panel				
MS1	=	142.1607	142.1607	KNm
MS2	=	187.2911	187.2911	KNm
MS3	=	90.2608	90.2608	KNm
Bending moment for exterior panel-column strip				
MSc1	=	106.6206	106.6206	KNm
MSc2	=	103.0101	103.0101	KNm
MSc3	=	677.6956	677.6956	KNm

Values		Manual Calculation	Matlab Calculation	Unit
Bending moment for exterior panel-middle strip				
MSm1	=	35.5402	35.5402	KNm
MSm2	=	84.281	84.281	KNm
MSm3	=	35.5402	35.5402	KNm
Bending moment for interior panel				
MS4	=	124.1086	124.1086	KNm
MS5	=	160.2129	160.2129	KNm
Bending moment for interior panel-column strip				
MSc4	=	93.0814	93.0814	KNm
MSc5	=	88.1171	88.1171	KNm
MSc6	=	93.0814	93.0814	KNm
Bending moment for interior panel-middle strip				
MSm4	=	31.0271	31.0271	KNm
MSm5	=	72.0958	72.0958	KNm
MSm6	=	31.02	31.02	KNm
Check for Maximum Moment in Slab				
Mposmax	=	103.0101	103.0101	KNm
Xumax	=	134.4	134.4	mm
Mslab	=	472.4698	472.4698	KNm
Check for Maximum Moment in Drop				
Mnegmax	=	106.6206	106.6206	KNm
Xumax	=	208	208	mm
Mdrop	=	1.13E+03	1.13E+03	KNm
Calculation of Reinforcement				
In longer directon				
For Column Strip top Reinforcement				
McsnegLmax	=	106.62	106.62	KNm
AstcstL	=	3417.80	3417.80	mm2
dcstL	=	12	12	mm
LbcstL	=	1004.90	1004.90	mm
QcstL	=	27.00	26.96	Kg

Values		Manual Calculation	Matlab Calculation	Unit
for column strip bottom reinforcement at mid				
McsposLmax	=	103.0101	103.0101	KNm
AstcsbL	=	1521.40	1521.40	mm2
ScstL=provided	=			mm
LbcstL	=	4998.80	4998.8	mm
QcsbL	=	59.70	61	Kg
For middle strip top reinforcement at support				
MmsnegLmax	=	35.5402	35.5402	KNm
AstmstL	=	3.08E+02	308.3333	mm2
LbmstL	=	2700.00	2700	mm
QmstL	=	6.54E+00	7	Kg
For middle strip bottom reinforcement at mid				
MmsposLmax	=	84.281	84.281	KNm
AstmsbL	=	1.23E+03	1.23E+03	mm2
LbcstL	=	9848.60	9848.60	mm
QmsbL	=	95.37	96.00	Kg
IN SHORTER DIRECTION				
For column strip top reinforcement at support				
McsnegSmax	=	106.6206	106.6206	KNm
AstcstS	=	3.42E+03	3.42E+03	mm2
LbcstS	=	1.00E+03	1.00E+03	mm
QcstS	=	26.9611	27	Kg

Values		Manual Calculation	Matlab Calculation	Unit
For column strip bottom reinforcement at mid				
McsposSmax	=	103.01	103.01	KNm
AstcsbS	=	1521.40	1529.60	mm2
LbcstS	=	3933.30	3933.30	mm
QcsbS =	=	46.98	47.00	Kg
For middle strip top reinforcement at support				
MmsnegSmax	=	35.54	35.54	KNm
AstmstS	=	345.83	345.83	mm2
dmstS	=	8.00	8.00	mm
LbmstS	=	2700.00	2700.00	mm
QmstS	=	7.33	8.00	Kg
For middle strip bottom reinforcement at mid				
MmsposSmax	=	84.28	84.28	KNm
AstmsbS	=	1233.60	1233.60	mm2
LbcstS	=	9848.60	9848.60	mm
QmsbS	=	95.37	96.00	Kg
Column Strip Top Reinforcement				
Column strip top reinforcement in longer direction				
Pt	=	0.13	0.13	KNm
AstdistL	=	731.25	731.25	mm2
ddistL	=	8.00	8.00	mm
LbdistL	=	2500.00	2500.00	mm
QdistL	=	14.35	15.00	Kg

Values		Manual Calculation	Matlab Calculation	Unit
Column strip top reinforcement in shorter direction				
Pt		0.13	0.13	KNm
AstdistS	=	731.25	731.25	mm2
SdistS=provided	=			mm
LbdistS	=	2500.00	2500.00	mm
QdistS		14.35	15.00	Kg
Calculation of Drop Panel Bottom Steel				
Drop panel bottom steel in longer direction				
Pt	=	0.13	0.13	KNm
AstdropL	=	736.67	736.67	mm2
ddropL	=	8.00	8.00	mm
SdropL		113.72	113.72	mm
SdropL=provided	=	113.00	113.00	mm
LbdropL	=	2576.70	2576.70	mm
QdropL	=	14.90	15.00	Kg
Drop panel bottom steel in shorter direction				
Pt		0.13	0.13	KNm
AstdropS	=	736.6667	736.6667	mm2
ddropS	=	8	8	mm
SdropS	=	113.7228	113.7228	mm
SdropS=provided	=	113	113	mm
LbdropS	=	2.58E+03	2.58E+03	mm
QdropS	=	14.9	15	Kg
Load Applied On Column				
WT	=	7808.20	7808.20	KN
Wte	=	312.33	312.33	KN
Design of main steel				
Pt	=	0.8	0.8	KN
Asc	=	2000	2000	mm2

Values		Manual Calculation	Matlab Calculation	Unit
Ties calculation				
dties	=	8	8	mm
Sties1	=	300	300	mm
Sties2	=	144	144	mm
Sties3		500	500	mm
Stiesmin	=	144	144	mm
Calculation of column reinforcement				
Qcolm	=	63.9226	63.9226	Kg
Lties	=	1880	1880	mm
Nties	=	28	28	no's
Aties	=	1407.40	1407.40	mm2
Qcolt	=	20.77	21	kg
Qcol	=	84.48	85	kg
Constraint Equation				
G1	=	-0.5	-0.5	
G2	=	-0.5	-0.5	
G3	=	-0.5	-0.5	
G4	=	**-0.0082**	**-0.0079**	
G5	=	-0.3333	-0.3333	
G6	=	-0.5186	-0.5486	
G7	=	-0.792	-0.782	
G8	=	-0.8058	-0.9058	
G9	=	-0.2248	-0.2148	
G10	=	-0.2342	-0.2273	
G11	=	-0.674	-0.787	
Quantity of Material				
Concrete				
Qcslab	=	91	90	Kg
Qcdrop	=	8	8	Kg
Qccolumn	=	1	1	Kg
Qconcrete	=	100	99	Kg
Steel				
Qsslab	=	1592	1592	kg
Qsdrop	=	750	750	kg
Qcolumn	=	5775	5775	kg
Qsteel	=	8117	8117	kg
Total cost				
COSTtotal	=	601060	601060	Birr