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CONSTRUCTION OF SMALL BUILDINGS IN SEISMIC AREAS†

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Abstract

The general principles of earthquake resistant construction as evidenced by studies of damage and nondamage in various past earthquakes are first described. Then recommendations are given for constructing buildings in masonry and timber or tubular framework. Finally a few designs of small houses are presented which could be adopted for construction of houses in a seismic area.

Introduction

The Koyna earthquake of December 11, 1967 rocked the supposedly stable area of Maharashtra causing irrepairable damage to about 40.000 houses rendering lakhs of people homeless. The author visited the area along with two of his colleagues and prepared a report on the damages observed to the buildings and the prevalent construction in the area[1] and as a first step suggested an earthquake resistant design with timber or pipe supports for rebuilding the houses in Koynanager utilising the plinths, roof trusses and sheets of damaged buildings. However, necessity was felt to bring out detailed design of small earthquake resistant houses which could be constructed on a large scale out of readily available materials.

This paper presents the general principles of earthquake resistant construction, detailed specifications to be adopted for load bearing wall buildings and those using timber or pipe supports and bracing members. A few designs of small houses are also included which could be adopted for construction of houses in a seismic area.

General Principles Regarding Constructional Features

A study of the damage to buildings during past earthquakes indicates that following principles may be observed in the design and construction of buildings to make them earthquake resistant[2,3,4].

Materials : Since the earthquake force is mainly a function of mass besides the ground acceleration and the stiffness of the structure, a building should be constructed as light as possible, consistent with the structural safety and functional requirements. In particular, the roofs and upper storeys of the building should be built of light materials or of light construction as far as possible.

Continuity of Construction : It has been observed that a building having elements which bind the walls, columns and other structural components together has stood the

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earthquake shocks better. It would therefore, be of advantage to have the floor slabs continuous as far as possible. If precast beams and concrete slab units are used, they should be connected together by positive means like insitu concrete, welding of protruding reinforcement or bolting etc.

Overhanging Parts : Overhanging parts such as projecting cornices, balconies, parapets and chimneys are the first to fall during an earthquake. Not noly that there is damage to the building but such parts, when they fall, injure the people who are running out of the houses or moving on the streets. Such projecting and overhanging parts should be avoided as far as possible or enough care should be taken to reinforce them and anchor them to the main structure adequately.

Suspended Ceilings : Suspended ceilings often used for aesthetic reasons, are usually brittle and weak and incapable of resisting horizontal forces with the result that during an earthquake they crumble and fall down. Thus special care is required in the design of suspended ceilings if they cannot be avoided. They should be strong and rigidly tied to the roof or ductile enough to withstand the strains during ground motion.

Similarly, the plaster on the ceiling frequently falls down. The thickness of such plaster should be kept to a minimum.

Separation of Adjoining Structures : Adequate separation of adjoining structures (or the parts of the same structure) having different heights or rigidities is necessary to avoid damage due to out of phase vibrations during an earthquake resulting in hammering action between them.

Workmanship : All reports regarding the damage to structures during earthquakes have repeatedly pointed out that structures built with the same material and in the same manner but with different quality of workmanship have behaved differently. Those having better workmanship stood the earthquake shaking but those of poor workmanship, were shattered to pieces. Therefore, the greatest emphasis must be laid on good quality of workmanship in all construction.

Damage to Non-Structural Parts : During the past earthquakes it has sometimes happened that whereas the structural frame was strong enough to resist the earthquake forces, the non-structural elements like brick filling in a timber frame, which is not supposed to carry any other loads besides its own weight, have fallen out of the frame. Therefore it is necessary that the non-structural parts should be well tied to the structural framing. To avoid damage to window frames or grazing, the drift in buildings should also be limited.

Fire Safety : In the past damage to life and property has occurred due to fires, caused by short circuiting of electric wires or kitchen fires during earthquake. Mention may be made of San Francisco (1906) and Tokyo (1923) fires after earthquakes. Therefore, buildings should be constructed to be fire resistant and other safety precaution against fire should be taken.

Shape of Building : It has been observed that a building having simple squarish plan and symmetry both with respect to mass and stiffness fares much better during an earthquake than long narrow or irregularly shaped buildings. Buildings having E, U or L shape plans tend to develop cracks at junctions of various limbs. In such cases the building should be sectionalised into parts by providing separation sections so that each part becomes rectangular, its length not exceeding about three times the width. At such sections, a complete separation of the parts should be made except below plinth level. The plinth beams or foundaiion beams and the footings may be continuous.

If the two separated parts are dissimilar in their height or weight and rigidity, they may collide with each other during an earthquake and get damaged. Therefore a minimum gap of about 1.5 cm per storey should be provided between them. Such a gap may be suitably covered by fragile or collapsible cover in the form of absestor or metallic sheets, if so desired.

Foundations : In several earthquakes in India and abroad, liquefaction of soil, occurrence of sand fountains or settlement of soil has been observed leading to catastrophic failure of structures. Therefore soft alluvium and loose sands and low lying water logged ground should be avoided and foundations should be supported on hard and dense strata. Where poor situations are unavoidable, adequately tied and capped pile foundations should be employed for major buildings. For small buildings, continuous reinforced concrete strip footings may be used.

Roofs and Floors ; Light roofing materials have obvious advantage in reducing the inertia force at top of building. To avoid the dislodging of the roofing units, they should be tied to the supporting members. For roof coverings, corrugated iron, aluminium and asbestos sheets are preferable to earthen tiles, slates etc.

In order to check relative movement due to shaking, joists of timber, reinforced concrete or steel, where used to support individual flooring units like brick tiles and prefabricated doubly curved units should be restrained by blocking the space between them at their ends and by fixing bridging members at their midspan or third-span points. Likewise, steel beams supporting jack or flat arches should be tied together in each bay to restrain their lateral movement and retain the arch uncracked.

In this respect continuous reinforced concrete or brick slabs are better. They have the further advantage of providing affective binding effect on the walls and columns and may therefore be preferred.

Recommendations for Small Masonry Buildings

Seismic Zones : For the purpose of these recommendations, the area is assumed to be divided into the following seismic zones :

(a) Highly seismic having M. M. intensities IX and over, referred to as Zone A subsequently. Such intensities were not observed in Koya earthquake.

(b) Moderately seismic having maximum M. M. intensity of VIII, referred to as Zone B.

(c) Lightly seismic having maximum M.M. intensity of VI and VII, referred to as Zone C.

(d) Feebly seismic having maximum M. M. intensity of I to V referred to as Zone D.

No special precautions are required in zone D except good workmanship. Great care is of course needed in Zones A and B.

Materials of Construction : Well burnt bricks, hollow concrete blocks and squared stones of adequate strength should be used for masonry work. It has repeatedly been observed (Kapkote 1958, Anjar 1956, and Agadir 1960) that random rubble masonry is extermely weak against shaking and should generally be avoided. If economic and other condition compel its use, it may be used in zone C with the specifications that it is brought to courses at not more than 60 cm intervals and *through bond stones* are provided at a maximum horizontal spacing of 1.2 m in every levelling course and the height is not more than one storey. Its use should however be avoided in Zones A and B. The mortars[5] should not be leaner than those given in Table 1.

TABLE 1

Mortar Specification

S. No.	Cement	Lime	Sand	Surkhi*	
1	1	1	6	—	In Zone A
2	1	2	9	—	
3	1	–	6	—	In Zones A & C
4	–	1	3	—	
5	–	1	–	3	

* Brick powder or cinder

Wall: The height of load bearing masonry walls should preferably be restricted to about a maximum of three storeys. The minimum thickness of load bearing walls in different storeys may be kept as traditionally adopted. Suggested thicknesses are one unit thick (or 20 cm minimum) upto two storeys in height or for the upper two storeys of three storeyed building and 1½ unit thick (or 30 cm minimum) for the bottom storey of three storeyed building. These minimum thicknesses may be used when walls are connected to cross walls not more than 6 m apart. For larger spacing, thickness should be increased.

Openings in Bearing Walls : Studies carried out on the effect of openings[6] on the strength of walls indicate that they should be small and more centrally located. IS : 4326–1967 provides the following restrictions on the size and position of openings.

(a) The openings shall preferably be located away from the corner by a clear distance equal to at least 1/4 of the height of opening.

(b) The length of opening shall not be more than half the length of the wall between consecutive cross walls.

(c) The horizontal distance (pier width) between two openings shall not be less than 1/2 of the height of the shorter opening.

(d) The vertical distance from an opening to an opening directly above it shall not be less than 60 cm nor less than 1/2 of the width of the smaller opening.

(e) Where the openings do not comply with the requirements (a) to (d) they shall either be boxed in reinforced concrete alround or the reinforcing bars provided around them through the masonry. See Fig. 1.

Observations in past earthquakes show that use of arches to span across the openings is a source of weakness and shall be avoided unless steel ties are provided.

Bond Beams, Runners or Bands : For tying the various walls of a building so that the building acts as one unit at the time of an earthquake, runners or bands or reinforced concrete or reinforced brick work should be provided in all the load bearing walls at different levels as specified for each zone and type of construction. Such runner shall be called as *plinth band* when used at the plinth level; *lintel band* when used at the *lintel level*; roof band when used just below the roof or floor and *gable band* when used at the top of gable end below the purlins.

The plinth band may be made in M150 (1:2:4) or richer concrete, having a minimum thickness of 7.5 cm (sufficient for damp proofing), width equal to the thicknes of the wall above it and reinforced with two bars 10mm dia, one near each face of the wall held together with 6mm dia links provided every 20 cm. Such a band need not be provided where the soil is stiff having a bearing capacity 20 t/m^2 or larger.

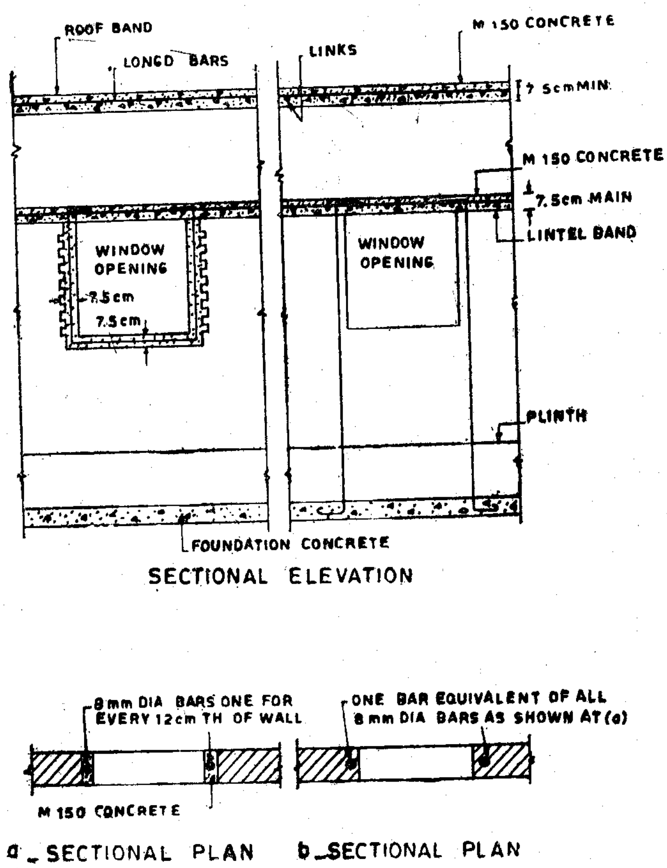


Fig. 1 Strengthening around openings.

The lintel band size depends upon the maximum span of the rooms and the design seismic coefficient. The width of the band may be kept not less than the thickness of the wall and minimum thickness, when of reinforced concrete, equal to the height of the masonry unit or multiple thereof. Alternatively the reinforcing bars may be located in the bedding joints, increasing the thickness of the joints so as to have a minimum mortar cover of 6mm alround the base. The sections of lintel band shown in Fig. 2 may be adopted for span of wall (distance between cross walls) of 6 m or smaller. For longer span the areas of longitudinal bars and links may correspondingly be increased.

The roof band need not be provided when floor or roof consists of reinforced concrete or reinforced brick slabs as they automatically bind the walls together and are capable of transmitting their inertial force to the shear walls. In other cases, sections similar to those of the lintel band may be adopted.

The gable band shall be provided on top of gable ends of walls and have the same section as the lintel band.

All bands shall have continuos connection at the corners and junctions of walls capable of developing positive and negative moments, fig. 3 shows typical details.

Vertical Reinforcemet in Walls : Use of vertical reinforcement in walls is desirable for increasing the strength of building against horizontal loads and for imparting ductility to them thereby increasing their energy absorbing capacity. For reasons of economy and ease of construction, vertical reinforcement may be provided at the critical sections only, that is, corners and juctions of walls and jambs of openings.

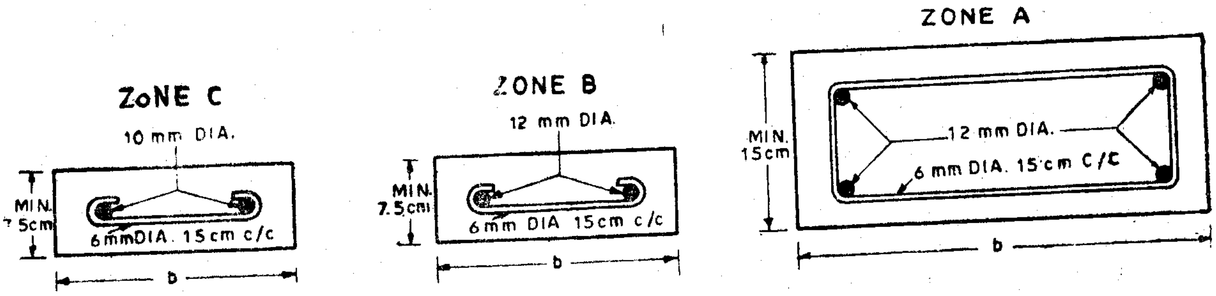


FIG. 2 -CROSS SECTIONS OF REINFORCED CONCRETE LINTEL BANDS (MAX SPAN OF WALL 6m)

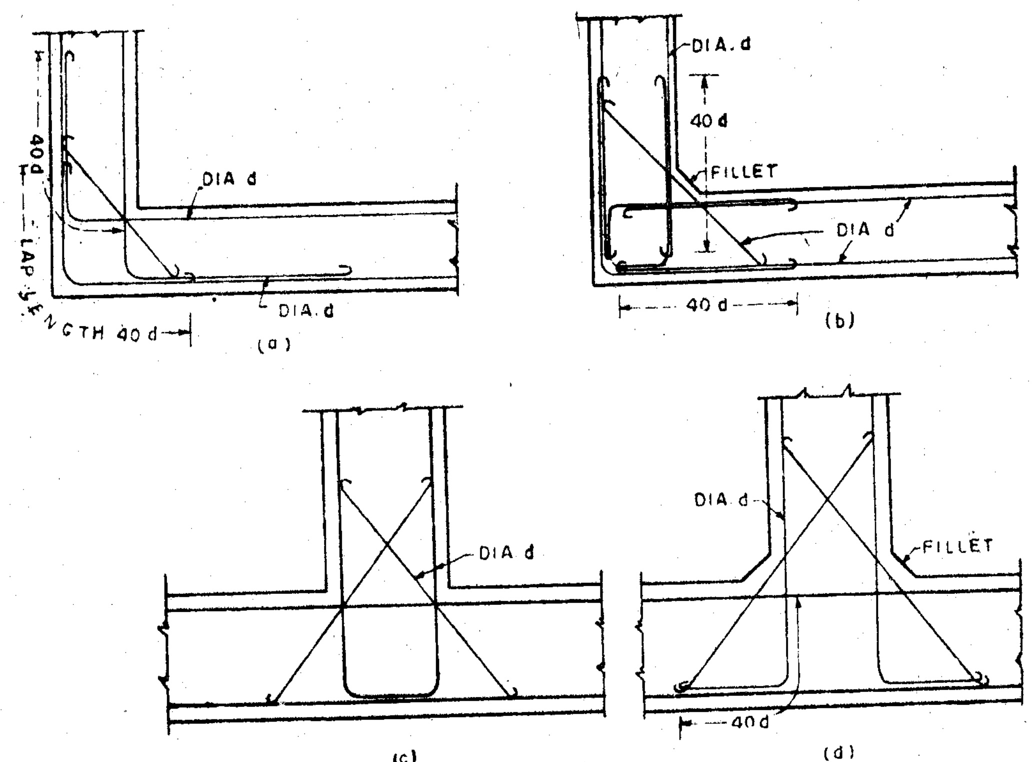
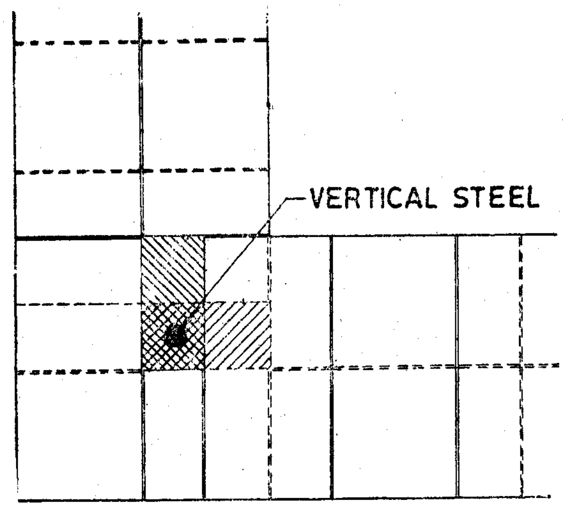


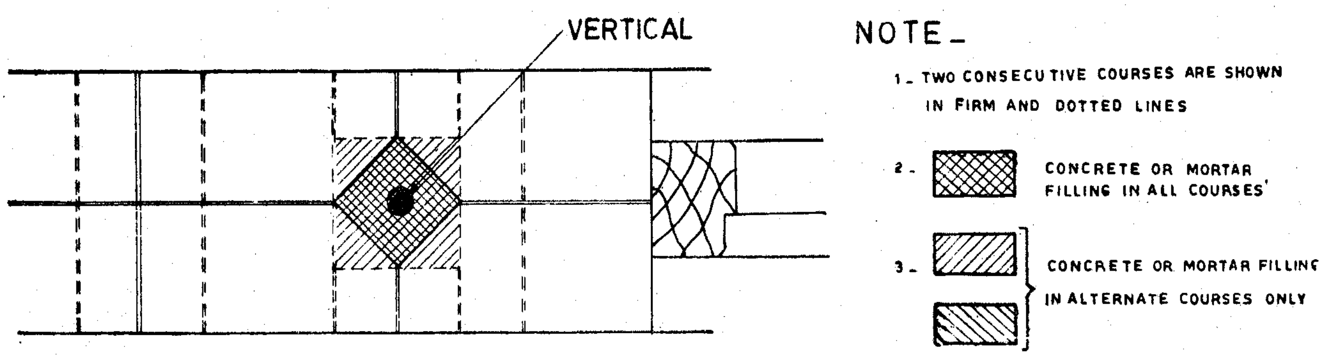
Fig. 3. Band reinforcement detail at corner and junction of walls

No vertical steel need be provided in zone C except where openings require it as discussed earlier.

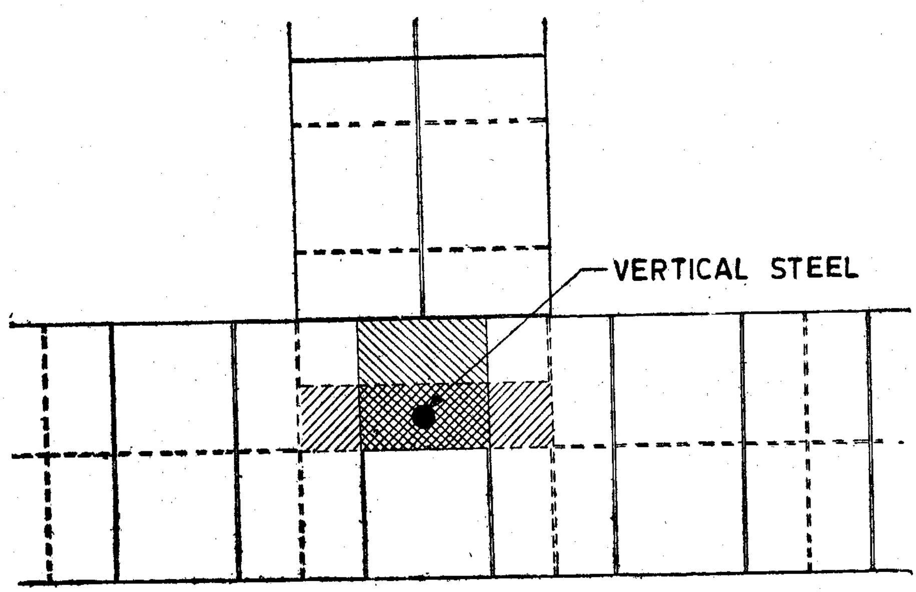
The total amount of vertical steel may be adopted as indicated in Table 2 as percentages of gross area of load bearing walls. The total area so calculated may be proportioned to the various piers between openings and beyond them (solid portions seen in a sectional plan of the building passing through door and window openings) in the ratio of their cross-sectional areas. The steel area in any pier may be provided half and half on each end of it. Where openings require reinforcing greater of the reinforcement required for the



Corner details for one brick wall



Jumb detail for one brick wall



T—Junction details for one brick wall

Fig. 4. Typical junction details for providing vertical steel in brick masonry (One brick wall)

same and as indicated in Table 2 need be provided. Alternatively the amount of vertical steel may be taken as per IS : 4326–1967.

Figure 4 show the method of placing of reinforceent in brick work and block masonry construction.

TABLE 2

Vertical Steel Reinforcement in Walls

No. of storeys	storey	Zone B	Zone A
One	—	0.04 %	0.06 %
Two	Top	0.05 %	0.08 %
	bottom	0.08 %	0.12 %
Three	Top	0.05 %	0.08 %
	Middle	0.08 %	0.12 %
	Bottom	0.10 %	0.15 %

The vertical reinforcing bars should be embedded into foundation concrete, pass through all intermediate bands, through floor slab reinforcement and be embedded into roof slab or roof band at the top. Fig. 6 shows an arrangement of horizontal bands and vertical steel.

Strengthening of Inferior Construction : At some places due to limited economic resources or shortage of building materials, it may not be feasible to adopt the construction specified above and it may be necessary to continue construction in mud mortar. In such situations the following improvements are suggested

The inferior construction consisting of inferior brick or dressed stone in mud morter may be limited to two storeys in zones C and to one torey in zone B and A, the ground story having 1½ brick thick and upper storey one brick thick walls. The lintel band reinforcement should be the same as specified earlier except that the reinforcing bars may be located in brick course laid in 1 : 3 cement sand mortar (see Fig. 5). Links may be omitted. The plinth band may be omitted. Roof band may be provided under similar conditions as indicated earlier The vertical reinforcement may now consist of one bar 12 mm dia. at each corner and junction of walls in zones B and A. Jamb steel may be omitted and openings restricted by the conditions stated earlier.

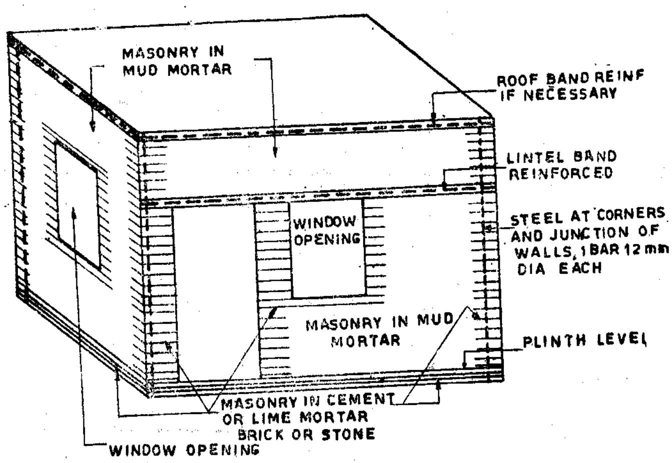


Fig. 5. Strenghtening Brickwork in Mud Mortar

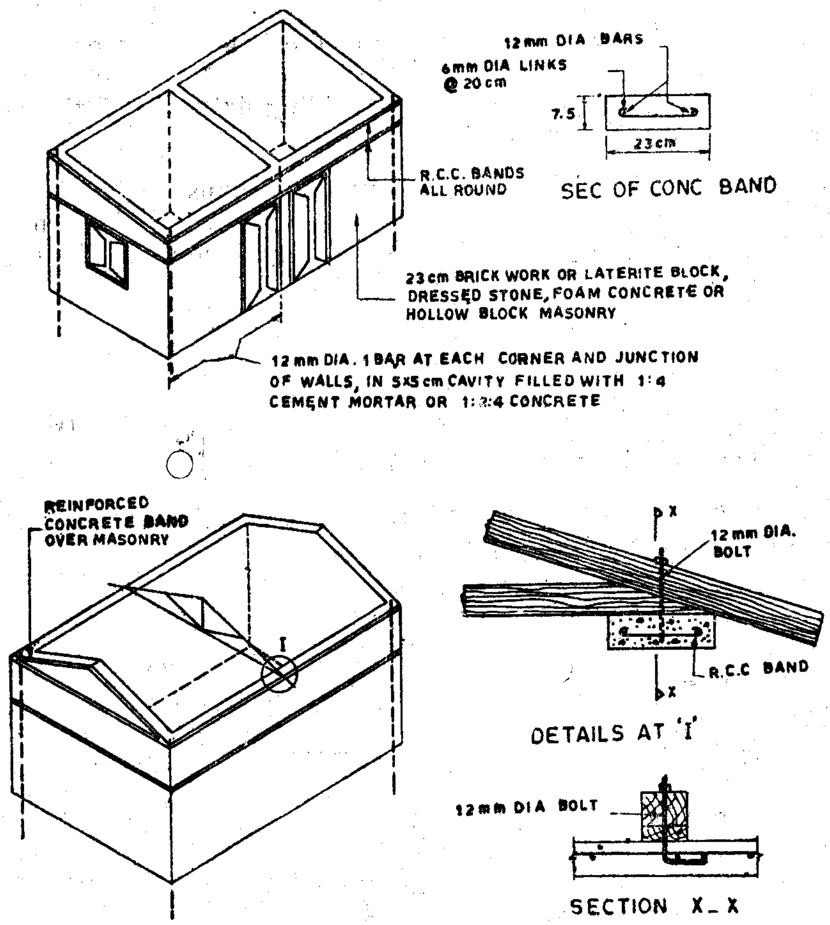


Fig. 6. Typical details of masonry constructian with band and vertical reinforcement

Recommendations for Timber Buildings

Timber Constructian : Timber has high strength per unit weight. It is therefore very suitable material for earthquake resistant buildings. IS : 883–1961 gives the specifications for structural timbers and may be referred to for detailed design.

The more important considerations in timber construction are that :

(a) to minimise danger due to fire, the roof covering and cladding walls should be of non-combustible materials.

(b) the number of storeys may be limited to two, the attic space may also be made use of.

(c) for imparting resistance to lateral load, adequate diagonal bracing should be used in plan and elevation.

(d) the connection between various members should be strong enough to take the load and kept tight by iron straps where possible.

Foundatian : In order to avoid deterioration of timber, for permanent buidings the footings, below the plinth level should be done in masonry or concrete and the columns of the superstructure should be securely connected with the footings either through sills or directly. For temporary huts, however, the timber poles, which act as posts for the superstructure, may be embedded in ground for providing fixity. Painting the embedded portion with hot tar before hand is very desirable.

Types of Construction : The commonly used types of construction in timber are the stud wall construction and brick nogged frame construction. Taking into account the considerations stated above for such constructions, the recommended details of construction are shown in Figs. 7 to 9.

(a) Three types of plans are considered :

- (i) Single row of rooms having one main span only (Fig. 7a)
- (ii) A row of main rooms with verandah or side rooms on one side (Fig. 7b)
- (iii) A row of main rooms with verandah or side rooms on both sibes (Fig. 7c)

The bracing in each case may be arranged around the main rooms only but made sufficiently strong so as to take the inertia force of the whole house.

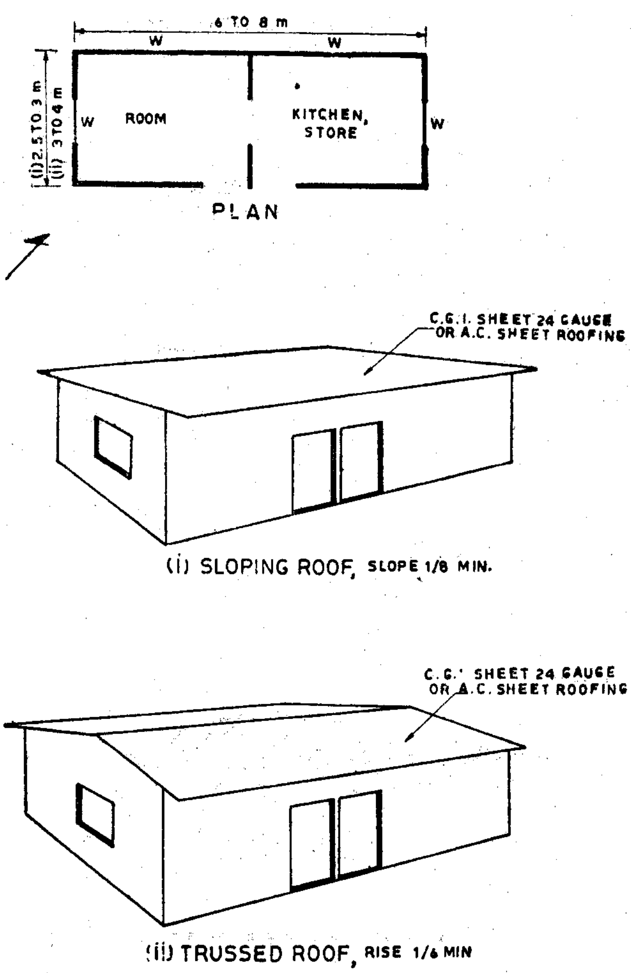


Fig. 7(a). Single row of rooms

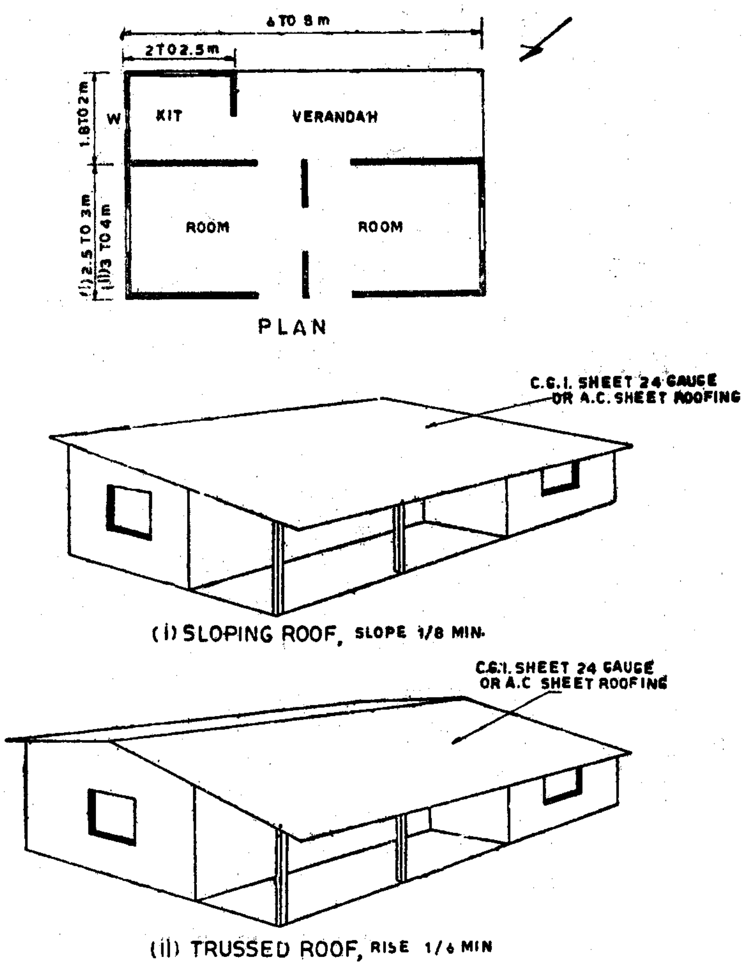


Fig. 7(b). One row of main rooms with verandah or side room on one side .

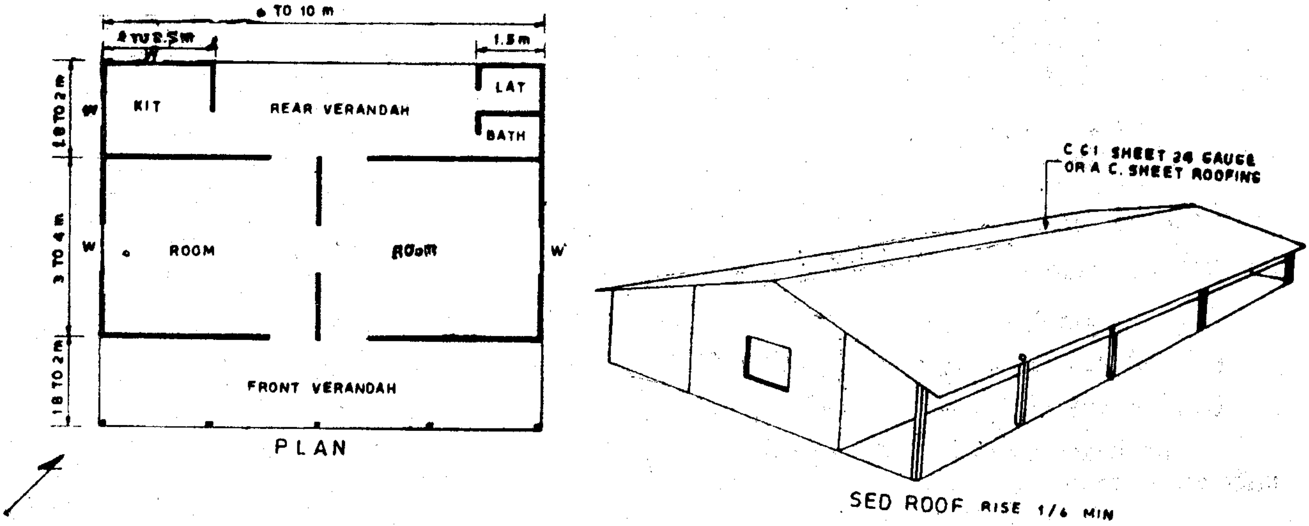


Fig. 7(c). One row of main rooms with verandah or side rooms on both side

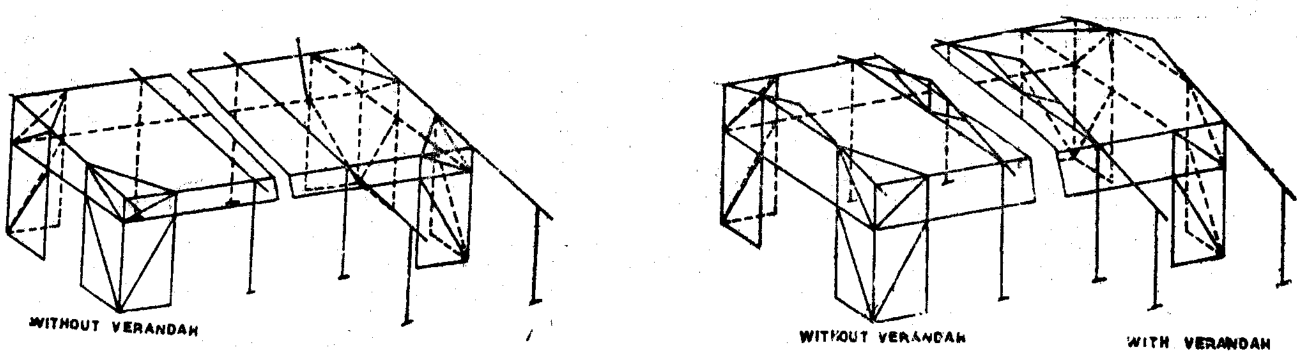


Fig. 8(a). Corner bracing srrangements

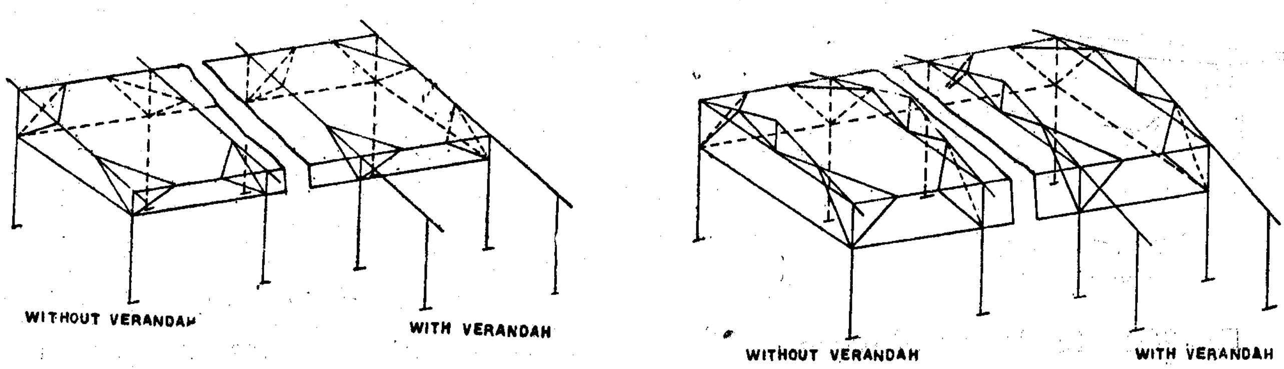


Fig. 8(b). Knee bracing arrangements

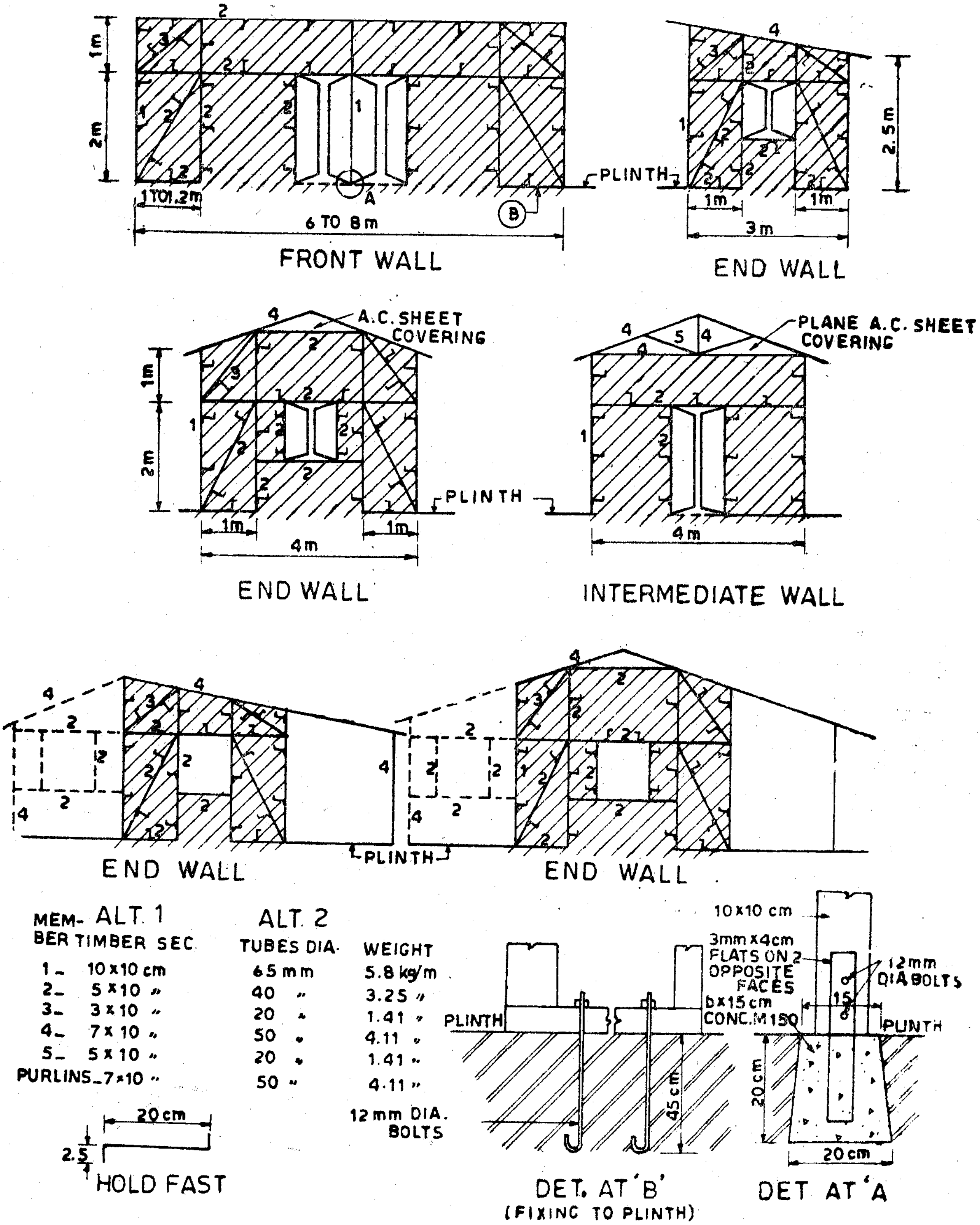
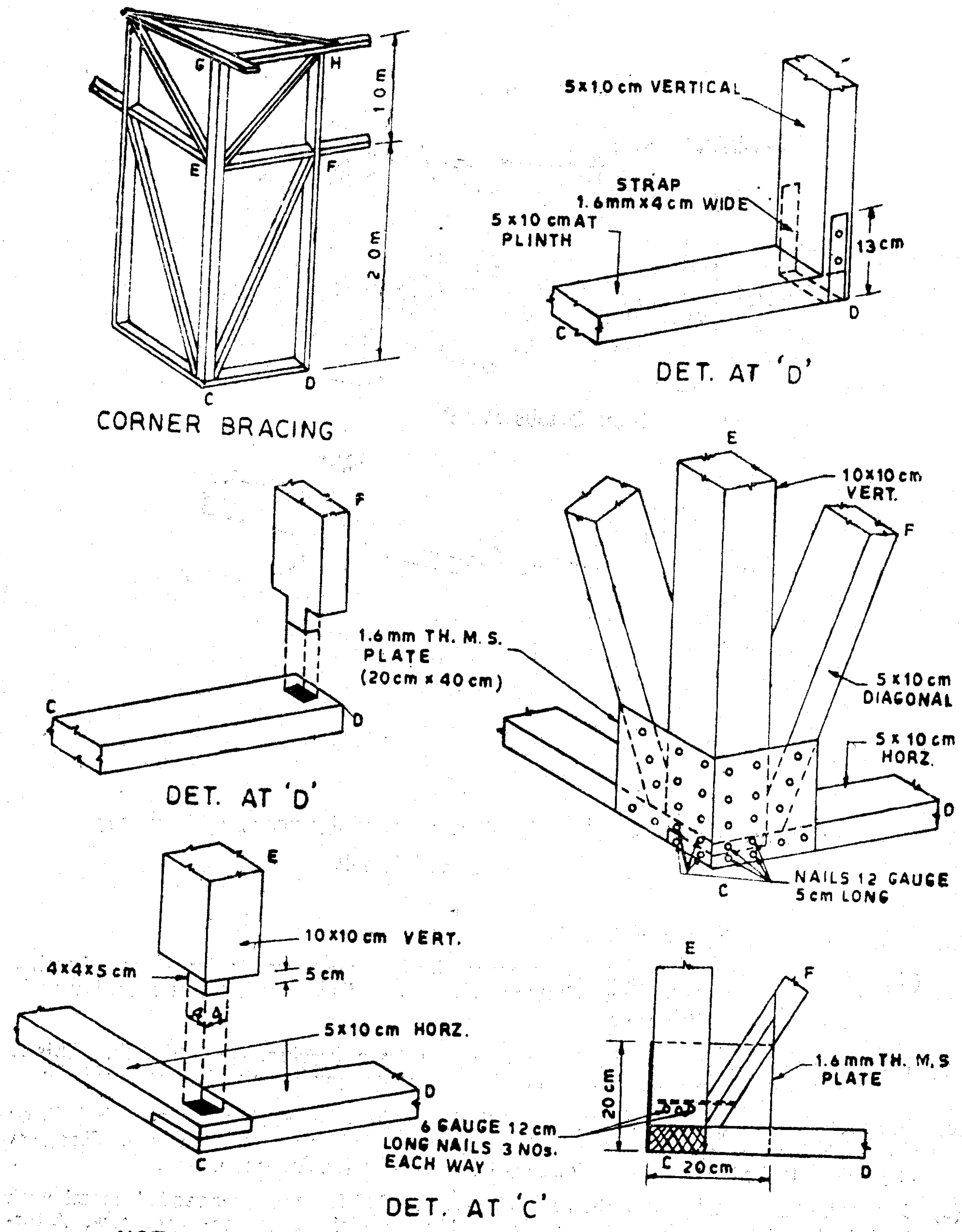
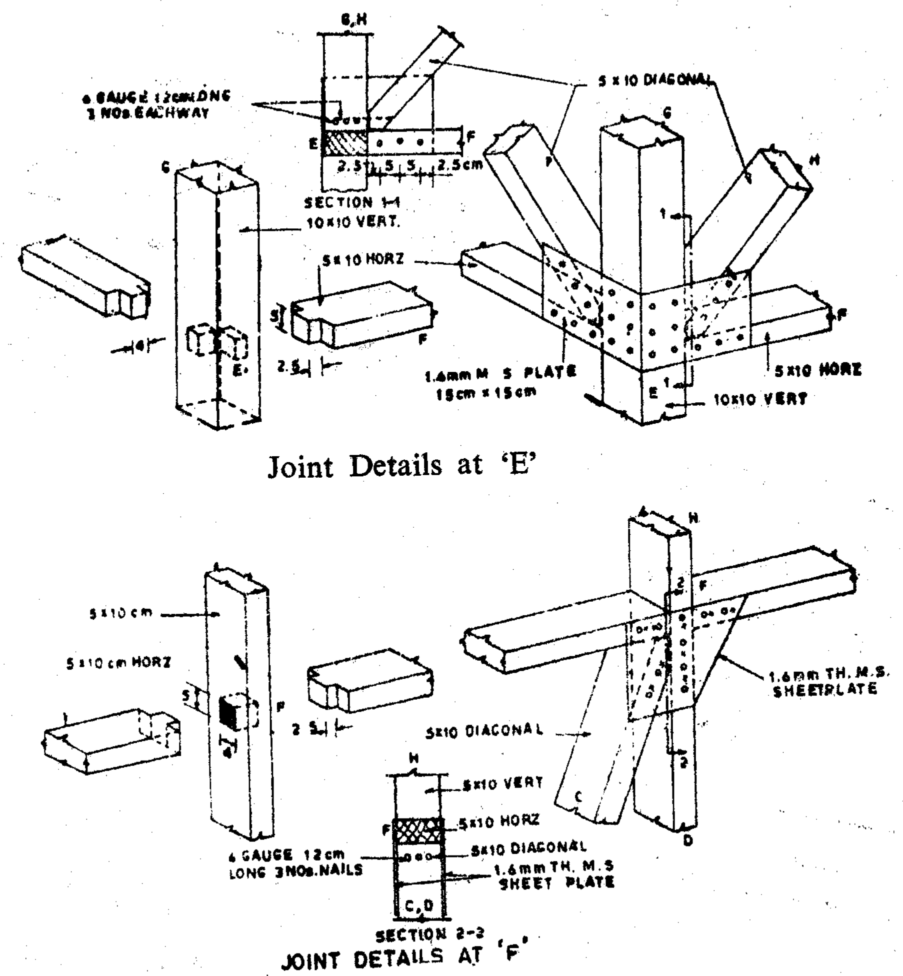


Fig. 9(a) Framing and joints detail



NOTE _ UNLESS MENTIONED OTHERWISE ALL NAILS, 6 GAUGE 10cm LONG

Fig. 9(b) Framing and joints detail



Note : Unless mentioned otherwise all nails are of 6 gauge and 10 cm long

Fig. 9 (c) Framing and joints detail

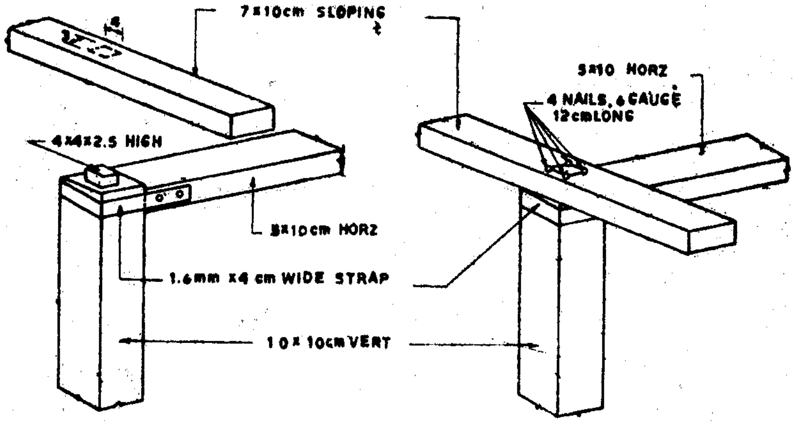
(b) Two types of bracing are indicated

(i) In one the lateral strength has been provided near corners or junctions of walls. See Fig. 8a. This is more suitable where cross walls are available at short intervals as is the case with residences.

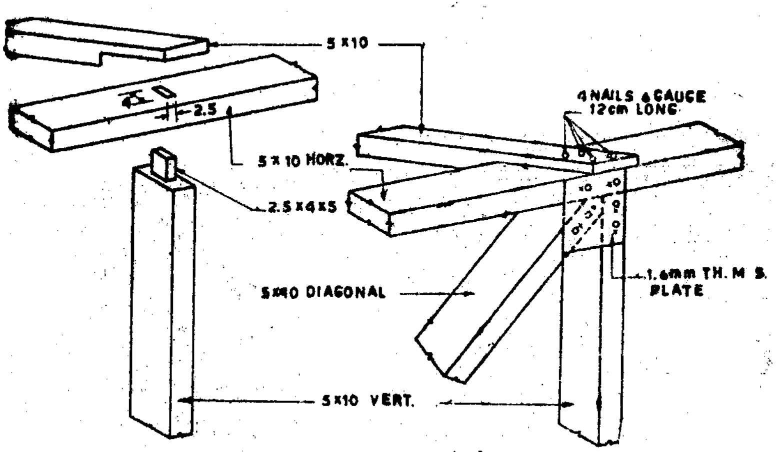
(ii) In the other, the strength is provided by knee bracing. See Fig. 8b. This is more suitable in the case of long halls, barracks type dormitories, godowns etc.

(c) The roof is arranged in the form of timber rafters or timber trusses with A.C. or C.G.I. sheet covering. Trusses could be framed, nailed or bolted as desired. Tightness of joints is to be emphasised which may be achieved with flat iron straps.

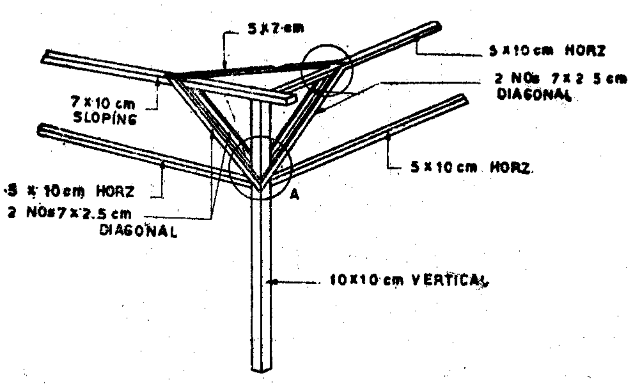
(d) The wall cladding may be in the form of A.C. or C.G.I. sheets, expanded metal with plaster or timber boards fixed to girts. No special details are necessary. Alternatively, the heavier elements like brick, squared stone, form concrete block, hollow concrete block etc. may be used for building the walls. Such panel walls must be



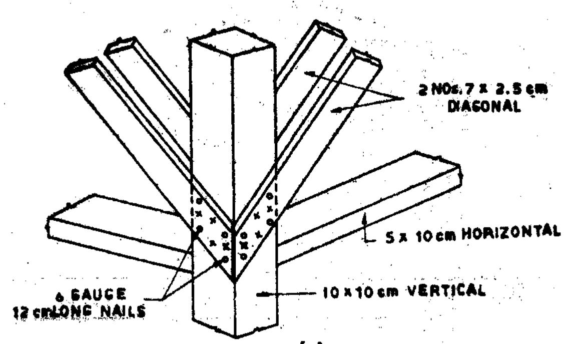
JOINT DETAILS AT 'G'



JOINT DETAILS AT 'H'



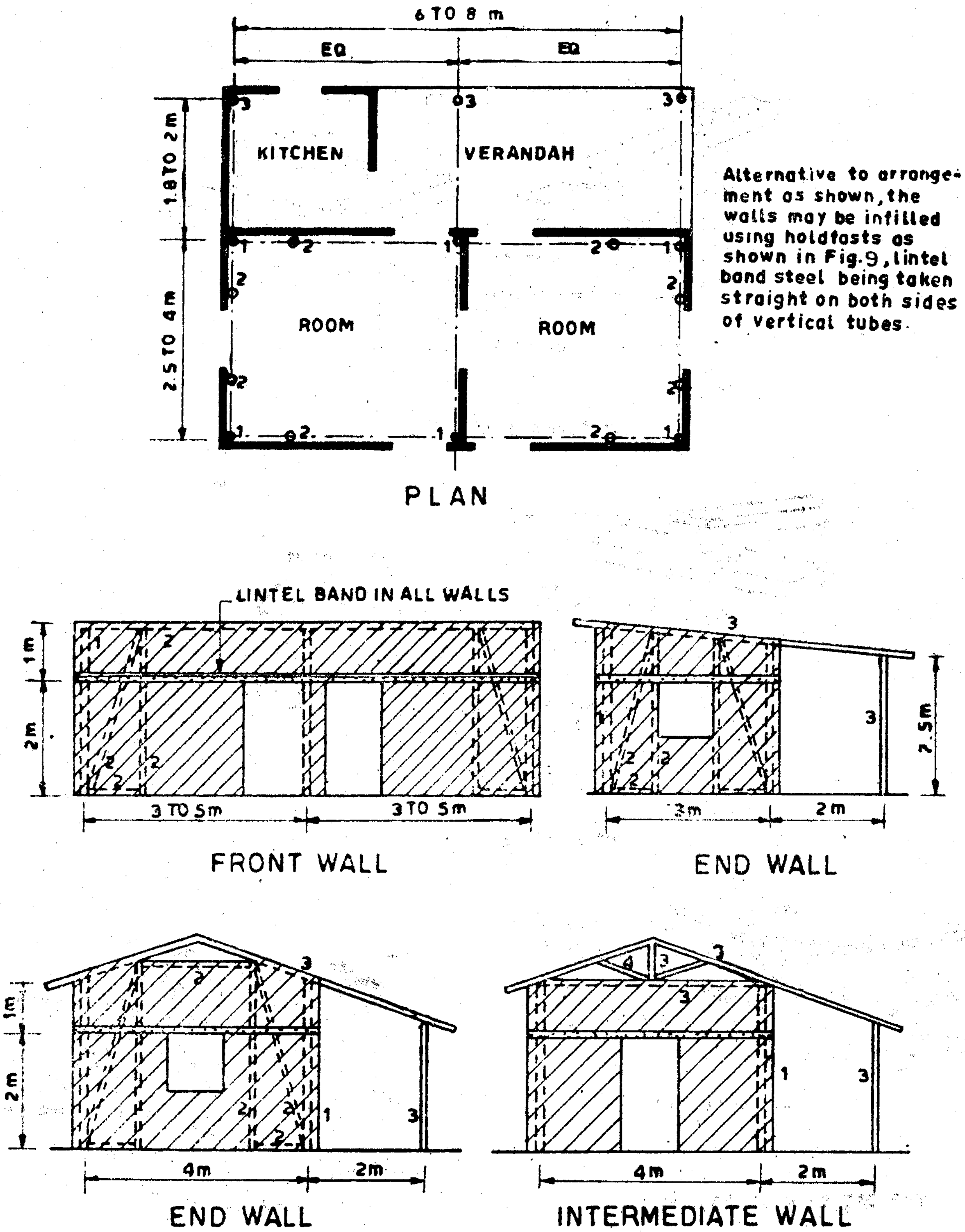
TYP. DET. OF KNEE BRACING



JOINT DET AT 'A'

Note : Unless mentioned otherwise all nails are of 6 gauge, 10 cm long

Fig. 9 (d) Framing and joints detail



MEMBER	TUBE DIA.	WEIGHT
1 -	65 mm	5.8 kg/m
2 -	40 „	3.25 „
3 -	50 „	4.11 „
4 -	20 „	1.41 „

PURLINS _ 50 mm DIA. 4.11 kg/m
LINTEL BAND _ 75 mm TH. R.C.C.

Fig. 10(a) Framing in tubular construction

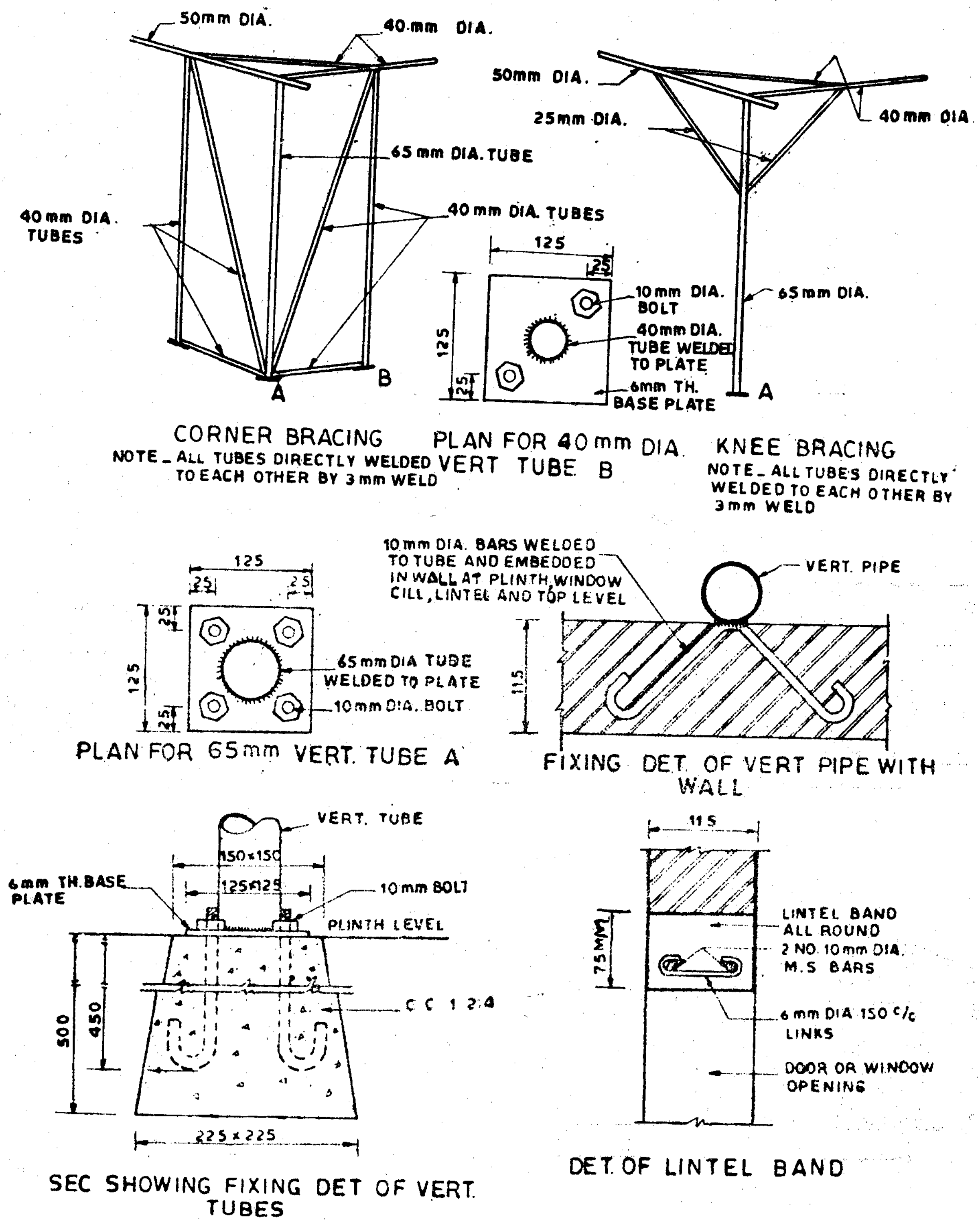


Fig. 10(b) Framing in tubular construction constructed with care and according to principles given for masonry buildings. Whereas the sheeting will be suitable for temporary use, the walls will be necessary as a permanent measure and also for providing protection from heat and cold. Details are given in drawings for construction of such walls, which are assumed to be not nore than 13 cm thick.

(e) Details for fixing the superstructure to footings columns and bracing members, joints and masonry infill are shown in Fig. 9.

Tabular Steel Construction

Steel piles can be made use of on a mass scale with speed in place of timber members. Recommended details of this type of construction are shown in Fig. 10.

Conclusion

Summarising the recommendations for earthquake resistance, it may be stated that the construction should be light, strong against lateral loads, ductile to absorb energy and present its resistance against the earthquake as an integral unit.

Acknowledgements

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References

1. Chandrasekaran, A.R., L.S. Srivastava and A.S. Arya, 'Behaviour of Structures in Koyna Earthquake of December 11, 1967' Indian Concrete Journal (under publication).
2. Krishna, J. and A.S. Arya, 'Building Construction in Seismic Zones of India' Second Symposium on Earthquake Engineering, University of Roorkee, November, 1962.
3. Krishna, J. and A.S. Arya, 'Earthquake Resistant Design of Buildings' Journal of the Institution of Engineers (India) Vol. XLV, No. 7, March 1965.
4. Arya, A.S., 'Design and Construction of Masonry Buildings in Seismic Areas' Bulletin of the Indian Society of Earthquake Technology, Vol. 4, No. 2, April 1967.
5. 'Code of Practice for Earthquake Resistant Construction of Buildings' (IS: 4326-1967), ISI, New Delhi, 1967.
6. Agnihotri, V.K., Strength of Single-storey Brick Shear Walls against Earthquake Forces', M.E. Thesis, University of Roorkee, 1962.
7. Code of Practice for Design of Structural Timber in Building's, (IS : 883-1966), I.S.I., New Delhi, 1966.