CHAPTER ONE

INTRODUTORY BACKGROUND

1.1 INTRODUCTION:

An important part of the total responsibility of the structural engineer is to select, from many alternatives, the best structural system for the given conditions. The wise choice of structural system is far more important, in its effect on overall economy and serviceability, than refinements in proportioning the individual members. Close cooperation with the architect in the early stages of a project is essential in developing a structure that not only meets functional and esthetic requirements but exploits to the fullest the special advantages of reinforced concrete, which include; versatility of form, durability, fire resistance, speed of construction, cost and availability of labor and material.

Slab is a structural system consisting of a deck supported on columns which is used to transfer dead and live loads to the supporting vertical members through bending, shearing and torsion. They are used in various places like buildings, bridges, and parking areas. As these places require large column free area with conventional flat slabs it is a major challenge.

Since concreting larger area means increased dead weight of the slab thereby resulting to simultaneous heavy structures which in-turn leads to a costly construction practice. Development in this field can be observed with the usage of waffle slabs which meets the requirement of reduction in dead weight. As the weight of slab decreases, slab moments get reduced and simultaneously material gets reduced, they also exhibit relatively less deformation and possess higher stiffness under heavy loads.

Waffle slabs as a structural system comprise of a flat plate or topping slab and a system of equally spaced parallel ribs running in both directions. The ribs are designed in such a way that the slab does not require any shear reinforcement. Waffle slab are economic in medium size floors ranging from span length of five to ten meters as further increasing their size increases the slab thickness and slab weight is increased. Services can also be easily incorporated without any complications due to uniform soffit, as thin topping within the ribs can be easily cut without the risk of cutting main reinforcement. The various factors which influence the functionality of waffle slabs are rib width, rib depth, rib spacing, distance of ribs from supports, column size and shape, drop panels and column capital, type of beam and rib stiffness

1.2 OBJECTIVES OF STUDY:

1. Identification of the types of reinforced concrete slab.

2. Analysis of waffle and flat slab using computer program (SAFE) and manual method (Direct method).

3. Design a waffle slab and a flat slab according to BS-8110.

4. Carry out a comparison between the analysis results.

5. Carry out a comparison between quantities of the waffle and flat slab.

6. Demonstrate that waffle slab with can be used to reduce the dead load on slab concrete structure.

1.3 METHODOLOGY OF STUDY:

1. Viewing the published literatures about reinforced concrete slabs, types of slabs and methods of analysis and design of slabs.
2. Apply analysis and design operation using the British standards (BS-8110)
3. Using SAFE program for analysis.
4. Comparison of results and then get recommendations.

1.4 CONTENTS:

The study is consisting of five chapters as following:

Chapter one: includes a general introduction about study, the importance of the choice of the structural system, the basic concept of waffle slab, aims and methodology of study.

Chapter two: includes a general definition, classification, common types and structural behavior of reinforced concrete slabs.

Chapter three: includes an explanation of the direct analysis and design method according to BS-8110. And also includes a brief identification of the basic concepts of finite element method of slab analysis.

Chapter four: includes analysis of slabs using program and manual method, manual design, quantities computation, and results comparison.

Chapter five: includes conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 General:

Reinforced concrete has long been one of the most widely used materials in construction applications. It has numerous material advantages, but one of its most significant benefits is the ability to be cast into a wide variety of shapes. In fact, reinforced concrete is only geometrically limited by the complexities or cost of the construction of formwork. As such, the behavior of concrete structures easily constructed in the field often falls beyond the scope of common frame analysis programs and conventional design methods. This is certainly true for the analysis of reinforced concrete systems where slabs, shear walls, shells, tanks, deep beams, and coupling beams must be modeled. If the structural element contains holes or is subjected to concentrated or otherwise irregular loadings, the analysis is further complicated.

Structure is a system formed from the interconnection structural members or the shape or form that prevents buildings from being collapsed. A structure supports the building by using a framed arrangement known as Structure

2.2 Slab definition:

A slab is a flat two dimensional planar structural element having thickness small compared to its other two dimensions. It provides a working flat surface or a covering shelter in buildings. It primarily transfers the load by bending in one or two directions.

Reinforced concrete slabs behave primarily as flexural members and the design is similar to that of beams.

Reinforced concrete slabs are used in floors, roofs and walls of buildings and as the decks of bridges. The floor system of a structure can take many forms such as in situ solid slab, ribbed slab or pre-cast units. Slabs may be supported on monolithic concrete beam, steel beams, walls or directly over the columns.

2.3 Classification of slabs:

Slabs are classified based on many aspects

1) Based of shape: Square, rectangular, circular and polygonal in shape.

2) Based on type of support: Slab supported on walls, Slab supported on beams, Slab supported on columns (Flat slabs).

3) Based on support or boundary condition: Simply supported, Cantilever slab, Overhanging slab, Fixed or Continues slab.

4) Based on use: Roof slab, Floor slab, Foundation slab, Water tank slab.

5) Basis of cross section or sectional configuration: Ribbed slab /Grid slab, Solid slab, filler slab, folded plate

6) Basis of spanning directions:

- One way slab – spanning in one direction.
- Two way slab _ spanning in two directions.

2.4 Common types of slabs:

2.4.1 Solid slab: A slab supported on beams on two opposite sides or on all sides of each panel, and a typical floor is shown in Fig.2.1. This system is a development from beam-and-girder systems by removal of the beams, except those on the column lines. As shown in Fig.2.2. Beam-and-girder system is still used with heavy timber and steel frame construction, especially when the column spacing becomes large.

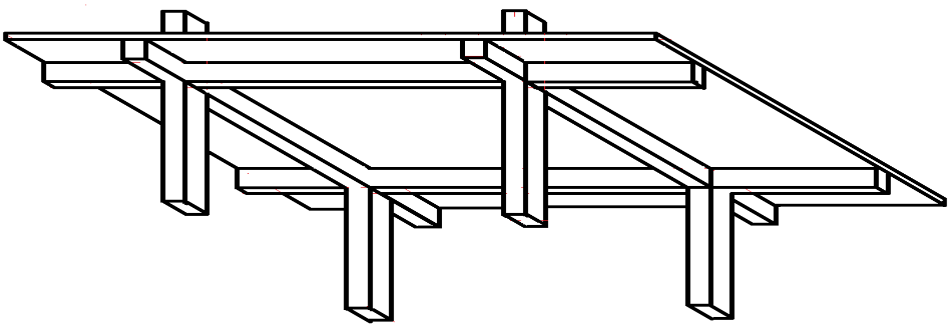


Figure 2.1 Solid slab

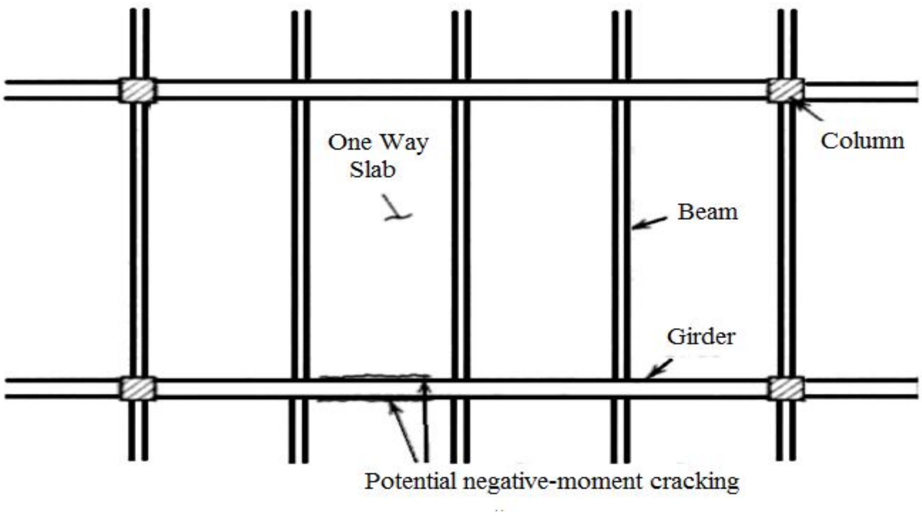


Figure 2.2 plane view of Beam-and-Girder system

2.4.2. Beamless slabs: are described by the generic terms *flat plates* and *flat slabs*.

Flat plate: is an extremely simple structure in concept and construction, consisting of a slab of uniform thickness supported directly on columns, as shown in Fig. 2.3. Flat plate floors have been found to be economical and otherwise advantageous for such uses as apartment buildings where the spans are moderate (up to about 9 m) and loads relatively light.

- **Advantages of Flat Plate Floors :**
  - The construction depth for each floor is held to the absolute minimum, with resultant savings in the overall height of the building.
  - The smooth underside of the slab can be painted directly and left exposed for ceiling, or plaster can be applied to the concrete.
  - Minimum construction time and low labor costs result from the very simple formwork.

- **Disadvantages of Flat Plate Floors :**
  - Shear stresses near the columns may be very high, requiring the use of special types of slab reinforcement there.
  - The transfer of moments from slab to columns may further increase shear stresses and requires concentration of negative flexural steel in the region close to the columns.
  - At the exterior columns, where such shear and moment transfer may cause particular difficulty, the design is much improved by extending the slab past the column in a short cantilever.

Flat slab: A beamless systems with drop panels or column capitals or both are termed flat slab systems. The basic form of the flat slab is shown in Fig. 2.4 and the most common subtypes are flat slab with column capitals which shown in Fig. 2.5.

Both of drop panels or column capitals serve a double purpose:

a) They increase the shear strength of the floor system in the critical region around the column,
b) And they provide increased effective depth for the flexural steel in the region of high negative bending moment over the support.

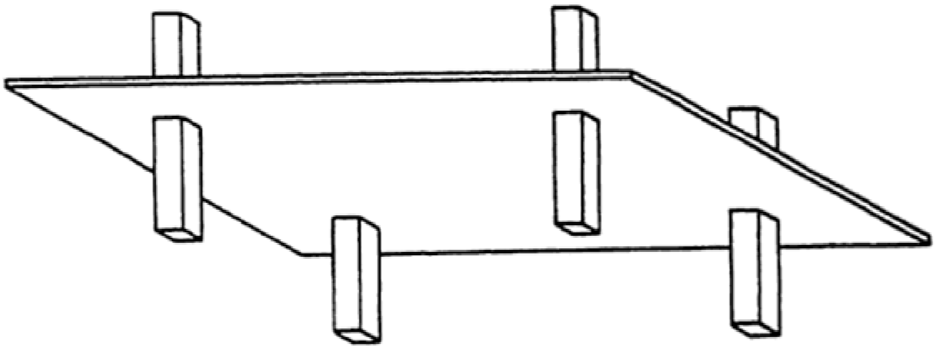


Figure 2.3 Flat Plate

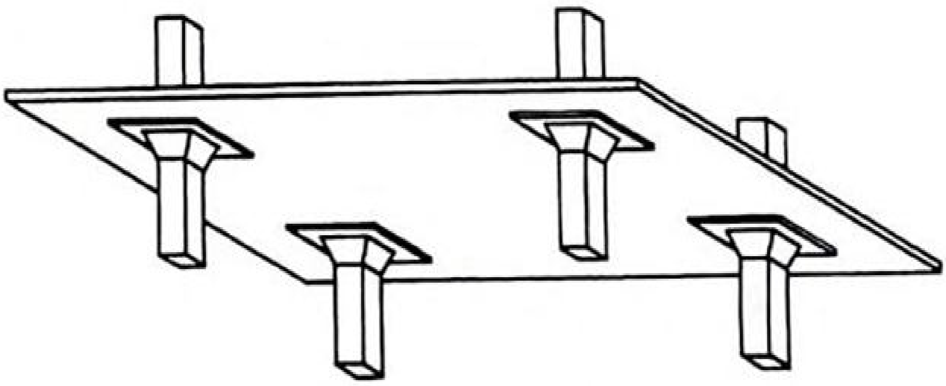


Figure 2.4 Flat Slab with drop panel and column capitals

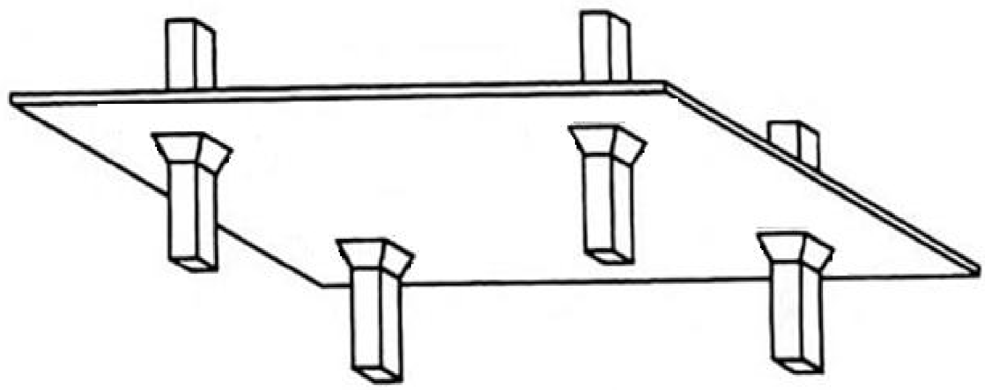


Figure 2.5 Flat Slab with column capitals

2.4.3 Ribbed slabs (with solid or hollow blocks or voids)

The term "ribbed slab" in this sub-clause refers to in-situ slabs constructed in one of the following ways:

a) Where topping is considered to contribute to structural strength:

1. as a series of concrete ribs cast in-situ between blocks which remain part of the completed structure; the tops of the ribs are connected by a topping of concrete of the same strength as that used in the ribs; as shown in Fig. 2.6.

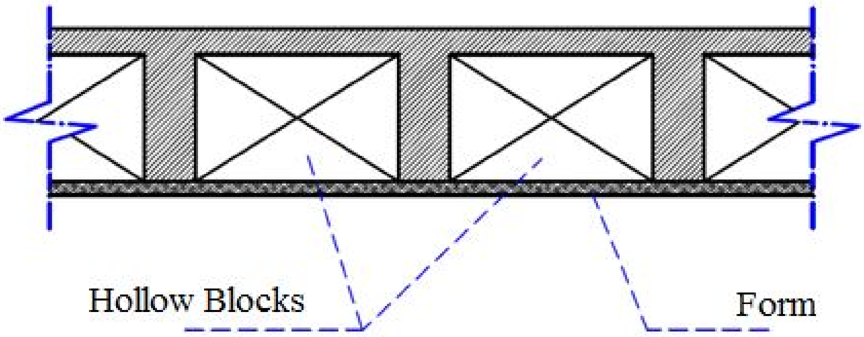


Figure 2.6 Ribbed slab with permanent blocks

2. as a series of concrete ribs with topping cast on forms which may be removed after the concrete has set; as shown in Fig 2.7.

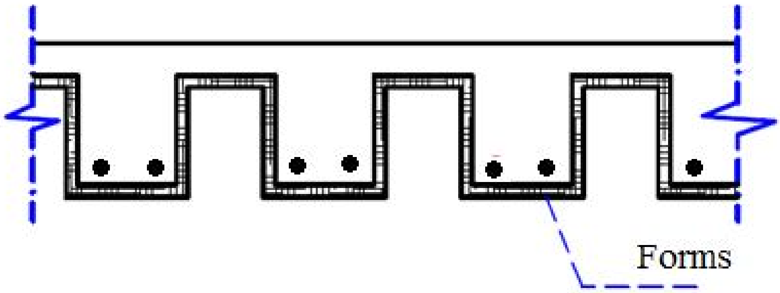


Figure 2.7 Ribbed slab without permanent blocks

3. with a continuous top and bottom face but containing voids of rectangular, oval or other shape, which termed Hollow core slab (shown in Fig. 2.8)

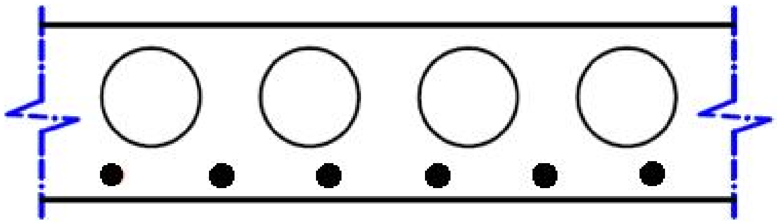


Figure 2.8 Ribbed hollow core slabs

b) Where topping is not considered to contribute to structural strength: as a series of concrete ribs cast in-situ between blocks which remain part of the completed structure; the tops of the ribs may be connected by a topping of concrete (not necessarily of the same strength as that used in the ribs).

Since the strength of concrete in tension is small and is commonly neglected in design, elimination of much of the tension concrete in a slab by the use of permanent or temporary pan forms or blocks results in a little change in the structural characteristics of the slab, and the removal of tension concrete leads to:

a) Decrease the weight of the slab.
b) Allow the use of a large effective depth without the accompanying dead load.
c) Stiffening the structure because of large depth.

Ribbed floors are economical for buildings, such as apartment houses, hotels, and hospitals, where the live loads are fairly small and the spans comparatively long. They are not suitable for heavy construction such as in warehouses, printing plants, and heavy manufacturing buildings.

- **Dimensions requirement according to "BS-8110":**

- Spacing of ribs should not exceed 1.5 m.
- Ribs depth, excluding any topping, should not exceed four times their width.
- The minimum width of rib will be determined by considerations of cover, bar spacing and fire.
- The thickness of the concrete slab or topping should not be less than:
  - 30mm for slab with permanent blocks contributing to structural strength and where there is a clear distance between ribs not more than 500mm.
  - 25mm when blocks jointed with a cement-sand mortar.

- 40mm or 1/10th of the clear distance between ribs, whichever is greater, for all other slabs with permanent blocks.
- 50mm or 1/10th of the clear distance between ribs, whichever is greater, for slabs without permanent blocks.

2.4.3.1 One-Way Ribbed Slab: consists of a series of small, closely spaced reinforced concrete T beams, framing into monolithically cast concrete girders, which are in turn carried by the building columns. The T beams, called ribs, are formed by creating void spaces in what otherwise would be a solid slab. Usually these voids are formed using special steel pans, or hollow blocks as shown in Fig 2.9. When permanent hollow blocks are used ribbed slab is termed *Hollow Block Slab*. Concrete is cast between the forms to create ribs, and placed to a depth over the top of the forms so as to create a thin monolithic slab that becomes the T beam flange. Fig 2.10 shows the arrangement of blocks in One-Way hollow block slab.

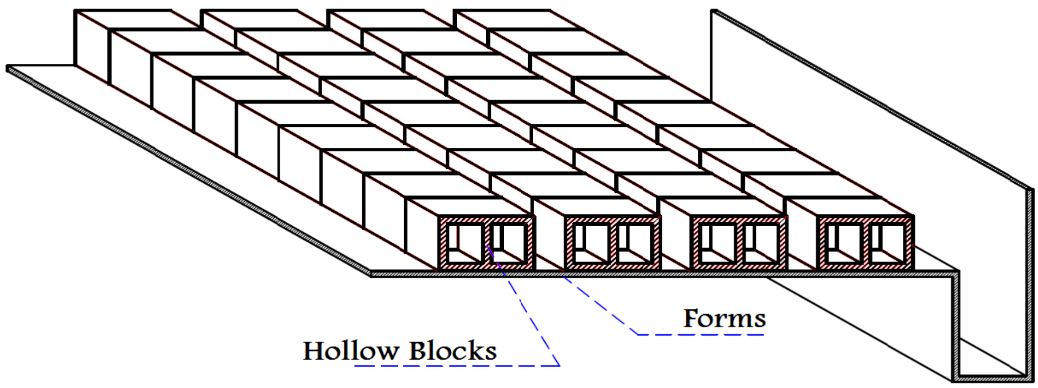


Figure 2.9 One-Way ribbed slab formed using blocks

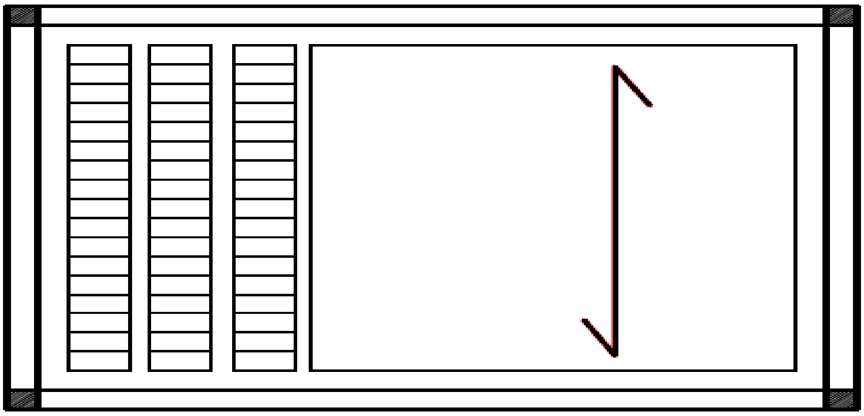


Figure 2.10 Arrangement of block in One-Way hollow blocks

The joists and the supporting girders are placed monolithically. Like the joists, the girders are designed as T beams. The shape of the girder cross section depends on the shape of the end pans that form the joists, as shown in Fig. 2.11.

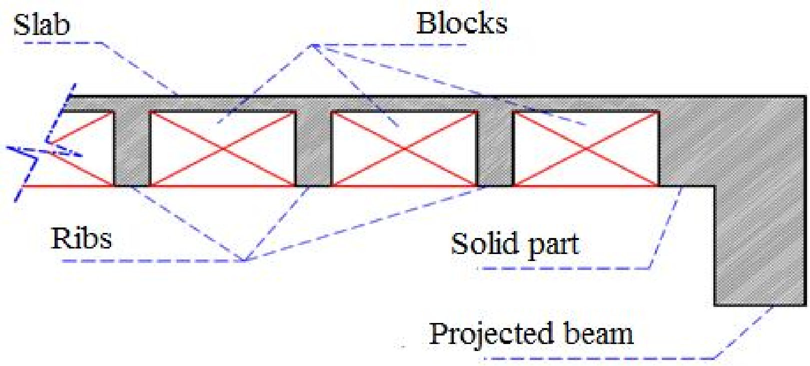


Figure 2.11 One-Way hollow block slab cross section

2.4.3.2 Two-Way Ribbed Slab "Waffle": is a variant of the solid slab, may be visualized as a set of crossing ribs, set at small spacings relative to the span, which support a thin top slab. Waffle slab may be designed as a flat slab or a solid slab depending on the arrangement of voids. Fig. 2.12 shows the possible arrangements of Waffle slab.

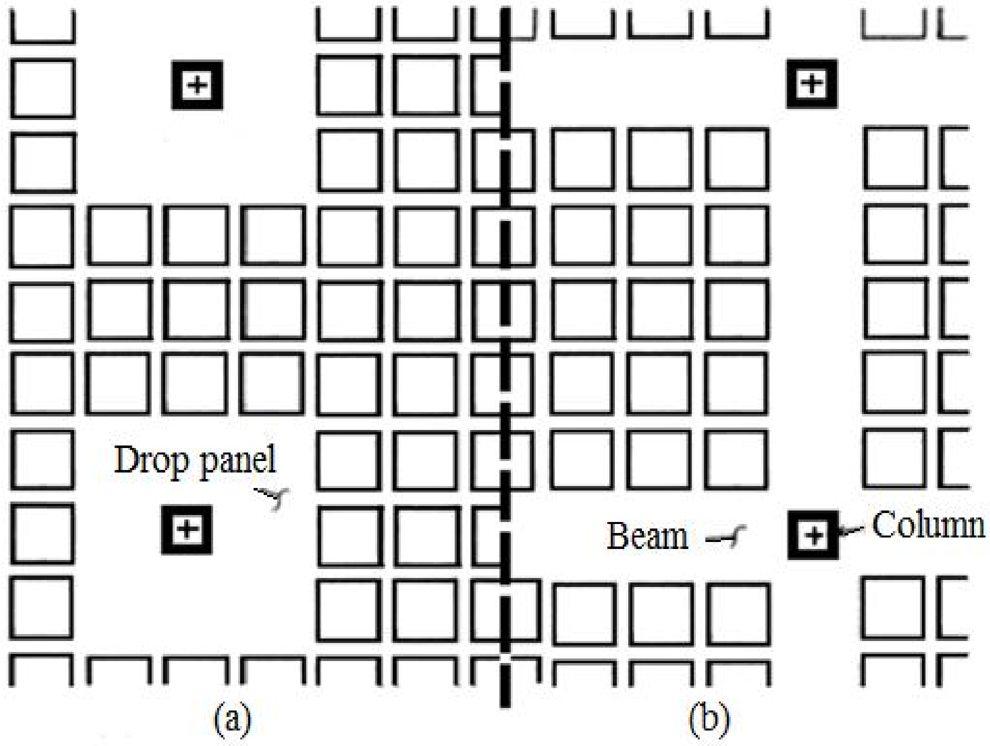


Figure 2.12 Arrangements of waffle slab (a) as a flat slab (b) as a solid slab

The bottom voids are usually formed using dome-shaped steel pans or hollow blocks that are placed on a plywood platform as shown in Fig. 2.13 and Fig. 2.14.

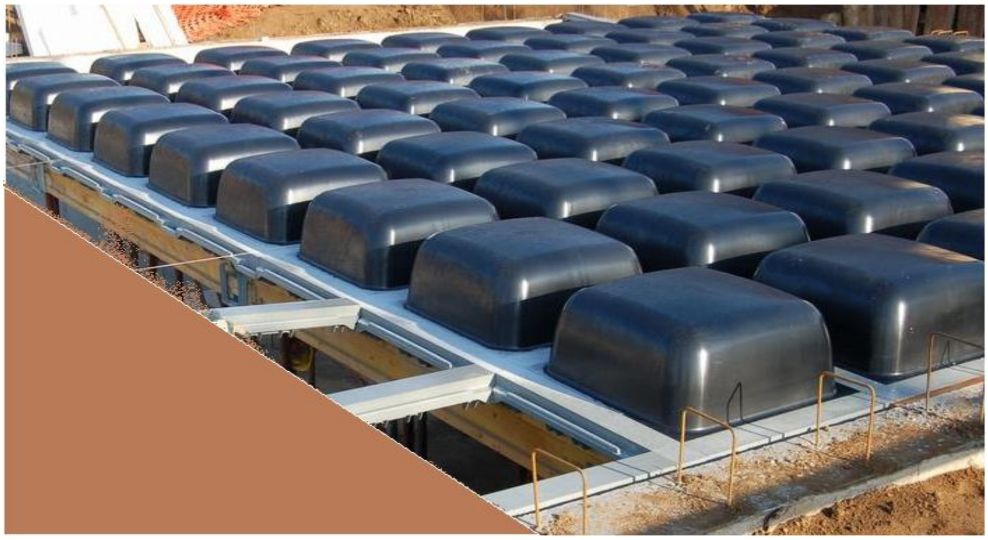


Figure 2.13 waffle slab formed using steel pans

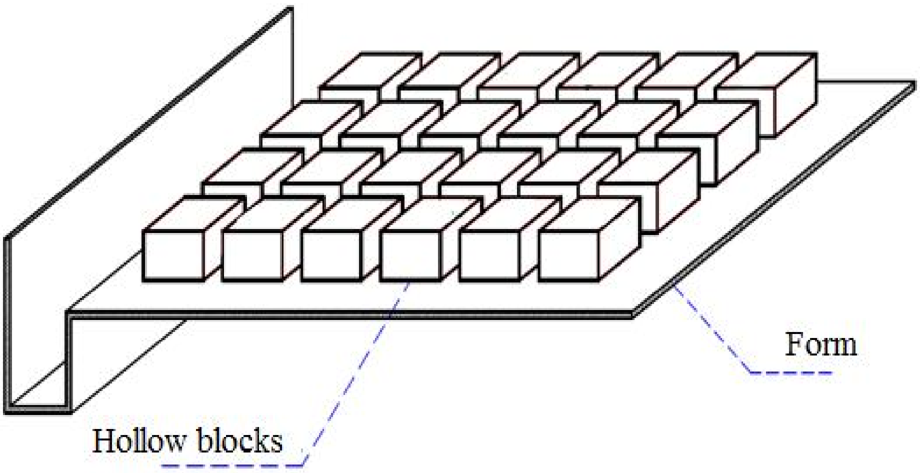


Figure 2.14 waffle slab formed using hollow blocks

Domes are omitted near the columns to obtain a solid slab in the region of negative bending moment and high shear. The lower flange of each dome contacts that of the adjacent dome, so that the concrete is cast entirely against a metal surface, resulting in an excellent finished appearance of the slab “A waffle-like appearance” as shown in Fig. 2.15.

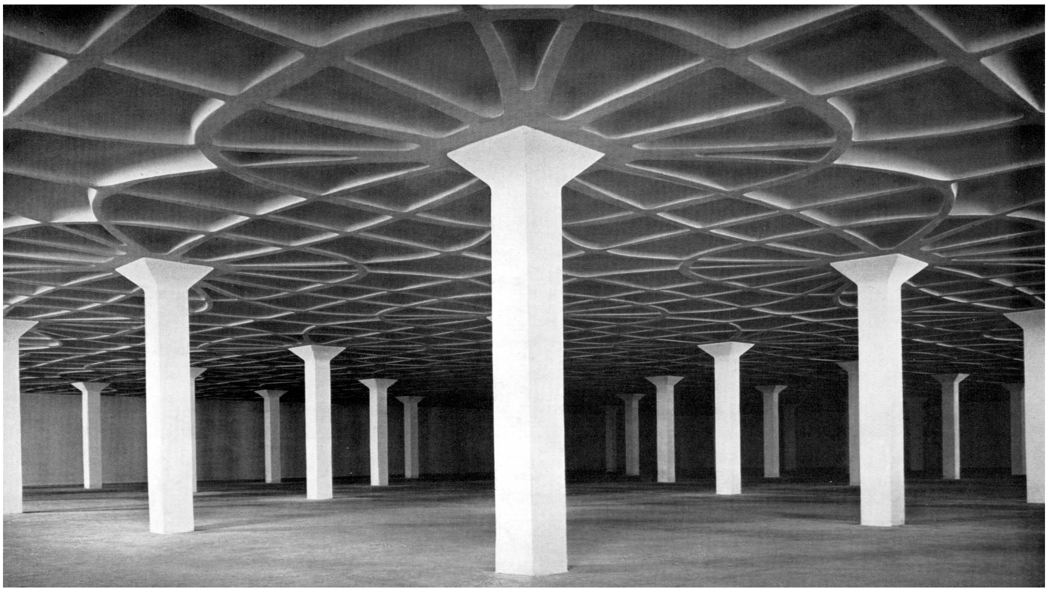


Figure 2.15 waffle slab appearance

2.5 Structural behavior of slabs:

2.5.1 Behavior of one –way slab:

The structural action of a one-way slab may be visualized in terms of the deformed shape of the loaded surface. Fig. 2.16 shows a rectangular slab, simply supported along its two opposite long edges and free of any support along the two opposite short edges. If a uniformly distributed load is applied to the surface, the deflected shape will be as shown by the solid lines. Curvatures, and consequently bending moments, are the same in all strips s spanning in the short direction between supported edges, whereas there is no curvature, hence no bending moment, in the long strips l parallel to the supported edges. The surface is approximately cylindrical.

For purposes of analysis and design, a unit strip of such a slab cut out at right angles to the supporting beams, as shown in Fig. 2.17, may be considered as a rectangular beam of unit width, with a depth h equal to the thickness of the slab and a span l_a equal to the distance between supported edges. This strip can then be analyzed by the methods that were used for rectangular beams, the bending moment being computed for the strip of unit width. The load per unit area on the slab becomes the load per unit length on the slab strip. Since all of the load on the slab must be transmitted to the two supporting beams, it follows that all of the reinforcement should be placed at right angles to these beams, with the exception of any bars that may be placed in the other direction to control shrinkage and temperature cracking. A one-way slab, thus, consists of a set of rectangular beams side by side. This simplified analysis, which assumes Poisson's ratio to be zero, is slightly conservative. Actually, flexural compression in the concrete in the direction of l_a will result in lateral expansion in the direction of l_b unless the compressed concrete is restrained. In a one-way slab, this lateral expansion is resisted by adjacent slab strips, which tend to expand also. The result is a slight strengthening and stiffening in the span direction, but this effect is small and can be disregarded.

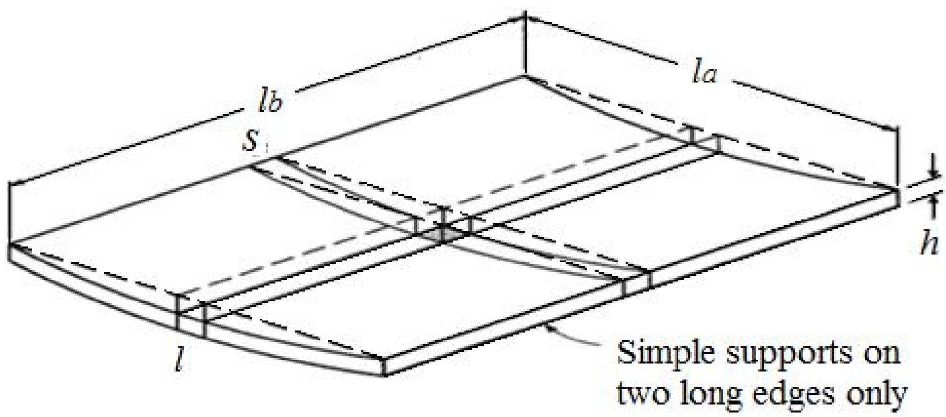


Figure 2.16 Deflected shape of uniformly loaded one-way slab

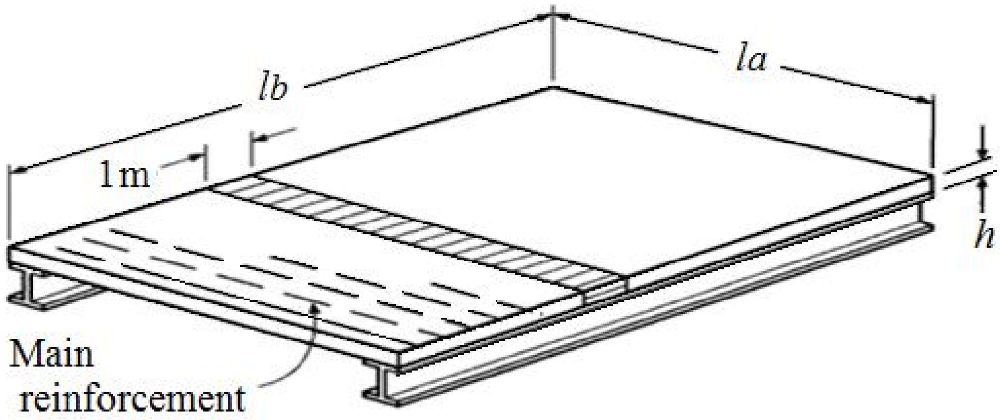


Figure 2.17 Unit strip basis for flexural design

2.5.2 Behavior of two-way slabs:

2.5.2.1 Two-way edge supported slabs:

In many cases, however, rectangular slabs are of such proportions and are supported in such a way that two-way action results. When loaded, such slabs bend into a dished surface rather than a cylindrical one. This means that at any point the slab is curved in both principal directions, and since bending moments are proportional to curvatures, moments also exist in both directions. To resist these moments, the slab must be reinforced in both directions, by at least two layers of bars perpendicular, respectively, to two pairs of edges. The slab must be designed to take a proportionate share of the load in each direction.

Types of reinforced concrete construction that are characterized by two-way action include slabs supported by walls or beams on all sides (Fig. 2.1), flat plates (Fig. 2.3), flat slabs (Fig. 2.5), and waffle slabs (Fig. 2.15).

The simplest type of two-way slab action is that represented by Fig. 2.1, where the slab, or slab panel, is supported along its four edges by relatively deep, stiff, monolithic concrete beams or by walls or steel girders. If the concrete edge beams are shallow or are omitted altogether as they are for flat plates and flat slabs, deformation of the floor system along the column lines significantly alters the distribution of moments in the slab panel itself such a slab is shown in Fig. 2.18a.

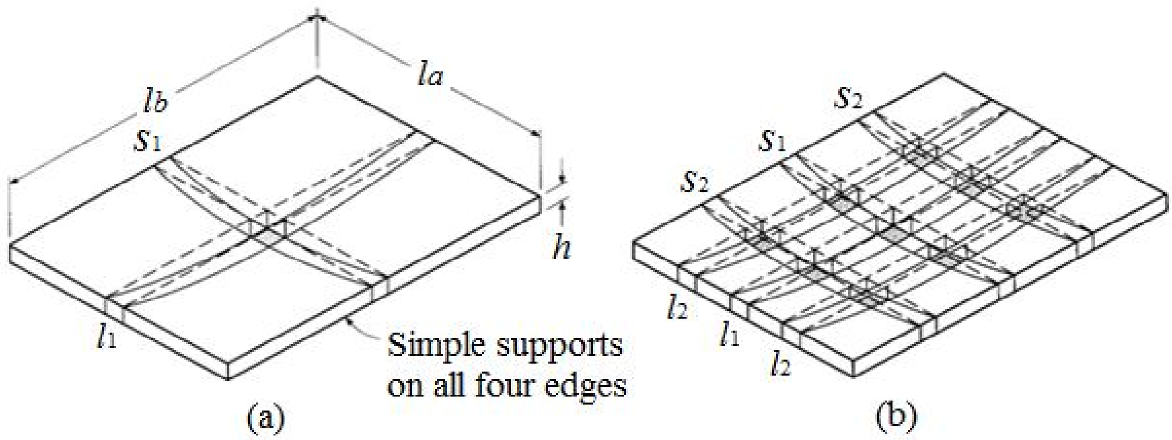


Figure 2.18 Two-way slab on simple edge supports: (a) bending of center strips of Slab (b) grid model of slab

To visualize the flexural performance, it is convenient to think of it as consisting of two sets of parallel strips, in each of the two directions, intersecting each other. Evidently, part of the load is carried by one set and transmitted to one pair of edge supports, and the remainder by the other.

Fig. 2.18a shows the two center strips of a rectangular plate with short span l_a and long span l_b if the uniform load is q per square foot of slab, each of the two strips acts approximately as a simple beam, uniformly loaded by its share of q. Because these imaginary strips actually are part of the same monolithic slab, their deflections at the intersection point must be the same. Equating the center deflections of the short and long strips gives

$$\frac{5q_a l_a^4}{384EI} = \frac{5q_b l_b^4}{384EI} \qquad (2.1)$$

Where q_a is the share of the load q carried in the short direction and q_b is the share of the load q carried in the long direction. Consequently,

$$\frac{q_a}{q_b} = \frac{l_b^4}{l_a^4} \qquad (2.2)$$

One sees that the larger share of the load is carried in the short direction, the ratio of the two portions of the total load being inversely proportional to the fourth power of the ratio of the spans.

This result is approximate because the actual behavior of a slab is more complex than that of the two intersecting strips. An understanding of the behavior of the slab itself can be gained from Fig. 2.18b, which shows a slab model consisting of two sets of three strips each. It is seen that the two central strips s_1 and l_1 bend in a manner similar to that shown in Fig. 2.18a. The outer strips s_2 and l_2 however, are not only bent but also twisted. Consider, for instance, one of the intersections of s_2 with l_2. It is seen that at the intersection the exterior edge of strip l_2 is at a higher elevation than the interior edge, while at the nearby end of strip l_2 both edges are at the same elevation; the strip is twisted. These twisting results in torsional stresses and torsional moments that are seen to be most pronounced near the corners. Consequently, the total load on the slab is carried not only by the bending moments in two directions but also by the twisting moments. For this reason, bending moments in elastic slabs are smaller than would be computed for sets of unconnected strips loaded by q_a and q_b. For instance, for a simply supported square slab:

$$q_a = q_b = {}^{q}/_{2}.$$

If only bending were present, the maximum moment in each strip would be:

$$\frac{(q/2)l^2}{8} = 0.0652ql^2 \qquad (2.3)$$

The exact theory of bending of elastic plates shows that actually the maximum moment in such a square slab is only $0.048ql^2$, so that in this case the twisting moments relieve the bending moments by about 25 percent.

The largest moment occurs where the curvature is sharpest. Fig. 2.18b shows this to be the case at midspan of the short strip s_1. Suppose the load is increased until this location is overstressed, so that the steel at the middle of strip s is yielding. If the strip were an isolated beam, it would now fail. Considering the slab as a whole, however, one sees that no immediate failure will occur. The neighboring strips (those parallel as well as those perpendicular to s_1, being actually monolithic with it, will take over any additional load that strip s_1 can no longer carry until they, in turn, start yielding. This inelastic redistribution will continue until in a rather large area in the central portion of the slab all the steel in both directions is yielding. Only then will the entire slab fail. From this reasoning, which is confirmed by tests, it follows that slabs need not be designed for the absolute maximum moment in each of the two directions (such as $0.048ql^2$ in the example given in the previous paragraph), but only for a smaller average moment in each of the two directions in the central portion of the slab. For instance, one of the several analytical methods in general use permits a square slab to be designed for a moment of $0.036ql^2$. By comparison with the actual elastic maximum moment $0.048ql^2$, it is seen that, owing to inelastic redistribution, a moment reduction of 25 percent is provided.

The largest moment in the slab occurs at midspan of the short strip s_1 of Fig. 2.18b. It is evident that the curvature, and hence the moment, in the short strip s_2 is less than at the corresponding location of strip s_1. Consequently, a variation of short-span moment occurs in the long direction of the span. This variation is shown qualitatively in Fig. 2.19. The short-span moment diagram in Fig. 2.19a is valid only along the center strip at 1-1. Elsewhere, the maximum-moment value is less, as shown. Other moment ordinates are reduced proportionately. Similarly, the long-span moment diagram in Fig. 2.19 applies only at the longitudinal centerline of the slab; elsewhere, ordinates are reduced according to the variation shown. These variations in maximum moment across the width and length of a rectangular slab are accounted for in an approximate way in most practical design methods by designing for a reduced moment in the outer quarters of the slab span in each direction.

It should be noted that only slabs with side ratios less than about 2 need be treated as two-way slabs. From Eq. (b) above, it is seen that for a slab of this proportion, the share of the load carried in the long direction is only on the order of one-sixteenth of that in the short direction. Such a slab acts almost as if it were spanning in the short direction only. Consequently, rectangular slab panels with an aspect ratio of 2 or more may be reinforced for one-way action, with the main steel perpendicular to the long edges.

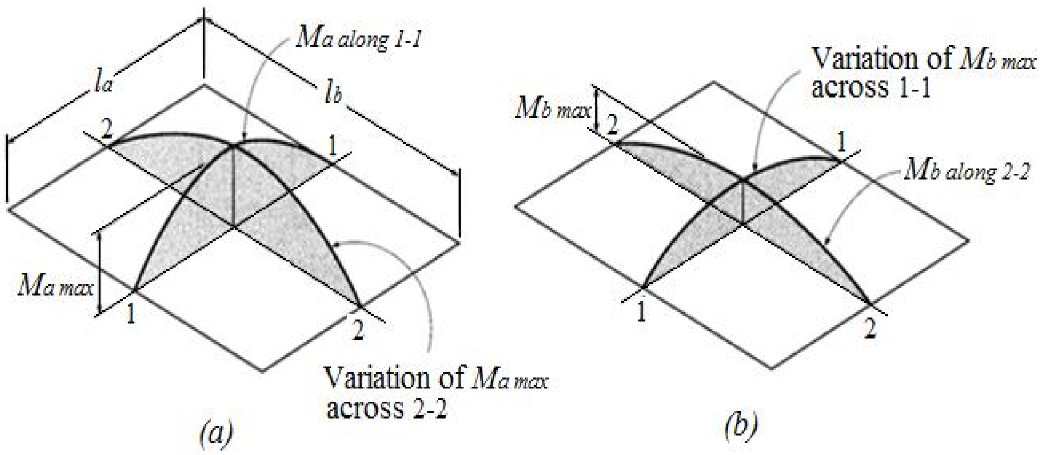


Figure 2.19 moments and moment variation in a uniformly loaded slab with simple supports on four sides

Consistent with the assumptions of the analysis of two-way edge-supported slabs, the main flexural reinforcement is placed in an orthogonal pattern, with reinforcing bars parallel and perpendicular to the supported edges. As the positive steel is placed in two layers, the effective depth d for the upper layer is smaller than that for the lower layer by one bar diameter.

Because the moments in the long direction are the smaller ones, it is economical to place the steel in that direction on top of the bars in the short direction. The stacking problem does not exist for negative reinforcement perpendicular to the supporting edge beams except at the corners, where moments are small.

Either straight bars, cut off where they are no longer required, or bent bars may be used for two-way slabs, but economy of bar fabrication and placement will generally favor all straight bars. The precise locations of inflection points (or lines of inflection) are not easily determined, because they depend upon the side ratio, the ratio of live to dead load, and continuity conditions at the edges.

2.5.2.2 Two-way column-supported slabs:

When two-way slabs are supported by relatively shallow, flexible beams, or if column-line beams are omitted altogether, as for flat plates, flat slabs, or waffle system, then a number of new considerations are introduced. Fig. 2.20a shows a portion of a floor system in which a rectangular slab panel is supported by relatively shallow beams on four sides. The beams, in turn, are carried by columns at the intersection of their centerlines. If a surface load q is applied, that load is shared between imaginary slab strips l_a in the short direction and l_b in the long direction. The portion of the load that is carried by the long strips l_b is delivered to the beams B_1 spanning in the short direction of the panel. The portion carried by the beams B_1 plus that carried directly in the short direction by the slab strips l_a sums up to 100 percent of the load applied to the panel.

Similarly, the short-direction slab strips l_a deliver a part of the load to long-direction beams B_2. That load, plus the load carried directly in the long direction by the slab, includes 100 percent of the applied load. It is clearly a requirement of statics that, for column-supported construction, 100 percent of the applied load must be carried in each direction, jointly by the slab and its supporting beams.

A similar situation is obtained in the flat plate floor shown in Fig. 2.3. In this case beams are omitted. However, broad strips of the slab centered on the column lines in each direction serve the same function as the beams of Fig. 2.19a; for this case, also, the full load must be carried in each direction. The presence of drop panels or column capitals (Fig. 2.4) in the double-hatched zone near the columns does not modify this requirement of statics.

Fig. 2.20a shows a flat plate floor supported by columns at A, B, C, and D. Fig. 2.20b shows the moment diagram for the direction of span l_1. In this direction, the slab may be considered as a broad, flat beam of width l_2. Accordingly, the load per meter of span is ql_2. In any span of a continuous beam, the sum of the midspan positive moment and the average of the negative moments at adjacent supports is equal to the midspan positive moment of a corresponding simply supported beam. In terms of the slab, this requirement of statics may be written:

$$\frac{1}{2}(M_{ab} + M_{cd}) + M_{ef} = \frac{1}{8} q l_2 l_1^2 \tag{2.4}$$

A similar requirement exists in the perpendicular direction, leading to the relation:

$$\frac{1}{2}(M_{ac} + M_{bd}) + M_{gh} = \frac{1}{8} q l_1 l_2^2 \qquad (2.5)$$

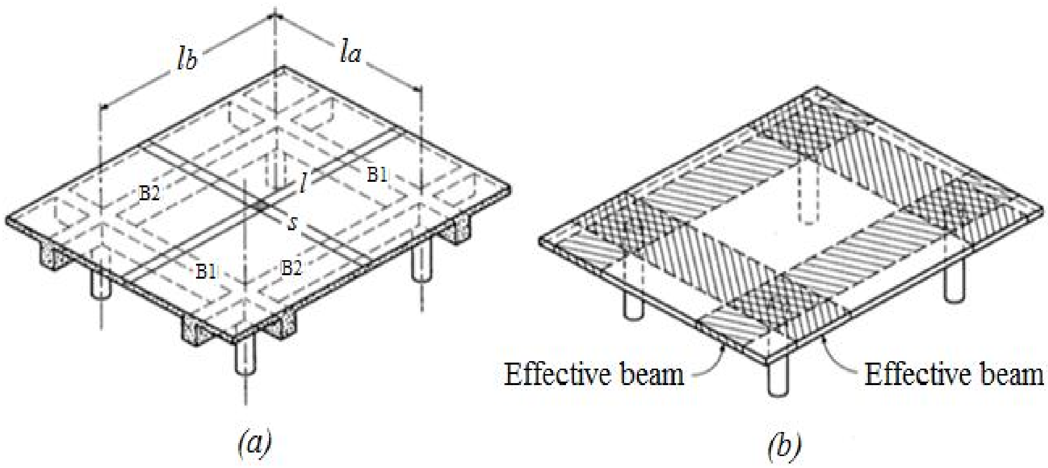


Figure 2.20 column supported two-way slabs (a) two-way slab with beam (b) two-way slab without beams

These results disclose nothing about the relative magnitudes of the support moments and span moments. The proportion of the total static moment that exists at each critical section can be found from an elastic analysis that considers the relative span lengths in adjacent panels, the loading pattern, and the relative stiffness of the supporting beams, if any, and that of the columns.

Alternatively, empirical methods that have been found to be reliable under restricted conditions may be adopted.

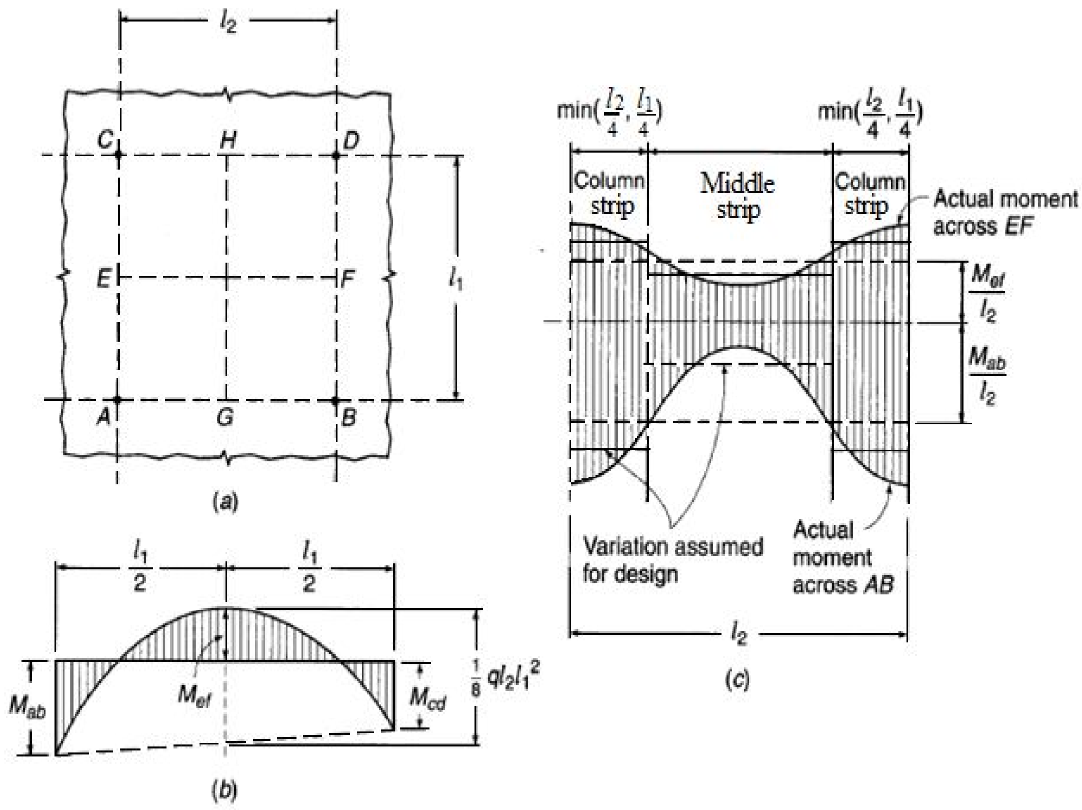


Figure 2.21 Moment variation in column supported two-way slab;

(a) Critical moment section (b) moment variation along a span

(c) moment variation across the width of critical section

The moments across the width of critical sections such as AB or EF are not constant but vary as shown qualitatively in Fig. 2.21c. The exact variation depends on the presence or absence of beams on the column lines, the existence of drop panels and column capitals, as well as on the intensity of the load. For design purposes, it is convenient to divide each panel as shown in Fig. 2.21c 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 a middle strip or column strip, as shown, unless beams are present on the column lines. In the latter case, while the beam must have the same curvature as the adjacent slab strip, the beam moment will be larger in proportion to its greater stiffness, producing a discontinuity in the moment-variation curve at the lateral face of the beam. Since the total moment must be the same as before, according to statics, the slab moments must be correspondingly less.

While permitting design "by any procedure satisfying the conditions of equilibrium and geometrical compatibility," specific reference is made to two alternative approaches: a semi empirical direct design method and an approximate elastic analysis known as the equivalent frame method.

In either case, a typical panel is divided, for purposes of design, into column strips and middle strips. A column strip is defined as a strip of slab having a width on each side of the column centerline equal to one-fourth the smaller of the panel dimensions l_1 and l_2. Such a strip includes column-line beams, if present. A middle strip is a design strip bounded by two column strips. In all cases, l_1 is defined as the span in the direction of the moment analysis and l_2 as the span in the lateral direction measured center to center of the support. In the case of monolithic construction, beams are defined to include that part of the slab on each side of the beam extending a distance equal to the projection of the beam above or below the slab h (whichever is greater) but not greater than 4 times the slab thickness (see Fig. 2.18).

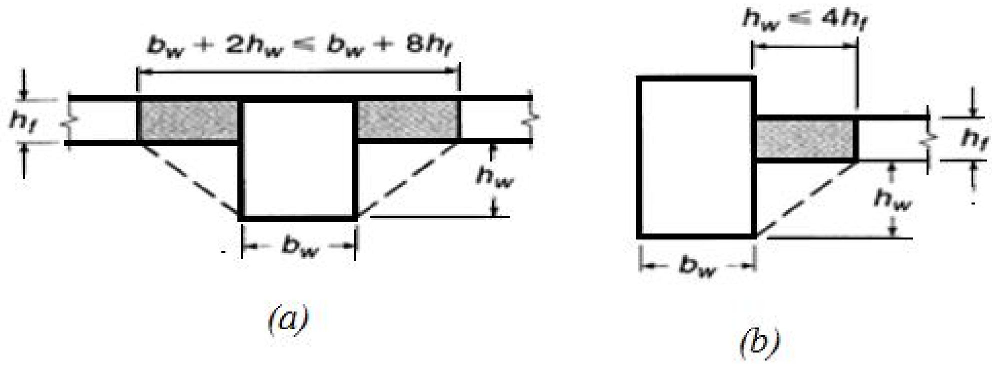


Figure 2.22 Portion of slab to be included with beam (a) symmetric slab (b) single side slab

CHAPTER THREE

METHODS OF ANALYSIS

3.1 Introduction:

The structural engineering community responded to this challenge with numerous approximate techniques that attempt to simplify the design of these reinforced concrete components.

For flat plates, these methods include the direct design, equivalent frame, yield line, and strip design techniques, all of which approximate the results of classical plate theory. These methods have gained wide acceptance among engineers because of their simplicity.

However, these approximate techniques have significant limitations. Direct design and equivalent frame methods are both limited to structures with very regular geometry.

3.2 The direct Method:

BS 8110 gives two principal methods for designing flat slabs which are supported on columns positioned at the intersection of rectangular grid lines for slabs where the aspect ratio is not greater than 2.

The first method is based on simple moment coefficients at critical sections. This can be used where the lateral stability is not dependent on the slab-column connections and is subject to the following provisions:

(a) the single load case is considered on all spans; and

(b) there are at least three rows of panels of approximately equal spans in the direction being considered.

The second approach is the equivalent frame method. which as the name suggests, involves subdividing the structure into sub frames and the use of moment distribution or similar analysis techniques to obtain the forces and moments at critical sections.

Other methods for designing flat slabs are again also acceptable, such as on yield-line analysis, Hillerborg's 'advanced' strip method and finite element analysis.

The simplified method of design is given by the following steps:

3.2.1 Division of flat slab structures into frames:

The structures may be divided longitudinally and transversely into frames consisting of columns and strips of slab. The width of slab used to define the effective stiffness of the slab will depend upon the aspect ratio of the panels and type of loading. In the case of vertical loading, the stiffness of rectangular panels may be calculated taking into account the full width of the panel. For horizontal loading, it will be more appropriate to take half this value.

The moments, loads and shear forces to be used in the design of individual columns and beams of a frame supporting vertical loads only may be derived from an elastic analysis of a series of sub-frames. Each sub-frame may be taken to consist of the beams at one level together with the columns above and below. The ends of the columns remote from the beams may generally be assumed to be fixed unless the assumption of a pinned end is clearly more reasonable (for example, where a foundation detail is considered unable to develop moment restraint).

The second moment of area of any section of slab or column used in calculating the relative stiffness of members may be assumed to be that of the cross-section of the concrete alone.

3.2.2 Load arrangement

While, in principle, a flat slab should be analyzed to obtain at each section the moments and shears resulting from the most unfavorable arrangement of the design loads, it will normally be satisfactory to obtain the moments and forces within a system of flat slab panels from analysis of the structure under the single load case of maximum design load on all spans or panels simultaneously, provided the following conditions are met:

a) In a one-way spanning slab the area of each bay exceeds 30 m^2.
   In this context, a bay means a strip across the full width of a structure bounded on the other two sides by lines of support (see Figure 3.1).
b) The ratio of the characteristic imposed load to the characteristic dead load does not exceed 1.25.
c) The characteristic imposed load does not exceed 5 kN/m^2 excluding partitions.

Where analysis is carried out for the single load case of all spans loaded, the resulting support moments except those at the supports of cantilevers should be reduced by 20 %, with a consequential increase in the span moments.

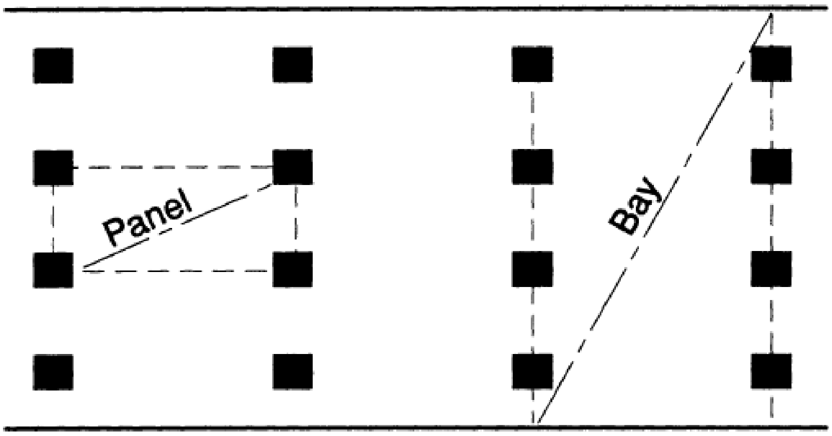


Figure 3.1 Definition of panels and bays

If the conditions of the single load case are not met, it is not appropriate to analyze for the single load case of maximum design load on all spans, and it will normally be sufficient to consider the following arrangements of vertical load:

a) All spans loaded with the maximum design ultimate load (1.4Gk + 1.6Qk);
b) Alternate spans loaded with the maximum design ultimate load (1.4Gk + 1.6Qk) and all other spans loaded with the minimum design ultimate load (1.0Gk).

3.2.3 Moments determination:

For flat-slab structures whose lateral stability is not dependent on slab-column connections, Table 3.1 may be used subject to the following provisions:

a) design is based on the single load case of all spans loaded with the maximum design ultimate load

b) there are at least three rows of panels of approximately equal span in the direction being considered;

c) moments at supports taken from Table 3.1 may be reduced by $0.15Fh_c$; and

Allowance has been made to the coefficients of Table 3.1 for 20 % redistribution of moments.

Table 3.1 Ultimate bending moment and shear forces

	End support/slab connection				At first interior support	Middle interior spans	Interior supports
	Simple		Continuous				
	At outer support	Near middle of end span	At outer support	Near middle of end span			
Moment Shear	0 0.4F	0.086Fl ----	-0.04Fl 0.4F	0.075Fl ----	-0.086Fl 0.6F	0.063Fl ----	-0.063Fl 0.5F

NOTE F is the total design ultimate load (1.4Gk + 1.6Qk);
l is the effective span.

3.2.4 Division of panels:

Flat slab panels should be assumed to be divided into column strips and middle strips (see Fig. 3.2).

In the assessment of the widths of the column and middle strips, drops should be ignored if their smaller dimension is less than one-third of the smaller dimension of the panel.

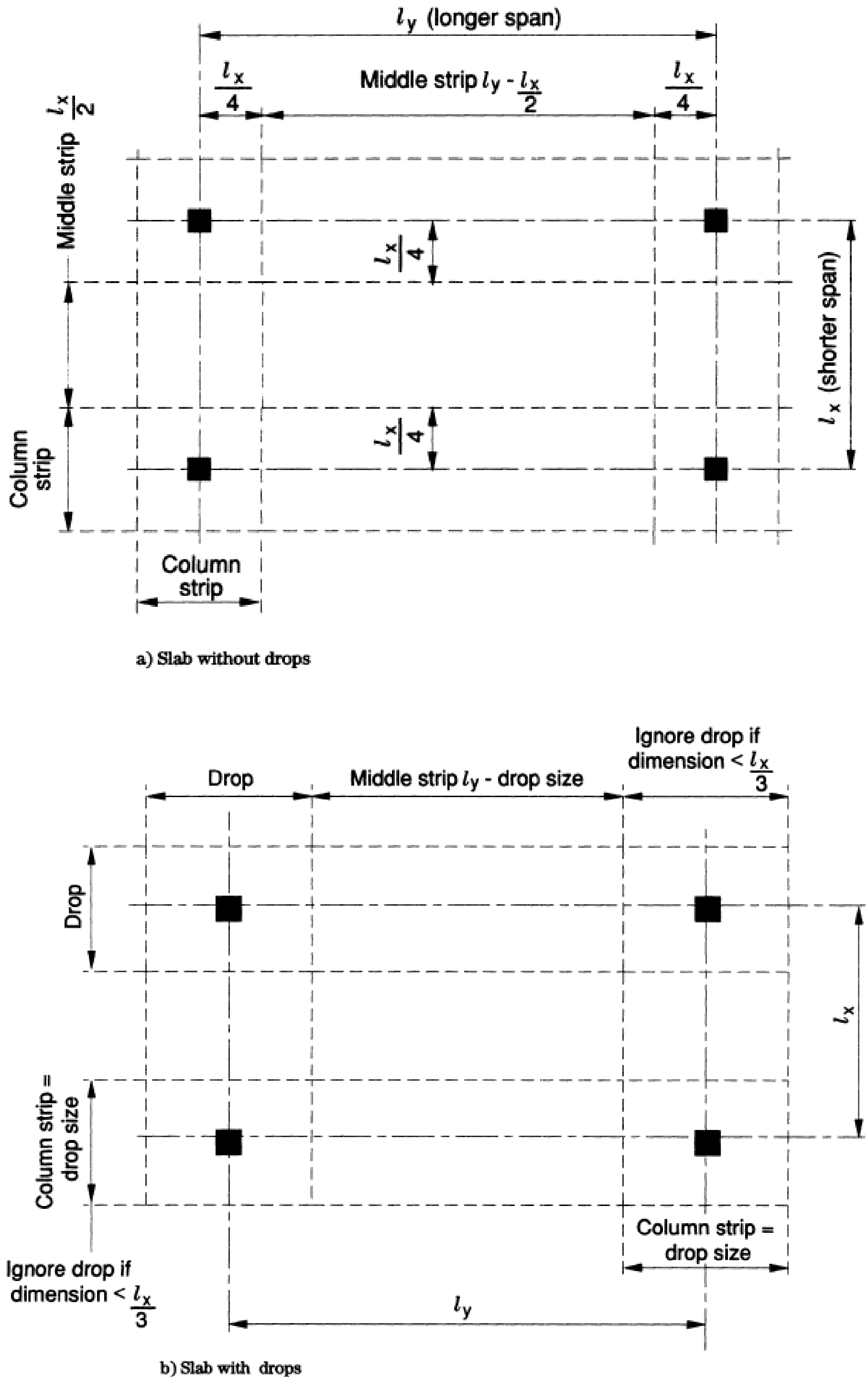


Figure 3.2 Division of panels in flat slabs

3.2.5 Division of moments between column and middle strips:

The design moments obtained from analysis of the continuous frames or from Table 3.1 should be divided between the column and middle strips in the proportions given in Table 3.2.

Table 3.2 Distribution of design moments in panels of flat slabs

Design moment	Apportionment between column and middle strip	
	Column strip %	Middle strip %
Negative	75	25
Positive	55	45

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

3.3 Finite Element Method:

Slabs are most widely used structural elements of modern structural complexes and the reinforced concrete slab is the most useful discovery for supporting lateral loads in buildings. Slabs may be viewed as moderately thick plates that transmit load to the supporting walls and beams and sometimes directly to the columns by flexure, shear and torsion. It is because of this complex behavior that is difficult to decide whether the slab is a structural element or structural system in itself. Slabs are viewed in this paper as a structural element.

The greatest volume of concrete that goes into a structure is in the form of slabs, floors and footings. Since slabs have a relatively large surface area compared with their volume, they are affected by temperature and shrinkage slabs may be visualized as intersecting, closely spaced, grid-beams and hence they are seen to be highly indeterminate. This high degree of indeterminacy is directly helpful to designer, since multiple load-flow paths are available and approximations in analysis and design are compensated by heavy cracking and large deflections, without significantly affecting the load carrying capacity. Slabs, being highly indeterminate, are difficult to analyze by elastic theories. Since slabs are sensitivity support restraints fixate, rigorous elastic solutions are not available for many practically important boundary conditions.

More recently, finite difference and finite element methods have been introduced and this is extremely useful. Methods have also been innovated to find the collapse loads of various types of slabs through the yield line theory and strip methods. In addition to supporting lateral loads (perpendicular to the horizontal plane), slabs act as deep horizontal girders to resist wind and earthquake forces that act on a multi-storied frame. Their action as girder diaphragms of great stiffness is important in restricting the lateral deformations of a multi-storied frame. However, it must be remembered that the very large volume and hence the mass of these slabs are sources of enormous lateral forces due to earthquake induced accelerations.

3.3.1 Principle conception:

The concept of finite element is that a body or continuum is divided into smaller elements of finite dimensions called finite elements interconnected at a number of joints called 'Nodes' or 'Nodal Points'. The original body or structure is then idealized as an assemblage of these elements connected at nodal points.

The displacements of these nodal points will be the basic unknown parameters of the problem. In most popular approach, a simple displacement function is assumed in terms of the displacements at the prescribed nodal points of elements. Then the principle of virtual displacements is used to derive a set of linear simultaneous equations called stiffness equations.

3.3.2 Formulation of the problem:

- **Finite Element Procedure:**

The finite element method can be considered as a generalized displacement method for two and three dimensional continuum problems. It is necessary to discrete the continuum into a system with a finite number of unknowns so that the problems can be solved numerically. The finite element procedure can be divided into the following steps:

1. Idealization of the continuous surface as an assembling of discrete elements.
2. Selection of displacement models.
3. Derivation of the element stiffness matrix.
4. Assembly of element stiffness matrix into an overall structure stiffness matrix.
5. Solution of the system of linear equations relating nodal points loads and unknown nodal displacements.
6. Computation of internal stress resultants by use of the nodal point displacements already found.

- **Displacement Function:**

In order to assure convergence to a valid result by mesh reinforcement, the following three sacred rules have emerged for the assumed displacement functions:

1. The displacement must be continuous within the element and the displacements must be compatible between adjacent elements. For plane stress and plane strain elements, continuity of the displacement functions

along is sufficient, whereas for bending elements, continuity of both the displacement and slope is needed.

2. The displacement function must include the states of constant strain of the element. This seems to be the most sacred of all the rules, since eventually, by mesh reduction, one is evitable going to reach small region where the strains are constant.
3. The displacement function must allow the element to undergo rigid body motion without any internal strain. For plane stress and plate bending elements, it is easy to establish displacement functions satisfying all these three requirements.

The displacement functions used in deriving the 20 × 20 stiffness matrix are:

$$u\,(x, y) = a1xy + a2x + a3y + a4 \tag{3.1}$$

$$v\,(x, y) = a5xy + a6x + a7y + a8 \tag{3.2}$$

$$w\,(x, y) = a9x3y + a10x3 + a11x2y + a12x2 + a13xy3 + a14xy2 + a15xy + a16x + a17y3 + a18y2 + a19y + a20 \tag{3.3}$$

Alternatively, in matrix form we can write this symbolically as follows:

$$\{\bar{u}\} = [P]\{ai\} \tag{3.4}$$

Where {ū} is vector of slab displacement and $[P]$ is matrix of displacement functions. Here the rectangular co-ordinate system is considered. The degree of freedom considered at each node (corner) of the element is u, v, w, wx and wy.

- **Element Stiffness Matrix:**

To simplify the derivation of the element stiffness matrix, a more convenient form of nodal displacement parameters with five degrees of freedom per node is listed as follows:

$$[ui]^T = u1, v1, w1, w1x, w1y, u2, v2, w2, w2x, w2y\ u3, v3, w3, w3x, w3y, u4, v4, w4, w4x, w4x \qquad (3.5)$$

Where, $wix = (\delta w / \delta x)i$, $= (\delta w / \delta y)i$; $i = 1\ to\ 4$ stands for the node number of the node of an element.

Substituting the values of co-ordinates of four nodes in the three displacement function and two derivatives of w stated above, we get the 20 nodal displacements of an element as follows:

$$\{ui\} = [H]\{ai\} \qquad (3.6)$$

Where, {ui} is vector of nodal displacement co-ordinates and [H] is called transformation matrix.

The strain displacement relationships used in the analysis of this of slab element may be expressed as:

$$\{e\} = [\delta]\{\bar{u}\} \qquad (3.7)$$

Therefore substituting Eq.(3.6) into Eq.(3.7) we get the strain expressed in terms of displacement parameters as follows:

$$\{e\} = [\delta]\{\bar{u}\} = [\delta][P]\{ai\} = [B]\{ai\} \qquad (3.8)$$

Where [B] is called strain matrix is a function of x and y co-ordinates.

The stress matrix can be expressed as follows:

$$\{AN\} = [D]\{e\} \tag{3.9}$$

The strain energy developed in the element is expressed by

$$Ut = ½ \times \int\int [AN]^T \{e\} dx\, dy \tag{3.10}$$

Substituting the expression for $[AN]$ and $\{e\}$ in the $Eq.6$ we get the strain energy

$$Ut = ½ \times \{ai\}^T \int\int [B]^T [D][B] dxdy] \{ai = ½ \{ai\}^T [U]\{ai\} \tag{3.11}$$

Where $[U] = \int\int [B]^T [D] [B]\, dx\, dy$

Now substituting $\{ai\}$ from $Eq.3.8$ into $Eq.3.11$ and finally making derivatives of strain energy Ut with respect to the nodal displacement parameters, we get the required element stiffness matrix $[S]$ and are given by

$$[S] = [H^{-1}]^T [U][H]^T \tag{3.12}$$

- **Overall Stiffness Matrix:**

The element stiffness matrix relates quantities defined on the surface. Therefore, co-ordinate transformations are completely avoided and the overall stiffness matrix SFF of the slab structure is assembled by direct summation of the stiffness contributions from the individual elements. The degree of freedom for the overall stiffness matrix is obtained by substituting joint restraint form, the total number of displacement co-ordinates.

The overall stiffness matrix is first partitioned so that the terms pertaining to the degrees of freedom are separated from those for the joint restraints. Then the matrix is rearranged by interchanging rows and columns in such a manner that stiffness corresponding to the degrees of freedom is listed first and those corresponding to joint restraints are listed second. Such a matrix is always symmetric. To computer time and storage, only the upper band of the stiffness matrix S_{FF} (for free joint displacements) is constructed.

- **Load Matrix:**

The vertical gravity load (mainly self-weight) is the major load for roof slab. The load intensity $'QL'$ is uniform over the area of a slab of uniform thickness. This load intensity $'QL'$ can be resolved into three components at a point in the three directions $x, y \; and \; z$ as follows in a matrix.

The above-distributed load is replaced by an equivalent nodal load matrix $\{AQ\}$ for each element. This load matrix $\{AQ\}$ is obtained by equating virtual work done by the uniform load $\{Q\}$ and the nodal loads $\{AQ\}$. According to the standard formulae from texts:

$$\{AQ\} = \int_{-A/2}^{A/2} \int_{-b/2}^{b/2} [H^{-1}]^T \, [P]^T \, [Q] \, dx \, dy \qquad (3.13)$$

Such a consistent load matrix will truly represent the distributed gravity load 'QL'. But the laborious process of $Eq.$ 9 can be avoided by using approximate overall nodal matrix $\{AQ\}$.
This can be worked out as follows:

The total vertical load on an element is assumed to be equally shared by its four nodes. The z components of this vertical load are the element nodal loads corresponding to displacements w. Contributions from all elements connected at a node together form the final values of nodal loads for that node. Hence in the overall load matrix, out of five load values for each node, only the third will be non-zero.

- **Expression for Stresses / Moments:**

From Equation 2 the expression for $\{ai\}$ is found as follows:

$$\{ai\} = [H]^{-1}\{ui\} \quad (3.14)$$

Using these values of $\{ai\}$ and combining Eq.3.8 with Eq.3.14, we get the matrix of resultant stresses / moments at any point (x, y) in terms of nodal displacements as follows:

$$\{AN\} = [D]\{e\} = [D][B]\{ai\} = [D][B][H]^{-1}\{ui\} \quad (3.15)$$

CHAPTER FOUR

ANALYSIS, DESIGN, QUANTITIES

AND RESULTS COMPARISON

4.1. ANALYSIS:

4.1.1. Manual analysis:

❖ **Flat slab manual analysis:**

Table 4.1: Flat slab information

<table>
<tr><td>Standards</td><td colspan="3">BS 8110 : 1997</td></tr>
<tr><td>Structure type</td><td colspan="3">Flat slab</td></tr>
<tr><td>Structure using</td><td colspan="3">Residential building floor</td></tr>
<tr><td rowspan="3">Material</td><td colspan="2" rowspan="2">Concrete</td><td>$fcu = 30\ N/mm^2$</td></tr>
<tr><td>$\gamma c = 24\ N/m^3$</td></tr>
<tr><td colspan="2">Steel</td><td>$fy = 460\ N/mm^2$</td></tr>
<tr><td rowspan="4">Loading</td><td colspan="2" rowspan="4">D.L</td><td>self weight=5.5 kN/m²</td></tr>
<tr><td>partitions=3.6 kN/m²</td></tr>
<tr><td>finishing=1.5 kN/m²</td></tr>
<tr><td>Total=10.6 kN/m²</td></tr>
<tr><td></td><td colspan="2">L.L</td><td>live load=3 kN/m²</td></tr>
<tr><td>Concrete cover</td><td colspan="3">20 mm</td></tr>
<tr><td>Bracing system</td><td colspan="3">Shear walls</td></tr>
<tr><td rowspan="3">Column</td><td rowspan="2">Dim.</td><td>C_1</td><td>(0.4×0.4) & 3m height</td></tr>
<tr><td>C_2</td><td>(0.4×0.6) & 3m height</td></tr>
<tr><td>Capital</td><td colspan="2">(1.5×1.5) & 0.6m depth</td></tr>
</table>

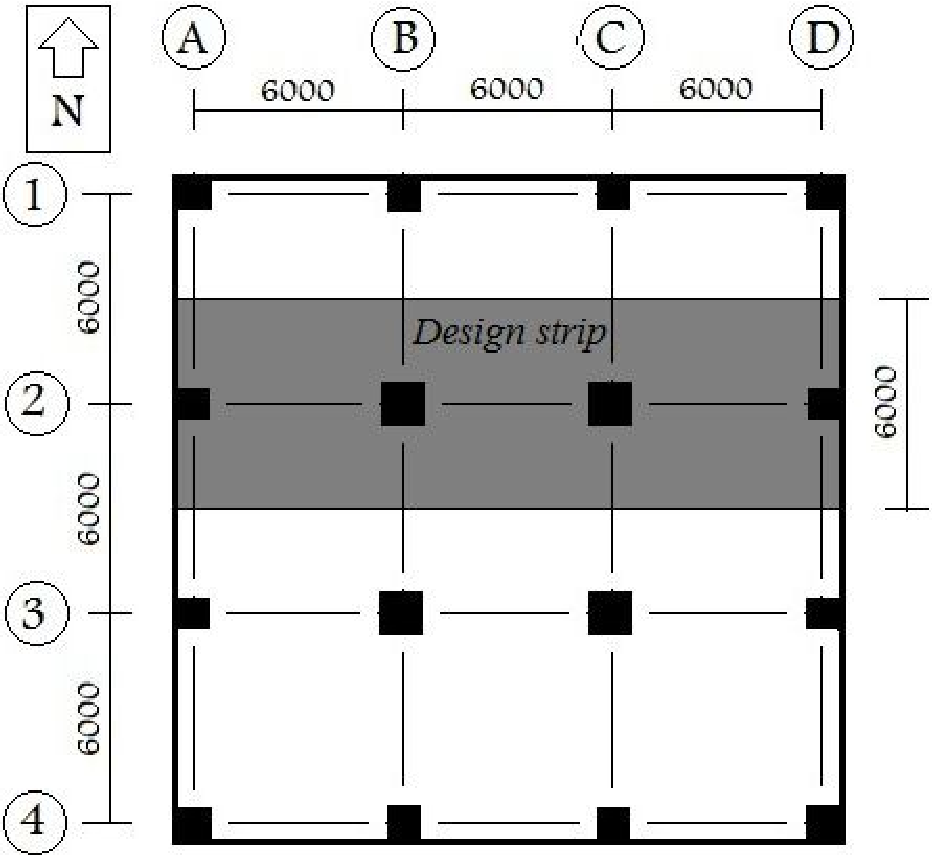


Figure 4.1: Flat slab-design strip under consideration

- **Slab thickness determination (considering the deflection):**

  - $\left(\frac{l}{d}\right)_{actual} \leq \left(\frac{l}{d}\right)_{limit} \times 0.9$ $\quad (for\ flat\ slab\ without\ effective\ drop\ panel)$
  - $\left(\frac{l}{d}\right)_{actual} \leq \left(\frac{l}{d}\right)_{basic} \times MFt \times 0.9$
  - $\frac{6000}{d} \leq 26 \times 1.3 \times 0.9$
  - $d = \frac{6000}{26 \times 1.3 \times 0.9} = 197\ mm$
  - $h = d + c + \frac{\varnothing}{2} = 197 + 20 + \frac{12}{2} = 223\ mm$

$$\Rightarrow \quad take\ [h = 230\ mm]$$

- **Load arrangement:**

- The conditions of Clause 3.5.2.3:

  - The ratio $\frac{characteristic\ imposed\ load}{characteristic\ dead\ load} = \frac{3}{10.6} = 0.28 < 1.25$

  - $charactaristic\ imposed\ load = 3\ kN/m2 < 5\ kN/m2$

are satisfied. So that;

1. It will be satisfactory to analyze for the single load case of maximum design load on all panels simultaneously.
2. The moments and shears will be calculated using the code coefficients given in table 3.12

$$\rightarrow\ [n = 1.4(10.6) + 1.6(3) = 19.64\ kN/m2\ ]$$

- Since the slab span are symmetric in both directions, so we will consider an internal line of columns in one direction (E-W).
- The lateral load is resisted by shear walls and thereby the equivalent frame method will be used.

- **Total design ultimate load & span length considered (*F&l*):**

  - $\rightarrow F = n \times (panel\ area) = 19.64 \times (6 \times 6) = 707\ kN$
  - $\rightarrow l = 6\ m$

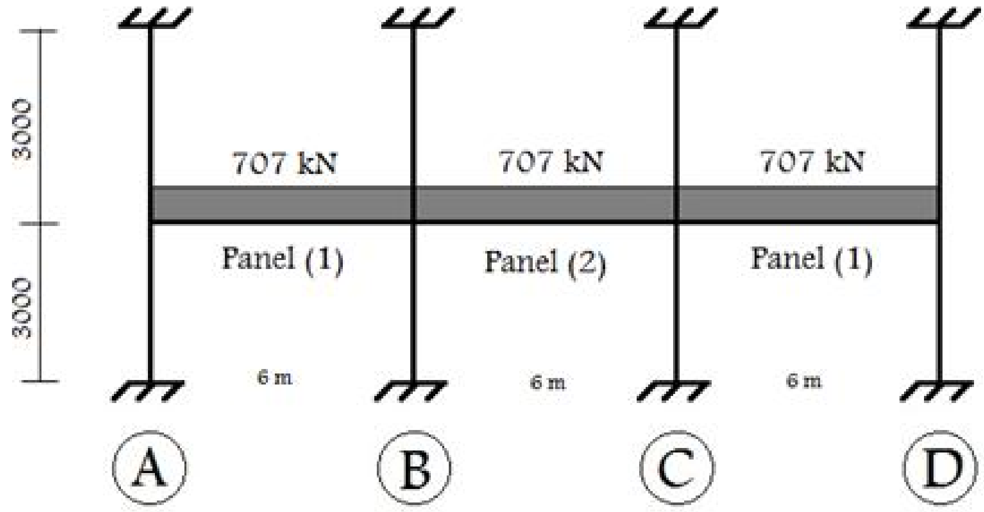


Figure 4.2: Ultimate load and span length

- **Design moment & shear:**

Table 4.2: Flat slab-design strip moments and shear forces

Position	At support (A&D)	At mid span (Panel 1)	At support (B&C)	At mid span Panel 2
Moment	"-0.04Fl"	"0.075Fl"	"-0.086Fl"	"0.063Fl"
	169.68	318.15	364.81	267.25
Shear	"0.46F"	----	"0.6F"	----
	325.22		424.2	

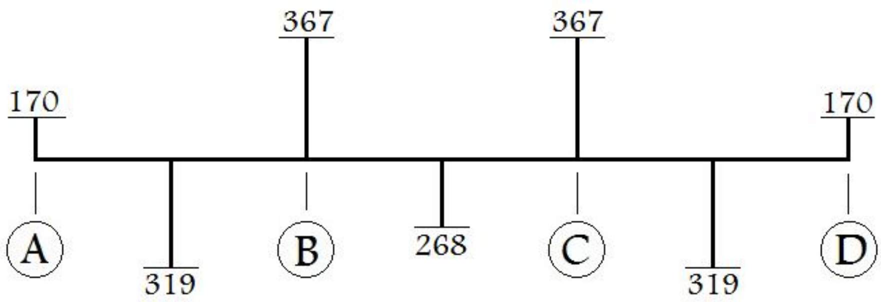


Figure 4.3: Ultimate moments in the design strip

- **Division of panels (into column & middle strips):**

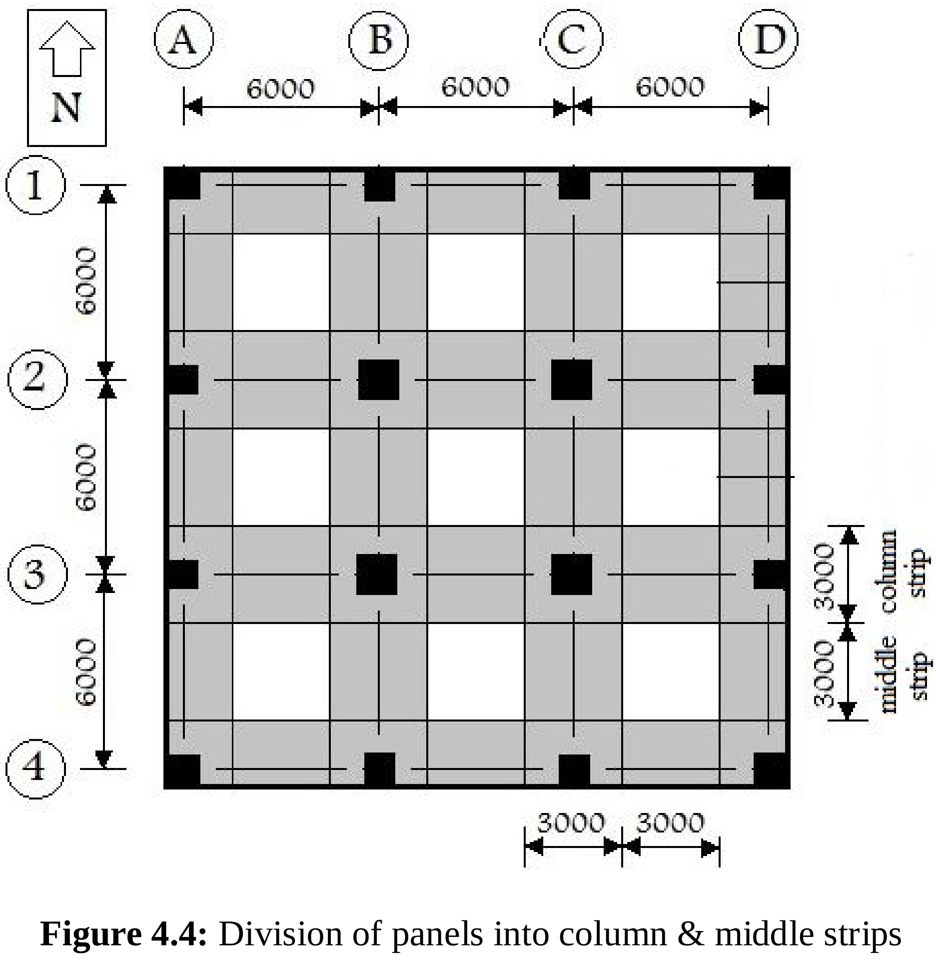


Figure 4.4: Division of panels into column & middle strips

- **Distribution of moment on column strip:**

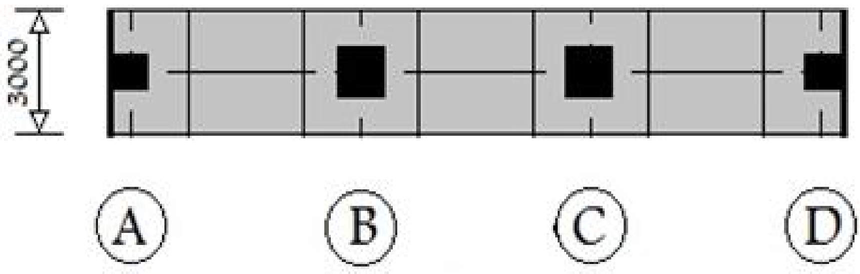


Figure 4.5: Column strip of flat slab

Table 4.3: Flat slab-column strip moments

Position	At support (A&D)	At mid span (Panel 1)	At support (B&C)	At mid span (Panel 2)
Moments (kN.m)	127.3	175	273.6	147
Strip width	3	3	3	3
Moments (kN.m)/m	42.4	58.3	91.2	49.0

- **Distribution of moment on middle strip:**

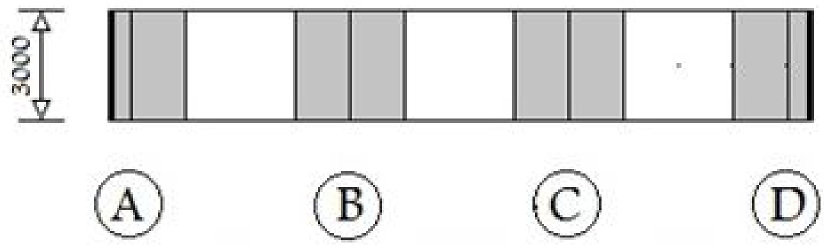


Figure 4.6: Middle strip of the flat slab

Table 4.4: Flat slab-middle strip moments

Position	At support (A&D)	At mid span (Panel 1)	At support (B&C)	At mid span (Panel 2)
Moment (kN.m)	42.4	143.2	91.2	120.3
Strip width	3	3	3	3
Moment (kN.m)/m	14.1	47.7	30.4	40.1

❖ **Waffle slab:**

Table 4.5: Waffle slab information

Standards	BS 8110 : 1997	
Structure type	Waffle slab	
Structure using	Residential building floor	
Material	Concrete	f_{cu}=30 N/mm²
		γ_c=24 N/m³
	Steel	f_y=460 N/mm²
Loading	D.L	self weight=4.5 kN/m²
		partitions=3.6 kN/m²
		blocks=0.6 kN/m²
		finishing=1.5 kN/m²
		Total=10.2 kN/m²
	L.L	live load=3 kN/m²
Concrete cover	20 mm	
Bracing system	Shear walls	
Solid part	(2×2) m (over columns)	
Columns	Dim	(0.4×0.4) & 3m height
	Capital	(1.2×1.2) & 0.6m depth

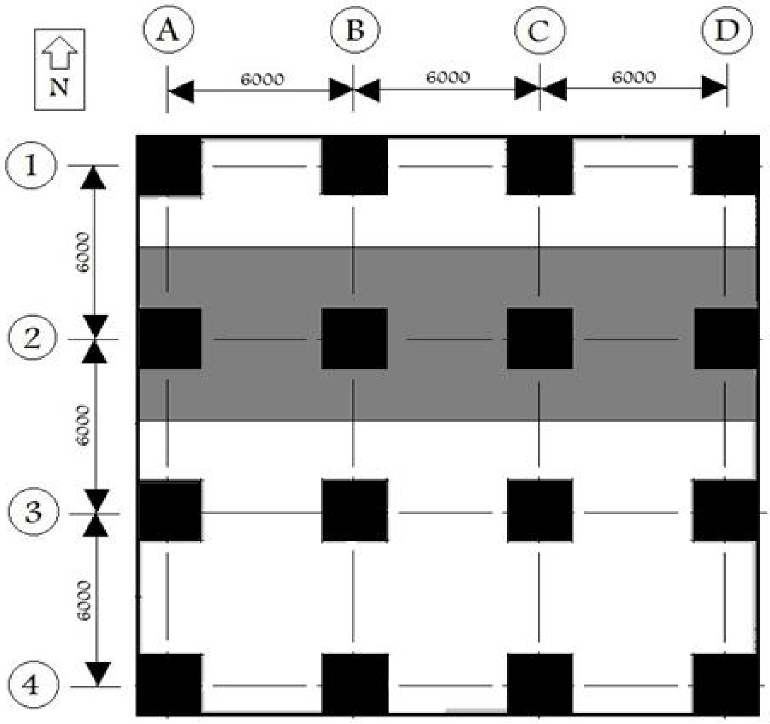


Figure 4.7: Waffle slab-design strip under consideration

- **Slab thickness determination (considering the deflection):**

  - $\left(\frac{l}{d}\right)_{actual} \leq \left(\frac{l}{d}\right)_{limit}$
  - $\left(\frac{l}{d}\right)_{actual} \leq \left(\frac{l}{d}\right)_{basic} \times MFt$
  - $\frac{6000}{d} \leq 20.8 \times 1.3$
  - $d = \frac{6000}{20.8 \times 1.3} = 222\, mm$
  - $h = d + c + \emptyset_{link} + \frac{\emptyset}{2} = 222 + 20 + 6 + \frac{12}{2} = 254\, mm$
  - $\Rightarrow \quad take \left[h = 260\, mm\right]$

- **Total design ultimate load & span length considered (F&l):**

$\rightarrow n = 1.4(10.2) + 1.6(3) = 19.1\ kN/m2$

$\rightarrow F = n \times (panel\ area) = 19.1 \times (6 \times 6) = 686\ kN$

$\rightarrow l = 6\ m$

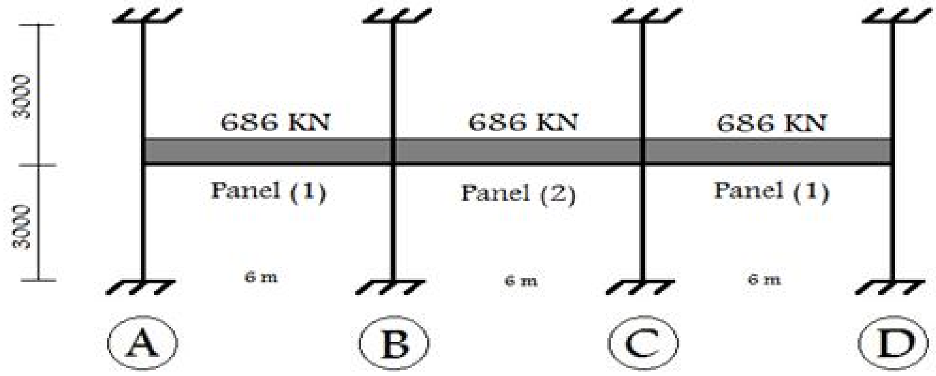


Figure 4.8: Ultimate load and span length

- **Design moment & shear:**

Table 4.6: Waffle slab-design strip moments and shear forces

Position	At support (A&D)	At mid span (Panel 1)	At support (B&C)	At mid span Panel 2
Moment	"-0.04Fl"	"0.075Fl"	"-0.086Fl"	"0.063Fl"
	164.6	308.7	354.0	259.3
Shear	"0.46F"	----	"0.6F"	----
	315.56		411.6	

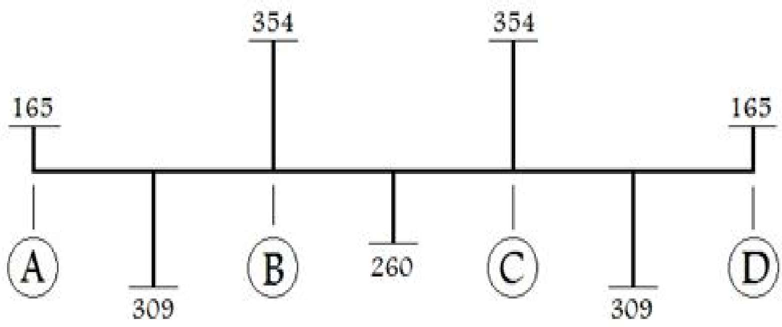


Figure 4.9: Ultimate moments in the design strip

- **Division of panels (into column & middle strips):**

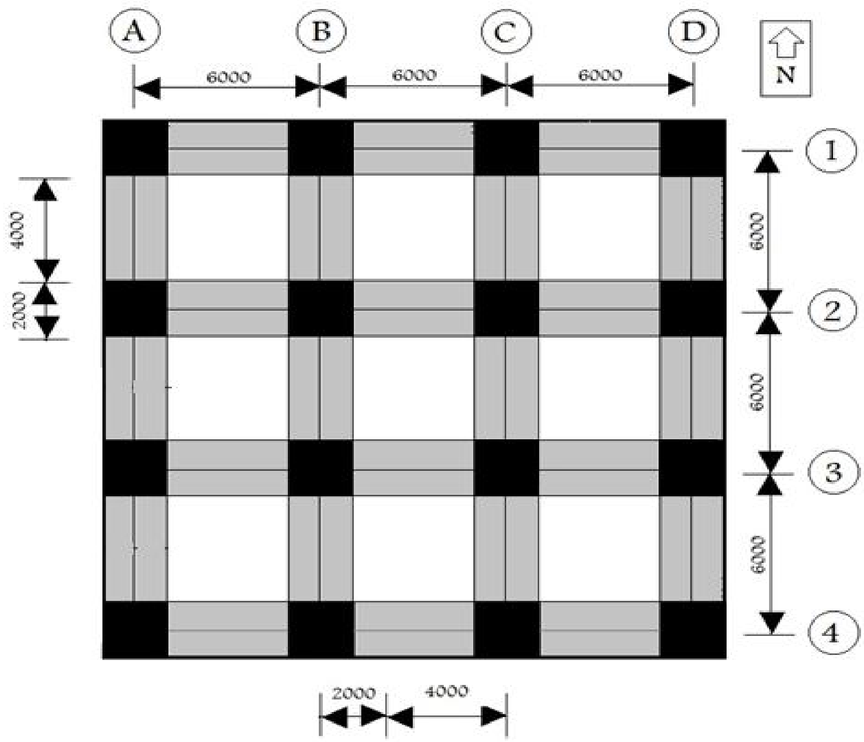


Figure 4.10: Division of panels into column & middle strips

The solid parts over the columns (which have dimensions more than one-third of span) will act as drop panels and there by:

- The column strip width will be equals to the drop panel width.

- The coefficients of moments distribution between column & middle strip will be modified by multiplying in:
  - $\left(\frac{2}{3}\right) = 0.67 \quad \rightarrow \textit{for column strip moments}$
  - $\left(\frac{4}{3}\right) = 1.33 \quad \rightarrow \textit{for middle strip moments}$

- **Distribution of moment on column strip:**

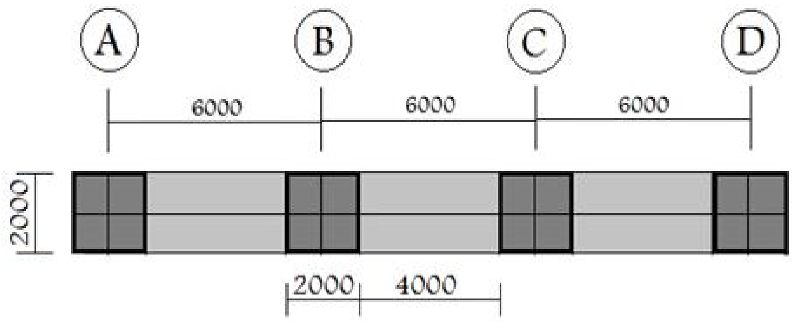


Figure 4.11: Column strip of waffle slab

Table 4.7: Waffle slab-column strip moments

Position	At support (A&D)	At mid span (Panel 1)	At support (B&C)	At mid span (Panel 2)
Moments (kN.m)	82.7	113.8	177.9	95.6
Strip width	2	2	2	2
Number of ribs/strip	4	4	4	4
Moments (kN.m)/rib	20.7	28.4	44.5	23.9

- **Distribution of moment on middle strip:**

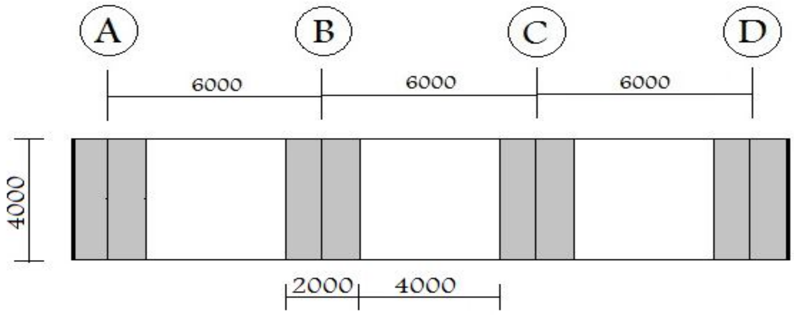


Figure 4.12: Middle strip of waffle slab

Table 4.8: Waffle slab-middle strip moments

Position	At support (A&D)	At mid span (Panel 1)	At support (B&C)	At mid span (Panel 2)
Moments (kN.m)	54.7	184.8	117.7	155.2
Strip width	4	4	4	4
Number of ribs/strip	8	8	8	8
Moments (kN.m)/rib	6.8	23.1	14.7	19.4

4.1.2. SAFE PROGRAME ANALYSIS:

❖ FLAT SLAB SAFE PROGRAME ANALYSIS:

- **Model geometry:**

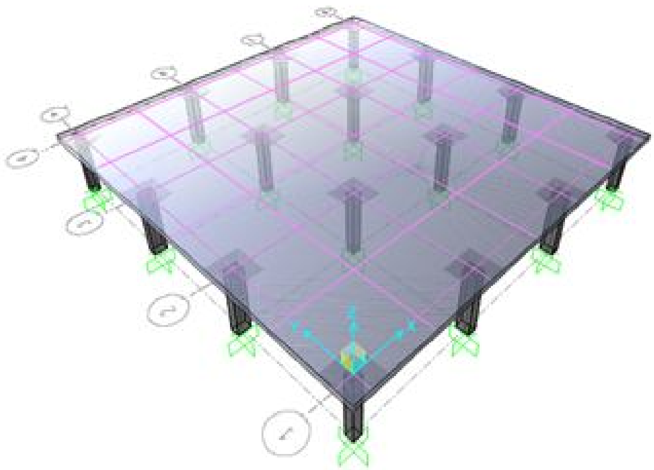


Figure 4.13: Model of flat slab

- **Displacements:**

Table 4.9: Maximum displacements in flat slab

Panel	Output Case	Case type	Uz (m)
1	Service	Combination	-0.00333
2	Service	Combination	-0.00209
3	Service	Combination	-0.00333
4	Service	Combination	-0.00209
5	Service	Combination	-0.00099
6	Service	Combination	-0.00209
7	Service	Combination	-0.00333
8	Service	Combination	-0.00209
9	Service	Combination	-0.00333

- **Reactions:**

Table 4.10: Reactions of flat slab

Point	Output Case	Case type	Fz (KN)
5	Ultimate	Combination	217.71
22	Ultimate	Combination	217.71
75	Ultimate	Combination	217.71
92	Ultimate	Combination	217.71
301	Ultimate	Combination	769.798
307	Ultimate	Combination	769.798
313	Ultimate	Combination	769.798
319	Ultimate	Combination	769.798
665	Ultimate	Combination	439.76
671	Ultimate	Combination	439.76
677	Ultimate	Combination	439.76
683	Ultimate	Combination	439.76
689	Ultimate	Combination	439.76
695	Ultimate	Combination	439.76
701	Ultimate	Combination	439.76
707	Ultimate	Combination	439.76

- **Moments:**

Table 4.11: Forces of the flat slab-design strip

Strip	Span	Location	Max V_2	Max M_3	Min M_3
SA2	Span 1	Start	28.647	80.047	3.24
SA2	Span 1	Middle	45.988	34.3744	-22.421
SA2	Span 1	End	-28.647	80.047	3.24
SA3	Span 1	Start	45.988	78.4603	1.151
SA3	Span 1	Middle	45.988	44.9291	-30.942
SA3	Span 1	End	-45.988	78.4603	1.1651
SA4	Span 1	Start	-213.383	-2.949	-75.533
SA4	Span 1	Middle	168.535	85.777	-10.662
SA4	Span 1	End	269.415	-11.449	-176.01
SA4	Span 2	Start	-250.377	-13.1062	-172.06
SA4	Span 2	Middle	-150.335	41.7933	-23.891
SA4	Span 2	End	250.377	-13.1062	-172.66
SA4	Span 3	Start	-269.415	-11.449	-176.01
SA4	Span 3	Middle	-168.535	85.777	-10.662
SA4	Span 3	End	213.383	-2.949	-75.533

❖ **WAFFLE SLAB SAFE PROGRAME ANALYSIS:**

- **Model geometry:**

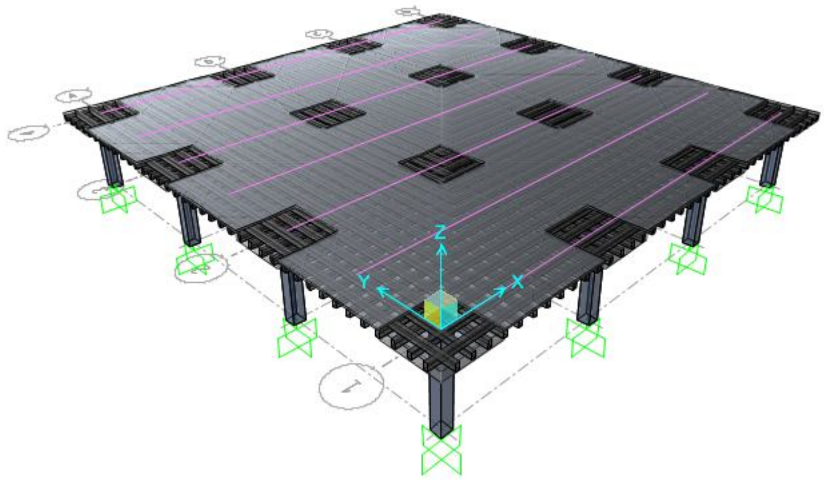


Figure 4.14: Model of the waffle slab

- **Displacements:**

Table 4.12: Maximum displacements in waffle slab

Point	Output Case	Case type	Uz (m)
1	Service	Combination	-0.005207
2	Service	Combination	-0.003558
3	Service	Combination	-0.005207
4	Service	Combination	-0.003558
5	Service	Combination	-0.001234
6	Service	Combination	-0.003558
7	Service	Combination	-0.005207
8	Service	Combination	-0.003558
9	Service	Combination	-0.005207

- **Reactions:**

Table 4.13: Reactions of waffle slab

Point	Output Case	Case type	Fz (KN)
69	Ultimate	Combination	261.618
74	Ultimate	Combination	437.835
80	Ultimate	Combination	437.835
86	Ultimate	Combination	261.618
91	Ultimate	Combination	437.835
97	Ultimate	Combination	770.712
103	Ultimate	Combination	770.712
109	Ultimate	Combination	437.835
115	Ultimate	Combination	437.835
121	Ultimate	Combination	770.712
127	Ultimate	Combination	770.712
133	Ultimate	Combination	437.835
139	Ultimate	Combination	261.618
144	Ultimate	Combination	437.835
150	Ultimate	Combination	437.835
156	Ultimate	Combination	261.618

- **Moments:**

Table 4.14: Forces of waffle slab-design strip

Strip	Span	Location	Max P	Max V_2	Max M_3	Min M_3
CSA2	Span 1	Start	-52.646	-151.04	1.6469	-43.2405
CSA2	Span 1	Middle	-42.793	95.234	72.989	14.931
CSA2	Span 1	End	-32.447	213.342	-6.8997	-147.0571
CSA2	Span 2	Start	-17.876	-192.94	-6.8559	-133.9212
CSA2	Span 2	Middle	-19.222	-79.739	46.4045	5.4304
CSA2	Span 2	End	-17.876	192.942	-6.8559	-133.9212
CSA2	Span 3	Start	-32.447	-213.34	-6.8997	-147.0571
CSA2	Span 3	Middle	-42.793	-95.234	72.989	14.931
CSA2	Span 3	End	-52.646	151.045	1.6469	-43.2405

4.2. DESIGN:

4.2.1. Flat slab design:

REF.	CALCULATIONS	OUTPUT
	▪ **Column strip:**	

Table 4.15: Flat slab-column strip design moments

Position	At mid span (Panel 1)	At support (B&C)
Moments (kN.m)	88.8	172.0
Strip width	3	3
Moments (kN.m)/m	29.6	57.3

At mid span :

- $M_{applied}$ = 29.6 $kN.m/m$

BS-8110 Part1 Clause 3.4.4

- $K = \frac{M}{bd^2 f_{cu}} = \frac{29.6*10^6}{1000*204^2*30} = 0.024$

- $\frac{z}{d} = 0.5 + \sqrt{0.25 - \frac{k}{0.9}}$

$$= 0.5 + \sqrt{0.25 - \frac{0.024}{0.9}} = 0.97$$

- $z = \left(\frac{z}{d}\right) * d = 0.95 * 204 = 194\ mm$

- $As = \frac{M}{0.95 * f_y * z} = \frac{29.6*10^6}{0.95*460*194} = 350 mm^2$

	➢ $As_{min} = \frac{0.13*Ac}{100} = \frac{0.13*1000*230}{100} = 299\ mm^2$ ➢ As > As_{min} ➢ $S = \frac{A_{bar}*1000}{As} = \frac{113*1000}{299} = 323\ mm$ ➢ $Use\ \ \emptyset\ 12\ @\ 300\ mm\ c/c\ \ \ bottom$ ➢ $As_{prov} = 452\ mm^2/m$	452mm^2
	At support : ➢ $M_{applied} = -57.3\ kN.m/m$ ➢ $K = \frac{57.3*10^6}{1000*204^2*30} = 0.046$ ➢ $\left(\frac{z}{d}\right) = 0.5 + \sqrt{0.25 - \frac{0.046}{0.9}} = 0.95$ ➢ $z = 0.95 * 204 = 194\ mm$ ➢ $As = \frac{57.3*10^6}{0.95*460*194} = 680\ mm^2$ ➢ As > ($As_{min} = 299\ mm^2$) ➢ $S = \frac{201*1000}{680} = 296\ mm$ ➢ $Use\ \ \emptyset\ 16\ @\ 250\ mm\ \ c/c$ $As_{prov} = 802\ mm^2/m$	802 mm^2

- **Middle strip moments:**

Table 4.16: Flat slab-middle strip design moments

Position	At mid span (Panel 1)	At support (B&C)
Moments (kN.m)	71.3	42.3
Strip width	3	3
Moments (kN.m)/m	23.8	14.1

At mid span :

- $M_{applied} = 23.8\ \text{kN.m/m}$
- $K = \frac{23.8*10^6}{1000*204^2*30} = 0.019$
- $\frac{z}{d} = 0.5 + \sqrt{0.25 - \frac{0.019}{0.9}} = 0.99$
- $z = 0.95 * 204 = 194\ mm$
- $As = \frac{23.8*10^6}{0.95*460*194} = 281\ mm^2$
- As > ($As_{min} = 299\ mm^2$)
- $S = \frac{113*1000}{299} = 378\ mm$

	➢ $Use \quad Ø\,12 @ 350\,mm \;\; c/c$ ➢ $As_{prov} = 339\,mm^2/m$ **<u>At support :</u>** ➢ $M_{applied} = -14.1\,kN.m/m$ ➢ $k = \frac{14.1*10^6}{1000*204^2*30} = 0.011$ ➢ $\left(\frac{z}{d}\right) = 0.5 + \sqrt{0.25 - \frac{0.011}{0.9}} = 0.99$ ➢ $\left(\frac{z}{d}\right)_{max} = 0.95$ ➢ $z = 0.95 * 204 = 194\,mm$ ➢ $As = \frac{14.1\,*10^6}{0.95*460*194} = 166\,mm^2 < As_{min} = 299\,mm^2$ ➢ $S = \frac{201*1000}{299} = 672\,mm$ ➢ $Use \quad Ø\,16 @ 650\,mm\;c/c \quad Top$ ➢ $As_{pro} = 402\,mm^2/m$		339mm^2 402mm^2

	<u>**Check for shear :**</u>	
Clause 3.7.6	(considering the critical internal column B2)	
	The force at the center of column : (force value is same in both direction)	
	$$\text{Reaction} = 770\ kN$$	
	The effective depth for shear :	
Clause 3.5.5	The average effective depth of the two directions :	
	$$d = \frac{192 + 204}{2} = 198\ mm$$	
Clause 3.7.6.4	<u>**At the face of column head :**</u>	
	o Applied shear stress:	
	$$V_{eff} = 1.15V_t$$	
	➢ $V_t = R = 770\ kN$	
	➢ $V_{eff} = 1.15 \times 770 = 885.5\ KN$	

	$$v = \frac{V}{ud}$$ ➢ V = V_{eff} = 885.5 KN ➢ $u = 4(h_c) = 4 \times 1.5 = 6\, m$ ➢ $v = \frac{885.5 \times 10^3}{6000 \times 198} = 0.75\, N/mm^2$ o Resistance : ➢ $v_c = \left(0.8\sqrt{f_{cu}}\right) = 0.8\sqrt{30} = 4.38 < 5\, N/mm^2$ [v = 0.75 N/mm^2 < 4.38 N/mm^2] __ OK	0.75 N/mm^2 4.38 N/mm^2
Clause 3.7.7.1	**Punching shear:** (at 1.5d from the face of column head) o **Applied shear stress:** ➢ V = V_{eff} = 885.5 KN ➢ $u = 4(h_c + 3d) = 4(1500 + 3(198)) = 8376\, mm$	

- $v = \frac{885.5 \times 10^3}{8376 \times 198} = 0.53\ N/mm^2$

0.53 N/mm^2

- **Resistance :**

$$v_c = \frac{0.79}{\gamma_m}\left(\frac{100As}{bd}\right)^{\frac{1}{3}}\left(\frac{400}{d}\right)^{\frac{1}{4}}\left(\frac{f_{cu}}{25}\right)^{\frac{1}{3}}$$

- $\frac{100As}{bd} = \frac{(100)(804)}{(1000)(198)} = 0.41 < 3$ ____ OK
- $\left(\frac{400}{d}\right)^{\frac{1}{4}} = \left(\frac{400}{198}\right)^{\frac{1}{4}} = 1.19 > 0.67$ ____ OK
- $\left(\frac{f_{cu}}{25}\right)^{\frac{1}{3}} = \left(\frac{30}{25}\right)^{\frac{1}{3}} = 1.06$
- $v_c = (0.79/1.25)(0.41)^{\frac{1}{3}}(1.19)(1.06) = 0.59\ N/mm^2$

0.59 N/mm^2

$[\ v < v_c\ ]$ ______ OK

Check for deflection :

- **Actual span/effective depth ratio :**

- $\left(\frac{l}{d}\right)_{attual} = \frac{6000}{204} = 29.4$

29.4

- Limited span/effective depth ratio :

$$\left(\frac{l}{d}\right)_{limit} = \left[\left(\frac{l}{d}\right)_{basic} \times MFt\right] \times 0.9$$

Table 3.9 Table 3.10	➢ $\left(\frac{l}{d}\right)_{basic} = 26$ $MFt = 0.55 + \frac{(477 - f_s)}{120\left(0.9 + \frac{M}{bd^2}\right)} \leq 2.0$ ➢ $f_s = \frac{2\, f_y\, A_{s\,req}}{3\, A_{s\,prov}} = \frac{2(460)(299)}{3(339)} = 270.5\ N/mm^2$ ➢ $\frac{M}{bd^2} = \frac{23.8\times10^6}{1000\times204^2} = 0.57$ ➢ $MFt = 0.55 + \frac{(477-270.5)}{120(0.9+0.57)} = 1.72 < 2.0$ ➢ $\left(\frac{l}{d}\right)_{limit} = 26 \times 1.72 = 44.7$ $\left[\ \left(\frac{l}{d}\right)_{attual} < \left(\frac{l}{d}\right)_{limit}\ \right]$ ________ OK	44.7

4.2.2. Waffle slab design:

REF.	CALCULATIONS	OUTPUT
	▪ **Column strip moments:**	

Table 4.17: Waffle slab-column strip design moments

Position	Near middle (Panel 1)	At support (B&C)
Moments (kN.m)	72.3	76.4
Strip width	2	2
Number of ribs	4	4
Moments (kN.m)/rib	18.1	19.1

At support :

$$M_{applied} = 19.1\ kN.m/rib$$

- $K = \frac{19.1*10^6}{525*228^2*30} = 0.023$
- $\frac{z}{d} = 0.5 + \sqrt{0.25 - \frac{0.023}{0.9}} = 0.97 > 0.95$
- $z = 0.95 * 228 = 217\ mm$
- $As = \frac{19.1*10^6}{0.95*460*217} = 202\ mm^2$
- $Flange\ M_{resistane} = 0.45 f_{cu} b_f h_f \left(d - \frac{h_f}{2}\right)$

	$= 0.45 * 30 * 525 * 60 * \left(228 - \frac{60}{2}\right) * 10^{-6}$ $= 84.2\ kN.m > \left(M_{applied} = 19.1\ kN.m\right)$ *This implies the neutral axis lies within the* *flange (The section is to be designed as rectangul* ➢ $As_{min} = \frac{0.18*b_w*h}{100} = \frac{0.18*125*260}{100} = 58.5\ mm^2$ [As > As_{min}] ➢ $Number\ of\ bars = \frac{As}{A_{bar}} = \frac{202}{113} = 1.8\ bars$ ➢ $Provide\ 2\ T\ 12\ bottom$ ➢ $As_{prov} = 226\ mm^2/rib$ **<u>At Support : (rectangular section)</u>** $M_{\boldsymbol{applied}} = -18.1\ kN.m/rib$ ➢ $k = \frac{18.1*10^6}{525*228^2*30} = 0.022$	226mm^2

	➢ $\left(\frac{z}{d}\right) = 0.5 + \sqrt{0.25 - \frac{0.022}{0.9}} = 0.97$ ➢ $z = 0.95 * 228 = 217\ mm$ ➢ $As = \frac{18.1*10^6}{0.95*460*217} = 191\ mm^2$ ➢ $As_{min} = \frac{0.13*525*260}{100} = 178\ mm^2$ [$As > As_{min}$] ➢ $Number\ of\ bars = \frac{191}{113} = 1.7\ \ bars$ ➢ $Provide\ 2\ T\ 12\ Top$ ➢ $As_{prov} = 226\ mm^2$ **Solid part :** $M_{applied} = -\frac{146}{2} = 73\ kN.m/m$ ➢ $k = \frac{73*10^6}{1000*228^2*30} = 0.047$	226mm^2

	➢ $\left(\frac{z}{d}\right) = 0.5 + \sqrt{0.25 - \frac{0.047}{0.9}} = 0.94$ ➢ $z = 0.94 * 228 = 214\ mm$ ➢ $As = \frac{73*10^6}{0.95*460*214} = 775\ mm^2$ ➢ $As_{min} = \frac{0.13*1000*260}{100} = 338\ mm^2$ [As > As_{min}] ➢ $S = \frac{201*1000}{775} = 259\ mm$ ➢ $Provide\ \varnothing 16\ @\ 250\frac{c}{c}\ \ Top$ ➢ $As_{prov} = 804\ mm^2/m$ ▪ **Middle strip moments:** **Table 4.18:** Waffle slab-middle strip design moments	804mm^2

Position	Near middle (Panel 1)	At support (B&C)
Moments (kN.m)	110.6	77.4
Strip width	4	4
Number of ribs	8	8
Moments (kN.m) / rib	13.8	9.7

Middle Strip ribs :

At Mid Span :

$$M_{applied} = 13.8 \text{ kN.m/rib}$$

- $K = \frac{13.8*10^6}{525*228^2*30} = 0.017$

- $\frac{z}{d} = 0.5 + \sqrt{0.25 - \frac{0.014}{0.9}} = 0.98 > 0.95$

- $z = 0.95 * 228 = 217\ mm$

- $As = \frac{13.8*10^6}{0.95*460*217} = 146\ mm^2$

- $Flange\ M_{resistane}$

$$= 0.45 * 30 * 525 * 60 * \left(228 - \frac{60}{2}\right) * 10^{-6}$$

$$= 84.2\ kN.m > \left(M_{applied} = 13.8\ kN.m\right)$$

This implies the neutral axis lies within the flange (The section is to be designed as rectangul

- $As_{min} = \frac{0.18*125*260}{100} = 58.5\ mm^2$

$$[\ As > As_{min}\ ]$$

	➢ $Number\ of\ bars = \frac{As}{A_{bar}} = \frac{146}{113} = 1.2 bars$ ➢ $Provide\ 2\ T\ 12\ bottom$ ➢ $As_{prov} = 226\ mm^2$	$226mm^2$
	At Support : $M_{\boldsymbol{applied}} = -9.7\ kN.m/rib$ ➢ $k = \frac{9.7*10^6}{125*228^2*30} = 0.023$ ➢ $\left(\frac{z}{d}\right) = 0.5 + \sqrt{0.25 - \frac{0.023}{0.9}} = 0.97$ ➢ $z = 0.95 * 228 = 217\ mm$ ➢ $As = \frac{11.1*10^6}{0.95*460*217} = 102\ mm^2$ ➢ $As_{min} = \frac{0.26*125*260}{100} = 84.5\ mm^2$ [As > As_{min}] ➢ $Number\ of\ bars = \frac{102}{79} = 1.3\ bars$ ➢ $Provide\ 2\ T\ 10\ Top$ ➢ $As_{prov} = 158\ mm^2$	$158mm^2$

Clause 3.6.6.2	**Topping reinforcement :** As = 0.12%(sectional area of topping) ➢ As = $\left(\frac{0.12}{100}\right)(100 \times 1000)$ = 120 mm^2/m Provide A142 mesh ($A_{s\,prov}$ = 142 mm^2/m)	142mm^2
Clause 3.7.7.1	**Punching shear:** at 1.5d from the face of column head : o Applied shear stress: $$v = \frac{V}{ud}$$ ➢ V_{eff} = 1.15V_t Clause 3.7.6.2 ➢ V_t = R = 771 kN ➢ V_{eff} = 1.15 × 771 = 887 KN ➢ V = V_{eff} = 887 KN ➢ $u = 4(h_c + 3d) = 4(1500 + 3(228))$ = 8736 mm ➢ $v = \frac{887 \times 10^3}{8736 \times 228}$ = 0.45 N/mm^2	0.45 N/mm^2

	o Resistance : $$v_c = \frac{0.79}{\gamma_m}\left(\frac{100As}{bd}\right)^{\frac{1}{3}}\left(\frac{400}{d}\right)^{\frac{1}{4}}\left(\frac{f_{cu}}{25}\right)^{\frac{1}{3}}$$ ➢ $\frac{100As}{bd} = \frac{(100)(804)}{(1000)(228)} = 0.35 < 3$ ____ OK ➢ $\left(\frac{400}{d}\right)^{\frac{1}{4}} = \left(\frac{400}{228}\right)^{\frac{1}{4}} = 1.15 > 0.67$ ____ OK ➢ $\left(\frac{f_{cu}}{25}\right)^{\frac{1}{3}} = \left(\frac{30}{25}\right)^{\frac{1}{3}} = 1.06$ ➢ $v_c = \left(\frac{0.79}{1.25}\right)(0.35)^{\frac{1}{3}}(1.15)(1.06) = 0.54 N/mm2$ $[\ v < v_c\ ]$ _______ OK	0.54 N/mm^2
	Check for deflection : Clause3.6.5 o Actual span/effective depth ratio : $$\left(\frac{l}{d}\right)_{attual} = \frac{6000}{228} = 26.3$$	26.3
Table 3.9	o Limited span/effective depth ratio : $$\left(\frac{l}{d}\right)_{limit} = \left(\frac{l}{d}\right)_{basic} \times MFt$$ ➢ $\left(\frac{l}{d}\right)_{basic} = 20.8$	
Table 3.10	$$MFt = 0.55 + \frac{(477 - f_s)}{120\left(0.9 + \frac{M}{bd^2}\right)} \leq 2.0$$	

	➢ $f_s = \frac{2\ f_y\ A_{s\ req}}{3\ A_{s\ prov}} = \frac{2(460)(146)}{3(226)} = 198\ N/mm^2$ ➢ $\frac{M}{bd^2} = \frac{13.8\times10^6}{125\times228^2} = 2.12$ ➢ $MFt = 0.55 + \frac{(477-198)}{120(0.9+2.12)} = 1.32 < 2.0$ ➢ $\left(\frac{l}{d}\right)_{limit} = 20.8 \times 1.32 = 27.5$ $\left[\ \left(\frac{l}{d}\right)_{attual} < \left(\frac{l}{d}\right)_{limit}\ \right]$ ______ **OK**	27.5

4.3. QUANTITIES:

4.3.1 Concrete quantities:

❖ **Waffle slab quantities:**

For the solid part = $2 \times 2 \times 0.26$ = 1.04 m^3 per panel

For the waffle part = $(2/3)(6\times6\times0.26-2\times2\times0.26)$ = 5.55 m^3 per panel

Total concrete quantity in one panel = 6.6 m^3

Total waffle slab concrete quantity = 6.6×9 = **59.3 m^3**

❖ **Flat slab quantities:**

For one panel = $6 \times 6 \times 0.23$ = 8.28 m^3

Total flat slab concrete quantity = 8.28×9 = **74.5 m^3**

4.3.2. Reinforcing steel quantities:

$$Steel\ value = As\ prov \times No.of\ ribs \times rib\ length \times 2\ (both\ sides)$$

- **Waffle slab steel quantities:**

Column strip:

Top: $226 \times 10^{-6} \times 4 \times 4 \times 2 = 7232 \times 10^{-6}\ m^3$

Bottom: $226 \times 10^{-6} \times 4 \times 4 \times 2 = 7232 \times 10^{-6}\ m^3$

Middle strip:

Top: $158 \times 10^{-6} \times 8 \times 6 \times 2 = 15168 \times 10^{-6}\ m^3$

Bottom: $226 \times 10^{-6} \times 8 \times 6 \times 2 = 21696 \times 10^{-6}\ m^3$

Solid part: $802 \times 10^{-6} \times 2 \times 2 \times 2 = 6328 \times 10^{-6}\ m^3$

Topping: $142 \times 10^{-6} \times 6 \times 6 \times 2 = 5112 \times 10^{-6}\ m^3$

Links:

$$\left(\frac{\pi \times 6^2}{4}\right) \times 570 \times 5 \times (8 \times 6 + 4 \times 4) \times 2 \times 10^{-9} = 0.01\ m^3$$

Total value of steel: $= 0.073\ m^3$

Weight = value × density = 0.073 × 7.85 = 0.57 Ton per panel

Total steel weight in the waffle slab = 0.57 × 9 = **<u>5.1 Ton</u>**

- **Flat slab steel quantities:**

$$Steel\ value = As\ prov \times Area \times 2\ (both\ sides)$$

Bottom: $4 \times 113 \times 10^{-6} \times 6 \times 6 \times 2 = 0.032\ m^3$

Top:

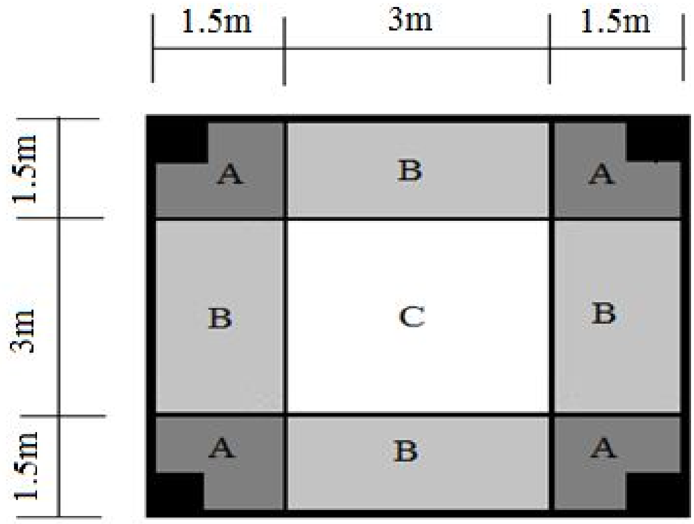


Figure 4.15: Flat slab top reinforcement

A $= 4 \times 201 \times 10^{-6} \times 3 \times 3 \times 2 = 0.0145\ m^3$

B $= 3 \times 201 \times 10^{-6} \times 3 \times 3 \times 2 \times 2 = 0.022\ m^3$

C $= 2 \times 201 \times 10^{-6} \times 3 \times 3 \times 2 = 0.0145\ m^3$

Total value of steel: $= 0.076\ m^3$

Weight = value × density = 0.076 × 7.85 = 0.60 Ton

Considering over lapping: 1.15 × 0.60 = 0.69 Ton per panel

Total steel weight in the flat slab = 0.69 × 9 = **6.2 Ton**

4.4. Comparison of results:

4.4.1 Analysis results:

- **Flat slab:**

  - **Bending moments in column strip:**

Table 4.19: Flat slab-column strip moment comparison

Position	At support (B&C)	At mid span (Panel 2)
Manual	273.6	147
Program	172.0	41.8
Error	37%	71%

  - Bending moments in middle strip:

Table 4.20: Flat slab-middle strip moment comparison

Position	At support (B&C)	At mid span (Panel 2)
Manual	91.2	120.3
Program	42.3	42.1
Error	53%	65%

❖ **Waffle slab:**

- **Bending moments in column strip:**

Table 4.21: Waffle slab-column strip moments comparison

Position	At support (B&C)	At mid span (Panel 2)
Manual	177.9	95.6
Program	76.4	45.8
Error	57%	52%

- Bending moments in middle strip:

Table 4.22: Waffle slab-middle strip moments comparison

Position	At support (B&C)	At mid span (Panel 2)
Manual	117.7	155.2
Program	77.4	52.5
Error	34%	66%

4.4.2. Quantities results:

- **Concrete quantities:**

Table 4.23: Concrete quantities comparison

Slab	Flat	Waffle	Difference
Concrete quantity	74.5 m^3	59.3 m^3	20%

- **Reinforcing steel quantities:**

Table 4.24: Reinforcing steel quantities comparison

Slab	Flat	Waffle	Difference
Reinforcing Steel quantity	6.2 Ton	5.1 Ton	18%

CHAPTER FIVE

CONCLUSION, RECOMMENDATIONS

5.1 Conclusion:

1. From the study results it is found that there is a large difference between the values of the manual and program analysis.

2. From the study results it is found that in waffle slabs concrete quantity is reduced up to 20% and the reduction of steel is 18%.

3. Economic aspect is an important parameter governing the superiority of waffle slab over flat slab which can be inferred from the study results.

5.2 Recommendations:

From the study results we recommend to:

1. Repetition of analysis operation in order to treat the large differences between the computer and manual analysis values.

2. Using the waffle slab as an economic alternative for flat slab.

For future studies we recommend to:

1. A comprehensive study of cost saving in buildings by considering all factors, such as cost of two way slabs, frames (beams and columns), foundations and the effect of time saving on the construction of such type of slab shall be done.

2. Studying the behavior of an edge and a corner panel of waffle slabs.

3. Studying another system of waffle slabs (beams zones between columns).

5.3 REFERENCES:

[1] Ahmed A.M. Civil Engineering, Zagazig University,2000
"Analysis of waffle slabs with openings"

[2] Arthur H.Nilson , George Winter,(1986),"Design of Concrete Structures"McGraw-Hill 10th
edition

[3] BS6399 (1996). Loading for buildings: Part1 - Code of practice for dead and imposed loads. British Standards Institution, London, UK.

[4] BS8110 (1997). Structural use of concrete: Part1 - Code of practice for design and construction. British Standards Institution, London, UK.

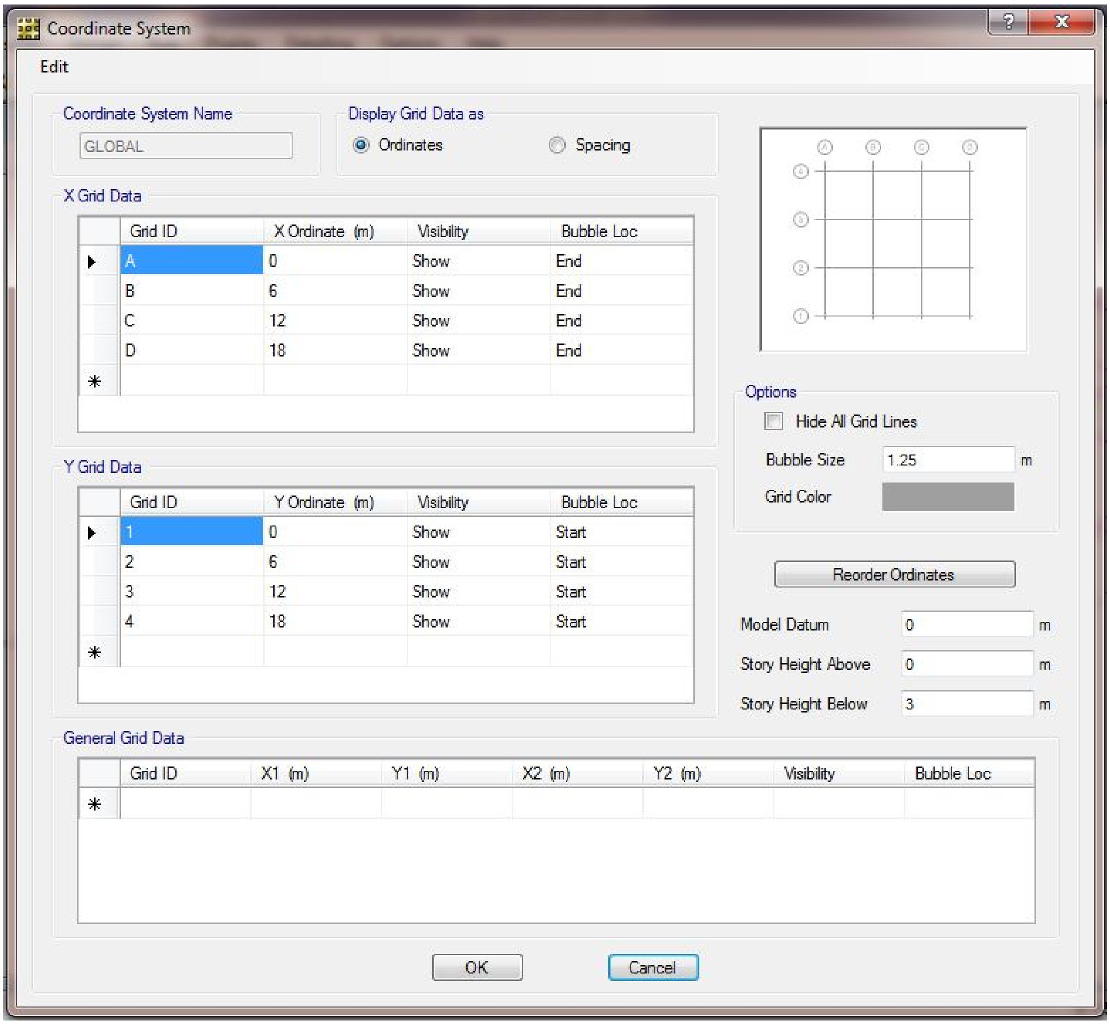
[5] Park ,R, and Gamble , W.L., (1980),"Reinforced Concrete Slabs",Willy Intersience , New York

[6] T.J.MacGinley, B. S. Choo, (1990), Reinforced Concrete: Design theory and examples 2nd Edition, London, UK

[7] W. H. Mosley. J. H. Bungey & R. Hulse, (1980) ,"Reinforced Concrete Design" 5th Edition

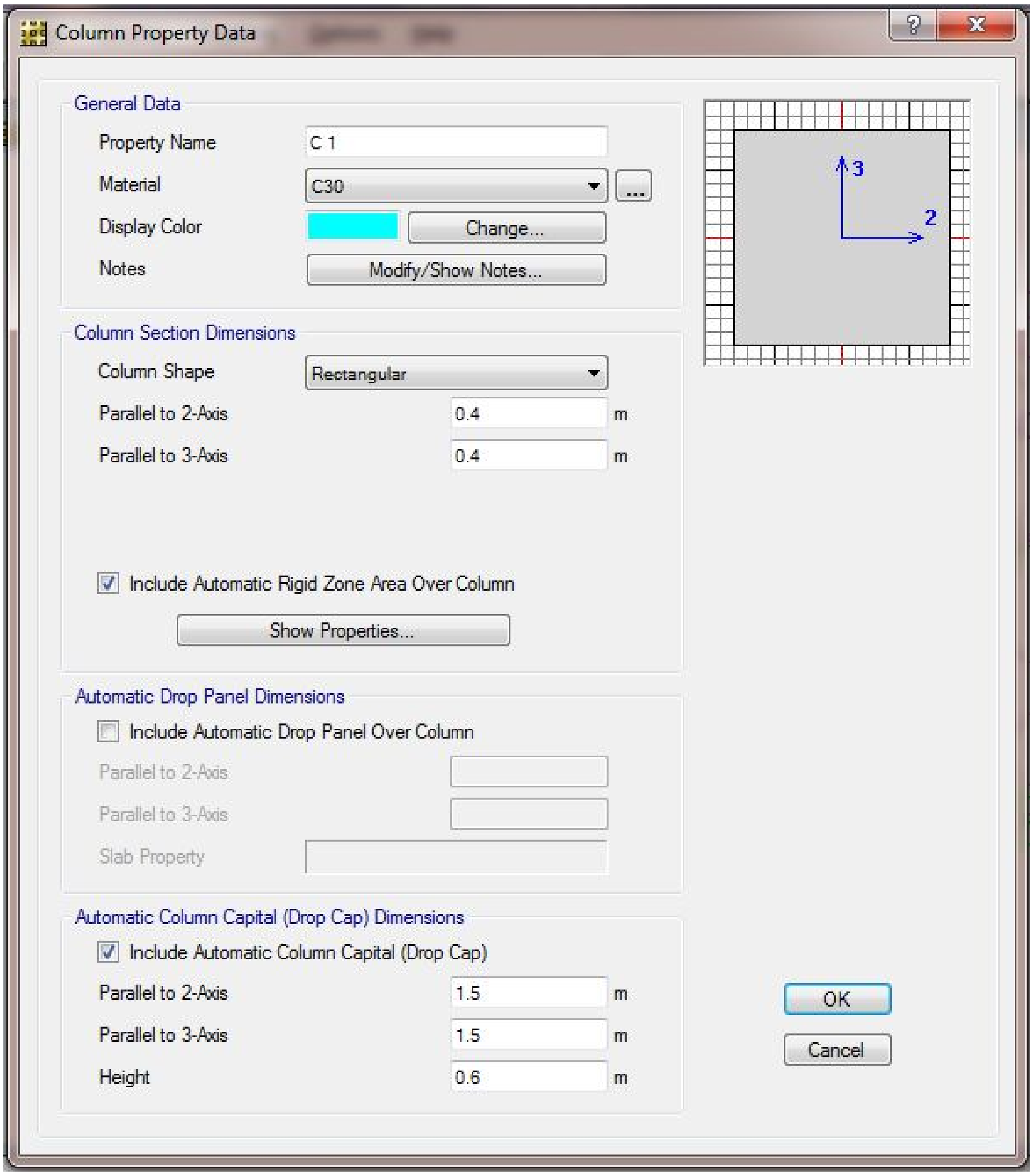
APPENDIX A: Flat slab analysis using SAFE program

❖ Coordinate system:

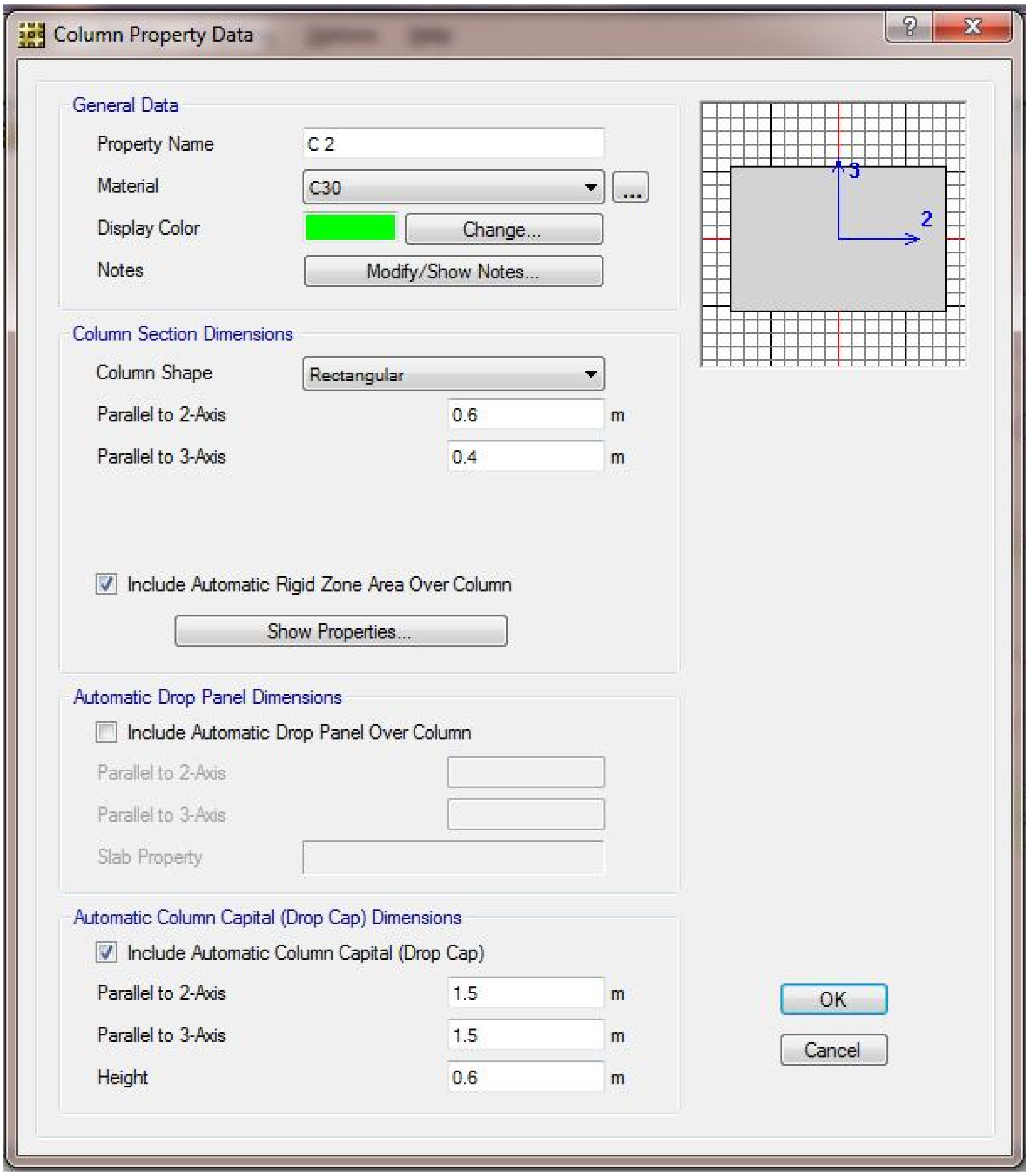


❖ **Columns Properties:**

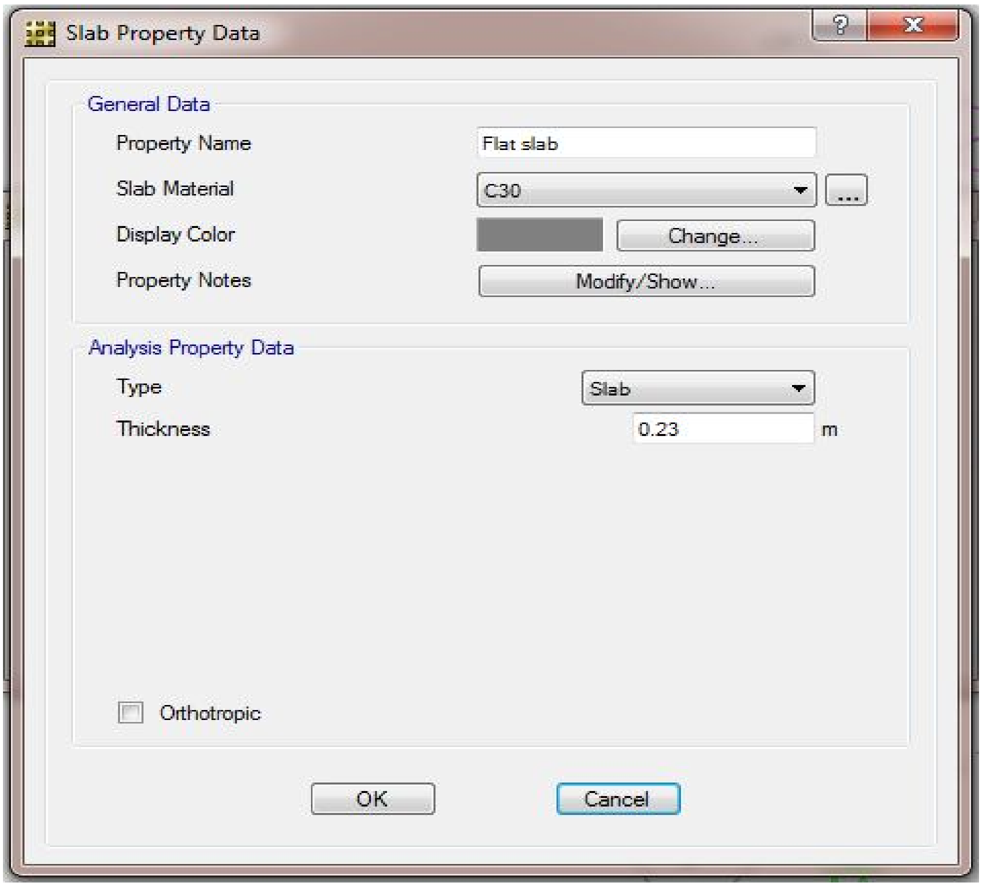
➢ Column 1:



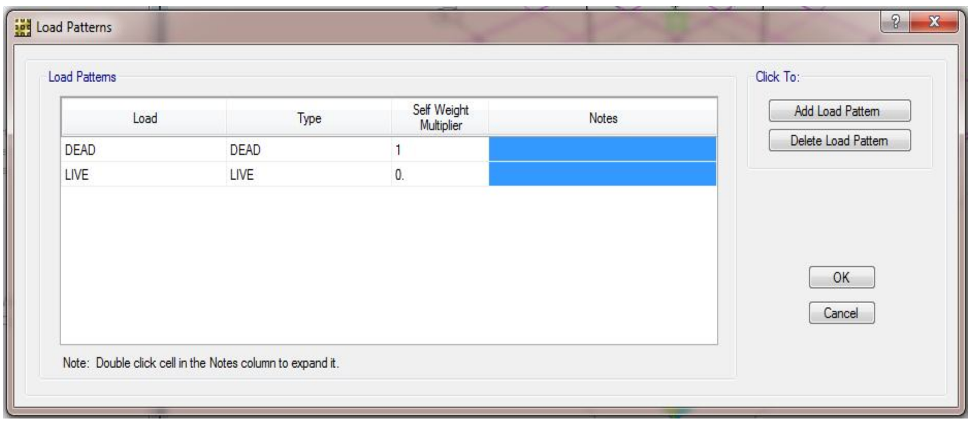
➢ Column 2:


Column Property Data
General Data
Property Name
C 2
Material
C30
Display Color
Change...
Notes
Modify/Show Notes...
Column Section Dimensions
Column Shape
Rectangular
Parallel to 2-Axis
0.6
m
Parallel to 3-Axis
0.4
m
Include Automatic Rigid Zone Area Over Column
Show Properties...
Automatic Drop Panel Dimensions
Include Automatic Drop Panel Over Column
Parallel to 2-Axis
Parallel to 3-Axis
Slab Property
Automatic Column Capital (Drop Cap) Dimensions
Include Automatic Column Capital (Drop Cap)
Parallel to 2-Axis
1.5
m
Parallel to 3-Axis
1.5
m
Height
0.6
m
3
2
OK
Cancel

❖ Flat slab properties:



❖ Load pattern:



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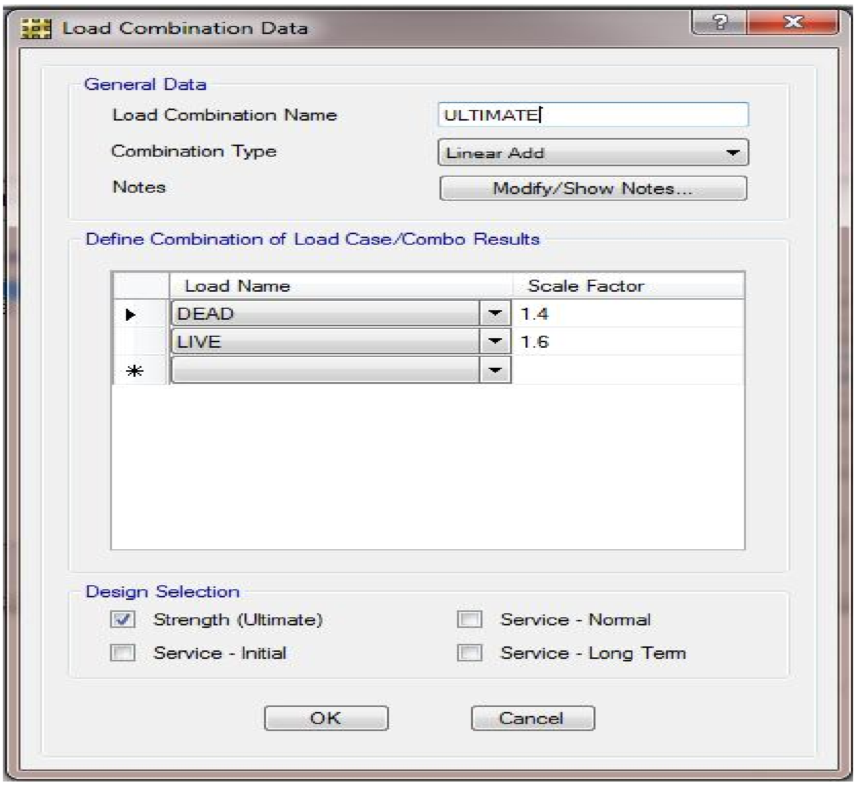
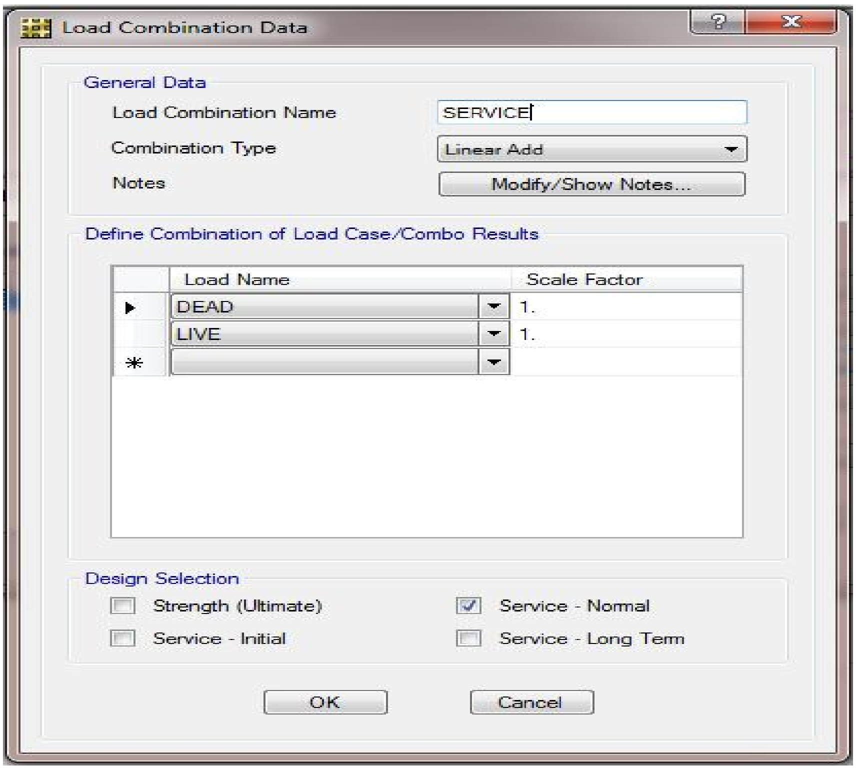
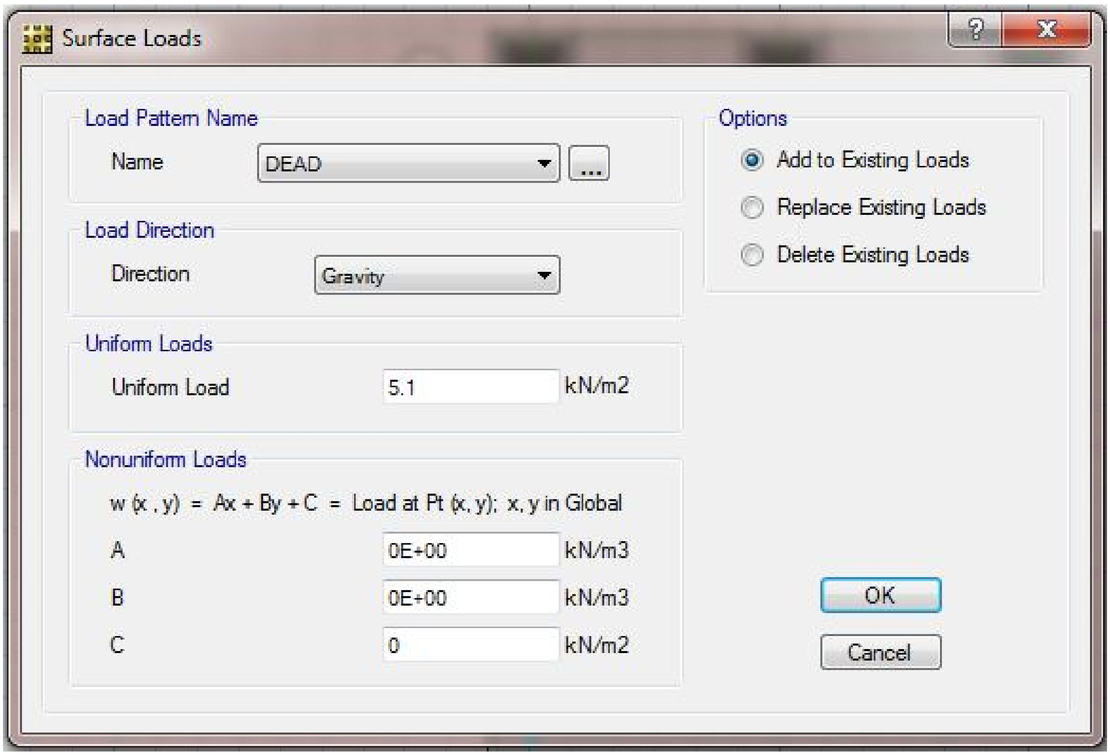
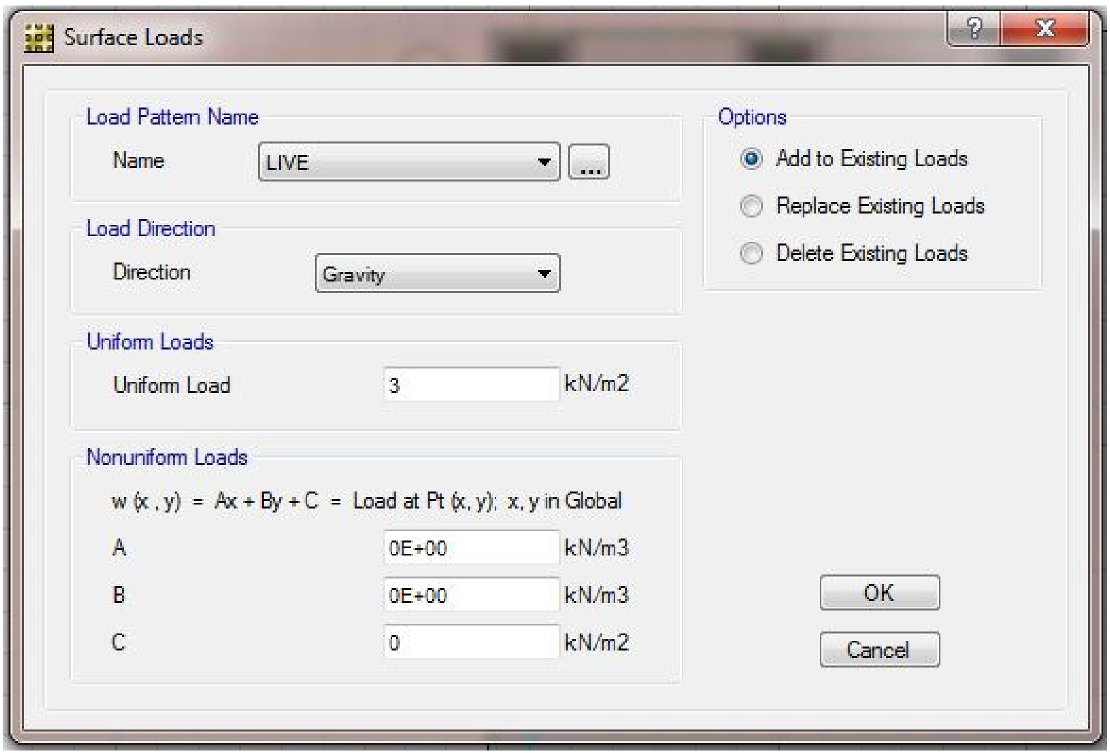


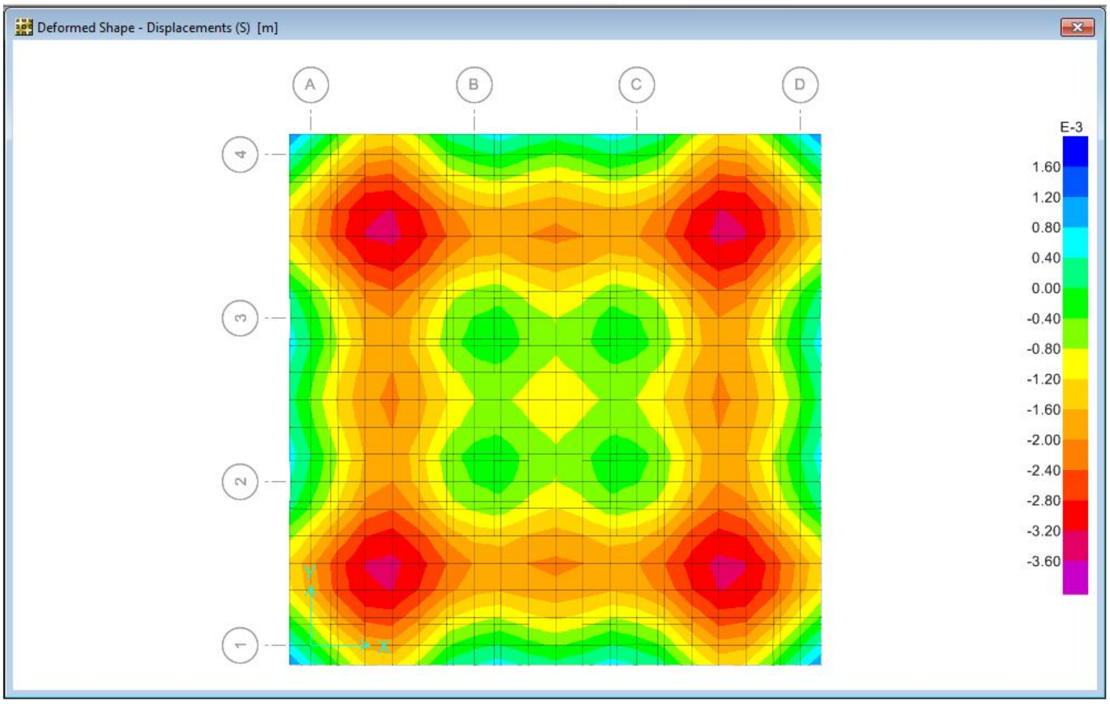


❖ Dead & Live Load

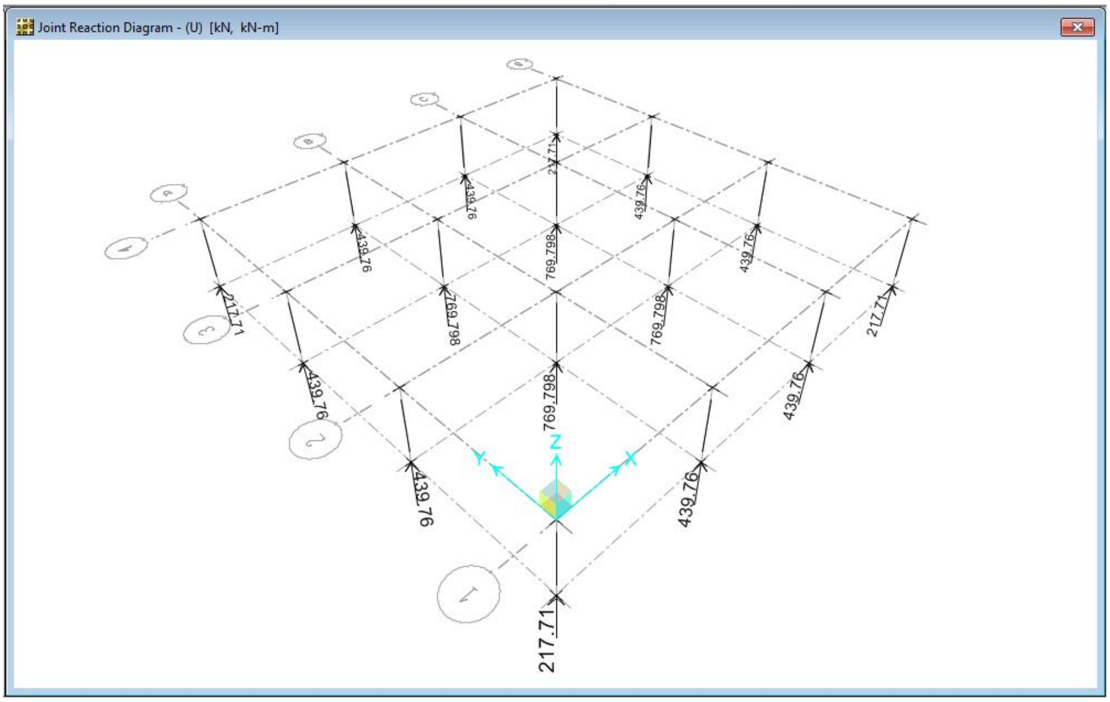




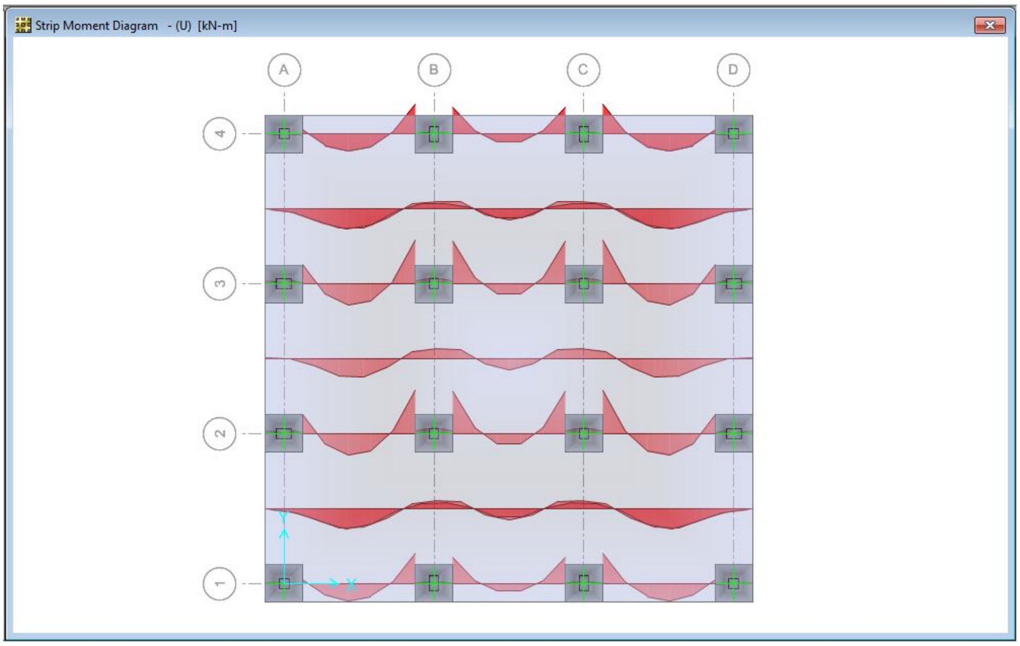
❖ Deformed Shape:



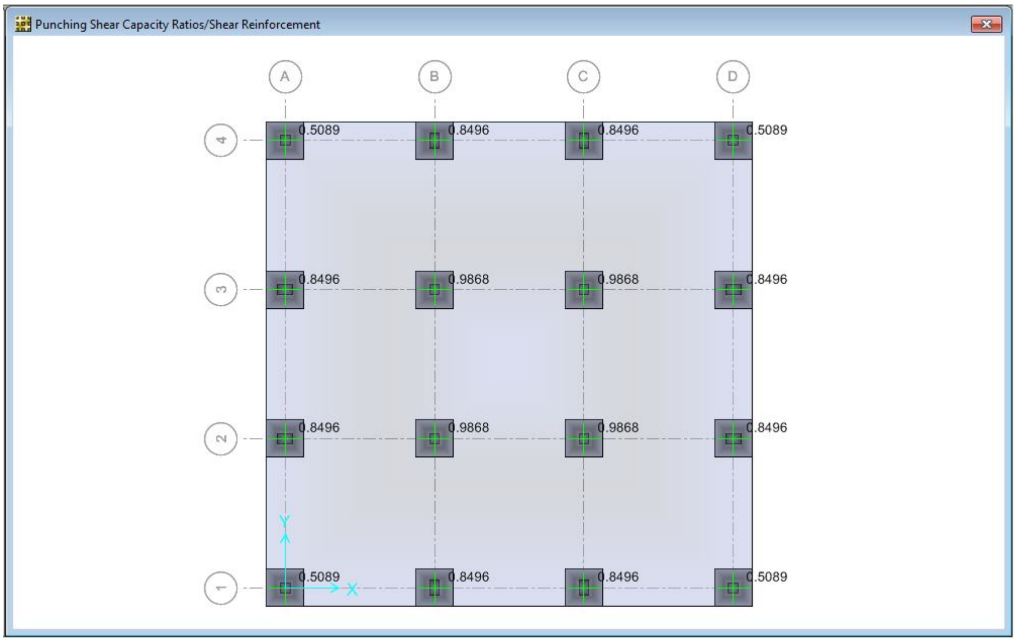
❖ Joint Reactions:



❖ Strip Moment:

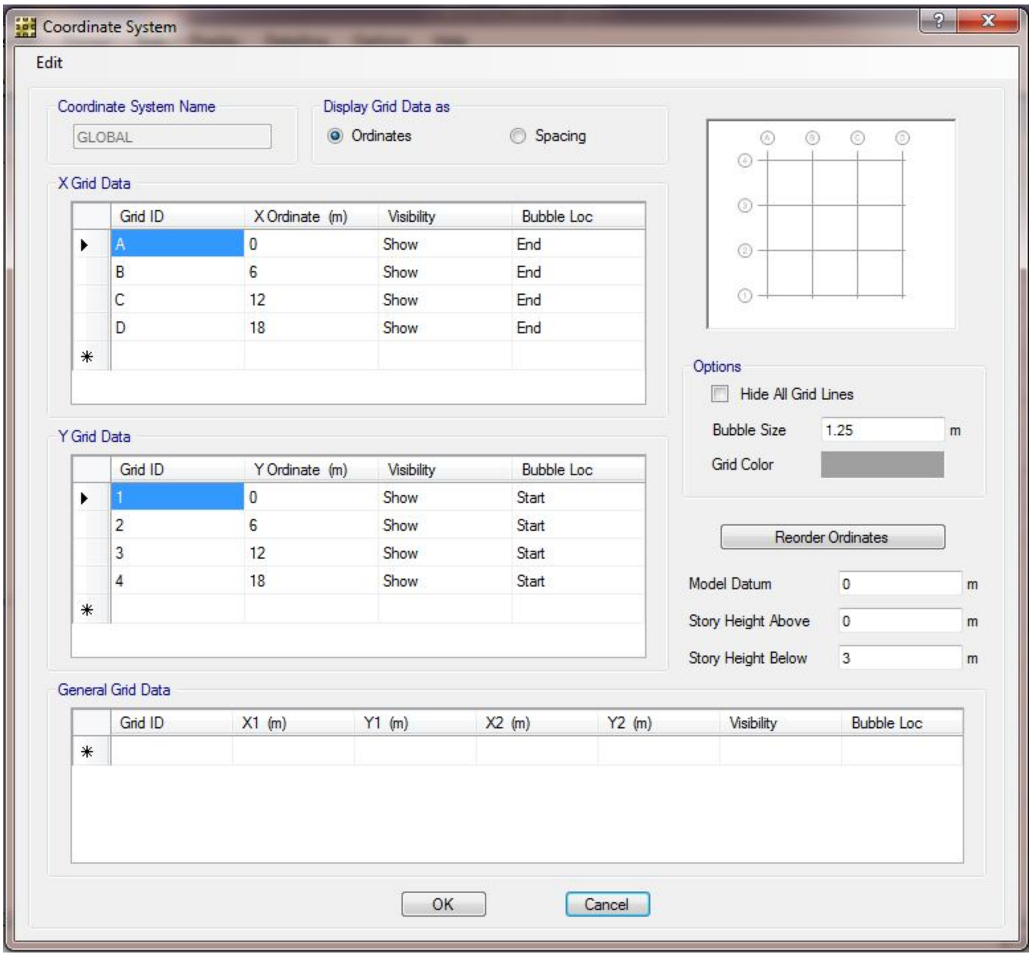


❖ Punching Shear Capacity Ratios:

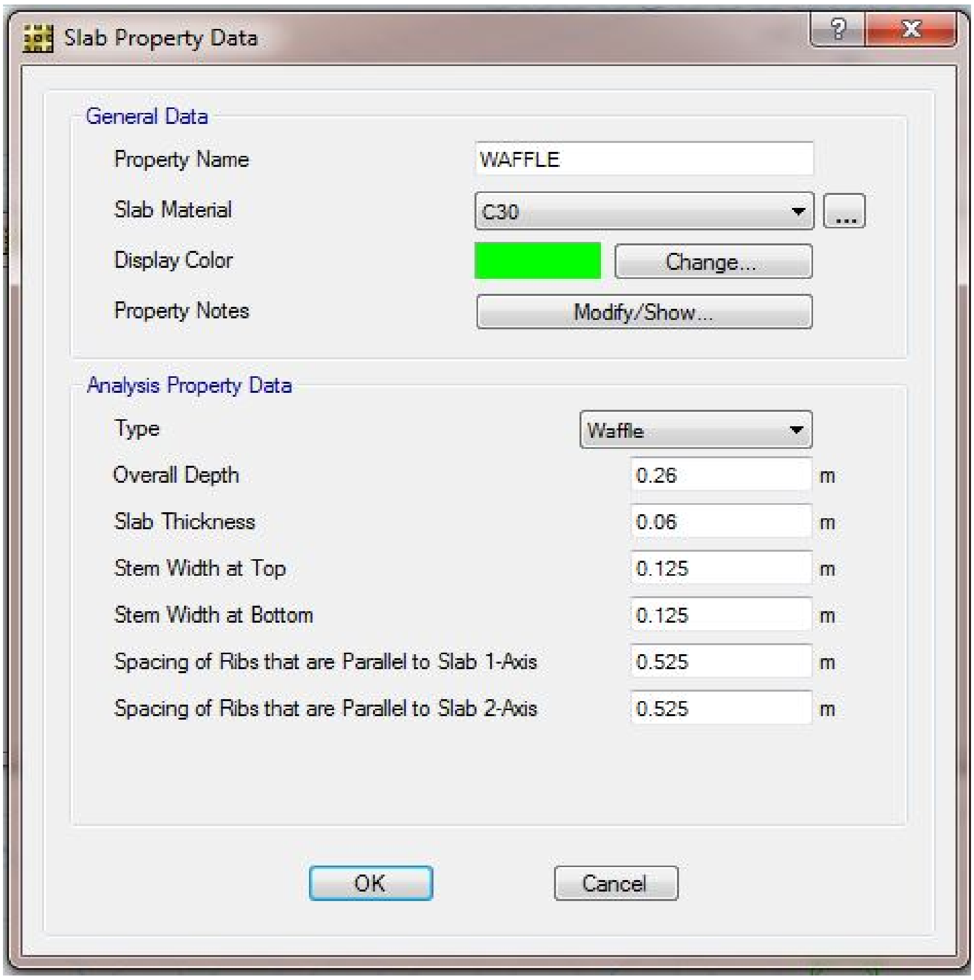


APPENDIX B: Waffle slab analysis using SAFE program

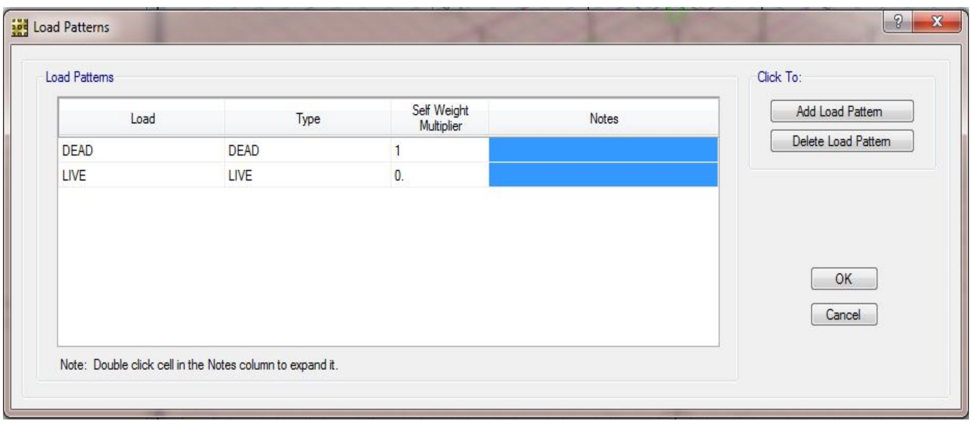
❖ Coordinate System:



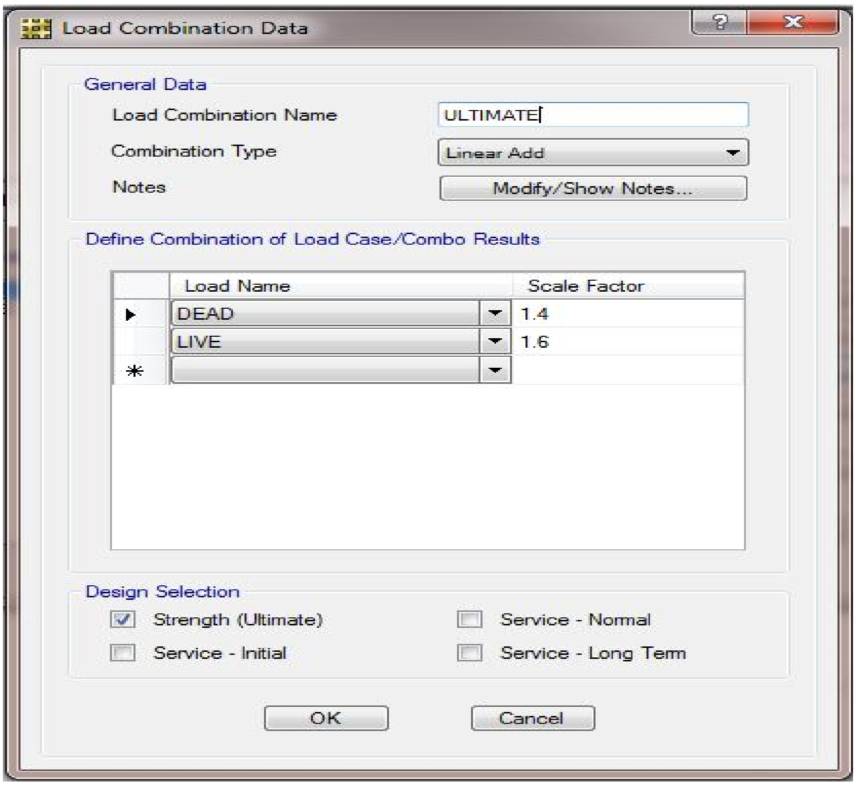
❖ Waffle Slab Properties:

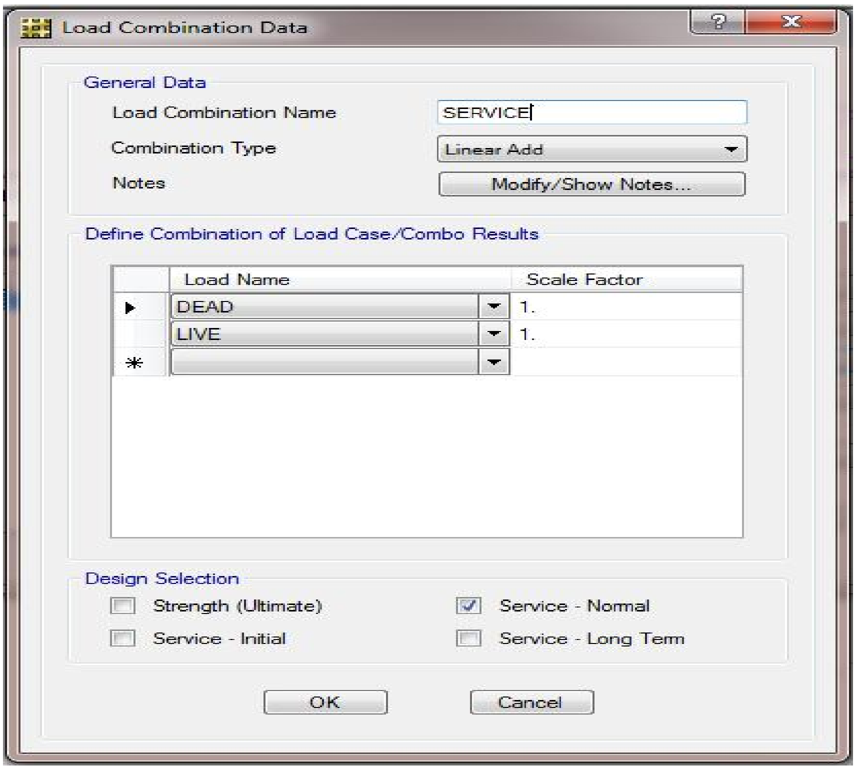


❖ Load Pattern:

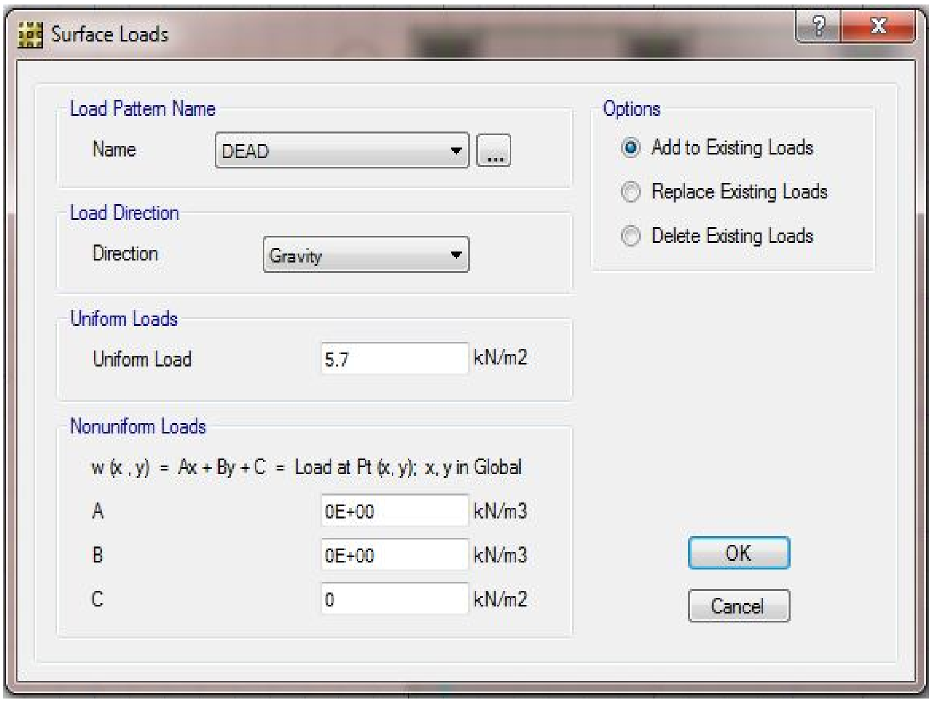


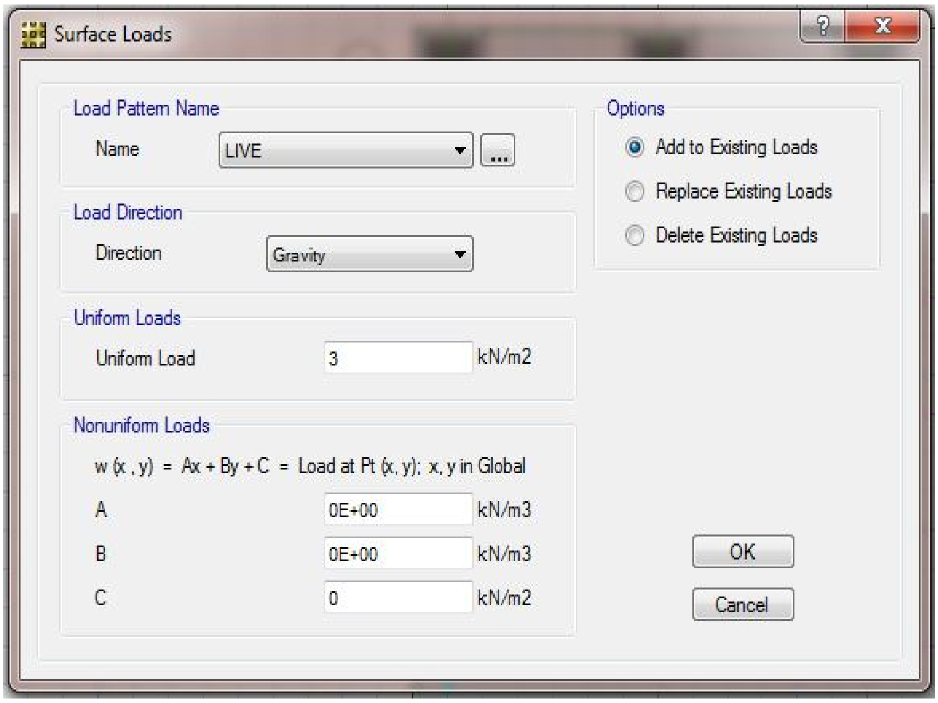
❖ **Load Combinations:**



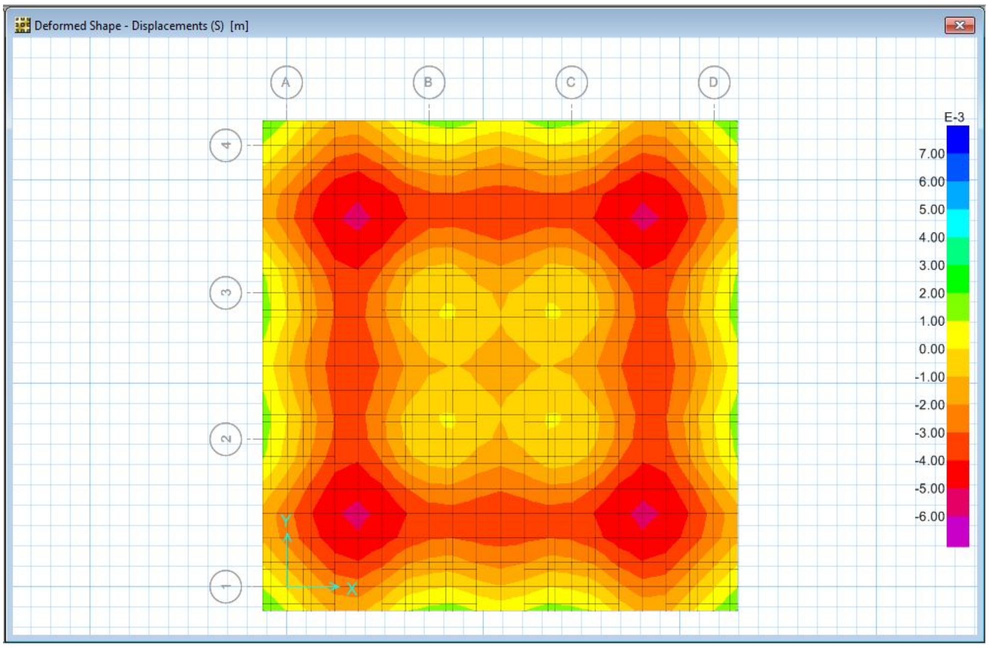


❖ Dead & Live Load:

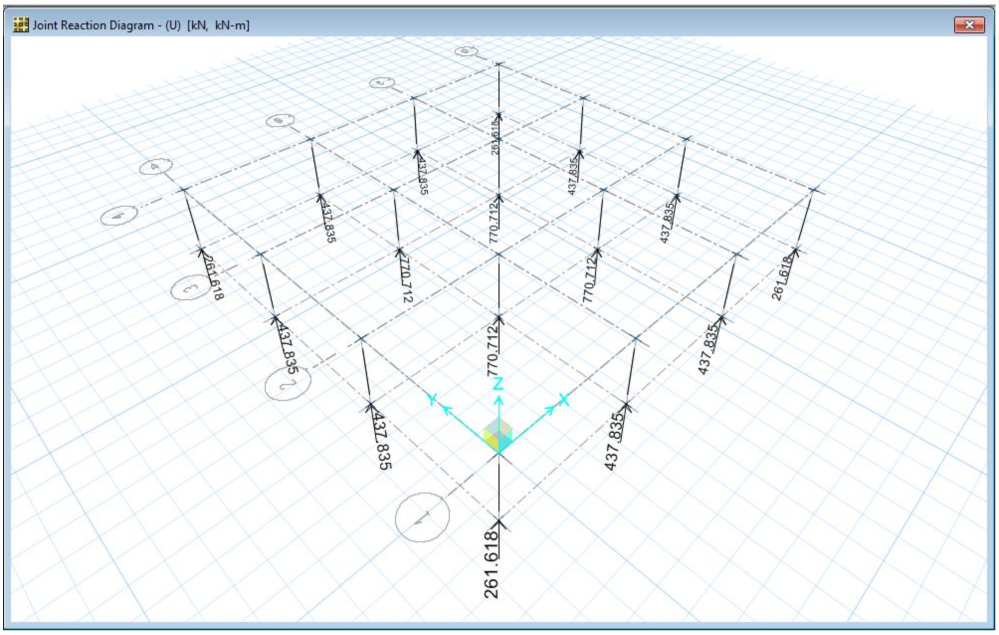




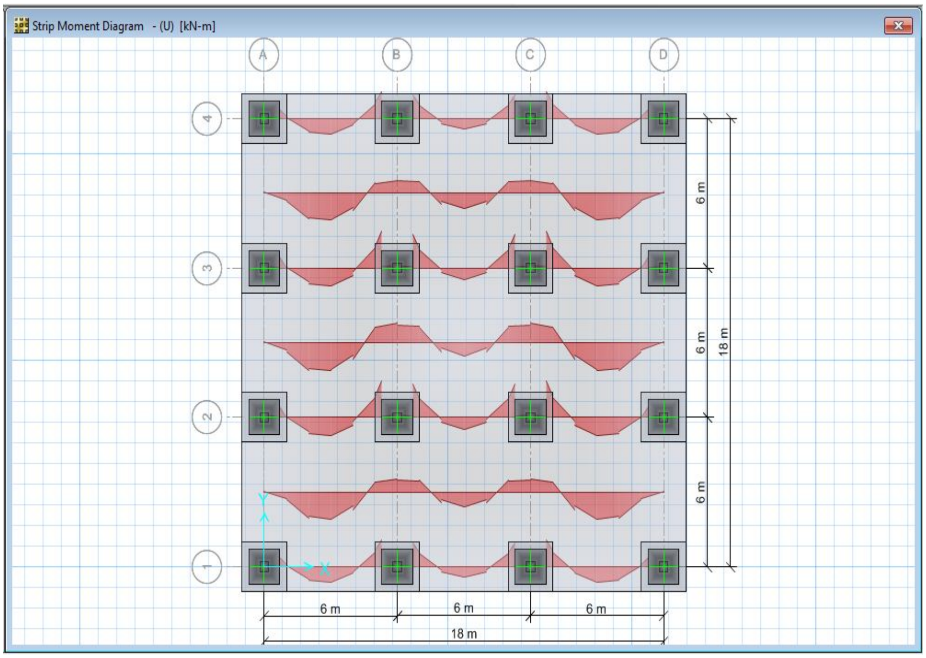
❖ Deformed Shape:



❖ Reactions:



❖ Strip Moment:



❖ Punching Shear Ratios: