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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/m² or larger.

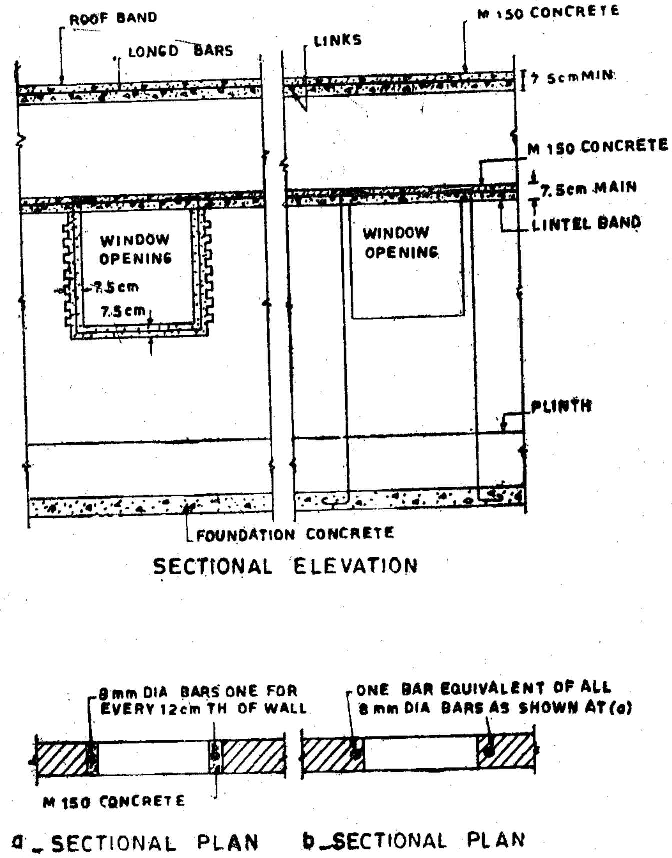


Fig. 1 Strengthening around openings.

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.

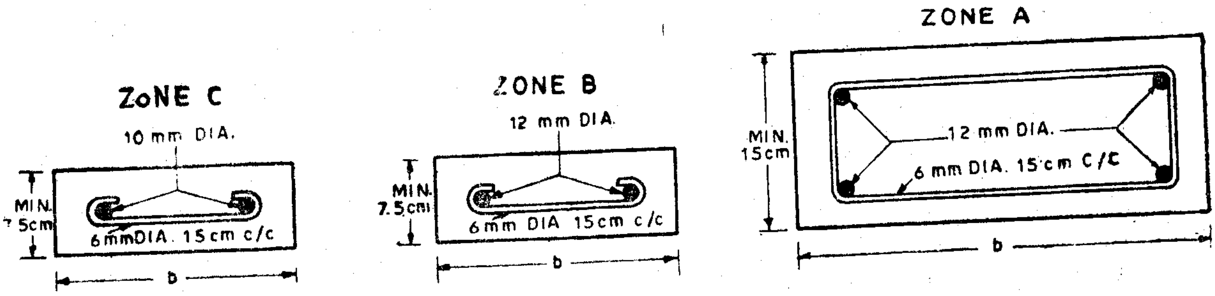


FIG 2 - CROSS SECTIONS OF REINFORCED CONCRETE LINTEL BANDS (MAX SPAN OF WALL 6m)

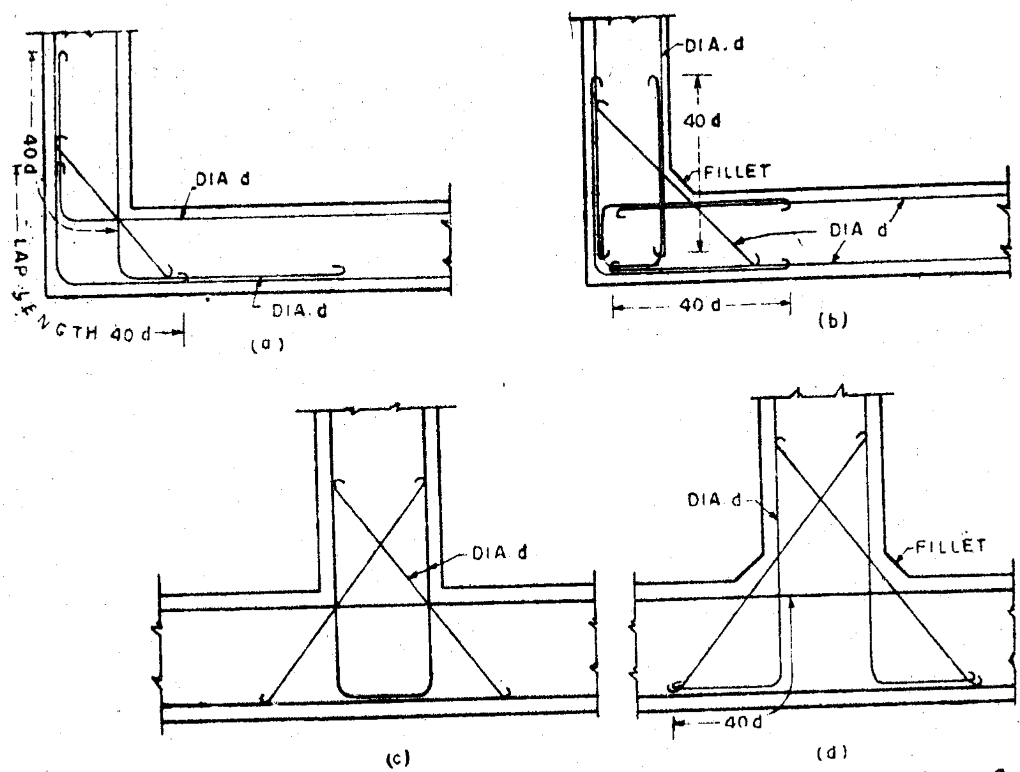
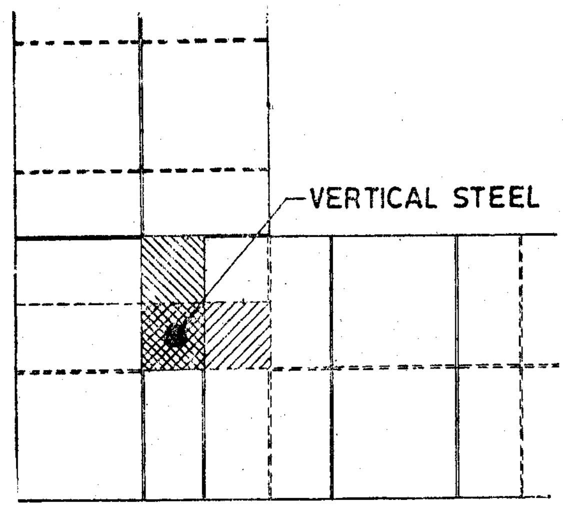


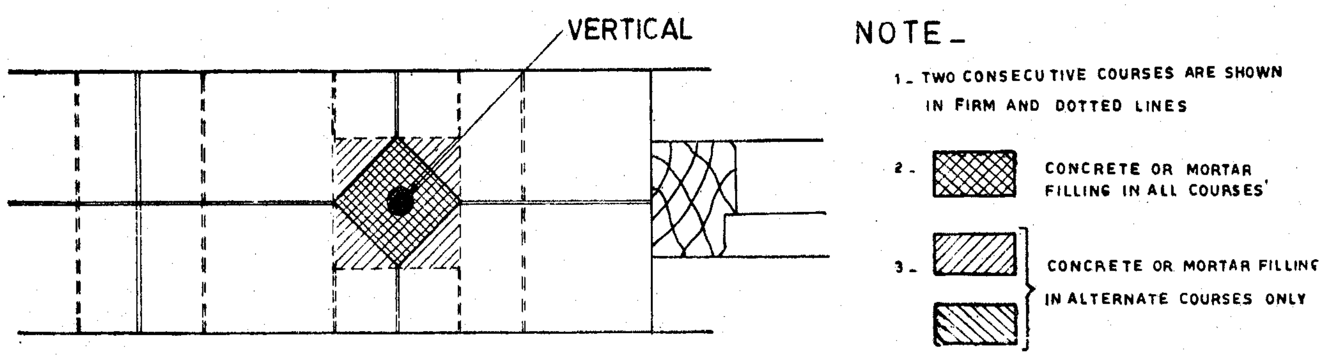
Fig. 3. Band reinforcement detail at corner and junction of walls

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

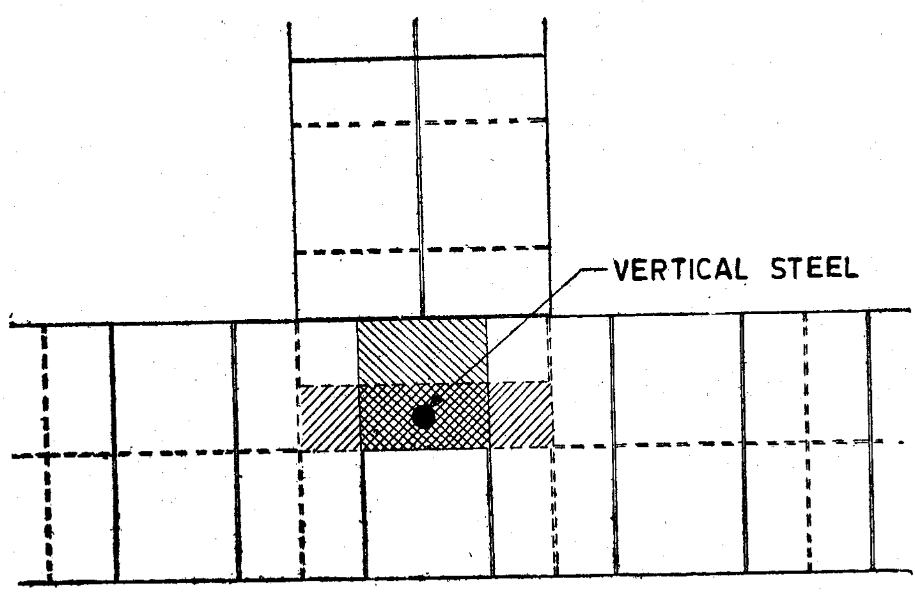
The total amount of vertical steel may be adopted as indicated in Table 2 as percentages of gross area of load bearing walls. The total area so calculated may be proportioned to the various piers between openings and beyond them (solid portions seen in a sectional plan of the building passing through 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.

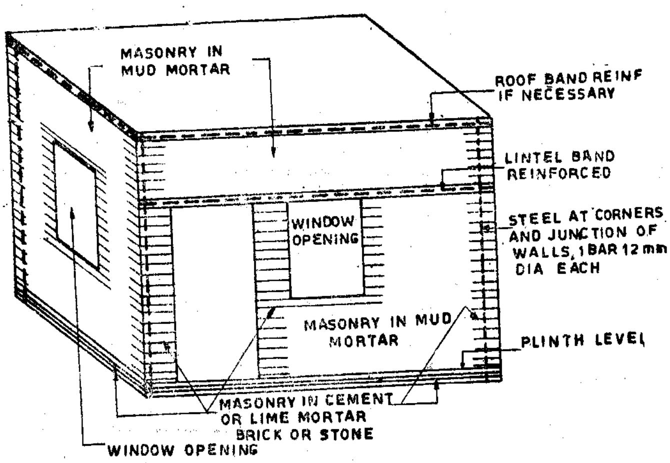


Fig. 5. Strenghtening Brickwork in Mud Mortar

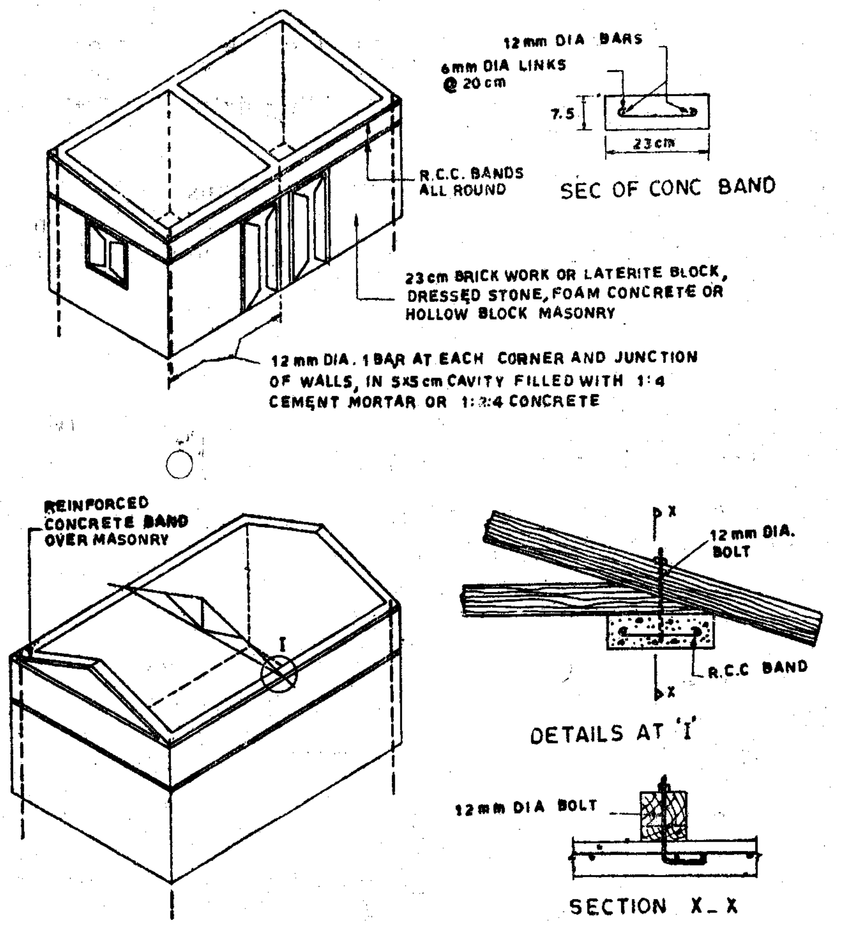


Fig. 6. Typical details of masonry constructian with band and vertical reinforcement

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)

(i i) 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.

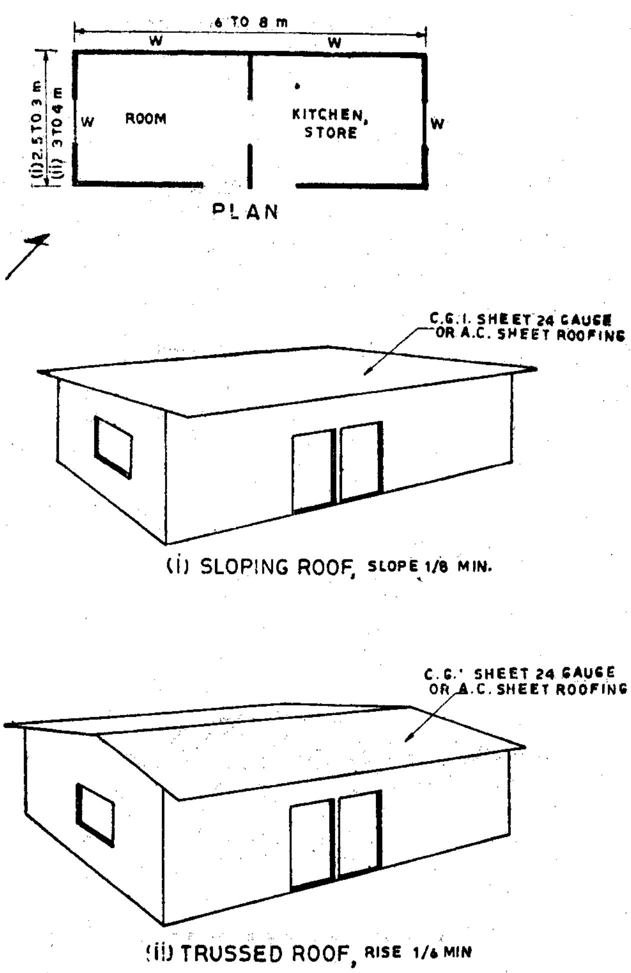


Fig. 7(a). Single row of rooms

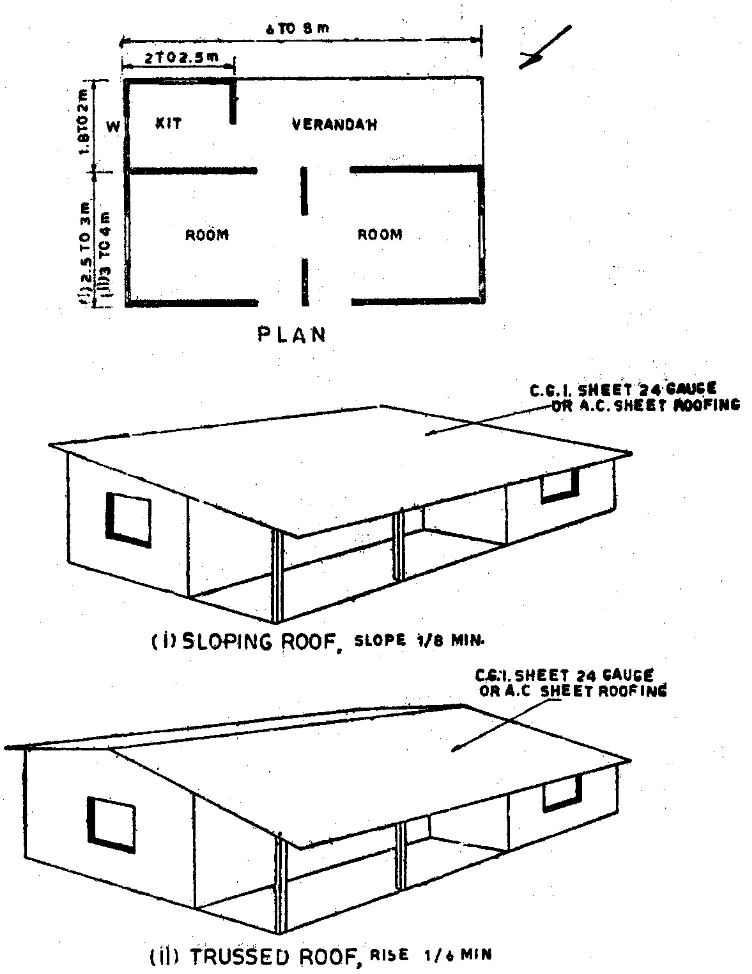


Fig. 7(b). One row of main rooms with verandah or side room on one side .

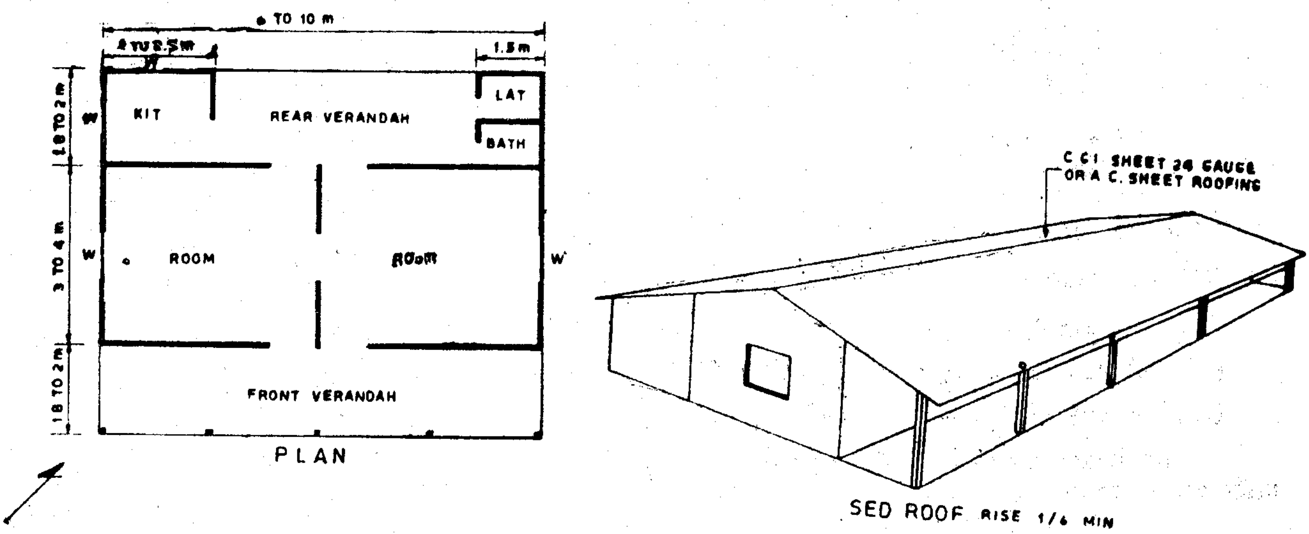


Fig. 7(c). One row of main rooms with verandah or side rooms on both side

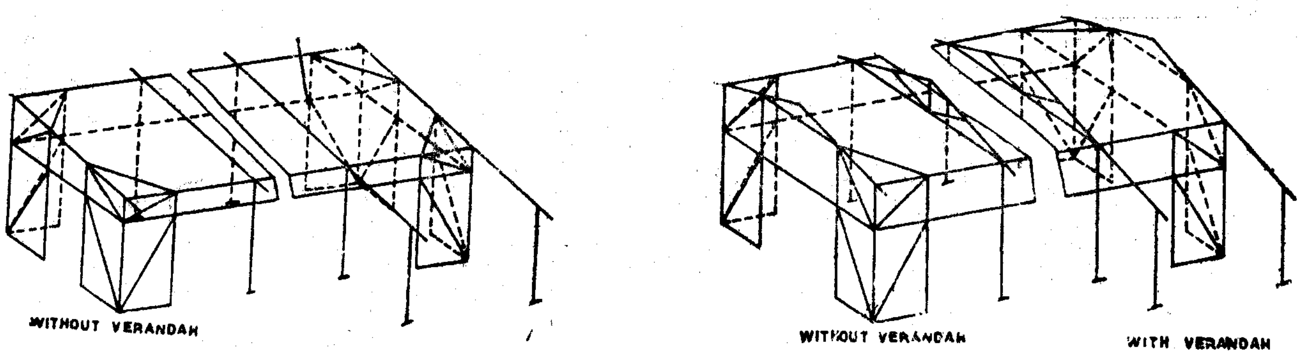


Fig. 8(a). Corner bracing srrangements

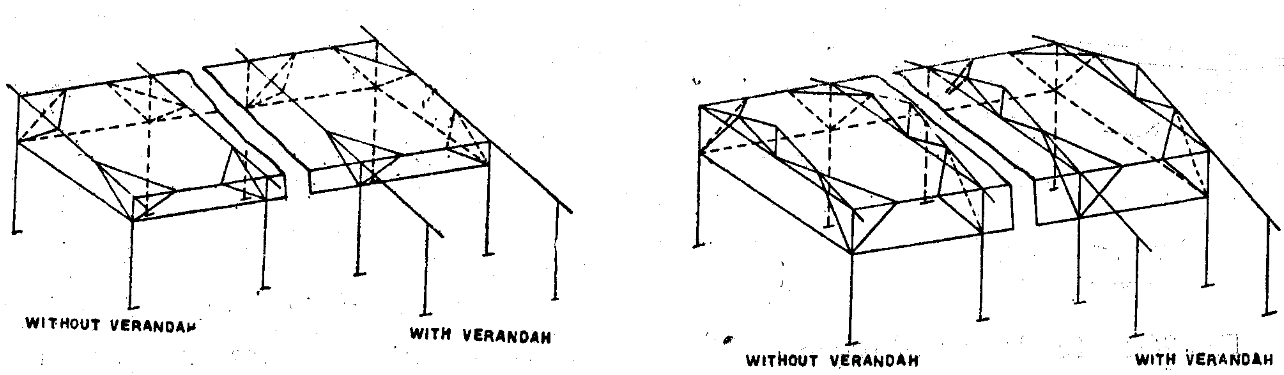


Fig. 8(b). Knee bracing arrangements

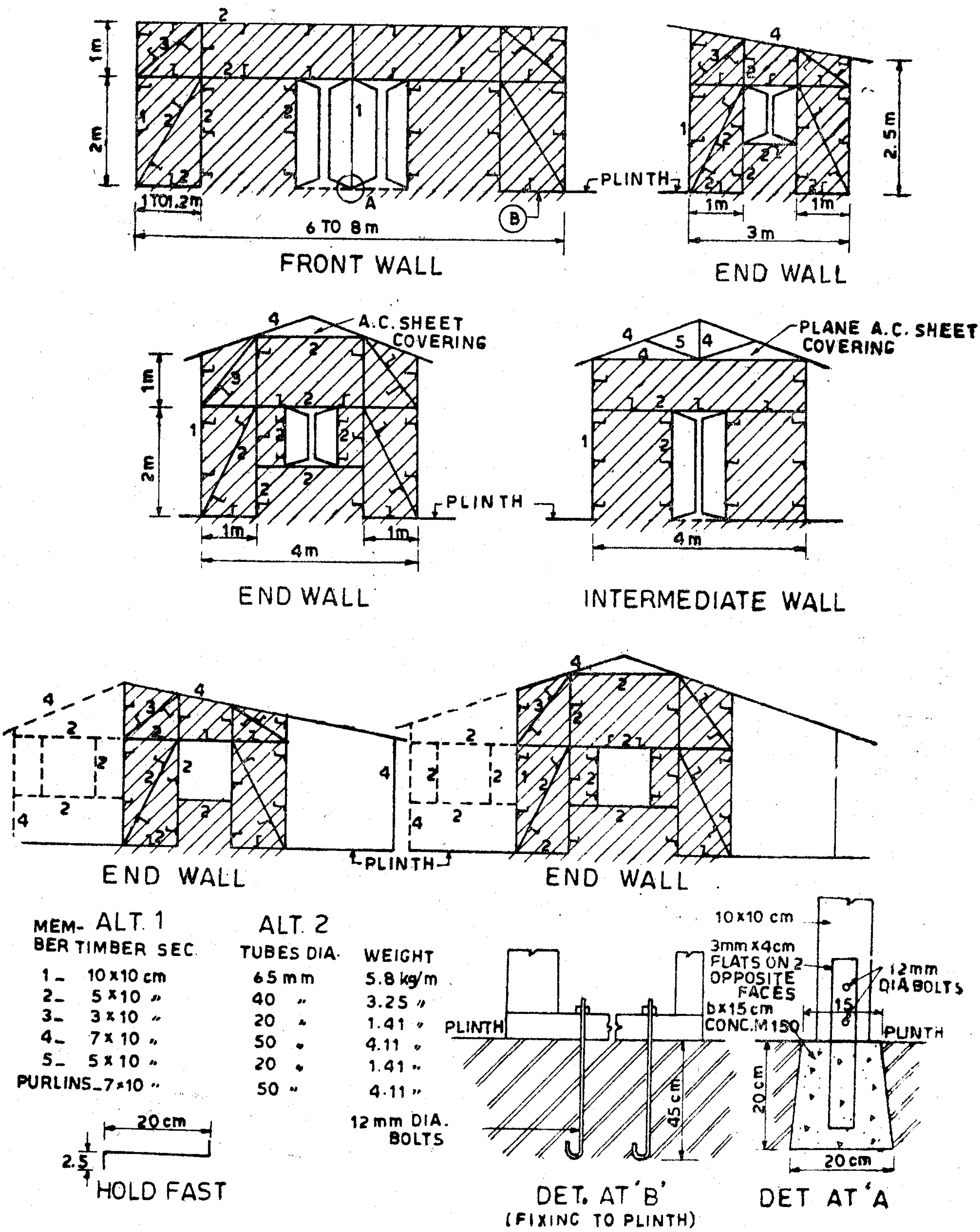
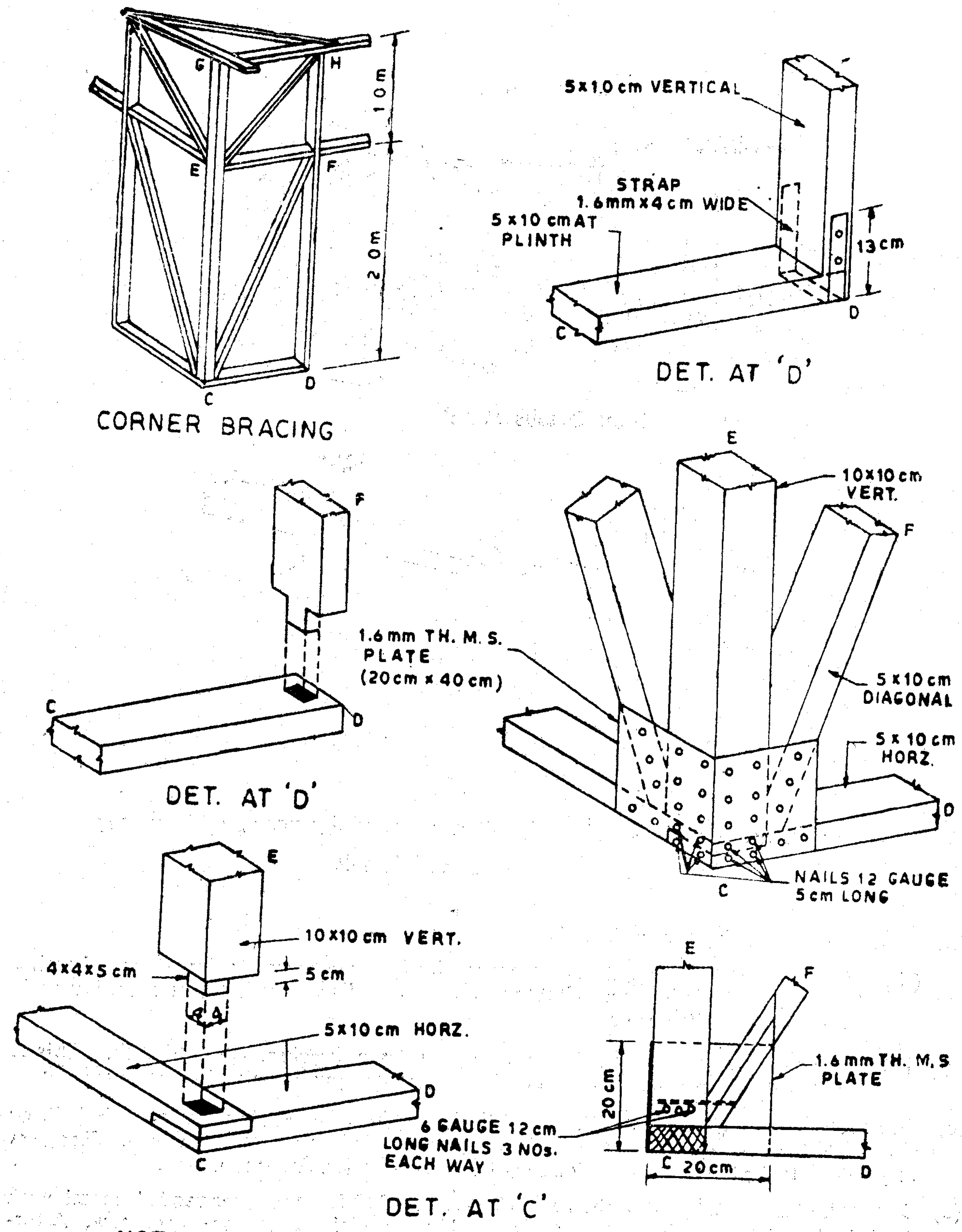
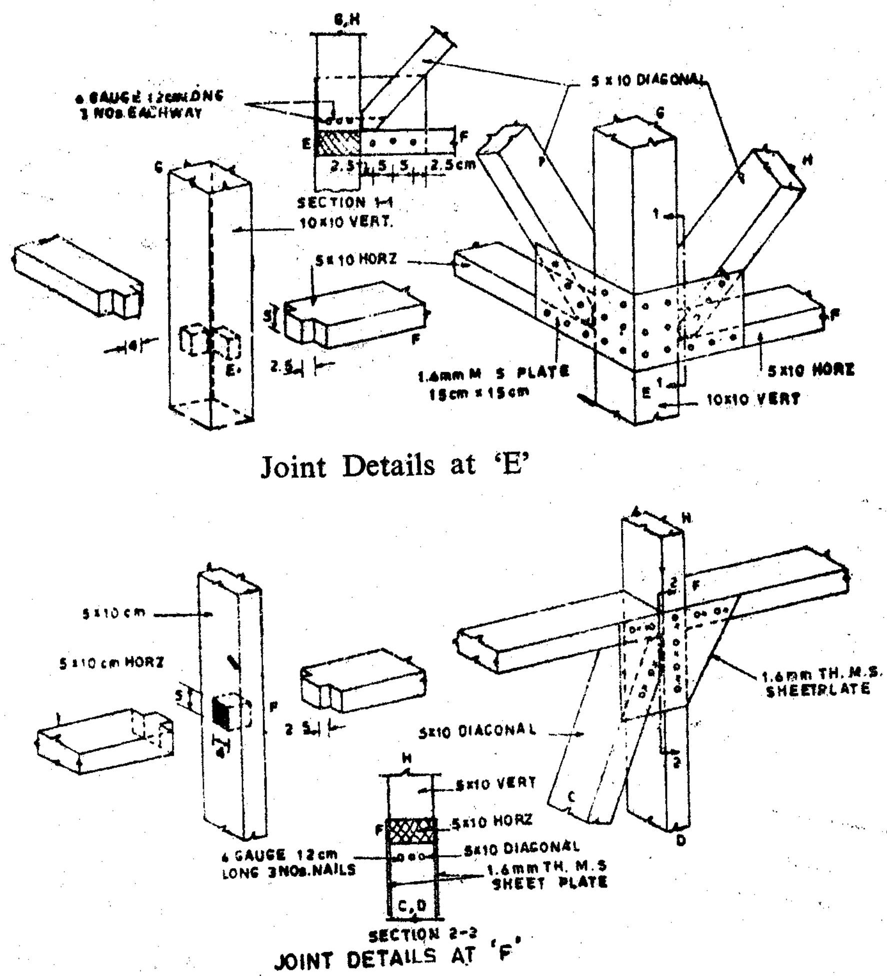


Fig. 9(a) Framing and joints detail



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

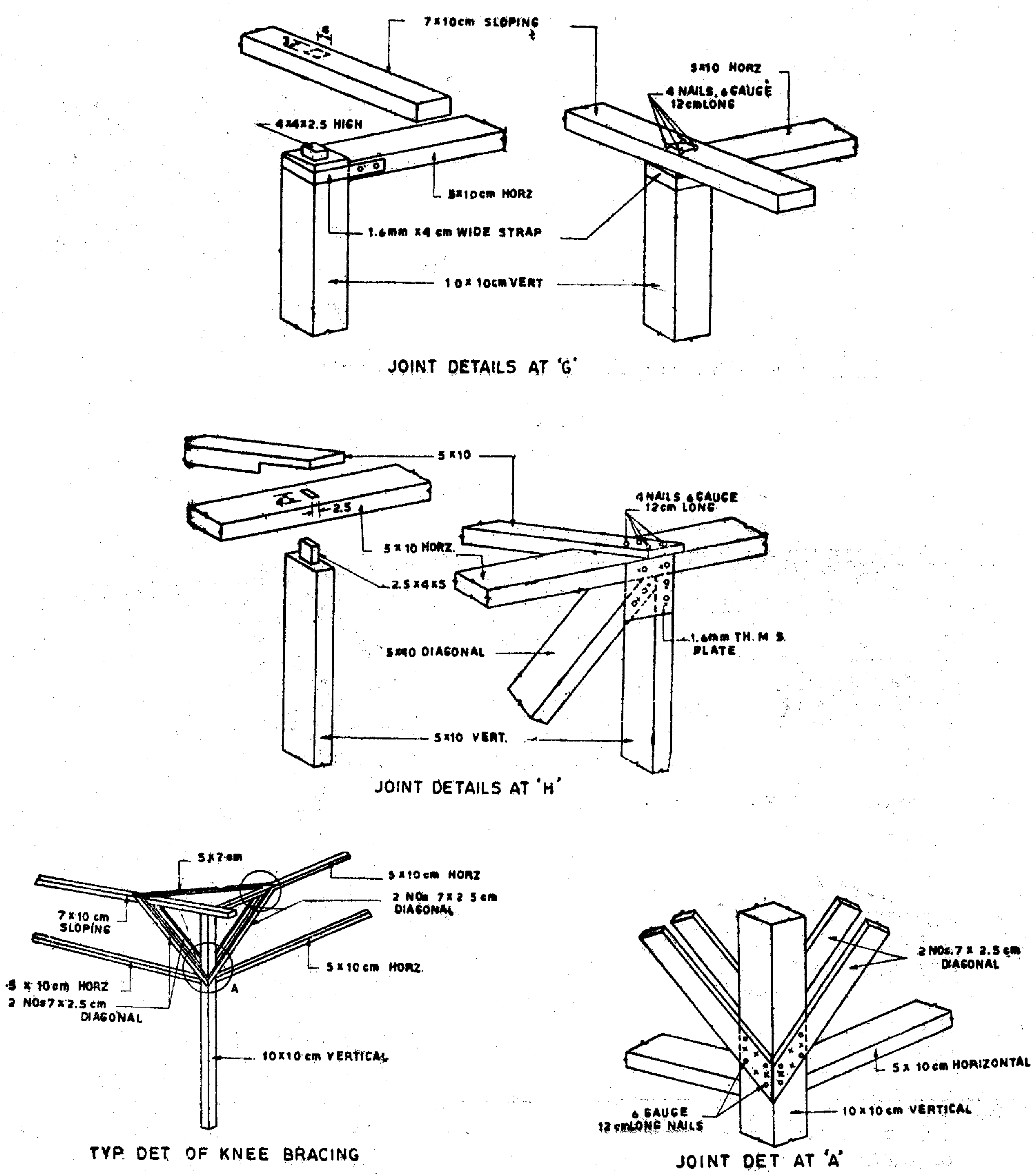
(b) Two types of bracing are indicated

(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.

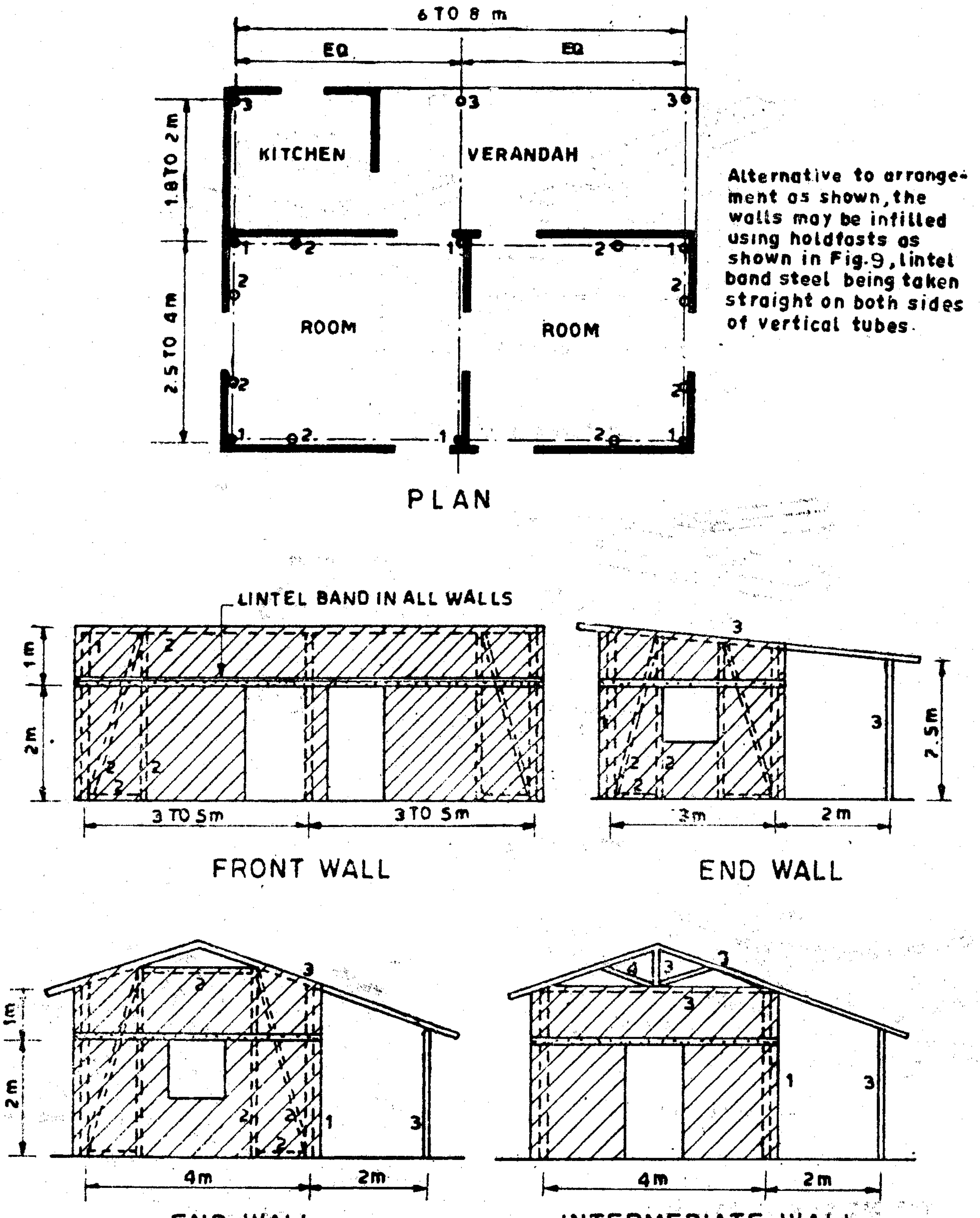
(c) The roof is arranged in the form of timber rafters or timber trusses with A.C. or C.G.I. sheet covering. Trusses could be framed, nailed or bolted as desired. Tightness of joints is to be emphasised which may be achieved with flat iron straps.

(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



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 _ 75mm TH. R.C.C.

Fig. 10(a) Framing in tubular construction

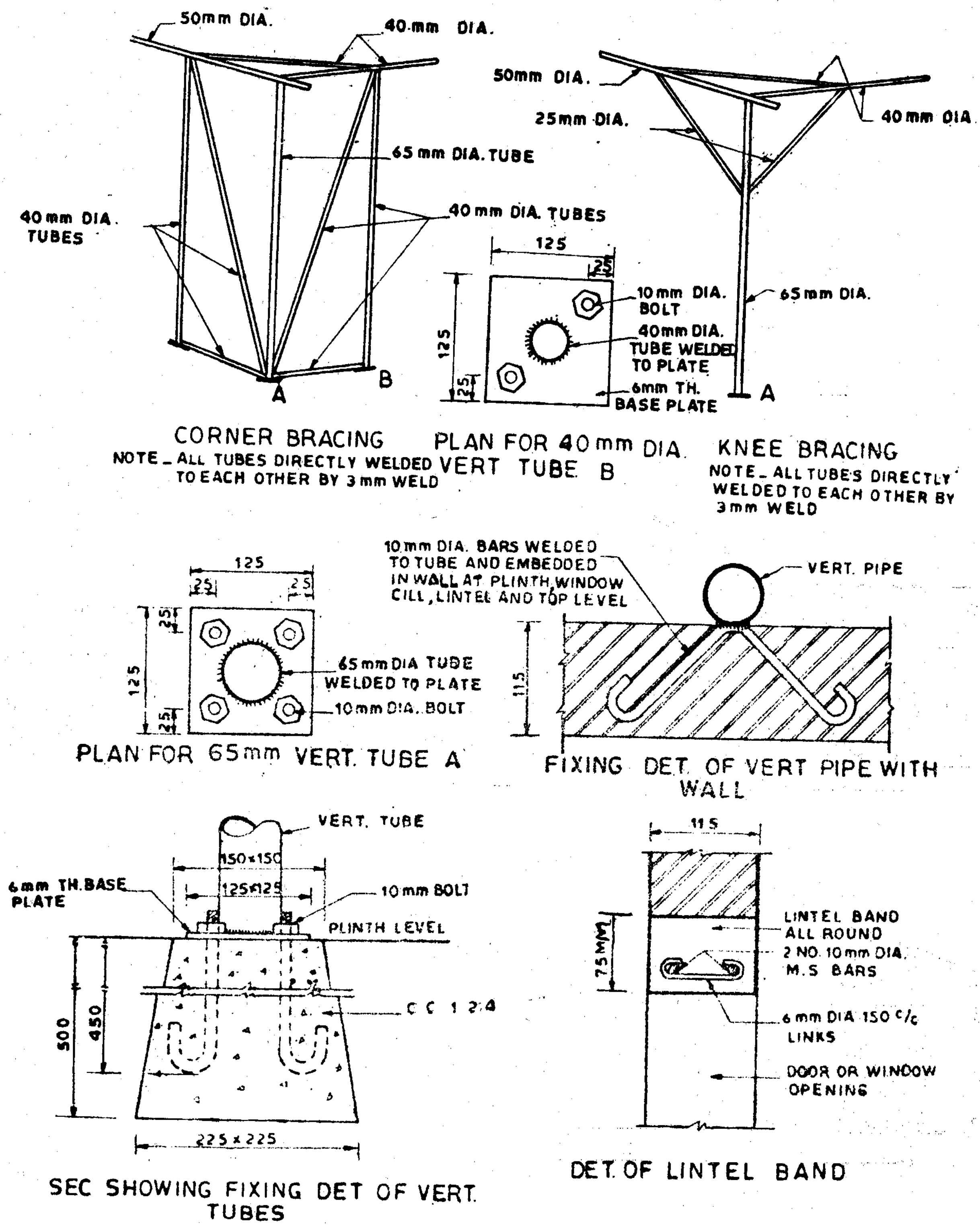


Fig. 10(b) Framing in tubular construction constructed with care and according to principles given for masonry buildings. Whereas the sheeting will be suitable for temporary use, the walls will be necessary as a permanent measure and also for providing protection from heat and cold. Details are given 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.

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VOLCANISM, TECTOGENESIS AND SEISMICITY OF DECCAN TRAPS

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Abstract

Deccan trap volcanism is regarded as a result of eruption through fissures. These fissures are considered to be represented by dykes. Three main regions showing concentration of such dykes are noted around Narbada trough, North Konkan and Kathiawar. The dykes show an alignment parallel and sub-parallel to the fractures in these regions. Both the fractures and the dykes in the Narbada trough are in general aligned in E-W direction, where as in the North Konkan they are in N-S direction. The two regions also show presence of eruptive centres and the associated acidic and alkaline rocks. Narbada trough and North Konkan region are geotectonically akin to one another and are probably an outcome of linear crustal uplifts in the E-W and N-S directions respectively. In Kathiawar, where similar central type of volcanism is also noted, the dykes and the fractures show a radial pattern. This suggests a domal uplifting of the region.

The three above noted areas represent separate units in the Deccan traps—the Narbada trough forming a part of the Satpura rift, North Konkan area lying within rift zone along the West Coast and Kathiawar situated at their intersection. The structure and volcanism of these three regions indicate that they are independent geotectonic provinces, which were responsible for the evolution of Deccan traps. It is therefore imperative that attempts to establish the volcanism and tectogenesis of the trappean province must take into consideration the presence of dykes, fractures and eruptive centres and their genetical inter-relationships.

Plotting the epicentres of past earthkuakes over Deccan traps show two areas where they are linearly distributed, one trending nearly N-S, parallel to the west coast of Maharashtra and the other extending from the mouth of Narbada river and stretching across Central India, spread over the ancient Satpura strike upto Rajmahal hills, and from the mouth of Ganges delta to Sylhet in Shillong Plateau. These epicentral zones bear a striking correspondence to the areas which have uudergone crustal upwarping. Further they also correspond to the delineated gravity anamolies along the regions.

This paper deals with the mechanics, evolution and emplacement of Deccan traps and attempts to examine the available evidence to see if any genetic or tectonic relation can be established between the rift phenomena and the epicentres of earthquakes in the area.

Introduction

The historical and scientific data collected after the December 11, 1967 Koyna Earthquake has revealed that Western Coast of India, particularly the portion occupied by Deccan traps, has shown seismicity in the past. Such a seismicity is noted to be episodic and of short durations, and followed by long period of quiescence. It has also been noted that probably the entire coast line extending from Daman in the North to Ratnagiri in South is seismogenic, that is liable to being visited by earthquakes. In can not be a mere coincidence that this seismogenic belt lies within the trappean province. Obviously there should exist a relationship between the two.

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Deccan trap activity of India ranges in age from Upper most Cretaceous to Oligocene, probable extending into Miocene or even Pleistocene. Very few contributions to the problem of the erruption of Deccan lavas extist in scientific literature. Views of Glennie first propounded in 1932 and improved upon by Auden (1949) do not differ considerably from those of West who is 1959 summed up the present status regarding the source for these erruptive rocks. Glennie on the basis of geophysical studies, postulated an upwarping of the crust along the West Coast of India. A similar upwarp, though on a much smaller scale extending from mouth of Narbada and Tapti into the Satpura belt was suggested by Auden. Auden further stated that "these two zones of upwarp may have been the main foci of extrusion". Such a view is quite probable although West considers the areas of swarms of dykes within the Trappean province to be the real source. Apparently there exists a general correspondence between the concentration of dykes and the areas of upwarp, the two having a possible genetical relationship.

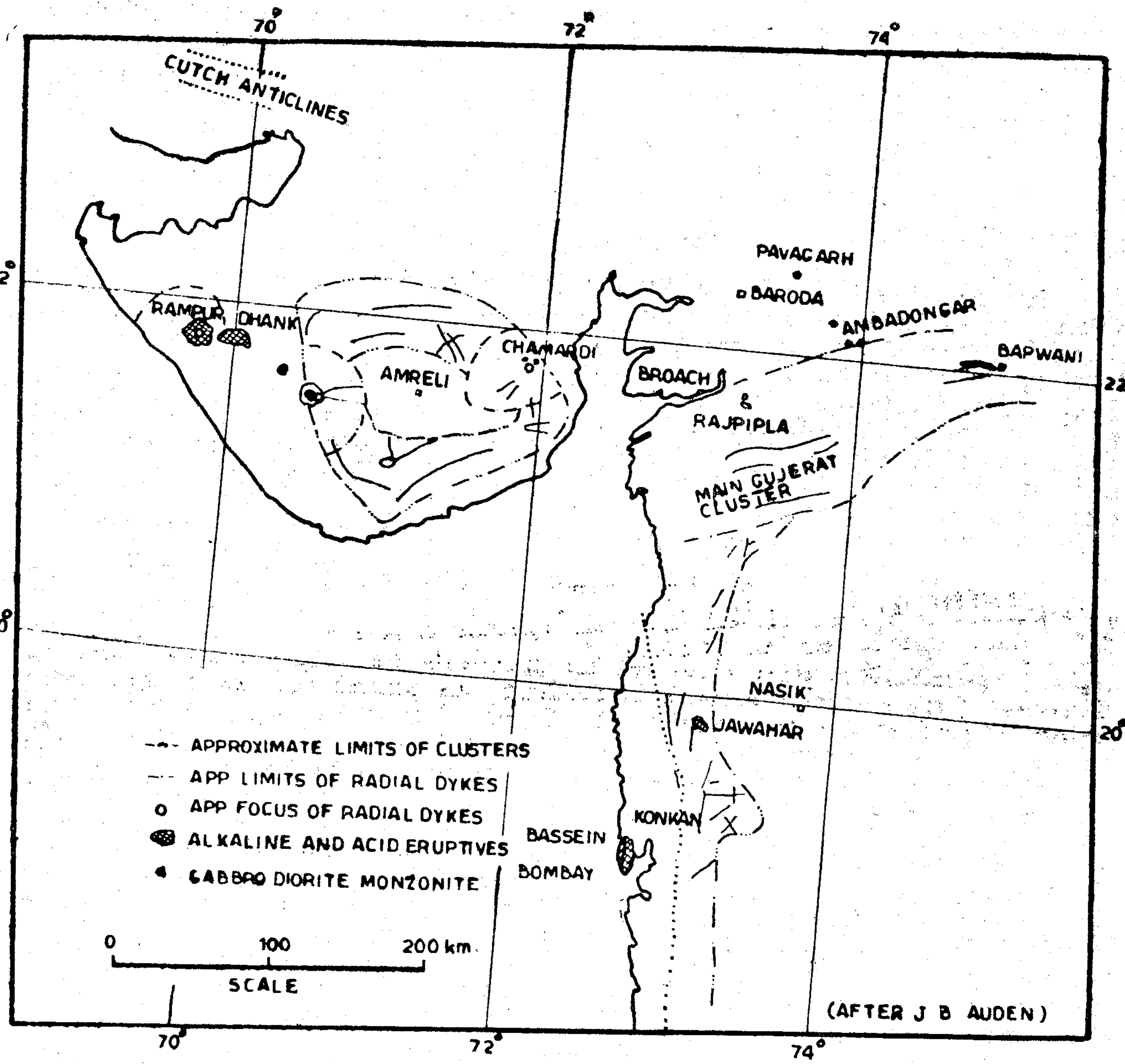
Based on geological studies over similar volcanic provinces in other countries attempts have been made to correlate Deccan volcanism with suboceanic eruptions similar to those associated with mid-oceanic rift valleys (Menard 1965, Francis and Shor 1966). It would not be out of place to mention here that Deccan Traps in their lithology and structure resemble the Scottish Hebrides (West 1958) and East Greenland Volcanics (Auden, op. cit.). Both these areas form a part of the Brito-Arctic province related to the Mid-Atlantic rift system (Menard 1965). Tomkeieff (1964) has in fact taken the help of hypothetical rifts to explain the association of plateau basalts with plutonic complexes and dyke swarms as seen in parts of Brito-Arctic province. Considering that no major lithological and structural difference exist between continental and oceanic rifts (Tipnis and Srivastava, 1968) and that volcanism in either case in attributed to the existence of deep fractures extending upto the 'wave—guide' of the tectonosphere serving as channels for upward movement of molten material (Beloussov 1968), Tomkeieffs speculations regarding the presence of hypothetical rifts deserves attention.

Detailed studies carried out by Auden (1949) has indicated three areas—Kathiawar region, Narbada Trough and North Konkan (North-east of Bombay), which show prominent net work of dykes occurring radially or in swarms (Fig. 1). The distribution of dykes in these areas show different patterns. They are arranged radially to the plutonic centres in Kathiawar hereby indicative of domal uplift, are aligned E—W parallelling the Narbada trough, and N–S in Konka region suggestive of linear upwarps parallel to these trends. These areas also possess certain common characteristic geological features such as distribution and pattern of fractures, presence of acid and basic volcanic eruptive centres and zone of mixed volcanism.

An attempt is made in this paper to utilise the presence of these geological features to build up a tectonic environment which can explain to satisfaction the volcanism of Deccan trap as well as some of its elusive aspects such as distribution of lava flows, presence of eruptive centres, the relationship between dykes and fractures and the seismicity.

Fractures

Fractures and fissures are supposed to represent the inherent lines of weakness in the Pre-Trappean basement. Their orientation therefore gains significance. It is seen that disposition of the fractures in the three regions is in general parallel to the trend of dykes. Such a close relationship between the two may imply that the phenomenon of dykes and fractures is contemporaneous, the dykes repereseniing the infilled fissures and fractures. The fractures and dykes pattern in Narbada trough is E–W while in Konkan it is N–S. These two trends imply deep seated tectonic control. At many places fractures and shear zones



MAP SHOWING DOMINANT TRENDS OF DYKE CLUSTERS AND NETWORKS AND LOCATIONS OF ERUPTIVE CENTRES

Fig. 1

have displaced the dykes indicating post-volcanic faulting of trappean rocks. Such displacements may be along transverse or oblique lineaments. These are of shallow depth and younger age.

Sengupta (1967) commenting on the structure of Gulf of Cambay states that the general N–S trend of the basin is disturbed by two major uplifts one of them being a subsurface extension of Kathiawar peninsula. This appears to continue eastwards between the Narbada and Tapti trough and is named as 'Satpura uplift' having an E–W to

ENE–WSW trend. As regards the Cambay basin, Sengupta further indicated that within the basin near its axial part there exists a system of median fractures along which subsidence has taken place. The eastern margin of basin coincides with the Western Coast of India and appears to be faulted. From this Sengupta has conculded that deep fractures exist within the traps which may be continuous upto Lacadiv Minicoy group of islands, their orientation being N–S. This fracture pattern follows the trend of the two orogenic belts namely Satpura and Dharwars which probably have served as the structural grains.

Volcanic Lineament

Presence of ancient volcanics linearly arranged implies to an eruption through volcanic cones as against the more common volcanism of Deccan traps through fissures. Along the West Coast these are noted at St. Mary's Island about 300 miles south of Bombay, along Western Ghats of Maharashtra (Agashe and Gupte 1966), the island of Bombay, Malad and nothwards. Another volcanic lineament showing an E–W arrangement was pointed out by Crookshank (in Auden 1949) along the Narbada trough and Satpura region, west of Barwani state. Sukheswala and Udas (1964) suggested the possibility of all such erruptive centres along Narbada trough as being of alkaline type and related to the extrusion of carbonatitic magma. In the absence of the detailed study of all these centres it is difficult to make any definite concluions regarding their alkaline or acidic affinities.

Eruptive centres similar to the two areas along Narbada trough and North Konkan, are also found in Girnar and Osham. Detailed study of Girnar area (Subba Rao, 1964) shows cone type activity in addition to fissure type (common in Deccan traps) in the region. Resemblance is evident between the main episodes of igneous activity between Girnar and Tertiary igneous complex of Scotland. As pointed out earlier, the igneous activity of Scotland has been corelated by Tomkeieff to rifts within the vicinity. This appears to bear conformity with the views expressed by Baily (1964) and Sveshnikova (1967), both of whom support the presence of alkaline magmatism of the central type to a special environment namely that of rift structure. Bailey is more convinced that uplifting of the continental crust is intimately related to the formation of rifts and the associated alkaline volcanism, where as Sveshnikova prefers to have a more difinite type of crust (either platform or stable block) dissected by deep fractures as the basic requirement for such igneous complexes (includin ring and cone intrusions), which may form independent provinces along the rift system. Since all these eruptive centres are confined to the western portion of Deccan traps, the region is indicative of a different tectonic enviornment as compared to the rest of the trappean province.

Mixed Province

Hybrid aspect of volanism confined to the western traps has led to the speculation that the area probably constitutes a mixed province (Bose, 1967). On the basis of rocks belonging to alkaline affinities Chatterjee (1964) considered this region to be an alkaline olivine basalt sub-province.

Presence of alkaline rocks in Konkan, Narbada trough and Kathiawar regions, which show the association of dykes, fractures, fissures and ancient volcanics, is considered significant and suggests a genetic inter-relationship. Occurrence of alkaline rocks in Deccan traps are reported from various places. Nepheline syenites are found to occur at Jawahar about 90 miles north-east of Bombay. Rocks of alkaline affinites are found to occur in the islands of Salsette and Trombay. The presence of carbonatite, and alkaline syenite has been noted at Amba Dongar, and Pheniamata in the Narbada trough. Pavagarh and Girnar in Kathiawar also show rocks of alkaline affinities.

Sukheswala has pointed out the possible tectonic implication of the presence of alkaline rocks of Narbada trough as belonging to similar environment as the alkaline rocks of East African Rift Valley, thereby implying that Narbada trough is a rift. A possible rift was also suggeted by him near and parallel to the Western Coast on the basis of occurrence of alkaline rocks. The seismicity of the region also supports such a postulation (Srivastava and Tipnis 1968).

Tectogenesis

The above mentioned petrological and tectonic observations as applied to the traps of the Deccan volcanics shows that the north Konkan, the Narbada trough and the Kathiawar regions have the following features in common.

1. Linear crustal uplifts in case of North Konkan and Narbada trough while domal uplifts in Kathiawar.
2. Fractures, generally conforming to the pattern of dykes, thereby, possibly representing initial tension cracks during the arching of crust.
3. Dyke swarms, which are parallel to the linearly oriented uplifts and radial in case of the uplift.
4. Subsidence along the axial fractures in the case of two linear uplift and into caldera in case of the domal one.
5. Linear disposition of ancient volcanic cones indicative of central type of eruption along with the normal fissure-types.
6. Presence of acidic and alkaline differentiates of volcanic rocks in the vicinity of these eruptive centres.

Working on Sveshnikova's hypothesis that tectonic magmatic complexes often form independent provinces along major rift zones it is suggested that Narbada trough and North Konkan are in fact independent complexes belonging to two major rift systems, the Satpura rift and West Coast rift. The Kathiawar igneous complex with its various plutonic centres of eruption is explained as resulting from intersection of rift systems by working upon Bailey's hypothesis that concentration of eruptive centres takes place at junctions of rift intersections or of a rift with fault. Such an intersection could be due to—(1) the westward extension of Satpura rift as suggested by Auden (1949) and confirmed by Sengupta (1967) ; (2) the northerly continuation of West Coast rift whose bend of strike to northwest would reflect its tendency to trend parallel to the Carlsberg ridge of the North-West Indian Ocean—a feature commonly observed in the case of marginal igneous activities (Menard 1964) ; and (3) the westward splaying of western strike of the ancient orogenic belt of Aravallis.

The suggestion of the possible presence of two intersecting systems of the rifts in Kathiawar complex has a precedence by the example of similar orthogonal set up of East African and Red Sea rifts. These also show definite intersection but do not bypass one another.

Mechanism and Significance of the Hypothesis

The mechanism which can explain the association of various geotectonic features as seen within the trappean province appears to result from upwarping of the crust as suggested by Bailey. Such a phenomenon is manifested in : (i) crustal uplifts situated above orogenic belts, (ii) rift or fractures occupying the crestal position of these uplifts, (iii) erruptive and intrusive centres of igneous activity confined within or outside the rifted zone and (iv) basaltic lava flows occupying the inside and outside spread of these rifts.

It is well known that orogenic belts are zones of isostatic imbalance and that crustal upwarps in pre-Cambrian shield in general develop along them due to uplifting of their roots.

Upwarping of the competent crust causes streching at the surface and relief of pressure in the underlying region of the tectonosphere. This is responsible for the formation of deep fractures and fissures at the crests which extend from the interior upto the surface of the uplifted crust as also in the melting of rocks at its base. The molten material move upwards through these associated fractures and fissures, whose disposition may be meridional at the crest or parallel to en echelon on the limbs of the upwarps extending on either side. It is important to note that main rift is due to lagging behind of the central block during general uplift of the area and that along other fractures accompanying the limbs subsidiary rifts and horsts get developed as a result of a series of overlapping step faults. All these fractures would show an orientation parallel to the uplift. Subsequent fractures. unrelated to the initial upwarp may result from subsurface and surface adjustments due to sliding and movement of magma. These trend parallal transverse or oblique to the tension cracks. Isostatic adjustment of the subsided crustal block is liable to give rise to further set of fractures and faults.

An outcome of the relief of pressure would also be in the partial melting of the rocks at depths. Such a melting would induce the flow of volaties and magma to areas of low pressures in the subcrust or at the surface, therefore, giving rise to intrusive and extrusive types of volcanism. The type of magma generated would be governed by the thermodynamic conditions, and inside the magma chamber which contain the molten upper mantle material there will be a tendency to adapt itself compositionally under the existing condition. Field evidences indicate that the magma thus generated is either tholeiitic or alakaline olivine types. The same area, therefore, can witness either or mixed type of volcanism.

From the position of the upwarp it is clear that the initial fractures and fissures which extend from the tectonosphere to the surface of the upwarp provide an easier channel for the transfer of material when they are *inclined* rather than *vertical*. In the latter case they would be met with greater resistance to upward movement. This view upholds Florensov's suggestion that bounding rift faults do not form the main conduites for lava flows and that fissures in the basement rocks are the major channels for the same. This also explains the field association of the intrusive comagmatic phases as dykes within or in the vicinity of the uplift areas and the general absence of extrusives in some of the rifted structures. The extrusion of magas more often through fractures and fissures accompanying the arched limbs cause large scale spreading of volcanics on the surface. Repeated extrusion in the different stages of crustal warping or episodic revival of activity produce huge sequences of lava flows thereby burrying the surface evidences of the presence of rifts and other fractures.

Erruptive centres are often seen confined to just within the rift zone or are met with at some distance away from it. Their genetical relationship to the rift however is irrefutable. They are younger to the main event of trappean volcanism. The concentration of erruptive centres especially, of the alkaline type appear to be related to either the junction of two rifts, or to a rift with a fault which would facilitate easier movements for magma from depths. Such areas are often represented by domed up volcanic cones signifying forceful injection.

The sequence of events for the development of eruptive centres seems to be: (i) initial upwarping of the crust and the extrusion of plateau basalts through fissures and fractures, (ii) formation of rift structures above the crest of the uplift, (iii) development of later fractures either parallel, oblique or transverse to the median rift, and (iv) coming into existence of intersecting fracture zones thereby facilitating upward migration of magma along them.

The eruptive centre developed by the mechanism stated above would be regions of volcanism where the generated magma would produce various differentiates and derivatives. The tholeiitic magma gives rise to acid differentiates while alkaline olivine magma forms the basic differentiates such as nepheline syenites, oceanites, and ankaramites. This also explains the appearance of andesitic or trachytic types during the later stages of basaltic volcanism in rift zones as pointed out by Florensov et al (1968).

Alkaline Eruptive Centres

Within the trappean province the presence of Alkaline eruptive centres show a concentration mainly along latitude 20°N between longitude 74° to 75°E. This needs explaination. It is envisaged that the Eastern Aravallis take a bend towards south in the vicinity of Panchmahals (Krishnan 1966) and then further join the E-W Satpura trend. The trend of eruptive centres is close to this postulated bend to the Aravalli strike. Movements involving frequent uplift have affected this region as is evident from the exposed cores of carbonatites. There is every possibility therefore, that the eruptive centres occur at the junction of Satpura rift being intersecied by Aravalli orogenic belt.

Working on the principle that alkaline eruptive centres are often concentrated at junction of two rift zones it is suggested that discovery of similar centres of eruptive rocks is not unlikely towards the western extremity of Satpura rift, especially in the vicinity of of Daman, Surat and parts of Baroda district.

To explain the alkaline eruptive centres of Kathiawar, it is felt that the possible deep seated intersecting system of fractures due to the Satpura and the West Coast rift as well as the presence of splayed Aravallis helped in easier movement of magma, the accompanying vertical uplift and doming achiveing a significant magnitude.

Satpura Rift

Sengupta (1967) suggested that the area between the Narmada and Tapti be mentioned as "Satpura Uplift" in view of the structural control exerted by the Satpura orogenic trend, upwarping of which has perhaps led to rift-formations. Satpura trend is seen to have E–W to nearly ENE–WSW direction. Between Narmada and Tapti it is made up of Deccan traps. The trend coutinues through Mahadeva Hills, Maikal range, Manipal hill and north of Chota Nagpur to Rajmahal hills which also occupy elevated regions. Further east the trend merges into the Garo hills in western Shillong plateau.

The Satpura rift, with the Narbada trough at its western end and Rajmahal and Sylhet at its eastern extremity is characterised by continued presence of extrusive igneous rocks all along its trend. Pre-Cambrians exposed within this belt strike parallel to Satpura orogenic trend and although several orogenic cycles are considered to be involved, granite-gneisses, ultra basic rocks, granophyres and soda granites also trend the same.

Towards west the Deccan traps are confined to a belt 70 kms wide and 700 kms long. Its external boundaries are occupied by the Narbada and Tapti troughs. The trough continues eastwards as Son-trough having nearly ENE–WSW trend. In this zone intrusives belong to Deccan trap age. Further east along the Damodar trough the Gondwanas have been intruded by igneous rocks of either Rajmahal or Deccan Trap age. These intrusive occurring as dykes or sills generally follow straight corurses and are controlled by fractures in the basement rock (Krishnan 1952).

There are certain evidences of laterites which suggest a much wider distribution for Deccan traps. Lateritic and bauxitic cappings of Lohardaga, Ranchi district, may mark the former extension of Deccan traps (Krishnan 1960). Ahmed (1962) has mentioned laterite cappings to the east of Shahabad. These are believed to be altered traps, thereby confirming their extension along the Son trough.

The above indicates that the Satpura rift seems to have witnessed activity not only confined within the Narbada–Son troughs as observed, but with extensions in adjacent areas and comagmatic intrusions upto Rajmahal and Sylhet region.

West Cost Rift

The Deccan trap activity covering major portions of Maharashtra is considered to be associated with the West Coast rift extending from Cambay to Ratnagiri. As stated earlier this zone is characterised by volcanic lineaments and fractures trending N–S. Hot springs also follows this alignment. Volcanic rocks of Deccan trap type are also exposed at St. Mary's island and Laccadiv group of islands off the coast of Mysore. This suggests a possible extension of rift further south of Ratnagiri extending upto Laccadiv islands.

The ancient land mass of Peninsula extended upto Laccadives, and strikes of Kerala and Laccadive rocks are similar, the crust between the Laccadives and India being mainly continental in character. The intervening area which is supposed to have existed as a Dharwarian ridge suffered intensive subsidence along meridional fractures during Paleogene and Neogene times thus giving to it the present appearance of an intra-crationic graben shaped northernly plunging basin (Eremanko 1967). It is suggested that this subsidence may have been associated with crustal unwarping, followed by wide spread volcanism similar to that of other rifts. Elevation of Western Ghats and Mysore plateau could be the aftermath of such a subsidence. This also conforms with Sengupta's suggestion of a "basinal depression and the presence of an uplift near the axial part" in the Cambay associated with horsts in the trap and the system of fractures within the trap which probably extends upto Laccadive Minocoy islands, the zone of positive gravity anamoly also showing a significant correspondence to this.

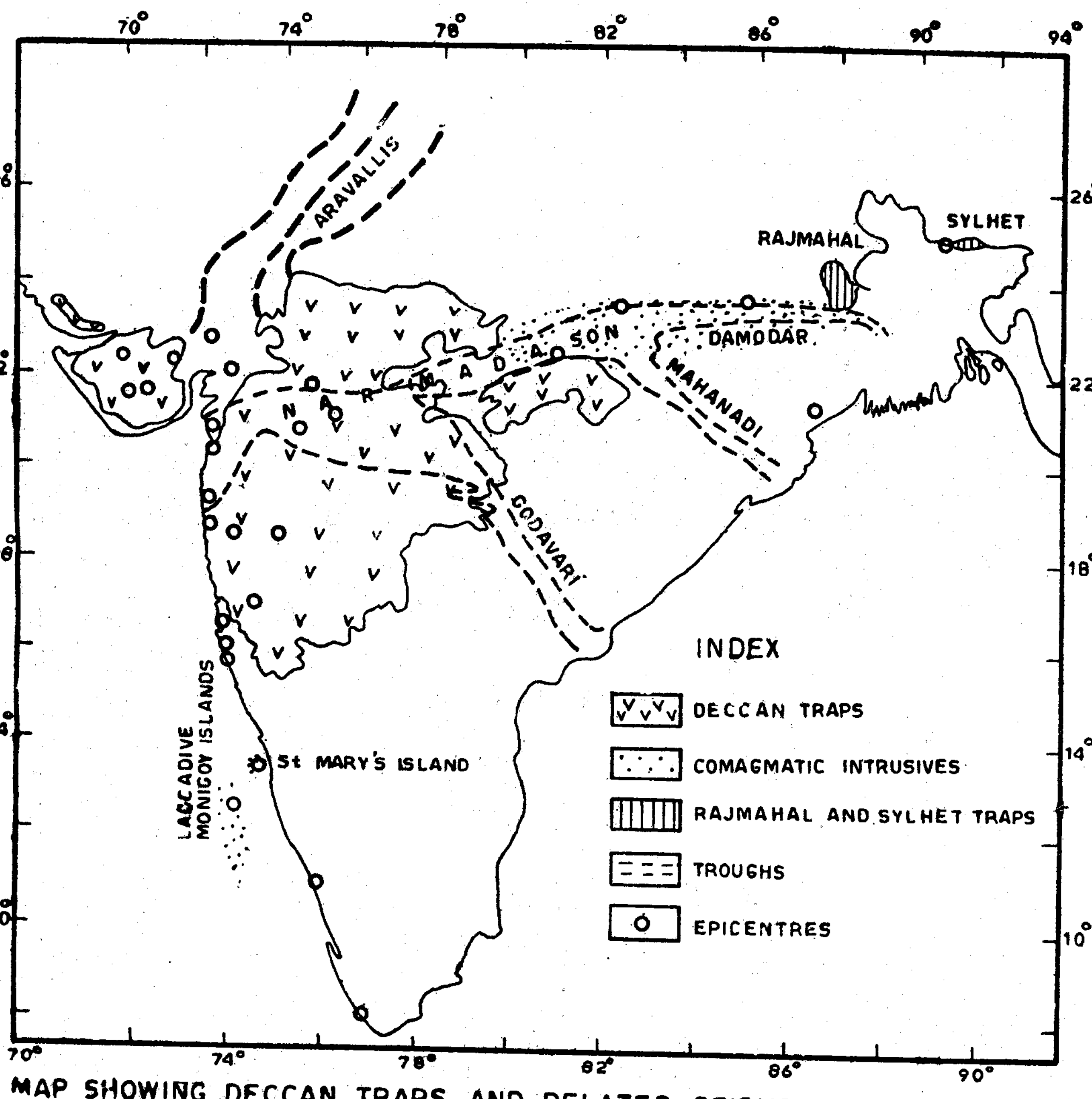
Seismicity of Rift Systems

The rift structure as mentioned above is closely connected with the Upper Mantle, its axis representing a deep lineament. The various orogenic, tectonic and thermodynamic processes acting at depth along such lineaments build up strain energy, release of which is responsible for the seismic activity observed along them (Beloussov 1968). It is now believed that the entire rift zone is not seismically active and that concentration of earthquake activity occurs either along bounding rift faults or wherever a rift intsects another rift, fault or other tectonic or volcanic lineament (Sutton in Tipnis and Srivastava 1968). In the latter case a marked increase in seismicity is noticed and absence of transverse lineament is attributed as the main cause for lesser seismic activity.

It is seen that along the main rift there is generally a tendency for dip slip movements for adjustment of stresses while transverse fracture zones show a predominence of strike slip movement. The earthquakes resulting from latter possess higher magnitudes. This may be due to the fact that dip slip movement under go relaxations due to isostatic adjustment prohibiting the accumulation of strain energy, while strike slip movements are indicative of lateral displacements involving considerable strain build up.

A plot of epicentres (Fig. 2) in the Peninsular shield reveals very clearly that the three areas showing occassional seismicity, namely West Coast Rift of Maharashtra the east-west trending Satpura Rift and Kathiawar region fall in the zones of crustal weakness.

Eruptive Centres and Seismicity :—It has been suggested earlier that presence of eruptive centre are indicative of a rift environment related also to probable zones of crustal



MAP SHOWING DECCAN TRAPS AND RELATED SEISMO-TECTONIC FEATURES

Fig. 2

weakness. Since the seismicity of a rift also obviates from movements along fractures at depths, a reasonable correlation ought to exist between epicentres and areas of central type of volcanic activity. Areas showing central type of volcanic activity are delineated and it is ascertained as to whether they have shown any seismic activity in the past. While doing so, however, a major handicap crops up namely in the lack of intimate knowledge about the Trappean province. Yet, on the basis of recent work (Sukheswala et al 1966, Agashe and Gupte 1966) along Narmada trough and western coast it would not be wrong to assume that cone type activity has a much wider distribution than what was once suspected for Kathiawar alone. The Kathiawar region is included in the seismic zone because of its nearness to the highly seismic belt of Kutch. It is felt, howerer, that even on the basis of geological evidence Kathiawar demands inclusion as an independent seismic belts. The past earthquake activity at Amreli, Paliyad and the very recent activity near Dhoraji and Jetpur can safely be correlated to this.

Epicentres along Satpura Rift : Satpura rift is made up of three troughs Narbada, Son and Damodar. The distribution of epicentres are such that the Narbada and Damodar troughs show greater seismccity as compared to the Son trough. The precise location of these epicentres can also be correlated to transverse or oblique lineaments intersecting E–W to ENE–WSW trending Satpura rift. This may possibly be the reason for increased seismicity noted at such junctions. The presence of earthquakes in Nimar province (22° N : 75° E) namely at Barwani, Satpura, Dhulia, Khandesh show a very significant correspondence with the eruptive centres possibly related to transverse Aravallis intersecting the Satpura rift. The earth tremors around lat. 24°N and long. 82°E can be related to the transverse Mahandi rift—with its northern extension cutting the northern bounding fault of Satpura rift. Satpura trend is regarded as a continuous belt extending upto Rajmhal hills. The presences of earthquakes around Hazaribagh, Manbhum and Damuda correspond to a possible bifuration of Damuda trough towards Rajmahal hills. This belt continues further into S W Shillong plateau which is the displaced part of the Rajmahal Plateau along the Dauki Tear fault. The Sylhet traps of Shillong plateau represent the displaced portion of Rajmahal traps. The active and youthful behaviour of this fault is evidenced in the high seismicity of the region around Sylhet.

Epicenters Along West Coast Rift : Many earthquakes of significant intensity have occured in this region, their epicentres generally aligned N–S, along a zone of crustal weakness which may be the bounding fault of the North–South oriented West Coast rift. A volcanic lineament trending N–S is seen paralleling it. The focal mechanism as revealed by detailed seismological study of the December 11, 1967, Koyna Eartquake shows that strike slip movement along a fault plane striking N 26°E and dipping at an angle of 66° towards north-west (Tandon and Chaudhary 1968) was probably responsible for this shock. If so, this could represent a fault oblique to the main rift along which higher seismicity is observed. The other epicentres in the region off-set from the general North–South alignment could also be lying along or at the intersection of other faults. Seismic activity at the junction of Narbada rift with postulated West Coast rift zone is another evidence of seismicity along transverse junction. This would incorporate the epicentres of Daman and Surat in south and Ahmedabad and Baroda in north. The presence of trans-current fractures similar to those observed at other places have not been reported from Western Ghats. However, a distinct off setting of the Ghat ridges is apparent over its entire length as seen even from topographical map of the area. It is possible that this displacement has resulted from transverse shear zones and could be the reason for concentration of most of the epicentres as well as eruptive centres along or on either side of the continental divide of Western Ghats. Fractures transverse to West Coast rift south of Ratnagiri are also likely to occur following the Burrard's hidden trough (Krishnan 1953) extending from Belgaum to Nellore through Bellary which also shows seismicity. Under these circumstances the coast between Vengurla and Devgarh is likely to be dissected by fractures, paralleling the hidden trough and lying transverse to the coast of that region. It it no wonder therefore, that the coastal region shows seismicity.

Conclusion

The geological observations on the rift systems situated over the continental crust having volcanism show the presence of lineaments of eruptive centres either parrallel or transverse to the main rift and vast lava flows erupted through fissures, fractures and volcanic cones. The volcanism is associated with dyke swarms, fractures and flexures having similar dispositions. Areal extent of such rifts overly areas which have undergone considerable crustal uplift whih subsidence along the crestal portions. These subsided blocks often show mild seimicity. Fortunately, Deccan traps of India show all these features. A rift environment for the volcanism of Deccan traps would explain the association of features such as volcanic vents and fissures, presence of tholeiitic and alkaline olivine magma types, their many derivative, and the parallelism between dykes, fractures and fissures. It would also explain the spread of volcanics to great areal extent on either side of the main soure of eruption by considering the extrusion through fractures and fissures which are connected to the magma chamber at great depths. These fractures and fissures may occur along the limbs of the upwarped crust and hence the lavas appear to have travelled large distances from the source. Any lack of evidence pointing to the presence of these fissures in such areas is probably due to younger lava flows burrying the features.

The seismicity of Deccan traps is very intimately related to their problem of tectogenesis. Distribution of various epicentre in relation to the main rifts, indicates that movements along the junction of transverse or oblique lineaments and the bounding faults are probably the main cause for the marked seismicity. Such areas of crustal weakness are also expressed by the presence of eruptive centres. To test the validity of this it would be desirable to establish the existence of eruptive centres, median, transverse or oblique fracture zones, zones of subsidence and crustal upwarps in the seismically active parts of the Deccan trap regions.

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References

Agashe L.V. and R.B. Gupte, (1966), Some Significant Features of the Deccan Traps, Geol. Soc. Ind. Bull., July, 1966.

Ahmed F., (1964), Origin and Significance of Vindhyan Scarp, Proc. Second Symposium on Earthquake Engineereing, U.O.R., Roorkee.

Auden J.B., (1949), Dykes in Western India, A Discussion of their relation-ships with the Daccan traps, Trans, Nat. Instt., Sc., India Vol. 3, No. 3, pp. 123-157.

Bailey D.K., (1964), Crustal Warping and Alkaline Magmatism, Jour. Geophys. Res.,69,1103.

Beloussov V.V., (1968), Certain general Problems of Development of Tectonosphere (of the Crust and Upper Mantle of the Earth), International Geol. Cong. Report of of the Twenty Third Session, Czechoslavakia, Academacia, Prague.

Glennie, E.A., (1932), Gravity Anamolies and Structures of Earths Crust, Survey of India. Prof. Paper 27.

Florensov, N. A. Logachev and V.P. Soloneko, (1968), Cenozoic Volcanism of Rift Zones, International Geol. Congress, Report of the Twenty Third Session, Czechoslavakia Academacia Prague.

Krishnan, M. S., (1953), Structure and Tectonic History of India, Memoir. Geol. Surv. India., 81.

Krishnan, M.S., (1966), Tectonics of India, Bull. Nat. Instt. Sci. India. No. 32, pp. 1–35.

Menard, H.W., (1964), Sea Floor Relief and Mantle Convection, Physics and Chemistry of Earth, Vol. 6, Pergamon Press, London.

Sengnpta, S.N., (1967), Structure of the Gulf of Cambay, Proc. Symp. on Upper Mantle Project, Nat. Geophys. Research Instt. Hyderabad. Jan. 1967.

Srivastava, L.S. and R.S. Tipnis (1968), A Note of the Seismicity of the Western Coast of Maharashtra, Symp. on Koyna Earthquake of 11th Dec. 1967 and Related Problem. June 1 and 2, Calcutta.

Subba Rao, S., (1964), The Geology of the Igneous Complex of Girnar Hills, Inter. Geol. Cong., Delhi, Proceedings of Section 7, Plateau Basalts.

Sukheswala, R.N. and Poldervaart, (1958), Deccan Basalts of the Bombay area, Bull. Geol. Soc. Amer. 69 : pp 1475–1494.

Sukheswala, R.N. and G.R., Udas (1963), Note on the Carbonatite of Amba Dongar (Gujarat State) and its Economic Potentialities, Science and Culture Vol. 29, pp. 563–568.

Sukheswala, R.N. and R.K. Avasia, (1966), Nepheline Syenites in the Deccan Traps of Jawahar, Bombay, Jour, Geol. Soc., India., No. 7.

Sveshnikova, E.V., (1967), Rift Structures As Favourable Structures for Tectonic Magmatic Complexes of Central Type, Fourth Symposium on African Geology.

Tandon, A.N. and H.M. Chaudhary, (1968), Seismometric study of the Koyna Earhquake December 1–, 1964, Symp. on Koyna Earthquake and related Problems, June 1-2, 1968, Calcutta.

Tipnis, R. S. and L.S. Srivastava, (1968), World Rift System, their Volcanism and Seismicity, Bull. Ind. Soc. Earthquake Tech., Vol. V. No. 1 and 2, April–June 1968.

Tipnis, R.S., (1968), On the Probable Cymatogenic Evolution of Deccan Traps (in press).

Tomkeieff S.I. 1964, Petrochemistry and Petrogenesis of the British Tertiary Igneous Province, Advancing Frontiers in Geology and Geophysics, Ind. Geoph. Union, Hyderabad.

West, W.D. (1937), 'Earthquake in India' Presidential Address, Section of Geology Geography, 24th Indian Science Congress, 1937.

West, W.D., (1962), Source of Deccan Traps, Jour. Geol. Soc., India, Vol. 1.

West, W.D., (1958), The Petrology and Petrogenesis of Forty Eight Flows of Deccan Traps, Nat. Ins. Sc. Vol. IV. No. 1, pp. 1–56.

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AN INSTRUMENT FOR OBSERVATIONS OF SECULAR GROUND TILT

P.N. Agrawal* and V.K. Gaur**

Abstract

This paper deals with the design and development of a portable water tube tiltmeter. This instrument can be used for measurements of the secular ground tilt in seismic areas. Field procedure for making these measurements have been outlined. Programmes for measuring the ground tilt with this system have already been commenced at the Yammuna Hydel Scheme Project site, Dehradun and in the Pophali Power House area in Maharashtra.

Introduction

It has long been known that in certain regions of the earth, geological processes continue to build up strain. When the strain at any point exceeds the breaking strength of the rocks, rupture starts and propogates for considerable distances. If it were possible to measure ground deformation accompanying the strain build-up in a seismically active region, it might show some correlation between the secular earth's surface tilting and the seismicity. It is felt that if the measurements are made over a long period in seismically active areas, these along with other relevent geophysical data may form a sound basis for predicting earthquakes.

In order to measure the secular ground tilt associated with ground deformations it was decided to develop a portable water tube tilt meter. Instruments for such observations employing same principle are available United states of America and Japan, but are not available commercially. The first set shown in figure 1 was completed in December 1967. The experience gained during the development of this set however led to an improved design. Another set was fabricated in April 1968 incorporating these new features. The paper is intended to report this second instrument in detail.

Description of the Portable Water Tube Tiltmeter System

The system is shown in Figure 2. It consists of two identical cylindrical vessels of 105 mm inner diameter, 120 mm outer diameter and 215 mm height. A built-in partition is provided at the mid height of the vessel. On the lower side of this partition is attached a micrometer spindle whose free end intrudes in the upper half of the vessel through a water leak proof cell, and is capable of being moved up and down by 30 mm. A rack and pinion arrangement is provided to slowly move the micrometer disc whose least count is .0005 mm (1/2 micron). The main scale is in mm and is fixed on the cylindrical vessel itself. A viewing window of 35 mm diameter, is placed above the partition. An adjustable torch bulb is attached to illuminate the free end of the micrometer spindle. The two vessels are connected by a suitable diameter alkathine tubing The water is let in either through the inspection window at the top lid or by removing the top lid. The base plates of these tiltmeters are provided with a seat to ensure their being fixed up in exactly the same position on the tilt base during successive mesurements. A microscope with 30 × magnification fixed to a suitable stand is used for viewing the micrometer spindle's free end when it just touchs the water surface from below. This is done by gradually raising the micrometer splindle to the water surface until the pointer just coincides with its image.

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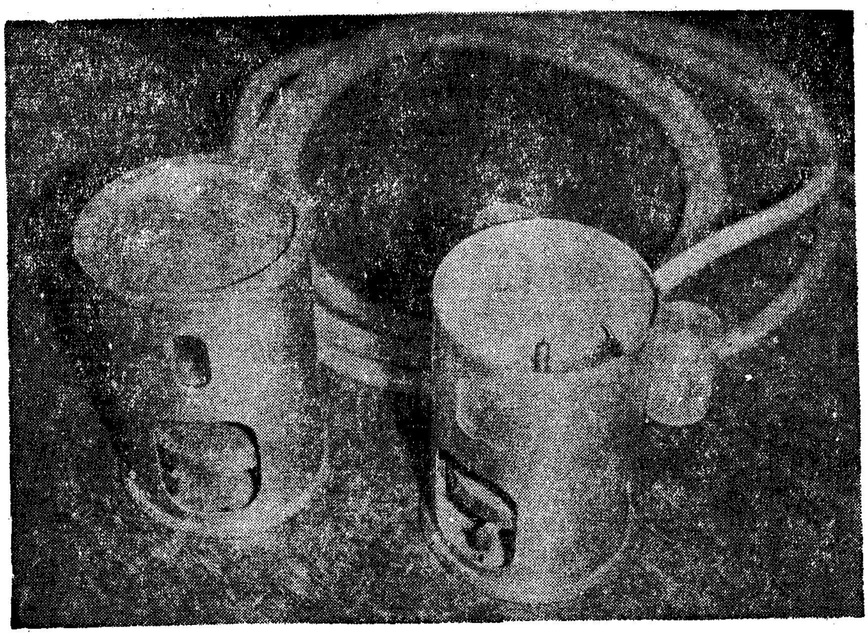

Fig. 1. Portable Water Tube Tiltmeter System in its first stage of development

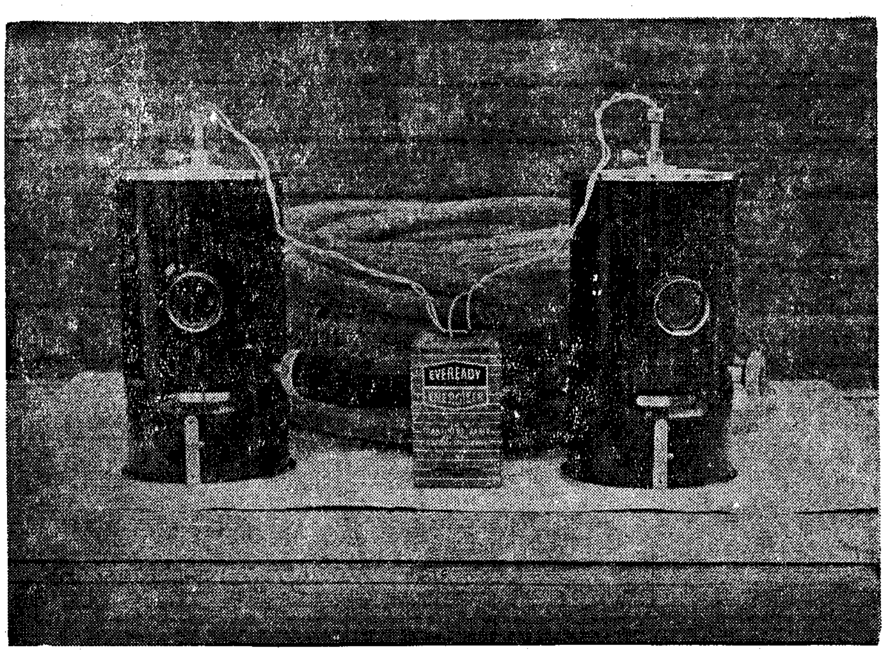

Fig. 2. Improved design of Portable water Tube Tiltmeter System being used for field measurements

Equation of motion of the water level in the system

For the present purpose, water can be considered as an ideal homogeneous, frictionless, continuous and imcompressible fluid. Let us consider the equation of motion of the water surface (Eaton 59) in the tiltmeter system as shown in Fig. 3.

From Eulers equation we can write –

$$\frac{\partial}{\partial s}\left(\tfrac{1}{2} v^2\right) + \frac{1}{\rho}\frac{\partial p}{\partial s} + g\frac{\partial z}{\partial s} + \frac{\partial v}{\partial t} = 0$$

Where the body force is conservative and other symbols have the following meaning.

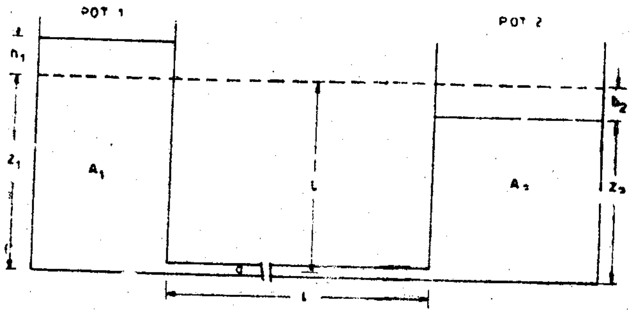

Fig. 3

v	Velocity of the water
ds	element of stream-line
p	external pressure
z	height above arbitrary datum
g	acceleration of gravity
ρ	density of the water

The line integral of Euler's equation along a stream line from Pot 1 to Pot 2 through the water tube can be written.

$$\tfrac{1}{2}\left(v_2^2 - v_1^2\right) + \frac{1}{\rho}\left(P_2 - P_1\right) + g\left(Z_2 - Z_1\right) + \frac{dV_1}{dt}\int_1^2 \frac{A_1}{A(s)}\,ds = 0 \qquad (1)$$

where A_1, A_2 are the cross sectional areas of Pot 1 and Pot 2.

a the cross sectional areas of the Water tube.

l the length of water tube.

L the height of water surfaces in the two pots above the centre of the water tube after equilibrium has been established.

Z ,Z_2 the heights above datum of the water surfaces in Pot 1 and Pot 2 and

h_1,h_2 the height of water surfaces in Pot 1 and Pot 2 above its equilibrium position.

equation (1) can than be written in the following form :

$$\rho\left(L + \frac{A_1}{a}\,l + \frac{A_1}{A_2}\,L\right) + \frac{\rho}{2}\left(1 - \frac{A_1^2}{A_2^2}\right)\left(\frac{dh}{dt}\right)^2 + \rho g\left(1 + \frac{A_1}{A_2}\right)h = 0 \qquad (2)$$

In the system chosen, the cross-sectional area of either pots is the same, thus

$$\rho\left(2L + \frac{A}{a}\,l\right)\frac{d^2h}{dt^2} + 2\,g\,h = 0 \qquad (3)$$

The first term is the inertia pressure resisting any change in the motion of the water and the second term is the pressure driving the system toward equilibrium. Another term need be included in the equation to account for the pressure required to overcome the internal friction in the water flowing through the tube, since the tube is long and narrow. By Hagen-Poiseuille law this term can be calculated and included in the equation.

$$\frac{d^2h}{dt^2} + \frac{8\,\pi\,\eta\,l\,A}{\rho\,a^2\left(2\,L + \frac{A}{a}\quad\right)}\,\frac{dh}{dt} + \frac{2\,g\,h}{\left(2L + \frac{A}{a}\,l\right)} = 0 \tag{4}$$

where η is the viscosity of water. For the system under discussion $2L << (A/2)\,l$. Equation (4) can therefore be written as follows :

$$\frac{d^2h}{dt^2} + \frac{\pi\,\eta}{a\,\rho}\,\frac{dh}{dt} + \frac{2\,g\,a}{l\,A}\,h = 0 \tag{5}$$

This equation can be solved for 'h' and the critical values of 'a' and 'A' to give critically damped movement of the water surface when connected by a usable tube length. Critical damping is necessary so that the water surface comes to rest in the shortest time after installation of the systems. The first set of tiltmeters was fabricated and tested in April 1968. These tiltmeter pots were initially designed in order to obtain critical damping with a tube length of 55 meters. This length was chosen to enable the system to be placed on tilt bases as far apart as about 50 meters. The resulting values for tube diameter and the pot diameter were respectively 15 mm and 105 mm. These are now being used for measurements of tilts at the Yammuna Hydel Scheme project site and also in the Koyna region. In both these cases the two vessels are placed on specially designed tilt base hubs which have been fixed at interval of about 20 and 30 meters depending upon the availability of tunnel space. The shorter distances between the bases however necessitate the tube to be coiled up, thus retaining the original response.

Laboratory Tests for studying the performance of the Portable Water Tube Tiltmeter System

The unaided eye can resolve a separation of upto 0.1 mm. However, in this system a microscope of only 30 × magnification has been used. As the setting is made by viewing the separation between the pointer and its image, the gap between the water surface and the pointer is effectively doubled. With these considerations it should be possible to make a setting with an accnracy of $\frac{0{\cdot}1}{30 \times 2}$ mm i.e. about two microns. The least count of the instrument which is 0.5 micron can therefore permit a convenient reading for this setting in order to tests the setting accuracy and also to study the influence of personal error, the following two kinds of tests were carried out in the laboratory.

(a) *Repeatability test :* The system was placed on two fixed bases and observations taken both with and without changing the common water level during the test. Each reading was found to deviate by not more than ± 3 micron thus giving an observation of of relative elevation correct within ± 6 micron. However, this error could be reduced by proper training of the eye, since the contribution of personal error was found to be considerable.

(b) *Testing by measurement of the sag af a beam supported at two ends and loaded at the middle :* A 6″ × 8″ steel channel of U shaped section and 18 feet in length was supported on two knife edges 16 feet apart. Arrangement was made for loading the channel in the centre at 1 kg. steps One tilt base was fixed a ltttle distance away from the beam and the other was built on the steel channel itself. The sag could be measured with an accuracy comparable with the results abtained theoretically.

Considerations influencing observation procedures

The ground deformation in any region may be considered to consist of two components (i) local deformation and (ii) the regional deformation. Local deformation may vary widely both in space and time and may arise from various causes, the most important of which are enumerated below :

(i) Differential surface heating,
(ii) Local surface loading,
(iii) Under Mining,
(iv) Action of ocean tides on the coast.

The deformation due to differential surface heating will in general show diurnal and seasonal variations. Local surface loading in a region may be due to heavy engineering installations, reservior loading at a dam site or volcanic activity, and may result in observable ground deformations. Similarly undermined areas might undergo a gradual subsidence producing an observable ground deformation. Deformations have also been reported in coastal areas with changes in the sea level. All these local deformations appear to have the same order but may be much larger as compared with the regional deformation associated with the elastic strain buid-up in the crust in seismically activc areas. The tiltmeter would respond to the total deformation suffered by the region but the effects of various local factors can be eliminated by planning the observations suitably.

The component of local deformation outlined above is expected to have different sign at different points. Thus, if the distance between two points selected for observation is large they should be expected to be eliminated from the readings. For the present purpose 20 to 30 M can be consihered large distance (Hagiwara 47). The influence of temperature variations on the tilt observations can also be eliminated by installing the measuring system in underground tunnels. A field procedure accordingly framed to bring out only the effect of the regional tilt is described below :

Field Procedure

The instrument is installed in L shaped underground tunnels. Three tilt bases are located at intervals of 30 M and each of these is allotted a number and its location specified in the records. The portable system with its accessories can be carried to the observatory in three boxes. The two smaller boxes contain one tiltmeter each along with their accessories and the third contains the alkathine tubing and other accessories and tools. Great care is taken to ensure that during successive observations the same pot, which is also numbered, is replaced on a given base. The reading are tabulated as shown in Table 1.

TABLE 1

Format for reporting Tiltmeter Observations

OBS No. First *Date* 22.9.68 *Time* 10.50 A.M.
Location Cable Passage, Power House, Pophali *Temperature* 26.5° C

Tilt Base No	(ONE)			(TWO)			Height of Tilt base in earlier Col. above the Other (mm).
Pot No.	(ONE)			(TWO)			
	mm			mm			
Sl. No.	00.0	.000/2	00.000	00.0	.000/2	00.000	
(1)	10.50	287	10.643	11.00	430	11.215	
(2)	10.50	283	10.542	11.00	435	11.213	11.214
(3)	10.50	280	11.540	11.00	428	11.214	10.642
							—.572

At least three set of readings with or without changing the water level in the system are taken at the time of one observation. If the zero error of the system has to be accounted for, the measurements should be repeated after inter-changing the pots on the two bases. It is felt that routine observations of the secular tilt should be satisfactory if the observations are repeated once every two months. Since such observations would in general be required to be made over several years the records need be maintained very systematically.

The system can also be adopted for studies of engineering problems such as the study of slow foundation settlements, rock srreep in tunnels, ground sinking in undermined areas and precise leveling. In such applications the field procedure in general would be further simplified as the observations would normally extend over a limited period. Such observations could even be made on suitabily constructed tilt bases on the surface. The effect of temperature variations then be accounted for by repeating observations at the same hour of the day during a particular study.

Ground Tilt Observations in the Kala-Amb drift

Three tilt basis have been constructed in the Kala-amb drift at the Yammuna Hydel Scheme project site, Dehradun. The first set of ground tilt observation have been already made with this system. The drift passess through the Krol and Nahan thrusts which are considered to be active. It is expected that measurements of tilt will throw light on the order of movements taking place along these thrusts.

Ground Tilt Observation in Pophali area

The underground construction in Pophali Power House of the Koyna Hydro-electric Project has made it possible to plan observations of secular tilt in this region also. Nine tilt bases have been established in this area at locations which are given below :

Location	No. of Bases
Approach Tunnel	2
Access passage to the value house	2
Cable passage	2
Intermediate Aqueduct	3

The first set of observations have been already taken in view of the frequent local tremors occurring in the area, it has now been planned to make tilt measurements every day for about a month. It is hoped that this will bring out the correspondence, if any between the ground tilt and the occurrence of tremors.

Conclusions

On the basis of trail tests, the portable Water Tube Tiltmeter system reported has been found suitable for measurements of the secular ground tilt. The system is expected to yield useful data in the Kala-amb drift at the Yammuna Hydel Scheme project site in the Himalayas and in the Pophali Power House area in Maharashtra. In the Pophali area these observations may enable establish correspondence between ground tilt and earthquake tremors.

Acknowledgement

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The paper is published with the permission of the Director.

References

Faton, J. P., (1959), "A Portable water Tube Tiltmeter", Bull. Seism. Soc. Am. Vol. 49, No. 4, pp. 301–316.

Hagiwara, T., (1947), "Observations of changes in the inclination of the Earths surface at Mt. Tsukuba", Bull. Earthq. Res., Inst., Tokyo Univ., 25 : 27–32.

Hagiwara, T., K. Kasahara, J. Yawada and S. Saito, (1951), "Observations of the defdr-mation of the earths surface at Aburasubo, Miru Peninsula", Bull. Earthq. Res. Inst., Tokoy Univ., 29 : 455–468.

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LETTERS TO THE EDITOR

Tectonics and Seismicity

Tectonics is primarily devoted to the problems connected with the structure and history of the earths crust. Its most important and fundamental aspect is enunciating the laws that govern the development and deformation of earths crust. It leads to a synthesis of geological events in space and time and to an understanding, though still incomplete, of the great units and elements in the structure of the continents and oceans. One of the most significant manifestation of the active tectonic forces in a region is its seismicity. Therefore the knowledge of tectonic history of a region is essential for delineating areas of varying seismicity. The interrelationship of tectonics and seismicity is still more intimate as the seismic observations occupy the foremost place amongst the methods available for the crustal investigations.

Data, such as, structural features, the distribution of sediments, the kind of rocks and their thickness, the location of igneous rocks and zones of metamorphism, deviations from isotatic compensations and other gravity anomalies etc. could be used for understanding the tectonic history and for constructing model stress field to fit in the tectonic activity of a region. Seismic observotions are of no direct utility for the purpose. These could be of advantage in verifying proposed models on the basis of other relevent data of tectonic activity in any region, whereas their application to suggest zones of tectonic activity could be misleading.

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November 10, 1968

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Summary of Disastrous Earthquakes 1967[1]

Date	*Country*	*Killed*	*Injured*	*Magnitude*	*Damage*
Jan. 05	Mongolia			$7\frac{1}{2}$	
Feb. 09	Colombia	61		6.7	\$20, million (Rs.150, million)
Feb. 19	Java	51	370	$6\frac{3}{4}$	2,000 homes destroyed
April 11	Celebes	71	100 (seriously)	5.2	
April 12	Sumatra	14		$6\frac{1}{2}$	2,000 homes destroyed
May 01	Greece	9	56	$5\frac{3}{4}$–6	4,800 homes destroyed
May 08	Colombia	2		4.4	Light
July 13	Algeria	10	15	5.0	40 homes destroyed
July 22	Turkey	173	183	$7\frac{1}{4}$	3,701 houses destroyed
July 26	Turkey	92	120	$5\frac{3}{4}$–6	
July 29	Columbia	20	150	$6\frac{1}{2}$–$6\frac{3}{4}$	\$2, million (Rs.15, million)
July 29	Venezuela	240	1536	$6\frac{1}{2}$	\$50, million (Rs.375, million)
July 30	Turkey	2	40	5.6	Several bldg. destroyed.
Aug. 13	Pyrenees	1	14	5.3	\$4, million (Rs.30, million)
Oct. 04	New Ireland			$6\frac{3}{4}$	Minor
Oct. 25	Taiwan	2	3	6.2–6.5	23 houses destroyed
Nov. 30	Albania	20	174	$6\frac{1}{2}$	Considerable
Dec. 10	India	180[2]	2232	$6\frac{1}{2}$	Major damage
Dec. 21	Chile	1	30	7	Major Damage
Dec. 27	Chile-Bolivia border			7–$7\frac{1}{2}$	
	Total ...	949	5023		

(1) Bulletin of the Seismological Society of America, Vol. 58, No. 3, pp. 1182, 1968.
(2) Report of Expert Committee for Koyna Earthquake, Government of India, New Delhi.

THE INDIAN SOCIETY OF

BALANCE SHEET AS AT

LIABILTIES & FUND		
Capital Fund :		
Balance as on 31-3-67 as per last Balance Sheet :	5,232.81	
Add: Excess of Income over Exp. as per Income & Expenditure Account for the year ending 31-3-68 hereunto annexed :	4,524.34	9,757.15
Liabilities for Expenses :		133.00
Bank Discrepancies (Fett) :		41.38
Total	Rs.	9,931.53

INCOME AND EXPENDITURE ACCOUNT

EXPENDITURE		
Cost of Bulletins issued to Members and cost of Sales :		2,043.19
Salary & Wages :		434.00
Postage & Telegrams :		369.12
Stationery & Printing :		273.69
Contingencies :		46.75
General Meeting Expenses :		11.89
Bank Charges :		28.25
Audit fee for 1966-67 for 1967-68	90.00 75.00	165.00
Excess of Income over Expenditure :		4,524.34
Total	Rs.	7,896.34

EARTHQUAKE TECHNOLOGY, ROORKEE:

31st. MARCH 1968.

ASSETS:

Furniture at Cost :			26.40
Stock of Bulletins (As taken, valued and certified by the Secretary valued at cost) :			2,516.15
Subscription Outstanding :			3,551.97
Bills Outstanding :			1,052.20
Cash & Bank Balances :			
Cash in hand :		42.65	
Stamps in hand :		1.16	
Balance with State Bank of India Roorkee ;			
In current Account :	1,241.00		
In Fixed Deposit :	1,500.00	2,741.00	2,784.81
Total		Rs.	9,931.52

FOR THE YEAR ENDING 31st MARCH 1968

INCOME

Subscription received :			
Individual Members :		1,281.45	
Institutions :		1,625.00	
Life Members :		1,143.25	4,049.60
Subscription outstanding :			
upto 31-3-67 :			
Individual Members :	675.97		
Institutions :	850.00	2,025.00	
For 1967-68 :			
Individual Members :	1,425.00		
Institutions :	600.00	2,025.00	3,591.97
Sale of Bulletins :			294.77
Total		Rs.	7,896.34

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