Preface to Second Edition

The first edition of this book came out of press on 26 June 1999 and it is now exhausted. The second edition is therefore being brought out to meet the demands of the profession.

Two extra chapters have been added in this edition giving aspects of structural design with emphasis on the new reinforced concrete code IS: 456-2000. Further, appendix II has also been added giving twenty four useful tables, chapter wise, which will be of benefit to structural designers in their day-to-day office work.

The text of the book has been thoroughly checked by my engineer friend Lt. Col. G.L. Sethi (MES, Retd) and corrections have been made wherever needed. I am grateful to him for his interest and efforts.

The book is humbly dedicated to the profession of structural engineering.

New Delhi
1 January 2002

Preface to First Edition

Having spent my entire professional life in the structural design of reinforced concrete buildings, I wish to share my knowledge and experience with the profession of Structural Engineering, in the form of this book.

The book consists of seventeen chapters. Chapter 1 is of a general nature and it serves to introduce the subject matter of the book. Chapter 2 gives vital information on structural systems for buildings, while chapters 3 and 4 give details of types of floors and stairs respectively. Design of masonry buildings, a topic which generally goes by default, is given in chapter 5. The core of the book is given in chapters 6 to 9, which deal with framed and shear-walled buildings under vertical and horizontal loads. Chapter 10 introduces the reader to space structures in their application to sloping roofs. Foundations of buildings are covered in Chapter 11. Chapter 12 again touches a vital aspect of design of reinforced concrete elements and it gives the material which can be considered as additional to my earlier book 'Manual for Limit State Design of Reinforced Concrete Members'. Detailing of reinforced concrete elements is given in chapter 13. Practical considerations like economy in building design and precautions in construction and site supervision are covered in chapters 14 and 15 respectively.

Chapter 16 gives a rare study of structural failures. Finally, steps in design , followed in design office practice, are given in the last chapter 17, together with the present stage of computer applications in the structural design of buildings. The text is interspersed with 32 numerical examples, 253 figures and 23 tables. The references studied during the preparation of the book are given in Appendix I and their numbers are noted within the text of the book. The notation is not given separately, it is rather explained where the symbols first appear in the text.

What is unique about this book is that the material otherwise spread in various technical journals and books is collected at one place and the subject matter is presented in the way as it is followed in a design office. There are not many books on the subject of structural design of multi-storeyed buildings, rather chapters on this subject can be found in many publications. So, a comprehensive book on this subject was called for and this book is expected to fill up the need of the profession of structural engineering.

I am highly obliged to my senior colleague Mr. J.D. Buch for his encouragement and advice in this venture and for the efforts put in by him in reviewing the entire manuscript and giving valuable suggestions for the improvement of the subject matter of the book. Heartfelt thanks are due to my colleagues – both engineers, draftsmen and typists – in the office who have been enthusiastically helpful in the preparation of the manuscript. Special thanks are due to Mr. Rajesh Kumar, Senior Structural Draftsman, for his willing help in the preparation of neat and clear figures and tables.

The acknowledgment of thanks will not be complete without the mention of my dear friend and a excellent engineer Mr. P.L. Assudani who is the co-author of the two papers published in the sixties which form the core of this book.

This book is humbly dedicated to the profession of structural engineering, with a hope that it will prove to be of immense benefit to all the readers, in the fact that it will give a second and considered opinion on most of the problems involved in the structural design of buildings.

New Delhi- U.H. VARYANI
13th April 1999

CHAPTER 1

Introduction

1.1 NEED OF MULTI-STOREYED BUILDINGS

Most of the existing buildings are multi-storeyed, in the sense that 'multi-storey' means more than one storey. Single storey buildings may comprise of workshops, factory sheds, cinema halls, auditorium, etc. Even ordinary residences can be thought of as multi-storeyed buildings as presently ordinary residences are allowed to be built of two and a half storeys. With increasing pressure of population, commerce and trade, land costs in cities have risen very high. Often, there is no other alternative except building high on a given plot of land. Educational and commercial buildings are, in general, eight storeys high with lifts provided. Without lifts, a building has to be less than or equal to four storeys in Delhi, but not more than five storeys in Bombay. These restrictions are imposed by the city bye-laws, keeping in view the pressure on the services like roads, water, electricity and sewage disposal. Some buildings are made extraordinarily tall out of prestige. For example, Delhi Development Authority's Vikas Minar is a 23-storey tower, while Hansalaya at Barakhamba Road in New Delhi, is a 22-storey building. Urban Arts Commission is one of the agencies which control the building height or the number of storeys of buildings in Delhi and New Delhi. Similar controls are exercised in all major cities in India.

1.2 STRUCTURAL MATERIALS FOR BUILDINGS

Traditionally, buildings have been built in brick (or stone) and mortar and also in timber in certain areas, where wood was available in plenty. Presently, wood has become scarce and prohibitively costly. Small buildings, particularly residences, are ideally built with load bearing brick walls. The horizontal members like slabs are built in reinforced concrete. In certain areas, brick walls may be replaced by random stone masonry walls, but these occupy more space in plan. Brick walls are, in general, 230 mm thick in plan, while stone walls may be 300 mm to 450 mm thick in plan. Concrete blocks, hollow or solid, are also available in the market, but these have not caught on for certain practical reasons, like difficulty in making notches for electrical conduits, etc.

In framed buildings, structural steel and reinforced concrete are the two alternative materials. Structural steel frames were previously used in Calcutta area for multi-storeyed buildings. But now, for reasons of economy, reinforced concrete has replaced structural steel in the construction of multi-storeyed buildings of medium height. With the introduction of shear walls and shear cores, reinforced concrete systems are working out well for tall buildings as well. Further, a reinforced concrete structure has better fire resistance than that of a steel structure. So, in the present scene, brick and reinforced concrete are the two most prevalent structural materials in building construction.

1.3 LOADS

1.3.1 Vertical Loads

Structurally speaking, buildings are built to support loads. The load, which is ever present and ever acting on a building, is the dead load which consists of the self-weight of members, finishes, plaster, etc. Dead load should be calculated very accurately, as it comprises most of the building load. IS:1911-1967[1]* gives a schedule of unit weights of building materials and it is used extensively to calculate the dead load.

Next in importance to dead load, is the live load, which is caused by the use of building. Live loads are given in IS:875.[2] Live loads are generally high (150 kg/m^2 to 1000 kg/m^2) on floors depending on the activity that is carried on there, while it is of a low value (75 kg/m^2 to 150 kg/m^2) on a roof, which may or may not be accessible. Snow loads on roofs in hilly areas are also specified in IS:875. In snow-incident areas, roofs are to be made sloping so that snow cannot get accumulated to a great height. IS:875 gives the loading due to snow at 2.5 kg/m^2 per cm depth of snow. With 30 cm snow depth, the snow loading will work out to be 75 kg/m^2, which may be reasonable for sloping roofs.

Partition loads are also important to be considered. Wooden or similar light-weight partitions anywhere on a floor give a general loading of 100 kg/m^2 of floor area. But in most buildings, 115 mm thick brick walls are arranged to divide space, this gives a heavier loading on the floor. IS:875[2] gives the partition walls loading at one-third the weight of 1.0 m run of the partition wall. For 115 mm thick brick walls of 3.0 m height anywhere, the equivalent loading works out to be $(0.115 \times 1.0 \times 3.0 \times 1900)/3 = 218.5$ kg/m^2 of the floor area. For 230 mm thick brick walls, we generally take care to provide beams to support directly such walls. In multi-storeyed buildings, 115 mm

* The numerals refer to the serial number of references given in Appendix I at the end of the book.

thick brick walls anywhere add substantially to the load of the building and it affects the design of slabs, beams, columns and footings too. But in the present practice, for flexibility in the use of the building, this provision is made in most buildings and wherever possible, 115 mm thick brick walls should be replaced by wooden partitions to achieve lighter partition loading, which finally leads to economy in structural design. In practice, wooden partitions are provided in office buildings, while in hospitals and institutional buildings , 115 mm thick brick walls are used as partition walls.

1.3.2 Temperature and Shrinkage Loading

Temperature and shrinkage also act on a building and these can also be regarded as a load on it. Shrinkage is equivalent to –15 °C, where negative stands for fall of temperature.[3] The temperature differential is taken at $\pm\frac{2}{3}(t_1 - t_2)$, where t_1 and t_2 are the maximum and the minimum temperatures observed in a day (24 hours) for a given place or locality.[4] Fall of temperature together with shrinkage will govern the design, while the rise of temperature will be substantially reduced in effect by the action of shrinkage. The design temperature differential is given by the Indian Road Congress[5] at ±17 °C for moderate climates and at ±25 °C for extreme climates. The combined effect of temperature and shrinkage is given below:

For moderate climates: $\pm 17 - 15 = +2, -32$ (°C)
For extreme climates: $\pm 25 - 15 = +10, -40$ (°C)

IS:456 1978[6] (hereafter called simply the Code) states in its clause number 17.5.1 that "in ordinary buildings, effect due to temperature fluctuations and shrinkage and creep can be ignored in the design calculations". It is, however, not explained,[7] what is meant by an ordinary building. It is, of course, clear that temperature and shrinkage loading has an effect on the design of long concrete buildings,[8] which can be neglected if the length of building is restricted to 45 m (clause 26.3 of the Code). Thus, it can be surmised that temperature and shrinkage effect can be neglected in short-length buildings. It is also seen that by providing minimum specified steel percentages in concrete members, temperature and shrinkage effects can be absorbed in short-length buildings, while in long concrete buildings, these members have to be designed for this extra loading or a long building has to be cut up in two or more short-length buildings. Further, this loading can be made use of in the evaluation of the gap of an expansion joint.[8]

1.3.3 Wind Loading

Dead and live loads are vertical or gravity loads, while wind and earthquake cause horizontal loads on a building. Temperature and shrinkage also result in a horizontal load on a building. Blast effects, earth and water pressures also cause horizontal loads on a structure. IS:875 gives values of wind pressures varying from 100 kg/m^2 to 200 kg/m^2 acting on building upto a height of 30 m above the mean retarding surface, i.e. the mean level of the adjoining ground. For buildings of height upto 10.0 m, these wind pressure values can be reduced by 25%.

1.3.4 Earthquake Loading

Details of earthquake loading are given in IS:1893.[9] India has been divided into five zones with basic horizontal seismic coefficient (α_0) varying from 0.01 to 0.08. The base shear (V_B) is given by

$$V_B = C\alpha_h KW \tag{1.1}$$

where,

C = coefficient defining the flexibility of structure, which depends on the time period of the building, which in turn, is a function of number of storeys

α_h = design seismic coefficient = $\beta I \alpha_0$

K = performance factor which is equal to unity for reinforced concrete framed building with detailing taking into account the requirements of ductility

W = total dead load + appropriate amount of live load (25% to 50% LL)

β = coefficient depending on the soil-foundation system (varying from 1.0 to 1.5)

I = coefficient depending upon the importance of structure varying from 1.0 to 1.5 for buildings

α_0 = basic horizontal seismic coefficient depending upon the zone in which the locality in question falls.

$$= \frac{a}{g} = \frac{\text{design acceleration in horizontal direction due to earthquake}}{\text{acceleration due to gravity}}$$

The vertical basic seismic coefficient is half the value of α_0. It has, in general, no effect on the structural design of buildings. All buildings, whether short or tall, shall be checked for horizontal effect of earthquake loading.

1.3.5 Blast Loading

In certain coalmine areas, where open cast methods of mining are used, blast is of regular occurrence. Buildings in these areas must be designed for blast effects. IS:6922[10] gives the blast effects,

$$\frac{a}{g} = \frac{\text{design acceleration in horizontal direction due to blast}}{\text{acceleration due to gravity}}$$

$$= K_2 \frac{Q^{0.83}}{R^2} \tag{1.2}$$

where, $K_2 = 4$

Q = charge per delay in kg

R = distance of structure from blast point in metres.

The calculated a/g value for blast may be taken as a fraction of earthquake effect given by α_0. The building can be analysed for, say, earthquake and then the blast effect can be evaluated by applying this fraction on the values obtained from the earthquake analysis. For a locality with α_0 = 0.04, Q = 20,000 kg, R = 1200 m, Eq. (1.2) gives,

$$\left(\frac{a}{g}\right)_{\text{blast}} = 4 \times \frac{(20{,}000)^{0.83}}{(1200)^2} = 0.01$$

This indicates that the blast effect is equivalent to (.01)/(.04) = .25, i.e. one-fourth the earthquake effect, in this particular case.

1.3.6 Impact

Live loads given in IS:875 include the effect of impact and this is clearly mentioned in clause 3.1.1 of this code. But for a moving machinery, these loads should be increased by an allowance varying from 20% to 100%, as per clause 3.4. In a lift machine room above the roof of a multi-storeyed building, we generally consider a live load of 1000 kg/m^2 together with an impact allowance of 100%, giving a load of 2000 kg/m^2.

1.3.7 Earth and Water Pressures and Surcharge Loads

These loads act on a retaining wall. In Fig. 1.1, a basement retaining wall is shown under the action of these loads. The base pressures acting on a retaining wall are given as under

$$p_e = \text{earth pressure} = \frac{1 - \sin\phi}{1 + \sin\phi} \gamma h \tag{1.3}$$

$$p_w = \text{water pressure} = w h' \tag{1.4}$$

$$p_s = \text{surcharge pressure} = \frac{1 - \sin\phi}{1 - \sin\phi} w_s \tag{1.5}$$

where, ϕ = angle of repose of earth

γ = unit weight of earth

w = unit weight of water

w_s = surcharge loading = 500 kg/m^2 for pedestrian traffic
= 1000 kg/m^2 for vehicular traffic
h = height of the earth retained
h' = height of the subsoil water retained

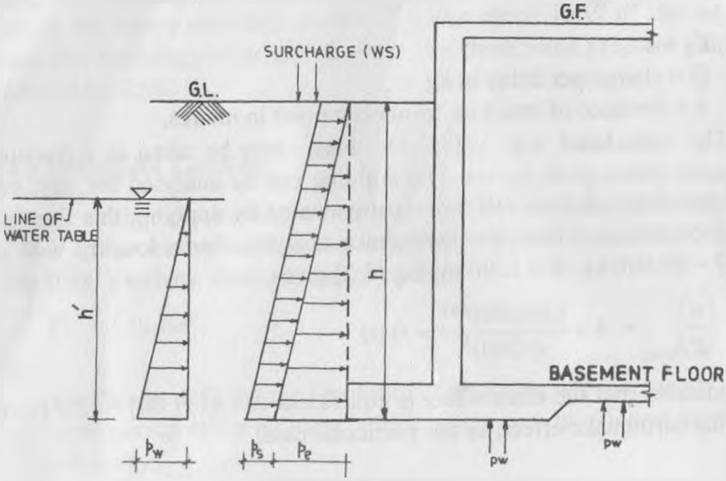

Figure 1.1. Pressures on a basement retaining wall.

1.3.8 Load Combinations

The load which is ever acting on a structure is the dead load which includes the load of partitions also. Then the effect of live load, which may vary in intensity from 0 to 100% of its value, is additive to the effect of the dead load, as both these loads are gravity or vertical loads. So, the structures should be designed by the limit state method for the dead and live load combination and it is given by the Code as

$$U = 1.5(D + L) \qquad (1.6)$$

Then, horizontal loads of wind, earthquake and temperature will act on the building. It is assumed that the worst effects of the above three loadings will not coexist at the same time. Further, it is assumed that the worst effects of these loadings will act only for a short while on a building so that its load factor can be reduced by 25% (or allowable stresses in materials are increased by 33.33% in the working stress method, resulting in the same effect). Hence, the next load combination for checking the structure is given by the Code,

$$U = 1.2\ (D + L \pm W \text{ or } E \text{ or } T) \qquad (1.7)$$

where the value of 1.2 is derived from $0.75 \times 1.5 = 1.125$ or 1.2 and ± sign is added to take care of the reversal of direction of horizontal loads. For checking overturning of certain isolated tall structures, live load in equation (1.7) may be made zero and 10% reduction may be made in the dead load to account for any inaccuracy in the calculation of the dead load. This will give the following load combination for isolated tall structures,

$$U = 1.2(0.9D \pm W \text{ or } E \text{ or } T) \tag{1.8}$$

For inclusion of the blast effect in structural design, we consider a load factor of 1.5 for blast loading, as it occurs frequently in the open-cast mining areas. So, for such areas, the governing load combination, in addition to those given above, is also,

$$U = 1.5\,(D + L + B) \tag{1.9}$$

Also, it is assumed that the worst effect of blast will not take place together with the worst effects of earthquake or wind or temperature. The notation in Eqs. (1.5) to (1.9) is explained below.

U = ultimate load
D = dead load
L = live load
W = wind load
E = earthquake load
T = temperature and shrinkage load
B = blast load

The above write-up is our explanation of Table 12 of the Code, which gives the relevant load combinations for structural design. The reader may take note of the changes called for in Table 12 of the Code, in the light of above explanation.

1.4 BUILDING – A RESULT OF COMBINED EFFORTS OF SEVERAL PROFESSIONALS

A client is one who has the necessary motivation and capital to make a building either for his own use or for sale. He engages an architect to prepare an architectural scheme and drawings and get these approved from the local municipal authority and these drawings form the basis on which the other professionals like structural, estimating, plumbing, electrical and airconditioning engineers work to prepare their own drawings and estimates. An architect is primarily concerned with the function and the area utilization of building. He takes care of the visual look of the building, its orientation and its position in the surrounding area. The structural engineer is to take care of the safety of the structure and he is to devise ways to support all the loads coming on the building in the most economical way. He is concerned with the design of both the superstructure and the sub-structure (i.e. foundations). A structural engineer is called upon, at an early stage, to work in close collaboration with the architect, to decide the structural grid and the sizes of structural members. An estimating civil engineer is also associated to prepare estimates and tender documents. After the tenders are called, these are compared and the client awards the work of construction of building to a contractor selected from the tenderers.

The role of the contractor and his engineers is of paramount importance in the construction of building. They have to ensure that the work at the site is carried out in accordance with the working drawings of the architect, the structural and other professional engineers. To supervise the work of the contractor, a separate agency or an individual (called clerk of works) is appointed, who coordinates the work of the several agencies at the site and ensures quality and timely completion of work at the site. The author has the highest regard for the work of contractor's site engineer, as he has to construct the building from both the architectural and the structural drawings. In cast-in-situ construction, there may remain, in practice, some gaps in these two sets of drawings and the site engineer, with the help of the clerk of works, closes up these gaps, reconciles these differences and gets the building constructed. The best site engineer is one who consults the architectural and the structural staff and with proper coordination, completes the building in accordance with the drawings. There are some site engineers who arrogate to themselves the powers of the design staff and these engineers, sooner or later, come to grief.

In some unusual structures, specialists or academic staff may be required to be associated with the structural design for consultation and/or checking as per the need. Further, the architect plays an initiatory, coordinating and controlling role and he is, thus, rightly called as the leader of the team of professionals involved in the design and construction of a building. Finally, it should be rightly understood that a building is the net result of the combined efforts of several professionals involved in the building industry.

CHAPTER 2

Structural Systems for Buildings

2.1 INTRODUCTION

Choice of an appropriate structural system for a given building is vital for its economy and safety. It is an important decision which is to be taken by a senior structural engineer. Small buildings like houses, etc. generally use load bearing brick walls with reinforced concrete floor slabs. For taller buildings, reinforced concrete frames in both the principal directions are provided with brick walls used as only filler walls. For still taller buildings, frames with shear walls will be provided to resist both the vertical and the horizontal loads. Likewise, more intricate and innovative structural systems may be thought of, in the case of unusual buildings. We describe below the various structural systems commonly used in buildings of different types.

2.2 LOAD BEARING MASONRY BUILDINGS

Houses, hostels and similar small buildings are built with load bearing brick walls with floor slabs being cast in reinforced concrete. This system is suitable for buildings upto four storeys or less in height (Fig. 2.1). It is quick in construction and economical in cost. However, care shall be taken to arrange walls over walls in plan and openings in walls shall be restricted. Bricks shall be of a crushing strength of 100 kg/cm^2 minimum for four storeys, but this value can be 75 kg/cm^2 for two storeys or less. Brick walls with reinforced concrete floor slabs are adequate for vertical loads. This system also serves to resist horizontal loads like wind, earthquakes or blast, by way of box-action in plan. Further, to ensure its action against earthquake, it is necessary to provide horizontal bands and vertical reinforcement in brick walls as per IS: 4326.[11] In some buildings, 115 mm thick internal walls in brick are provided. As 115 mm thick walls are incapable of supporting vertical loads, beams have to be provided along their lengths in order to support the adjoining slab panels and the weight of 115 mm thick brick walls. These beams are to rest on 230 mm thick walls or reinforced concrete columns if required, resulting in a mixed system of load bearing brick walls with reinforced concrete columns wherever necessary. IS: 1905[12] is the code governing the design of brick wall structures.

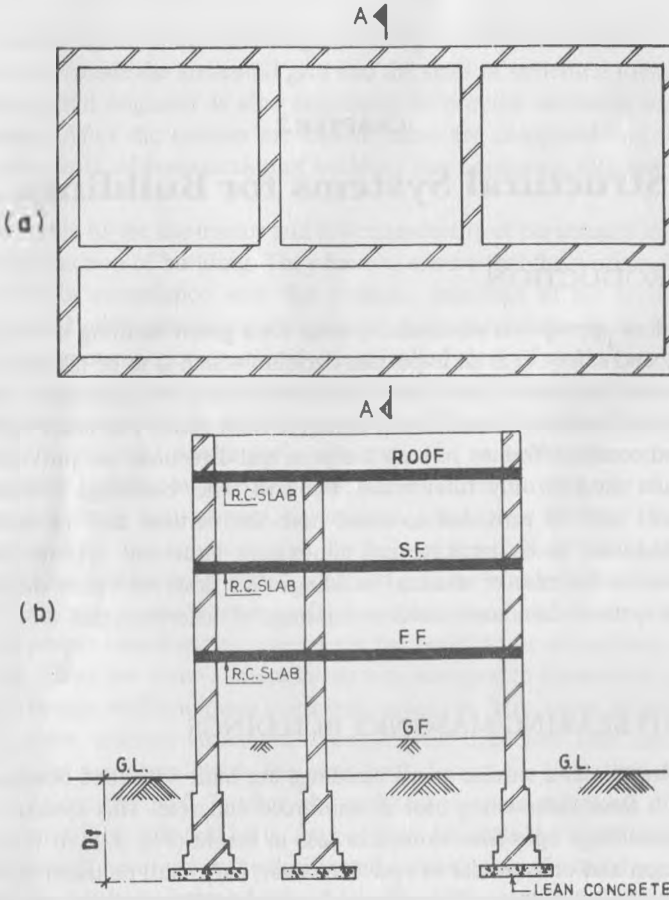

Fig. 2.1. Structural system consisting of load bearing brick walls. (a) Plan of buidling; (b) Section A-A.

2.3 TWIN SYSTEM OF BRICK WALLS AND REINFORCED CONCRETE COLUMNS

In this system, vertical load is to be resisted by beam-column system and the horizontal loads are to be resisted by brick walls by way of box-action in plan (Fig. 2.2). In this system, column sizes are restricted to, say, 230 mm × 230 mm. Beams are designed as continuous beams on knife-edge supports, i.e. columns being flexible, carry only vertical load and no moment. This system is suitable for four storeys for apartment buildings, the limitations being, firstly, 230 mm × 230 mm column capacity may be fully utilized for the storeys indicated and secondly, the box-action of brick walls under horizontal loads may be fully utilized for the height of four storeys. Beyond four storeys, undesirable stresses may develop in masonry walls due to horizontal loads. This system is suitable where 115 mm thick walls may be required to afford greater use of the covered area and where rooms are large, in which case, system of Fig. 2.1 of load bearing brick walls will require excessively thick walls, restricting optimum use of the covered area. This is an innovative structural system, leading to great economy, where applicable.

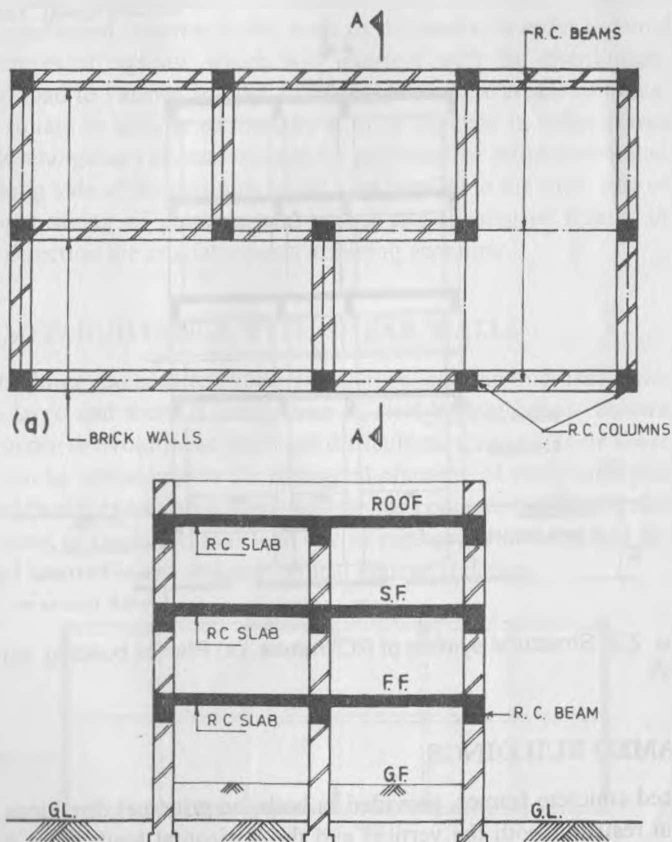

Fig. 2.2. Twin system of brick walls and RC columns. (a) Plan of building; (b) Section A-A.

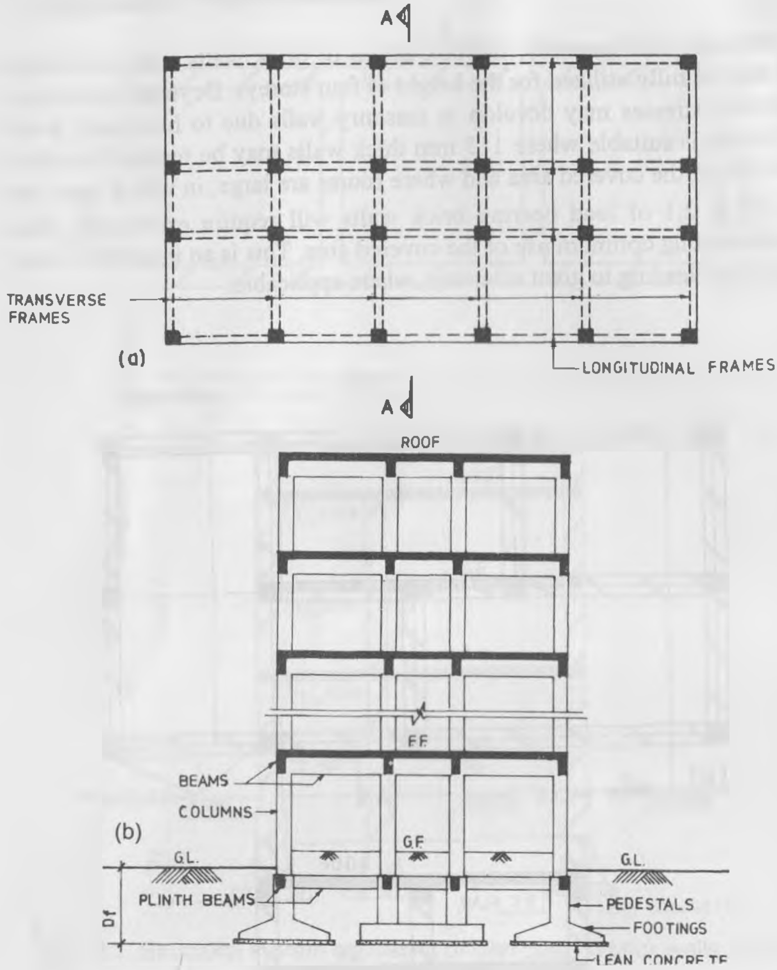

Fig. 2.3. Structural system of RC frames. (a) Plan of building; (b) Section A-A.

2.4 FRAMED BUILDINGS

Reinforced concrete frames, provided in both the principal directions, are effective in resisting both the vertical and the horizontal loads (Fig. 2.3). The brick walls are to be regarded as non-load bearing filler walls only. The spacing of frames varying from 4.0 m to 7.0 m or more (7.0 m is relevant for hospital buildings) is closely related to the function of building. The slab thickness should be as close to 100 mm as possible. This can be achieved by providing subsidiary beams in addition to the frame beams. The finishes and the partition walls should be kept light in weight. This is important for multi-storeyed buildings in order to reduce the dead load. This system is suitable for buildings of more than four storeys. But, in certain blast-or earthquake prone areas, even single or double storey buildings are made framed structures for reasons of safety. Single storey buildings of large storey heights (5.0 m or more), like electric sub-stations, etc. are also made framed structures, as brick walls of large height are slender and these may not be relied on to support vertical loads.

When the lifts are provided, the optimum number of storeys is eight, in order to make full use of lifts. For eight to twelve storeys, it is advisable to avoid all reinforced concrete walls, even for lift-wells, in order to avoid undesirable centres of rigidity, which will interfere with the distribution of the horizontal load to various frames. In earthquake prone areas, columns should be made square in size, as earthquake is to be checked in either principal direction. Rectangular columns should be provided in wind-dominated areas, with the long side of the columns being kept parallel to the short side of buildings. Proper sizing of columns and beams and spacing of frames in either principal direction are crucial aspects affecting economy.

2.5 FRAMED BUILDINGS WITH SHEAR WALLS

When a building exceeds ten to twelve storeys, column and beam sizes work out quite large and there is congestion of steel bars at beam– column junctions. In order to avoid these practical difficulties, shear walls or shear boxes or cores can be introduced in the structural planning of multi-storeyed buildings. Shear walls consume a great quantity of concrete but these relieve columns of most of the horizontal load due to earthquake or wind and in the net result, lead to an efficient and economical structural design.

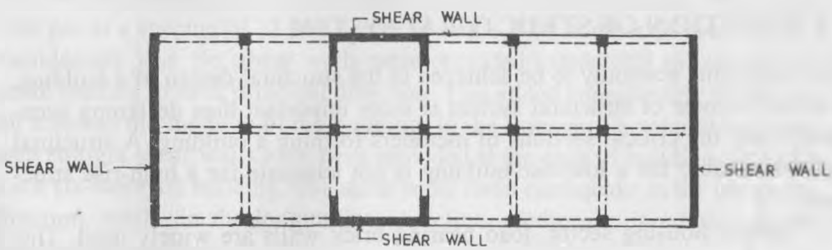

Fig. 2.4. Plan of framed building with shear walls.

Straight deep reinforced concrete walls may be provided at the ends of a building with lift walls and/or stair wells in the interior (Fig. 2.4). In general, shear walls shall be so arranged in plan as to attract as much vertical load as possible, for which, the nearby columns are to be omitted and the loads brought to shear walls by means of long-span beams.[13] This system is suitable for 10 to 20 storeys.

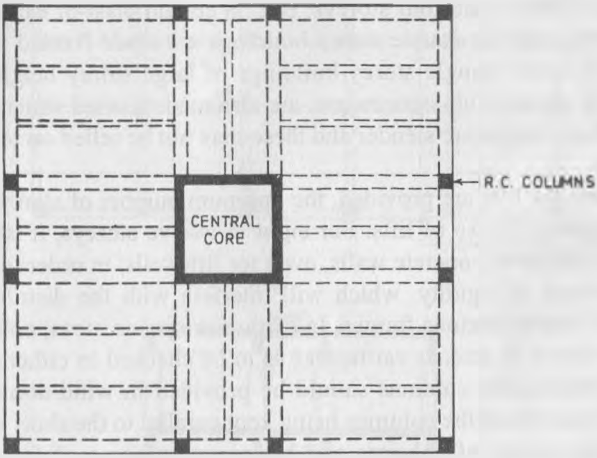

Fig. 2.5. Plan of framed building with central shear core.

A shear core (or box) housing lifts, toilets and other services may be provided preferably placed at the centre of the building. This system is suitable for 15 to 40 storeys (Fig. 2.5). In the upper range of storeys (say, 25 to 40 storeys), the core may require to be assisted by other shear walls either in the interior or on the periphery of the building – like four angular walls at corners or a system of closely spaced fins or grid on the periphery to act as a core-within-core system (Fig. 2.6).[14] For buildings higher than 40 storeys, multi-cored systems may have to be devised.[15]

2.6 SELECTION OF STRUCTURAL SYSTEM

For substantial economy to be achieved in the structural design of a building, a correct choice of structural system is more important than designing accurately only the critical sections of members forming a building. A structural system suitable for a low-rise building is not adequate for a high-rise structure.

In the housing sector, load bearing brick walls are widely used. This system is quick in construction and economical in cost. A mixed system of brick walls with reinforced concrete columns is also widely used. Reinforced concrete beam-column system for vertical loads and brick walls box-shaped in plan for horizontal loads are used upto four storeys. For buildings beyond four storeys, reinforced concrete framed structure is economically sound to resist both the vertical and the horizontal loads. With tall buildings, reinforced concrete frames are to be combined with shear walls and/or shear cores in order to get reasonable beam sizes and get reasonable steel consumption in buildings.

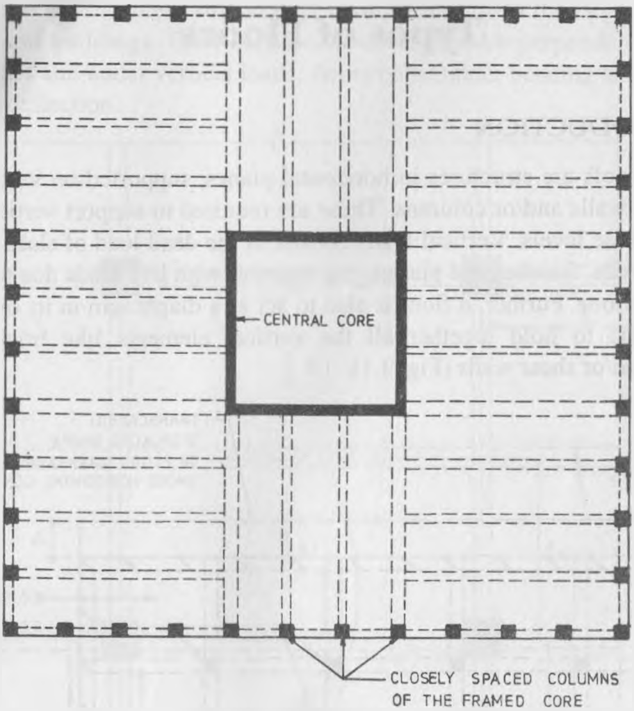

Fig. 2.6. Plan of building with a core-within-core system.

Inspite of the above general rules, striking variations may occur in practice. In the planning of a six-storeyed building with a basement, the frames were put at a spacing of 12.0 m centre to centre. The number of columns was considerably less. So, shear walls were provided extensively to resist earthquake loading in each principal direction. This added considerably to the cost but it suited the function of the building. In the Srinagar Secretariat building, deep straight shear walls have been provided at the ends of building, although it is a six-storeyed building. The shear walls resist earthquake in the transverse direction, while, in the longitudinal direction, earthquake is resisted by the longitudinal frames.

CHAPTER 3

Types of Floors

3.1 INTRODUCTION

Floors or roofs are structures in horizontal planes, supported on vertical elements like walls and/or columns. These are required to support vertical loads acting at these levels. Vertical loads consist of the dead load of slabs, beams, partition walls, finishes and plaster, etc. together with live loads due to the usage of the floor. Further, a floor is also to act as a diaphragm in its own horizontal plane to hold together all the vertical elements like brick walls, columns and/or shear walls (Fig. 3.1).

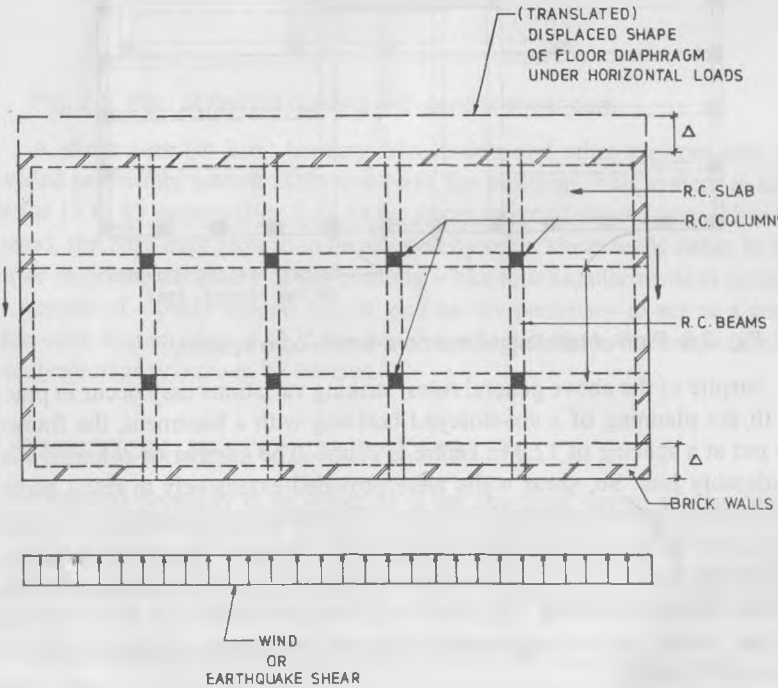

Fig. 3.1. Diaphragm action of floor.

This action is similar to the action of bracings at the eaves level in steel structures. This diaphragm action of a floor is, often, not appreciated. But it is basic to the integrity of the building as a whole, under horizontal loads like wind or earthquake, which are erratic in magnitude and direction.[16] The floor diaphragms are infinitely stiff in their own planes due to the large in-plan dimensions of buildings. The floors are, however, flexible perpendicular to their own planes and under vertical loads, floors come under bending and shear and undergo deflection.

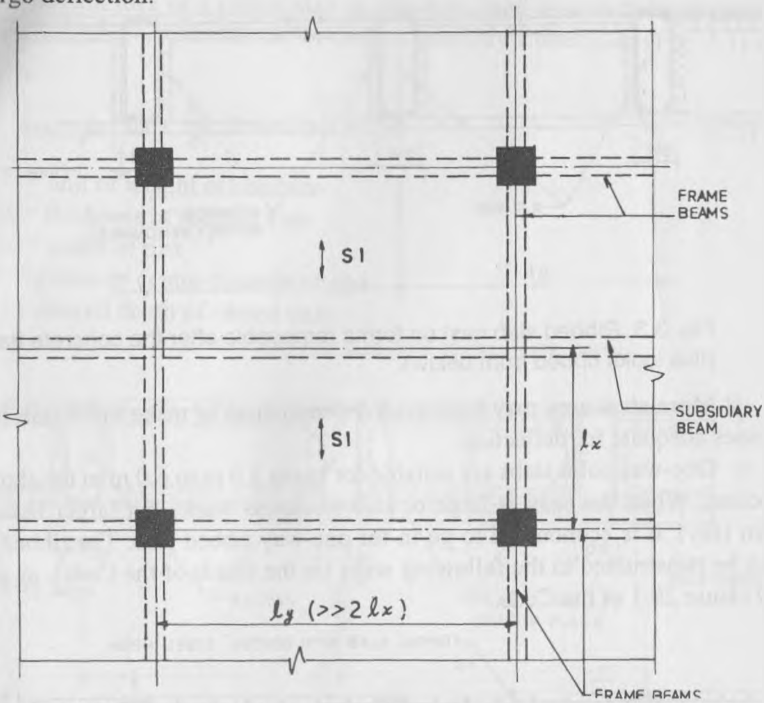

Fig. 3.2. Arrangement of one-way slab panels in a floor plan.

3.2 ONE-WAY SLAB SYSTEMS

Studies have shown that one-way slab systems resting on beams lead to economy, although the material is stressed in one direction only, the other direction being unstressed. Slab panels with $l_y/l_x \gg 2$, will be designed as one-way slab, in that, the load goes fully in the short direction (Fig. 3.2). Slab thickness is governed by deflection, while the steel area is governed by the bending moment at the centre of the short span (l_x). For general economy of structural design, slab thickness shall be kept as small as practicable, i.e. about 100 mm to 150 mm. Minimum slab thickness can be kept as given by IS: 456-1964.[3] For,

Single span one-way slab : $D = l/30$
Continuous one-way slab : $D = l/35$

where, l = span of one-way slab

D = over all depth of concrete slab

l_x = span in short direction

l_y = span in long direction

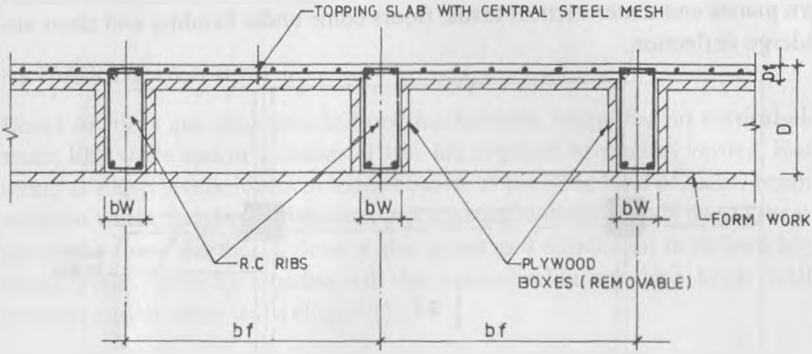

Fig. 3.3. Ribbed slab cast on forms removable after the concrete has set (this looks ribbed from below).

More steel area may be provided at mid-span to make these slab thicknesses adequate for deflection.

One-way solid slabs are suitable for spans 3.0 m to 6.0 m in the short direction. When the span is large or slab thickness works out larger than 200 mm (say), it is economical to go in for one-way ribbed slab. The ribbed slab can be constructed in the following ways (in the words of the Code), as given by clause 29.1 of the Code.

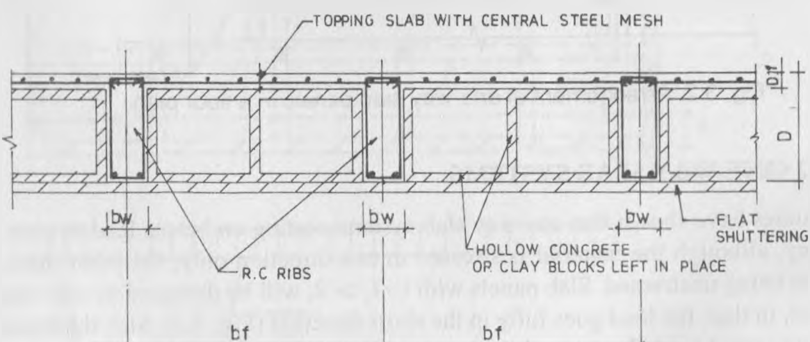

Fig. 3.4. Ribbed slab with precast blocks left in place (this looks flat from below).

a) As a series of concrete ribs with topping cast on forms which may be removed after the concrete has set (Fig. 3.3).

b) As a series of concrete ribs between precast blocks which remain part of the completed structures, the top of the ribs may be connected by a topping of concrete of the same strength as that used in the ribs (Fig. 3.4).

c) With a continuous top and bottom face but containing voids of rectangular, oval or other shapes (Fig. 3.5).

The main idea of a ribbed slab is to reduce dead load of the slab panel. The self-weight (w_s) per unit m^2 of area of one-way ribbed slab (Fig. 3.3) is given by,[17]

$$w_s = \rho_c \left[D_f + \frac{b_w}{b_f}(D - D_f) \right] \quad (3.1)$$

whre ρ_c = unit of weight of concrete
D_f = thickness of topping slab
b_w = width of ribs
b_f = centre to centre distance of ribs
D = overall depth of ribbed slab

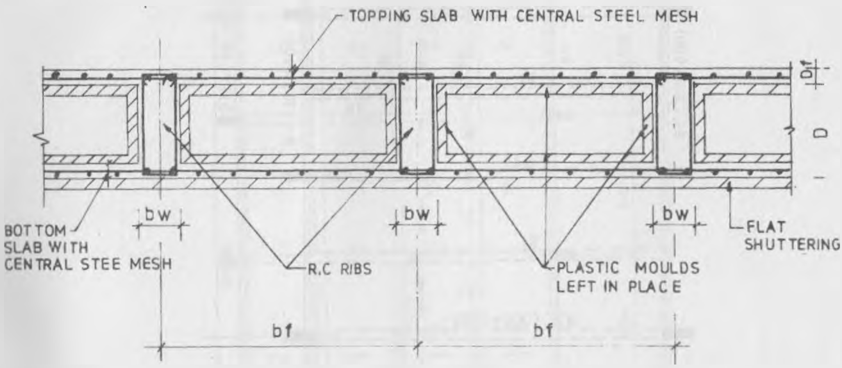

Fig. 3.5. Ribbed slab with continuous top and bottom slab (this looks flat from bottom).

This value of w_s should be less than the self-weight of the equivalent solid slab for the same span. This can be made clear by an example. Let l = 6.0 m. The solid slab thickness $D = l/30$ = 600/30= 20 cm. The self-weight of 20 cm thick slab = 0.20 × 2500 = 500 kg/m^2. With b_w = 0.15 m, b_f = 0.75 m, D_f = 0.05 m, D = 0.30 m and ρ_c = 2500 kg/m^3, the self-weight of the ribbed slab is given by Eq. (3.1),

$$w_s = 2500\left[0.05 + \frac{0.15}{0.75}(.3 - .05)\right] = 2500\,(.05 + .05) = 250 \text{ kg/m}^2$$

The proposed ribbed slab has a self-wieght of only 250 kg/m^2, while the solid slab will have a weight of 500 kg/m^2. This is the gain of adopting a ribbed slab in place of a solid slab. Clause 29.5 of the Code gives that $b_w \nless 65$ mm and $b_f \ngtr 1.5$ m. Also, it specifies that $(D - D_f) \ngtr 4\ b_w$. It is seen that for adequacy in deflection, depth of a ribbed slab shall be 25% to 50% more than the depth of the solid slab for the same span.

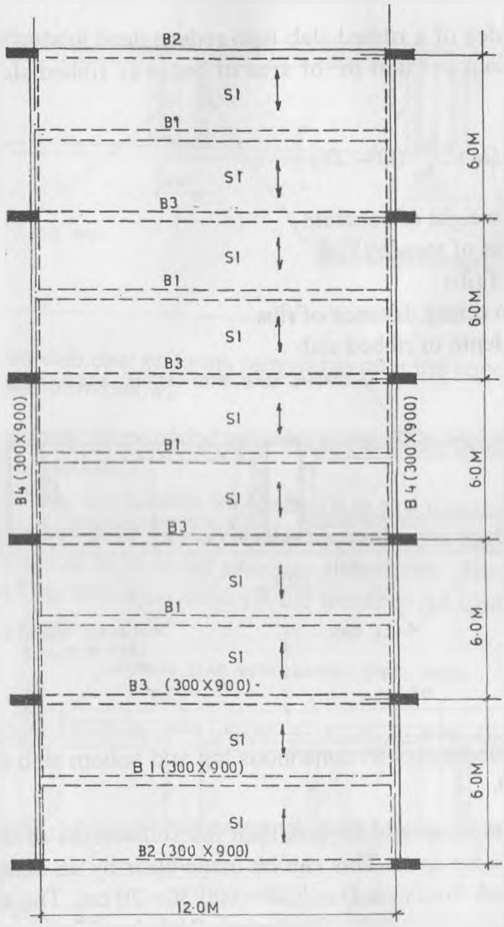

Fig. 3.6. Efficient arrangement of one-way slab panels in a floor plan.

Two structural arrangements for a floor with one-way slab panels are given in Figs. 3.6 and 3.7, in order to illustrate the efficiency of a floor system. The arrangement shown in Fig. 3.6 is structurally efficient, as long-span beams like B1, B2 and B3 have less loading, while the short-span beam B4 has more load, leading to a uniform concrete size for all beams, giving an elegant look to the ceiling and also resulting in less consumption of steel reinforcement. In Fig. 3.7, the floor arrangement has long beams with heavy loading, resulting in more consumption of steel. Further, with unequal sizes of beams, the ceiling may look ugly. It is however, seen that the concrete quantity is nearly the same in these two arrangements.

Fig. 3.7. Inefficient arrangement of one-way slab panels in a floor plan.

3.3 TWO-WAY SLAB SYSTEMS

Two-way slab panels are efficient as the material gets stressed in the two perpendicular directions. This system is suitable for square or squarish panels with $l_y/l_x \leq 2$ (Fig. 3.8). The slab panel bends in the two cross directions and it assumes a saucer-like deflected shape. The load gets divided in the two directions, depending on the ratio of the sides. When $l_x/l_y > 2$, a two-way slab panel tends to behave like a one-way panel, then most of the load goes in the short direction. The two-way slab system is suitable for a panel size upto 6.0 m × 6.0 m, which may give a slab thickness of 150 mm to 200 mm. Minimum slab thickness for two-way solid slabs can be kept as given by IS: 456-1964.[3]

For a panel simply supported on four sides $D = l_x/35$

For a panel with continuous four sides $D = l_x/40$

where l_x = short span of slab panel; l_y = long span of slab panel

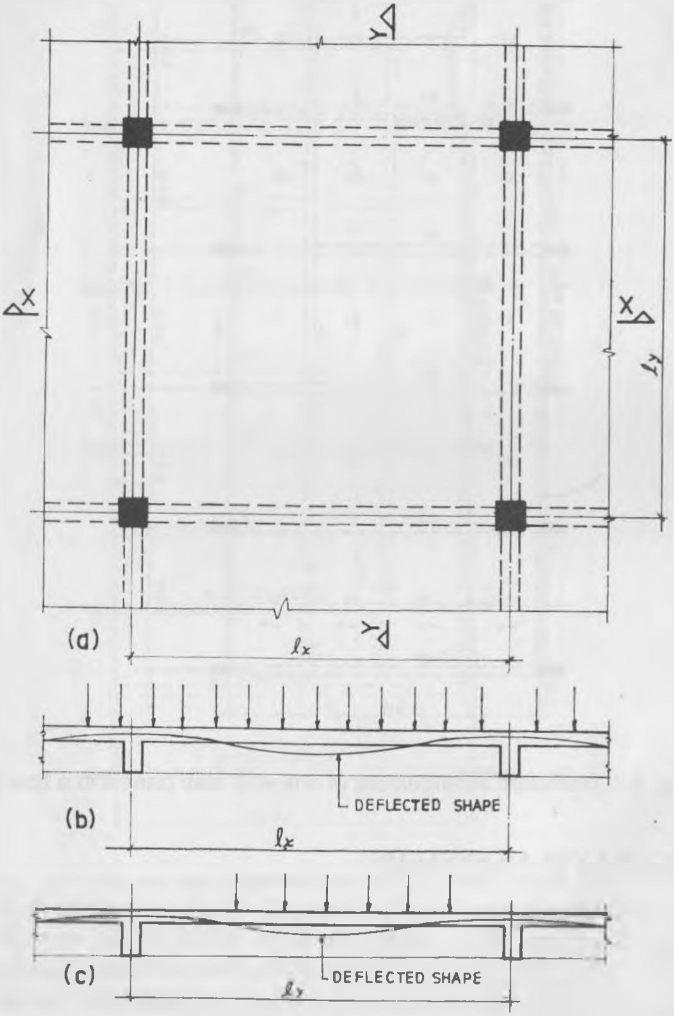

Fig. 3.8. Two-way slab panel in plan. (a) Plan of slab panel. (b) Section X-X; (c) Section Y-Y.

By putting more steel at midspan in either direction, we may check the slab panels to be adequate for deflection. For an overall economy of the buildings as a whole, we would like to have the minimum slab thickness in order to reduce dead load.

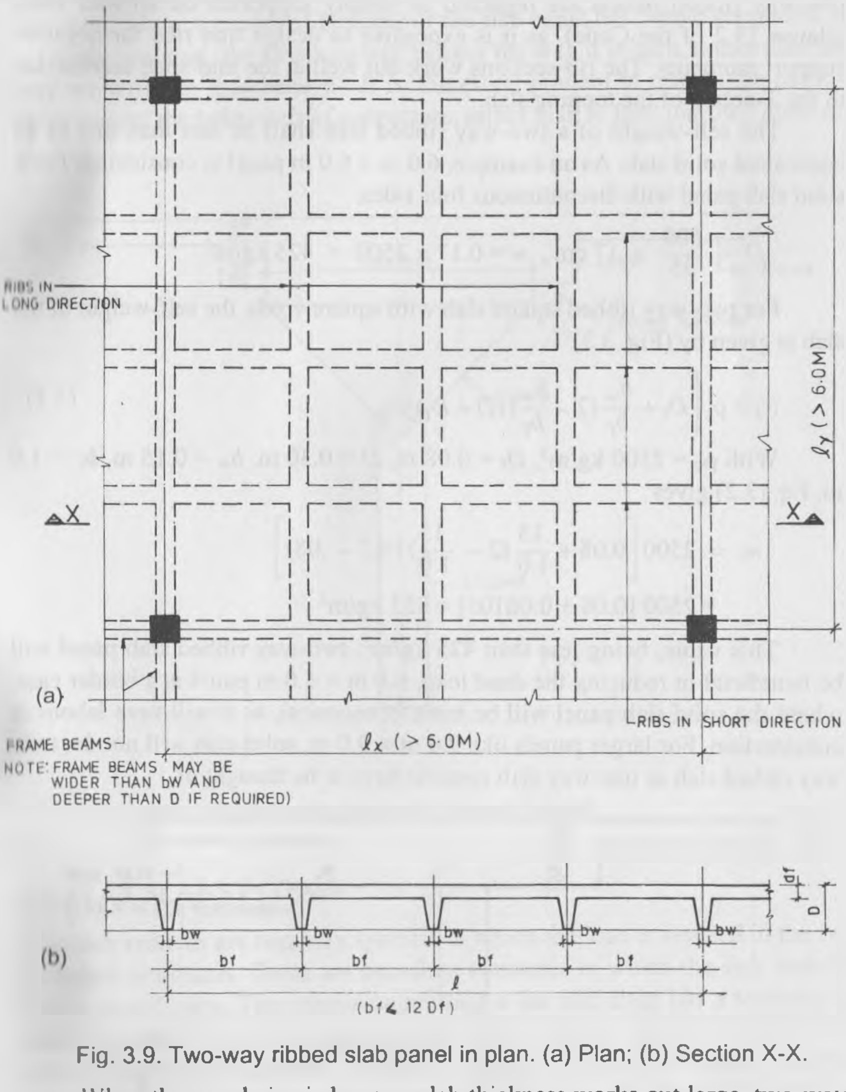

Fig. 3.9. Two-way ribbed slab panel in plan. (a) Plan; (b) Section X-X.

When the panel size is large or slab thickness works out large, two-way ribbed slab may be used to save on the self-weight of the slab-panel (Fig. 3.9). The construction systems as given in Figs. 3.3 to 3.5 for one-way ribbed slab panels are valid for the two-way ribbed slab panels also. Restrictions on the