A COMPUTATIONAL INVESTIGATION ON EFFECTIVE SLAB STRIP WIDTH OF FLAT PLATE STRUCTURES SUBJECTED TO LATERAL LOAD

by
A. K. M. Rezaul Islam
Roll No. 040004318 P

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Certification

The project titled "A Computational Investigation on Effective Slab Strip Width of Flat Plate Structures Subjected to Lateral Load" submitted by A. K. M. Rezaul Islam, Roll No. 040004318 P, Session April 2000, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Engineering in Civil Engineering (Structural) on March 23, 2003.

BOARD OF EXAMINERS

1. Dr. Khan Mahmud Amanat, Associate Professor, Deptt. of Civil Engineering, BUET, Dhaka. — Chairman (Supervisor)

2. Dr. AMM Taufiqul Anwar, Professor, Deptt. of Civil Engineering, BUET, Dhaka. — Member

3. Dr. Ishtique Ahmed, Professor, Deptt. of Civil Engineering, BUET, Dhaka. — Member

Declaration

Declared that except where specified by reference to other works, the studies embodied in this project is the result of investigation carried by the author. Neither the thesis nor any part has been submitted to or is being submitted elsewhere for any other purposes.

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Abstract

There are two distinct methods (Direct Design Method and Equivalent Frame Method) for the analysis of structures for vertical loads but there is a lack of well-guided code for plane frame idealization of a flat plate or slab with column line beam structure for lateral load analysis. In 2D plane frame analysis, it is required to take an appropriate width of the panel, which is structurally representative of the actual 3D frame. The ratio of this slab strip width to the total panel width is known as effective slab strip ratio. In this work, an investigation is made to find the effects of various geometric parameters relating to flat plate structures, so that a definite guideline on determining the effective width of slab strip can be developed. The investigation is also continued with structures having slab with column line beams to identify the influence of geometric parameters on effective slab strip ratio as well.

To carry out the investigation, both 2D and 3D frames were modeled using finite element methods. Applying the appropriate wind load on the 3D frame, lateral deflections are computed. Then applying the same wind load on the 2D frame and at the same time adjusting beam width the two deflections are matched as closely as possible. The ratio of reduced width by total panel width gives the value of effective strip ratio. The process is a simple trial and error method. The whole process is carried out under various parametric conditions.

It has been found that some parameters like column size; slab thickness etc. has no effect on effective slab strip width for both types of floor. On the other hand, bay width and span length have found to have significant effect on effective strip width for both types of floor system. For structures with column line beams, the beam stiffness also has significant effect. Based on the results of the analysis, a chart for values of effective strip ratios as well as an equation are developed to explicitly determine the value of the slab strip width for flat plate structures. It has been shown with the help of a few examples that the suggested chart and equation are useful in structural analysis for predicting the width of effective slab strip with acceptable accuracy.

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Chapter 1

INTRODUCTION

1.1 GENERAL

A flat plate is a monolithic concrete slab reinforced in both directions supported by columns only without any aid of beam or girder. The broad strips of the slab centered on the column lines in each direction serve the purpose of beam. When the thickness of the plate is increased symmetrically around the columns or the column top is flared to provide high punching shear resistance, the plate is called flat slab. The thickened part is called drop panel or drop, while the flared column is called capital.

Either the direct design method or the equivalent frame method may be used for the analysis of two-way slab systems for gravity loads, according to ACI Code. However, the ACI Code provisions are not meant to apply to the analysis of buildings subject to lateral loads, such as, loads caused by wind or earthquake for lateral load analysis. Plane Frame Analysis, with the building assumed to consist of parallel frames each bounded laterally by the panel centerlines on either side of the column lines, has often been used in analyzing unbraced buildings for horizontal loads, as well as vertical.

The main difficulty in equivalent frame analysis for horizontal loads lies in modeling the stiffness of the region at the beam column (or slab beam column) connections. Transfer of forces in this region involves bending, torsion, shear, and thrust, and is further complicated by the effects of concrete cracking in reducing stiffness, and reinforcement in increasing it. Frame moments are greatly influenced by horizontal displacements at the floors, and a conservatively low value of stiffness should be used to ensure that a reasonable estimate of drift is included in the analysis.

The slab in this approach is treated just like an ordinary beam, as in a moment resisting frame and can be modeled easily in any elastic frame analysis program. There are, however, no guidelines available to assist the designer in making such a decision. Because of the complexity of the moment-transfer mechanism between the slab and the column under lateral loading, the assumptions regarding the effective slab width and its stiffness have been very subjective. However, assumptions can give a misleading prediction of the building response. There are still significant scopes to investigate this matter in order to assist the design engineer with some definite guideline to estimate the effective slab strip ratio.

1.2 BACKGROUND

Fraser (1983) made an extensive parametric study based on finite element analysis using beam and plate elements and proposed a few empirical equations for determination of the effective beam stiffness. His equations included a parameter R_b that is the ratio of the slab rigidity (flexural) and flexural stiffness of the beam stem for floors having column line beam. For flat plate floors, the effective width of the slab is expressed as a function of column size and span. In his parametric study, column zones in the finite element model of floors were assumed rigid. It appears that the influence of other structural parameters like slab thickness, floor height, bay width etc. are not taken into account.

Luo *et al.* (1994) studied the response of flat plate buildings and made an extensive experimental investigation on plate column sub assemblages and proposed an effective slab width concept to be used for hysteretic static analysis to represent earthquake type loadings. Based on the findings of the experimental results, they proposed some constant factors to be used in their hysteretic model.

Luo and Durrani (1995) proposed an equivalent beam model for flat slab building based on experiments of 40 interior and 41 exterior connections. They determined the effective slab width using Pecknold's (1975) method and compared it with experimental results. Based on the comparison, they suggested simpler formula for effective slab strip ratio (α) in terms of the sides of the rectangular column sections and spans.

Smith and Coull (1991) suggested 5 curves of bay/span ratios for different values of column size to find out α for flat plate structures. However, it is suggested that the stiffness calculated by using this effective slab strip ratio should be reduced to 50% in the analysis due to cracking as the slab bends.

A number of researchers have addressed the problem of determining effective slab width of flat plate structures in the past as discussed above. Textbooks still do not include any definite guidelines for determining "α" based on the findings of any of the above researchers due to lack of simplicity and unsuitability of these guidelines for design purposes. As such, there is a need to develop rational analysis procedures that approximate the actual behavior of the flat-slab buildings.

1.3 OBJECTIVES

The objective of this present study is to develop a definite guideline to determine the effective width of the slab strip for flat plate structures. The structures with column-supported slabs subjected to lateral loads will be considered. For this purpose, a few typical problems shall be studied under various parametric conditions that influence the phenomena. Based on the study, an attempt shall be made to present a guideline to find effective slab strip width that is structurally effective for flat plate structures. Also, a few typical problems shall be studied under various parametric conditions for slab with column line beam structures with a view to investigate the influence of the geometric parameters on α, the effective slab strip ratio.

1.4 METHODOLOGY

To carry out the investigation, six storied flat plate and slab with column line beam structures would be studied under different parametric conditions using 3D modeling as well as its 2D plane frame idealization. Material has been assumed to be isotropic and homogeneous and it has also been assumed that the loading would not cause the structure into inelastic conditions.

Three-dimensional model of the building would be developed using typical frame elements (two nodes with six degrees of freedom per node) for beams and columns and four nodded rectangular plate/shell elements for the slab. For good accuracy, each slab panel would be divided into several elements. Wind load for Dhaka city as per BNBC (1993) would be taken as the lateral load. The same structure would be modeled as two-dimensional plane frame using only frame elements where a portion of the slab would be considered as beam. Considering the deflections (at top) of the 3D model as representative, the inertia of the beam of 2D model would be adjusted so that same deflection is obtained. Then from adjusted moment of inertia, a reduced panel width is obtained using geometry. Finally, the ratio of reduced width to total panel width gives the value of effective strip ratio. The process is a simple trial and error method but very effective in finding the effective slab ratio for flat plates. The whole process is carried out under various parametric conditions within certain range.

1.5 ORGANIZATION OF THIS REPORT

The report is organized to best represent and discuss the problem and findings that come out from the studies performed. Chapter 1 introduces the project, in which an overall idea is presented before entering into the main studies and discussion. Chapter 2 represents the slab system in brief as well as the work performed so far in connection with it collected from different references. It also describes the strategy of advancement for the present project to a success.

Chapter 3 is all about the finite element modeling exclusively used in this project and it also shows some figures associated with this study for proper presentation and understandings. Chapter 4 is the heart of this project write up, which describes the computational investigation made throughout the study in details with presentation by many tables and figures followed by some definite remarks. Chapter 5 is the decisive part of this project work, where a proposal for estimating effective slab strip width is made. The last chapter is Chapter 6, which summarizes the whole work as well as points out some further directions.

CHAPTER 2
FLOOR SYSTEM

2.1 INTRODUCTION

A flat plate is a monolithic concrete slab reinforced in both directions supported by columns only without any aid of the beam or girder. This special system has advantages over other systems and it requires proper attention during analysis particularly for effective slab strip ratio that takes part effectively while horizontal loads are applied to it. This chapter discusses about composition of slab system, methods for analysis, concept of effective slab strip ratio and lateral loads considered in the study.

2.2 DEFINITIONS

Based on support conditions slab floors can be classified as follows:

- **Flat Plate:** Slabs are carried directly by columns without the use of beams or girder. Such slabs are commonly used where spans are not large and loads are not heavy.
- **Slab With Column Line Beams:** Floor system having beam and slab cast monolithically, where beam supports slab and column supports the beams.
- **Flat Slab With Capital:** Beamless but incorporates a thickened region in the vicinity of the column and employs flared column tops. Both are devices to reduce stresses due to shear and negative bending moment around the columns.
- **Waffle or Grid Slab:** Waffle slabs may be designed as a slab suitable for long spans. To reduce the dead load of solid–slab construction, voids are formed in a rectilinear pattern through use of fiberglass form inserts.
- **Slab Band Type:** For convenient each panel is divided into column strips having a width of one fourth the panel width on each side of the column centerlines and middle strips in the one-half panel width between two column strips. Moments may be considered constant within the bounds of any strip.

2.3 COMPONENTS OF SLAB SYSTEM

The customary standard for deciding the width of strips and making proportionate other components of a flat slab as per ACI code are as follows:

(a) ***Column Strip:*** Column strip means a design strip having a width of 0.25 l_2 but not greater then 0.25 l_1 on each side of the column center line, where l_1 is the span in the direction in which moments are being determined, measured center to center of supports and l_2 is the span transverse to l_1 measured center to center of support.

(b) ***Middle Strip:*** Middle strip means a design strip bounded on each of its opposites sides by the column strip.

(c) ***Panel:*** Panel means that part of a slab bounded on each of its four sides by the column strip.

(d) ***Thickness of Flat Plate:*** The thickness of flat plate shall be generally controlled by the considerations of span to effective depth ratios. For slab with drops conforming to clause (e) below, span to effective depth ratios shall be applied directly; otherwise, the span to effective depth ratios shall be multiplied by 0.9. For this purpose, the longer span shall be considered. The minimum thickness of slab shall however not be less than 125 mm.

(e) ***Drops:*** Drops, when provided may be square or rectangular in plan. The length of the drop in each direction shall not be less than one third of the panel length in that direction. For exterior panels the width of drops at right at angles to the non continuous edge and measured from the center line of the columns shall be equal to one half of the width of drop for interior panels.

(f) ***Column Heads:*** When column heads are provided, that portion of the column head which lies within the largest right circular cone or pyramid that has a vertex angle of 90 and can be included entirely within the outlines of the column and the column head shall be considered for design purposes.

2.4 ANALYSIS FOR GRAVITY LOADS

Analysis for gravity loads can be performed by the two following methods described below:

2.4.1 Direct Design Method

Moments in two-way slabs can be found using this semi-empirical method with specified restrictions on geometry and load.

2.4.2 Equivalent Frame Method

For the case otherwise to the specification applicable to direct design Method Equivalent frame method is a more general method. The structure is divided into continuous frames centered on the column lines and extending both longitudinally and transyersely. Each frame is composed of a row of columns and a broad continuous beam. This slab beam includes the portion of the slab bounded by panel centerlines on either side of the columns together with column line beams or drop panels if used.

2.5 ANALYSIS FOR LATERAL LOADS

Idealizing the structure as a series of linked plane frames, lateral analysis can be carried out. This assumption is reasonable for the flexural action of the slab if the parallel frames are more or less similar so that torsion effect does not produce significant irregularities in the distribution of forces. If the irregularities in the framing of the building are too severe, a three-dimensional analysis should be done to capture the torsion effects.

The ACI code provisions are not supposed to apply to the analysis of buildings subject to lateral loads. For lateral load analysis, the designer may select any method that is shown to satisfy equilibrium and geometric compatibility and to give results that are in reasonable agreement with available test data. The results of the lateral load analysis may then be combined with those from the vertical load analysis according to the ACI code. For vertical load analysis by the

Equivalent Frame Method, a single floor is usually studied as a substructure with attached columns assumed fully fixed at the floors above and below. For frame analysis under horizontal load, the equivalent frame includes all floors and columns extending from the bottom to the top of the structure.

While a completely satisfactory basis for modeling the beam-column joint stiffness has not been developed, at least two methods have been used in practice (Vanderbilt and Corley, 1983). The first is based on an equivalent beam width αl_2, less than the actual width to reduce the stiffness of the slab for purposes of analysis.

Alternatively the beam column stiffness can be modeled based on a transverse torsional member correspond to that used in deriving the stiffness of the equivalent column for the vertical load analysis of two way slabs by the equivalent frame method. Rotational stiffness of the joint is a function of the flexural stiffness of the columns framing into the joint from above and below and the torsion stiffness of the transverse strip of slab or slab beam at the column. The equivalent column stiffness is found from the following equation (Nilson and Winter, 1991):

$$\frac{1}{K_{ec}} = \frac{1}{\sum K_c} + \frac{1}{K_t} \qquad (2.1)$$

Where, K_{ec} - flexural stiffness of equivalent column,

K_c - flexural stiffness of actual column,

K_t - torsional stiffness of edge beam.

The floor slab distributes the lateral load to the various resisting elements mainly through the forces in its own plane. The actual in plane deformation of the floors seldom has an effect on this distribution. Therefore the assumption that the floor slab is rigid can be used in almost all analysis without meaningful loss in accuracy. The out of plane bending of the slab however has a significant effect on the behavior of the entire system.

The lateral analysis of the column and slab system is therefore no more difficult than that for an assemblage of horizontal and vertical elements. However the designer faces a special problem when the horizontal connecting system consists a flat plate, beam slab or waffle system. This is because there is a nagging question as to what width of the slab will be effective as a connecting beam. However other parameters such as the slab span width ratio, the relative dimension of the column with respect to the longitudinal and transverse spans of the slab have significant influence on the effective width of slab.

2.6 CONCEPT OF EFFECTIVE SLAB WIDTH

The concept of an "effective width" is usually used in the analysis of such building subjected to lateral loads. Although physically no beam exists between the columns for analytical purposes it is convenient to consider a certain width of slab behaving as a beam between the columns when the lateral loads are considered. The effective width factor is dependent on various parameters such as column aspect ratios, distances between the columns and thickness of slab etc. Assuming that one can determine the effective width, the lateral resistance of the system is analytically equivalent to a rigid frame consisting of columns and equivalent beams connected to the columns.

Figure 2.1 shows a plate fixed at the far edge and supported by a column of width C_2 at the near side. If a rotation θ is imposed at the column, the plate rotation along the axis "A" will vary as shown by Fig.2.2 from θ at the column to smaller values away from the column. An equivalent width factor α is obtained from the requirement that the stiffness of a prismatic beam of width αl_2 must equal the stiffness of the plate of width l_2. This equality is obtained if the areas under the two rotation diagrams of Fig.2.2 are equal. Thus frame analysis is based on a reduced width of slab or slab beam and stiffness is found using αl_2 rather than l_2. Comparative studies indicate that for flat plate floors a value of α between 0.25 and 0.50 may be used.

2.7 LATERAL LOAD FOR THE STUDY

Building structures are generally subjected to two types of lateral loads namely wind and earthquake load. In this paper, an assumed wind load is applied to the modeled flat slab frame as lateral load. The method is used in the calculation of wind load and the basic parameters involved in the calculation are stated below (BNBC, 1993).

The sustained wind pressure q_z on a building surface at any height z above ground level shall be calculated from the following relation:

$$q_z = C_c C_i C_z V_b^2 \text{, kN/m}^2 \quad (2.2)$$

$$p_z = C_G C_p q_z \text{, kN/m}^2 \quad (2.3)$$

Where,

q_z = Sustained wind pressure at height z, kN/m²

C_i = Structure importance co-efficient as given in table 6.2.9 of BNBC (1993)

C_c = Velocity to pressure conversation efficient = 47.2×10^{-6}

C_z = Combined height and exposure coefficient as given in the table 6.2.10. Of BNBC (1993)

V_b = Basic wind speed in km/h obtained from sec 2.4.5 of BNBC (1993) = 210 km / hr for Dhaka city.

p_z = Design wind pressure at height z, kN/m²

C_G = Gust co-efficient which shall be G_z, G_h or G set forth in sec 2.4.6.6 of BNBC (1993)

C_p = Pressure co-efficient for structures or components as set forth in section 2.4.6.7 of BNBC (1993)

q_z = Sustained wind pressure obtained from equation 2.2 for different nodes of the structure is different for different heights and consequently p_z will be obtained accordingly.

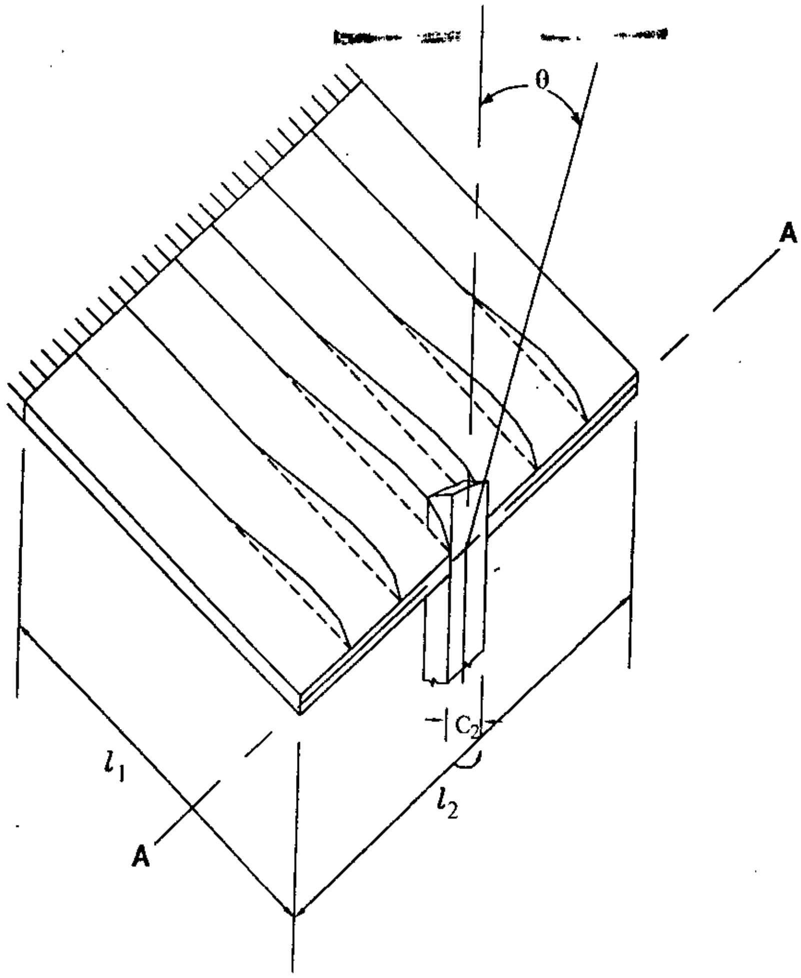

Fig. 2.1 Effective Slab Strip Ratio of Flat Plate Structure Under Horizontal Load

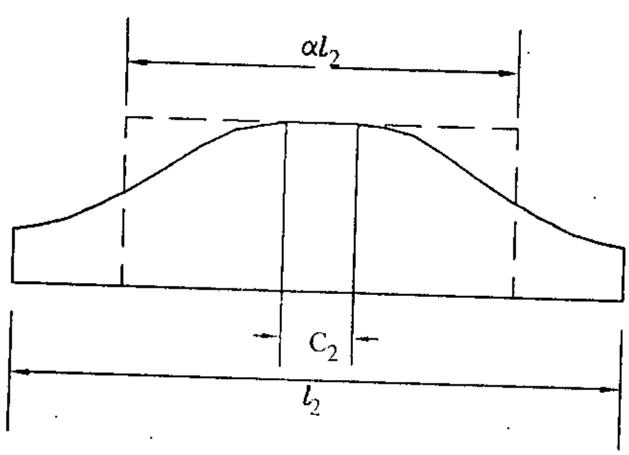

Fig. 2.2 Effective Slab Strip Ratio and Beam Width

CHAPTER 3
FINITE ELEMENT MODELING

3.1 GENERAL

A building's response to loading is administered by the components that are stressed as the building deflects subject to loadings. In an ideal case, for simplicity and precision of the structural analysis, the participating components would include only the major structural elements: the slabs, beams, girders, and columns. As a matter of fact, however, other nonstructural elements are stressed and subsequently contribute to the building's actions, such as, the staircases, partitions and cladding. To make a problem simpler in modeling for analysis, it is necessary to take into account only the most important structural members provided that the effects of the nonstructural components are not significant.

3.2 MODELING FOR ANALYSIS

It is virtually impossible to obtain analytical mathematical solutions for many engineering problems. Analytical solutions can be obtained only for certain simplified situations. For problems involving complex material properties and boundary conditions, the engineer resorts to numerical methods that provide approximate but acceptable solutions. The finite element method is such technique that is essentially a product of the electronic digital computer age. Therefore, although the approach shares many of the features common to the previous numerical approximations, it processes certain characteristics that take advantage of the special facilities offered by the high-speed computers. In particular, the method can be systematically programmed to accommodate such complex difficult problems as non-homogeneous materials, non linear stress strain behavior, and complicated boundary condition. Considering above advantages, a finite element based computer software STADD-Pro is used in the project.

The basis of the finite element method is the representation of a body or a structure by an assemblage of subdivisions called finite elements and the process is known as finite element modeling. Both two-dimensional and three-dimensional modelings are done so that the comparison of two types of modeling enables to determine the parameter effective slab strip ratio. The systematic generality of the finite element procedure makes it a powerful and versatile tool for a wide range of structural problems. There are a few comprehensive finite element softwares available in the market. Using such a good program it is possible to model and analyze virtually all types of structures. Examples of such packages are:

ANSYS	PROKON
DIANA	ROBOTICS
MICROFEAP	STRAND 6
SAP 2000	ABAQUS
STADD PRO	ETAB etc

3.3 ASSUMPTIONS

An attempt to analyze a high rise building and account accurately for aspects of behavior of all the components and materials, even if their sizes and properties were known, would be virtually impossible, simplifying assumptions are necessary to reduce the problem to a viable size. Although a wide variety of assumptions are available, some are more valid than others, the one adopted in forming a particular model depends on the arrangement of the structure, its anticipated mode of behavior, and the type of analysis. The most common assumptions are provided below.

3.3.1 Materials

The material of the structure components is linearly elastic. This assumption allows the superposition of actions and deflections and, hence, the use of linear methods of analysis. The development of linear methods and their solutions by computer has made it possible to analyze large complex statically indeterminate structures. Although nonlinear methods of analysis have been and are still being developed, their use at present for high-rise buildings is more for research than for the design place of work.

3.3.2 Participating Components

Only the primary structural components participate in the overall behavior, i.e. beam, column and slab. The effects of secondary structural components and nonstructural components are assumed to be negligible and conservative. Although this assumption is generally valid, exceptions occur. For example, the effects of heavy cladding may not be negligible and may significantly stiffen a structure; similarly, masonry in fills may significantly change the behavior and increase the forces unconservatively in a surrounding frame.

3.4 FINITE ELEMENT MODELING OF STRUCTURES

Flat plate structures are basically a slab or plate structure supported by columns. Slab with column line beam structures have beam along column lines cast monolithically with slab. Therefore, a comprehensive finite element model for both types of structures in three dimensions must include three dimensional elements as well as plate/shell elements. In this study plate elements were used to model the slab in three dimensions and frame elements were used to model the beams and columns.

3.4.1 Modeling of Slab

This section describes the technique used to model the slab elements used to represent the slab, material properties, and boundary conditions and load application. Four nodded quadrilateral shell element is used to model the floor slab. The element has membrane capabilities. Both in plane and normal loads are permitted. The element has six degrees of freedom at each node; translations in the nodal x, y, and z directions and rotations about the nodal x, y and z-axes. Stress stiffening and large deflection capabilities are included.

3.4.2 Modeling of T-Beam

All reinforced concrete floors are always monolithic. Forms are built for beams soffits and side and for the underside of the slab, and the entire construction is poured at once from the bottom of the deepest beam on the slab. The resulting beam cross section is T shaped. Considering this practical viewpoint, T beam for slab with column line beams has been modeled.

When the slab with column line beam structure is modeled using plate element and ordinary beam element for the column line beams, plate elements are connected to the nodes of beams. These beam nodes are along the centerline of the beams. This type of modeling is not capable of representing the T beam action. In order to represent T beam behavior properly it is necessary to have the beam element offset downward. Therefore in the present investigation, element with appropriate amount of offset from neutral axis is used with plate element to model the flat slab.

3.4.3 Boundary Conditions

In 3D modeling appropriate boundary conditions are applied. The supports are restrained by assigning zero value for F_x, F_y, F_z, $\varnothing_x$, $\varnothing_y$ and $\varnothing_z$. In 2D model F_x, F_y and $\varnothing_z$ each are equal to zero at the support.

3.5 REFERENCE PROBLEM UNDER STUDY

In order to facilitate the investigation, two types of problems are selected; the one with slab or plate only and the other one containing slab with column line beams. The building frames of these two types of problems are modeled both as a two-dimensional frame using frame element only and three-dimensional structures consisting of frame and plate element. The results of the three dimensional modeling with plate elements are considered to be correct and the property of two-dimensional modeling are adjusted so that the deflection closely match with the solution of the three dimensional structure. Then width of the beam in two-dimensional modeling is used to determine the effective slab strip ratio. This process is repeated for various parametric conditions to determine which parameters influence most.

3.5.1 Flat Plate

Six storied building structures situated in Dhaka City have been studied. No beams, drop panels, or column capitals are considered. The columns are square in plan and floor-to-floor height of the structure is 4 m. The main parameters of the six storied building are stated below in table 3.1.

Table 3.1 Study Parameters for Reference Flat Plate Structures

Parameter	Reference Value
Span Length	6 m
Span No	6 Nos
Bay Width	6 m
Bay No	6 Nos
Column Size	450x450 mm
Floor Height	4 m
Slab Thickness	254 mm

3.5.2 Slab With Column Line Beam Structures

Six-storied concrete building structures have been studied for the Dhaka city. The building floor system is composed of slab panels supported by column line beams cast monolithically with the slab. The six-storied building with the data given in table 3.2 is studied for structures.

3.6 WIND LOAD APPLIED TO THE STRUCTURE

Calculation of lateral forces due to wind is shown below:

Dhaka, $V_b = 210$ km/h

For a building with dimension 36 m x 36 m and height = 24 m,

Table 3.2 Study Parameters for Reference Slab With Column Line Beam

Parameter	Reference Value
Span Length	6 m
Span No	6
Bay Width	6 m
Bay No	6
Column Size	450 mmx450 mm
Floor Height	4 m
Slab Thickness	254.0 mm
Beam Size	300 mmx500 mm

$$\frac{L}{B}=\frac{36}{36}=1, \frac{h}{B}=\frac{24}{36}=0.67$$

Thus $C_p =$ 1.4 [from table 6.2.15 of BNBC, 1993.]

$$q_z = C_c\, C_i\, C_z\, V_b^2$$
$$= 47.2x10^{-6}\, x1.0\, xC_z x\, 210^2$$

$$p_z = C_g\, C_p\, q_z$$
$$= 2.08\, C_g\, C_p\, C_z$$
$$= 2.08x1.342\, C_p\, C_z$$
$$= 2.79\, C_p\, C_z$$
$$= 2.79x1.4\, C_z,\ kN/m^2$$
$$= 3.91\, C_z,\ kN/m^2$$

For different bay widths, wind forces are shown in the following table 3.3:

For different bay width and wind face area, wind forces have been worked out for the respective nodal points and applied for different bay width and story height.

Table 3.3 Lateral Forces (in kN) at Different Nodal Points

Height (m)	C_z	P_z (kN/m²)	Force (kN)	Force (N)
0	0.368	1.44		
4	0.368	1.44	34.56	34560
8	0.469	1.833	44.00	44000
12	0.563	2.201	52.8	52800
16	0.642	2.51	60.24	60240
20	0.709	2.77	66.48	66480
24	0.769	3.00	72.0	72000

3.7 SAMPLE ANALYSIS OUTPUT

A three dimensional perspective view of the finite element model constructed for a flat plate structure is shown in Fig. 3.1. This figure also shows qualitatively the applied loads as shown by white arrows. This model consists of 3799 nodes, 294 frame elements and 3456 plate elements. Figure 3.2 shows a typical deflected shape.

The FE model for structures with column line beam is shown in Fig. 3.3. Figure 3.4 shows a close up view of a corner to highlight the beam offsets to simulate T beam action. This model consists of 3799 nodes, 2310 frame elements and 3456 plate elements. A typical deflected shape of this model is shown in Fig. 3.5.

Two dimensional plane frame idealization of the flat plat structures is shown in Fig. 3.6 followed by its deflected shape in Fig 3.7.

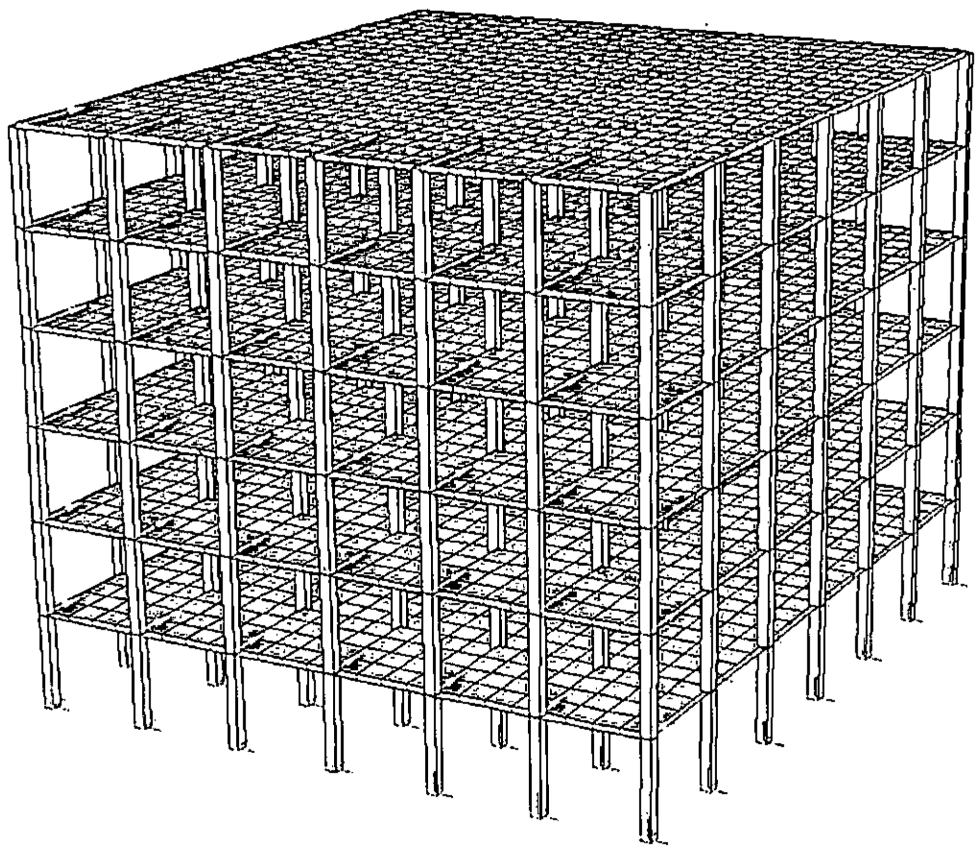

Fig. 3.1 3D Perspective View of the FE Model for Flat Plate Structures

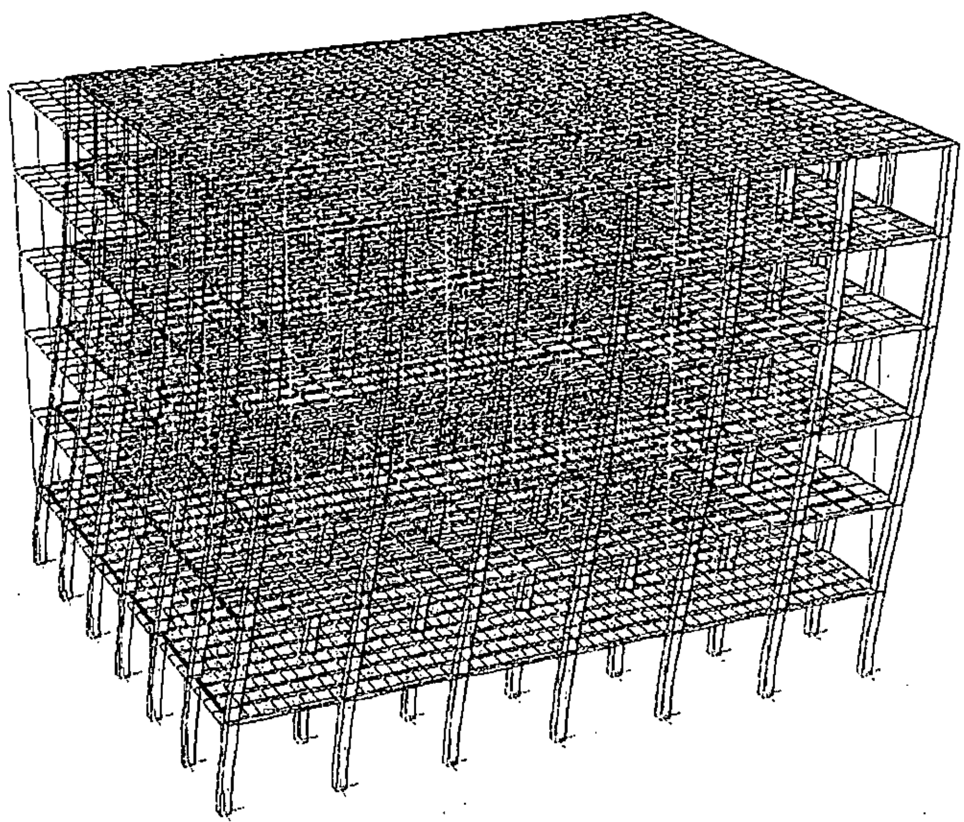

Fig. 3.2 3D Deflected View of the FE Model for Flat Plate Structures

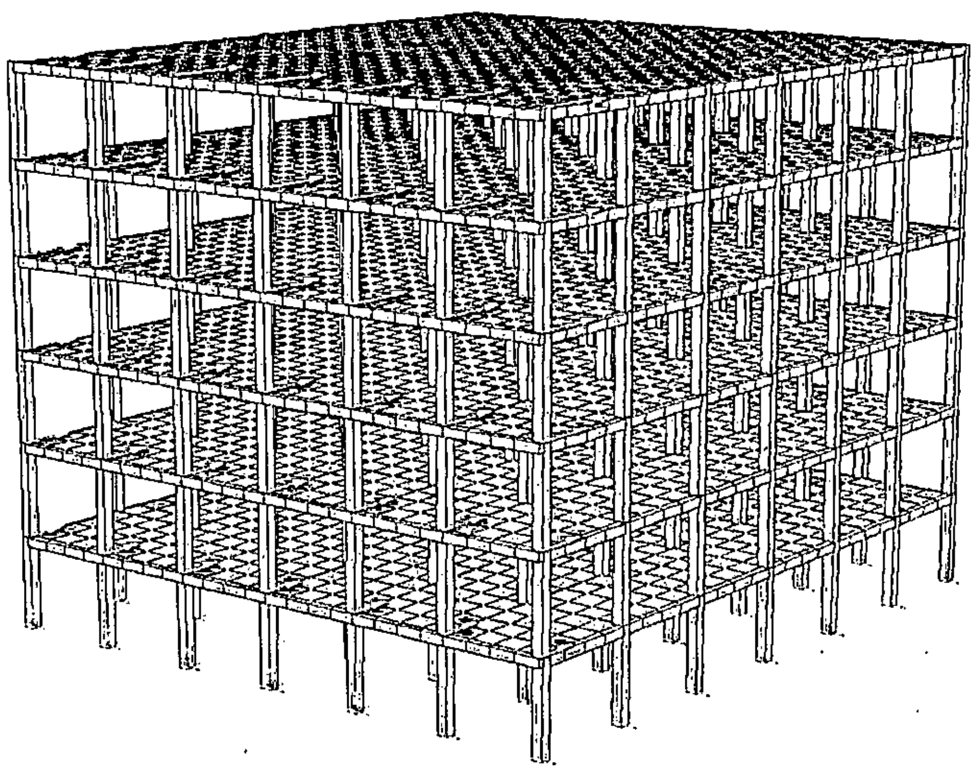

Fig. 3.3 3D Perspective View of the FE Model for Structures With Column Line Beam

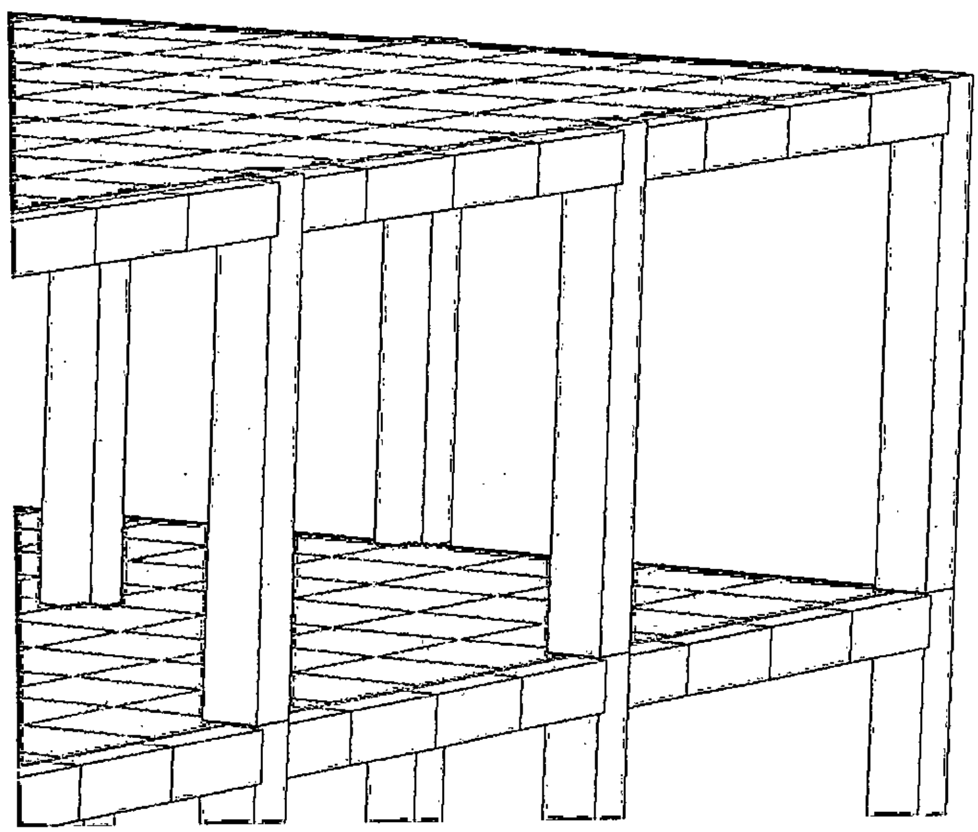

Fig. 3.4 A Close Up View of a Corner to Highlight the Beam Offsets to Simulate T beam Action.

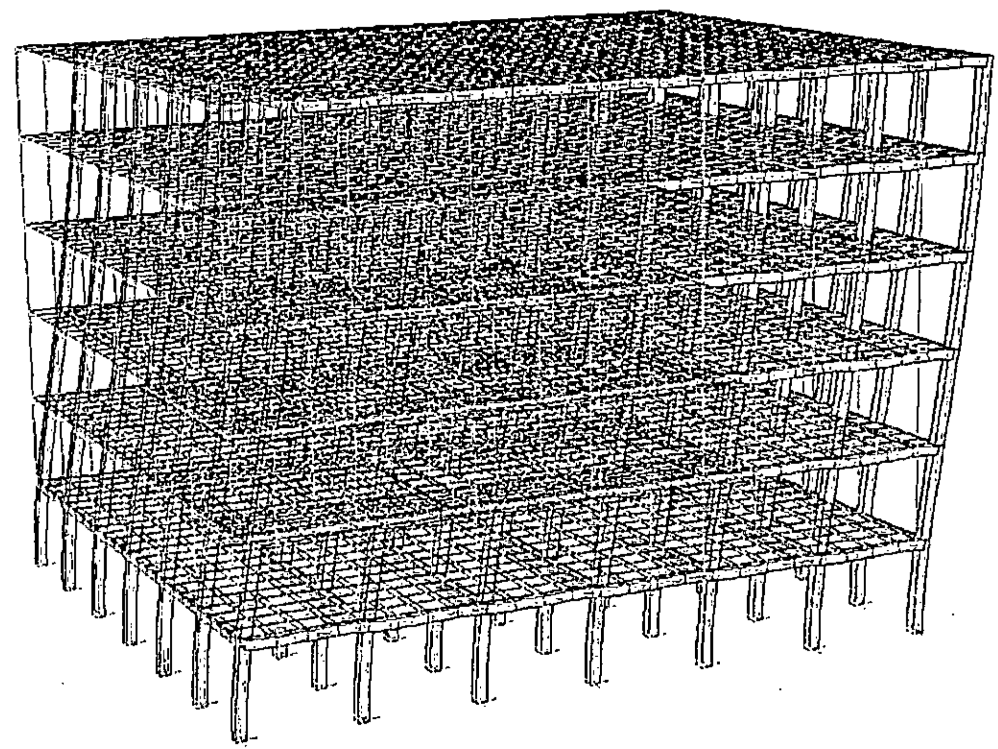

Fig. 3.5 Deflected Shape of the FE Model for Structures With Column Line Beam

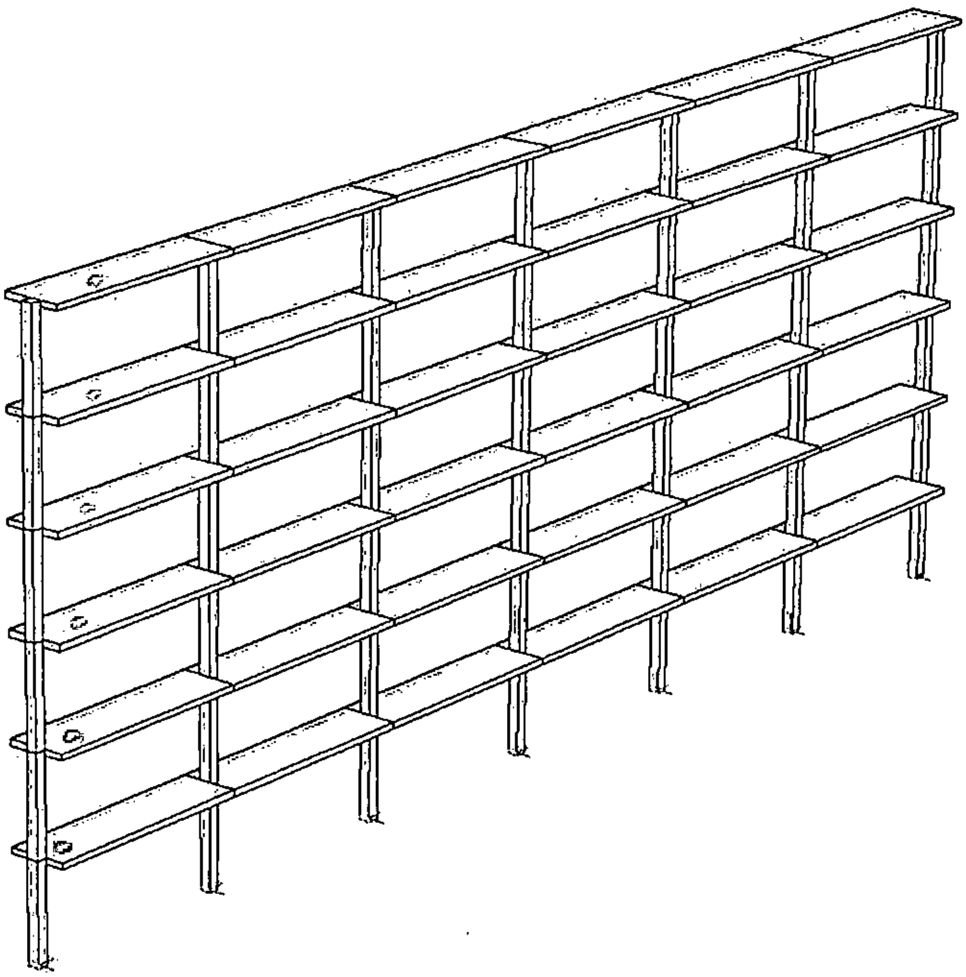

Fig. 3.6 Two Dimensional Plane Frame Idealization of the Flat Plat Structures

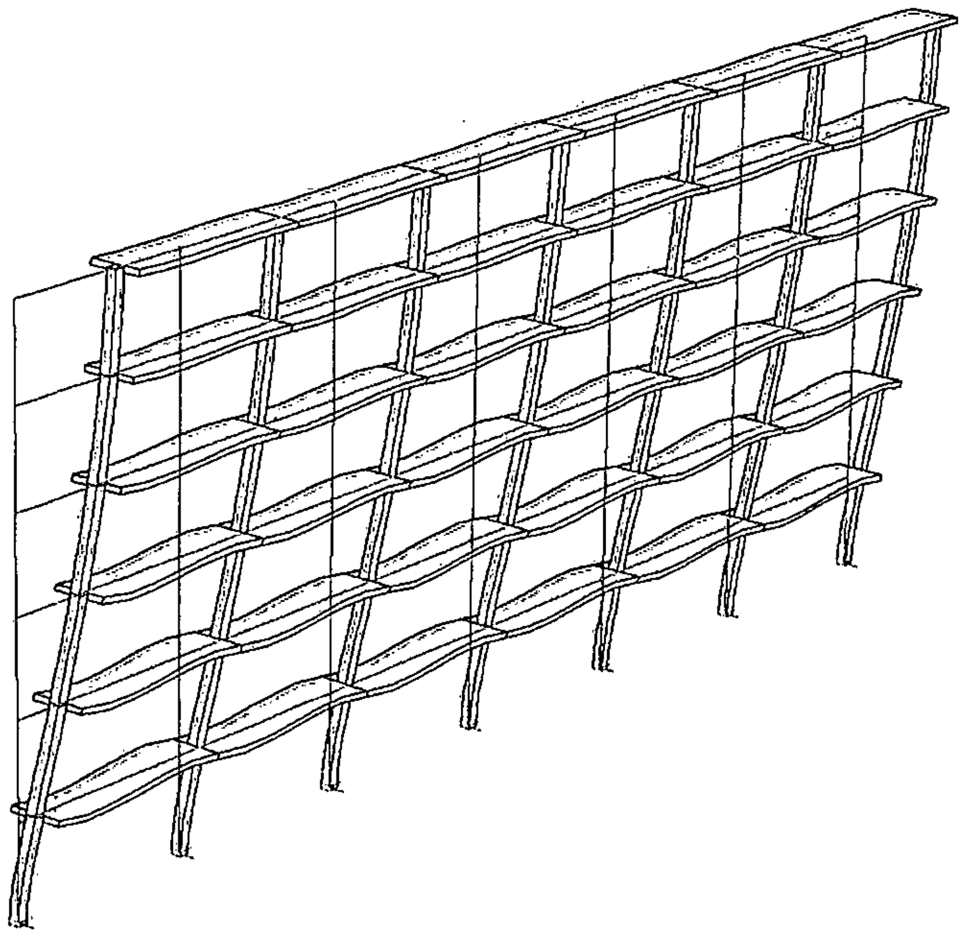

Fig. 3.7 Deflected Shape of Idealized Two Dimensional Plane Frame of the Flat Plat Structures

CHAPTER 4
COMPUTATIONAL INVESTIGATION

4.1 INTRODUCTION

Detailed modeling procedure of frames is described in the previous chapter. Both 2D and 3D actual frames are modeled for the analysis. In this chapter, details of the investigation to determine the controlling parameter for effective strip ratio for slab, as defined in chapter 2 is described with supported findings.

4.2 SAMPLE PROBLEMS

The sample problems under investigation with the variable data within certain range are described in the following table 4.1 and 4.2. While one of the parameters is varied, the other values of parameters are maintained equal to the reference values as mentioned below. The representable 2D Model is generated where beam depth is equal to the slab thickness. By adjusting the beam width, deflection is maintained equal for 2D and 3D model. Now, the slab width found in the 2D Model can be termed as effective slab width, which is actually effective in 3D Model. The effective slab width is plotted against different varying parameters as mentioned above and different curves are found. The effective slab strip ratios as obtained from solving the problems are plotted against the above varying parameters and the graphs are obtained for each case representing the phenomenon being discussed.

For each set of variable data for the structure, the model thus is analyzed with finite element methods to obtain the results for deflection. Then, a representable model of two-dimensional frame is so generated and adjusted by varying the width of the beam that the two values of deflection are equal resulting in the determination of effective strip ratio, α.

Table 4.1: Study Parameters for Flat Plate Structures.

Parameter	Reference Value	Variable Data
Span Length	6 m	3, 4.5, 6.0, 7.5 and 9.0 m
Span No	6 Nos	4, 5, 6, 7 and 8
Bay Width	6 m	3.0, 4.5, 6.0, 7.5 and 9 m
Bay No	6 Nos	4, 5, 6, 7 and 8
Column Size	450x450 mm	300x300, 375x375, 450x450 525x525 and 600x600 mm
Floor Height	4 m	3.0, 3.5, 4.0, 4.5 and 5.0 m
Slab Thickness	254 mm	203.2, 228.6, 254.0, 279.4, 304.8 mm

Table 4.2: Study Parameters for Slab with Column Line Beam Type Structures.

Parameter	Reference Value	Variable Data
Span Length	6 m	3.0, 4.5, 6.0, 7.5, 9.0 m
Span No	6	4, 5, 6, 7, 8 nos
Bay Width	6 m	3.0, 4.5, 6.0, 7.5, 9.0 m
Bay No	6	4, 5, 6, 7, 8 nos
Column Size	450 mmx450 mm	300x300, 375x375, 450x450, 525x525 and 600x600 mm
Floor Height	4 m	3.0, 3.5, 4.0, 4.5 and 5.0 m
Slab Thickness	254.0 mm	127.0, 152.4,177.8,203.2 228.6, 254.03 mm,
Beam Size	300 mmx500 mm	300x500, 400x500, 500x500, 600x500, 700x500 mm

4.3 RESULTS AND DISCUSSION

The results followed by finite element analysis has been described in the following articles according to the parameters involved:

4.3.1 Effect of Column Size

For flat plate structures, the effective slab strip ratios obtained for different column sizes are given in table 4.3 followed by its graphical representation in Fig. 4.3, which represents the value of effective strip ratios for different column stiffness. For Structures having slab with column line beam, the effective slab strip ratios obtained for different column sizes are illustrated in the table 4.4 followed by a curve, Fig. 4.4, which represents the value of effective strip ratios for different column stiffness. It may be observed that for both types of structures, the trend line of the curve is almost horizontal in nature under the study parameters. It is evident from the curves that column size has no significant effect on effective slab strip ratio for both types of structures studied in this project.

4.3.2 Effect of Slab Thickness

For flat plate structures, the effective strip ratios obtained for different slab thickness are given in table 4.5 and that for slab with column line beam is also represented in table 4.6. The curves as generated with the help of each effective slab strip ratio against slab thickness from the above tables are shown in Fig. 4.5 and 4.6 respectively. It may be observed that, the trend line is more or less a straight horizontal one under the study parameters. It is observed from the figures that slab thickness does not demonstrate any remarkable effect on effective strip ratio.

4.3.3 Effect of Bay Width

The effective strip ratios as obtained for different bay widths (in terms of bay width/ floor height ratios) are given in table 4.7 and table 4.8 for flat plate and for slab with column line beam respectively. The curves as obtained with the help of each effective strip ratio against different B/H ratios from the respective tables are represented in Fig. 4.7 and Fig. 4.8. It is observed that, the trend lines of the curves are downtrend with a parabolic nature for increasing B/H ratios under the study parameters. It is evident from the figures that effective strip ratio decreases with the increase of B/H ratio for both the cases. This states that, for the same height of structures, increasing bay width results in decreasing effective strip ratio.

4.3.4 Effect of Bay Numbers

The effective strip ratios as obtained for different bay nos are given in table 4.9 and table 4.10 for flat plate and slab with column line beam respectively. The curves as obtained with the help of each effective strip ratio against different bay nos from the respective tables are represented in Fig. 4.9 and Fig. 4.10. It may be observed that, the trend lines of the curves are almost horizontal under the study parameters. The findings thus come out from those curves indicate that it does not influence the effective strip ratio appreciably.

4.3.5 Effect of Floor Height

For flat plate structures, the effective strip ratios obtained for different floor heights are represented in table 4.11 and for structures having slab with column line beam, the effective strip ratios obtained for different floor heights are represented in table 4.12. The curves as generated with the help of each effective strip ratio against respective floor heights from the above tables are drawn and demonstrated in Fig 4.11 and Fig. 4.12 respectively. It is observed that, the trend line is more or less a straight horizontal one under the study parameters. It is evident from the figures that it has very little effect on the effective strip ratio.

4.3.6 Effect of Number of Span

For flat plate structures, the effective strip ratios obtained for different span nos are given in table 4.13. For slab with column line beam, the effective strip ratios obtained for different span nos are illustrated in table 4.14. The curves as produced with the help of each effective strip ratio against respective span nos from the above two tables are portrayed in Fig. 4.13 and Fig. 4.14 respectively. It is learnt that, the trend line is more or less a straight horizontal one under the study parameters. Those curves as regards with it, point out that the number of span of a structure has very little effect on effective strip ratio.

4.3.7 Effect of Span Length

For flat plate structures, the effective strip ratios obtained for different panel aspect ratios come out from different span lengths are given in table 4.15. For structures with column line beam, the effective strip ratios obtained for different panel aspect ratios as a result of different span lengths are illustrated in table 4.16. The curve as produced with the help of each effective strip ratio against respective panel aspect ratios from the above tables are portrayed below in Fig. 4.15 and Fig. 4.16 respectively. It may be observed that, the trend line is more or less a straight upward one under the study parameters. It is evident from the figures that effective strip ratio increases for both types structures with the increase of panel aspect ratio. This states that, for the same height of structures, increasing span length results in escalating effective slab strip ratio.

4.3.8 Effect of Beam Depth

For slab with column line beam, the effective strip ratios obtained for different beam depths are illustrated in table 4.17. The curve as produced with the help of each effective strip ratio against respective beam depths from the above table is portrayed in Fig 4.17. It may be learnt that, the trend line is almost parabolic in nature and downward one with increasing beam depth under the study parameters. It is evident from the figures that beam depth has significant effect on effective strip ratio. The effective strip ratio decreases with the increase of beam depth.

4.4 REMARKS

From the above observations and studies performed, one can converge to a understanding that column size, slab thickness, number of bays, number of span and floor height do not have any appreciable effect upon effective slab strip ratio for both types of structures under the research.

Beam depth has significant effect upon effective slab strip ratio in case of slab system having column line beams and it is observed that effective slab strip ratio decreases with increasing beam depth.

Panel aspect ratio (L/H) has significant influence on effective slab strip ratio and it is noticed that effective slab strip ratio increases with increasing panel aspect ratio (L/H).

Width of the bay also has significant effect on effective slab strip ratio and the study shows that it decreases with increasing width of bay (B) or (B/H).

As a consequence it is conclusive that, B/H and L/H are the two parameters, which influence the effective slab strip ratio significantly for both types of structures under investigation. In view of the above, it is required to study further the two parameters namely B/H and L/H to establish their effect conclusively for the case of structures having flat plate type floor system. Other parameters (except beam depth for slab with column line beam) exhibit evidence for negligible effect on effective slab strip ratio.

4.5 TABLES AND GRAPHS

All the tables and figures mentioned earlier in article 4.3 above are provided in the following pages one after another cases so as to best express the phenomena they are found to relate with the effective slab strip ratio.

Table 4.3: Effective Strip Ratio and Column Size for Flat Plate Structures

Column Size (mm)	Deflection (mm)	Slab Width (mm)	Effective Width (mm)	Effective Slab Strip Ratio	Moment of Inertia (m^4)
300X300	101.16	6000	1635	0.2725	0.000675
375X375	58.254	6000	1695	0.2825	0.00164795
450X450	41.65	6000	1736	0.28933333	0.00341719
525X525	33.654	6000	1760	0.29333333	0.00633076
600X600	28.981	6000	1790	0.29833333	0.0108

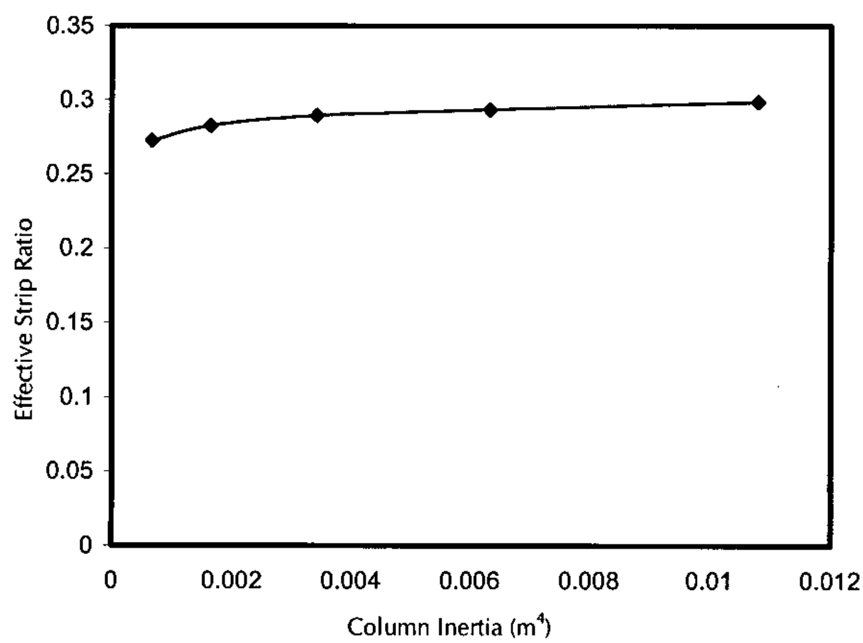

Fig. 4.3 Effect of Column Inertia on α for Flat Plate Structures.

Table 4.4: Effective Strip Ratio and Column Size for Slab with Column Line Beam

Column Size (mm)	2D Beam Width (mm)	Slab Width (mm)	Effective Slab Strip Ratio	Actual Effective Width (mm)	Moment of Inertia (mm⁴)	Deflection (mm)
300X300	11500	6000	0.0613043	705	1.57E+10	73.834
375X375	11350	6000	0.0603524	685	1.55E+10	33.515
450X450	11300	6000	0.0597345	675	1.54E+10	18.779
525X525	11280	6000	0.0598404	675	1.54E+10	12.307
600X600	11250	6000	0.5955560	670	1.54E+10	9.064

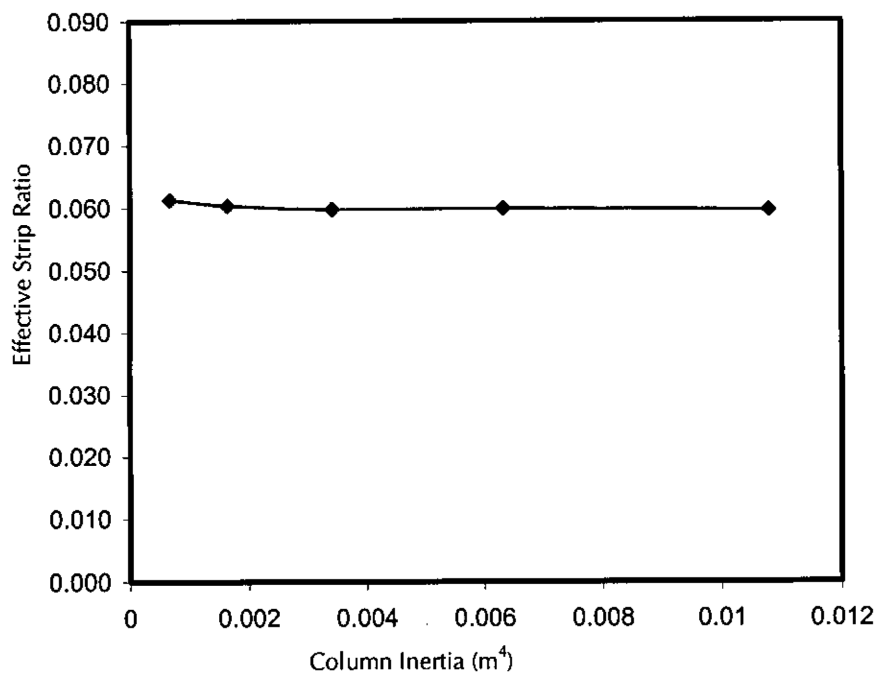

Fig. 4.4 Effect of Column Inertia on α for Slab with Column Line Beam

Table 4.5 Effective Strip Ratios and Slab Thickness for Flat Plate Structures.

Slab Thickness (mm)	Deflection (mm)	Slab Width (mm)	Effective Width (mm)	Effective Strip Ratio
203.2	64.025	6000	1785	0.2975
228.6	50.603	6000	1765	0.29416667
254.0	41.65	6000	1745	0.29083333
279.4	35.453	6000	1735	0.28916667
304.8	31.025	6000	1700	0.28333333

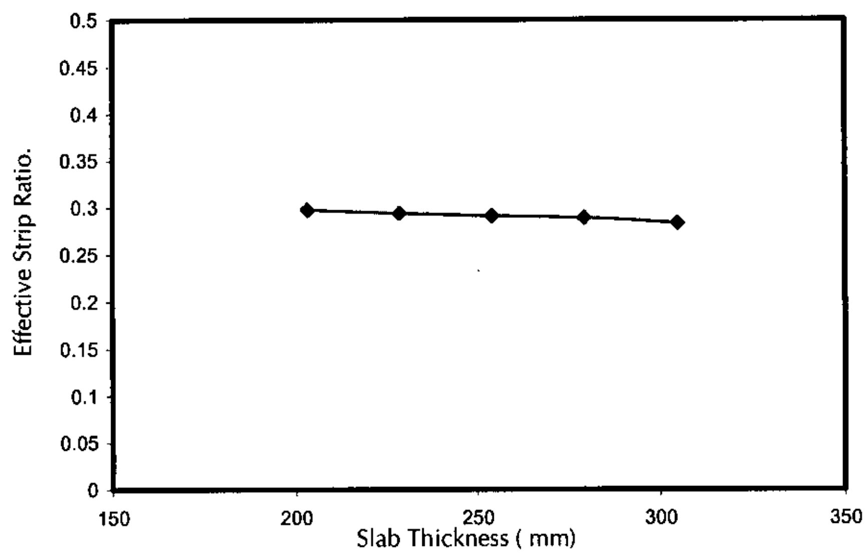

Fig. 4.5 Effect of Slab Thickness for Flat Plate Structures.

Table 4.6 Effect of Slab Thickness on α for Slab with Column Line Beam

Beam Depth (mm)	2D Beam Width (mm)	Effective Strip Ratio	Deflection (mm)	Slab Thickness (mm)	Actual Equivalent Width (mm)	Location of Neutral Axis (Y Bar) mm	Moment of Inertia mm ^{4} (2D and 3D)
500	50000	0.11033	22.271	127	662	264.39	8.53E+09
500	32800	0.1085	21.354	152.4	651	272.53	9.67E+09
500	23600	0.1115	20.570	177.8	669	277.91	1.11E+10
500	17750	0.11167	19.897	203.2	670	285.91	1.24E+10
500	13890	0.11117	19.287	228.6	667	294.96	1.38E+10
500	11450	0.1165	18.755	254.0	699	299.65	1.56E+10

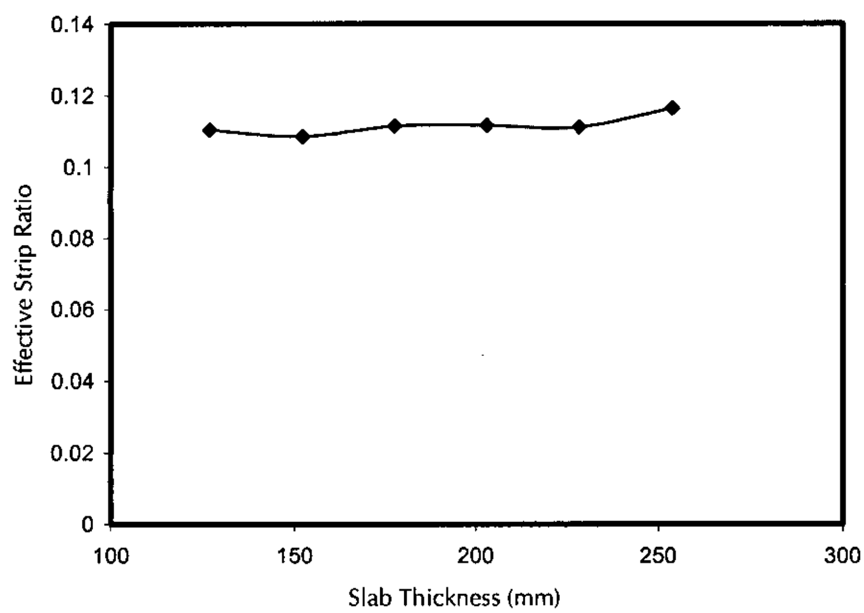

Fig. 4.6 Effect of Slab Thickness on α for Slab with Column Line beam

Table 4.7 Effective Strip Ratio and Bay Widths for Flat Plate Structures.

Bay Width (mm)	Floor Height (mm)	Deflection (mm)	Slab Width (mm)	Effective Width (mm)	Effective Strip Ratio	B/H Ratio
3000	4000	22.649	3000	1525	0.508333	0.75
4500	4000	32.397	4500	1650	0.366667	1.125
6000	4000	41.742	6000	1735	0.289167	1.5
7500	4000	50.325	7500	1840	0.245333	1.875
9000	4000	58.155	9000	1960	0.217778	2.25

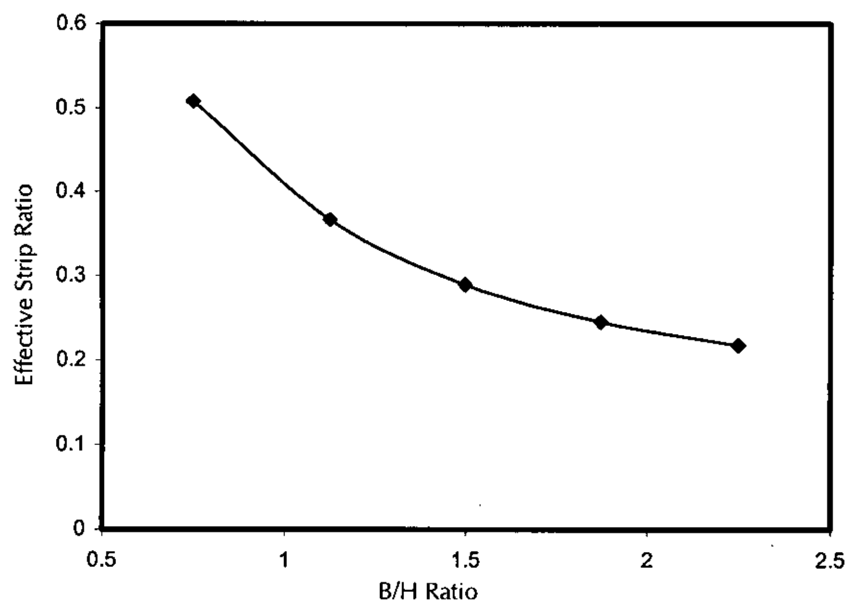

Fig. 4.7 Effect of B/H Ratio on α for Flat Plate Structures.

Table 4.8 Effective Strip Ratio and Bay Widths for Slab with Column Line Beam

Bay Width (mm)	Beam Depth (mm)	B/H Ratio	Floor Height (mm)	Deflection (mm)	Effective Strip Ratio	Slab Thickness (mm)	Equivalent T Beam Width (mm)
3000	500	0.75	4000	27.09	0.173333	254	520
4500	500	1.125	4000	22.2162	0.146667	254	660
6000	500	1.5	4000	18.755	0.114167	254	685
7500	500	1.875	4000	16.26	0.097333	254	730
9000	500	2.25	4000	14.354	0.083333	254	750

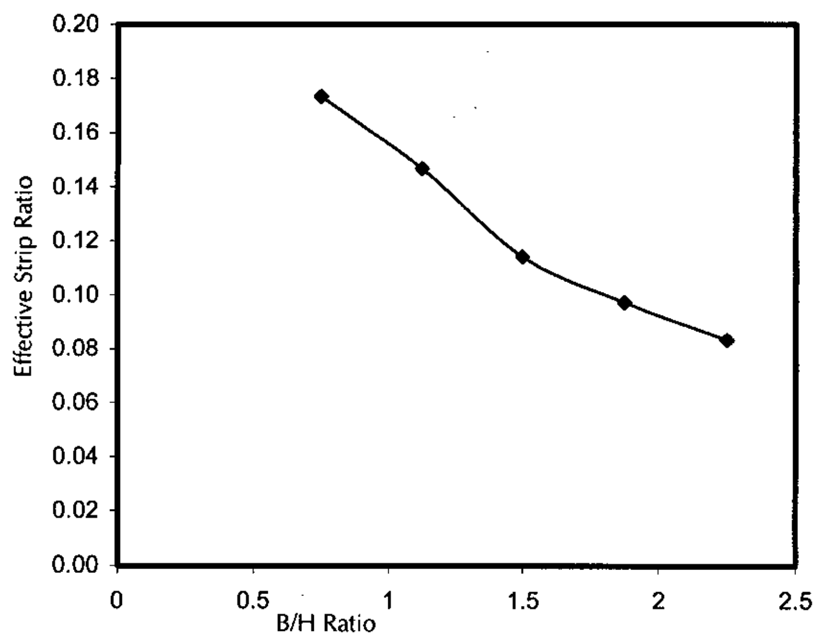

Fig. 4.8 Effect of B/H Ratio on α for Slab With Column Line Beam

Table 4.9 Effective Strip Ratio and Bay Nos for Flat Plate Structures

Bay Nos	Deflection (mm)	Slab Width (mm)	Effective Width (mm)	Effective Slab Strip Ratio
4	43.853	6000	1605	0.2675
5	42.596	6000	1685	0.280833
6	41.742	6000	1740	0.29
7	41.128	6000	1780	0.296667
8	40.662	6000	1815	0.3025

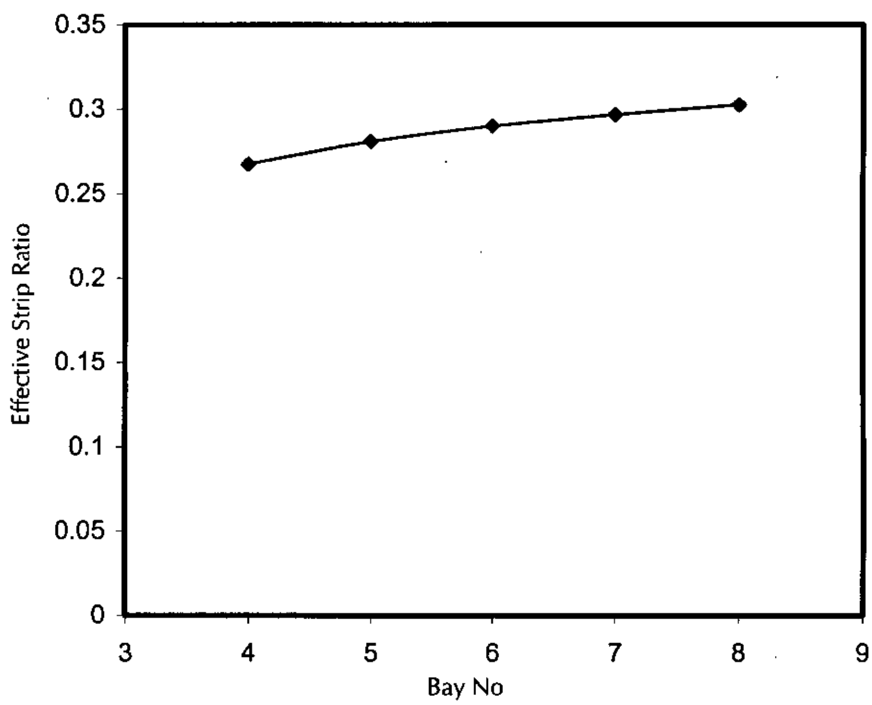

Fig. 4.9 Effect of Bay numbers on α for Flat Plate Structures

Table 4.10 Effective Strip Ratio and Bay Nos for Slab with Column Line Beam

Bay No	Beam Depth (mm)	Deflection (mm)	Floor Height (mm)	Slab Width (mm)	Effective Strip Ratio	Slab Thick (mm)	Equivalent Width (mm)
4	500	18.964	4000	6000	0.102333	254	614
5	500	18.842	4000	6000	0.109167	254	655
6	500	18.755	4000	6000	0.114167	254	685
7	500	18.692	4000	6000	0.118333	254	710
8	500	18.642	4000	6000	0.121667	254	730

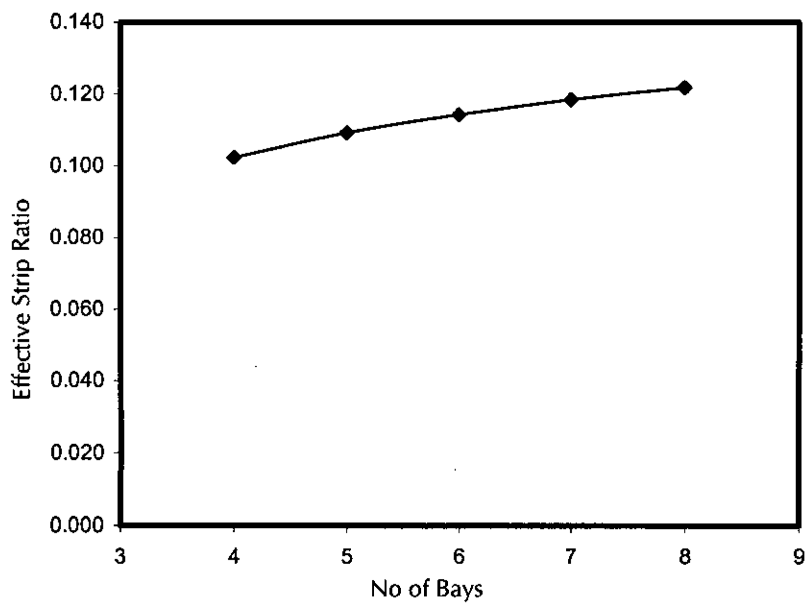

Fig. 4.10 Effect of Bay Nos on α for Slab with Column Line Beam

Table 4.11 Effective Strip Ratio and Floor Heights for Flat Plate Structures

Floor Height (mm)	Deflection (mm)	Bay Width (mm)	Effective Width (mm)	Effective Strip Ratio
3000	15.884	6000	1760	0.293333
3500	26.574	6000	1755	0.2925
4000	41.65	6000	1750	0.291667
4500	62.089	6000	1740	0.29
5000	88.974	6000	1730	0.288333

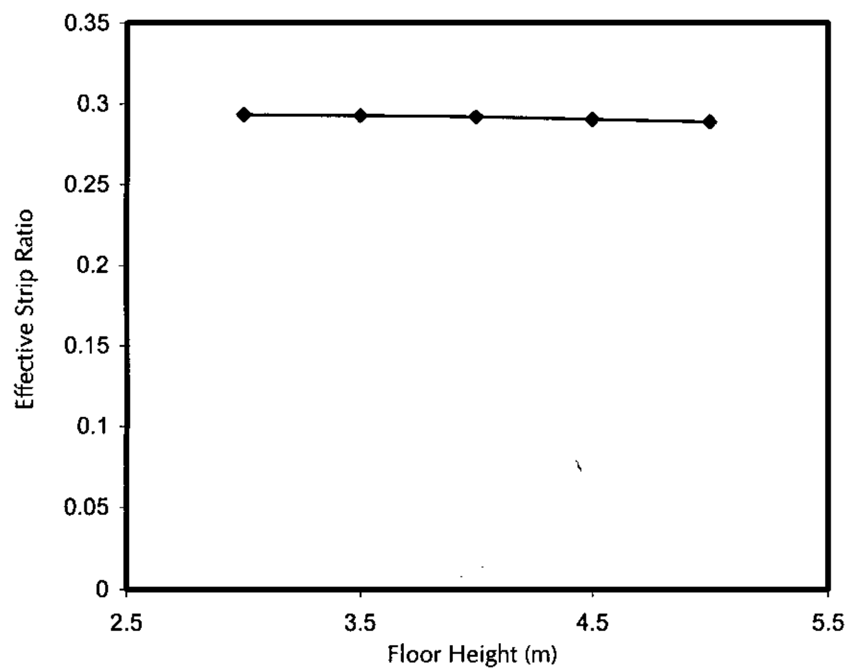

Fig. 4.11 Effect of Floor Height on α for Flat Plate Structures

Table 4.12 Effective Slab Strip Ratio and Floor Height for Slab with Column Line Beam

Floor Height (mm)	Beam Depth (mm)	Deflection (mm)	Slab Width (mm)	Effective Strip Ratio	Slab Thickness (mm)	Equivalent Width (mm)
3000	500	6.524	6000	0.110000	254	660
3500	500	11.448	6000	0.112500	254	675
4000	500	18.755	6000	0.115000	254	690
4500	500	29.087	6000	0.116667	254	700
5000	500	43.204	6000	0.116667	254	700

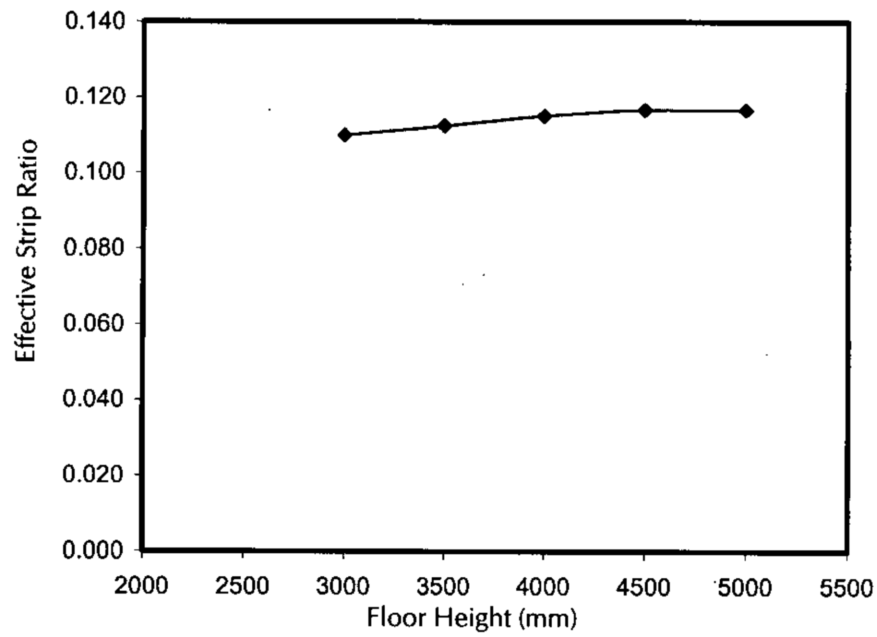

Fig. 4.12 Effect of Floor Height on α for Slab with Column Line Beam

Table 4.13 Effective Strip Ratio and Span Nos for Flat Plate Structures

Span No	Deflection (mm)	Slab Width (mm)	Effective Width (mm)	Effective Strip Ratio
4	62.397	6000	1700	0.283333
5	49.95	6000	1730	0.288333
6	41.65	6000	1750	0.291667
7	35.721	6000	1765	0.294167
8	31.273	6000	1775	0.295833

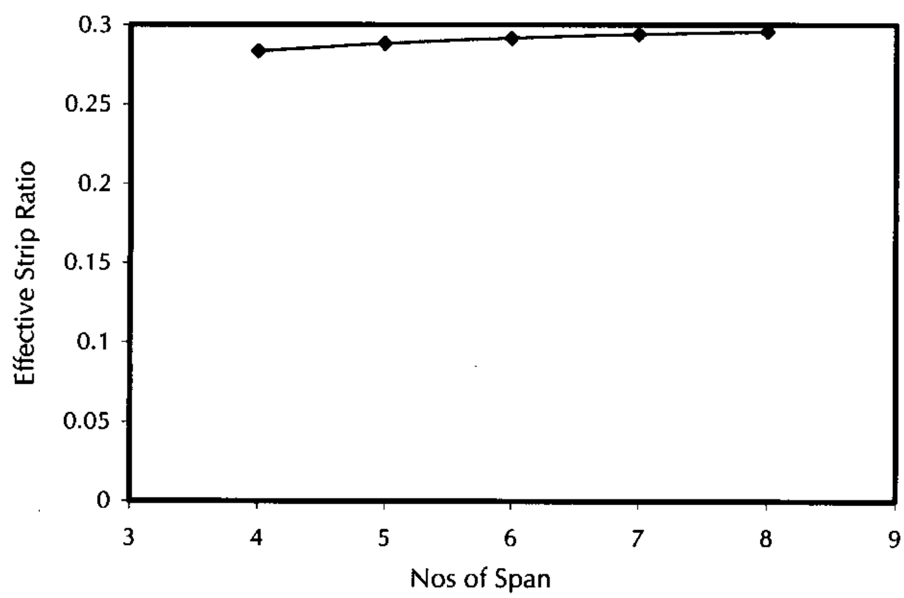

Fig. 4.13 Effect of Span Nos on α for Flat Plate Structures

Table 4.14 Effective Strip Ratio and Span No for Slab with Column Line Beam

Span No	Beam Depth (mm)	Floor Height (mm)	Slab Width (mm)	Effective Strip Ratio	Slab Thickness (mm)	Equivalent T-Beam Width (mm)	Deflection (mm)
4	500	4000	6000	0.117500	254	705	27.09
5	500	4000	6000	0.117500	254	705	22.162
6	500	4000	6000	0.117500	254	705	18.755
7	500	4000	6000	0.117500	254	705	16.26
8	500	4000	6000	0.117500	254	705	14.354

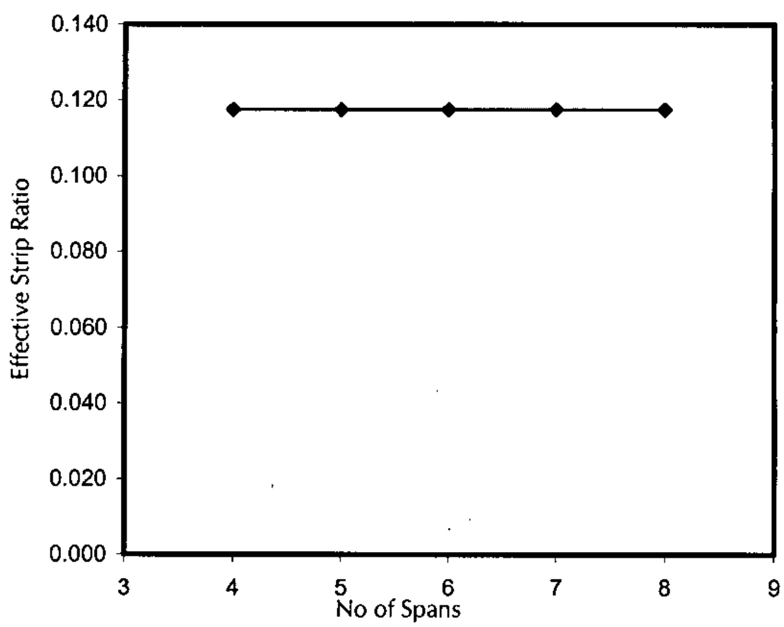

Fig. 4.14 Effect of Span Nos on α for Slab with Column Line Beam

Table 4.15 Effective Strip Ratio and Panel Aspect Ratio for Flat Plate Structures

Span Length (mm)	Floor Height (mm)	Deflection (mm)	Bay Width (mm)	Effective Width (mm)	Effective Strip Ratio	Panel Aspect Ratio
3000	4000	37.402	6000	1100	0.183333	0.75
4500	4000	40.172	6000	1580	0.263333	1.125
6000	4000	41.65	6000	1745	0.290833	1.5
7500	4000	42.451	6000	2100	0.35	1.875
9000	4000	42.992	6000	2470	0.411667	2.25

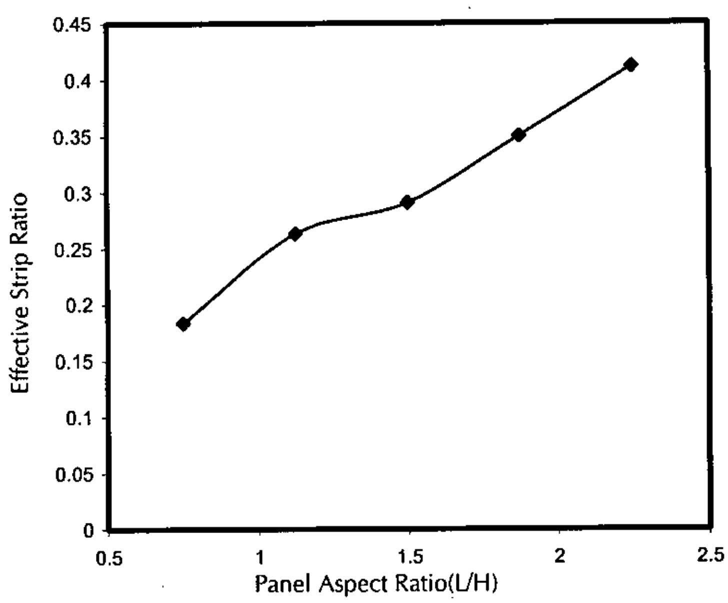

Fig. 4.15 Effect of Panel Aspect Ratio on α for Flat Plate Structures

Table 4.16 Panel Aspect Ratio and α for Slab with Column Line Beam

Span Length (mm)	Beam Depth (mm)	Panel Aspect Ratio	Floor Height (mm)	Slab Width (mm)	Effective Strip Ratio	Slab Thickness (mm)	Equivalent Width (mm)	Deflection (mm)
3000	500	0.75	4000	6000	0.063667	254	382	18.07
4500	500	1.125	4000	6000	0.088333	254	530	18.284
6000	500	1.5	4000	6000	0.117500	254	705	18.755
7500	500	1.875	4000	6000	0.146667	254	880	19.295
9000	500	2.25	4000	6000	0.170000	254	1020	19.848

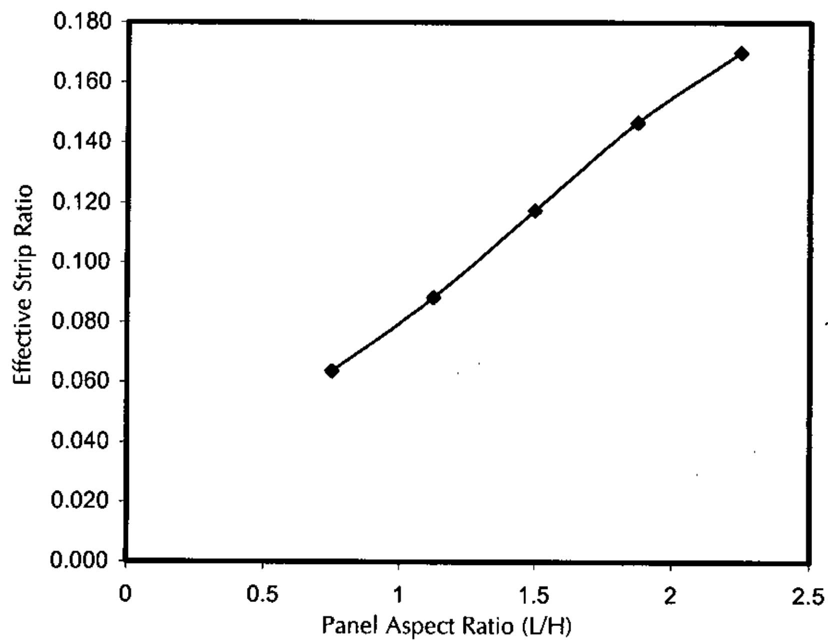

Fig. 4.16 Effect of Panel aspect Ratio on α for Slab with Column Line Beam

Table 4.17: Effect of Beam Depth Variation on α for Slab with Column Line Beam

	2 D Model				3D Model			
Deflection (mm)	Beam Depth (mm)	Beam Width (mm)	Effective Strip Ratio	Moment of Inertia (mm^4)	Slab Thickness (mm)	Equivalent Width (mm)	Location of Neutral Axis (Y Bar) (mm)	Moment of Inertia (mm^4)
23.899	300	3200	0.17	7.20E+09	254	1020	198.41	7.19E+09
20.742	400	2100	0.14833	1.12E+10	254	890	240.39	1.12E+10
18.755	500	1530	0.1225	1.59E+10	254	735	294.95	1.59E+10
17.472	600	1200	0.10367	2.16E+10	254	622	354.40	2.16E+10
16.625	700	1050	0.10417	3.00E+10	254	625	398.64	3.00E+10

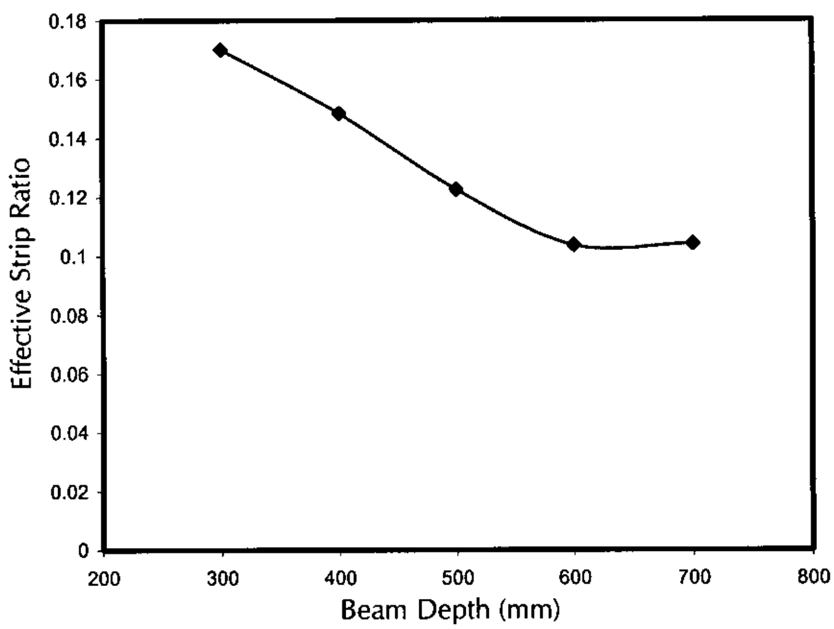

Fig. 4.17 Effect of Beam Depth on α for Slab with Column Line Beam

CHAPTER 5

A RATIONALE FOR EFFECTIVE SLAB STRIP RATIO

5.1 INTRODUCTION

As far as the intensive studies followed by observations are concerned, it can be pronounced that other than B/H and L/H, all other parameters have negligible influence upon effective slab strip ratio for flat plate structures. Beam depth has significant effect upon effective slab strip ratio in case of slab with column line beams.

Accordingly, it is important to study further the two most influential parameters namely B/H and L/H for flat plate structures. Therefore, more studies have been conducted with these two parameters and the findings as well as decisive ideas are presented in this chapter. Due to limited scope of this present research, structures having slabs with column line beams are not studied further.

5.2 DEVELOPMENT OF A RATIONALE

As it is more thought about the most wanted converging solution, it cannot be preceded without the two sensitive parameters namely B/H and L/H. In view of the line of thinking, this can be done by determining the value of effective strip ratio for all the combinations of B/H and L/H for flat plate structures. Since there are 5 sets of studied values for each of the B/H and L/H, there are 25 combinations possible under the scope of the research. Accordingly, the effective strip ratio is determined for all the 25 combinations (keeping other parameters equal to the reference values) and shown in the table 5.1 and simultaneously the same results are shown in Fig. 5.1 in three dimensional form, where the effective strip ratio is illustrated in the vertical axis and B/H and L/H are represented in the two horizontal axis. After all, this illustration provides a surface for α under the parameters in the investigation.

Table 5.1 Chart for Effective Strip Ratio with respect to Variable Span and Bay Width for Flat Plate Structures.

Bay Width (mm) →		3000	4500	6000	7500	9000
Span (mm) ↓	B/H →	0.75	1.25	1.5	1.875	2.25
	L/H ↓					
3000	0.75	0.278333	0.213333	0.183	0.165333	0.154444
4500	1.25	0.396667	0.287778	0.263	0.204	0.185556
6000	1.5	0.5	0.367	0.289	0.245	0.218
7500	1.875	0.606667	0.446667	0.35	0.292667	0.255
9000	2.25	0.681667	0.521111	0.41	0.34	0.293889

Thus a surface of effective strip ratio in terms of B/H and L/H is obtained. This surface can be expressed as a function of B/H and L/H. It can be expressed in a mathematical relationship as stated below:

$$\alpha = f\left(\frac{B}{H}, \frac{L}{H}\right)$$

Now, at this stage, next step is to determine the actual form of this most wanted equation. The approach could be the determination of polynomial regression equation corresponding to each row of table 5.1, which is discussed in detail in the following paragraph.

There are 5 sets of curves as may be obtained from values of α and corresponding L/H from table 5.1, where each curve represents a definite value of B/H as has been shown in the following Fig. 5.2.

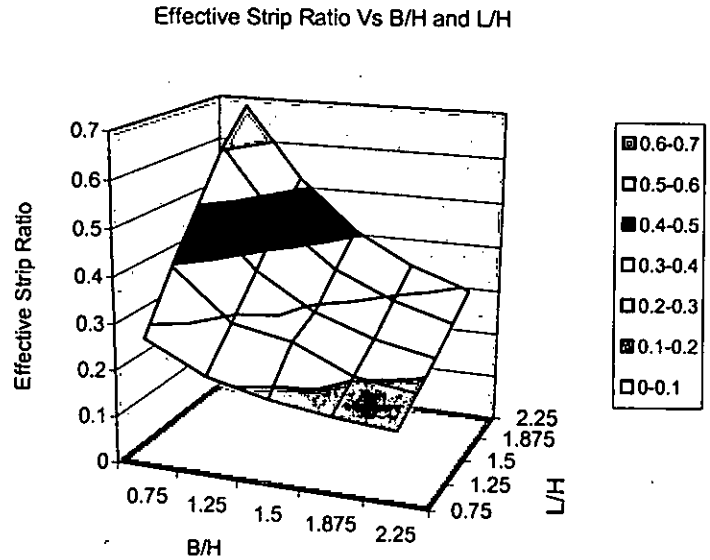

Fig. 5.1 Effective Strip Ratio with respect to B/H and L/H in a 3 Dimensional Mode.

Fig. 5.2 shows 5 sets of curves corresponding to 5 different values of B/H. where, each of the curves can be approximated by a linear regression equation of the form stated below:

$$\alpha = m\frac{L}{H} + C \qquad (5.1)$$

Actual equations corresponding to the 5 sets of data are determined and these are shown in Fig. 5.2. Thus it can be uttered that in this equation, the co-efficient "m" and constant "C" are function of B/H. Table 5.2 summarizes these co-efficient "m" and constant "C" against different values of B/H. Based on the data of this table, two graphs can be obtained by plotting the co-efficient "m" vs. B/H and the constant "C" vs. B/H. This is shown in Fig. 5.3.

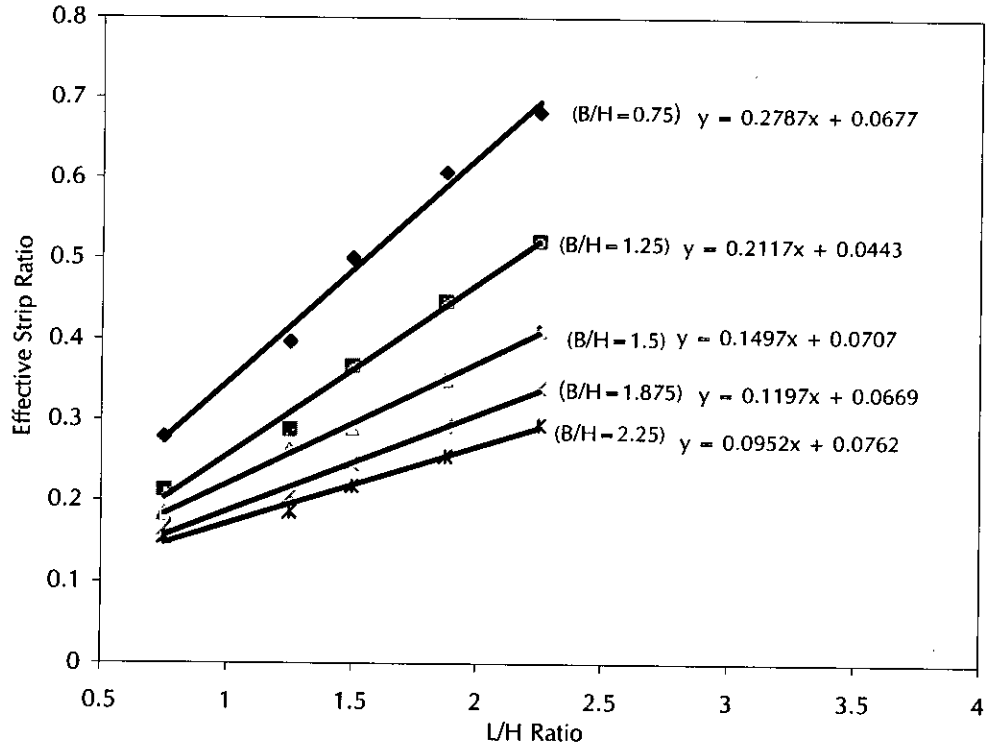

Fig. 5.2 Effective Strip Ratio with respect to B/H and L/H.

By means of regression analysis, the equations for these two sets of data are determined and are shown in Fig. 5.4. Therefore the derivation for "m" and "C" are as follows:

$$m = 0.0464\left(\frac{B}{H}\right)^2 - 0.2662\frac{B}{H} + 0.4562 \qquad (5.2)$$

$$\text{and } C = 0.0092\frac{B}{H} + 0.0511 \qquad (5.3)$$

Now. Using the value of "m" and "C" from equation 5.2 and 5.3 in equation 5.1, α can be expressed in terms of B/H and L/H as shown below:

$$\alpha = \left[0.0464\left(\frac{B}{H}\right)^2 - 0.2662\frac{B}{H} + 0.4562\right]\frac{L}{H} + 0.0092\frac{B}{H} + 0.0511 \qquad (5.4)$$

From the above equation, the value of effective slab strip ratio can be directly determined, once B/H and L/H are known for a flat plate structure.

Table 5.2 B/H and Corresponding Co-efficient of X and Constants for Curves of Fig. 5.2.

B/H Ratio	Co-efficient of X	Value of Constant
2.25	0.095	0.0762
1.875	0.1167	0.0669
1.5	0.1497	0.0707
1.25	0.2117	0.0443
0.75	0.2787	0.0677

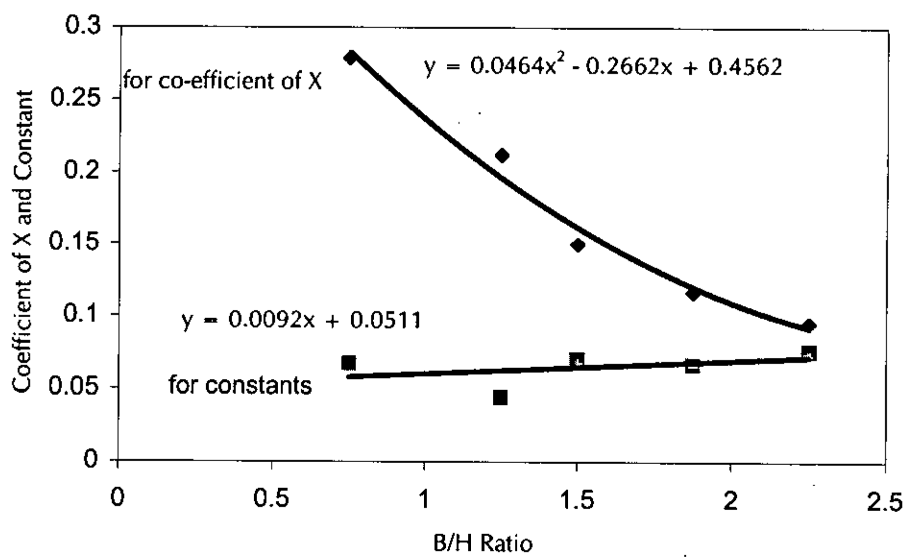

Fig 5.3 B/H Ratio and Co-efficient for Curves of Fig. 5.2

5.3 VERIFICATION OF THE PROPOSAL

In the previous article, an equation for α in terms of parameter B/H and L/H has been proposed for flat plate structures. It is essential that the validity of this equation is to be established. This is done by means of determining α from 10 arbitrary selected examples of flat plate building and comparing them with the same as determined by means of finite element analysis. The data for 10 arbitrary selected problems are given in table 5.3. In these 10 examples, span length and bay widths are arbitrarily chosen, while the value of the other parameters are taken as those shown in table 4.1 in Chapter 4.

Table 5.3 Data for 10 Arbitrary Examples of Flat Plates Structures.

Sl No.	Bay Size (mm)	Span Length (mm)	Other Data
1	3000	4000	No. of Span = 6
2	3000	7000	No. of bays = 6
3	3000	8000	Floor Height = 4000 mm
4	4000	3000	Column Size = 450X450
5	4000	6000	Slab Thickness = 254 mm
6	4500	5000	
7	4500	9000	
8	7000	5000	
9	7000	9000	
10	9000	5000	

Table 5.4 α from Analysis and as Obtained with the Help of the Developed Equation

Bay Width B (m)	Span Length L (m)	Floor Height H (m)	B/H Ratio	L/H Ratio	α From Analysis	α From Equation	% of Deviation
3	4	4	0.75	1	0.357	0.34	4.6
3	7	4	0.75	1.75	0.6167	0.55	10.4
3	8	4	0.75	2	0.633	0.62	1.5
4	3	4	1	0.75	0.229	0.24	3.8
4	6	4	1	1.5	0.384	0.41	8.0
4.5	5	4	1.125	1.25	0.313	0.33	5.7
4.5	9	4	1.125	2.25	0.522	0.55	4.6
7	5	4	1.75	1.25	0.228	0.23	2.1
7	9	4	1.75	2.25	0.361	0.37	1.2
9	5	4	2.25	1.25	0.2	0.19	6.5

The results of comparison are shown in table 5.4. From table 5.4, it is distinguished that the value of α as determined from the proposed equation are in close agreement with the values determined from analysis, the maximum deviation being around 10%, which can be considered acceptable.

5.4 ALTERNATIVE PROPOSAL

Instead of using the proposed equation, one can directly use the chart given in table 5.1 to determine the value of α for flat plate structures. When structural configuration is finalized, the ratios, B/H and L/H will be known. Using linear interpolation technique, one can easily determine the value of α for flat plate structures from table 5.1. However, it should be kept in mind that the magnitude of B/H and L/H must be within limits as shown in the chart.

5.5 REMARKS

In this chapter, a rationale for establishing the value of effective slab strip ratio, α, has been proposed for a regular flat plate structure. The value of α can be determined by using the chart mentioned in table 5.1 or by using the proposed equation 5.4. This shall enable the design engineers for quickly idealize flat plate structures into equivalent frames with correct proportion of beams.

CHAPTER 6
CONCLUSION

6.1 GENERAL

The project started with an aim to find out the effective slab strip ratio for flat plate structures that has long been an indeterminate aspect for structural analysis. The project has been so planned to find out a reasonable solution of the wanted problem in question under some parametric conditions. Firstly, some variable parameters are chosen for flat plate and slab with column line beam structures followed by analysis with finite element method. The effective slab strip ratio, α, is then determined for each type of problem by adjusting beam width of the 2D model (representative model of the main 3D structure) maintaining the same deflection as obtained from 3D analysis for the problem under investigation. Then, curves are drawn for each type of problem representing "α" vs. the variable parameter under study to find out precisely the effect of it on α. This shows that, except bay width and span length, other variable parameters do not have any significant effect on α for flat plate structures under the study. The same suggestion is also applicable for slab with column line beam structures, except that beam depths also have remarkable influence on α. Under the scope of the study, by regression analysis, an equation is developed to find out α for flat plate structures with the known parameter of bay width and span length. There after, 10 arbitrary problems have been taken up and analyzed by finite element methods to find out α. For validation, α has also been determined for the same 10 arbitrarily problems with the help of developed equation. It is observed that the results as come out of the two procedures are in close agreement with a little variation, which can be acceptable. A chart for α has also been provided; one can also obtain α by interpolation with the relevant values of bay width and span length for flat plate structures under certain range of parametric conditions. Thus, the objective of this project comes out successfully with validation.

6.2 FINDINGS

The outcome of the project are summarized as follows:

- Column size, slab thickness, number of bays, number of spans and floor height do not have any appreciable effect upon effective slab strip ratio for flat plate and slab with column line beam structures under research.
- Beam depth has significant effect upon effective slab strip ratio in case of slab having column line beams and it is observed that effective slab strip ratio decreases with increasing beam depth.
- Panel aspect ratio (L/H) has significant influence on effective slab strip ratio and it is noticed that effective slab strip ratio increases with increasing panel aspect ratio (L/H) for both types of structures.
- Width of the bay also has significant effect on effective slab strip ratio and the study shows that it decreases with increasing width of bay (B) or (B/H) for both types of structures.

6.3 RATIONALE FOR ESTIMATING SLAB STRIP RATIO

In this project, by means of computational finite element investigation, a rationale for determining α has been developed. Either a chart or an equation can be used for this purpose, detail of which is described in Chapter 5. It must be kept in mind that this rationale for estimating effective slab strip ratio is valid only within certain range of structural design parameters for flat plate type structures.

6.4 SCOPE FOR FUTURE INVESTIGATION

The equation developed for α is valid only for flat pale structures under certain range of parametric condition. In future, investigation can be performed to develop analytical relationship of this kind of effects, in the form of mathematical equations or charts, combining the individual equations found in each graph for different study parameters so that effective slab strip ratio α can also be determined for slab with column line beam structures taking into account the effect of beam depth/width for that particular problem concerned. Also, floor height, number of floors, span length, bay width and beam depth are maintained constant for all the floors throughout this study, which can also be varied and further studied to obtaine solution concerning those if required.

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