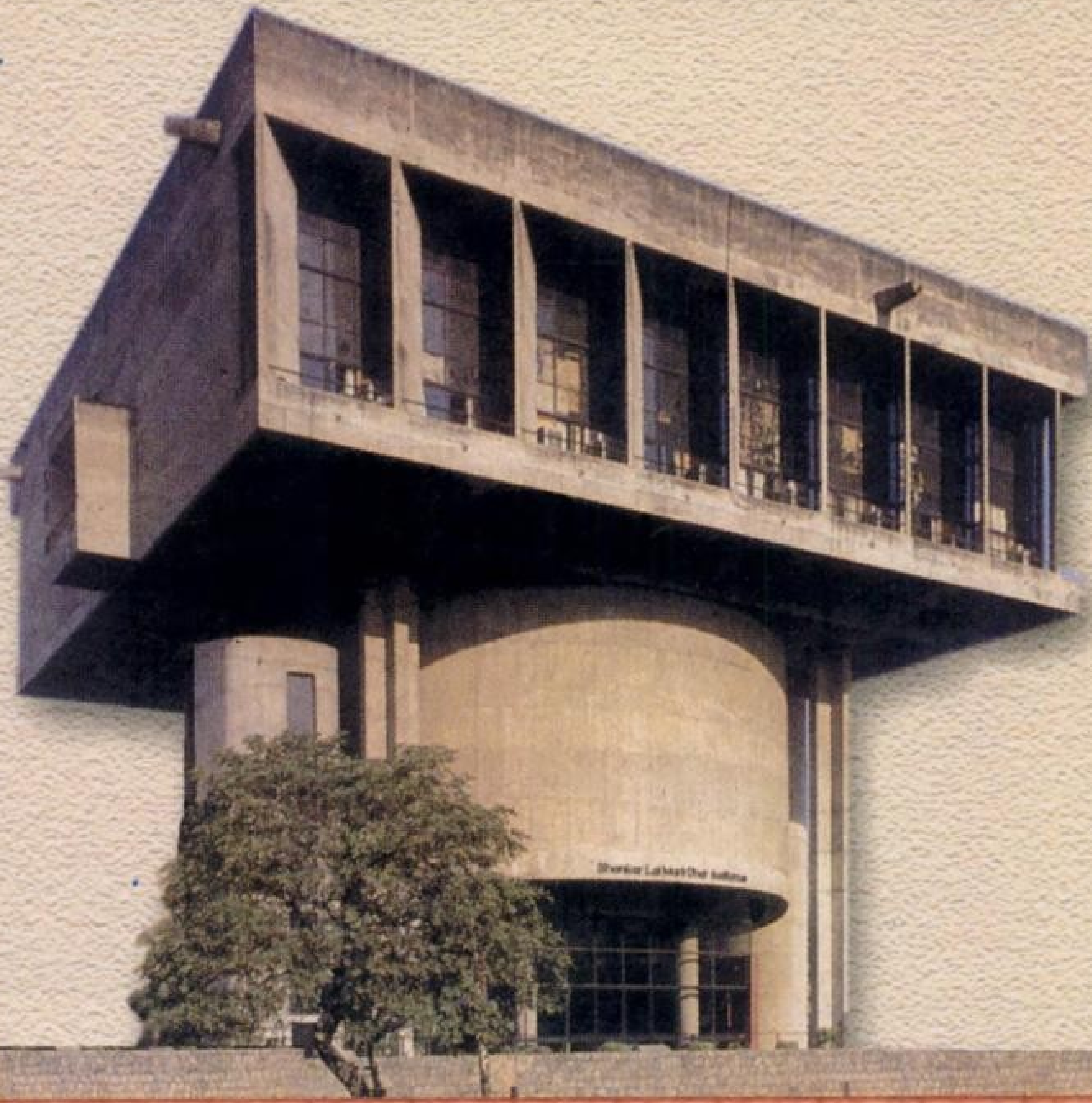
BUILDING CONSTRUCTION

Dr. B.C. PUNMIA



8. King closer. It is the portion of a brick which is so cut that the width of one its end is half that of a full brick, while the width at the other end is equal to the full width (Fig. 6.3 *d*). It is thus obtained by cutting the triangular piece between the centre of one end and the centre of the other (lay) side. It has half-header and half-stretcher face.

9. Bevelled closer. It is a special form of a king closer in which the whole length of the brick (*i.e.*. stretcher face) is bevelled in such a way that half width is maintained at one end and full width is maintained at the other end (Fig. 6.3 *e*).

10. Mitred closer. It is a portion of a brick whose one end is cut splayed or mitred for full width. The angle of splay may vary from 45° to 60°. Thus, one longer face of the mitred closer is of full length of the brick while the other longer face is smaller in length (Fig. 6.3 *f*).

11. Bat. It is the portion of the brick cut across the width. Thus, a bat is smaller in length than the full brick. If the length of the bat is equal to half the length of the original brick, it is known as *half bat* (Fig. 6.3 *g*). *A three-quarter-bat* (Fig. 6.3 *h*) is the one having its length equal to three-quarters of the length of a full brick. If a bat has its width bevelled, it is known is bevelled bat (Fig. 6.3 *i*).

12. Arris. It is the edge of a brick.

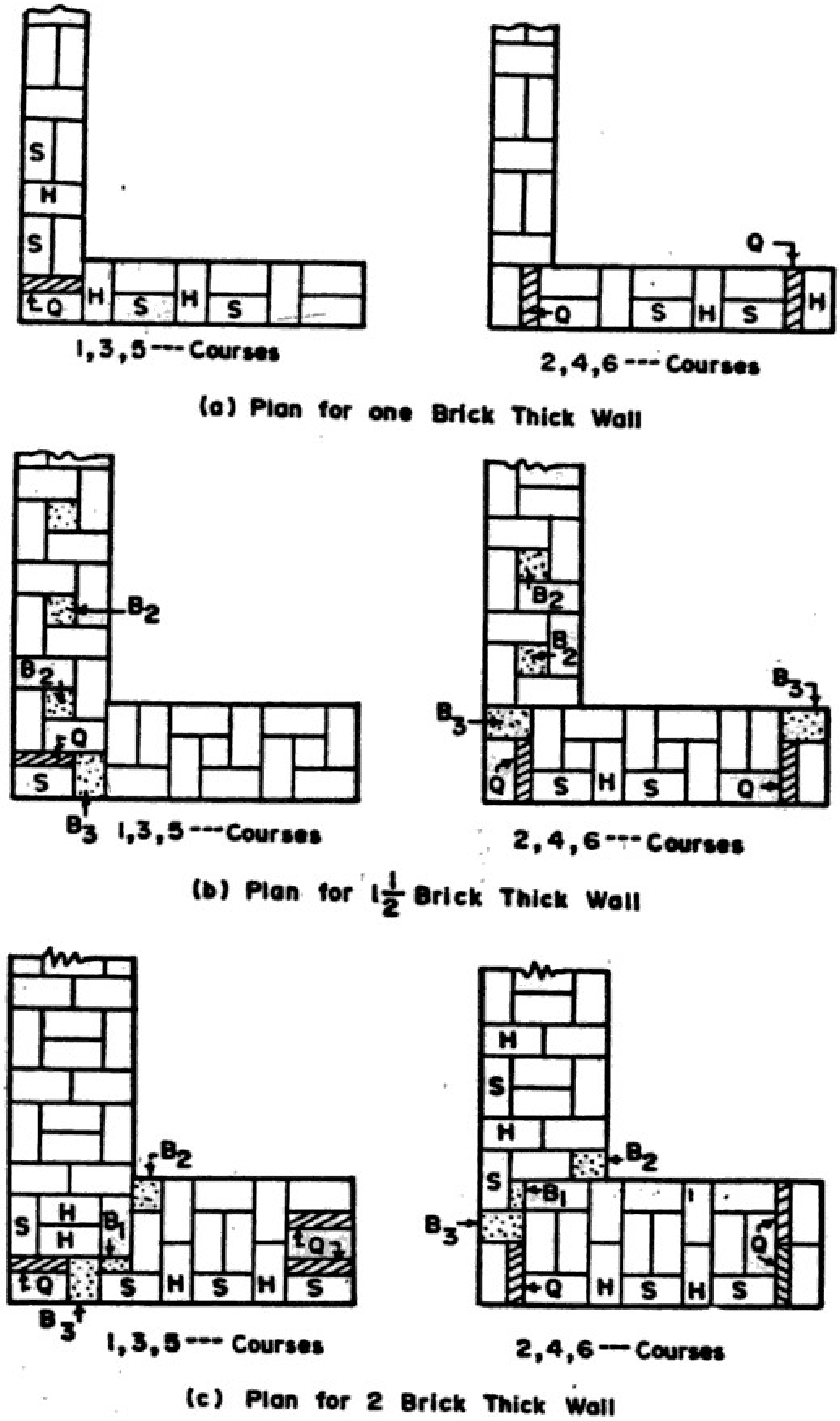
13. Bull nose. It is a special moulded brick with one edge rounded (*single bull nose*, Fig. 6.1 *a*) or with two edges rounded (double bull nose, Fig. 6.1 *b*). These are used in copings or in such positions where rounded corners are preferred to sharp arises.

14. Splays. These are special moulded bricks which are often used to form plinth. *Splay stretcher* (plinth stretcher) and *splay header* (plinth header) are shown in Fig. 6.1 (*j*) and (*k*) respectively.

15. Dogleg or angle. It is also special form of moulded bricks (Fig. 6.1 *l*) which are used to ensure a satisfactory bond at quoins which are at an angle other than right angle. The angle and lengths of the faces forming the dogleg vary according to requirements. These are preferred to mitred closer.

16. Quoin. It is a corner or the external angle on the face side of a wall. Generally, quoins are at right angles. But in some cases, they may be at angles greater than 90° also.

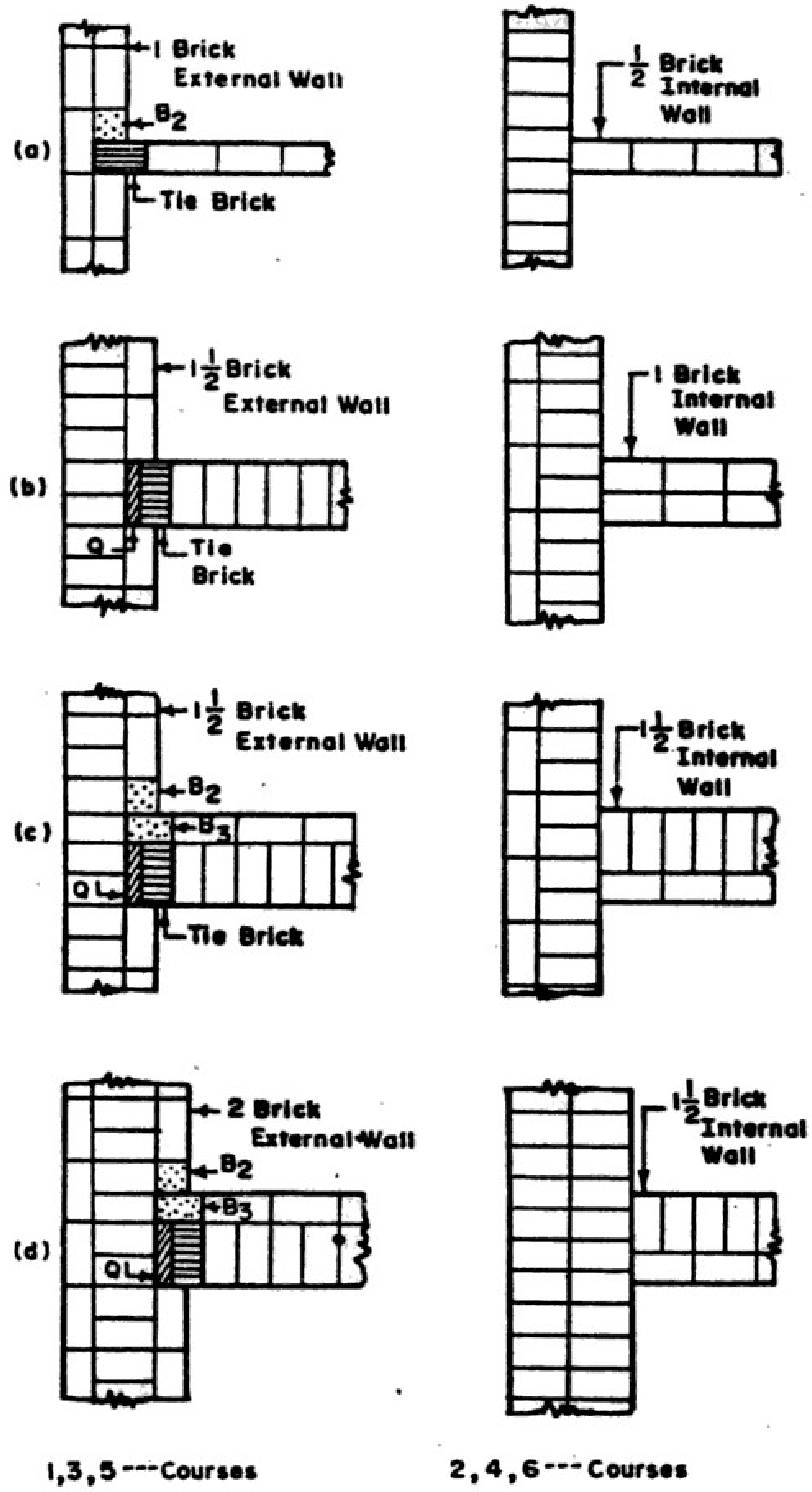
17. Frog or kick. A frog is an indentation in the face of a brick to form a key for holding the mortar. When frog is only on one face, that brick is laid with that face on the top. Sometimes, frogs are provided on both the faces. However, no frogs are provided in wire-cut bricks. A pressed brick has two frogs (as a rule) and a hand-made brick has only one frog.



S = STRETCHER ; H = HEADER ; Q = QUEENS CLOSER ;
B_2 = HALF BAT ; $B_3 = \frac{3}{4}$ BRICK ; B_1 = QUARTER BAT

FIG. 6.10. DOUBLE FLEMISH BOND.

external wall and one-brick thick internal (cross) wall, both the walls being constructed in English bond. Here, the header course of the internal wall centres the stretcher course of the main wall through half of its width. Due to this, lap of quarter-brick is obtained through the tie-brick, which is placed near the queen closer (Q). Alternate courses of both the walls remain unbonded.



B_2 = HALF BRICK ; $B_3 = \frac{3}{4}$ BRICK

FIG. 6.18. T-JUNCTIONS IN ENGLISH BOND

on the other side. Alternate courses of both the walls remain unbonded.

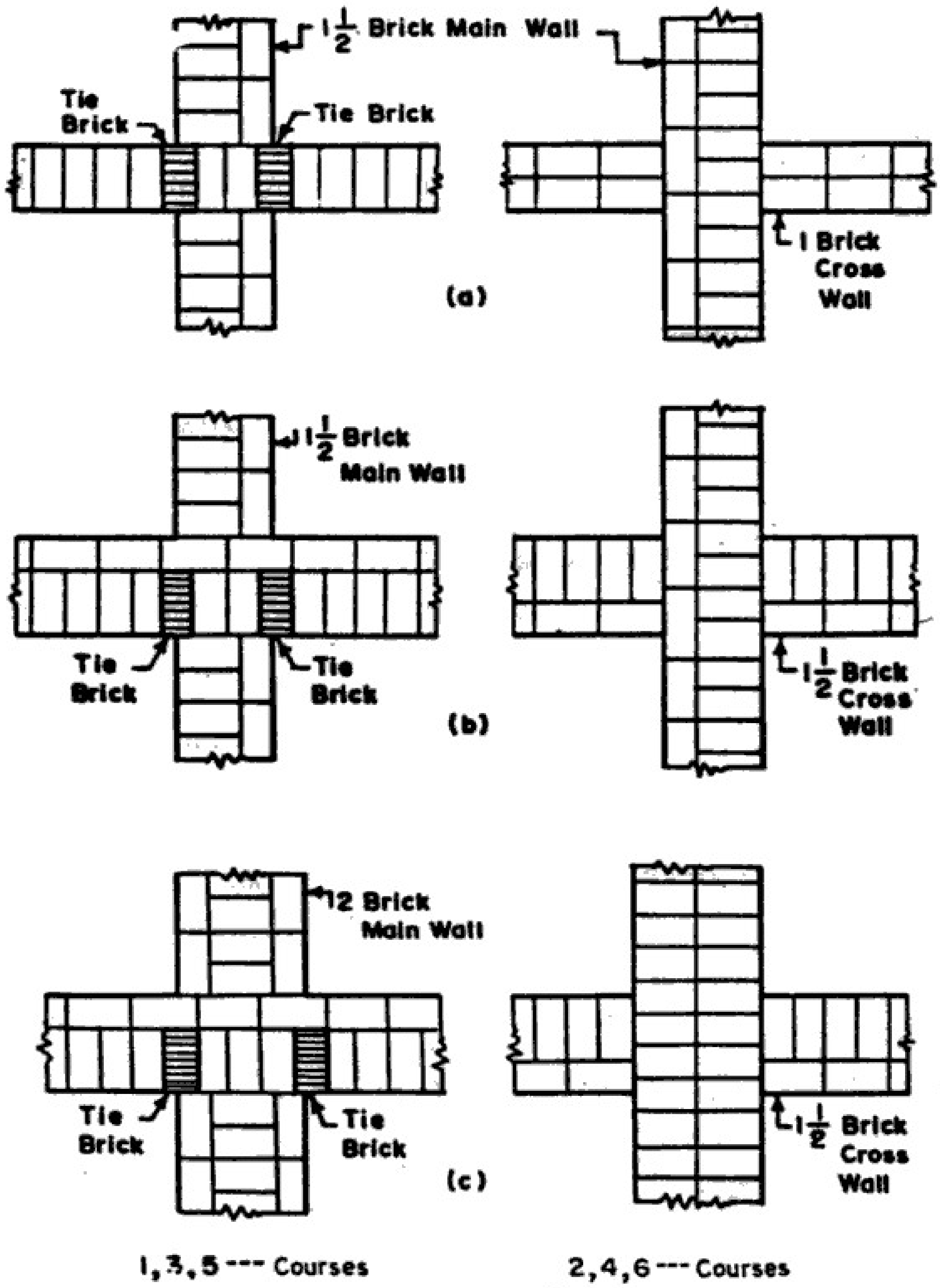


FIG. 6.21. CROSS-JUNCTION IN ENGLISH BOND.

3. Squint junction

A squint junction is formed when an internal wall meets an external continuous wall at an angle other than 90°. Usually, the angle of squint is kept at 45°, though squint junctions are not very common in brick work.

(a) Squint junction in English bond

Fig. 6.22 (*a*) shows a squint junction between a $1\frac{1}{2}$-brick thick external wall and a 1-brick thick internal wall, both being constructed in English bond. The header couses of the cross-wall is taken inside the main wall, thus getting the required bond. Alternate courses of both the walls remain unbonded.

(*i*) to provide larger bearing area for supporting heavy girders, roof etc. and

(*ii*) to provide stiffness to the wall.

(*a*) English bond

Fig. 6.29 (*a*) shows attached-pier and wall in English bond. The wall thickness is 1 brick, the pier width is 1 brick and the pier projection is half brick. Fig. 6.29 (*b*) gives English bond for wall of $1\frac{1}{2}$-brick thickness, pier of $1\frac{1}{2}$-brick thickness and pier projection of $\frac{1}{2}$-brick. Fig. 6.29 (*c*) shows English bond for $1\frac{1}{2}$-brick wall with pier width equal to 2-bricks and pier projection equal to $\frac{1}{2}$-brick.

(*b*) Double Flemish bond

Fig. 6.30 (*a*) shows double Flemish bond for wall $1\frac{1}{2}$-brick thick, pier 1 brick wide and pier projection of $\frac{1}{2}$ brick. Fig. 6.30(*b*) shows double Flemish bond for wall $1\frac{1}{2}$-brick thick, pier $1\frac{1}{2}$-brick wide and pier projection $\frac{1}{2}$-brick. Fig. 6.30 (*c*) shows the double Flemish bond for wall $1\frac{1}{2}$-brick thick, pier 2 brick wide and pier projection of $1\frac{1}{2}$ brick.

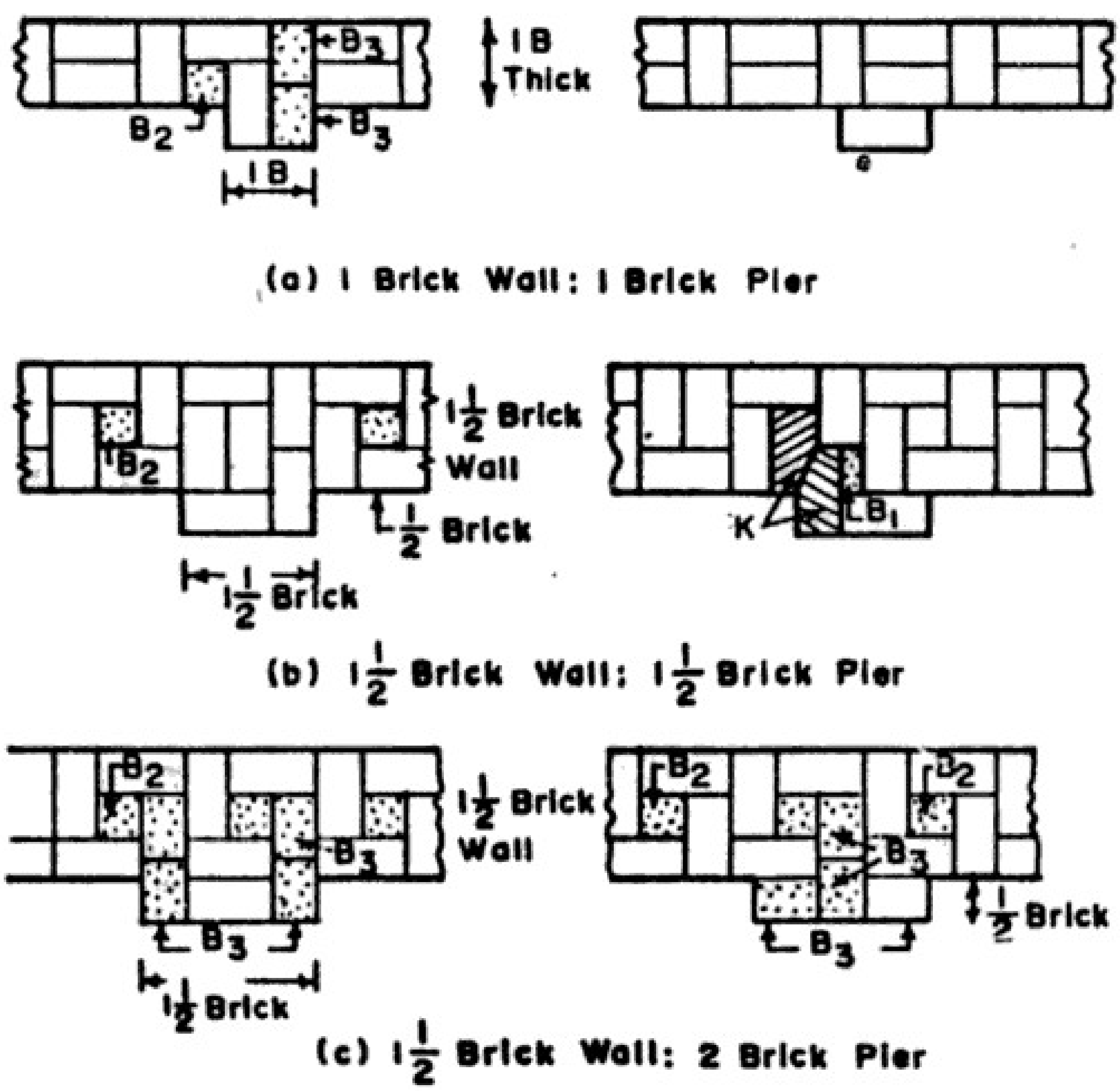


FIG. 6.30. ATTACHED PIERS IN FLEMISH BOND.

K= KING CLOSER ; $B_2=\frac{1}{2}$ BRICK BAT ; $B_1=\frac{1}{4}$ BRICK BAT ;

corner brick, such that 1 cm thick vertical joint is obtained. The excess mortar from the sides will squeeze out, which is cleaned off with trowel (Fig. 6.34 *a*).

4. The level and the alignment is checked. If the brick or closer is not in level, they are pressed gently further. Simiarly, the placement of the edges of the bricks is checked so that correct offset of concrete is available.

5. Few headers and stretchers are then laid in the first course, adopting the same method as described in step 3 for the closer brick. That is, mortar is applied on the side of the brick to be laid and it is pressed against the previous brick laid earlier, so that excess mortar squeezes out from the sides (Fig. 6.34 *b*). The level and alignment of these are properly checked.

6. After having laid the first course *at the corner*, mortar is laid and spread over the first course, to a depth of about 1.5 cm and end stretcher is laid first, by pressing it into the mortar and then hammering it slightly so that the thickness of bed-joint is 1 cm. Mortar is then applied on the side of another stretcher and pressed to the side of the corner stretcher so that thickness of vertical

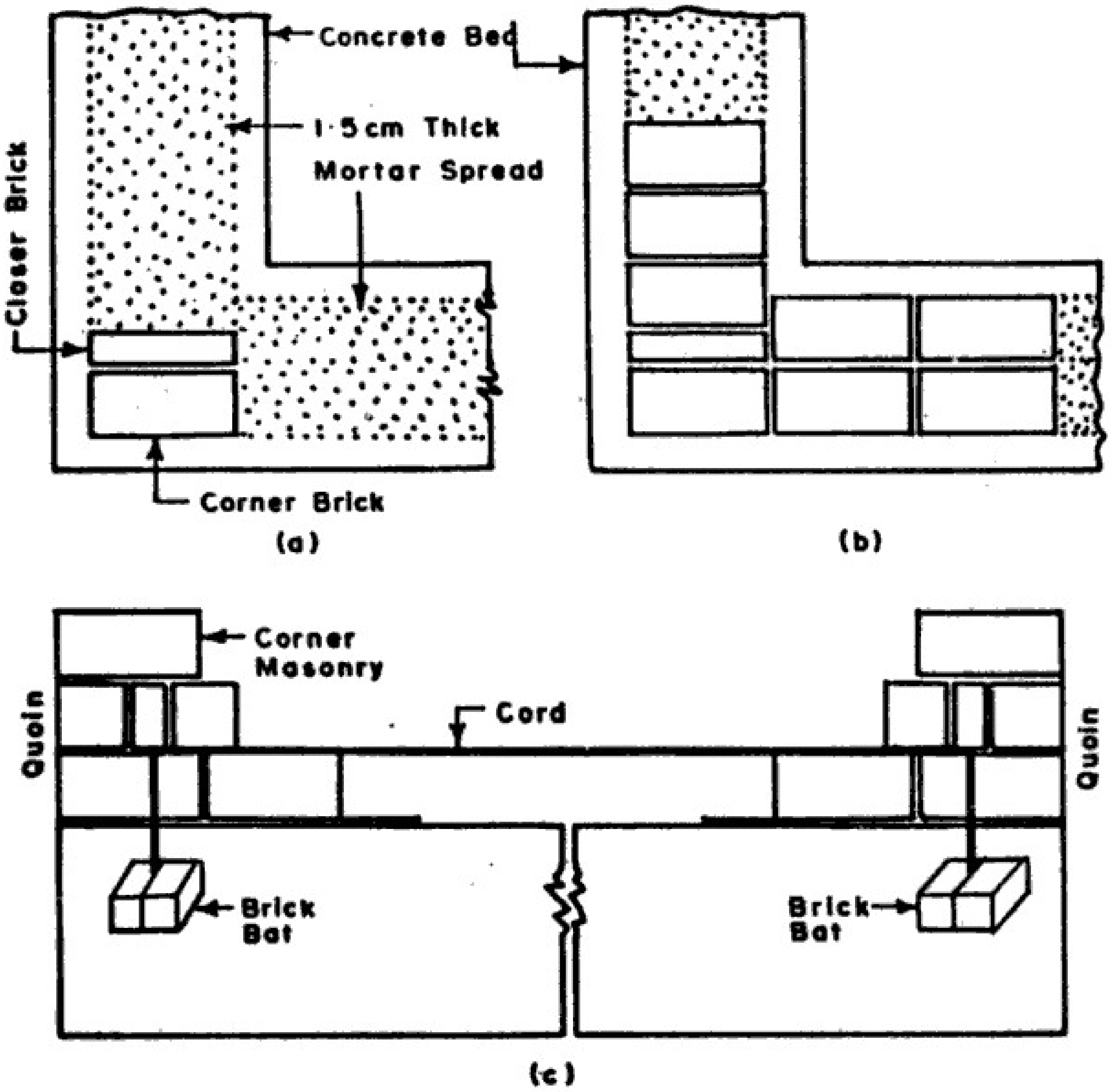


FIG. 6.34. BRICK LAYING BY CONVENTIONAL METHOD.

750 mm from the end of corner and inserting 10 mm mild steel rods threaded at both ends into the grooves on the mild steel flats in and on the frame and tightening them by butterfly nuts. Having fixed the end-frames, a string-holder, having brick-layers thread mainly passing through the slit and part of thread tied to the wood screws is positioned on the end-frame as fair face of the wall at appropriate course level. The thread is kept pulled and the other end of the thread is passed through the slit of second string-holder. Keeping the length of thread equal to the wall, the thread is tied to the wood screws of the string-holder and it is positioned at appropriate level of the end frame.

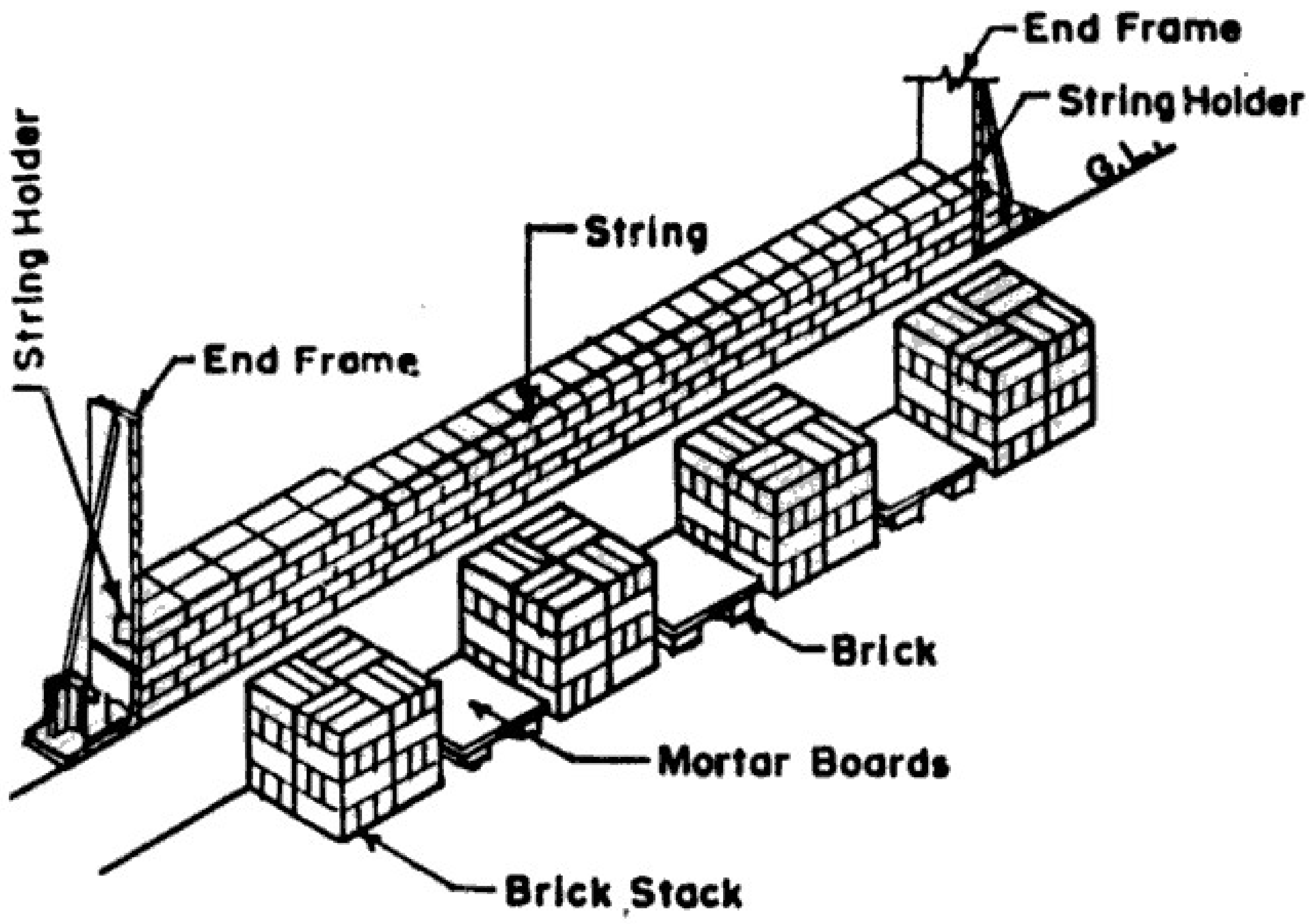


FIG. 6.36. LAYOUT AT WORK PLACE.

(b) At the opening for door and windows

In case the frames for doors and windows are not kept along with the building of wall, these openings also need the plumbing operation for each brick at the jambs. To reduce the plumbing time in such case, end frames are fixed for the door and window opening, as shown in Fig. 6.37 (*b*). In this case the end frames are fixed by 10 mm dia. mild steel rods fixed to a mild steel flat placed on the base board and the other one placed in brick joint in one of the courses below the sill level. It is preferable to provide a loop at the lower end of the mild steel rod and threads at the upper end. The end frames fixed for the door window openings also help in fixing the string-holders on to them, in case the brick-layers build the wall in part lengths.

TABLE 6.3
STRESS FACTOR FOR SLENDERNESS RATIO

S.No.	*Slenderness ratio*	*Stress factor*
1	6	1.000
2.	8	0.920
3.	10	0.835
4.	12	0.750
5.	14	0.660
6.	16	0.565
7.	18	0.480
8.	21	0.448
9.	24	0.415

TABLE 6.4
MODIFICATION FACTOR FOR SHAPE OF BRICK

Ratio of height to thickness of brick or block	*Factor*
0.75	1.0
1.0	1.2
1.5	1.6
2.0 to 3.0	2.0

The values of basic stresses (Table 6.5) are suitable when the units are of common brick shape, but may be unnecessarily low for same units whose ratio of height to thickness is greater than that of common brick. For units of crushing strength not greater than 55 kg/cm^2 (5.5 N/mm^2) and with a ratio of height to thickness as laid greater than 0.75 but not greater than 3, the *basic stress* (Table 6.5) may be modified by the factors specified in Table 6.4.

Permissible compressive stress of brick masonry

Table 6.5 gives the safe or permissible compressive stress for brick masonry using bricks of various basic stress and for various types of mortars. The permissible compressive stresses recommended in the table apply to masonry walls consisting of squared units built to horizontal courses, with broken vertical joints. The effects of slenderness ratio and shape factor should be taken into consideration as explained above.

The following *notes* refer to table 6.5.

Note 1. The table is valid for slenderness ratio 6 and loading with zero eccentricity.

Note 2. Linear interpolation is permissible for units whose

3. The thickness of wall should not be less than 1/6 of the storey height.

4. For basement walls, the thickness should not be less than one-third the height of retained soil above basement level, nor should it be less than the thickness of wall at ground floor plus 10 cm.

5. Table 6.6 is applicable for walls built of bricks or concrete blocks, using lime mortar (1 : 3), or cement mortar (1 : 6) or composite mortar (1 : 2 : 9).

6.27. TYPICAL STRUCTURES IN BRICK WORK

Following are the common structures constructed in brick-work:

1. Walls
2. Piers
3. Footings
4. Buttresses
5. Thresholds
6. Window sills
7. Corbels
8. Copings
9. Jambs
10. Ornamental brick work
11. Brick work curved in plan
12. Brick knogging
13. Retaining walls and breast walls
14. Fire places and flues
15. Chimneys
16. Arches
17. Lintels
18. Cavity walls.

Out of these, walls, piers and footings have already been discussed in earlier articles of this chapter. Fire places and flues, chimneys, arches, lintels and cavity walls have been discussed in separate chapters.

6.28. BUTRESSES

Buttresses are piers that are provided to resist thrusts from roof trusses or strengthen main walls or boundary walls. They give lateral support to the main load bearing walls. They are usually in the form of projections and are usually completed with cappings. Two forms of cappings : (*i*) splayed capping, and (*ii*) tumbled-in-capping are shown in Fig. 6.39.

Buttresses are usually designed to resist overturning moment due to lateral thrust. Their thickness is found in such a way that the resultant of the vertical and lateral loads remain within the middle third of the section so that no tension is developed. Buttresses

1

Introduction

1.1. GENERAL

Man requires different types of buildings for his activities: houses, bungalows and flats for his living ; hospitals and health centres for his health ; schools, colleges and universities for his education; banks, shops, offices, buildings and factories for doing work ; railway buildings, bus stations and air terminals for transportation ; clubs, theatres and cinema houses for recreation, and temples, mosques, churches, dharmshalas etc. for worship. Each type of the above buildings has its own requirements. The above building activities are an important indicator of the country's social progress.

Houses, bungalows, flats, huts etc. provide shelter to man. The first hut with bamboos and leaves can be taken as the first civil engineering construction carried out to satisfy the needs for a shelter. Before that, caves were his early abode. The history of development of housing facilities reveals that man has been moulding his environment throughout the ages, for more comfortable living. India still has many old cave temples with halls and rooms having beautiful carvings. Egyptians constructed huge pyramids. The Greeks developed a style of proportions of building elements ; these proportions are known as the *Orders of Architecture.* Romans developed arches for vaults and domes. They used pozzolana sand, mortar, plaster and concrete. During the Gothic period of architecture(1100-1500 A.D.) churches with pointed arches and the ribs supporting masonry vaults were constructed. The arched ribs were supported by stone pillars strengthened by buttresses. These structures led to the idea of framed structures.

The period from 1750 A.D. onwards is known as the period of Modern Architecture. Due to economic pressure after the war, and due to industrial development , many new methods and materials of construction were developed. The use of reinforced concrete construction triggered the rapid development of modern architecture.

6.32. COPINGS

Copings are provided to serve as a protective coverings to walls at its top. Coping throws the rain water clear off the wall. Sometimes, special moulded bricks are used for coping, having proper weathering and throating. If copings are made of regular bricks, they are to be properly shaped. Bricks used for coping should be hard and strong enough to resist weathering actions. The joints in the coping should be fewer. They should be invariably constructed to cement mortar.

Fig. 6.43. shows some common types of brick copings.

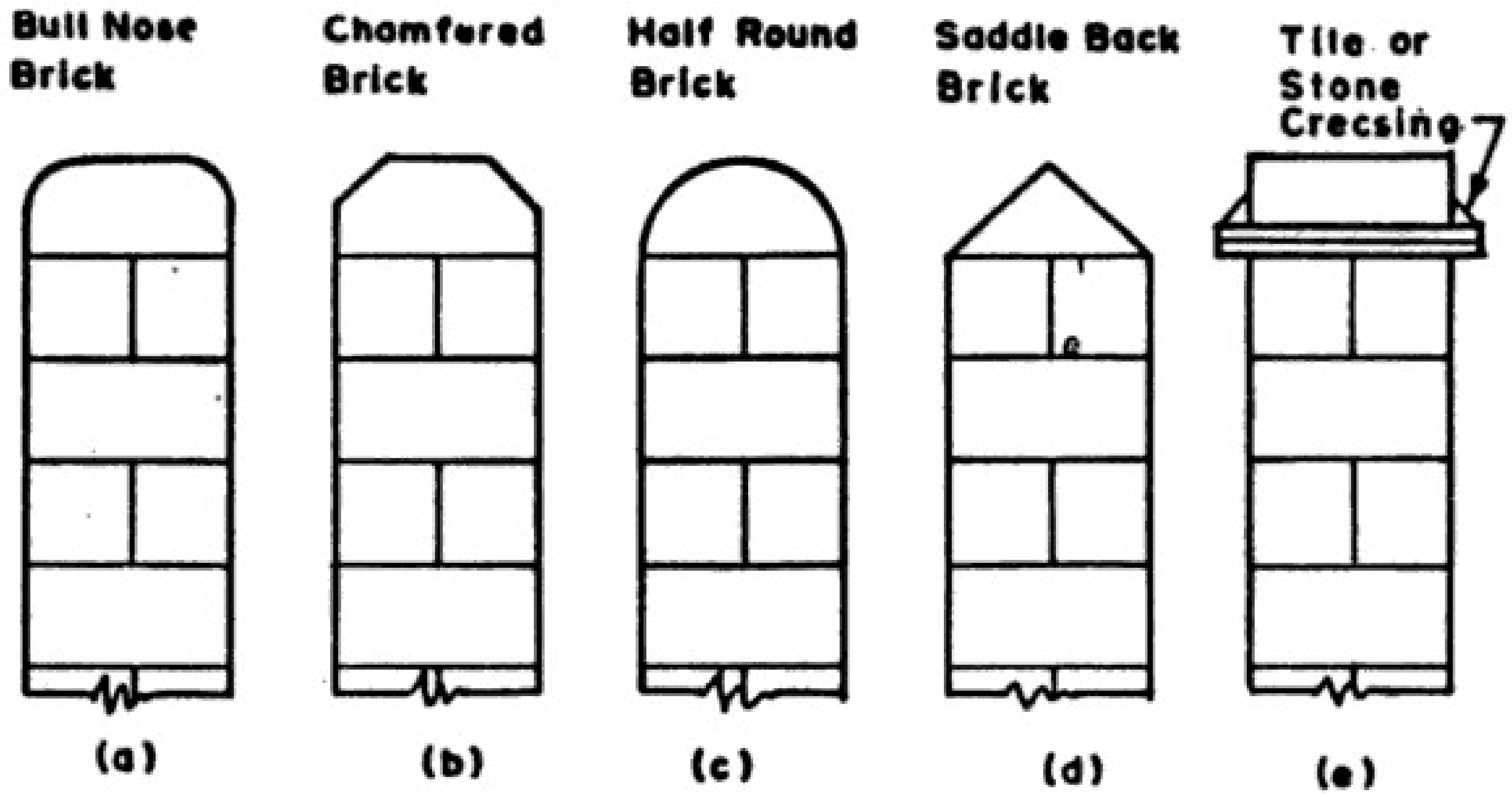


FIG. 6.43. COPINGS.

6.33. JAMBS

Jambs are the vertical sides of the openings left in the walls to receive doors, windows, fire-places etc. These are built either square through or with a recess. A square through jamb is used only when there is sheltered opening. Otherwise, any weakness in joint between the frame and the brickwork will let the rain water through. A recessed jamb is better because the projecting nib of brickwork protects the joint through which rain may otherwise be driven to the inside. *Recessed jambs* are also known as *rebated jumbs.* The recess may be either on the inside of the jamb or the outside. If it is on inside, then the frame which is set within it will be partly concealed from outside. If the recess is on the outside, the whole of the frame will be visible. A *square through jamb* may have splay at its outside face in which it is known as *splayed jamb.* Jambs may be constructed either in English bond or in Flemish bond. The square jambs in brick work are constructed as stopped ends. For construction of brick jambs with proper bond to avoid continuous vertical joints, it is essential to use bevelled bats and king, queen or bevelled closers.

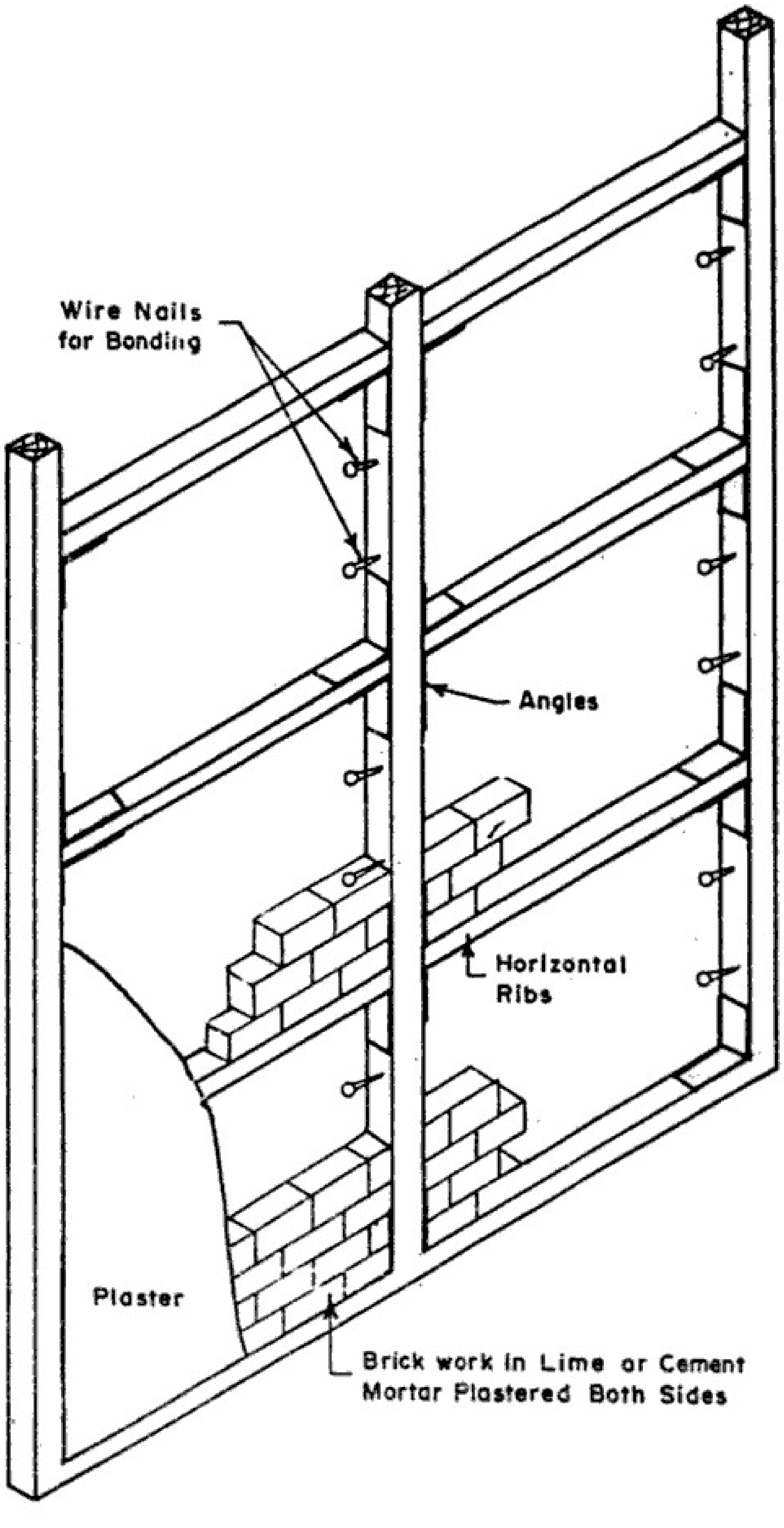


FIG. 6.47. BRICK KNOGGING.

6.37. RETAINING WALLS AND BREAST WALLS

A *retaining wall* is a wall of increasing thickness, which is constructed to retain artificial filling (mostly earth fill) to one side. A *breast wall* is similar to retaining wall, but it is constructed to without stone facing. A *hollow unit*, is defined as that unit which has core-void area greater than 25% of the gross area. Various types of *concrete masonry units*, depending upon shape and size, are manufactured, and these can be grouped in two heads :

(*i*) Regular concrete blocks
(*ii*) Hollow concrete units.

Regular concrete blocks are manufactured from dense aggregate, and they are used in load bearing walls. *Hollow concrete units* are manufactured from light weight aggregates. They may be used both for load bearing as well as non-load bearing walls. They are light in weight. Fig. 7.3 shows various forms of concrete masonry units.

Concrete Association of India recommends that the face thickness of the hollow blocks should atleast be 5 cm, and the net area should atleast be 55 to 60% of the gross area. The cores in the blocks should atleast be two in number and should preferably be oval shaped. The recommended size of common blocks are 39 cm×19 cm× 30 cm ; 39 cm× 19 cm× 20 cm and 39 cm× 19 cm× 10 cm. The aggregate used in the block manufacture consists of 60% fine (*i.e.* sand) and 40% course aggregate of 6 to 12 mm size, with a combined fineness modulus of 2.9 to 3.6. The cement-aggregate mix is in 1:6 proportion. The strength of the blocks should be atleast 30 kg/cm^2.

Concrete masonry blocks are manufactured in the following *surface finishes:*

(*i*) Common finished surface.
(*ii*) Glazed finish.
(*iii*) Slumped finish.
(*iv*) Specially faced finish.
(*v*) Coloured finish.

Common finish surface has fine to course texture which can be obtained by varying the mix proportions and by using appropriate aggregates. If the exposure of the aggregates is required, it can be obtained either by treating the surface by dilute acid solution or by scrubbing it while the concrete has not fully set. *Glazed finish* is used for decorative work. It can be obtained in a manner similar to glazing of tiles. Glazed finish concrete blocks are water resistant. *Slumped finish* is the *rough finish* which is obtained by using the concrete of desired slump. When the forms are open, the blocks settle slightly, causing rough surface. In *specially faced finish*, finishing material such as marble etc. is incorporated on the facing side of the block. *Coloured finish* can be obtained by mixing various pigments to the concrete mix.

Manufacture of concrete masonry blocks

The following points should be kept in mind while manufacturing the concrete masonry bricks :

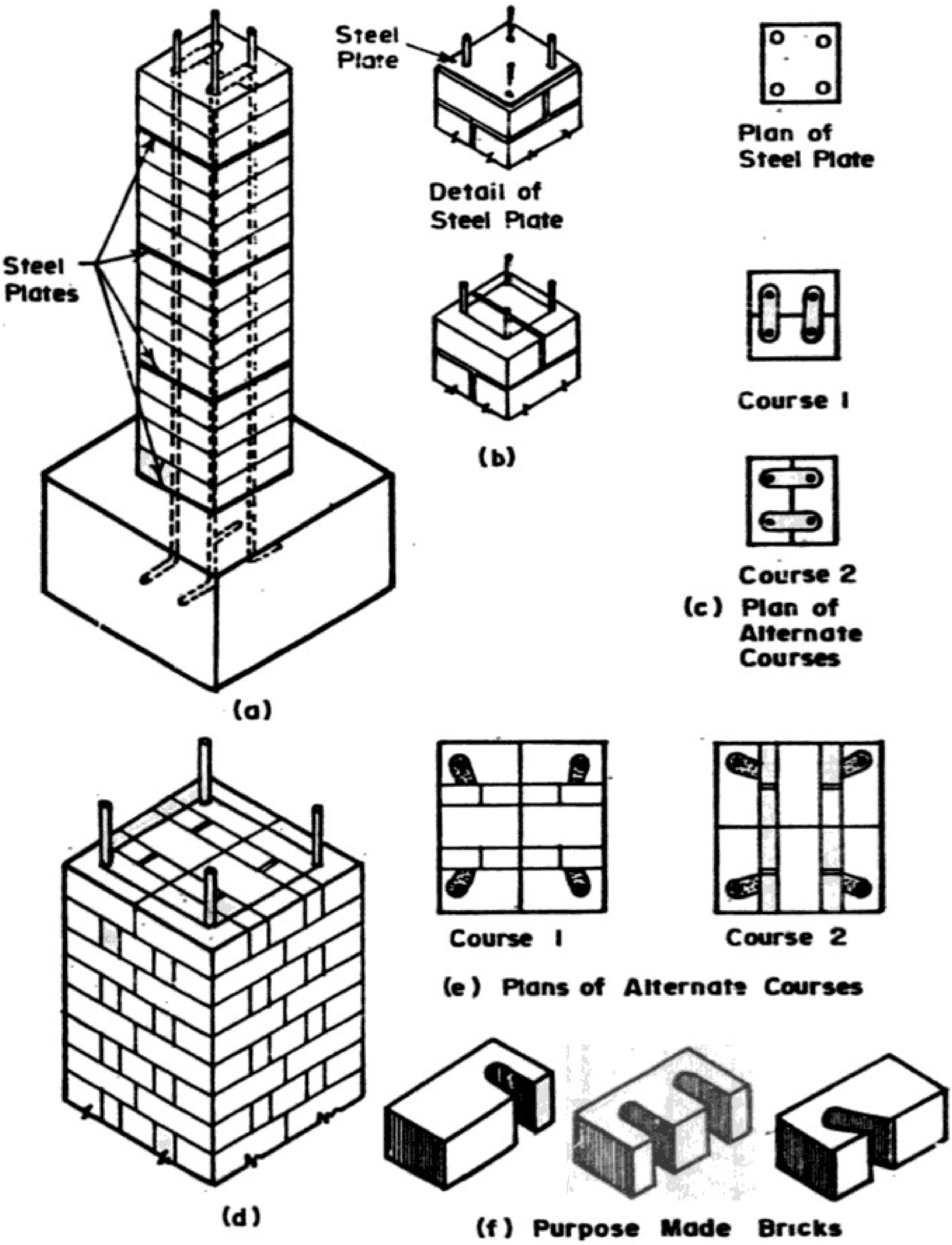


FIG. 7.7. REINFORCED BRICK WORK PIERS.

Brick retaining walls are often reinforced since such a work is cheaper than the reinforced cement concrete, when the height of the wall is upto 3 m. Vertical reinforcing bars are placed vertically near each face, in addition to steel meshed strips at every fourth course. The bricks opposite each bar are purpose made, having a groove. The size of the groove is kept slightly more than the diameter action under load (See Fig. 7.2).

A *veneered wall* is a wall in which the facing is attached to the backing but not so bonded as to result in a common action under load.

8.2. DESIGN CONSIDERATIONS

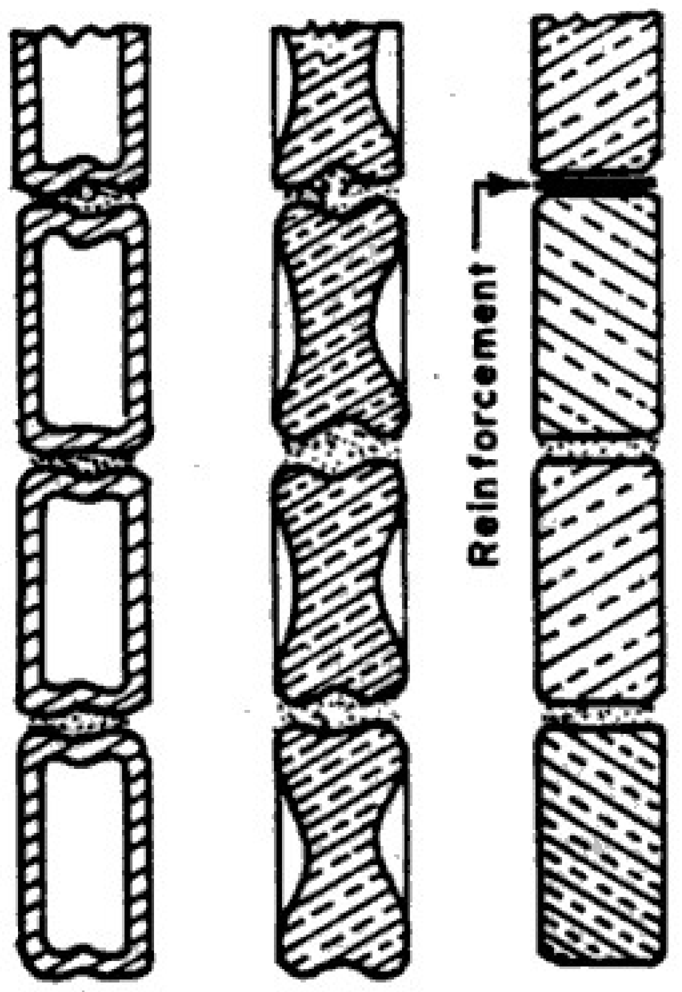
Load-bearing walls may be subjected to a variety of loads, *viz.,* live loads (super–imposed loads), dead loads, wind pressure, earthquake forces etc. Live loads and dead loads act in vertical direction. When the floor slabs transferring the loads to the wall are not supported through the full width of the wall, the loads act eccentrically, causing moments in the wall.

Load-bearing walls are structurally efficient when the load is uniformly distributed and when the structure is so planned that eccentricity of loading on the wall is as small as possible. The *strength* of a wall is measured in terms of its resistance to the stresses set up in it by its own weight, by super–imposed loads and by lateral pressure such as wind, etc .; its stability by its resistance to overturning by lateral forces and bucking caused by excessive slenderness.

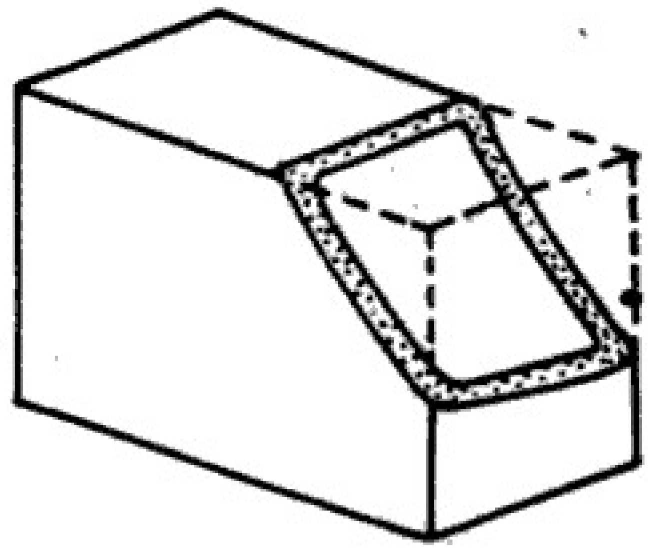
In order to ensure uniformity of loading, openings in walls should not be too large and these should be, as far as possible, of 'hole in wall' type; bearings for lintels and bed blocks under beams should be liberal in size ; heavy concentration of loads should be avoided by judicious planning and sections of load-bearing members should be varied with the loadings so as to obtain more or less uniform stresses in adjoining parts of members. One of the commonly occurring causes of cracks in masonry is wide variation in stress in masonry in adjoining parts. Eccentricity of loading on walls should be reduced by providing adequate bearing of floors/roofs on the walls and making than as rigid as possible consistent with economy and other considerations.

The *strength* of a masonry wall depends primarily upon the strength of the masonry units and the strength of the mortar. In addition, the quality of workmanship and the method of bonding is also important. Mortar strength shall be in general not greater than that of the masonry unit. An un-necessarily strong mortar concentrates the effect of any differential movement of masonry in fewer and wider cracks while a weak mortar (*i.e..*, mortar having more of lime and less of cement) will accommodate movements, and cracking will be distributed as thin hair cracks which are less noticeable. Also, stresses due to expansion of masonry units are reduced, if a week mortar is used. Lean cement mortars of cement alone, are harsh, pervious and less workable. Hence, when strong mortars are not required from strength considerations, it is preferable to use composite mortars of cement, lime and sand in appropriate proportions.

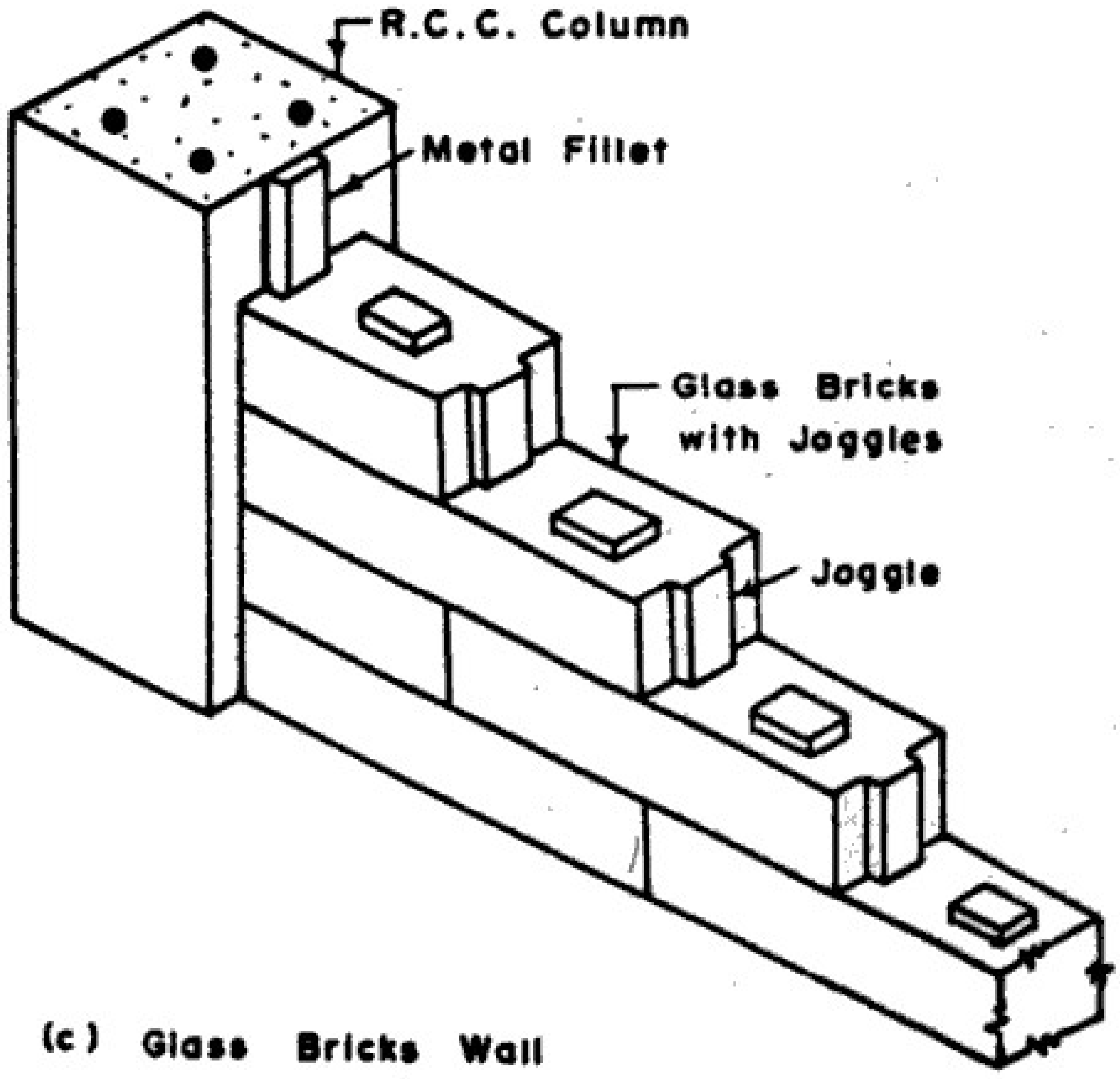
thicknesses. They are usually square (14 ×14 cm or 19×19 cm), with a normal thickness of 10 cm. The jointing edges are painted internally and sanded externally to form a key for mortar. The front and back faces may be either decorative or plain. The front and back faces are sometimes fluted. The glass blocks are usually laid in cement-lime mortar (1 : 1 : 4), using fine sand. All joints should be filled carefully. For blocks upto 15 cm in height, expanded metal strip reinforcement is placed in every third or fourth course. If the



(a) Glass Block Walls



(b) Hollow Glass Block



(c) Glass Bricks Wall

FIG. 10.6. GLASS BLOCK AND GLASS BRICKS WALLS.

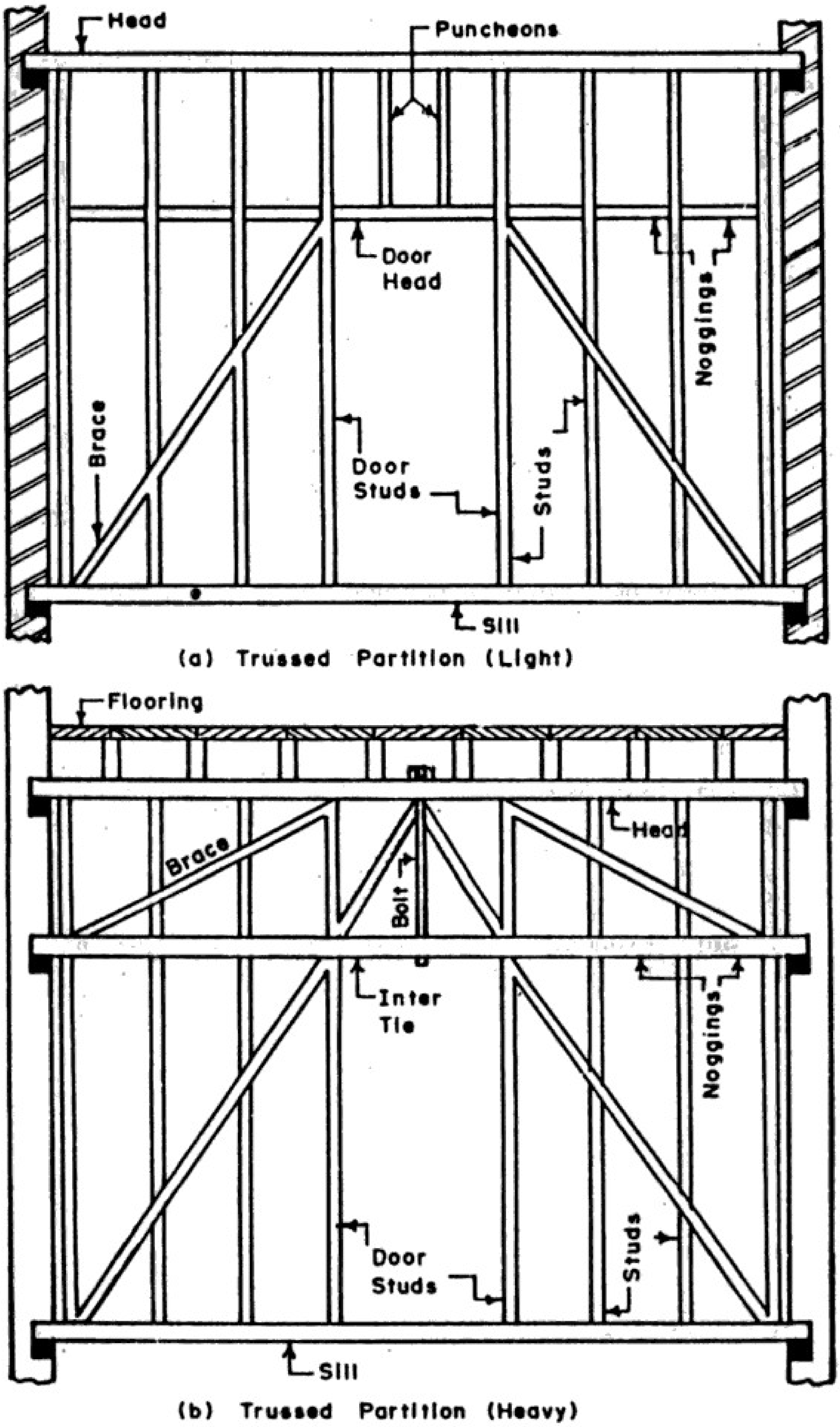


FIG. 10.10. TRUSSED PARTITION.

11.2. COMPONENTS OF A FLOOR

A floor is composed of two essential components :

(*i*) sub-floor, base course or floor base

(*ii*) Floor covering, or simply, flooring.

The *floor base* is a structural component, which supports the floor covering. For the ground floors, the object of *floor base* is to give proper support to the covering so that it does not settle, and to provide *damp resistance* and *thermal insulation.*

Ground floors may either rest directly on the ground, or may be supported a little distance above the ground. The floors supported directly on the ground are known as *solid floors* (Fig. 11.1) while the floors supported above the ground level are called *suspended floors* (Fig. 11.2). Suspended floors are generally made of timber.

11.3. MATERIALS FOR CONSTRUCTION

Materials used for construction of *ground floor* base are :

(*i*) Cement concrete

(*ii*) Lime concrete

(*iii*) Stones

(*iv*) Bricks

(*v*) Wooden blocks (for wooden flooring only).

The floor base for a solid ground floor is shown in Fig. 11.1. The lowest layer, just above ground surface is that of compacted earth fill. The second layer may either of lean cement concrete or lime concrete or sometimes broken brick bats or stones rammed properly. The third course may be either of cement concrete or of bricks or stones arranged and packed properly. The third layer of cement concrete is more common since it gives proper rigidity to the floor base. Over the third layer of floor base, *floor finish or flooring* is laid.

The materials used for *floor finish* or *floor covering* or flooring are :

1.	Mud and Muram	9.	Granolithic finish
2.	Bricks	10.	Wood or timber
3.	Flag stones	11.	Asphalt
4.	Concrete	12.	Rubber
5.	Terrazzo	13.	Linoleum flooring
6.	Mosaic	14.	Cork
7.	Tiles	15.	Glass
8.	Marble	16.	Plastic or P.V.C.

11.4. SELECTION OF FLOORING MATERIAL

Following are the factors that affect the choice of a flooring materials :

1. Initial Cost. The cost of the material should be in conformity falls lower than the string level, it is re-laid by putting fresh layer of stiff mortar. When the stone slabs are properly set, mortar in the joints is raked out to a depth of about 15 to 20 mm and then flush pointed with 1 : 3 cement mortar. Proper slope is given to the surface for drainage. The work is properly cured.

11.8. CEMENT CONCRETE FLOORING

This is commonly used for residential, commercial and even industrial building, since it is moderately cheap, quite durable and easy to construct. The floor consists of two components: (*i*) base concrete, and (*ii*) topping or wearing surface. The two components of the floor can be constructed either monolithically (*i.e.* topping laid immediately after the base course is laid) or non-monolithically. When the floor is laid monolithically, good bond between the two components is obtained resulting in smaller over all thickness. However, such a construction has three disadvantages : (*i*) the topping is damaged during subsequent operations, (*ii*) hair cracks are developed because of the settlement of freshly laid base course which has not set, and (*iii*) work progress is slow because the workman has to wait atleast till the initial setting of the base course. Hence in most of the cases, non-monolithic construction is preferred.

The base course may be 7.5 to 10 cm thick, either in lean cement concrete (1 : 3 : 6 to 1 : 5 : 10) or lime concrete containing 40% mortar of 1 : 2 lime-sand (or 1 lime : 1 surkhi : 1 sand) and 60% coarse aggregate of 40 mm nominal size. The base course is laid over well-compacted soil, compacted properly and levelled to rough surface. It is properly cured.

When the base concrete has hardened, its surface is brushed with stiff broom and cleaned thoroughly. It is wetted the previous night and excess water is grained. The topping is then laid in square or rectangular panels, by use of either glass or plain asbestos strips or by use of wooden battens set on mortar bed. The panels may be 1 × 1 m, 2 × 2 m or 1 × 2 m in size. The topping consists of 1 : 2 : 4 cement concrete, laid to the desired thickness (usually 4 cm) in one single operation in the panel. Alternate panels are laid first. Prior to laying the concrete in the panel, a coat of neat cement slurry is applied. This cement slurry laid on rough-finished base course ensures proper bond of topping with the base course. Glass strips or battens should have depth equal to thickness of topping. Topping concrete is spread evenly with the help of a straight edge, and its surface is thoroughly tamped and floated with wooden floates till the cream of concrete comes at the top. Steel trowel is used for something and finishing the top surface. Further troweling is done when the mix has stiffened. Dusting of the surface with neat cement and then troweling results in smooth finish at the top. Other alternate

Functional structural components such as columns, chajjas, canopies, R.C.C. slabs became increasingly popular because of the increased speed in construction. Use of plywood, glass, decoratives etc. helped the designers to make the new structures look more elegant.

The building design has traditionally been the responsibility of the architect, though the building construction has been the responsibility of the civil engineer. Also, the structural designs of the building are the responsibility of a civil engineer. On small projects, a civil engineer may sometimes be entrusted with the architectural design work, along with structural designs. The main considerations in architectural design of buildings for all purposes are as follows :

(1) Climate and its effect,
(2) People and their requirements,
(3) Materials for construction and method of construction,
and (4) Regulations and bye-laws of sanctioning authority.

1.2. TYPES OF BUILDINGS

National Building Code of India (SP : 7–1970) *defines* the building as 'any structure for whatsoever purpose and of whatsoever materials constructed and every part thereof whether used as human habitation or not and includes foundations, plinth, walls, floors, roofs, chimneys, plumbing and building services, fixed platforms, verandah, balcony cornice or projection, part of a building or any thing affixed thereto or any wall enclosing or intended to enclose any land or space and signs and outdoor display structures'. Tents, shamianas and tarpaulin shelters are not considered as building.

According to the National Building Code of India (1970), Buildings are classified, based on *occupancy,* as follows:

Group A : Residential buildings.
Group B : Educational buildings.
Group C : Institutional buildings.
Group D : Assembly buildings.
Group E : Business buildings.
Group F : Mercantile buildings.
Group G : Industrial buildings.
Group H : Storage buildings.
Group J : Hazardous buildings.

1. Group *A* : Residential Buildings

These are those buildings in which sleeping accommodation is provided for normal residential purposes, with or without cooking or dining or both facilities, except any building classified under category *C*. Buildings of group *A* are further sub-divided as follows :

of available stone slabs. The joists have the clear span equal to the width of the room (Fig. 12.1 *a*). The bearing of joists on the wall should at least be equal to depth of the joist, but in no case less than half the width of the wall. It is better if bearing is kept just equal to the width of the wall so that eccentric load of the wall is eliminated. A bed plate is provided below each end of the joist, to suitably distribute the load to the wall.

Sometimes stone slabs are available in lengths of 2.5 to 3.5 m, such as those at Jodhpur. If the width of the room is slightly less than this value, stone slabs can be directly supported on the walls, without using steel joists (Fig. 12.1 *d*). Such a construction is quite cheap.

12.3. JACK ARCH FLOORS

Jack arch is an arch of either brick or concrete, supported on lower flange of mild steel joists (R.S.J.). The joists are spaced 1 to 1.5 m centre to centre, and are supported at their ends either on the walls or on longitudinal girders. The rise of the arch is kept equal to $\frac{1}{12}$th of the span. The minimum depth of concrete at the crown is kept equal to 15 cm. Since the super-imposed load is being borne by arch action, tension is developed on the supporting walls, specially at the end span. Due to this, steel tie rods are provided at the end span, at suitable spacing, usually 1.8 to 2.4 m c/c. The

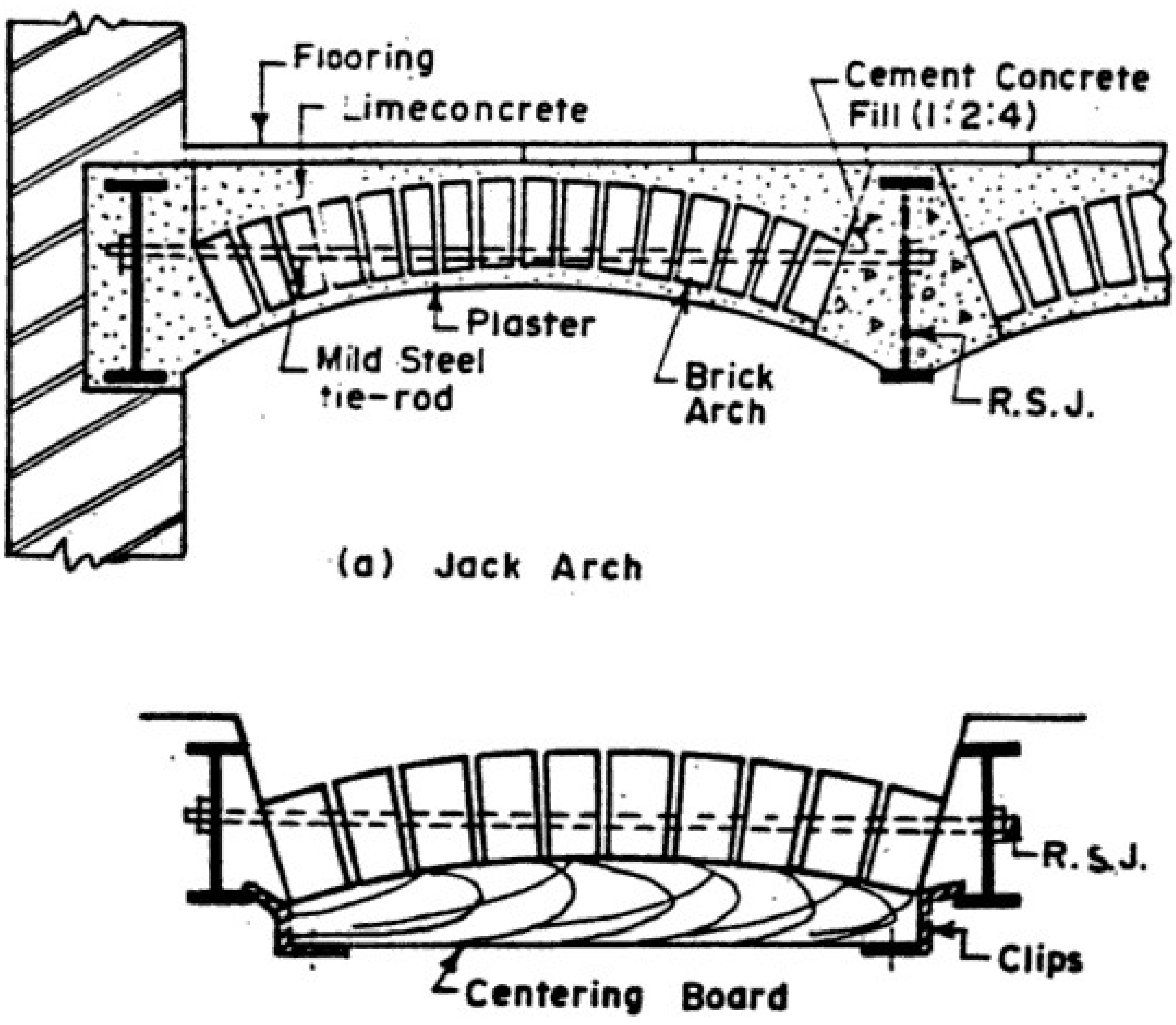


FIG. 12.2. BRICK JACK ARCH FLOORING.

wooden supports, called *binders*. Thus, the loads of bridging joists are first transferred to the *binders* and through them to the end

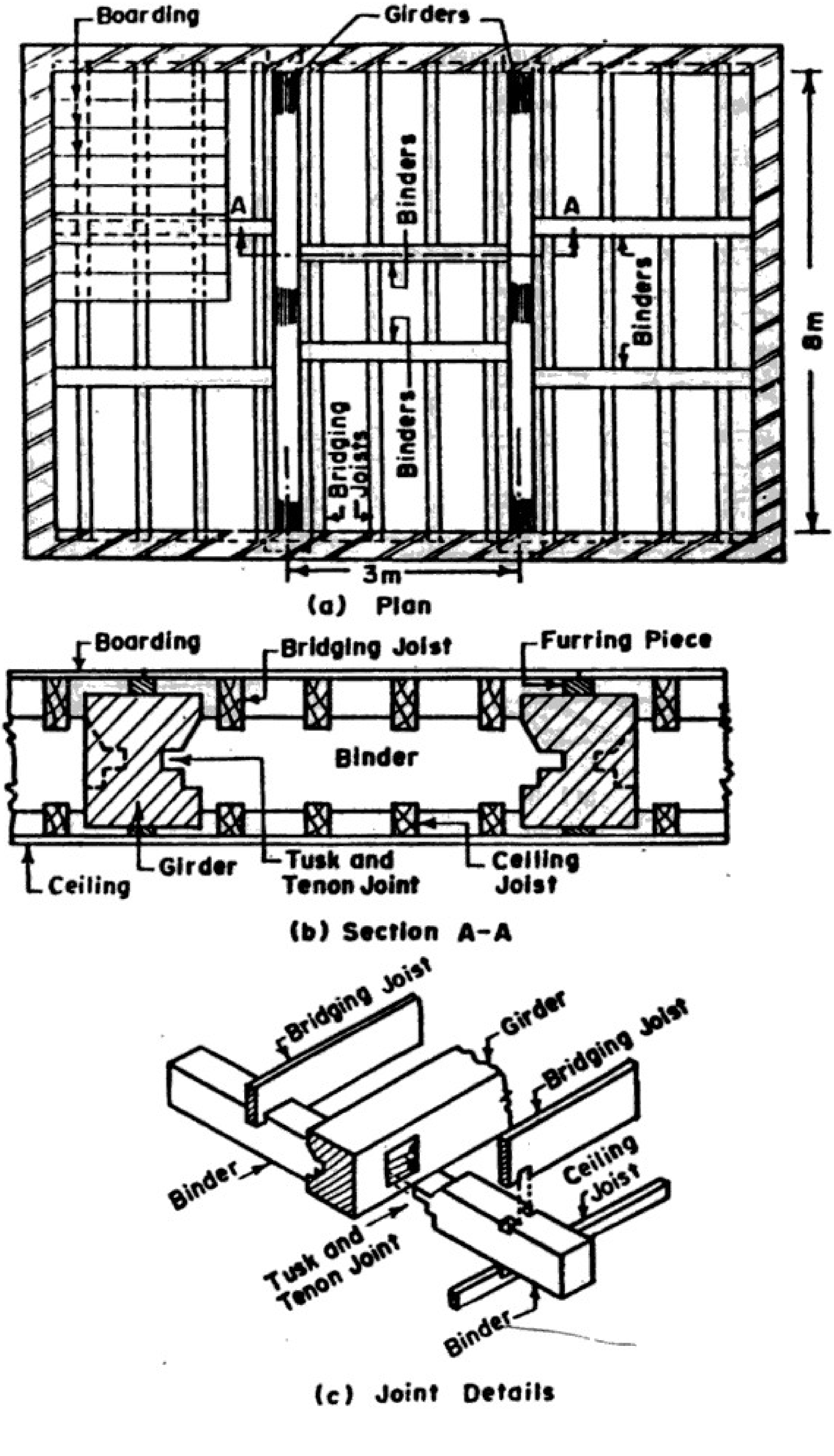


FIG. 12.13. FRAMED OR TRIPLE JOISTS TIMBER FLOORING.

the materials of their construction :

1. Timber lintels.
2. Stone lintels.
3. Brick lintels.
4. Steel lintels
5. Reinforced concrete lintels.

13.3. TIMBER LINTELS

Timber lintels are oldest types of lintels, though they are not commonly used now-a-days, except in hilly areas. Timber lintels are relatively costlier, structurally weak and vulnerable to fire. They are also liable to decay if not properly ventilated.

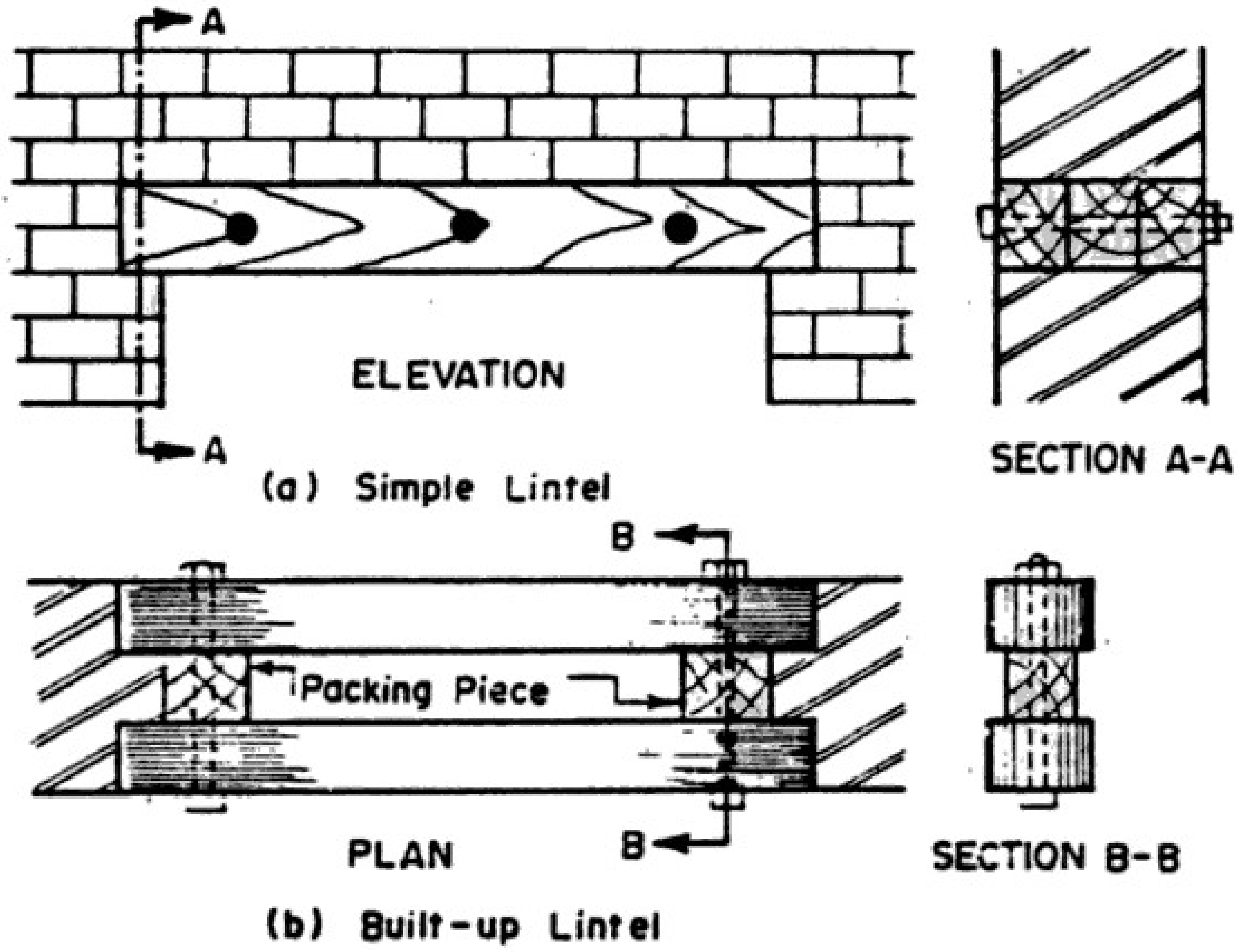


FIG. 13.1. WOODEN LINTEL.

Fig. 13.1 (*a*) shows a wooden lintel provided over the full width of the wall, by jointing together three timber pieces with the help of steel bolts. Fig. 13.1. (*b*) shows wooden lintel for a wider wall. The lintel is composed of two wooden pieces kept at a distance with the help of wooden distance pieces. Sometimes, timber lintels are strengthened by the provision of mild steel plates at their top and bottom, such lintels are called *flitched lintels.*

13.4. STONE LINTELS

Stone lintels are the most common types. Specially where stone is abundantly available. A stone lintel consists of a simple stone slab of greater thickness. Stone lintels can also be provided over openings in brick walls. Dressed stone lintels give good architectural appearance.

quite common, form work is required for construction.

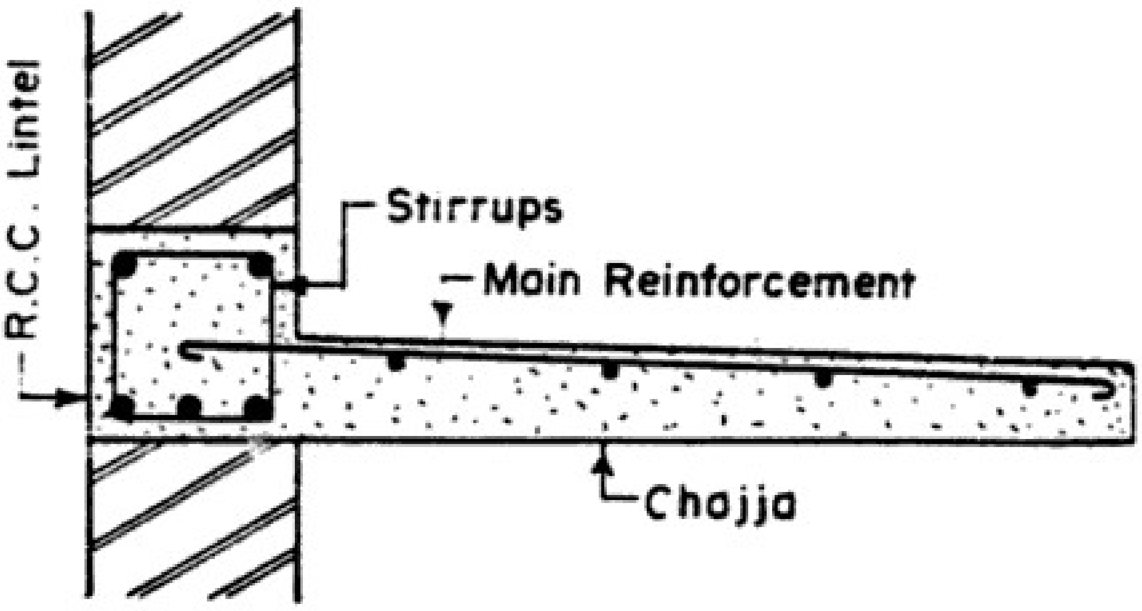


FIG. 13.7. R.C.C. LINTEL WITH CHHAJJA PROJECTION.

R.C.C. Boot lintels

R.C.C. boot lintels are provided over cavity walls. Such a lintel gives better appearance, and reduces quantity of concrete. However, the toe section of the boot lintel should be strong enough to sustain the loads. A flexible D.P.C. (damp-proof course) is provided above the lintel, as shown in Fig. 13.8.

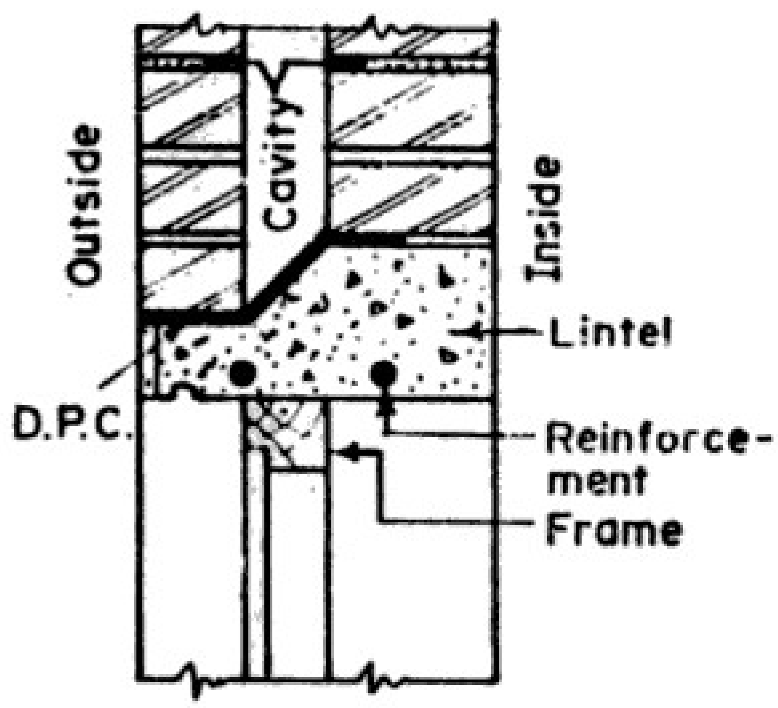


FIG. 13.8. R.C.C. BOOT LINTEL.

13.8. LOADING ON LINTELS

Lintels usually support the load of the wall over it and sometimes also the live load transferred by the slab-roof of the room. The following five cases may arise from point of view of distribution of load over the lintels :

1. When the length of wall on each side is more than half the effective span (L) of the lintel.

2. When the length of wall on each side is less than half the effective span.

3. When the length of walls to each side is less than half the effective span.

4. When there are openings on the lintel.

5. When there is load-carrying slab falling within dispersion triangle.

stairs in which newel posts are provided at the beginning and end of each flight. These may be of two forms : (*i*) with half space landing, and (*ii*) with quarter space landing and winders. Generally,

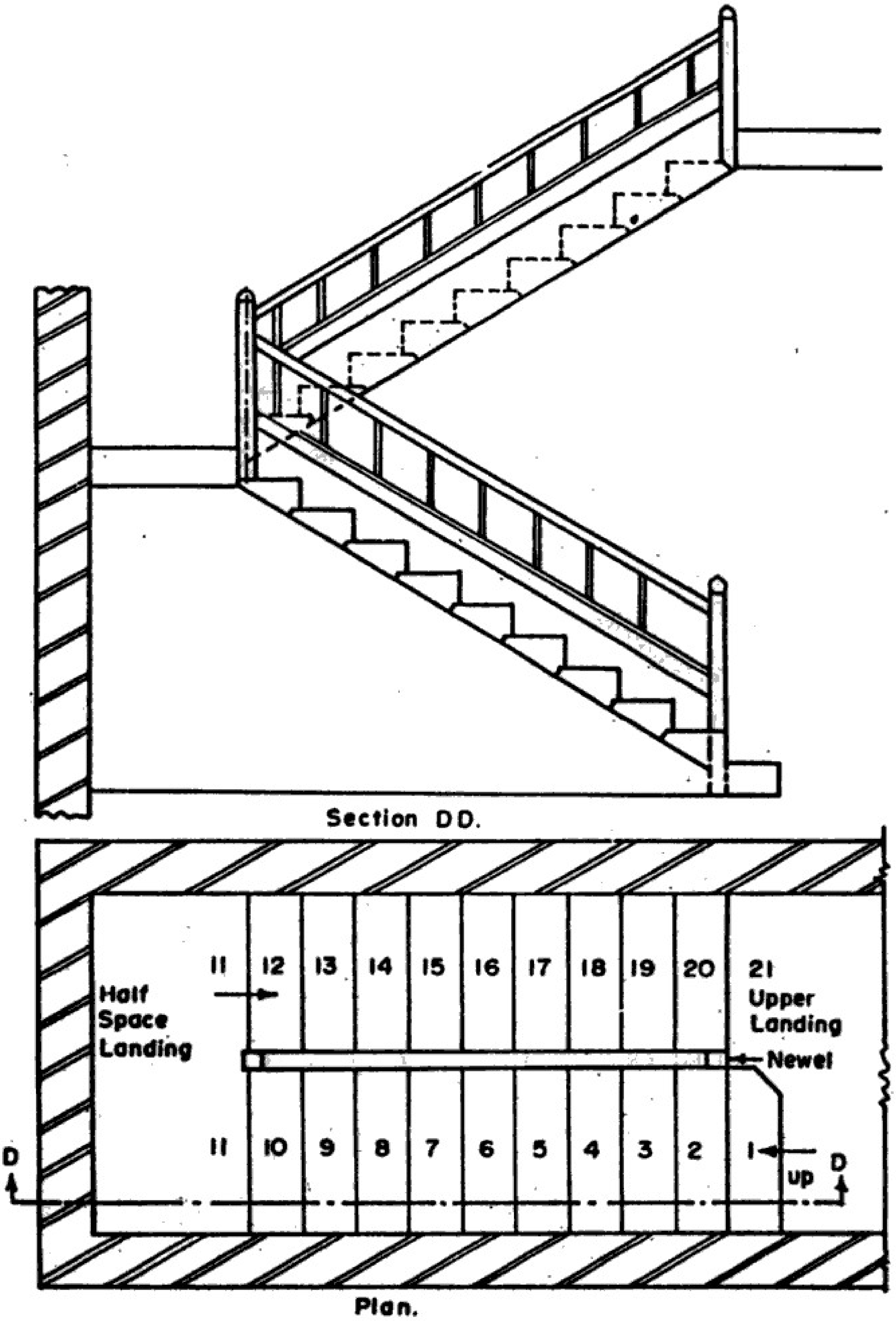


FIG. 14.6. DOG-LEGGED STAIR.

cut to receive the treads and risers; such strings improve very much the appearance of a stairs. However, its lower edge is kept parallel to the pitch of the stair. Because of cuts made, it becomes weak. A *housed or closed stringer* has its top and bottom edges parallel to the pitch of the stair. Grooves are cut on its inside to receive the treads and risers of the steps, which are generally nailed, glued and wedged to the stringers. The grooves or housings are tapered so that wedges may be driven below the treads and risers, thus forming a tight joint on the upper surface (Fig. 14.13). These wedges are best made from hard wood; they are dipped in glue before driving these. To add rigidity, blocks are glued between the string and the treads, and the treads and the risers. A *rough string* is an intermediate bearer provided for wider steps, as shown in Fig. 14.12. The carriage giving support to the treads and risers has rough brackets under the tread. A *wreathed string* is a curved or geometrical stair string, which may be either of cut or closed type.

Landing : A landing is constructed of tongued and grooved boarding on timber joists which are supported on walls. In the case of half space landing, a timber joist, known as *timber,* is placed across the full width of the stair case. In the case of quarter space landing, a timber joist, known as *pitching piece,* is placed in the wall at one end and housed with the newel at the other end.

2. STONE STAIRS

Stone stairs are widely used at places where ashlar stone is readily available. Stone stairs are quite strong and rigid, though they are very heavy. Stone used for the construction of stairs should be hard, strong and resistant to wear ; stones are fire resistant also. The simplest form of stone stairs are those supported on both the ends, though an open well stair case can also be built. Dog-legged stairs, with cantilevered spandril steps are also constructed of sand stones, such as the type available at Jodhpur.

Stone stairs may have following types of steps :

(*i*) Rectangular steps with rebated joint.
(*ii*) Spandril steps.
(*iii*) Tread and riser steps.
(*iv*) Cantilever tread steps.
(*v*) Built-up steps.

1. Rectangular steps

These are the simplest type, prepared from rectangular blocks of stone ashlar. The steps are arranged with the front edge of one step resting on the upper back edge of the step below, with rebated joint cut into it (Fig. 14.14).

2. Spandril steps

These steps are nearly triangular in shape so as to get a plain

$\therefore$ No. of risers required $= \frac{180}{15} = 12$ in each flight.

No. of treads in each flight $= 12 - 1 = 11$

$\therefore$ Space occupied by treads $= 11 \times 25 = 275$ cm.

$\therefore$ Space left for passage $= 5 - 1.2 - 2.75 = 1.05$ m.

Example 14.2. *Fig. 14.26 shows the plan of a stair hall of a public building, which measures* 4.25 m × *5.25 m. The vertical distance between the floors is 3.9 m. Design a suitable stair for the building.*

Solution. Since it is a public building, let us fix the width of stairs =1.5 m. Since the width of room is 4.25 m, space left between the two flights = 4.25 − 2×1.5 = 1.25 m. This suggests that we can provide an open well-type stairs.

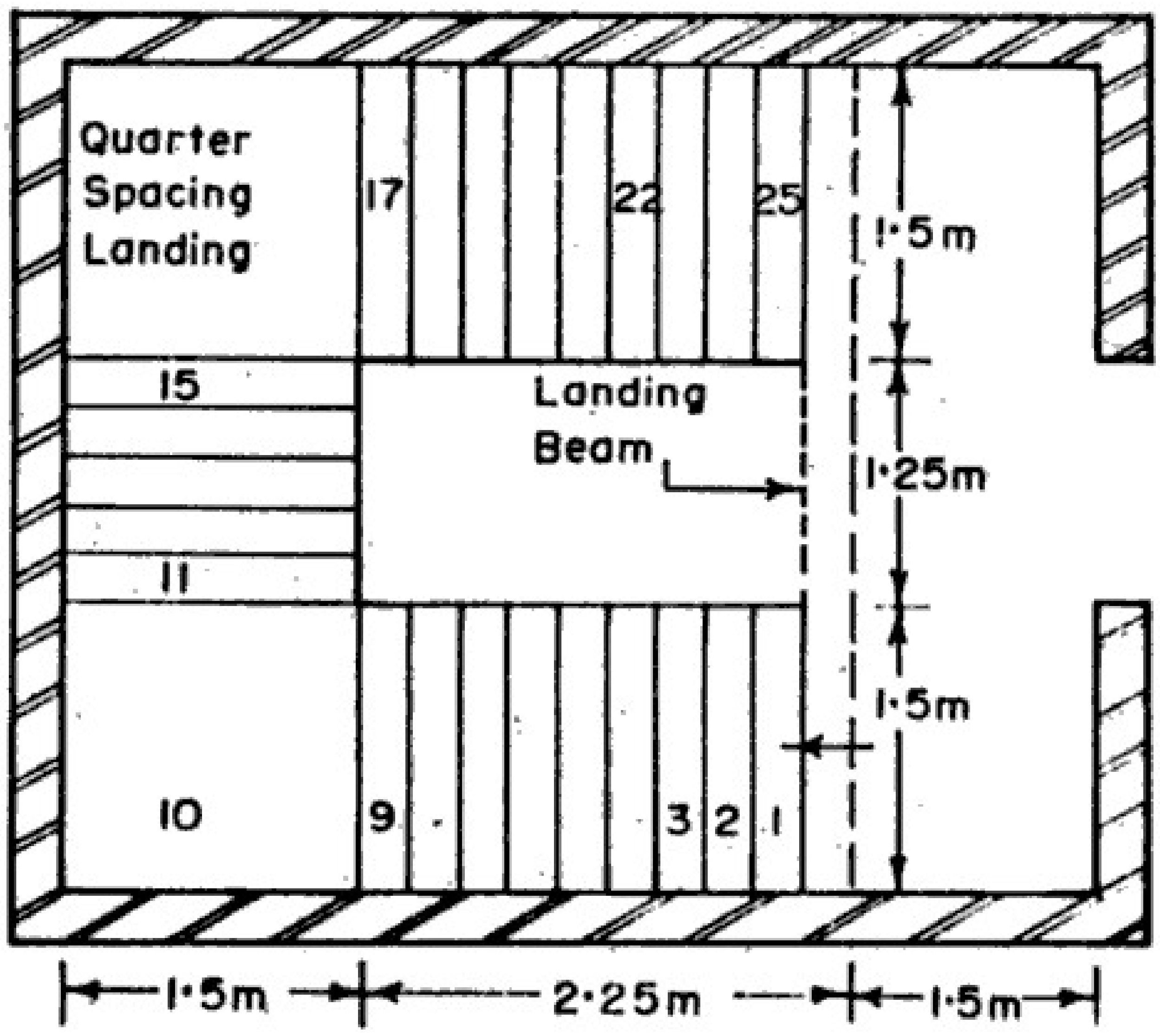


FIG. 14.26.

Let the height of risers be 15 cm. Keeping two flights, No. of riser in each flight $= \frac{1}{2} \times \frac{3.9 \times 100}{15} = 13$

$\therefore$ No. of treads in each flight $= 13 - 1 = 12$

Keeping width of tread = 25 cm, and width of landing =1.5, horizontal distance required to accommodate these =(25×12)+150 =450 cm =4.5 m. This will leave width of passage = 5.25−4.5=0.75 m only which is not sufficient. Also, in public buildings, maximum number of treads in each flight is limited to 9.

insulation against sound from external sources.

15.2. TYPES OF ROOFS

Roofs may be divided into three categories :

1. Pitched or sloping roofs,
2. Flat roofs or terraced roofs, and
3. Curved roofs.

The selection of the type of roof depends upon the shape or plan of the building, climatic conditions of the area and type of constructional materials available. *Pitched roofs* have sloping top surface. These are suitable in those areas where rainfall/snowfall is very heavy. Broadly, buildings with limited width and simple shape can generally be covered satisfactorily by pitched roofs. Buildings irregular in plan, or with long spans, present awkward problems in the design of a pitched roof, involving numerous valleys, gutters and hips. Buildings of large area, such as factories, when covered by a series of parallel pitched roofs, require internal guttering in the valleys. *Flat roofs* are considered suitable for buildings in plains or in hot regions, where rainfall is moderate, and where snowfall is not there. Flat roofs are equally applicable to buildings of any shape and size. *Curved roofs* have their top surface curved. Such roofs are provided to give architectural effects. Such roofs include cylindrical and parabolic shells and shell domes, doubly curved shells such as hyperbolic paraboloids and hyperboloids of revolution, and folded slabs and prismatic shells. Such roofs are more suitable for public buildings like libraries, theatres, recreation centres etc.

15.3. PITCHED ROOFS : BASIC ELEMENTS

A roof with sloping surface is known as a pitched roof. Pitched roofs are basically of the following forms :

1. Lean-to-roof
2. Gable roof
3. Hip roof
4. Gambrel roof
5. Mansard or curb roof
6. Deck roof.

Lean-to-roof: This is the simplest type of sloping roof, provided either for a room of small span, or for the verandah. It has slope only one side (Fig. 15.1 *a*).

Gable roof: This is the common type of sloping roof which slopes in two directions. The two slopes meet at the ridge. At the end face, a vertical triangle if formed (Fig. 15.1 *b*).

Hip roof: This roof is formed by four sloping surfaces in four directions (Fig. 15.1*c*). At the end faces, *sloped triangles* are formed.

Gambrel roof: This roof, like gable roof, slopes in two directions, but there is a break in each slope, as shown in Fig. 15.1(*d*). At the feet of the common rafters. These are embedded from sides and bottom in masonry of the walls, almost at the centre of their thickness. Wall plates actually connect the walls to the roof.

19. Post plate. This is similar to a wall plate except that they run continuous, parallel to the face of wall, over the tops of the posts, and support rafters at their feet.

20. Battens. These are thin strips of wood, called scantlings, which are nailed to the rafters for lying roof materials above.

21. Boardings. They act similar to battens and are nailed to common rafter to support the roofing material.

22. Template. This is a square or rectangular block of stone or concrete placed under a beam or truss, to spread the load over a larger area of the wall.

23. Cleats. These are short sections of wood or steal (angle iron), which are fixed on the principal rafters of trusses to support the purlins.

24. Truss. A roof truss is a frame work, usually of triangles, designed to support the roof covering or ceiling over rooms.

15.4. TYPES OF PITCHED ROOFS

Pitched roofs may be broadly classified into the following :

(a) Single roofs

1. Lean-to-roof (verandah roof).
2. Couple roof.
3. Couple-close roof.
4. Collar beam roof or collar tie roof.

(b) Double or purlin roofs

(c) Triple-membered or framed or trussed roofs

1. King-post roof truss.
2. Queen-post roof truss.
3. Combination of king-post and queen-post trusses,
4. Mansard roof truss.
5. Truncated roof truss.
6. Bel-fast roof truss or latticed roof truss.
7. Composite roof trusses.
8. Steel sloping roof trusses.

Single roofs consist of only common rafters which are secured at the ridge (to ridge beam) and wall plate. These are used when span is less so that no intermediate support is required for the rafters. A *double roof* is the one in which *purlins* are introduced to support the common rafters at intermediate point. Such roofs are used when the span exceeds 5 metres. The function of a purlin is to tie the rafters together, and to act as an intermediate support to the rafters. A *triple membered or trussed roof* consists of three (*i*) ***Sub-division A-1 : Lodging or Rooming Houses***

These include any building or group of buildings under the same management, in which separate sleeping accommodation for a total of not more than 15 persons, on either transient or permanent basis with or without dining facilities, but without cooking facilities for individuals, is provided.

A lodging or rooming house is classified as a dwelling in sub-division *A-2* if no room in any of its private dwelling units is rented to more than three persons.

(*ii*) ***Sub-division A-2 : One or two Family Private Dwellings***

These include any private dwelling which is occupied by members of a single family and has a total sleeping accommodation for not more than 20 persons.

If rooms in a private dwelling are rented to outsiders, these should be for accommodating not more than 3 persons.

If sleeping accommodation for more than 20 persons is provided in any one residential building, it should be classified as a building sub-division *A-3* or *A-4* as the case may be.

(*iii*) ***Sub-division A-3 : Dormitories***

These include any building in which group sleeping accommodation is provided, with or without dining facilities, for persons who are not members of the same family, in any one room or a series of closely associated rooms under joint occupancy and single management, for example, school and college dormitories, students and other hostels and military barracks.

(*iv*) ***Sub-division A-4 : Apartment Houses (Flats)***

These include any building or structure in which living quarters are provided for three or more families living independently of each other and with independent cooking facilities, for example, apartment houses, mansions and chawls..

(*v*) ***Sub-division A-5 : Hotels***

These include any building or group of buildings under single management in which sleeping accommodation, with or without dining facilities, is provided for hire to more than 15 persons who are primarily transient, for example hotels, inns, clubs and motels.

2. Group *B* : Educational Buildings

These include any building used for school, college, or day-care purposes for more than 8 hours per week involving assembly for instruction, education or recreation and which is not covered by Group *D*.

3. Group *C* : Institutional Buildings

These include any building or part thereof, which is
purposes such a medical or other treatment or care of persc

The head of each strut is fixed to the principal rafter by an 'oblique' mortise and tenon joint. The king-post is provided with splayed shoulders and feet, and is tenoned into the upper edge of the tie beam for a sufficient distance. It is further strengthened by mild steel or wrought iron strap. At its head, the king-post is jointed to the ends of principal rafters by 'tenon and mortice' joint. The joint is secured by means of a three-way wrought iron or mild steel strap on each side. *Purlins,* made of stout timber, are placed at right angles to the sloping principal rafters, and are secured to them through cogged joints and cleats. Cleats, fixed on principal rafter, prevent the purlins from tilting. Fig. 15.11 shows the details of the joint. The common rafters may be connected to eaves board or to *pole plate* at the other end. *Pole plates* are horizontal timber sections which run across the tops of the tie beams at their ends, or on principal rafters near their feet. They thus run parallel to purlins.

2. Queen-post truss

A queen-post truss differs from a king-post truss in having two vertical posts, rather than one. The vertical posts are known as queen-posts, the tops of which are connected by a horizontal piece, known as *straining beam.* Two struts are provided to join the feet of each queen-post to the principal rafter, as shown in Fig. 15.12. The queen-posts are the tension members. The straining beams receives the thrust from the principal rafters, and keeps the junction in stable position. A *straining sill* is introduced on the tie beam between the queen-posts to counteract the thrust from inclined struts which are in compression. In absence of the straining sill, the thrust from the strut would tend to force the foot of the queen-post inwards. Purlins, with cleats, are provided as in the king-post truss. These trusses are suitable for spans between 8 to 12 metres.

The joint at the head of queen-post is formed due to the junction of two compression members (principal rafter and straining beam) and a tension member(queen-post). The head of the queen-post is made wider, and the head of the principal rafter and the end of straining beam are tenoned into it. The joint is further strengthened by fixing a 3-way strap of wrought-iron or steel on each face as shown in Fig. 15.12 (*b*). Similarly, the feet of queen-post is widened to receive the tenon of the inclined strut, forming a 'single abutment and tenon joint'. The queen-post then tenons into the tie beam. The joint is further strengthened by stirrup straps and bolts.

Steel trusses may be grouped in the following categories :

(*a*) Open trusses
(*b*) North light trusses
(*c*) Bow string trusses
(*d*) Arched rib trusses and solid arched ribs.

The various shapes of these, along with their suitability for different span ranges, are shown in Figs. 15.19, 15.20, and 15.21.

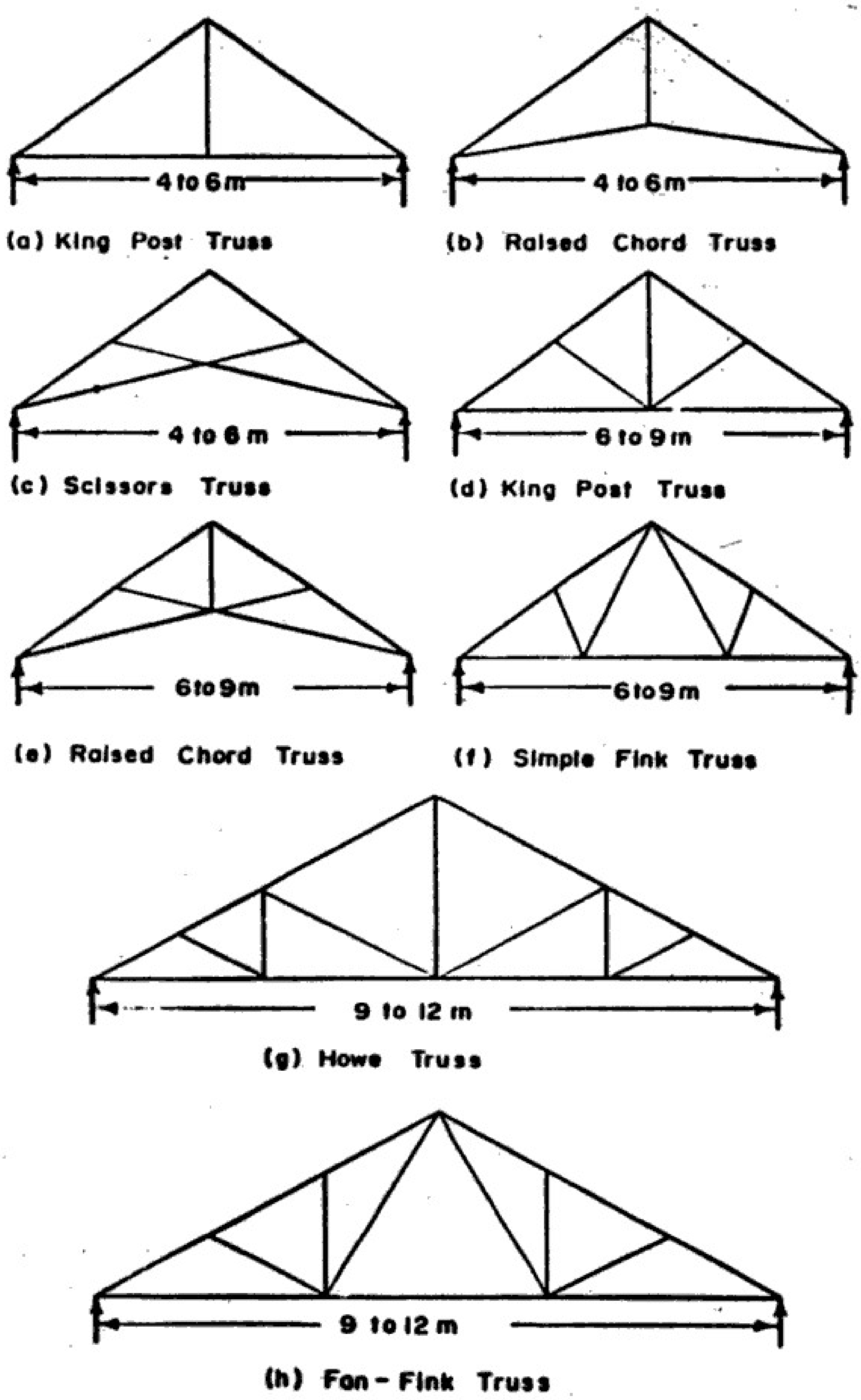


FIG. 15.19. STEEL TRUSSES.

to timber trusses. The members are equally strong in tension as well as compression.

4. Steel trusses can be used over any span, while timber trusses are suitable only upto 15 m span.

5. Steel trusses are fire-proof.

6. Steel trusses are termite proof.

7. Steel trusses are most resistant to other environmental agencies, and have longer life.

8. The fabrication of steel trusses is easier and quicker, since the sections can be machined and shaped in the workshop, and then transported to the construction site for erection.

15.9. ROOF COVERINGS FOR PITCHED ROOFS

Roof covering is an essential component of pitched roof, to be placed over the roof frame work, to protect it from rain, snow, sun, wind and other atmospheric agencies. Various types of roofing materials are available, and their selection depends upon (*i*) type of building, (*ii*) type of roof framework, (*iii*) initial cost, (*iv*) maintenance requirements, (*v*) fabrication facilities, (*vi*) appearance and special features of the locality, (*vii*) durability, (*viii*) availability of the material itself, and (*ix*) climate of the locality.

The following are the roof-covering materials commonly used for pitched roofs :

1. Thatch covering
2. Wood shingles
3. Tiles
4. Asbestos cement sheets
5. Galvanised corrugated iron sheets
6. Eternit slates.
7. Light weight roofing.

(*a*) Thatch covering

This is the cheapest roof-covering, commonly used in villages. It is very light, but is highly combustible. It is unstable against high winds. It absorbs moisture and is liable to decay. It harbours rats and other burrowing animals, and gives bad smell in rainy season. Thatch roof-covering consists of bundles of reeds or straw . The frame work to support thatch consists of round bamboo rafters spaced 20 to 30 cm apart and tied with split bamboos laid at right angles to the rafters. The reed or straw must be well-soaked in water or fire-resisting solution to facilitate packing, and the bundles are laid with their butt ends pointing towards the eaves. The thatch is tightly secured to the frame work with the help of ropes or twines dipped in tar. In order to drain the roof effectively, a minimum slope of 45° is kept. The thickness of thatch covering should at least be 15 cm ; normal thickness varies from 20 to 30 cm according to constructed in the following steps :

(*i*) Wooden joists are placed on R.S.J. with a furring piece in-between. The furring piece height at the centre is so adjusted that the required slope of the roof is obtained.

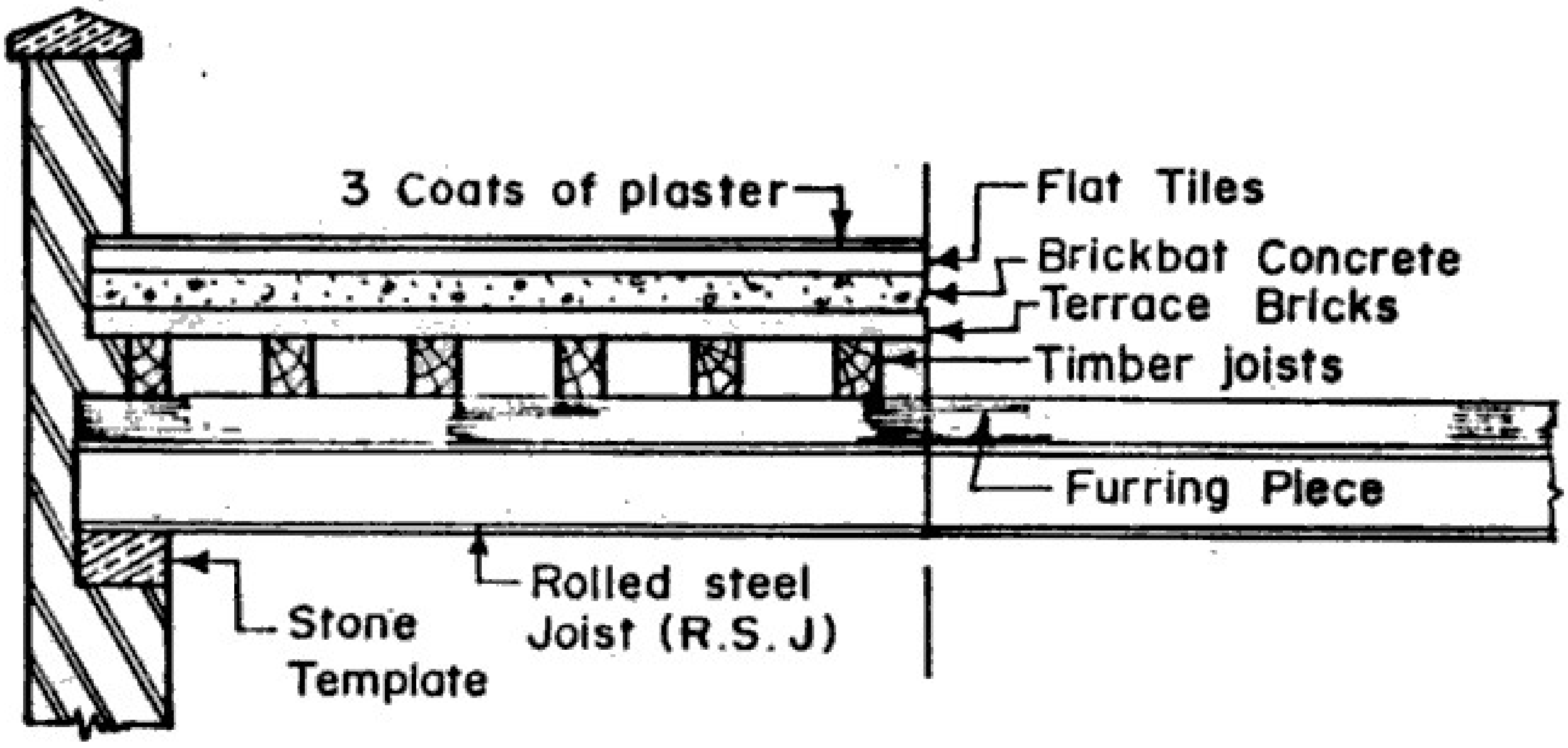


FIG. 15.37. MADRAS TERRACE ROOF.

(*ii*) A course of specially prepared bricks of size 15 cm× 5 cm×12 mm is placed on edge in lime mortar (1 : 1.5) laid diagonally across the joists.

(*iii*) After the brick course is set, a 10 cm thick layer of brick-bat concrete is laid, consisting of 3 parts of brick-bats, 1 part of gravel and sand, and 50 percent of of lime mortar by volume. The concrete is well-rammed for 3 days, so that the thickness reduces to 7.5 cm, by wooden hand beaters. The surface is cured for 3 days, by sprinking lime water.

(*iv*) When the brick-bat concrete has set, three courses of Madras flat tiles(15 cm × 10 cm × 12 mm) are laid in lime mortar ($1 : 1\frac{1}{2}$), making a total thickness of 50 mm. The vertical joints of the tiles in successive layers should be broken. The joints of tiles in top layer are left open to provide key for top plaster. Alternatively, China mosaic tiles may be used.

(*v*) Finally, the top surface is plastered with three coats of lime mortar. The surface is rubbed and polished.

3. Mud-phuska terracing with tile paving

This method of terracing is equally suitable to hot as well as arid regions, and is commonly used over R.C.C. roofing. The section of roofing is shown in Fig. 15.38. The work is carried out in the following steps :

1. The R.C.C. slab is cleaned off dust and loose material. A layer of hot bitumen is spread over it at the rate of 1.70 kg of bitumen per square metre of roof surface.

6. Differentiate clearly between (*i*) single roof, (*ii*) double roof, and (*ii*) trussed roofs.

7. Compare steel roof trusses and timber roof trusses.

8. Explain the following :

(*i*) Tiles roofing on pitched roofs.

(*ii*) A.C. sheet roofing.

(*iii*) Mud-phuska roofing.

(*iv*) Slate roofing.

9. Explain any method of providing water proof terracing on R.C.C. roof slab.

10. Explain Jodhpur type lime terracing.

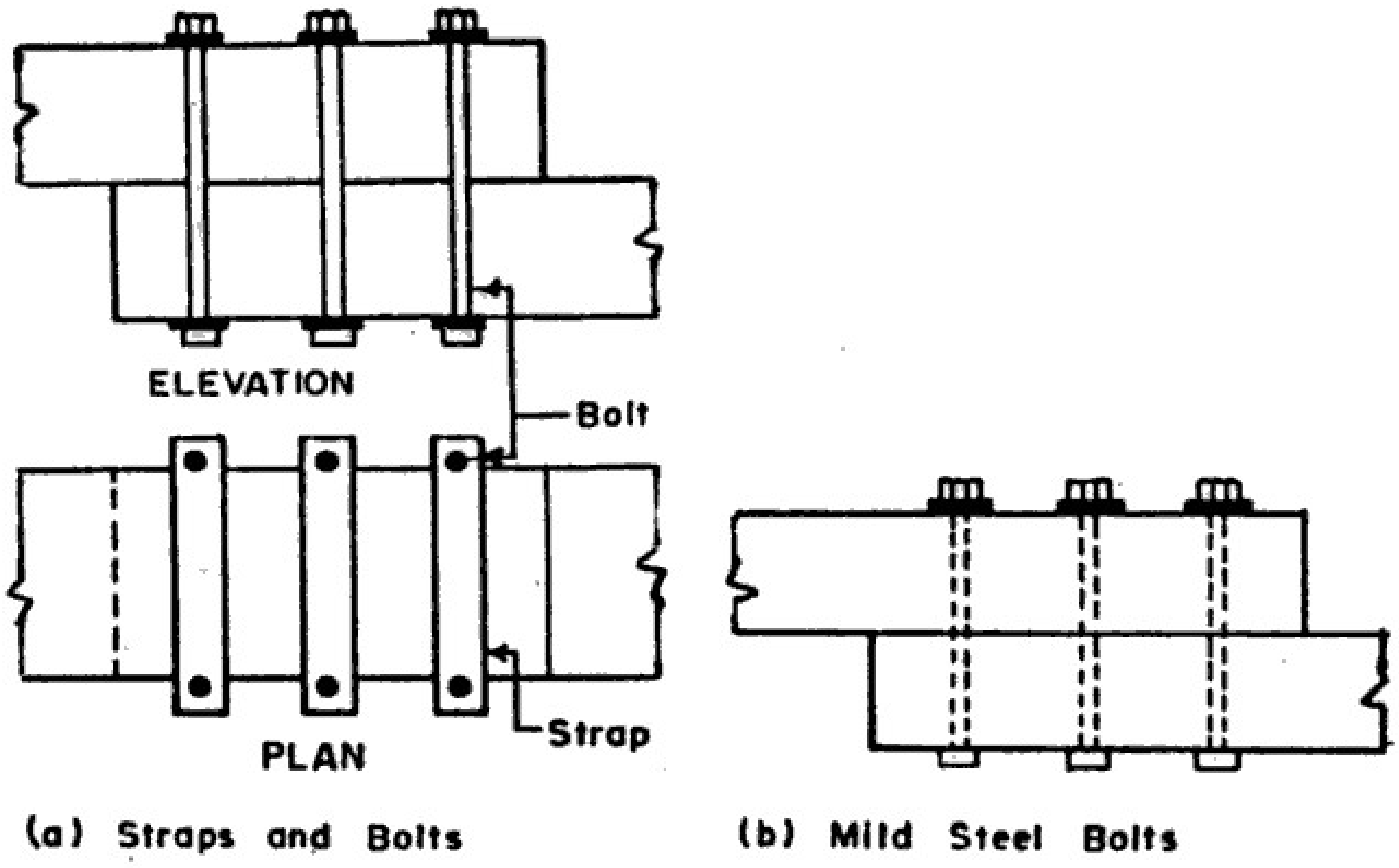


FIG. 16.1. LAPPED JOINT.

2. Fished Joint

In this joint, the ends of the two members are cut square and placed touching each other (or butted). They are then jointed together placing wooden or iron fish plates on opposite faces and securing these by passing bolts through them, as shown in Fig. 16.2(*a*). The ends of fish plates are slightly bent and then pressed into the

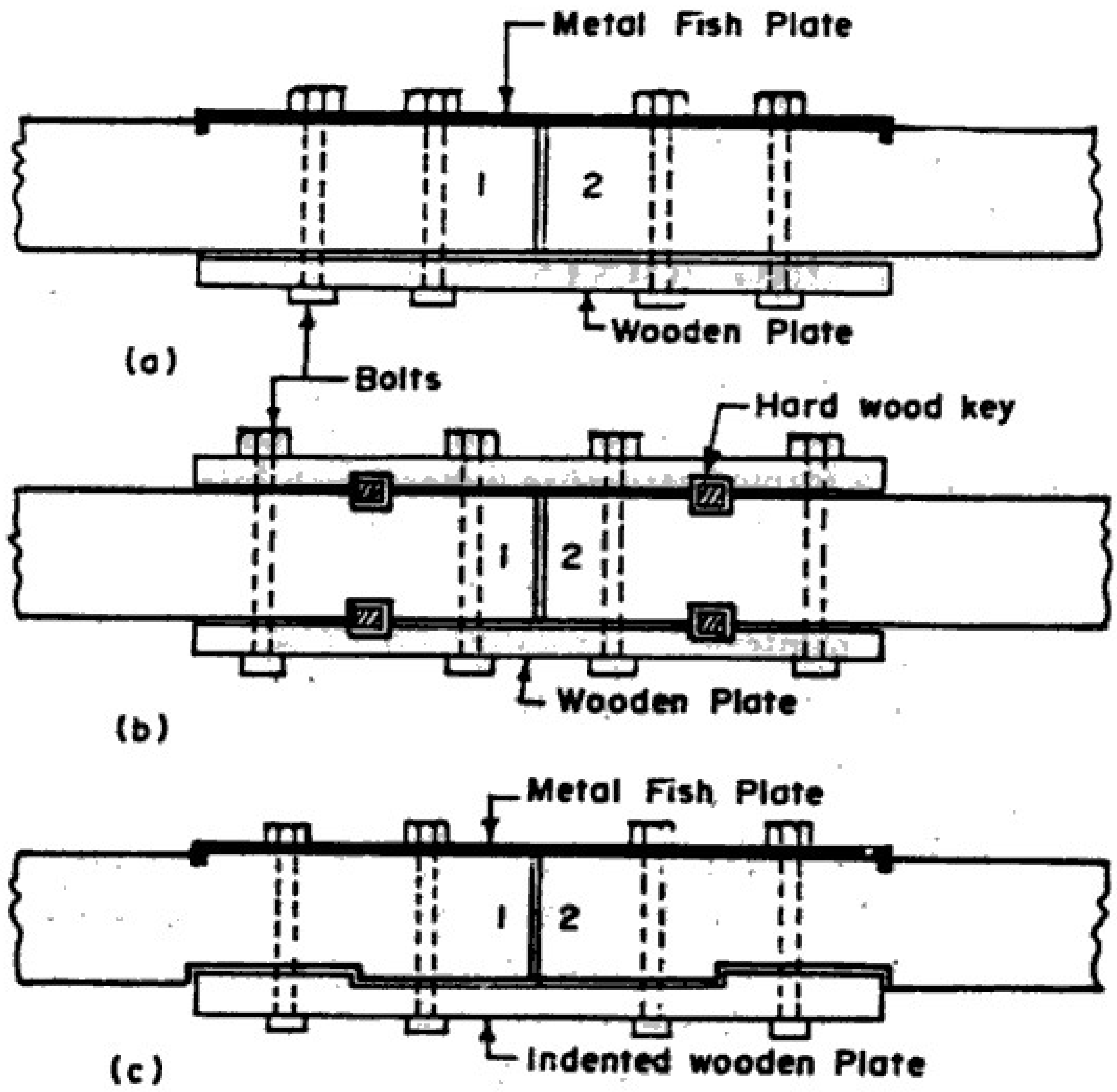
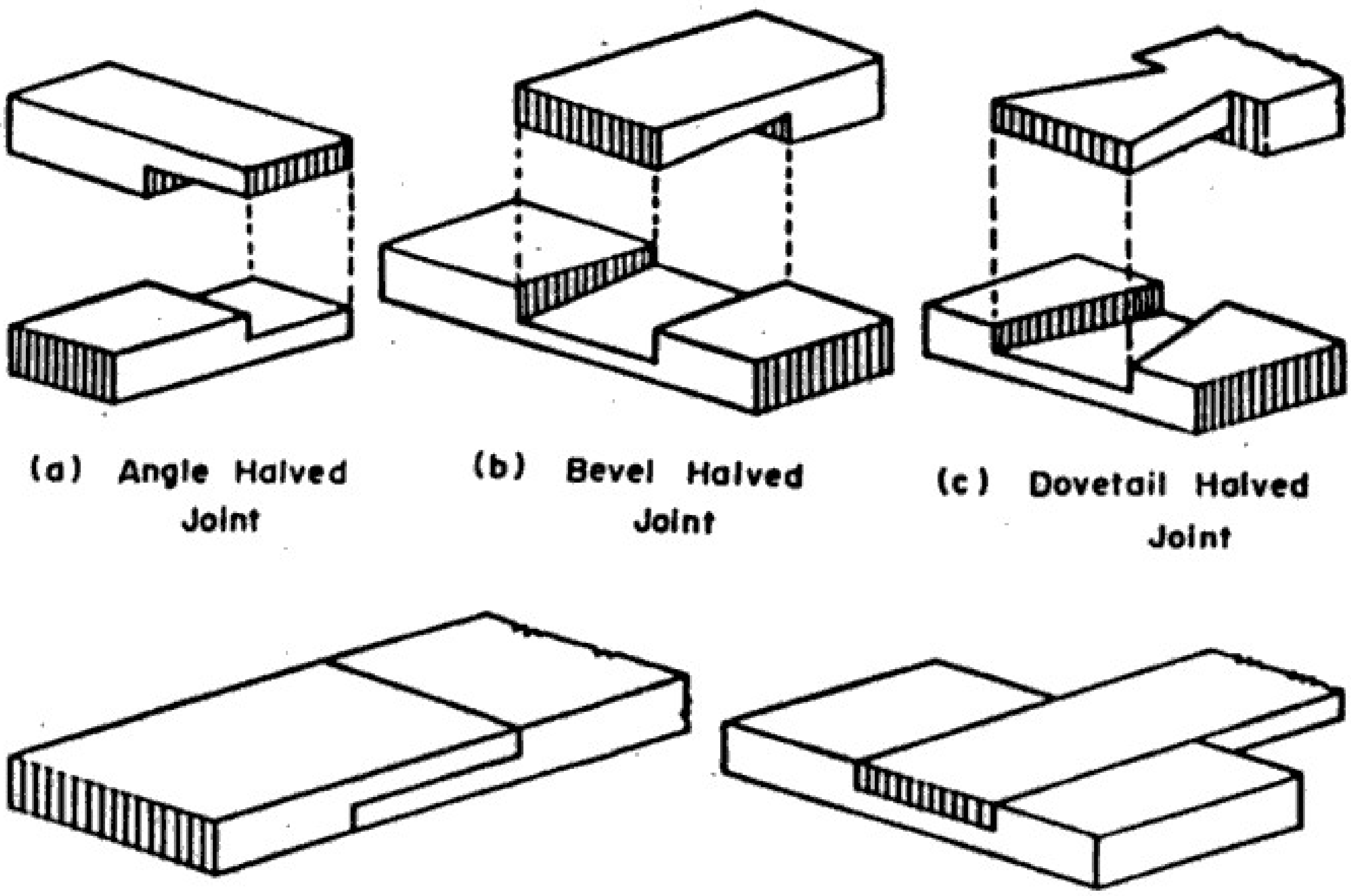


FIG. 16.2. FISHED JOINTS.

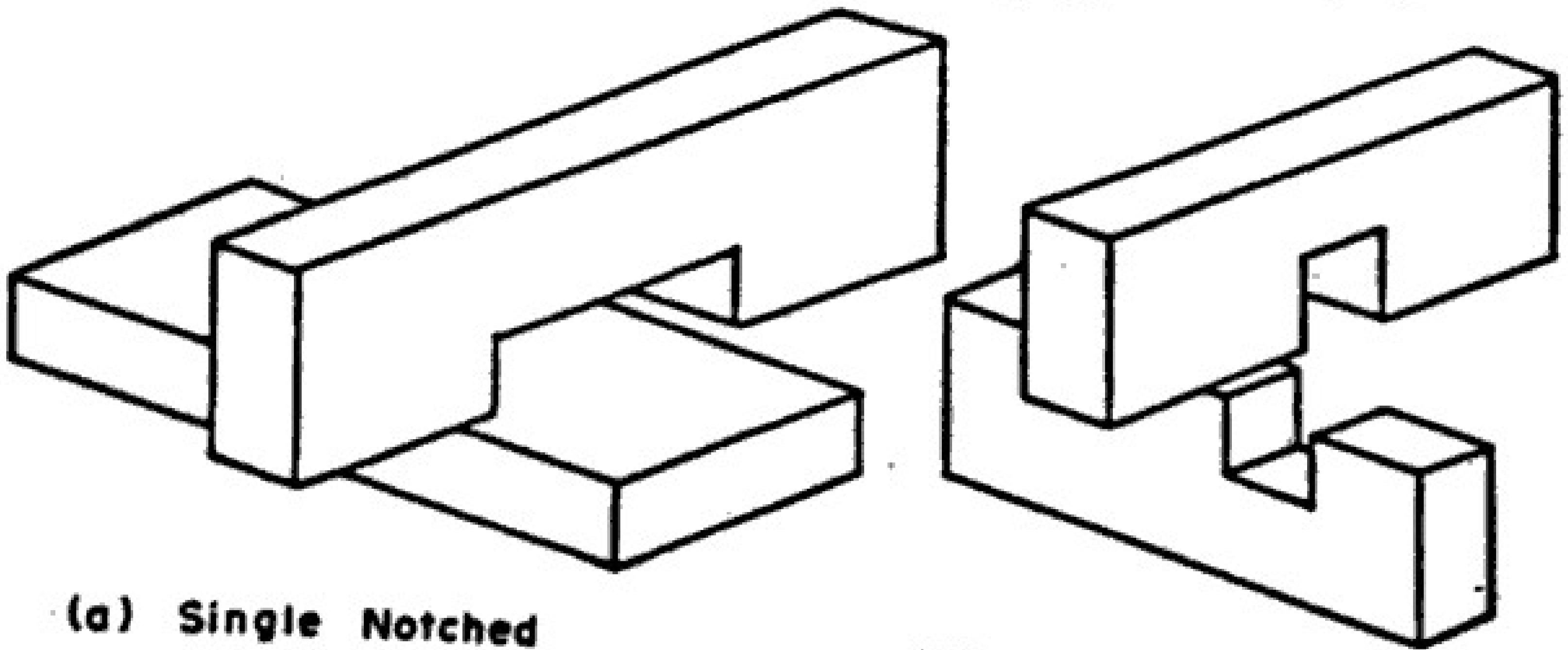


(a) Angle Halved Joint (b) Bevel Halved Joint (c) Dovetail Halved Joint

(d) Longitudinal Halved Joint (e) Tee Halved Joint

FIG. 16.6.

2. Notched Joint. It is formed by forming notch in one or both the members to be connected (Figs. 16.7 *a*, *b*).



(a) Single Notched (b) Double Notched

FIG. 16.7. NOTCHED JOINT.

3. Cogged joint (Fig. 16.8). This joint is formed by cutting small notch in the beam or timber member and providing notches on the lower member with a projection in the centre. The projection is known as *cog*. The upper portion, in which only small notch has been formed, retains its strength.

4. Housed joint (Fig. 16.9 *a*). It is formed by fitting the entire tickness of the end of one member for a short distance into another piece. It is used in stairs in which the ends of risers and treads are housed in the strings.

cutting an angular notch (called *bird's mouth*) in the main member, to which the other member is partly inserted and fitted.

5. Oblique tenon joint (Fig. 16.13 *a*). This is used for connecting a horizontal member to an inclined member, both the members being of bigger size. The tenon of inclined member is oblique, which fits into the corresponding mortise hole of the horizontal member. The joint is further strengthened by bolts, keys, straps etc.

16.11. FASTENINGS

Timber joints are secured in position with the help of following commonly used fastenings (Fig. 16.14).

1. Wire nails. These are circular or oval in shape, made of wrought iron or steel.

2. Cut nails. These are trapezoidal in section, and are smaller in length.

3. Floor brads. These are tapering nails of rectangular section, with head at one end, and are used for securing floor boards.

4. Lath nails. It is in the form of iron clout, square and

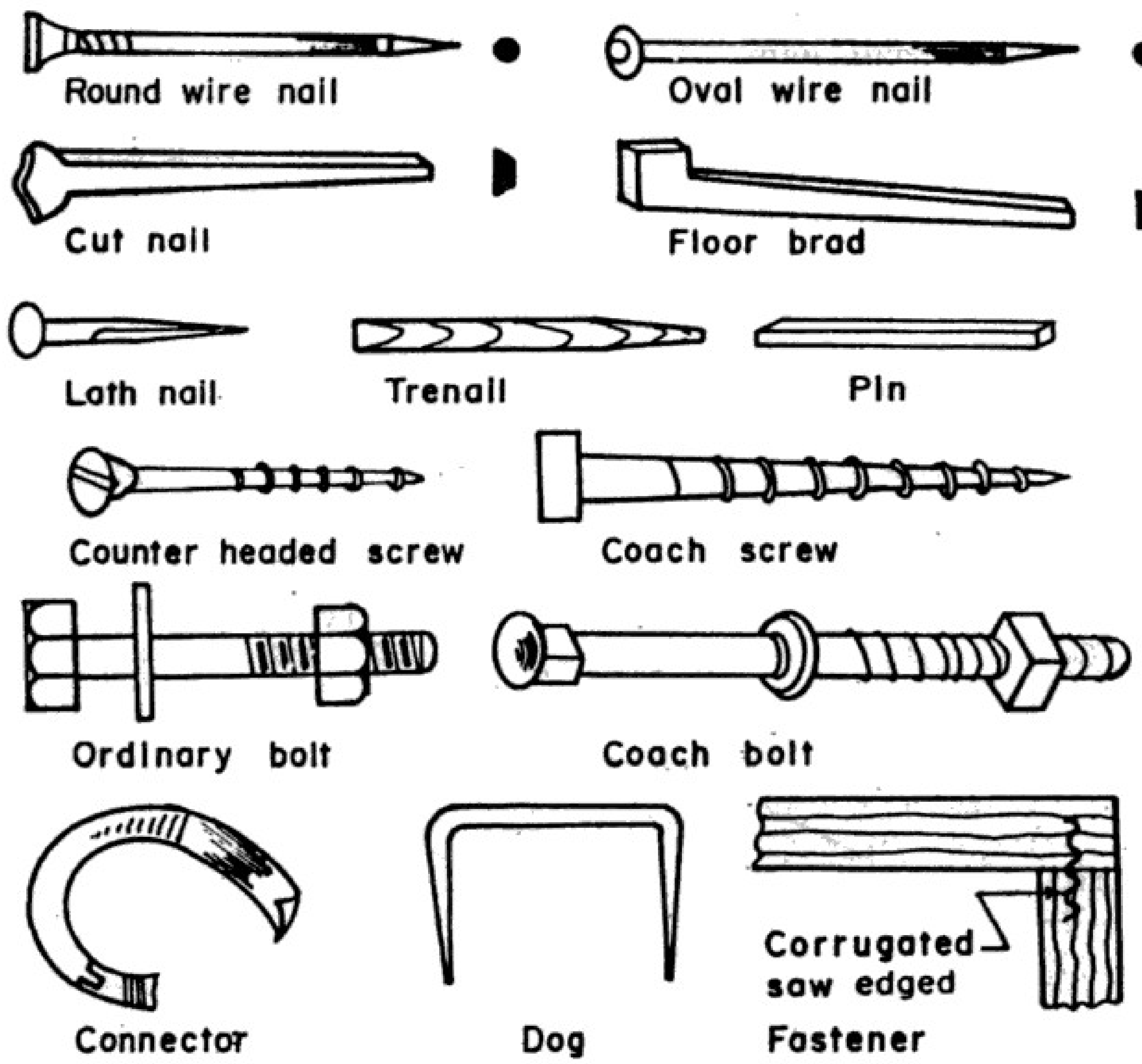


FIG. 16.14. FASTENINGS.

the basis if important factors such as distribution of light, control of ventilation, and privacy of the occupants.

5. The location of a window should also meet the functional requirements of the room, such as interior decoration, arrangement of furniture etc.

6. A window should be located in opposite wall, facing a door or another window, so that cross-ventilation is achieved.

7. From the point of view of fresh air, a window should be located on the northern side of a room.

8. From the point of view of fresh air, a window should be located in the prevalent direction of wind.

9. The sill of a window should be located about 70 to 80 cm about floor level of the room.

17.3. DEFINITION OF TECHNICAL TERMS

Figs. 17.1 and 17.2 show respectively a door and a window. The following are the technical terms applied to doors and windows :

1. Frame. It is an assembly of horizontal and vertical members, forming an enclosure, to which the shutters are fixed.

2. Shutters. These are the openable parts of a door or window. It is an assembly of styles, panels and rails.

3. Head. This is the top or uppermost horizontal part of a frame.

4. Sill. This is the lowermost or bottom horizontal part of a window frame. Sills are normally not provided in door frames.

5. Horn. These are the horizontal projections of the head and sill of a frame to facilitate the fixing of the frame on the wall opening. The length of horns is kept about 10 to 15 cm.

6. Style. Style is the vertical outside member of the shutter of a door or window.

7. Top rail. This is the top most horizontal member of a shutter.

8. Lock rail. This is the middle horizontal member of a door shutter, to which locking arrangement is fixed.

9. Bottom rail. This is the lowermost horizontal member of a shutter.

10. Intermediate or cross-rails. These are additional horizontal rails, fixed between the top and bottom rails of a shutter. A rail fixed between the top rail and lock rail is called *frieze rail.*

11. Panel. This is the area of shutter enclosed between the adjacent rails.

12. Mullion. This is a vertical member of a frame, which is employed to sub-divide a window or a door vertically.

from physical or mental illness, disease or infirmity ; care of infants, conval escents or aged persons and for penal or correctional detension in which the liberty of inmates is restricted. Institutional buildings ordinarily provide sleeping accommodation for the occupants.

Buildings under group *C* are further sub-divided as follows:

(i) Sub-division C-1 : Hospitals and Sanitaria

This sub-division includes any building or group of buildings under single management, which is used for housing persons suffering from physical limitations because of health or age, for example, hospitals, infirmaries, sanitaria and clinics.

(ii) Sub-division C-2 : Custodial Institutions

This sub-division includes any building or group of buildings under single management, which is used for the custody and care of persons such as children, convalescents and the aged, for example, homes for the aged and infirm, convalescent homes and orphanages.

(iii) Sub-division C-3 : Penal Institutions

This sub-division includes any building or a group of buildings under single management, which is used for housing persons under restraint, or who are detained for penal or corrective purposes, in which the liberty of the inmates is restricted, for examples, jails, prisons, mental hospitals, mental sanitaria and reformatories.

4. Group *D* : Assembly Buildings

These include any building or part of a building, where group of people congregate or gather for amusement, recreation, social, religious, patriotic, civil, travel and similar purpose, for example, theatres, motion picture houses, assembly halls, auditoria, exhibition halls, museums, skating rinks, gymnasiums, restaurants, places of worship, dance halls, club rooms, passenger stations and terminals of air, surface and marine public transportation service, recreation piers and stadia.

Buildings under group *D* are further sub-divided as follows:

(i) Sub-division D–1

This sub-division includes any building primarily meant for theatrical or operatic performances and exhibitions and which has a raised stage, proscenium curtain, fixed or portable scenery or scenery loft, lights, motion picture booth, mechanical appliances or other theatrical accessories and equipment and which is provided with fixed seats over 1000 persons.

(ii) Sub division D–2

This sub-division includes any building primarily meant for use as described for sub-division *D–1* but with fixed seats for less than 1000 persons.

2. BATTENED, LEDGED, AND BRACED DOORS

These doors are improved versions of battened and ledged doors, in which additional inclined (or diagonal) members, called *races* are provided, as shown in Fig. 17.7, to give more rigidity. Hence these doors can be used for wider openings. The braces, 100

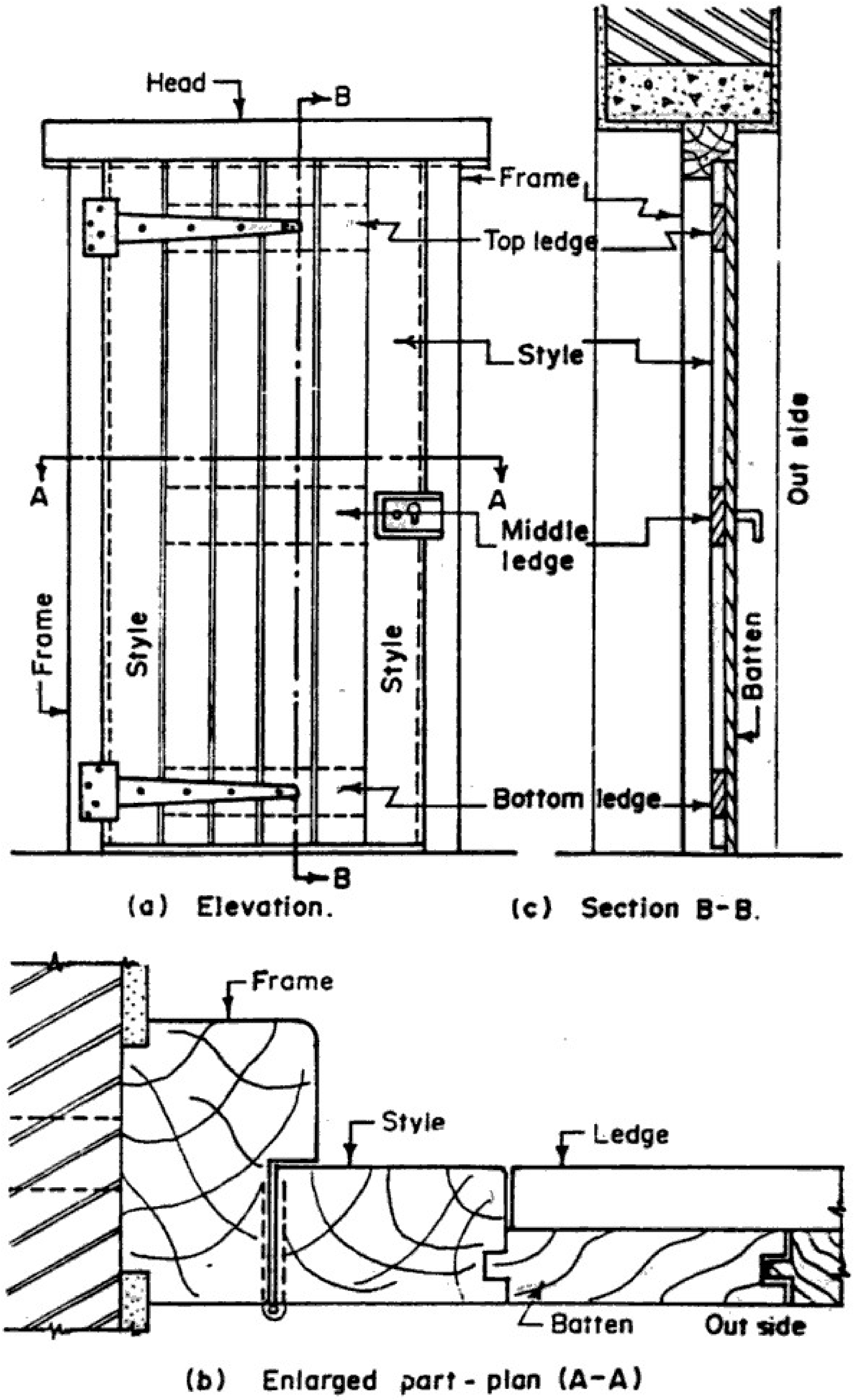


FIG. 17.8. BATTENED, LEDGED AND FRAMED DOOR.

room. Such doors are commonly used in residential as well as public buildings like hospitals, schools, colleges etc. The doors may be either fully glazed, or they be partly glazed and partly panelled. In the latter case, the ratio of glazed portion to panelled portion is kept 2 : 1 ; the bottom one-third height is panelled and the top two-thirds height is glazed. Figs. 17.12 and 17.13 show some common forms of glazed doors, and partly glazed doors. The glass is received into rebates provided in the wooden sash bars and secured by 'rails putty' or by wooden beads fixed to the frame.

Partly glazed doors are sometimes provided with stiles which gradually diminish at lock rail, to improve the elevation and to permit more area for the glazed panels. Such a door is shown in Fig. 17.13(*a*). Such types, which decrease in width at the lock- rail level are called *'diminishing stiles'* or *'gun stock stiles'*. Fig. 17.13 (*b*) shows a partly glazed, louvered and panelled door. The louvers permit natural ventilation even when the door is closed.

7. FLUSH DOORS

Flush doors are becoming increasingly popular these days because of their pleasing appearance, simplicity of construction, less cost, better strength and greater durability. They are used both for residential as well as public and commercial buildings. These doors consist of solid or semi-solid skeleton or core covered on both sides with plywood, face veneers etc., presenting flush and jointless surface which can be neatly polished.

Flushed doors are of two types :

(*i*) Solid core flush door or laminated core flush door.

(*ii*) Hollow and cellular core flush door.

(*i*) Solid core flush door or laminated core flush door (Fig. 17.15)

Such a door consists of the wooden frame consisting of styles, and top and bottom rails is used for holding the core. The core consists either of core-strips of timber glued together under great pressure and faced on each side by plywood sheets, or of block board, particle board or a combination of particle board and block board, faced with plywood sheets. In the laminated core, the wooden strips are of maximum width of 25 mm glued together, and the length of each strip is equal to the length of the laminated core. In each type of core, plywood sheets are glued under pressure to the assembly of core housed in the frame on both faces. Alternatively, separate cross-bands and face veneers can be glued on both the faces, with the grains of crossband at right angles to the core and grain of veneer at right angles to that of the cross-band. The core is housed in the outer frame having stiles, top and bottom rails each of not less than 75 mm width. Such doors are quite strong, but are heavy and require more material.

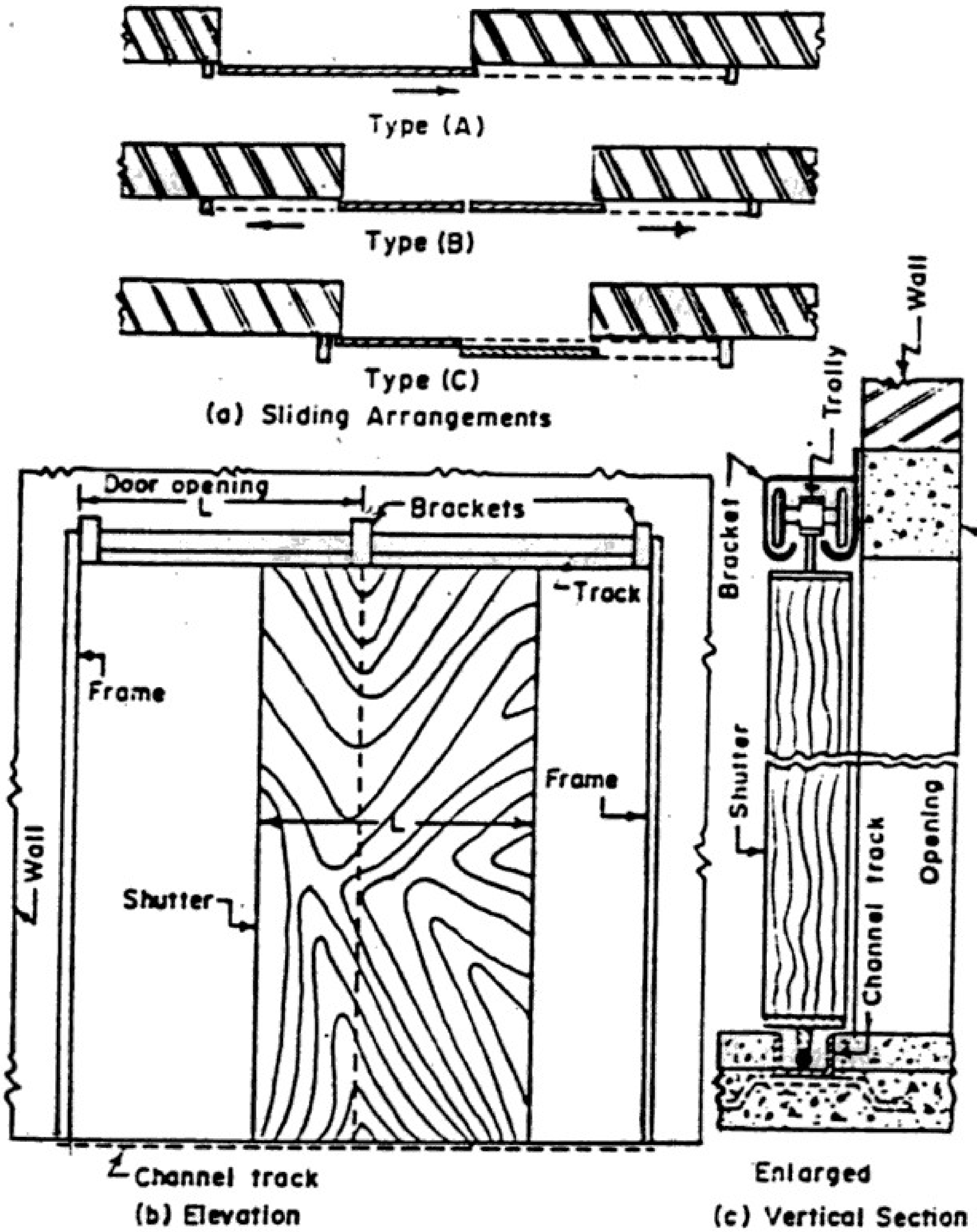


FIG. 17.20. SLIDING DOOR.

12. SWING DOORS

A Swing door has its leaf attached to the door frame by means of special *double action spring hinge,* so that the shutter can move both inward or outward as desired. Generally, such doors have single leaf, but two leafs can also be provided. Such doors are not rebated at the meeting styles , the closing edges of which should be segmental. When the door is to be used, a slight push is made and then the action of spring brings the shutter in closed position . The return of the shutter is with force, and hence in order to avoid accident, either the door should be fully glazed or a peep hole should be provided at the eye level, as shown in Fig. 17.21.

manner of fixing and their location.

1. Fixed Windows.
2. Pivoted windows.
3. Double hung windows.
4. Sliding windows.
5. Casement windows.
6. Sash windows.
7. Louvered windows.
8. Metal windows.
9. Bay windows.
10. Clerestorey windows.
11. Corner windows.
12. Dormer windows.
13. Cable windows.
14. Lantern windows.
15. Skylights.
16. Ventilators.
17. Combined windows and ventilators.

1. FIXED WINDOWS

These windows are provided for the sole purpose of admitting light and/or providing vision in the room. The window consists of

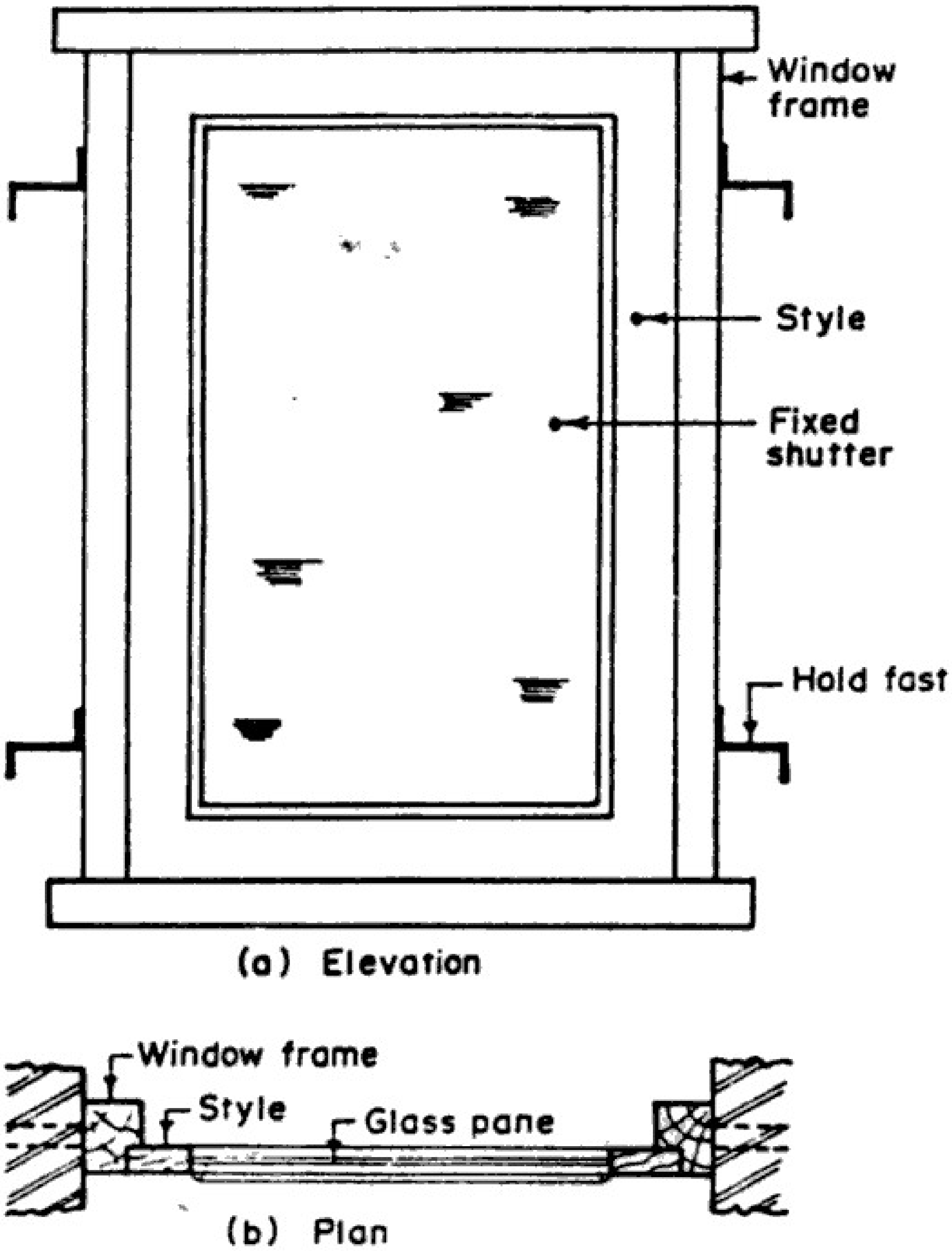


FIG. 17.24. FIXED WINDOWS.

Method of fixing steel windows

1. The prepared opening, in which steel window frame is to be fixed is cleared, and exact position of the window frame is marked by drawing chalk-lines along the verticals and head and sill of the window frame.

2. The distances of fixing holes are measured on the frame, and these positions are marked on the chalk lines drawn in the joints of the opening.

3. Holes are cut in the brick masonry, of size 5 cm square and 5 to 10 cm deep, to accommodate hold fasts or *lugs*.

4. The frame is placed in the opening and its position is adjusted in correct alignment by striking wooden wedges in correct position. Since there is little gap between the opening and the window frame, temporary wooden wedges can be easily driven. After adjusting the window in correct alignment, the lugs are screwed tight to the frame.

5. The lugs are grouted into the holes with cement mortar.

6. After the grout has set, wooden wedges are removed, and the space between the opening and the frame (known as *surrounds*) is filled with cement mortar.

7. In the case of stone masonry or R.C.C. work, where it is difficult to cut holes for lugs, wooden plugs are embedded at appropriate places during the construction itself. the window frame is then fixed to these plugs with the help of galvanised iron wood screws.

Advantages of Steel windows

Steel windows have following advantages over timber windows:

1. Steel windows are generally manufactured in factories, with greater precision and better quality control.

2. They exhibit elegant appearance and stream lined-finishing.

3. Steel windows are stronger and more durable than wooden windows.

4. There is no contraction or expansion due to weather effects in the steel windows. Wooden windows have this defect.

5. They are rot proof and termite proof.

6. They are highly fire resistant.

7. Since steel windows are fabricated from thin sections, they provide more effective area for light and ventilation.

8. They grant better facilities for providing different types of openable parts.

9. They are easy to maintain, and the cost of maintenance is almost negligible.

9. BAY WINDOWS

Bay windows project outside the external wall of the room.

15. SKY LIGHTS

A sky light is provided on a sloping roof, to admit light. The window projects above the top sloping surface. They run parallel to the sloping surface. The common rafters are suitably trimmed and the sky light is erected on a curb frame shown in Fig. 17.37. The opening so made is properly treated by lead flashing to make the roof, surrounding the opening, water-proof.

16. VENTILATORS

Ventilators are small windows, fixed at a greater height than the window, generally about 30 to 50 cm below roof level. The ventilator has a frame and a shutter, generally glazed, which is horizontally pivoted. The shutter can be opened or closed by means of two cords, one attached to the top rail and other to the bottom rail of the shutter. The top edge of the shutter opens inside and bottom edge opens outside, so that rain water is excluded.

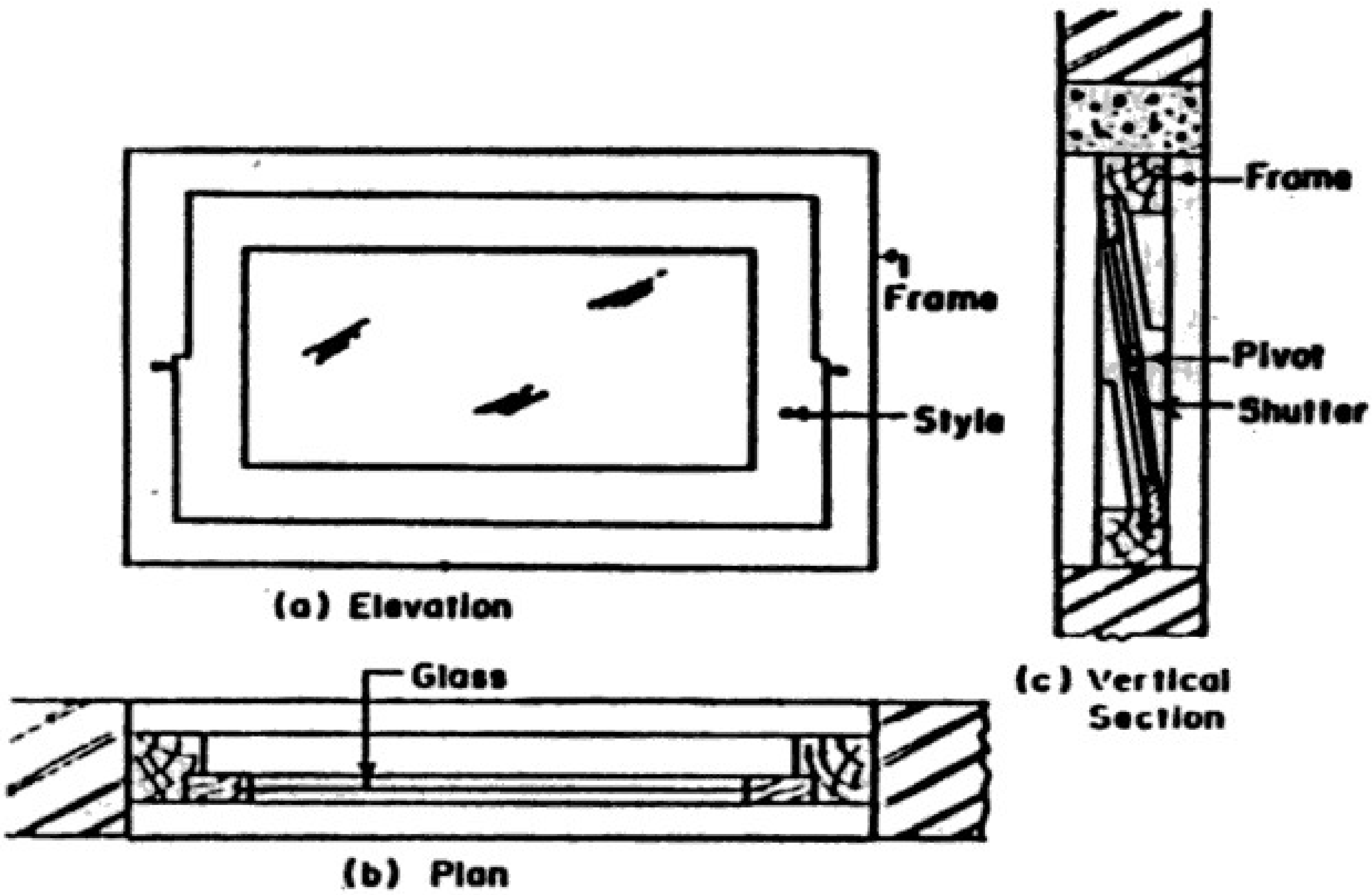


FIG. 17.38. VENTILATOR.

TABLE 17.3 DIMENSIONS OF VENTILATORS

S.No.	*Designation*	*Size of opening (mm)*	*Size of ventilator frame (mm)*	*Size of ventilator shutter (mm)*
1	*2*	*3*	*4*	*5*
1.	6 V 6	600×600	590×590	500×500
2.	10 V 6	1000×600	990×590	900×500
3.	12 V 6	1200×600	1190×590	1100×500

Table 17.3 gives the dimensions of ventilator openings, size of ventilator and size of ventilator shutter. In the designation, the

The following *points* are note worthy :

1. Rakers should be inclined to the ground by 45°, to make them more effective. However, in practice, the angle may vary from 45° to 75°. The top raker should not be inclined steeper than 75°.

2. For tall buildings, the length of raker can be reduced by introducing *rider raker.*

3. Rakers should be properly braced at intervals.

4. The size of the rakers should be decided on the basis of anticipated thrust from the wall.

5. The centre line of a raker and the wall should meet at floor level.

6. If longer length of the wall needs support, shoring may be spaced at 3 to 4.5 m spacing, depending upon the requirements.

7. The sole plate should be properly embedded into the ground, at an inclination, and should be of proper section. The size of the sole plate should be such that it accommodates all the rakers, and a cleat provided along the outer edge.

8. Wedges should not be used on sole plates since they are likely to give way under vibrations which are likely to occur.

18.3 . FLYING OR HORIZONTAL SHORES

Such shores are used to give horizontal support to two adjacent, parallel party walls which have become unsafe due to removal or collapse of the intermediate building. All types of arrangements of supporting the unsafe structure in which the shores do not reach

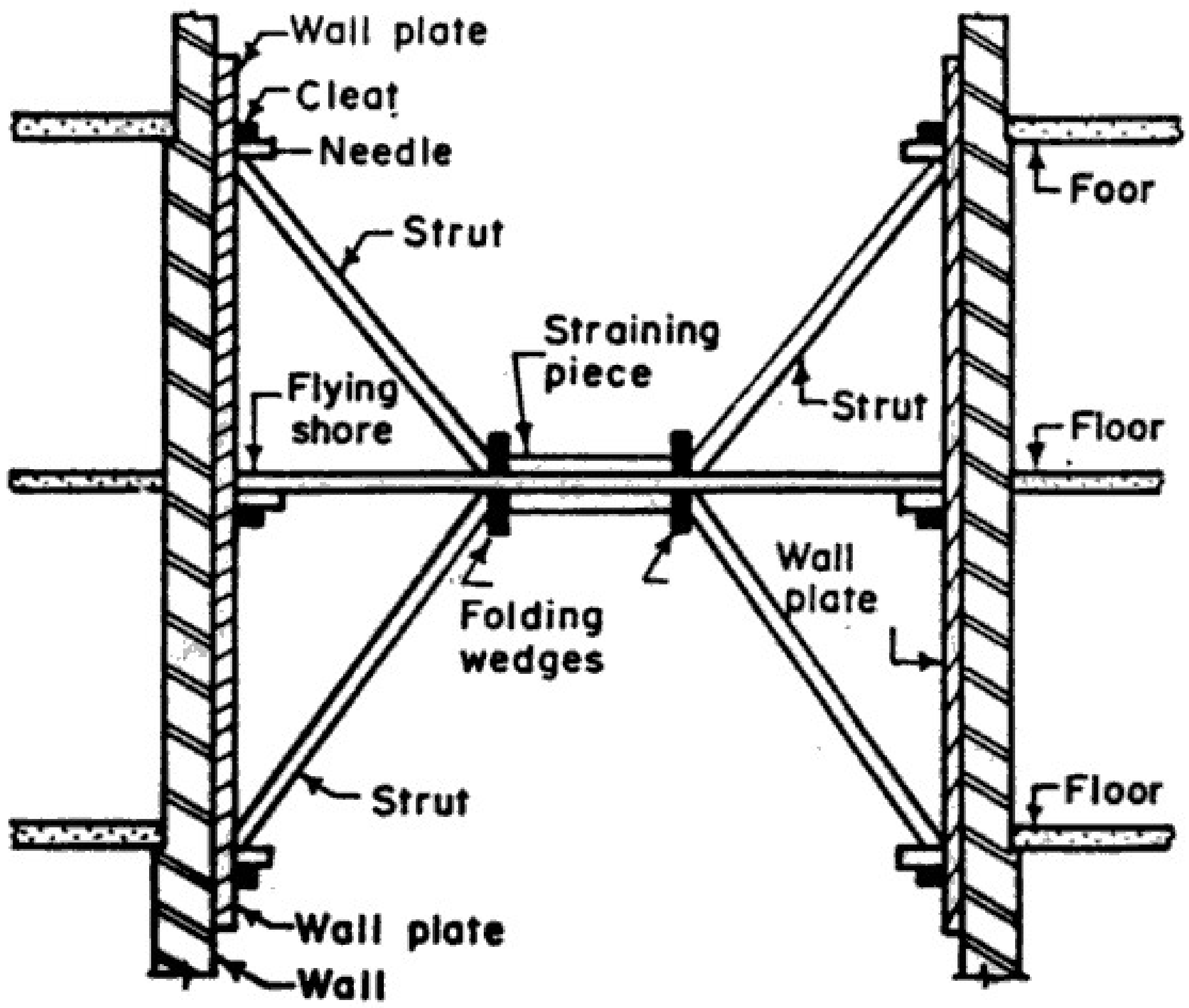


FIG. 18.2 SINGLE FLYING SHORE.

1. Single Scaffolding (Brick layer's scaffolding)

This consists of a single frame work of standards, ledgers, putlogs etc., constructed parallel to the wall at a distance of about 1.20 metres. The standards are placed at 2 to 2.5 m interval. Ledgers connect the standards, and are provided at a vertical interval of 1.2 to 1.5 m. Putlogs are placed with one end on the ledgers and other end in the hole left in the wall, at an interval of 1.2 to 1.5 m. Guards, boarding and other members are placed as shown in Fig. 18.8. Such a scaffolding is commonly used for bricklaying, and is also called *putlog scaffolding*.

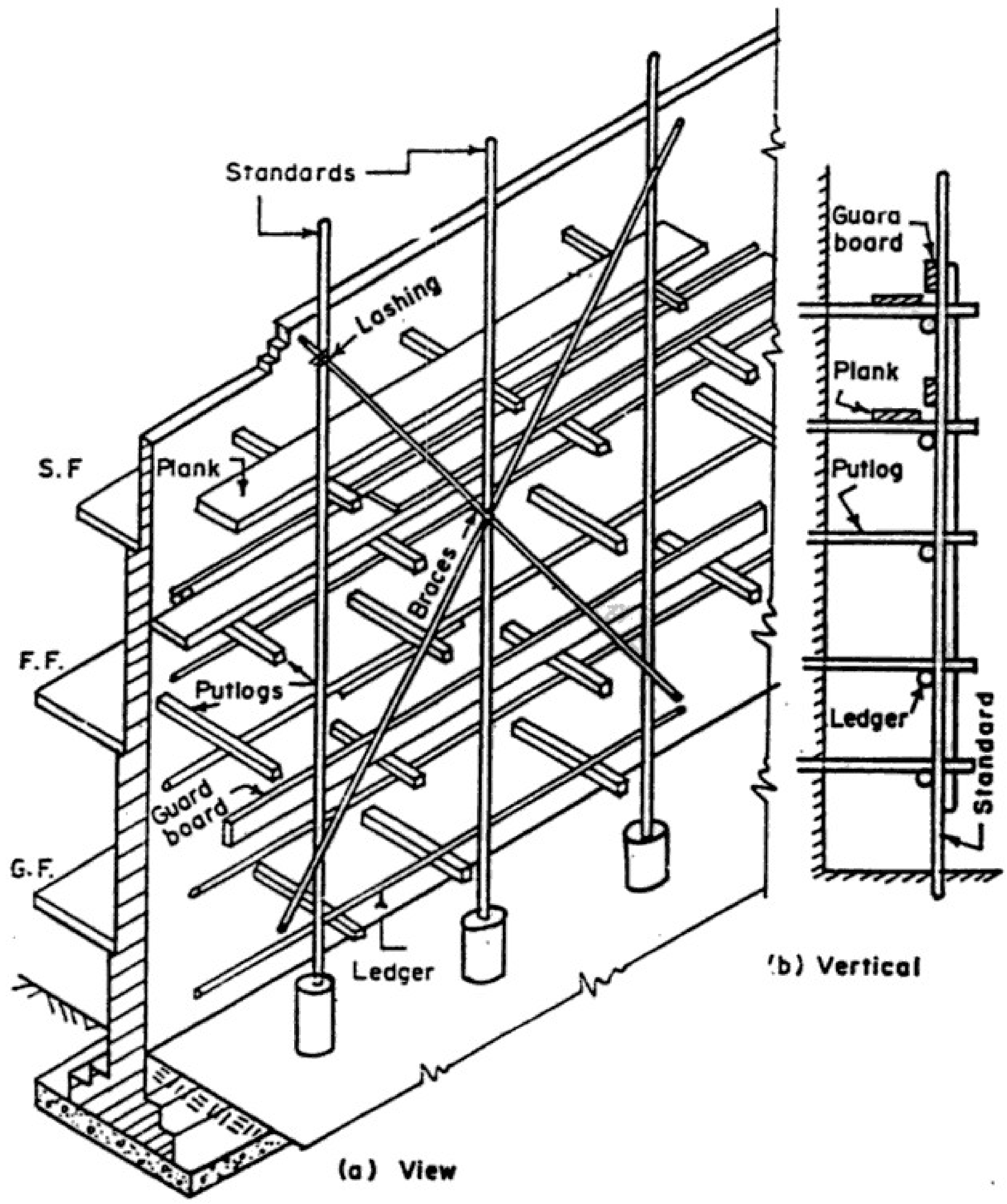


FIG. 18.8. BRICK LAYERS SCAFFOLDING.

mortar to be used in various situations.

TABLE 19.1
RECOMMENDED MORTAR MIXES

	Situation	*Composition of mortar*	*I.S. grading of lime*
1.	External Plaster in localities where rainfall is less than 500 mm per year and where subsoil water is not within 2.5 m below the ground surface :		
	(*a*) Below D.P.C.	1 cement 6 sand	—
		1 cement 2 lime 9 sand	B or C
		1 lime 2 sand	A
		1 lime 1 sand 1 surkhi	B or C
		1 lime 2 surkhi	B or C
	(*b*) Above D.P.C.	1 cement 2 lime 9 sand	B or C
		1 lime 2 sand	A
		1 lime 1 surkhi 1 sand	B or C
		1 lime 2 surkhi	B or C
2.	External plaster in localities where rain fall is more than 1300 mm per year and where subsoil water is not within 2.5 m below ground surface :		
	(*a*) Below D.P.C.	1 cement 4 sand	—
		1 cement 1 lime 6 sand	B or C
		1 lime 2 surkhi	B or C
	(*b*) Above D.P.C.	1 cement 2 lime 9 sand	B or C
		1 lime 2 sand	A
		1 lime 1 sand 1 surkhi	B. or C
		1 lime 2 surkhi	B or C
3.	External plaster in localities where the subsoil water is within 2.5 m of the ground :		
	Below D.P.C.	1 cement 3 sand	—
4.	Internal plaster in all localities	1 lime 2 sand	A
		1 lime 1 surkhi 1 sand	B or C
		1 lime 2 surkhi	B or C
		1 cement 2 lime 9 sand	B or C

Note. The ratio of lime varies with % purity of lime and these ratios may be suitably adjusted depending upon local practice.

19.3. TERMINOLOGY USED IN PLASTERING WORK

1. Back ground. It is the surface to which the first coat of plaster is applied.

2. Blistering. This is the development of local swellings on the finished plastered surface, due to residual unslaked lime nodules.

8. *Weathered pointing* (Fig. 19.3 *h*)

This pointing is made by making a projection in the form of V- shape.

PROBLEMS

1. (*a*) Explain in brief the objects of plastering and pointing.
   (*b*) What are the requirements of good plaster ?
   (*c*) Write a note on 'mortars' required for plastering and pointing.
2. (*a*) What do you understand by preparation of back ground for (*i*) plastering, (*ii*) pointing ?
   (*b*) Write a note on number of coats used in plastering.
3. Explain various types of plaster finishes.
4. Explain the method of three-coat lime plaster.
5. Explain the method of two-coat lime plaster.
6. Write a note on various types of special materials used in plastering.
7. Write a note on various defects in plastering.
8. (*a*) Explain the method of pointing.
   (*b*) Describe various types of pointings.

2. Blue	: Indigo ; Prussian blue ; cobalt blue ; ultramarine.
3. Brown	: Burnt umber, raw umber, burnt seinna, vandyke brown.
4. Green	: Paris green : chrome green; green earth; virdigris copper sulphate.
5. Red	: Indian red; venitean red; vermillion red; carmine; red lead.
6. Yellow	: Chrome yellow; raw seinna; yellow occhre; zinc chrome.

The concentration of pigment in a paint is denoted by *pigment volume concentration number* (P.V.C.N.) defined by the equation.

$$\text{P.V.C.N.} = \frac{V_1}{V_1 + V_2}$$

where V_1 = volume of pigment in the paint.
V_2 = Volume of non-volatile vehicle or carrier in the paint.

The durability and gloss of a paint is inversely proportional to the value of P.V.C.N. The following table gives P.V.C.N. for paints used for various purposes :

P.V.C.N. range	*Type of paint*
25 to 40	Paint for prime coat on metals.
35 to 40	Paint for prime coat on timber.
28 to 40	Paint for exterior surfaces of buildings.
35 to 45	Semi-gloss paint.
50 to 75	Faint paint.

5. Solvents or thinners

Solvents are added to the paint to make it thin so that it can be easily applied on surfaces. It also helps the paint in penetrating through the porous surface of the background. The thinning agent commonly used is the spirit of terpentine. Other solvents contain some part of spirit of terpentine, and therefore inferior. Thinner reduces the gloss of the paint. Terpentine oil is affected by weather; hence minimum quantity of thinner should be used for painting external surfaces. Following is the list of thinners for various types of paints :

Type of paint	*Thinner*
1. Oil paints	(*i*) Spirit of terpentine. (*ii*) Naphtha, (*iii*) Benzine
2. Spirit liquors	Alcohol.
3. Cellulose paints	Ethyl amyl acetate.
4. Distempers	Water.

or oil. It is applied on wood surfaces with the following objects:

(*i*) To intensify or brighten the appearance of natural grains in wood.

(*ii*) To render brilliancy to the painted surface.

(*iii*) To protect painted surface from atmospheric action.

(*iv*) To protect unpainted wooden surfaces of doors, windows, floors, roof trusses etc. from atmospheric action.

Characteristics of a good varnish

A good varnish should possess the following characteristics

1. It should dry quickly.

2. The protective film obtained on drying should be hard, tough, durable and resistant-to wear.

3. The finished surface should be uniform in nature and pleasing in appearance.

4. It should exhibit a glossy surface.

5. It should not shrink or show cracks on drying. It should have sufficient elasticity.

6. The colour of Varnish should not fade a way with time.

Ingradients of varnish

A varnish has the following essential ingradients :

(*i*) Resins or resinous substances.

(*ii*) Solvents.

(*iii*) Driers.

1. *Resins or resinous substances*

The quality of varnish depends largely on the type of resin used. Various types of resins in use are copal, lac or shellac, resin, amber,mastic, gum dammer etc. Copal is a hard and lustrous resin obtained from ground where pine tree existed in past. Resin is obtained from pine trees. Lac or shellac is obtained by exudation of some insects which grow on some type of trees in India. Raw copal, an inferior type, is obtained from standing pine trees :

2. *Solvents*

Different types of solvents are available, but each is used only in conjunction with some specific resin. The following table gives the solvents for different resins :

Type of solvent	*Type of resin*
1. Boiled linseed oil	Amber, copal
2. Methylated sprit of wine	Lac or shellac
3. Turpentine	Mastic, gum dammer, rosin
4. Wood naphtha	Raw copal and other cheap varieties of resin.

3. *Driers*

Driers accelerate the process of drying of a varnish. Common

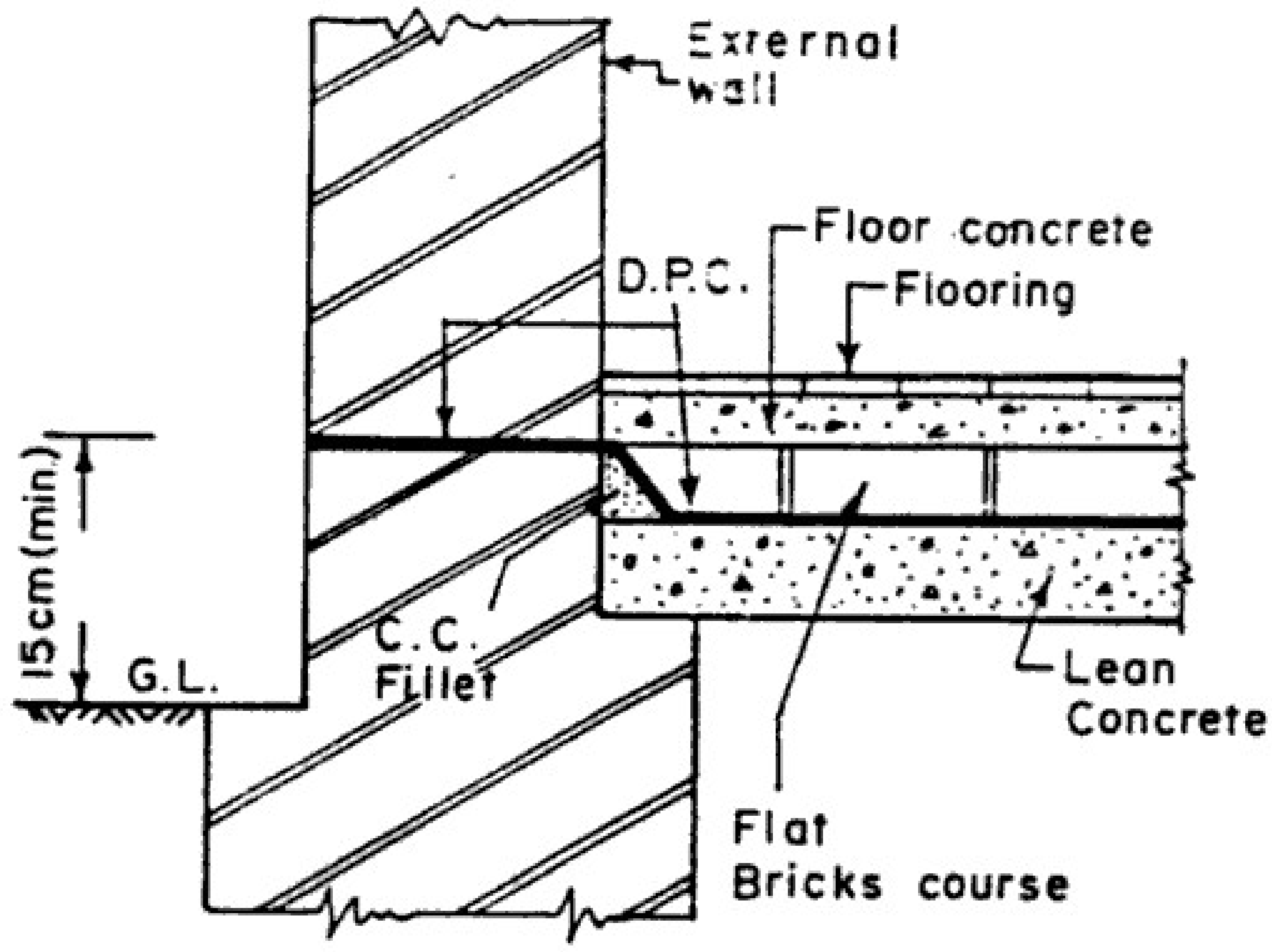


FIG. 21.6. D.P.C. FOR FLOORING.

felt. A layer of flat bricks is laid on a cushion of find sand over D.P.C. to protect it from damage during the construction of floor slab.

Before laying bituminous felt, a coat of hot bitumen, at the rate of 1.5 kg/m^2 is applied over the foundation concrete, to serve as primer coat. After laying bituminous felt over it, a finishing coat of hot bitumen is applied at the rate of 1.5 kg/m^2 over the felt.

4. Treatment to walls

For basement walls, a vertical D.P.C. is laid over the external

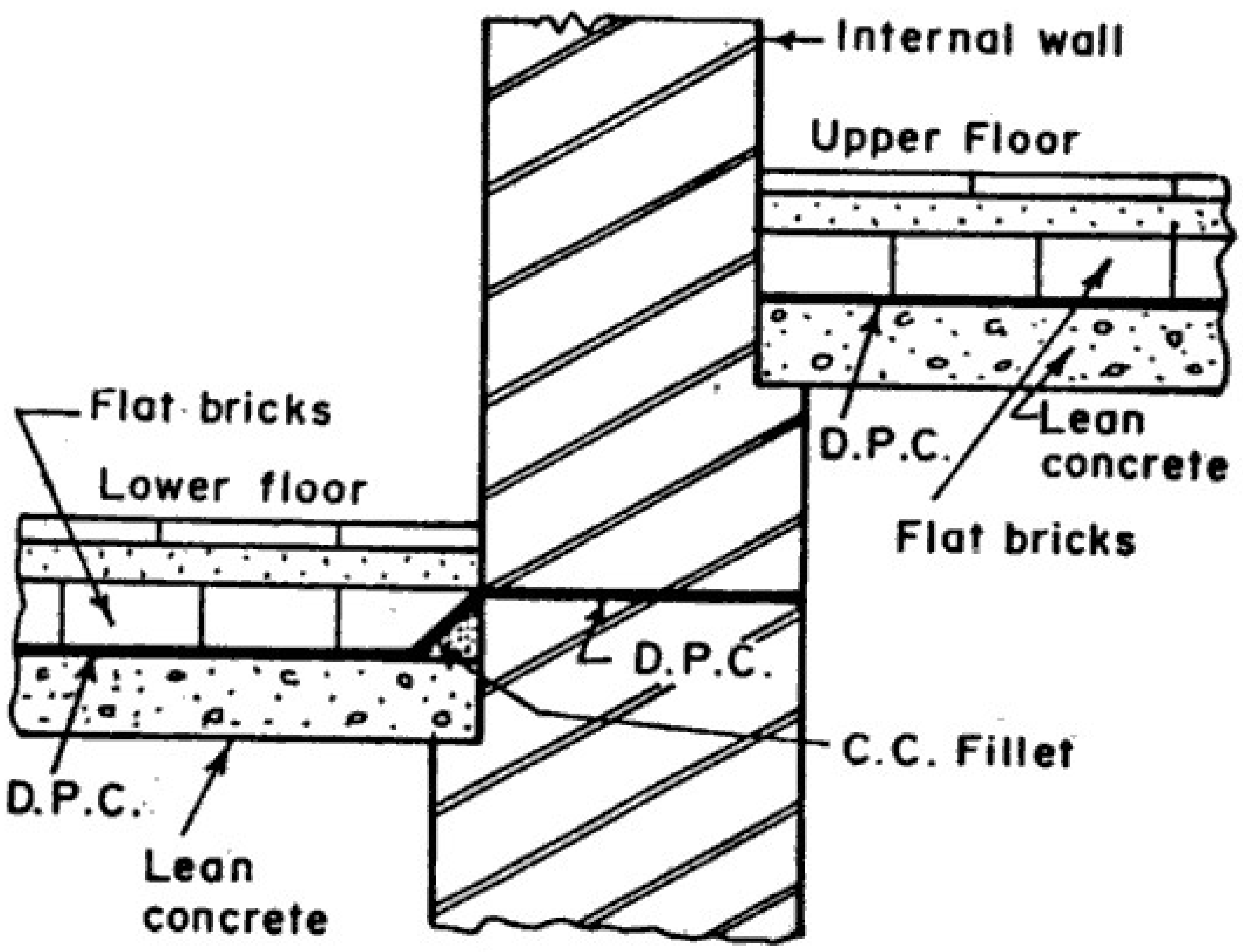


FIG. 21.7. D.P.C. FOR INTERNAL WALL.

Chemical	Concentration by weight
(*i*) Aldrin	0.5%
(*ii*) Heptachlor	0.5%
(*iii*) Chlordane	1%

Out of the above chemicals and several other chemicals, *Aldrex* 30 E.C. has proved to be the most effective. It has the following advantages :

(*i*) It is highly toxic to termites.

(*ii*) It can easily be applied after dilution with water.

(*iii*) It is insoluble in water. In other words, this chemical will not dissolve in sub-soil water and disappear quickly from the site.

(*iv*) It is effective even many years after application.

One part of '*Aldrex*' 30 E.C. is diluted with 59 parts of water. This provides an emulsion containing 0.5% *aldrin.*

The emulsion should be applied evenly either with a watering cane or sprayer at the following stages :

Stage 1. In foundation pits, to treat the *bottom* and *sides*

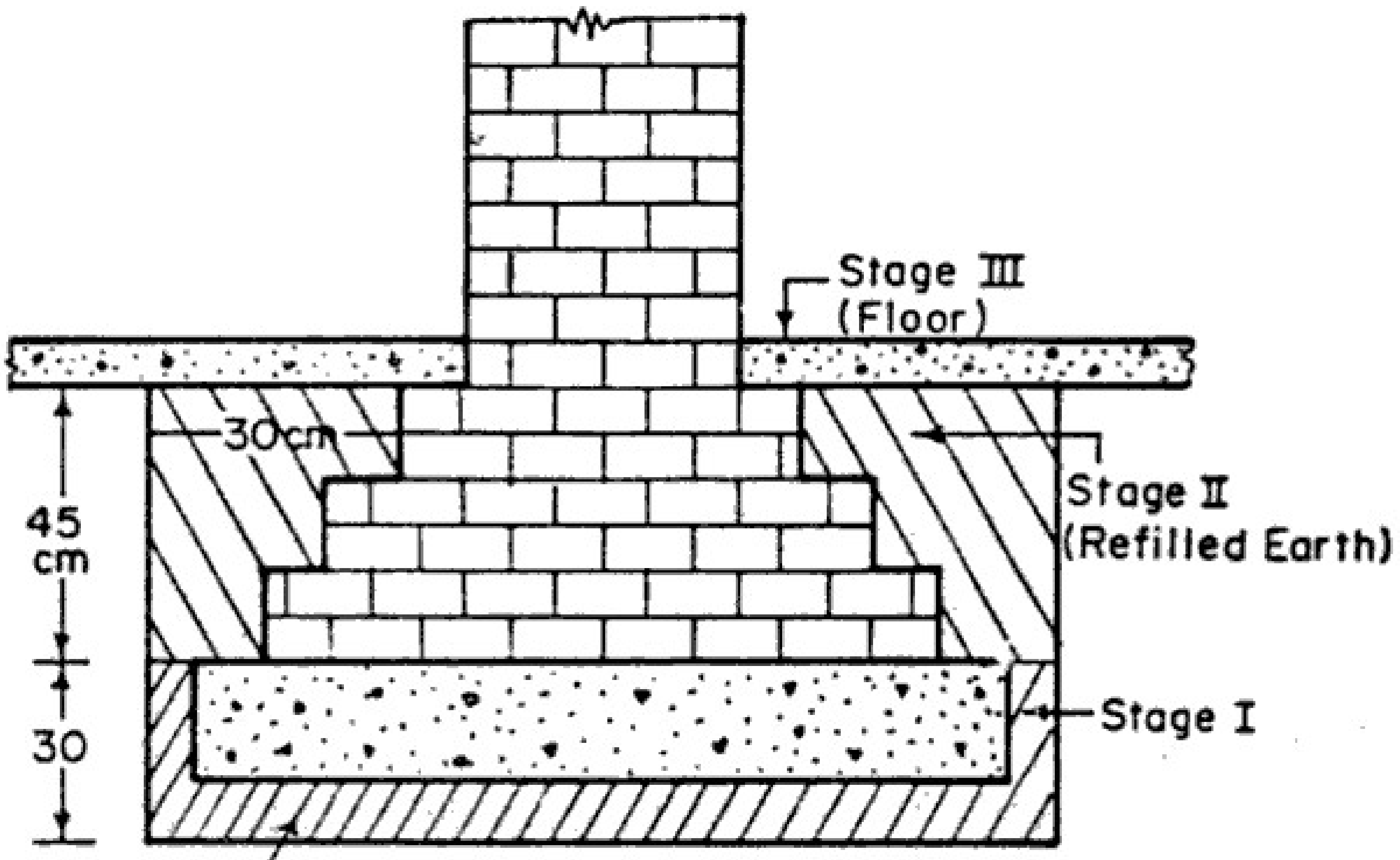


FIG. 22.1 STAGES OF SOIL TREATMENT.

upto a height of about 30 cm. The emulsion required is at the rates of 5 litres per square metre.

Stage 2. The *refill earth* on both the sides of all built up walls, for width of 30 cm and depth of 45 cm approximately. The emulsion required is at the rate of 5 litres per square metre.

Stage 3. Before laying the floor, the entire levelled surface is to be treated at the rate of 5 litres of emulsion per square metre.

The stages of treatment are shown diagrammatically in Fig. 22.1. When used as recommended above, approximately 200 ml of to one hour severity in the test, then the structural element should resist the building fire without failure.

TABLE 23.1.
CLASSIFICATION OF STRUCTURAL ELEMENTS

Grade No	*Time-in-hours (min.resistance against standard fire*	*Fire load and class of fire which the structural element can withstand*	
		Fire load in k cal/m²	*Class of fire*
1	6	1100000 and over	Very high
2	4	500000 to 1100000	High
3	2	275000 to 500000	Medium
4	1	Less than 275000	Low
5	$\frac{1}{2}$	–	Very low

23.5. GRADING OF BUILDINGS ACCORDING TO FIRE RESISTANCE

Structural precautions aid in giving a building the necessary resistance to a complete burn and restrict any spread of fire and also minimize the personal hazard. In grading building according to fire resistance and structural precautions provided, it has been assumed that no assistance will be forthcoming from municipal fire brigade and that no fire fighting apparatus has been provided or attached to building. National Building Code of India (SP : 7-1970) divides buildings into the following *four* types according to the *fire load* the building is designed to resist :

(*i*) *Type 1 construction.* All structural components have 4-hours fire resistance.

(*ii*) *Type 2 construction.* All structural components have 3-hour fire resistance.

(*iii*) *Type 3 construction.* All structural components have 2-hour fire resistance.

(*iv*) *Type 4 construction.* All structural components have 1-hour resistance.

Experience shows that with fire fighting equipment installed in the premises, the duration of fire in buildings having a fire load between 500000 to 1100000 kcal/m² is usually less than 3 hours. Hence type 1 construction prescribed for this class of buildings generally ensures sufficient protection. However, in buildings covered under type 1, proper ventilation and provision for escape of hot gases through a material. The amount of heat transfer by conduction depends upon (*i*) temperature difference, (*ii*) thickness of solid medium, (*iii*) area of exposed surface, (*iv*) time for which heat flow takes place, (*v*) conductivity of the medium, and (*vi*) density of the medium.

2. **Convection.** Heat is transmitted by convection in fluids and gases, as a result of circulation. Air movement causes the heat insulator, it is preferable to ensure that excessive air change is avoided.

3. **Radiation.** Heat is transferred by radiation through space in the form of radiant energy. When the radiation strikes an object, some of the energy is absorbed and transformed into heat. One of the ways of reducing heat absorption from radiation is to introduce a suitable reflecting surface.

4. **Thermal conductivity** (*k*). The thermal conductivity of a material is the amount of heat that will flow through an unit area of material, of unit thickness is one hour, when the difference of two temperatures is maintained at 1°C. It is expressed as $\frac{\text{k cal cm}}{\text{m}^2\text{ h deg C}}$

Values of *k* for various building materials and insulating materials are given in Table 24.1.

5. **Thermal resistivity** (*l/k*) This is the reciprocal of thermal conductivity and is denoted by *l/k*.

6. **Thermal conductance** (*c*). It is the thermal transmission of a single layer structure per unit area divided by temperature difference between the hot and cold faces. It is expressed by $\frac{\text{k cal}}{\text{m}^2\text{ h . deg C}}$. The values of thermal conductance of air gaps of different thickness are given in Table 24.3.

7. **Thermal resistance** (*R*). It is the reciprocal of thermal conductance. For a structure having plane parallel faces, thermal resistance is equal to thickness (*L*) divided by thermal conductivity

$$R = \frac{L}{k}$$

It is expressed as $\frac{\text{m}^2\text{ h deg C}}{\text{k cal}}$

The usefulness of this quantity is that when heat passes in succession through two or more components of the building unit, the resistance may be added together to get the total resistance of the structure.

8. **Surface coefficient** (*f*). It is the thermal transmission by convection, conduction or radiation from unit area of the surface, for unit temperature difference between the surface and the surrounding medium. It is expressed as $\frac{\text{k cal}}{\text{m}^2\text{ h deg C}}$

The chief chemical constituents of Portland cement are as follows :

Lime (CaO)	60 to 67%
Silica (SiO_2)	17 to 25%
Alumina (Al_2O_3)	3 to 8%
Iron oxide (Fe_2O_3)	0.5 to 6%
Magnesia (MgO)	0.1 to 4%
Sulphur trioxide (SO_3)	1 to 3%
Soda and/or Potash (Na_2O + K_2O)	0.5 to 1.3 %

The above constituents forming the raw materials undergo chemical reactions during burning and fusion, and combine to form the following compounds (called Bogue compounds) in the finished product :

Compound	*Abbreviated designation*
1. Tricalcium solicate ($3CaO.SiO_2$)	C_3S
2. Dicalcium Silicate ($2CaO.SiO_2$)	C_2S
3. Tricalcium aluminate ($3CaO.Al_2O_3$)	C_3A
4. Tetracalcium alumino-ferrite ($4CaO.Al_2O_3.Fe_2O_3$)	C_4AF

The proportion of the above four compounds vary in the various Portland cements. Tricalcium silicate and dicalcium silicates contribute most to the eventual strength. Initial Portland cement is due to the tricalcium aluminate. Tricalcium silicate hydrates quickly and contributes more to the early strength. The contribution of dicalcium silicate takes place after 7 days and may continue for upto 1 year. Tricalcium aluminate hydrates quickly, generates much heat and makes only a small contribution to the strength within the first 24 hours. Tetracalcium alumino-ferrite is comparatively inactive. All the four compounds generate heat when mixed with water, the aluminate

TABLE 25.1 COMPOSITION AND COMPOUND CONTENT OF PORTLAND CEMENT (AFTER LEA)

Contents	*Normal*	*Rapid hardening*	*Low heat*
(*a*) **Composition : Percent**			
Lime	63.1	64.5	60
Silica	20.6	20.7	22.5
Alumina	6.3	5.2	5.2
Iron oxide	3.6	2.9	4.6
(*b*) **Compounds : Percent**			
C_3S	40	50	25
C_2S	30	21	45
C_3A	11	9	6
C_4AE	12	9	14

The predetermined amount of water is then sprinkled over the mix. The mass is then turned till the colour of concrete obtained is homogeneous and workable mix is obtained.

(*b*) **Machine mixing.** Concrete should normally be mixed in a mechanical mixer. The main part of mixer is a drum in which the ingradients are mixed thoroughly by mechanically rotating the drum. The drum is made of steel plates, with a number of blades put in inclined position in the drum. As the drum rotates, the materials encounter resistance to rotation from the blades and this disturbing effect helps in a good mixing of the ingradients. The mixers are either operated electrically or else are driven by oil engines attached to them. Coarse aggregate should be fed first, then sand and lastly cement. In the revolving state, when the three get thoroughly mixed, water should be added either with the help of a can or automatically through the pipe attached to the mixer. Mixing should be contained until there is a uniform distribution of the materials and the mass is uniform in colour and consistency, but in no case shall the mixing be done for less than two minutes.

Concrete mixers may be of two types : (*i*) Batch mixers, and (*ii*) Continuous mixers. Batch type mixers are employed for work of relatively small magnitude. Batch type mixers can either be of titling drum type or closed drum type. In the tilting drum type, drum rotates about a trunnion axis and is so arranged that it is quite easy to rotate and tilt it when it is empty as well as when full. In the close drum type, the drum remains rotating in one direction and is emptied by means of the hopper which tilts to receive the discharge. Continuous mixers are used in mass concreting work where a large and continuous flow of concrete is required. In these mixers, processes of feeding, mixing and emptying go on continuously without break.

2. **Transporting concrete.** Concrete should be handled from the place of mixing to the place of final deposit as rapidly as practical by methods which will prevent the segregation or loss of any of the ingradients. If the segregation does occur during transport, the concrete should be remixed before being placed. During hot or cold weather, concrete should be transported in deep containers, on account of their lower ratio of surface area to mass, reduce the rate of loss of water by evaporating during hot weather and loss of heat during cold weather.

3. **Placing concrete.** The concrete should be placed and compacted before setting commences and should not subsequently be disturbed. Method of placing should be such as to preclude segregation. Before concrete is placed, it should be ensured that the forms are rigid, in their correct position, well cleaned and oiled. Oiling of

(*iii*) ***Sub-division D–3***

This sub-division includes any building, its lobbies, rooms and other spaces connected thereto, primarily intended for assembly of people, but which has no theatrical stage or theatrical and/or cinematographic accessories and has accommodation for more than 300 persons, for example, dance halls, night clubs, halls for incidential picture shows, dramatic, theatrical or educational presentation; lectures or other similar purposes, having no theatrical stage except a raised platform and used without permanent seating arrangement ; art galleries; museums; lecture halls; libraries ; passenger terminals and buildings used for educational purposes for less than 8 hours per week.

(*iv*) ***Sub-division D–4***

This sub-division includes any building primarily intended for use as described in sub-division *D–3* but with accommodation for less than 300 persons.

(*v*) ***Sub-division D–5***

This sub-division includes any building meant for outdoor assembly of people not covered by sub-division *D–1* to *D–4*, for example, grand stands, stadia, amusement park structures, reviewing stands and circus tents.

5. Group *E* : Business Buildings

These include any building or part of a building, which is used for the transaction of business(other than that covered by building in Group *F*); for the keeping of accounts and records and similar purposes; doctors' and dentists' (unless these are covered by the provisions of Group *C*); service facilities, such as new stands, lunch counters serving less than 100 persons, barber shops and beauty parlours.

City halls, town halls, court houses and libraries should be classified in this group in so far as the principal function of these is transaction of public business and the keeping of books and records.

Minor office occupancy incidental to operation is another type of occupancy should be classified under the relevant group for main occupancy.

6. Group *F* : Mercantile buildings

These include any building or part of a building, which is used as shops, stores, markets, for display and sale of merchandise, either wholesale or retail.

Office, storage and service facilities incidental to the sale of merchandise and located in the same building should be included under this group.

27

Ventilation and Air-Conditioning

27.1. VENTILATION : DEFINITION AND NECESSITY

Ventilation may be defined as supply of fresh outside air into an enclosed space or the removal of inside air from the enclosed space. In other words, ventilation is the removal of all vitiated air from a building and its replacement with fresh air. Ventilation may be achieved either by natural or by artificial (or mechanical) means.

Ventilation is necessary for the following reasons :

1. Creation of air movement.
2. Prevention of undue accumulation of carbon dioxide.
3. Prevention of flammable concentration of gas vapour.
4. Prevention of accumulation of dust and bacteria-carrying particles.
5. Prevention of odour caused by decomposition of building material.
6. Removal of smoke, odour and foul smell generated/liberated by the occupants.
7. Removal of body heat generated/liberated by the occupants.
8. Prevention of condensation or deposition of moisture on wall surfaces.
9. Prevention of suffocation conditions in conference rooms, committee halls, cinema hall, big rooms, etc.

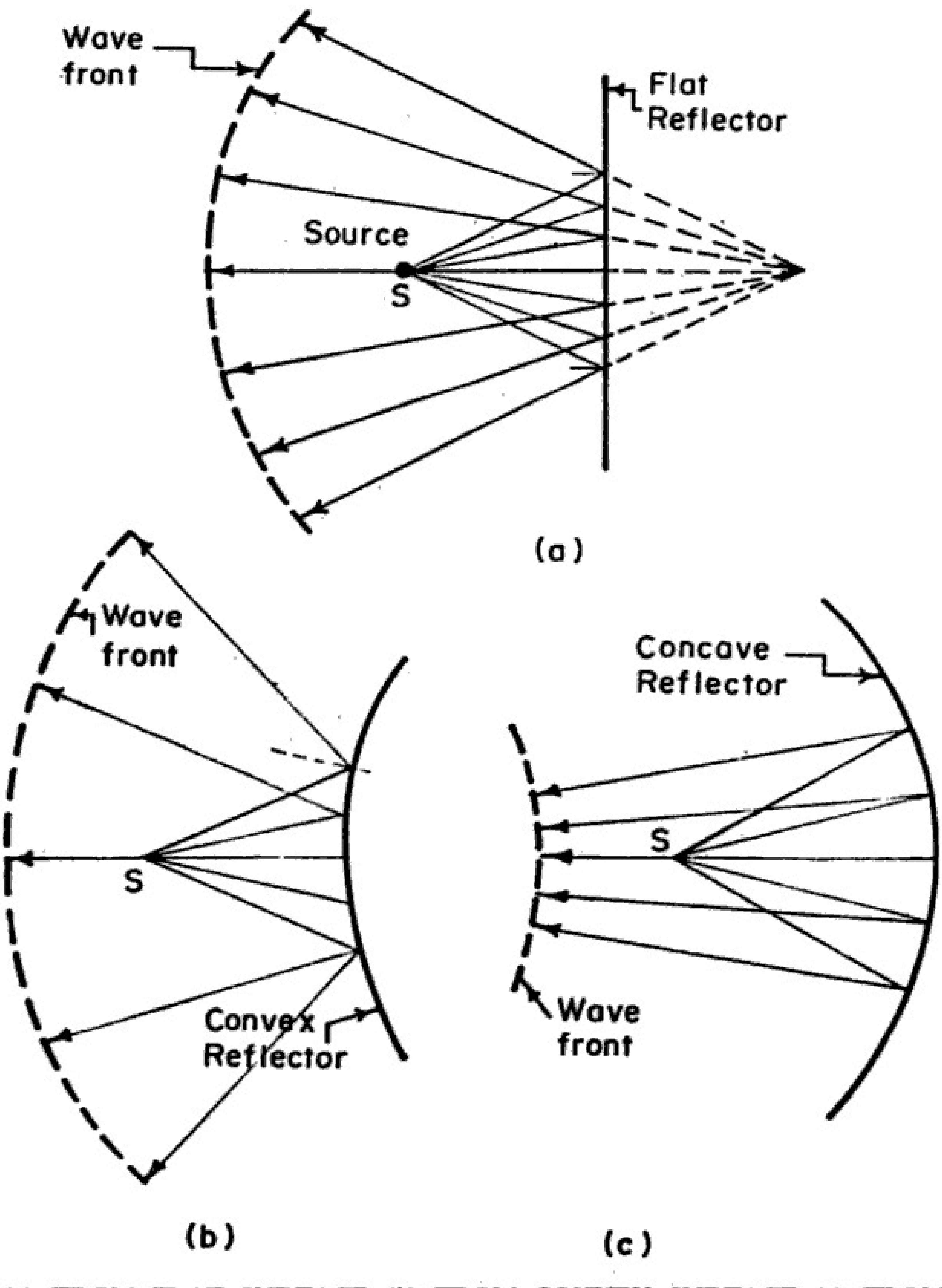
27.2. FUNCTIONAL REQUIREMENTS OF VENTILATION SYSTEM

From the point of view of human comfort, ventilation system should meet the following functional requirements :

1. Air changes or air movement.
2. Humidity.

3. Sound waves reflected at a convex surface are magnified and are considerably bigger Fig. 28.2 (*b*). They are attenuated and are therefore weaker. Convex surfaces may be used with advantage to spread the sound waves throughout the room.

4. The sound waves reflected at a concave surface are considerably smaller Fig. 28.2 (*c*). The waves are most condensed and therefore amplified. The concave surfaces may be provided for the concentration of reflected waves at certain points.



(*a*) FROM FLAT SURFACE (*b*) FROM CONVEX SURFACE (*c*) FROM CONCAVE SURFACE
FIG. 28.2. REFLECTION OF SOUND WAVES.

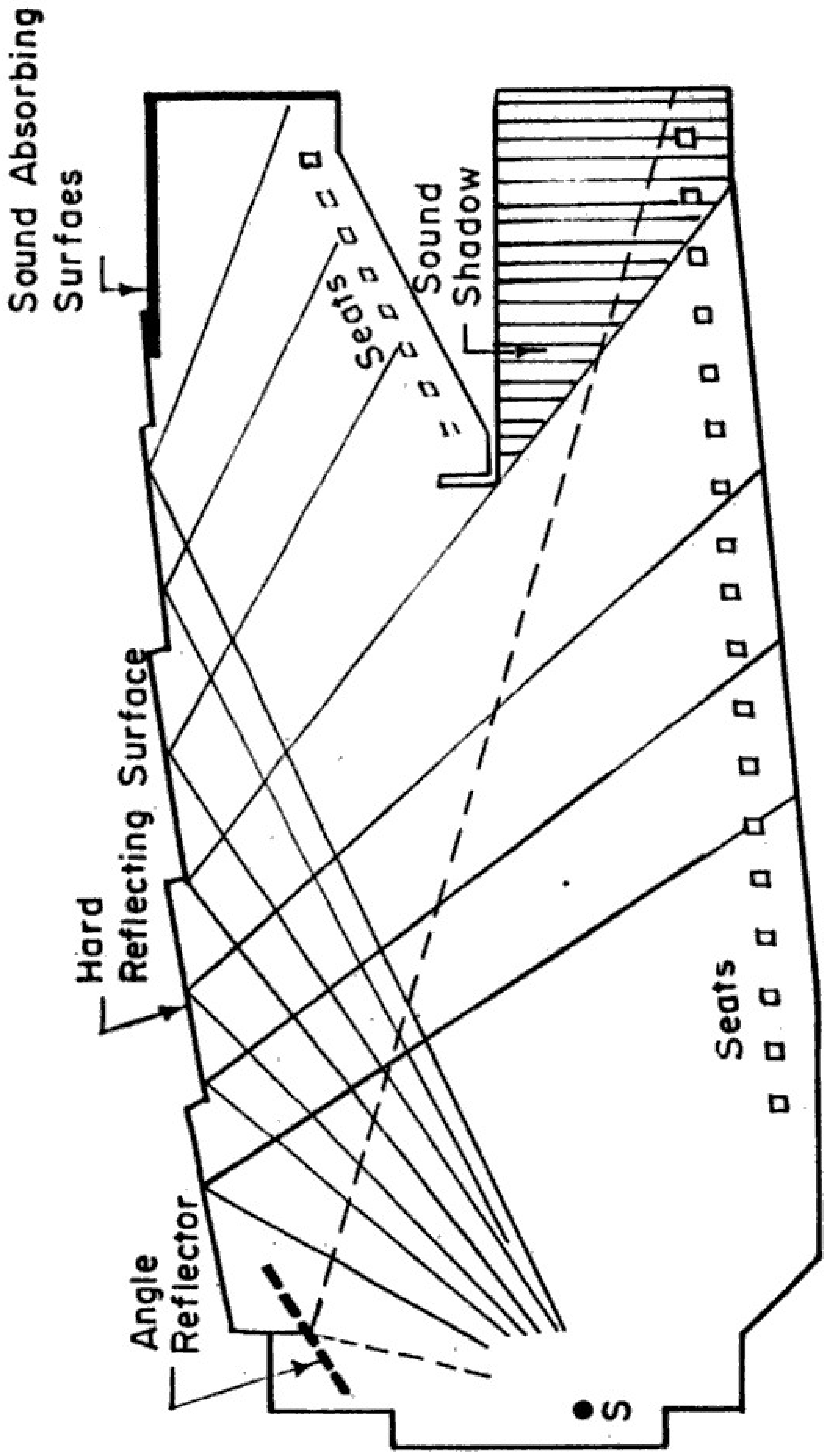


FIG. 28.6. SOUND SHADOWS.

that reaches the rear parts of a big auditorium.

The auditorium rear wall(s) should be either flat or convex in shape. This should not be concave in shape, but where it cannot be avoided, the acoustical design should indicate either the surface to be splayed or convex corrugations given in order to avoid any tendency for the sound to focus into the hall.

Where the side walls are non-parallel as in the case of a

Floors and ceilings insulation : Horizontal barriers

Insulation of floors and ceilings act as horizontal barriers to both airborne as well as impact sounds. Normally, the rigid construction materials (*i.e.* R.C.C, stones etc.) used for floors and ceilings offer excellent insulation against airborne noise, but they do not function well for impact or structure borne sounds. Hence the objective of sound-proofed floors and ceilings is aimed at offering good insulation against impact sounds, and this can be achieved by the following constructional features.

1. Use of resilient surface material on floors

This consists of providing thin concrete screed as the R.C.C. floor slab, and then providing soft floor finish or covering of resilient material such as linoleum, insulation board, cork, asphalt mastic, carpet etc. This provision helps to damp the impact noises but has no appreciable effect on air-borne sound. An insulation of 5 to 10 dB over a base concrete floor is obtained with such a material.

2. Concrete floor floating construction

Fig. 28.11 shows a typical construction, in which an additional floor is constructed and isolated (or floated) from the existing concrete floor. Resilient material like quilted mineral or glass wool is laid over the R.C.C. floor/roof. A water proof paper is then laid over it, and then 5 cm thick concrete screed is provided. It is important that both the quilt and the water-proof paper are lapped so as to prevent concrete from getting through. Such a construction provides good insulation against impact sounds.

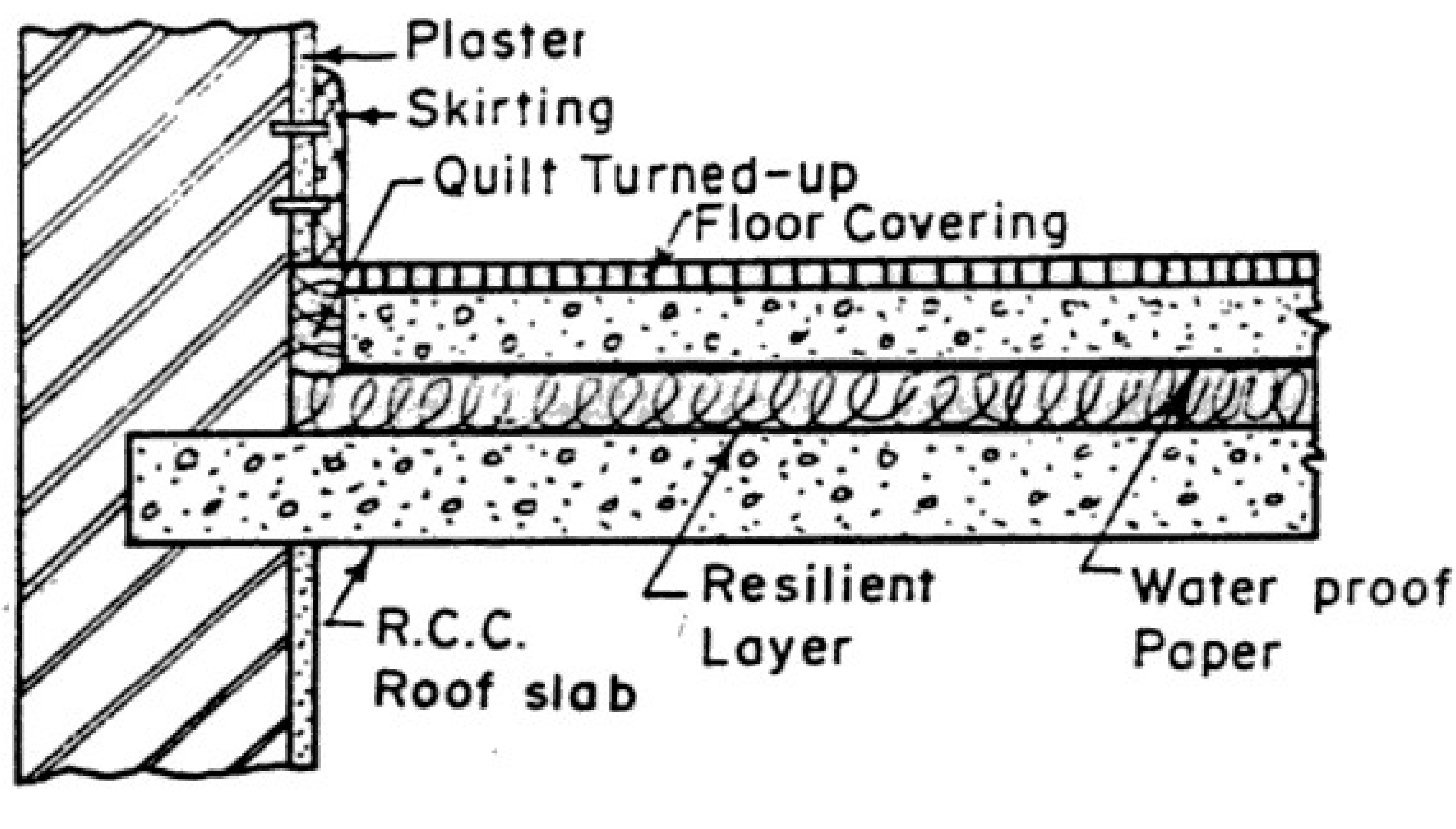


FIG. 28.11. CONCRETE FLOOR FLOATING CONSTRUCTION.

3. Timber floor floating construction

In case of floors constructed of wooden joists, the problem of sound insulation becomes more difficult particularly in the presence of heavy mechanical impact sounds. Fig. 28.12 shows the methods of insulating such existing floors while Fig. 28.13 shows new timber

29

PERT and CPM

29.1. PROJECT MANAGEMENT

A project is composed of jobs, activities, functions or tasks that are related one to the other in some manner, and all of these should be completed in order to complete the project. Every project has one specific purpose : it starts at some specific moment and it is finished when its objectives have been fulfilled. For completion of a project, two basic things are required : (*i*) material resources, (*ii*) man power resources. Many countries, rich in material resources are exceedingly poor in terms of level of production oı plan achievement, while there are other countries which have very limited natural resources but have achieved higher level of productivity mainly because of talents, skills, experience and know how of their people. Availability, quality and use of human resources is a single determinant factor in accomplishing project objectives.

Rapid accumulation of scientific technique in the recent past has not been matched by a corresponding improvement in the sphere of human group relations. In other words, sociology has not kept pace with technology. We are not in a position to utilize fully our technology advancement unless we are also able to advance in social sphere. Here comes the role of *management*. While *technology* deals with *material things, management* deals with both *material things* as well as *human beings.*

Management increases the productivity through technological innovation taking into account human factors involved in these advances:

Each project, whether big or small has three *objectives* :

(*i*) The project should be completed with a minimum of elapsed time.

(*ii*) It should use available manpower and other resources as sparingly as possible, without delay.

From the bar chart shown in Fig. 29.2, we find that project will be complete on 30th November-48 days after its start. Also, the progress upto 10th November will be as follows :

(*a*) Activities 1, 2, 3 and 5 will be completely over.

(*b*) Activities 4, 6, 7 and will have 2 days work left.

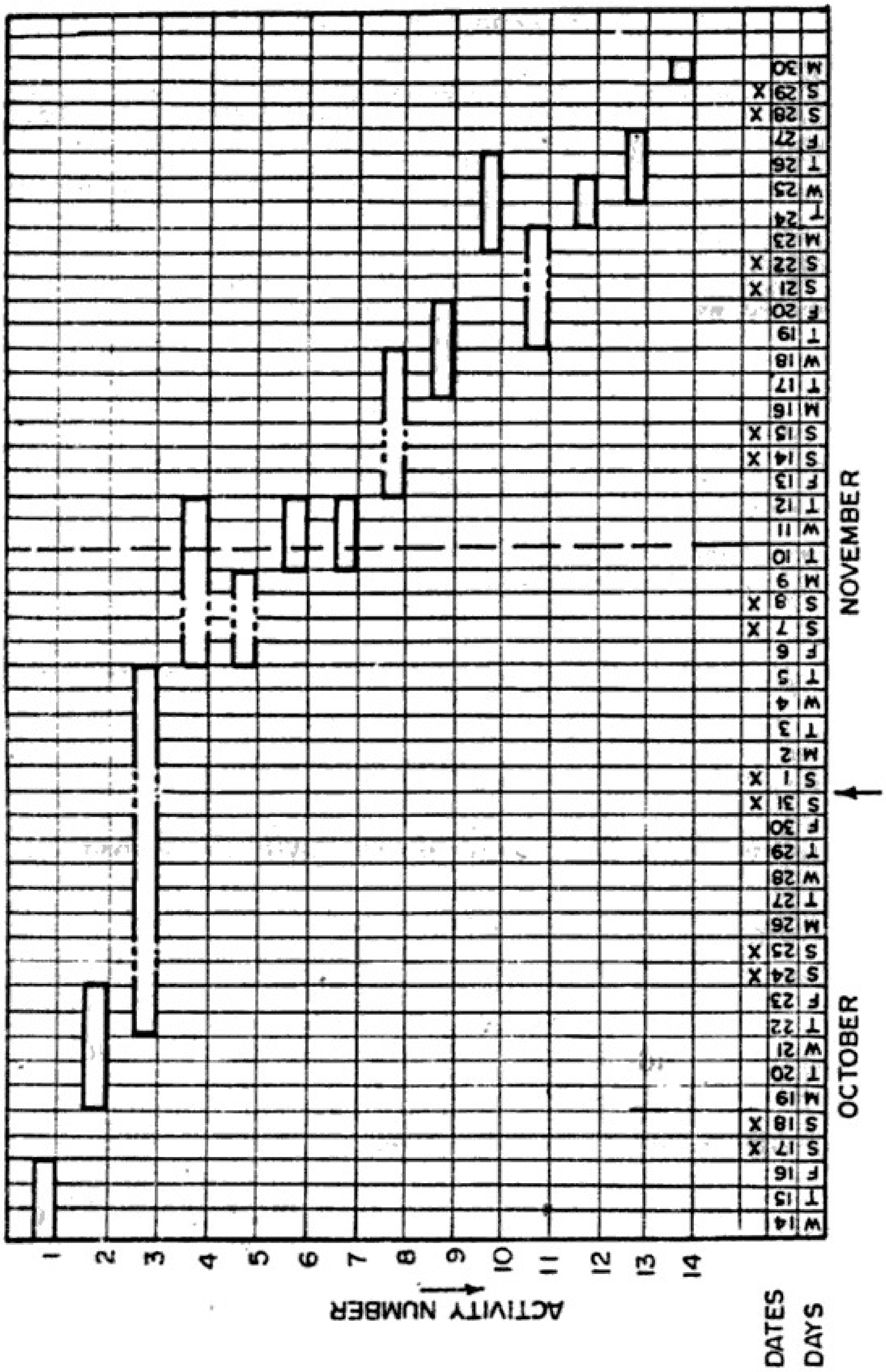


FIG. 29.2. BAR CHART FOR CONSTRUCTION OF A HOUSE.

29.4. SHORTCOMINGS OF BAR CHARTS AND REMEDIAL MEASURES

Bar charts have following short comings. These short comings can be partly overcome by following the suggested remedial measures.

these are specific points in time which mark the completion of certain portions of the main activity. These points are those which can be easily identified over the main bar. We have already seen that when a particular activity, represented by a bar on a bar chart is very long, the details lack. If however, the activity is broken or sub-divided into a number of sub-activities, each one of which can be easily recognised during the progress of the project, controlling can be easily done and inter-relationships between other similar activities can be easily established. The beginning and end of these sub-divided activities or tasks are termed as *milestones.*

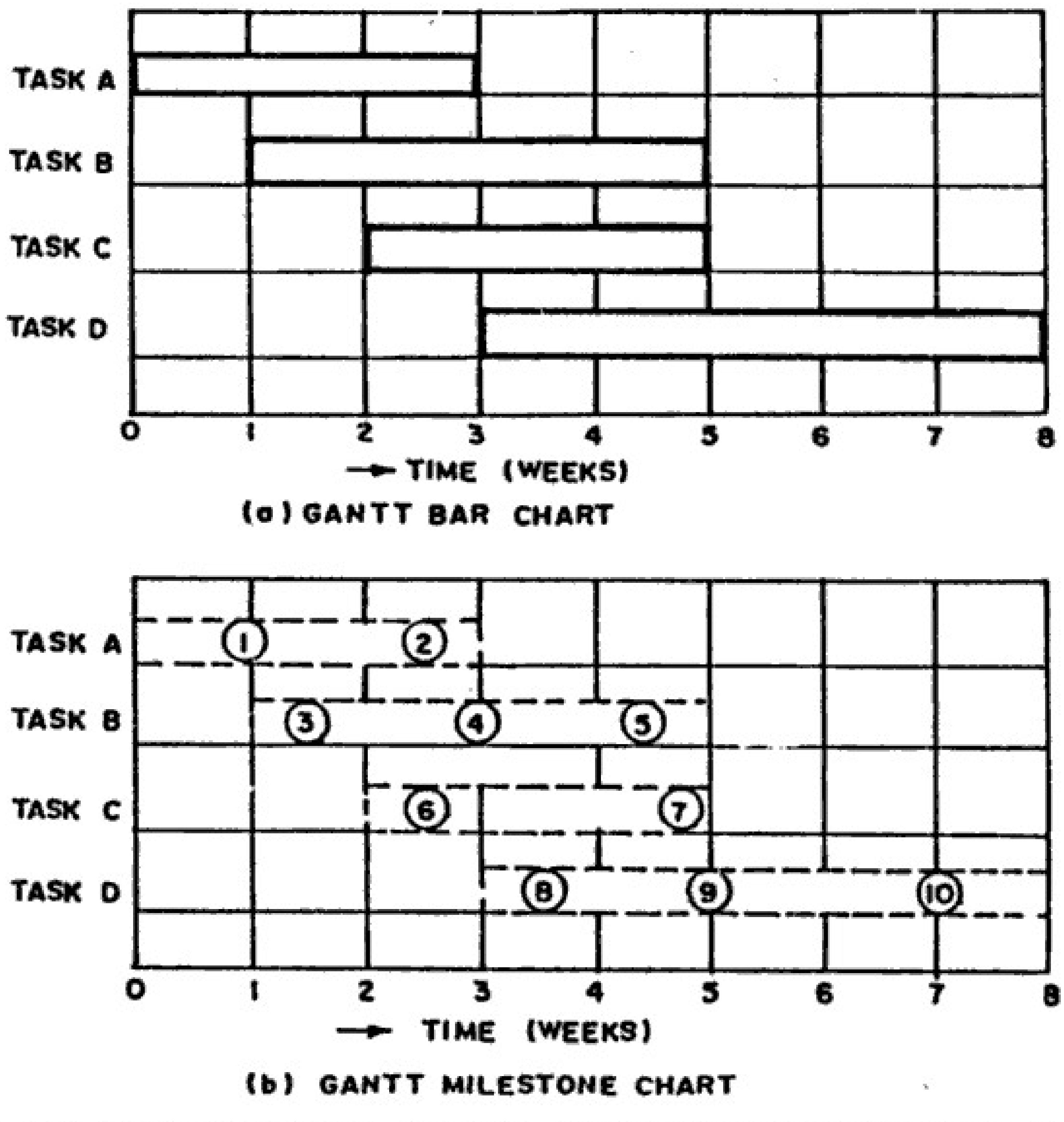


FIG. 29.8. MODIFICATION OF BAR CHART INTO MILESTONE CHART.

For example, consider a bar chart diagram shown in Fig. 29.8 (*a*). It consists of four jobs or tasks or activities : task *A*, task *B*, task *C* and task *D*.

Fig. 29.8 (*b*) shows some 'milestones' on each bar. Each main task contains some specific points in time which can be easily recognised, and through which *controlling* can be achieved. Each milestone can be considered to be specific *event* along the main activity or job or task. This chart is therefore called the *milestone chart* . Each milestone is represented either by a circle or by a square, and is serially marked.

Minor merchandising operations in buildings primarily meant for other uses should be covered by group under which the predominant occupancy is classified.

7. Group *G* : Industrial Buildings

These include any building or part of a building, or structure in which products or materials of all kinds and properties are fabricated, assembled or processed, for example, assembly plants, laboratories, dry cleaning plants, power plants, pumping stations, smoke houses, gas plants, refineries, dairies and saw mills.

8. Group *H* : Storage Buildings

These include any building or part of a building, used primarily for the storage or sheltering (including servicing, processing or repairs incidental to storage) of goods, wares or merchandise (except those that involve highly combustible or explosive products or materials), vehicles or animals, for example, warehouses, cold storages, freight depots, transit sheds, store houses, truck and marine terminals garages, hangers (other than aircraft repair hangars), grain elevators, barns and stables.

9. Group *J* : Hazardous Buildings

These include any building or part of a building which is used for the storage, handling, manufacture or processing of highly combustible or explosive materials or products which are liable to burn with extreme rapidity and/or which produce poisonous fumes or explosions; for storage, handling, manufacturing or processing which involve highly corrosive, toxic or noxious alkalies, acids or other liquids or chemicals producing flame, fumes and explosive, poisonous, irritant or corrosive gases; and for the storage, handling or processing of any material producing explosive mixtures of dust or which result in division of matter into fine particles subject to spontaneous ignition. Examples of buildings in this class are those buildings which are used for :

(*a*) Storage under pressure of more than 0.1 N/mm^2 and in quantities exceeding 70 m^3 of acetylene, hydrogen, illuminating and natural gases, ammonia, chlorine, phosgene, sulphur dioxide, carbon dioxide, methyl oxide and all gases subject to explosion, fume or toxic hazard;

(*b*) Storage and handling of hazardous and highly flammable liquids;

(*c*) Storage and handling of hazardous and highly flammable or explosive materials other than liquids; and

(*d*) Manufacture of artificial flowers, synthetic leather, ammunition, explosives and fireworks.

TABLE 30.1. WATER REQUIREMENTS FOR BUILDINGS OTHER THAN RESIDENCES

	Type of building	*Rate per head per day in litres*
1.	Factories, where bath rooms are required to be provided.	45
2.	Factories where no bath rooms are required to be provided.	30
3.	Hospital (including laundry) per bed.	
	(*i*) Number of beds not exceeding 100	340
	(*ii*) Number of beds exceeding 100	450
4.	Nurses homes and medical quarters.	135
5.	Hostels	135
6.	Hotels (per bed)	180
7.	Offices	45
8.	Restaurants (per seat)	70
9.	Cinemas, concert halls and theatres (per seat).	15
10	Schools	
	(*a*) Day Schools	45
	(*b*) Boarding Schools	135

30.3. MATERIAL FOR SERVICE PIPES

The pipe leading from the distribution main of the municipal water supply to the plumbing system of the house is known as the *service main* . The following materials are commonly used for service pipes :

(*i*) Copper pipe or brass pipe

(*ii*) Galvanised iron, either lined or unlined

(*iii*) Load pipe, either lined or unlined

(*iv*) Polythene pipe.

1. Copper tubing. Copper tubing is non-corrosive with most waters. It is used extensively in better grade houses and where ground water is highly corrosive to steel pipe. It has considerable strength, reasonable ductility, and is obtainable in long lengths. There are two types of copper water service pipes : *heavy gauge* and *light guage.* The former can be threaded and is used for high pressure work in industrial layouts. For general purpose work where pressure does not exceed 1.5 kg/cm^2, and for interval domestic work, light gauge tube is used. For underground work, as for the pipe from the main to the building, special copper tube is used having a heavier guage. The copper tube can be attached to the main without the use of conventional goose neck, the flared end of the tubing being connected directly to the corporation cock without threading.

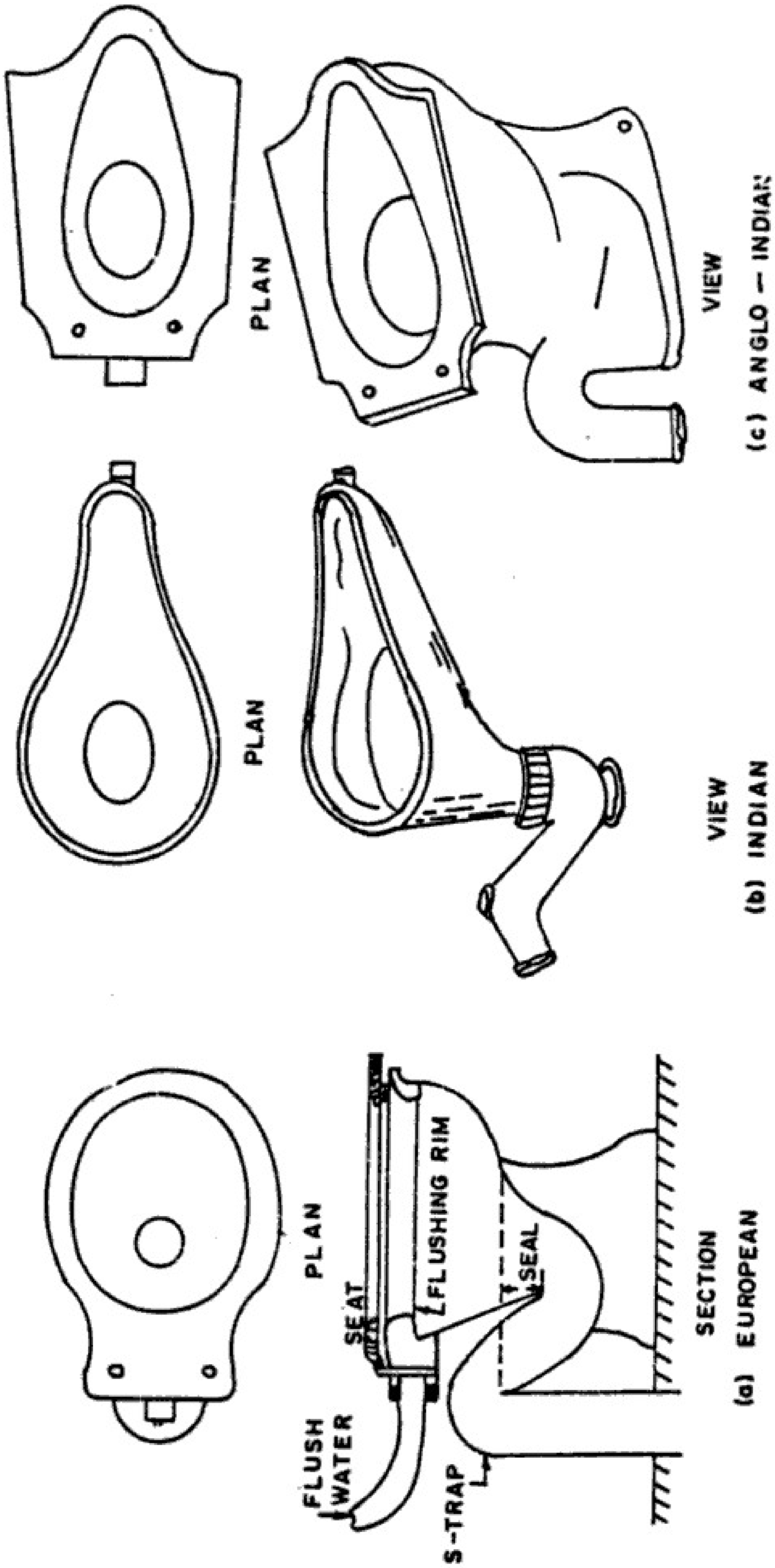


FIG. 30.14. WATER CLOSETS.

1.3. COMPONENTS OF A BUILDING

A building has two basic parts:

(*i*) Sub-structure or foundations, and

(*ii*) Super-structure.

Sub-structure or Foundation is the lower portion of the building, usually located below the ground level, which transmits the loads of the super-structure to the supporting soil. *A foundation is therefore that part of the structure which is in direct contact with the ground to which the loads are transmitted.*

Super-structure is that part of the structure which is above ground level, and which serves the purpose of its intended use. A part of the super-structure, located between the ground level and the floor level is known as *plinth.*

Plinth is therefore defined as the portion of the structure between the surface of the surrounding ground and surface of the floor, immediately above the ground. The level of the floor is usually known as the *plinth level.* The built-up covered area measured at the floor level is known as *plinth area.*

A *building* has the following components :

1. Foundations.
2. Masonry units : walls and columns.
3. Floor structures.
4. Roof structures.
5. Doors, windows and other openings.
6. Vertical transportation structures, such as stairs, lifts, ramps etc.
7. Building finishes.

1. Foundations

The basic function of a foundation is to transmit the dead loads, live loads and other loads to the subsoil on which it rests in such a way that (*a*) settlements are within permissible limits, without causing cracks in the super-structure and (*b*) soil does not fail in shear. Since it remains below the ground level, the signs of failure of foundations are not noticeable till it has already afffected the building. It should therefore be designed very carefully. Various types of foundations and their design principles have been discussed in chapters 2, 3 and 4.

2. Masonry units : walls, columns etc.

Masonry may be defined as the construction of building units bonded together with mortar. These building units, commonly known as *masonry units* may be stones, bricks or precast blocks. Masonry is used for the construction of foundation walls, columns and other by dividing the total covered area (plinth area) on all floors and 100 by the area of the plot:

$$\text{Thus, F.A.R.} = \frac{\text{Total area covered of all floors} \times 100}{\text{Plot area}}$$

4. Roof structures

A roof is the upper most part of a building. It is a covering provided on the top of the building with a view to keep out rain, snow, sun and wind and to protect the building from their adverse effects. Just as a floor, a roof consists of two components : (*i*) The roof decking and (*ii*) the roof covering. *Roof decking* is a structural component which supports the roof covering. Roof decking may be either flat or sloping, and may be in the form of flat slab, dome, truss, portal or shell. The *roof covering or roofing* is provided on the roof deck to safeguard the building against weather effects. These may be in the form of tiles, thatch covering, slates, flagstone covering, and corrugated sheets of galvanised iron or asbestos cement.

5. Doors, Windows and other Openings

A *door* is a movable barrier provided in the opening of a wall, to provide access to various spaces of a building. A door is a frame work of wood, steel etc. secured in the wall opening for the purpose of providing access to the users of the building. Similarly, a window may be defined as an opening made in the wall for the purpose of providing day light, vision and ventilation. Windows are also made of frame work of wood, steel, aluminium etc., provided with shutters.

Since doors and windows are provided in the openings in the walls, a discontinuity is formed in the wall, in the vertical direction. *Lintels* are therefore essential. A *lintel* is a horizontal structural member provided over the doors, windows or other openings, to span the gap, so as to support the super-imposed load carried by the wall above the opening. Lintels may be made of timber, stone, steel or reinforced cement concrete (R.C.C.).

Sometimes, an *arch* may be provided to span the opening, in the place of a lintel. An arch is a structure consisting of a number of small wedge-shaped units and jointed together with mortar, which is constructed to bridge across any opening in the wall. The arch may also be constructed in R.C.C.

6. Vertical Transportation Structures

These consists of stairs, ramps, ladders, lifts and escalators etc. to afford access between various floors. Out of these, stairs

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similar structural components. The construction with stone units, bonded with mortar is known as *stone masonry,* while the construction with brick units, bonded with mortar is known as *brick masonry. A composite masonry* may use different types of building units for the construction.

Walls are the most essential components of a building. The primary function of the wall is to enclose or divide space of the building to make it more functional and useful. Walls provide privacy, afford security and give protection against heat, cold, sun and rain. Walls may be either load bearing or non-load bearing. Load bearing walls are those which are designed to carry the super-imposed loads (transferred through roofs), in addition to their own(self) weight. Non-load bearing walls carry their own load only. They generally serve a *divide walls or partition walls.* Wall may be of several types, such as cavity walls, party walls, partition walls, dwarf walls, retaining walls. These have been discussed in chapter 8, 9 and 10.

A *column* is an isolated vertical load bearing member, the width of which is neither less than its thickness nor more than four times its thickness. A *pier* is a member similar to a column except that it is bonded into load bearing wall at the sides to form integral part and extends to the full height of the wall. A pier is used to increase the stiffness of the wall to carry additional load or to carry vertical concentrated load.

3. Floor structures

Floors are the horizontal elements which divide the building into different levels for the purpose of creating more accommodation within a restricted space one above the other and provide support for the occupants, furniture and equipment of a building.

The floor of a building immediately above the ground is known as *ground floor.* All other floors which are above the ground floor are known as the *upper floors.* The floors of the first storey is known as the *first floor* and that of the second storey is known as the second floor etc, etc. In case, part of the building is constructed below the ground level, or the building has the basement, the floor is known as *basement floor.*

Every floor has two components : (*i*) the *sub-floor,* which is a structural component to impart strength and stability to support the super-imposed loads and (*ii*) *floor covering or flooring* consisting of suitable floor finish.

Floor area is the usable covered area of a building at any floor level.

Floor area ratio (F.A.R.) is defined as the quotient obtained

TABLE 1.2. LIVE LOADS ON FLOORS (IS: 875-1964)

Loading Class No. (1)	*Types of floors* (2)	*Min. Live Load per m^2 of floor area* (3)	*Alternative minimum live load* (4)
200	Floors in dwelling houses tenements, hospital wards, bed rooms and private sitting rooms in hostels and dormitories.	200 kg/m^2 (2 kN/m^2)	Subject to a min. total load of 2.5 times the values in col. 3 for any given slab panel and 6 times the value in col. 3 for any given beam. This total load shall be asuumed uniformly distributed on the entire area of the slab panel and the entire length of the beam.
250	Office floor other than entrance halls, floors of light workrooms.	250*–400 kg/m^2 (2.5–4 kN/m^2)	
300	Floors of banking halls, office entrance halls and reading rooms	300 kg/m^2 (3 kN/m^2)	
400	Shop floors used for display and sale of merchandise ; floors of workrooms generally ; floors of classrooms in schools ; floors of places of assembley with fixed seating ; restaurants ; circulation space in machinery halls ; power stations etc., where not occupied by plant or equipments.	400 kg/m^2 (4 kN/m^2)	
500	Floors of warehouses, workshops, factories and other buildings or parts of buildings of similar categories for light weight loads ; office floors for storage and filling purposes ; floors of places of assembly without fixed seating ; public rooms in hotels, dance halls , waiting halls etc.	500 kg/m^2 (5 kN/m^2)	–
750	Floors of warehouses, workshops, factories and other buildings or parts of buildings of similar categories for medium weight- loads.	750 kg/m^2 (7.5 kN/m^2)	–
1000	Floors of warehouses workshops , factories and other buildings or parts of buildings of similar categories for heavy weight loads, floors of book stores and libraries, roofs and pavement lights over basements projecting under the public footpath.	1000 kg/m^2 (10 kN/m^2)	–

3. Wind Loads

Wind is the air in motion relative to the surface of the earth. Since vertical components of atmospheric motion are relatively small, 'specially near the surface of the earth, the term 'wind' denotes almost exclusively the horizontal wind. Wind pressure, therefore, acts horizontally on the exposed vertical surfaces of walls, columns etc, and inclined roof of the structure. *Wind pressure or wind loading* is expressed in terms of a *basic pressure p* which is an equivalent static pressure in the direction of flow of wind. The *basic wind pressure p* should be decided on the basis of local meteorological data and local conditions, such as characteristics and location of structure and characteristics and duration of wind flow. In absence of any other data, the following relationship may be obtained by the expression.

$$p = kV^2 \quad \text{...(1.1)}$$

where p = wind pressure, kg/m^2

V = wind velocity, km/hours

and k = co-efficient, the value of which depends upon a number of factors, such wind speed, the type, proportion and shape of structure and the temperature of air. National Building Code has adopted $k = 0.006$ for the preparation of wind pressure maps. For detailed study, reference may be made to these maps. These maps and the associated charts give the variation in wind pressure with height.

For structures of various plan shapes other than rectangular plan shape, the external pressures acting on the projected area in the plane perpendicular to the wind, should be the product of the basic pressure (p) given above and the shape factors given in Table 1.4.

TABLE 1.4. PLAN SHAPE FACTORS

Plan shape of the structure	*Factor*		
	Ratio of height to base width 0–4	*Ratio of height to base width 4–8*	*Ratio of height to base width 8 or over*
1. Circular	0.7	0.7	0.7
2. Octagonal	0.8	0.9	1.0
3. Square (wind perpendicular to diagonal	0.8	0.9	1.0
4. Square (wind perpendicular to face)	1.0	1.15	1.3

The effect of wind shall be calculated on the basis of basic wind pressure(p) for the entire height of the building and any projection building against damage or distress caused by swelling or shrinkage of the sub-soil.

4. Foundations should be so located that its performance may not be affected due to any unexpected future influence.

2.4. TYPES OF FOUNDATIONS

Foundations may be broadly classified under two heads :

(*a*) Shallow Foundations

(*b*) Deep Foundations.

According to Terzaghi, a foundation is *shallow* if its depth is equal to or less than its width. In case of *deep foundations,* the depth is equal to or greater than its width.

(A) SHALLOW FOUNDATIONS

From the point of view of design, shallow foundations may be of the following types:

1. Spread footings.
2. Combined footings
3. Strap footings.
4. Mat foundation.

Various types of *shallow foundations* are shown in Fig. 2.1. . A brief description of these is given below. Details about the design requirements etc. are discussed in Chapter 3.

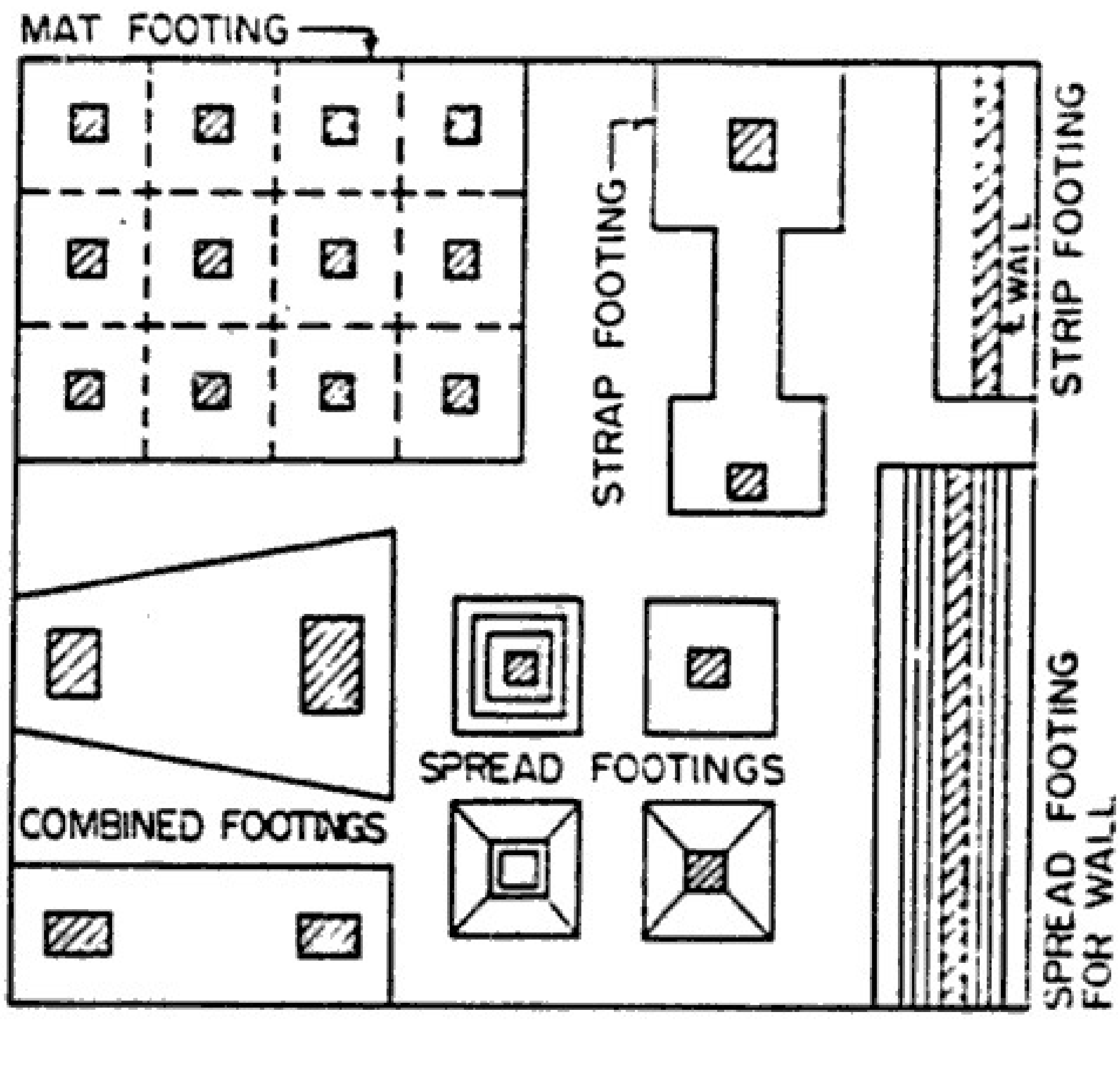


FIG. 2.1. VARIOUS TYPES OF SHALLOW FOUNDATIONS.

1. Spread Footings

Spread footings are those which spread the super-imposed load of wall or column over a larger area. Spread footings support concrete to keep the joists in position and to prevent their corrosion. The detailed method of construction has been explained in § 3.6. Grillage foundation is also constructed of timber beams and planks (Fig. 3.12 and 3.13).

2. Combined Footings

A spread footing which supports two or more columns is termed as combined footing. The combined footings may be of the following kinds:

(*i*) Rectangular combined footing [Fig. 2.5 (*a*)]

(*ii*) Trapezoidal combined footing [Fig 2.5(*b*)]

(*iii*) Combined column-wall footings [Fig. 2.5(*a*),(*b*)]

Combined footings are invariably constructed of reinforced concrete.

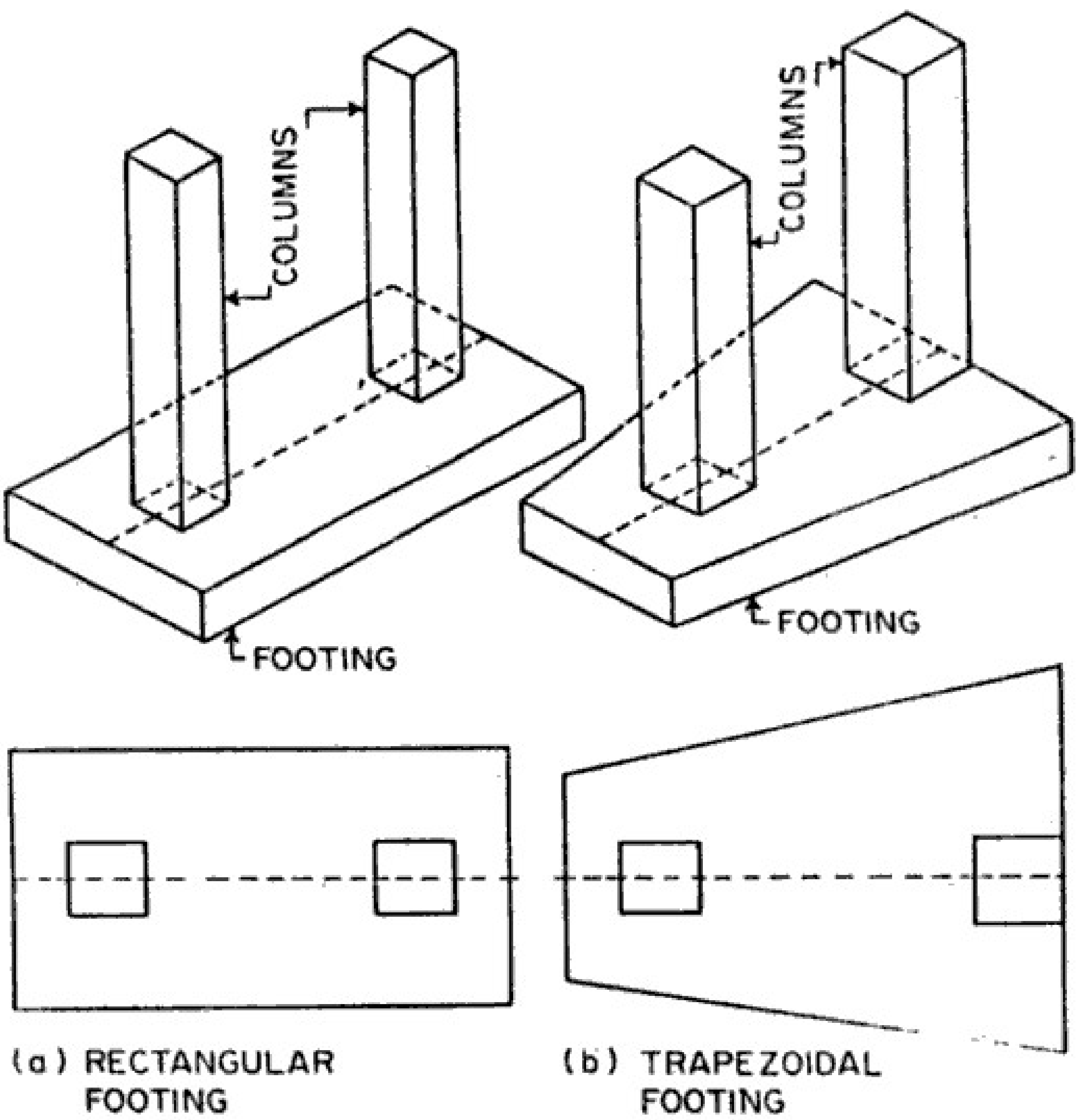


FIG. 2.5. COMBINED FOOTINGS FOR COLUMNS.

The combined footing for columns will be rectangular in shape if they carry equal loads. The design of rigid rectangular combined loads are taken to a low level by means of vertical members which may be of timber, concrete or steel. Pile foundation may be adopted (*i*) instead of a raft foundation where no firm bearing strata exists at any reasonable depth and the loading is uneven, (*ii*) when a firm bearing strata does exist but at a depth such as to make strip or spread footing uneconomical, and (*iii*) when pumping of sub-soil water would be too costly or timbering to excavations too difficult to permit the construction of normal foundations.

Piles used for building foundation may be of four types :

(*i*) End bearing pile [Fig. 2.8 (*a*)]

(*ii*) Friction pile [Fig. 2.8 (*b*)]

(*iii*) Combined end bearing and friction pile [Fig. 2.8 (*c*)] and

(*iv*) Compaction piles [Fig. 2.8 (*d*)]

End bearing piles [Fig. 2.8 (*a*)] are used to transfer load through water or soft soil to a suitable bearing stratum. Such piles are used

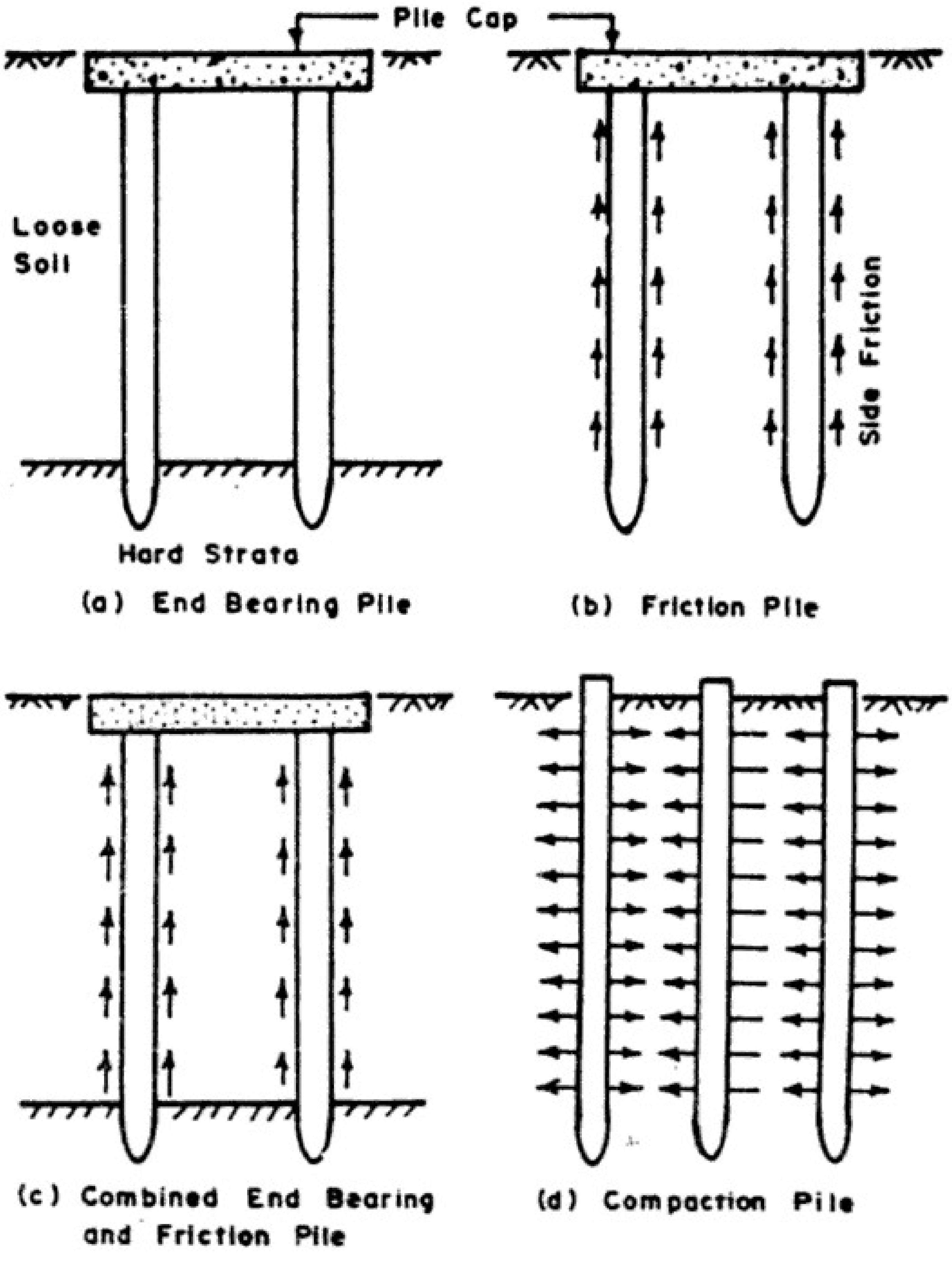


FIG. 2.8. PILE FOUNDATIONS

2.5. SITE INVESTIGATION AND SUB-SOIL EXPLORATION

Since the foundations have to transfer the load to the sub-soil, *surface conditions* at any given site must be adequately explored to obtain information required for the design and construction of foundations.

Sub-soil exploration is done for the following purposes:

(*a*) For New Structures

1. The selection of *type and depth* of foundation.
2. The determination of bearing capacity of the selected foundation.
3. The prediction of *settlement* of the selected foundation.
4. The determination of the *ground water level.*
5. The evaluation of the *earth pressure* against walls, basements, abutments etc.
6. The provision against constructional *difficulties.*
7. The suitability of soil and degree of compaction of soil.

(*b*) For Existing Structures

1. The investigation of the safety of the structure.
2. The prediction of settlement.
3. The determination of remedial measures if the structure is unsafe or will suffer detrimental settlement.

SITE RECONNAISSANCE

An inspection of the site and study of topographical features is often helpful in setting useful information about the soil and ground water conditions and in deciding the future programme of exploration. On going over the site, a study of the following features may be useful : local topography, excavations, cuttings, quarries, escarpments evidence of erosion or land slides, fills, water level in wells and drainage pattern for the building site. If there has been an earlier use of the site, information should be gathered, in particular about the underground workings, if any, and about the location of fills and excavations.

SITE EXPLORATION

The object of the site exploration is to provide reliable, specific and detailed information about the soil and ground water conditions of the site which may be required for a safe and economic design of foundations. For this purpose, an exploration of the region likely to be affected by the proposed works should yield precise information about the following :

(*i*) the order of occurrence and extent of soil and rock strata.

(*ii*) the nature and engineering properties of the soil and rock formation, and for major foundation works, such as for :

(*i*) bridge piers and abutments in rivers, lakes etc.

(*ii*) Wharves, quay walls, docks.

(*iii*) Break waters and other structures for shore protections.

(*iv*) Large water front structures such as pump houses, subjected to heavy vertical and horizontal loads.

Well foundations or caissons are hollow from inside, which

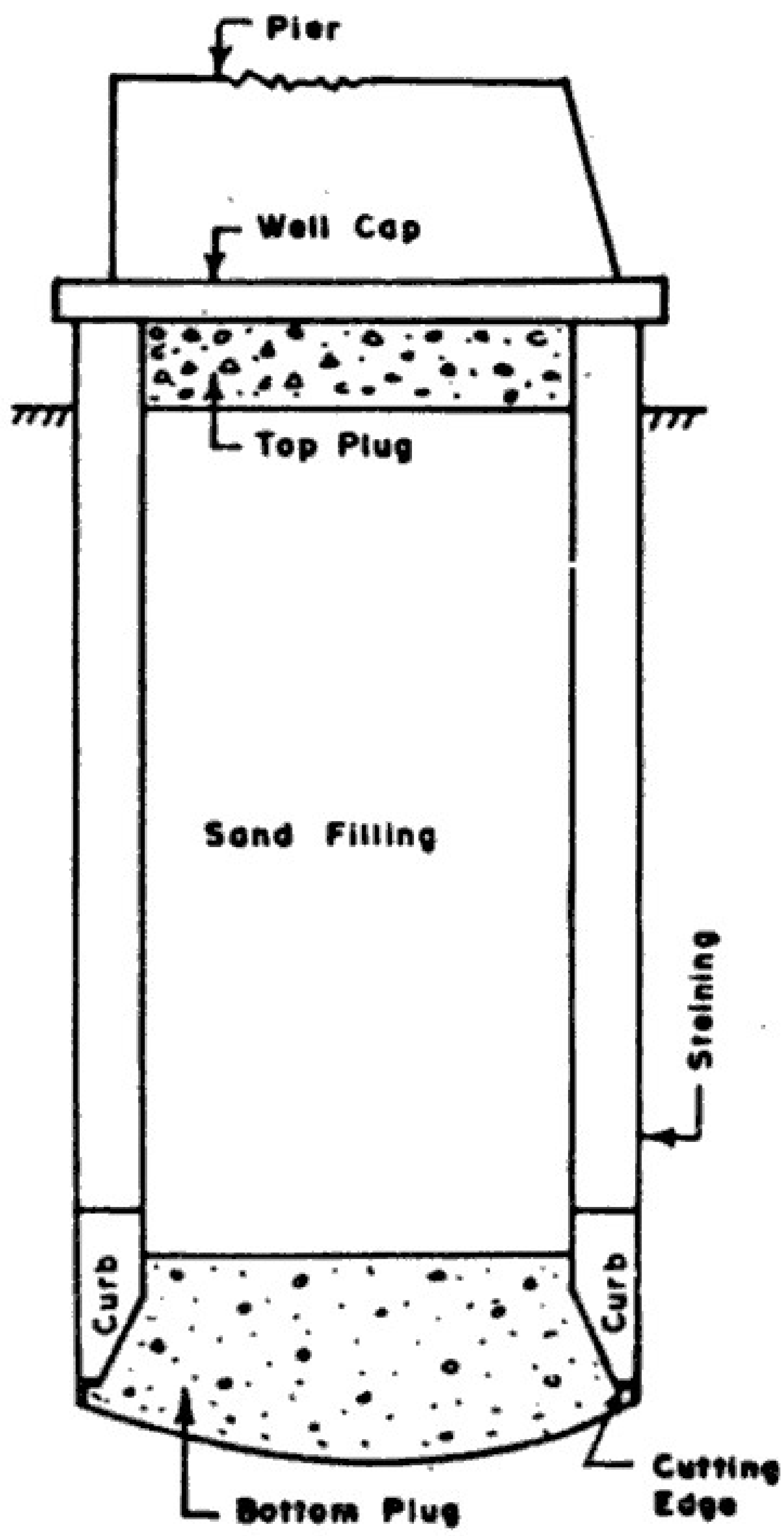


FIG. 2.10. WELL FOUNDATION.

may be filled with sand, and are plugged at the bottom. The load is transferred through the perimeter wall, called steining (Fig. 2.10).

Well foundations are not used for buildings.

1. OPEN EXCAVATION (OPEN TRIAL PITS)

Trial pits are the cheapest method of exploration in shallow deposits, since these can be used in all types of soils. In this method, pits are excavated at the site, exposing the sub-soil surface thoroughly. Soil samples are collected at various levels. The biggest advantage of this method is that soil strata can be inspected in their natural condition and samples (disturbed or undisturbed) can be conveniently taken. A typical trial pit is shown in Fig. 2.11.

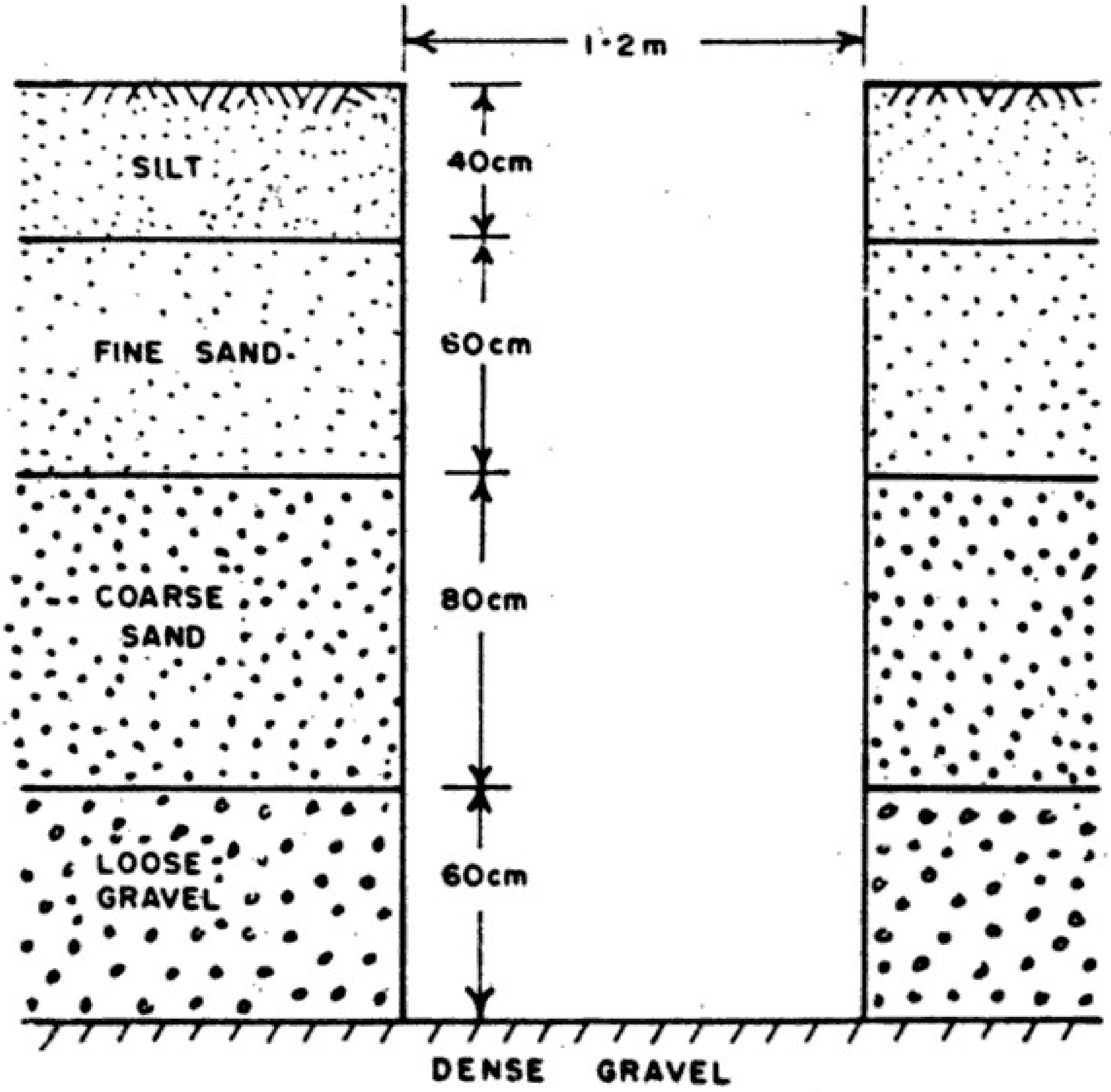


FIG. 2.11. TRIAL PIT

The method is generally considered suitable for shallow depths, say upto 3 m. The cost of open excavation increases rapidly with depth. For greater depths and for excavation below ground water table, specially in pervious soils, measures for lateral support and ground water lowering becomes necessary.

2. BORING METHODS

The following are the various boring methods commonly used:

(*i*) Auger boring (*ii*) Auger and shell boring

(*iii*) Wash boring (*iv*) Percussion boring

and (*v*) Rotary boring.

(*iii*) the location of ground water and its variation.

Depth of exploration

Exploration, in general, should be carried out to a depth upto which the increase in pressure due to structural loading is likely to cause perceptible settlement or shear failure of foundations. Such a depth, known as *significant depth*, depends upon the type of structure, its weight, size, shape and disposition of the loaded areas, and the soil profile and its properties. The significant depth may be assumed to be equal to one-and-a-half to two times the width (smaller of the lateral dimension) of the loaded area.

The depth of exploration at the start of the work may be decided according to the following guide rules, which may need modification as exploration proceeds :

1. *Isolated spread footing or raft*: One and a half times the width.

2. *Adjacent footings with clear spacing less than twice the width*: One and a half times the length.

3. *Pile foundation*: 10 to 30 metres, or more, or at least one and a half times the width of the structure.

4. *Base of the retaining wall*: One and a half times the base width or one and a half times the exposed height of face of wall, whichever is greater.

5. *Floating basement*: Depth of construction.

6. *Weathering considerations* : 1.5 m in general and 3.5 m in black cotton soils.

National Building Code of India (SP:7-1983) suggests that *normally* the depth of exploration should be one and half times the estimated width (lower dimension) of the footing, single or combined, from the *base level* of the foundation; but in weak soils, the exploration should be continued to a depth at which the loads can be carried by the stratum in question without undesirable settlement or shear failure. In any case, the depth to which weathering processes affect the soil should be regarded as a minimum depth for the exploration of sites and this should be taken as 1.5 metres. But where industrial processes affect the soil characteristics, this depth may be more.

2.6 METHODS OF SITE EXPLORATION

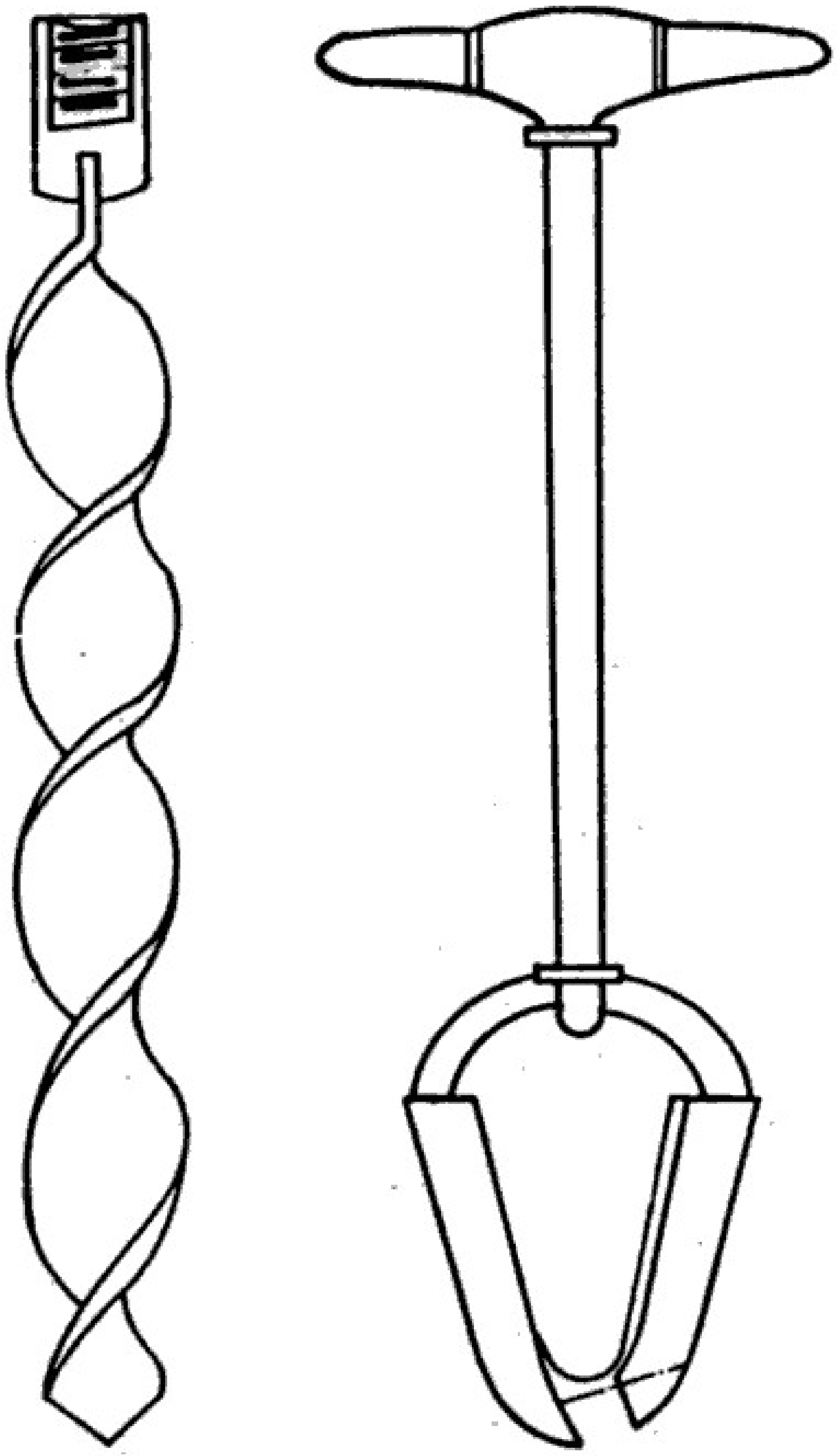
The various methods of site exploration may be grouped as follows:

1. Open excavations
2. Borings
3. Sub-surface soundings
4. Geo-physical methods.

Contents

(i) Auger boring

Augers are used in cohesive and other soft soils above water table. They may either be operated manually or mechanically. Hand augers are used upto a depth upto 6 m. Mechanically operated augers are used for greater depths and they can also be used in gravelly soils. Augers are of two types: (*a*) spiral auger and (*b*) post-hole auger.



(a) HELICAL AUGER (*b*) POST-HOLE AUGER.

FIG. 2.12. AUGER.

Samples recovered from the soil brought up by the augers are badly disturbed and are useful for identification purposes only. Auger boring is fairly satisfactory for explorations at shallow depths and for exploratory borrow pits.

(ii) Auger and shell boring

Cylindrical augers and shells with cutting edge or teeth at lower end can be used for making deep borings. Hand operated rigs are used for depths upto 25 m and mechanised rigs up to 50 m. Augers are suitable for soft to stiff clays, shells for very stiff and hard clays, and shells or sand pumps for sandy soils. Small boulders, thin soft strata or rock or cemented gravel can be broken by chisel bits attached to drill rods. The hole usually requires a casing. Fig. 2.13 shows a typical sand pump.

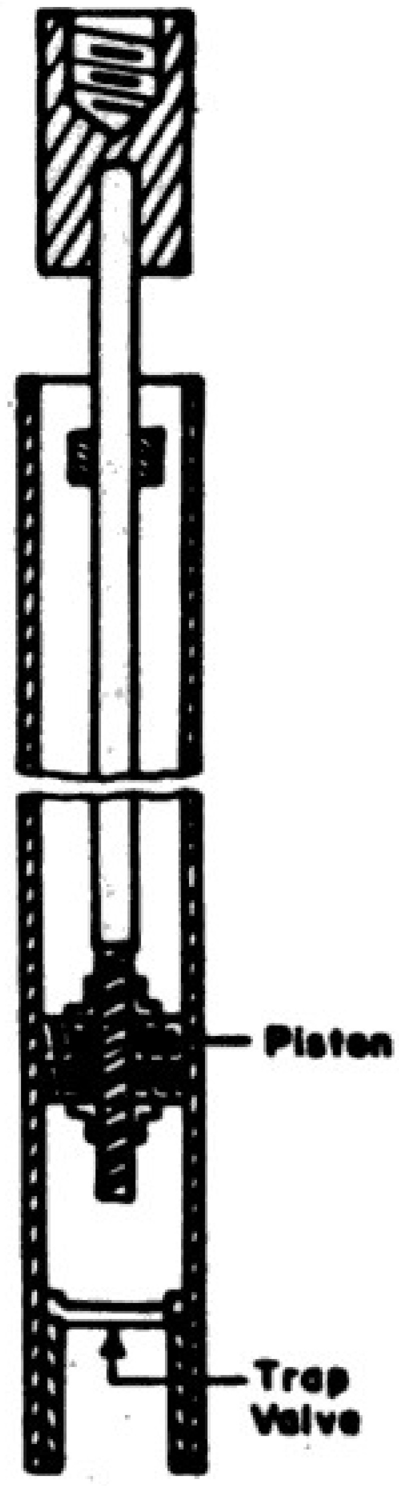


FIG. 2.13. SAND PUMP

(iii) Wash boring

Wash boring is a fast and simple method for advancing holes in all types of soils. Boulders and rock *cannot* be penetrated by this method. The method consists of first driving a casing through which a hollow drilled rod with a sharp chisel or chopping bit at the lower end is inserted. Water is forced under pressure through the drill rod which is alternatively raised and dropped, and also rotated. The resulting chopping and jetting action of the bit and water disintegrates the soil. The cuttings are forced upto the ground surface in the form of soil-water slurry through the annular space between the drill rod and the casing. The change in soil stratification could be guessed from the rate of progress and colour of wash water. The samples recovered from the wash water are almost valueless for interpreting the correct geo-technical properties of soil.

Fig. 2.14 shows a set-up for wash boring.

(iv) Percussion boring

In this method, soil and rock formations are broken by repeated blows of heavy chiesel or bit suspended by a cable or drill rod. Water is added to the hole during boring, if not already present and the slurry of pulverised material is bailed out at intervals. The method is suitable for advancing a hole in all types of soils, boulders and rock. The formations, however, get disturbed by the impact.

(v) Rotary boring

Rotary boring or *rotary drilling* is a very fast method of advancing hole in both rocks and soils. A drill bit, fixed to the lower end of the drill rods, is rotated by a suitable chuck, and is always kept in firm contact with the bottom of the hole. A drilling mud, usually

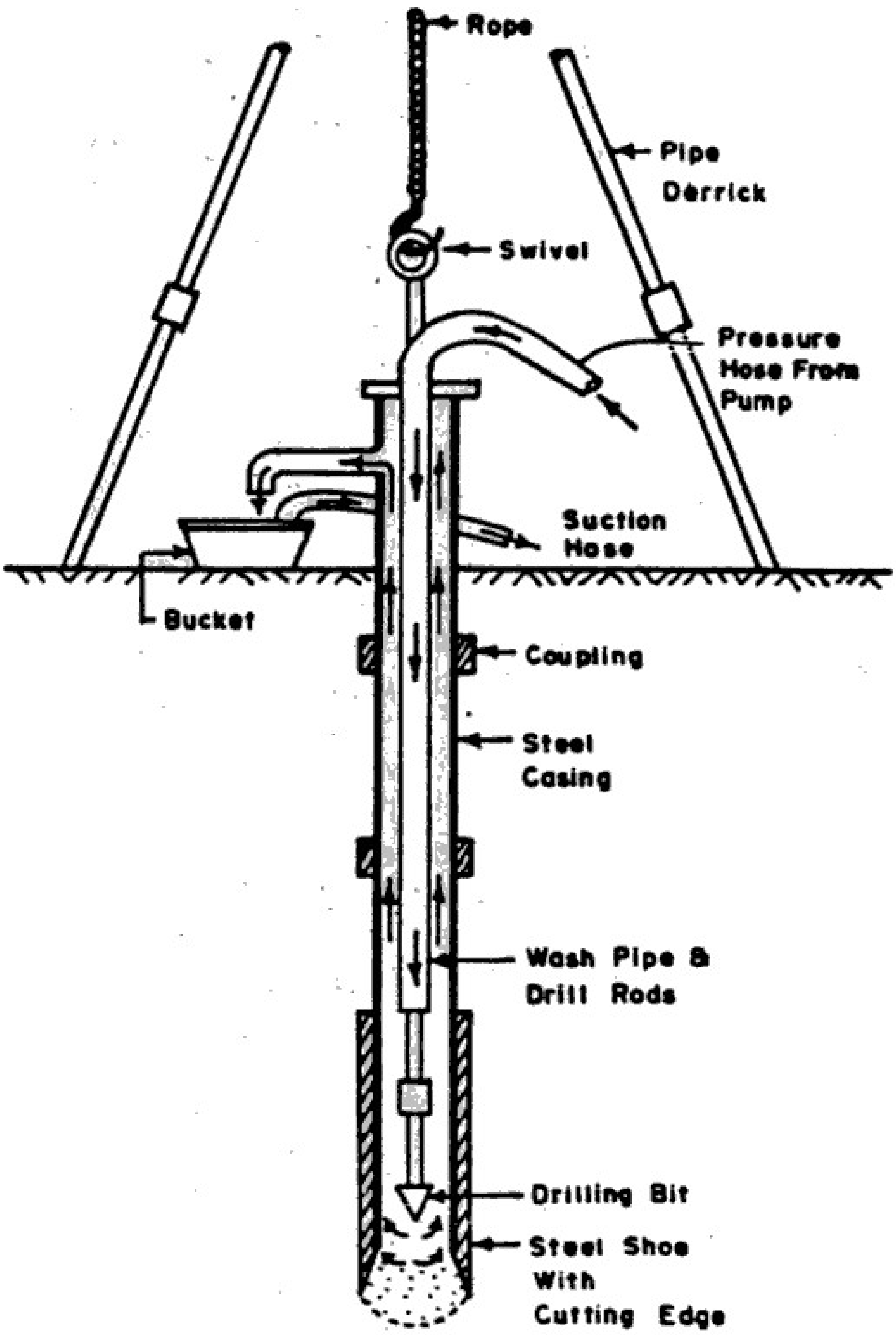


FIG. 2.14. WASH BORING.

a water solution of bentonite, with or without other admixtures, is continuously forced down to the hollow drill rods. The mud returning upwards brings the cuttings to the surface. The method is also known as *mud rotary drilling* and the hole usually requires no casing.

Rotary core barrels, provided with commercial diamond-studded bits or a steel bit with shots, are also used for rotary drilling and simultaneously obtaining the rock cores or samples. The method is then also known as *core boring or core drilling.* Water is circulated down the drill rods during boring.

Record of borings

The sounding methods consist of measuring the resistance of the soil with depth by means of *penetrometer* under static or dynamic loading. The penetrometer may consist of a sampling spoon, a cone or other shaped tool. The resistance to penetration is empirically correlated with some of the engineering properties of soil, such as density index, consistency, bearing capacity etc. The value of these tests lie in the amount of experience behind them. These tests are useful for general exploration of erratic soil profiles, for finding depth to bed rock or stratum, and to have an approximate induction of the strength and other properties of soils, particularly for cohesionless soils, from which it is difficult to obtain undisturbed samples. The two commonly used tests are *standard penetration test* and *the cone penetration test.*

4. GEO-PHYSICAL METHODS

Geo-physical methods are used when the depth of exploration is very large, and also when the speed of investigation is of primary importance. Geo-physical investigations involve the detection of significant differences in the physical properties of geological formations. These methods were developed in connection with prospecting of useful minerals and oils. The major method of geo-physical investigations are : gravitational methods, magnetic methods, seismic refraction method, and electrical resistivity method. Out of these, seismic refraction method and electrical resistivity methods are the most commonly used for Civil Engineering purposes.

Seismic refraction method

In this method, shock waves are created into the soil at their ground level or a certain depth below it by *exploding* small charge in the soil or by striking a plate on the soil with a hammer. The radiating shock waves are picked up by the *vibration detector* (also called *geophone or seismometer*) where the time of travel of the shock waves gets recorded. A number of geophones are arranged along a line (Fig. 2.16). Some of the waves, known as *direct or primary waves* travel directly from the shock point along the ground surface and are picked *first* by the geophone. The other waves which travel through the soil get refracted at the interface of two soil strata. The refracted rays are also picked up by the geophone. If the underlying layer is denser, the refracted waves travel much faster. As the distance between the shock point and the geophone increases, the refracted waves are able to reach the geophone earlier than the direct waves. By knowing the time of travel primary and refracted waves at various geophones, the depth of various strata can be evaluated, by preparing distance-time graphs and using analytical methods.

Seismic refraction method is fast and reliable in establishing profiles of different strata provided the deeper layer have increasingly

In all exploration work it is very important to maintain an accurate and explicit record of borings. Soil/rock samples are collected at various depths, during boring. These samples are tested in the laboratory for identification and classification. The samples are suitably preserved and arranged serially according to the depth at which they are found. A boring chart, similar to the one shown in Fig. 2.15 is prepared for each bore hole. A site plan should be prepared, showing the disposition of various bore holes on it.

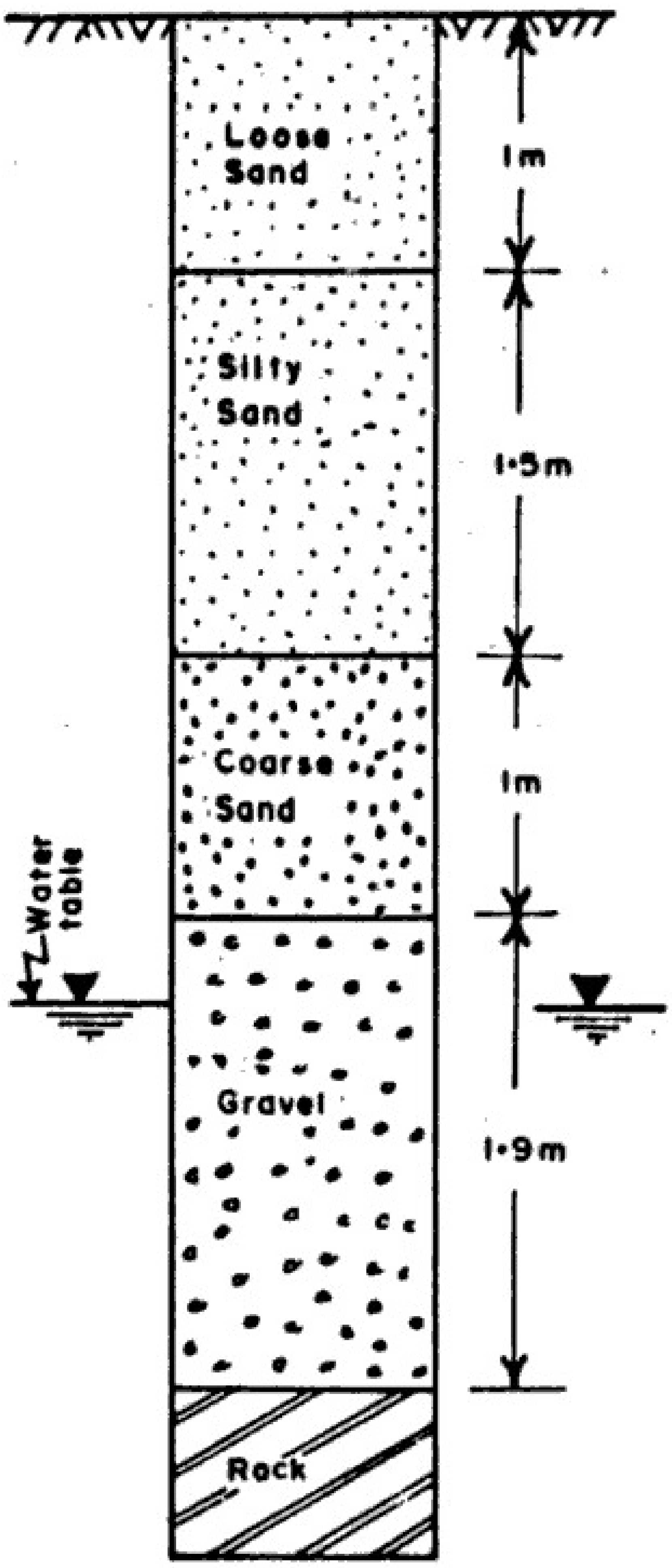


FIG.2.15. DETAILS OF BORING.

Number and disposition of trial pits and borings

The number and disposition of the test pits and borings should be such as to reveal any major changes in the thickness, depth or properties of the strata affected by the works, and the immediate surroundings. The National Building Code of India : (SP : 7–1983) gives the following recommendations for this:

(*a*) for a compact building site covering an area of about 0.4 hectares, one bore hole or trial pit in each corner and one in the centre should be adequate.

(*b*) For small and less important buildings, even one bore hole or trial pit in the centre will suffice.

(*c*) For very large areas covering industrial and residential colonies, the geological nature of the terrain will help in deciding the number of bore holes or trial pits. Dynamic or static cone penetration tests may be performed at every 100 metres by dividing the area into grid patterns and number of bore holes or trial pits decided by examining the variation in the penetration curves.

3. SUB-SURFACE SOUNDINGS

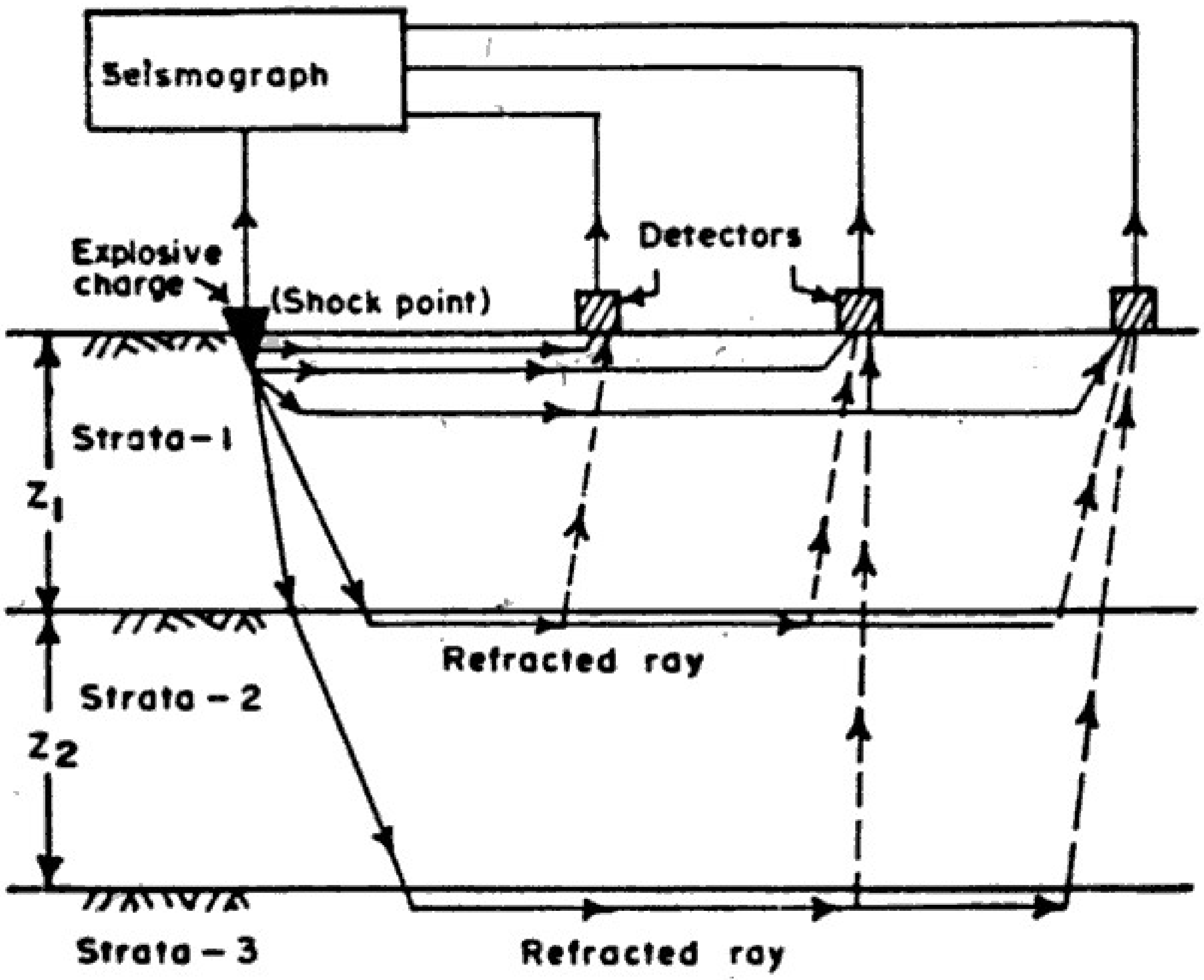


FIG. 2.16. SEISMIC REFRACTION METHOD.

greater density and thus higher velocities and also increasingly greater thickness. Different kinds of materials such as gravel, clay hardpan, or rock have characteristic seismic velocities and hence they may be identified by the distance-time graphs. The exact type of material cannot, however, be recognised and the exploration should be supplemented by boring or soundings and sampling.

Electrical Resistivity Method

The electrical resistivity method is based on the measurement and recording of changes in the *mean resistivity* of various soils.

Each soil has its own resistivity depending upon its water content, compaction and composition; for example, it is low for saturated silt and high for loose dry gravel or solid rock.

The test is conducted by driving four metal spikes to serve as electrodes into the ground along a straight line at equal distance. A direct voltage is imposed between the two outer electrodes, and the potential drop is measured between the inner electrodes. The mean resistivity Ω (ohm-cm) is computed from the expression

$$\Omega = 2\pi D \frac{E}{I} \quad ...(2.1)$$

where D = distance between the electrodes (cm)

E = potential drop between inner electrodes (volts)

I = current flowing between outer electrodes (amperes)

The depth of exploration is roughly proportional to the electrode

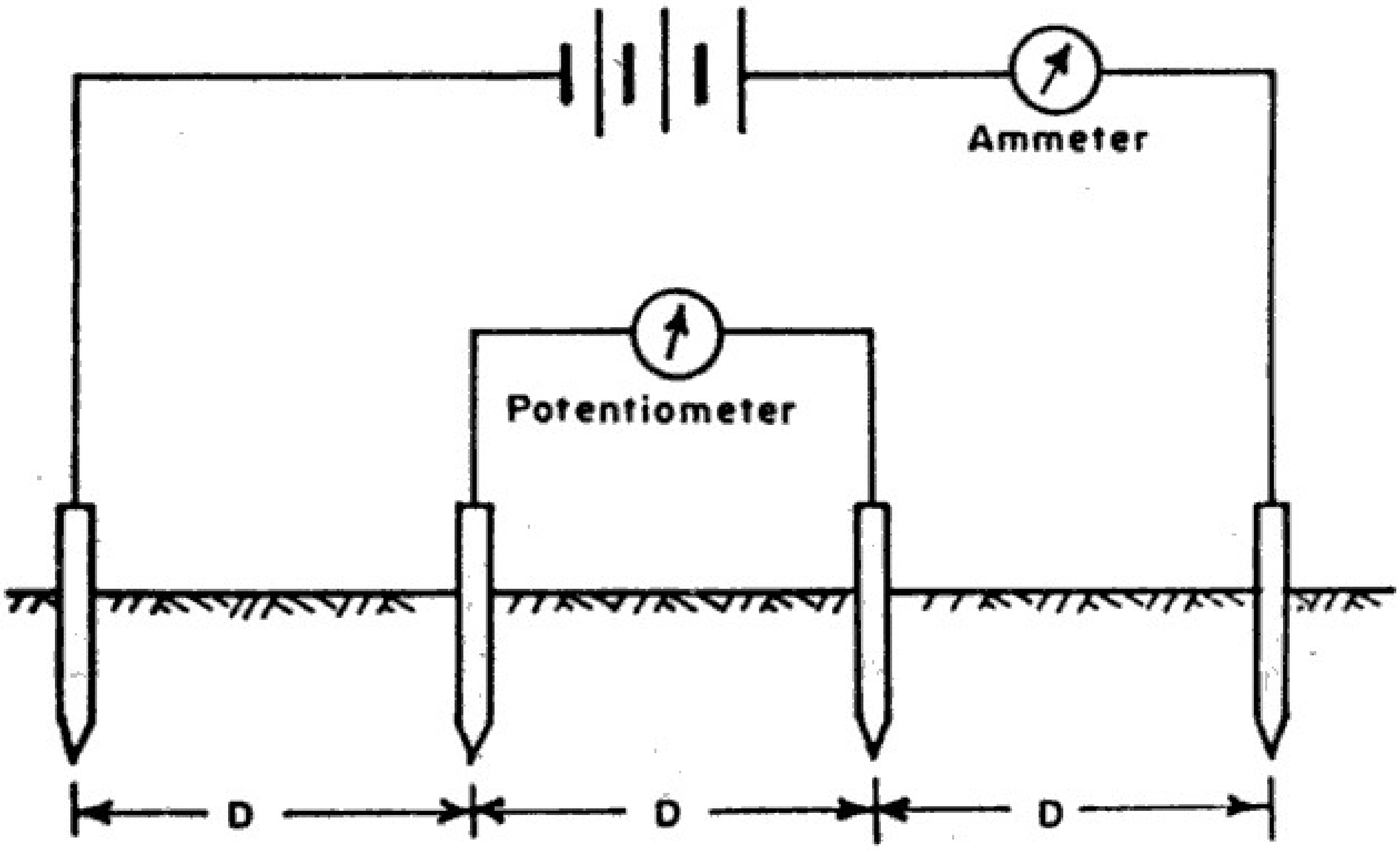


FIG. 2.17. RESISTIVITY METHOD.

spacing. For studying vertical changes in the strata, the electrode system is expanded, about a fixed central point, by increasing the spacing gradually from an initial small value to a distance roughly equal to the depth of exploration required. The method is known as *resistivity sounding.*

To correctly interpret the resistivity data for knowing the nature and distribution of soil formation, it is necessary to make preliminary trial or calibration tests on known formations.

CHOICE OF EXPLORATION METHOD

The choice of a particular exploration method depends on the following factors: (*a*) nature of ground (*b*) topography and (*c*) cost.

1. Nature of ground

In clayey soils, borings are suitable for deep exploration and pits for shallow exploration. In sandy soils, boring is easy but special equipment should be used for taking representative samples below the water table. Such samples can however, be readily taken in trial pits provided that, where necessary, some form of ground water lowering is used.

Borings are suitable in hard rocks while pits are preferred in soft rocks. Core borings are suitable for the identification of types of rock but they cannot supply data on joints and fissures which can only be examined in pits and large diameter borings.

When the depth of exploration is large, and where the area of construction site is large, geophysical methods (specially the electrical resistivity method) can be used with advantage. However, borings at one or two locations should be carried out, for calibration purposes. In soft soil, sounding method may also be used to cover large area in relatively shorter duration.

2. Topography

In hilly country, the choice between vertical openings (for example, boring sand trial pits) and horizontal openings (for example, headings) may depend on the geological structure, since steeply inclined strata are most effectively explored by headings and horizontal strata by trial pits or borings. Swamps and areas overlain by water are best explored by borings which may have to be put down from a floating craft.

3. Cost.

For deep exploration, borings are usual, as deep shafts are costly. However, if the area is vast, geophysical methods or sounding methods may be used in conjunction with borings. For shallow exploration in soil, the choice between pit and borings will depend on the nature of the ground and the information required for shallow exploration in rock; the cost of boring a core drill to the site will only be justified if several holes are required; otherwise trial pits will be more economical.

SOIL SAMPLES AND SAMPLERS

Soil samples can be of two types:

(*i*) Disturbed samples.

(*ii*) Undisturbed samples.

A *disturbed sample* is that in which the natural structure of soil gets partly or fully modified and destroyed although with suitable precautions the natural water content may be preserved. Such a soil sample should, however, be *representative* of the natural soil by maintaining the original proportion of the various particles intact. An *undisturbed sample* is that in which the natural structure and properties remain preserved.

The *sample disturbance* depends upon the design of the samplers and the method of sampling. To take undisturbed samples from bore holes properly designed sampling tools are required. The sampling tube when forced into the ground should cause as little remoulding and disturbance as possible. The design features of the sampler, that govern the degree of disturbance are (*i*) cutting edge (*ii*) inside wall friction and (*iii*) non-return valve.

Fig. 2.18 shows a typical cutting edge of a sampler, with the lower end of the sampler, with the lower end of the sampler tube. The following terms are defined with respect to the diameters marked in Fig. 2.18.

Area ratio

$$= \frac{D_2^2 - D_1^2}{D_1} \times 100$$

Inside clearance

$$= \frac{D_3 - D_1}{D_1} \times 100$$

Outside clearance

$$= \frac{D_2 - D_4}{D_4} \times 100$$

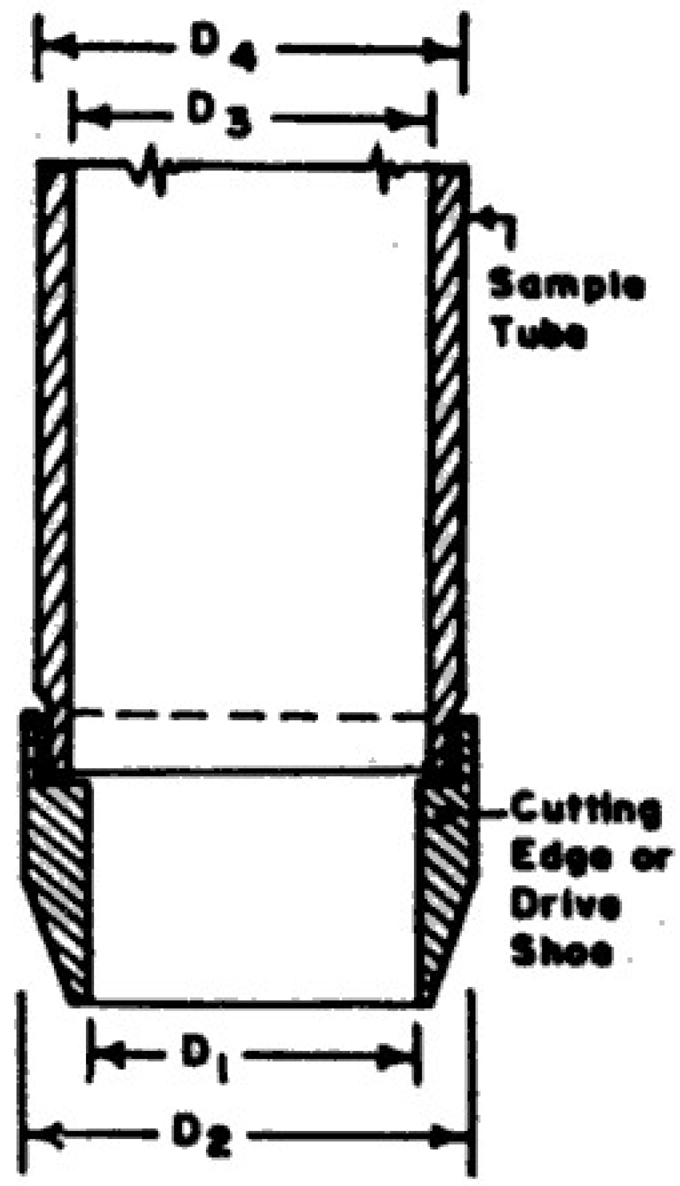


FIG. 2.18. LOWER END OF A SAMPLER.

The area ratio should be as low as possible. It should not be greater than 25 percent; for soft sensitive soil, it should preferably not exceed 10 percent. The inside clearance should lie between 1 to 3 percent and the outside clearance should not be much greater than the inside clearance. The walls of the sampler should be smooth and should be kept properly oiled so that *wall friction* is minimum. Lower value of inside clearance allows the elastic expansion of soil and reduces the frictional drag. The *non-return valve*, invariably provided in samplers, should permit easy and quick escape of water and air when driving the sampler.

Types of Samplers

The samplers are classified as *thick wall or thin wall* samplers depending upon the area ratio. Thick wall samplers are those having the area ratio greater than 10 percent. Depending upon the mode of operation, samplers may be classified in the following three common types : (*i*) open drive sampler (including split spoon samplers), (*ii*) stationary piston sampler and (*iii*) rotary sampler.

The *open drive sampler* is a tube open at its lower end. The sampler head is provided with vents (valve) to permit water and air to escape during driving. The check valve helps to retain sample when the sampler is lifted up. The tube may be seamless or it may be split in two parts; in the latter case it is known as *split spoon sampler*.

The *stationary piston sampler* consists of a sample cylinder and the piston system. During lowering of the sampler through the hole, the lower end of the sampler is kept closed with the piston. When the desired sampling elevation is reached, the piston rod is clamped, thereby keeping the piston stationary, and the sampler tube is advanced down into the soil. The sampler is then lifted up, with piston rod clamped in position. The sampler is more suitable for sampling soft soils saturated sands.

Rotary samplers are the core barrel type having an outer tube provided with cutting teeth and a removable thin wall liner inside. It is used for firm to hard cohesive soils and cemented soils.

2.7. BEARING CAPACITY OF SOILS

As stated earlier, a foundation should be designed to satisfy two essential conditions:

(*i*) It must have some specified safety against ultimate failure.

(*ii*) The settlements under working loads should not exceed the allowable limits for the super-structure.

The *bearing capacity* of the soil, used for the design of foundations (*i.e.* for determining the dimensions of the foundations) is determined on the basis of the above two criteria.

In general, the supporting power of a soil or rock is referred to as its *bearing capacity*. The term bearing capacity is defined after attaching certain qualifying prefixes, as defined below:

1. *Gross pressure intensity* (q). The gross pressure intensity q is the total pressure at the base of the footing due to the weight of the super-structure, self weight of the footing and the weight of the earth fill, if any.

2. *Net Pressure intensity* (q_n). It is defined as the excess pressure, or the difference in intensities of the gross pressure after the construction of the structure and the original overburden pressure. Thus, if D is the depth of the footing

$$q_n = q - \gamma D \qquad ...(2.2)$$

where γ is the unit weight of soil above the level of footing.

3. *Ultimate bearing capacity* (q_f) The ultimate bearing capacity is defined as the minimum gross pressure intensity at the base of the foundation at which the soil fails in shear.

4. *Net ultimate bearing capacity* (q_{nf}). It is the minimum net pressure intensity causing shear failure of the soil. The ultimate bearing capacity q_f and net ultimate bearing capacity (q_{nf}) are evidently connected by the relation

$$q_f = q_{nf} + \gamma D \qquad ...(2.3)$$

Terzaghi gave the following equations:

$$q_f = c\,.\,N_c + \gamma\, D\, N_q + 0.5\,\gamma\, B N_\gamma. \qquad ..(2.9)$$

or

$$q_s = \frac{1}{F}\,[c.N_c + \gamma\, D\,(N_q - 1\,) + 0.5\gamma B N_\gamma] + \gamma\, D. \qquad ..(2.10)$$

where N_c, N_q and N_γ are the dimensionless numbers, called the *bearing capacity factors*, the values of which can be obtained from Table 2.1. The above analysis corresponds to *general shear failure* in which the soil properties are such that a slight downward movement of footing develops fully plastic zones and the soil bulges out [Fig. 2.20 (*c*)]. In case of fairly soft or loose and compressible soil, large deformation may occur below the footing before the failure zones are fully developed. Such a failure is known as *local shear failure* [Fig. 2.20 (*d*)] which is associated with considerable vertical soil movement before soil bulging takes place. The bearing capacity factors corresponding to the local shear failure are indicated with dashes, *i.e.* N_c', N_q' and N_γ' (Table 2.1). Terzaghi gave the following equation for local shear failure :

$$q_f = \tfrac{2}{3}\, c\,.\,N_c' + \gamma\, D\, N'_q + 0.5\,\gamma\, B\, N'_\gamma \qquad ...(2.11)$$

or

$$q_s = \frac{1}{F}\,[\,\tfrac{2}{3}\, c\,.\,N_c' + \gamma D(N_q' - 1) + 0.5\,\gamma\, B N_\gamma'] + \gamma\, D \qquad ...(2.12)$$

TABLE 2.1 TERZAGHI'S BEARING CAPACITY FACTORS

ϕ	*General shear failure*			*Local shear failure*		
	N_c	N_q	N_γ	N_c'	N_q'	N_γ'
0	5.7	1.0	0.0	5.7	1.0	0.0
5	7.3	1.6	0.5	6.7	1.4	0.2
10	9.6	2.7	1.2	8.0	1.9	0.5
15	12.9	4.4	2.5	9.7	2.7	0.9
20	17.7	7.4	5.0	11.8	3.9	1.7
25	25.1	12.7	9.7	14.8	5.6	3.2
30	37.2	22.5	19.7	19.0	8.3	5.7
34	52.6	36.5	35.0	23.7	11.7	9.0
35	57.8	41.4	42.4	25.2	12.6	10.1
40	95.7	81.3	100.4	34.9	20.5	18.8
45	172.3	173.3	297.5	51.2	35.1	37.7
48	258.3	287.9	780.1	66.8	50.5	60.4
50	347.5	415.1	1153.2	81.3	65.6	87.1

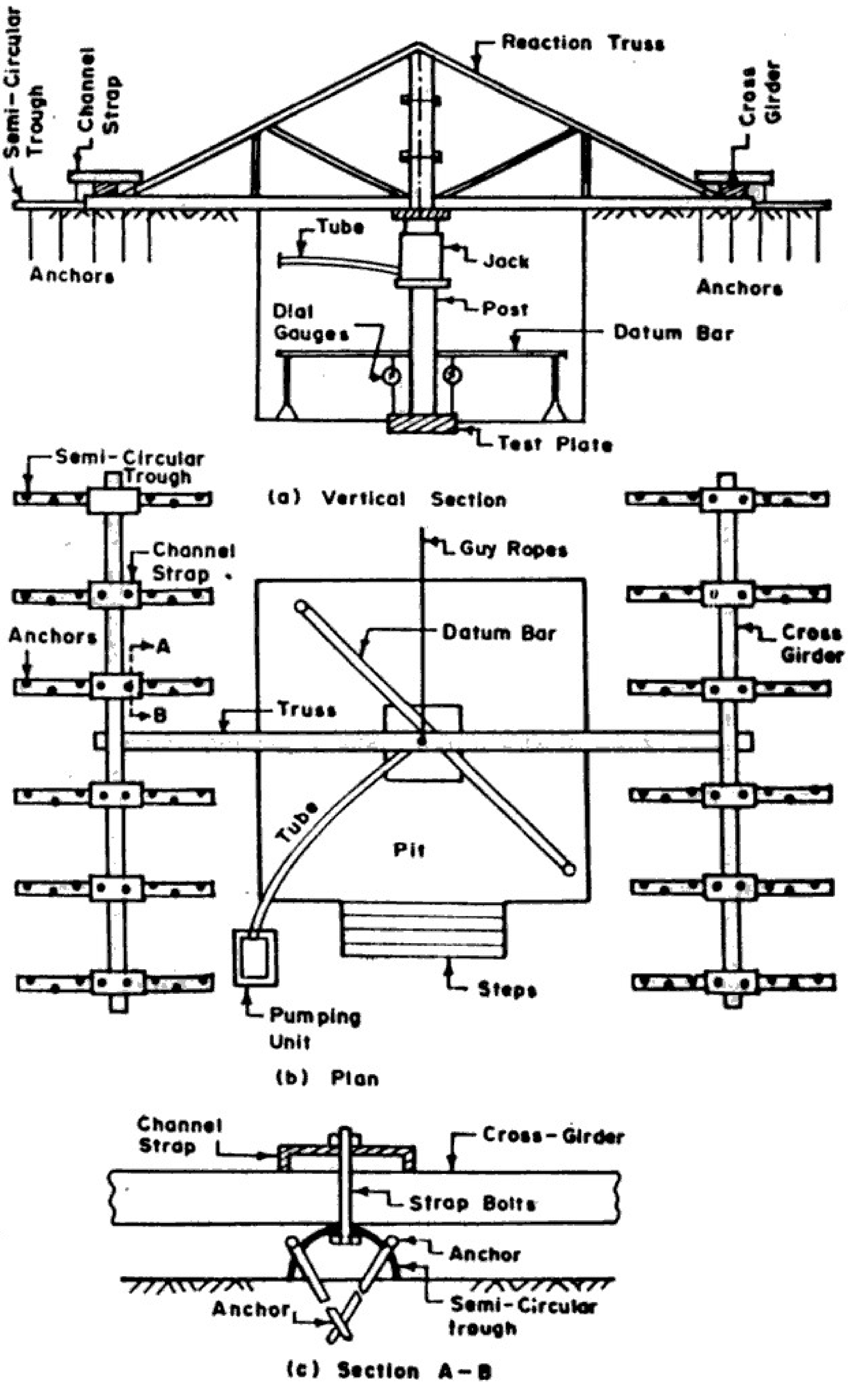


FIG. 2.23. PLATE LOAD TEST : REACTION BY TRUSS.

should be taken as 0.5

$$R_d = \text{depth factor} = \left(1 + \frac{0.2\,D}{B}\right) \leq 1.20$$

The standard penetration test is very useful for the design of rafts. The safe bearing value for rafts may be taken as *smaller* of the values of q_1 and q_2 given below:

$$q_1 = 21.4\,N^2B\;R_{w1} + 64(100 + N^2)\,DR_{w2} \quad \text{...(2.17)}$$

and

$$q_2 = 1950\;(N - 3)\;R_{w2} \quad \text{...(2.18)}$$

where q_1 and q_2 = allowable soil pressure under raft foundation, in kg/m^2 (using a factor of safety of three)

R_{w1} = water reduction factor

$$= 0.5\left(1 + \frac{Z_{w1}}{D}\right) \leq 1$$

Z_{w1} =depth of water table below ground surface. If the water table is at ground level, $R = 0.5$.

Dutch cone test

This test is used for getting a continuous record of the resistance of soil by penetrating steadily under static pressure a cone with a base of $10\,cm^2$ (3.6 cm in dia.) and an angle of 60° at vertex. The cone is carried at the lower end of a steel driving rod which passes through a steel tube (mantle) with external diameter equal to the base of the cone. Either the cone or the tube, or both together can be forced into the soil by means of jack. To know the cone resistance, the cone along is first forced down for a distance of 8 cm and the maximum value of resistance is recorded. The steel tube is then pushed down upto the cone, and both together are further penetrated through a depth of 20 cm to give the total of cone resistance and the frictional resistance along the tube.

The cone test is considered very useful in determining the bearing capacity of pits in cohesionless soils, particularly in fine sands of varying density. The cone resistance q_c (kg/cm^2)is approximately equal to 5 to 10 times the penetration resistance N.

2.11. PRESUMPTIVE BEARING CAPACITY VALUES FROM CODES

For the design of foundations of lightly loaded structures and for a preliminary design of any structure the presumptive safe bearing capacity may be used. The presumptive safe bearing capacities of various types of soils are given in Table 2.2.

2. *Inelastic (or plastic) compression* of the underlying soils, which is much larger than the elastic compression. The inelastic compression can be predicted by the theory of consolidation.

3. *Ground water lowering.* Repeated lowering and raising of water level in loose granular soil tends to compact the soil and cause settlement of the ground surface. Lowering of water level in fine grained soils cause consolidation settlement. The major settlements in the city of Maxico has been due to ground water lowering, and due to this, the city has been called as the 'sinking city of Maxico'.

4. *Vibrations* due to pile driving, blasting and oscillating machineries may cause settlement in deposits of granular soils.

5. *Seasonal swelling and shrinkage* of expansive clays.

6. *Ground movement on earth slopes,* such as surface erosion, slow creep or landslide.

7. *Other causes* such as adjacent excavation, mining subsidence, underground erosion, etc.

A certain amount of elastic and inelastic settlement of foundations is unavoidable, and it should be taken into account in design. Provided the settlement is uniform over the whole area of the building and is not excessive, it does little damage. If, however, the amount of settlement varies at different points under the building, giving rise to what is known as relative or differential settlement, stresses will be set up in the structure. These may be relived in the case of brick structure, for example, by the setting up of a large number of cracks at the joints, but in more rigid structures, overstressing of some structural members might occur.

It is suggested that the allowable pressure should be selected such that the maximum settlement of any individual foundation is 2.5 cm. It has also been suggested that the *differential settlement* of uniformly loaded continuous foundation and of equally loaded spread foundations of approximately the same size, is unlikely to exceed half the maximum settlement, and that normal structures such as office buildings and flats can satisfactorily withstand differential settlements of about 18 mm between adjacent columns spaced 6 to 8 m apart.

According to National Building Code of India (SP: 7-1983), the differential settlement shall be kept within limits to which the super-structure can accommodate itself without harmful distortion, by suitably designing the foundation. Total settlements shall be so restricted or special arrangements made so that connections to the building, such as drains, are not damaged. For simple spread footings on sands, the allowable bearing pressure should be such that the differential settlement does not exceed 1/300; this condition is generally satisfied if the total settlement is limited to 50 mm. For simple spread footings on clayey soils, the allowable bearing pressure should be such that the differential settlement does not exceed 1/300 ; this condition is generally satisfied if the total settlement is limited to 75 mm.

The recommendations of American Codes are based upon the simple logic that if the maximum total settlement is kept within a reasonable limit, the differential settlement will be only a fraction (generally about three-quarters of this limit), depending upon the type of structure and pattern of loading. The allowable maximum settlement values are given below:

Type of structure	*Allowable Maximum Settlement (mm)*
Commercial and institutional buildings	25
Industrial buildings	38
Warehouses	50
Special machinery foundations	Often less than 0.5 mm

According to Polshin and Tokar(1957), brick masonry will crack(due to differential settlement) when the unit elongation amounts to 0.0005. Based on this criterion, the *permissible differential settlement* of brick walls is shown in Fig. 2.25, and is as follows

For $\frac{L}{H} \leq 2$,

Rate of differential settlement $= 0.0003$ cm/cm

For $\frac{L}{H} = 8$, Rate of differential setlement $= 0.0010$ cm/cm

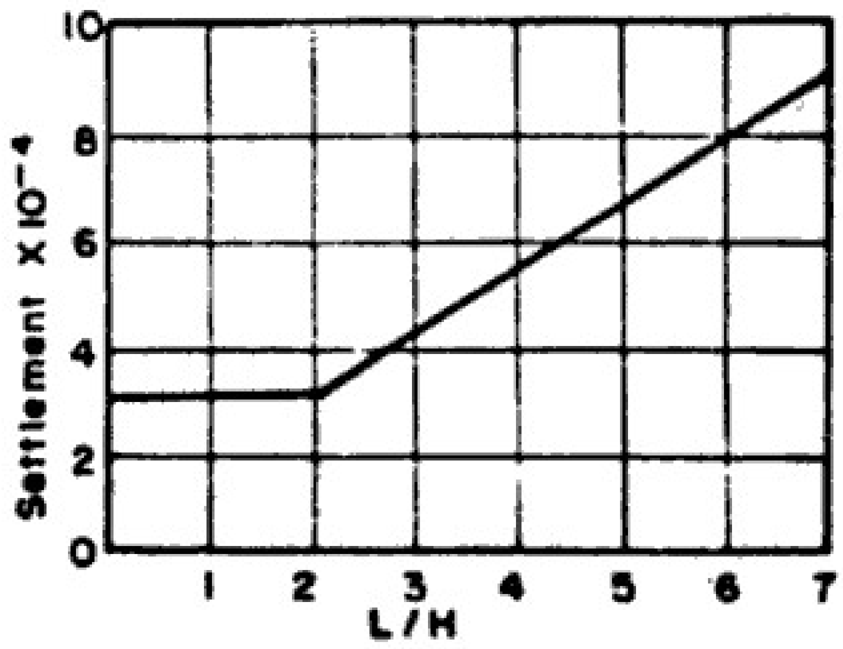


FIG. 2.25. PERMISSIBLE DIFFERENTIAL SETTLEMENT OF BRICK-WALLS.

where L is the wall length and H is the height of wall measured above the base of footing. The rate of differential settlement is defined as the slope or the relative settlement between two points divided by the horizontal distance.

2.13. METHODS OF IMPROVING SAFE BEARING PRESSURE OF SOILS

Sometimes, the safe bearing pressure of soil is so low that the dimensions of the footings work out to be very large and uneconomical. In such a circumstance, it becomes essential to improve the safe bearing pressure, which can be done by the following methods : (*i*) increasing depth of foundation (*ii*) compacting the soil (*iii*) draining the soil (*iv*) confining the soil (*v*) grouting and (*vi*) chemical treatment.

1. Increasing depth of foundation. It has been found that in granular soil, the bearing capacity increases with the depth due to the confining weight of overlying material. However, this is not economical since the cost of construction increases with the depth. Also, the load on the foundation also increases with the increase in the depth. The method is useful only when better bearing stratum is encountered at greater depth.

2. Compaction of soil. It has found that compaction of *natural* soil deposits (loose) or man-made fills results in the improvement of bearing capacity and reduction in the resulting settlements. Compaction of soil can be effectively achieved by the following means:

(*a*) *Ramming moist soil.* The foundation soil is moistened and then compacted with the help of hand rammers or mechanically operated frog rammers or vibratory rollers. The voids of the soil are very much reduced, resulting in the reduction in settlements.

(*b*) *Rubble Compaction into the soil.* A layer of 30 to 45 cm thick well-graded rubble is spread over the foundation level (Fig. 2.26) and well-rammed. If this layer of rubble gets buried in the soil (specially when it is very loose) another layer of 15 cm thick rubble is spread and well rammed manually. This results in an increase in the bearing value of the soil

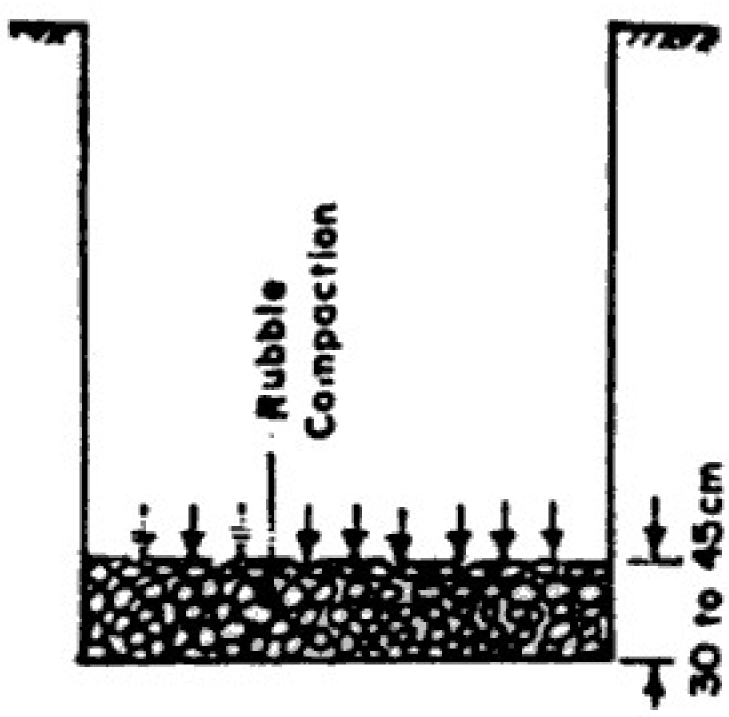


FIG. 2.26. RUBBLE COMPACTION INTO THE SOIL.

(*c*) *Flooding the soil.* The bearing pressure of very loose sands can be increased by flooding the soil. The method is very effective in improving the safe bearing pressure of dune sands, which cannot otherwise be effectively compacted. The Author has an experience of improving the bearing power of desert soils by this method at many locations where it was required to support heavy loads.

(*d*) *Vibration.* Heavy vibratory rollers and compactors may compact a layer of granular soils to a depth of 1 to 3 m. If the method of flooding and then vibration is used, sandy soil can be very effectively compacted, resulting in increased safe bearing power and decreased settlements when super-structure loads come on the soil. After flooding the soil, so that moisture penetration is at least 1 to 2 m, form vibrators or platform vibrators (about 1 m×1.5 m base area, with a pair of eccentrically loaded motors) can be slided on the sand surface with the help of two labourers. A large area can be covered by this process, without the help of sophisticated vibrating equipment.

(*e*)*Vibroflotation.* It is a commercial method which combine the effect of vibration and jetting. A heavy cylinder, known a vibroflot is inserted in the ground (soil) while the cylinder vibrates due to a rotary eccentric weight. A water jet on the tip of the vibro flot supplies a large amount of water under pressure. As the vibro flot sinks, clean sand is added into a crater that develops on the surface. The method is very useful when foundation is required to support heavy loads spread over a greater area.

(*f*) *Compaction by pre-loading.* This method is useful when the footing is founded on clayey soils which result in long term settlements. Pre-loading results in accelerated consolidation, so that settlements are achieved well before the actual footing is laid. The load used for this process is removed before the construction of the footing.

(*g*) *Using sand piles.* This method is very useful in sandy soils or soft soils. Hollow pipes are driven in the ground, at close interval. This results in the compaction of soil enclosed between the adjacent pipes. These pipes are then gradually removed, filling and ramming sand in the hole, resulting in the formation of *sand piles.*

3. Drainage of soil. It is a well known fact that presence of water decreases the bearing power of soil, specially when it is saturated. This is because of low shearing strength of soil in presence of excess water. Drainage results in decrease in the voids ratio, and improvement of bearing power.

4. Confining the soil. Sometimes the safe bearing pressure of the soil is low because of settlements resulting due to the lateral movement of loose granular soil. Such a tendency of lateral movement can be checked by confining the soil, outside the perimeter of foundation area, by driving sheet piles, thus forming an enclosure and confining the soil.

5. Grouting. This method is useful in loose gravels and fissured rocky strata. Bores holes in sufficient numbers are driven in the ground and cement grout is forced through these under pressure. The cracks, voids and fissures of the strata are thus filled with the grout, resulting in the increase in the bearing value.

6. Chemical treatment. In this method, certain chemicals are grouted in the place of cement grout. The chemical should be such that it can solidify and gain early strength.

2.14. CAUSES OF FAILURES OF FOUNDATIONS AND REMEDIAL MEASURES

The foundations may fail due to the following reasons:

1. Unequal settlement of sub-soil. Unequal settlement of the sub-soil may lead to cracks in the structural components and rotation thereof. Unequal settlement of sub-soil may be due to (*i*) non-uniform nature of sub-soil throughout the foundation, (*ii*) unequal load distribution of the soil strata, and (*iii*) eccentric loading. The failures of foundation due to unequal settlement can be checked by : (*i*) resting the foundation on rigid strata, such as rock or hard moorum, (*ii*) proper design of the base of footing, so that it can resist cracking, (*iii*) limiting the pressure in the soil, and (*iv*)avoiding eccentric loading.

2. Unequal settlement of masonry. As stated earlier, foundation includes the portion of the structure which is below ground level. This portion of masonry, situated between the ground level and concrete footing(base) has mortar joints which may either shrink or compress, leading to unequal settlement of masonry. Due to this, the superstructure will also have cracks. This could be checked by (*i*) using mortar of proper strength, (*ii*) using thin mortar joints, (*iii*) restricting the height of masonry to 1 m per day if lime mortar is used and 1.5 m per day if cement mortar is used, and (*iv*) properly watering the masonry.

3. Sub-soil moisture movement. This is one of the major causes of failures of footings on cohesive soil, where the sub-soil water level fluctuates. When water table drops down, shrinkage of sub-soil takes place. Due to this, there is lack of sub-soil support to the footings which crack, resulting in the cracks in the building. During upward movement of moisture, the soil (specially if it is expansive) swells resulting in high swelling pressure. If the foundation and superstructure is unable to resist the swelling pressure, cracks are induced. For such a situation, special precautionary measures are taken, as discussed in chapter 3.

4. Lateral pressure on the walls. The walls transmitting the load to the foundation may be subjected to lateral pressure or thrust from a pitched roof or an arch or wind action. Due to this, the foundation will be subjected to a moment (or resultant eccentric load). If the foundation has not been designed for such a situation, it may fail by either overturning or by generation of tensile stresses on one side and high compressive stresses on the other side of the footing.

5. Lateral Movement of sub-soil This is applicable to very soft soil which are liable to move out or squeeze out laterally under vertical loads, specially at locations where the ground is sloping. Such a situation may also arise in granular soils where a big pit is excavated in the near vicinity of the foundation. Due to such movement, excessive settlements take place, or the structure may even collapse. If such a situation exists, sheet piles should be driven to prevent the lateral movement or escape of the soil.

6. Weathering of sub-soil due to trees and shrubs. Sometimes, small trees, shrubs or hedge is grown very near to the wall. The roots of these shrubs absorb moisture from the foundation soil, resulting in reduction of their voids and even weathering. Due to this the ground near the wall depresses down. If the roots penetrates below the level of footing, settlements may increase, resulting in foundation cracks.

7. Atmospheric action. The behaviour of foundation may be adversely affected due to atmospheric agents such as sun, wind, and rains. If the depth of foundation is shallow, moisture movements due to rains or drought may cause trouble. If the building lies in a low lying area, foundation may even be scoured. If the water remains stagnant near the foundation, it will remain constantly damp, resulting in the decrease in the strength of footing or foundation wall. Hence it is always recommended to provide suitable plinth protection along the external walls by (*i*) filling back the foundation trenches with good soil and compacting it, (*ii*) providing gentle ground slope away from the wall and (*iii*) providing a narrow, sloping strip of impervious material (such as of lime or lean cement concrete) along the exterior walls.

2.15. SETTING OUT FOUNDATION TRENCHES

Setting out or ground tracing is the process of laying down the excavation lines and centre lines etc. on the ground, before excavation is started. After the foundation design is done, a *setting out plan*, sometimes also known as *foundation layout plan*, is prepared to some suitable scale (usually 1:50). The plan is fully dimensioned.

For setting out the foundations of small buildings, the centre line of the longest outer wall of the building is first marked on

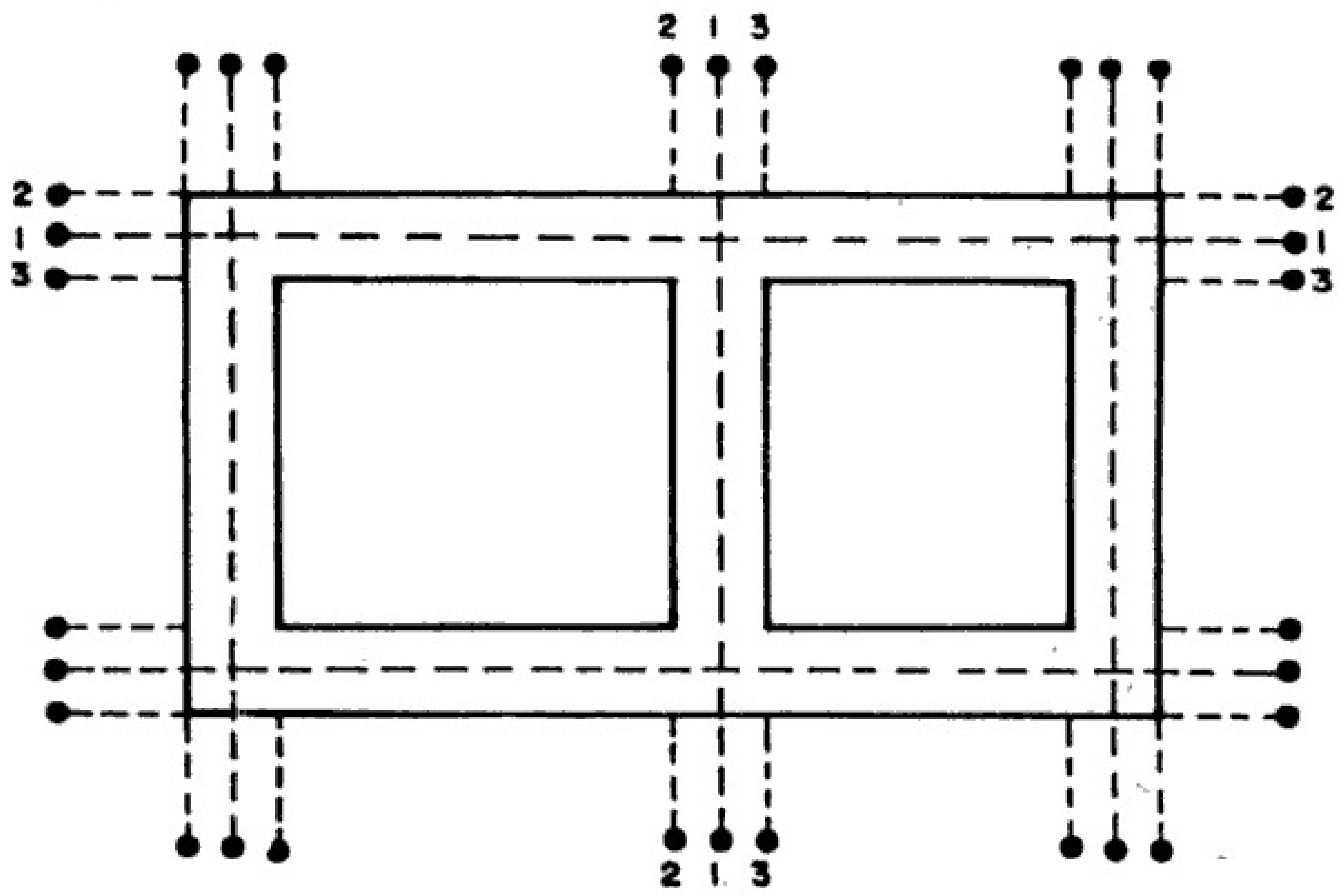


FIG. 2.27. SETTING OUT WITH THE HELP OF PEGS.

2.16. EXCAVATION AND TIMBERING OF FOUNDATION TRENCHES

Excavation of foundation trenches can be done either manually with the help of conventional implements, shown in Fig. 2.29, or with the help of special mechanical equipment. Fig 2.30 (*a*) shows a

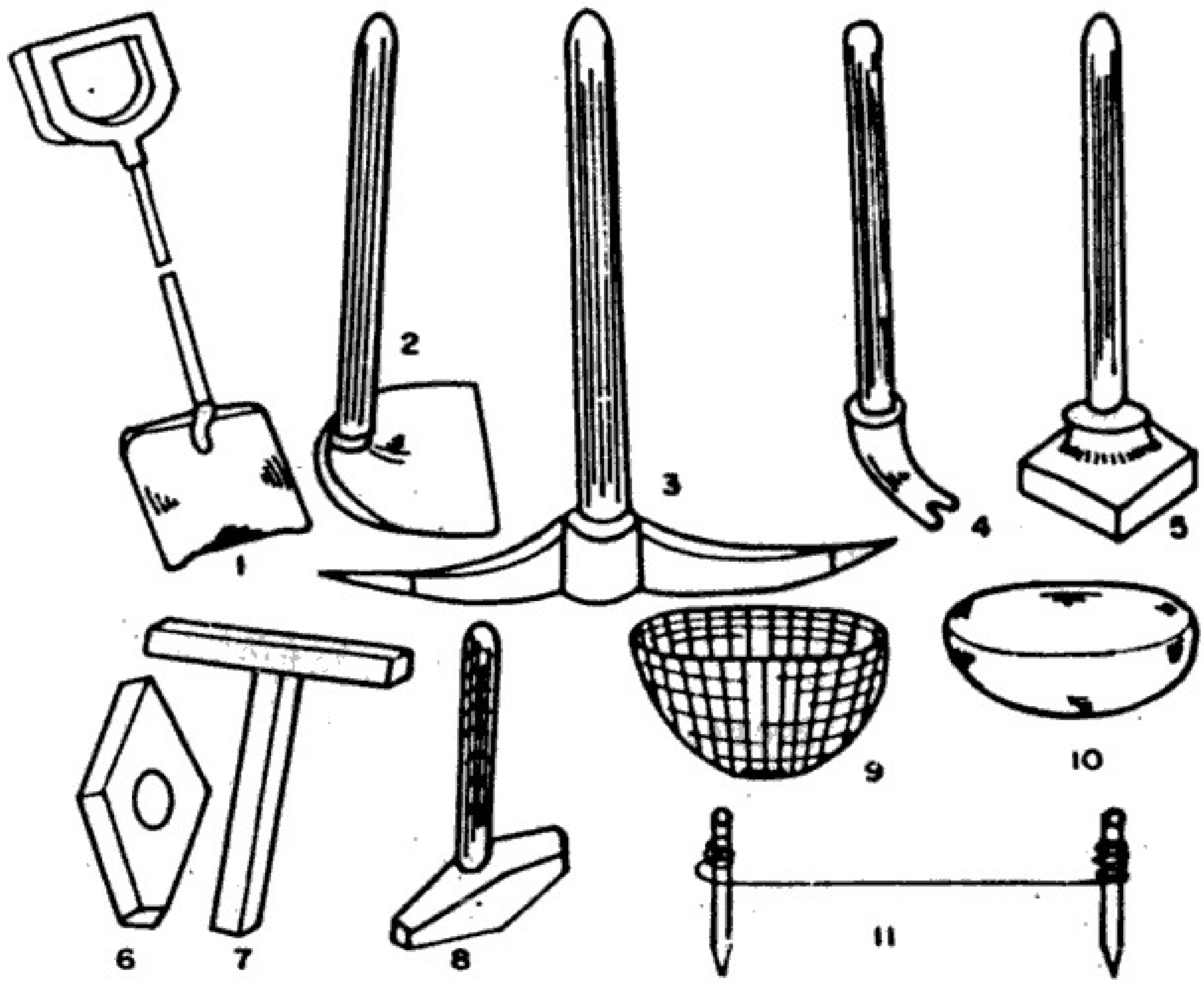


FIG. 2.29. IMPLEMENTS FOR FOUNDATION EXCAVATION.

1. Spade	2. Kassi or phawrah
3. Pick axe	4. Crow bar
5. Rammer	6. Wedge
7. Boning rod	8. Sledge hammer
9. Basket	10. Iron pan
11. Line and pins.	

drag shovel which can excavate the foundation trench upto a width of 1.7 m. Fig. 2.30 (*b*) shows a multi-bucket *trencher or* a *itcher,* which can excavate treches upto 1.5 m width and 5 m deep. The boom is raised and lowered as required by the driver moving a lever and can be locked in any position. The spoil is carried up from the trench by buckets (having cutting teeth) attached to a continuous steel chain and tipped on to a belt conveyor at the top the rise, from where it is deposited to either left or right hand side of the trench.

the ground by stretching a string between wooden or mild steel pegs driven at the ends. This line serves as reference line. For accurate work, nails can be fixed at the centre of the pegs. Two pegs, one on either side of the central peg, are driven at each end of the line. Each peg is equidistant from the central peg, and the distance between the outer pegs corresponds to the width of foundation trench to be excavated. Each peg may project about 25 to 50 mm above ground level and may be driven at a distance of about 2 m from the edge of excavation so that they are not disturbed.

When string is stretched joining the corresponding pegs (say 2-2) at the two extremities of the line, the boundary of the trench to be excavated can be marked on the ground with dry lime powder. The centre lines of other walls, which are perpendicular to the long wall, are then marked by setting out right angles. A right angle can be set out by forming a triangle with 3, 4 and 5 units long. These dimensions should be measured with the help of a steel tape. Alternatively, a theodolite or prismatic compass may be used for setting out right angles. Similarly, outer lines of the foundation trench of each cross-wall can be set out, as shown in Fig. 2.27.

For a big project, reference pillars of masonry may be constructed as shown in Fig. 2.28. These pillars may be about 20 cm thick, and about 15 cm wider than the width of the foundation trench. The top of the pillars is plastered, and is set at the same level, preferably at the plinth level. Pegs are embedded in these pillars and nails are then driven in the pegs to represent the centre line and the outer lines of the trench. Sometimes, additional walls are provided to represent plinth lines.

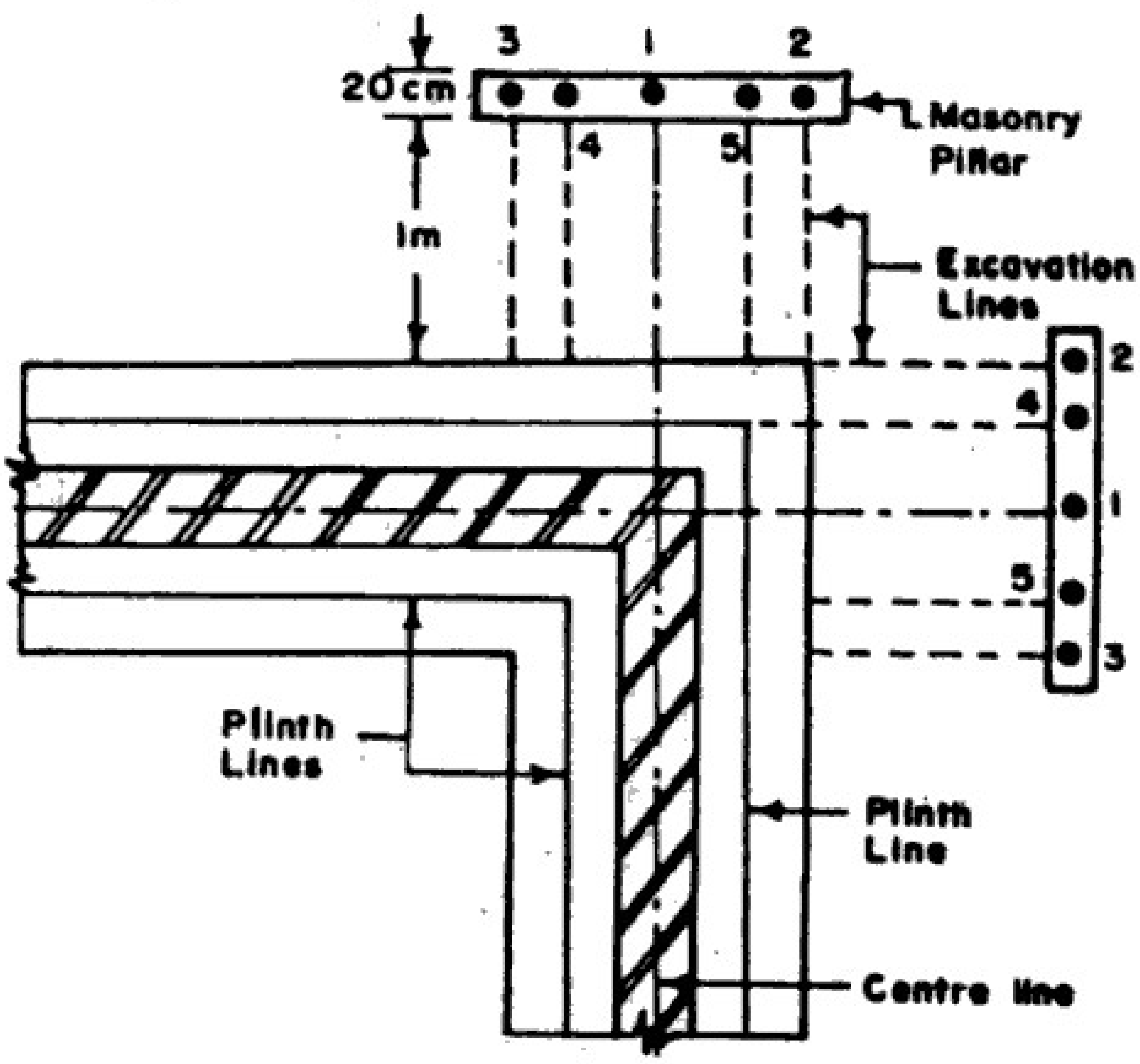


FIG. 2.28. SETTINGS OUT USING MASONRY PILLARS.

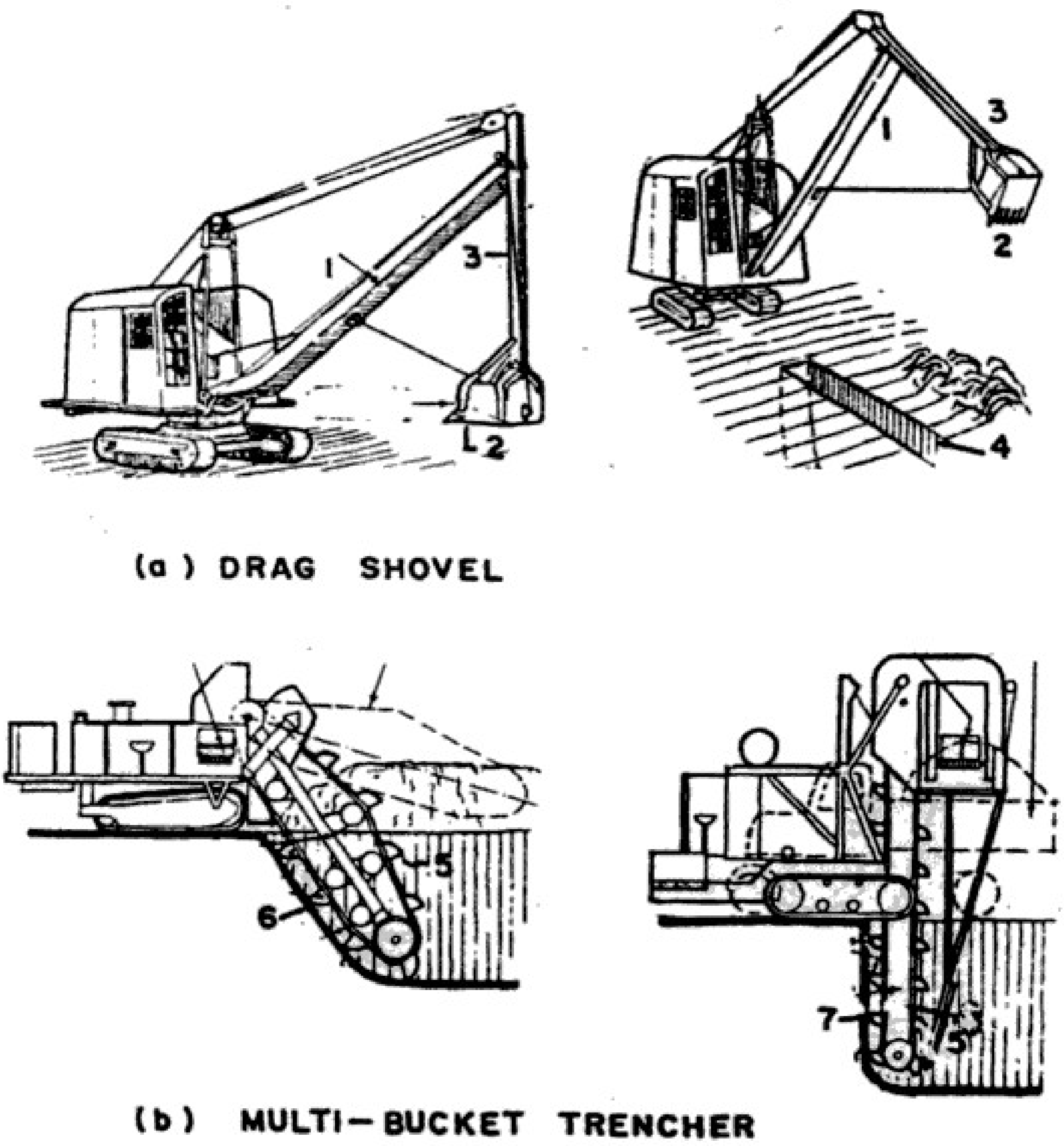


FIG. 2.30. EXCAVATING EQUIPMENT.

1. Boom
2. Bucket
3. Dipper handle
4. Trench
5. Chain mounted buckets
6. Raking cut
7. Vertical cut.

TIMBERING OF TRENCHES

When the depth of trench is large, or when the sub-soil is loose, the sides of the trench may cave in. The problem can be solved by adopting a suitable method of *timbering*. Timbering of trenches, sometimes also known as *shoring* consists of providing timber planks or boards and struts to give temporary support to the sides of the trench. Timbering of deep trenches can be done with the help of the following methods:

1. Stay bracing.
2. Box sheeting
3. Vertical sheeting
4. Runner system
5. Sheet piling.

1. Stay bracing. This method (Fig. 2.31) is used for supporting the sides or a bench excavated in fairly firm soil, when the depth progresses. The system is similar to vertical sheeting of box system, except that in the place of vertical sheeting, runners, made of long thick wooden sheets or planks with iron shoe at the ends, are provided. Wales and struts are provided as usual (Fig. 2.34). These runners are driven about 30 cm in advance of the progress of the work, by hammering.

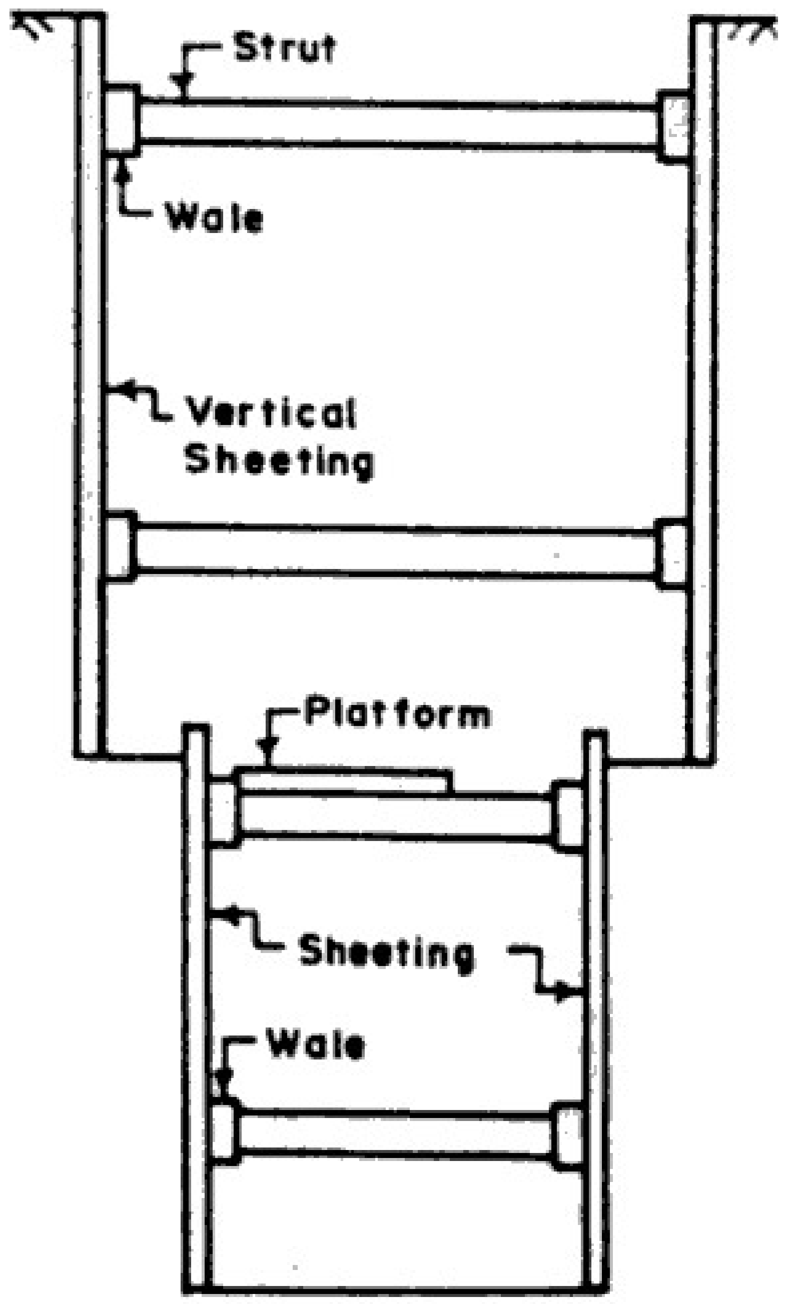


FIG 2.33. VERTICAL SHEETING.

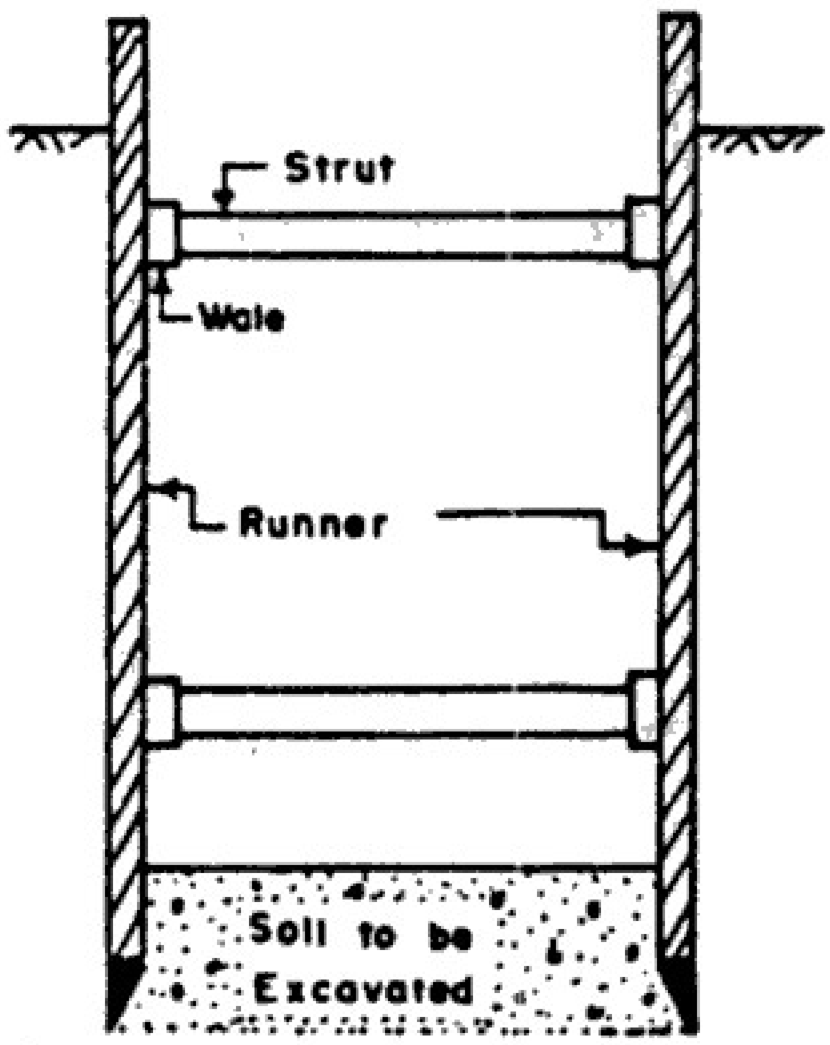


FIG. 2.34. RUNNER SYSTEM.

5. Sheet piling. This method is adopted when (*i*) soil to be excavated is soft or loose (*ii*) depth of excavation is large (*iii*) width of trench is also large and (*iv*) there is sub-soil water. Sheet piles are designed to resist lateral earth pressure. These are driven in the ground by mechanical means (pile driving equipment). They can be used for excavating to a very large depth.

2.17. EXCAVATIONS IN GROUND WITH SUB-SOIL WATER

Excavations of foundation trenches in ground having high water table, or in water-logged area pose great problems because of water oozing in the trench from sides, bringing with it the soil from the sides. The timbering, if provided, would become loose and collapse. Excavations can be carried out by dewatering the sub-soil water. Foundation dewatering can be done by the following methods:

(*i*) Ditches and sumps

(*ii*) Well point system

3. Shallow well system

In this system, a hole of 30 cm in diameter or more is bored into the ground to a depth not exceeding 10 m below the axis of the pump. A strainer tube of 15 cm diameter is lowered in the bore hole having a casing tube. A gravel filter is formed around the strainer tube by gradually removing the casing tube and simultaneously pouring filter material, such as gravel etc. in the annular space. A suction pipe is lowered into the filter well so formed. The suction pipes from a number of such wells may be connected to one common header leading to the pumping unit.

4. Deep well system

When the depth of excavation is more than 16 m below the water table, deep well drainage system may be used with advantage. The system is also useful where artesian water is present. A 15 to 60 cm diameter hole is bored and a casing with a long screen (5 to 25 cm) is provided. A submersible pump with a capacity to

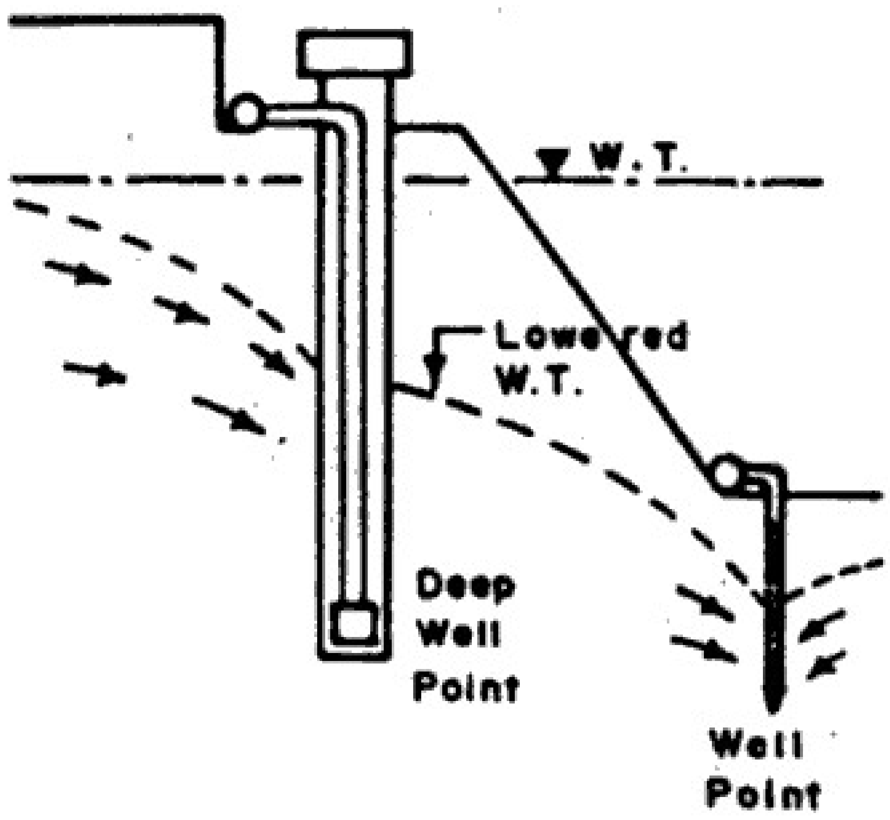


FIG. 2.39. DEEP WELL SYSTEM.

push the water upto a height of 30 m or more is installed near the bottom to the well. Each well has its own pump. Along with the deep wells arranged on the outer side of the area under excavation, a row of well points is frequently installed at the toe of the side slopes of the deep excavation.

5. Vacuum method : Forced flow

The above methods are effective only in coarse grained soils. For fine grained soils, the well point system can be extended by the vacuum method. For successful dewatering in the fine, non-cohesive soils, such as silty sands and other fine sands, it is necessary to apply a suction head to the dewatering system. Both the well point system and deep well system can be adopted for dewatering such

3

Foundation -2 : Shallow Foundations

3.1. INTRODUCTION

Foundations may be broadly classified under two heads:

(*a*) Shallow foundations

(*b*) Deep foundations

According to Terzaghi, a foundation is *shallow* if its depth is equal to or less than its width. A shallow foundation is also known as an *open foundation*, since such foundation is constructed by open excavation. Hence those foundations, which have depth even greater than its width, but are constructed by way of open excavation also come under *'shallow foundations'*. A shallow foundation is placed immediately below the lowest part of the super-structure supported by it.

The term *footing* is commonly used in conjunction with shallow foundations. A *footing* is a *foundation unit* constructed in brick work, masonry or concrete under the base of a wall or column for the purpose of distributing the load over a large area.

From the point of view of design, *footings* are classified into four types:

1. Spread footing
2. Combined footing
3. Strap footing

and 4. Mat or raft foundation.

A *Spread footing* is the one which supports either one wall or one column. A spread footing may be of the following types:

1. *Strip footing.* It is the spread footing for wall.

2. *Pad footing.* It is the isolated footing for a column.

When a spread footing supports the load of more than one column or wall, it is called a *combined footing* or *strap footing*. A such as the one shown in Fig. 3.2 (*a*) is provided. The wall directly rests on the concrete base, and no masonry offsets are provided since spread is not required. However, the concrete base should project out by value a on either side of the wall face, where the value of offset a may vary from 10 to 20 cm. As a thumb rule, the width of concrete base should not be less than twice the width of the wall. The thickness of concrete block should at least be equal to offset a in the case of cement concrete and $\frac{3}{2}a$ in the case of lime concrete base.

National Building Code of India recommends that the angle of spread of the load from the wall base to the outer edge of the ground bearing shall not exceed $n_1 : 1$ (n_1 horizontal and 1 vertical), where $n_1 = 2/3$ for lime concrete and $n_1 = 1$ for cement concrete.

(*b*) **Stepped Footing.**

When the wall carries heavy loads, or when the safe bearing pressure of the soil is not very high, the base width required from Eq 3.2 will be much greater than $(T + 2a)$. In that case, it is essential to provide masonry offsets, to achieve larger spread, before the load is transferred to concrete base. The height and width of each offset should be so proportioned that rate of spread does not *exceed* the permissible value for the masonry Fig. 3.2(*b*) shows such a stepped footing in which the rate of spread through masonry is $n : 1$ and that through concrete base is $n_1 : 1$. As per National Building Code, the angle of spread of the load from the wall base to the outer edge of the ground bearing shall not exceed the following values:

(*i*) In brickwork and stone masonry : $\frac{1}{2}$ horizontal to 1 vertical

(*ii*) In lime concrete : $\frac{2}{3}$ horizontal to 1 vertical

(*iii*) In cement concrete : 1 horizontal to 1 vertical

Thus, $n = \frac{1}{2}$ and $n_1 = \frac{2}{3}$ (for lime concrete) and $n_1 = 1$ (for cement concrete)

The implication of the above recommendations is that in order to spread the bearing width from original T (width of wall) to B (footing width), the *minimum depth* required would workout as follows:

$$n : 1 :: \frac{B - T}{2} : D_{min}$$

or

$$D_{min} = \frac{1}{2n}(B - T) \qquad ...(3.3)$$

(Assuming uniform rate of spread)

If different rates of spread are taken, and if d is the thickness of concrete block (see Eq. 3.4), we have

$$(B - T) = 2\,[n(D_{min} - d) + n_1 d]$$

masonry offsets, to achieve larger spread, before the load is transferred to the concrete base. The height and width of each offset shold be so proportioned that rate of spread does not exceed the permissible value for the masonry. Fig. 3.5 shows the stepped footing, in which the rate of spread is $n:1$ for masonry and $n_1:1$ for concrete, where $n=\frac{1}{2}$ for masonry, and $n_1 = 2/3$ for lime concrete and 1 for cement concrete.

In the case of brick pillar, the offsets should not exceed 5 cm. In the case of masonry pillar, the offset may vary between 10 to 15 cm corresponding to the step height of 15 to 22.5 cm respectively.

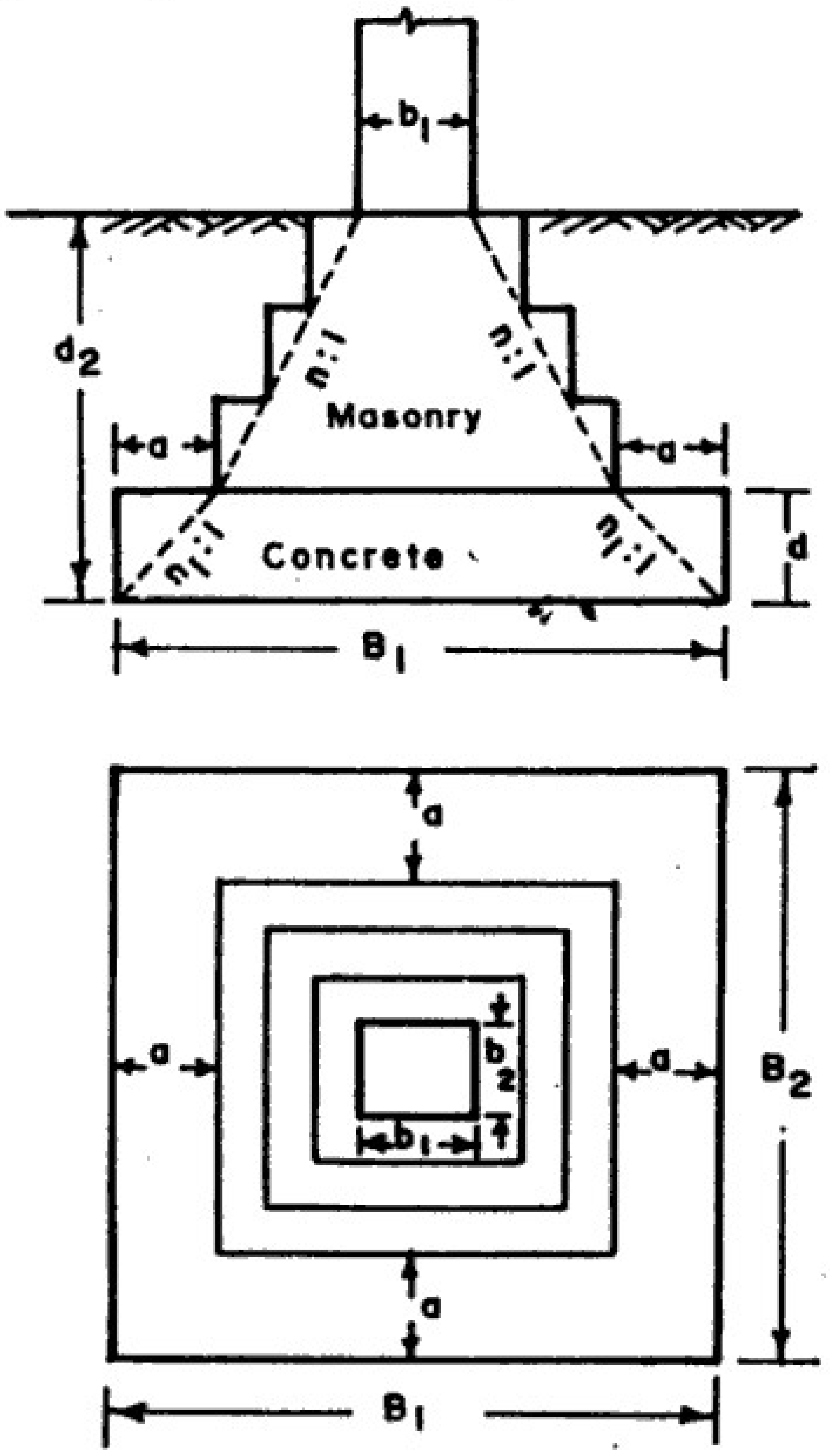


FIG. 3.5. STEPPED PAD FOOTING.

The depth of concrete block is given by

$$d = a\sqrt{\frac{3q}{m}} \qquad \text{...(3.6)}$$

where q and m are in the same units (*i.e.* in kg/m^2 or t/m^2 or kN/m^2), and d and a are in the same units (*i.e.* in cm or m or mm).

γ = unit weight of soil = 1700 kg/m^3 = 1.7 t/m^3,
ϕ = angle of repose = 30°

$$\therefore \quad D_{min} = \frac{15.45}{1.7}\left(\frac{1 - \sin 30°}{1 + \sin 30°}\right)^2 \approx 1 \text{ m.}$$

However, the minimum depth is also governed by Eq. [3.3(a)] which is based on the requirement that the angle of spread of load should not exceed the permissible values.

$$\therefore \quad D_{min} = \frac{1}{2n}[(B - T) - 2d(n_1 - n)]$$

For computation of D_{min}, either we have to assume some suitable value of d (*i.e.* thickness of concrete block), or n_1 may be assumed to be equal to n. In the latter case, we have

$$D_{min} = \frac{B - T}{2n}$$

where B = width of footing = 1 m,
T = width of wall = 30 cm = 0.3 m,
$n = \frac{1}{2}$ for masonry

$$\therefore \quad D_{min} = \frac{(B - T)}{2 \times \frac{1}{2}} = \frac{(1 - 0.3)}{1} = 0.7 \text{ m.}$$

This is lesser than the value found earlier. Hence adopt

$$D = 1 \text{ m.}$$

(*iii*) ***Proportioning of foundation.***

The width is to be increased from 30 cm at ground level to 100 cm at base. Increase on one side of wall face = $\frac{1}{2}(100 - 30)$ = 35 cm.

Let us fix the concrete projection as equal to 15 cm. Hence the total width of offsets to one side of wall = 35 − 15 = 20 cm.

Since the maximum offset in brick masonry is 5 cm, there will be four offsets as shown in Fig. 3.8 (a). The minimum height of each offset = 2 × 5 = 10 cm.

(*iv*) ***Thickness of concrete block.***

Offset a = 15 cm.

Thickness of concrete block is given by

$$d = a\sqrt{\frac{3q}{m}}$$

where q = bearing pressure on soil = 15.45 t/m^2
m = safe modulus of rupture for lime concrete = 16 t/m^2

$$\therefore \quad d = 15\sqrt{\frac{3 \times 15.45}{16}} = 25.5 \text{ cm}$$

$$\therefore \quad d = 15\sqrt{\frac{3 \times 98.75}{160}} = 20.4 \text{ cm}$$

Minimum value of d with a dispersion of $n_1 : 1$ is

$$d_{min} = \frac{a}{n_1} = \frac{15}{2/3}$$

$$= \frac{15 \times 3}{2} = 22.5 \text{ cm.}$$

Hence keep $d = 22.5$ cm.

6. *Check.* The foundation section is shown in Fig. 3.9. Weight of foundation below G.L.

$$= [(0.3 \times 0.075) + (0.4 + 0.5 + 0.6 + 0.7 + 0.8 + 0.9) \times 0.1]\, 1.95 + [0.225 \times 1.2 \times 20]$$

$$= 8.04 + 5.4 = 13.44 \text{ kN/m}$$

(Against assumed value of $0.1 \times 107.73 = 10.77$ kN)

Super-imposed load

$$= 107.73$$

$\therefore$ Total load

$$= 13.44 + 107.73$$

$$= 121.17 \text{ kN}$$

$$\text{Soil pressure} = \frac{121.17}{1.2}$$

$$\approx 101 \text{ kN/m}^2$$

This is slightly more than safe bearing pressure of100 kN/m^2, the increase being only 1%. Hence O.K.

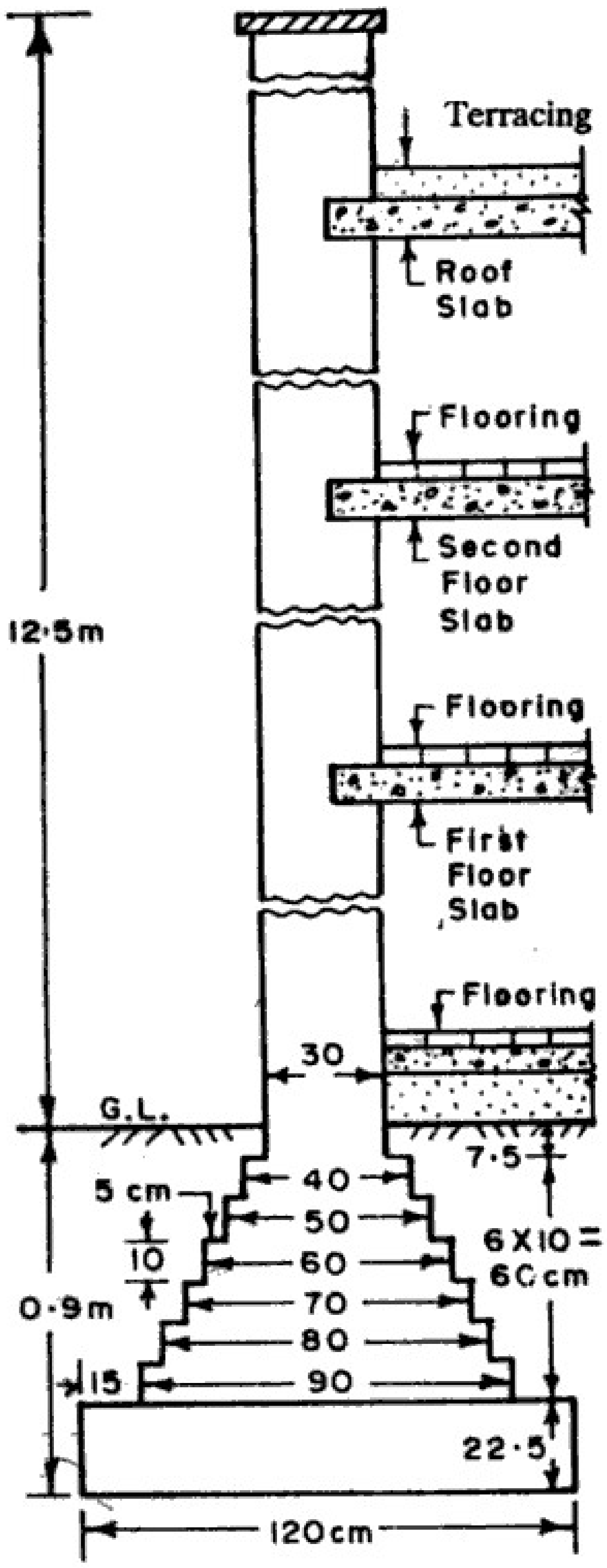


FIG. 3.9

3.6. GRILLAGE FOUNDATIONS

A *grillage foundation* is a special type of isolated footing, generally provided for heavily loaded steel stanchions, specially in those locations where bearing capacity of soil is poor. The depth of foundation is limited from 1 m to 1.5 m. The load of the column or stanchion is distributed or spread to a very large area by means in steel grillage foundation is replaced by timber platform constructed of timber planks.

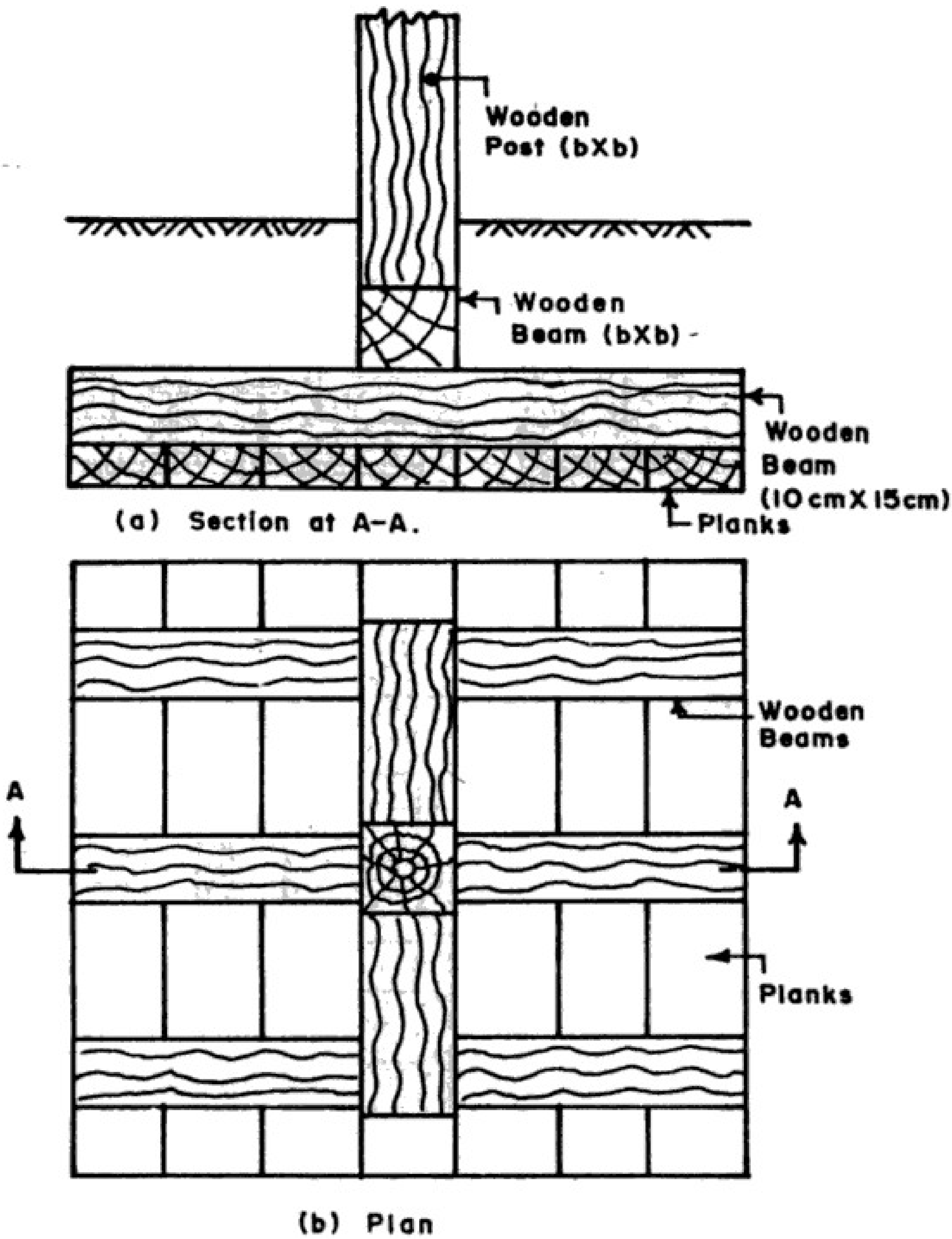


FIG. 3.12. TIMBER GRILLAGE FOUNDATION FOR WOODEN POST.

Fig. 3.12 shows a typpical timber grillage foundation for a timber column. After excavating the foundation of the desired depth and levelling it, the bottom layer of planks 5 to 7.5 cm thick and 20 to 30 cm wide is laid. The planks are arranged side by side, without any gap between them. Over this platform, a tier of wooden beams, about 15 cm × 10 cm in size, spaced 30 to 50 cm apart, is laid at right angles to the direction of the planks. Over the top of this laycr, a timber beam of the same section as that of the

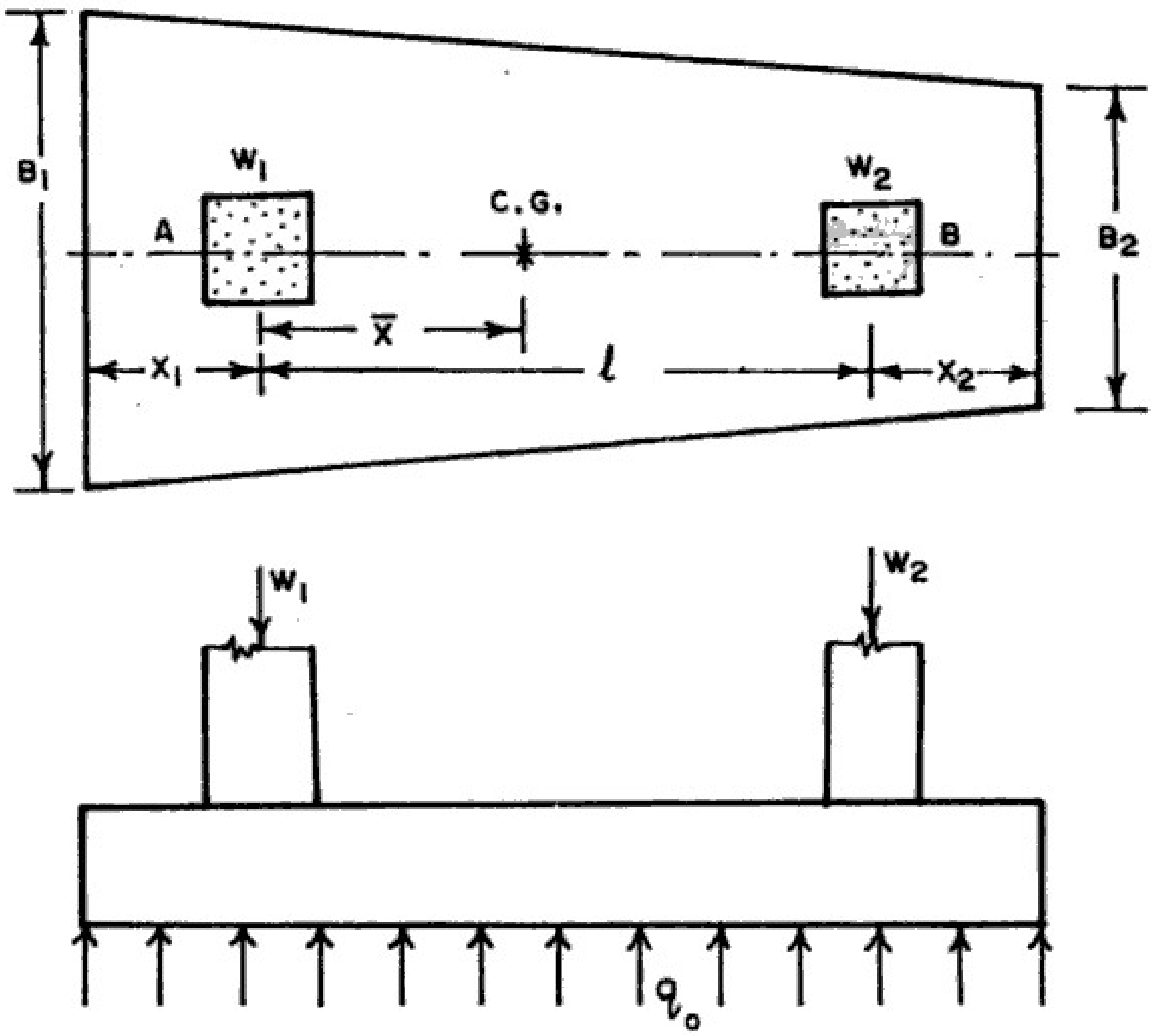


FIG. 3.18. TRAPEZOIDAL COMBINED FOOTING WITH UNIFORM SOI PRESSURE.

or
$$(B_1 + B_2) = \frac{2\,(W_1 + W_2 + W')}{q_s \,.\, L} \qquad ...(3.11)$$

Also distance of C.G. of load from W_1 is given by

$$\bar{x} = \frac{W_2\, l}{W_1 + W_2} \qquad ...(iii)$$

Distance of C.G. of trapezium from long edge

$$= \frac{L}{3}\left(\frac{B_1 + 2\,B_2}{B_1 + B_2}\right) \qquad ...(iv)$$

From *(iii)* and *(iv)* we have

$$a_1 + \frac{W_2\, l}{W_1 + W_2} = \frac{L}{3}\left(\frac{B_1 + 2\,B_2}{B_1 + B_2}\right) \qquad ...(3.12)$$

From Eqs. 3.11 and 3.12, unknowns B_1 and B_2 can be determined. The *net* upward soil pressure intensity p_o will be *uniform* throughout, and its magnitude is given by

$$p_o = \frac{W_1 + W_2}{\frac{1}{2}(B_1 + B_2)\, L} \qquad ...(3.13)$$

The function of the strap beam is to transfer the load of heavily loaded outer column to the inner one. In doing so, the strap beam is subjected to bending moment and shear force and it should be suitably designed to withstand these.

Fig. 3.23 shows variety of ways in which straps may be arranged, and their choice depends upon the physical conditions of each specific case.

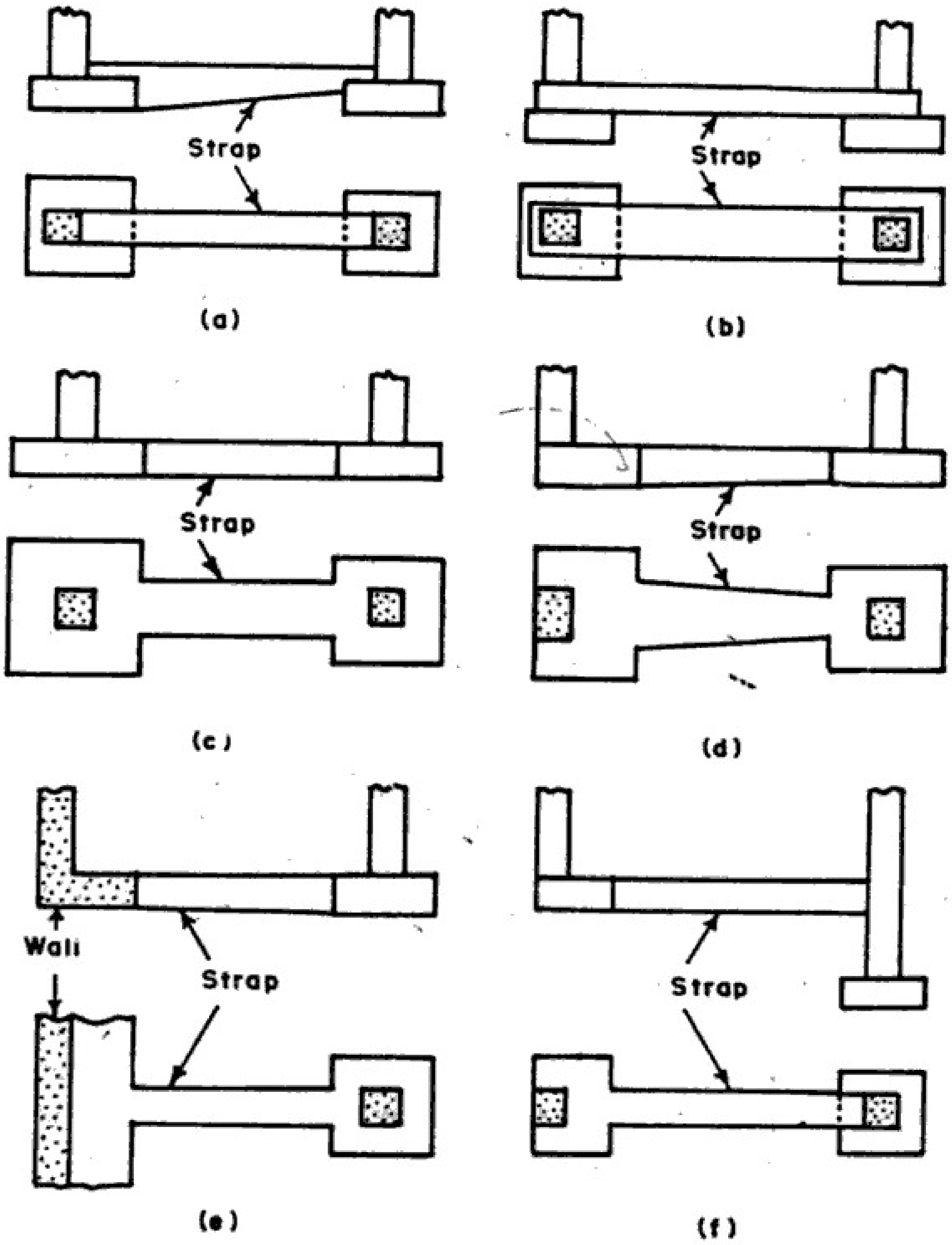


FIG. 3.23. COMMON ARRANGEMENTS OF STRAP FOOTINGS.

Proportioning of strap footing. Fig. 3.24 shows two columns *A* and *B*, transmitting axial loads W_1 and W_2 and are spaced l apart, centre to centre. Let W' be the total weight of both the individual footings. If A_1 and A_2 are the individual footing areas, and q_s is

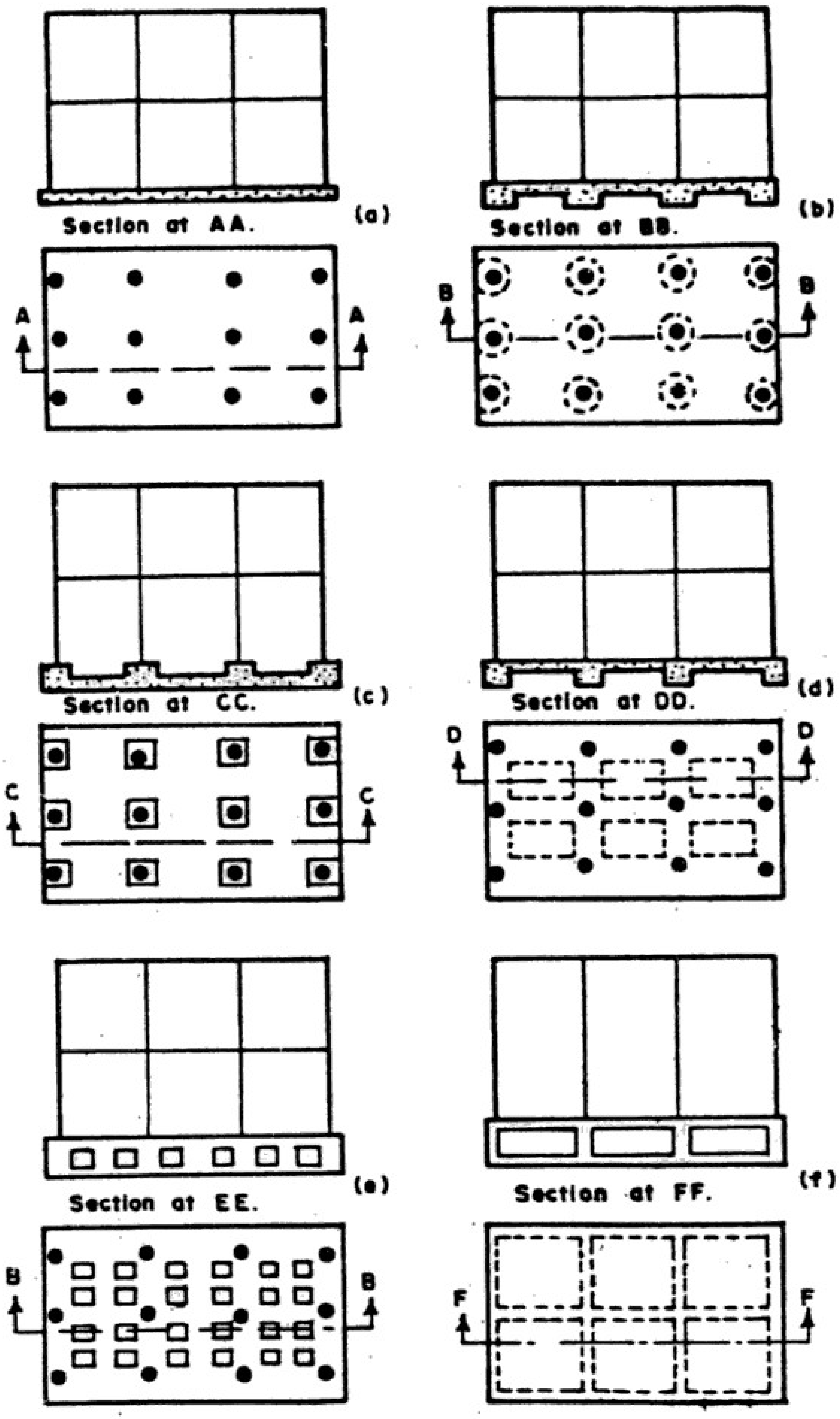


FIG. 3.26. COMMON TYPES OF RAFT FOUNDATIONS.

(*a*) Flat plate type (*b*) Flat plate thickened under columns (*c*) Flat plate with padestals (*d*) Two way beam and slab type (*e*) Cellular construction (*f*) Basement walls as rigid frame.

Solution. Refer Fig. 3.24 for the general arrangement of the footing. Let the width of two spread footing be B metres each. Let the length of footing under column A be L_1 and that under column B be L_2 centrally arranged under B.

Given $W_1 = 600$ kN; $W_2 = 900$ kN.

Let weight of footing, $W' = 10\,\%$ of$(W_1+W_2) = 0.1(600+900)$

$= 150$ kN.

Hence $$B(L_1 + L_2) = \frac{600 + 900 + 150}{120} = 13.75 \text{ m}^2$$

or $$L_1 + L_2 = \frac{13.75}{B} \qquad ...(1)$$

Let $\bar{x}$ = distance of C.G. of loads from centre of column B.

$$\bar{x} = \frac{W_1 l}{W_1 + W_2} = \frac{600 \times 5}{600 + 900} = 2 \text{ m}.$$

If $\bar{x}$ is also the distance of C.G. of areas, from the centre of column B, we have

$$\bar{x} = \frac{B \times L_1 \left(l + \frac{b_1}{2} - \frac{L_2}{2}\right)}{B(L_1 + L_2)}$$

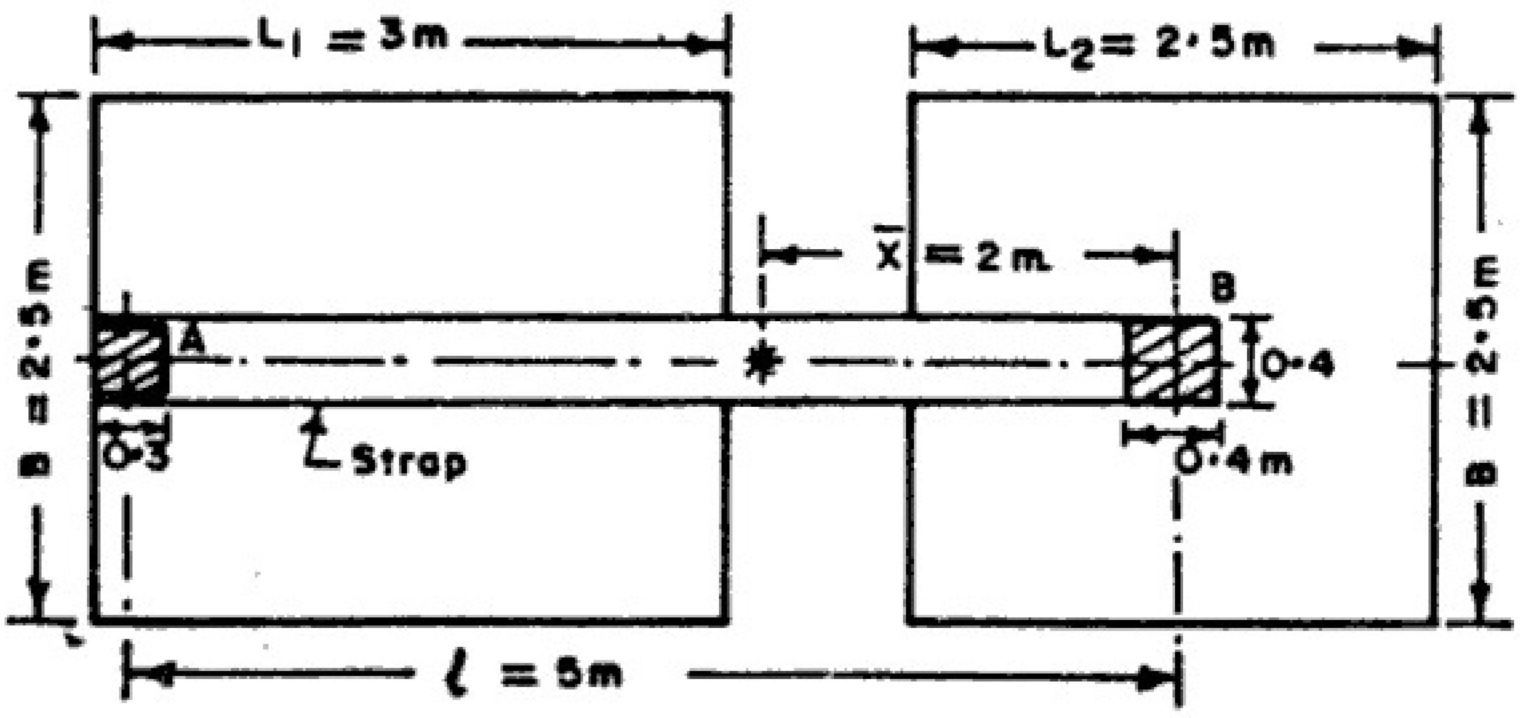


FIG. 3.29.

Substituting the values of $\bar{x}$, $b_1$and l_1 , we get

$$2 = \frac{L_1(5 + 0.15 - 0.5\,L)}{(L_1 + L_2)} \qquad ...(2)$$

Substituting the value of $(L_1 + L_2)$ from (1), and choosing $B = 2.5$ m, we get

$$\frac{L_1(5.15 - 0.5\,L_1)}{13.75/2.5} = 2$$

$$L_1^2 - 10.3\,L_1 + 22 = 0$$

From which $L_1 = 3.052 \approx 3$ m (say) pressure. When the soil shrinks, the sand layer would expand, but there will be no discontinuity in the soil support. Sand fill should also be used below flooring. Section of Fig. 3.31 (*b*) is suitable where the swelling pressures are relatively high. The alternate layers of mooram (or ballast) and sand act as a spring which can compress or expand along with the sub-soil movements. It will, thus absorb all the movements, thus keeping the footing free from these effects. If the soil is soft and has poor bearing capacity, a 30 cm thick layer of ballast and mooram should first be rammed into the soil. Over the top of it, a min. of 30 cm thick layer of coarse grained sand may be placed. In all the three cases, the foundation concrete may be done in rigid cement concrete, and if possible, it may contain nominal reinforcement. Fig. 3.31 (*d*) shows a section which may be used for soils of high swelling pressure, and having high shrinkage properties. After compacting the base of the tranch, 25 to 30 cm wide strips of concrete, 25 to 30 cm thick, may first be laid and compacted. After the strip concrete is cured, the space between the two is filled with sand. The space between the two strips of concrete(i.e. width of sand fill) may be kept equal to width of the bottom course of masonry. On the top of this, the foundation concrete layer, preferably of reinforced concrete is laid. The sides of the masonry footings is filled with sand as usual. In addition to this, 80 mm dia. pipes spaced at 1.5 to 2 m etc. are placed through masonry and concrete bed, so as to reach the bottom sand fill a shown, and sand is filled in the pipe. A plug may be placed on the top of the pipe, to facilitate the inspection from time to time, and to pour fresh sand if required.

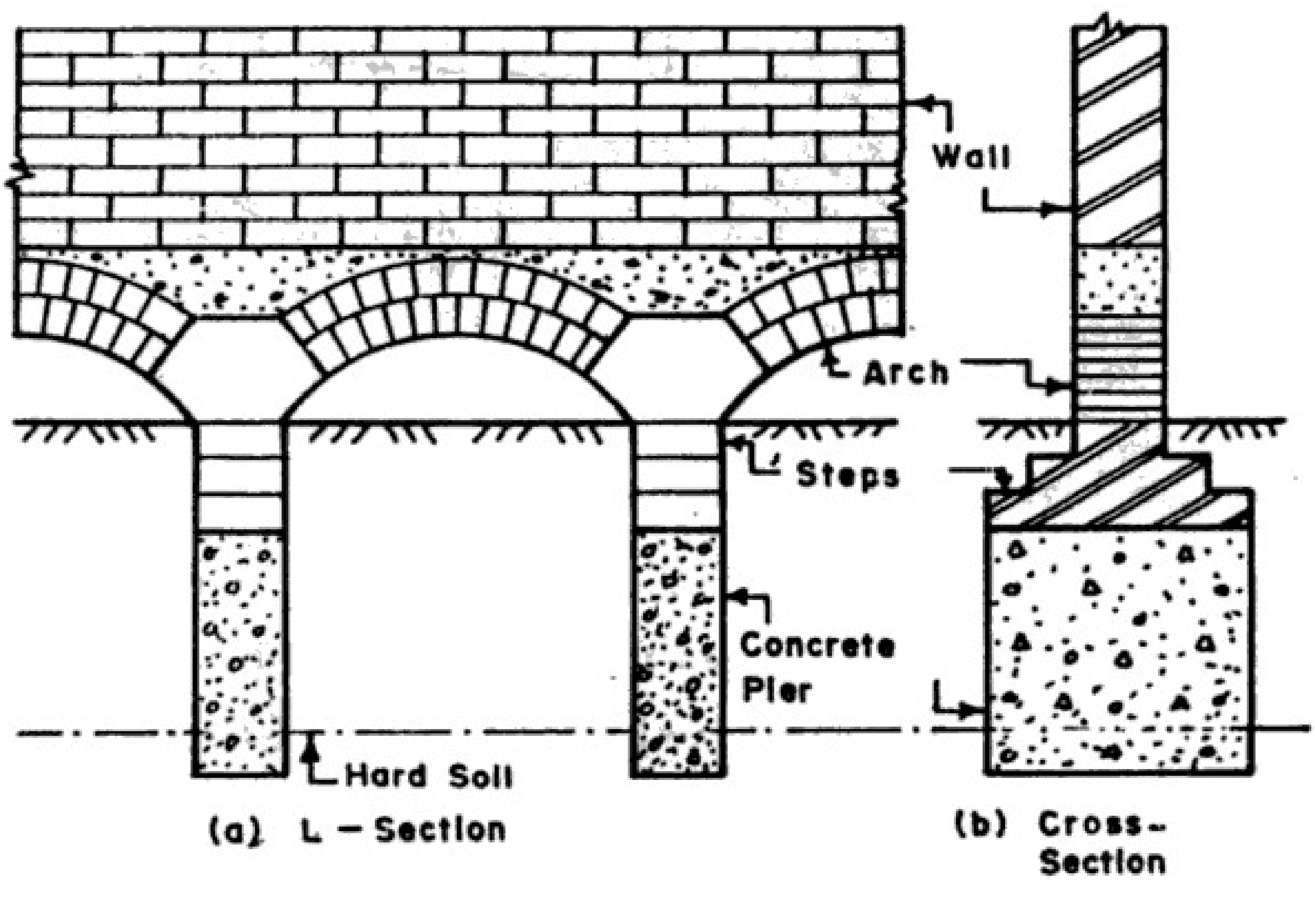


FIG. 3.32. PIER FOUNDATIONS WITH ARCH.

rock, b should not exceed a. A minimum clear distance of half the width of footing is recommended by National Building Code. It is always a good practice to construct the lower footing first, and when necessary to construct the lower footing at a greater depth than contemplated, the elevation of the upper footing can be adjusted accordingly.

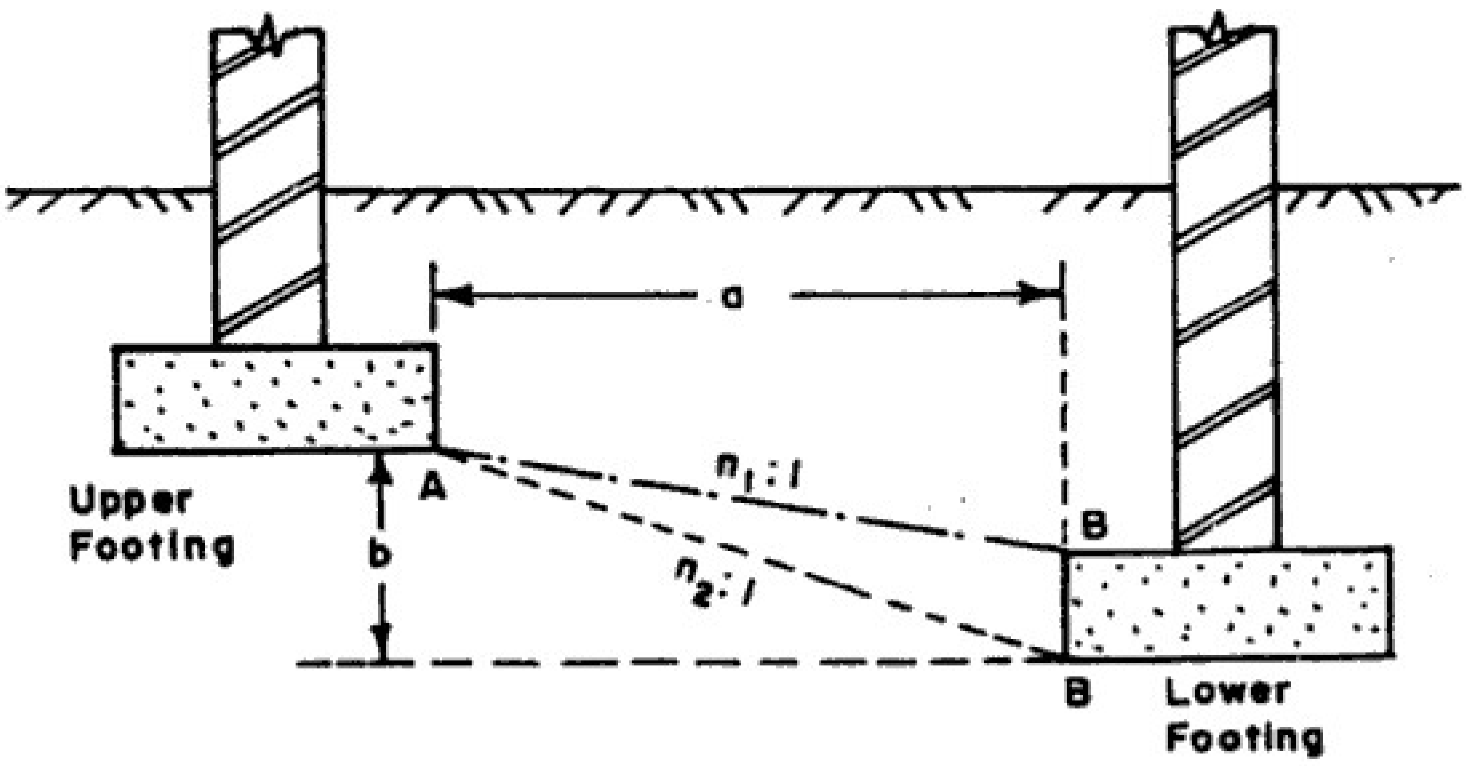


FIG. 3.36. ADJACENT FOOTINGS AT DIFFERENT LEVELS.

In clayey soils, the line (AB) drawn between the *lower* adjacent edge of the *upper footing* and *upper* adjacent edge of the lower footing should not have a steeper slope than n_1 (horizontal) : 1 (vertical), where n_1 is equal to 2.

In granular soils, the line (AB_1) drawn between the lower adjacent edges of adjacent footings should not have steeper slope than n_2 (horizontal) : 1 (vertical), where n_2 is equal to 2.

3.13. MACHINE FOUNDATIONS

The design of foundations for machine requires careful study of vibration characteristics of the foundation system. The design of foundations of turbines, motors, generators, compressors, forge hammers and other machines, having a rhythmic application of unbalanced forces require special knowledge of theory of harmonic vibrations. Inertial forces of rotating elements of machines contribute, besides their *static loads* additional *dynamic loads*. The machinary vibration influences adversely the foundation supporting soil by densifying it which may, in turn, cause differential settlement of the soil and foundation.

Usually mass concrete is used for machine foundations. The excessive vibrations can be eliminated by use of heavy foundations. As a rough guide, the ratio of the weight of foundation to the engine weight may be kept beteween 2.5 to 3.5 in most of the machines.

Design criteria 1. The stresses produced at the time of impact in the foundation base (soil, timber, sleepers, cork, spring elements, or piles etc.) should be within 0.8 times the allowable static stresses.

2. The design of entire foundation system should be such that the centres of gravity of the anvil, and of the foundation block, as well as the joints at which the resultants of the forces in the elastic joints J_1 and J_2 act, coincide with the time of fall of the hammer tup. While determining the centre of gravity of the foundation block, the weight of the frame of the tup could also be considered.

3. The maximum vertical vibrational amplitude of the foundation block should not be more than 1.2 mm. In case of foundation on sand below the ground water, the permissible amplitude should not be more than 0.8 mm.

4. For the anvil, the permissible amplitude, which depends upon the weight of the tup should be taken from the following table:

Weight of tup	*Maximum permissible amplitude*
Upto 1t (10 kN)	1 mm
2t (20 kN)	2 mm
More than 3t (30 kN)	3 to 4 mm

5. The area of foundation block should be such that the safe loading intensity of the soil is never exceeded during the operation of the hammer. The depth of the foundation block should be so designed that the block is safe both in punching shear and bending. However, the following minimum thickness of foundation block should be provided:

Weight of tup (tonnes)	*Minimum depth of foundation block*
up to 1.0	1.00 m
1.0 to 2.0	1.25 m
2.0 to 4.0	1.75 m
4.0 to 6.0	2.25 m
over 6.0	2.50 m.

6. The weight of the anvil may be generally kept at 25 times the weight of the tup. The weight of the foundation block W_b generally varies from 66 to 120 times the weight of the tup. Where the foundation rest on stiff clays or compact sandy deposits, the weight should be from 75 to 80 times the weight of the tup. For moderately firm to soft clays and for medium dense to loose sandy deposits, the weight of the block should be from 90 to 120 times the weight of the tup.

The approximate weight of the foundation block may also be determined from the following formula :

Safe bearing capacity of soil $= 20\ t/m^2\ (200\ kN/m^2)$.

The footing is not to project more than 0.4 m beyond the outer faces of the columns.

25. What do you understand by raft foundation ? When do you prefer this?

Explain with the help of sketches common types (or forms) of raft foundation.

26. What are the problems of foundations on black cotton soils ? What points should be kept in mind while designing foundations in such soild ?

27. Draw typical sketches of sections of shallow foundations on expansive soils. Explain the functions of special provisions made in each case.

28. Write notes, explaining design criterion for the following :

(*i*) Stepped footing for sloping ground.

(*ii*) Adjacent strip footings at different levels.

29. Explain in brief general rules for the design of foundation for reciprocating engines.

30. Explain in brief the design criteria for foundation for impact type machines.

due to driving and the handling stresses. Cast-in-situ piles may be classified into two classes : (*i*) *driven piles* (cased or uncased) and *bored piles* (pressure piles, pedestal piles and under-reamed piles). A variety of cast-in-situ piles are in use, each bearing the name of the manufacturer.

Under-reamed pile is a special type of bored pile having an increased diameter or bulb at some point in its length, to anchor the foundation in expansive soil subjected to alternate expansion and contraction.

Concrete filled steel piles and *steel H-piles* are used as long piles with high bearing capacity. They are rarely used unless they reach a stratum of exceptionally high supporting capacity, since their cost is very high. *Timber piles* have small bearing capacity, and are not permanent unless treated. They are prone to damage by hard driving, and should not be driven through hard stratum or boulders. *Composite piles* are suitable where the upper part of a pile is to project above water table. Such a pile consists of a lower portion of untreated timber and an upper portion of concrete. In other types of composite piles, steel piles are attached to the lower end of cast-in place concrete piles. This type is used in case where the required length of pile is greater than that available for the cast-in-place type.

4.3. CASED CAST-IN-SITU CONCRETE PILES

Cased cast-in-situ piles are suitable in practically all ground conditions. The shell is driven into intimate contact with the surrounding soil and remains in place to maintain driving resistance and protect the concrete filling during the placing of other adjacent piles and during the critical setting period. Cased piles can be easily cut or extended to meet variations in shell length. One of the main advantages is that it is subject to internal inspection after it is driven. The following are the common types of cased cast-in-situ concrete piles :

(*i*) Raymond standard pile and step-taper pile
(*ii*) Mc-Arthur cased pile
(*iii*) Union metal monotube pile
(*iv*) Swage pile
(*v*) Western button bottom pile.

1. Raymond piles.

In 1897, A.A. Raymond patented the Raymond pile system and was first to develop a practical, economical way of placing cast-in-situ concrete piles. Two types of Raymond piles are in use (*a*) Raymond standard concrete pile and (*b*) Raymond step-taper concrete pile.

the fourth stage, the shaft is formed by introducing successive charges of concrete, ramming each in turn, and withdrawing gradually (about 300 mm at a time) the casing [Fig. 4.9 (*d*)]. Fig. 4.9 (*e*) shows the finally formed pile which has corrugations all along its height. Reinforcement cage can be installed, if desired, after the enlarged base has been formed (Stage 3). In that case, the hammer goes inside the cage of reinforcement. The pile diameters in Franki piles vary from 50 cm to 60 cm, while the enlarged base may have a diameter of about 90 cm or more. The pile has a carrying capacity of 60 t (600 kN) to 90 t (900 kN).

3. Vibro-piles.

These piles are used where the ground is soft, thus offering little frictional resistance to the flow of concrete. Both *'standard'* and *'expanded'* piles are formed by the vibro-process. Vibro piles are formed by driving a steel tube and shoe, filling with concrete, and extracting the tube, using upward extracting and downward tamping blows alternatively.

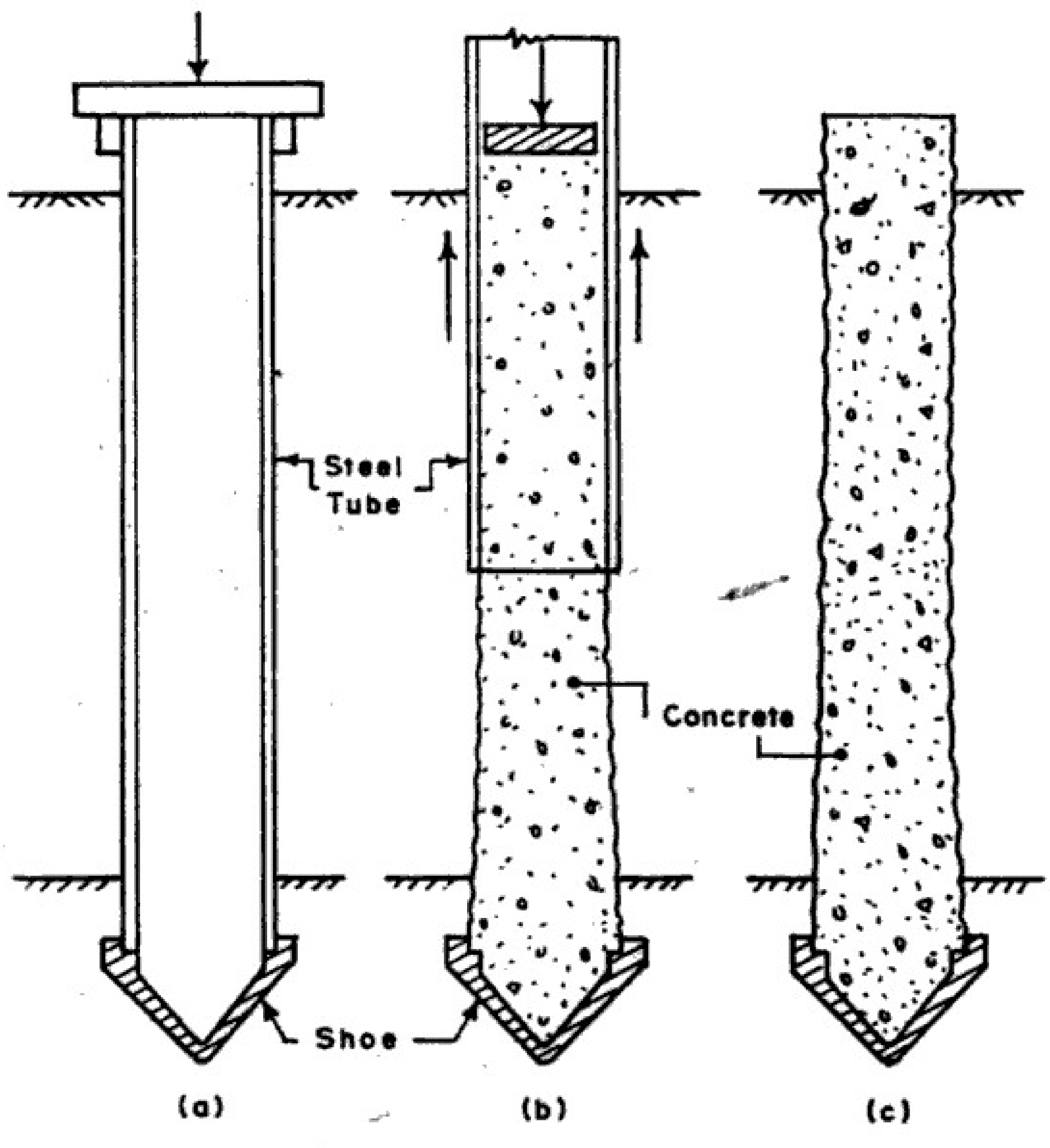


FIG. 4.10. STAGES IN THE FORMATION OF STANDARD VIBRO-PILES

In the *first stage* [Fig. 4.5 (*a*)] a thin steel pile (known as shell) is placed on a *precast* concrete plug, and a steel core, which is not long enough to reach the plug is inserted in the shell. In the *second stage* [Fig. 4.5(*b*)] as the pipe is driven over the plug until the core reaches the plug, the pipe is *swaged out* by the taper of the plug, thus forming a water tight joint. In the *third stage* [Fig. 4.5 (*c*)] the pipe is driven to a specified depth. The driving force is practically all exerted by the core on the plug and the pipe pulled down rather than driven. In the fourth stage [Fig. 4.5 (*d*)] after the pipe has reached the desired depth, the core is removed, and the pipe left open until it is desired to fill it. In the *final stage* [Fig. 4.5 (*e*)] the pipe is filled with concrete.

5. Western button bottom pile.

These piles are used in locations where increase in the end bearing area is desired. The pile uses a concrete plug, of the shape of a button. This button forms and enlarged hole in the soil during driving. Due to this, the side friction is reduced temporarily. These piles have been used upto lengths of about 23 m, and for loads upto 50 tonnes. The four stages in the pile driving are shown in Fig. 4.6.

In the *First Stage* [Fig. 4.6 (*a*)], a steel pipe, with 12 mm thick walls and reinforced base of cast steel, is set over the concrete

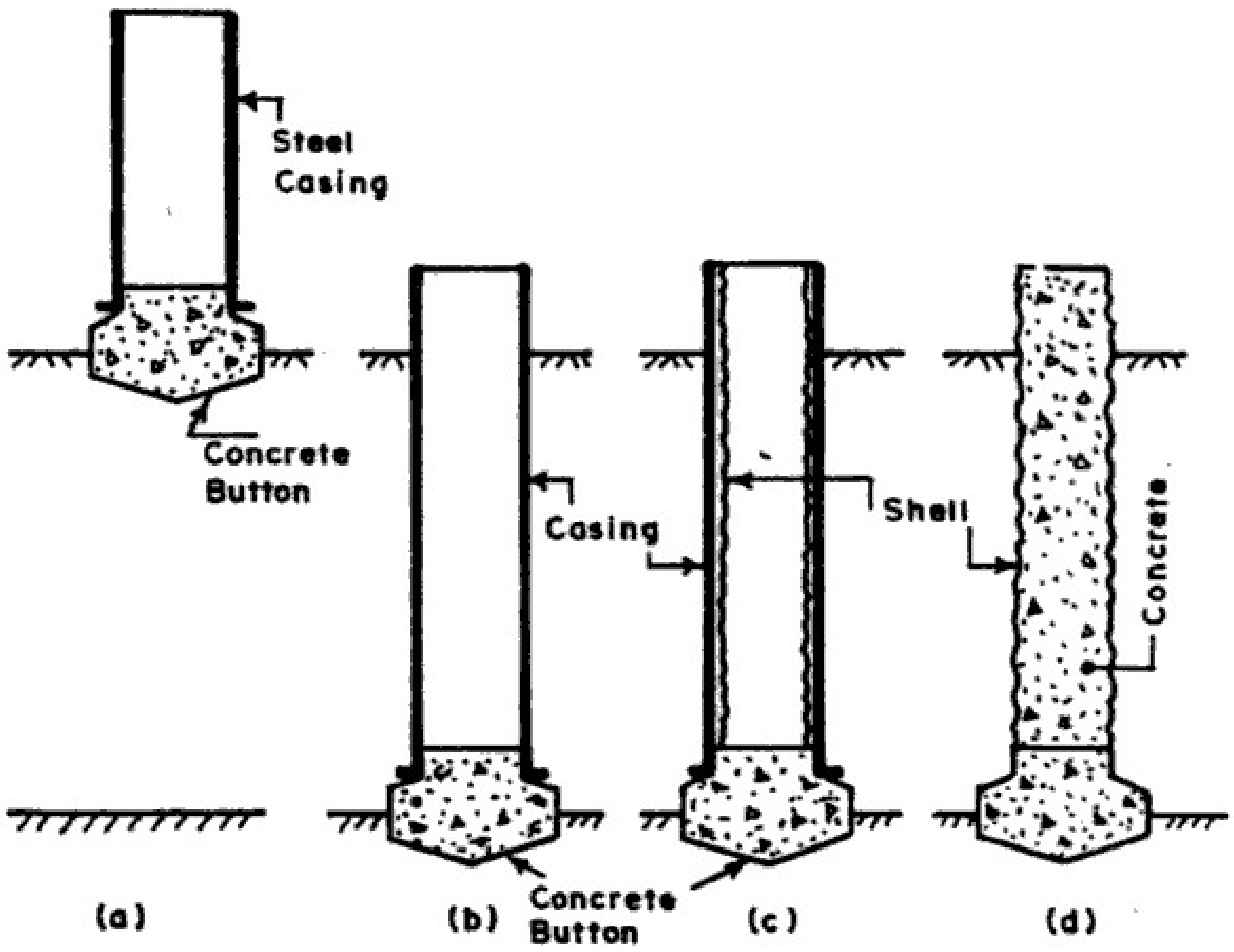


FIG. 4.6. STAGES IN BUTTON-BOTTOM PILE CONSTUCTION.

button. The concrete button has a diameter about 25 mm larger than the pipe. In the *second stage* [Fig. 4.6 (*b*)] the pipe and button are driven to a specified depth. In the *third stage* [Fig. 4.6 (*c*)] a

4.5 BORED PILES

Bored piles are those which are formed by forming a bore hole in the ground and then concreting it, either with the help of a casing tube or without a casing tube. Their procedure of construction is thus different than the cast-in-situ driven pile where a heavy pile driving equipment is required. Evidently, these piles have advantage over the driven piles, in those locations and those situations where the vibrations and noise caused by driving of piles are to be avoided or the strata of adequate bearing capacity is so deep that they are difficult to reach by *driven piles.*

Bored piles are of three types :

1. Pressure piles
2. Under-reamed piles and
3. Bored compaction piles.

Under-reamed piles and bored compaction piles have been discussed in § 4.16 and § 4.17 respectively.

PRESSURE PILES

They are formed with the help of a casing tube, boring auger and compressed air equipment. These piles are especially suitable for those congested sites where heavy vibrations and noise are not permissible, and also where heavy pile driving machinery can not move in. The stages in the construction of a pressure pile are shown in Fig. 4.13.

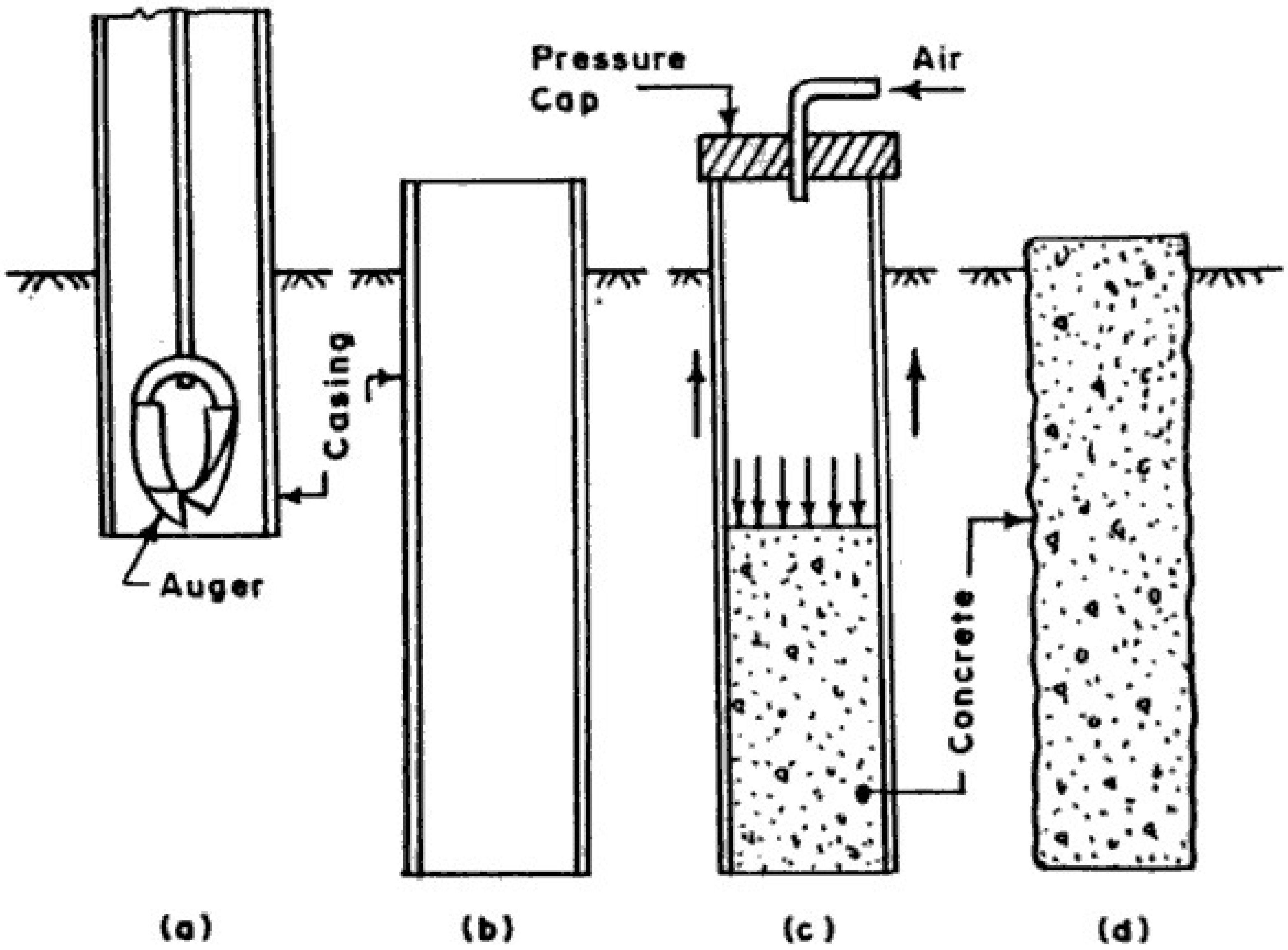


FIG. 4.13. STAGES IN THE CONSTRUCTION OF PRESSURE PILE.

2. The position of reinforcement in the pile is not liable to be disturbed.

3. The casting defects can be easily discovered after the removal of forms, and these defects (such as hollows, etc.) can be properly repaired before driving the pile.

4. Since a large number of piles are manufactured at a time, in the factory or any other convenient place,the cost of manufacturing these will be less.

5. These piles can be driven under water. If the subsoil water contains more sulphates, the concrete of cast-in-situ piles would not set. Thus precast concrete piles have added advantage in such a circumstance.

6. The precast concrete piles are highly resistant to biological and chemical actions of the subsoil.

Disadvantages of precast concrete piles

1. These piles are very heavy. Therefore they require special equipments for handling and transportation.

2. If sufficient care is not taken, these piles may breack during transport or driving.

3. They require heavy pile driving equipment.

4. Extra reinforcement is required to bear handling and driving stresses. Hence these piles are costly.

5. The length of the pile is restricted since it depends upon the transport facilities.

6. It is very difficult to increase the length of the pile, previously estimated on the basis of bore holes.

7. If the pile is found to be too long, during driving, it is difficult and uneconomical to cut. Also cutting of extra length results in the wastage of material.

8. These piles are not available at short notice. Hence delay of work will occur, specially for emergency projects.

Precast Prestressed Concrete Piles

Precast piles of prestressed concrete have now been developed. Solid and hollow prestressed piles were first driven in Great Britain in 1949. Prestressed concrete piles are claimed to be stronger than the normal reinforced concrete piles and, therefore, because of the reduction in the cross-sectional area, they are lighter and can be more easily handled. A prestressed concrete pile has the following advantages: (*i*) it has greater ability to withstand extremely hard driving (*ii*) it is more durable in sea water because of absence of cracks (*iii*) it has greater column capacity (*iv*) it has lesser handling costs because of light weight (*v*) it requires lesser pick up points, 25 mm less than the diameter or size of the pile head. Timber piles can take loads upto 20 tonnes.

Advantages of timber piles.

1. They are cheap and more economical.

2. They can be easily stored and transported, without the aid of any heavy equipment.

3. They can be driven very rapidly.

4. Because of their elasticity they are better suited to the conditions where piles are subjected to unusual lateral forces.

5. They are specially useful when sub-soil water is present.

Disadvantages of timber piles

1. Timber piles deteriorate or decay very fast when subjected to alternate wetting and drying. Hence it is essential to cut them below the water line and capped with concrete.

2. They cannot be driven, without damage, in made up grounds.

3. They are not very useful in hard, rocky strata.

4. They have low carrying capacity, because of its low structural strength.

5. Because of restrictions in their length, they cannot be used in situations where long piles are essential.

6. They are easily damaged by over-driving.

4.9. COMPOSITE PILES

Composite piles are those which are made of two portions of two different materials driven one above the other. Two common types of composite piles in use are : 1. Timber and concrete and 2. Steel and concrete.

1. Timber and concrete composite pile.

In the timber and concrete composite pile, timber portion is used below the permanent or lowest water level, while concrete piles, usually cast-in-situ, is formed above it. Due to this combination, the advantages of both the types of piles are combined. Also, the total cost of the pile is reduced though the entire length of the pile is permanent.

Fig. 4.17 shows the stages in formation of such a pile :

Procedure:

1. A steel casing tube and steel core are driven into the ground, well below the lowest ground water level [Fig. 4.17(*a*)].

2. The core is withdrawn and timber pile is placed in the casing. [Fig. 4.17 (*b*)].

3. Core is placed on the top of timber pile. The timber pile guided by the casing is driven down to the pre-determined level.

4. Core is withdrawn and a charge of concrete is placed in the casing on the top of the timber pile. The core is replaced over

of fall. The weight of single acting hammer is about 2 tonnes (20 kN), the fall is about 1 metre and the number of blows of the hammer may vary from 50 to 60 per minute.

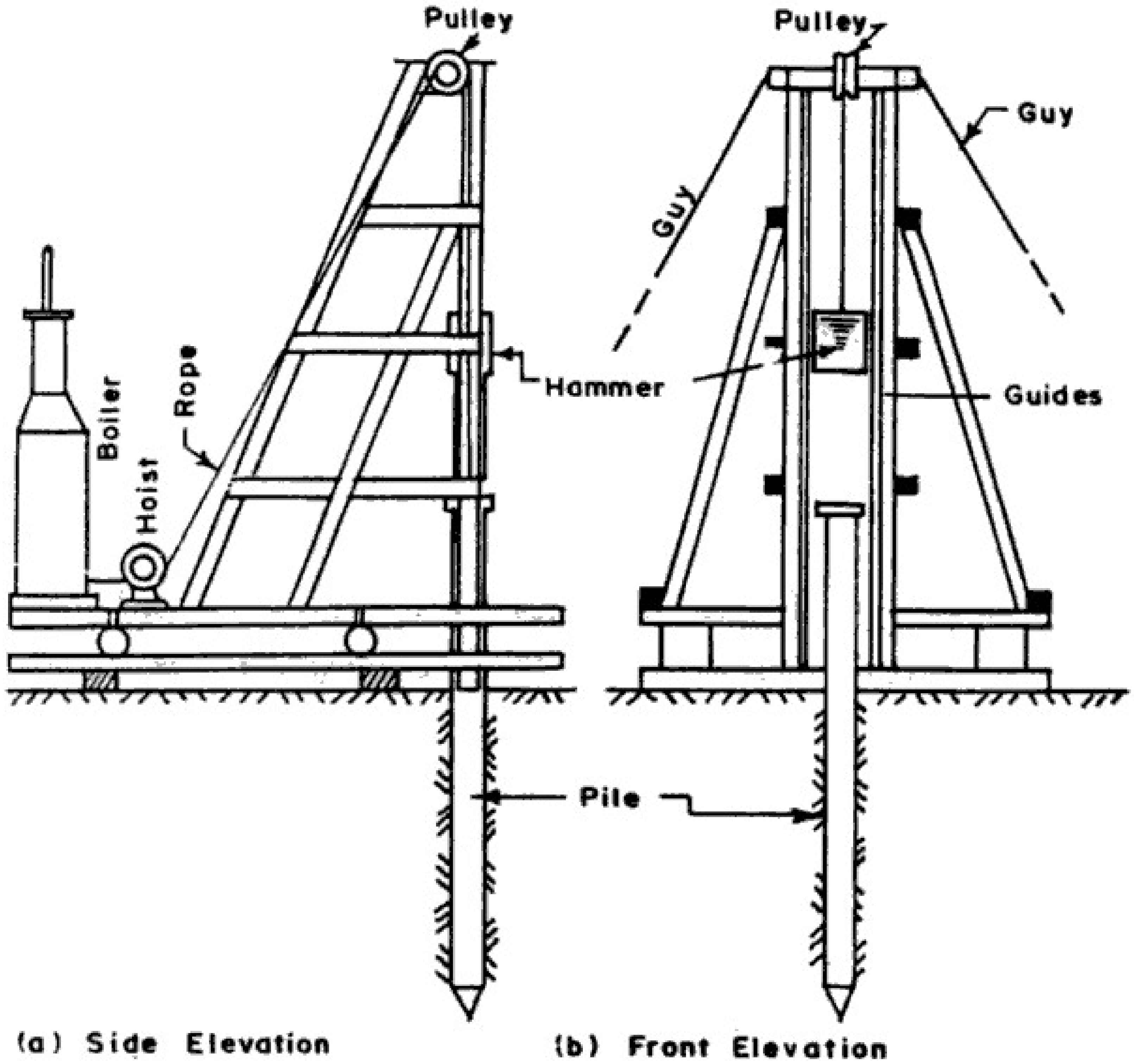


FIG. 4.20. PILE DRIVING WITH DROP HAMMER.

3. Double acting hammer. The double acting hammer employs steam or air for lifting the ram and for accelerating the downward stroke. It operates with succession of rapid blows, the number varying from 100 to 200 blows per minute. The weight of the hammer is only 500 kg (5 kN) but because of accelerating effect of steam(or air) pressure, it has an effect of a weight of 3 tonnes (30 kN). For light hammers, the number of blows may be even as high as 300 per minute. Because of such large number of blows, the pile drivind is very quick. The double-acting steam hammer is completely enclosed in a steel case. Therefore, these hammers are very useful for driving piles under water. Also, pile frame is not required, and the hammer is attacahed to the top of the pile by leg guides. A timber framework is provided to guide the pile. However, because of light weight of hammer, the equipment is not suitable for driving heavy piles through hard strata. In such cases, single acting hammers are generally used.

times referred to as the *effective fall* of the hammer.

For double acting hammers, the *rated energy* in the same length unit as S and C is substituted for WH. The allowable load is obtained by using a factor of safety of 2 or 2.5.

Comments about the use of dynamic formulae.

1. Dynamic formulae are best suited to coarse grained soils for which the shear strength is independent of rate of loading, because they allow to development of excess pore pressure around the pile during driving if saturated or dry.

2. The great objection to any one of the pile driving formulae is the uncertainty about the relationship between the dynamic and static resistance of soil.

3. In case of submerged loose uniform fine sands, impact of driving may cause liquefacion of soil, thus showing much less resistance than that which will occur under a static load. Similarly a very dense saturated fine sand may show an increased driving resistance which decreases with time.

4. For clays, the dynamic formulae are valueless because the skin friction developed in clay during driving is very much less (due to change in soil structure) than which occurs after a period of time. Also, the point resistance is much more at the time of driving because of pore pressure developed in clay, which reduces later on when the pore pressure dissipate.

5. Dynamic formulae give no indication about probable future settlement or temporary changes in soil structure.

6. The formulae do not take into account the reduced bearing capacity when in a group.

7. Law of impact used for determining energy loss is not strictly valid for piles subjected to restraining influence of the surrounding soil.

8. In Engineering News Formula, the weight of the pile and hence its inertia effect is neglected.

9. Energy losses due to vibrations, heat and damage to dolly or packing are not accounted for.

10. In Hiley's formula, a number of constants are involved, which are difficult to be determined.

(*b*) STATIC FORMULAE

The static formulae are based on the assumption that the ultimate bearing capacity Q_f of a pile is the sum of the total ultimate skin friction R_f and total ultimate point or end bearing resistance R_p :

$$Q_f = R_f + R_p$$

or

$$Q_f = A_s \, . \, r_f + A_p \, . \, r_p \qquad ...(4.6)$$

pile cap, to distribute the load to the individual piles. The pile cap consists of a rigid, deep, reinforced concrete slab which acts monolithically with the group of piles. The piles should be arranged symmetrically about the axis of the column so that the load from column is distributed uniformly to all the piles. The pile cap slab is provided in uniform thickness. The pile cap should be extended beyond exterior piles by 10 to 15 cm. The pile should be embedded by at least 15 cm in the pile cap, and the reinforcement in the cap should be placed at least 10 cm above the pile head. The pile cap, provided over the entire area of piles is considered to be divided into a framework of rectangular beams, along which main reinforcement is provided. The arrangement of these beams depends upon the number of piles and the width of beam is taken equal to the width of the pile. Fig. 4.23 (*a*) and (*b*) shows the plan of the pile caps for three piles and four piles respectively.

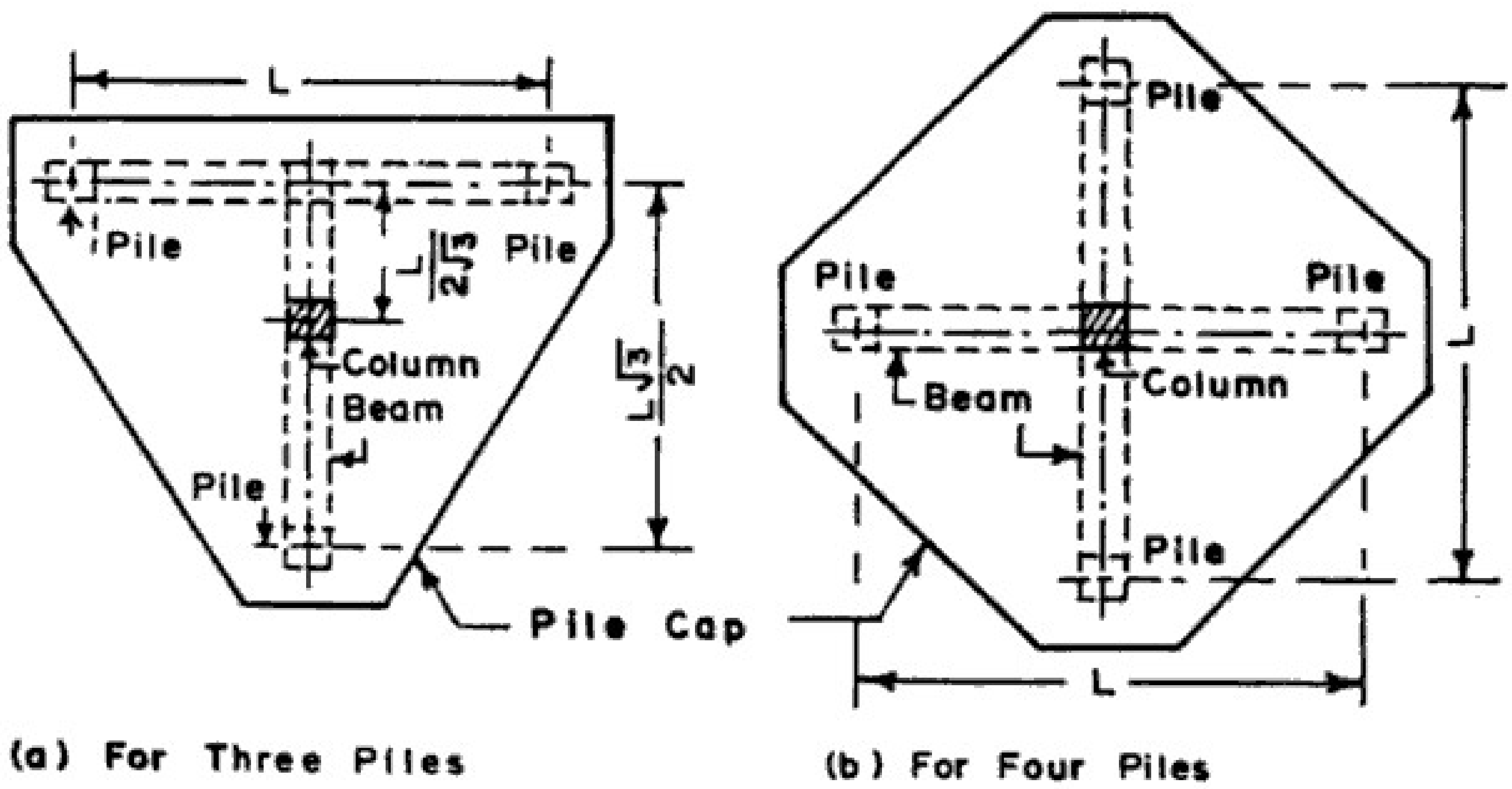


FIG. 4.23. PILE CAPS.

In order to prevent outward splaying tendency of piles, secondary reinforcement should always be provided. The reinforcement is provided at the bottom of pile cap, running round the longitudinal reinforcement projecting from the piles into the cap. It should be so bent that there is change of its direction at the head of every pile. The area of secondary reinforcement changing direction at every head of pile should not be less than 20% of the tensile reinforcement.

4.15. GROUP ACTION IN PILES

When several closely spaced piles are grouped together, it is reasonable to expect that the soil pressure developed in the soil as resistance will overlap. The bearing capacity of a pile group may or may not be equal to the sum of the bearing capacity of individual piles constituting a group. Theory and tests have shown that the total bearing value Q_g of a group of the friction piles, particularly is reached. The second bulb is then formed with the help of under-reaming tool. The process is continued till the desired depth is reached.

In deep layers of expansive soils, the minimum length of pile required is 3.5 m where the ground movements become negligible. In shallow depths of expansive soils and other poor soils depending upon the load requirements, the length may be reduced and the piles may be taken upto at least 50 cm in stable zone(i.e. the zone where there are no ground movements due to seasonal moisture changes). The length may be increased for higher loads.

The diameter of manually bored piles range from 20 cm to 37.5 cm. The spacing of piles is considered in relation to the nature of the ground, the types of piles and the manner in which the piles transfer the loads to the ground. Generally, the centre to centre spacing for under-reamed piles should not be less than 2 D_u where D_u is the under-reamed diameter). It may be reduced to 1.5 D_u when a reduction in load carrying capacity of 10% should be allowed. For the spacing of 2 D_u, the bearing capacity of pile group may be taken equal to the number of piles multiplied by the bearing capacity of individual pile. If the adjacent piles are of different diameter, an average value for spacing should be taken. The maximum spacing of the under-reamed pile should not normally exceed $2\frac{1}{2}$ metres so as to avoid heavy capping beams. In buildings, the piles should generally be provided under all wall junctions to avoid point loads on beams. Positions of intermediate piles are then decided trying to keep the door opening fall in between two piles as far as possible.

In double and multi-under-reamed piles of size less than 30 cm dia., the centre to centre vertical spacing between the two under-reams may be kept equal to 1.5 D_u, while for piles of 30 cm or more, this distance may be reduced to 1.25 D_u. The upper bulb should not be placed too close to the ground. The minimum desirable depth of the centre of the bulb is 1.5 m or 2 D_u whichever is greater.

The under-reamed pile is normally reinforced with 10 to 12 mm dia. longitudinal bars and 6 mm of rings. The details of the reinforcement are shown in Table 4.1. A clear cover of 4 cm is provided.

The under-reamed piles are connected by a reinforced concrete beam, known as *capping beam or grade beam*. Fig. 4.26 shows the details of under-reamed pile foundation, along with the grade beam. For expansive soils, the grade beam is kept above the ground, with a clear air gap of 8 to 10 cm to provide space for the expansion(swelling) of the subsoil. In case of non-expansive soil however, mass concrete (1 : 3 : 6 or 1 : 4 : 8 mix) of 8 to 10 cm thickness is provided between the ground and the bottom of the beam, as shown in Fig. 4.26 (*d*). Fig. 4.26 (*c*) shows the details of the interior or exterior for factory buildings, machine foundations and transmission line towers and poles. In black cotton soils and other expansive soils, the under-reamed pile anchors the structure at a depth where the volumetric changes in soil due to seasonal and other variations is negligible.

Safe loads from IS Code Tables

The load carrying capacity of an under-reamed pile may be determined from load test. In the absence of actual load tests, the safe load allowed for piles under-reamed to 2.5 D_u may be taken from Table 4.1 based on IS : 2911, Part III-1975. The safe load given in the table apply to both medium compact sandy soil and clayey soils of medium consistancy. For dense sandy ($N \geq 30$) and stiff clayey ($N \geq 8$) soils the loads may be increased by 25%. However, the values of the lateral thrust should not be increased unless stability of the top soil (*i.e.*, strata to a depth of about 3 times the stem dia.) is ascertained. On the other hand, a 25 percent reduction should be made in case of loose sandy ($N \leq 10$) and soft clayey ($N \leq 4$) soils.

Load test on Under-reamed Piles

Piles are usually tested for determining the load-carrying capacity in compression, tension and lateral loading. Two categories of tests are conducted: (*a*) *initial tests* and (*b*) *routine tests*.. Initial tests should be carried out on test piles or working piles, but preferably on test piles. In case the initial tests show consistently higher or lower values than the estimated safe allowable loads on piles, designs should be re-examined and necessary modifications made. Routine tests are carried out at a check on working piles.

(a) Procedure for Initial Test (Compression)

Following are the recommendations of Indian Standard IS: 2911 (Part III): 1973:

1. The test shall be carried out by applying a series of loads to the pile unaided by any other support. Pile groups may be tested as free standing piles or piled foundations as specified.

The load shall preferably be applied by means of hydraulic jack reacting against a loaded platform (Fig. 4.22 *a*) or rolled steel joists or suitable load frame held down by soil anchors and piles(Fig. 4.22 *b*) or other anchorage. The anchor piles may also be working piles but they shall be sufficient in number and adequately reinforced to take the full tension with proper factor of safety. The reaction available for loading should not be less than 3 times the estimated safe load-carrying capacity of piles. The jack should be of adequate capacity, preferably with a remote control pump and shall have pressure gauge or other suitable device for reading the applied load.

2. Readings of settlement shall be recorded with the help of at least 3 dial gauges of 0.02 mm sensitivity, positioned at equal

of loose subsoil, such as sand, and to safeguard against settlement.

2. To retain the sides of the trenches and general excavation.

3. To form water tight enclosure (known as *coffer dam*) necessary in the construction of foundations in water.

4. To construct retaining walls in docks, wharfs and other marine structures.

5. To protect river banks.

6. To prevent seepage below dams and other hydraulic structures.

7. To confine the soil, thereby increasing the bearing capacity of soils.

8. To construct coastal defence works (as a protection against sea erosion).

9. To protect the foundations from scouring actions of nearby river, stream etc.

Sheet piles are made of the following materials :

(*a*) Concrete sheet piles, (*b*) Timber sheet piles, (*c*) Steel sheet piles.

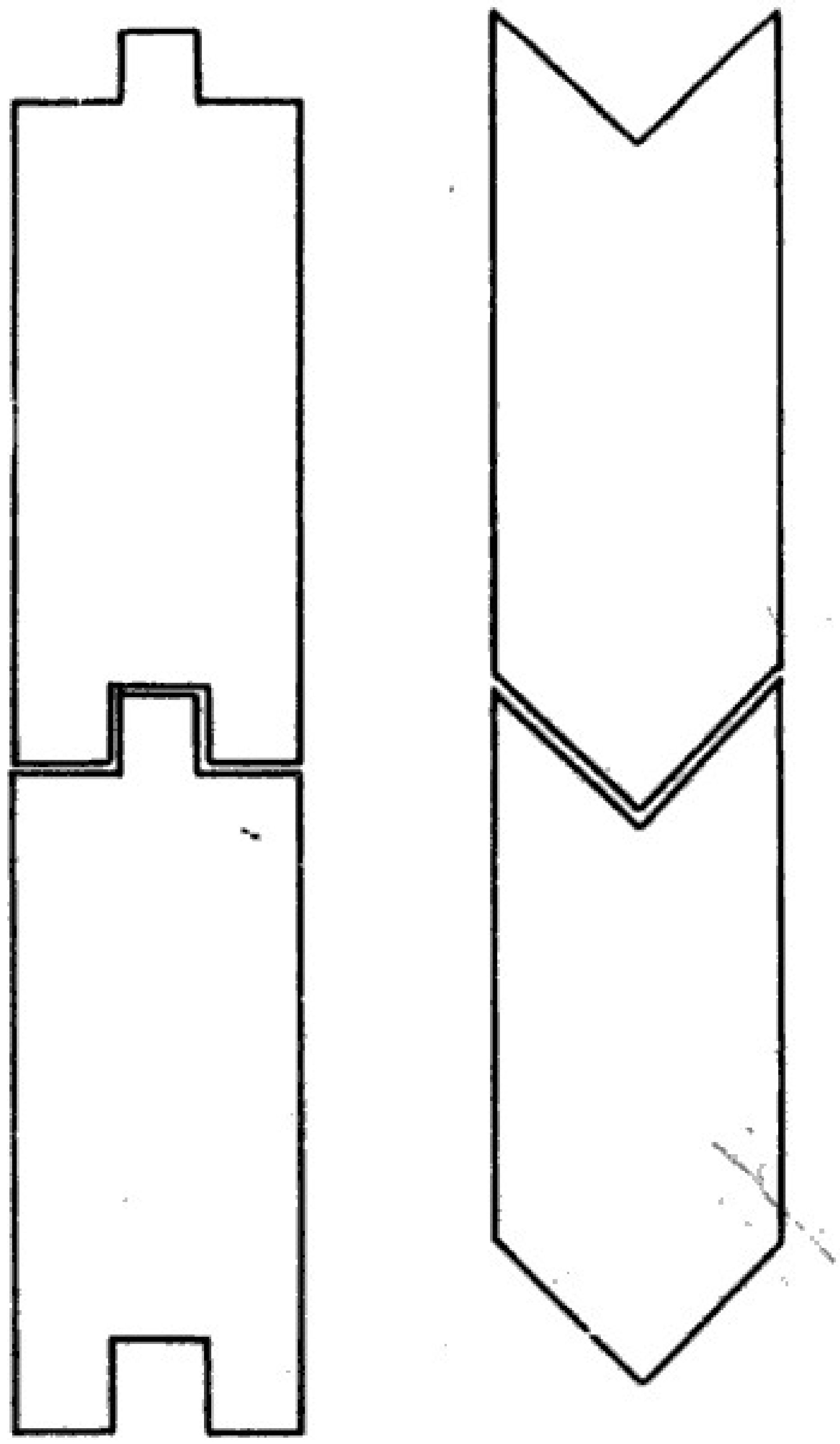


FIG. 4.29. PRE-CAST R.C.C. SHEET PILES

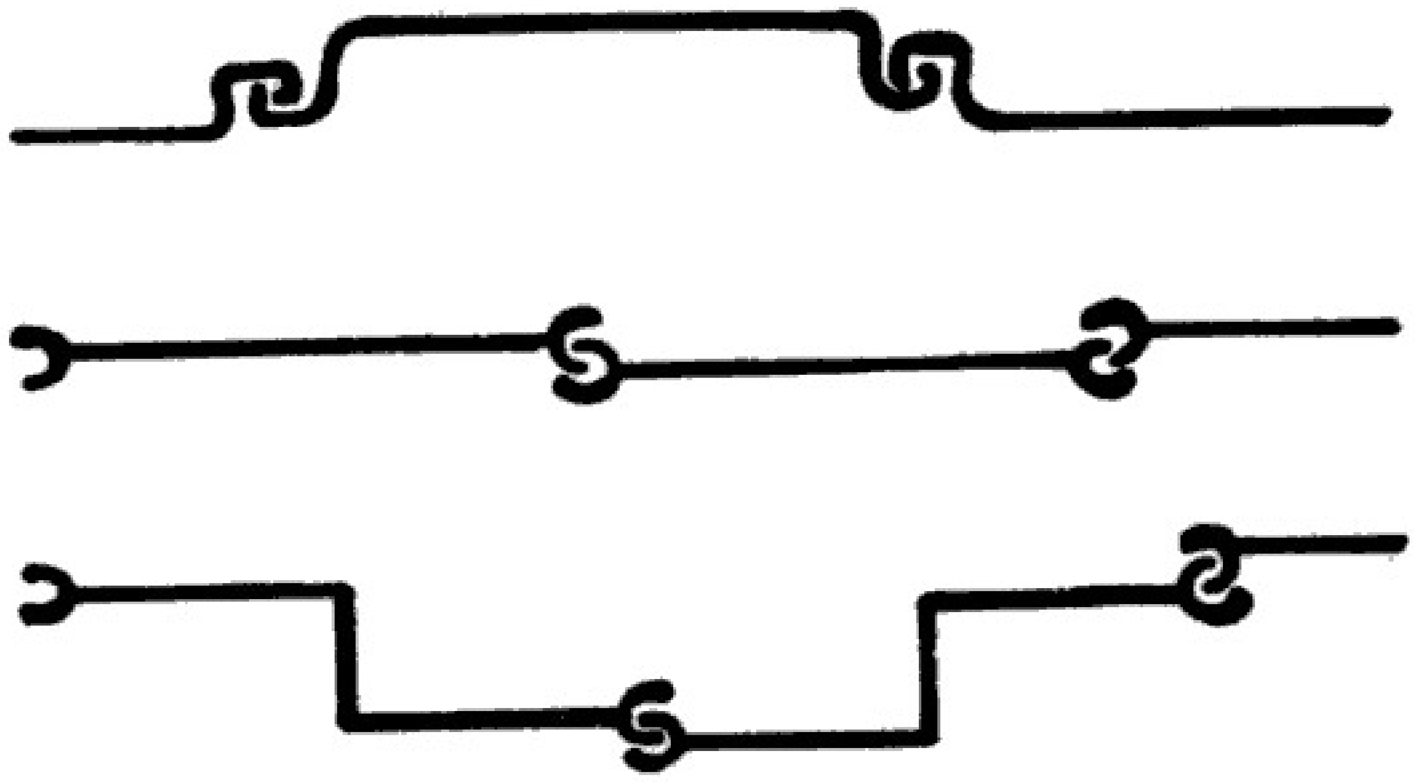


FIG. 4.31. STEEL SHEET PILES.

cm wide and 4 to 5 metres long. Fig. 4.31 shows some common forms of steel sheet piles.

4.20. COFFER DAMS

A coffer dam is a temporary enclosure in a river, lake etc. built round a working area for the purpose of excluding water during construction. During the construction period, a certain amount of pumping is constantly needed because some water will leak through the coffer dam and the foundation. A coffer dam may be made of earth materials, timber or steel sheet piling, or a combination thereof. The following are some of the common types of coffer dams:

1. Cantilever sheet pile coffer dam
2. Braced coffer dam
3. Embankment protected coffer dam
4. Double wall coffer dam
5. Cellular coffer dam.

These are shown in Fig. 4.32.

Cantilever sheet pile coffer dams are suitable for small heights, since these are susceptible to large leakage and flood damage. Braced coffer dams are economical for small to moderate height. For earth embankment type coffer dams, there is no height limitation, but since they occupy large base area, they are adopted only when the area to be excavated is very large. Double wall coffer dams are suitable for moderate height, while cellular coffer dams are suitable for moderate and large heights. A cellular coffer dam consists of a series of adjoining cells of circular or other curved shape, made of sheet piling. Each cell is huge vertical cylinder, 9 to 12 m in lateral dimension, and is filled with rock gravel and sand.

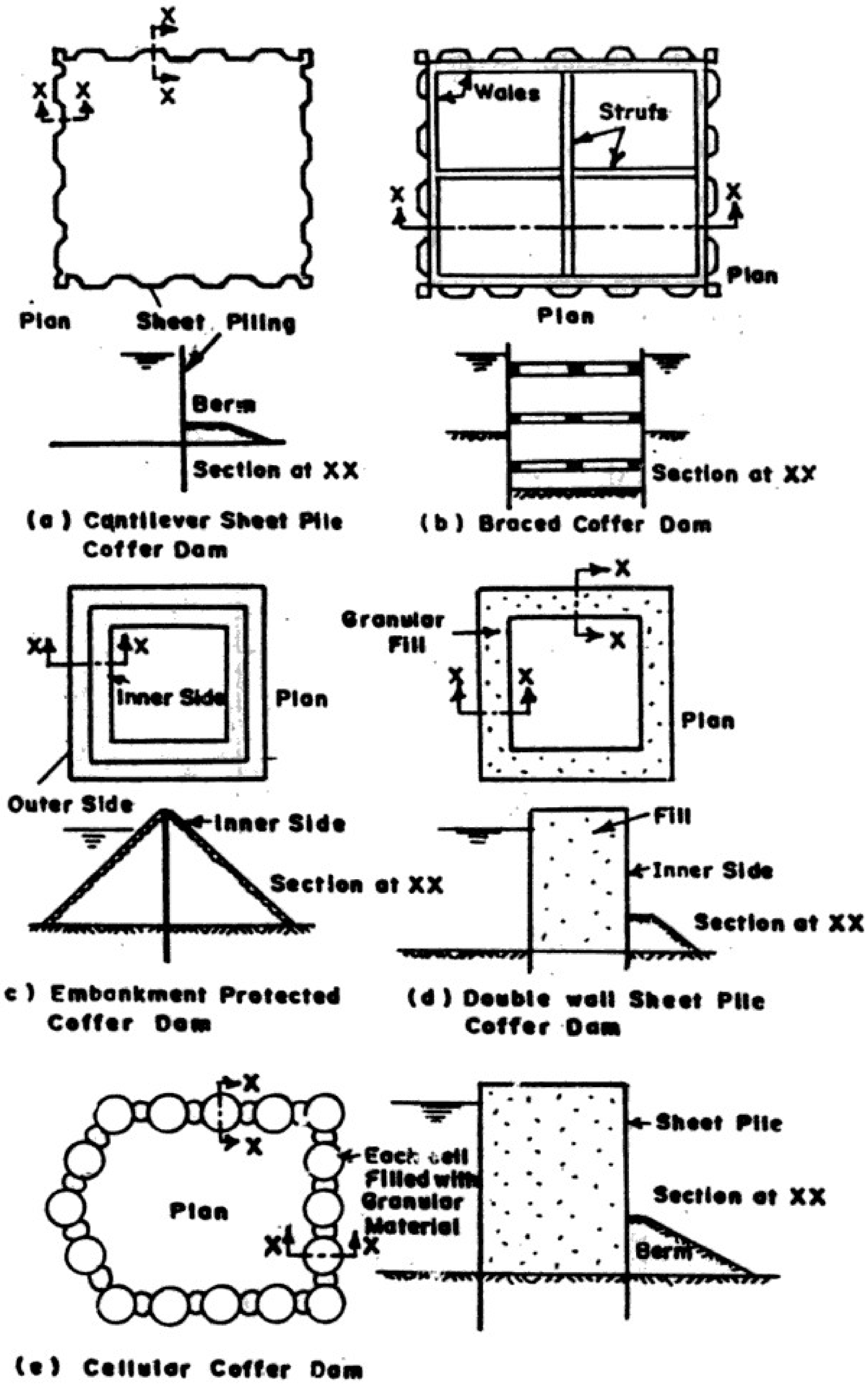


FIG. 4.32. COMMON TYPES OF COFFER DAMS.

4.21. CAISSONS : WELL FOUNDATIONS

The term 'Caisson' is derived from French word, *caisse* meaning a chest or box. Caisson has come to mean a box like structure, round or rectangular, which is sunk from the surface of either land

(a) Concrete sheet piles

Concrete sheet piles are reinforced, precast units. The width of each unit may vary from 50 cm to 60 cm and thickness varies from 2 cm to 6 cm. Fig. 4.29 shows typical sheet piles with proper jointing arrangements. For important works, pre-stressed pre-cast concrete sheet piles are used.

(b) Timber sheet piles

These are used only for temporary work. The width of the sheet may vary from 225 to 280 mm, while thickness should not be less than 50 mm. They may be jointed by either butt or V-joints. Their feet are bevelled, and some times shod with sheet iron.

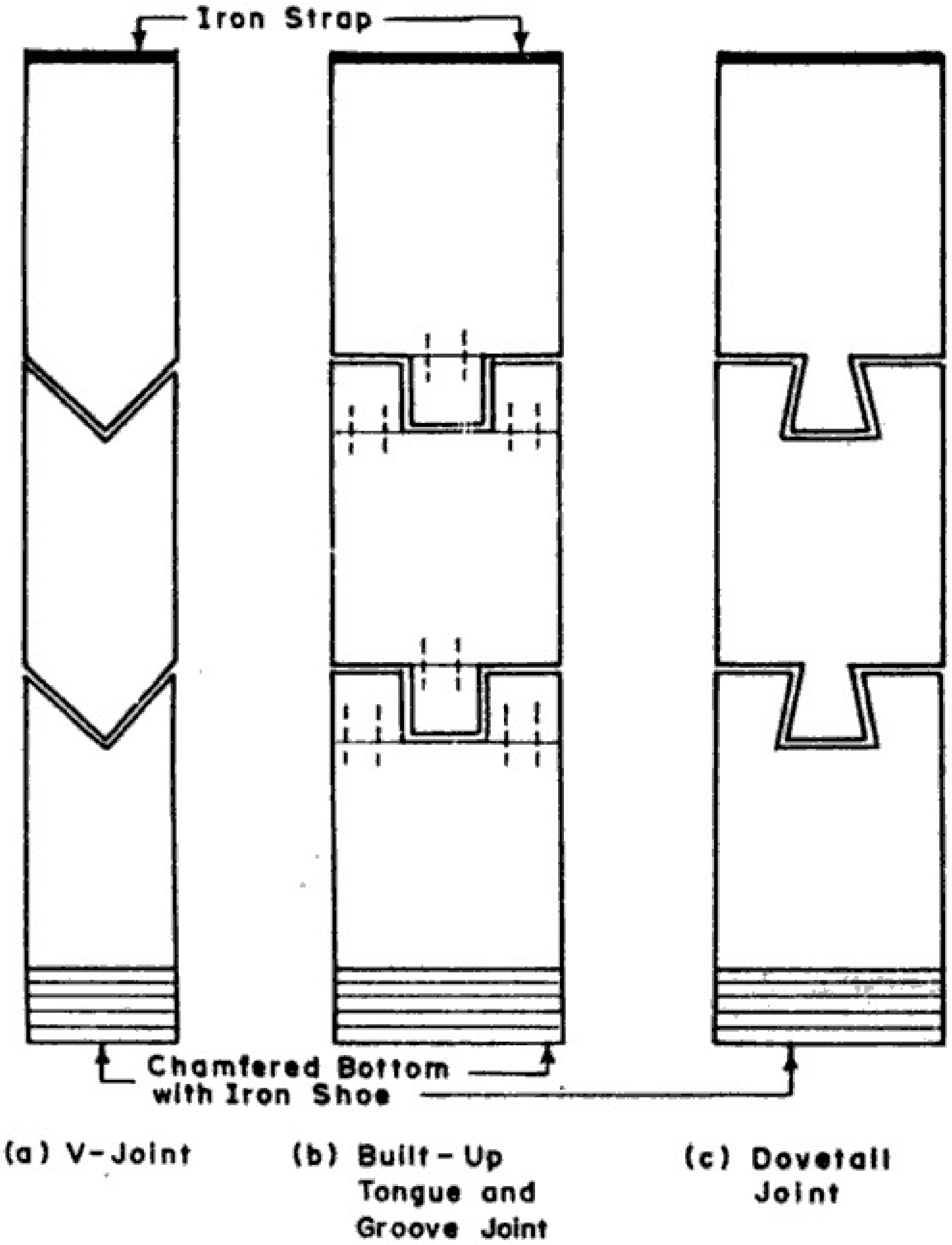


FIG. 4.30. TIMBER SHEET PILES.

(c) Steel sheet piles.

Steel sheet piles are most commonly used. They are trough shaped and, when driven, the piles are interlocked with alternate ones reversed. Sheet piles are available in different shapes, under different trade names. These are made from steel sheets 20 to 30 position. Such a type of caisson is used where bearing stratum is available at shallow depth, and where loads are not very heavy. Closed box caissons are used for break waters and sea walls.

Fig. 4.33 shows a box caisson of concrete. Before placing the precast, launched caisson, a level bearing surface is prepared by dredging or by the divers. Sand filling is usually done to achieve this. The launched caisson is then sunk, by filling it with suitable material, usually sand or gravel. The top of the caisson is sealed.

2. Open caissons (Well foundation).

An *open caisson* is a box of timber, metal, reinforced concrete or masonry which is open both at the top and at the bottom, and is used for building and bridge foundations. Open caissons are called *wells*. *Well foundation* form the most common type of deep foundations for bridges in India.

Whenever considerations for scour or bearing capacity require foundations being taken to a depth of more than 5 to 7 metres, open excavations become costly and uneconomical, as heavy timbering has to be provided. Also, because of the greater earthwork involved due to side slopes, the progress of work in open excavation will be very slow. Another disadvantage in adopting the ordinary type of footing is that excavated material refilled around the structure is loose and hence easily scourable as compared to natural ground. The above disadvantages are avoided in a well foundation which is a shell sunk by dredging inside of it and which finally becomes a part of the permanent structure.

Shapes of wells and component parts

The common types of well shapes are as follows (Fig. 4.34):

(1) Single circular
(2) Twin circular
(3) Dumb well
(4) Double-D
(5) Twin-hexagonal
(6) Twin-octagonal
(7) Rectangular.

The choice of a particular shape depends upon the dimensions of the base of the pier or abutment, the care and cost of sinking, the considerations of tilt and shift during sinking and the vertical and horizontal forces to which the well is subjected. A circular well has the minimum perimeter for a given dredge area and hence the ratio of sinking effort to skin friction is maximum. Also, since the perimeter is equidistant at all points from the centre of the dredge hole, the sinking is more uniform than for other shapes. However, the disadvantage of a circular well is that in the direction parallel to the span of the bridge, the diameter of the well is much more than the minimum size required to accommodate the bridge pier and hence the circular well causes more obstruction to waterway

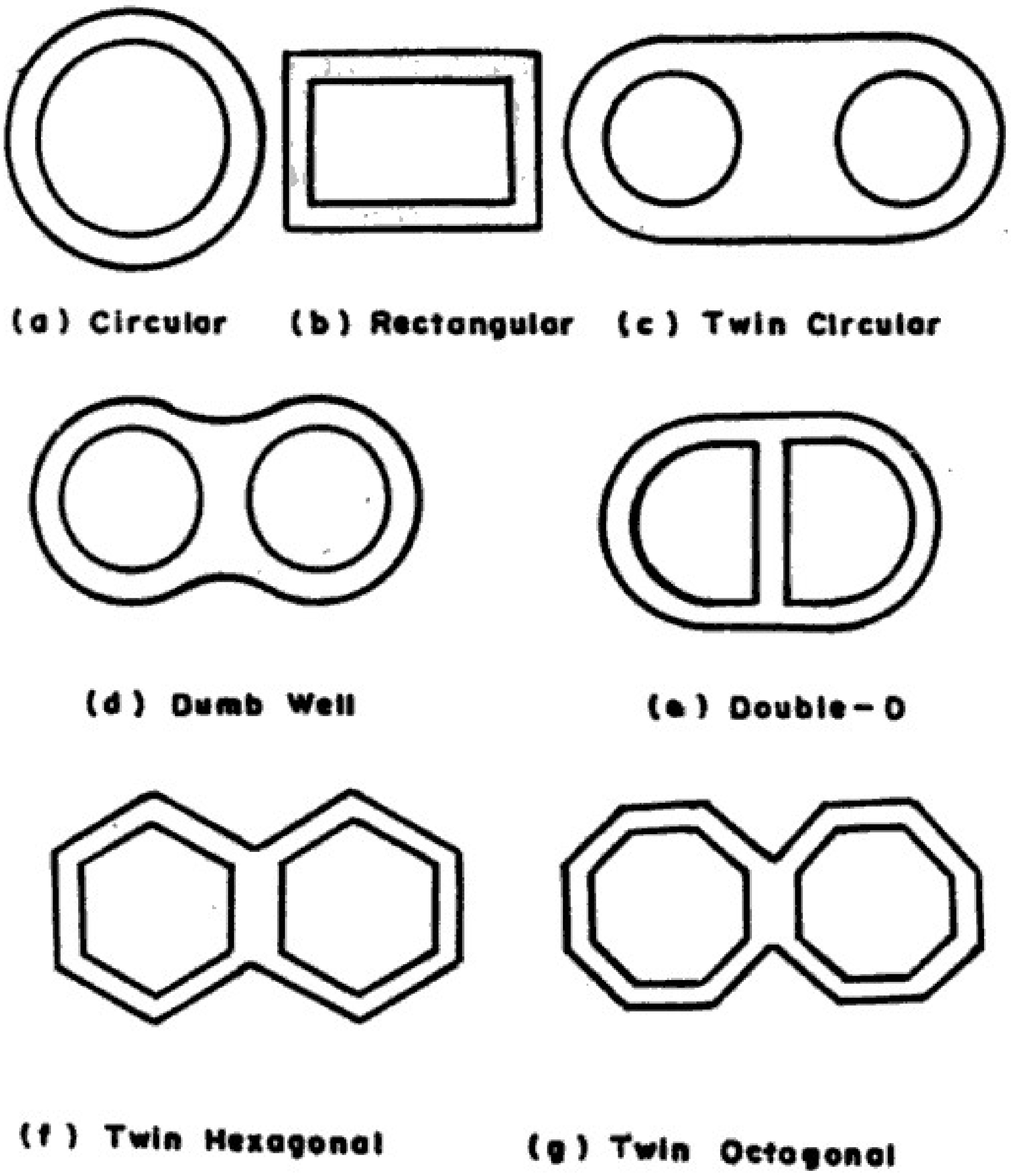


FIG. 4.34. SHAPES OF WELLS.

than the bridge pier does. This disadvantage is avoided in the case of a double-D shape which conforms to the shape of the bridge pier in plan. The dredge area is smaller for double-D. Hence for large piers, a double-D is more economical than a single circular well. Twin circular well aim at combining the advantage of a circular well and of a double-D, but the only snag is that the two wells sunk close to each other have a tendency to close in or move apart. However, in abutments and wing walls where the tilt and shift in position are not important, a battery of small diameter wells.

Fig. 4.35 shows a typical section of a well foundation with its component parts. The following components of a well have to be considered in the design of a well foundation :

(*i*) Well curb and cutting edge

or water to some desired depth. Caissons are of three types:

(*i*) Box caissons

(*ii*) Open caissons (wells)

(*iii*) Pneumatic caissons.

1. Box Caissons

A box caisson is open at top and closed at the bottom and is made of timber, reinforced concrete or steel. This caisson is built on land, then launched and floated to pier site where it is sunk in

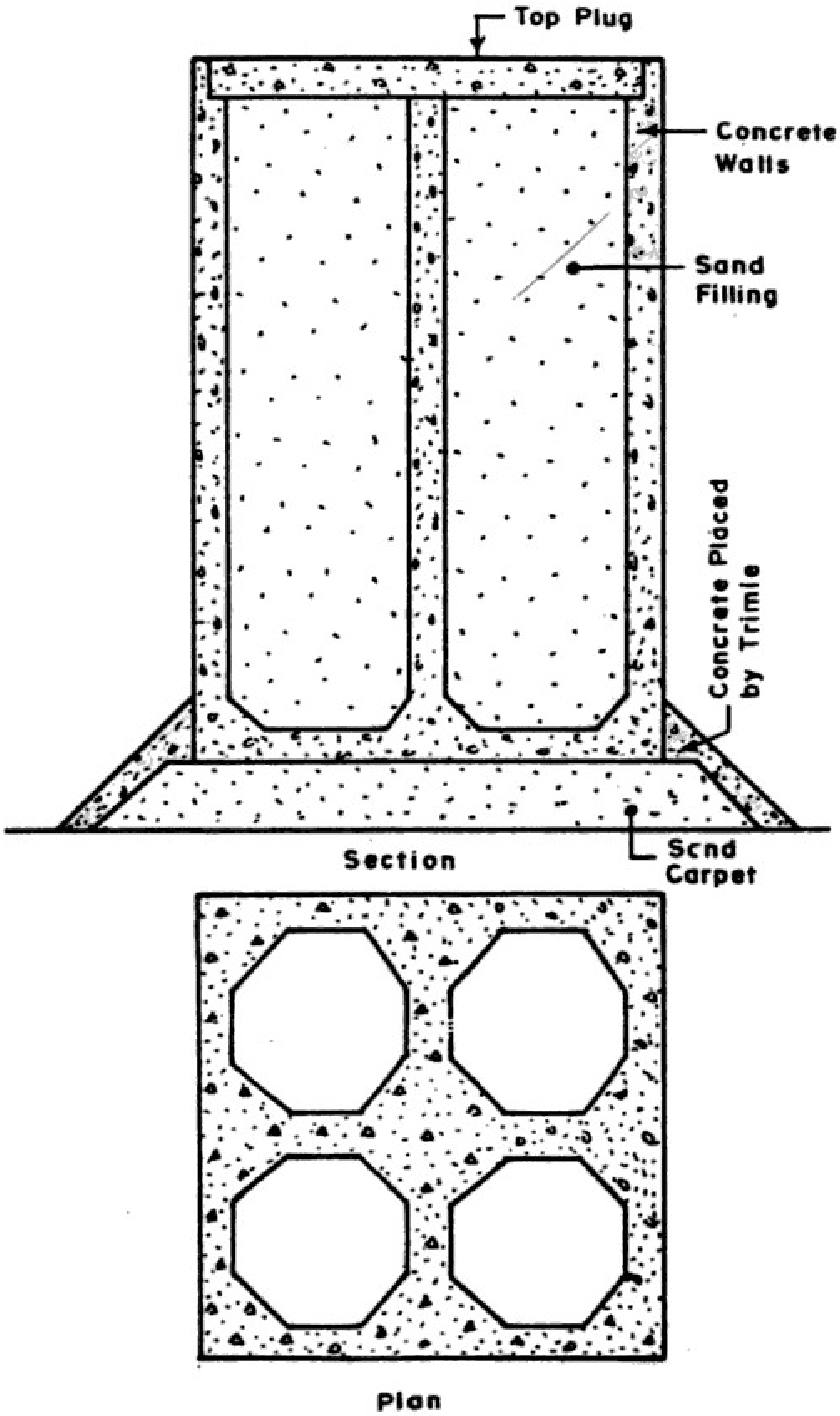


FIG. 4.33. BOX CAISSON (CONCRETE).

(ii) Cutting edge

The cutting edge should have as sharp an angle as practicable for knifing into the soil without making it too weak to resist the various stresses induced by boulders, blows, blasting etc. An angle to the vertical of 30°, or a slope of 1 horizontal to 2 vertical has been found satisfactory in practice. In concrete caissons, the lower portion of the cutting edge is wrapped with 12 mm steel plates which are anchored to the concrete by means of steel straps. A sharp vertical edge is generally provided along the outside face of the caisson. Such an edge facilitates the rate of sinking and prevents air leakage in the case of pneumatic caissons.

(iii) Steining

The thickness of steining is designed in such a way that at all stages the well can be sunk under its own weight, as the need for weighting with kentledge takes time and retards progress considerably. The following values are usually adopted

Outside dia. of well	*Steining thickness*
3 m	0.75 m
5 m	1.20 m
7 m	2.00 m

(iv) Bottom plug

The bottom plug of concrete has to be designed for an upward load equal to the soil pressure (including the pore water pressure) minus self weight of the bottom plug and filling. The bottom plug is made bowl-shaped so as to have inverted arch action. As generally under-water concreting has to be done for bottom plug, no reinforcement can be provided.

Well sinking operations

1. ***Laying the well curb***

If the river bed is dry, laying of well curb presents no difficulty. In such a case, excavation upto half a metre above subsoil water level is carried out and the well curb is laid. If, however, there is water in the river, suitable coffer dams are constructed around the site of the well and islands are made. The sizes of the island should be such as to allow free working space necessary to operate tools and plane for movement of labour etc. When the island is made, the centre point of the well is accurately marked and the cutting edge is placed in a level plane. It is desirable to insert wooden sleepers below the cutting edge at regular intervals so as to distribute the load and avoid setting of the cutting edge unevenly during concreting. These sleepers are, however, removed once the shuttering of the well curb has been stripped off. The inside shuttering of the curb

(*ii*) Steining
(*iii*) Bottom plug
(*iv*) Well cap.

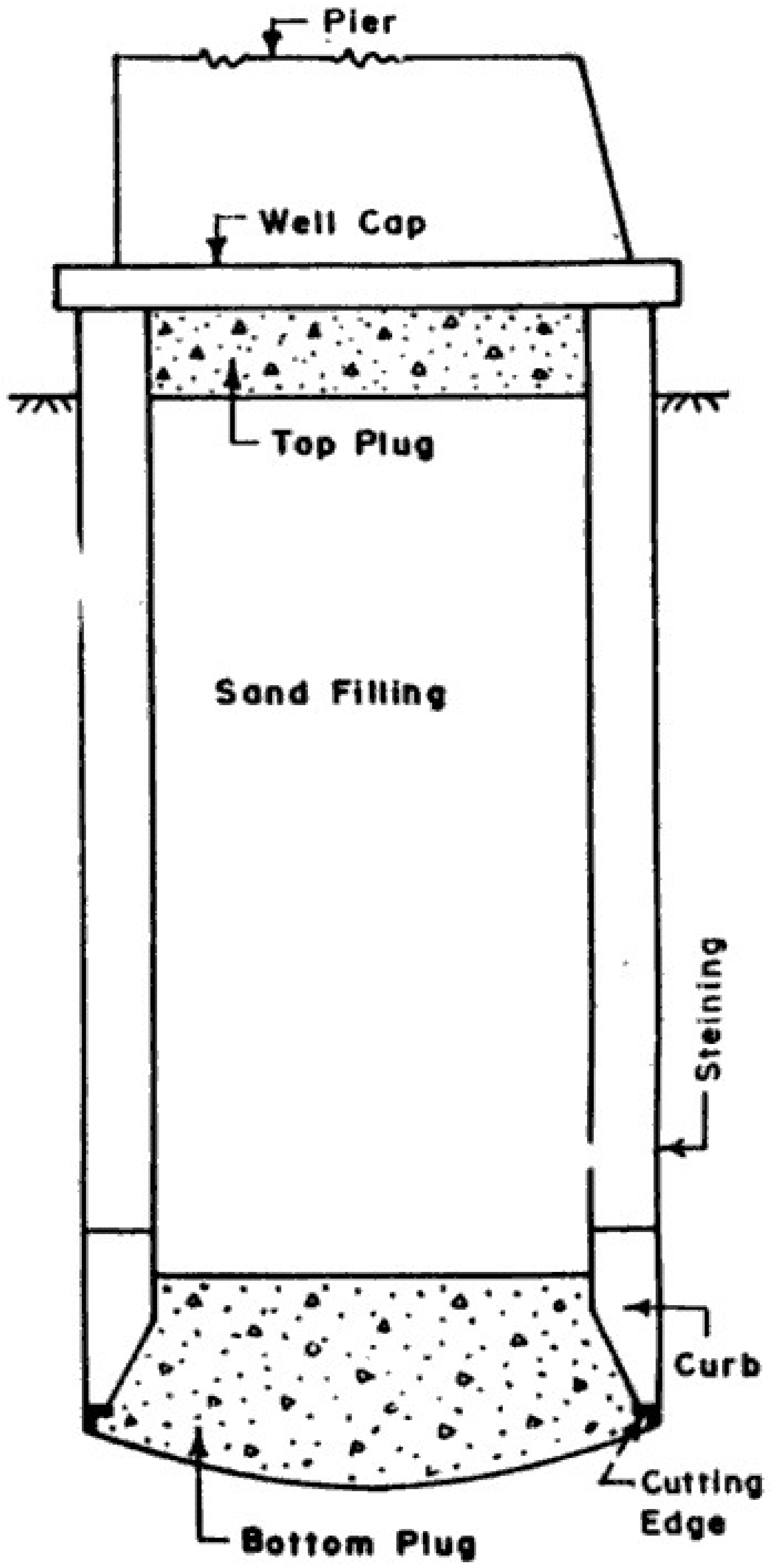


FIG. 4.35. SECTION OF A WELL FOUNDATION.

(*i*) ***Well curb.***

The well curb is designed for supporting the weight of the well with partial support at the bottom of the cutting edge, i.e., when only part of the cutting edge is in contact with soil and the remaining portion is only held by skin friction. A three point support of the cutting edge resting on a log may be assumed for design purposes. The load coming on the well curb is uncertain as considerable part of it is borne by skin friction. The well curb has also to withstand stresses due to *sand blows* as well as due to light blasting required when boulder obstruct the sinking of the well.

If maximum air pressure is limited to 3.5 kg/cm^2 , the limiting head of water is given by

$$h_{lim} = \frac{3.5}{0.1} = 35 \text{ m.}$$

This is the maximum value. However, pneumatic Caissons are adopted *only* if the head of water is more than 12 m. Thus a pneumatic Caissons can be used for depths of water ranging from 12 to 35 m.

Sinking of pneumatic Caissons is tedious, time consuming and expensive. However, theser are adopted at places where it is difficult to use bulky equipment required for sinking wells. Another advantage of pneumatic caissons is that the entire process of sinking of well is carried out under controlled conditions. It affords easy inspection of work.

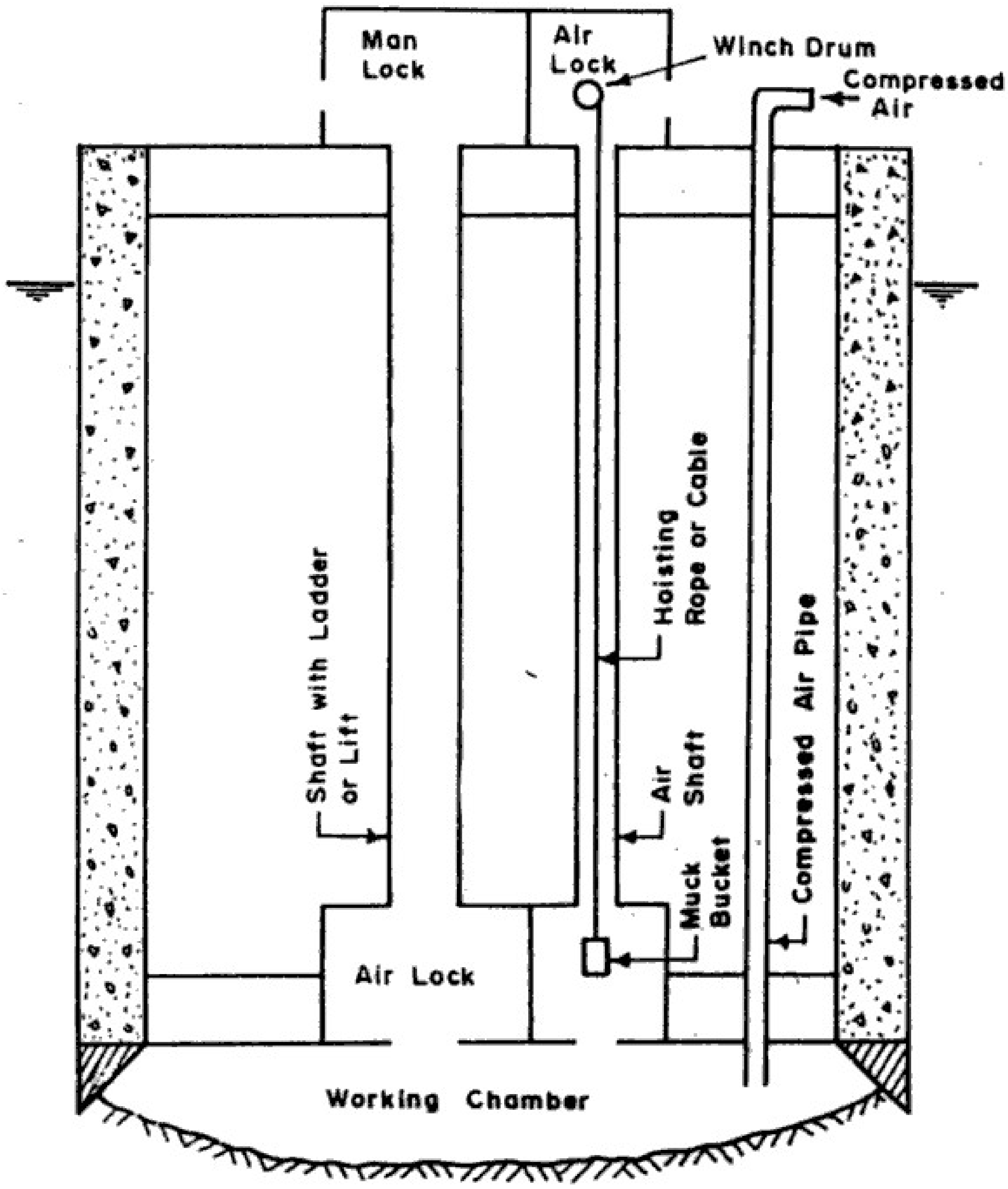


FIG. 4.36. SECTIONS OF A PNEUMATIC CAISSON.

Fig. 4.36 shows a typical section of a pneumatic Caisson. The

29. What is a coffer dam ? Where do you use it ? With the help of sketches, explain in brief various types of coffer dams.

30. What is a box caisson ? When do you use it ? Explain the method of installing a box caisson.

31. Explain, with the help of a sketch, the components of a well foundation. How do you construct a well curb ?

32. Write a note on well sinking operations.

33. With the help of a neat sketch, explain the method of sinking a pneumatic Caisson. What is the optimum depth under water upto which you can sink a pneumatic Caisson ?

upon which masonry courses are laid. Joints perpendicular to the face of the wall is known as *cross-joint or vertical joints*. All joints are formed in cement mortar, lime mortar or mud mortar. A joint which is parallel to the face of the wall is known as wall joint.

16. Closer. It is the portion of brick cut in such a manner that its one long face remains uncut. Thus, a closer is a header of small width.

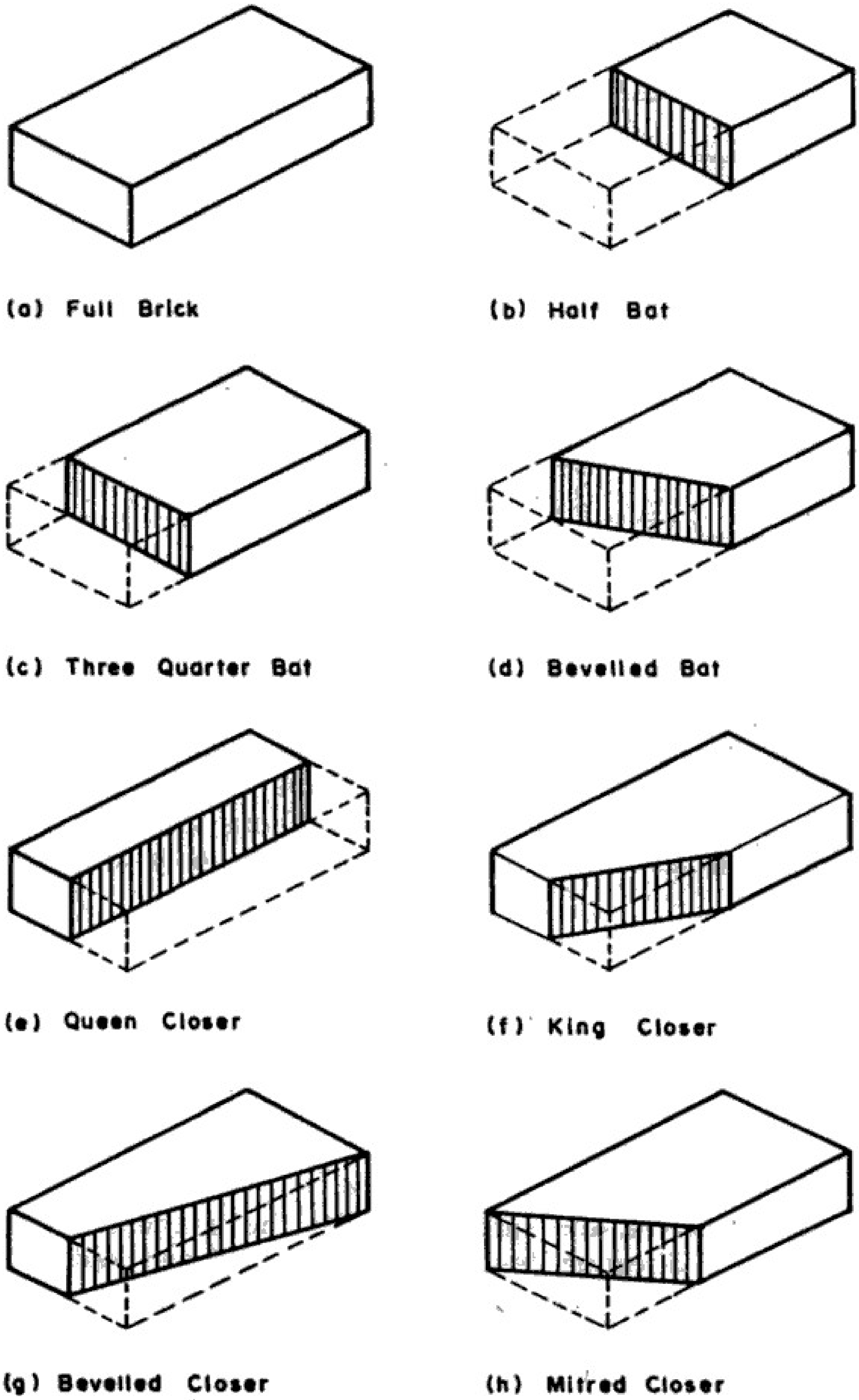


FIG. 5.2. VARIOUS FORMS OF BRICK PORTIONS.

the cornice, along the external face of the wall, intended to improve the appearance of the wall.

41. Blocking course. It is another course of stone placed immediately above the cornice. Apart from improving the appearance of the wall, it adds to the stability of the cornice against overturning.

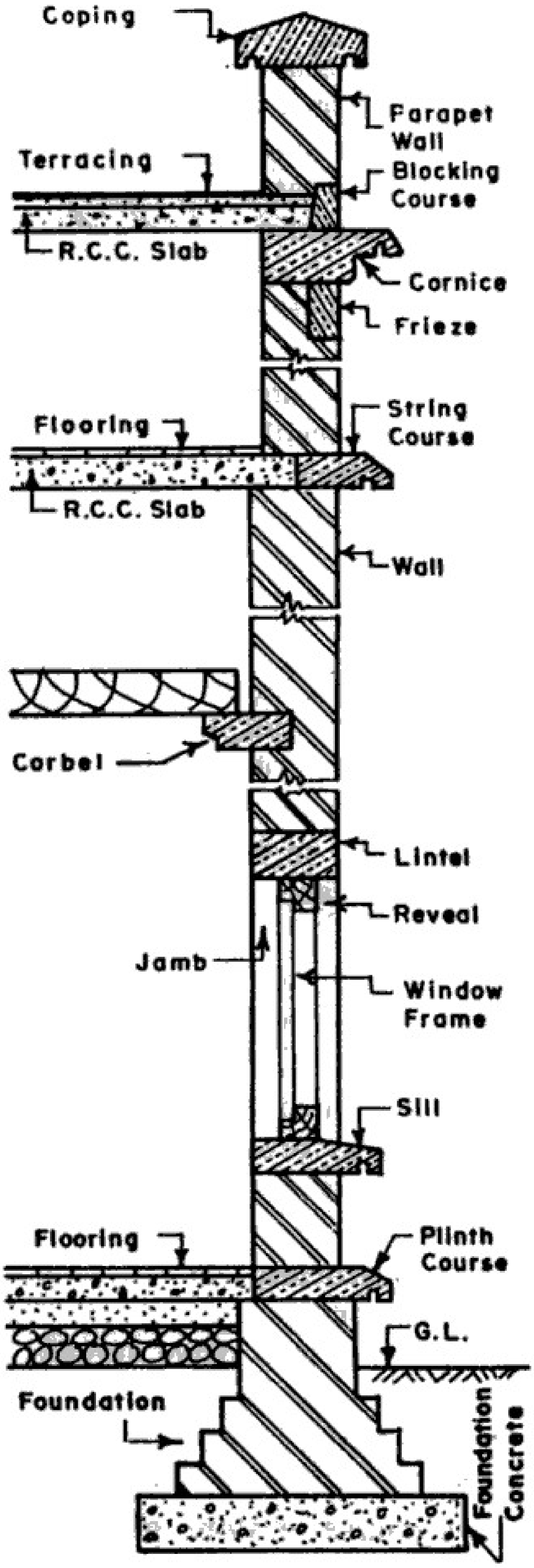


FIG. 5.6. SECTION THROUGH A WALL.

subsequently hardened by pressure. The principal building stones in this group are *lime stones* and *sand stones.*

Lime stones. They consist of particles of carbonate of lime cemented together by a similar material. These are used in floors, steps and walls.

Sand stones. These are composed of consolidated sand and consist chiefly of grains of quartz (silica) united by cementing material. Sand stone is the most widely used building stone for steps, facing work, columns, walls etc.

3. Metamorphic rocks. These rocks form a group which embraces either igneous or sedimentary rocks which have been changed from their original form (or metamorphosed) by either pressure, or heat, or both. The common building stones that fall under this category are *slates and marbles. Slates* easily spilt along natural bedding planes. They are not very suitable for masonry work. They are used for roofing work, sills, damp-proof course etc. *Marbles* can take fine polish. Since they are costly, they are not used for masonry work.These are used for flooring, facing work, steps, ornamental work etc. Marbles can be easily sawn and carved.

Table 5.4 gives the recommendations for use of different types of stones for different purposes.

TABLE 5.4
RECOMMENDATIONS FOR TYPE OF STONES TO BE USED

Purpose	*Type of stone to be used*
1. Heavy engineering works such as docks, break waters, bridges, piers, etc., carry high intensity of pressure.	Fine grained granite and gneisses.
2. Masonry work in industrial area, exposed to smoke and chemical fumes.	Granite, compact sand stone, and quartzite
3. General building work.	Lime stone and sand stone.
4. Face work of buildings.	Marble, granite and closed grained sand stone
5. Carvings and ornamental work.	Marble, laterite and soft sand stone.
6. Pavings, door sills, steps.	Slate, sand stone, marble.
7. Fire resistant masonry.	Compact sand stone.

5.4. CLASSIFICATION OF STONE MASONRY

Depending upon the arrangement of stones in the construction, degree of refinement used in shaping the stone and finishing adopted, stone masonry can be classified as follows :

height of the larger stones, to complete the course.

5. Square rubble : Regular coursed

In this type of masonry, the wall consists of various courses of varying heights, but the height of stones in one particular course is the same.

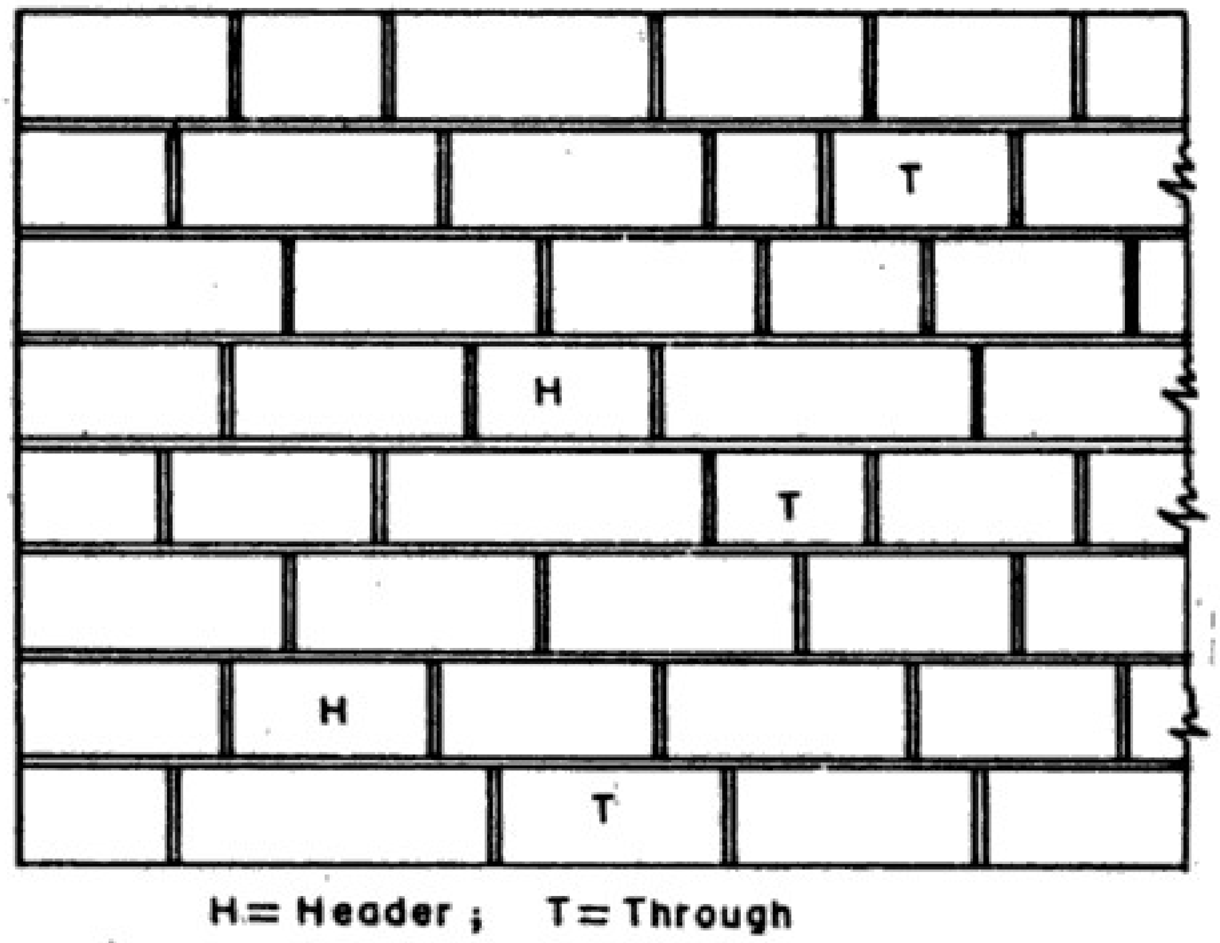


FIG. 5.18. SQUARE RUBBLE : REGULAR COURSED.

6. Polygonal Walling (Polygonal rubble masonry)

In this type the stones are hammer finished on face to an irregular polygonal shape. These stones are bedded in position to show face joints running irregularly in all directions. Two types of polygonal walling may be there : in the first type the stones are only roughly shaped, resulting in only rough fitting. Such a work is known as *rough picked*. In the second type, the faces of stones

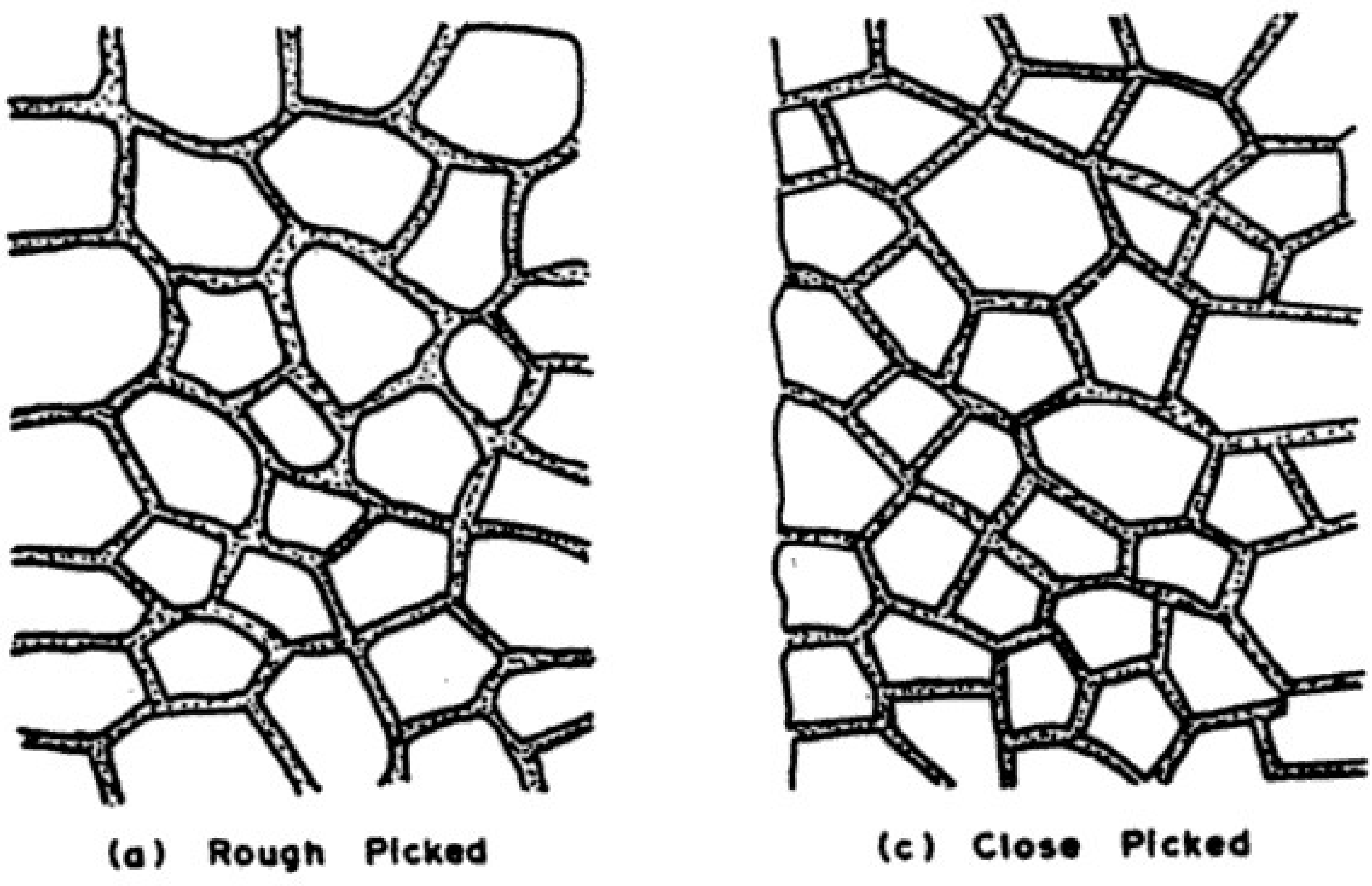


FIG. 5.19. POLYGONAL RUBBLE MASONRY.

kept rock faced except that large bushings in excess of 80 mm projections are removed by a hammer.

5. Ashlar block in course

This type of masonry is intermediate between rubble masonry and ashlar masonry. The faces of each stone are hammer dressed, and the height of blocks is kept the same in any course, though it is not necessary to keep uniform height for all the courses. The vertical joints are not as straight and as fine as in ashlar masonry. The depth of courses may vary from 15 to 30 cm. This type of masonry is adopted in heavy works such as retaining walls, bridges etc.

6. Ashlar facing

Ashlar facing masonry is provided along with brick or concrete block masonry, to give better appearance. The sides and beds of each block are properly dressed so as to make them true to shape. The exposed faces of the stone are rough tooled and chamfered. The backing of the wall may be made in brick masonry.

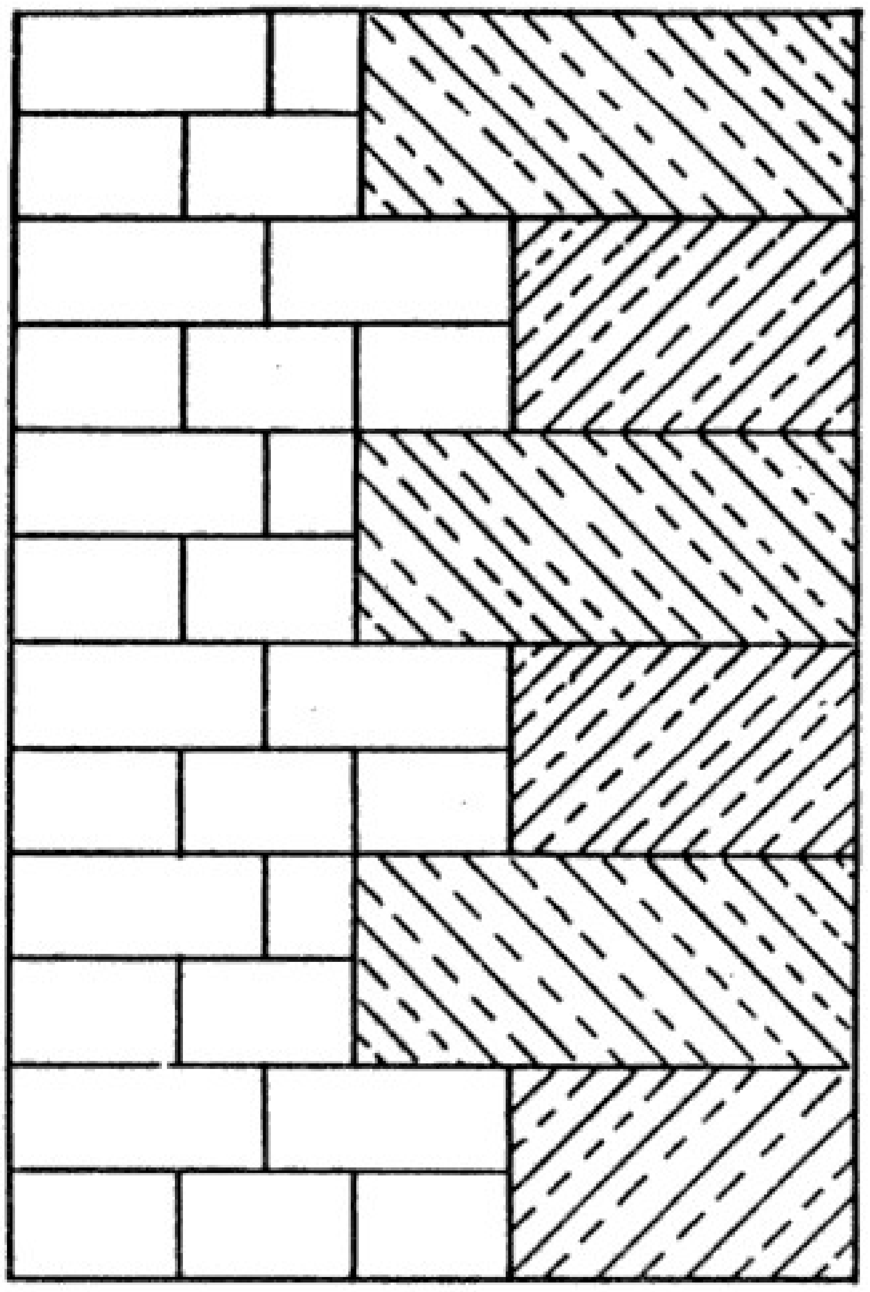


FIG. 5.23. ASHLAR FACING MASONRY.

5.5. DRESSING OF STONES

The surfaces of stones obtained from quarry are rough. The blocks are irregular in shape and non-uniform in size. Hence their dressing is essential. The dressing of stones is sometimes done at the quarry itself because freshly quarried stones are soft due to the moisture (called *quarry sap*) contained by them. The local workers

2. Scabbling finish

This is type of rough dressing in which the irregular projections are removed by a scabbling hammer.

3. Hammer-dressed finish (Fig. 5.26 *b*)

The stone blocks are made roughly square or rectangular by means of Waller's hammer. The exposed face is roughly shaped by means of a mash hammer. The beds and joints are dressed back some 75 to 100 mm from the face. This is done by using the square to mark the boundaries and using pitching tools along the boundaries.

4. Axed finish

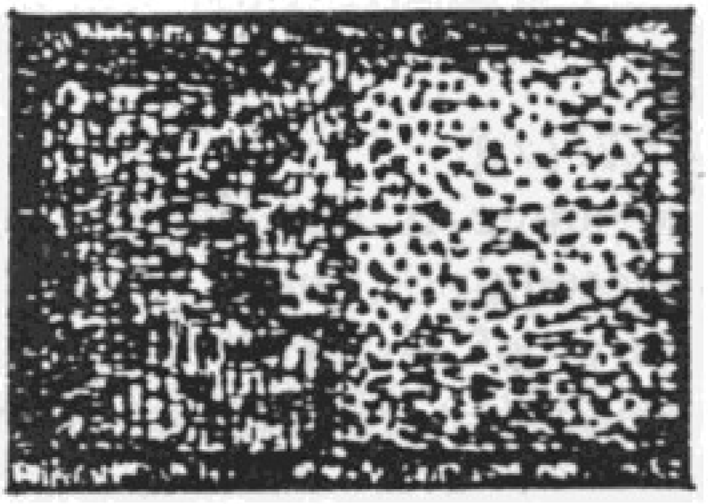
This type of finishing is used in hard stones like granites, where the dressing is done with the help of an axe.

5. Punched, Broached or Stugged finish (Fig. 5.27 *a*).

This is another form of rough dressing, usually used for lower portions of the buildings. The exposed face of the stone is dressed with the help of a punch, thus making depressions or punch holes on at some regular distance (say 25 mm) apart. A 25 mm wide strip is made around the perimeter of the stone with the help of chisel.

6. Picked finish (Fig.5.27 *b*)

This is similar to the above except that a point is used in the place of punch, thus forming small pits on the exposed face.


(a) PUNCHED FINISH

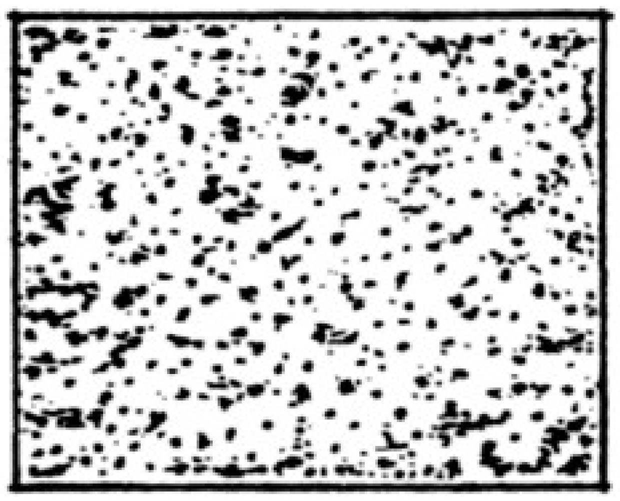

(b) PICKED FINISH

FIG. 5.27

7. Boasted or Droved finish (Fig 5.28 *a*)

In this, the dressing is done with the help of a boaster and hammer, forming a series of 38 to 50 mm wide *bands* of more or less parallel tool marks, which cover the whole surface. These marks may be horizontal, vertical or inclined at 45°.

8. Tooled or Batted finish (Fig. 5.28 *b*)

This type of dressing is done as a further step to boasting. After having boasted the surface, a series of continuous and parallel fine chisel lines are formed with the help of batting or broad tool. *This is common dressing for ashlar work.* The lines are deeper and continuous.

Fig. 5.32 shows the stages of assembling three legged lewis. A dovetailed hole is made first. The dovetailed steel pieces are then inserted in the hole. A rectangular steel piece is then inserted or driven between them. The shakle is secured to the three steel pieces by means of pin.

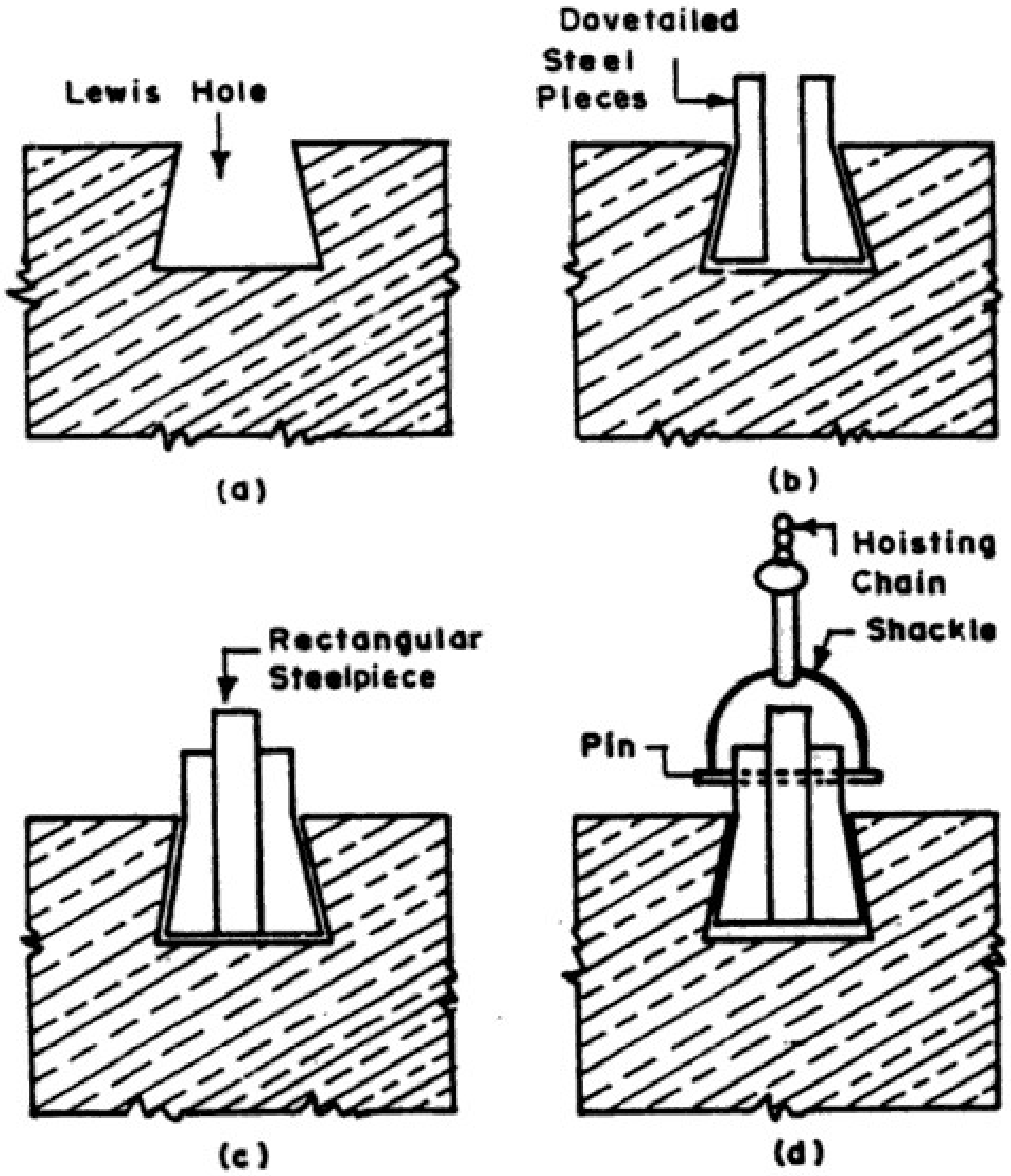


FIG. 5.32. USE OF THREE LEGGED LEWIS.

Fig. 5.33 shows a modified form of three legged lewis, which consists of a central wedge shaped piece and a frame. The wedge shaped piece or block can freely slide between the frame consisting of steel plates. When the stone is being lifted, the central wedge presses against the two sides of the frame.

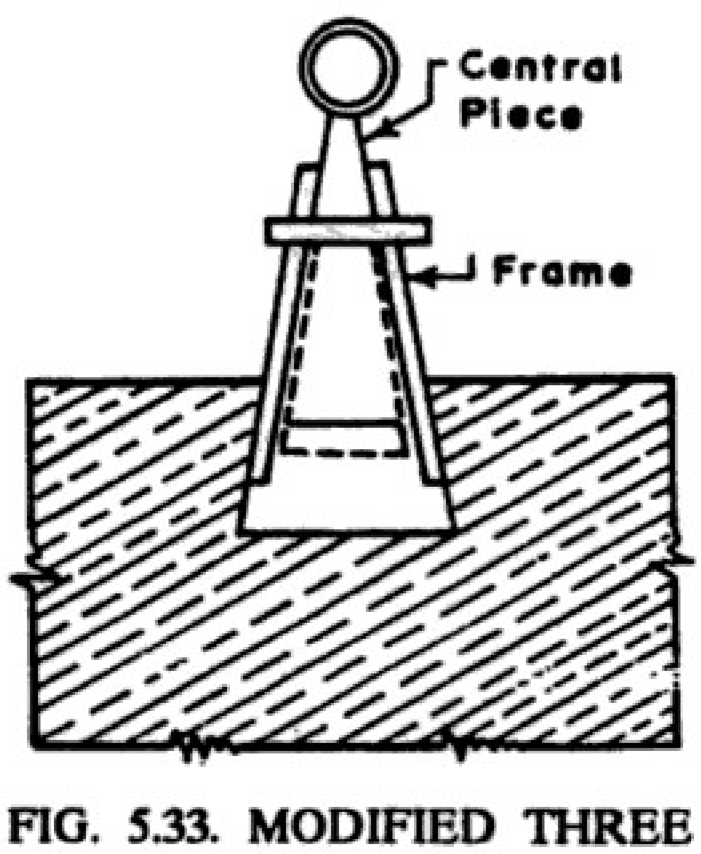


FIG. 5.33. MODIFIED THREE LEGGED LEWIS.

Fig. 5.34 shows a lewis for use under water. It consists of a wedge shaped piece (called plug) having one side vertical and another side inclined, and a straight key with a separate thin chain. The wedge is inserted first and the key is placed next. While lowering the stone in water, the chain of the key is kept slack. When the stone oc-

PROBLEMS

1. Discuss the comparative merits of various types of building units used for masonry.

2. Define the following terms :

Header ; stretcher ; bond ; quoin ; hearting ; closer ; perpend ; string course ; lacing course ; through stone and reveal.

3. Draw typical sketches, showing the following, constructed of stone masonry.

(*i*) Reveals
(*ii*) Corbel
(*iii*) Cornice
(*iv*) Jambs
(*v*) Coping
(*vi*) Threshold

4. (*a*) Distinguish between (*i*) wall (*ii*) pier (*iii*) buttress and (*iv*) column

(*b*) Draw a typical vertical section of a wall, through openings, and show various important elements of construction.

5. Explain in brief various types of mortars used in stone masonry.

6. What are the requirements of a good mortar ? How do you determine the consistency of mortar ?

7. Classify various types of stone masonry. Draw typical sketches to illustrate the same.

8. Write short notes on the following:

(*i*) Flint walling
(*ii*) Polygonal rubble masonry
(*iii*) Squaie rubble uncoursed masonry
(*iv*) Random rubble built to courses.

9. Enumerate various types of surface finishes used in stone masonry.

10. Write a note on various appliances used for lifting stones.

11. Explain, with sketches, various types of joints used in ashlar stone masonry.