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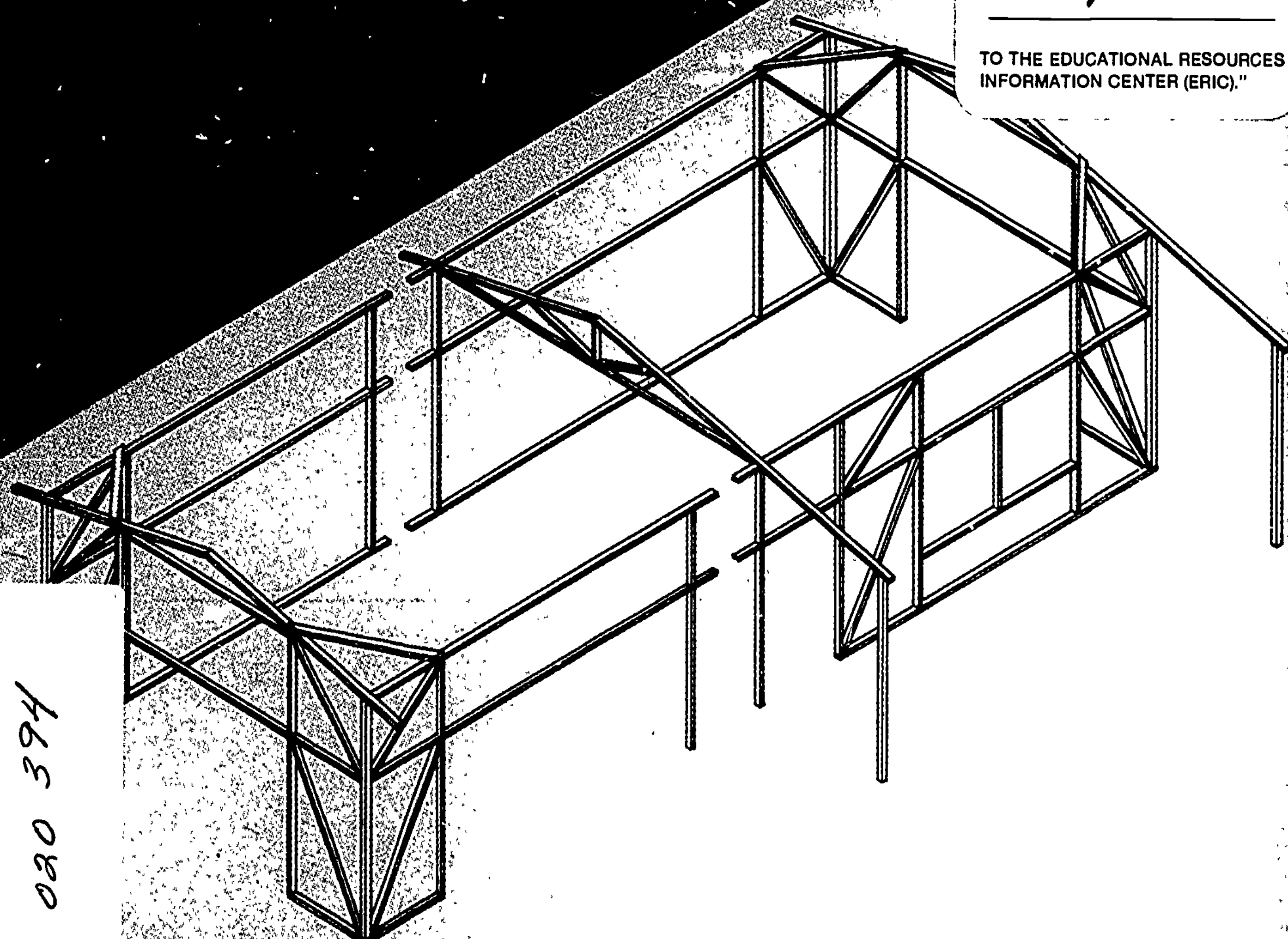
ABSTRACT

This manual presents, in illustrated form, the protective measures needed to save educational buildings from the effects of earthquakes. The information may be used at the community level as a guide to the construction of earthquake resistant educational buildings. Primarily, the manual deals with the construction techniques used for school buildings, student hostels, and teachers' houses built of traditional materials--brick, stone masonry, wood, and adobe. The manual covers the following material: (1) where earthquakes occur and how they damage buildings; (2) design of new educational buildings; and (3) strengthening of existing buildings. Numerous figures and tables are included and two appendixes provide the international earthquake intensity scale and seismic zoning maps of some Asian and Pacific countries. Ten references are included. (SI)

EDUCATIONAL BUILDING REPORT 13



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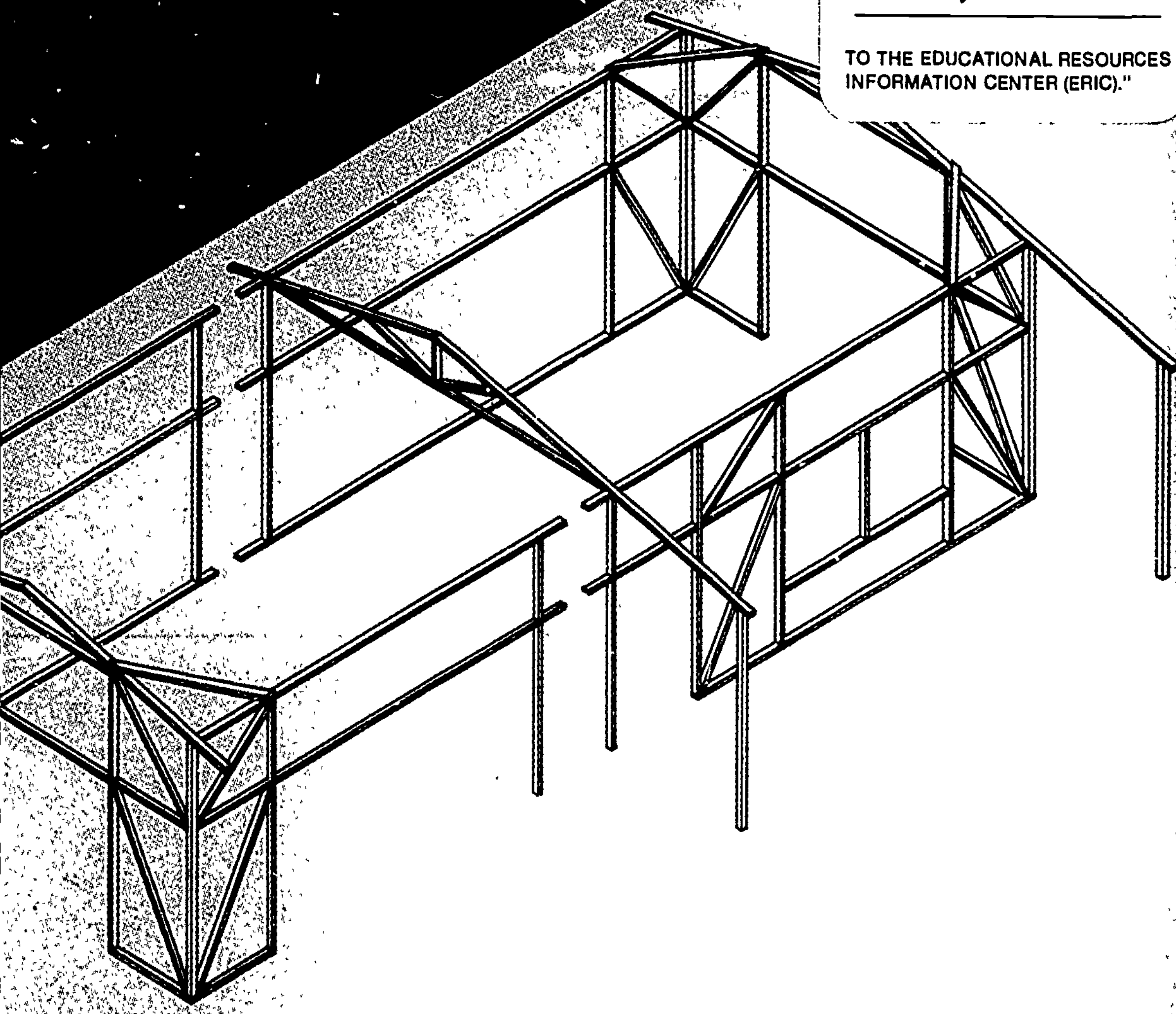

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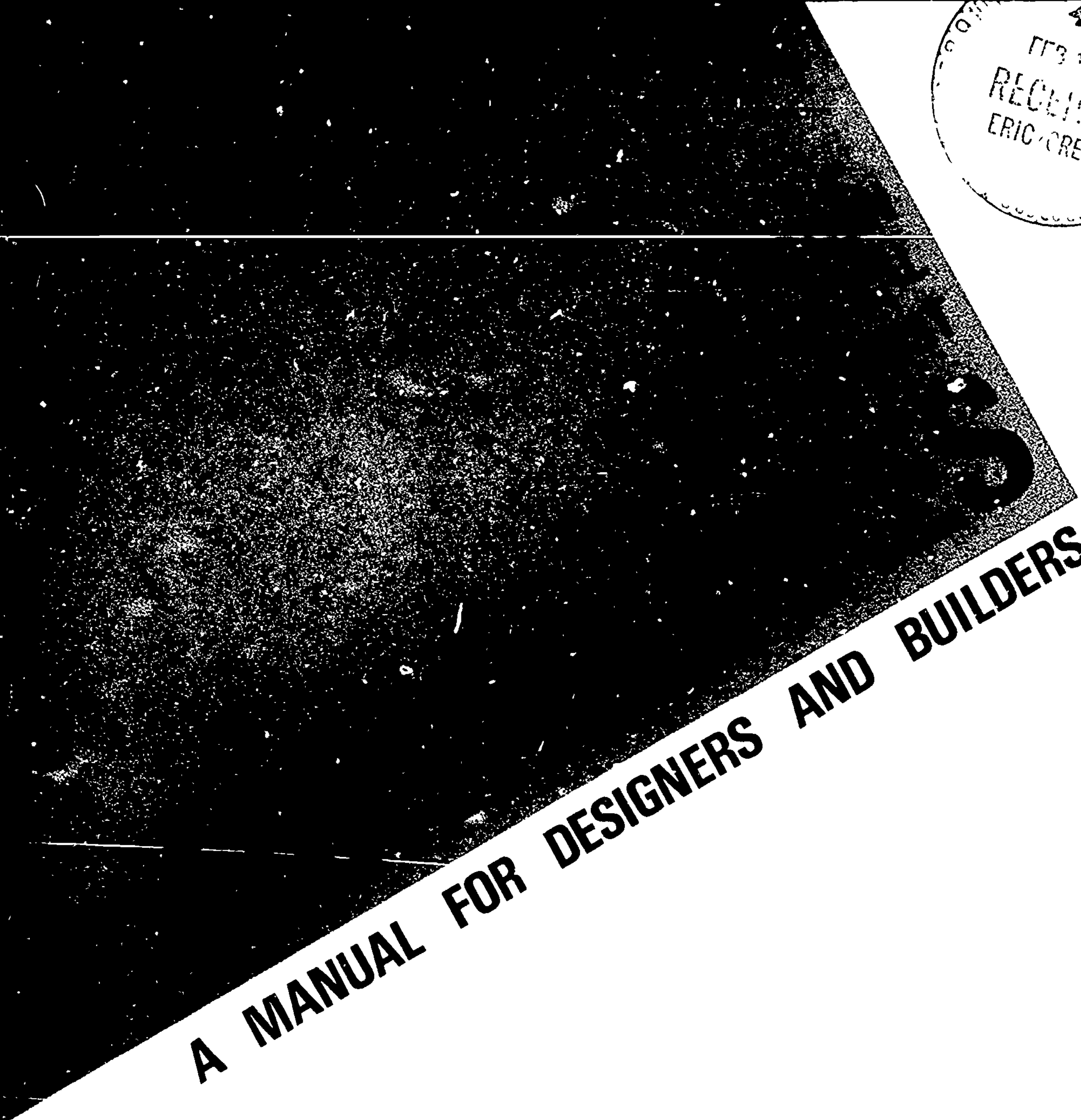

A MANUAL FOR DESIGNERS AND BUILDERS

by Prof. A.S. Arya

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PREFACE

UNESCO has long been concerned with the mitigation of natural disasters. Some of the most tragic loss of life can occur when public buildings such as schools which have a large numbers of occupants are damaged by earthquakes. Even if the users are fortunate enough not to be in the buildings when a tremor strikes, the building may be rendered unusable for educational purposes. For this reason, UNESCO has given special emphasis during the 1982-1987 medium-term plan to undertake studies on the design of earthquake-resistant schools.

This Educational Building Report is the product of such a study for the Asia and Pacific region. The author, Prof. A.S. Arya is Professor, at the Department of Earthquake Engineering at the University of Roorkee. He has long been associated with the work of the UNESCO Regional Office for Education in Asia and the Pacific (ROEAP) as a consultant on the design of schools in the region. He has also undertaken for UNESCO, along with his colleague Dr. B. Chandra, a survey of educational buildings in Asia and assessed their vulnerability to damage by earthquakes. This report is, therefore, the product of Professor Arya's long and vast experience in this field.

The report has, however, received substantial contributions from other persons. In particular, Mr. Roland Sheath, a retired staff member of Unesco ROEAP, has assisted in ensuring that the building details were consistent with regional practice of educational building design and construction. He has also co-ordinated the text and the many illustrations. The illustrations have been prepared by Miss Lipda Udomvarakulchai, a young architect from Thailand.

It is hoped that this book will become a standard reference work in the region. It is particularly intended for the design and reinforcement of educational buildings for which there is no engineer available or where the engineer may not have been trained in anti seismic design.

1. INTRODUCTION

Aim of the manual

This manual presents in simple illustrated form, the protective measures needed to save educational buildings from the disastrous effects of earthquakes. It is written in such a way that the information may be used at the community level as a guide to the construction of earthquake resistant educational buildings.

Scope of the manual

Primarily, the manual deals with the construction techniques used for school buildings, student hostels and teachers' houses built of traditional materials - brick, stone masonry, wood and adobe. These buildings are usually non-engineered and constructed using traditional methods.

This manual lays heavy stress on how materials normally classified as "unsuitable" or "slightly suitable" can be made "moderately suitable". It also includes methods for correct use of normally "moderately suitable" materials and includes mention of reinforced concrete for situations where it is typically used without the benefit of an engineer. Since steel and large reinforced concrete structures are normally designed by engineers, these materials are not included in this manual.

The protective measures suggested for new constructions are intentionally kept simple and inexpensive and can be adopted with little modification to normal building practice. While repair, restoration and strengthening methods are recommended for existing buildings, this document does not cover repairs to damaged buildings because the assessment of the damaged state and the repairability of the building must be carried out by a qualified engineer. Damage assessment is very much dependent on specific locations making it difficult to give recommendations of a general nature.

The recommendations regarding seismic strengthening of buildings in this manual cover buildings of one to three storeys having rooms with a maximum length of up to 9 m. The data regarding school buildings collected from countries of west, south and southeast Asian countries showed that most schools were one or two storeys high, very few three storeys and rarely four storeys, and that the classroom sizes ranged from 5 to 8 m. in width and 6 to 9 m. in length*. Thus the recommendations should cover almost all buildings except those which are four storeys tall or have large assembly halls. The latter will need reinforced concrete or steel frames and should be professionally designed. Large one storeyed halls could alternatively be constructed using load-bearing masonry walls with external buttresses. This type of construction is also described.

Effect of natural hazards (earthquakes) on educational facilities, UNESCO, Paris, 1978 (unpublished).

2. EARTHQUAKES

2.1 How caused

Earthquakes consist of horizontal and vertical vibrations of the ground. These vibrations are random in character. Earthquakes are caused by tectonic movements in the crust of the earth, or volcanic movements underneath. Collapse of subterranean cavities and underground explosions also produce earthquakes.

2.2 Earthquake regions of the world

Figure 2.1 shows the regions of the world where shallow tectonic earthquakes, which are the most damaging, frequently occur. This includes two major seismic belts which are wholly or partially in the Asia and Pacific region. These are, the Circum-Pacific Belt with several branches and the Himalayan Alpine Belt. There are also other minor, more local regions, some of which are also in Asia and the Pacific. The seismic intensity in these areas varies (section 2.5).

2.3 Earthquake magnitude

The destructive energy of the earthquakes is transmitted in all directions through various types of waves which are registered on special instruments called seismographs. The Magnitude of an earthquake is a measure of its total energy released. It is instrumentally measured and expressed on the Richter Scale. Magnitude is denoted by the symbol M. The Richter Scale is logarithmic so the energy of an earthquake of $M = 8.0$ is about 30 times that of $M = 7.0$, or that of $M = 7.6$ about 30 times that of $M = 6.6$. A given earthquake will be described with a single index number.

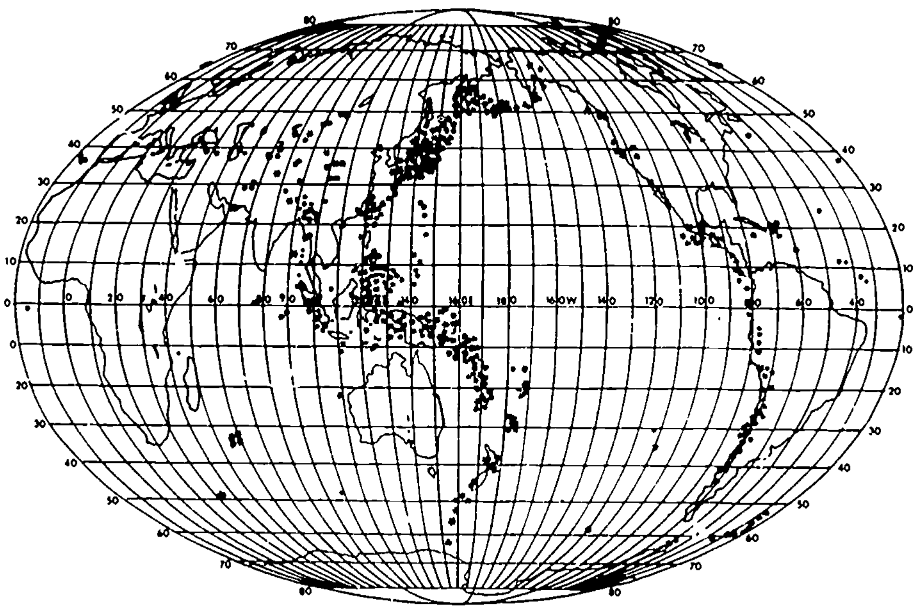


Figure 2.1 World seismicity map (showing major shallow earthquakes)
Source: Elements of seismicity: Richter

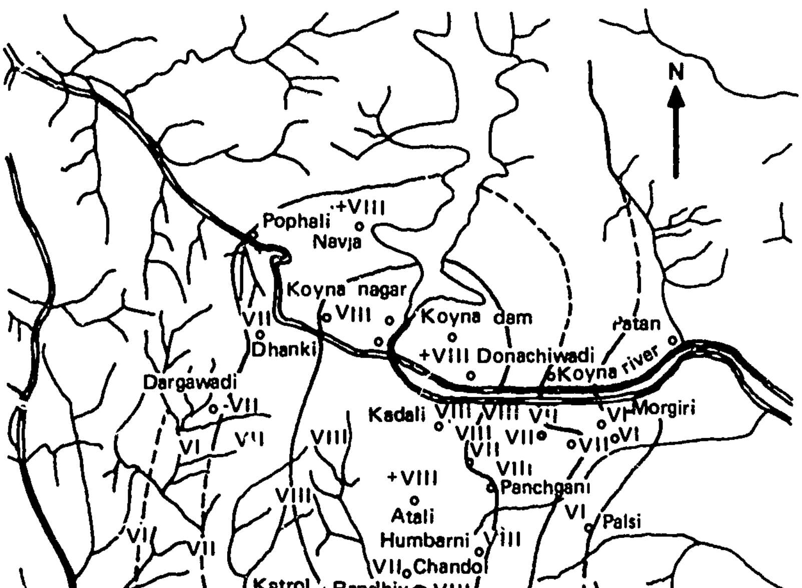
2.4 Earthquake intensity

For an earthquake of a given magnitude its damaging effect goes on reducing as the distance increases from the epicenter. Thus a given earthquake will cause a number of different intensities. An example is shown in Figure 2.2.

The earthquake effect is usually assessed in terms of Modified Mercalli Intensity Scale (abbreviated as MM) or the more detailed international scale called as Medvedev-Sponhever-Karnik (MSK) scale. Both follow a twelve step scale as follows:

I. Not noticeable
II. Scarcely noticeable
III. Weak, partially observed
IV. Largely observed
V. Awakening
VI. Frightening
VII. Damage of buildings
VIII. Destruction of some buildings
IX. General damage of buildings
X. General destruction of buildings
XI. General destruction
XII. Landscape changes

A description of the damage to buildings corresponding to each intensity is given in Appendix A. It will be seen that intensities I to VI indicate little or no damage. The last three intensities (X to XII) are too severe to achieve earthquake safety in traditional non-engineered buildings at economical costs. But luckily the area affected with these intensities even in large magnitude earthquakes is rather small and such quakes are infrequent, as shown in Table 2.1. Seismic zones of Intensity VII, VIII and IX are amenable for incorporation of earthquake protection measures at reasonable cost.



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...ure 2.2 Isoseismal map (showing intensities during 1967 Koyna earthquake of M = 6.5)

Table 2.1 Approximate relationships between M, MM intensity and felt area

Earthquake magnitude richter, M	Expected annual number	Maximum expected intensity MSK	Radius of felt area (kilometres)	Felt area (Km)2
4.0 – 4.9	6,200	IV – V	50	7,700
5.0 – 5.9	800	VI – VII	110	38,000
6.0 – 6.9	120	VII – VIII	200	125,000
7.0 – 7.9	18	IX – X	400	500,000
8.0 – 8.7	1	XI – XII	800	2,000,000

• ***Earthquakes*** by Don de Nevi, Celestial Arts, Calif., May 1977, p. 102.

2.5 Seismic risk maps

Seismic risk maps are prepared using variables such as probable maximum 'Intensity' level, strain energy release rate, probable horizontal ground acceleration etc. In most countries, however, the seismic zoning maps have been prepared on a 'macro' scale using MM or MSK intensities, which are particularly pertinent for the design of buildings since the intensities are, in fact, directly related to building damage. The boundaries of seismic zones in such maps are fixed by National Committees on the basis of geologic, tectonic and lithologic features, the observed earthquake occurrences and their mutual relationship. Such maps for a number of Asian and Pacific countries are shown in Appendix B.

It will be useful to prepare micro-level seismic risk map for locations of whole new settlements including the effect of local soil conditions, water table and the like. School building designers should refer to micro-level maps if they are available. Otherwise, designs can be based on national, or macro-scale, seismic zoning maps.

2.6 Nature of strong ground motion

The strong ground motion is recorded on accelerographs in the form of ground acceleration versus time curves in three mutually perpendicular directions. The motion is random in nature both in terms of acceleration values and time intervals as shown in Figure 2.3.

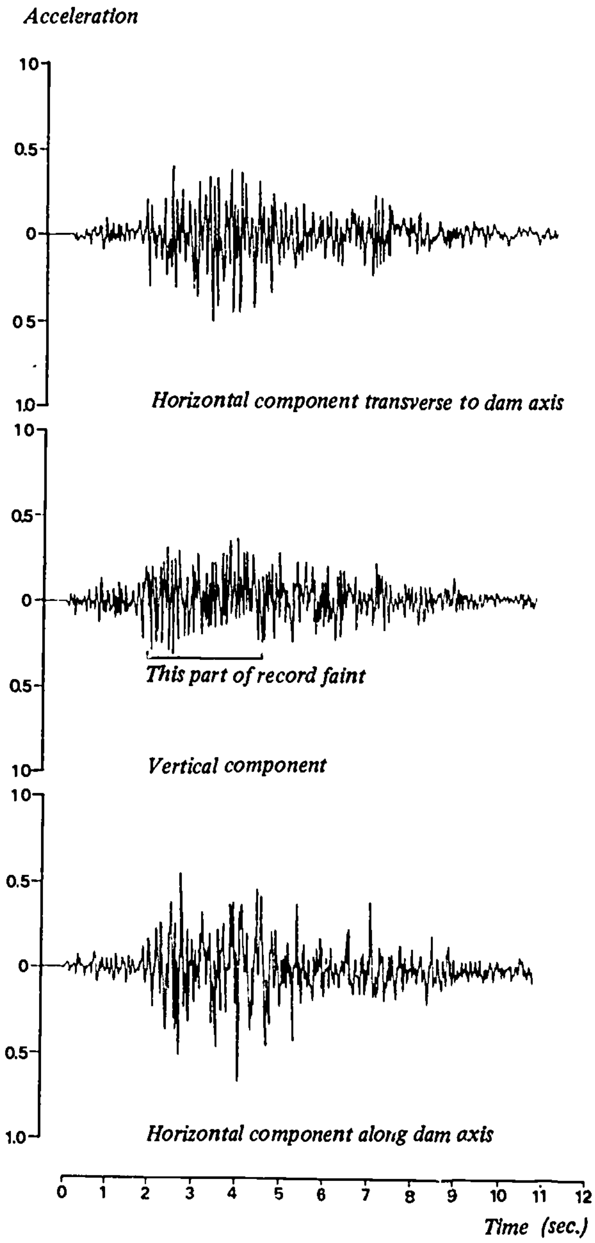

Figure 2.3 Accelerograms of koyna earthquake (India) 11 December 1967

3. EARTHQUAKE EFFECTS

3.1 Ground effects

Earthquake induced ground failure has been observed in the form of ground rupture along the fault zone, land slides, settlement and soil liquefaction as briefly described below:

Ground rupture:

Ground rupture along the fault zone may be none, of very small extent, or may extend over hundreds of kilometres. Ground displacement along the fault may be horizontal, vertical or both, and may be a few centimetres or metres. Obviously a building directly traversed by such a rupture will be severely damaged or collapse.

Liquefaction settlements:

If the foundation soil consists of uniform loose sands within a depth of about 8 m. below the ground surface and is either saturated by or submerged under water, it may behave like a fluid when shaken by a strong earthquake (MM VIII or more). The buildings resting on such ground may sink or tilt and crack or collapse.

Land slides:

Land slides are caused by earthquakes where the hill slopes are unstable due to badly fractured rocks or consist of loose material.

Rock falls:

Many times rock falls also occur when precariously supported rock pieces or boulders are shaken loose and roll down the hill slopes.

3.2 Seismic sea waves (Tsunamis)

A Seismic sea wave or 'tsunami' is produced by a sudden movement of land mass during an earthquake with its focus on shore or off-shore under the sea. As the wave approaches the land, its velocity decreases but its height increases to 6 m. or even 9 m. Obviously, tsunamis can be devastating to buildings built in coastal areas.

3.3 Effects on buildings

Mechanism:

Buildings as a whole and all their components and contents are badly shaken during severe earthquakes by the ground motion referred to in section 2.6. Since earthquakes are earth movements (which, in effect cause the ground to move from under a building), the forces which occur in the buildings come from the inertia of its masses. Inertia force caused on any mass (m) can be described by the formula $F = ma$ where a = acceleration effectively acting on mass m (Figure 3.1).

The force is proportional to mass. Hence the less the mass, the less is the inertia force caused by the earthquake on the building.

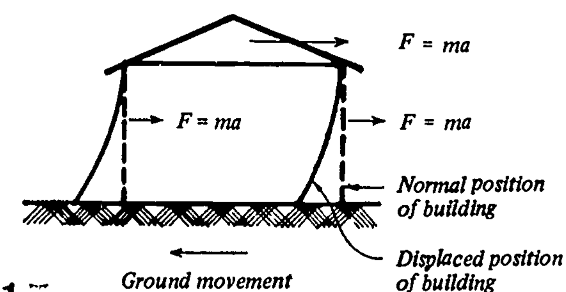

Figure 3.1 Ground motion inertia force

Building damage

The types of damage to buildings seen to occur during earthquakes are listed below.

Roofs:

- Falling of parapets, cornices, chimneys, cantilever balconies

- Displacement and falling of roofing tiles, cracking of asbestos cement sheet roofing, side coverings and ceilings

- Dislocation of roof trusses, wooden logs or joists and other roof beams from the walls and where the dislocations are large, their collapse

- Collapse of heavy roofs due to the inability of the supporting structure to carry applied horizontal forces

Walls:

- Falling of plaster from ceiling and walls

- Fine or wide cracks in walls

- Horizontal and vertical cracks in walls due to bending of wall normal to its plane

- Gaps in walls due to collapse of portions of the walls

- Overturning of boundary walls, free standing partitions

- Diagonal cracking of wall piers between window and door openings, shearing of columns

- Shattering of random rubble masonry walls, falling of inner and outer wythes (layers) of the wall away from each other

- Fall out of infill walls, cladding walls, and gable ends

Damage caused by foundation failure:

- Sinking, tilting and cracking or collapse of buildings due to foundation soil failure

- Spreading of individual column footings in soft soils

General damage:

- Partial collapse of building

- Complete collapse of free standing staircases

- Collapse of old wooden frames due to deterioration of joints

- Torsional failure of unsymmetrical buildings

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4. SEISMIC CONDITIONS FOR BUILDING DESIGN

4.1 Seismic zones

For design purposes, the seismic zones are defined as below.

Zone A - Seismic zone of destruction risk (MSK IX or more)

Zone B - Seismic zone of heavy damage risk (MSK VIII)

Zone C - Seismic zone of moderate risk (MSK VII)

Zone D - Seismic zone of small risk (MSK VI or less)

For seismic risk maps which describe these zones in a number of countries in Asia and the Pacific, see Appendix B.

4.2 Soil condition

For purposes of school building design it is assumed that the site chosen is free of situations indicated in Section 3.1. (e.g. liquefication, rock and landslides). Then two conditions are differentiated:

Soft soil - having safe bearing value less than 11 t/m2.

Firm soil - having safe bearing value equal to or more than 11 t/m2.

4.3 Importance of building based on occupancy.

Protecting buildings against damage by earthquakes may be costly. It is therefore sometimes necessary to make a distinction between buildings which will be given higher protection against earthquake damages and those which will be given lower protection. In the case of schools, all spaces which hold large numbers of persons at one time should be given higher protection as suggested below.

Higher - Classroom blocks, dormitory blocks, dispensary, assembly halls.

Lower - Teachers' residences, stores, lavatory blocks, other auxiliary buildings.

4.4 Classification of constructions for strengthening purposes

Combining the conditions of seismic zones (section 4.1), soil conditions (section 4.2) and importance of building (section 4.3) four categories of conditions have been worked out for selecting the strengthening measures in seismic zones A, B and C. No special protection measures are required in zone D. Table 4.1 shows how these categories relate to the above conditions. Note that category I is the most severe combination of conditions requiring the highest protection measures.

Table 4.1 Categories of buildings for strengthening purposes

Protection level	Soil at site	Seismic zone A	B	C	D
Higher	Soft	I	II	III	No special protection required
	Firm	II	III	IV	
Lower	Soft	II	III	IV	
	Firm	III	IV	IV	

5. SITE CONSIDERATIONS

5.1 Choice of site

The soils of the type that can liquefy as described in 3.1 should be avoided as far as possible. Compaction of such soils will be too costly for school buildings.

The site on hill slopes should be chosen so as to avoid the potential slide and rockfall areas. Stable slopes should be chosen on both down-hill and uphill sides of the building. In coastal areas high ground should be chosen for construction of educational buildings.

5.2 Site treatment

Since saturation of foundation soil is dangerous from liquefaction and land slide view points, the site should be kept well drained. A waterproof apron may be provided all round the buildings to prevent seepage of water under the foundations. Water drains should be constructed away from the buildings at the edges of the apron.

In the areas where it is impossible to avoid selection of a site with saturated soil, pile foundations going to depths of 8 to 10 m. will generally be adequate. In coastal areas where high ground is not available, earthen mounds may be created above the probable height of tsunami or the building may be built on stilts. See figure 5.1.

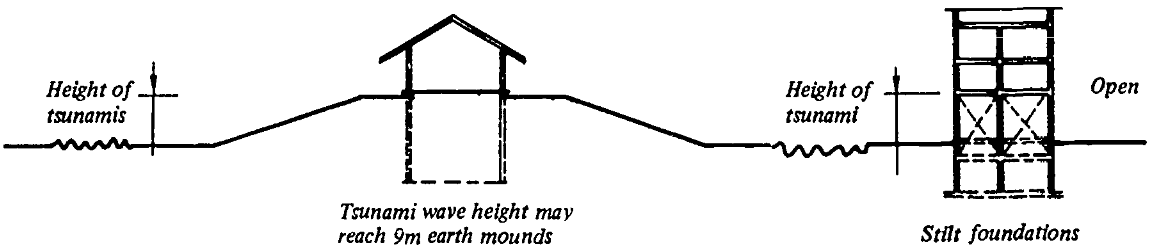

Figure 5.1 Protection from Tsunamis

6. GENERAL PRINCIPLES REGARDING BUILDING FORMS

The appropriate choice of the form of buildings can lead to stable behaviour during earthquakes. The aspects of form which are important include the building plan, internal partitions and size and location of openings in both internal and external walls. These are explained in this chapter.

6.1 Building shape in plan and elevation

For the overall form of buildings being planned there are two basic rules to follow: (1) Simple rectangular buildings are the most desirable, the length of the block being not more than about three times the width; and (2) Symmetrical buildings in plan and elevation are better than asymmetrical ones.

Figure 6.1 shows a number of plans of schools and hostels typically used in Asia and the Pacific. Of these plans 'A' and 'B' are perfect since they are symmetrical about both axes. 'C'approaches symmetry and is tolerable. Plans D and E are too long and narrow, plan F has excessively long projections while plan G is unsymmetrical about both axes and plan H has weak linkage between strong wings. Plans D through F are not suitable unless modified.

In order to make unsuitable building plans seismically acceptable, they need to be divided into a number of rectangular or symmetrical units conforming to the principles stated above by using separation/crumple sections as necessary. The same principle can be applied to the elevations of the buildings, thus ensuring that any separated unit of the overall building is of a uniform height. Figure 6.2 illustrates how this can be done. For details at separation/crumple sections, see section 9.12 and Figure 9.17.

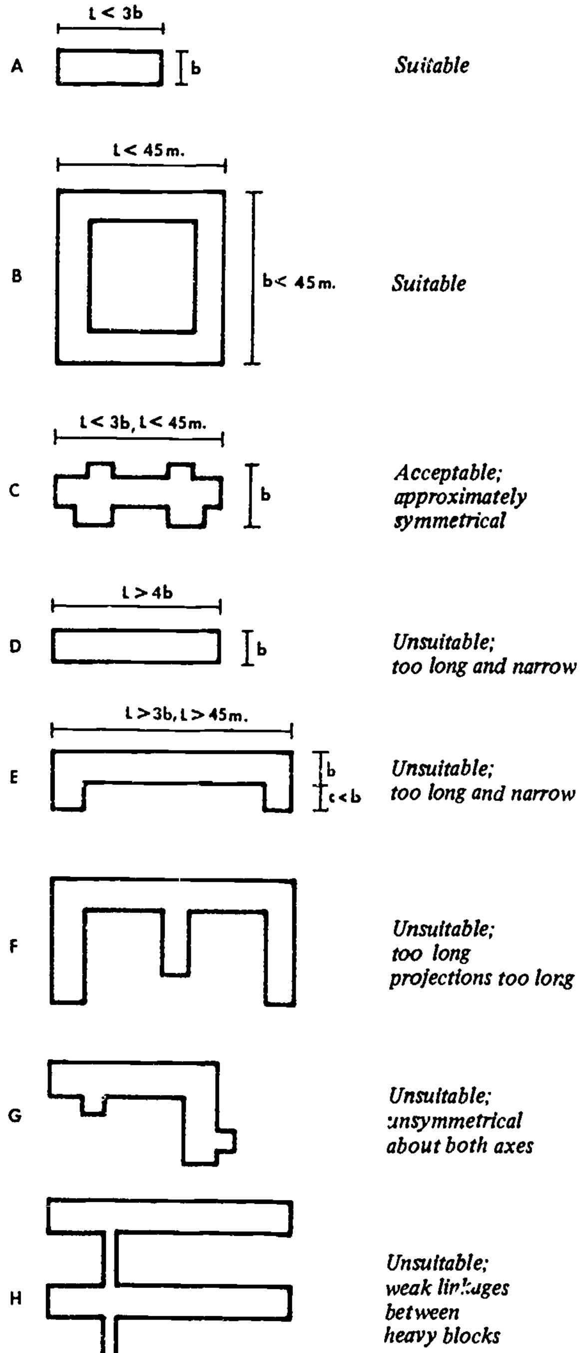

Figure 6.1 Suitability of typical school building plan types in Asia and the Pacific

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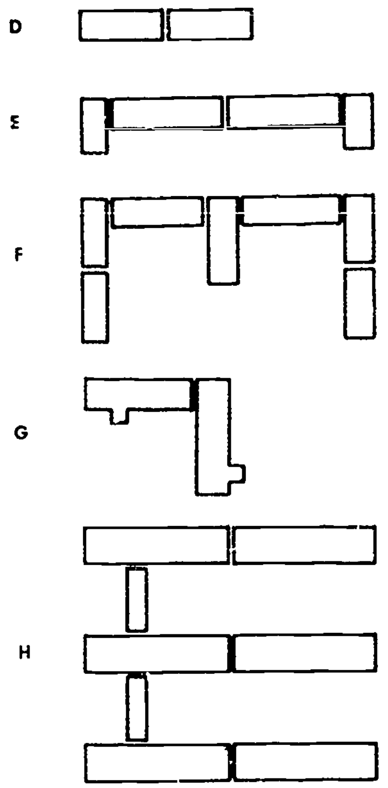


See Fig. 9.17 for details of crumple sections
Divide buildings into segments where block lengths oreater than 40 m and L greater than 36 using crumple joints

Figure 6.2 Modification of plan types

Overhangs

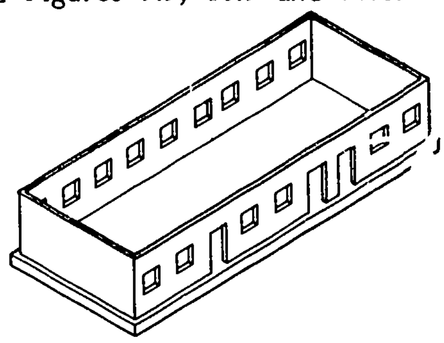
Ornamentation involving large projections should be avoided. Parapets and cantilever projections should be reinforced and the reinforcement anchored into structural slabs.

Internal subdivision of space

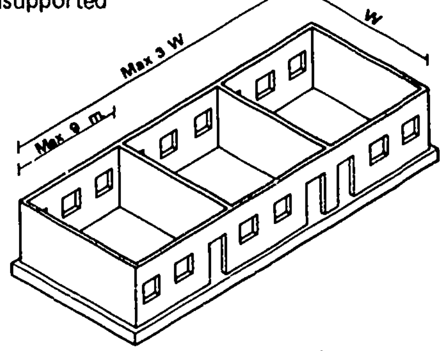
The performance of buildings during earthquakes show better behaviour where wall elements exist along both axes of a building subdividing it into small box-like enclosures. The maximum length envisaged in the recommendations of this manual is 9 m. Hence cross walls should be arranged at a maximum spacing of 9 m. If the functional requirements do not permit the use of cross walls, the longer walls will have to be supported by external buttresses or reinforced concrete columns at a spacing not more than 6 m. apart. See Figure 6.3.

6.2 Door and window openings

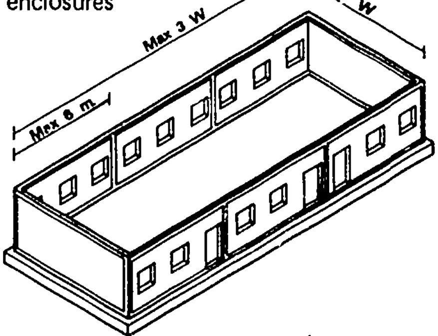
Openings in walls are a source of weakness and tend to change the behaviour of the walls under lateral loading. The unsymmetrical position of openings even in symmetrical buildings may introduce structural unsymmetry which is not desirable under seismic conditions. Hence openings should be kept as small and as symmetrically located as functionally possible. Specific recommendations for use with different types of building materials are given in sections 9.5 and 10.5 and Figures 9.5, 10.5 and 10.6.



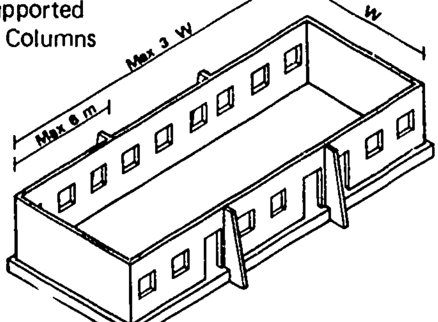
a) Unsatisfactory; long unsupported walls



b) Satisfactory; box-like enclosures



c) Satisfactory; long walls supported by R.C. Columns



d) Satisfactory; long walls supported by buttresses

Figure 6.3 Lateral supports to long walls

7. MATERIALS AND QUALITY OF CONSTRUCTION

7.1 Materials of construction

The suitability of materials for construction is dependent on the characteristics of the materials themselves as well as their combination with other materials. To resist the internal forces caused by earthquakes it is helpful if the materials perform well both in compression and in tension. Materials which perform well only in compression are often reinforced by others with good tensile strength qualities.

From the earthquake safety viewpoint, the suitability of materials of construction could be classified as follows:

Highly suitable: Steel, wood, reinforced concrete.

Moderately suitable: Reinforced block masonry, reinforced brickwork, wood with brick nogging, reinforced adobe.

Slightly suitable: Unreinforced brick/block/stone masonry with good mortar.

Unsuitable: Unreinforced masonry with mud mortar, earthen walls without reinforcement, wood logs without anchoring.

The information collected regarding the school buildings and teachers' houses in west, south, and Southeast Asian region brought out that, by virtue of using the predominant construction materials, the one and two storeyed buildings could be classified as follows.

- Masonry load bearing wall buildings with strip footings and flat or sloping roofs. The most used masonry unit is fired brick, followed by stone and concrete block.
- Wooden buildings with stud-wall or brick-nogged construction of walls, sloping roof and strip or pedestal type footings.
- Earthen wall buildings with flat or sloping log roofs and little or no footings. The classroom size in such school buildings was generally smaller than other types.
- In some cases, more industrialized constructions have been adopted for schools consisting of vertical steel columns and steel trussed roofs.

It is thus seen that most existing school buildings will fall under slightly suitable and unsuitable categories and few in moderate and highly suitably levels.

To overcome this situation it may be argued that schools in earthquake areas should be built only of highly suitable materials (i.e. steel, reinforced concrete or wood). However, in many localities this is not feasible in light of the unavailability of these materials, the large demand for schools and the scarce financial resources. What is needed, therefore, are suitable measures (including reinforcement) which can ensure that bricks, stone, adobe, and wood logs can be the main materials which are classified as moderately suitable.

Simple, as well as economical, methods for strengthening buildings made of traditional materials have been developed both for constructing new buildings and for upgrading existing ones. These methods have been scientifically developed through analytical research, observation of damage occurring during earthquakes and the physical testing of large scale models. Thus, when applied to educational buildings and teachers houses these measures should prevent the collapse or severe damage of these buildings during earthquakes of the intensities which may probably occur.

As pointed out in the introduction, this manual refers only to materials used in buildings designed without the benefit of an engineer. Thus steel and large reinforced concrete structures are not included.

7.2 Quality of construction

Performance of non-engineer designed buildings during past earthquakes has demonstrated again and again that the quality of construction of brickwork, stone masonry, block masonry or woodwork has had an undoubted influence on the extent of damage suffered, those having better quality suffering less damage. The following quality control measures are therefore emphasized:

- Materials should conform to appropriate specifications e.g. properly fired bricks of uniform sizes, seasoned or dried heart wood;

- Proper mortar should be used in construction, filling all horizontal and vertical joints. The masonry units should be laid with proper bond avoiding continuation of vertical joints particularly at the intersection of walls;

- Joints in wood elements should be tight, nailed or bolted and covered with steel straps.

- Stone masonry walls must have appropriate mortar filling in the hearting and use of 'through' stones or bonding elements is a must.

8. WOOD BUILDINGS

8.1 General guidelines

Height of building

The height of school buildings should be restricted to two storeys and that of residential blocks to two storeys plus attic.

Protection of wood

- Seasoned timber should be used for building construction so as to maintain the joints in tight condition.
- Preservative treatment of the timber used in building construction will be desirable to achieve long, trouble-free life.
- Mechanical barriers against termite action should be incorporated and soil poisoning of the building site should also be carried out wherever possible (Figure 8.1).

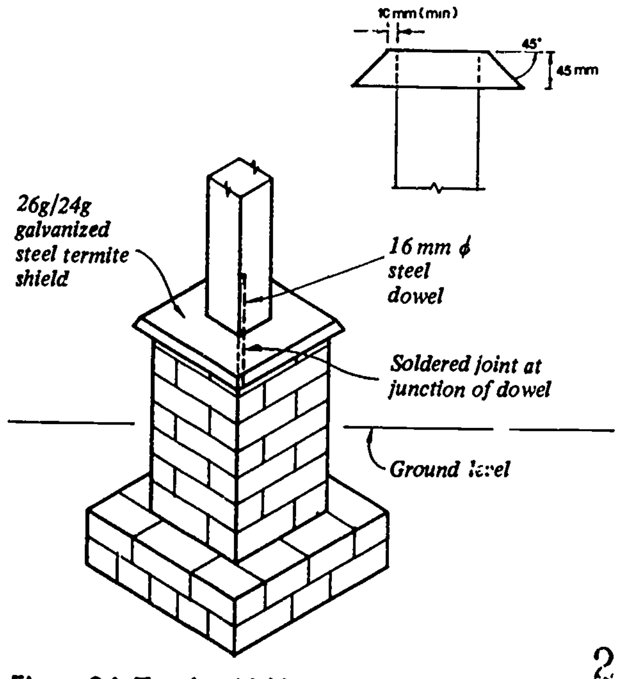


Figure 8.1 Termite shield

- Precautions should be taken to prevent/minimize fire hazard by using appropriate fire-retardant paints.

Preservation of structural strength and stiffness:

The joints between truss members, from truss to wall plates, or between elements of wall framing should initially be made tight and strong using framing of members into each other or by using appropriate nailed, bolted or disc-dowelled joints. Covering the joints with steel straps with screws or bolts will help maintain the strength and stiffness of the joints (Figures 8.2 and 8.3).

Bracing against earthquake forces

To resist the lateral load of the earthquake and the torsional effects, wood buildings need to be braced as follows:

- Diagonal bracing in the plane of roof slopes.
- Diagonal bracing in plane of roof framing at ceiling or eaves level.
- Diagonal bracing should be provided in the plane of the roof slopes in the end bays (Figure 8.4(a)) or the roof should be "hipped" to create rigidity (Figure 8.4(b)).
- Diagonal bracing needs to be provided in all bays of the roof plan at the tie level to ensure integral action of the roof and to enable it to develop diaphragm action (Figure 8.5).
- Diagonal cross bracing in vertical plane of walls (stud wall or brick-nogged) along both axes of the building (Figure 8.4(c)).

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- Holding down of trusses/rafters to the top wall plates (Figure 8.3).

- Holding down of bottom wall plates or vertical columns/studs to the foundations (Figures 8.1, 8.8).

8.2 Roofs

Wooden buildings invariably have sloping roofs. Trussed roofs are better than roofs using rafters and little bracing. Sheeting is preferable to the use of tiles. The following recommendations are made:

- Elements like tiles should be suitably tied to the battens and interlocked with each other so as to restrain their sliding during earthquake shaking.

- Roofing sheets should be held securely to the purlins with J-bolts using spring washers as far as possible.

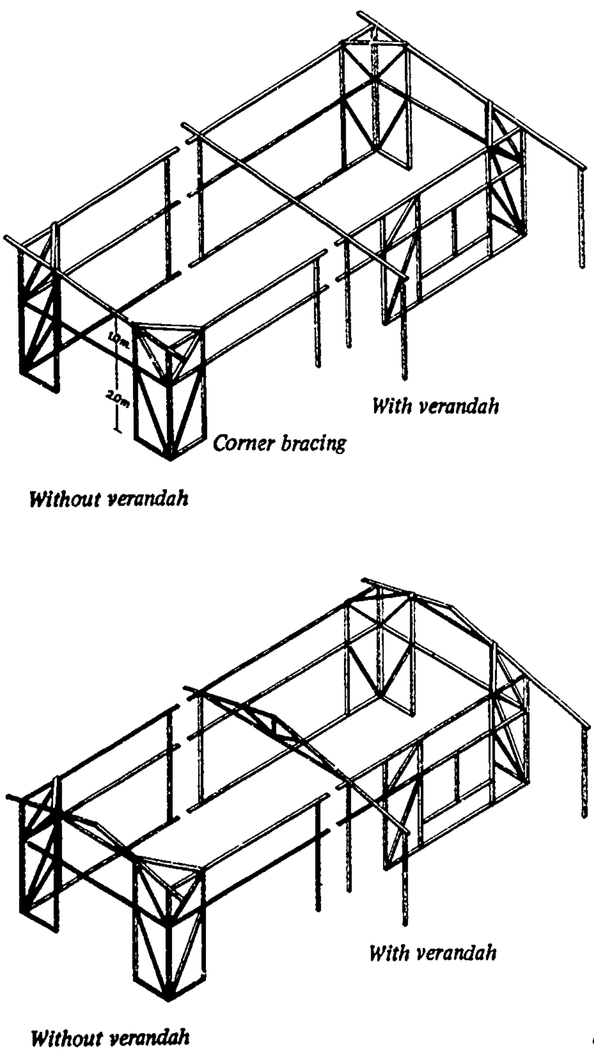


Figure 8.2 Bracing of wooden buildings

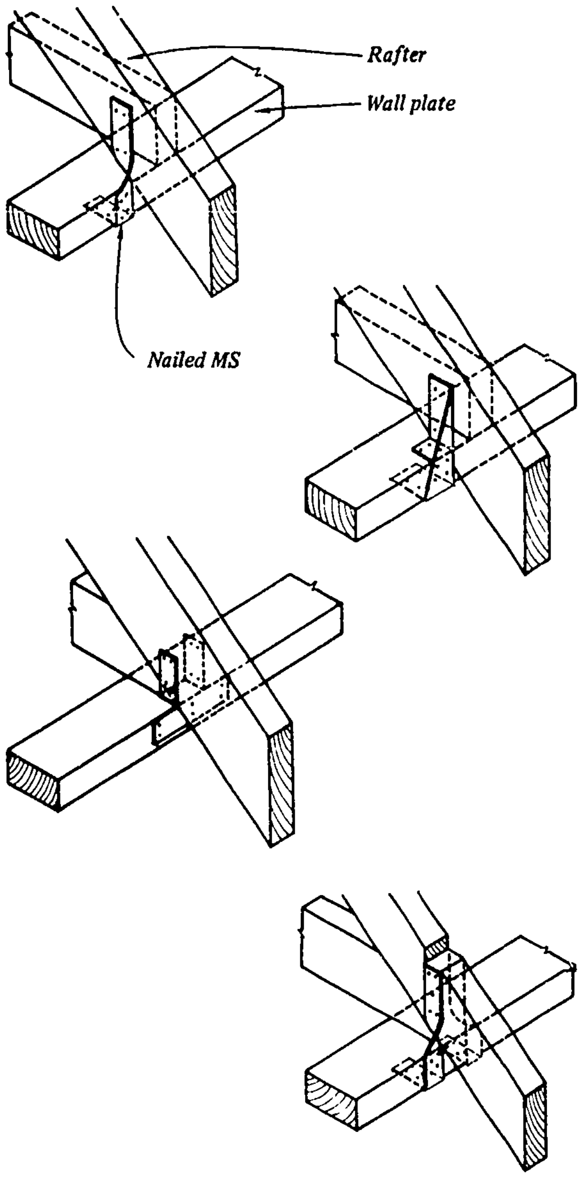
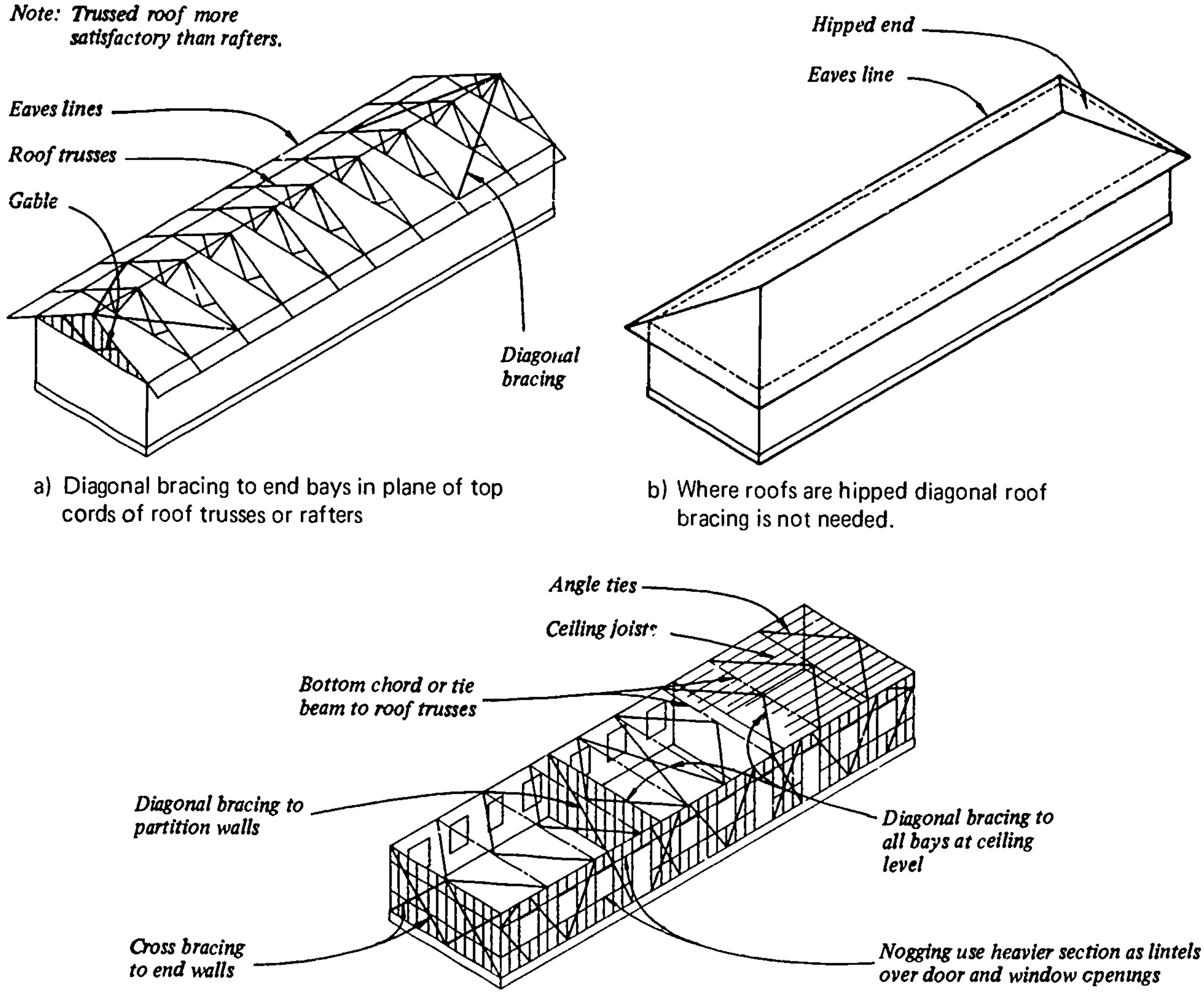


Figure 8.3 Rafter to wall plate connection

- Battens and purlins should be secured to the rafters or top chords through bolting/nailing and to the gable frame at the ends of the building.

- Rafters of pent roofs or the trusses must be fully anchored to the wall top plates that their inertia force is transmitted to the wood walls (Figure 8.3).

- Chimneys projecting above the roof should preferably be made out of pipes and use of masonry should be avoided. If unavoidable, it should be reinforced with vertical steel bars 10 mm in diameter; one at each corner, which should be anchored to the masonry below. The four bars may be enclosed in horizontal stirrups of steel 6 mm in diameter placed in the four corners.

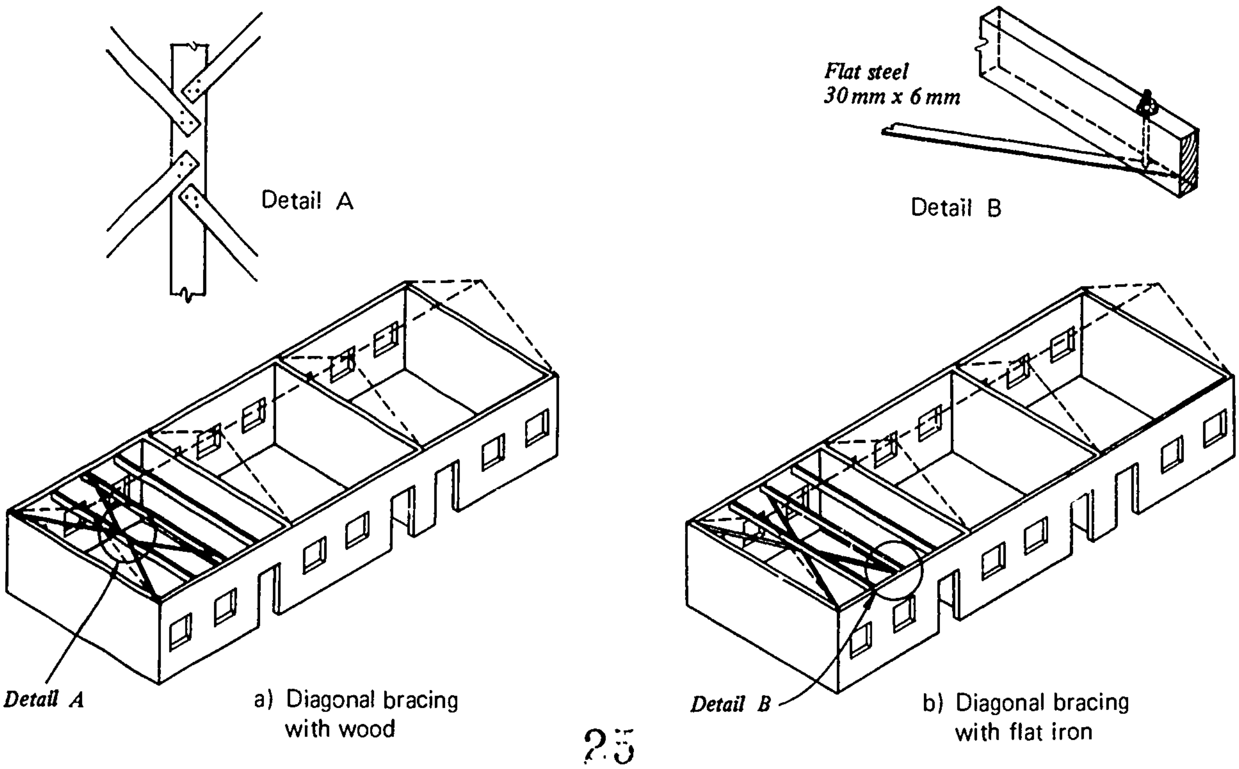


a) Diagonal bracing to end bays in plane of top cords of roof trusses or rafters

b) Where roofs are hipped diagonal roof bracing is not needed.

c) Typical arrangement of bracing to walls and ceiling framing

Figure 8.4 Roof bracing



a) Diagonal bracing with wood

b) Diagonal bracing with flat iron

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Figure 8.5 Diagonal bracing in plan

8.3 Stud wall construction

In this, timber studs and corner posts are framed into sills and horizontal noggings and diagonal braces are used to stiffen the frame, as shown in Figure 8.6.

- Timber studs of minimum size 40 mm x 90 mm may be used.

- Maximum spacing of timber studs may be about 40 cm on the ground floor of two storeyed buildings and about 80 cm on single storey and the first floor of two storeyed buildings. The type of material used for cladding will, in most cases, determine the maximum spacing.

- The finished size of diagonal braces may be kept to 20 mm x 90 mm minimum.

- Wall coverings may be of bamboo or reed matting covered with plaster, wooden boards, plain asbestos cement sheets, or corrugated galvanized steel sheeting. These should be securely fixed to the wall elements to increase the stiffness and strength of the building. Where sheeting is used, the edges of the sheeting should be fixed to the studs and horizontal members.

8.4 Brick nogged timber frame construction

This consists of intermediate verticals, columns, horizontal nogging members and diagonal braces framed into each other. The space between framing members is filled with tight fitting brick masonry. In some areas brick may be replaced with flat stones.

Vertical framing members should have a minimum size of about 60 mm x 100 mm. Horizontal nogging members should be about 50 mm x 100 mm for 1.00 m spacing of verticals. For closer spacing of verticals the size may be smaller and for further spacing, it may be larger. For holding the brick nogging panels to the wood frame 6 mm diameter iron nails projecting out by about 50 mm from the wood or iron holdfasts may be embedded in the brickwork. Figure 8.7 shows the typical form of such construction.

8.5 Foundations

The superstructure timber buildings may be rigidly fixed into plinth masonry or concrete foundation as shown in Figure 8.8.

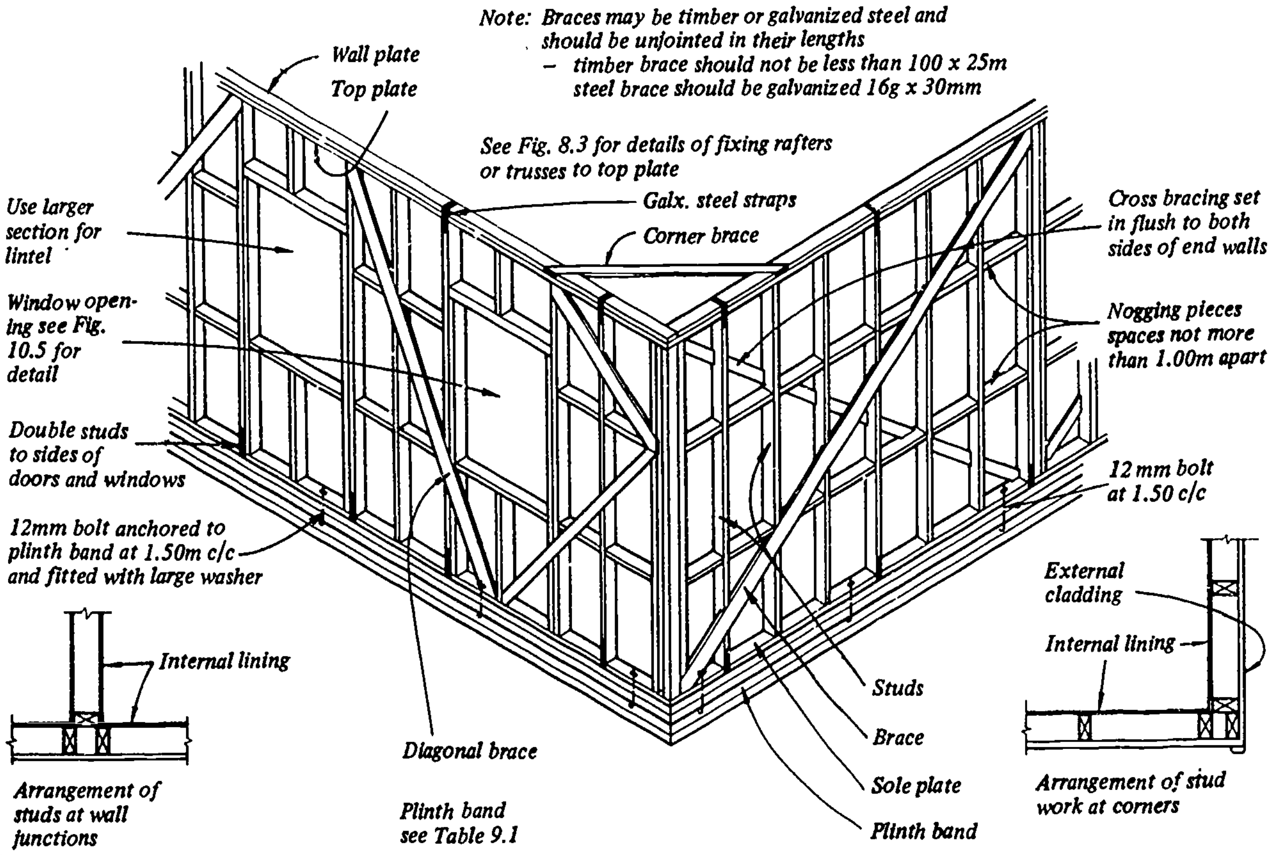

Figure 8.6 Stud wall construction

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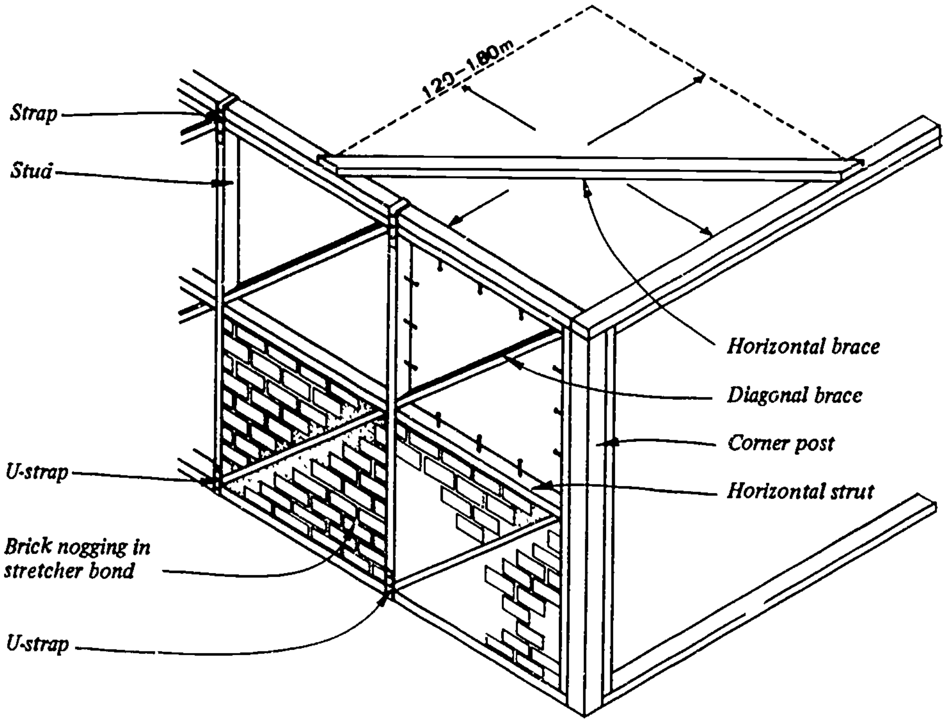


Figure 8.7 Brick nogged timber frame

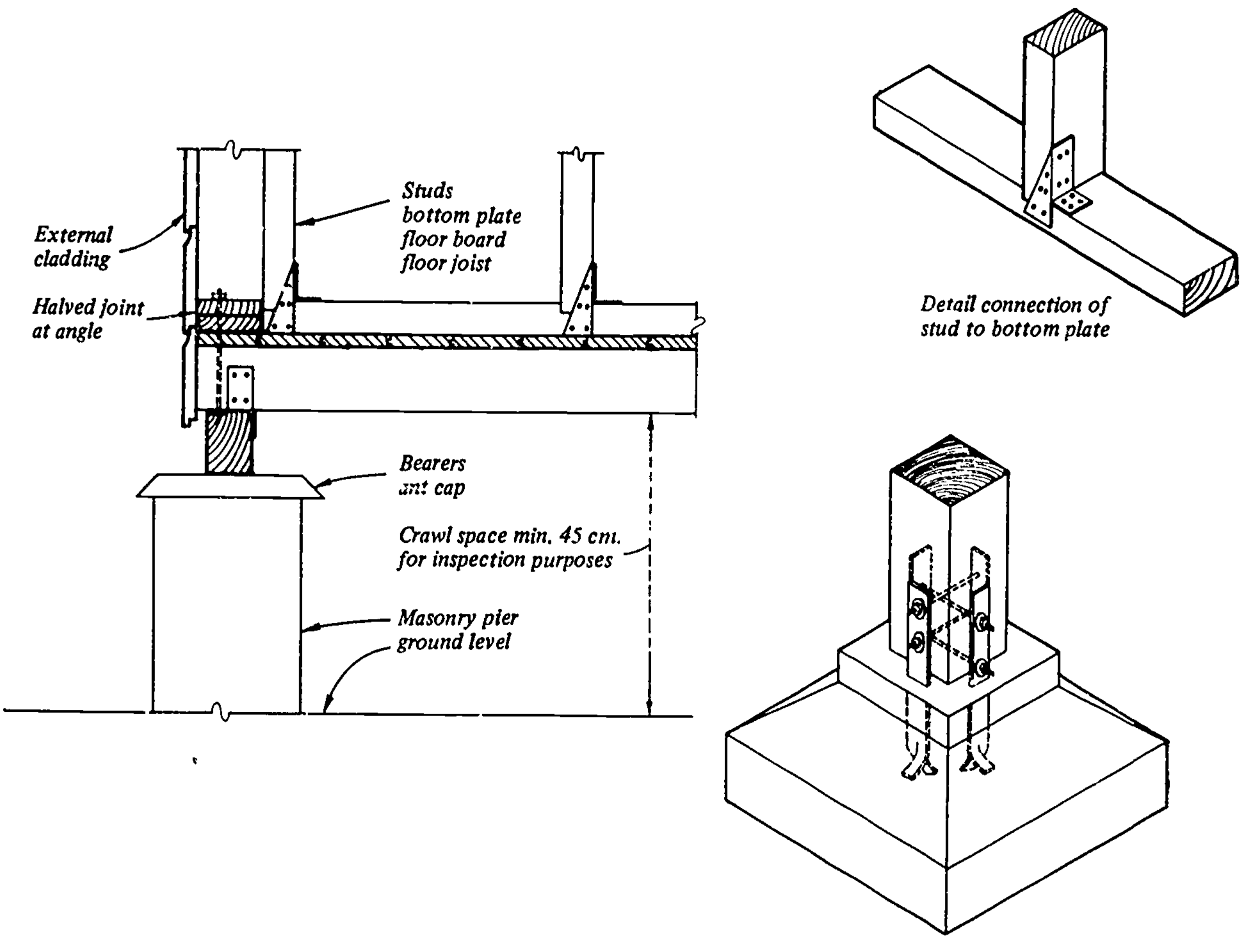


Figure 8.8 Footings for wooden buildings

9. MASONRY BUILDINGS

9.1 Reinforcing against earthquake forces

To resist the lateral inertia forces caused by earthquake ground motion (Figure 3) masonry buildings need to have the following reinforcing features:

- Integrity of roof trusses by use of bracing elements as in the case of wooden buildings (section 8.2);
- Where gable ends are used, reinforcing around gables and adequate connection of purlins to them;
- The trusses held to masonry walls by adequate bolts;
- A reinforcing element on top of the wall capable of transferring the inertia force of the roof trusses to the walls;
- Integrity of roofs of other types if used and their connection with walls;
- An improvement in the lateral out-of-plane bending resistance of masonry walls by use of horizontal/vertical reinforcement;
- Lateral in-plane bending and shearing resistance of masonry walls by using vertical reinforcing and control on opening sizes thus preventing crack propagation from corners of openings; and
- Transfer of earthquake inertia forces from the superstructure to the foundations.

Figure 9.1 shows the critical locations for providing horizontal and vertical reinforcing in walls. The amount and the actual provision of reinforcement depends upon and varies with the combination of design seismic conditions as categorized in Table 4.1 and as detailed in the following sections wherein the terms as explained below may be recognized. For category I conditions, all types of reinforcing may be needed whereas for categories II, III and IV some of this reinforcing is not required:

Horizontal reinforcing (see section 9.6 for details)

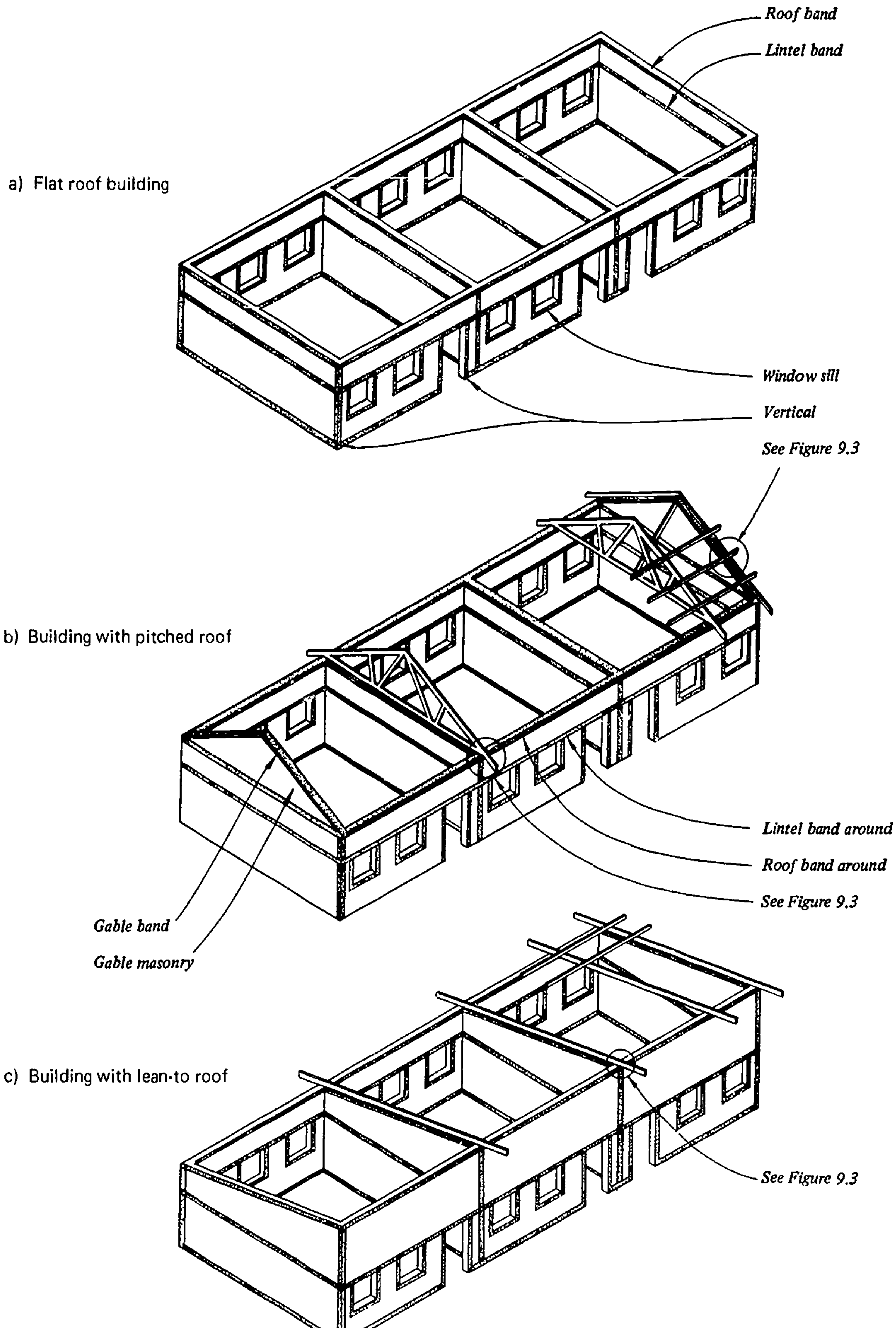
- A circumferential band, also called 'ring beam' or 'collar beam', is a reinforced concrete or wooden runner provided at a defined level in all walls of the building for tying them together as a box and imparting horizontal bending resistance.
- Gable bands are used to bind the gable end of masonry and holding the purlins in the end bay.
- Eave bands are used at the eave level of trusses or sloping roofs.
- Lintel bands are used at the lintel level of door and window openings forming part of the lintels.
- Plinth bands are used at the plinth level of building.

Vertical reinforcing (see section 9.7 for details)

- At junctions of walls meeting at right angles, that is, corners and T junctions; and
- At jambs of door and window openings.

9.2 General construction features

A well designed building also needs careful construction detailing in order to achieve the safety objectives of design.



Note: Two or three storey structures can be built following the same reinforcing locations in each storey with continuous vertical reinforcement from ground to top of the building

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Figure 9.1 Critical reinforcing locations in masonry buildings

In this section, various features of earthquake resistant construction are explained.

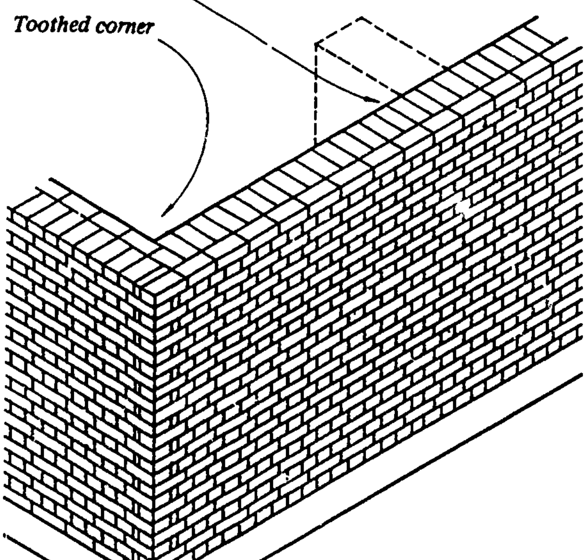
Quality control:

Proper quality of construction is an insurance for good earthquake behaviour. Substandard material, inadequate skill in bonding, or inadequate connections must not be allowed in construction.

Mortar:

Only one of the following mortars, or those having equivalent tensile and shear strengths, may be used for various constructions:

Building situation	Mixtures
Category I	Cement sand 1:4 or cement lime sand 1:1:6
Category II	Cement lime sand 1:2:9 or cement sand 1:6
Category III	Cement sand 1:6
Category IV	Cement sand 1:6 or lime cinder 1:3

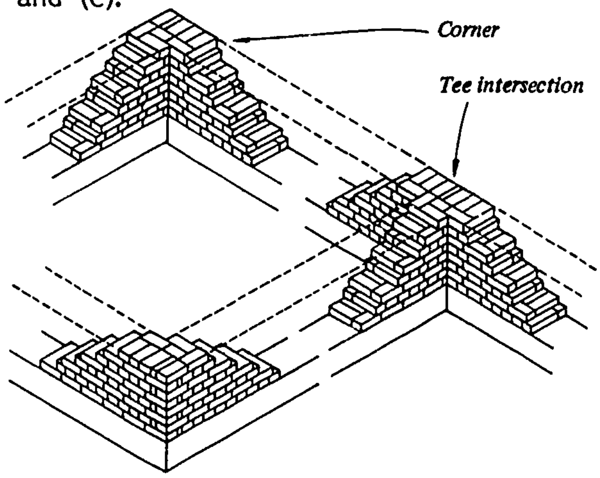


a) Continuous toothed joint from ground to top of wall (unsatisfactory)

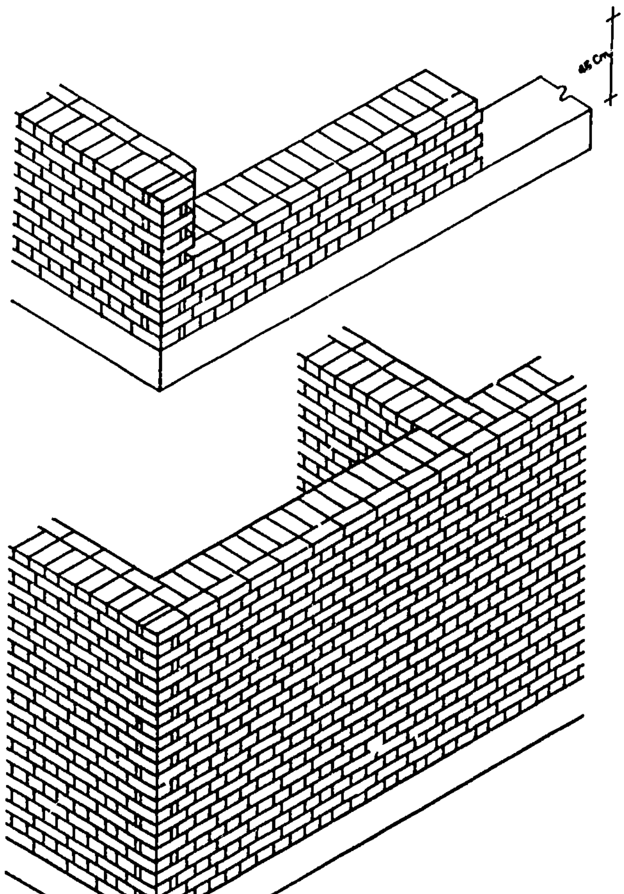
Figure 9.2 Bonding of walls at junctions

Bonding at wall junctions:

Vertical joints between two perpendicular walls should be made so as to avoid continuous straight or toothed joint in only one wall as shown in 9.2(a). This may be done either by building the corner first with sloping walls or by making toothed joint in both walls alternately in lifts of about 45 cm. See Figure 9.2(b) and (c).



b) Sloping joints at corners (most satisfactory)



c) Alternating toothed joint in walls (satisfactory)

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9.3 Roofs

As a general rule heavy roofs are a seismic hazard. Hence roofs as well as floors should be made as light as structurally and functionally possible. Masonry buildings can have pitched or flat roofs. Both are dealt with below. In each case, the recommendations made for the roofing units under section 8.2 may be followed.

Pitched roofs:

Pitched roofs may be trussed with top of walls generally at one level except the masonry gables at the ends of the building. Alternatively, the longitudinal and cross walls may be raised to varying heights up to the roof slope and the rooms spanned by rafters and purlins. From the seismic angle, the trussed arrangement is preferable particularly for school buildings.

Trussed roofs:

In trussed roofs, all trusses must be supported on the eave or roof band. Where a trussed roof adjoins a masonry gable, the ends of purlins shall be carried on and secured to a plate adequately bolted to the band at the top of gable end masonry (Figure 9.3(a) and (b)).

Lean-to roofs:

All masonry walls should be topped by a reinforced concrete roof band to which rafters and purlins should be securely held by means of bolts. Alternatively wall plates may be used which are bolted to the band and to which the rafters and purlins are fixed (Figure 9.3(c).

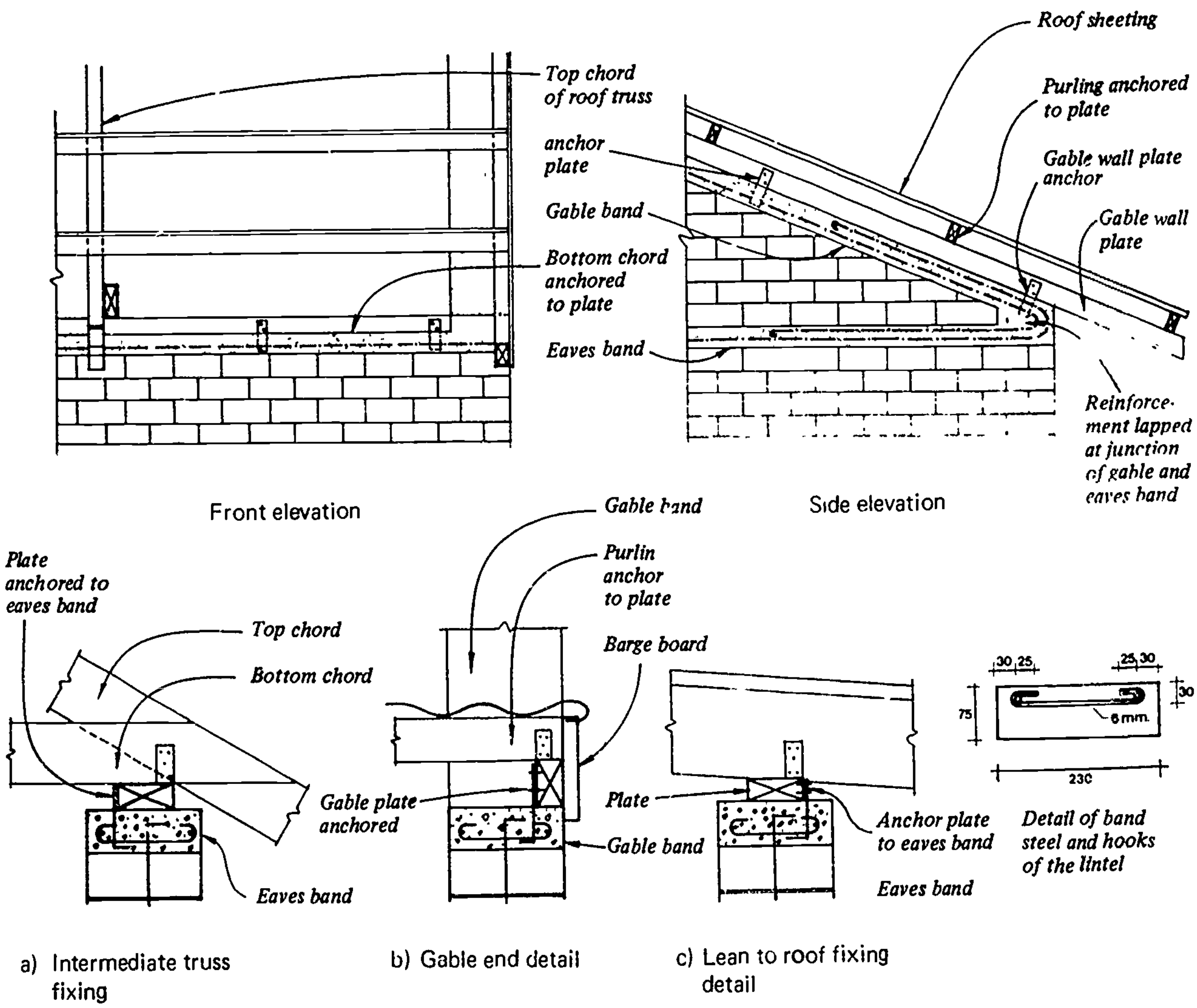


Figure 9.3 Details for fixing roofs to walls

9.4 Flat roofs and floors

Jack arches:

Jack arch roofs or floors must be provided with mild steel ties in the end spans. Where the number of spans is large, such ties must also be provided in every fourth span (Figure 9.4).

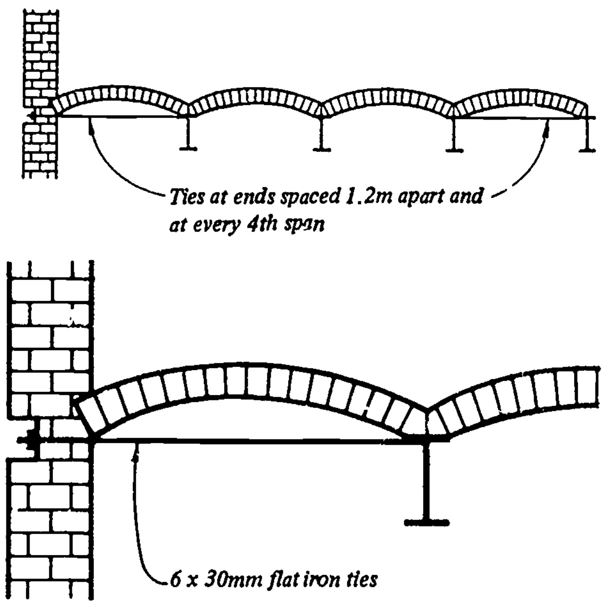


Figure 9.4 Ties in Jack Arch floors and roofs

Reinforced concrete slabs:

Reinforced concrete slabs or slab and beam floors constructed in-situ and bearing on a minimum of three quarters of the wall thicknesses, provide a binding effect on the walls besides rigid diaphragm action. In such cases the provision of a roof band may be omitted.

Roofs and floors using precast joists and planks:

In such cases, provision of the roof band below the roof or floor is essential and an arrangement should be made in the precasting scheme to connect the elements together and to fix them to the roof band.

9.5 Control on door and window openings

Size and position of openings:

Large size openings weaken the masonry walls against vertical as well as horizontal loads. A control on their size and location is desirable, consistent of course, with functional requirements.

The following rules should be followed:

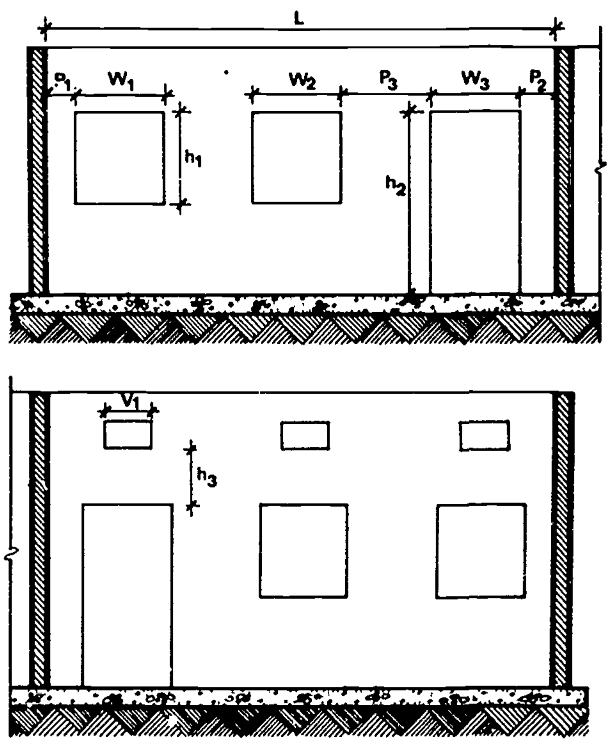
1. Openings should be located away from the inside corner of a wall by a clear distance at least equal to one quarter of height of the opening or one brick or block length which ever is the greater.

2. Total length of openings should not exceed the following fractions of the length of wall between consecutive supports or cross walls:

   0.50 for one storey buildings
   0.42 for two storey buildings
   0.33 for three storey buildings

3. The width of the pier between two openings should be greater than half the height of the opening and in stone walls not less than 45 cm.

4. The vertical distance between two openings should not be less than 60 cm nor less than half the width of the smaller opening width. Figure 9.5 illustrates the above points.



Rule 1: P1 ≥ 0.25 h_1 and P2 ≥ 0.25 h_2

Rule 2: W1+W2+W3 ≤ 0.5L for one storey building
≤ 0.42L for two storey building
≤ 0.33L for three storey building

Rule 3: P3 ≥ 0.5h_2 (or ≥ 450mm in store masonry walls)

Rule 4: h3 ≥ 600mm or ≥ 0.5 V1 (whichever is more)

Figure 9.5 Opening sizes in bearing walls

Reinforcing around openings:

Where openings do not comply with the above geometrical requirements they should be strengthened as shown in Figure 9.6 for categories I, II and III where the diameter of bar 'd' will be the same as in Table 9.2. Such reinforcement should be provided in category I, II and III buildings in any case.

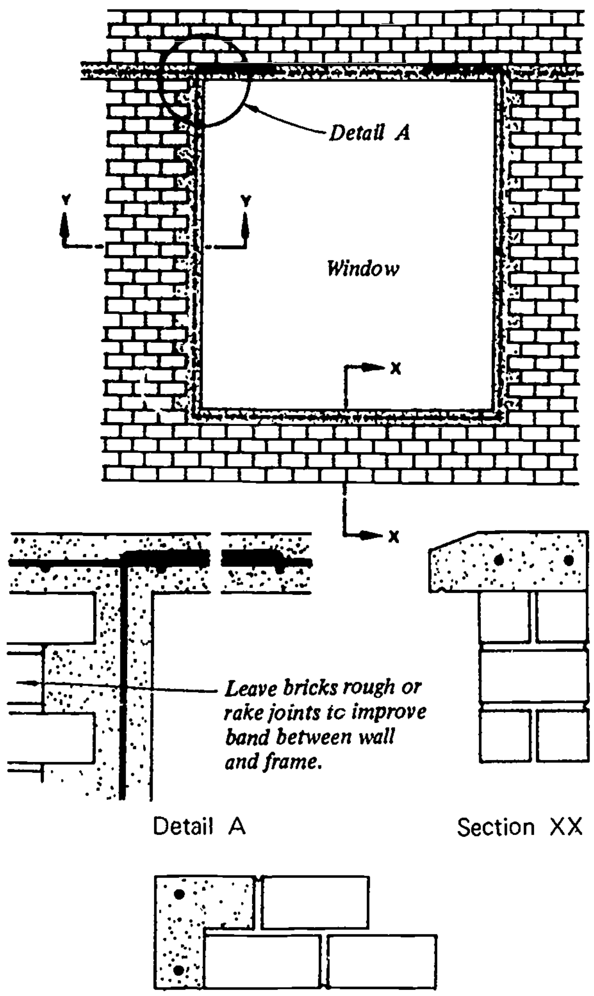


Figure 9.6 Reinforcement around openings

9.6 Horizontal band or ring beam

Specifications:

Such bands are provided for tying the walls together and for providing horizontal bending strength. For various sizes of wall lengths and categories of construction, the reinforcement of such bands should be as shown in Table 9.1. The bar diameters are given for mild steel (M.S.) and high strength deformed bars (H.S.D.) which may be adopted for the steel type available. The placing of this reinforcement is shown in Figure 9.7. (For categories of buildings, see Table 4.1).

Horizontal bands should be provided as follows:

Lintel band:

A band of specifications given above should be provided at lintel level of door and window openings in each storey.

Roof band (Eave level band):

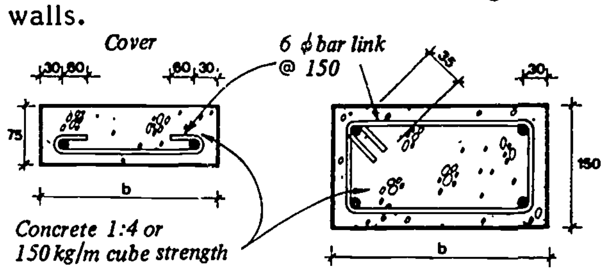
A band of the above specifications should be provided at eave level of trussed roofs and just below such roofs and floors which consist of joists, stone slabs, etc. Such a band is not necessary where the roof or floor consists of a reinforced concrete slab or slab and beam.

Plinth band:

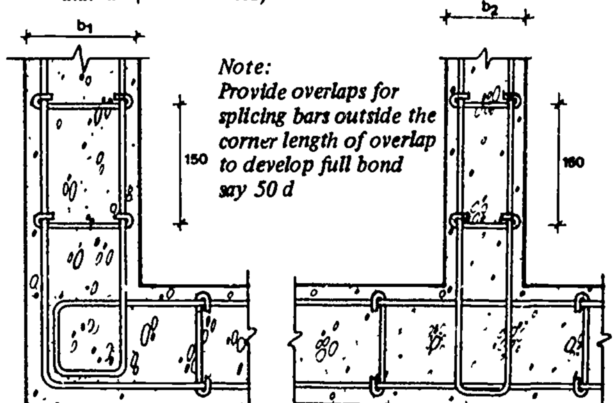
Where soil is soft or non-uniform a horizontal reinforced concrete band should also be provided at plinth level. Such a band is not necessary where the soil is firm.

Gable band:

Masonry gable ends (triangular part) must also be enclosed in a band, the horizontal part is to be continuous with the eave level band on longitudinal walls.



a) Cross section of R.C. band for two bars and four bars of dia. 'd' (see Table 8.1)



b) R.C. band reinforcement – details at corner and T junction

Figure 9.7 Reinforced concrete band details

Table 9.1 Number and diameter of mild steel bars in bands

Span of wall between cross walls (m)	Category I			Category II			Category III			Category IV		
	No. of bars	Dia, mm		No. of bars	Dia, mm		No. of bars	Dia, mm		No. of bars	Dia, mm	
		M.S.	H.S.D.		M.S.	H.S.D.		M.S.	H.S.D.		M.S.	H.S.D.
5	2	12	10	2	10	8	2	10	8	2	8	8
6	2	16	12	2	12	10	2	10	8	2	10	8
7	2	16	12	2	16	12	2	12	10	2	10	8
8	4	12	10	2	16	12	2	16	12	2	12	10
9	4	16	12	4	12	10	2	16	12	2	12	10

Notes: 1. *Band to be of full width of wall.*
2. *Thickness of band 7.5 cm minimum where two bars are used and 15 cm where four bars are used.*
3. *Longitudinal bars to be held by links/stirrups 6 mm dia @ 15 cm c/c as shown.*

Dowels at wall junctions:

As an alternative to the lintel band in Categories III and IV, steel dowel bars or metallic mesh may be provided at about 60 cm intervals throughout the height of walls at their corners and T-junctions (Figure 9.8 and 9.9). It will be useful to provide such dowels at corners and junctions of walls at window-sill levels in categories I and II buildings in addition to the lintel band.

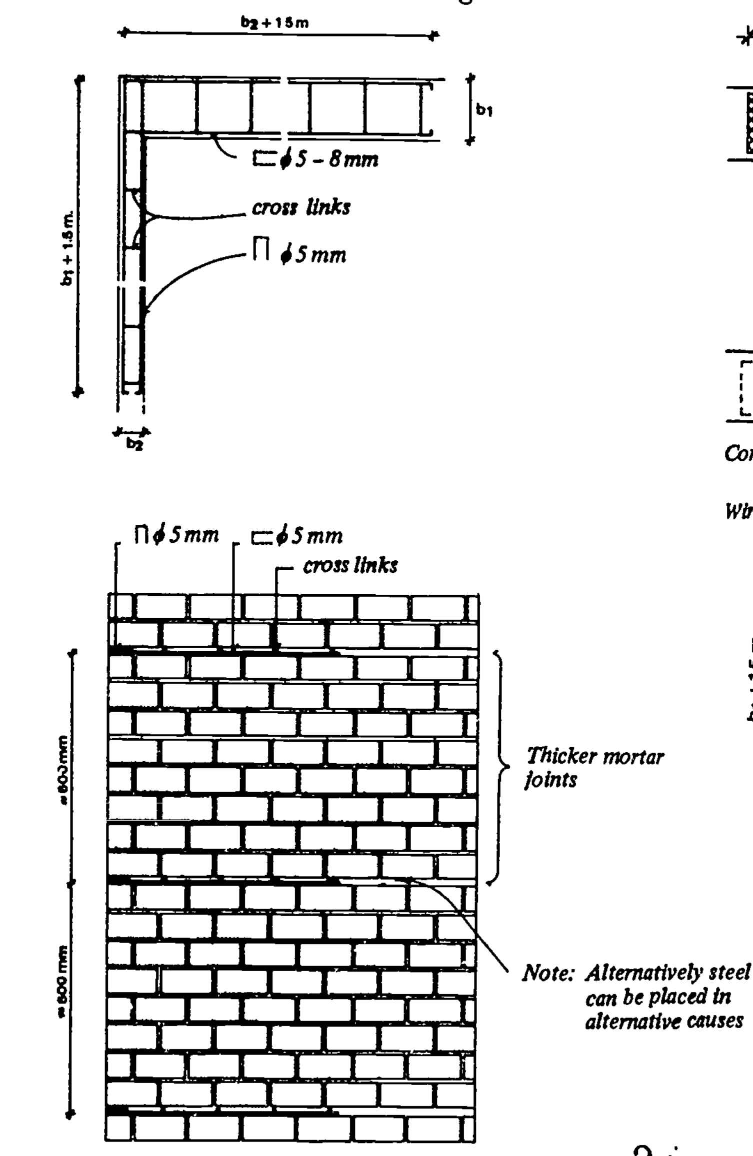


Figure 9.8 Dowel bars at corners and T-junctions

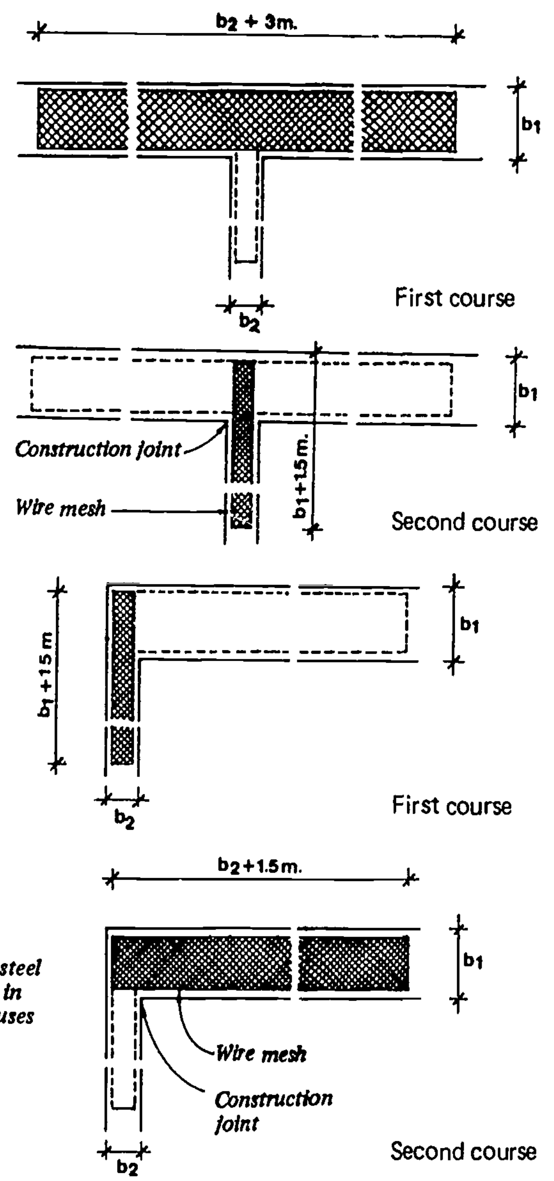


Figure 9.9 Use of weld-mesh at corners and T-junctions

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9.7 Vertical reinforcement in walls

For the various categories of construction, the quantity of vertical steel to be provided at critical sections (corners of walls, and jambs of doors and windows) is given in Table 9.2.

The arrangement for providing vertical reinforcing steel in brick walls is shown in Figure 9.10 for one brick and 1 1/2 brick thick walls. It is not unusual to use thicker walls in the first storey and thinner walls in upper storeys. It is therefore important to arrange the bars in the various storeys in the same vertical line. Figure 9.10 has adopted this approach so that splicing of the vertical bars is carried out easily. The appropriate locations of splicing are just above the plinth of the first storey and just above the upper floors. An overlap length equivalent to 50 diameters of the rod is recommended bound well by binding wire.

Table 9.2 Sizes of vertical reinforcement in walls

No. of storeys	Storey	Dia. of single bar at each critical section						
		Category I*		Category II		Category III		Category IV
		M.S.	H.S.D.	M.S.	H.S.D.	M.S.	H.S.D.	
One	–	16	12	12	10	Nil	Nil	Nil
Two	Top	16	12	12	10	12	10	Nil
	Bottom	20	16	16	12	12	10	Nil
Three	Top	16	12	12	10	12	10	Nil
	Middle	20	16	16	12	12	10	Nil
	Bottom	20	16	16	12	16	12	Nil

** For category of buildings see Table 4.1.*

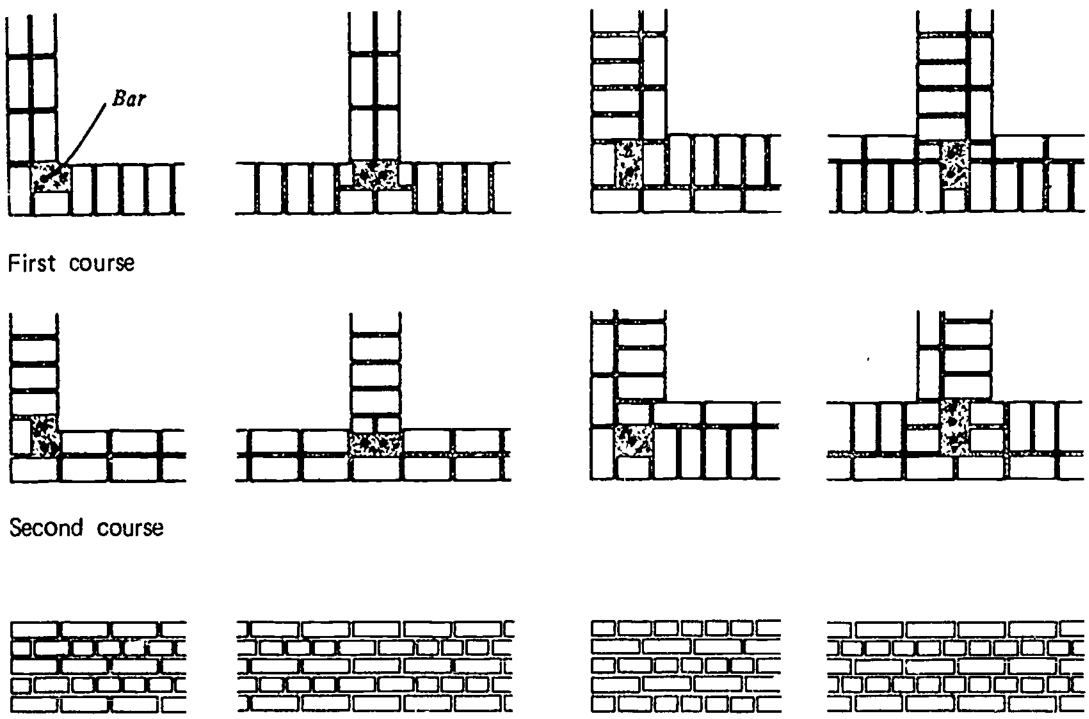

Figure 9.10 Vertical reinforcement in brick walls

9.8 Stone masonry

The recommendations made for brick masonry generally apply to stone masonry construction. Special recommendations are made here below as distinctly necessary for stone masonry.

Wall thickness:

In order to reduce inertia forces and to achieve better interlocking of the stones on the two faces of the wall, it will be desirable to keep the wall thickness limited to 45 cm.

Building height:

Using dressed stone masonry, buildings may be constructed up to three storeys. But using random rubble masonry, it is recommended to limit the school buildings to one storey and houses to two storeys high.

Through stones:

In random rubble masonry, walls must be brought to courses at about every 60 cm and the inner and outer wythes of stones bonded together by providing 'through' stones one per m2 of wall area, e.g. one every 1.2 m horizontally in every 0.9 m height. Use steel bars or wood dowels if through stones are not available (Figure 9.11).

Providing vertical reinforcement:

To cater for the increased inertia forces due to a greater thickness of wall than used in brick masonry the vertical steel bars should be kept as shown in Table 9.3.

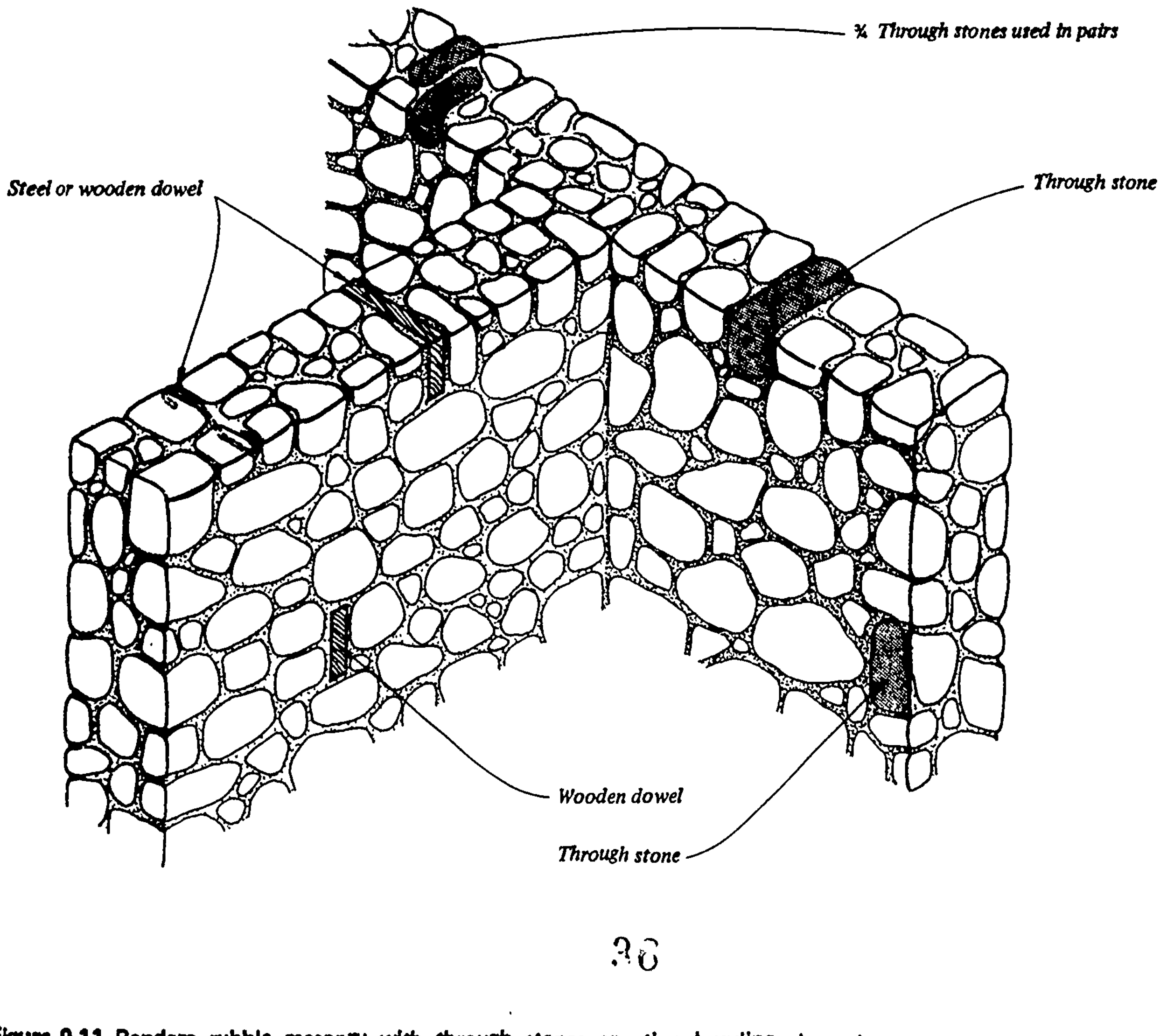

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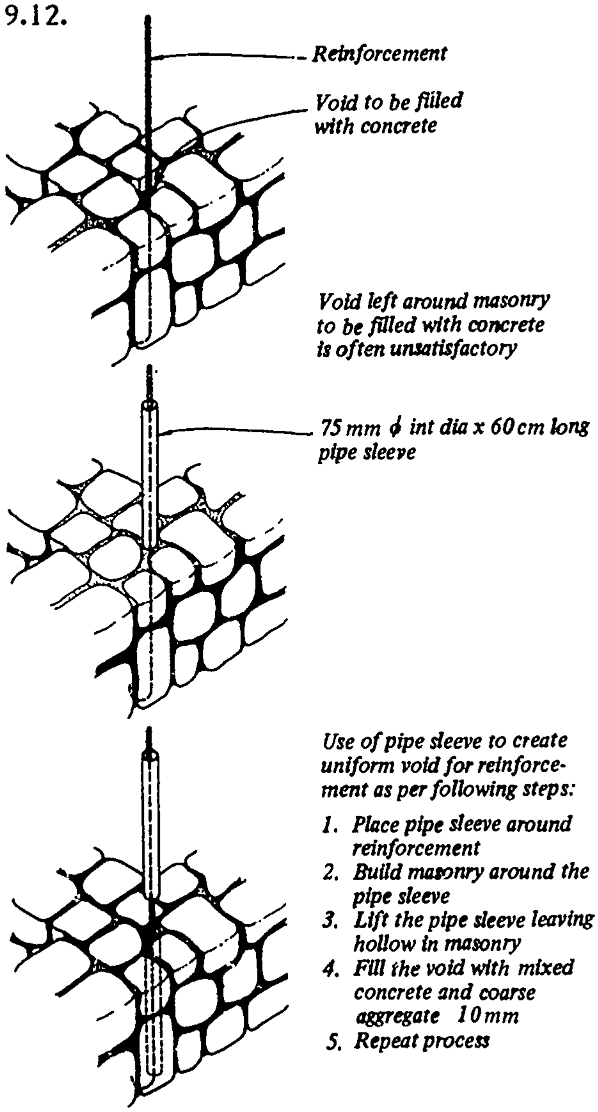
Figure 9.11 Random rubble masonry with through stones or other bonding elements

Table 9.3 Vertical steel bars in stone masonry

No. of storeys	Storey	Dia of single mild steel bar at a critical section						
		Category I		Category II		Category III		Category IV
		M.S.	H.S.D.	M.S.	H.S.D.	M.S.	H.S.D.	
One	–	20	16	16	12	Nil	Nil	Nil
Two	Top	20	16	16	12	12	10	Nil
	Bottom	25	20	20	16	16	12	Nil
Three	Top	20	16	16	12	12	10	Nil
	Middle	25	20	20	16	16	12	Nil
	Bottom	25	20	20	16	16	12	Nil

M.S. = *Mild steel*
H.S.D. = *High strength deformed bars*

The installation of a vertical bar in stone masonry can easily be affected by using a 75 mm diameter pipe casing 60 cm long around the bar while constructing masonry, then raising the casing up and filling the cavity around the bar with micro-concrete as shown in Figure 9.12.



…ure 9.12 Vertical reinforcement in rubble stone masonry

9.9 Concrete block walls

The recommendations made for brick masonry generally apply to concrete block masonry construction assuming that their vertical crushing strength is adequate for resisting the vertical loads, say 70 kg/cm2 for three and four storey buildings and 35 kg/cm2 for one and two storeyed buildings measured on the gross plan area of the solid or hollow concrete block.

Construction of horizontal bands

Use of channel shape concrete units will avoid the employment of formwork. The horizontal reinforcement may be placed in the channels and concrete cast to form the bands. Figure 9.13.

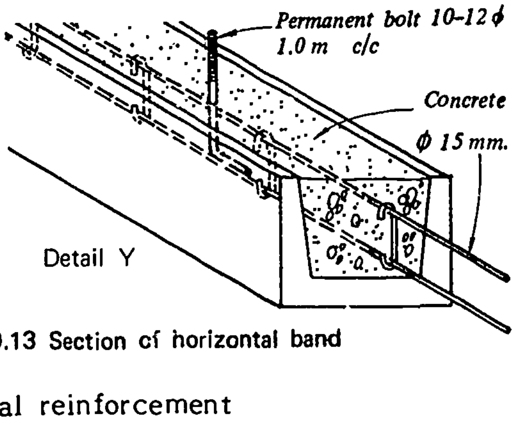


Figure 9.13 Section of horizontal band

Vertical reinforcement

Provision of vertical reinforcement through holes of hollow concrete blocks requires splicing of vertical bars at heights of about 1.8 to 2.0 m so that the blocks have not to be lifted too high. Besides the usual lap-splice with an overlap of 50 diameters, a method found satisfactory is shown in Figure 9.14.

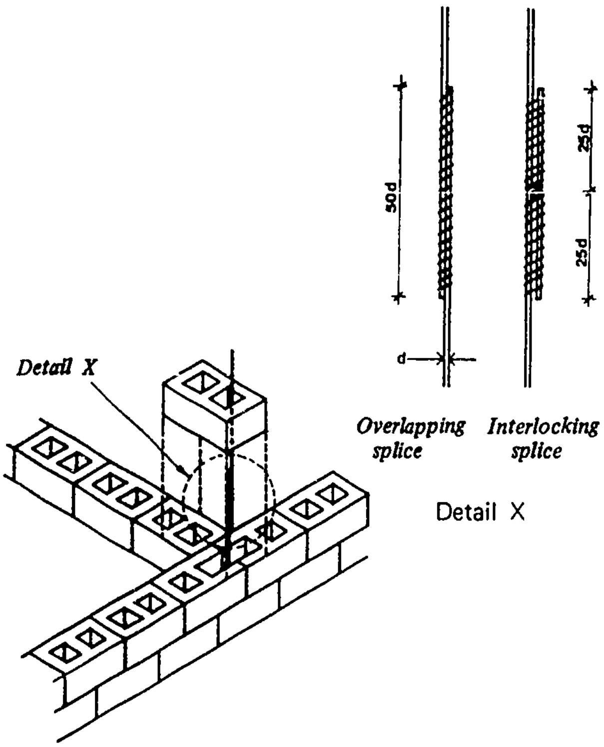


Figure 9.14 Vertical bars in hollow concrete blocks and their splicing

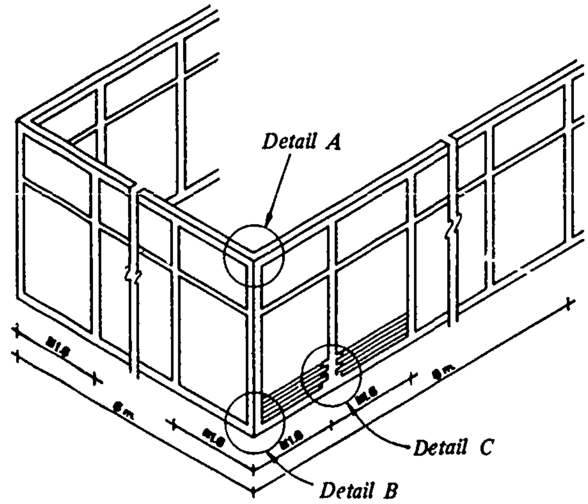
9.10 Load bearing thin-wall construction

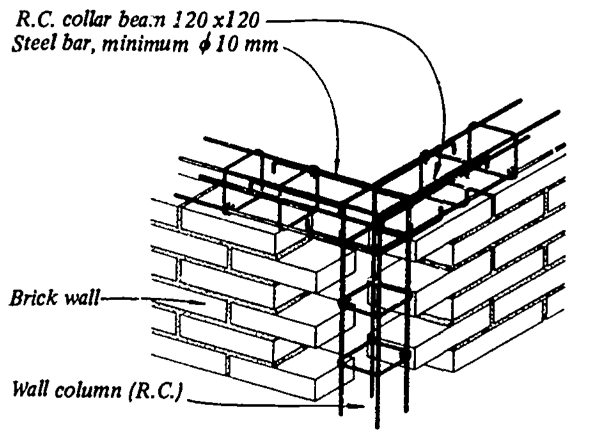
Thin wall construction (e.g. 1/2 brick thick or using 15 cm wide blocks) may be used for one storey high school buildings and up to two storeys high residential buildings.

The concrete should be made of 1:2:4 mix or strength 15 N/mm2 using coarse aggregate of 10 mm maximum size.

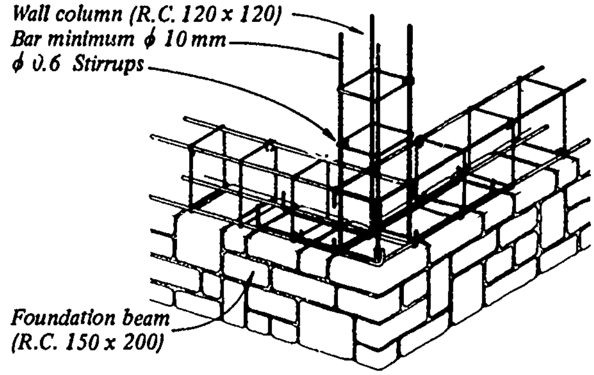
In case of thin walls (say less than 20 cm), reinforced concrete columns and collar beams are necessary to have full bond with masonry walls. Columns are located at all corners and junctions of walls as well as both sides of door openings and at a spacing of not more than 1.6 m. Collar beams are provided at bottom, lintel level, as well as top of storeys. Typical details are shown in Figure 9.15 modification of reinforcement for different categories.

It is important that the concrete filling should be poured following the laying of about six courses (about 45 cm) of masonry on each side of the columns so that the concrete is cast against the masonry and gets bonded with it.

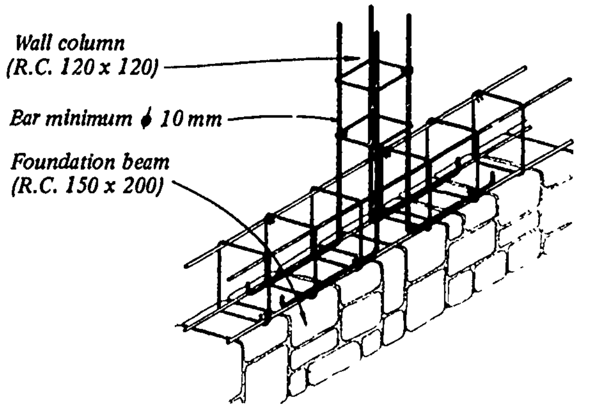




Detail A Corner column collar beam



Detail B Corner column foundation beam



Detail C Intermediate column foundation beam

Figure 9.15 Loading bearing thin wall construction

9.11 Foundations

For load bearing wall construction, strip footing of masonry, plain concrete or reinforced concrete is commonly used. Whereas reinforced concrete strip footing will be most effective from seismic and settlement consideration in soft as well as firm soils, masonry footings are most frequent. The following recommendations are made for the latter:

- Depth of footing should go below the weathering zone. Usually a depth of 75 to 90 cm below ground level will be adequate except in special problem soils (e.g. black cotton highly plastic soils).

- The footing should have adequate width to meet the requirements of safe bearing pressure. Widths of 75 cm for one storey, 1 m for two storey and 1.2 m for 3 storeys are frequently used in alluvial soils. These may be reduced for rocky foundations.

- The footing should be a firm base of mum thickness of 20 cm over which the masonry footings may be built using gradually reducing steps to obtain the final wall thickness. Often, the footing stem is kept a half unit wider than the superstructure wall at plinth level. Figure 9.16.

9.12 Separation and crumple sections

Besides improving the building form seismically, physical separation of blocks prevents damage from hammering and pounding. A gap of 3 to 4 cm throughout the height of the building is desirable for buildings up to 3 storeys. Separation must be complete except below plinth level.

- In case of beam-column construction, members may be duplicated on either side of separation section.

- Details of separation (or Crumple) sections may be as shown in Figure 9.17 (a), (b), (c) and (d).

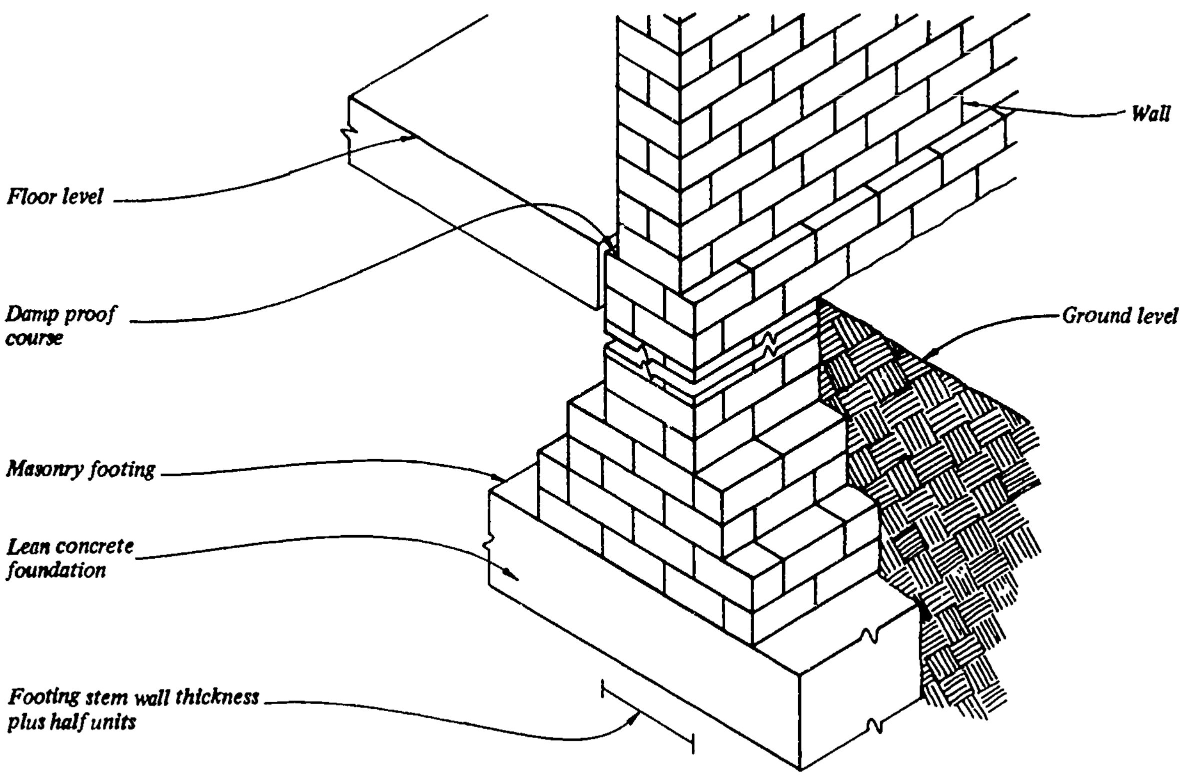


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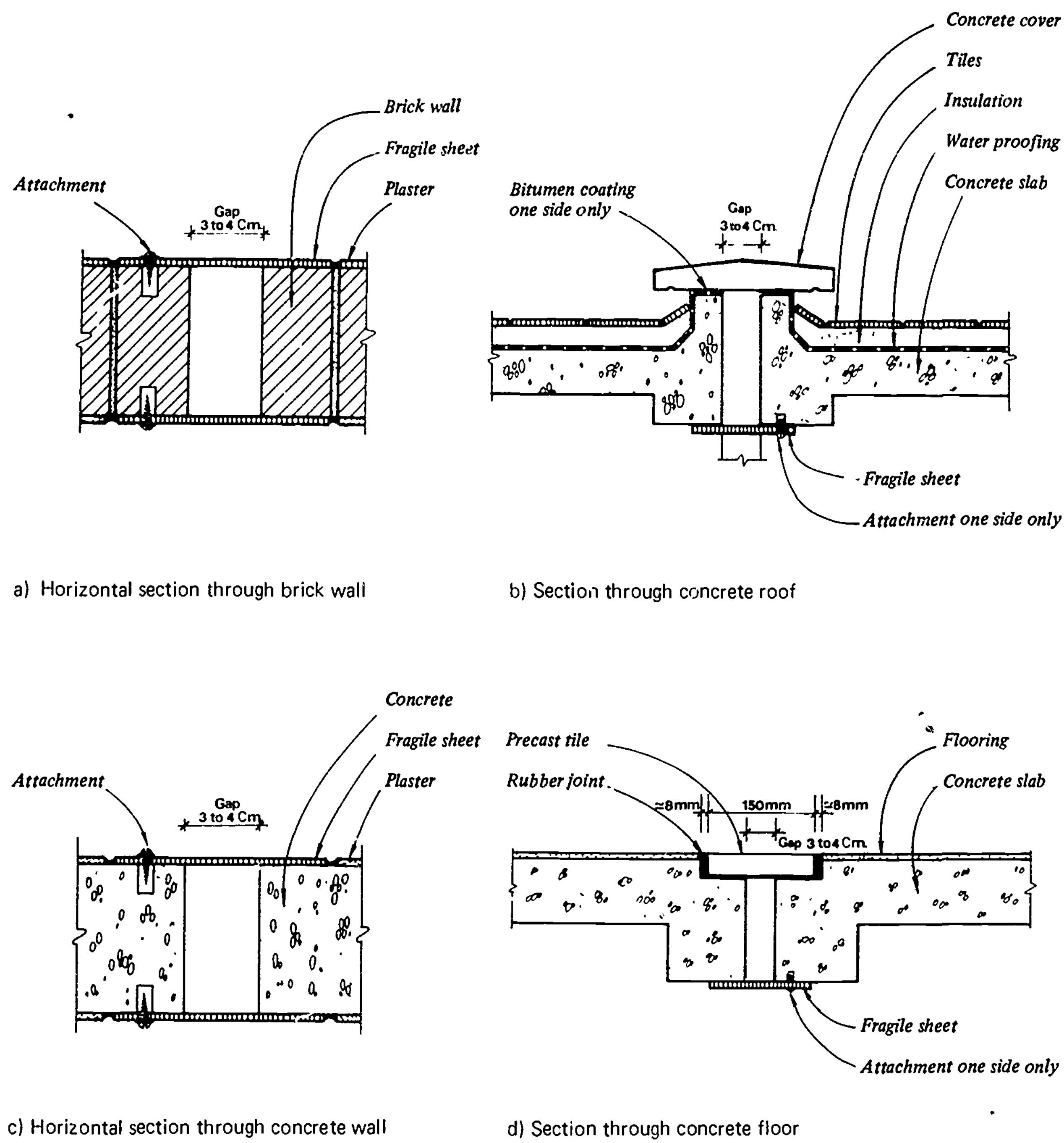
Figure 9.16 Masonry footing for load bearing walls



a) Horizontal section through brick wall

b) Section through concrete roof

c) Horizontal section through concrete wall

d) Section through concrete floor

Figure 9.17 Crumple sections

10. LOW QUALITY MASONRY AND ADOBE CONSTRUCTION

As stated in section 7.1, constructions of brick or stone masonry in mud mortar or using unburnt clay bricks or blocks, called adobe, are very vulnerable to severe damage in seismic zones A and B and their use for school buildings is therefore discouraged. However, where unavoidable, their strength will be considerably enhanced by using the precautions and strengthening measures presented in this chapter.

10.1 Limitations on use

- Brickwork or squared stone masonry in mud mortar may be used for construction of one storey buildings of categories I and II and not more than 2 storeys of categories III and IV.

- Adobe construction and random rubble masonry in mud mortar is to be avoided in category I, and used for only one storey construction in categories II, III and IV. Only buildings of lower occupancy importance may be made up to two storeys high in category IV.

10.2 Strengthening measures

The main seismic strengthening measures are the following:

- Integral action of sloping roofs as stated in section 8.2;

- Bracing and integral action of flat joist type roofs and floors as detailed in this chapter;

- Provision of horizontal bands in walls as in masonry walls, see section 9.6 or as detailed in this chapter; and

- Provision of vertical buttresses for enhancing stability of walls.

10.3 Material

- The mud used for making adobe or mud mortar should be capable of being rolled in the form of a thin thread between 5 and 15 cm long without cracking.

- Sufficient quantity of fibrous material (straw, cane baggasse, horse hair) should be added to the clay before making adobe.

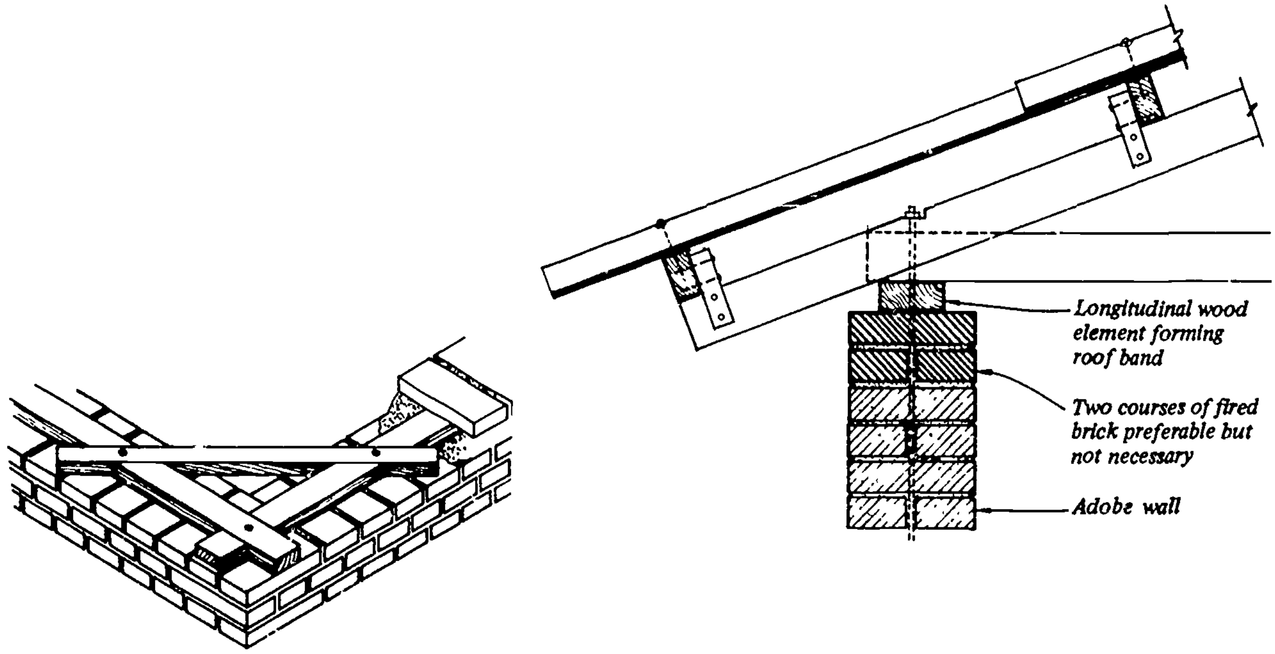
- While different adobe sizes are used around the world suitable sizes would be 38 cm x 19 cm x 8 cm or 38 cm x 38 cm x 8 cm with 2 cm mud mortar joints between the units during construction.

10.4 Roofs

- Light sheeted roof should preferably be used for school buildings. Wooden roof trusses will be better than the use of rafters alone. For bracing and other details see sections 8.2 and 9.3 as applicable.

- If thatch is used for roof covering, it will be better and safer if made water proof and fire resistant by applying mud plaster mixed with bitumen cutback on both surfaces of the thatch, the preparation of which is explained in 10.7.

- The roof beams or rafters should be rested on longtitudinal wooden elements for distribution of the load on adobe. The longitudinal wooden elements should be spliced and carried on all walls to form a roof band. (Figure 10.1). Preferably two top courses of fired bricks may be laid instead of adobe for resting the longitudinal wooden elements.



a) Roof band

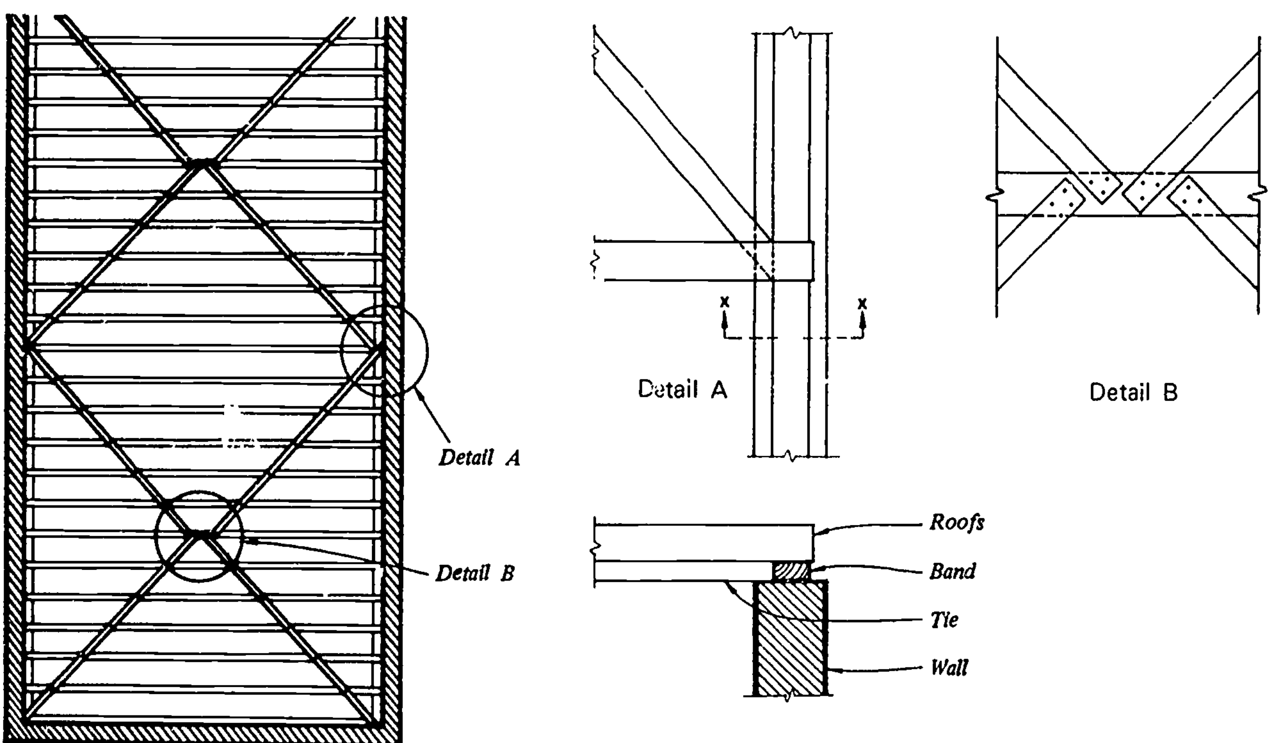
b) Fixing detail

Figure 10.1 Roof band and fixing roof to adobe wall

Wood logs or joists with earth fill:

Such roofs or floors should be planned to have diagonal bracing through wooden planks nailed or spiked to the logs/joists and the space at their ends blocked by cut pieces from the logs. Alternative to blocking, the logs/joists may be spiked to wooden wall plates which should be anchored to the roof bands through bolts (Figure 10.2).

- Where roof beams or rafters are located above door or window lintels, the lintel should be reinforced by additional wood lintels (Figure 10.3).



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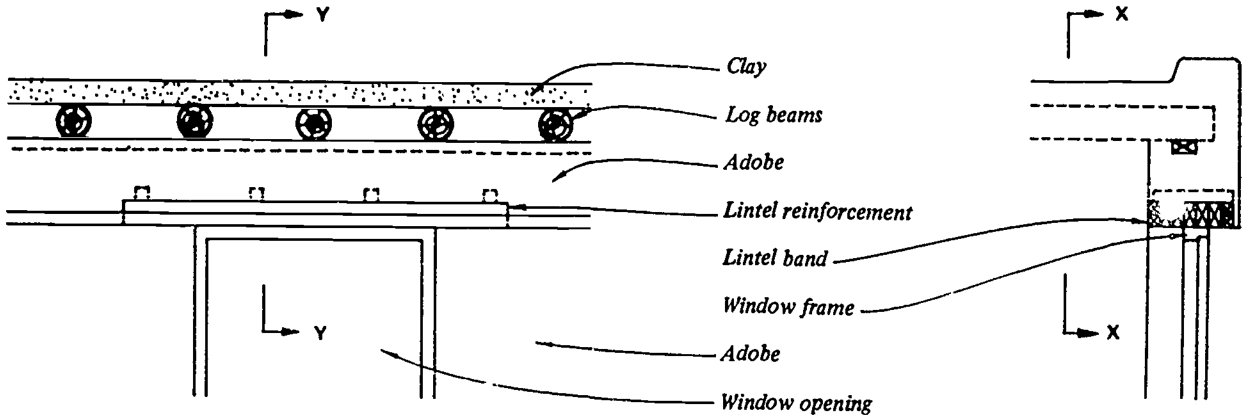
re 10.2 Bracing of wooden joist roofs and floors



Section XX through room

Section YY through window

Figure 10.3 Reinforcing lintels under log beams

10.5 Walls

- Masonry in mud mortar. The minimum brick wall thickness may be made 1 1/2 units, that is, 30 cm for 20 cm long units and 35 cm for 23 cm long units. All rules to achieve good bonding will apply as discussed in sections 9.2.

- Stone masonry in mud mortar. The wall thickness may be kept 45 cm only and details as per 9.8 adopted for construction.

- Adobe construction. All courses should be laid level. Vertical joints should be broken between two consecutive courses by overlap of adobes. Clay mud should be the same as used in making the adobe. Right angle joints between walls should be made such that the walls are properly joined together and a through vertical joint is avoided. Walls should be covered with water repellent plaster on the outside by mixing bitumen cut-back in mud-mortar (section 10.7).

The thickness of load bearing walls may be kept one, 1 1/2, 2 or more units of the adobe length depending on the desired length and height of wall. The length of a wall, between two consecutive walls at right angles to it, should not be greater than ten times the wall thickness. When a longer wall is required, the walls should be strengthened by intermediate vertical buttresses. The height of the wall should not be greater than eight times its thickness.

- Buttresses. Construction of buttresses by projecting walls beyond the corner and T-junctions will help to retain the integral action of walls and facilitate the connection of collar beams with each other (Figure 10.4). Width of buttress including wall thickness should at least be equal to 1/3 of the wall height.

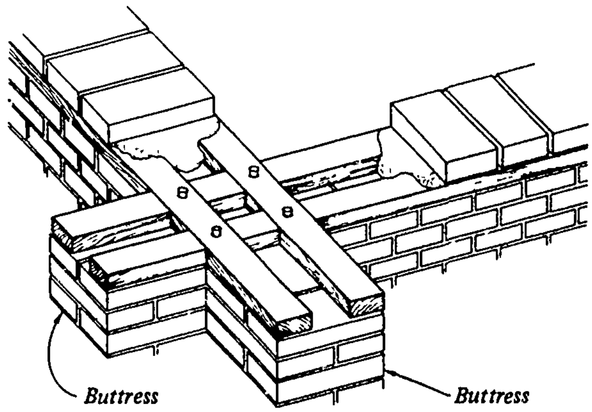


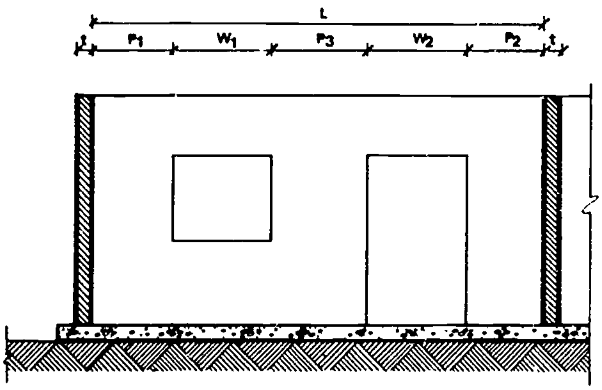
Figure 10.4 Use of buttress

- Openings in squared unit masonry walls. The controlling guidelines given in Section 9.5 will be applicable with the further restriction that the sum of widths of openings shall not exceed 40 per cent of the length of wall between consecutive supports or cross walls, the width of pier between two consecutive openings being not less than 45 cm (Figure 10.5).

- Openings in Adobe or stone walls in mud. The width of an opening should not be greater than 1.20 m. The distance between an outside corner and the opening should not be less than 1.2 m. The sum of the widths of openings in a wall should not exceed one-third of the total wall length. The bearing length (embedment) of lintels on each side of an opening should not be less than 38 cm, the width of pier being not less than 1.2 m (see Figure 10.6).

- Horizontal bands. Brick and stone masonry buildings using mud mortar should be strengthened with reinforced concrete bands at various levels as detailed in section 9.6.

Random rubble masonry in mud mortar and adobe constructions may also be strengthened with R.C. bands. But alternatively, bands may be formed using timber runners as shown in Figure 10.7.

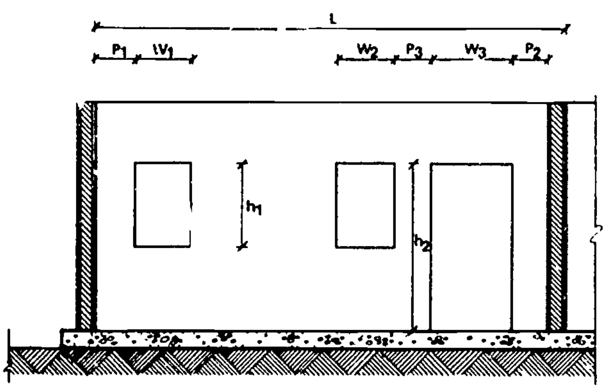


Rule 1: $P_1 \geq 0.25h_1$ *and* $P_2 \geq 0.25h_2$

Rule 2: $W_1 + W_2 + W_3 \leq 0.4L$

Rule 3: $0.5h_1$ *and* P_1 *or* P_2 *or* $P_3 \geq 450\,mm$

Figure 10.5 Opening sizes in bearing walls constructed from squared units in mud mortar



$P_1 + t \geq 1.2m \quad P_2 + t \geq 1.2m \quad P_3 \geq 1.2m$

$W_1 + W_2 \leq \frac{L}{3} \quad W_1, W_2 \leq 1.2m$

Figure 10.6 Opening sizes in bearing walls constructed from random rubble and mud or adobe

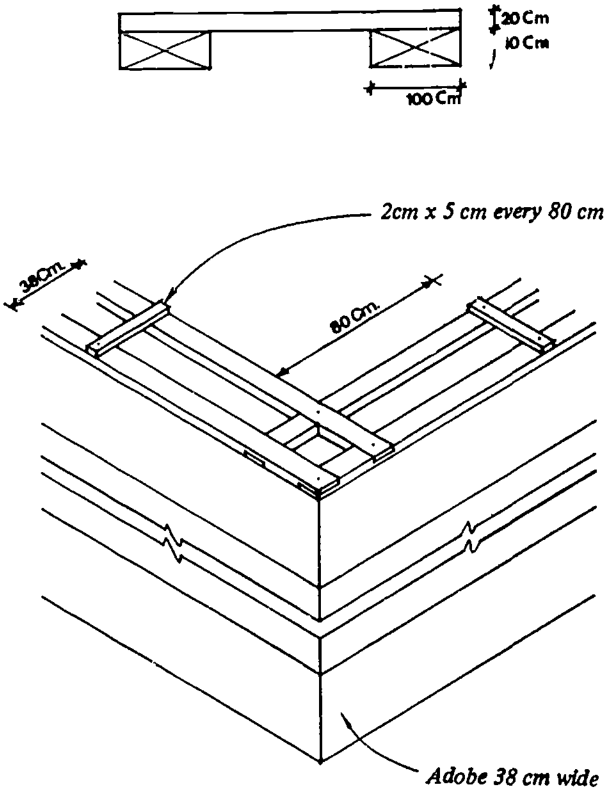


Figure 10.7 Detail of a wooden band

10.6 Foundations

Masonry walls

Use strip footings as per guidelines in section 9.11.

Adobe walls

The strip foundation for the walls should have its width at least 1 1/2 times the thickness of wall and its depth a minimum of 40 cm below ground level.

A footing base of 20 cm thickness should preferably be made in lean cement concrete (cement:sand:gravel:stones as 1:4:6:10) or lime concrete in the ratio lime : sand : gravel as 1:4:8.

A footing masonry up to plinth level should preferably be constructed from stone or burnt bricks laid in lime mortar 1:3 or clay mud. The height of the plinth should be above the flood water line or a minimum of 30 cm above ground level.

10.7 Prevention of erosion and damp proofing

Masonry in mud mortar as well as adobe walls needs the protection of mortar from erosion caused by rain and also damp proofing at plinth level.

Brickwork or stone masonry in mud mortar may either be plastered with 1:1:6 cement-lime-sand mortar or pointed with 1:3 cement-sand mortar on all external faces including roof parapets. Alternatively these may be plastered over with water proof mud plaster as for adobe walls described below.

Adobe buildings should be plastered with mud mixed with bitumen "cut-back" from footing to the outside faces of the roof parapets. "Cut-back" is prepared by mixing bitumen 80/100 grade, kerosene oil and paraffin wax in the ratio 100:20: 1. For 1.8 kg cut-back, 1.5 kg bitumen is melted with 15 g of wax and this mixture is poured in a container having 300 mil kerosene oil with constant stirring till all ingredients are mixed. This mixture can now be mixed with 0.03 m3 of mud mortar to make it both water repellent as well as a fire protection for the thatch.

For preventing dampness from rising into the superstructure walls from the footings, a damp-proof layer should be prepared at the plinth level. It may consist of 1:3 cement-sand mortar with damp-proofing compound mixed with it in a thickness of 25 mm or concrete of 1:2:4 mix with damp-proofing compound in a thickness of 75 mm. These will be suitable for brick or stone masonry walls and may be used in adobe walls as well. For the latter, alternatively a 50 mm thick layer of water proof mud plaster or black polyethylene sheet of heavy gauge may be used as a damp proofing course.

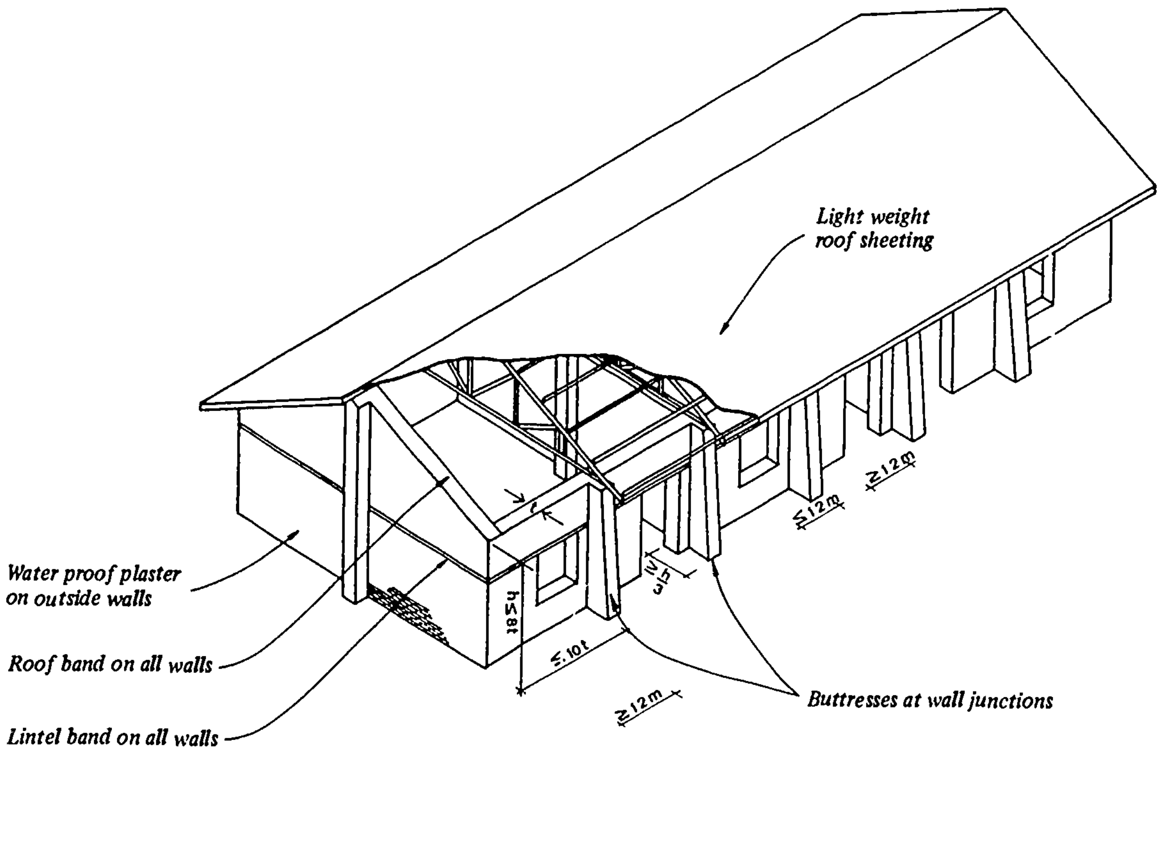


Figure 10.8 Earthquake resistant features in adobe buildings

11. SEISMIC STRENGTHENING OF EXISTING BUILDINGS

The seismic behaviour of old existing buildings is affected by their original structural inadequacies, material degradation due to time, and alterations carried out during use over the years such as making new openings, addition of new parts inducing dissymmetry in plan and elevation.

11.1 General features of repair, restoration and strengthening

Repairs

The main purpose of repairs such as the following is to maintain the architectural shape of the building. These are needed even in normal working life. They, however, do not restore the original structural strength of walls of columns if they get cracked.

- Patching up of defects such as cracks and fall of plaster;
- Repairing doors, windows, replacement of glass panes;
- Checking and repairing electric wiring;
- Checking and repairing gas pipes, water pipes and plumbing services;
- Rebuilding nonstructural walls, smoke chimneys, boundary walls;
- Replastering of walls as required;
- Rearranging disturbed roofing tiles;
- Relaying cracked flooring at ground level; and
- Redecoration - white washing, painting.

Restoration:

The main purpose of restoration is to carry out structural repairs to load bearing elements so that the original strength is more or less restored. Some of the approaches are stated below:

- Removal of portions of cracked masonry walls and piers and rebuilding them in richer mortar. Use of non-shrinking mortar will be preferable.
- Injecting cement slurry or epoxy like material, which is strong in tension, into the cracks in walls, columns and beams.
- Replacing defective or weathered elements of wooden roof trusses.
- Tightening the joints of roof trusses with thin wires/ropes or covering them with steel straps.

Strengthening:

Seismic strengthening of existing buildings may cost in some cases as high as 50 per cent of the cost of rebuilding. Therefore justification of such costly strengthening must be fully considered and the most economical alternatives worked out.

The main items related to seismic strengthening are as follows:

a) Modification of roofs;

b) Substitution or strengthening of floors; and

c) Modifications in plan and strengthening of walls.

11.2 Materials required for restoration and strengthening

Common materials:

a) Steel bars, flats, angles, channels, bolts, nails, spikes, expanded metal, welded wire fabric;

b) Ordinary portland cement; aluminium powder admixture for non-shrinking mortar; and

c) Wood and bamboo poles, joists. Ropes.

Special materials and techniques:

a) Shot-crete is a method of applying a combination of sand and portland cement which is mixed pneumatically and conveyed in dry state to the nozzle of a pressure gun, where water is mixed and hydration takes place just prior to expulsion. The material bonds perfectly to properly prepared surface of masonry and steel.

b) Epoxy resins are excellent binding agents with high tensile strength. These are chemical preparations. The low viscosity type can be injected in fine cracks. The high viscosity type is formed into mortar by mixing with sand which can be used for filling larger cracks and voids.

c) Quick-setting cement and non-shrinking cement.

d) Anchors. Mechanical anchors employ wedging action to provide anchorage. Some of the anchors provide both shear and tension resistance. Alternatively, chemical anchors bonded in drilled holes with polymer adhesives can be used.

When using a) and b) above the feasibility and cost should be carefully determined before adopting them.

11.3 Techniques to restore original strength

Since even fine cracks in load bearing unreinforced members, like masonry and plain concrete reduce strength, all cracks must be located and marked carefully and the critical ones fully restored.

- Small cracks: If the cracks are fine (opening width less than 1 mm), the technique to restore the original tensile strength of the cracked element is by pressure injection of epoxy.

- Wider cracks: Cement-water 1:1 grout may be used for injection into cracks not wider than 6 mm by using the following technique (Figure 11.1).

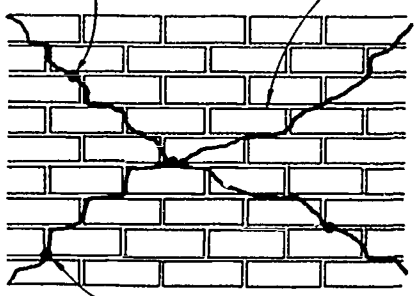


Figure 11.1 Repairing cracks

The external surfaces are cleaned of non-structural materials and plastic injection ports are placed along the surface of the cracks on both sides of the wall and are secured in place with mortar 1:2. The centre to centre spacing of these ports may be approximately equal to the thickness of the wall. After the sealant has cured, the cement grout is injected into one port at a time, beginning at the lowest part of the crack in case where it is vertical or at one end of the crack in cases where it is horizontal. The grout is injected until it is seen flowing from the opposite sides of the wall at the corresponding port or from the next higher port on the same side of the wall. The injection port should be closed at this stage and injection equipment moved to the next port and so on.

This technique is appropriate for all types of structural elements beams, columns, walls and floor units in masonry as well as concrete structures.

- Very wide cracks and crushed masonry: For cracks wider than about 6 mm or for regions in which the concrete or masonry has been crushed, the following procedure may be adopted.

a) The loose material is removed and replaced with non-shrinking or quick setting cement mortar.

b) Where found necessary, additional shear or flexural reinforcement e.g. expanded metal is provided in the region of repairs and then covered by mortar.

c) Alternatively steel is provided on both sides of a badly cracked surface, fixed to the wall, and then, covered with cement plaster or micro-concrete.

- Fractured wooden members and joints: The strength of timber, beams, columns, struts and ties is restored by splicing additional material after removing the weathered or rotten wood. Nails, wood screws or steel bolts are used as connectors. It will be advisable to use steel straps to cover all such splices and joints so as to keep them tight and stiff.

11.4 Modification or strengthening of roofs

Pitched roofs:

- slates and roofing tiles should be replaced with corrugated iron or asbestos sheeting where possible.

- False ceilings of non brittle material like hessian cloth, bamboo matting, plywood or light foam substances may be used but not heavy and brittle materials such as asbestos cement sheets.

- Roof truss frames should be braced by welding or clamping suitable diagonal bracing members in the sloping as well as horizontal planes. See Figure 11.2.

- Anchors of roof trusses to supporting walls should be improved. The roof thrust on walls should be eliminated. Figure 11.3 illustrates a method in which the rafters are connected with each other at the ridge and horizontal planks are added to take horizontal tension. Where a longitudinal wall goes up to the ridge level, the wall top should be dismantled in parts starting from one end, the horizontal plank fixed into position and then the wall rebuilt.

Flat roofs and floors:

Where the roof or floor consists of wooden poles or joists carrying brick tiles and earth, integration of such units is necessary. Diagonally placed wood planks may be nailed to wood joists from below along with peripheral planks to create a grillage action of all joists (Figure 11.4).

In roofs or floors consisting of steel joists and flat or segmental arches, ties consisting of flat iron, may be welded/bolted to the joists from below for holding the joists horizontally in each arch span so as to prevent the spreading of arches (see Figure 9.4).

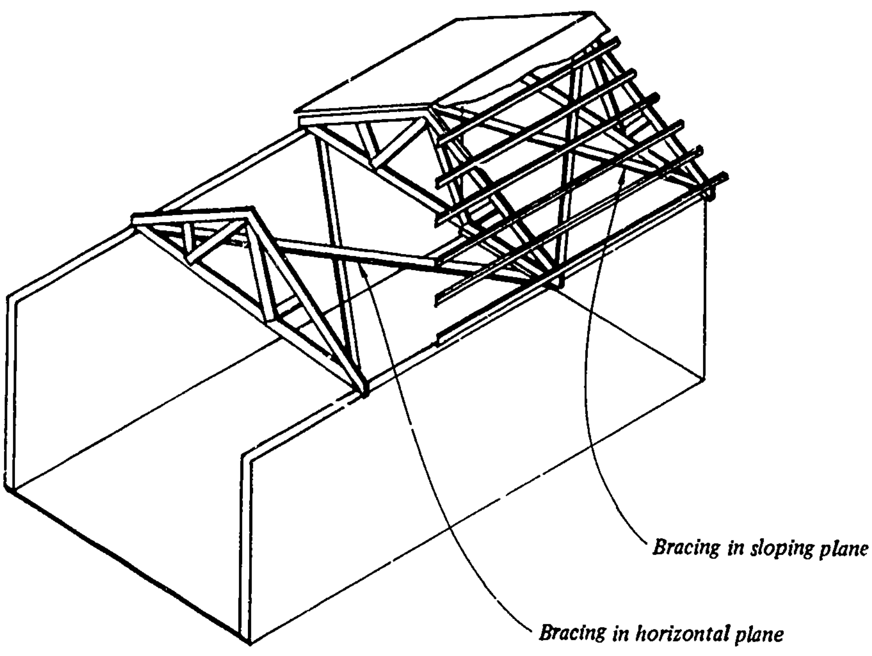
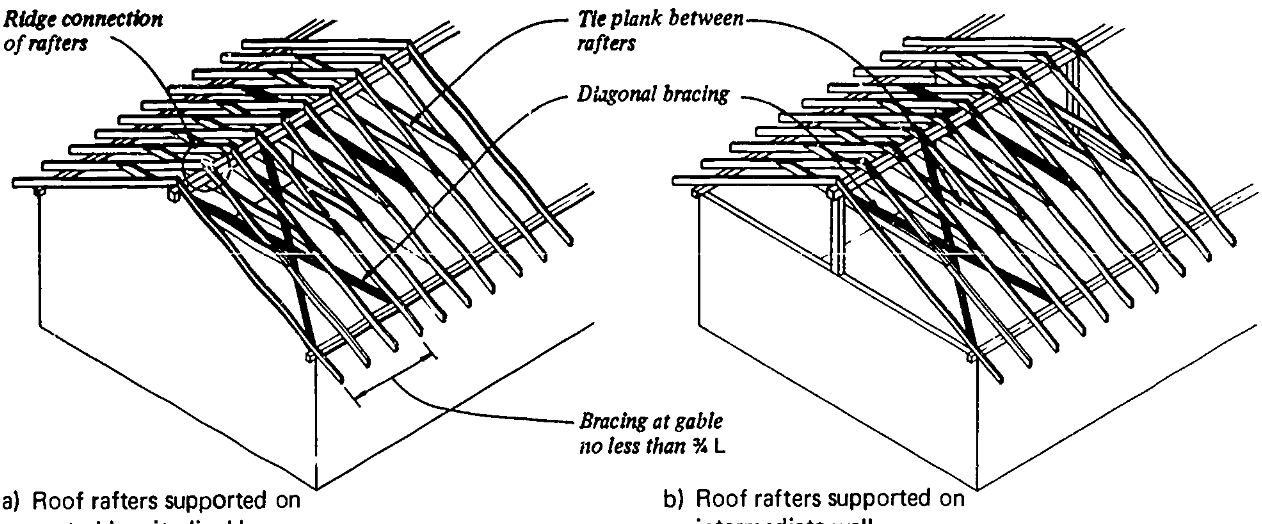


Figure 11.2 New roof bracing



a) Roof rafters supported on central longitudinal beam

b) Roof rafters supported on intermediate wall

Figure 11.3 Roof modification to reduce thrust on walls

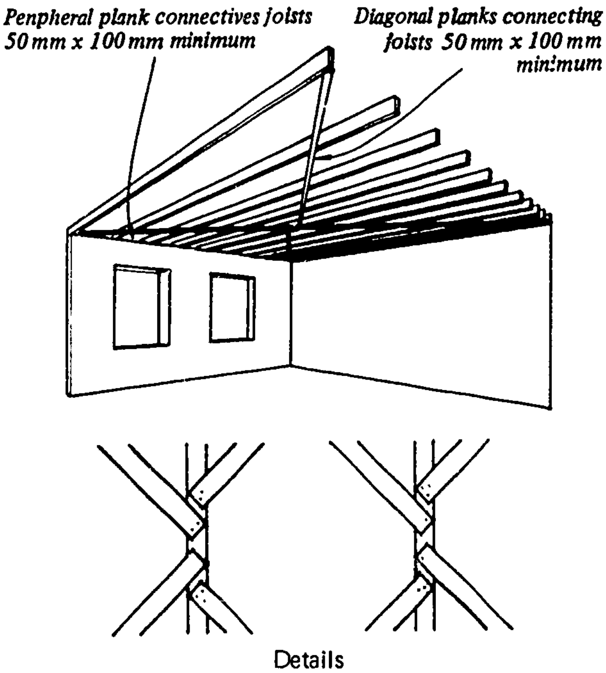


Figure 11.4 Bracing of floors

Existing wooden floors can be stiffened by planks nailed perpendicularly to the existing ones (Figure 11.5). When this is done, the diagonal bracing described above need not be carried out.

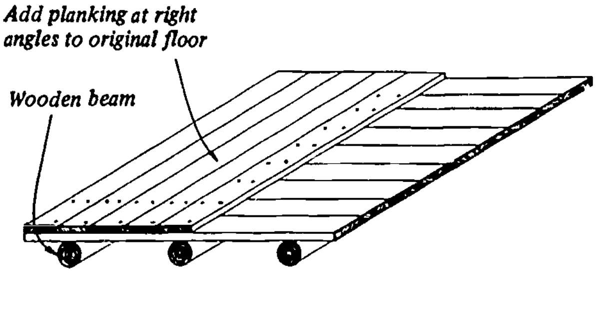


Figure 11.5 Stiffening of wooden floor by wooden planks

11.5 Strengthening existing walls

The lateral strength of buildings can be improved by increasing the strength and stiffness of existing individual walls.

Vertical R.C. covering plates:

Steel mesh (welded wire fabric with mesh of approximately 15 x 15 cm) is placed on the two sides of the wall, and connected by passing steel (each 50 to 75 cm apart), through the wall or held to the wall by driving spikes (Figure 11.6). A 3 to 4 cm thick cement mortar or micro-concrete layer is then applied on the two networks thus giving rise to two interconnected vertical plates. This system can also be used to improve the connection of walls at right angles.

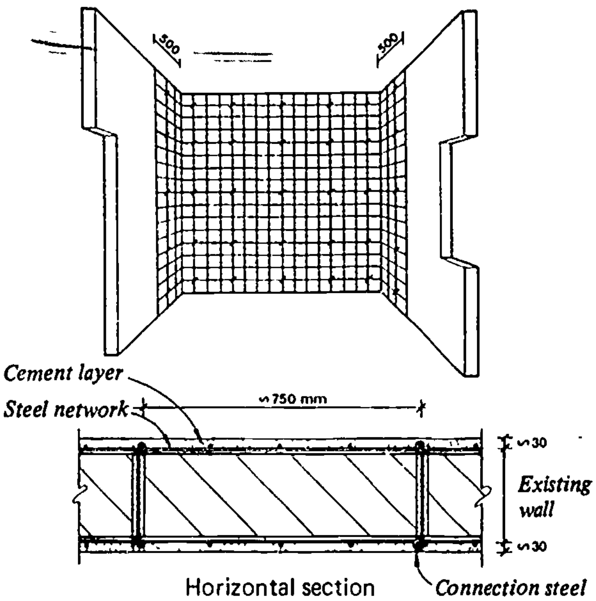


Figure 11.6 Vertical reinforced concrete covering plates

Prestressing:

A horizontal compression state is induced by placing two steel rods on the two sides of the wall and stretching them by turnbuckles (Figure 11.7). Note that good effects can be obtained by light horizontal prestressing (about 1 kg/cm2) on the vertical section of the wall. Prestressing is also useful to strengthen the spandrel beam between two rows of openings in cases where there are no rigid slabs in between.

Opposite parallel walls can also be held to internal cross walls by prestressing as illustrated above, the anchoring being done against horizontal steel channels instead of small steel plates. The steel channels running from one cross wall to the other will hold the walls together and improve the integral box like action of the walls.

External binding:

The technique of covering the wall with steel mesh and mortar or micro-concrete may be used only on the outside surface of external walls but maintaining continuity of steel at the corners. The covering may be in the form of vertical splints between openings and horizontal bandages over spandrel walls at suitable number of points only (Figure 11.8).

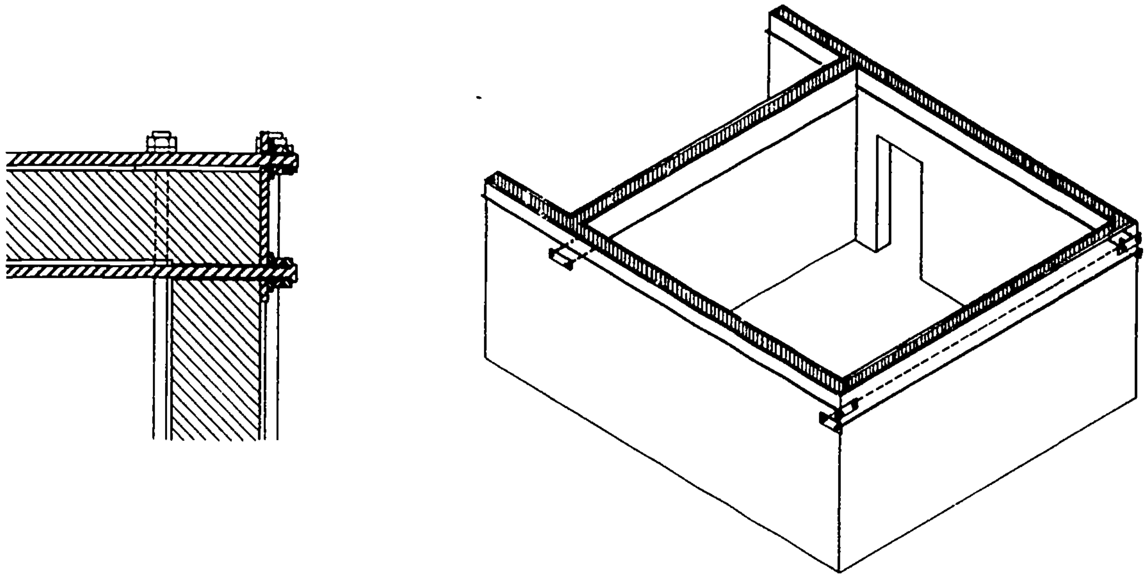


Figure 11.7 Strengthening of walls by prestressing

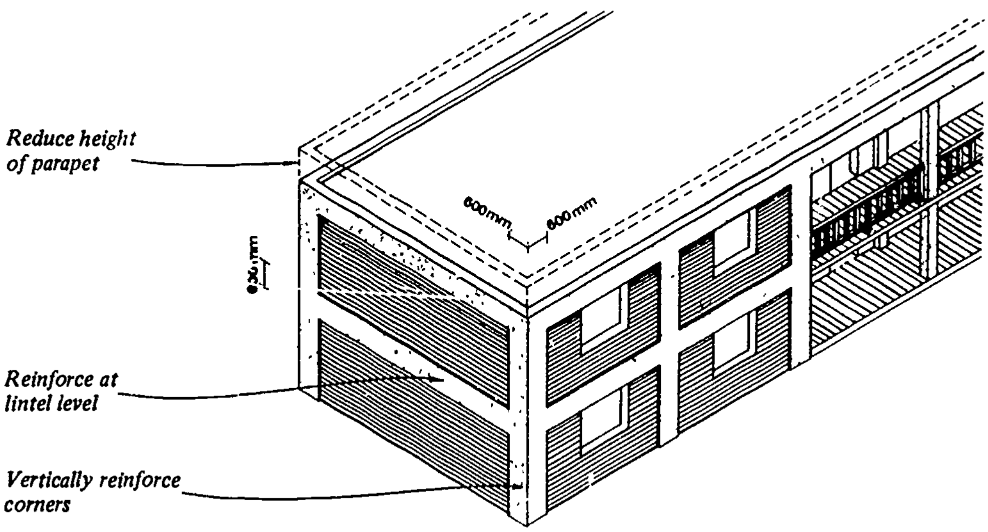


Figure 11.8 Splint and bandage strengthening technique

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Internal cross walls:

Long barrack type halls may be subdivided by building cross-walls at intermediate points. The walls should be at least 20 cm thick and properly bonded with the longitudinal walls by keying masonry units into them. Appropriate foundation must be used for the new walls. Door openings and lintel band may be introduced in the new wall bonded with the external walls by passing bars through holes and grouting them (Figure 11.9).

Buttressing:

Where subdividing the space by internal cross walls is not practicable due to functional or other reasons, for bracing the longitudinal walls of long barrack type buildings, masonry buttresses may be added externally as shown in Figure 11.10. They should of course be bonded with the existing walls through key bricks. A more positive connection can be achieved by using reinforced concrete key stones as shown in section 11.10(c).

Treating large arch openings:

If the size of the opening may functionally be reduced, it will be best to build piers on both sides in the opening, bonded with existing walls, spanned by a lintel and the opening above the lintel filled solid with masonry. Alternatively install tie rods at springings or slightly above them by drilling holes on both sides and grouting steel rod in the holes (Figure 11.11).

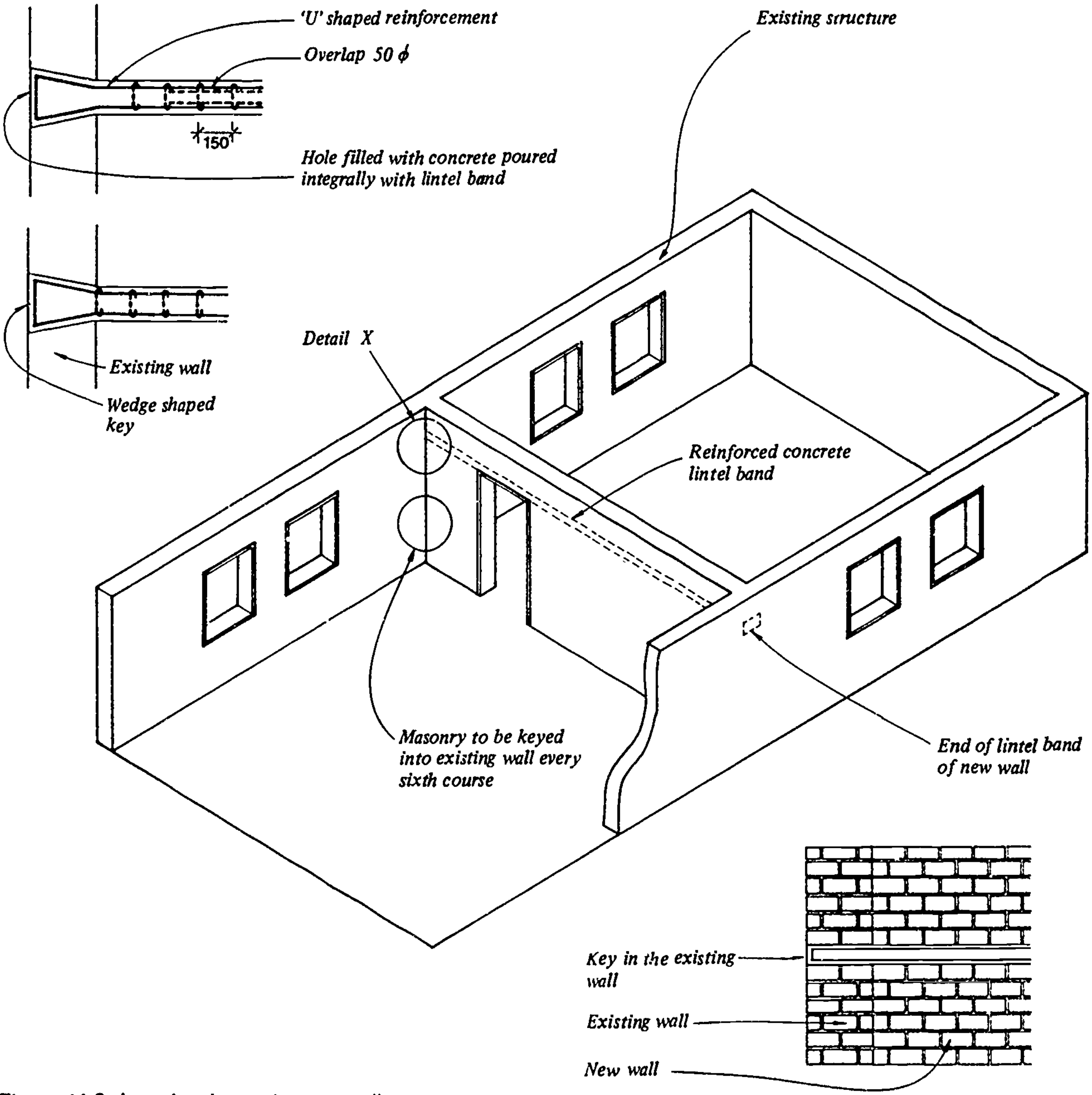


Figure 11.9 Inserting internal cross walls

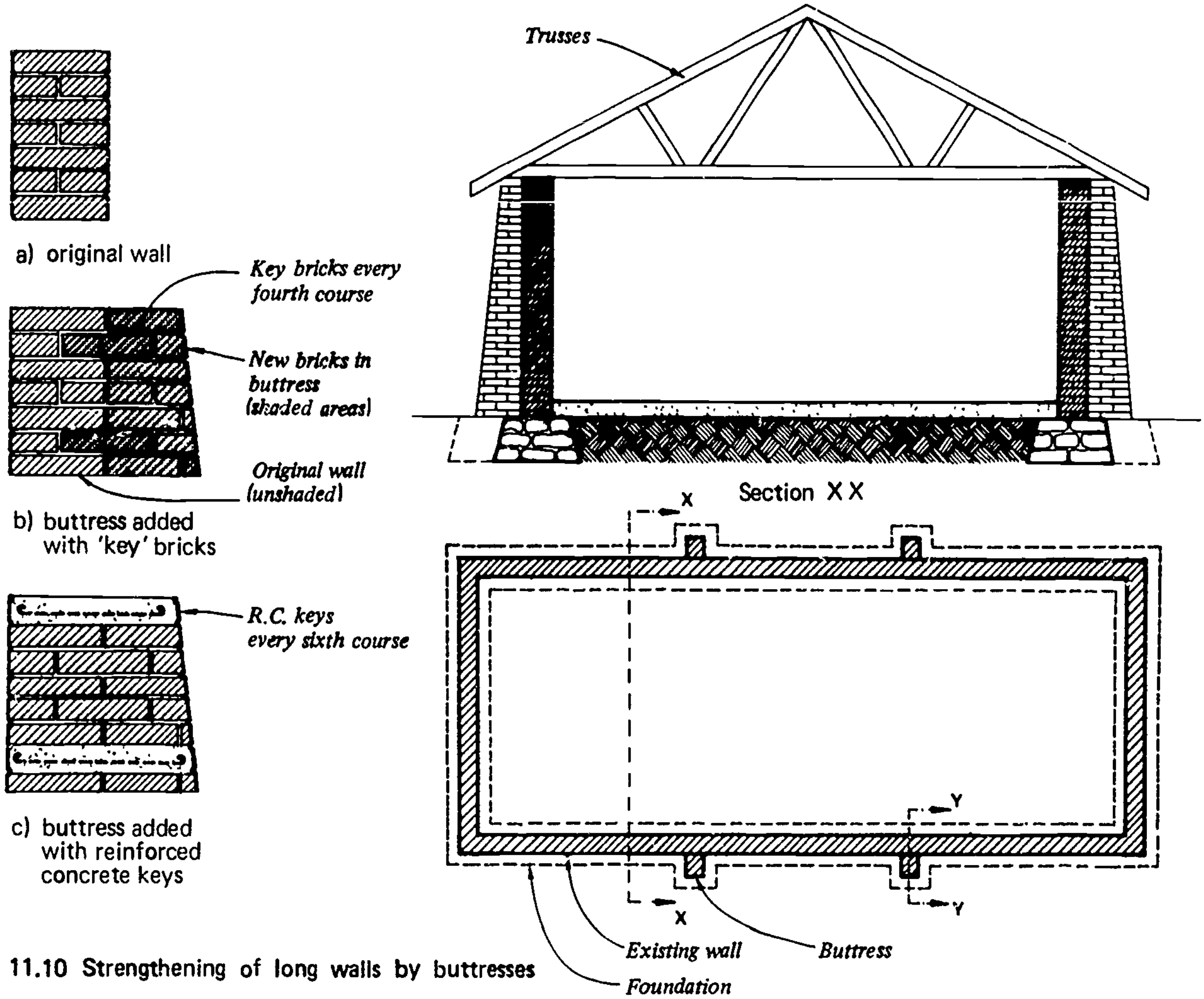


Figure 11.10 Strengthening of long walls by buttresses

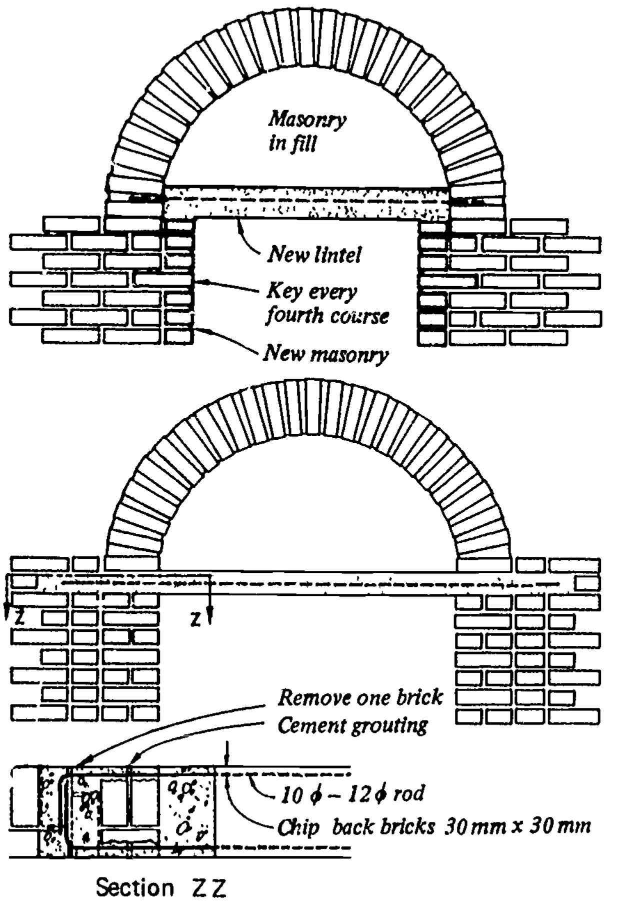


Figure 11.11 Strengthening of arch openings

11.6 Strengthening wooden buildings

The main strengthening measures for wooden buildings will consist of the introduction of diagonal bracing members in the roof slope of the trusses, in the plan of the building at tie level, knee bracing between the roof trusses and the columns, and diagonal bracing in the wall panels. The bracing should be introduced wherever found deficient with reference to the bracing requirements given in Chapter 8. The bracing may conveniently be in the form of wooden planks which may be nailed or screwed on the inner or the outer faces of the stud wall or brick nogged frames.

APPENDIX A.

MSK INTENSITY SCALE

The main definitions used in the scale are as follows:

a) Types of Buildings

Type A : Buildings in field-stone, rural structures, adobe houses, clay houses.

Type B : Ordinary brick buildings, buildings of the large block and prefabricated type, half timbered structures, buildings in natural hewn stone.

Type C : Reinforced buildings, well-built wooden structures.

b) Definiton of Quantity

Single, few	About 5 per cent
Many	About 50 per cent
Most	About 75 per cent

c) Classification of Damage to Buildings

Grade 1.	Slight damage	: Fine cracks in plaster; fall of small pieces of plaster.
Grade 2.	Moderate damage	: Small cracks in walls; fall of fairly large pieces of plaster, pantiles slip off; cracks in chimneys; parts of chimney fall down.
Grade 3.	Heavy damage	: Large and deep cracks in walls; fall of chimneys.
Grade 4.	Destruction	: Gaps in walls; parts of buildings may collapse; separate parts of the building lose their cohesion; inner walls collapse.
Grade 5.	Total damage	: Total collapse of buildings.

d) Intensity Scale

MSK Scale No.	Lable and description	
I.	Not noticeable	
II.	Scarcely noticeable (very slight)	) No
III.	Weak, partially observed only	) damage
IV.	Largely observed	) to
V.	Awakening	) building
VI.	Frightening: Damage of Grade 1 is sustained in single buildings of Type B and in many of Type A. Damage in few buildings of Type A is of Grade 2.	

VII. Damage of buildings: In many buildings of Type C damage of Grade 1 is caused; in many buildings of Type B damage is of Grade 2. Most buildings of Type A suffer damage of Grade 3, few of Grade 4. In single instances land-slips of roadway on steep slopes; cracks in roads; seams of pipelines damaged, cracks in stone walls.

VIII. Destruction of buildings: Most buildings of Type C suffer damage of Grade 2, and few of Grade 3. Most buildings of Type B suffer damage of Grade 3, and most buildings of Type A suffer damage of Grade 4. Many buildings of type C suffer damage of Grade 4. Occasional breaking of pipe seams. Memorials and monuments move and twist. Tombstones overturn. Stone walls collapse.

IX. General damage to buildings: Many buildings of Type C suffer damage of Grade 3, a few of Grade 4. Many buildings of Type B show damage of Grade 4; a few of Grade 5. Many buildings of Type A suffer damage of Grade 5. Monuments and columns fall. Considerable damage to reservoirs; underground pipes partly broken. In individual cases railway lines are bent and roadway damaged.

X. General destruction of buildings: Many buildings of Type C suffer damage of Grade 4, a few of Grade 5. Many buildings of Type B show damage of Grade 5; most of Type A have destruction of Grade 5; critical damage to dams and dykes and severe damage to bridges. Railway lines are bent slightly. Underground pipes are broken or bent. Road paving and asphalt show waves.

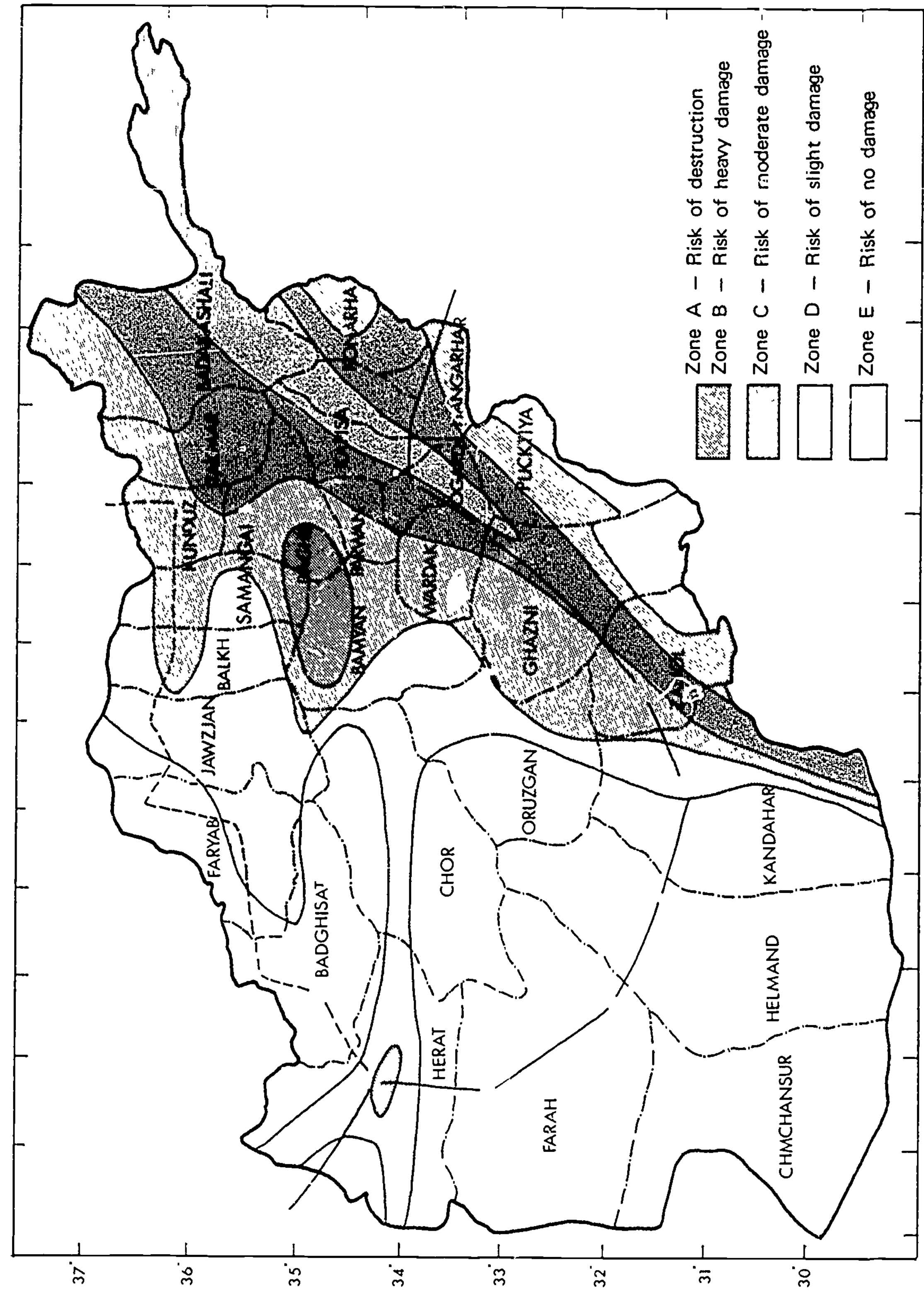
XI.	Destruction	) Complete
		) destruction of
XII.	Landscape changes	) buildings

APPENDIX B.

Seismic zoning maps of some Asia and Pacific countries

Afghanistan
Australia
Bangladesh
Burma
India
Indonesia
Japan
Nepal
New Zealand
Philippines
Turkey
USSR

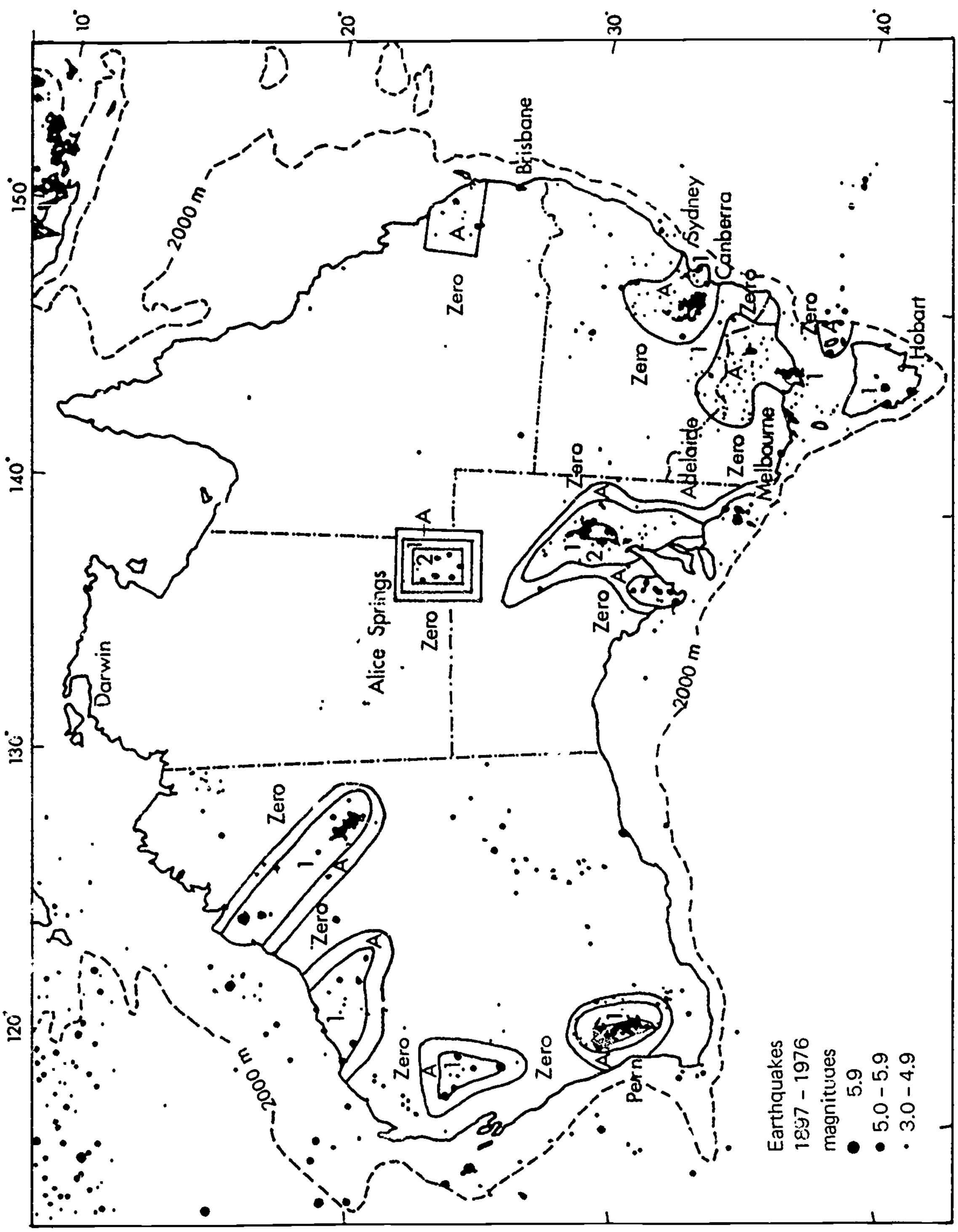
54



SEISMIC ZONE MAP OF AFGHANISTAN

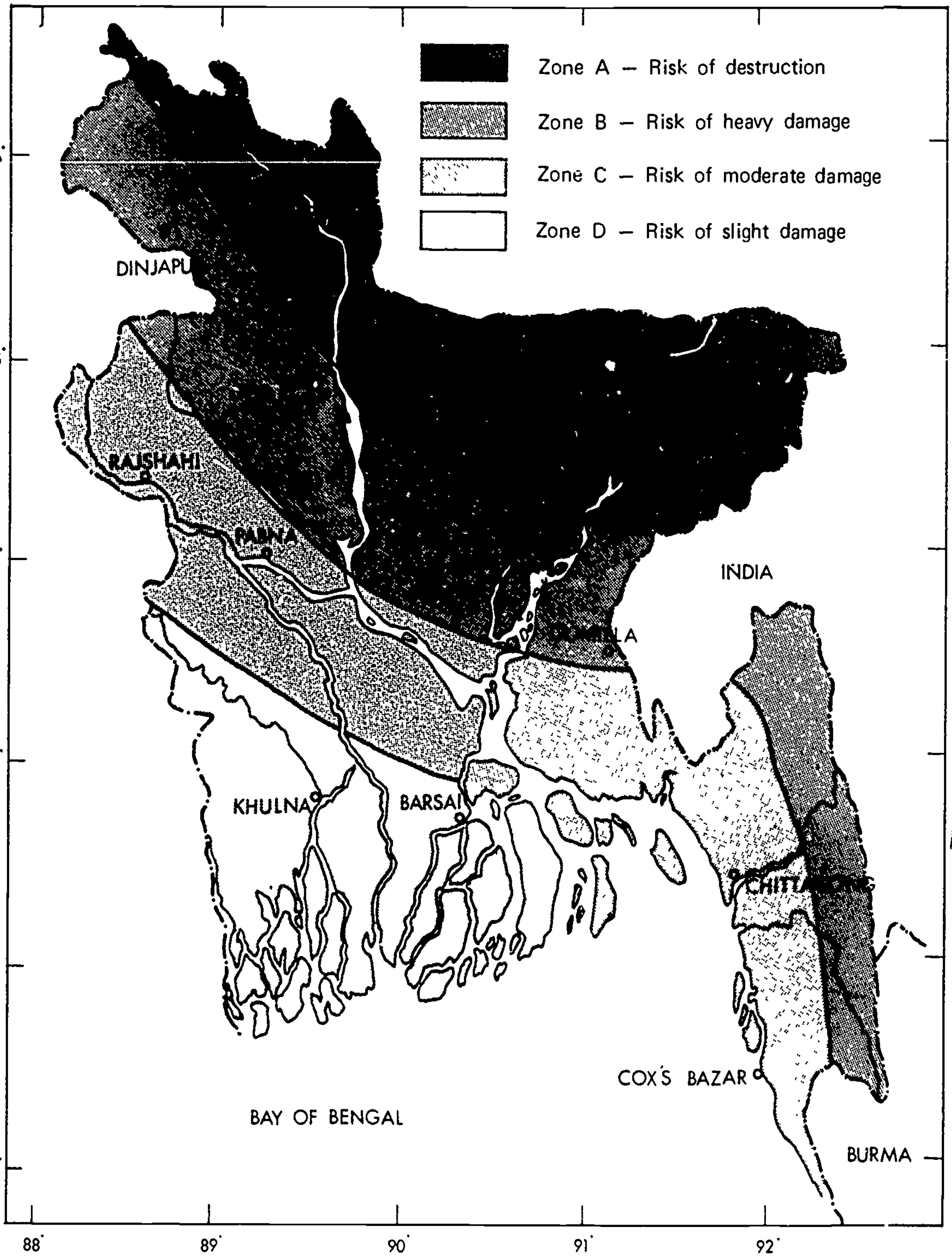
55

Source: Prepared by A.S. Arya



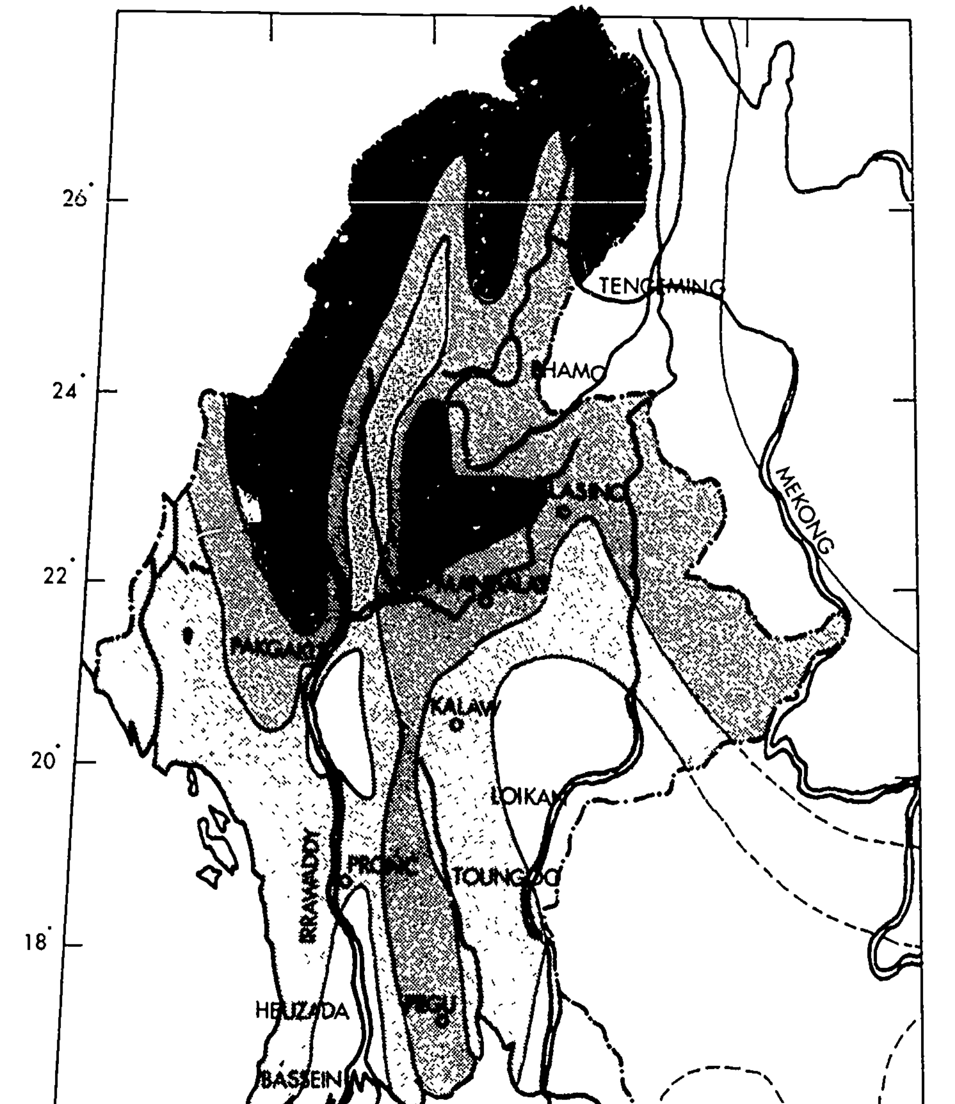
SEISMIC ZONE MAP OF AUSTRALIA

Source: *Earthquake resistant regulations; a world list* (Reference: A52121M)



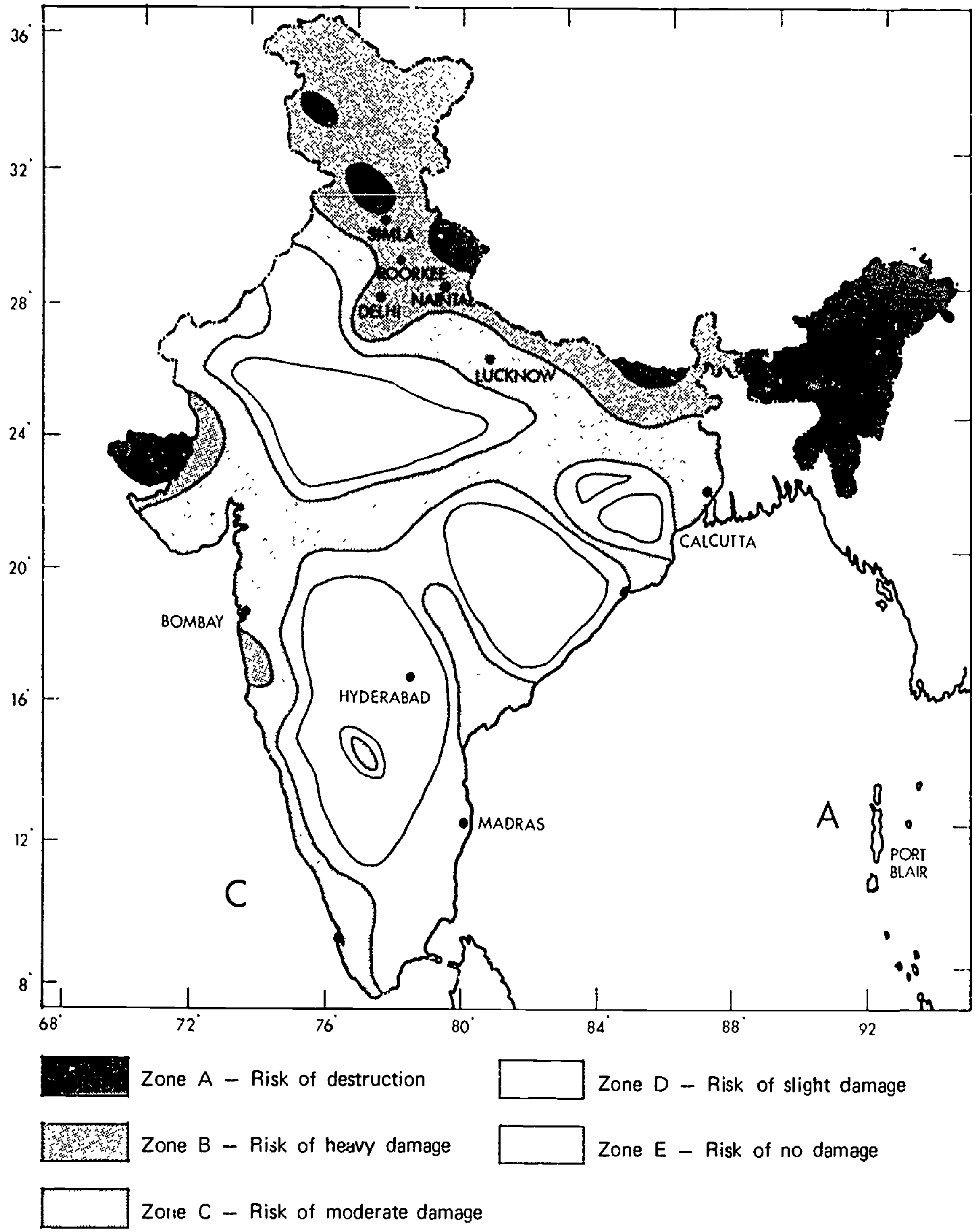
SEISMIC ZONE MAP OF BANGLADESH

Source: Preliminary may prepared by the Meteorological Department of Bangladesh (Ref. E277-14, Part I, p. 25)



SEISMIC ZONE MAP OF BURMA

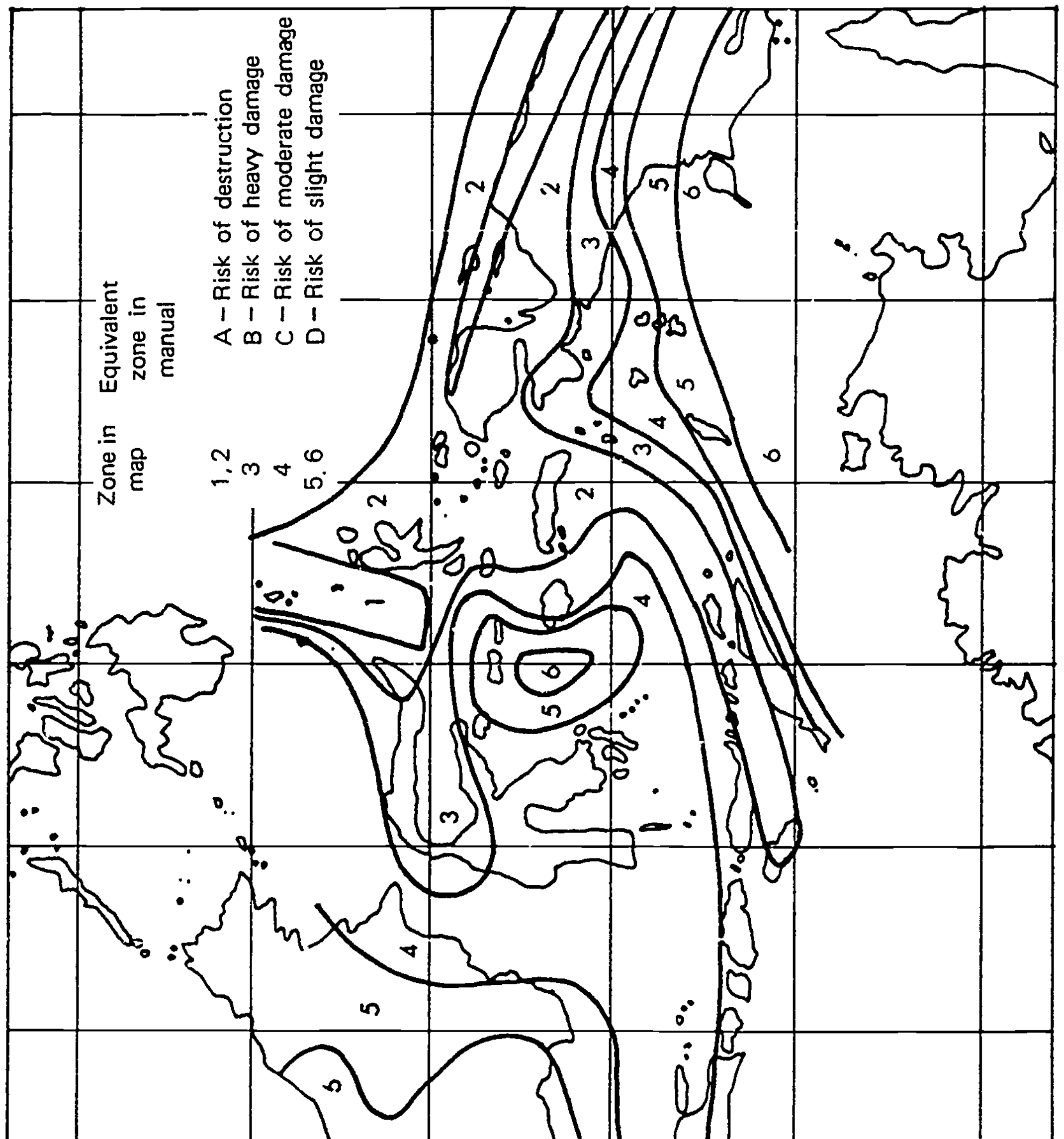
Source: Prepared by G.P. Gorshkov for the Meteorological Department of Burma



SEISMIC ZONE MAP OF INDIA

5)

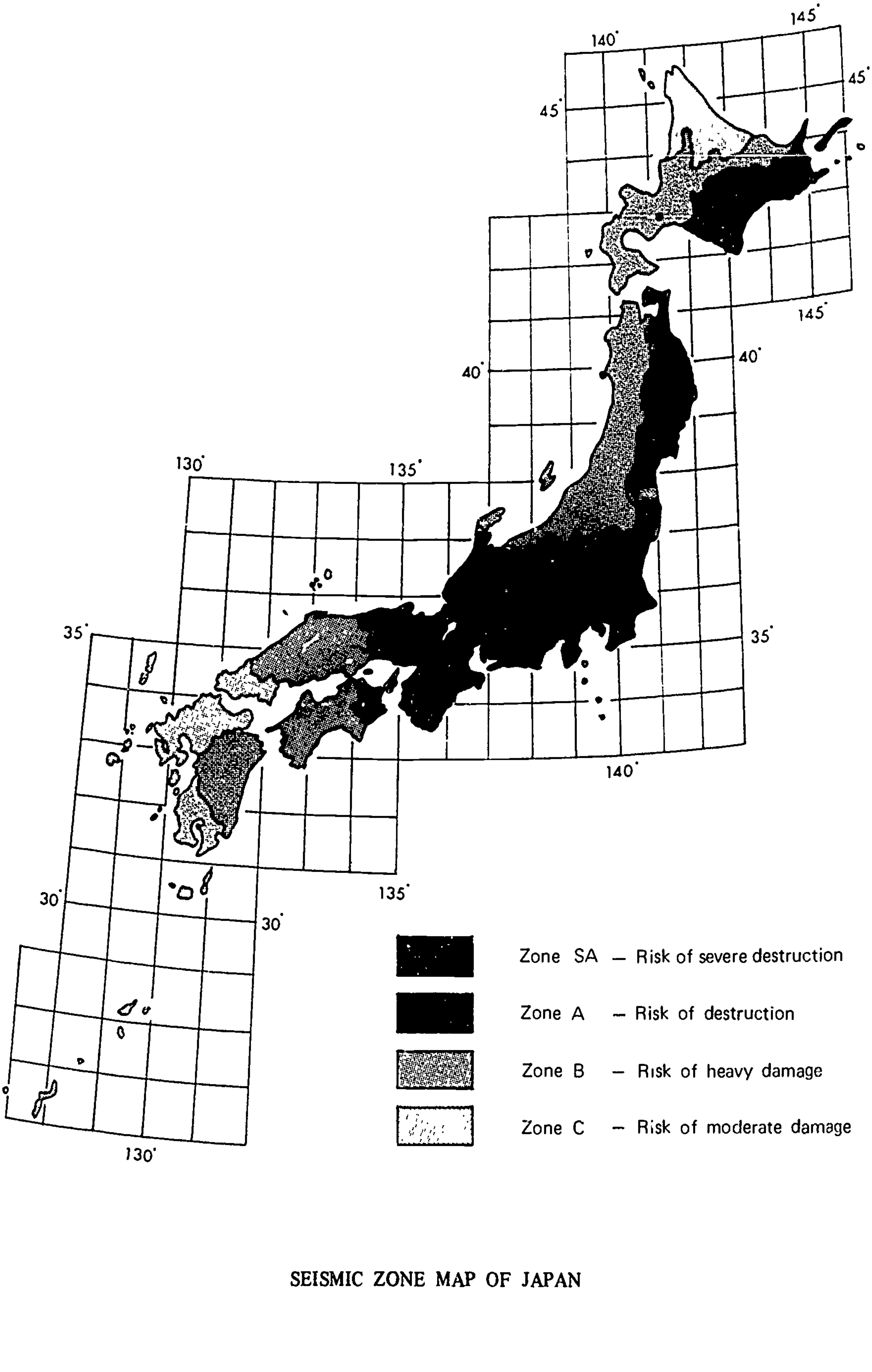
Source: *Earthquake resistant regulations; a world list (Reference: IS 1893 - 1975)*



SEISMIC ZONE MAY OF INDONESIA

Source: *Earthquake resistant regulations; a world list*

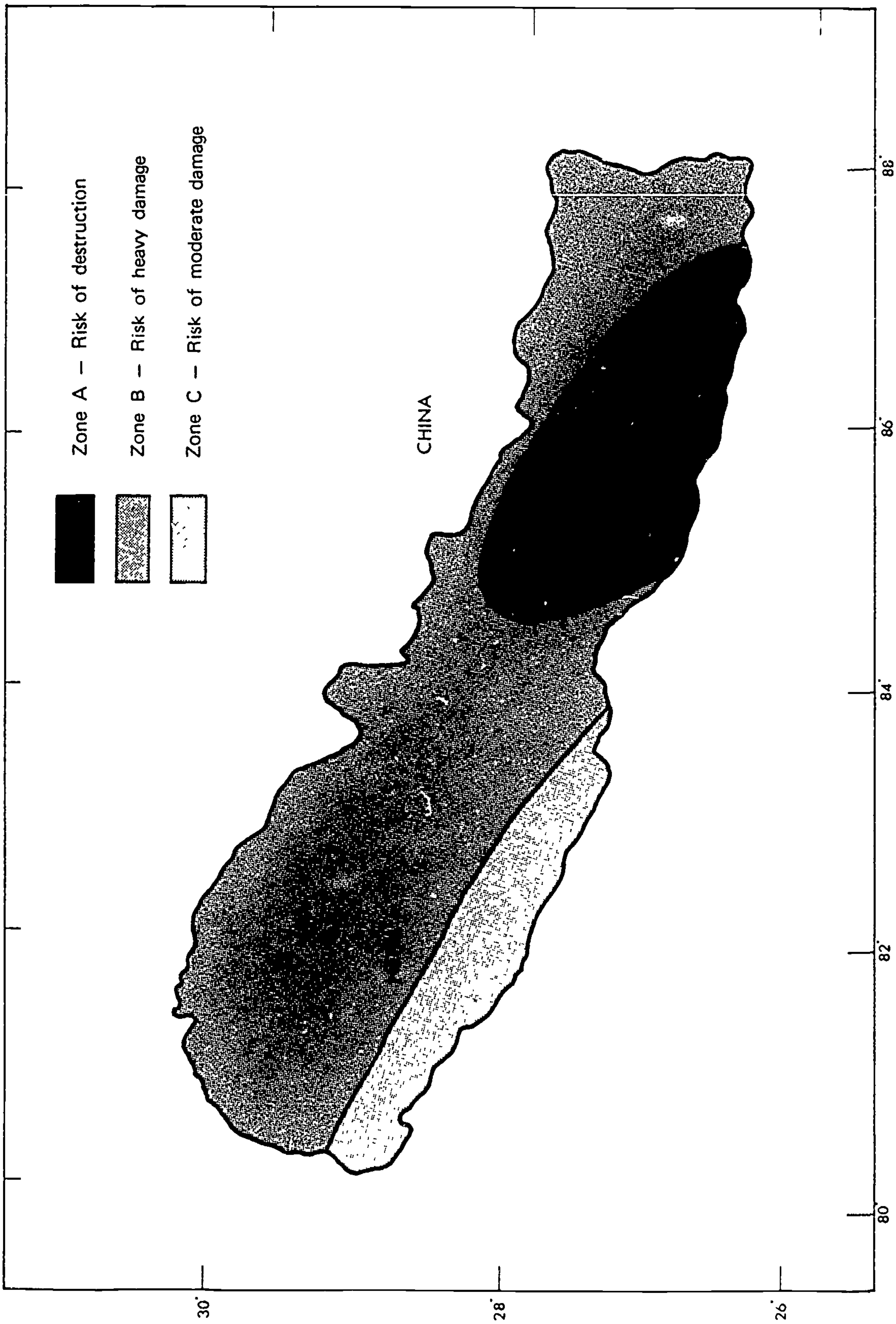
60



SEISMIC ZONE MAP OF JAPAN

Source: *Earthquake resistant regulations; a world list*

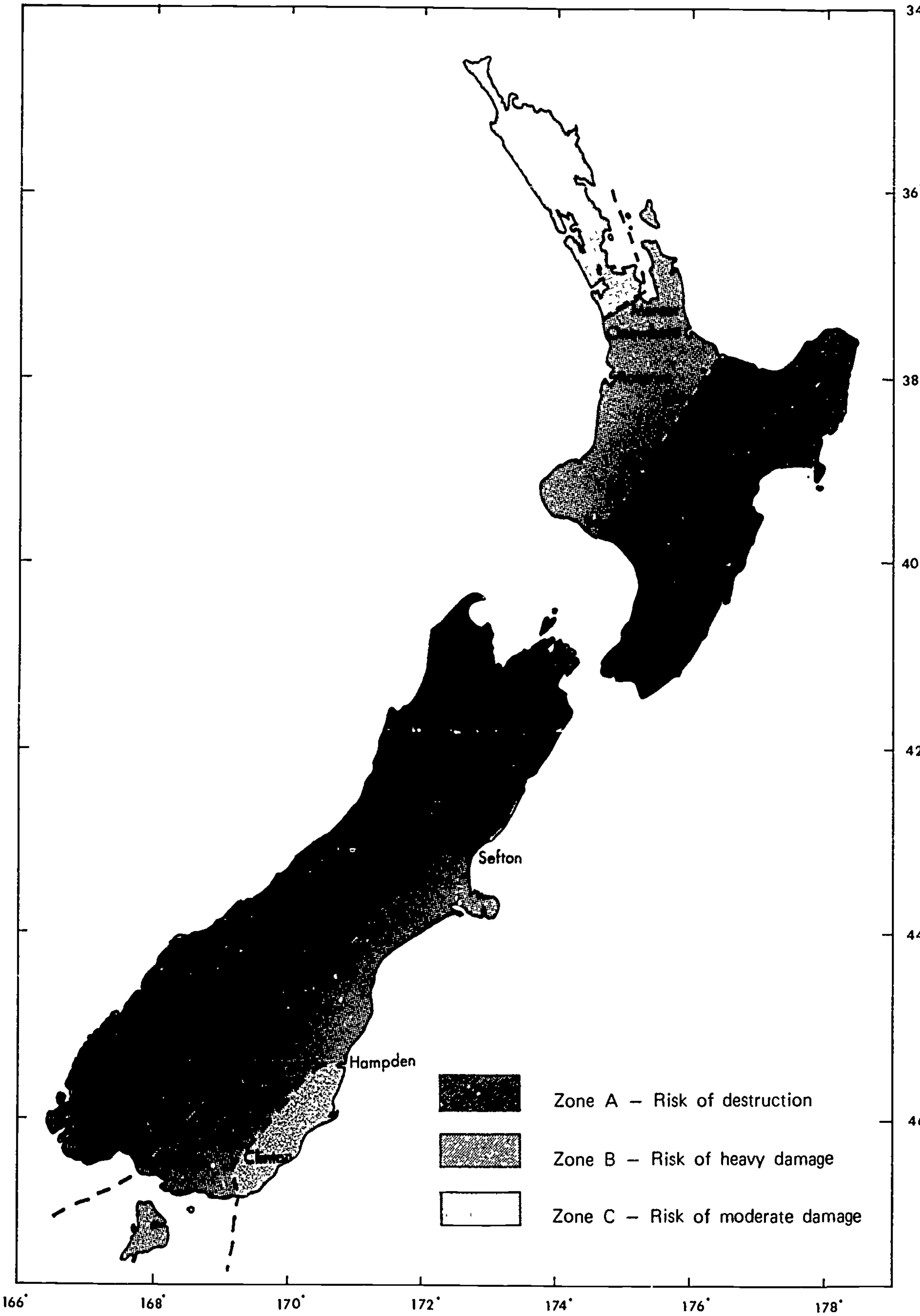
61



PRELIMINARY SEISMIC ZONE MAP OF NEPAL

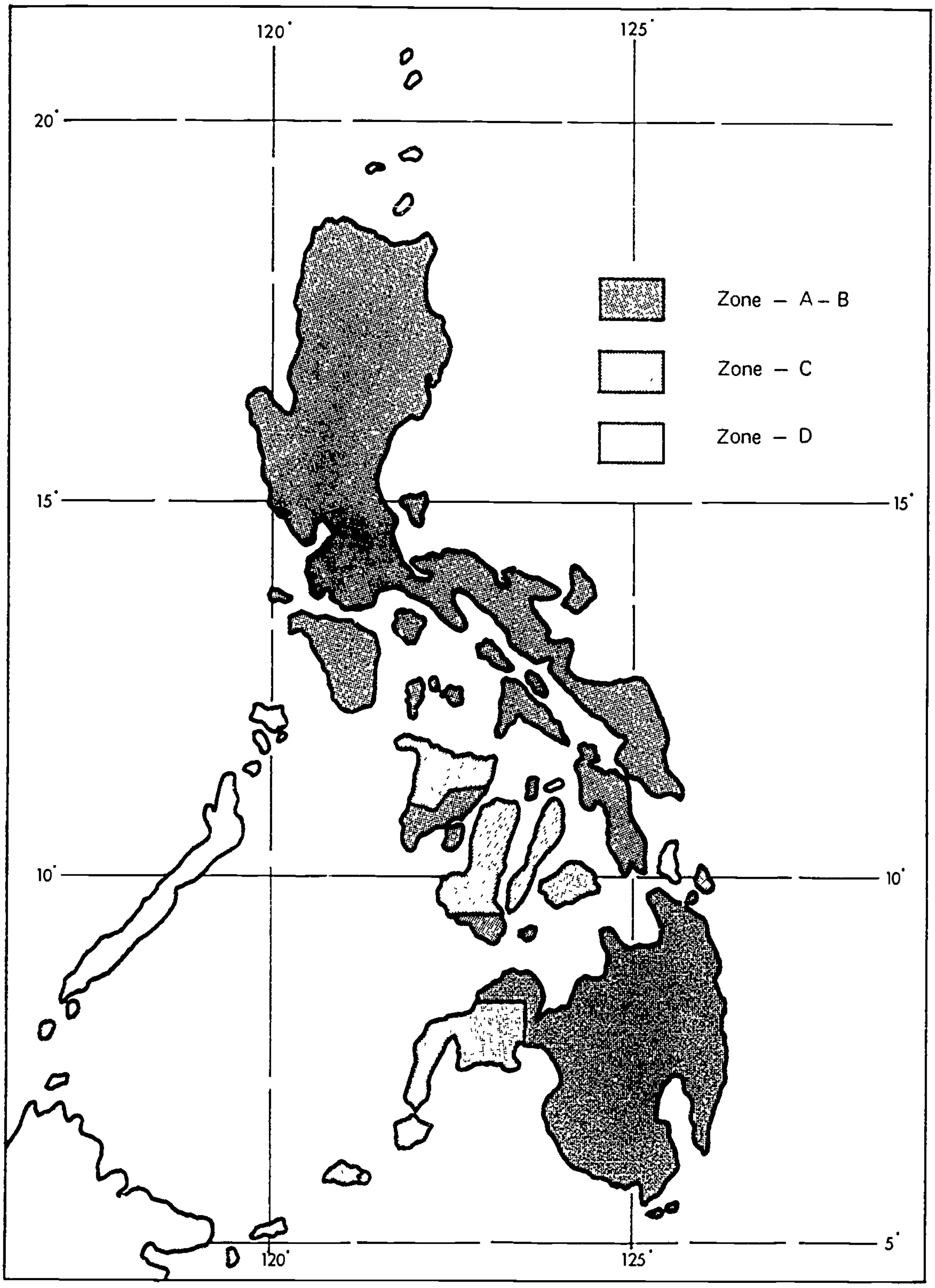
62

Source: Prepared by B.M. Pradhan of Tribhuvan University, Nepal



SEISMIC ZONE MAP OF NEW ZEALAND

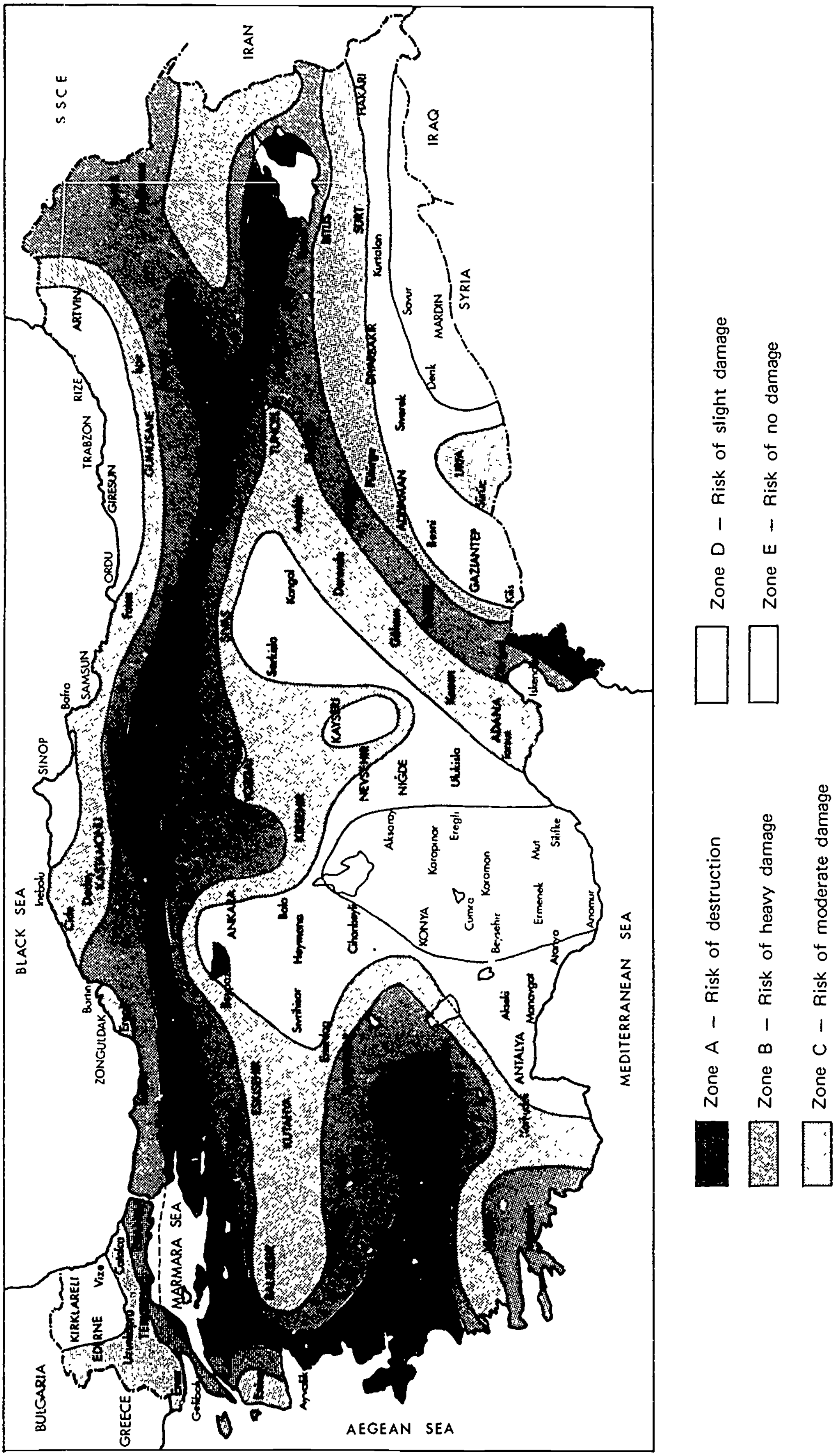
Source: *Earthquake resistant regulations; a world list.* (Reference: NZS 4203: 1976)



SEISMIC ZONE MAP OF PHILIPPINES

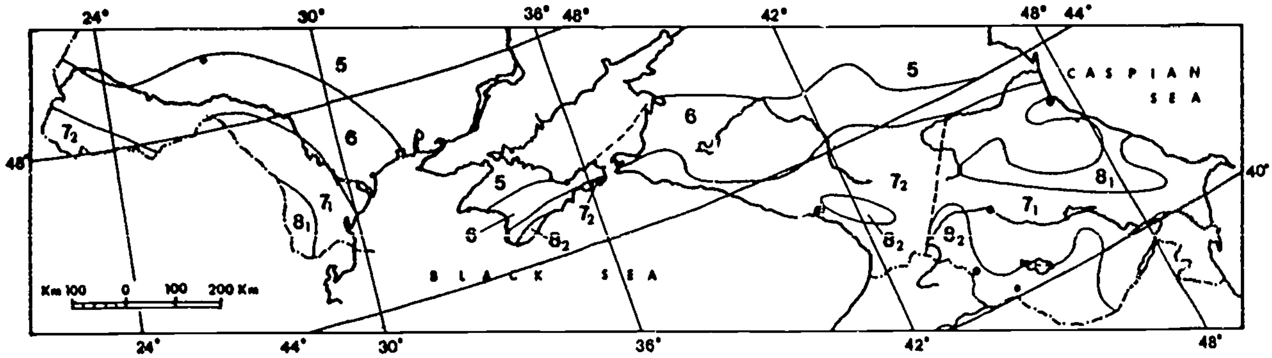
64

Source: *Earthquake resistant regulations. a world list.*

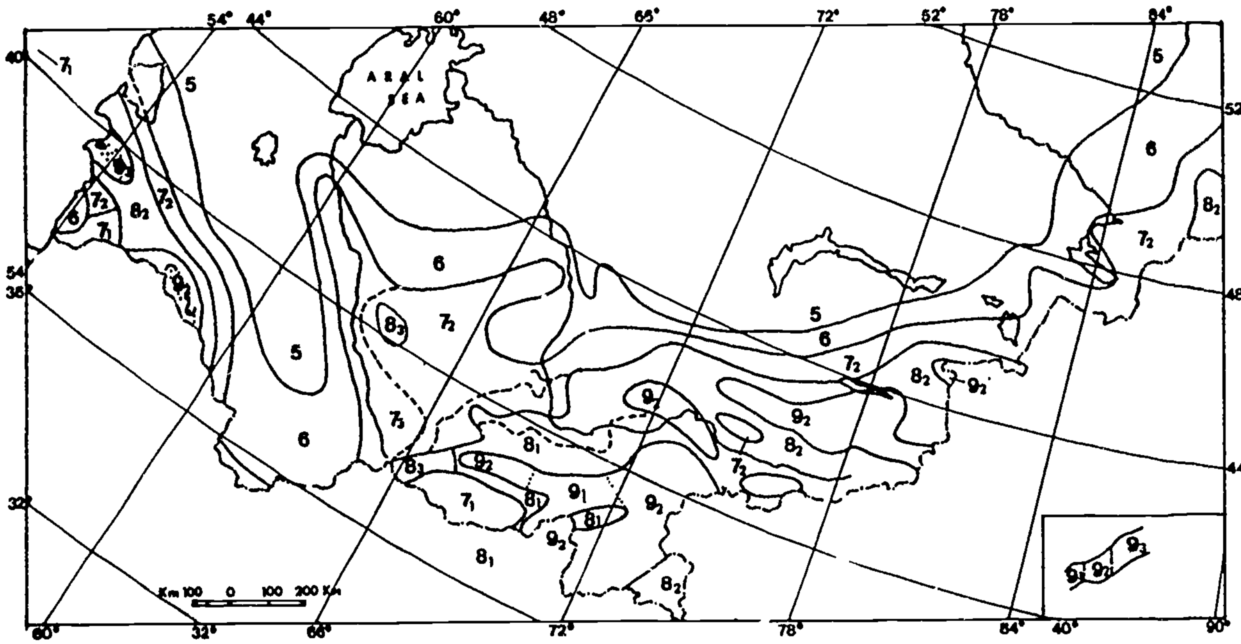


SEISMIC ZONE MAP OF TURKEY

Source: *Influence of natural disasters (earthquake) of educational facilities. School of research and training in earthquake engineering.* University of Roorkee, India.



MAP 1



MAP 2

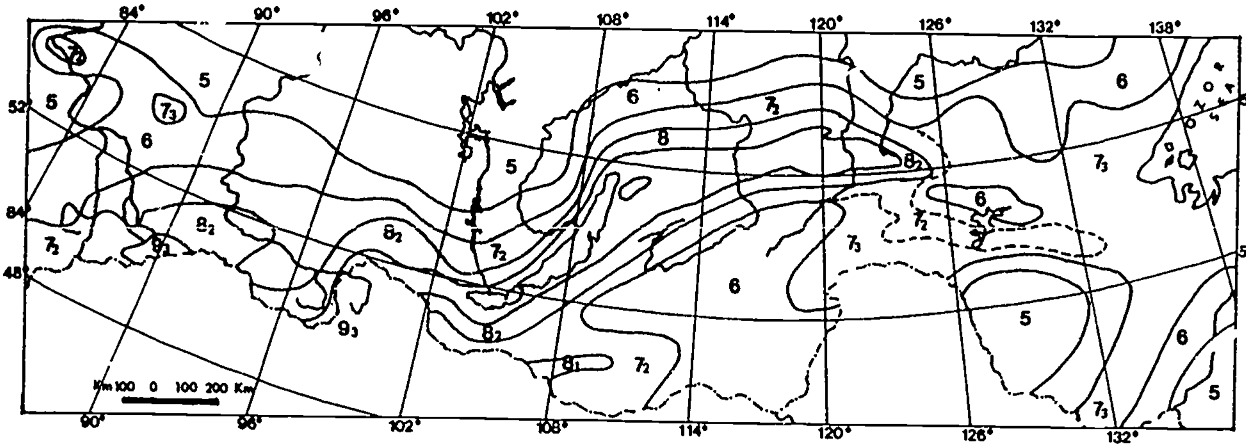
5 – lightest damage

9 – heaviest damage

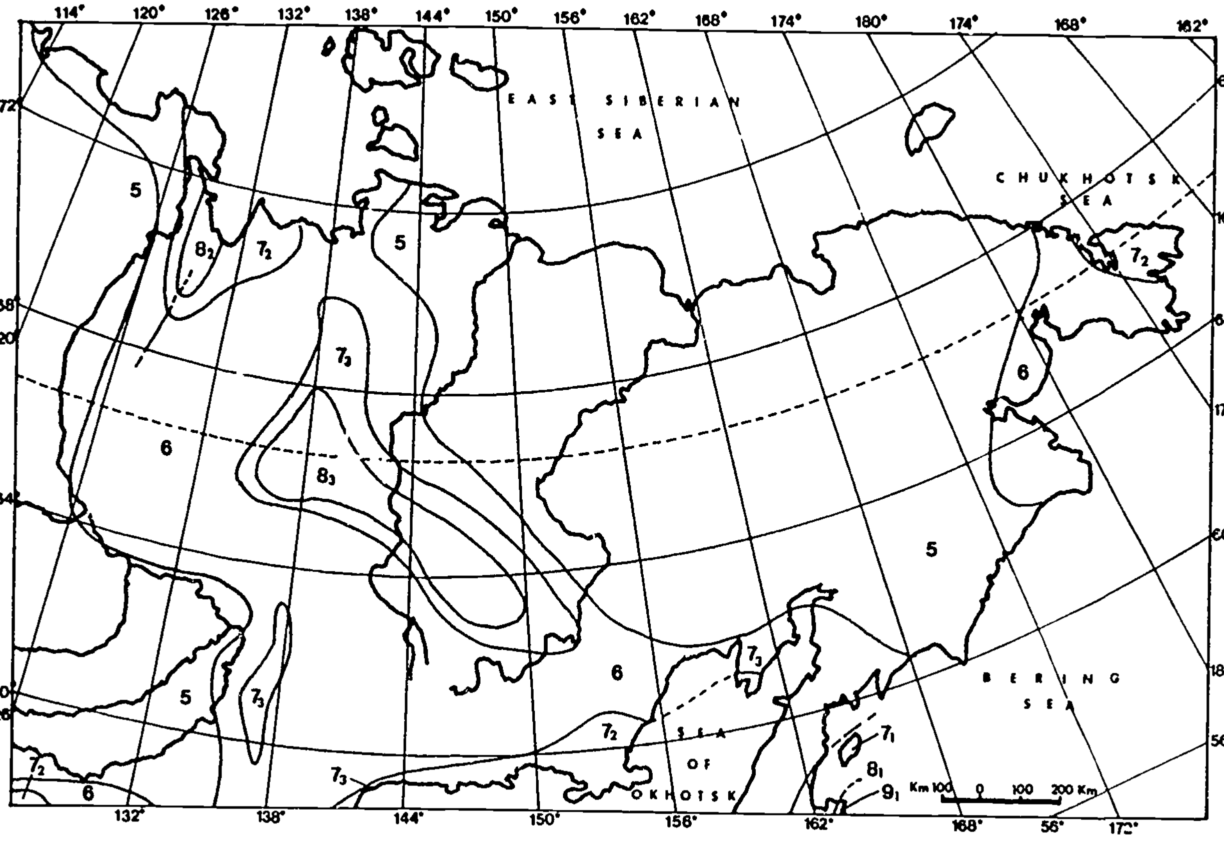
SEISMIC ZONE MAP OF USSR

60

Source: *Earthquake resistant regulation; a world list*


84° 90° 96° 102° 108° 114° 120° 126° 132° 138°
52° 84° 48° 56° 52°
Km 100 0 100 200 Km
90° 96° 102° 108° 114° 120° 126° 132°

MAP 3


114° 120° 126° 132° 138° 144° 150° 156° 162° 168° 174° 180° 174° 168° 162°
EAST SIBERIAN SEA
CHUKHOTSK SEA
BERING SEA
SEA OF OKHOTSK
72° 68° 120° 64° 60° 126°
68° 168° 64° 174° 60° 180° 56°
Km 100 0 100 200 Km
132° 138° 144° 150° 156° 162° 168° 56° 172°

MAP 4

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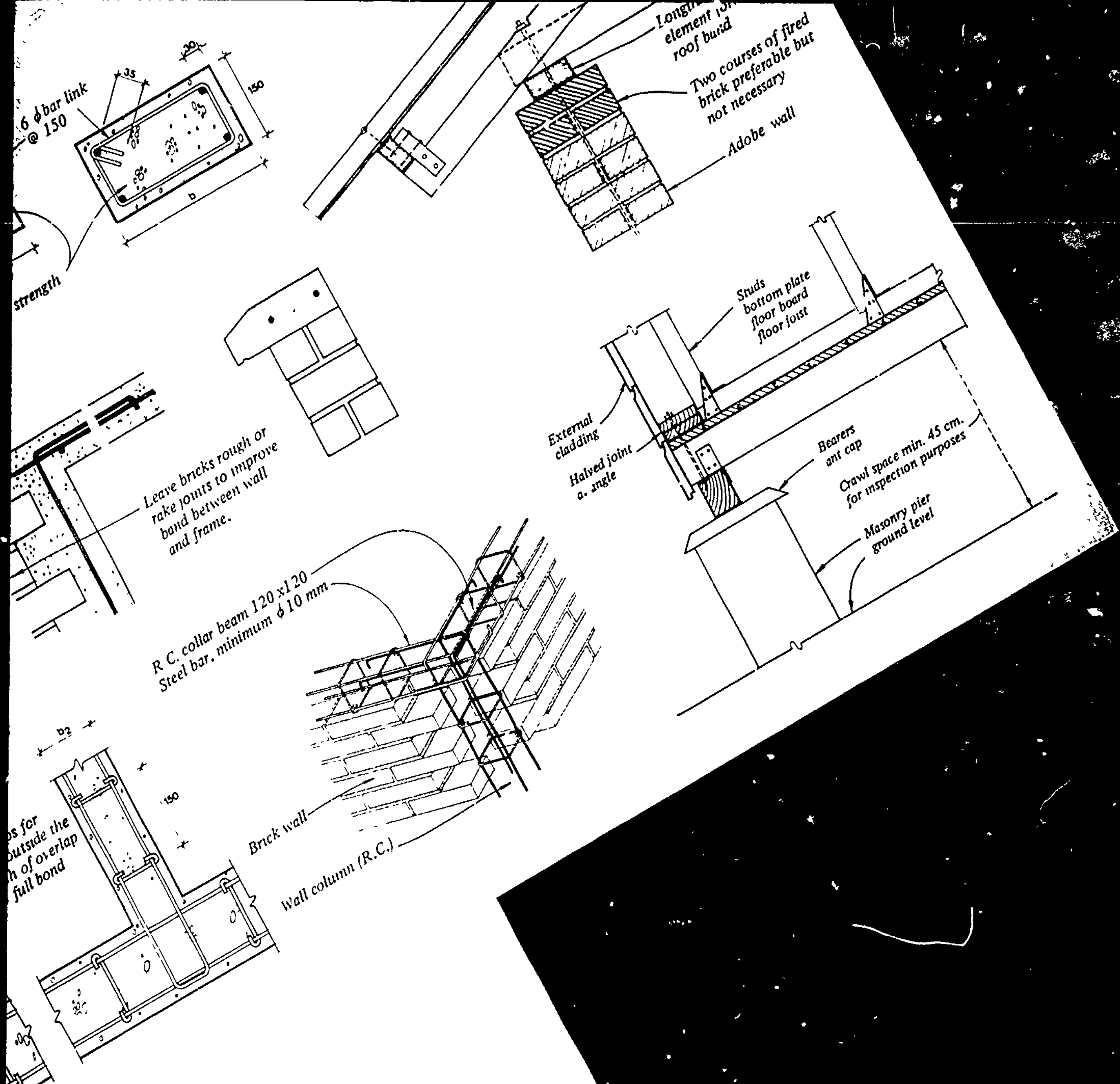

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