CHAPTER 9

Housing in Disaster Prone Areas

Introduction

Natural disasters like floods, earthquakes, cyclones, landslides, floods, a[...] lanches, volcanic eruptions and tsunamis, etc., cause great loss of hum[...] life and property. Human settlements in India, too, are often subject to[...] vagaries of natural disaster. Earthquakes, cyclones and floods are m[...] frequent natural calamities to hit the Indian subcontinent. In this chap[...] nature and extent of damage caused to structures by such calamities, [...] the precautionary measures to be adopted in the event of their occurre[...] to make ~~the structures,~~ especially the non-engineered buildings more re[...] tant to the devastating effects of natural catastrophes, have been discus[...] at length. In view of the large-scale damage of the non-engineered build[...] and houses belonging to the low strength masonry (LSM) category, in[...] earthquakes of recent past occurring in North Bihar (October 1988), [...]tarkashi (October 1991) and Killari, Maharashtra (September 1993), a w[...] up on repair and restoration of earthquake damaged non-enginee[...] buildings is also included in this chapter.

Earthquake

Earthquake is nature's one of the most catastrophic natural disasters kn[...] to the mankind since time immemorial. On an average, nearly 10[...] quakes stronger than magnitude 4 on Richter scale are observed every [...] across the globe. In the past, several devastating earthquakes in var[...] parts of the world have caused immense loss in terms of human lives [...] property. According to the Secretary General's report in the 43rd UN G[...]eral Assembly, more than 50% of deaths due to natural calamities in [...] world during the period 1900-87 has been due to earthquakes alo[...] (Table 1).

About two-thirds of India are known to lie in seismic zones of mo[...]ate to severe intensity. Conventionally, Himalayan-Naga Lushai reg[...] Indo-Gangetic plains, Western India and Kutch and Kathiawar regions [...] geologically unstable parts of the country, and some devastating ea[...]quakes of the world have occurred in these regions. The 1993 earthqu[...] in the Marathwada region (Latur and Osmanabad districts) of Maharash[...] which is known to be a stable zone from the point of view of tecto[...] movements within the earth, has however, posed a serious threat to [...] earlier demarcation of the seismic zones within the country. The Penins[...]

India where the above earthquake occurred had hitherto been branded as a seismically stable zone. Besides, a heavy casualty in terms of lost lives (about 10,000) and property in the Deccan plateau has necessitated the urgency to review the seismic map of India as indicated in IS : 1893-1984.

Table 1
Deaths in natural hazards (1900-87)
(after Bibl. 7—reproduced with permission from The Indian Concrete Journal, Bombay)

Natural hazard	Deaths, percent	Region of the world	Deaths, percent
Earthquakes	50.9	Asia, south and west pacific	85.5
Floods	29.7	Europe	7.0
Cyclonic storms	16.8	America	7.0
Volcanic eruptions	1.9	Africa	0.5
Tsunamis	0.5		
Landslides	0.1		

Earthquake Forecast

Despite tremendous advancements in the field of seismology, it is not yet possible for seismologists the world over to make any prediction regarding timing and placing of any future earthquake, unlike the cyclones. In recent years, there has been greater reliance on the Very Long Baseline Interferometry (VLBI) equipment for a possible solution in this direction. There has been yet another advancement in the field of earthquake forecast. Some French scientists have recently reported the viability of the Synthetic Aperture Radar (SAR) technique being used for earthquake prediction with fair degree of precision. They claim to have experimented the above technique for recording changes in ground motion produced by the 1992 earthquake in Landers, California. Their findings, as reported in the prestigeous science journal, *'Nature'* (Vol. 364, dt. 8.7.1993) provides an account of first ever actual mapping of earthquake done with the help of European Remote Sensing ('ERS-1') satellite.

North India faces grave threats of a devastating earthquake of magnitude eight or nine on Richter scale comparable to the Alaskan earthquake of 1964 which was one of the greatest ever measured, arising out of the possible release of the accumulating stresses along the plate margins of the Indian and Asian plates over past 300-700 years in the Central Himalayan region. The building up of stresses along the plate margins in the region is on account of persistent-thrust Indian plate is exerting on the Asian plate along the plate boundary. The Indian plate is believed to be moving at a speed of 2 cm a year, the same rate at which the two sides of the notorious San Andreas fault (crack) that runs for more than 1,000 km through California (USA), are sliding past each other. The Indian earthquake prediction is based on the recent studies carried out by the groups of American and Indian scientists, of the past Indian earthquakes and analysis of plate tectonics of the region backed up by satellite observation. The scientists have employed Global Positioning System (GPS) for undertaking study of the movement of tectonic plates in the Central Himalayan region. The GPS, a network of satellites and ground stations, was used to accurately detect movement of a set of points on the Indian and Asian tectonic plates between 1991 and 1994. In recent past, the Indian Remote Sensing satellite IRS-1B had observed ruptures on ground and formation of 'horst', a block of the earth's surface bounded by faults near Killari which is reckoned as the probable reason for the powerful earthquake that rocked Killari and its surrounding villages on September 30, 1993 leaving about 10,000 dead. In light of the above, the recent forecast of a catastrophic earthquake in the Central Himalayan region cannot be taken lightly.

Lack of sensitive earthquake monitoring systems such as 10 broad-band digital stations which are capable of recording even minutest tremors to a great degree of accuracy, and poor history of earthquake recording (compared to China's earliest recorded earthquakes dating back to 1500 BC, the earliest date of the Indian earthquakes goes back by 350 years only) have been inhibitory factors in proper monitoring and realistic forecast of Indian earthquakes in the past.

Validity of Plate Tectonics

The occurrence of earthquakes in zones designated as 'stable' from seismic considerations questions the validity of the well-established theory of Plate Tectonics according to which the potential earthquake belts globally are the zones along the margin of lithosphere plates which constitute earth's crust. The most well known of these are the Circum-Pacific belt, around the perimeter of the Pacific ocean and Alpine belt running across Central Asia to the Mediterranean Sea. India, particularly its Himalayan mountaneous region, forms a part of the Alpine belt which extends from Indonesia to Spain, through Myanmar, India, Middle East and Southern Europe. The Circum-Pacific belt has been the home of about two-thirds of world's largest earthquakes. In not too distant past (December 1989) there has been report of occurrence of earthquake in Eastern Australia, a zone which is well away from the edges of tectonic plates, as has also recently happened in seismically stable zone of Marathwada (Maharashtra) in September 1993. More recently, the devastating earthquake (of magnitude 7.2 on Richter scale) which rocked the Kansai (Kobe-Osaka) region of Japan claiming more than 5,400 human lives and destroying around 1,00,000 buildings (albeit many of them were pre-1980 construction, i.e. before stricter seismic regulations for design and construction of earthquake resistant houses were enforced in Japan) had struck in a region which was hitherto reckoned as one of the most quake-safe regions in Japan. The Kobe earthquake occurred not along the major inter-plate faults (cracks) where continent-size plates grind against one another but on intra-plate faults that spiderwel a single giant plate. These instances speak of uncertainties of occurrence of earthquakes. To be more precise, no place on the earth is free from the possibility of earthquake and necessiate review of the existing seismic map on global scale.

Damages to Houses

Of all the man-made structures, the collapse of buildings during an earthquake has been the largest contributor to the loss of lives and injuries to the people. Study of some catastrophic earthquakes which have occurred over the past two decades indicates that it is the non-engineered buildings constructed spontaneously and informally in traditional manner without resorting to any or little intervention by qualified architects and engineers, which bear the maximum brunt of this natural disaster (Table 2). This fact is supported by the collapse of a large number of unreinforced masonry houses in the past earthquakes of Guatemala (1976), Armenia (December 1988), Kangra (April 1986), North Bihar (August 1988), Uttarkashi (October 1991) and Killari, Maharashtra (September 1993) and Algeria (August 1994). In the Guatemala earthquake, more than 25,000 people had perished due to collapse of about 2,50,000 adobe houses. The Armenian earthquake had well exposed the vulnerability of precast constructions too. Massive death toll (about 25,000) in the said earthquake was attributed to collapse of hundreds of precast concrete and unreinforced masonry buildings. On the contrary, the experience of Loma Prieta earthquake (October 1989) suggests that the properly-designed earthquake reasistant structures very well stood the devastating effects of earthquake leading to much less casualty in terms of loss of human lives (only 300 compared to Armenia's 25,000) and damage to buildings. Ironically, the earthquake intensity on Richter Scale in the two earthquakes were nearly similar. Likewise, the casualty figure in case of the Kllari earthquake measuring 6.4 m on Richter scale had been around 10,000 while earthquake of almost similar intensity (magnitude 6.6) in the Northridge, earthquake (January, 1994) in California claimed only 57 lives.

Table 2
Building types for housing in India (1981 census)
(after Bibl. 7—reproduced with permission from The Indian Concrete Journal, Bombay)

Category (vide MSK)	Type of wall material	Rural, percent	Urban, percent	Total, percent	Destruction vulnerabilty in earthquake
A	Clay mud	37.1	4.0	41.1	High
	Unburnt bricks, adobe	6.2	1.4	7.6	High
	Stone (in mud)	8.1	2.0	10.1	High
B	Fired Bricks	13.4	13.0	26.4	Medium
C	Wood	0.7	0.4	1.1	Low
	Cement concrete	0.3	1.4	1.7	Low
Others	Metal sheets	0.1	0.4	0.5	Low
	Other (grass, reeds etc.)	10.0	1.7	11.7	Low

The safety of non-engineered buildings from the devastating effects of earthquakes warrants serious consideration in view of the fact that more than 90% of the population in zones prone to earthquake in the world live and work in such buildings and most losses of lives during earthquakes have occurred due to their collapse. It is unfortunate that risk to life in su belts is increasing instead of decreasing on account of rising populati abject poverty of the people, scarcity of modern building materials, v cement and steel, lack and awareness and skill. The increasing magnitu of seismic risk in earthquake prone areas, especially in the developing co tries, could be gauged from the fact that number of dwelling units a other related small-scale constructions might double over the next 20 years due to the population explosion in most of the developing count including India. The large scale loss of lives and property in the re Maharashtra earthquake of relatively moderate intensity (measuring 6.4 the Richter Scale) is also attributed to poverty, ignorance large popula and non-engineered constructions in the quake hit areas of Latur and O manabad districts.

Traditional Housing in Disaster Prone Areas

In Jammu and Kashmir, which lies in a zone of severe seismic intensit age-old 'dhaji diwari' technique is adopted to minimise the destructi fects of earthquakes. This method of construction uses a timber frame struction with diagonal bracing in the body of mud walls, which make structure more rigid and helps give better performance in the eve earthquakes. In Assam, also in a severe-intensity earthquake zone, the tem of 'ikra' walling (Fig. 9.1) is adopted which comprises of timber-f construction with panels of reed or split bamboo with mud plaster on side. Mud houses with thatched or bamboo matting walls and thatched on account of their light weight and flexibility generally withstood earthquake forces without any damage during the 1988 North Bihar ea quake.

The colossal destruction of houses in the moderate earthquakes of lari (September 1993) and Uttarkashi (October 1991) was due to

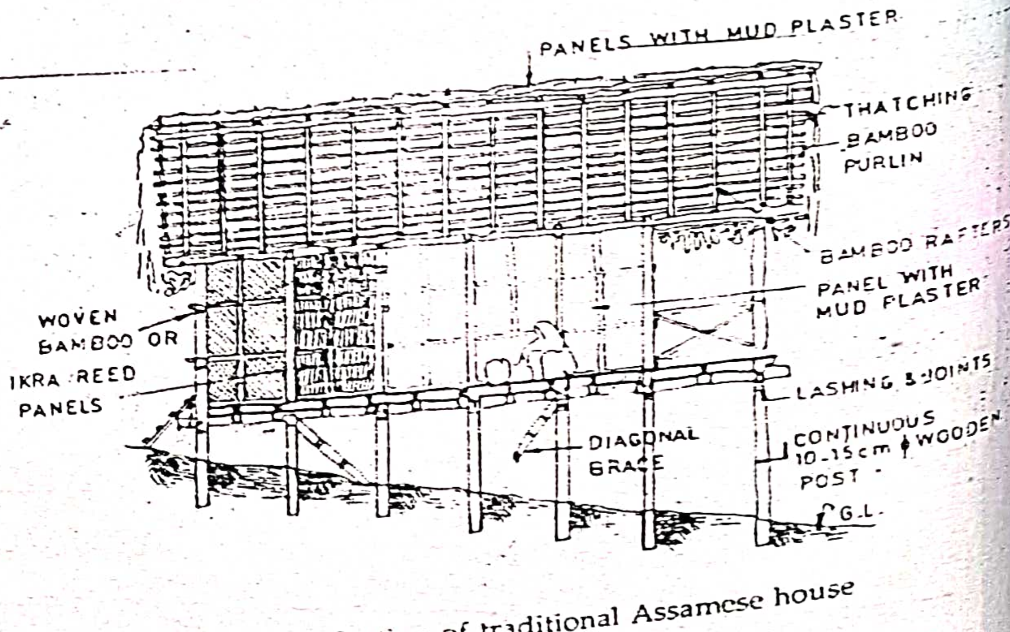

Fig. 9.1 Section of traditional Assamese house

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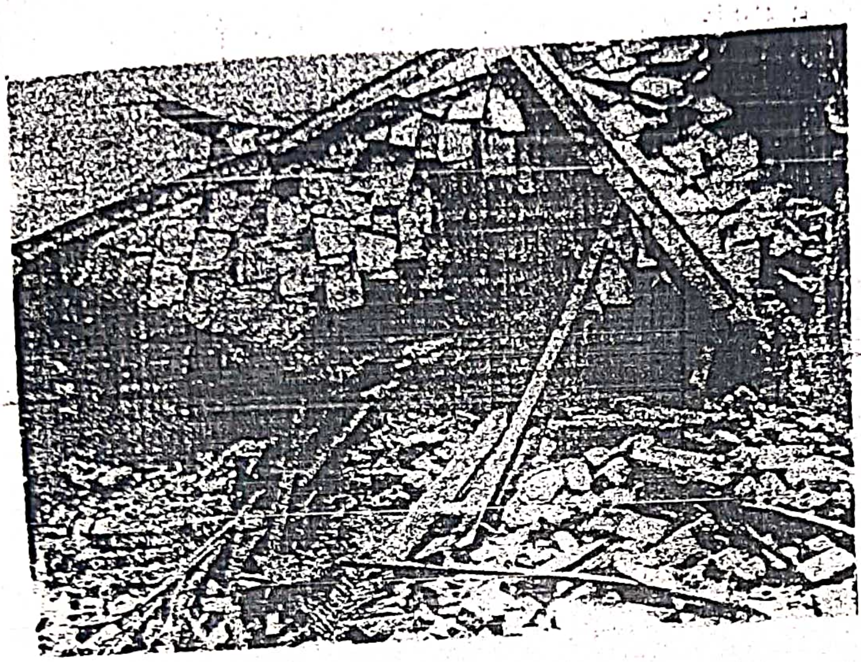


Fig. 9.2 A view of completely damaged stone masonry house with slate tiles as roofing material

iality and weakness of the stone masonry construction (Fig. 9.2) using, in ost cases, non-plastic soil mortar. The tragedy of the present times is that e traditional earthquake resistant constructions like 'dhaji-diwari' in mmu and Kashmir or Himachal Pradesh and the 'ikra'-wall construction most seismic region of the north-eastern states has gone into disuse in vour of the more damage-prone stone and brick constructions.

ypes of Damages and Failures of Non-Engineered Buildings

lasonry Buildings

iduction of tensile and shear stresses in walls of masonry buildings is the rimary cause of different types of damage suffered by such building in he event of earthquakes. The typical damages and modes of failure are riefly described below:

Typical Damages

Non-Structural Damage

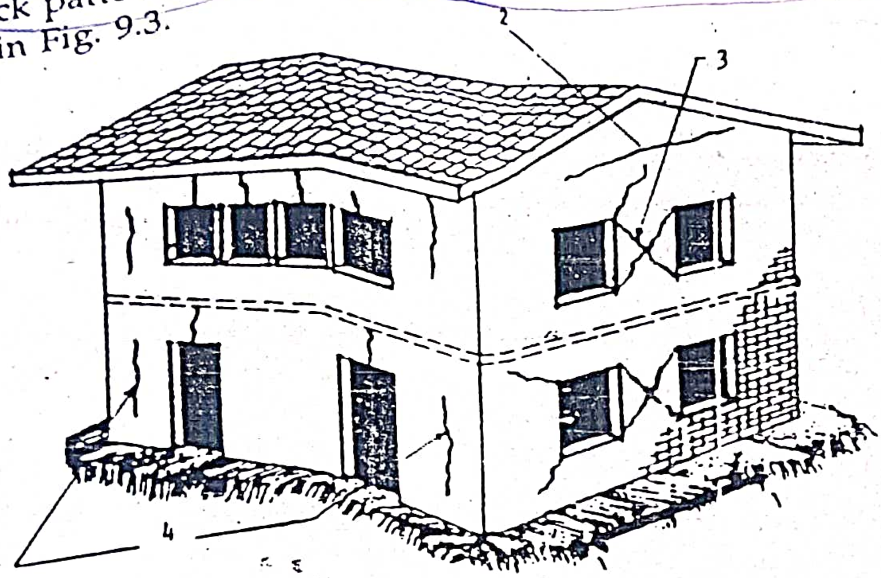
The non-structural damage is the one due to which the strength and stability of the building is not affected. Such damage occurs very frequently even under moderate intensities of earthquakes. Cracking and overturning of masonry parapets; large cantilever cornices and balconies; failing of plaster from walls and ceiling; cracking and overturning of partition walls; cracking and falling of ceilings; and cracking of glass panes are some common examples of non-structural damage.

Bam.

Damage and Failure of Bearing Walls

i) Failure due to racking shear is characterised by diagonal cracks which could be due to diagonal compression or diagonal tension.

ii) Crack patterns in load bearing walls due to bending and shear are illustrated in Fig. 9.3.



1-1 Earthquake motion, 2-Horizontal crack in gables, 3-Diagonal cracks due to shear. 4-Cracks due to bending of wall.

Fig. 9.3 Cracking in bearing wall building due to bending and shear (after Bibl. 152).

iii) Unreinforced gable end masonry walls are very unstable and strutting action of purlin's imposes additional force to cause their failure. Horizontal bending tension cracks are caused in the gables.

iv) Damage in unsymmetrical building occurs due to torsion and warping in an earthquake. This mode failure causes excessives cracking due to shear in all walls. Larger damage occurs near the corner of the building.

v) Arches across the openings in walls are often badly cracked since the arches tend to lose their end thrust under in-plane shaking of walls.

Modes of Failure

Failure of Ground

i) *Inadequate depth of foundation*: Shallow foundations deteriorate as a result of weathering and consequently become weak for earthquake resistance.

ii) *Differential settlement of foundation*: During severe ground shaking, liquefaction of loose water-saturated sands and differential compaction of weak loose soils occurs which leads to excessive cracking and tilting of building which may even collapse completely.

iii) *Sliding of slopes*: Earthquakes cause sliding failures in man-made as well as natural hill slopes and any buildings resting on such slopes have a danger of complete disastrous disintegration.

Failure of Roofs and Floors

Improperly tied roofing material is dislodged due to inertia forces acting on the roof. This mode of failure is typical of sloping roofs, particularly when slates, clay tiles, etc., are used as roofing material. Brittle material like asbestos cement may be broken if the trusses and sheeting purlins are not properly braced together.

Causes of Damages in Masonry Buildings

The following are the main weaknesses in the materials and unreinforced masonry constructions and other reasons for the extensive damage of such buildings (Fig. 9.4).

- Heavy weight and very stiff buildings, attracting large seismic interia forces
- Very low tensile strength, particularly with poor mortars
- Low shear strength, particularly with poor mortars
- Brittle behaviour in tension as well as compression
- Weak connection between wall and wall
- Weak connection between roof and wall
- Stress concentration at corners of windows and doors
- Overall unsymmetry in plan and elevation of building
- Unsymmetry due to imbalance in the sizes and positions of openings in the walls
- Defects in construction such as use of substandard materials, unfilled joints between bricks, not-plumb walls, improper bonding between walls at right angles etc.

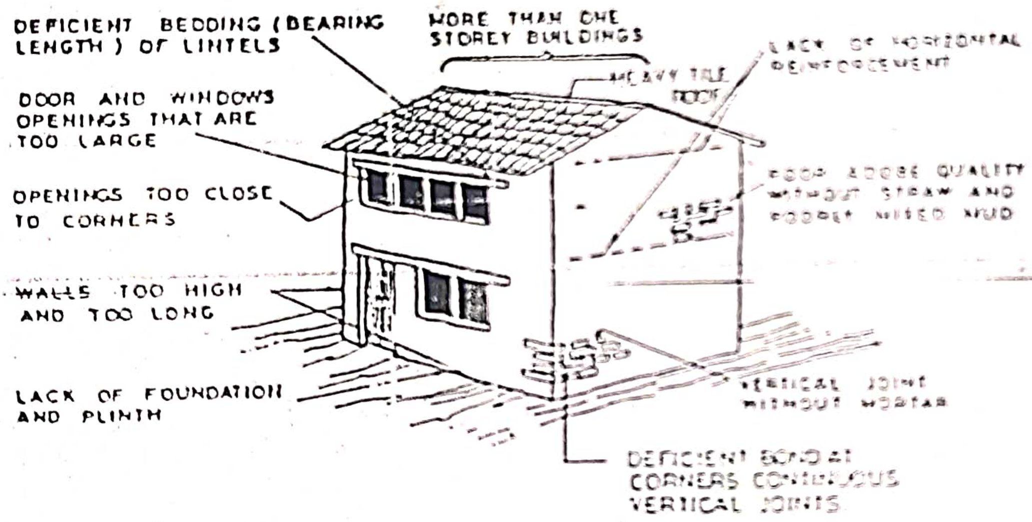


Fig. 9.4 Graphic summary of causes of failure (after Bibl. 152)

Repair and Restoration of Earthquake Damaged Non-Engineered Buildings

Concepts of Repair and Restoration

The methods of repair and restoration depend largely on factors like structural scheme, materials used in construction of building, feasible technology for repair and restoration and the availability of funds. Some methods like

'Splints and bandage,' wire mesh with gunite, 'epoxy injection,' etc., have been tried out for repair and strengthening of earthquake damaged buildings in some countries.

The underlying concepts in repair and restoration of earthquake-damaged buildings are described as below:

Repairs

The main purpose of carrying out repairs of damaged building is to bring back the architectural shape of the building dealing with non-structural components so that all services could start working and the functional utility of the building is restored quickly. Repair does not improve the structural strength of the building, and can be very deceptive for meeting the strength requirements of the future earthquake. The actions involved in repair include the following:

a) Patching up of defects such as cracks and fall of plaster
b) Repairing doors, windows, replacement of glass panes
c) Checking and repairing electric wiring
d) Checking and repairing gas pipes, water pipes and plumbing services
e) Re-building non-structural walls, smoke chimneys, boundary walls, etc.
f) Replastering of walls as required
g) Rearranging disturbed roofing tiles
h) Relaying cracked flooring ~~at ground level~~
i) Redecoration-white washing, painting, etc.

Restoration

This activity envisages restoration of the original structural strength of the building by appropriate treatment of the damaged structural components of the building such as load bearing walls, beams, columns, etc. It may involve cutting portions of the elements and rebuilding them or simply adding more structural material so that the original strength is more or less restored. The process may involve inserting temporary supports, underpinning, etc. In ~~most~~ instances, the relative cost of retrofitting to reconstruction cost determines the decision regarding undertaking any restoration work. As a thumb rule, if the cost of repair, restoration and strengthening is less than about 50% of the reconstruction cost, retrofitting is the preferred choice.

Some of the techniques of restoration are stated as below:

a) Removal of portions of cracked masonry walls and piers and rebuilding them in richer mortar. Use of non-shrinking mortar will be preferred.
b) Addition of reinforcing mesh on both faces of the cracked wall, holding it to the wall through spikes or bolts and then covering it suitably. Several alternatives have been used.
c) Injecting epoxy like material, which is strong in tension, into the cracks in walls columns, beams etc.

Repair Materials

The most common materials for damage repair works of various types are cement and steel. In many situations non-shrinking cement or an admixure like aluminium powder in the ordinary portland cement will be admissible. Steel may be required in many forms, like bolts, rods, angles, channels, expanded metal and welded wire fabric. Wood and bamboo are the most common materials for providing temporary supports and scaffolding etc., and will be required in the form of rounds, sleepers, planks, etc. Besides, special materials and techniques are available for best results in the repair and strengthening operations. They are described below:

Epoxy Resins

Epoxy resins are excellent binding agents with high tensile strength. There are chemical preparations the compositions of which can be changed as per requirements. The expoxy components are mixed just prior to application. The product is of low viscosity and can be injected in small cracks too.

The higher viscosity epoxy resin can be used for surface coating or filling larger cracks or holes. The epoxy mixture strength is dependent upon the temperature of curing (lower strength for higher temp.) and method of application.

Epoxy Mortar

For larger void spaces, it is possible to combine the epoxy resins of either low viscosity or higher viscosity, with sand aggregate to form epoxy mortar. Epoxy mortar mixture has higher compressive strength, higher tensile strength and a lower modulus of elasticity than Portland cement concrete.

Thus the mortar is not a stiff material for replacing reinforce concrete. It is also reported that epoxy is a combustible material.

Therefore, it is not used alone. The sand aggregate mixed to form the epoxy mortar provides a heat sink for heat generated and provides increased modulus of elasticity as well.

Gypsum Cement Mortar

It has got rather limited use for structural application. It has the lowest strength at failure among these three materials.

Quick-setting Cement Mortar

This material is patented and was originally developed to be us as a repair material for reinforced concrete floors adjacent to steel blast furnaces. It is a non-hydrous magnesium phosphate cement with two components, a liquid and a dry, which can be mixed in a manner similar to Portland cement concrete.

Gunite

Gunite, also called shotcrete, is pneumatically applied on concrete. Two different methods of operation are employed. In the first method the wet concrete mix, usually Ready Mix, is pumped through a hose to a nozzle at the point of application. Compressed air is injected near the nozzle forming a spray that is directed against the surface. Concrete applied by this method is termed 'Shotcrete' by the equipment manufacturers and is called wet mix. In the second method, the concrete may also be Ready Mix, except ... delivered dry on the job. It is then placed in a gunite machine from which it is delivered through a hose by compressed air to a nozzle at forming a spray. Concrete placed by this method is termed 'gunite' by the equipment manufacturers and is called dry mix.

Gunite is widely used for strengthening or repairing concrete and masonry structures. Experience has shown that gunite bonds well with brick walls in the repair of masonry buildings. In fact, gunite bonds to almost any surface-hard, soft, wet or dry, and even to polished steel. Gunite is preferred to shotcrete because of its better bonding capability on account of higher velocity of concrete emerging out of the nozzle.

Restoration Techniques

While considering restoration work, it is important to realise that even fine cracks in load bearing members, which are unreinforced, like masonry and plain concrete reduce their resistance very largely. Therefore, all cracks must be located and marked carefully and the critical ones fully repaired either by injecting strong cement or chemical grout or by providing external bandage. The techniques are described below along with other restoration measures.

Small Cracks

If the cracks are reasonably small (opening width - 0.075 cm), the technique to restore the original tensile strength of the cracked element is by pressure injection of epoxy. The procedure is as follows (Fig. 9.5 and 9.6).

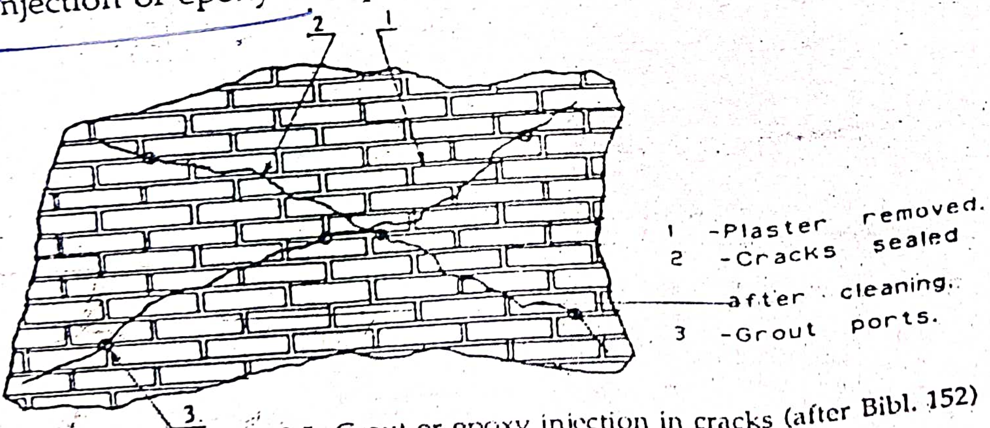


Fig. 9.5 Grout or epoxy injection in cracks (after Bibl. 152)

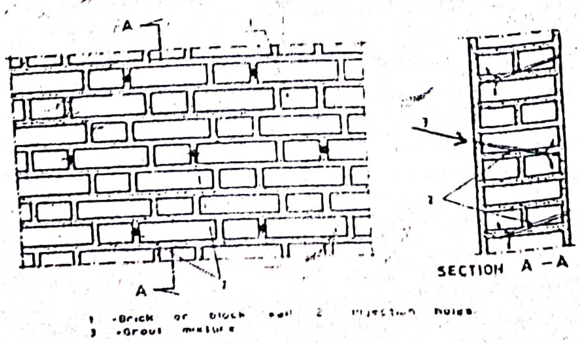


Fig. 9.6 Grout or epoxy injection in existing weak walls (after Bibl. 152)

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 member and are secured in place with an epoxy sealant. The centre-to-centre spacing of these ports may be approximately equal to the thickness of the element. After the sealant has cured, a low viscosity epoxy resin is injected into one port at a time beginning at the lowest part of the crack in case it is vertical or at one end of the crack in case it is horizontal.

The resin is injected till it is seen flowing from the opposite sides of the member at the corresponding port or from the next higher port on the same side of member. The injection port should be closed at this stage and injection equipment moved to the next port and so on.

The smaller the crack, higher is the pressure or more closely spaced should be the crack, higher is the pressure or more closely spaced should be the ports so as to obtain complete penetration of the epoxy material throughout the depth and width of member. Larger cracks will permit larger port spacing, depending upon width of the member. This technique is appropriate for all types of structural elements-beams, columns, walls and floor units in masonry as well as concrete structures. Two items should however, be taken care of in such type of repair.

a) In the case of loss of bond between reinforcing bar and concrete, if the concrete adjacent to the bar has been pulverised to a very fine powder, this powder will dam the epoxy from saturating the region. So it should be cleaned properly by air or water pressure prior to injection of epoxy.

b) It is earlier stated that cracks smaller than about 0.75 mm may be difficult to pressure inject. So cracks smaller than this should not be repaired by this method.

Large Cracks and Crushed Concrete

For cracks wider than about 6 mm or for regions in which the concrete or masonry has crushed, a treatment other than injection is suggested. The following procedure may be adopted.

a) The loose material is removed and replaced with any of the materials mentioned earlier, i.e., expansive cement mortar, quick setting cement or typsum cement mortar.

b) In the case of damage to walls and floor diaphragms, steel mesh could be provided on the outside of the surface and nailed or bolted to the wall. Then it may be covered with plaster or micro-concrete.

Fractured, Excessively Yielded and Buckled Reinforcement

In the case of severely damaged reinforced concrete member, it is possible that the reinforcement would have buckled, or elongated or excessive yielding may have occurred. This element can be repaired by replacing the old portion of steel with new steel using but welding or lap welding.

Splicing by overlapping will be risky if repair has to be made without removal of the existing steel, the best approach would depend upon the space available in the original member. Additional stirrup ties are to be added in the damaged portion before concreting so as to confine the concrete and enclose the longitudinal bars to prevent their buckling in future.

In some cases it may be necessary to anchor additional steel into existing concrete. A common technique for providing the anchorage uses the following procedure:

A hole larger than the bar is drilled. The hole is filled with epoxy, expanding cement or other high strength grouting material. The bar is pushed into place and held there until the grout has set.

Strengthening RC Members

The strengthening of the RC members is a task that should be carried out in consultation with a structural engineer. Here a few suggestions are briefly described to illustrate the ways in which the strengthening could be undertaken.

i) The RC columns can best be strengthened by jacketing. This is done by providing additional cage of longitudinal and lateral tie reinforcement around the columns and casting a concrete ring (Fig. 9.7 and 8). The RC beams and shear walls could be also strengthened in similar way.

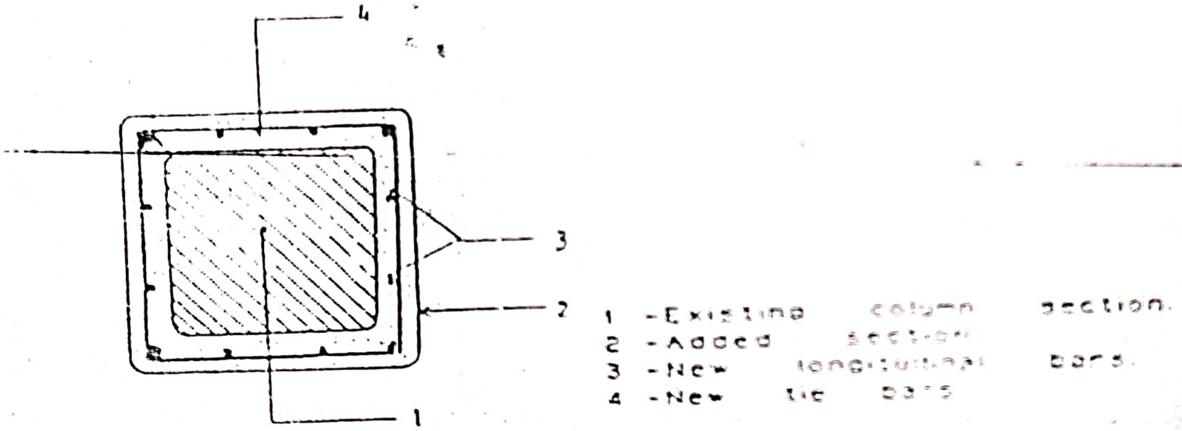


Fig. 9.7 Jacketing a concrete column (after Bibl. 152)

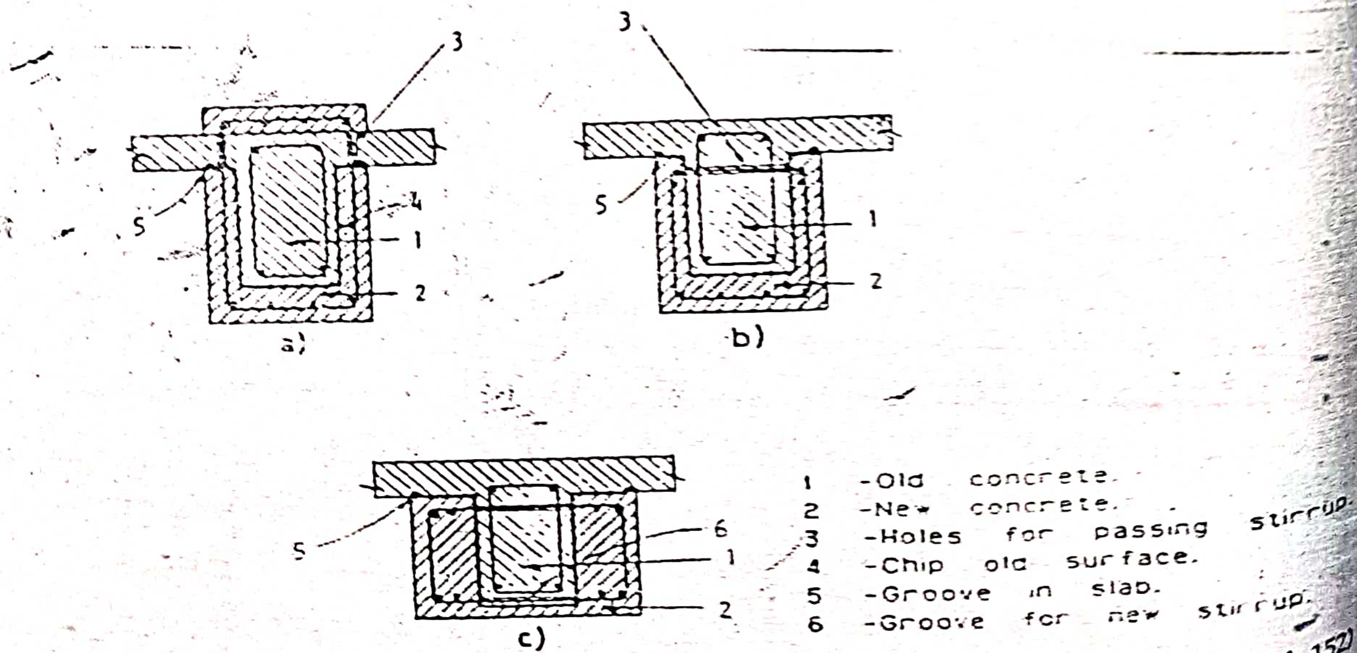


Fig. 9.8 Increasing the section and reinforcement of existing beams (after Bibl. 152)

ii) Inadequate sections of the RC columns and beams can also be strengthened by removing the cover to the old steel, welding new steel to old steel and replacing the cover. In all cases of adding new concrete to old concrete, the original surface should be roughened, grooves made in the appropriate direction for proving shear transfer. The ends of the additional steel are to be anchored in adjacent beams or columns as the case may be.

Recommendations for Future Construction

Low Strength Masonry (LSM)

a) Burnt Brick Buildings

For earthquake resistance the following measures have been found effective not only in preventing collapses but also in controlling the propagation and widening of cracks in the burnt brick buildings.

(i) Restriction of height of load bearing wall is necessary for better seismic performance. The guidelines in respect of suggestive neight for various types of low strength masonry buildings are provided in Table 3.

Table 3

Suggested height restrictions on buildings in moderate and severe seismic zones (Zones III, IV and V of India)

(after Bibl. 7—reproduced with permission from The Indian Concrete Journal, Bombay)

Sr. No.	Building type	Suggested maximum height
1.	Adobe house	One storey, or one storey + attic
2.	Field stone (random rubble) masonry in caly mud mortar	Same as above
3.	Dressed stone masonry in cement mortar	Two storeys, or two storeys + attic
4.	Brick masonry in mud with critical sections in cement mortar	Same as above
5.	Brick or cement block masonry in good cement mortar	Three storeys, or three storeys + attic
6.	Reinforced masonry	Five storeys, or as per design by a qualified engineer
7.	Wood frame	Two storeys, or two storeys + attic

(ii) There should be symmetry and rectangularity in the building plan.

(iii) There should be symmetry in the location of opening in masonry walls.

(iv) Width of piers between openings or from opening to wall corner should not be less than half the height of opening.

(v) The most important concept in strengthening of masonry buildings in the provision of horizontal seismic bands. A seismic band is a continuous runner (beam) of reinforced concrete or wood running into all external and internal walls with proper connections at the corners and T-junctions of the wall. The seismic bands are generally provided at the plinth, lintel and roof levels of the building.

Plinth band should be provided in these situations wherein the soil is soft or uneven in its properties as it usually happens in the hilly tract.

Lintel band is the most important band and incorporates in itself all door and window lintels, the reinforcement of which should be extra to the lintel band steel. From earthquake stability considerations, it is necessary that such band is provided in all the storeys in the building.

Roof band should be provided at the eave level of trussed roofs or where flexible wood joist roof or precast roofing units are used. Such band may not be provided where concrete slabs having full bearing on all four walls is used for roof or floor.

(vi) Vertical reinforcement should be provided in the walls in the shape of vertical steel bars or bamboo/cane at the critical sections of the walls. The critical sections for vertical reinforcements are the corner walls and jambs of window and door openings.

(vii) Steel or wooden dowels should be provided at the corners or T-junctiions to provide effective bonding between them, say every fourth course (Fig. 9.9 to 9.12).

(viii) Use of stronger mortar is masonry, say cement-sand 1 : 6 or even richer mortar should be made in construction of walls.

(ix) Overall arrangement of reinforcing a masonry building is shown in Fig. 9.13.

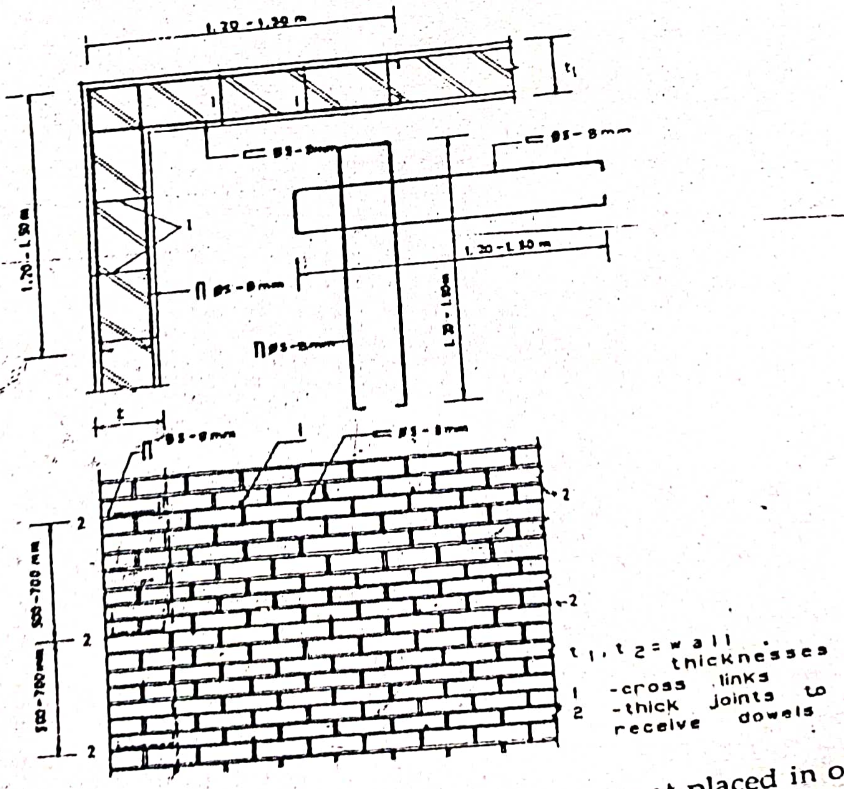
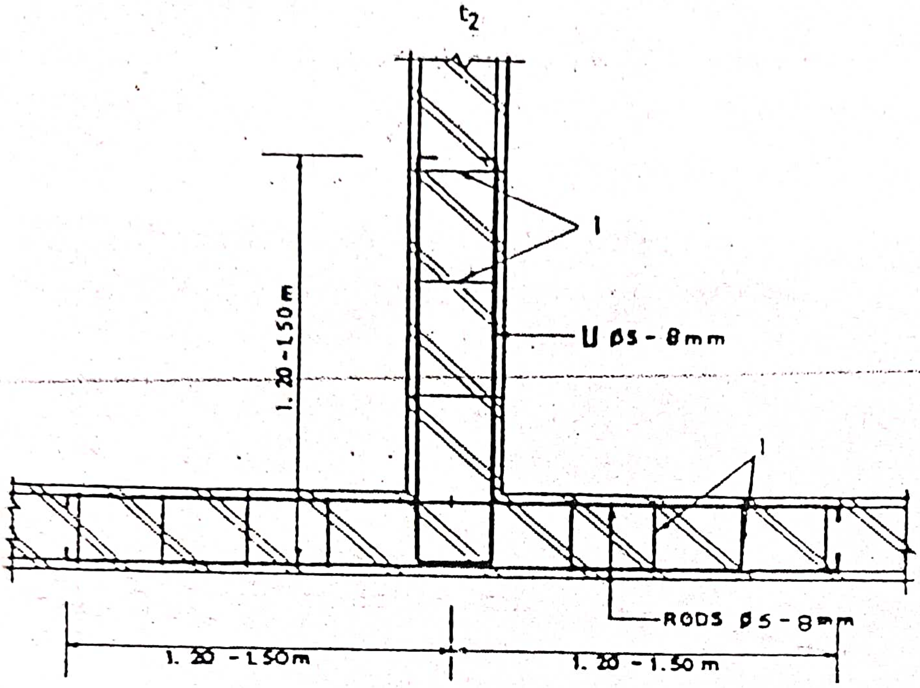
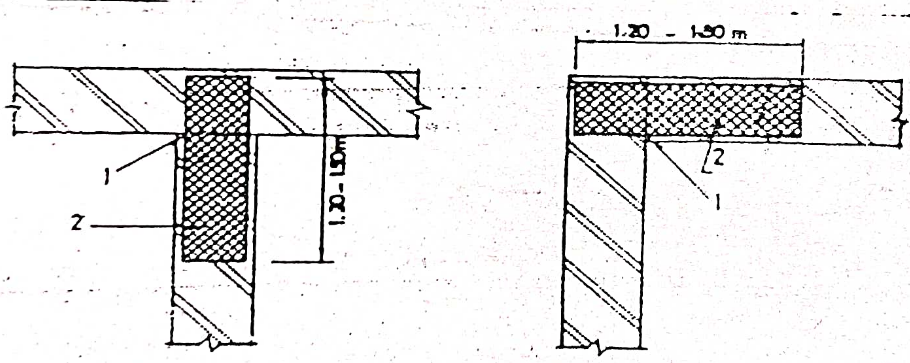


Fig. 9.9 Corner-strengthening by dowel reinforcement placed in one joint (after Bibl. 152)



t_1, t_2 = wall thicknesses, 1 - cross links.

Fig. 9.10 T-junction strengthening by dowel reinforcement (after Bibl. 152)



1 - construction joint, 2 - wire mesh.

Fig. 9.11 Strengthening by wire fabric at junction and corner (after Bibl. 152)

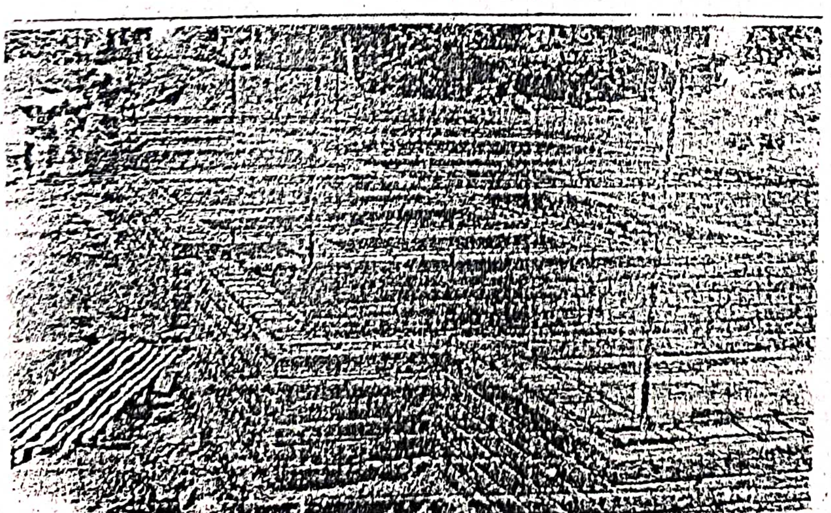


Fig. 9.12 Reinforcement for lintel band and placement of corner steel

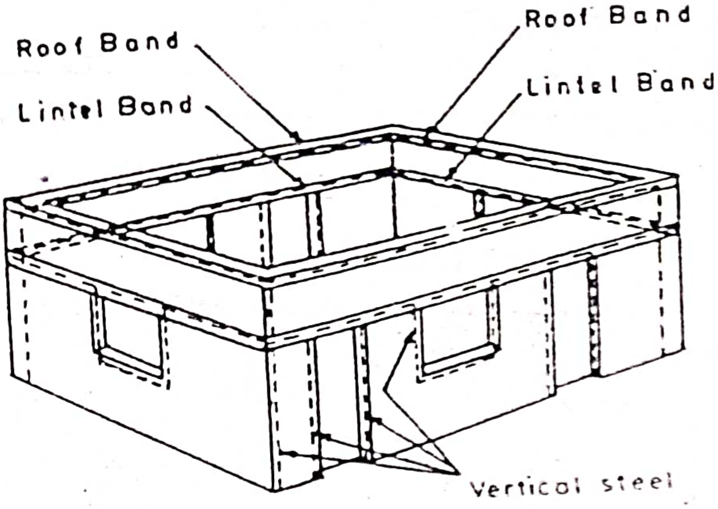


Fig. 9.13(a) Overall arrangement of reinforcing masonry building

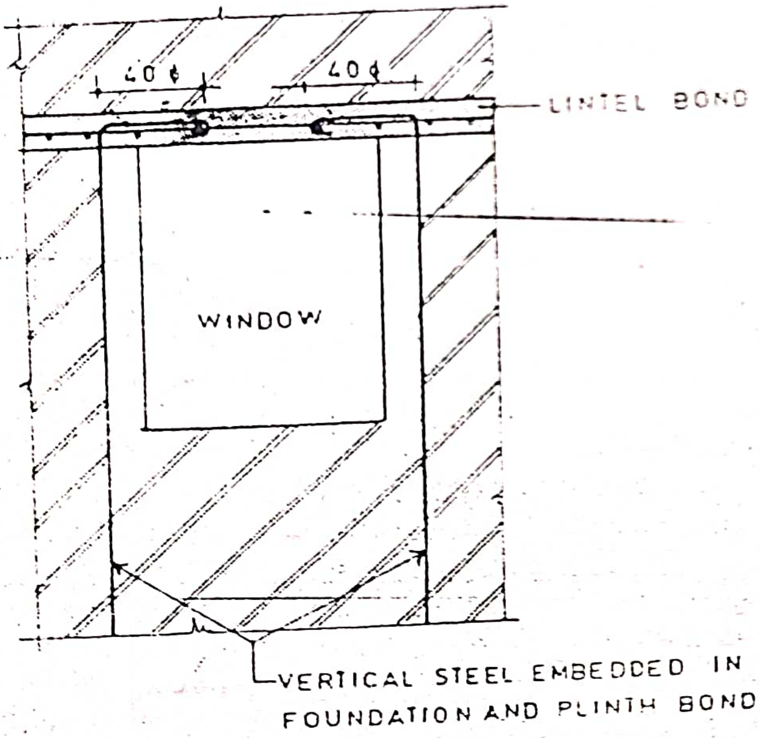


Fig. 9.13(b) Strengthening of masonry around openings

b) Stone Masonry Buildings

For stone masonry buildings, all the protective measures as for brick buildings, are found useful. For random rubble and half dressed masonry, the following additional measures are absolutely necessary.

i) Provision of 'through stones or bonding' elements (Fig. 9.14 & 9.15) along the wall thickness in every 60 cm lift at not more than 1.2 m apart horizontally.

ii) Restriction of the thickness to not more than 45 cm since larger thickness encourages undesirable filling material, inside, adding to mass but reducing the strength.

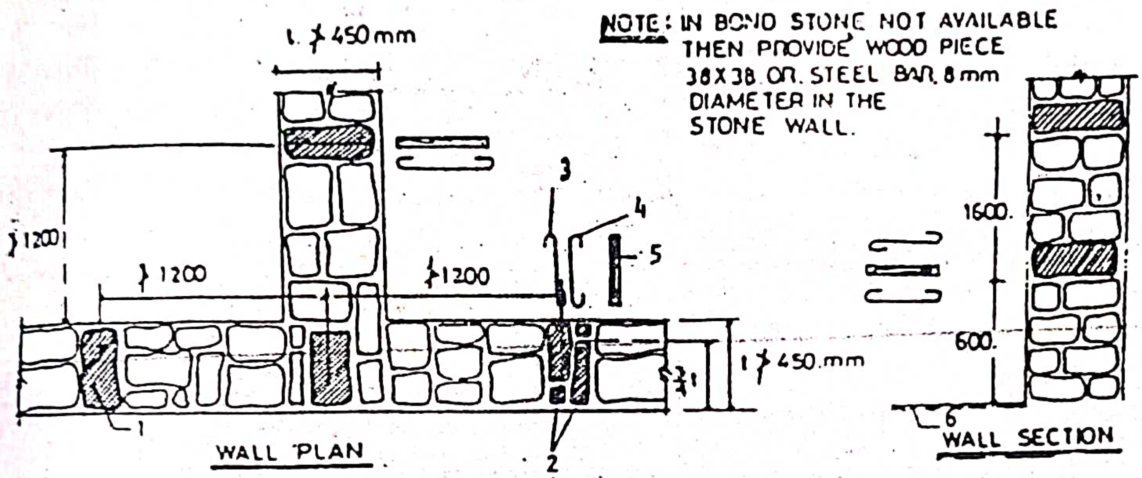


Fig. 9.14 "Through" stones or "Band" elements. (after Bibl. 152)

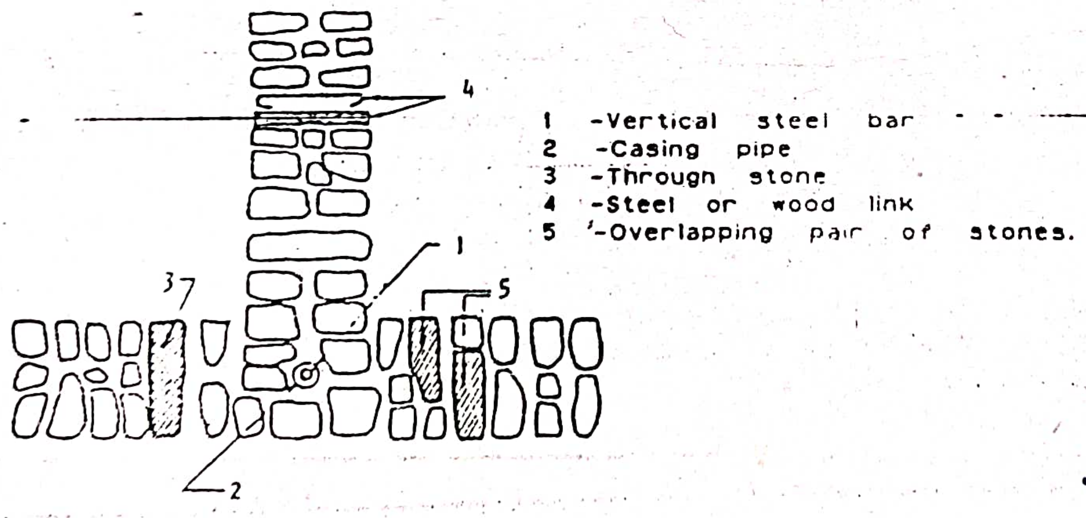


Fig. 9.15 Vertical steel in random rubble masonry

c) *Earthen Houses*

i) In view of poor performance of earthen houses during the past earthquakes, the height of such houses should be restricted to one storey only or one storey plus attic (Table 3).

ii) Length of rooms should be restricted to 4m maximum and storey height to about 2.8 m.

iii) As a thumb rule, openings' width should be restricted to one-third of the wall length, and these should be away from the corners by about three times the wall thickness.

iv) Soil should be adequately stabilised using suitable stabilisers like cement, lime, asphalt, etc. to improve the structural performance of earthen houses in the event of earthquakes. For adobe units and mortar, clayey soil with about 20% clay content and adequate fibrous admixtures should be used.

v) Earthen (adobe) houses should be strengthened by using lintel bands and roof bands made of wood. The roof rafters should be held to the roof band through spikes.

vi) Mud walls are made stronger for better performance during an earthquake by using buttresses or pillasters at the corners and wall junctions.

vii) Roof should be as light as possible in order to reduce inertial forces generaged by its mass. It is also important that the roof acts as a stiff diaphragm capable of transmitting lateral forces to the stronger walls in each direction. Instead of burnt clay tiles and slates which are brittle and dislodged, corrugated iron, asbestos or asphaltic sheets should be preferred for roofing.

viii) Earth should be protected from deterioration by weathering effect, except in zones of very arid climate or when earth has been stabilised with stabilising agents like cement, lime or asphalt. The exterior walls should be adequately covered with waterproof mud plaster. Mixing bitumen cut back in mud mortar is a preferred alternative. Cut back is prepared by mixing bitumen 80/100 grade, kerosene oil and paraffin wax in ratio 100:20:1. For 1.8 Kg cut back, 1.5 Kg bitumen is melted with 15 gm of wax and this mixture is poured into a container having 0.3 litre kerosene oil followed by constant stirring till all the ingredients are properly mixed. This mixture is now ready for mixing with 0.03 cu.m. of mud plaster prepared by mixing chopped rice/paddy husk, soil, cow dung and water. A combination thus prepared is both water repellent for walls and fire retardent for thatch.

Requirements of Structural Safety of Thin Precast Roofing Units against Earthquake Forces

The Armenian earthquake had exposed the vulnerability of precast roofing components to the forces of earthquake. Precast concrete frame buildings suffered extensive damage during the said earthquake. On the contrary, precast large panel buildings gave better performance during the earthquake due to proper bracings. Different parts of such buildings were better tied together than the previously quoted type of buildings. As such, it becomes necessary to take adequate precautions in design and construction of roof using precast elements. The following measures may be adopted for the structural safety of precast roofing units against earthquake forces.

a) Precast roofing/flooring, viz., RC channel units, RC planks and joists, etc., may be cambered to counteract the elastic as well as creep deflection.

b) The units should be transversely connected with reinforcing bars to avoid opening of joists (Fig. 9.16).

c) Use of such units may be avoided in wet areas, for e.g., baths, WCs and kitchens unless treated with reinforced topping concrete. Use of topping concrete could also eliminate the problem of transmission of sound inherent in thinner sections of precast units.

d) All elements of an earthquake resistant structure must be tied together to ensure box-type action i.e. walls act as shear wall and roof as diaphragm.

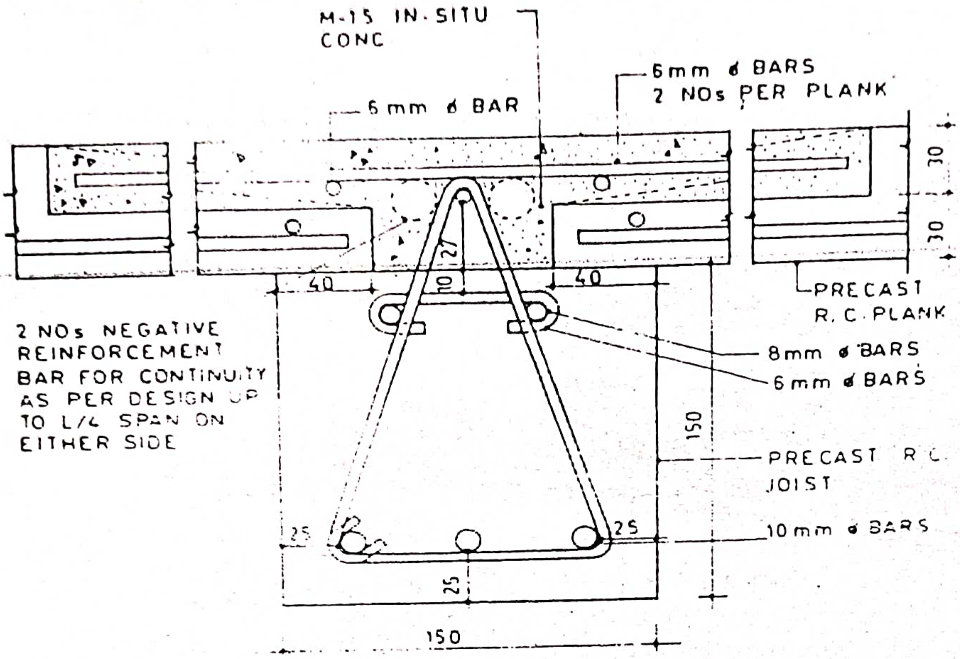


Fig. 9.16 Joint at beam support near wall

e) Field inspection and quality control during construction are important for stronger construction which could sustain the damaging effects of earthquake.

f) In case of precast flooring/roofing units, due attention should be given to the proper detailing of joints and for ensuring diphragm action of such floor/roof. The revised edition of IS: 4326 incorporates all the precautionary measures required to be adopted in respect of design and construction of precast building in earthquake prone areas.

Status of R and D in Earthquake Strengthening Measures

Provision of proper earthquake strengthening measures in buildings to be constructed in earthquake prone areas has assumed greater significance from the point of view of providing structural stability to buildings and security to the lines of inmates. Considerable research has been undertaken in this direction. The Department of Earthquake Engineering, University of Roorkee, has done pioneering research in evolving measures for suitable strengthening of buildings against seismic forces of variable magnitude. Based on the research and development work done in India and abroad, the Bureau of Indian Standards (BIS) has formulated number of Codes of Practice for construction of earthquake resistant buildings in different seismic zones of the country. It will be noteworthy to mention here that research in earthquake engineering has been undertaken in India since 1960, and it was the first country in the world to formulate the Code on Earthquake Resistant Building Construction in 1967 which has since been adopted by several countries.

In the wake of large-scale damage of buildings in the earthquakes of recent past namely Kangra (Himachal, 1986), North Bihar (1988) and Uttarkashi (U.P., 1991), the BIS has recently revised IS:4326. The IS:4326-1993 (Second Revision) covers wide-ranging issued concerning earthquake strengthening measures. It deals with the selection of material for earthquake resistant construction, special features of design and construction of earthquake resistant building including masonry construction, timber construction and buildings with prefabricated flooring/roofing elements. Other useful IS codes on earthquake resistant construction brought out by the BIS are IS:13827:1993, 'Improving earthquake resistance of earthen buildings'; IS:13828:1993, 'Improving earthquake resistance of low strength masonry buildings-Guidelines,' IS: 13920:1993, 'Code of Practice for ductile detailing of reinforced concrete structures subject to seismic forces,' and IS: 13935-1993, 'Repair and seismic strengthening of buildings — Guidelines.'

In recent years, 'Base Isolation' technique is being increasingly used in Japan, USA, New Zealand and Australia to safeguard structures from catastrophic effects of earthquake forces. Base Isolation is a concept whereby the motion of a structure during an earthquake is decoupled from the ground motion by the introduction of a low stiffness layer between the super, structure and the ground. Of late, combination of layers of natural rubber and mild steel plates has been successfully tried out as a viable base isolator. Today, more than 50 patented base isolators have been developed the world over. The additional cost likely to be incurred over provision of base isolator in a building is only to the extent of 5% of the cost of the structure. Provision of base isolators and shear walls in important structures such as school buildings, hospitals, and high rise residential apartments and commercial buildings will help provide adequate safety and stability to such structure in the event of earthquakes. Shear walls help in resisting lateral force induced on structures due to earthquakes a great deal. They are usually provided between column lines, in stair wells, lift wells and in shafts that house other utilities. Buildings mounted on base isolators and incorporating provision of shear walls have been observed to sustain strong earthquakes forces admirably.

Floods

Among several natural disasters, floods are more recurrent in the South Asian region. The recurring floods in the developing countries like India and Bangladesh cause extensive damage to crops, livestocks, communication, irrigation works, houses and property, not to mention loss of a large number of human lives every year.

Data available from the United Nations Disaster Relief Coordinator (UNDRC) indicates that the major impact of natural disaster is concentrated among the developing countries, mainly located in Asia, where agriculture is the principal economic activity. It is estimated that over 90% of disaster losses in these countries are attributable to floods, indicating the importance of flood hazard assessment and mitigation planning in the background of their impact on agricultural economy.

Magnitude of Losses in India

Among several natural disasters that India experiences every year, flood ranks the uppermost in terms of losses it causes to housing/building and other property.

Flood is a perennial problem in India. It is an annual feature in majority of the states in the country. A large number of States like Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, Orissa, Assam, Tripura, Kerala, Karnataka, Andhra Pradesh, Gujarat and Maharashtra are flood prone. Off and on floods also occur in other States due to swallon rivers, resulting from cloud burst and unusual rains. Cloud burst caused untold misory in terms of loss of life and property in the otherwise dry and arid Rajasthan 1986, and in Himachal Pradesh in 1994.

As per the estimates of the National Commission of Floods, 40 million hectares (MHA) out of 329 MHA of the country's geographical area are prone to flood. Relatively, problem of floods causing heavy devastation is more frequent in the Brahmaputra basin in Assam; the Ganga basin in Uttar Pradesh, Bihar and West Bengal, and the Brahmani, Baitarani, Subernrekha and Mahanadi basins in Orissa.

Extensive efforts have been made to mitigate flood damages through several schemes under the five-year plans. Nevertheless, floods still continue to cause extensive damage to life and property every year in the country. In 1987, floods were responsible for the loss of 1,612 human lives and property damage worth Rs 15,870 million. An area of 16.90 million hectares was affected by the 1987 floods throughout India. Floods of 1988 had a much higher tally. As many as 3065 human lives and 0.14 million cattle heads perished in the 1989 floods that caused havoc in a large portion of the country. The people belonging to the EWS category are the worst sufferers in the event of floods as their dwellings, which are generally of non-durable materials and construction, are easily damaged or washed away by the water currents.

The national policy on flood control was launched in 1954, but floods still, on an average, claim over 1,500 human lives and 10,000 cattles heads every year, besides damages to thousands of houses of the common people.

Types of Floods

Flood is a situation created when the river enters a flow in excess of its transporting capacity. It may also be caused by an overfill of storage tank or breach of a reservoir. Depending on its nature a flood can be categorised as follows:

a) Local Flood

It is caused by intense local rainfall. The inadequacy of the drainage system to carry away the water quickly results in flooding of the locality and low lying areas.

b) Tidal Flood

Cyclonic winds cause high tidal waves which spill over land flooding low-lying areas in the interior.

c) Flash Floods

Flood flow develops gradually in many large rivers. In contrast, flash flood, as the name suggests is a sudden phenomena. In this type the time lag between start of flood and peak discharge is much smaller in comparison. It is caused by isolated and local intense rainfall as from a thunderstorm (cloudburst) and by steep catchment slope conducive to fast run off. They are particularly dangerous because of the suddenness and speed with which they occur.

Damage to Houses by Floods

Floods constitute a hazard to houses and buildings when the flood plains which perform the natural function of carrying away excess water are used for human settlements. In spite of some awareness of the hazard, more and more people are moving to and building in flood prone areas due to pressure of population and economic compulsions.

Depending ~~on their location~~ the houses can suffer damage by different kinds of floods.

The type and extent of damage to houses depend on the particular type of flood they are exposed to. Flash floods, riverine floods, local floods and coastal waves have their own dynamic characteristics and leave distinct marks of distress on the structure after they recede. Damage of different degrees takes place is described below.

Severe Damage

Houses subjected to a large mass of water striking them with force collapse totally. This is typical of coastal waves following cyclonic winds (Tsunamis ~~which~~ are also in this category do not ~~occur~~ India) which may ~~reach~~ several meters above the sea-shore level. In the case of coastal flood, it might be possible to retrieve some of the building materials from the collapsed structures.

Flash floods also bring upon sudden pressure on the structure due to the high velocity of water and cause complete destruction. Even strong buildings of RCC construction are badly damaged. In locations where the houses are built on loose soil, severe inundation takes place leading to collapse of the structure. The swift water currents take with them most of the debris. In the case of 'kutcha' structures built of thatch, mud etc., not a trace of the house is left. Very little of building materials, if any, can be retrieved in the case of structures lying directly in the path of flash floods.

Partial Damage

Riverine floods are characterised by low velocity and longer duration. Prolonged inundation is expected from riverine floods which gives rise to two types of damages to houses.

a) The soil gets softened leading to sinking of the foundation. This will result in uneven sagging of roof with consequent damages to roof covering and supporting members, cracks in the wall and sinking of floors. Scouring of foundation by a slow and steady flow of flood water can further aggravate the problem. Repairs and restoration can be done with considerable expense depending on the extent of damage.

b) The standing water causes deterioration of the building finishes like painting, distempering, plastering, etc. Timber works in doors, windows, storage shelves, pelmets are soaked leading to their decay.

Flooding of low lying areas by local heavy rainfall also damages houses in the manner described above.

Other Effects

Floods can also have a devastating effect on land by eroding the upper strata leaving behind a rugged surface which is unsuitable for construction. The reverse process is also a common phenomenon when the flood water brings with it large volumes of fine silt, and or other materials and deposits them on an existing settlement. This is very typical of flash floods which have the requisitive momentum to carry soil and boulders in their way. In this case the clearing operations and restoration become difficult tasks.

Vulnerability of Mud Houses

By and large damages to houses and buildings depend on the topography of the area soil erosion characteristics, wall area exposed to the water pressure, foundation type and depth and the strength of the structure. However, houses of the 'kutcha' type, especially those constructed with mud, sudried bricks, thatch, bamboos, etc., are damaged extensively. Poor people who are able to afford only such type of houses are the worst sufferers.

Disaster Mitigation in Flood Prone Areas

Habitation in river valleys, around lakes and along coastal belts, will continue due to compulsions of occupation, in spite of their being prone to flood hazard. A total evacuation of the population and their resettlement at a safer site appears to be inpracticable proposition. It leads to unfavorable socio-economic consequences. The flood problem, therefore, ought to be tackled with two fold objectives of prevention of exposure of habitation to floods and mitigating the effects of floods.

Land Use and Building Regulations

Three aspects namely a) urban and rural land use b) flood plain occupation control, and c) building regulation have to be taken into account for a planned development to mitigate the effect of flood disasters.

Land Use

Changes in the land use can have an effect on the hydrology of the area thereby increasing the flood potential of catchments. In urban areas causes attributed are i) reduction in the surface absorption causing higher volumes of run off, and ii) reduction of time of concentration giving higher volume of run off. These aspects have to be carefully considered.

In rural areas, vegetation and afforestation have the effect of altering the catchment flood response. Studies in the USA have demonstrated that for an increase in afforestation on a small watershed, equivalent peak discharges are reduced gradually over a period of approximately of 25 years by an average value of about 60 per cent. The effects of rainfall induced floods have not been clearly understood. Different types of vegetation and rural land management cause differing effects in soil water consumption and retardance of run-off.

Settlements of Flood Plain

The height of land surface gradually increases above the river bank level as one goes farther away. Consequently, the flood hazard gets reduced as the distance of land from the river increases. However, for socio-economic reasons, the occupation of flood plains cannot be avoided. It is, therefore, advisable to exercise some control on building houses in such cases by confining the constructions to zones involving least risk. The concept of Flood Plain Zoning incorporates this idea.

By taking into account the variability of the flood hazard in river, zones are demarcated depending on the degree of risk and potential damage. Through legislation, the type and density of occupation could be controlled. Three zones are identified which are discussed below.

a) Prohibited Zone

This is the essential part of the flood way, the velocity and discharge of which contribute significantly to prohibited zone in the flood plain. Development in this zone of any kind should be totally disallowed to avoid damage to the property and also to avoid backlash flood effects up-stream, posing hazard to other settlemtns. The prohibited zone can be put to uses like cattle grazing, etc.

b) Restricted Zone

The area in the river bed where inundation is not too frequent and contributes small volume to the total flood discharge can be used as a restricted zone where the velocity of flow is low. Limited building-development and planned agricultural activity are feasible. However, restriction should be stipulated not only on the density and use but also on the design criteria. Minimum ground floor level, flood proofing arrangements, etc., should be considered for buildings.

c) Warning Zone

The inundation beyond the design flood level and upto the estimated maximum flood level is rare and, therefore, the potential disaster is negligible

People who wish to settle in this zone should be warned and advised of the risk involved regarding the safe floor levels, etc. The choice of settling and developing will be their own and little or no restriction is imposed from the point of view of flood disaster prevention.

Building Regulations

Damage to individual buildings and structures may be prevented, to some extent; by incorporating in their design, the ability to withstand inundation and effect of high water velocity. It is desirable to enforce some building regulations in this regard in order to see that the welfare of the individual as well as the community is protected. If such a control is exercised at regional and national levels, it would contribute substantially to mitigate flood disasters and save life and property in a large measure.

Flood Resistant House Construction

Floods affect the whole community and the related problems can be tackled adequately and satisfactorily only at the community level. Nevertheless, each aspect of flood disaster mitigation warrants its own special consideration and a solution which will at least partially meet the situation. The strengtheing and protection of individual houses is one issue which should be given due priority and importance. Total flood proofing of dwelling would necessitate incorporation of strong reinforcing measures which will entail considerable cost. Such a type of construction is generally not within the means of majority of the people who are vulnerable to flood disaster. However, the following steps could be taken to provide some protective measures to the houses which may at the least help to save lives:

a) Good siting of houses should be aimed at to minimise risk of damage. The buildings should be constructed on the best bearing soil on the highest ground available.
b) Ground drainage and escape lanes should be incorporated in the settlement layout.
c) The houses may be raised on individual mounds which are prepared by spreading and throughly compacting soil. The mound should be constructed with suitable locally available soil. The roof level which is a critical factor during rising of flood water is raised adding a good measure of protection.
d) The buildings may be designed in such a way that their roof spaces are above the designed flood level. The choice of roof type and area should be such that it gives protection for a period of at least 24 hours to the people who take shelter.
e) It is a common practice to raise houses on stilts. However, such type of construction increases considerably the risk of damage/overturn in the event of a flood. Such buildings should therefore have a rigid frame construction for strength or adequately braced.
f) The plinth should be preferably raised to a height of 0.75 m (minimum) so that the occupants of the houses get some breathing time in the event of flood waters surrounding the house and rising gradually.
g) The mud houses should be preferably provided with pucca founda-

tion of stone or brick masonry in lime mortar over a bed of lime concrete.

h) Houses constructed with mud are highly vulnerable. They must be given water proofing treatment.

i) Parapet pillars in cement mortar 1:6 should be provided over the roof to hold bamboos/poles in order to enable the victims to climb up and survive even when the flood water level rises to about 3.5 to 4.0 m.

j) In areas subjected to heavy rains and floods, the foundations of walls and the plinth upto a height of 1 metre should be of burnt bricks.

Cyclone

Cyclone is a devastating natural disaster the onslaught of which has been experienced by the littoral States of the country since time immemorial. It causes untold misery in terms of loss of human life and property. In India, tropical cyclones develop in the Bay of Bengal and the Arabian Sea. From the point of view of the frequency of occurrence of cyclones, the Bay of Bengal is more vulnerable than the Arabian Sea. In India, coastal districts of the states of Tamil Nadu, Andhra Pradesh and Orissa are more succeptible to cyclonic storms. The months of May, June, October and November are the stormiest of the year. In the post monsoon period, the peak storm activity is reached in the second half of October and the first half of November. Compared to the pre-monsoon season, particularly the months of October and November are known for severe storms. The highest wind speeds in cyclones which have hit the Indian coast in the past hundred years have been about 120-130 knots is 220-240 km/hr. According to one survey of the past records, the population of India's eastern coast has experienced cyclones almost every year between 1891 and 1981. During this period, more than 100 cyclonic storms are reported to have crossed the Bay of Bengal.

Magnitude of Damages Caused

Large-scale damage and destruction is caused to lives and property in the event of cyclones and the accompanying tidal waves and heavy rainfalls. The Bay of Bengal cyclone of 1737 claimed 5,00,000 lives. In recent past, the cyclonic storm that hit the coastal region of Andhra Pradesh in November 1977 caused untold misery to lives and property. Approximately, 7.1 million persons in 2302 villages were affected by the onslaught of cyclonic storm. In the Krishna district alone, the death toll was estimated over 10,000 besides loss of 2,31,000 cattle and 45,000 of other livestock. The aftermath of the cyclone was that million people were rendered homeless. It is estimated that some 6,90,000 houses were damaged by the vagary of the said natural disaster. About 86,000 huts were completely washed away.

Guidelines for Making Common Man's House Cyclone Resistant

More than three-fourths of the population in coastal districts live in rural areas and most of them occupy non-engineered buildings which are built of low quality materials. Such buildings are constructed by the people through masons, carpenters and petty contractors having limited construction skills and knowledge. Even in the urban centres, many people live in 'kutcha' (temporary) houses, not so much as a matter of choice, but as a matter of economic compulsion. All these constructions are vulnerable to the hazards of cyclone. Based on the experience and analysis of the structural failure of non-engineered buildings during the past cyclones, the following guidelines are suggested for making common man's house cyclone resistant.

a) Location

Natural windbreaks such as trees or hedges should be taken advantage of when deciding on a site for building. Such a location can reduce the impact of prevailing winds (Fig. 9.17).

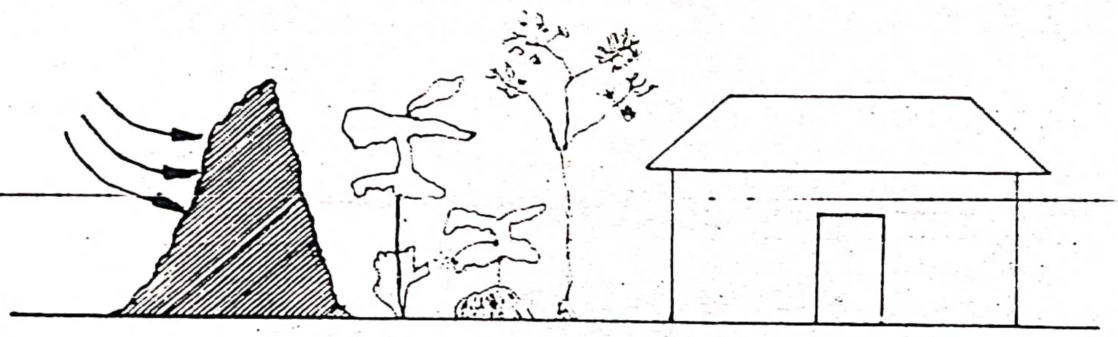


Fig. 9.17 Protection to house by hillock/trees

b) Shape of Building

Based on the research done on the effect of geometry of a structure in withstanding wind forces, the following ratios are recommended (Fig. 9.18).

(i) Length : Width = 1.5

(ii) Height : Width = 1

Square houses are safer against winds. Pyramid-shaped deep steep roofs defy winds best. The following shapes should be avoided:

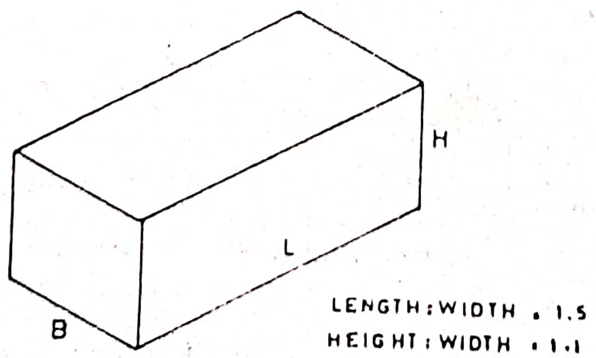


Fig. 9.18 Preferred shape of building in cyclone prone areas

a) Very long dwellings
b) 'L' shaped and zig-zag shapes
c) Extra wings added to the main unit.

c) Orientation of Buildings

The lay-out of building in relation to the direction from which the tidal wave is expected is an important factor. A wave striking at right angles can break a wall; at an oblique angle its force is dissipated (Fig. 9.19).

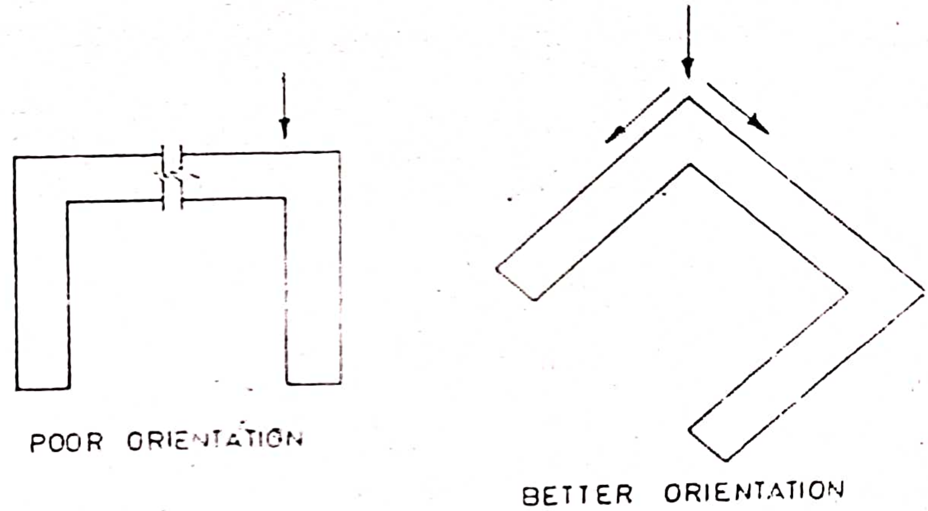


Fig. 9.19 Effect of orientation of building

d) Construction Details

i) It should be ensured that every part of the building is securely tied together; all roof elements, roof-to-wall, wall-to-wall, wall-to-floor and floor-to-foundation (Fig. 9.20).

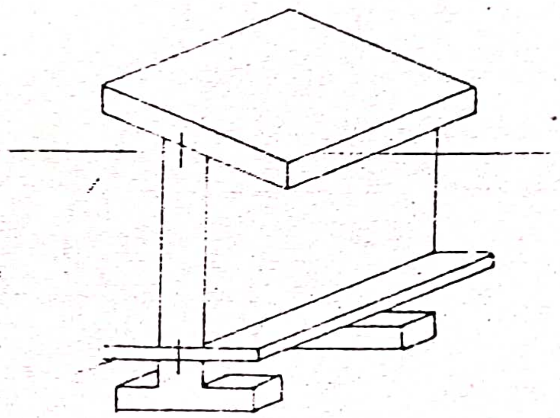


Fig. 9.20 Ensuring that every part of the building is securely tied together.

ii) Reinforced masonry should be encouraged in cyclone prone areas. Where necessary, the walls should be reinforced with vertical steel reinforcement (Fig. 9.21)
iii) Horizontal reinforcement should be provided around corners between the intersecting walls and between columns and infill walls (Fig. 9.22).
iv) Providing reinforced concrete band (ring beam on all external and

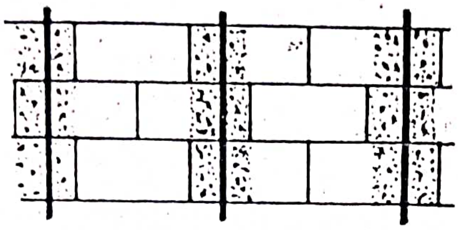


Fig. 9.21 Reinforcing masonry wall

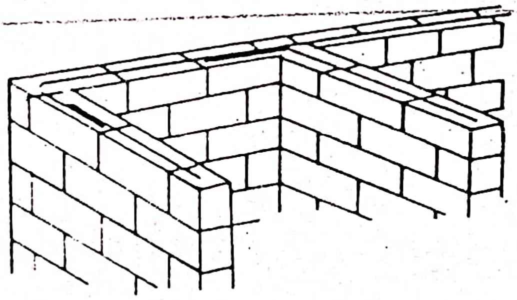


Fig. 9.22 Proving horizontal reinforcement around corners and between intersecting walls

internal load bearing walls) will greatly improve their individual stability as well as integral box like action and increase the stability of buildings to make them cyclone resistant to a great extent. Joint reinforcement should alternatively be provided at wall junctions, say in every fourth layer.

v) If a suspended floor construction is used, it should be ensured that the entire sub-structure is traced and positively anchored to the foundation (Fig. 9.23).

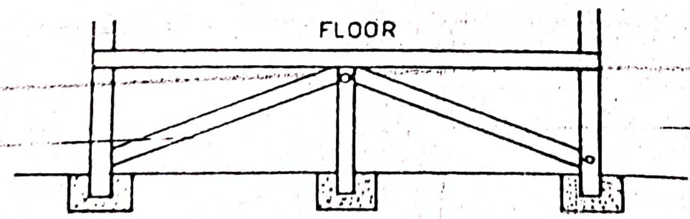


Fig. 9.23 Bracing the sub-structure of suspended floor

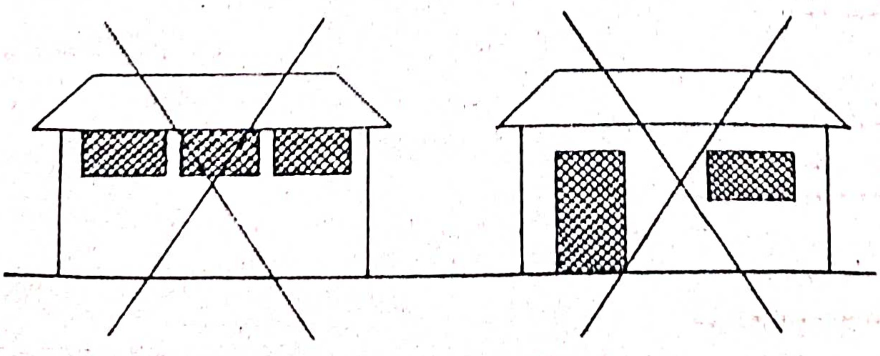


Fig. 9.24 Faulty placing of openings near roof lines and near the corners of walls

vi) Large openings near the roof lines or near the corners of wall should be avoided (Fig. 9.24). These tend to weaken the structure, they are located in areas of greatest loading.

vii) Bracing provides lateral stability to masonry walls (Fig. 9.25).

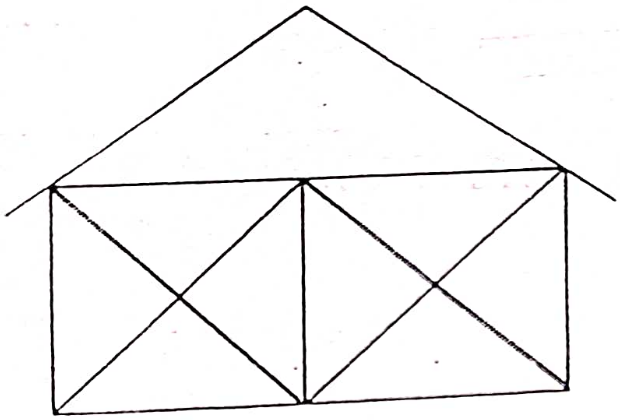


Fig. 9.25 Bracing of walls

:) *Roof Construction*

i) Whatever the form of construction it should be ensured to tie it securely to its supporting walls or posts (Fig. 9.26). Ignoring this caution is the greatest single cause of damage due to hurricane winds.

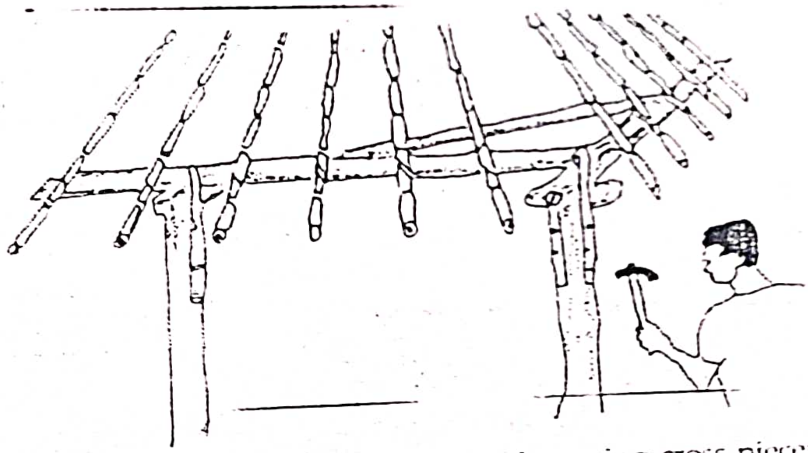


Fig. 9.26 Securing roof to supporting walls and proving cross pieces at corners

ii) The angle of roof is important in case of sloping roofs. The angle less than 30 produces suction of the wind on the roof and it can be blown away. An angle of more then 30° deflects the force of the wind (Fig. 9.27 and 9.28).

iii) A hip-angle roof is preferred to gable ends. Roof suctions are less in hip-angle roof (Fig. 9.29).

iv) When connecting a timber roof to a masonry wall, a fastening strap a reinforcing bar should be used which is firmly embedded in the concrete or masoncy (Fig. 9.30).

v) Failures by separation of the entire roof structure from the walls due to uplift and lateral forces have occurred during the past cyclones. It is, therefore, necessary to properly anchor the roof to the walls and

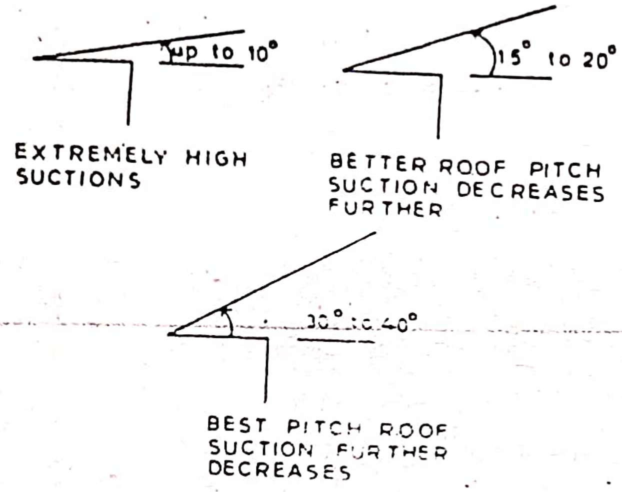


Fig. 9.27 Preferred roof slopers

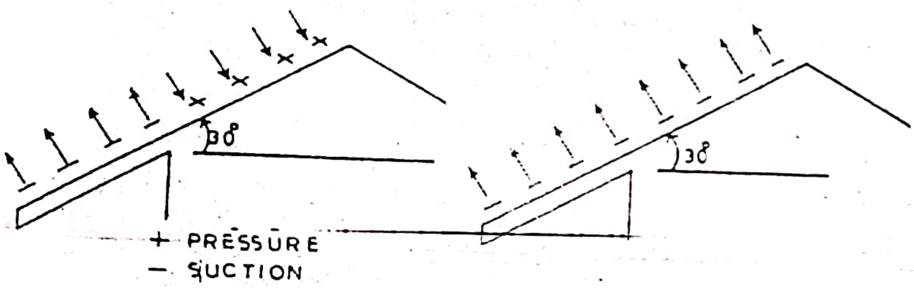


Fig. 9.28 Effects of roof slope on wind pressure

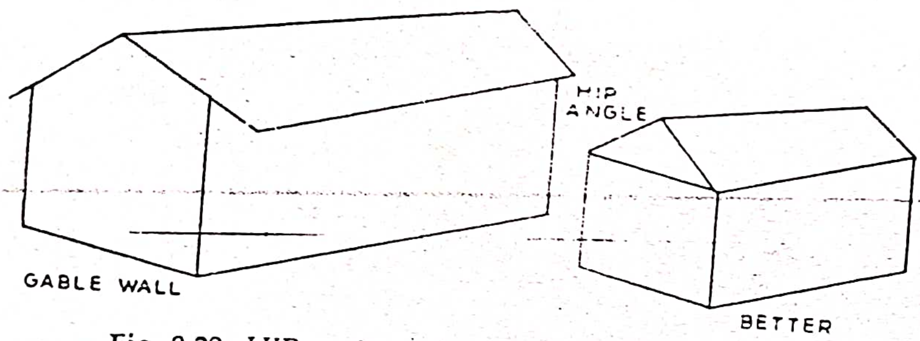


Fig. 9.29 HIP angle roof preferred to gable end

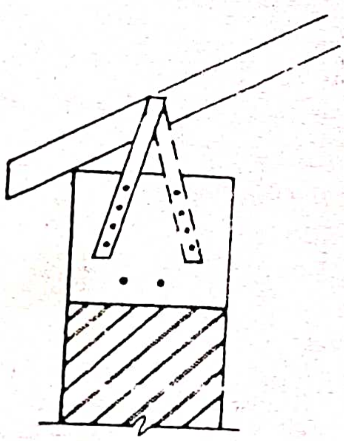


Fig. 9.30 Connecting timber roof to wall

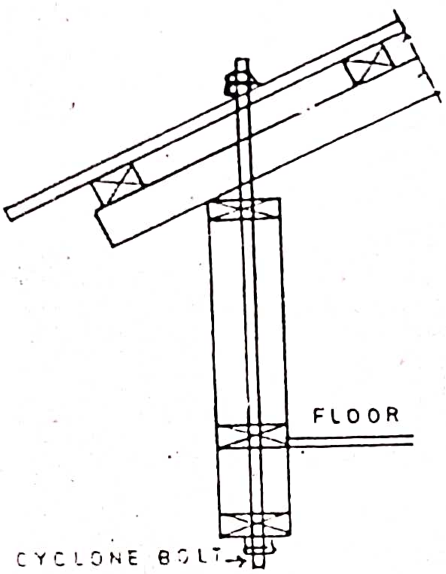


Fig. 9.31 Cyclone bolting

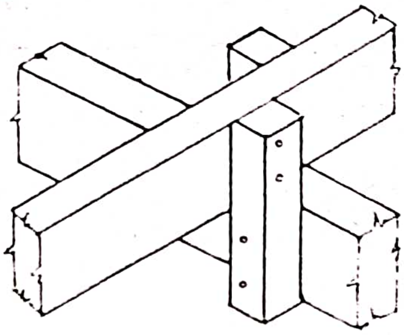


Fig. 9.32 Wooden cleats nailed to purlin and rafter

then to the foundation. Cyclone bolts (Fig. 9.31) are provided to achieve structural continuity from the roof to the foundation.

vi) All purlins should be tied to rafters by at least one and preferably two connectors. It should be ensured that nails are driven laterally, not in direct pull (Fig. 9.32 & 9.33). Various cyclone resistant joints and connections ar shown in Fig. 9.33 to 9.36.

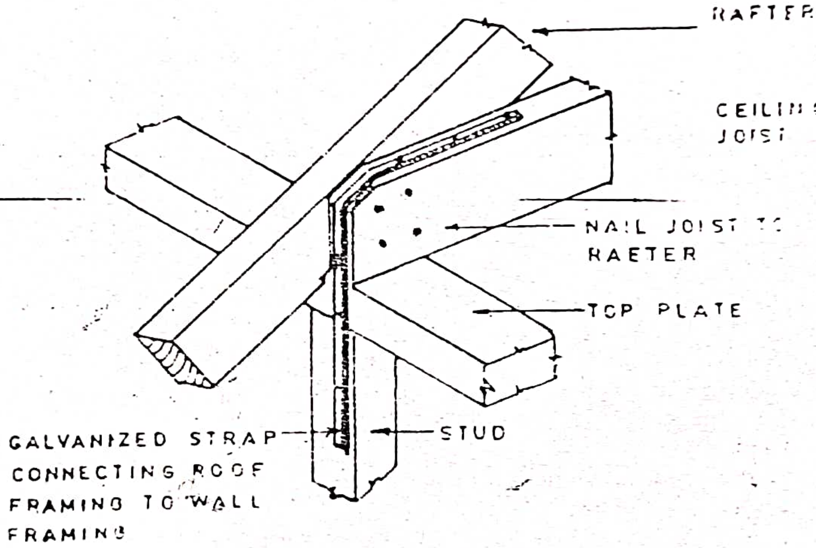


Fig. 9.33 Connection of roof frame

vii) When nailing corrugated roof sheetings to purlins, nailing should be done through the top of corrugations and a washer at least ¾" (18 mm) should be used (Fig. 9.37).

viii) Every corrugation along the bottom purlin (at the lanes) should be

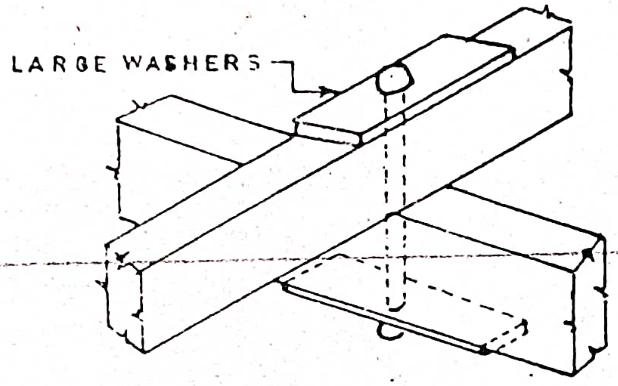


Fig. 9.34 Steel bolt fixing

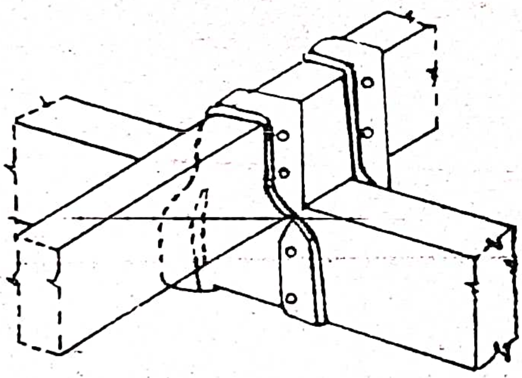


Fig. 9.35 Steel strap fixing

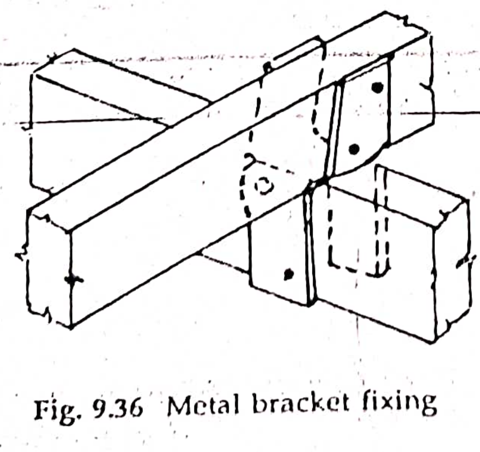


Fig. 9.36 Metal bracket fixing

nailed, and it should be nailed along the top of the purlin (at the edge) (Fig. 9.38). Ignoring these nailing recommendations often lead to the blowing away of the sheeting in the hurricane winds.

ix) The probability of bamboo roofs covered with straw or palmyrah leaves being blown away could be greatly reduced by covering them with a form of netting made from customary local materials such as coconut fibre rope.

x) A roof or clay tiles could be considerably strengthened and tiles

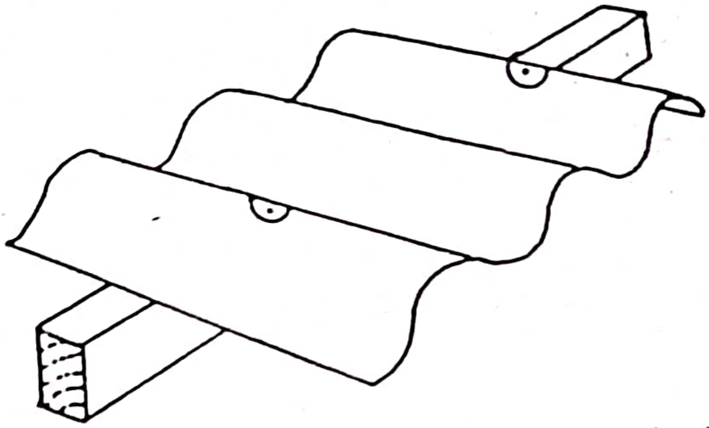


Fig. 9.37 Use of washer in nailing corrugated roof sheeting to purlins

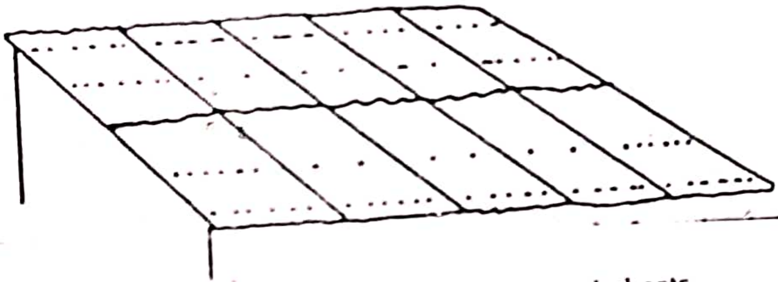


Fig. 9.38 Proper nailing of corrugated sheets

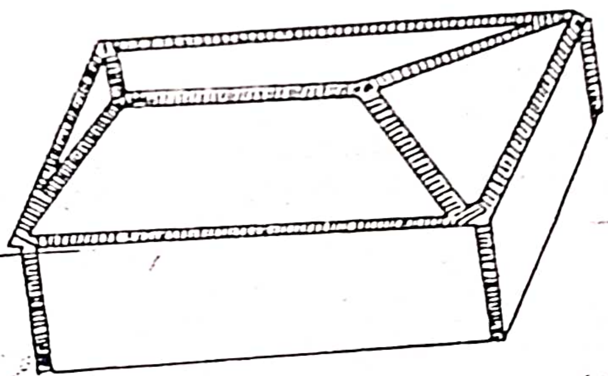


Fig. 9.39 Provision of mortar bands on roof top

prevented from blowing away by weighing it down with bands of mortar (Fig. 9.39).

The above measures could go a long way in making common man's house cyclone resistant.

Future Strategy

(1) The Municipal Bye-laws and Building Regulations should incorporate mandatory provisions for strengthening of houses and buildings in

areas prone to natural disasters. Strict enforcement of such provisions should be ensured. Existing Building By-laws and Regulations should be examined in depth to identity shortcomings in the provisions for adequate and satisfactory strengthening arrangements taking into account the type and the intensity of disaster experienced locally.

(2) North India faces a serious threat of a devastating earthquake of probable magnitude eight or nine on Richter scale in near future as per the recent forecast of the groups of American and Indian scientists based on the detailed study of past India earthquakes and analysis of plate tectonics of the region backed up by satellite data. The region being a zone of high seismic risk and large number of buildings (around 1,00,000) in the Kobe, Japan earthquake (7.2 on Richter scale) in January, 1995 which claimed more than 5,400 human lives, provides a grim warning to the safety of houses and buildings in the event of occurrence of earthquake on the predicted lines in the northern part of India. With a view to minimising damage to structure during future earthquakes, all buildings in seismic prone zones should be designed and constructed for earthquake resistance as per the codal provisions of IS: 4326 and other IS codes recently brought out by the BIS on earthquake resistant construction.

(3) Real seismic forces are much greater than provided in the design codes as revealed by the analysis of the Armenian earthquake. As such, all members of earthquake resistant structures should be detailed to perform in the inelastic range, well beyond the normal elastic capacity.

(4) Like unreinforced masonry, precast constructions run high risk in the event of earthquakes. In view of the large-scale collapse of prefabricated buildings in the Armenian earthquake, future precast constructions in the country must take adequate precautions to ensure the integrity of precast elements. All precautionary measures as envisaged in the second revised edition of IS:4326 should be strictly followed to ensure structural stability of precast constructions in future earthquakes.

(5) Micro-zoning pattern should be evolved for disaster prone areas to provide guidelines for planning and siting of housing and human settlements.

(6) Guidelines for working out methodology of vulnerability analysis should be prepared for land-use planning.

(7) Cyclone shelter belts should be created in the coastal areas by tree plantation. Emergency cyclone shelters should be constructed on a large scale in the coastal areas.

(8) Much attention is required to be paid to drainage in forming new settlements, and escape lanes should be incorporated in the lay-out for rapid flow-out of water.

(9) The importance of flood plain zoning should be recognised for orderly settlement free from undue hazards. Survey should be undertaken in flood prone areas to demarcate prohibited restricted and warming zones and the inhabitants should be made aware of these zones with proper demarcation. The concerned authorities should develop flood-plain zoning maps which should be implemented in establishing human settlements.

(10) Well-designed and maintained drainage system should be provided in towns to avoid local flooding.

(11) Growing of regular plantation in the catchment area on the banks of the rivers as well as coastal areas, should be encouraged to retard run-off.

(12) Plants and shrubs should be grown around the house as they provide a measure of protection by breaking the force of gushing water.

(13) People should be educated about the importance of keeping the drains clean in order to avoid choking.

(14) With a view to creating awareness among masses more TV and video films on natural calamities should be prepared on the lines of the one prepared by the NBO on earthquake, and shown on the national network of Doordarshan. Natural disaster should form a part of the syllabi of school and college level education. In areas prone to severe earthquakes, mock exercises should be carried out as is regularly done in the quake prone areas of Japan.