SOFTWARE FOR ANALYSIS AND DESIGN OF FLAT SLAB

By

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Major Project

Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology in Civil Engineering
(Computer Aided Structural Analysis & Design)

By

Sonawane Sandip Prakash
(06MCL019)

Guide
Mr. R.V. Shah

DEPARTMENT OF CIVIL ENGINEERING
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CERTIFICATE

This is to certify that the Major Project entitled "Analysis and Design of flat slab" submitted by Mr. Sonawane Sandip Prakash (06MCL019), towards the partial fulfillment of the requirements for the degree of Master of Technology in Civil Engineering (Computer Aided Structural Analysis and Design) of Nirma University of Science and Technology, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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ABSTRACT

Girder less floor directly resting on support (column and/ wall) is known as flat slab. Because of this, large bending moment and shear force is developed at / near the column head hence there is a need to increase the area at top of column to withstand the stresses. This enlarged truncated portion at the top of column is known as column head/ column capital.

Flat slabs are subjected to gravity and lateral loads. Gravity load analysis of flat slab is carried out by Direct Design Method (DDM) and Equivalent Frame Method (EFM) as prescribed by different standards, however three dimensional finite element analysis of flat slab is carried out for gravity and lateral loads using software SAFE.

I.S.456-2000, ACI 318-02 prescribed the fixed coefficients for analysis of flat slab as per DDM. Three dimensional analysis of flat slab is carried out to compare the coefficients prescribed by different standards and by three dimensional finite element analysis using software for distribution of moments along longitudinal and transverse direction, when it is subjected to gravity and lateral loading.

Slab is divided into column strip and middle strip. I.S.456-2000 specifies the fixed value of column strip and middle strip irrespective of interior span and mid span, the present study also incorporates the comparison of distribution of width of column strip and middle strip as per I.S. 456 and as per 3D finite element analysis.

Software is prepared for analysis and design of flat slab as per DDM and EFM. DDM includes analysis as per I.S.456, ACI-318 and using the distribution coefficients along longitudinal and transverse direction calculated by the 3D analysis.

From the analysis results it is found that the distribution of negative moment at support is more as compared to distribution prescribed by I.S.456 and ACI 318 and B.S.8110, also it is observed that the width of column strip in end span is smaller than the interior span.

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ABBREVIATION NOTATION AND NOMENCLATURE

δ_x	Deflection at mid span in X direction
δ_y	Deflection at mid span in Y direction
l_x	Span length in X direction
l_y	Span length in Y direction
M_0	Total moment
l_n	Clear span in the direction of moments
w	Total factored load
w_D	Factored dead load
w_L	Factored live load
α_c	Ratio of flexural stiffness of exterior columns to flexural Stiffness of slab
K_C	Sum of flexural stiffness of columns meeting at a joint
K_S	Flexural stiffness of slab
K_{ec}	Flexural stiffness of equivalent column
K_C	Flexural stiffness of original column
K_t	Torsional stiffness of transverse slab/ beam
L_1	Span in the direction in which moments are determined From centre to centre of support
L_2	Span transverse to L_1
l_n	Length of clear span in the direction of M, measured face to Face of support
$M_c^{'}$	Moment carried by exterior column
$M_{t\max}$	Maximum torsional moment carrying capacity of column
f_{ck}	Characteristic cube compressive strength of concrete
b_c	Width of slab
E_b	Modulus of elasticity of beam
E_c	Modulus of elasticity of column
I_b	Moment of inertia of the effective beam
I_s	Moment of inertia of the effective slab
h	Minimum slab thickness

α_m	Average value of α for all beams on edge panel
β	Ratio of clear span in longer direction to shorter direction
β_c	Ratio of longer side to shorter side of column capital
C	Torsional constant of the transverse torsional members
E_C	Modulus of elasticity of concrete
C_1	Size of support in direction parallel to lateral load
C_2	Size of support in direction transverse to support
αl_2	Effective width of slab
K_{ec}	Flexural stiffness of equivalent column
K_C	Flexural stiffness of actual column
K_t	Torsional stiffness of actual column
K_{fp}	Factor adjusting αl_2 at edge, exterior and corner support
K_D	Stiffness degradation factor
K_{EFM}	Lateral stiffness of equivalent frame method model
K_{FEM}	Lateral stiffness of finite element method model
Δ	Total lateral displacement of frame
Δ_C	Displacement due to column deformation
Δ_S	Displacement due to slab deformation
R_K	Stiffness reduction factor for structure
R_{KS}	Stiffness reduction factor for slab
E_R	Reduced modulus of elasticity
E	Original modulus of elasticity
υ	Shear stress in slab
τ_p	Punching shear stress in slab
F	Total design ultimate load
C.S.	Column strip
M.S.	Middle strip
I.F.	Interior Frame
E.F.	Exterior Frame
L. D.	Longitudinal distribution
T. D.	Transverse Distribution

1. INTRODUCTION

1.1 GENERAL

Although the introduction of Reinforced Concrete flat slab floors is a significant advancement in the building technology, historical literature on their development is ambiguous. Up to 1910- 1911 slab, beam and girder system reigned supreme but at this time the girderless floors sometimes called as Mushroom slab, which is also known as flat slab begin to build.

Historically, flat slabs predate both two- way slabs on beams and flat plates. Several systems of placing of reinforcement have been developed since then such as four way system, two way system, three way system and a circumferential system.

Claud A. P. Turner was one of the early advocates of flat slab system known as "mushroom" system. About 1908, flat slab began and recognized as acceptable floor system. C.A.P. Turner constructed flat slabs in U.S.A. in 1906 mainly using intuitive and conceptual ideas, which was start of this type of construction.

Flat slabs are being used mainly in office buildings due to reduced formwork cost, fast excavation, and easy installation. Flat slab system possesses many advantages in terms of architectural flexibility, use of space, easier formwork, and shorter construction time.

1.2 NECESSITY OF FLAT SLABS

Architectural demand for better illumination, lesser fire resistance of sharp corners present in the form of beams, increase in the formwork cost, optimum use of space leads to the new concept in the field of structural engineering as Reinforced concrete flat slabs.

1.3 COMPONENTS OF FLAB SLAB

Flat slab means a reinforced concrete slab with or without drop, supported generally without beams by column. Main components of flat slab are.

1. Drop.
2. Panel.
3. Column Head
4. Column strip.
5. Middle strip.

1.3.1 Drop

The thickened part of the slab over the column is called drop. 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. For exterior panels, width of drops at right angles to the non continuous edge and measured from centre line of columns shall be equal to one half the width of drop for interior panels.

1.3.2 Panel

Part of the slab bounded on each of its four sides by centre line of a column or centre line of adjacent columns.

1.3.3 Column head

Widened area at the top of column to provide more resistance to shear and bending developed at the top of column, because of transfer of load from slab to column is called as column head or column capital.

1.3.4 Column strip

Bands of slab in both directions along column lines are considered to act as beams, which are known as strips and the strip which pass through the column is known as Column strip. Width of the column strip is 0.25 $l_{2,}$ but not greater than 0.25 l_1 on each side of a column centre line where l_1 is the span in the direction in which moments are determined and l_2 is the span transverse to l_1, measured centre to centre of supports.

1.3.5 Middle strips

A design strip bounded on each of its opposite sides by the column strip. Middle strip behaves as a continuous beam supported on column strip.

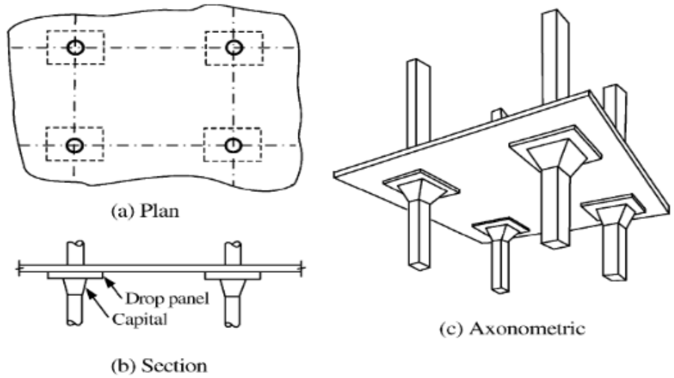


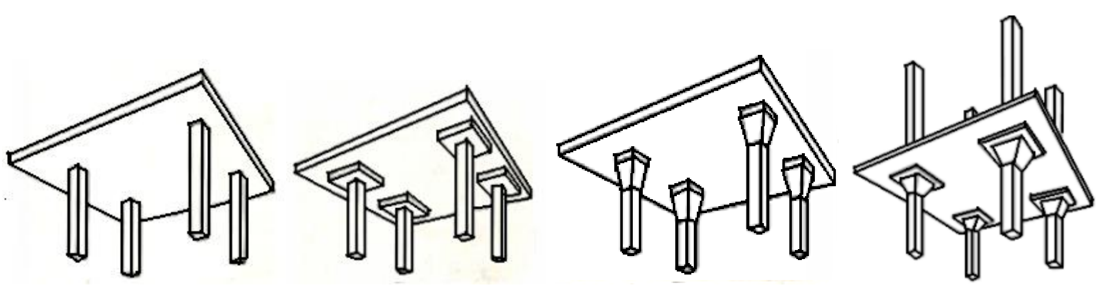
Fig. 1.1 Components of Flat slab

1.4 TYPES OF FLAT SLABS

Slabs supported directly on the column with or without beams are known as flat slabs. In such slabs large bending moments and shears develop near the junctions with columns. Therefore there is a need to spread the column at its top end or thicken the slab over column. The flat slabs (as shown in fig. 1.2) are classified as

1. Flat slab without Drop and column head.
2. Flat slab with drop but without column head.
3. Flat slab without drop but with column head.
4. Flat slab with drop and column head.

Flat slab without drop and column head/ column capital is known as flat plate.



(a) (b) (c) (d)

Fig. 1.2 Types of Flat slab

1.5 BEHAVIOR OF FLAT SLAB

Behavior of flat slab and flat plates are identical to those of two way slab. Bands of slab in both directions along column lines are considered to act as beams. Such bands of slabs are referred as column strips which pass through the columns and middle strips, occur in the middle of two adjacent columns.

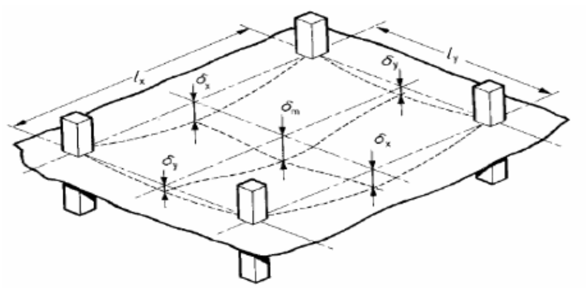


Fig. 1.3 Deflection profile of Flat slab

Column strips behave as a continuous beam supported on column. The middle strip also behaves as a continuous beam supported on column strips and deflects as shown in fig. 1.3. The deflections are minimum at supports and maximum at mid spans. The deflected flat slab at the centre of panel shall have saucer shape. Where δ_x and δ_y is the deflection at midspan in X and Y direction and l_x and l_y is the span length in X and Y direction.

Transfer of load from slab to column causes excessive shear stresses in the slab adjacent to column. This causes initiation of shear cracks at a distance of effective depth of slab from the face of column. These cracks propagate from bottom towards top. The failure occurs at the bottom compressed edge surrounding the column through punching.

1.6 OPENINGS IN FLAT SLAB

Quite often openings are provided in the flat slab panels to get the natural light from the top, when it is not possible to get it from any of the sides. If the opening size is small as compared to overall dimensions of the slab panel, no special beams are necessary but thickening of edges of the opening and extra reinforcement in thickened portions is required to take care of stress concentration. This extra reinforcement normally equals the amount of steel saved because of opening. However, if the opening is quite large special beam arrangement is provided. Sometimes these beams are concealed in the floor thickness for aesthetic reasons.

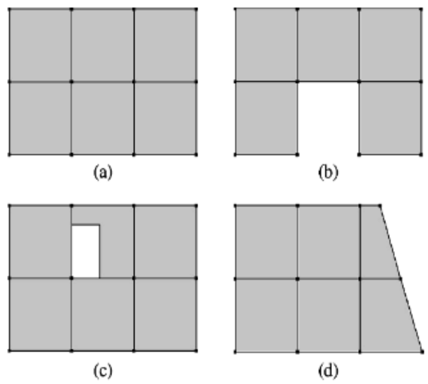


Fig. 1.4 Openings in flat slab

It should be noted that openings of any size may be provided in the flat slab if it is shown by analysis that the requirements of strength and serviceability are met. However for openings conforming to the following, no special analysis is required.

a. Openings of any size may be placed within the middle half of the span in each direction, provided he total amount of reinforcement required for the panel without the opening is maintained.
b. In the area common to two column strips, not more than one-eighth of the width of strip in either span shall be interrupted by the openings.
c. In the area common to two column strips and one middle strip, not more than one quarter of the reinforcement in either strip shall be interrupted by openings. The equivalent of reinforcement interrupted shall be added on all sides of the openings.

1.7 ADVANTAGES AND DISADVANTAGES OF FLAT SLABS

1.7.1 Advantages

- Flat slab floors require less thickness thus allowing for reduction in storey height.
- As no beams are provided the formwork is simple.

- Reduced loads on foundation because of less thickness and less height of structure.
- It has plain ceiling which gives an attractive appearance and better illumination to the room.
- Curing is easy because of flat surface.
- Reduction in total height required for each storey thus increasing the number of floors that can be built in a specified height.

1.7.2 Disadvantages

- Lack of resistance to lateral loads.
- Flat slab system is inherently flexible and can have excessive lateral drift when subjected to lateral loads.
- Excessive flexibility may lead to excessive deformation that causes damage in nonstructural members when subjected to lateral loads.

1.8 OBJECTIVE

A Reinforced Concrete flat slab floor is a significant advancement in the building technology. Although Flat slabs possesses many advantages but their lateral load resisting capacity is questionable also it has been observed that possible failure mode of the Reinforced concrete Flat slabs is punching that occurs in the vicinity of a column or concentrated load. The main objective of the study is to study method of analysis of flat slabs and design of flat slab by different standards. The code has specified the fixed coefficients for lateral and transverse distribution of moments as per direct design method, the project is aimed to check whether the that coefficients are remain the same when we analyze the flat slab by 3 dimensional finite element method.

code has prescribed the width of column strip and middle strip irrespective of the interior frame and exterior frame to verify the column strip width and middle strip width is the another objective of the project.

Project is also aimed to prepare the software for analysis and design of the flat slab with column capital and with drop by direct design method, equivalent frame method and with the direct design coefficients calculated by 3 dimensional analysis of flat slab using the SAFE software using Visual basic tool. It is always necessary to check the feasibility of the structure in terms of cost, so the cost comparison of the flat slab with R. C. C. slab is the another objective of the project.

1.9 SCOPE OF WORK

The project works is concerned with the Analysis and Design of Flat slab and to prepare the software for analysis and design of flat slabs. The flow of work will be as below.

- Introduction
- Literature review
- Methodology of Analysis of flat slab by
    1. Direct Design Method
    2. Equivalent Frame Method.

- Comparison of standards
- 3 Dimensional analysis of flat slab
- Design of flat slab by
    1. I.S.456-2000
    2. ACI-318-02
    3. B.S.8110;1997
- Software for analysis and design of flat slabs using Visual Basic.

1.10 ORGANIZATION OF MAJOR PROJECT

Major Project is concerned with the analysis and design of flat slabs. The report of major project entitled "Analysis and Design of Flat slabs" been divided into eight chapters. Overview of each chapter and its content are explain briefly as under:

- Chapter 1 deals with the general introduction, necessity, components, behavior, openings and features of flat slabs. Scope of work and layout of report is also discussed in this chapter.
- Chapter 2 includes the literature survey carried out during the project work. The survey is done to be familiar with recent advancements in project area and decide line of action for the work. It also explains the

approach towards the initiation of the survey and work done during it. Abstracts for some of the papers, which are closely related to the topic, are given.

- Chapter 3 Provides detailed information regarding the methodology of analysis of flat slabs.
- Chapter 4 deals with the comparison of standards such as I.S.456-2000, ACI-318-02 and B.S.8110;1997 .
- Chapter5 concerning with the detailed 3 Dimensional analysis of flat slab with the use of SAFE software.
- Chapter 6 includes the design of flat slab by I.S.456, ACI-318 and B.S.8110
- Chapter 7 deals with software for analysis and design of flat slabs.
- Chapter 8 is the final chapter of major project. In this chapter summary of entire project along with the conclusions is given. This chapter also gives guidelines for the future scope of work.

2. LITERATURE REVIEW

2.1 GENERAL

Literature survey is carried out to familiar with the amount of work done in this area throughout the world. The survey gives ideas about the extent of work to be carried out during project. It helps in framing the scope of work. It also helps in deciding the line of action of work. It generates the clear vision of the work and gives the overall scenario of it. During this survey many new things, concepts, and ideas will emerge which improve the clarity of the topic. The literature is summarized as below.

2.2 LITERATURE REVIEW

Initially material related to the topic are searched out and collected through various sources. Papers from ASCE journals, Science direct, ICJ, ACI etc. are collected and complied. Books related to Flat slabs are referred. The literature is summarized as below.

2.2.1 Abstracts

Abstracts for some of the papers, which are very much related to the topic, searched during survey are given.

H.S. Kim and D. G. Lee [1] discussed merits and demerits of conventional methods of analysis of flat slabs such as Equivalent frame method and Finite Element Method. The author introduces the new and efficient method of analysis which is known as analysis of flat slabs by using super elements which is developed by using fictitious beams. This method significantly reduces the computational time and memory required for analysis as compared to conventional methods.

D.A. Gasparini [2] gives the contribution made by C.A.P. Turner towards development of reinforced concrete flat slab from 1905 to 1910 in the United States. Turner disclosed his flat slab system which includes features such as four way reinforcement and shear head with a diameter of approximately one half of span, which he referred as Mushroom system. Turner never used the term mushroom to refer small column capital. Mushroom system has been applied to buildings of all kinds and height up to 12 storey without single case of collapse or accident. Turner also applied his flat slab system to bridges.

K. Pilakoutas and X. Li [3] states properly designed shear reinforcement can prevent brittle punching failure and increase the strength and ductility of the slab column connection. The author had introduced the new concept of shear reinforcement called as "Shear band" system. This system consists of steel strip punched with holes to enhance the bond strength. The author had designed and tested four reinforced concrete slabs of 175 mm thickness and 2000 m square shaped and 200 * 200 * 200 mm size of column supported at midspan. Different forms of shear reinforcement had been provided in all the four slabs. Author concluded that vertical shear reinforcement in slab performed better than inclined shear reinforcement. Author also examined that ACI 318 code is more conservative than BS 8110 for calculating shear in reinforced concrete slab.

Armund Fiirst and Peter Marti [4] presents the brief overview of the Maillart's design approach which has not been systematically reviewed yet. Model test results given by Maillart considerably underestimated moments. Bending moments at selected locations were derived by multiplying associated curvatures with flexural stiffness of slab and maximum positive moments are obtained by alternating strip loadings. But Maillart does not check negative moments also Maillarts publications are silent about magnitude of flexural stiffness of test slabs. Hence it can not be decided in which way this factor is influenced in assessment of moments coefficients.

Uwe Albrecht [5] discussed the design of flat slabs for punching by seven codes (European and American), as the rules for design are differ considerably around the world. Paper analyze and compare provisions for punching with respect to the punching shear capacity of the concrete for the office building to demonstrate the possibilities and limitations of different codes. The punching shear resistance of flat slab is calculated on critical perimeter which is located between 0.5d to 2d from face of the column as per different codes. Author concluded that punching shear capacities, amount and distribution of shear reinforcement and integrity reinforcement are substantially different for different codes.

Y. H. Luo, A. Durrani and J. Conte [6] presents the analytical approach to assess the vulnerability of reinforced concrete flat slab buildings subjected to earthquakes and the analysis was carried out for typical 3 and 10 storey flat slab building in which the detailing is made as per older flat slab buildings. Author used general purpose reliability analysis program CALREL. The 1st and 2nd order reliability method (FORM/ SORM) were used for static loading and simulation technique such as Monte Carlo method was used for dynamic loading. Author concluded that low probability of failure affirms the safety of those buildings under pure gravity loads while under seismic loading probability of punching failure increased with increasing expected Peak Ground Acceleration and number of storey in buildings. Local soil conditions have also significant effect on probability of punching failure. The study indicated that probability of failure of flat slab buildings on soft soils was about 1.5 times the probability of failure on hard soils.

Mary Hueste and Jong- wha Bai [7] presents the seismic performance of a typical 1980's reinforced concrete building in central U. S. using commentary for seismic rehabilitation of buildings. Author used nonlinear static (pushover) and nonlinear dynamic (time history) analysis to compute global structural parameters such as stiffness, strength and deformation capacity for Reinforced concrete structure and the results of Pushover analysis are compared with Time history analysis to evaluate how closely push over analysis estimates dynamic nonlinear response of structure. FEMA 356 criteria were used to assess the seismic performance of the case study building based on ZEUS- NL response analysis. Author also discussed three retrofit techniques are for case study structure, responses for three schemes demonstrate that retrofits improve the overall seismic behavior performance significantly.

Mary Houste, Jong Bai [8] discussed the seismic fragility of typical five storey Reinforced Concrete building in central U. S. Several different drift limits for development of seismic fragility were evaluated. In this study two different analyses namely regular pushover analysis and critical response pushover analysis were used for determining most critical inter storey drift. Author evaluated the quantitative limit states based on limits described by Wen et al in addition to FEMA 356 global level and member level criteria for IO (Immediate occupancy), LS (Life Safety), CP (Collapse Prevention).

M. G. Sahab, A. F. Ashour, V. V. Toropov [9] presents cost optimization of Reinforced concrete flat slab buildings according to BS 8110 where total cost of building is considered as an objective function. Author carried out structural analysis using Equivalent frame method and restricted to rectangular plan form buildings only. Optimization techniques also known as Genetic Algorithms is inspired by natural evolution laws which start by searching the design space with a population of designs. It uses mainly three operators such as selectors (reproduction), crossover and mutation to direct density of population to wards optimum point. Author carried out cost optimization of Reinforced concrete flat slab buildings as per B.S.8110 and compared cost components for different elements of optimum and conventional designs.

M. Erberik and Amr. Elnashai [10] presents the procedure for assessing the loss estimation for flat slab structures taking into account their specific characteristics. The assessment comprises of comparison of methods used in current study for derivation of fragility curves with existing HAZUS function, Loss assessment software of the Federal Emergency Management Agency, implementation of derived fragility curves into HAZUS function and prediction of earthquake losses in flat slab buildings in comparison with existing structural types in HAZUS subjected to different earthquakes in a selected study regions. Author concludes that the prediction results are consistent with seismic response characteristics of the compared structural types.

3. METHODOLOGY OF ANALYSIS OF FLAT SLAB

3.1 GENERAL

Flat slabs are subjected to gravity and lateral loads. Analysis of flat slabs is mainly categorized into gravity load analysis and lateral load analyses. Flat slabs subjected to gravity loads are typically analyzed by direct design method and equivalent frame method. However flat slabs are also subjected to lateral loads due to wind and earthquake. The equivalent frame method can also be applied for lateral load analysis. Therefore the lateral load analysis is carried out by equivalent frame method and linear finite element analysis. Three dimensional Finite Element approach is computationally intensive even for flat slab buildings of moderate heights, hence 3 D analyses is carried out using software.

Analysis of flat slab is mainly categorized into three parts as Gravity load analysis, Lateral load analysis and combined gravity and lateral load analysis. Different standards such as I.S.456-2000, ACI 318-02, B.S.8110-1;1997 prescribed the use of different methods for analysis of flat slab.

3.2 GRAVITY LOAD ANALYSIS

Codes of different countries prescribed the use of different methods for gravity load analysis such as Direct Design Method and Equivalent Frame Method

3.2.1 I.S. 456 CODE

I.S. 456 code suggests the use of Direct Design Method for gravity load analysis of flat slab.

3.2.1.1 DIRECT DESIGN METHOD

Moments in two way slabs can be found using direct design method are subject to the following restrictions.

3.2.1.1.1 Limitations of direct design method

1. There shall be minimum of three continuous spans in each direction.
2. The panels shall be rectangular and the ratio of the longer span to the shorter span within a panel shall not be greater than 2.00

3. It shall be permissible to offset the columns to a maximum of 10 percent of the span.
4. The successive span lengths in each direction shall not differ by more than one third of the longer span. The end spans may be shorter but not longer than interior spans.
5. Loads should be gravitational only with the live load not more than 2 times dead load. They should be uniformly distributed in the entire panel.
6. In the two way slabs with beams on all sides, it should also satisfy the following additional condition. The ratio of beam relative stiffness in the two directions is given by the expression $(\alpha_1/\alpha_2)(L_2/L_1)^2$ must lie between 0.2 to 5.0
7. Redistribution of resultant moments obtained by DDM is not permitted.

3.2.1.1.2 Explanation of limiting conditions

The first condition ensures that the first interior support is neither fixed against rotation nor discontinuous. The second condition ensures two- way slab action. If the ratio exceeds 2 one way slab action predominates. The third and fourth conditions are related to possibility of developing negative moments at or near mid span. The fifth assumption ensures that there are no lateral loads and the limit on the LL to DL ratio of 2 shows the necessity for checking the effect of pattern loading. The sixth condition is applicable to slab with beams and it ensures that the beams are stiff enough relative to each other. Otherwise the distribution of moments will deviate very much from that assumed in the elastic analysis

3.2.1.1.3 Total static moment at factored loads

The total static moment Mo should be distributed firstly as positive and negative moments in the longitudinal direction and secondly these assigned positive and negative moments are again distributed transversely to the column and middle strips.

3.2.1.1.4 Longitudinal distribution of total moment Mo

For purpose of calculating the total static moment Mo in a panel, the clear span l_n in the direction of moments is used. The clear span is defined to extend from face to face of columns, capitals or walls but not be less than $0.65l_1$. The total factored moment in a span, for a strip bounded laterally by the centerline of panel on each side of the centerline of supports is

$$M_o = \frac{Wl_n}{8} \qquad \text{... (3.1)}$$

When the span adjacent and parallel to an edge is being considered, the distance from the edge to the centerline of the panel shall be substituted for l_2 in above equation.

3.2.1.1.5 Negative and positive moments

In an interior span, the total design moment Mo shall be distributed in the following proportions

Negative design moment 0.65

Positive design moment 0.35

In the case of end spans, the total static moment among the three critical moment sections (interior negative, positive and end exterior negative) depends upon the flexural restraint provided for the slab by the exterior column or the exterior wall and depends also upon the presence or absence of beams on the column lines. In the end span the total design moment M_O shall be distributed in the following proportions.

Interior negative design moment:

$$0.75 - \frac{0.10}{1 + \frac{1}{\alpha_c}} \qquad \text{... (3.2)}$$

Positive design moment

$$0.63 - \frac{0.28}{1 + \frac{1}{\alpha_c}} \qquad \text{... (3.3)}$$

Exterior negative design moment:

$$\frac{0.65}{1+\frac{1}{\alpha_c}} \qquad \text{... (3.4)}$$

α_c is the ratio of flexural stiffness of the exterior columns to the flexural stiffness of the slab at a joint taken in the direction moments are being determined is given by

$$\alpha_c = \frac{\sum K_c}{K_s} \qquad \text{... (3.5)}$$

Where, K_C is the sum of the flexural stiffness of the columns meeting at the joint and K_S is the flexural stiffness of the slab, expressed as the moment per unit rotation.

It shall be permissible to modify these design moments by up to 10 percent, so long as the total design moment, Mo for the panel in the direction considered is not less than that required by equation above.

3.2.1.1.6 Transverse distribution of moments

Having distributed the moment M_O longitudinally to the positive and negative moments at the two ends, these moments are again distributed in the column strip and middle strips of respective sections.

The main factors that affect the transverse distribution of the moments are the relative stiffness of the beam in the column strip to that of slab, L_2/L_1 (the aspect ratio; torsional resistance of the edge beam (if present) in the exterior span; type of wall in case of the slab whose exterior end is supported on wall.

When the flat slabs are supported by walls on the column lines analyzed by DDM the walls are to be considered as very stiff beams and the torsional resistance of the beams is to be taken as zero for masonry walls and 2.5 for reinforced concrete walls (shear walls). The column strip cannot deflect with beams of large moment of inertia and no distribution of moments can occur in the middle strip.

IS 456(2000) prescribed three formulae for obtaining the transverse distribution factors.

1. percentage of positive moment to column strip

$$= 60 + 30\frac{\alpha_2 L}{L_1}\left(1.5 - \frac{L_2}{L_1}\right) \quad \text{... (3.6)}$$

2. percentage of negative moment to column strip at interior support

$$= 75 + 30\frac{\alpha_2 L}{L_1}\left(1.5 - \frac{L_2}{L_1}\right) \quad \text{... (3.7)}$$

3. percentage of negative moment to column strip at exterior support

$$= 100 - 10\beta_t + 12\beta_t\frac{\alpha L_2}{L_1}\left(1 - \frac{L_2}{L_1}\right) \quad \text{... (3.8)}$$

In these equations, if the value of $\frac{\alpha_1 L_2}{L_1}$ is greater than unity, it should be limited to unity. Similarly if β_t is greater than 2.5 it should be limited to 2.5. However, in flat slab with no beams the values in the above three equations will be 60%, 75% and 100% respectively as given in IS 456(2000)

3.2.1.1.7 Design loads on the beams

Beams in the column strip can be considered as rigid or flexible depending on the relative stiffness $\frac{\alpha_1 L_2}{L_1}$. If this value is unity, the beams can be considered as rigid and it carries 85% of the moment in the column strip. If this value is zero, no moments are transferred to beams. If $\frac{\alpha_1 L_2}{L_1} < 1.0$ they are considered as flexible beams and the moments carried will be in proportion to its relative stiffness value as shown in table 3.3

3.2.1.1.8 Shear in flat slabs

Flat slabs must be designed to resist the shear as well as moment, when designing by direct design method. The critical section for shear shall be at a distance d/2 from the periphery of the column/ capital/ drop panel, perpendicular to the plane of the slab where d is the effective depth of the section.

Table 3.1 Distribution of moments taken by beams

$\frac{\alpha_1 L_2}{L_1}$	Moment from column strip to beam (%)
0	0
≥1	85

Punching shear produces cracking at top of the slab where negative moment steel is also provided. This will leave only concrete at the bottom of the slab to resist shear. Hence this detailing is very important in flat slabs. However it should also be noted that when adjacent spans are unequal the extension of the negative steel beyond the face of support should be based on the longer span. The spacing of bars in the flat slab shall not exceed two times the slab thickness.

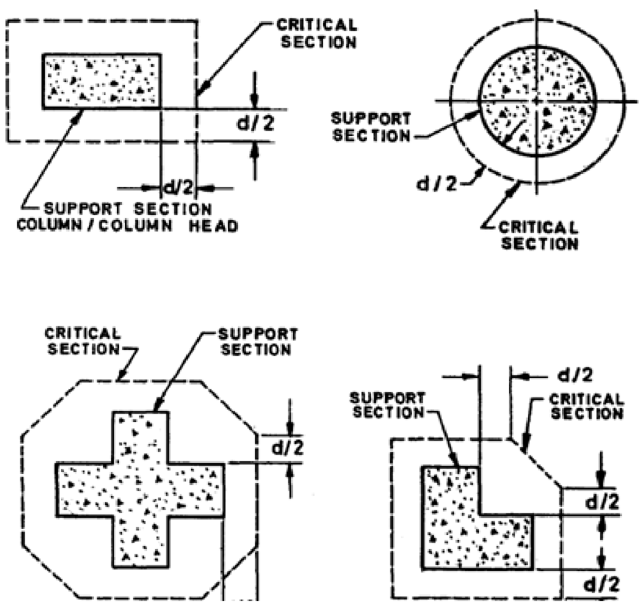


Fig. 3.1 Critical sections for shear

3.2.2 ACI 318

ACI 318 suggests any of the two methods as direct design method and equivalent frame method for gravity load analysis of flat slab.

3.2.2.1 Direct Design Method

3.2.2.1.1 Negative and positive moments

Longitudinal distribution of moments in the interior span is in the same proportion as that of I.S.456 code as

Negative design moment 0.65

Positive design moment 0.35

ACI 318 prescribed fixed values for distribution of moments in the end span for various cases as shown in table 3.1 that can occur in practice and these coefficients can be directly chosen for design.

Table 3.2 Longitudinal distribution of moments in end span

	(a)	(b)	(c)	(d)	(e)
	Exterior edge Unrestrained	Slab with Beams Between all Supports	Slab without beams Between interior Supports		Exterior edge Fully Restrained
			Without edge Beam	With edge bam	
Interior Negative Moment	0.75	0.7	0.7	0.7	0.65
Positive Moment	0.63	0.57	0.52	0.5	0.35
Exterior Negative Moment	0	0.16	0.26	0.3	0.65

3.2.2.1.2 Transverse distribution of moments

Having distributed the moment M_O longitudinally to the positive and negative moments at the two ends, these moments are again distributed in the column strip and middle strips of respective sections, which carried out using table 3.2.

The main factors that affect the transverse distribution of the moments are the relative stiffness of the beam in the column strip to that of slab, L_2/L_1 (the aspect ratio; torsional resistance of the edge beam (if present) in the exterior span; type of wall in case of the slab whose exterior end is supported on wall.

Table 3.3 Transverse distribution: Assignment of moments to column strips (percentages)

	Moments to be Distributed	Type of beams Present	$\frac{\alpha_1 L_2}{L_1}$	β_t	L_2/L_1 0.5	1.0	2.0
1.	Positive moment in all spans	(a)No internal beam	0	Nil	60	60	60
		(b)With internal beam	≥1	Nil	90	75	45
2.	Negative Moment in Interior spans	(a)No internal beam	0	Nil	90	75	75
		(b) With internal beam	≥1	Nil	90	75	75
3.	Negative moment at exterior support	(a) No internal beam No edge beam	0	0	100	100	100
		(b) No internal beam With edge beam	0	≥2.5	75	75	75
		(c)with internal beam No edge beam	≥1	0	100	100	100
		(d)with internal beam Edge beams	≥1	≥2.5	90	75	45

3.2.3 EQUIVALENT FRAME METHOD

Flat slab subjected to gravity loads are typically analyzed by direct design method and equivalent frame method. In both methods the two way slab system is converted into series of rigid frames in either of two directions (x and y direction) by means of vertical cuts through the slabs at section midway between the column lines. The difference in analysis of flat slab by DDM and EFM is that in the direct design method fixed coefficients are used for calculating moments in various parts of the slab while in the equivalent frame method, the actual frames are analyzed by any one of the classical methods of structural analysis, like moment distribution, slope deflection or matrix method. Because of this DDM will only be applicable to more or less symmetrical layout of columns and slabs, however EFM can be used for any layout.

The two way slab system which does not satisfy the limitations of the direct design method (DDM) shall be analyzed by the equivalent frame method (EFM). The equivalent frame method is very similar to DDM but it uses the classical method of analysis, instead of using the coefficients, to give the positive and negative moments in the longitudinal direction. Thus the difference between DDM and EFM analysis for gravity loads lies only in the procedure of getting the magnitude of the longitudinal negative and positive moments.

3.2.3.1 Definition of equivalent frame

The equivalent frame is a simple substitute of a two dimensional model for a three dimensional frame consisting of slabs and columns. Building frame is cut vertically from top to bottom first in longitudinal direction and then in the transverse direction along the centre lines of the adjacent panels. In EFM analysis the spans are considered from centre to centre of slabs. In general the frame used for analysis in EFM is consist of three members.

1. Series of slabs (or slab beams) in the longitudinal direction.
2. Columns extending above and below the slabs.
3. The transverse moment transfer elements (torsional members) consisting of the slab and beams (if any) at the columns in the transverse direction.

The resulting frames are then reduced to two-dimensional model with columns as vertical members and the slabs compressed to equivalent beams as horizontal members. These two dimensional models are equivalent frames and they are to be analyzed by methods of elastic analysis such as moment distribution, slope deflection or matrix methods. Each floor is analyzed separately with the columns assumed fixed at the floors above and below for the worst live load condition (pattern loading) on the ‘slab beams’, as this method is considered as an exact method redistribution of moments is allowed. The analysis is made in both the longitudinal and transverse direction.

3.2.3.2 Equivalent column method

An equivalent frame is a two dimensional representation of the three dimensional structures. For analysis of frame appropriate moment of inertia and expressions of rigidity is assigned to beams and columns. These values are determined from results of extensive tests carried by various researchers, so that the results obtained from theoretical analysis match with the results of the laboratory tests. It has been observed that the test values of the span moments are more while the support moments are less than the theoretical values. This shows that the column sides are not as rigid as imagined. In the theoretical model the column and the slab-beam are considered as fixed, however in reality it is not so fixed. Beyond the immediate vicinity of the columns, slab tends to rotate freely as it is restrained only by torsional stiffness of the slab which is quite small.

There is considerable '*leakage of moments*' at the support as shown in fig. 3.2, this tends to increase the positive bending moment in the span and decrease the negative bending moment at the support. In other words, the actual rotational restraint of the columns on the slab is less than that indicated by the 'simple equivalent frame'. This is due to lack of the torsional stiffness of the slab that is supposed to fix at the supports, the fixity offered to the member is not only the function of the bending stiffness of the column but also the torsional stiffness of the slab and that of any torsional stiffness of the beam if present. If there are no beams to fix, the slabs along the column line, the torsional stiffness of the strip of slab of width equal to c1 (i.e. the width of column in the longitudinal direction) and the length equal to transverse span (L_2) should be taken into account. The real column with the torsional members is called as equivalent column.

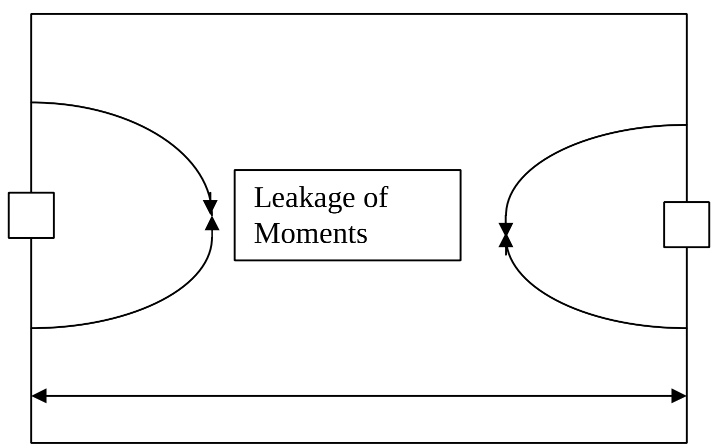


Fig.3.2 Leakage of moment from supports to span

For physical concept, it may be imagined that the end moments are first transferred the transverse beam or strip and then by torsion to the column. Thus the flexibility of the equivalent column is taken as the flexibility of the actual column above and below the 'slab beam' plus the flexibility of the 'attached torsional members' on each side of the column. Thus the relationship can be expressed as

$$\frac{1}{K_{ec}} = \frac{1}{\sum K_c} + \frac{1}{K_t} \qquad \text{... (3.9)}$$

$$K_{ec} = \frac{\sum K_c \times \sum K_t}{\sum K_c + \sum K_t} \qquad \text{... (3.10)}$$

Where K_{ec}= flexural stiffness of the equivalent column

K_c = flexural stiffness of the actual column.

K_t = torsional stiffness of the transverse slab or edge beam.

Thus K_{ec} will always smaller than K_c, i.e. the equivalent column is more flexible than the actual one. When K_t=0 then ($1/K_t$) is infinity and the value of K_{ec} will also be small.

Empirical formula has been developed for calculating the torsional stiffness of the 'attached torsional member', so that the results of the analysis of equivalent frame with the 'equivalent column' member close to those obtained in the laboratory. The expression for attached torsional member is

$$K_t = \frac{\left(\sum 9 E_c C\right)}{L_2 \left[1 - \left(c_2 / L_2\right)\right]^3} \qquad \text{... (3.11)}$$

Where, C= torsional constant of transverse torsional members.

E_C=Modulus of elasticity of concrete

L_2= span of member subjected to torsion on either side of column.

C_2= span length of the side of the column in the transverse direction.

When there is a parallel beam spanning between columns along L_1 as in two way slab on beams, the value of K_t is enhanced by K_{ta} by multiplying factor I_{sb}/I_s to K_t.

The torsional constant c for the transverse member is to be evaluated for the cross section as in R.C. design by dividing it into separate rectangular parts and carrying out the summation as

$$C = \sum \left(1 - 0.63\frac{x}{y}\right)\left(\frac{x^3}{3}\right) \qquad \text{... (3.12)}$$

Where, x is less than y, in rectangle.

This method of analysis is called the 'equivalent column method' recommended for design in ACI (1977) commentary.

If the flat slab analyzed by equivalent frame method also satisfy the requirements of analysis by direct design method, then the total moment as the sum of negative and positive moments determined by the equivalent frame method should not be greater than that by the direct design method. Otherwise the moments determined by the equivalent frame method may be reduced in such a proportion that the numerical sum of the positive and negative moments is equal to the design moment obtained by the direct design method, such a recommendation has been made in the code as the direct design method has led to satisfactory results in the past.

3.2.3.3 Summary of equivalent column method

Any two way slab system can be considered as equivalent frames on column lines both in longitudinal and transverse directions. The whole load is assumed to be carried on both directions as in direct design method. Moment of inertia of slab beams and the equivalent moment of inertia of the columns is determined. The torsional member attached to the column in absence of beam will be a slab of width c_1(i.e. width of the column in the longitudinal direction) and length equal to half of the transverse span on each side of the column. If there are beams present then its effect should be taken into consideration. ACI 318(1977) recommends equivalent column method for analysis of all types of loads.

Substitute frame may also be used for the simplification of the analysis for gravity loads.

3.2.3.4 Arrangement of live load

Effect of pattern loading should be considered while analyzing the flat slab by equivalent frame method [ACI and IS 456(2000) Clause 31.5.2.2], when the live load is variable but does not exceed three quarter of dead load or nature of the live load is such that all panels are loaded simultaneously, the maximum moments may be assumed to occur at all the sections when full design live load is on the entire slab system. However when using DDM in case of frames of equal spans, effect of pattern load can be neglected when live load is even up to twice the dead load.

3.2.3.5 B.S.8110

B.S. 8110 prescribed the use of equivalent frame method for gravity load analysis of flat slabs. Total moment and shear force is distributed as shown in table 3.4. Where F is the total design ultimate load and l is the effective span .
The moments calculated above are distributed in panels of slab as in table 3.5.

Table 3.4 Coefficients for distribution of moment and shear

	End support/ slab connection				At first Interior support	Middle Interior Spans	Interior Supports
	Simple		Continuous				
	Outer support	Near middle of end support	Outer support	Near middle of end support			
Moment	0	0.086Fl	-0.04Fl	0.075Fl	-0.086Fl	0.063Fl	-0.063Fl
Shear	0.4F	-	0.46F	-	0.6F	-	0.5F

Table 3.5 Coefficients for distribution of moments in column and middle strip

Design moment	Apportionment between column and middle strip as % of total negative and positive moment	
	Column strip (%)	Middle strip (%)
Positive	75	25
Negative	55	45

3.2.3.6 Limitations of Equivalent frame method

Equivalent frame method has limitations in the applications and accuracy because the slabs are modeled by an equivalent frame method can be easily applied to a flat slab structures having the regular plan. However, it is hard to apply the equivalent frame method to flat slab structures having irregular spans this is because of the fact that this method was originally derived from the buildings having regular arrangement of columns and slabs.

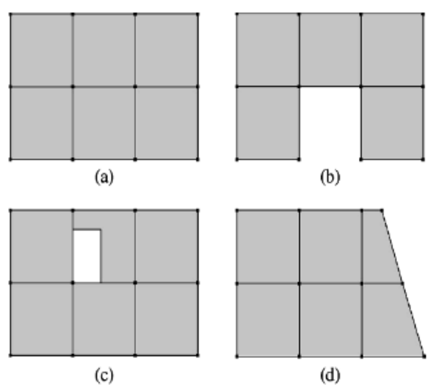


Fig.3.3 Plan of flat slabs

In case of the plan as shown in fig.3, there is a slab in each of the three quadrants around the inside columns but not in the fourth quadrant. The factor K_{FP} for the column location in this case was not defined in the Grossman method. Also it is difficult to apply equivalent frame method to the structures having openings in the slab. Since the equivalent frame method cannot accurately represent the stress distribution that is one of the most important factors in the design of slabs. In spite of the limitations above, the equivalent frame method is widely used by the engineers because there is no appropriately simple analytical method for flat slab structures.

Table 3.6 Stiffness degradation factor depending on the lateral drift

Lateral drift	K_D
$h_s/800$	1.1
$h_s/400$	1.0
$h_s/200$	0.8
$h_s/100$	0.5

3.3 Lateral load analysis

Either the direct design method or equivalent frame method (equivalent column method) are used for the analysis of two way slab systems for gravity loads. In case of the tall building where the design is governed by the lateral loads, the structural system should preferably be braced by lateral load resisting elements such as shear walls so that the frames have to withstand only gravity loads.

Flat slabs are inherently not very strong under lateral loads. Flat slabs subjected to combined gravity and lateral loads are typically analyzed by linear finite element analysis and equivalent frame approaches. Three dimensional Finite Element approach is computationally intensive even for flat slab buildings of moderate heights. Since flat slab buildings behave inelastically even in earthquakes of moderate intensity, a 3-dimensional nonlinear analysis for seismic loading is not practical. Lateral load analysis is carried out using software by 3D analysis of flat slabs using SAFE.

4. COMPARISON OF STANDARDS

4.1 GENERAL

Criteria for analysis and design of flat slab differ widely in standards of various countries. Different aspects of analysis and design as per I.S.456-2000, ACI 318-02 and B.S.8110-1; 1997 are compared shown in table 4.1.

Table 4.1 Comparison of codes

	I.S. 456-2000	ACI 318-02	B.S. 8110-1;1997
A	**Definition** A R.C. slab with or without drop, supported generally without beams, by columns with or without flared column head		A slab with or without drop and supported generally without beams by columns with or without column heads.
	Column strip A design strip having a width of $0.25xl_2$, but not greater than $0.25x\ l_1$ on each side of the column centerline.	A design strip with a width on each side of a column centerline equal to $0.25xl_2$ or $0.25x\ l_2$, whichever is less.	
	Middle strip A design strip bounded on each side of its opposite sides by column strip		
	Panel Part of a slab bounded on each of its four sides by centerline of column or centerline of adjacent spans		
B	**Gravity load analysis** It shall be permissible to design the slab by 1.Direct design method 2.Equivalent frame method In each case the applicable limitations given in code shall met [cl.31.3.1]	Design of a slab system for gravity loads including slab and beams (if any) between supports or walls forming orthogonal frames by either Direct design method or Equivalent frame method shall be permitted. [cl.13.5.1.1]	Provisions are given for the design of flat slabs supported by generally rectangular arrangement of columns using 'Equivalent frame method' and where the ratio of longer to shorter spans does not exceed [cl.3.7.1.2]

Contd. Table 4.1

<table>
<tr>
<td></td>
<td>Total design moment

$$M_0 = \frac{Wl_n}{8} = \frac{wl_2 l_n^2}{8}$$
Negative and positive factored moments

Interior span

Total static moment Mo shall be distributed as
Negative Factored moment= 0.65
Positive factored moment = 0.35

End span

Interior negative

$$M_{oni} = \left[0.75 - \left(\frac{0.1}{1+1/\alpha_c}\right) \times M_0\right]$$
Interior positive

$$M_{op} = \left[0.63 - \frac{0.28}{1+1/\alpha_c}\right] \times M_0$$
Exterior negative

$$\left(\frac{0.65}{1+1/\alpha_c} \times M_0\right)$$</td>
<td>Total design moment Mo

$$M_0 = \frac{Wl_n}{8} = \frac{wl_2 l_n^2}{8}$$
Total static moment Mo shall be distributed as
Negative Factored moment= 0.65
Positive factored moment = 0.35

End span

<table>
<tr><th rowspan="2"></th><th rowspan="2">Exterior edge unrestrained</th><th rowspan="2">slab with beams between all supports</th><th colspan="2">slab without beams between interior supports</th><th rowspan="2">exterior edge fully restrained</th></tr>
<tr><th>with edge beam</th><th>without edge beam</th></tr>
<tr><td>Interior negative moment</td><td>0.75</td><td>0.7</td><td>0.7</td><td>0.7</td><td>0.65</td></tr>
<tr><td>Positive moment</td><td>0.63</td><td>0.57</td><td>0.5</td><td>0.52</td><td>0.35</td></tr>
<tr><td>Exterior negative moment</td><td>0</td><td>0.16</td><td>0.3</td><td>0.26</td><td>0.65</td></tr>
</table>
</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moment Redistribution

Bending moments at critical cross section shall be distributed to the column strips</td>
<td>Moment redistribution shall not be applied for slab systems designed by DDM</td>
<td></td>
</tr>
</table>

Contd. Table 4.1

<table>
<tr>
<td></td>
<td>Equivalent frame method
Width of frame

Each frame consists of a row of equivalent columns or supports, bounded laterally by centerlines of panels.
The structures shall be considered to be made up of equivalent frames on column lines taken longitudinally and transversely through building

</td>
<td>

Three dimensional building is divided into series of two dimensional frame centered on columns or support centerlines with each frame extending the full height of building Width of each equivalent frame is bounded by centerlines of adjacent panels [cl.13.7.2]</td>
<td>

I. Structure may be divided longitudinally and transversely into frames consisting of columns and strips of slabs Width of the slab for vertical loading taking into account the full width of panel
Method for determining moments
a. Design is based on single load case of all spans loaded with maximum design ultimate load.
b. At least 3 rows of panels of approx. 3 spans in the direction being considered.
c. Allowance has to be made to the coefficient given below for 20% redistribution
Drop should be ignored in assessment of column strip and middle strip, if their smaller dimension is less than 1/3rd of smaller dimension of panel.

<table>
<tr><td rowspan="3"></td><td colspan="4">End support/ slab connection</td><td rowspan="3">At first interior support</td><td rowspan="3">Middle interior spans</td><td rowspan="3">Interior supports</td></tr>
<tr><td colspan="2">simple</td><td colspan="2">Continuous</td></tr>
<tr><td>Outer support</td><td>Near middle of end support</td><td>Outer support</td><td>Near middle of end support</td></tr>
<tr><td>Moment</td><td>0
0</td><td>0.086Fl</td><td>-0.04Fl
0</td><td>0.075Fl
0</td><td>-0.086F
0</td><td>0.063Fl
0</td><td>-0.063Fl
0</td></tr>
<tr><td>Shear</td><td>0.4F</td><td>-</td><td>0.46F</td><td>-</td><td>0.6F
0</td><td>-</td><td>0.5F
0</td></tr>
</table>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Moments obtained from above table are distributed in column strips and middle strips in proportion as

<table>
<tr><td>Moment</td><td>Column strip</td><td>Middle strip</td></tr>
<tr><td>Negative</td><td>75</td><td>25</td></tr>
<tr><td>Positive</td><td>55</td><td>45</td></tr>
</table>
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</tr>
<tr>
<td>C.</td>
<td>Flat slab subjected to lateral loads</td>
<td>
Designer may model the structure for lateral load analysis using methods such as plate bending, F.E.A. method model</td>
<td></td>
</tr>
</table>

4.2 DISTRIBUTION OF MOMENTS

The moment in flat slab is distributed firstly along negative and positive moment in longitudinal direction and further this moment is distributed along transverse direction in column strip and middle strip.

Direct design method is based on the use of fixed coefficients for longitudinal and transverse distribution of moments. ACI 318-02, and B.S. 8110 prescribed the fixed coefficients for distribution of moments, however I.S.456-2000 gives the equations for calculation of distribution factors along longitudinal and transverse direction. Coefficients for distribution of moments in flat slab with drop and with column capital are shown in table 4.2.

Table 4.2 Coefficients for distribution of moments

	Types of moments	Longitudinal Distribution			Transverse distribution					
		ACI	I.S.456		ACI		I.S.456		B.S. 8110	
			I.F.	E.F.	C.S.	M.S.	C.S.	M.S.	C.S.	M.S.
1	Interior span									
	Negative (support)	0.65	0.65	0.65	0.75	0.25	0.75	0.25	0.55	0.45
	Positive (Mid span)	0.35	0.35	0.35	0.6	0.4	0.6	0.4	0.75	0.25
2	End span									
	Interior (Negative)	0.7	0.7	0.72	0.75	0.25	0.75	0.25	0.55	0.45
	Positive	0.52	0.5	0.54	0.6	0.4	0.6	0.4	0.75	0.25
	Exterior (Negative)	0.26	0.31	0.2	1	0	1	0	0.55	0.45

4.3 COMPARISON OF MOMENTS

Longitudinal and transverse moments are compared for three codes considering different span. Plan dimension of flat slab considered for comparison of moments for 3 storey are 24m x 24 m (3 bay 8m x 8m), 30m x30m (3 bay 10m x 10m) and 18m x 18m (3 bay 6m x 6m). Moments are compared along longitudinal and transverse direction. Fig. 4.1 shows the plan of flat slab having plan dimensions 24m x 24m. table 4.3 shows the moments as per I.S. 456-2000 and ACI-318, however table 4.4 shows the moments as per B.S.8110 code.

Table 4.3 Comparison of moments as per I.S.456 and ACI-318

Method Of analysis	Frame	Types of moments	3 bay 8m x 8m span			3 bay 10m x 10m span			3 bay 6m x 6m span		
			Longitudinal Moment in kN.m	Transverse moment C.S. kN.m	Transverse moment M.S. kN.m	Longitudinal Moment kN.m	Transverse distribution C.S. kN.m	Transverse distribution M.S kN.m	Longitudinal moment kN.m	Transverse distribution C.S. kN.m	Transverse distribution M.S kN.m
Direct Design Method	Interior	**Interior span**									
		Total moment =	360kN.m			703.13kN.m			151.87kN.m		
		Negative	234	175.5	58.5	457.03	342.77	114.26	98.72	74.04	24.68
		Positive	126	75.6	50.4	246.1	147.66	98.44	53.15	31.89	21.26
		End span analysis (ACI)									
		Interior (Negative)	252	189	63	492.19	369.14	123.05	106.31	79.73	26.58
		Span (Positive)	187.2	112.3	74.88	365.63	219.38	146.25	78.97	47.38	31.59
		Exterior (Negative)	93.6	93.6	0	182.81	182.81	0	39.49	39.49	0
		End span analysis (I.S. 456)									
		Interior (Negative)	252.9	189.7	63.23	490	367.5	122.5	107.8	80.85	26.95
		Span (Positive)	178.9	107.4	71.57	338.5	203.1	135.4	78.5	47.1	31.4
		Exterior (Negative)	111.11	111.1	0	242.5	242.5	0	39.9	39.9	0
	Exterior	**Interior span moment**									
		Negative	159.25	119.4	39.81	311.038	233.2785	77.7595	67.31	50.49	16.83
		Positive	85.75	51.45	34.3	167.482	100.4892	66.9928	36.25	21.75	14.50
		End span analysis (ACI)									
		Interior (Negative)	171.5	128.6	42.87	334.964	251.223	83.741	72.49	54.37	18.12
		Span (Positive)	127.4	76.44	50.96	248.8304	149.2982	248.4304	53.85	32.31	53.45
		Exterior (Negative)	63.7	63.7	0	124.4152	124.4152	0	26.93	26.93	0.00
		End span analysis (I.S. 456)									
		Interior (Negative)	176.1	132.1	44.03	339.7492	254.8119	84.9373	74.56	55.92	18.64
		Span (Positive)	133	79.8	53.2	253.6156	152.1694	101.4462	57.99	34.80	23.20
		Exterior (Negative)	49.6	49.6	0	110.0596	110.0596	0	16.57	16.57	0.00

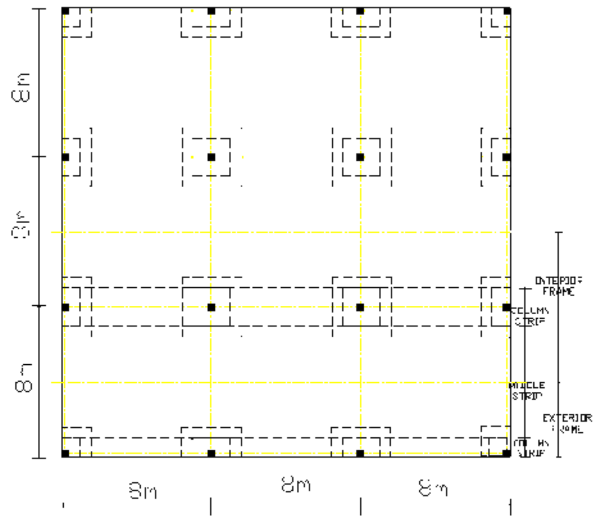


Fig. 4.1 Plan of flat slab

Table 4.4 Comparison of moments as per B.S.8110

Method of analysis	Frame	Types of moments	3 bay 8m x 8m span			3 bay 10m x 10m span			3 bay 6m x 6m span		
			Longi. moment in kN.m	Transverse moment		Longitudinal moment in kN.m	Transverse distribution		Longitudinal moment in kN.m	Transverse distribution	
				C.S. kN.m	M.S. kN.m		C.S. kN.m	M.S kN.m		C.S. kN.m	M.S kN.m
B.S.	Interior	Total moment =	762.3kN.m			1490kN.m			321.84kN.m		
		Negative	440.32	242.2	198.144	860	473	387	185.76	102.17	83.59
		Positive	321.96	241.9	80.04	630	472.5	157.5	136.08	102.06	34.02
		End span analysis									
		Interior (Negative)	440.32	242.2	198.144	860	473	387	185.76	102.17	83.59
		Span (Positive)	384	288	96	750	562.5	187.5	162	121.5	40.5
		Exterior (Negative)	204.8	112.6	92.16	400	220	180	86.4	47.52	38.88
	Exterior	**Interior span**	190.7kN.m			372.5 kN.m			80.46 kN.m		
		Negative	110.08	60.54	49.54	215	118.25	96.75	46.44	25.54	20.9
		Positive	80.64	60.48	20.16	157.5	118.125	39.375	34.02	25.515	8.505
		End span analysis									
		Interior (Negative)	110.08	60.54	49.54	215	118.25	96.75	46.44	25.54	20.9
		Span (Positive)	96	72	24	187.5	140.625	46.875	40.495	30.37	10.125
		Exterior (Negative)	51.2	28.16	23.04	100	55	45	21.6	11.88	9.72

5. 3D ANALYSIS OF FLAT SLAB

5.1 GENERAL

3D analysis of flat slab for gravity and lateral loading is carried out using software. As conventional methods of analysis of flat slab prescribed by codes of different countries are not suitable for lateral loading. Also for gravity loading methods proposed by codes are not exact hence 3D analysis of flat slab is carried out using software.

ETABS software is used for modeling of flat slabs, while Software SAFE is used for design of flat slab which uses the analysis results of the ETABS software for design purpose as the SAFE software gives the detailed design of flat slabs, for gravity loading as well as lateral loading and the results of the different methods are compared.

5.2 MODELING OF FLAT SLAB

Flat slabs are modeled for three dimensional analysis using software. Column dimensions are taken as that of the original frame and shape of columns is assumed to be rectangular or square, while in case of circular columns cross-sectional area of the rectangular or square column selected for modeling purpose should be equal to that of cross-sectional area of the circular column. All columns are assumed to be fixed at all the supports. Modeling for flat slabs is carried out as under,

1. First step of modeling of flat slab building is to define the grid dimensions and to specify the storey dimensions, select flat slab as structural object.

2. Specify the overhangs (if present) in X and Y direction, size of drop panel and assign the restraint at bottom of column.

3. Assign the sectional properties of column

4. Define the slab and drop properties assign it, however it should be noted that similar storey option should be selected.

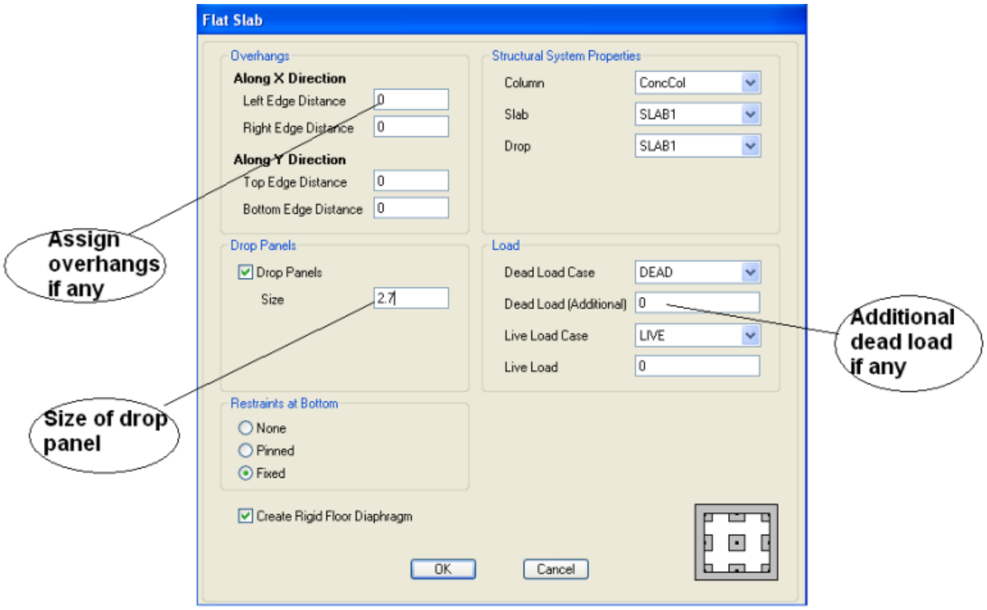


Fig. 5.1 Specification of flat slab

5. Define the slab and drop properties assign it, however it should be noted that similar storey option should be selected.

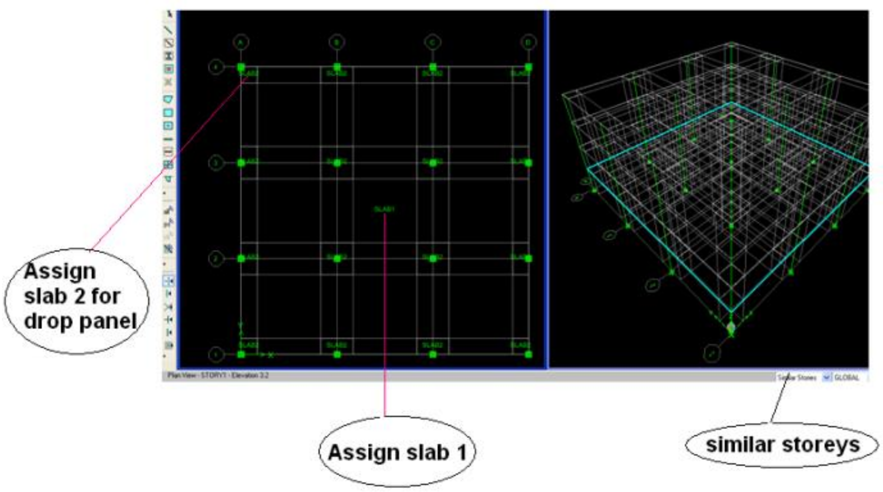


Fig. 5.2 slab properties

6. Define the load cases as Dead load, live load and Earthquake load. Select modify lateral load option and assign the earthquake properties. It is preferable to assign time period of building user defined instead of

program calculated. Select storey range and specify response reduction factor as 5 for S.M.R.F. and 3 for O.M.R.F. also specify the seismic properties such as soil type, zone factor and importance factor.

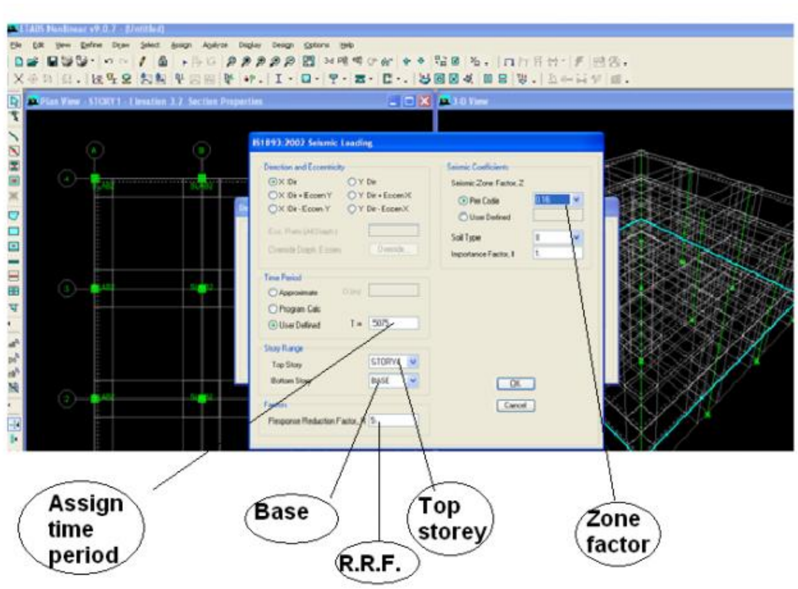


Fig. 5.3 Earthquake load properties

7. Assign the loads for all the load cases the particular frame system

8. Analyze the model

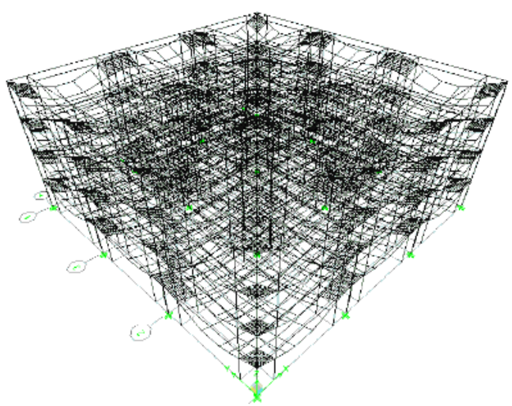


Fig. 5.4 Deflected shape under gravity load

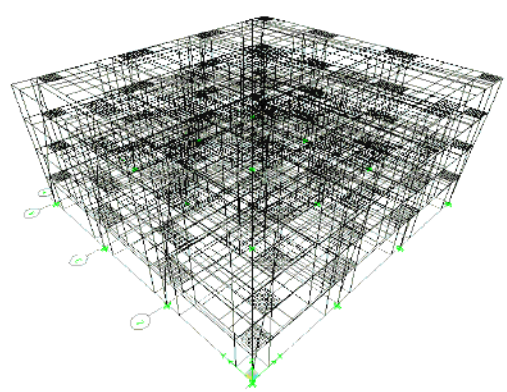
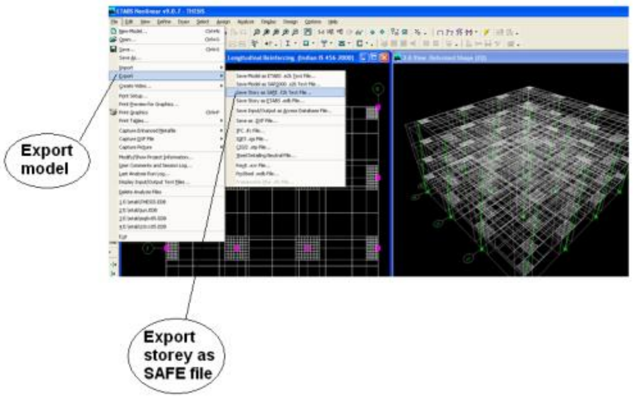


Fig. 5.5 Deflected shape under lateral load

9. To design the flat slab SAFE software is used. Hence the above model file is exported in SAFE software



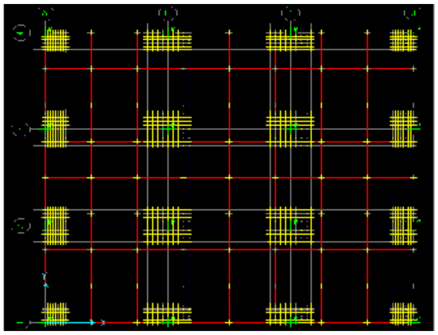


Fig. 5.6 Export of ETABS model to SAFE

Fig. 5.7 Plan of flat slab

10. Properties of restraint (Column and column capital) are assigned to the model.

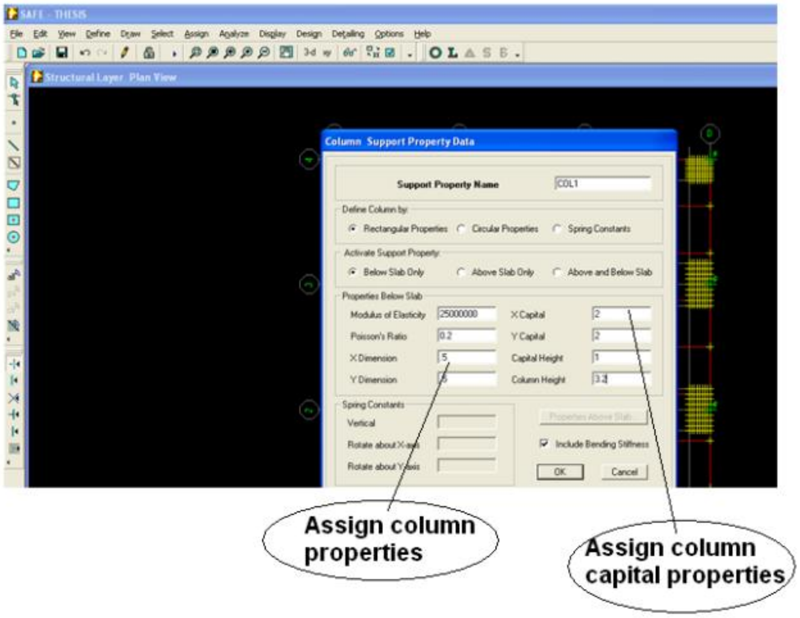


Fig. 5.8 Assign restraint properties

11. Analyze the model

12. Select the code for which we want to design the flat slab

13. Steel and concrete quantities can be calculated using SAFE software.

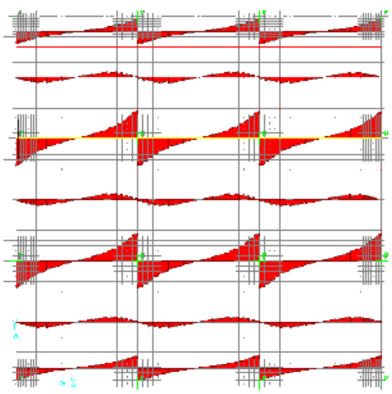


Fig. 5.9 Strip forces due to earthquake load

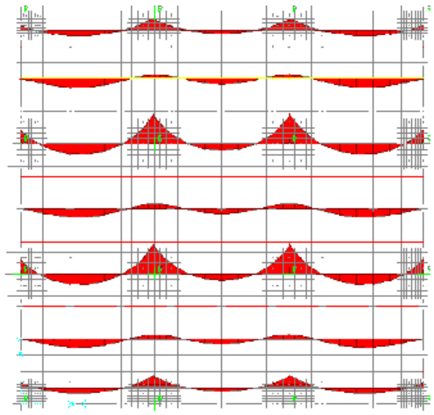


Fig. 5.10 Strip forces due to gravity load

5.3 DISTRIBUTION OF MOMENTS

The moment in flat slab is distributed firstly along negative and positive moment in longitudinal direction and further this moment is distributed along transverse direction in column strip and middle strip.

Distribution coefficients are calculated for different layout of plans such as 3 bay 8m x 8m , 3 bay 10m x 10m, 3 bay 6m x 6m, 3 bay 10m x 8m, 3 bay 8m x 6m plan for different number of storey. Coefficients are calculated for gravity loading as well as combined gravity and lateral loading. Table 5.1 shows distribution coefficients for gravity loading and table 5.2 shows coefficients for combined gravity and lateral loading

Table 5.1 Distribution coefficients for gravity loading

	Types of moments	6m x 6m span			8m x 8m span			10m x 10m span			10m x 8m span			8m x 6m span		
		Longi. Distri.	Transverse Distri.		Longi. Distri.	Transverse Distri.		Longi. Distri.	Transverse Distri.		Longi. Distri.	Transverse Distri.		Longi. Distri.	Transverse Distri.	
			C.S.	M.S.		C.S.	M.S.		C.S.	M.S.		C.S.	M.S.		C.S.	M.S.
1	**Interior Frame**															
	Interior span															
	Negative (support)	0.85	0.9	0.1	0.85	0.9	0.1	0.82	0.88	0.12	0.82	0.9	0.1	0.82	0.9	0.1
	Positive (Midspan)	0.15	0.6	0.4	0.15	0.6	0.4	0.18	0.55	0.45	0.18	0.55	0.45	0.18	0.54	0.46
	End span															
	Interior (Negative)	0.85	0.9	0.1	0.85	0.9	0.1	0.82	0.88	0.12	0.82	0.9	0.1	0.82	0.9	0.1
	Positive	0.3	0.55	0.45	0.25	0.55	0.45	0.32	0.55	0.45	0.28	0.54	0.46	0.25	0.54	0.46
	Exterior (Negative)	0.7	0.85	0.15	0.6	0.85	0.15	0.66	0.82	0.18	0.6	0.87	0.13	0.6	0.9	0.1
2	**Exterior Frame**															
	Interior span															
	Negative (support)	0.77	0.78	0.22	0.75	0.78	0.22	0.75	0.76	0.24	0.8	0.85	0.15	0.8	0.86	0.14
	Positive (Midspan)	0.23	0.47	0.53	0.25	0.5	0.5	0.25	0.5	0.5	0.2	0.6	0.4	0.2	0.54	0.46
	End span															
	Interior (Negative)	0.77	0.78	0.22	0.77	0.78	0.22	0.75	0.76	0.24	0.8	0.85	0.15	0.8	0.86	0.14
	Positive	0.32	0.55	0.45	0.32	0.55	0.45	0.32	0.55	0.45	0.35	0.55	0.45	0.3	0.55	0.45
	Exterior (Negative)	0.23	0.25	0.75	0.3	0.4	0.6	0.25	0.25	0.75	0.25	0.4	0.6	0.2	0.45	0.55

Table 5.2 Distribution coefficients for combined gravity and lateral loading

	Types of moments	3 bay 8m x 8m span G+5			3 bay 8m x 8m span G+10			3 bay 8m x 8m span G+15			3 bay 10m x 10m span G+5			3 bay 10m x 8m span G+5		
		Longi Distri..	Transverse Distri.		Longi Distri.	Transverse Distri.		Longi. Distri.	Transverse Distri.		Longi. Distri.	Transverse Distri.		Longi. Distri.	Transverse Distri.	
			C.S.	M.S.		C.S.	M.S.		C.S.	M.S.		C.S.	M.S.		C.S.	M.S.
1	**Interior Frame**															
	Interior span															
	Negative (support)	0.84	0.89	0.11	0.8	0.85	0.15	0.77	0.84	0.16	0.8	0.87	0.13	0.82	0.9	0.1
	Positive (Midspan)	0.16	0.57	0.43	0.2	0.57	0.43	0.23	0.55	0.45	0.2	0.55	0.45	0.18	0.54	0.46
	End span															
	Interior (Negative)	0.84	0.89	0.11	0.8	0.85	0.15	0.77	0.84	0.16	0.8	0.87	0.13	0.82	0.9	0.1
	Positive	0.28	0.55	0.45	0.3	0.55	0.45	0.3	0.54	0.46	0.32	0.55	0.45	0.28	0.53	0.47
	Exterior (Negative)	0.68	0.84	0.16	0.77	0.84	0.16	0.62	0.8	0.2	0.66	0.8	0.2	0.56	0.84	0.16
2	**Exterior Frame**															
	Interior span															
	Negative (support)	0.75	0.77	0.23	0.72	0.73	0.27	0.78	0.81	0.19	0.74	0.76	0.24	0.78	0.84	0.16
	Positive (Midspan)	0.25	0.5	0.5	0.28	0.5	0.5	0.22	0.5	0.5	0.26	0.5	0.5	0.22	0.56	0.44
	End span															
	Interior (Negative)	0.75	0.77	0.23	0.72	0.73	0.27	0.78	0.81	0.19	0.74	0.76	0.24	0.78	0.84	0.16
	Positive	0.35	0.55	0.45	0.4	0.55	0.45	0.28	0.54	0.46	0.33	0.55	0.45	0.34	0.54	0.46
	Exterior (Negative)	0.3	0.37	0.63	0.3	0.32	0.68	0.24	0.36	0.64	0.21	0.16	0.84	0.24	0.42	0.58

5.4 COMPARISON OF MOMENTS

Longitudinal and transverse moments are compared for plan dimensions of 3 bay 6m x 6m, 3 bay 8m x 8m, 3 bays 10m x 10m, 3 bay 10m x 8m, 3 bay of 8m x 6m. Considering different number of storey.

Moments in flat slab due to gravity loading of 10kN/m^2 are shown in table 5.3, however table 5.4 shows the moments due to combined gravity load 10kN/m^2 and earthquake loading as per I.S. 1893-2002.

Table 5.3 Moments in flat slab for 3D gravity load analysis

			3 bay 6m x 6m			**3 bay 8m x 8m**			**3 bay 10m x 10m**			**3 bay10m x 8m**			**3 bay 8m x 6m**		
Method of analysis	Frame	Types of moments	Longi. Direction Moment	Transverse direction		Longi. Direction Moment	Transverse direction		Longi. Direction Moment	Transverse direction		Longi. Direction Moment	Transverse direction		Longi. Direction Moment	Transverse direction	
				C.S.	M.S.		C.S.	M.S		C.S.	M.S.		C.S	M.S		C.S.	M.S.
3D analysis using software	**X1**	**Interior span**															
		Total moment=	147			312			665.5			678.5			163.3		
		Negative	121.9	108	14.4	266	239	27	401	355	46	558.5	509	50	133.3	123	10
		Positive	25.1	14.4	10.7	46	27	19	84	47	37	120	66	54	30	16	14
		End span analysis															
		Interior (Negative)	121.9	108	14.4	266	239	27	401	355	46	558.5	509	50	133.3	123	10
		Span (Positive)	46	25	21	77.5	42.5	35	153	83	70	188	100	88	40.5	22	19
		Exterior (Negative)	102.5	86.5	16	180.2	150	30.2	317.4	261	56.4	408	353	55	98	87	11
	X2	**Interior span**															
		Total moment =	147			253.8			500			573			147.5		
		Negative	111.5	86.5	25	192	150	42	343.5	262	82	451	377	74	116	100	16
		Positive	35	16	19	61.8	30.3	31.5	116.5	56.5	60	122	72	50	31.5	17	15
		End span analysis															
		Interior Negative	111.5	86.5	25	191.7	149.2	42.5	343.5	262	82	451	377	74	116	100	16
		Span	47.6	25.6	22	80.5	44.5	36	156	86	70	198	106	92	44	24	20
		Exterior (Negative)	34.6	9	25.6	76.1	31.5	44.6	112	27	85	136	55	81	29	13	16

Table 5.4 Moments along longitudinal direction (L.D.) and Transverse Direction(T.D.) of 3D analysis for combined gravity and lateral loading

			3 bay 8m x 8m									**3 bay 10m x 10m**									**3 bay 8m x 6m**			**3 bay 10m x 8m**		
Method Of Analysis	Frame	Types Of Moment	5 storey			10 storey			15 storey			5 storey			10 storey			15storey			5storey			5 storey		
			L.D.	T.D.		L.D.	T.D.		L.D.	T.D.		L.D.	T.D.		L.D.	T.D.		L.D.	T.D.		L.D.	T.D.		L.D.	T.D.	
				C.S.	M.S.		C.S.	M.S.		C.S.	M.S		C.S.	M.S.		C.S.	M.S.		C.S.	M.S.		C.S.	M.S.		C.S.	M.S.
3D analysis	**X1**	**Interior span**																								
		Total moment =	286			253.4			261			486			482			473			462			686		
		Negative	239	212	27	202.4	173	29.4	202	170	32	395	344	51	381	325	55.5	359	298	61	380	352	27.5	562	513	49
		Positive	47	27	20	51	29	22	59.6	33	27	91	50	41	101	55	46	114	61	53	82	44	38	124	67	57
		End span analysis																								
		Interior (Negative)	239	212	27	202.4	173	29.4	202	170	32	395	344	51	364	325	39	359	298	61	380	352	27.5	562	513	49
		Span (Positive)	80.5	45	36	73	40	33	78	42	36	156	85	71	140	77	63	148	80	68	118	62	56	191	101	90
		Exterior (Negative)	195	164	31	196	165	31	163	130	32.5	322	262	60	285	231	54	310	245	65	267	237	30	382	325	57
	X2	**Interior span**																								
		Total moment	247			209			287			472			419			418			344			594		
		Negative	185	142	43	150	110	40	223	181	42	350	265	85	304	227	77	293	213	80	258	214	43.5	465	390	75
		Positive	62	31	32	59	30	29	64	32	32	122	60	62	115	60	55	125	65	60	86	47	39	129	73	56
		End span analysis																								
		Interior (Negative)	185	142	43	150	110	40	223	181	42	350	265	85	304	227	77	293	213	80	257	214	43.3	465	390	75
		Span (Positive)	86	47	39	82	45	37	81	44	37	157	86	71	142	82	60	151	83	68	124	66	58	202	109	93
		Exterior (Negative)	70.5	26	45	62	20	42	67.5	24	43.5	101	16	85	116	37	79	120	37	83	84	35	49	142	60	82

5.5 WIDTH OF COLUMN STRIP AND MIDDLE STRIP

The slab is divided into column strip and middle strip. Width of the flat slab is calculated along column strip and middle strip due to gravity and lateral loading. The plan dimensions of the slab are taken as 3 bay 6m x 6m, 3 bay 8m x 8m, 3 bays 10m x 10m, 3 bay 10m x 8m, 3 bay of 8m x 6m. Table 5.5 shows the width of column strip in percentage due to gravity loading of 10kN/m2. While table 5.6 shows the width of column strip (C.S.) and middle strip (M.S.) subjected to gravity load of 10kN/m^2 and earthquake load as per I.S. 1893-2002.

Table 5.5 Effective width of flat slab for gravity loading

	8m x 8m				10m x 10m				6m x 6m				8m x 6m				10m x 8m			
	Software				software				Software				software				Software			
	Interior frame		Exterior frame		Interior		Exterior		Interior		Exterior		Interior		Exterior		Interior		Exterior	
	End span	Mid span	End span	Mid span	End span	Mid span	End span	Mid span	End span	Mid span	End span	Mid span	End span	Mid span	End span	Mid span	End span	Mid span	End span	Mid span
Gravity load analysis																				
Width of column strip	1.26 16%	2.18 27	1.08 14	1.92 24%	1.92 19	2.63 26	1.39 14	2.51 25	0.855 14	1.5 25	0.87 15	1.36 23	0.855 14	1.5 25	0.87 15	1.36 23	0.855 14	1.5 25	0.87 15	1.36 23
Width of middle strip	4.56 57%	3.64 46%	5 63	4.16 52%	5.45 55	4.74 47	6.1 61	4.98 50	3.645 61	3.00 50	3.77 63	3.28 55	3.645 61	3.00 50	3.77 63	3.28 55	3.645 61	3.00 50	3.77 63	3.28 55

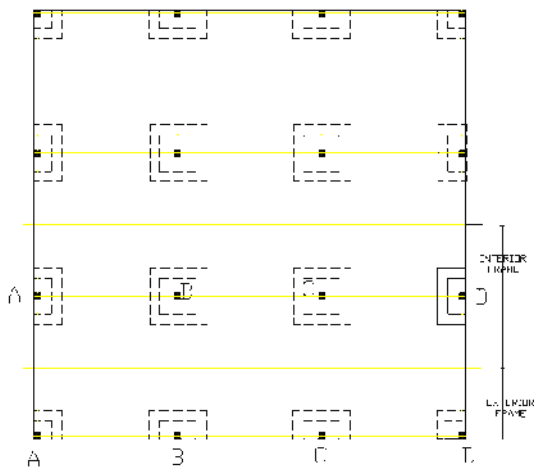


Fig.5.11 Plan of flat slab

Table 5.6 Effective width of flat slab for combined gravity and earthquake loading

	Interior frame								Interior frame							
	End span						Mid span		End span						Mid span	
	AB			CD			BC		AB			CD			BC	
	C.S.		M.S.	C.S.		M.S.	C.S.	M.S.	C.S.		M.S.	C.S.		M.S.	C.S.	M.S.
	Exterior	Interior		Exterior	Interior				Exterior	Interior		Exterior	Interior			
3 bay 8mx8m																
5 storey	10.5	27	62.5	16	21	63	27	46	8	25	67	14	20.5	65.5	26	48
10storey	14	24.5	61.5	19	18	63	28	44	9	24.6	66.4	16	20	64	23	54
15storey	17	22	61	20	14	66	20	60	11	23	66	17	18	65	24	52
3 bay 10m x 10m																
5 storey	10	20.5	69.5	10	20	70	26	48	9	19	72	9	18	73	21	58
10storey	12	22	66	14	19	67	20	60	10	20	70	10	19	71	21	58
15storey	13	19	68	14	18	68	22	56	10	19	71	11	18.5	70.5	19	62
3 bay 6m x 6m																
5 storey	10	24	66	15	21	64	24	52	9	24	67	14	20	66	22	56
3 bay 10m x 8m																
5 storey	14	25	61	18	23	59	23	54	12	25	63	14	18	68	25	50
3 bay 8m x 6m																
5 storey	13	25	62	12	24	64	24	52	12	24	64	10	26	64	24	52

6. DESIGN OF FLAT SLAB

6.1 GENERAL

Flat slabs can be designed by limit state method as well as working stress method. In order to satisfy strength as well as serviceability criteria codes of different countries such as I.S. 456-2000, ACI- 318 and B.S. 8110 recommends the design of flat slab by limit state method, however design rules differ considerably in codes of different standards.

6.2 PROPORTIONING OF FLAT SLAB COMPONENTS

Design of flat slab requires proportioning of dimensions of its different components and determination of reinforcement to satisfy both the serviceability and strength requirements. Proportioning includes deciding the thickness of slab, size of drop and size of column head.

6.2.1 Thickness of slab

Thickness of slab is chosen such that it satisfy both strength and serviceability criteria. Generally the thickness of slab is governed by the serviceability requirement for deflection than the requirements of strength. I.S. 456-2000 code recommends following limiting values of deflection for reinforced concrete structures, however in no case thickness of slab shall be less than 125mm.

a. Final deflection of horizontal members below the level of casting should not exceed span/250.
b. Deflection after the construction of partitions or application of finishes should not exceed span/350 or 20mm whichever is less.

6.2.2 Drop

Drop shall be rectangular in plan whose minimum length in each direction shall not less than one third of the panel length in that direction. The maximum length of drop in each direction shall not greater than half the panel length in that direction. Thickness of the drop shall be 1.25 to 1.5 times thickness of the slab elsewhere.

6.2.3 Column head

It may be rectangular or circular. The length of rectangular column head in each direction shall not be more than one forth of panel length in that direction. In case of circular column head, diameter shall not exceed one forth of the average of the panel length in each direction. The portion of the column head lying within the largest right angle cone or pyramid that has a vertex angle of 90^0 .

6.3 DESIGN REQUIREMENTS

General design requirements in flat slabs include serviceability requirements and strength requirements.

6.3.1 Serviceability Requirements

The design of flat slab is made to satisfy the serviceability requirements of deflection and crack. The serviceability requirement of deflection is controlled by effective span to effective depth ratio as shown in table 6.1. For two way slabs shorter of the two spans shall be used for calculating the span to effective depth ratio. The minimum thickness of the slab shall not be less than 125mm.

Table 6.1 Basic values of effective span to Effective depth ratios

Support conditions	Effective span/ Effective depth	
	Span≤10m	Span>10m
Cantilever	7	Deflection calculation shall be made
Simply supported	20	20×10/span
Continuous	26	26×10/span

The increasing use of limit state method of design and high strength steel lead to a wide cracks in concrete structures, thus necessitating control for cracking. The maximum width of crack is limited on the basis of appearance of structure, durability and corrosion. I.S. 456-2000, Cl.35.3.2recommends maximum crack width 0.3 mm for structures not subjected to aggressive environment while in members where cracking in the tensile zone is harmful I.S. 456 code suggests maximum width of crack 0.2 mm. The serviceability requirement for crack is controlled by the spacing of reinforcement. Usually the spacing of reinforcement based on design for strength requirement is smaller than the maximum spacing for crack control.

6.3.2 Strength Requirements

The design of reinforcement is made to satisfy strength requirements for moment and shear as

6.3.2.1 Design for moment

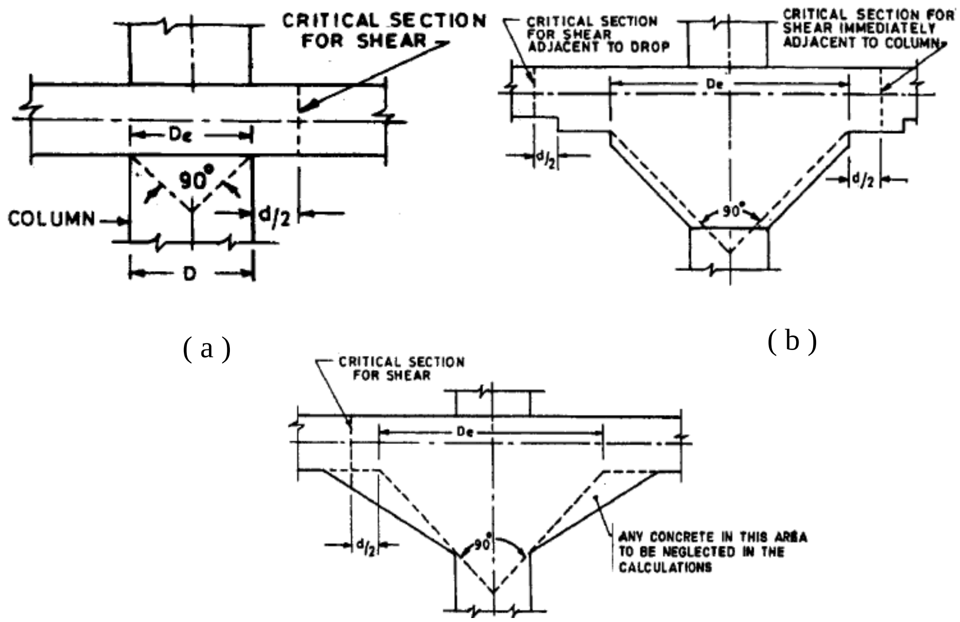
The reinforcement required for positive and negative moments in the column and middle strips can be determined either by limit state method or working stress method.

When drops in flat slabs are provided, reinforcement at the face of support may be determined based on the thickness of drop. In some cases the thickness of drop may be very large mainly from the consideration of punching shear, in such cases it is not desirable to adopt the thickness of drop in calculation of reinforcement. Therefore I.S. 456 code limits the thickness of the drop for the purpose of computing support reinforcement as the thickness of slab plus one quarter of the distance between the edge of drop and edge of capital.

6.3.2.2 Design for shear

The design for shear is made for shear force at critical section which are at a distance half the effective depth of the slab from the periphery of column or capital or drop. Fig. 6.1 shows the critical sections for shear.

When openings in flat slab are located at a distance less than ten times the thickness of slab from a concentrated reaction or when the openings are located within the column strips, the critical section shall be modified so that part of the periphery of the critical section enclosed by radial projections of the openings to the centroid of the reaction area shall be considered ineffective and opening shall not encroach upon column head. Fig. 6.2 shows the effect of opening while consideration of critical section for shear.



(c)

Fig.6.1 Critical sections for shear

The nominal ultimate shear stress is given by

$$\tau_{UV,A} = \frac{V_u}{b_0 d_d} \qquad ...(6.1)$$

Where, V_u= ultimate shear force on critical section.

b_o= periphery of the critical section.

d = effective depth of slab.

The ultimate shear force Vu causes the uniform ultimate punching shear stress all around the critical section for shear. If the total shear stress is less than shear strength of concrete, no shear reinforcement is required, however if the shear stress at critical section exceeds the shear strength of concrete but less than 1.5 times the shear strength of concrete, shear reinforcement shall be provided up to a section where the shear stress does not exceed 0.5 times shear strength of concrete.

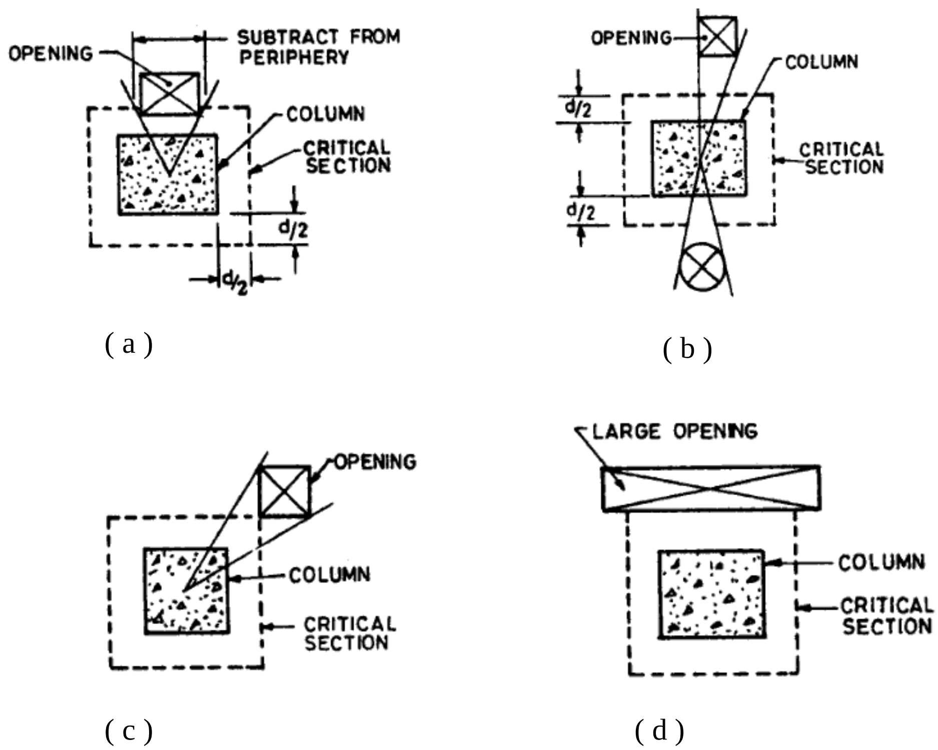


Fig. 6.2 Effect of opening on critical section for shear

The shear reinforcement shall be provided along the perimeter of column, spacing of stirrups shall not exceed 0.75 times effective depth of slab. If the shear stress exceeds 1.5 times shear strength of concrete, the flat slab shall be redesigned such that shear stress does not exceed 1.5 times shear strength of concrete.

6.4 DESIGN EXAMPLE

Flat slab with drop and column capital is considered for design purpose. Plan dimensions of flat slab are 24m x 24m as shown in fig. 6.3. Design of flat slab is carried out as per I.S.456-2000 code, ACI- 318, B.S. 8110 code. Loading considered for design purpose are gravity load 10 kN/m^2 and earthquake load is considered as per I.S. 1893-2002.

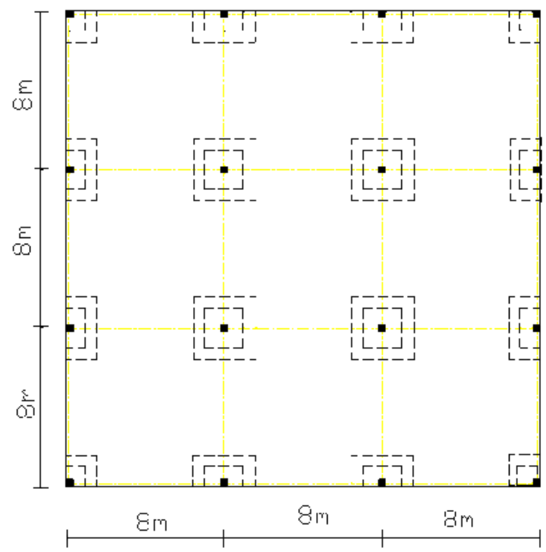


Fig. 6.3 Plan of flat slab

6.4.1 Design as per I.S. 456-2000

Flat slab is designed for gravity load of $10kN/m^2$. Moments are calculated as per the procedure stated in chapter 3. Resulting moments in flat slab along column strip and middle strip in kN.m are shown in fig. 6.4. Flat slab is designed as per I.S.456-2000 standard, reinforcements along column strip and middle strip are calculated and shown in fig. 6.5, however fig. 6.6shows the spacing of reinforcement along column strip and middle strip. Detailing of reinforcement is shown in fig. 6.7.

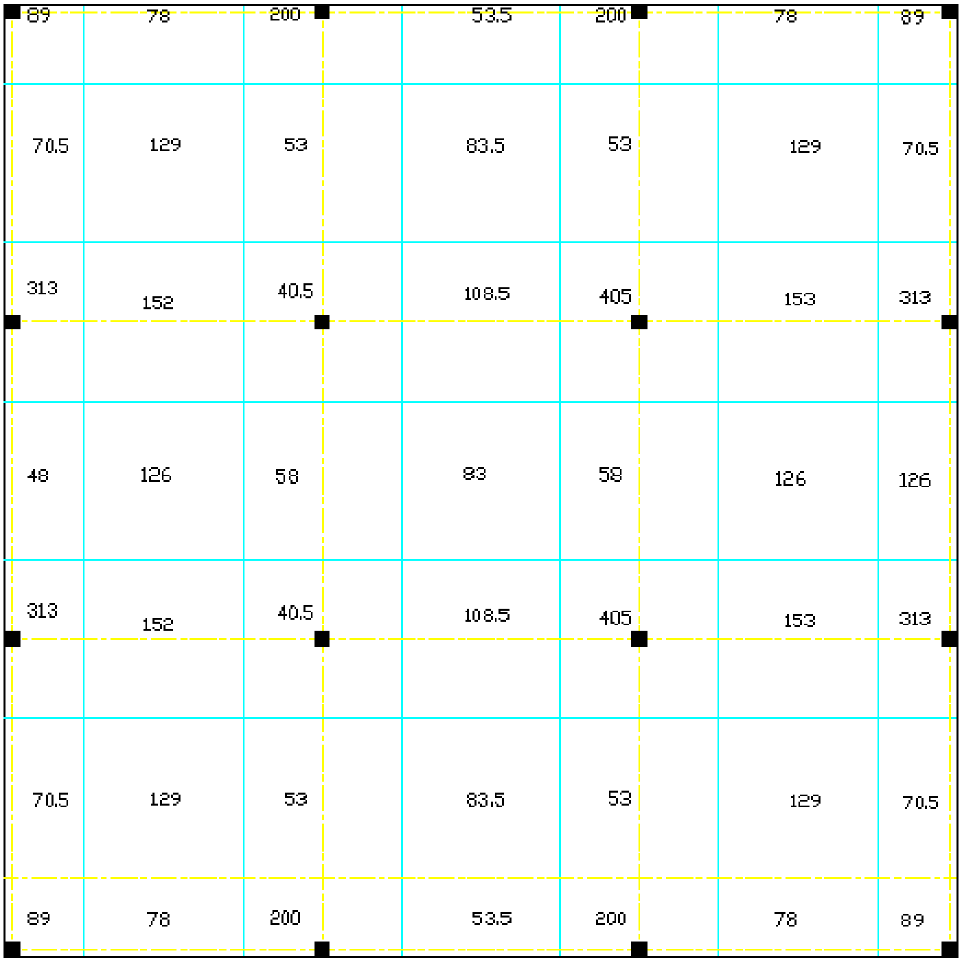


Fig. 6.4 Moments in kN.m along column strip and middle strip

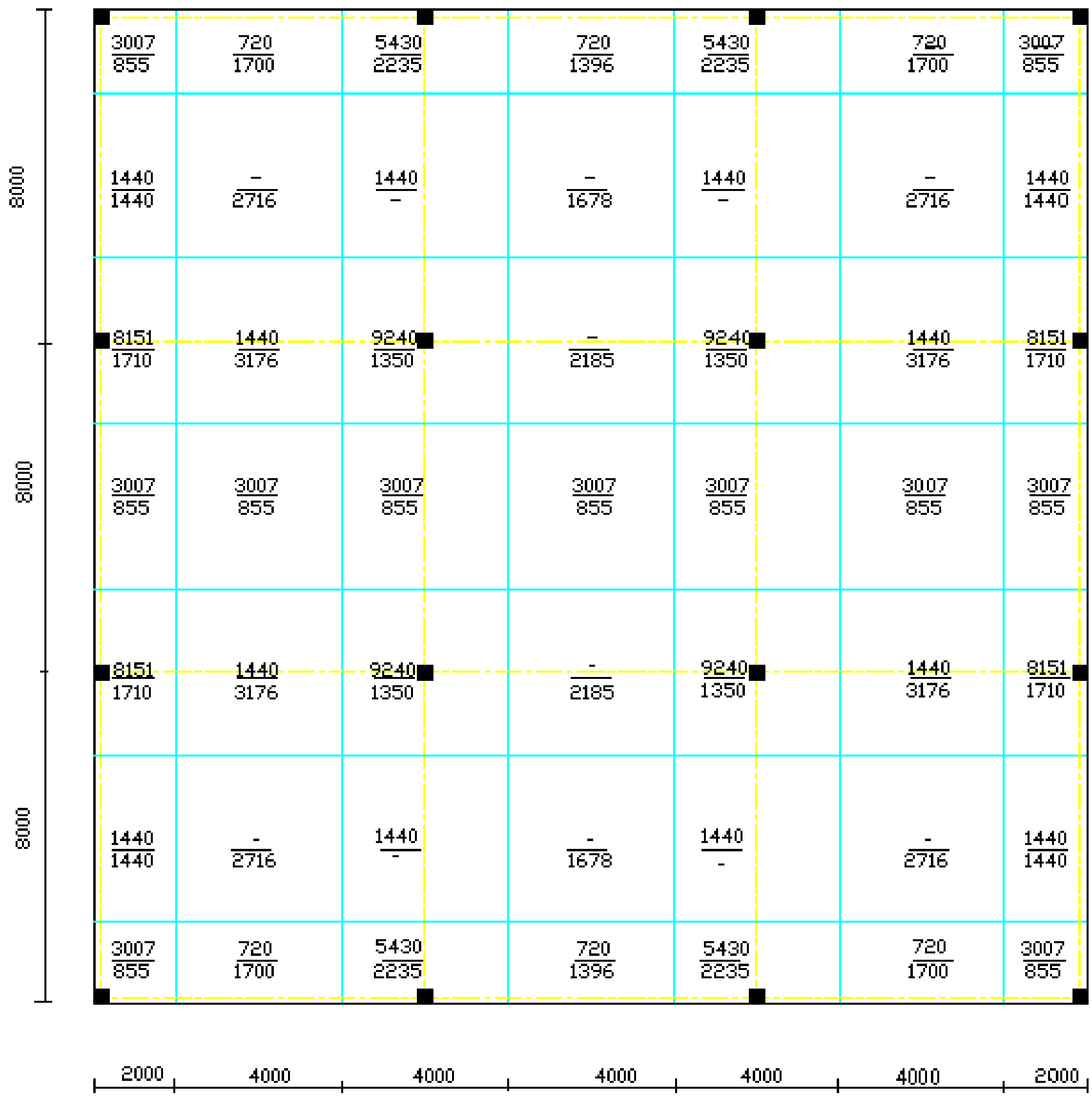
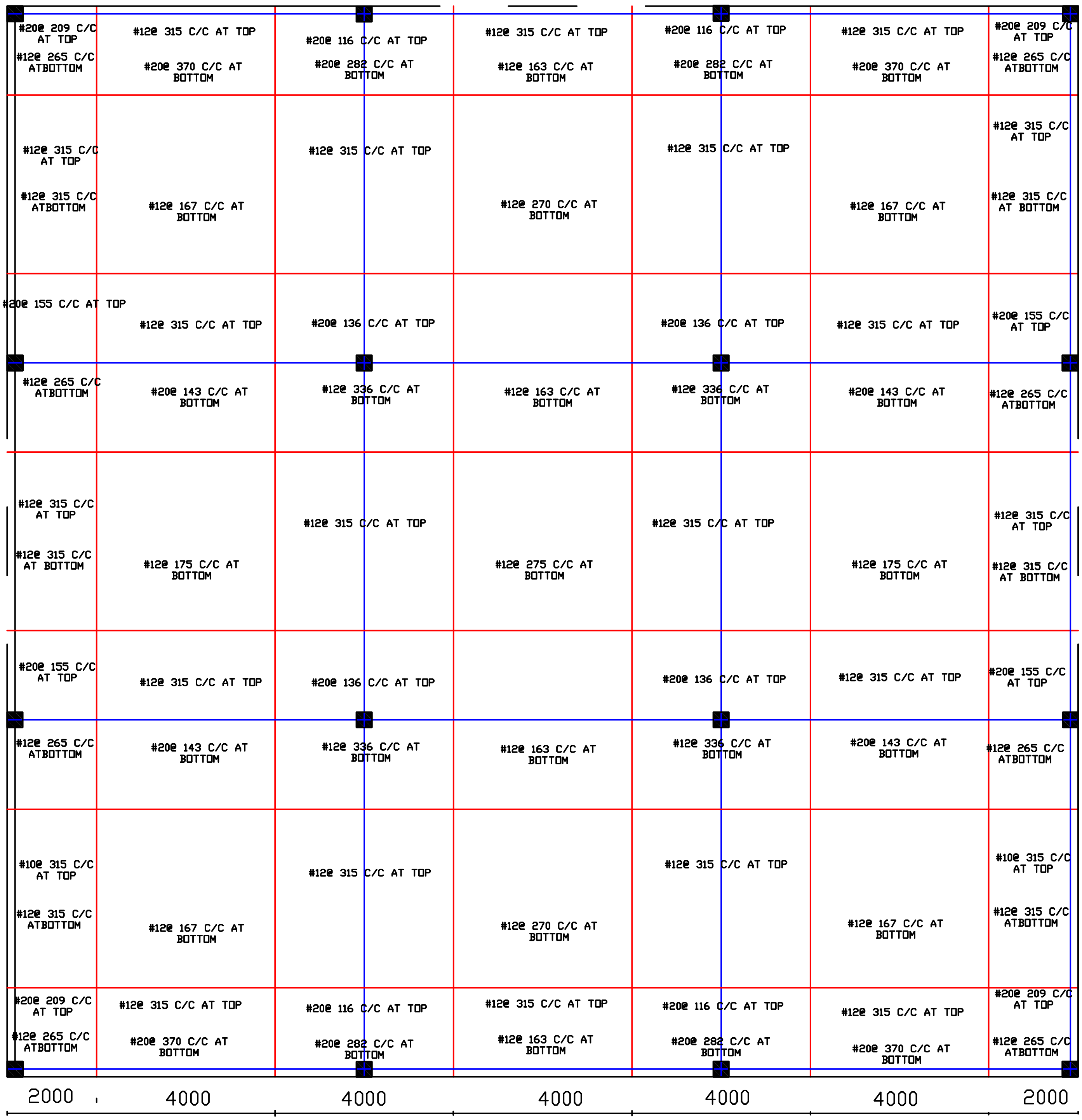


Fig. 6.5 Reinforcement in mm^2 along column strip and middle strip in flat slab



REINFORCEMENT SPACING AS PER I.S.456

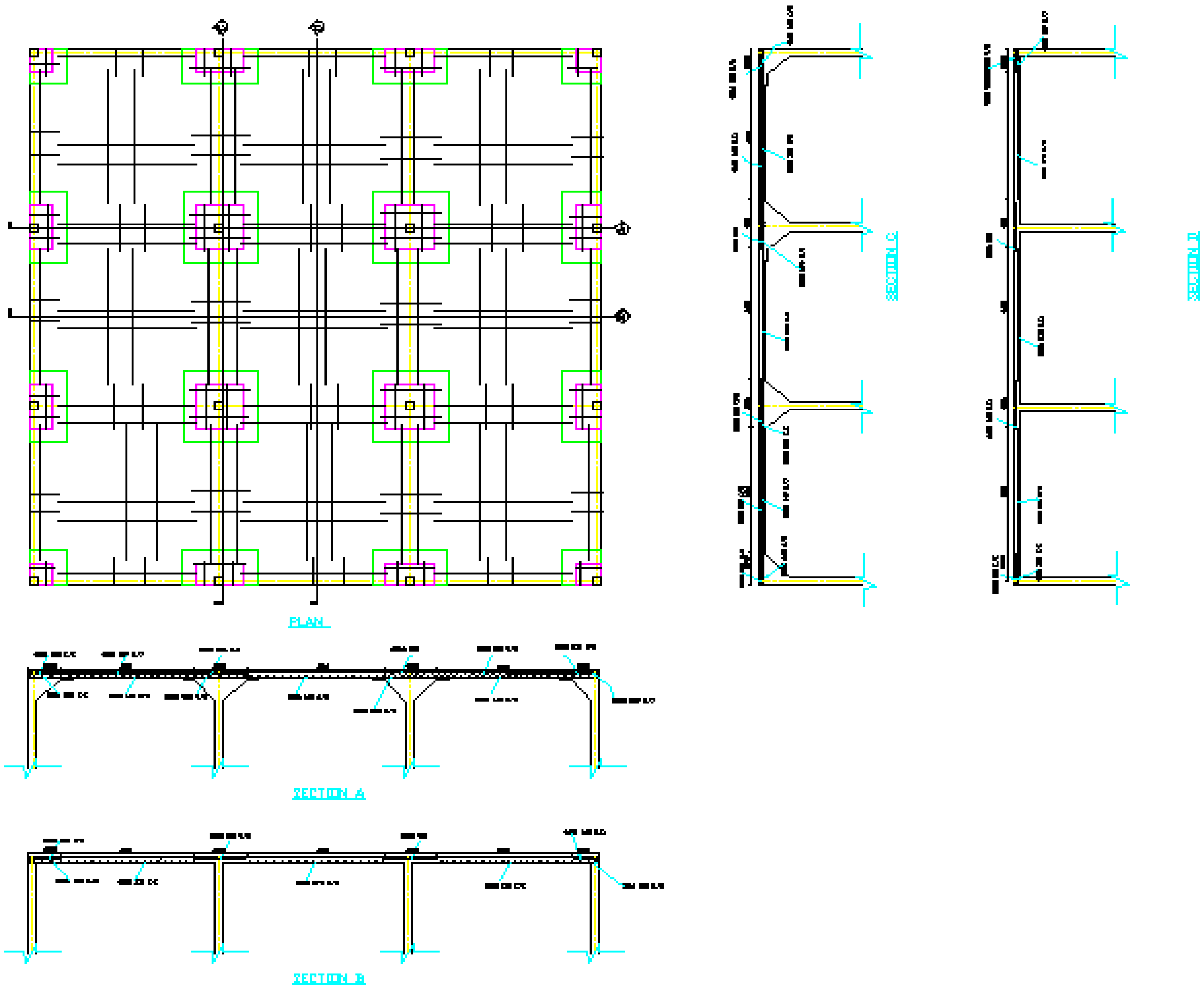


Fig. 6.7 Detailing of reinforcement in flat slab

6.4.2 Design of flat slab as per ACI-318

Flat slab is designed as per ACI- 318 code and reinforcement (in mm^2) is calculated as shown in fig. 6.8 along column strip and middle strip. Spacing of reinforcement is shown in fig. 6.9.

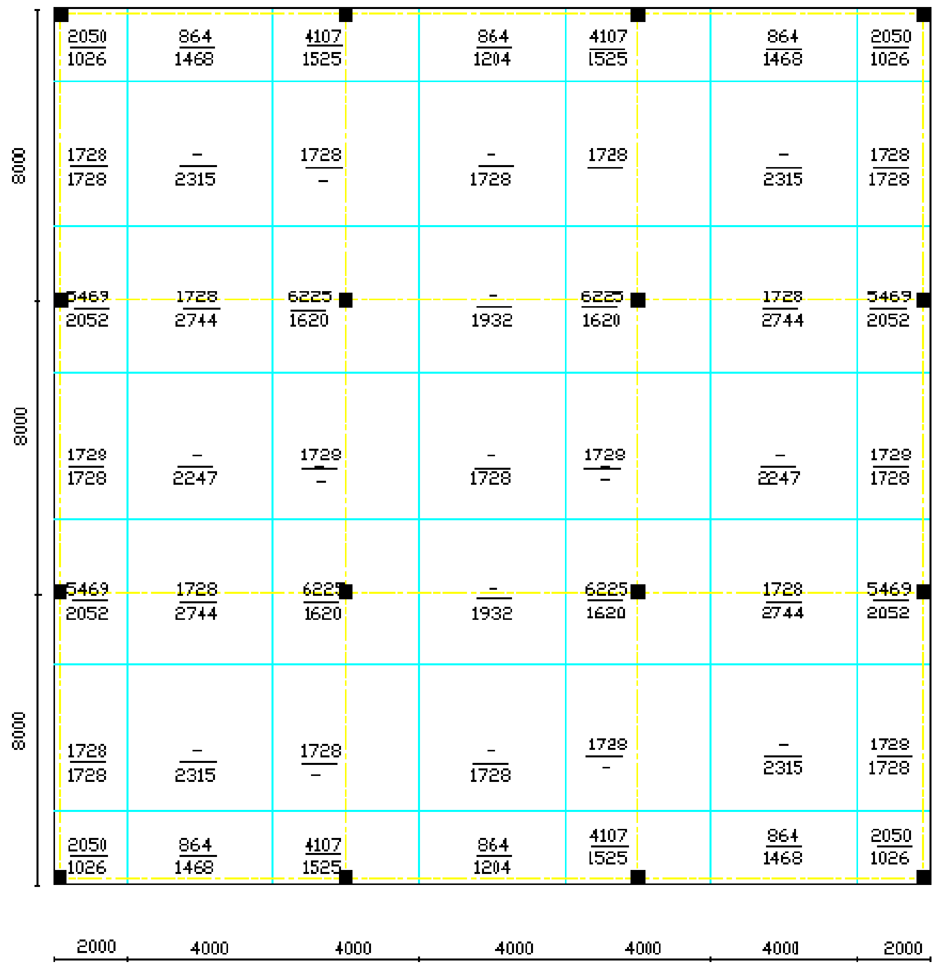


Fig. 6.8 Reinforcement in mm^2 along column strip and middle strip in flat slab

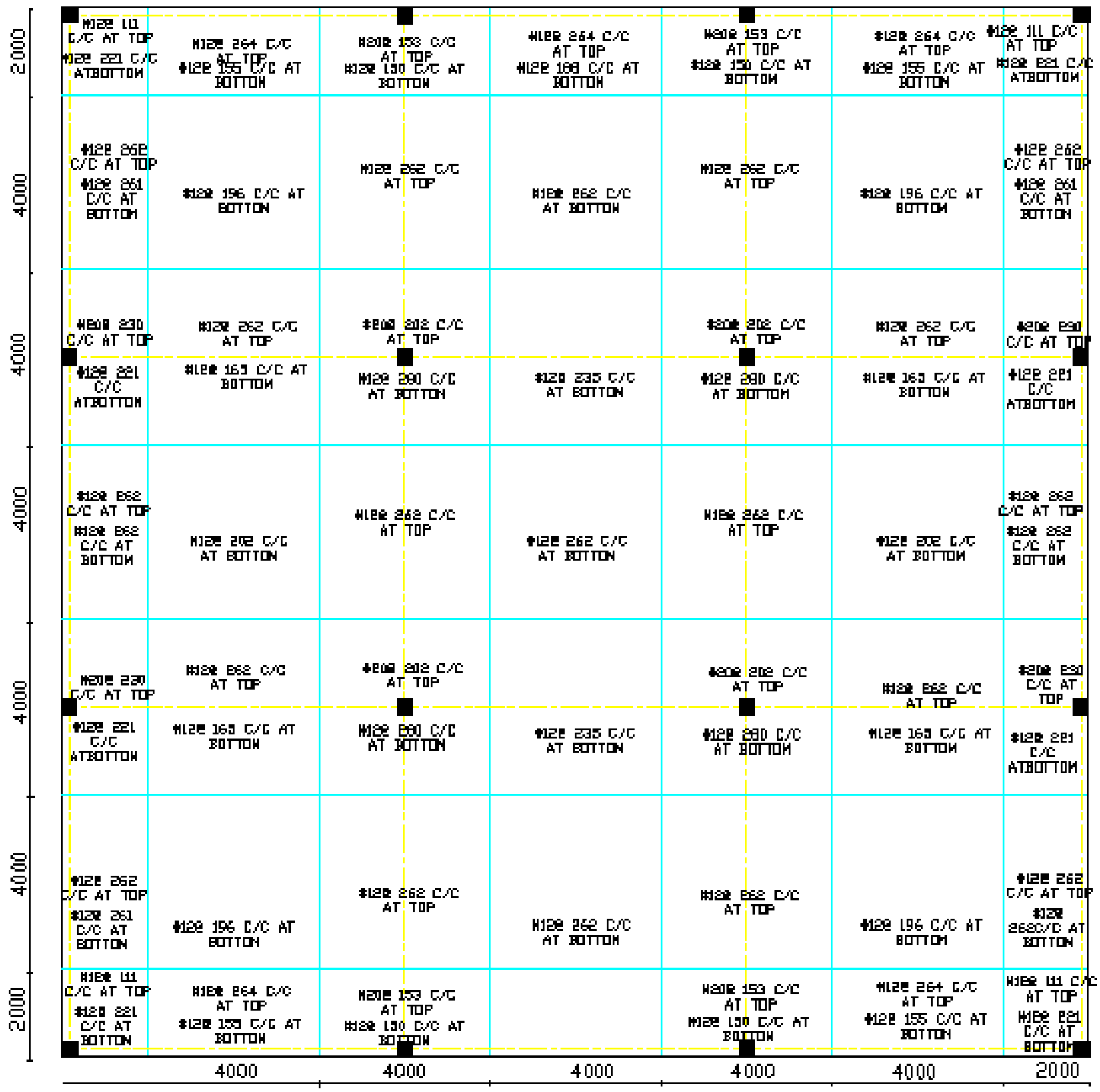


Fig. 6.9 Spacing of reinforcement in mm along column strip and middle strip in flat slab

6.4.3 Design as per B.S. 8110

Flat slab is designed as per B.S. 8110 code and reinforcement (in mm^2) is calculated as shown in fig. 6.10 along column strip and middle strip. Reinforcement spacing is shown in fig. 6.11

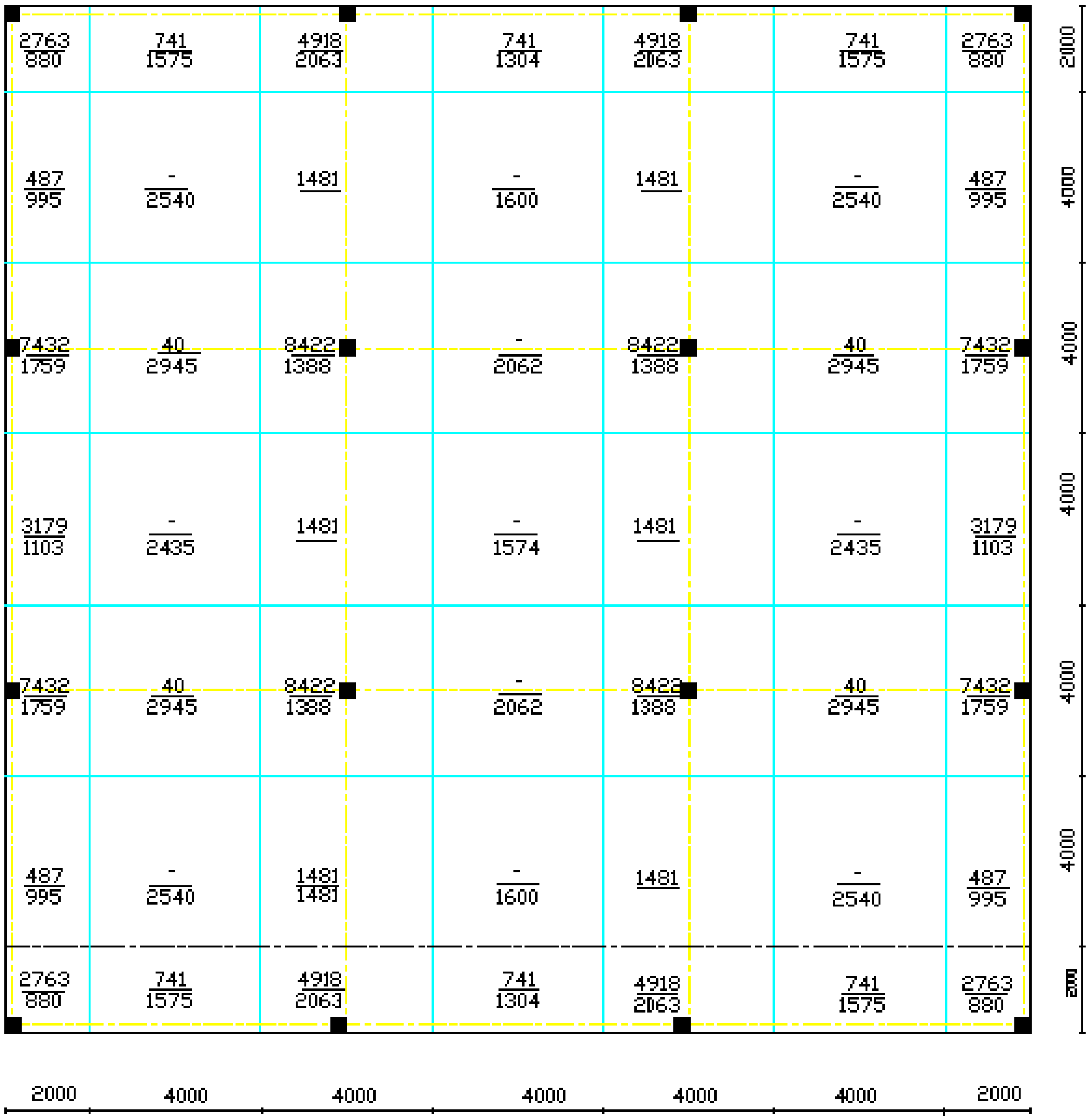


Fig. 6.10 Reinforcement (in mm^2)along column strip and middle strip in flat slab

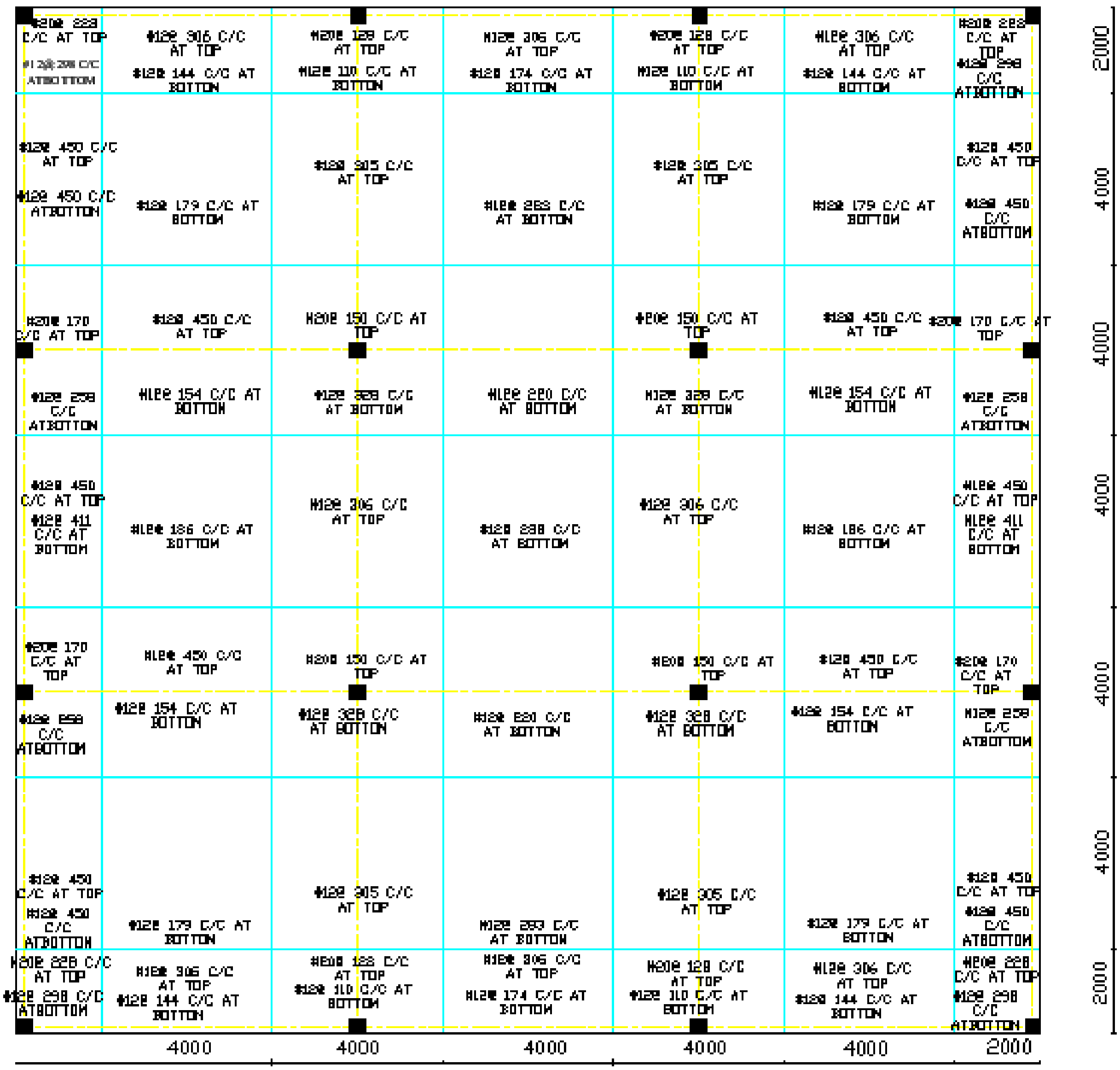


Fig. 6.11 Spacing of reinforcement along column strip and middle strip in flat slab

7. SOFTWARE FOR ANALYSIS AND DESIGN OF FLAT SLAB

7.1 GENERAL

Software for analysis and design of flat slab with drop and column capital is prepared using Visual Basic as a tool. Software is capable of analyzing the flat slab by Direct Design method, Equivalent Frame Method and using software coefficients for distribution of moments along longitudinal and transverse direction calculated by three dimensional analysis of flat slab using SAFE software (ref. section 5.3). Software designs the flat slab with column capital and with drop as per I.S.456-2000 and ACI-318.

7.2 ANALYSIS OF FLAT SLAB DY DIRECT DESIGN METHOD

Input data for analysis of flat slab is span of flat slab in longitudinal and transverse direction, column size, load, offset distance etc. as shown in fig.7.1. analysis of flat slab is carried out using three methods such as Direct design Method as per I.S.456-2000, Equivalent frame method and Direct Design Method using the coefficients calculated using 3D analysis of flat slab building. Software gives facility to select the method of analysis as shown in fig. 7.2.

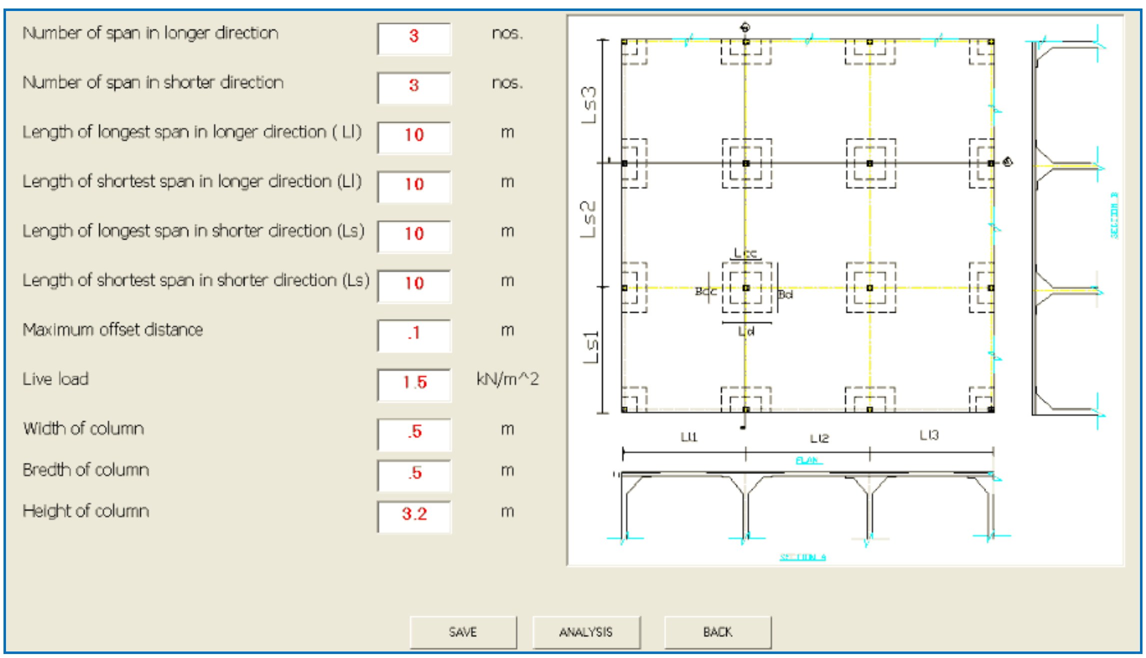


Fig. 7.1 Input for analysis of flat slab by Direct Design Method

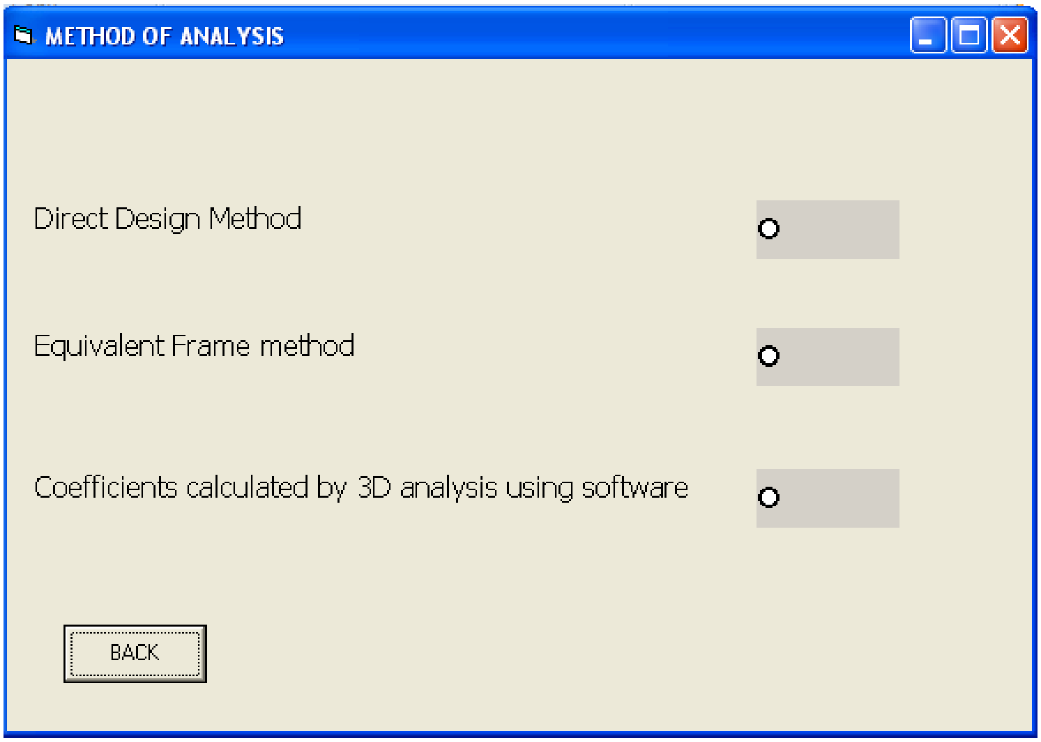


Fig. 7.2 Methods of analysis of flat slab

Direct Design Method will be applicable provided that the limitations of this method are satisfied. Hence the software checks the applicability of Direct Design Method as shown in fig. 7.3. Analysis of flat slab with column capital and with drop is carried out by software using DDM and moments in column strip and middle strip are calculated as shown in fig. 7.4. It is very important to satisfy the shear stress criteria in order to fail the flat slab in punching. Hence shear stress is checked at different column locations such as corner column, edge column and central column at different critical sections such as at section near column capital and drop as the slab may fail in any of the section. Fig. 7.5 shows the shear stress check for flat slab.

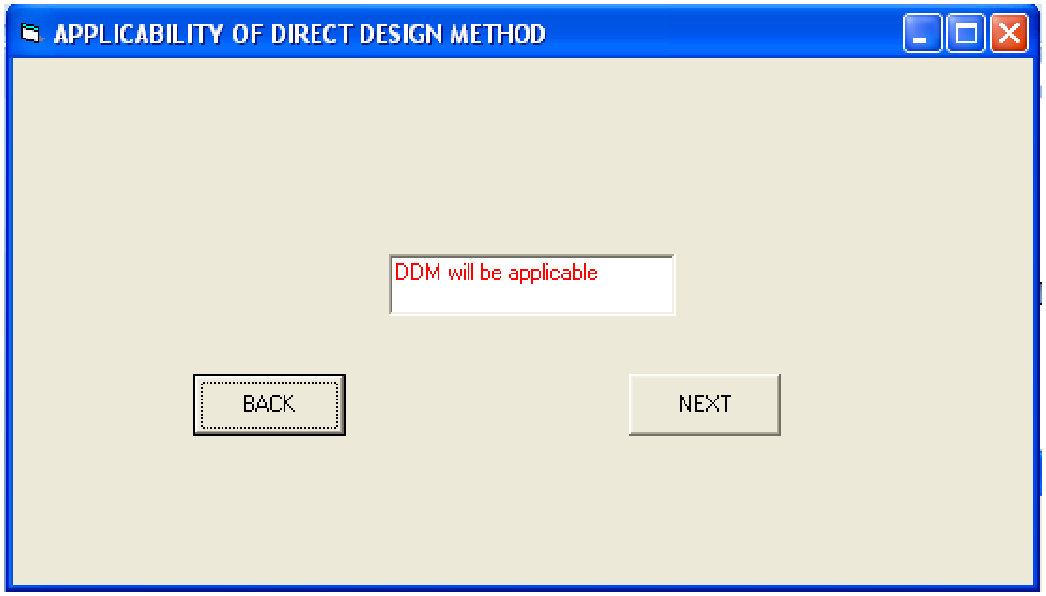


Fig. 7.3 Applicability of Direct Design Method

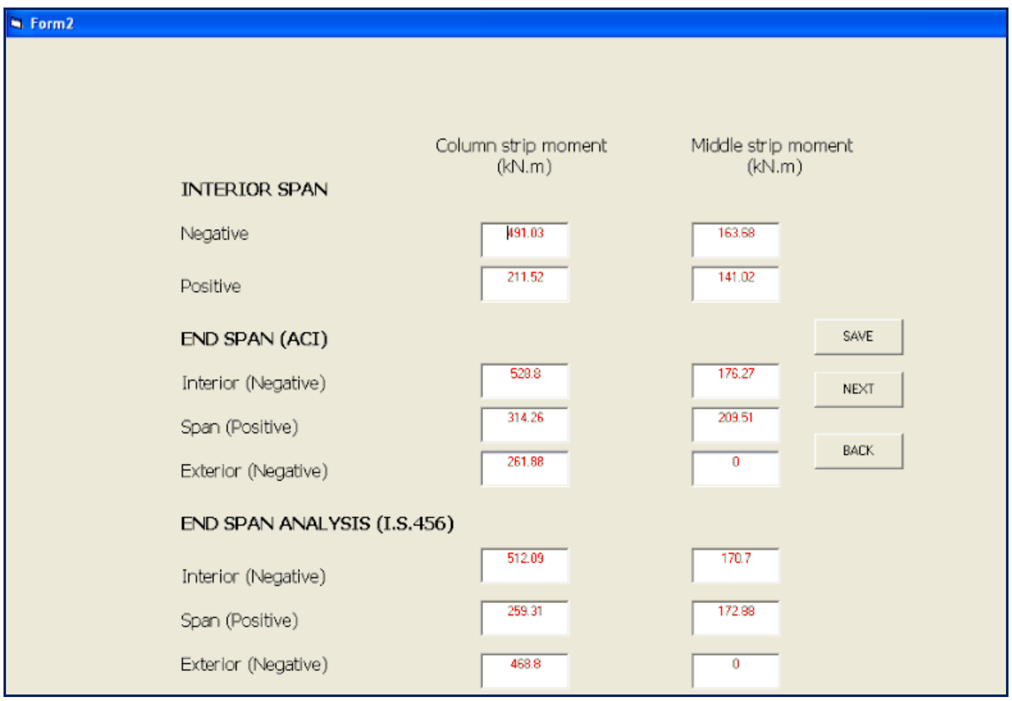


Fig. 7.4 Moments along column strip and middle strip by DDM

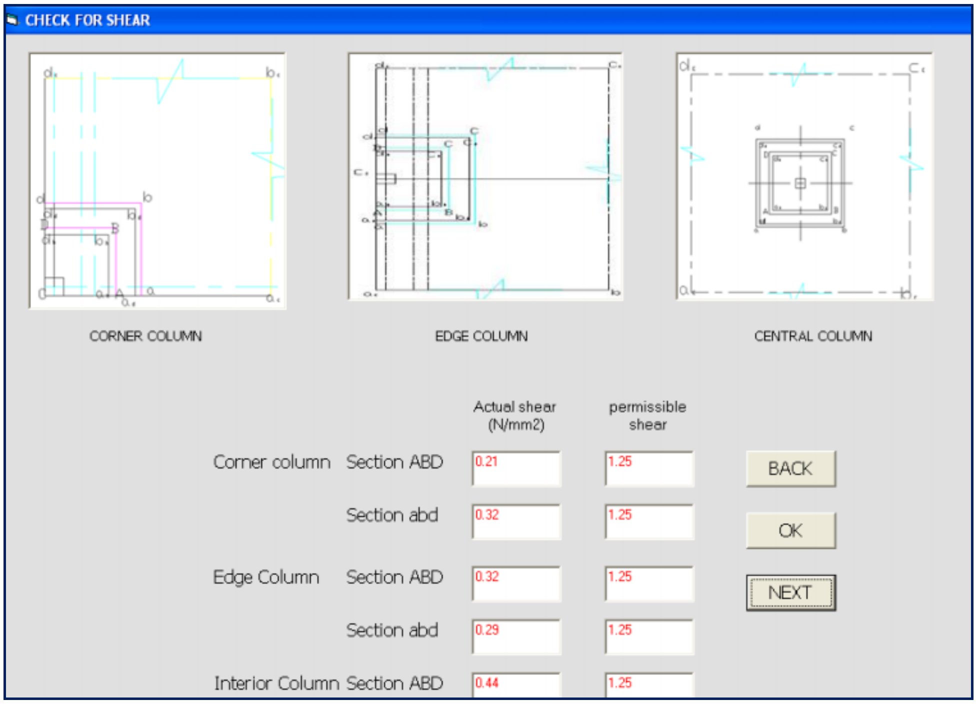


Fig. 7.5 Check for shear

After the shear stress check is satisfied the design of flat slab is carried out in software. Fig. 7.6 shows the designed output dimensions of slab, drop and column capital. Reinforcement and spacing for any bar diameter can be calculated in software. Fig.7.7 shows the reinforcement and spacing of bars at column strip and middle strip.

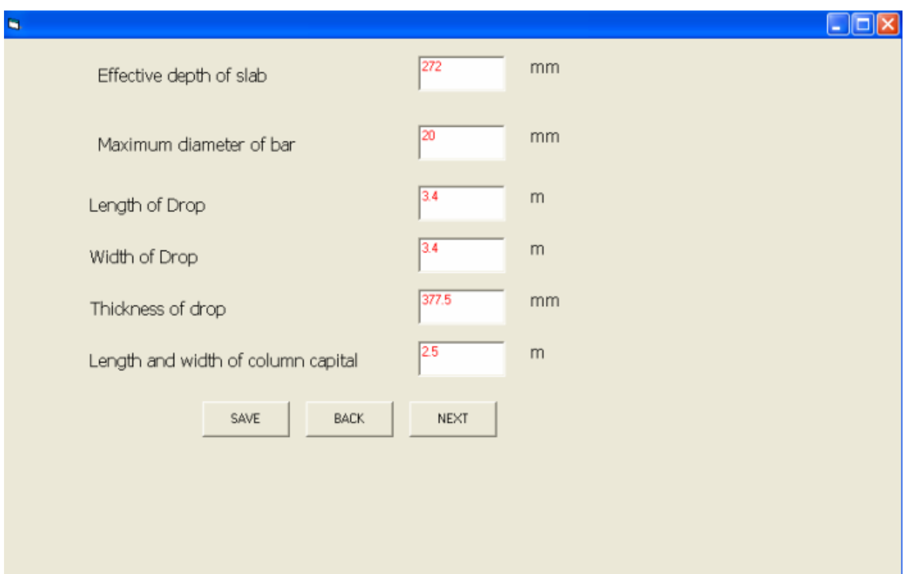


Fig. 7.6 Designed dimensions of slab, drop and column capital

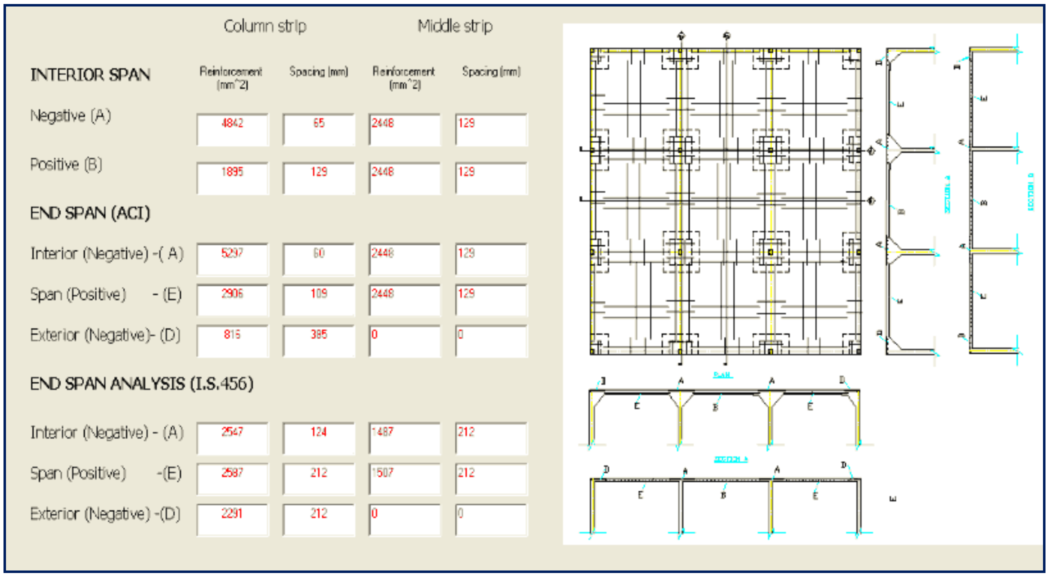


Fig. 7.7 Reinforcement and spacing along column strip and middle strip

7.3 ANALYSIS OF FLAT SLAB DY EQUIVALENT FRAME METHOD

The two way slab system which does not satisfy the limitations of the direct design method (DDM) shall be analyzed by the equivalent frame method (EFM). The equivalent frame method is very similar to DDM but it uses the classical method of analysis, instead of using the coefficients, to give the positive and negative moments in the longitudinal direction. Thus the difference between DDM and EFM analysis for gravity loads lies only in the procedure of getting the magnitude of the longitudinal negative and positive moments.

Software analyzes the flat slab by equivalent frame. Input data for analysis of flat slab is as shown in fig.7.8. after assigning the input data software calculates the designed thickness of flat slab, dimensions of drop and column capital as shown in fig.7.9

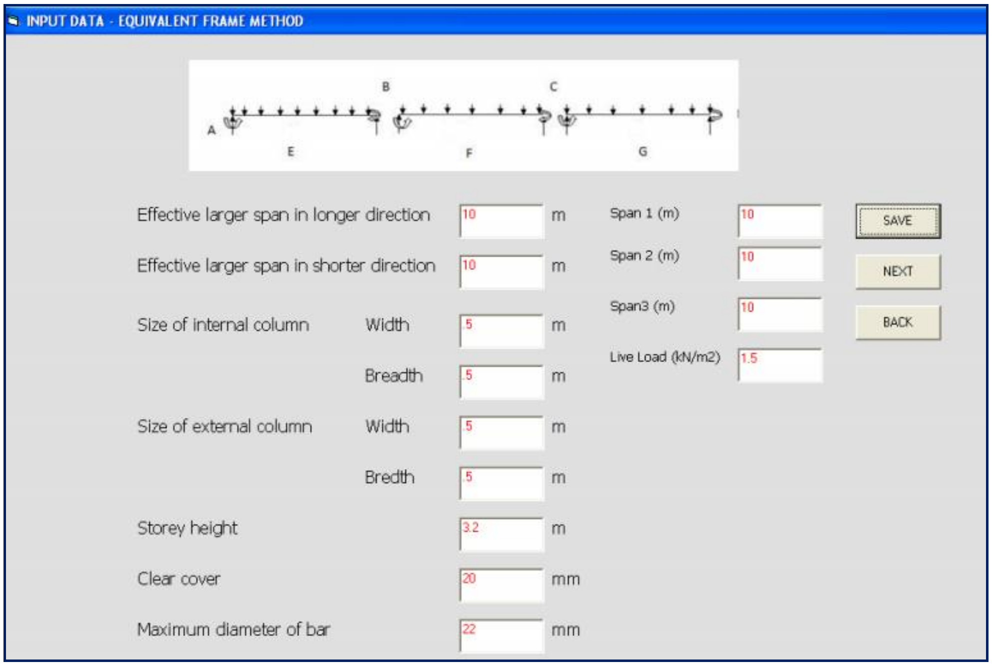


Fig. 7.8 Input for equivalent frame method

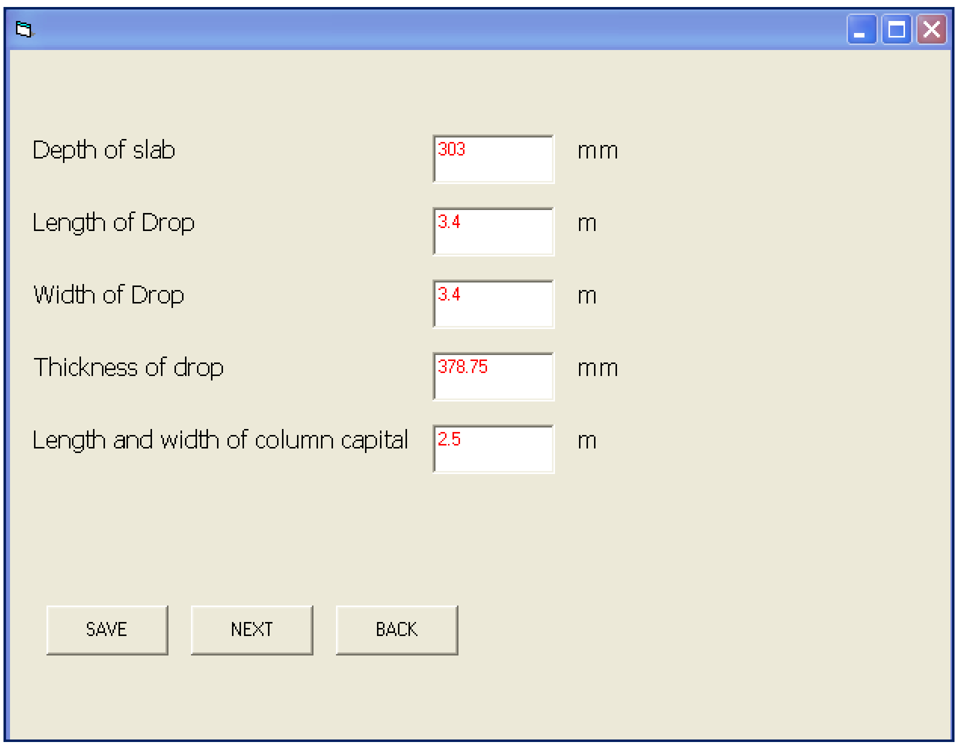


Fig. 7.9 Design dimensions of slab, drop and column capital

Moments are in the frame are calculated as shown in fig.7.10. After calculation of moments reinforcement is calculated and spacing is calculated for the bar diameter which we specify as shown in fig. 7.11

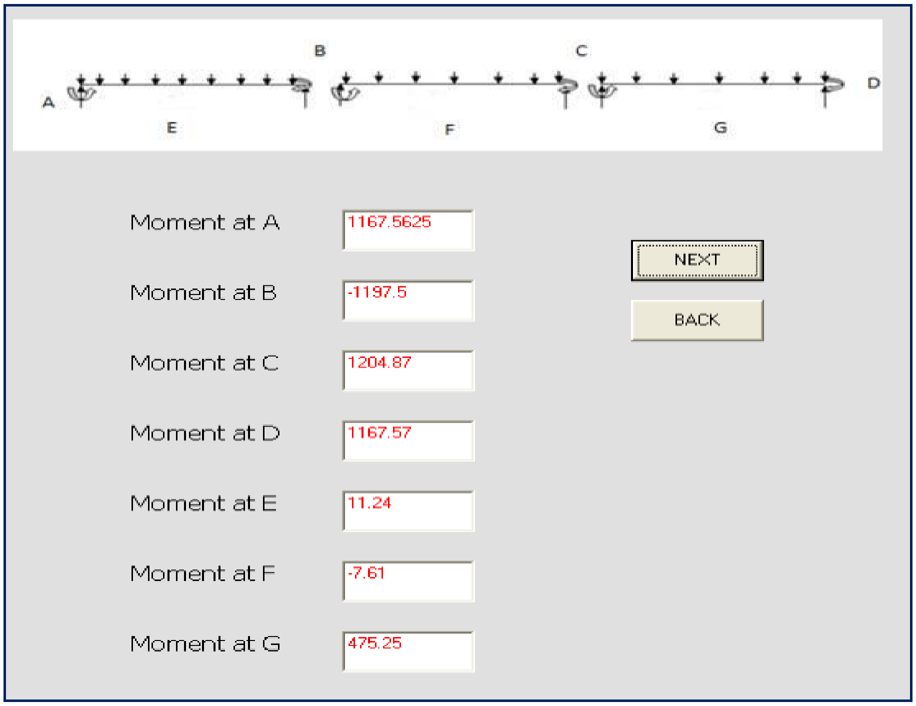


Fig. 7.10 Moments along column strip and middle strip for EFM

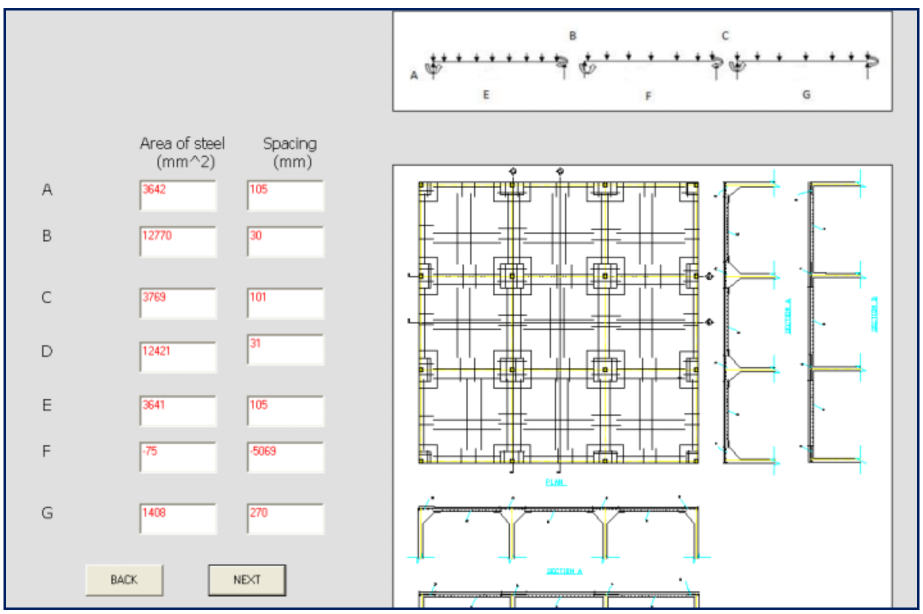


Fig. 7.11 Reinforcement and spacing for Equivalent frame method

7.4 ANALYSIS OF FLAT SLAB DY SOFTWARE COEFFICIENTS

Three dimensional analysis of flat slab is carried out using software SAFE. Total moment is distributed along longitudinal and transverse direction. The distribution of moment distribution coefficients are calculated by performing the parametric study of flat slab building (ref. chapter 5). Analysis and design of flat slab is carried out using the above calculated coefficients. Moments in interior and exterior frame along column strip and middle strip are calculated as shown in fig. 7.12. The designed dimensions of slab, drop and column capital is calculated as shown in fig. 7.13, however reinforcements and spacing shown in fig. 7.14 and fig. 7.15 respectively.

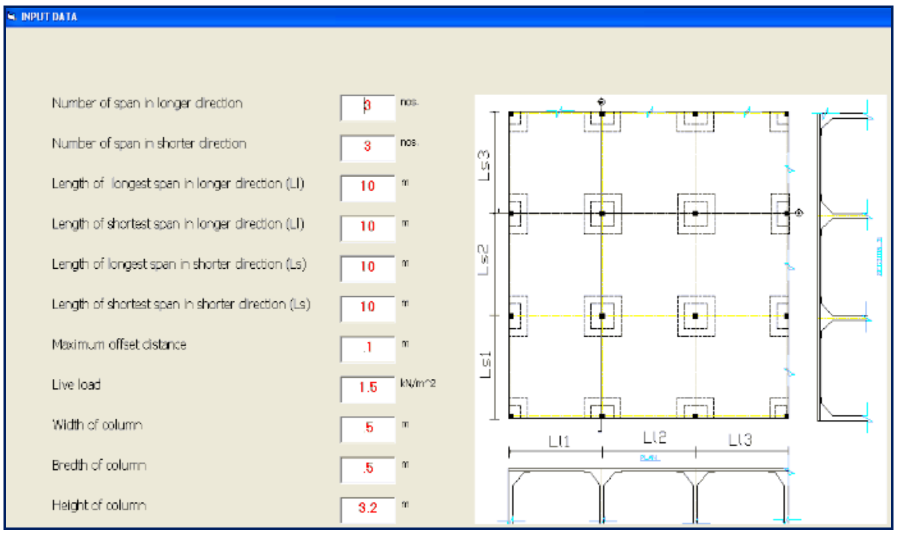


Fig. 7.12 Input data for analysis by DDM using calculated coefficients

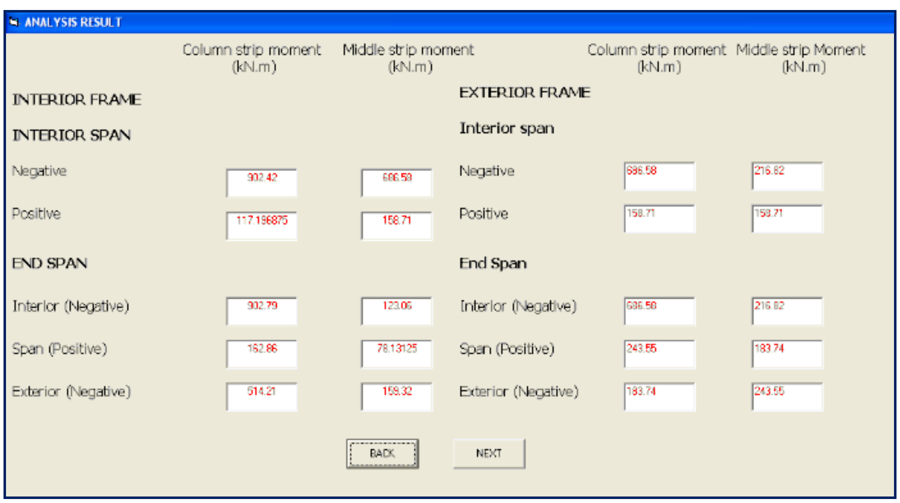


Fig. 7.13 Column strip and middle strip moments

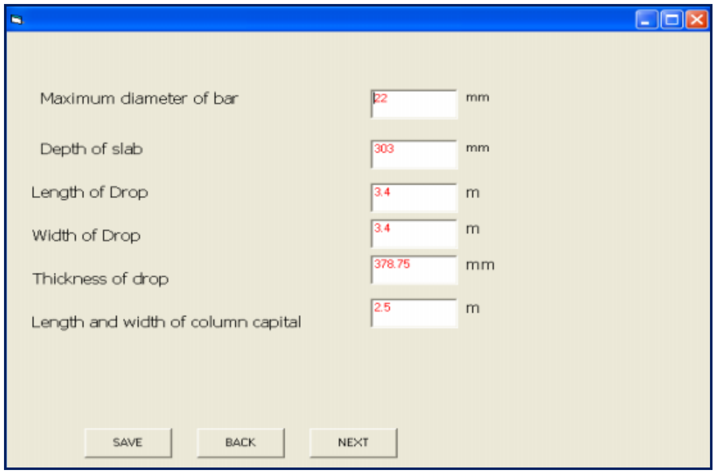


Fig. 7.14 Design dimensions of slab, drop and column capital

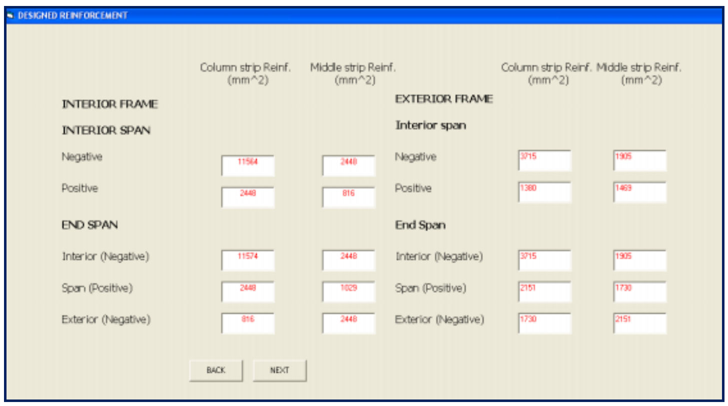


Fig. 7.15 Reinforcement along column strip and middle strip

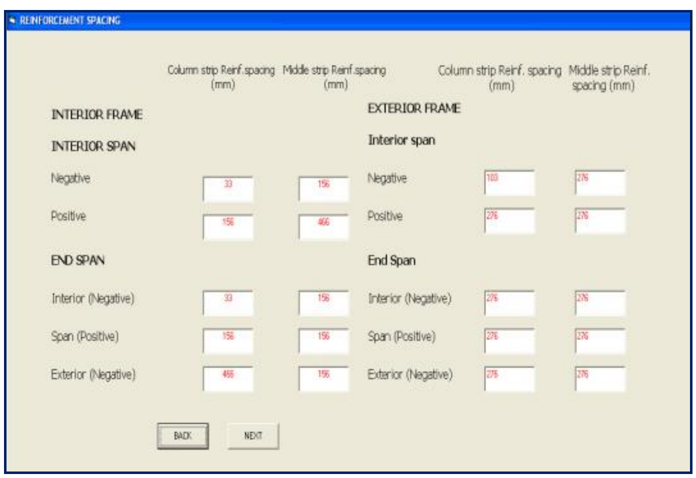


Fig. 7.16 spacing along column strip and middle strip

8. SUMMARY AND CONCLUSION

8.1 SUMMARY

Flat slabs are the reinforced concrete slabs with or without drop, supported generally without beams by columns with or without flared columns at top (column capital). There are several advantages of flat slabs such as reduction in total height required for each storey, attractive appearance of ceiling; better illumination to room also results in reducing the load on foundation.

Main components of flat slab are drop, column head, column strip and middle strip. Flat slabs are classified as slabs with drop and column capital, with drop and without column capital and slab without drop and column capital which is also known as flat plate.

Analysis of slat slab is mainly categorized into gravity and lateral load analysis. Direct design method and equivalent frame method is adopted for gravity load analysis. Three dimensional finite element analysis of flat slab is carried out using software SAFE for gravity and earthquake loads.

When flat slab is subjected to gravity loads the total moment is distributed along longitudinal direction into negative and positive moments while further it is distributed in column strips and middle strips. When flat slab is analyzed with direct design method the standards of different countries such as I.S. 456, ACI-318 and B.S.8110 prescribed the fixed coefficients for distribution of moments. While when the flat slab is analyzed by equivalent frame method the actual analysis of frame is carried out using any of elastic method of analysis such as moment distribution method. Comparison of standards as I.S. 456-2000, ACI-318 and B.S.8110 is carried out to study the effect of gravity loads on flat slabs.

Three dimensional finite element analysis of flat slab is carried out for combined gravity and lateral loads using software. The modeling of flat slab building is carried out in ETABS software while the design is performed in SAFE software by exporting the model to SAFE software as SAFE is the only special software for design of flat slab. The study is also made to check the effect of earthquake loads on the negative and positive moments in the longitudinal and transverse direction.

The standards also specify the fixed width of column strip and middle strip. the width of column strip and middle strip is compared by different methods such as I.S. 456 code method and three dimensional finite element analysis using software.

Software for analysis and design of flat slab with drop and column capital is prepared. The software analyzes the flat slab by Direct Design Method using the codal coefficients for distribution of moments, Equivalent frame method and direct design method using the coefficients for lateral and transverse distribution of moments calculated from the three dimensional analysis of flat slab. the software also gives detailed design of flat slab as reinforcement and spacing for reinforcement.

8.2 CONCLUSION

From the above study following conclusions can be made

- It is observed that in the interior span the total static moment Mo is distributed into positive and negative moments as 75% and 25% in the exterior frame, while in the interior frame the distribution of total static moment into negative and positive moment as 85% and 15%, however I.S. 456 and ACI 318 standards prescribed the distribution as 65% and 35% irrespective of the interior or exterior frame.

- In the end span the total moment is distributed into interior negative, span positive and exterior negative moment as 75%, 35% and 30% in the exterior frame, while 85%, 30% and 70% in the interior frame respectively, however I.S.456 and ACI 318 standards prescribed the value as 70%, 50% and 30%.

- The moments are further distributed transversely in the column strip and middle strip. It is observed that 90% of negative moment in the interior span is distributed into column strip for interior frame and 75% for the exterior frame, however I.S.456 and ACI 318 specifies the value as 75%.

- The I.S.456 specifies the width of column strip as maximum 25% of span and width of the middle strip as 50% of span irrespective of the end span or mid span, however it is observed that width of the column strip in the end span is 15% of the span and 25% in the interior span, in the same way width of the middle strip is 60% of span at end span while 50% in the interior span.

8.3 FUTURE SCOPE OF WORK

- Brittle failure of flat slab is observed during earthquakes hence the pushover analysis of flat slab can be carried out to study the actual behavior of flat slab during earthquakes.
- Software for flat slab is prepared only for flat slab with drop and with column capital hence the software can be developed for all types of flat slabs.

REFERENCES

Papers

1. K. Pilakoutas and X. Li, "Alternative shear reinforcement for reinforced concrete flat slab", *Journal of Structural Engineering*,vol.129, No.9, September 2003, ASCE, pp. 1164- 1172.
2. D.A. Gaspirini, "Contributions of C.A.P. turner to Development of reinforced concrete flat slab", *Journal of Structural Engineering*, vol. 128, No.10,october 2002, ASCE, pp. 1243- 1252.
3. A.J. Durani et al, "Earthquake response of flat slab buildings", *Journal of structural Engineering*, Vol. 120, March 1994, ASCE, pp. 947- 964.
4. M. A. Erberik and A.S. Elnashai,"Loss estimation analysis of flat slab structures", *Natural Hazards Review*, Vol.7. No.1, February 2006, ASCE, pp. 26- 37.
5. R. B. Gomes and P.E. Regan," Punching resistance of reinforced concrete flat slab with shear reinforcement", *Journal of Structural Engineering*, Vol. 125, No. 6, June,1999, ASCE, pp. 684-692.
6. Armand Furst and Peter Marti, "Robert millarts design approach for flat slab", *Journal of Structural Engineering*, vol. 123, No.8, August, 1997, ASCE, pp.1102- 1110
7. Y.H. Luo, A. Durani and J. Conte, "Seismic reliability assessment of R.C. flat slab buildings" *Journal of Structural Engineering*, vol.121, No.10, October 1995, ASCE, pp.1522- 1530
8. John K. Bright, John R. Mays, "Temperature effects on cellular rigid pavements compared to flat slabs", *Journal of Transportation Engineering*, Vol. 123, No. 2, March/ April,1997, ASCE, pp. 142- 147.
9. D. Uuan Ngo, "Punching shear resistance of high strength concrete slab", *Electronics Journal of Structural Engineering*, vol. 1, 2001, pp.52- 57.
10. H. S. Kim and D.G. Lee, "Efficient analysis of flat slab subjected to lateral loads", *Journal of Structural Engineering*, October 2005, pp. 251- 263.

Books

11. P.C. Varghese, *Advanced reinforced concrete design*, prentice hall of India limited, New Delhi, EEE 2002.
12. Wang and salmon, *Reinforced concrete design.* Sixth edition, Addition Wesley.
13. Arthur Nilson, *Design of concrete structures*. Twelfth edition, Tata Mc graw hill.
14. M.Nadim, A. Almanaser, *structural concrete theory and design.* Third edition, Wiley.
15. Syel and Goel, *Reinforced concrete structures.* S. chand publications, 2002.

Codes

16. IS 456:2000, "*Plain and Reinforced Concrete*, - Code of Practice", Bureau of Indian Standards, New Delhi.
17. B.S. 8110- 1:1997, "*structural use of concrete*, - code of practice", British Standards.
18. ACI 318, "*Building code requirements for structural concrete and commentary*, - code of practice", American standard.

APPENDIX A

INPUT AND OUTPUT OF SOFTWARE

1. INPUT DATA FOR DIRECT DESIGN METHOD

Parameter	Value
Number of span in shorter direction	3
Number of span in shorter direction	3
Length of longest span in longer direction	12
Length of shortest span in longer direction	12
Length of longest span in shorter direction	10
Length of shortest span in shorter direction	10
Maximum offset distance	0.1
Live load	1.5
width of column	0.5
Breadth of column	0.5
Height of column	3.2

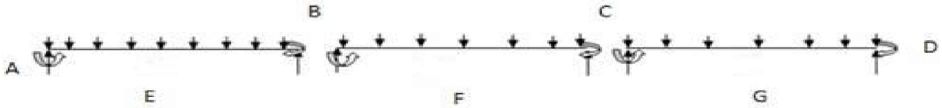
2. OUTPUT OF DIRECT DESIGN METHOD

Method	Type of moment	Moments		Reinforcement	
		Column strip	Middle strip	Column strip	Middle strip
I.S.456- 2000	Interior span				
	Negative	903.32	301.11	7905	3718
	Positive	389.12	259.42	2960	3718
	End span				
	Interior Negative	950.43	316.81	4230	2304
	Span positive	498.07	332.05	4512	2418
	Exterior Negative	777.24	0	3264	0
ACI-318	Interior span				
	Negative	903.32	301.11	7905	3718
	Positive	389.12	259.42	2960	3718
	End span				
	Interior Negative	972.8	324.27	8733	3718
	Span positive	578.12	385.42	4593	3718
	Exterior Negative	481.77	0	979	0
Software coefficients	Interior span				
Interior frame	Negative	1307.16	994.52	13966	3728
	Positive	169.76	229.89	3728	981
	End span				
	Interior Negative	1307.76	178.25	13978	3728
	Span positive	235.9	113.17	3728	1240
	Exterior Negative	744.83	230.77	981	3728
Software coefficients	Interior span				
Exterior frame	Negative	994.52	314.06	4480	2276
	Positive	229.9	229.9	1864	1771
	End span				
	Interior Negative	994.52	314.06	4480	2276
	Span positive	352.79	266.04	2567	2085
	Exterior Negative	266.14	352.79	2085	2568

3 INPUT DATA FOR EQUIVALENT FRAME METHOD

PARAMETER	Value
Spacing of columns in X direction	12
Spacing of columns in Y direction	10
span AB	12
span BC	12
span CD	12
Width of internal column	0.5
Breadth of internal column	0.5
Width of external column	0.5
Breadth of external column	0.5
Storey height from centre to centre of main slabs	3.2
Live load	1.5
Clear cover	20
Maximum diameter of bar	22

4. OUTPUT OF EQUIVALENT FRAME METHOD



Section	Moment	Reinforcement
A	1854	1412
B	1881	1452
C	1892.5	1462
D	1833.98	1412
E	17.66	450
F	11.96	450
G	17.66	450

APPENDIX B

DESIGN OF FLAT SLAB AS PER I.S.456

1. Proportioning of flat slab components

As the spans are large, it is provided with drop and column head

Different components are proportioned as follows.

a. Thickness of slab

Consider uniform thickness which is governed by corner slab s1 with the adjacent edge discontinuous and the remaining edges are continuous.

$$d_s = \frac{l_y}{0.5 \times (20 + 26) m_{ft}}$$

Where

Effective larger span	= 10 m
Shorter span	= 10 m
Clear cover	= 15 mm
Maximum diameter of bar	= 16 mm
Modification factor for tension reinforcement	= 1.6
Effective depth of slab	= 272 mm
Overall depth of slab = D_s	= 295 mm
Provided overall depth of slab=Ds	= 295 mm

b. Drop

Consider rectangular drops whose minimum dimensions are given by,

Length of drop= Longer span/3	= 3.33 m
Width of drop = shorter span/3	= 3.33 m

Dimensions of drop may be chosen such that it is common area of column

strip of width = 0.5 x shorter span	= 5 m
Provide length of the drop	= 3.4 m
Width of drop	= 3.4 m
thickness of drop=t_d= 1.25x Ds	= 368 mm

c. Column head

As the drop is square, column head of square shape is provided

dimension not more than shorter span/4 = 2.5 m

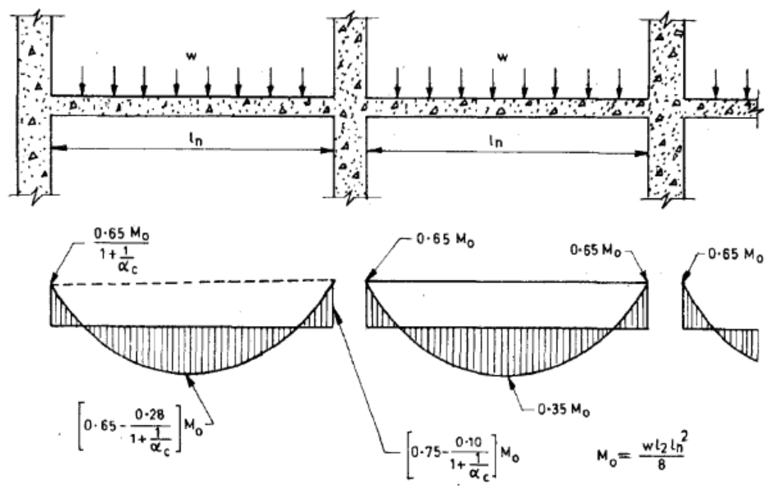
Dimension of square shape column head = 2.5 m

2. Design for moment

Number of span in shorter direction	=	3	
Number of span in shorter direction	=	3	
Length of longest span in longer direction	=	10	m
Length of shortest span in longer direction	=	10	m
Length of longest span in shorter direction	=	10	m
Length of shortest span in shorter direction	=	10	m
Maximum offset distance	=	0.1	m
Live load	=	4	kN.m
Dead load	=	7.37	kN.m
width of column	=	0.35	m
Breadth of column	=	0.35	m
Height of column	=	3.2	m
overall depth of slab	=	295 mm	

	Item	X frames		Y frames	
		X1	X2	Y1	Y2
1	C.C. span	10	10	10	10
2	Clear span (L_n)	7.5	7.5	7.5	7.5
3	Width of span(L_2)	10	5	10	5
4	Width of column strip	2.500	1.25	2.500	1.25
5	Width of middle strip	7.5	3.75	2.500	3.75
6	L_2/L_1	1	1	1	1

Factored load= Wu= 17.053 kN/m



Total Design Moment

where,		
uniformly distributed design load per unit surface area =W	17.053	kN/m^2
Clear span between face to face of column, column capitals,		
brackets or walls but not less than 0.65l1 $=l_n$	7.5	m
Span in the diretion of moment $M_0 = l_1$	10	m
average of the spans transverse to l_1 on either sides of suppor	10	m
Total ultimate moment in longer direction	1199.02	kN.m

$M_{ol} = 17.053 * 6*(8- 1.5)^2 /8$

1 **Moments in longer direction**

Distribution of moments in the column and middle strips are made as follows-

Width of the column strip	=	2.5	m
Width of middle strip	=	7.5	m

a. **Interior panel :**

total negative and positive moments are as

Negative moment, Mon= 0.65 Mo	=	779.36	kN.m
Negative moment in the column strip	=	584.52	kN.m
$(0.75 \times M_{on})$			

Negative moment in the middle strip	=	194.84	kN.m
(0.25 x M_{on})			
positive moment, M_{op}= 0.35 M_o	=	419.66	kN.m
Positive moment in the column strip	=	251.79	kN.m
(0.60 x M_{op})			
Positive moment in the middle strip	=	167.86	kN.m
(0.40 x M_{op})			

Total ultimate moment in shorter direction 1199.02 kN.m

M_{os}=16.51 * 8*(6- 1.5)^2 /8

The total design moments in longer and shorter directions of exterior and interior panels are distributed first into total negative and positive moments and into column and middle strips

b. **End panel:**

Total negative and positive moments are given by ,

Exterior negative moment , M_{one}= $\left(\frac{0.65}{1+1/\sigma_c} \times M_0\right)$ = 281.49 kN.m

The entire moment is distributed in the column strip only

Negative moment in the exterior column strip= 112.59 kN.m

Interior Negative Moment= 855.96 kN.m

$$M_{oni} = \left[0.75 - \left(\frac{0.1}{1+1/\sigma_c}\right) \times M_0\right]$$

Negative moment in interior column strip= 641.97 kN.m

(0.75 x M_{oni})

Negative moment in interior middle strip = 213.99 kN.m

(0.25 x M_{oni})

Positive design Moment = $M_{op} = \left[0.63 - \frac{0.28}{1+1/\sigma_c}\right] \times M_0$ =634.126 kN.m

Positive moment in the column strip = 380.486 kN.m

(0.60 x M_{op}/column strip width)

Positive moment in the middle strip = 253.63 kN.m

(0.4 x M_{op}/column strip width)

$$\sigma = \frac{\sum K_c}{K_s} = 0.565$$

σ = Ratio of the Flexural stiffness of the exterior columns to that of slab

$\sum K_C$=Sum of the flexural stiffness of the columns meeting at the joint.

K_s =Flexural stiffness of the slab

Calculation of flexural stiffness of column

Width of Column = 0.35 m

Breadth of Column = 0.35 m

Length of Column = 3.2 m

K_c = 0.0004

Calculation of flexural stiffness of slab

width of Slab = 10 m

Depth of Slab = 0.295 m

K_s = 0.0014

2. Moments in shorter direction :

Distribution of moments in the column and middle strips are made as follows-

Width of column strip = 2.5 m

Width of middle strip = 2.5 m

a. Interior panel

total negative and positive moments are given by

Negative moment, Mon= 0.65 M_o = 779.36 kN.m

Negative moment in the column strip = 584.52 kN.m

(0.75 x M_{on}/column strip width)

Negative moment in the middle strip = 194.84 kN.m

(0.25 x M_{on}/middle strip width)

positive moment, Mop= 0.35 M_o = 419.66 kN.m

Positive moment in the column strip = 251.79 kN.m

0.60 x M_{op}/column strip width

Positive moment in the middle strip = 167.86 kN.m

0.40 x M_{on}/middle strip width

b. End panel

Total negative and positive moments are given by ,

Exterior negative moment = $M_{one} = \left(\frac{0.65}{1+1/\sigma_c} \times M_0 \right)$ = 349.76 kN.m

The entire moment is distributed in the column strip only

Negative moment in the exterior column strip = 349.76 kN.m

(1.0 x M_{one}/ Width)

Interior Negative Moment= $M_{oni} = \left[0.75 - \left(\frac{0.1}{1+1/\sigma_c} \right) \times M_0 \right]$ = 854.46

Negative moment in interior column strip = 634.09 kN.m

(0.75 x M_{oni}/column strip width)

Negative moment in interior middle strip = 211.36 kN.m

(0.25 x M_{oni}/middle strip width)

Positive design Moment = $M_{op} = \left[0.63 - \frac{0.28}{1+1/\sigma_c} \right] \times M_0$ = 604.72 kN.m

Positive moment in the column strip = 362.83 kN.m

(0.60 x M_{op}/column strip width)

Positive moment in the middle strip = 241.89 kN.m

(0.4 x M_{op}/middle strip width)

$\sigma = \frac{\sum K_c}{K_s}$ = 0.8141

σ = Ratio of the Flexural stiffness of the exterior columns to that of slab

$\sum K_c$=Sum of the flexural stiffness of the columns meeting at the joint.

K_s=Flexural stiffness of the slab

Calculation of flexural stiffness of column

Width of Column = 0.35 m

Breadth of Column = 0.35 m

Length of Column = 3.2 m

K_c = 0.004

Calculation of flexural stiffness of slab

width of Slab = 10 m

Depth of Slab = 0.295 m

Ks = 0.001

The effective depth of slabs considered for determining the area of steel in the two directions for positive moments at the intersections of middle strip are computed by considering the reinforcement in longer direction below the reinforcement in shorter direction giving higher value of effective depth of slab in larger direction. Similarly, the reinforcement in the longer direction for negative moment at the intersection of column strips is provided above the reinforcement in the shorter direction giving higher value of effective depth of slab in the larger direction. This is because the positive and negative moments in the longer direction are larger than those in the shorter direction.

Consider 16 m dia. Bars in the middle and column strips with clear cover of 15 mm .

The effective depth of slab in the two directions is computed

Diameter of bar used in the middle strip = 16 mm

Diameter of bar used in the column strip =16 mm

a At the intersection of middle strips:

The effective depth in the longer and shorter directions are

Effective depth in longer direction = (295 -15- 16/2) = 274 mm

Effective depth in shorter direction = (295 -15-16- 16/2)= 261 mm

b At the intersection of column strips:

The effective depth in the longer and shorter directions are -

Effective depth in longer direction = (295 -15- 16/2) = 274mm

Effective depth in shorter direction = (295 -15-16- 16/2)= 261 mm

c At the intersection of column and middle strips:

The effective depth in direction of column and middle strips are

Effective depth in direction of column strip = 295-15- 16/2 = 274 mm

Effective depth in direction of middle strip = 295-15-16- 16/2 = 261 mm

APPENDIX C

DESIGN OF FLAT SLAB FOR DIRECT DESIGN METHOD AS PER ACI-318

1 Proportioning of flat slab components
As the spans are large, it is provided with drop and column head
Different components are proportioned as follows.

a. **Thickness of slab**
Consider uniform thickness which is governed by corner slab s1 with the adjacent edge discontinuous and the remaining edges are continuous.

$$d_s = \frac{l_y}{0.5 \times (20 + 26) m_{ft}}$$

wher l_y	Effective larger span	=	10	m
	Shorter span	=	10	m
	Clear cover	=	15	mm
	Maximum diameter of bar	=	16	mm
	Modification factor for tension reinforcement	=	1.6	
d_s	Depth of slab	=	271.7	mm
	Overall depth of slab = D_s	=	294.7	mm
	Provided overall depth of slab=Ds	=	295	mm

b. **Drop**
Consider rectangular drops whose minimum dimensions are given by,

Length of drop= Longer span/3	=	3.333	m
Width of drop = shorter span/3	=	3.333	m

Dimensions of drop may be chosen such that it is common area of column

strip of width = 0.5 x shorter span	5	m
Provide length of the drop	3.400	m
Width of drop	3.400	m
thickness of drop=t_d= 1.25x Ds	368	mm

c. **Column Head**
As the drop is square, column head of square shape is provided

dimension not more than shorter span/4	=	2.5	m
Dimension of square shape column head	=	2.5	m

2 **Design for moment**
Slab shall be designed for maximum positive and negative moments in column and middle strips and the reinforcement required shall be provided along the span of the slab with necessary curtailment in accordance with I.S. code.

Number of span in shorter direction	3	
Number of span in shorter direction	3	
Length of longest span in longer direction	10	m
Length of shortest span in longer direction	10	m
Length of longest span in shorter direction	10	m
Length of shortest span in shorter direction	10	m
Maximum offset distance	0.1	m
Live load	4	kN/m^2
Dead load	7.37	kN/m^2
width of column	0.35	m
bredth of column	0.35	m
Height of column	3.2	m
overall depth of slab	0.24	m
Width of perimeter beam (if present)	0	m
Depth of perimeter beam (if present)	0	m

	Item	X frames		Y frames	
		X1	X2	Y1	Y2
1	C.C. span	10	10	10	10
2	Clear span (Ln)	7.5	7.5	7.5	7.5
3	Width of span(L2)	10	5	10	5
4	Width of column strip	2.500	1.25	2.500	1.25
5	Width of middle strip	7.5	3.75	7.500	3.75
6	L2/L1	1	1	1	1

Factored load= Wu 17.053 kN/m^2

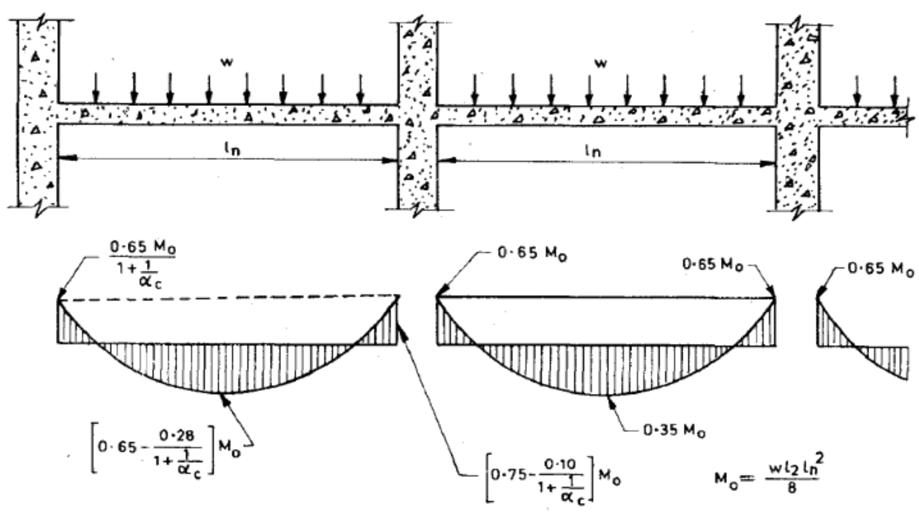


Fig.1 Bending moment diagram

Total Design Moment

$$M_0 = \frac{Wl_n}{8} = \frac{wl_2l_n^2}{8}$$

where,

uniformly distributed design load per unit surface area =W = 17.053 kN/m^2

Clear span between face to face of column, column capitals,

brackets or walls but not less than 0.65l1 =l_n = 7.5 m

Span in the diretion of moment M0 = l_1 = 10 m

average of the spans transverse to l_1 on either sides of supports=l_2 10 m

Total ultimate moment in longer direction = 1199.0 kN.m

M_{ol} = 16.51 * 6*(8- 1.5)^2 /8

Total ultimate moment in shorter direction = 1199.02 kN.m

M_{os}=16.51 * 8*(6- 1.5)^2 /8

The total design moments in longer and shorter directions of exterior and interior panels are distributed first into total negative and positive moments and into column and middle strips

1 **Moments in longer direction**

Distribution of moments in the column and middle strips are made as follows-

Width of the column strip 2.5 m

Width of middle strip 7.5 m

a. **Interior panel :**

total negative and positive moments are as

Negative moment, Mon= 0.65 Mo = 779.3625 kN.m

positive moment, M_{op}= 0.35 M_o = 419.6567 kN.m

b. **End panel:**

	Exterior edge unrestrained	slab with beams between all supports	slab without beams between interior support: with edge beam	slab without beams between interior support: without edge beam	exterior edge fully restrained
Interior negative moment	0.75	0.7	0.7	0.7	0.65
Positive moment	0.63	0.57	0.5	0.52	0.35
Exterior negative moment	0	0.16	0.3	0.26	0.65

Interior negative moment= 0.7x Mo = 839.3134 kN.m

Span positive moment = 0.5xMo = 623.49 kN.m

Exterior negative moment = 0.3x Mo = 311.745 kN.m

2 Transverse Distribution

Transverse Distribution: Assignments of moments to column strips (percentages)

1 Percentage of positive moment to column strip (kN.m) 374.094

$$60+30\frac{\alpha_1 L_2}{L_1}\left(1.5-\frac{L_2}{L_1}\right)$$

2 Percentage of negative moment to column strip at interior support (kN.m) 629.485076

$$75+30\frac{\alpha_1 L_2}{L_1}\left(1.5-\frac{L_2}{L_1}\right)$$

3 Percentage of negative moment to column strip at exterior support (kN.m) 311.74499

$$100-10\beta_t+12\beta_t\frac{\alpha L_2}{L_1}\left(1-\frac{L_2}{L_1}\right)$$

APPENDIX D

LIST OF USEFUL WEBSITES

- www.google.com
- www.sciencedirect.com
- www.asce.org