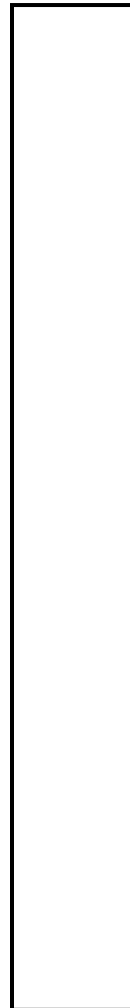


**GUIDELINES  
FOR RECONSTRUCTION OF HOUSES  
AFFECTED BY TSUNAMI IN TAMILNADU**



**REVENUE ADMINISTRATION,  
DISASTER MANAGEMENT & MITIGATION  
DEPARTMENT  
GOVERNMENT OF TAMIL NADU**



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## 1. Introduction

Most of the losses of life in past earthquakes and cyclones have occurred due to the collapse of buildings, constructed in traditional materials like stone, brick, and wood, which were not particularly engineered to be earthquake and cyclone resistant. Tamil Nadu state has been identified by the vulnerability Atlas of India as prone to multi-hazards, which include severe cyclones, moderate earthquakes, tidal waves in costal regions, severe corrosion environment and other man made disasters like fire and blasts. In view of the continued use of such buildings in our country due to socio economic situation, it is essential to introduce disaster resistant features in their planning, design and construction.

From the results of studies on the performance of buildings during past disasters the following recommendations emerge:

1. Certain building types, such as, earthen houses, random rubble masonry as well as brickwork in clay mud/mortar, should be ruled out in severe disaster prone zones, costal zones vulnerable for cyclone and Tsunami.
2. Rich mortars involving cement and lime should be used in fired brick and/or coursed stone masonry.
3. Required steel reinforcement should be introduced in the walls in both directions of the building.
4. Light roofs should be properly anchored.

A building is to be designed and constructed in such a way that even in the event of the probable earthquake or cyclone in the region,

1. An ordinary building should not suffer total or partial collapse.
2. It should not suffer such irreparable damage which would require demolishing and rebuilding
3. It may sustain such damage, which could be repaired quickly, and the building put back to its usual service.
4. The damage to an important building should even be less so that the functioning of the activities during post-emergency period may continue unhampered and this will enable the community buildings to be used as temporary shelters for the affected people.

The present state of knowledge indicates that the above structural safety can be achieved by adopting appropriate design and construction details involving only small extra expenditure.

## 2. Scope and Objectives

The construction of houses for fishermen near coastal area for resettlement is the primary objective of the Project. This is intended to be achieved by constructing housing schemes with Reinforced masonry, Reinforced concrete or Steel frame buildings and buildings using various types of structural systems. The choice of building material and construction technologies will depend upon local conditions such as social living pattern, economic affordability and accessibility of site, strong wind speeds, yearly and daily temperature variations and rainfall in the area. Industrial buildings and institutional structures are excluded from the purview of this guideline. Some of the principals stated herein will also apply to this situation with suitable modification.

Thus the scope of these guidelines is to highlight the basic concepts involved in achieving, appropriate resistance to multi hazards of such buildings. The detailed technical guidelines include the data for preparing technical details such as reinforcement details, planning aspects, quality control and inspection necessary for achieving desired long term performance of the reconstructed settlement. The structural components for the various types of building proposed include the following,

- a) Isolated strip footing or pile foundation.
- b) Load bearing walls for single storey buildings
- c) Framed construction for more than two stories.
- d) Flat roofing for all types of building.
- e) In order to make the structure cost effective certain proven cost effective technologies.

The detailing aspects of these have been included so that the technical recommendations made can be adopted for any type of option based on fishermen user preference.

The document include following appendices:

- Appendix1 - Categories of Earthquake
- Appendix2 - Building Categories of various MultiHazard Resisting Features
- Appendix3 – Information on Costal Regulation Zone
- Appendix4 – MSK Intensity Scale
- Appendix5 – Design Procedure for Wind Resistance in Buildings

### 3. Disaster and Effects

The coastal areas of Tamilnadu are mainly affected by moderate earthquakes and serve cyclones. Therefore effects of cyclones and earthquakes should be considered while designing the structure.

#### 3.1 Earth Quake

Earthquake damages depend on many parameters, including intensity, duration and frequency content of ground motion, geologic and soil condition, quality of construction, etc. Building design must be such as to ensure that the building has adequate strength, high ductility, and will remain as one unit, even when subjected to very large deformation.

Observation of structural performance of buildings during an earthquake can clearly identify the strong and weak aspects of the design, as well as the desirable qualities of materials and techniques of construction, and site selection. The study of damage, therefore, provides an important step in the evolution of strengthening measures for different types of buildings.

The following are the basic causes of building damages during earthquake:

- Ground shaking
- Ground failure
- Tsunamis and Tidal waves
- Fire

- Appendix 1 lists the categories of earthquake damages. According to extent of damage, the post disaster actions to be taken for various damage categories are also suggested in this appendix.

##### 3.1.1 Ground Shaking

The principal cause of Earthquake-induced damage is ground shaking. As the earth vibrates, all buildings on the ground surface will respond to that vibration in varying degrees. Earthquake-induced acceleration, velocities and displacements can damage or destroy a building unless it has been designed and constructed or strengthened to be earthquake resistant. Therefore, the effect of ground shaking on building is a principal area of consideration in the design of earthquake resistant buildings. The Seismic loads are extremely difficult to determine because of the random nature of earthquake motions. However experiences from past strong earthquakes have shown that reasonable and prudent practices can keep a building safe during an earthquake.

### 3.1.2 Ground Failure

Earthquake-induced ground failure has been observed in the form of ground rupture along the fault zone, landslides, settlement and soil liquefaction.

Ground rupture along a fault zone may be very limited or may extend over hundreds of kilometers. Ground displacement along the fault may be horizontal, vertical or both, and can be measured in centimeters or even in meters. While landslide can destroy a building, the settlement may only damage the building.

Soil liquefaction can occur in low-density saturated sands of relatively uniform size. The phenomenon of liquefaction is particularly important for dams, bridges, underground pipelines, and buildings standing on such loose sandy soils.

### 3.1.3 Tsunamis and Tidal waves

A sudden movement of the ocean floor generally produces tsunamis or seismic sea waves. As the water waves approach land, their velocity decreases and their height increases from 5 to 8m, or even more. Obviously, tsunamis can be devastating for buildings built in coastal areas. Tidal waves are caused by the effect of planets on the sea level. Tidal waves can cause flooding and damage buildings in the coastal zone.

### 3.1.4 Fire

When the fire starts, it becomes difficult to extinguish it. Since a strong earthquake is accompanied by the loss of water supply and fire due to electric short circuit. Therefore, the earthquake damage increases with the earthquake-induced fire in addition to the damage to buildings directly due to earthquakes. Thatch houses are extremely vulnerable for fire damage and consequent loss of property and life.

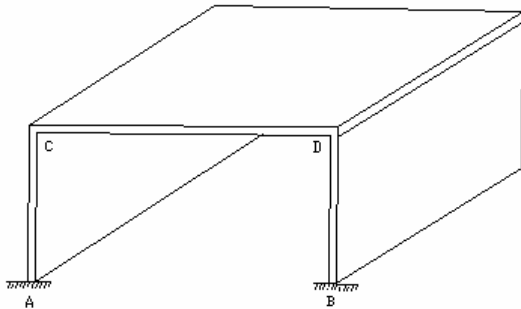
### 3.1.5 Ground Shaking Effect on Structures

#### a) Inertia Force

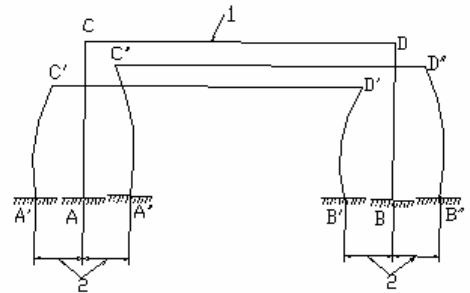
Buildings are fixed to the ground as shown in Fig.1(a). As the base of building moves the superstructure including its contents tends to shake and vibrate from the position of rest, in a very irregular manner due to the inertia of the masses. When the base of the building suddenly moves to the right, the



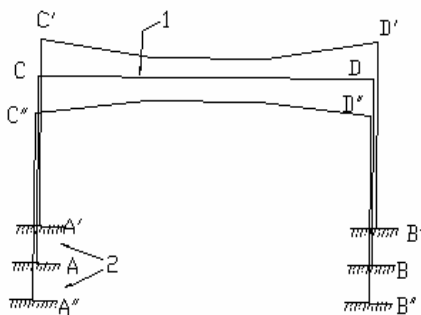
building moves to the left relative the base Fig.1(b), as if it was being pushed to the left by an unseen force which we call **“Inertia Force”**. Actually there is no push at all; but because of its mass, the building resists any motion. The process is much more complex because the ground moves simultaneously in three mutually perpendicular directions during an earthquake as shown in Fig.1(b), (c) and (d).



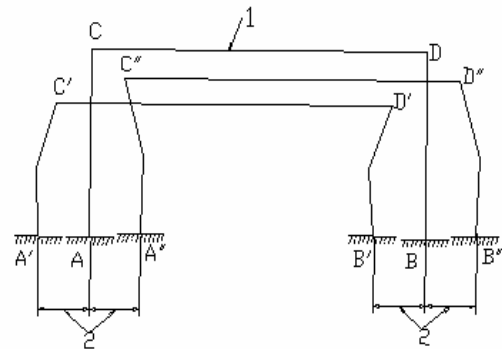
(a) Section of Building



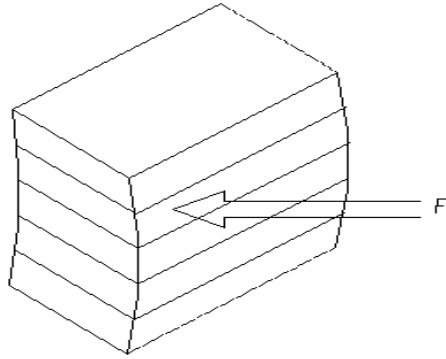
(b) Transverse Vibration



(c) Vertical Vibration



(d) Longitudinal Vibration



(e) Resultant Inertia Force on Building

**Note:**

1. Original Position
2. Base Movement

**Fig.1. Seismic Vibration of a Building and Resultant Earthquake Force**

b) Seismic Load

The resultant internal force or seismic load is represented by the force  $F$  as shown in Fig.1 (e). The force  $F$  is distinctly different from the dead, live, snow, wind, and impact loads. The horizontal ground motion action is similar to the effect of horizontal force acting on the building; hence the term “**Seismic Load**”. As the base of the building moves in an extremely complicated manner, inertia forces are created throughout the mass of the building and its contents. It is these reversible forces that cause the building to move and sustain damage or collapse.

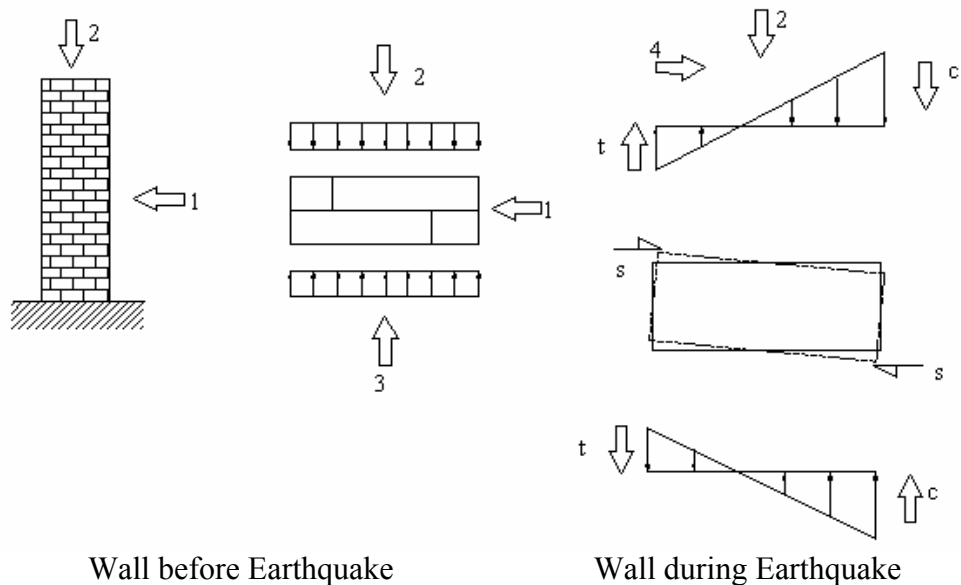
Additional vertical load effect is caused on beams and columns due to vertical vibrations. Being reversible, at certain instants of time the effective load is increased. The stress condition in a typical wall element before and during earthquake is shown in Fig.2.

The earthquake loads are dynamic and impossible to predict precisely in advance, since every earthquake exhibits different characteristics. The following equivalent minimum total lateral force is, used for seismic design:

The design horizontal seismic coefficient  $A_h$  for a structure shall be determined by the following expression.

$$A_h = (Z/2)(I/R)(S_a/g)$$

$$V_B = A_h * W$$

**Note:**

- 1- Wall element, 2-Vertical load from above wall element  
 3-Reaction from below, 4-Earthquake force  
 c- Compressive force, t- Tensile force, s- Shearing stress

**Fig.2.Stress Condition in a Wall Element**

Where,

$V_B$  is design seismic base shear.

$Z$  is earthquake zone factor, which depends upon the ground intensity of the earthquake. The value of  $Z$  usually is plotted on maps in terms of seismic intensity isolines or maximum acceleration isolines. Obviously, the higher the intensity or acceleration, the larger will be the seismic force.

$I$  is the occupancy importance or hazard factor, which depends upon the usage of the building. The higher the importance or larger the hazard caused by the failure of the building, the greater the value of the factor  $I$ .

$R$  is the response reduction factor, which depends on the ductility of the structure. If the structure is built with more detailing to resist earthquake, this factor will be more compared to the ordinarily built frame.

$(S_a/g)$  is the factor which depends on the natural period of vibration of the structure and the site on which the structure stands and the intensity of earthquake.

$W$  is the total weight of the superstructure of a building including its contents. The inertia forces are proportional to the mass of the building and only that part of the loading action that possesses mass will give rise to seismic force on the building. Therefore, the lighter the material, the smaller will be the seismic force.

### 3.1.6 Roofs and Floors

The earthquake-induced inertia force can be distributed to the vertical structural elements in proportion to their stiffness, provided the roofs and floors are rigid to act as horizontal diaphragms. Otherwise, the roof and floor inertia will only go to the vertical elements on which they are supported. Therefore, the stiffness and integrity of roofs and floors are important for earthquake resistance.

The roofs and floors, which are rigid and flat and are bonded or tied to the masonry, have a positive effect on the wall, such as the slab or slab and beam construction directly cast over the walls. Others that simply rest on the masonry walls will offer resistance to relative motion only through friction, which may or may not be adequate depending on the earthquake intensity. In the case of floor consisting of timber joints placed at center-to-center spacing 20 to 25cm with brick tiles placed directly over the joists and covered with clayey earth, the brick tiles have no binding effect on the joists. Therefore, relative displacement of the joists is quite likely to occur during an earthquake, which could easily bring down the tiles, damaging property and causing injury to people. Similar behavior may be visualized with the floor consisting of pre-cast reinforced concrete elements not adequately tied together. In this case, relative displacement of the supporting walls could bring down the slabs.

## **3.2 Cyclones**

The costal areas of Tamil Nadu have experienced a number of cyclonic wind storms causing devastation over large area due to

1. High speed wind velocity, which destroy traditional houses and uproot trees and electric line supports.
2. Local floods caused by heavy rains
3. Storm surge waters, first flowing towards lands and receding back drown people; destroy homes, agriculture, trees etc, whatever comes in the path of flowing water.

High speed wind storms on main land also many times cause severe damage to buildings particularly for the light weight roofs, free standing walls etc. Agricultural fields suffer badly at the seacoast and in the inland under high-speed winds.

The main destruction during cyclones occur in the traditional non-engineered buildings built using local clay, brick, stones, adobe or agro based building materials. The engineered buildings which have high pitched roofs also suffer damage unless appropriate precautions are taken in design as well as construction. Even in heavy construction substantial non-structural damages occur to doors, windows, cladding wall panels, Glass, panes, etc.

The Macro level wind speed zones of India have been formulated and published in IS: 875(part 3) – 1987 titled “ Indian Standard Code of Practice for Design Loads (other than earth quakes) for building and structures, Part 3 Wind Loads”. There are Six basic wind speeds ‘ $V_0$ ’ considered for zoning namely 55, 50, 47, 44, 39, 33 m/s. From wind speed viewpoint, these could be classified as follows:

55 m/s (198 km/h)	- Very high Damage risk Zone – A.
50 m/s (180 km/h)	- Very high Damage risk Zone – B.
47 m/s (169.2 km/h)	- High Damage risk Zone.
44 m/s (158.4 km/h)	- Moderate damage risk Zone - A.
39 m/s (140.4 km/h)	- Moderate damage risk Zone - B.
33 m/s (118.8 km/h)	- Low damage risk Zone.

### 3.2.1 Design Wind speed and Pressure

The value of wind pressure depends on

1. Aerodynamic flow of wind around the building.
2. The windward vertical faces of the building
3. the leeward faces getting suction effects
4. Slope of the pitched roofs

The projected elements of the building like window sunshades, roof at eave levels are subjected to uplift pressures several times the intensity of horizontal wind pressure  $p_z$ . These factors play an important role in the vulnerability of a building type in a given wind speed zone.

The design Wind pressure at a height  $Z$  above the ground level on a surface normal to the wind stream is given by  $p_z = 0.0006 V_z^2$

Where,

$V_z$  = Design wind velocity m/s

$p_z$  = Design wind pressure kN/m<sup>2</sup>

The basic wind speed being the same in a given zone.

### 3.2.2 Coastal Areas

The Coastal areas are subjected to severe windstorms and cyclonic storms. It is known that in certain events, the wind gusts could appreciably exceed the specified basic wind speeds (by as much as 40 to 55%). However for design of structures (except those considered very important) the above mentioned macro-level zoning stated is considered as adequate.

The frequency of occurrences of cyclones on different portions of the east coast has been different. Even for the same design wind speed, the risk of damage per year will be higher in areas subjected to more frequently occurring cyclones.

### 3.2.3 Storm Surge/Tidal Waves

Besides the very high velocity winds, the coastal areas suffer from the onslaught of seawater over the coast due to storm surge generated by cyclones. A storm surge is the sudden abnormal rise in sea level caused by the cyclones. The surge is generated due to interaction of air, sea and land. The seawater flows across the coast as well as inland and then recedes back to the sea. Huge loss of life and property takes place in the process. The height of the storm surge is even higher during the period of high tides.

### 3.2.4 Types of Damage during Cyclones

The Wind Pressures and suction effects on flat objects could be sufficient to lift them off and fly away from their place of rest unless adequately tied down to firm supports, due to the aerofoil effects of cyclonic wind storms. Table 1 summarizes general aerofoil effects of wind storms

**Table1: Aerofoil Effect of Wind**

<b>Wind Speed , m/sec</b>	<b>Typical Possible Movement</b>
30-35	Roof Sheets fixed to purlins fly
35-40	Small Aircrafts take off automatically (if not held down)
40-45	Roof tiles nailed to battens fly
45-50	Garden walls blow over and fall
50-55	Un-reinforced brick walls fail
55-60	Major damage is caused by flying debris
60-65	70 mm thick concrete slabs fly

The resistance required to be provided for multihazard depends on the various categories of buildings as specified in Appendix 2

## **4. Construction and Planning Aspects for resistance against disasters**

### **4.1 Site/soil particulars**

#### 4.1.1 Site Selection

The choice of site for a building from the failure prevention point of view is mainly concerned with the stability of the ground. The very loose sands or sensitive clays are liable to be destroyed by the earthquake so much as to lose their original structure and thereby undergo compaction. This would result in large unequal settlements and damage the building. If the loose cohesion less soils are saturated with water they are likely to lose their shear resistance altogether during ground shaking. This leads to liquefaction.

Although such soils can be compacted, for small buildings the operation may be too costly and the sites having these soils are better avoided. For large building complexes, such as housing developments, new colonies, etc., this factor should be thoroughly investigated and the site selected appropriately.

Therefore a site with sufficient bearing capacity and free from the above defects should be chosen and its drainage condition improved so that no water accumulates and saturates the ground especially close to the footing level.

#### 4.1.2 Bearing Capacity of Foundation Soil

Three soil types are considered here:

- Firm – Those soils which have an allowable bearing capacity of more than  $10\text{t/m}^2$
- Soft – Those soils, which have allowable bearing capacity less than or equal to  $10\text{t/m}^2$
- Weak – those soils, which are liable to large differential settlement or liquefaction during an earthquake.

Buildings can be constructed on firm and stiff soils but it will be dangerous to build them on weak soils. Hence appropriate soil investigation should be carried out to establish the allowable bearing capacity and nature of soil. Weak soils must be avoided or compacted to improve them so as to qualify them either as firm or stiff.



## **4.2 Foundations**

For the purpose of making a building truly disaster resistant, it will be necessary to choose an appropriate foundation type. Since loads from typical low height buildings will be light, providing the required bearing area will not usually be a problem. For choosing the type of footing from the earthquake angle, the soils may be grouped as firm and soft avoiding the weak soil.

### 4.2.1 Firm Soil

In firm soil conditions, any type of footing (individual or strip type) can be used. It should of course have a firm base of lime or cement concrete with requisite width over which the construction of the footing can be started. It will be desirable to connect the individual reinforced concrete column footings by means of RC beams just below plinth level (plinth band).

### 4.2.2 Soft Soil

In soft soil, it will be desirable to use a plinth beam on all walls and where necessary to connect the individual column footings by means of ground beams as well. It may be mentioned that continuous reinforced concrete footings are considered to be most effective from disaster resistance considerations as well as storm surge resistance consideration. Such foundations also avoid differential settlements under normal vertical loads. Continuous footing should be reinforced both in the top and bottom faces, width of the footing should be wide enough to make the contact pressures uniform, and the depth of footing should be below the lowest level of possible scour.

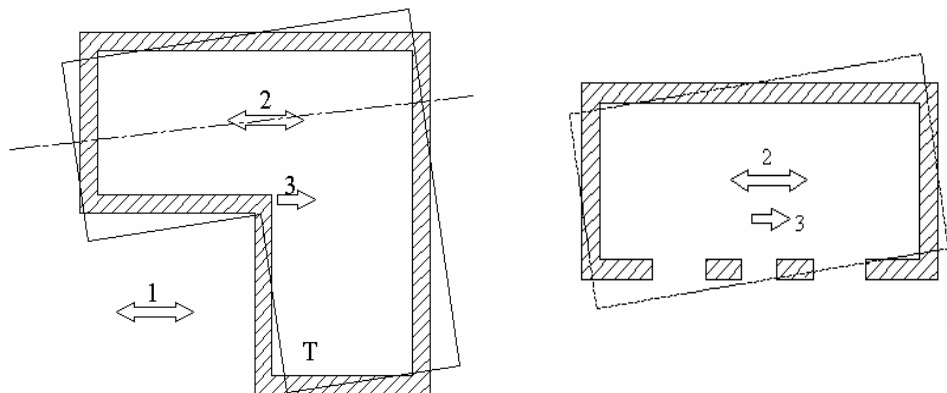
### 4.2.3 Selection of Foundations type

Certain type of foundation is more susceptible to damage than others. Isolated footings of columns are likely to be subjected to differential settlement particularly where the supporting ground consists of soft type of soil. Mixed type of foundation within the same building may also lead to damage due to differential settlement. The following types of foundation are suggested for shallow or deep foundation (Table.2).

**Table2: Type of Foundation**

Type	Description
Shallow Foundation	Wall or column embedded in soil, without footing (To be avoided)
	Rubble stone (field stone) isolated footing
	Rubble stone (field stone) strip footing
	Reinforced concrete isolated footing
	Reinforced concrete strip footing
	Mat foundation
Deep Foundation	Reinforced concrete bearing piles
	Reinforced concrete skin friction piles
	Steel bearing piles
	Wood piles
	Steel skin friction piles
	Cast in place concrete piers
	Caissons

### 4.3 Plan of Building



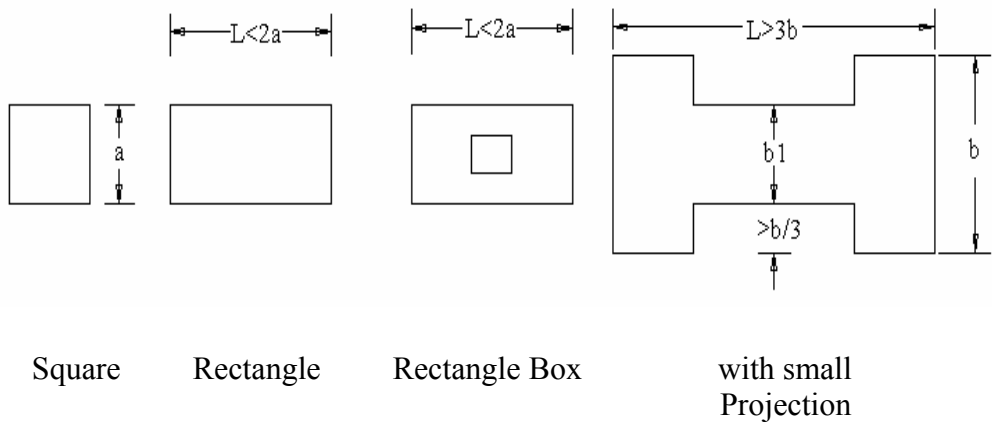
**Note:**

- 1- Earthquake force
- 2- Center of Stiffness or Resistance Force
- 3- Center of Gravity or the Applied Inertia Force
- T- Twisted Building

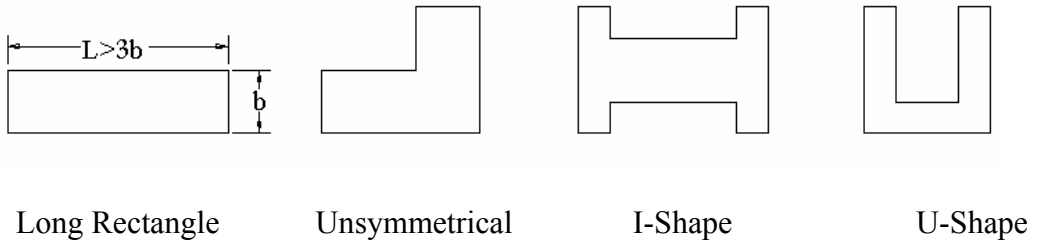
**Fig.3. Torsion of Unsymmetrical Building**

4.3.1 Symmetry

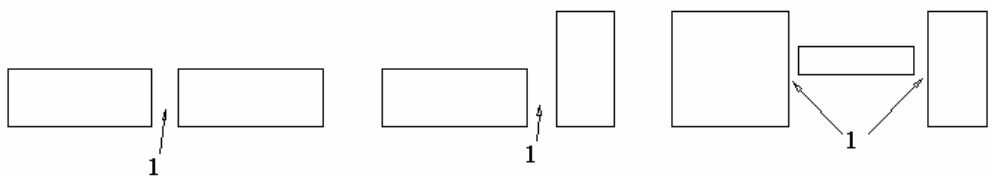
The building as a whole or its various blocks should be kept symmetrical about both the axes. Asymmetry leads to torsion during earthquakes and is dangerous. Torsion due to asymmetric bending is shown in Fig.3. Symmetry is also desirable in the placing and sizing of door and window openings as far as possible.



(a) Symmetrical desirable plans



(b) Long or Unsymmetrical Undesirable plans



**Note:**

1-Separations

(Separation should be 1 cm per story height with a minimum of 3cm)

(c) Use of Separation for improving behaviour of building

**Fig.4.Plan of Building Block**

### 4.3.2 Regularity

Simple rectangular shapes (Fig.4(a)) behave better in an earthquake than shapes with projections (Fig.4(b)). Torsional effects of ground motion are pronounced in long narrow rectangular blocks. Therefore, it is desirable to restrict the length of a block to three times its width. If longer lengths are required two separate blocks with sufficient separation in between should be provided (Fig.4(c)).

### 4.3.3 Regulations on Gaps between buildings

Separation of a large building into several blocks may be required so as to obtain symmetry and regularity of each block. For preventing hammering or pounding damage between blocks a physical separation of 3 to 4 cm throughout the height above the plinth level will be adequate as well as practical for buildings upto 3 storey height.

### 4.3.4 Simplicity

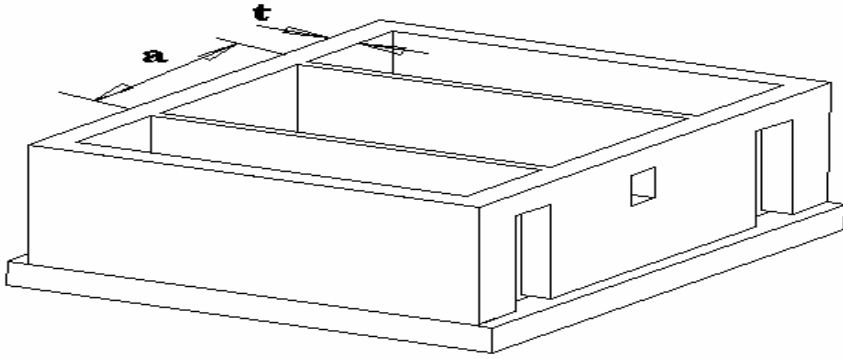
Ornamentation involving large cornices, vertical or horizontal cantilever projections, fascia stones and the like are dangerous and undesirable from disaster resistance viewpoint. Simplicity is the best approach. Where ornamentation is insisted upon, it must be reinforced with steel, which should be properly embedded or tied into the main frame of the building.

### 4.3.5 Enclosed Area

A small building enclosure with properly interconnected walls acts like a rigid box. The strength of long walls is derived from transverse walls. Therefore structurally it will be advisable to have separately enclosed rooms, Fig.5(a) rather than one long room, Fig.5(b). For unframed wall of thickness  $t$  and wall spacing of  $a$ , ratio of  $a/t = 40$  should be the upper limit between the masonry cross walls made with mortars of cement sand 1:6 or richer and less for poorer mortars. For larger panels or thinner walls, framing elements should be introduced as shown at Fig 5(c).

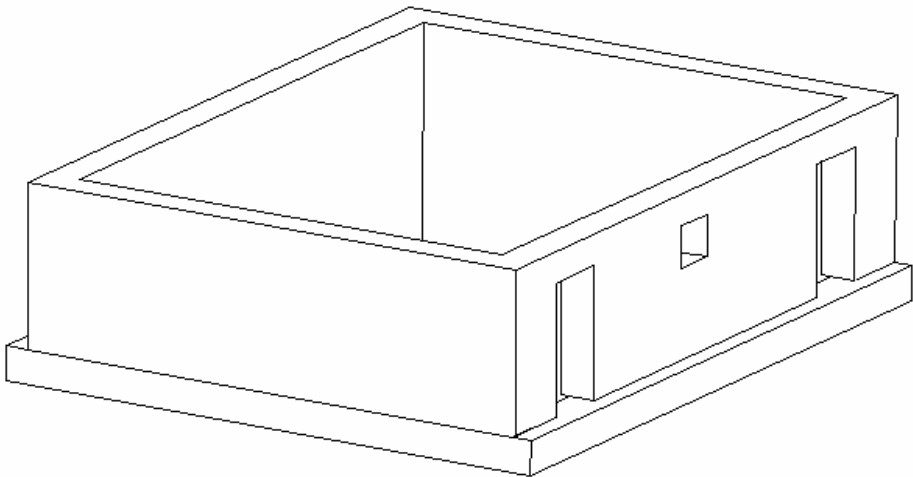
### 4.3.6 Separate Buildings for Different Functions

In view of the difference in importance of hospitals, schools, assembly halls residences, communication and security buildings, etc., it may be economical to plan separate blocks for different functions so as to effect economy in strengthening costs.

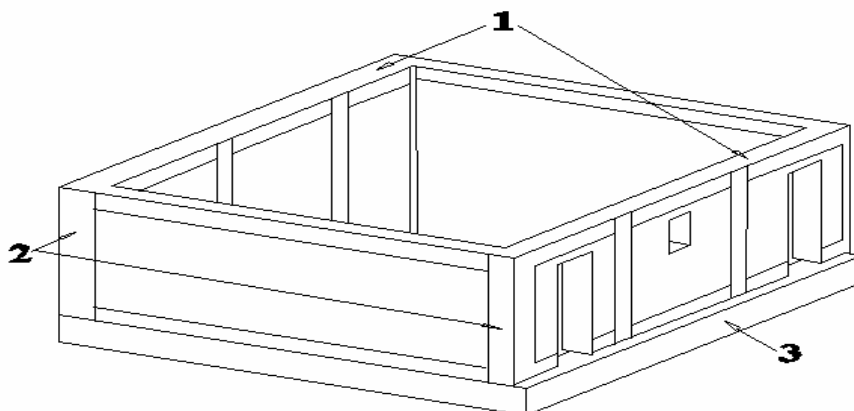
**Note:**

For  $t$  thickness of wall, 'a' should be such that  $a/t \leq 40$ . Otherwise framing should be used as shown as shown in (c).

(a) Many cross walls, small boxes, seismically strong



(b) No cross walls- large boxes are seismically weak

**Note:**

- 1-Collar beam,
- 2-Column (or)  
Buttress,
- 3-Foundation.

(c) Wall with framing elements (usually Reinforced Concrete)

**Fig.5.Enclosed area forming box units**

For various types of occupancies the dead load and load to be considered are give in annexure 7.

The institutional building such as hospital, dispensaries and educational institutions should have provisions for physically challenged and aged as given in annexure8

#### **4.4 Building with Fired Brick Masonry Units**

The masonry wall fails in a brittle manner during disaster. Herein we discuss on causes of failure of masonry units, its strength and reinforcement requirement in wall construction to avoid sudden failure.

##### 4.4.1 Causes of Failure

The load bearing walls is to be built either with rectangular blocks or stone masonry in cement – sand mortar. The following are the main weakness in the un-reinforced masonry constructions. These weakness lead to extensive damages during disasters.

1. Heavy weight and very stiff buildings, attracting large seismic inertia forces.
2. Very low tensile strength, particularly with poor mortars.
3. Low shear strength, particularly with poor mortars.
4. Brittle behavior in tension as well as in compression.
5. Weak connection between the longitudinal and transverse walls

6. Weak connection between the roof and wall
7. Stress concentration at corners of windows and doors.
8. Overall un-symmetry in plan and elevation of building.
9. Un-symmetry due to imbalance in the sizes and positions of openings in the walls.
10. Defects in construction such as use of substandard materials, unfilled joints between bricks, out of plumb walls, improper bonding between walls at right angles etc.

#### 4.4.2 Typical strengths of Masonry

The crushing strength of masonry used in the walls depends on many factors such as the following:

- a) Crushing strength of the masonry unit brick.
- b) Mix of the mortar used and age at which tested. The mortar used for different wall constructions varies in quality as well as strength. It is generally described on the basis of the main building material such as cement or lime mortar, cement lime composite mortar, lime-pozzolana or hydraulic lime mortar. Clay mud mortar is also used in rural areas.
- c) Slenderness ratio of the wall, that is, smaller of the ratio of effective height and effective length of the wall to its thickness. Larger is the slenderness ratio, smaller is the strength.
- d) Eccentricity of the vertical load on the wall – larger the eccentricity, smaller is the strength.
- e) Percentage of openings in the wall – Larger the openings, smaller will be the strength. The tensile and shearing strengths of masonry mainly depend upon the bond.

Adhesion at the contact between the masonry unit and the mortar is only a small percentage of the crushing strength. Richer the mortar in cement or lime content, higher is the percentage of tensile and shearing strength in relation to the crushing strength. Test carried out on brick-couplets using hand made bricks in cement mortar give compressive strength values shown in Table.3.

**Table3: Typical Strengths of Masonry**

Mortar Mix		Tensile Strength Mpa	Shearing Strength Mpa	Compressive Strength in MPa Corresponding to crushing strength of masonry unit			
Cement	Sand			3.5	7.0	10.5	14.0
1	12	0.04	0.22	1.5	2.4	3.3	3.9
1	6	0.25	0.39	2.1	3.3	5.1	6.0
1	3	0.71	1.04	2.4	4.2	6.3	7.5

The modulus of elasticity of masonry very much depends upon the density and stiffness of masonry unit, besides the Mortar mix. For brickwork the values are of the order 2000 MPa for cement-sand mortar of 1:6 proportions. The mass density of masonry mainly depends on the type of masonry unit. For example brickwork will have a mass density of about 19 kN/m<sup>3</sup> and dressed stone masonry 24 kN/m<sup>3</sup>

#### 4.4.3 Mortar

Since tensile and shear strength are important for seismic resistance of masonry walls, use of mud or very lean mortars are unsuitable. Mortar mix of cement: sand equal to 1:6 by volume or equivalent is recommended.

Appropriate mixes for various categories of construction are recommended in Table 4. Use of a rich mortar in narrow piers between openings will be desirable even if a lean mix is used for the walls in general.

**Table4: Recommended Mortar Mixes**

Category of Construction	Proportion of Cement-Lime-Sand
I	Cement-sand 1:4 or cement-lime-sand 1:1:6 or richer
II	Cement-Lime-sand 1:2:9 or richer
III	Cement-sand 1:6 or richer
IV	Cement-sand 1:6 or Lime-surki 1:3 or richer
Category of construction is defined in Annexure I	

#### 4.4.4 Wall Enclosure

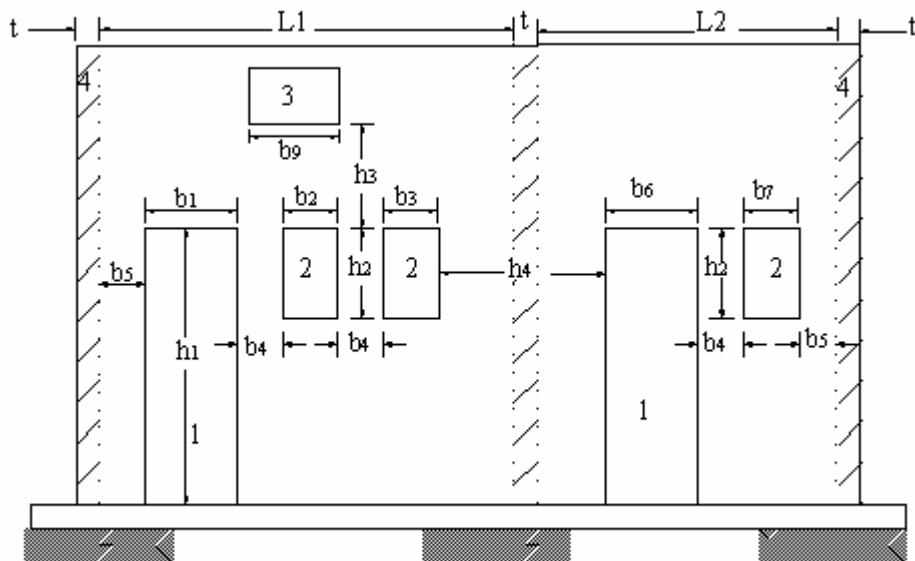
In load bearing wall construction, the wall thickness 't' should not be kept less than 190mm, wall height not more than 20t and wall length between cross-walls not more than 40t. If longer rooms are required, either the wall thickness is to be increased, or buttresses of full height should be provided at 20t or less apart. The minimum dimensions of the buttress shall be equal to thickness and top width equal to t and bottom width equal to one-sixth the wall height.

#### 4.4.5 Openings in Walls

Studies carried out on the effect of openings on the strength of walls indicate that they should be small in size and centrally located. The following are the guidelines on the size and position of openings (Fig 6).



1. Openings to be located away from the inside corner by a clear distance  $b_5$  equal to at least  $\frac{1}{4}$  of the height of openings but not less than 60cm
2. The total length of openings ( $b_1+b_2+b_3$ ) not to exceed 50% of the length ( $L_1$ ) of the wall between consecutive cross walls in single storey construction, 42% in two storey construction and 33% in three storey buildings.
3. The horizontal distance  $b_4$  (pier width) between two openings to be not less than  $\frac{1}{2}$  of the height of the shorter opening but not less than 60cm.
4. The vertical distance from an opening to an opening directly above it  $h_3$  shall not be less than 60 cm nor less than  $\frac{1}{2}$  of the width of the smaller opening
5. When the openings do not comply with requirements mentioned above, they should either be boxed in reinforced concrete all-round or reinforcing bars provided at the jambs through the masonry (Fig.7).



**Note:**

1-Door, 2-Window

3-Ventilator, 4-Cross wall

$$b_1+b_2+b_3 \leq 0.5L_1 \text{ for one storey}$$

$$\leq 0.42L_1 \text{ for two storey}$$

$$\leq 0.33L_1 \text{ for three storey}$$

$$b_6+b_7 \leq 0.5L_2 \text{ for one storey}$$

$$\leq 0.42L_2 \text{ for two storey}$$

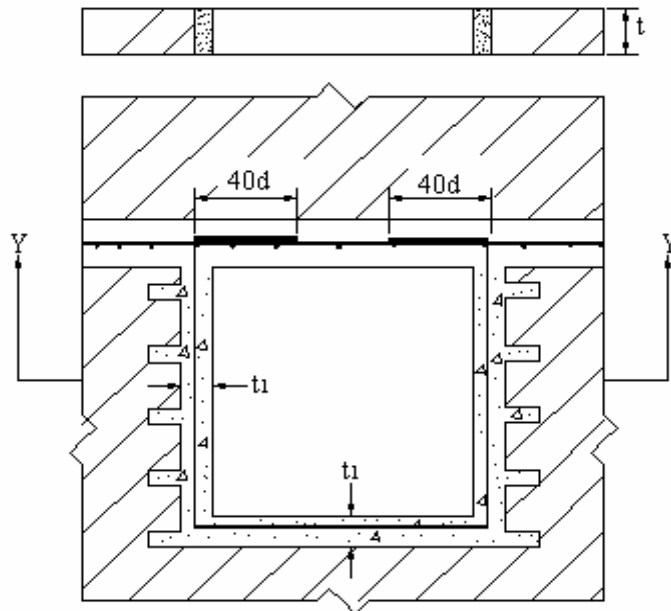
$$\leq 0.33L_2 \text{ for three storey}$$

$$b_4 \geq 0.5h_2 \text{ but not less than 600mm}$$

$$b_5 \geq 0.25h_1 \text{ but not less than 600mm}$$

$$h_3 \leq 600\text{mm } 0.5 (b_2 \text{ or } b_9 \text{ whichever is more})$$

**Fig.6. Recommendations regarding opening in bearing wall.**

**Note:**

t-thickness of wall

$t_1$ -thickness of R.C band

d-dia of reinforcing bar

**Fig.7. Strengthening masonry around opening (window)**

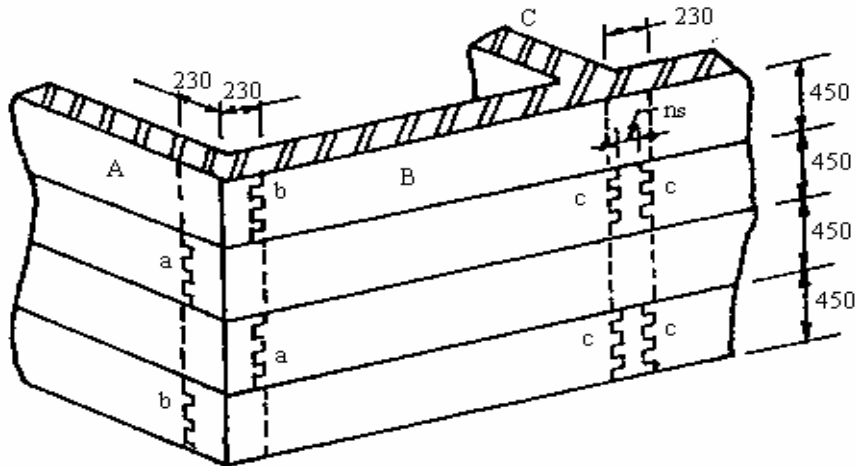
#### 4.4.6 Masonry Bonds

For achieving full strength of masonry the usual bonds specified for masonry should be followed so that the vertical joints are broken properly from the course to course. The following deserves special mention.

For convenience of constructions, builders prefer to make a toothed joint (Fig.8) which is many times left hollow and weak. To obtain full bond it is necessary to make a slopping (stepped) joint by making the corners first to a height of 600mm and then building the wall in between them. Otherwise the toothed joint should be made in both the walls alternately in lifts of about 45cm.

#### 4.4.7 Horizontal Reinforcement in Walls

Horizontal reinforcement in walls is required for imparting to them horizontal bending strength against plate action for out of plane inertia load and for tying the perpendicular walls together. In the partition wall, horizontal reinforcement helps preventing shrinkage and temperature cracks. The following reinforcing arrangements are necessary.

**Note:**

a, b, c-toothed joint in walls

**Fig.8. A typical detail of masonry**

a) Horizontal Band or Ring Beams

Reinforced concrete bands are provided continuously through all load bearing longitudinal and transverse walls at plinth, lintel, and roof-eave levels, also top of gables according to requirements stated below:

1) Plinth band:

This should be provided to resist lateral loads and to avoid differential settlement in coastal areas. It will also serve as damp proof course.

2) Lintel band:

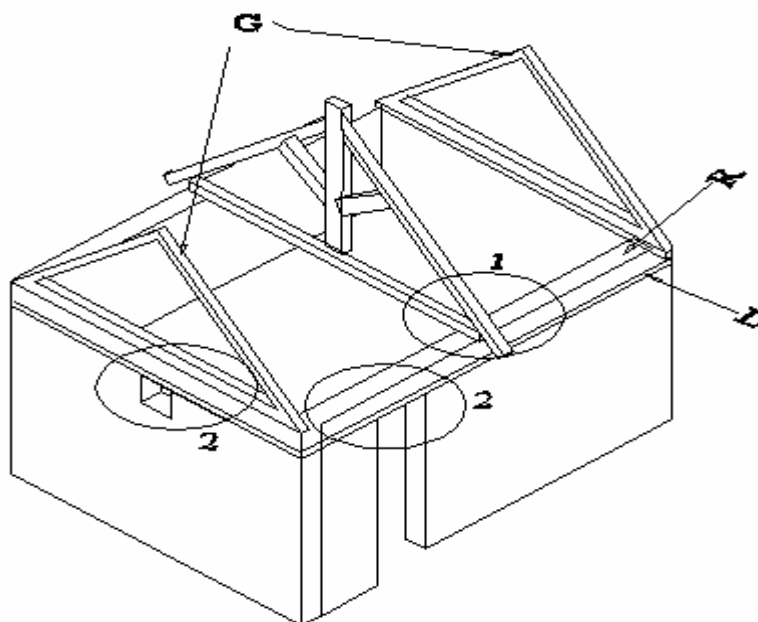
This is the most important band and will incorporate in itself all door and window lintels the reinforcement required for lintel for bridging the door/window opening should be extra to the lintel band steel. It must be provided on all walls in a storey and in all storeys.

3) Roof band:

This band will be required at eave level of roofs and also below or in level with such floors, which consist of joists and covering elements so as to properly integrate them at ends and fix them into the walls.

4) Gable Bands:

The masonry gable ends must have the triangular portion of masonry enclosed in a band, the horizontal part will be continuous with the eave level band on longitudinal walls as shown in Fig.9.

**Note:**

L- Lintel band, R-Roof band, G-Gable band

1. As an alternative to the gable masonry, a truss or open gable may be used and the opening covered with light material like sheeting, mat, etc
2. If the wall height upto eave level is less than or equal to 2.5 m, the lintel level band may be omitted and the lintels integrated with the eave level band.

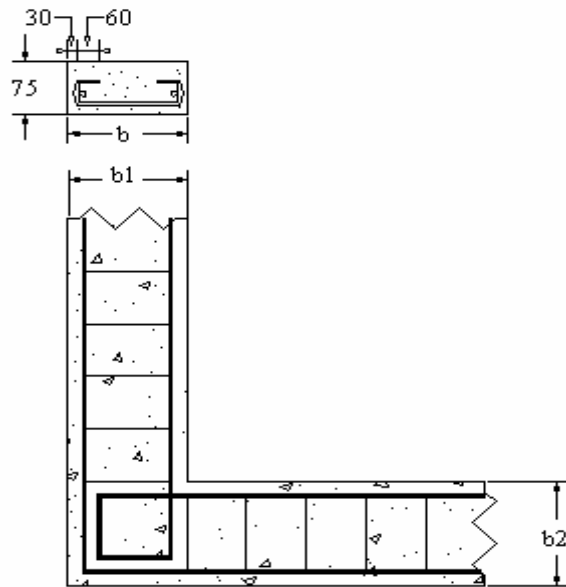
**Fig.9. Gable band and Roof band in building**

b) Selection of Bands or Ring Beams

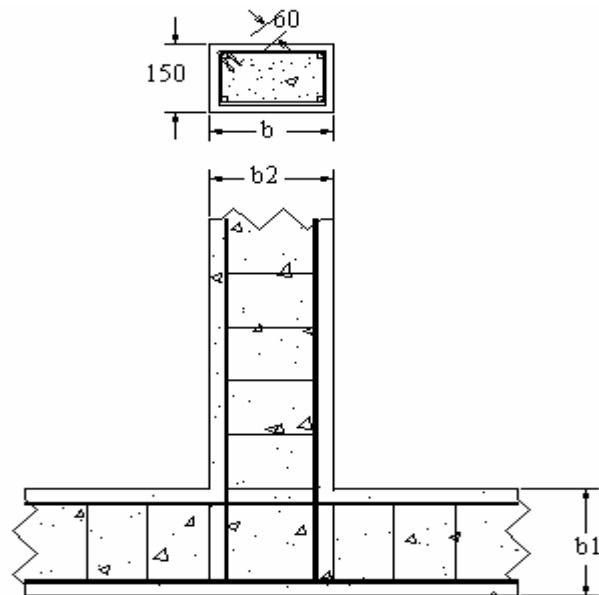
The reinforcement and dimensions of these bands may be kept as follows for wall spans upto 9m between the cross walls or buttresses. For longer spans, the size of band must be specially designed.

A band consists of two (or four) longitudinal steel bars with links or stirrups embedded in 75mm (or 150mm), thick concrete (Fig.10). The thickness of band may be made equal to or a multiple of masonry unit and its width should equal the thickness of wall. The steel bars are located close to the wall faces with 25mm cover and full continuity is provided at corners and junctions. The minimum size of band and amount of reinforcing will depend upon the unsupported length of wall between cross walls and the effective seismic coefficient based on seismic zone, importance of buildings, and type of soil and wind zone as defined by building category (see appendix 2).

Appropriate steel and concrete sizes are recommended for various buildings in Table.5. Bands are to be located at critical levels of the building, namely, plinth, lintel, roof and gables according to requirements (Fig.10).



(a) R.C Band Reinforcement at corner



(b) R.C Band Reinforcement at T-junction

**Fig.10. Reinforcement detail in R.C.Band**

**Table5: Recommendation for steel in RC Band**

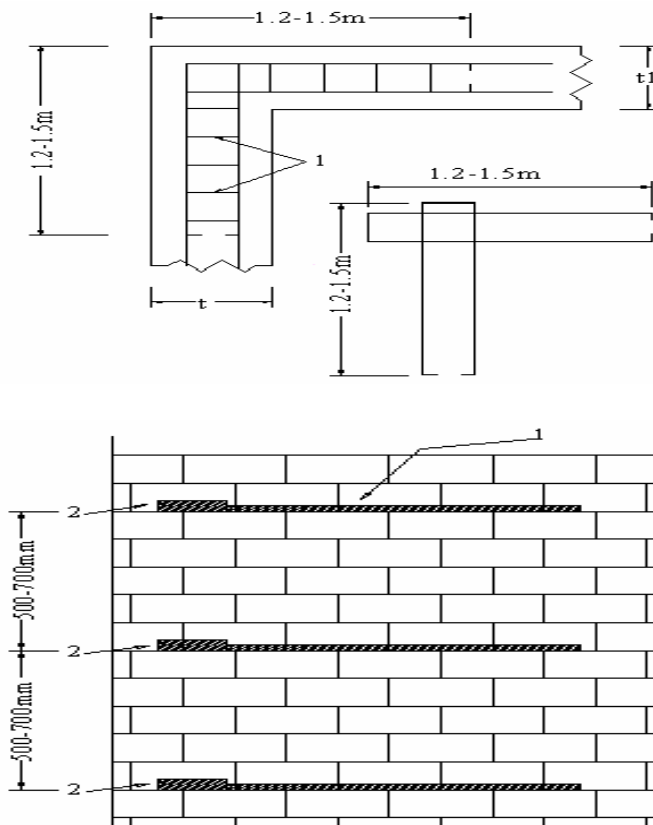
Span (m)	Category I		Category II		Category III		Category IV	
	No.of Bars	Dia.of Bars (mm)	No.of Bars	Dia.of Bars (mm)	No.of Bars	Dia.of Bars (mm)	No.of Bars	Dia.of Bars (mm)
5	2	12	2	10	2	10	2	10
6	2	16	2	12	2	10	2	10
7	2	16	2	16	2	12	2	10
8	4	12	2	16	2	16	2	12
9	4	16	4	12	2	16	2	12

*Notes:*

- 1. Width of the RC band is assumed to be the same as the thickness of wall. Wall thickness shall be 20cm minimum. A cover of 25mm from face of wall should be maintained. For thicker walls, the quantity of steel need not be increased.*
- 2. The vertical thickness of RC band may be kept as minimum 75mm where two longitudinal bars are specified and 150mm where four longitudinal bars are specified.*
- 3. Concrete mix to be 1:1.½:3 by volume or having 20 MPa cube crushing strength at 28 days. W/c ratio to be less than 0.4. In coastal area richer mortar mix having 30 MPa should be used.*
- 4. The longitudinal bars shall be held in position by steel links or stirrups 6mm dia. spaced at 150mm apart.*
- 5. Stirrups may be provided as given in general guidelines.*

#### 4.4.8 Dowels at Corners and Junctions

As a supplement to the bands described above, steel dowel bars may be used at corners and T-junctions to integrate and create the box action of walls. Dowels (Fig.11) are placed in every fourth course or at about 50cm intervals and taken into the walls to sufficient length so as to provide the full bond strength. Wooden dowels can also be used instead of steel. However, the dowels do not serve to reinforce the walls in horizontal bending except near the junctions. It is preferable to embed the dowel reinforcement in concrete of at least 40mm cover to protect them against corrosion.

**Note:**

$t$  &  $t_1$  - Wall thickness

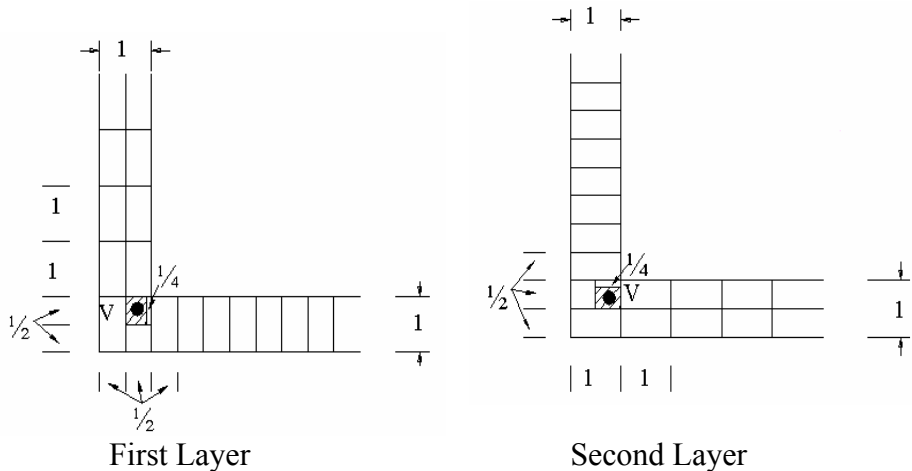
1 - Cross links

2 - Thicker joints to receive bars

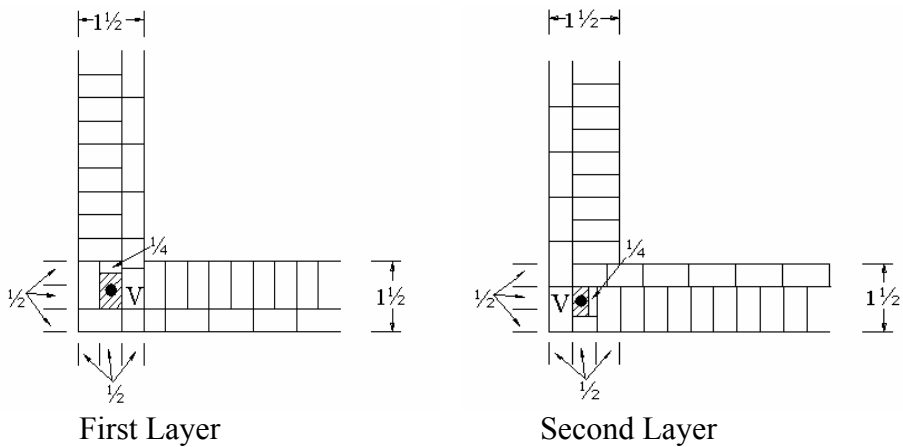
**Fig.11. Corner strengthening by Dowel Reinforcement**

#### 4.4.9 Vertical Reinforcement in Walls

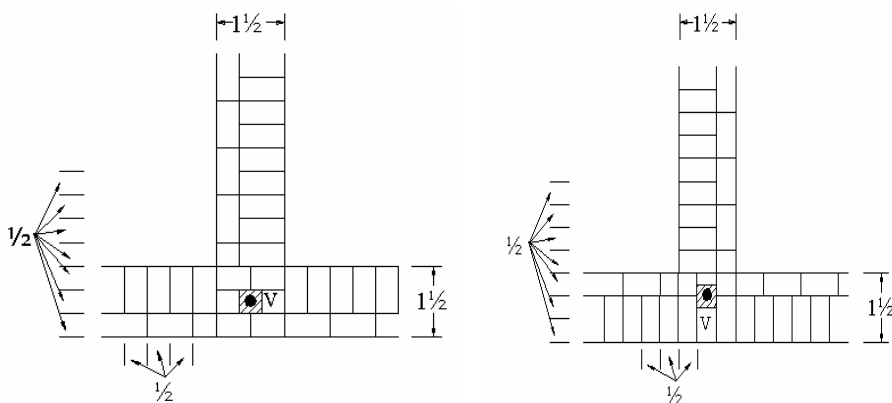
The critical sections are the jambs of openings and the corners of walls. The amount of vertical reinforcing steel will depend upon several factors like the number of storey, storey heights, the effective seismic force based on seismic zone, importance of building and soil foundation type. Values based on rough estimates for building are given in Table.6 for ready use. The steel bars are to be installed at the critical sections that is the corners of walls and jambs of doors, right from the foundation concrete and covered with cement concrete in cavities made around them during masonry construction. This concrete mix should be kept 1:1.½:3 by volume or richer (W/c ratio to be less than 0.4). Typical arrangements of placing the vertical steel in brick work are shown in Fig.12. In coastal area concrete of grade M30 is to be used.



(a) Corner junction details for one brick wall for providing Vertical Steel



(b) Corner junction details for one and a half brick wall for providing Vertical Steel.



(c) T-junction details for one and a half brick wall for providing Vertical Steel.

**Note:**  
V-Vertical steel

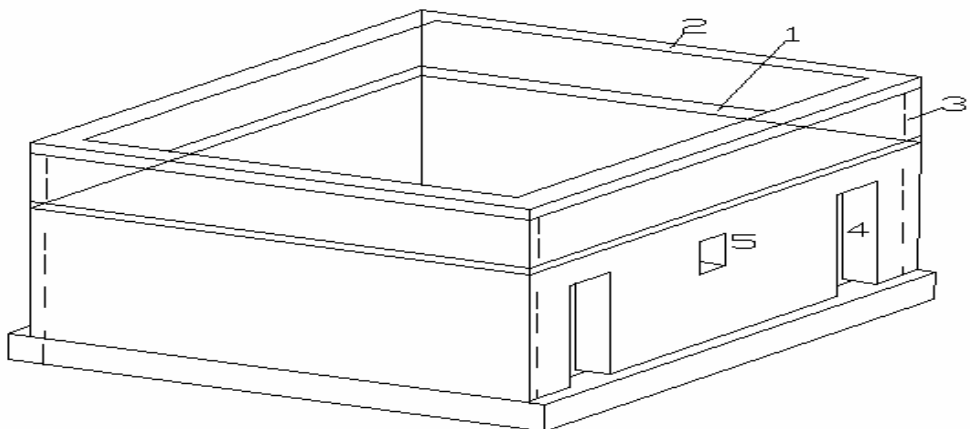
**Fig.12. Vertical Reinforcement in walls**



**Table6: Diameter of steel bar to be provided at critical section**

No of Storey	Storey	Diameter of steel bar in mm at each critical Section for the respective category			
		Category I	Category II	Category III	Category IV
One		16	12	12	Nil
Two	Top	16	12	12	Nil
	Bottom	20	16	16	Nil
Three	Top	16	12	12	Nil
	Middle	20	16	12	Nil
	Bottom	20	16	16	Nil
Four	Top	(2)	(2)	12	12
	Third			12	12
	Second			16	12
	Bottom			16	12
<p>(1) Category of construction is defined in Appendix 2</p> <p>(2) Four storied load bearing wall construction should not be used for categories I and II buildings.</p>					

The jamb steel of window openings will be easiest to provide in box form around it. The vertical steel of opening may be stopped by embedding it into the lintel band but the vertical steel at the corners and junctions of walls must be taken into the floor or roof slabs or into roof band (Fig.13).



**Note:**

- 1-Lintel band, 2-Roof band  
 3-Vertical steel, 4-Door, 5-Window

**Fig.13.Overall arrangement of reinforcing low strength masonry building**

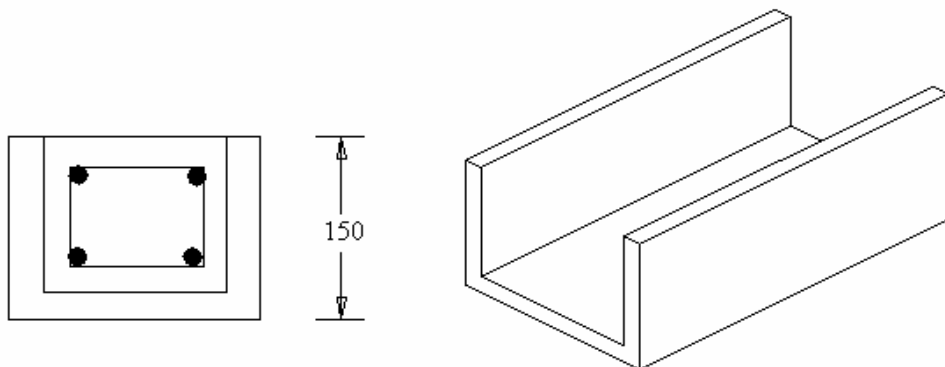
## 4.5. Building with Cost Effective Masonry units

### I. Hollow Block Masonry

The following details may be followed in placing the horizontal and vertical steel in hollow block masonry using cement-sand or cement concrete block.

#### 4.5.1 Horizontal Reinforcement

U-shaped block may be used for construction of horizontal bands at various levels of storey as per seismic requirements as shown in Fig.14. The amount of horizontal reinforcement may be taken 25% more than that given in Table.5 and provide by using 4 bars and 6mm dia strippus. Other details shall be followed as shown in Fig.10.

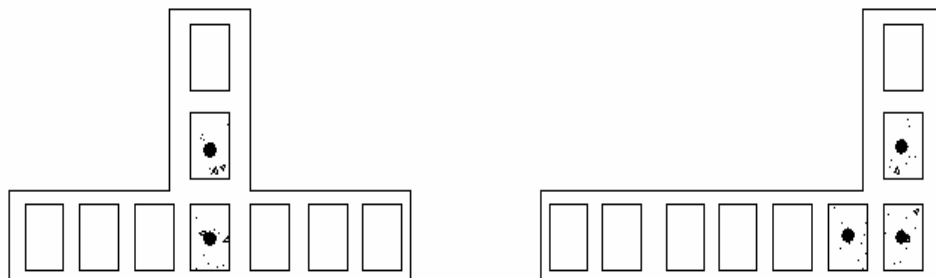


**Fig.14. U-Block for Horizontal Bands**

#### 4.5.2 Vertical Reinforcement

Vertical bars specified in Table.6 may conveniently be located inside the cavities of hollow block, one bar in one cavity. When more than one bar is planned, they should be place in 2 or 3 consecutive cavities as shown in Fig.15. Cavities having bars are filled with micro-concrete (1:2:3) or cement sand mortar (1:3) and properly compacted.

Practical difficulty is faced in threading the bar through the hollow block since the bars have to be set in footings and has to be set vertically while lifting the blocks for a whole story heights, threading the bar into the cavities and lowering it down to the bedding level. To avoid lifting of block too high, the bars are made shorter and lapped adequately with upper portion of bars.



**Fig.15. Vertical Reinforcement in Cavities for Hollow Block Masonry**

## **II. Compressed Stabilized Earth Block (CSEB) Masonry**

The earth is a locally available material. It can be stabilized with cement. The interlocking keys of a typical block (Appendix 6) increase the strength of the wall against lateral forces. The interlocking blocks can be suitable reinforced for disaster resistance.

The CSEB technology can be effectively used based on training manual given in the reference 7 of Appendix 7.

However, when using this technology, for ensuring adequate quality blocks have to be tested and a record has to be kept with respect to strength under wet and dry condition.

Other cost effective techniques like rat-trap bond masonry etc, can also be used provided the disaster resistance features are incorporated in them.

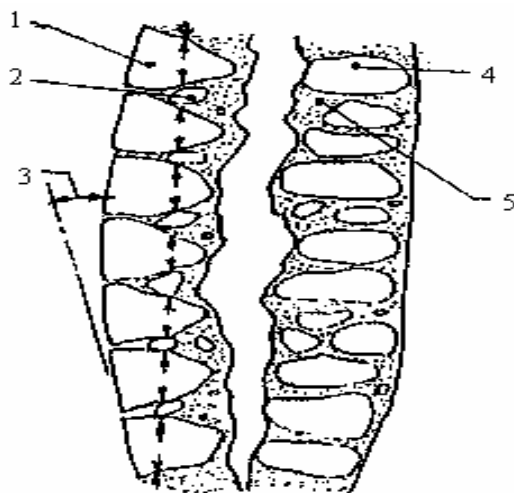
### **4.6. Construction Guidelines for Building with Stone Masonry**

#### **4.6.1 Stone Masonry Construction**

Stone buildings using fully dressed rectangularized stone units, or cast solid blocks consisting of large stone pieces in cement mix 1:3:6 (cement: sand: large stone pieces) may be built. Those also generally apply to the random-rubble and half-dressed stone buildings.

#### **4.6.2 Typical Damage and Failure of Stone Buildings**

Random rubble and half-dressed stone buildings (Fig.16) have suffered extensive damage and complete collapse during past earthquakes and other disaster.



Note:

1-Half-dressed conical stone, 2- Small alignment stone, 3- Rotation of Wythe  
4-Random rubble, 5- Mud or weak lime mortar

**Fig.16.Wall Delaminated with Buckled Wythe**

The following are the main ways in which such buildings are seen to be damaged:

- Separation of walls at corners and T-junctions takes place even more easily than in brick buildings due to poor connection between the walls.
- Delamination and bulging of walls that is vertical separation of internal wythe and external wythe through the middle of wall thickness. This occurs due mainly to the absence of “through” or bond stones and weak mortar filling between the wythes. In half-dressed stone masonry, the surface stones are pyramidal in shape having more or less an edge contact one over the other. Thus the stones are in an unstable equilibrium and they get easily disturbed under minor shaking of the ground.

Crumbling and collapsing of bulged wythes after delamination under heavy weight of roofs/floors, leading to collapse of roof along with walls or causing large gaps in walls are common occurrences during earthquakes.

Outward overturning of stone walls occur after separation at corners due to inertia of roofs and floors and their own inertia when the roofs are incapable of acting as horizontal diaphragms. This particularly happens when the roof is flexible and consists of round poles, reed matting and clay covering.

Frequently, such stone houses are completely shattered and razed to the ground, the walls reduced to only heaps of rubble. People get buried and more often killed. Thus such buildings, without the structural improvements as suggested here below, can be considered as dangerous particularly in seismic zone III or higher or during high tidal waves.

#### 4.6.3 Typical Structural Properties

Test data on the strength characteristics of random rubble and half-dressed stone masonry is not available. It is, however, qualitatively known that the compressive strength even while using clay mud as mortar will be enough to support three storeys but the tensile strength could only be near about zero. Sliding shear strength will only be due to frictional resistance.

#### 4.6.4 General Construction Aspects

##### a) Overall Dimensions

1. The height of the construction may be restricted to one storey for Category I and II and two storeys for categories III and IV buildings. Where light sheeted roof is used, an attic floor may also be provided. The height of storey may be kept as low as 2.5m
2. The Wall Thickness should be as small as feasible, say 300 to 450mm.
3. The unsupported length of a wall between cross walls may be limited to 7m.
4. For longer walls, buttresses may be used at intermediate points not farther apart than 3m. The size of buttress may be kept as:  
Thickness = top width =  $t$  and  
Base width =  $h/6$   
where,  
 $t$  = thickness and  $h$  = actual height of the wall respectively.

##### b) Mortar

Clay mud mortar should be avoided. Mortars as specified and recommended in Table.4 may be used for stone walls.

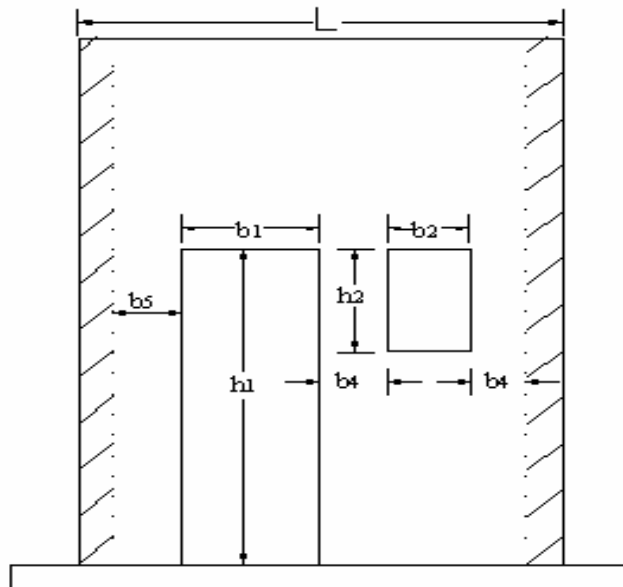
##### c) Openings in Walls

Openings should be as small and as centrally located as practicable. The recommended opening limitations are shown in Fig17. Ventilator, where used, may be made of size 450 x 450mm or smaller.

#### d) Masonry Bond

Random rubble masonry construction should be brought to courses at not more than 600mm lift.

“Through” stones of full length equal to wall thickness should be used in every 600mm lift at not more than 1.2m apart horizontally. If full length stones are not available, stones in pairs, each of about  $\frac{3}{4}$  of the wall thickness may be used in place of one full length stone so as to provide an overlap between them



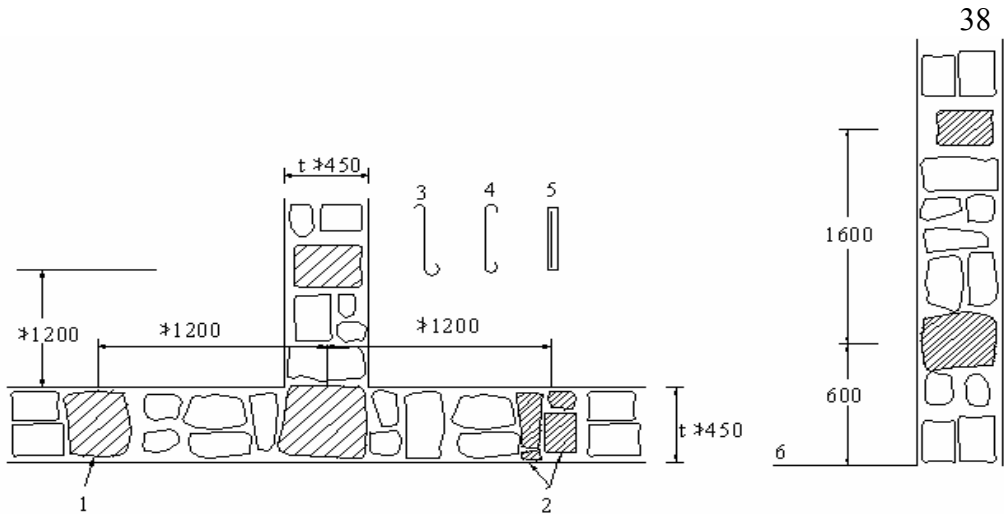
**Notes:**

$$b_1 + b_2 < 0.3L$$

$$b_4 \geq 0.5h_2 \text{ but not less than } 600\text{mm}$$

$$b_5 \geq 0.25h_1 \text{ but not less than } 600\text{mm}$$

**Fig.17.Recommended Opening in Bearing Walls in Rubble Masonry**



**Note:**

- 1. through stone, 2. Pair of overlapping stone, 3. S-shape tie
- 4. Hooked tie, 5. Wood plank, 6. Floor level

**Fig.18.Through Stone and Bond Elements**

In place of “through” stones, bonding elements made of steel bars 8 to 10 mm diameter in S-shape or as a hooked link may be used with a cover of 25mm from each face of the wall (Fig.18)

Alternatively, wood bars of 38mm x 38mm cross-section or equivalent may be used for the “through” stones. Wood should be well preserved through seasoning and chemical treatment so as to be durable against weathering action and insect attack (Fig.18). Use of bond stones should also be made at corners and junction of walls to break the vertical joint and provide bonding between perpendicular walls.

e) Horizontal Reinforcement for Walls

All the horizontal reinforcements recommended for brick buildings may be used for random rubble constructions as well.

f) Vertical Reinforcement for Walls

The amount of vertical steel in masonry walls required to be provided at the corners and T- Junctions of walls and at jambs of openings is shown in Table.7 and in Fig.19.

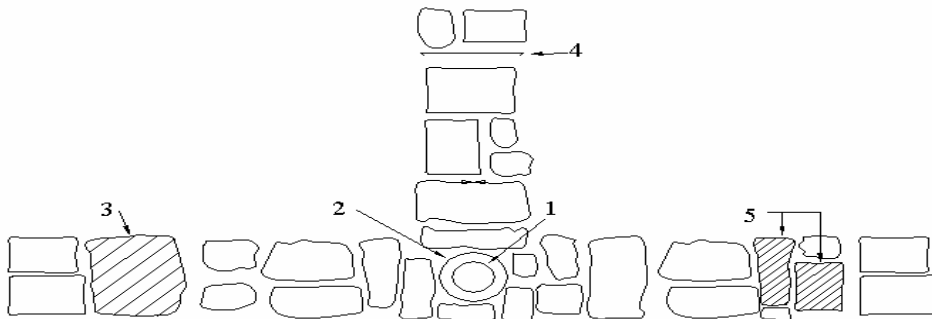
**Table7: Recommended Vertical Steel at Critical Sections**

No. of storey	Diameter of bar in mm at each critical section for category (See note 1)		
	Category I	Category II	Category III
One	20	16	14
Two	Note (2)	Note (2)	16

Notes:

- 1) Category of construction is defined in Appendix2. Equivalent area of twisted grip bars or a number of mild steel bars could be used alternatively, but the diameter should not be less than 12mm.
- 2) Two storeyed buildings with load bearing stone masonry of random rubble or half-dressed stone type are not recommended in categories I and II.

Buildings of Category IV need not have the vertical steel. For providing vertical bar in stone masonry a casing pipe is recommended around which the masonry is built to heights of every 600mm.

**Note:**

- 1-Vertical Steel Bar
- 2-Casing pipe
- 3-Through stone
- 4-Steel or wood link
- 5-Overlapping pair of stones

Typical Construction Details for Installing Vertical Steel Bar in Random Rubble Stone Masonry

**Fig.19. Vertical Steel Reinforcement in Low Strength Masonry Walls**



The pipe is kept loose by rotating it during masonry construction. Then the casting pipe is raised and the cavity below is filled with 1:1½:3 concrete mix and rodded to compact it. The concrete will not only provide the bond between the bar and the masonry but is also intended to protect the bar from corrosion. In coastal areas care should be taken to use M30 grade concrete and restrict w/c ratio to 0.4 only.

The jamb steel may be taken from the footing up to the lintel band and anchored into it. The corner steel must be taken from the footing up to the roof slab or roof band and anchored into it (similar to anchorage shown in general guidelines).

#### **4.7. Building with Reinforced Cement Concrete**

With the spread of reinforced concrete construction to semi-urban and rural area in Tamil Nadu, often buildings are constructed using reinforced concrete columns and beams, without proper engineering design, based on the experience of local masons and petty contractors. Use of isolated columns together with load bearing walls for supporting long internal beams or those in verandahs and porches is becoming quite common. In most cases, such constructions suffer from deficiencies from the disaster resistance viewpoint since no consideration is given for the effect of lateral loads and the connection details are usually such that no moment carrying capacity due to lateral forces can be relied upon. Beams simply rest on top of columns and mostly held in position by friction. The friction can be overcome by buoyancy or upward movements due to either wind or earthquake or water uplift pressure due to Tidal waves or Tsunami.

The other serious deficiency is in concrete quality in respect of mixing, placing, compacting and curing. The aim of this section is to provide working guidelines for such low-rise, (upto three storeys) small buildings in R.C. frame constructions in which columns are supposed to resist vertical loads as well as horizontal forces and the filler walls are assumed to be neither load bearing nor taking part in the lateral resistance of the building. Large halls for gymnasias, assembly halls, etc., having a floor area more than 60m<sup>2</sup> or beam spans more than 7m must be designed and proof checked for adequacy.

#### 4.7.1 Typical Damage and Collapse of RC Buildings

The following types of damage are quite common in reinforced concrete buildings:

##### a). Sliding of Roofs off supports

Where the beams simply rest on walls or columns, they slide when the lateral load intensity exceeds the Frictional resistance and many times leave the support and fall down, particularly if the bearing length is inadequate.

##### b). Falling of Infill Walls

The infill panel walls in between reinforced concrete columns overturn outside the framework if not held tight or connected properly with the frames.

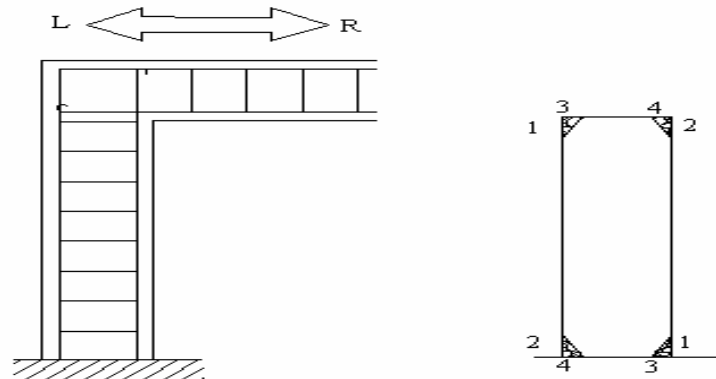
##### c). Crushing of Column Ends and Virtual Hinging

During severe shaking, the column ends are subjected to heavy eccentric compressive stresses. Due to this concrete gets crushed and spalls off from the outer surfaces. In repeated cycles damage progresses inwards. The effective section gets very much reduced. The columns ends virtually start behaving as pins and the whole framework collapses forming a mechanism as shown in Fig.20.

##### d) Short Column Effect

When infill walls with wide openings are attached to the columns, the portions of the columns that will deform under lateral seismic loads become very short as compared to their normal height. Such short columns become

much stiffer than other columns and attract much larger shear forces under which they get severe diagonal tension cracking which lead to failure and collapse of the column.

**Note:**

‘Crushing Sequence’

1-I Cycle movement L to R

2-I Cycle movement R to L

3-II Cycle movement L to R

4-II Cycle movement R to L

**Fig.20.Crushing of Concrete at Ends of Column**

e) Diagonal Cracking in Columns

Columns are subjected to diagonal cracking due to large seismic shears caused under, severe ground shaking. If twisting of the building also occurs, the cracks may take spiral form reducing the load capacity of the columns severely.

f) Diagonal Cracking of Column-Beam Joint

Many times diagonal cracking occurs through the junction of the column with the beam, which seriously impairs the strength of the frame.

#### g) Pulling out of Reinforcing Bars

Where the anchor length of column bars or overlaps between the longitudinal bars are not adequate for developing full tensile strength of the bar, they are often pulled out due to tension caused in the column under severe reversal of stresses.

#### h) Collapse of Gable Frames

Reinforced concrete gable frames, often used for schools, workshops, gymnasia and assembly halls, or cinema halls, have a tendency of spreading out with no secondary resistance available once the joint fails. These are often found to fail and collapse, unless very carefully designed and detailed.

#### i) Foundation Sinking and Tilting

Sinking or tilting of foundations of columns due to seismic shaking occurs in loose soft soils and can lead to severe cracking of the superstructure and can lead to even collapse.

### 4.7.2 Care in Concrete Construction

In reinforced concrete work, the most important requirement for good behavior is good quality of concrete, which is not usually achieved in non-engineered construction. Here simple guidelines are given for making concrete of adequate strength and durability.

#### a) Measuring Materials

In non-engineered reinforced concrete constructions the proportions of concrete mix are usually to be kept as 1:1½:3 by volume of cement: sand: aggregate. Under no circumstance w/c ratio more than 0.45 should be adopted. In non costal areas M20 and M30 in costal area should be the minimum strength adopted. In costal areas w/c ratio should be restricted to 0.4. The aggregate may be in the form of river shingle, or crushed stone, of maximum 20mm size. A 50kg cement sack has a nominal volume of 0.0317m<sup>3</sup>. It will be best to make the concrete mixture using whole bags of cement. For measuring sand and aggregate, a wooden box with handles having a volume equal to one sack of cement will be most accurate as well as convenient to use. The measurement box can also be made of steel sheets.

## b) Mixing Materials

Where mixing is done manually without using a power driven mixer, it should be done on an impervious platform, say, using iron sheets or cemented floor. For making a mix of 1:1½:3, six boxes of aggregates should first be measured and flattened on the platform, and then three boxes of sand should be spread on the aggregate and finally two full sack of cement opened on top. The material should first be mixed thoroughly in dry state so as to obtain uniform colour and then water should be added. The quantity of water should be enough to make a soft ball of the mixed concrete in hand. A little wetter mix is better for hand compaction and drier mix where vibrator is used for compaction. On any account water excess of 0.45 w/c ratio should not be used. It is advisable to limit w/c ratio to 0.4. If necessary, suitable plasticizers can be used for enhancing workability of mix.

## c) Formwork

The quality of not only the concrete surface but also the strength of concrete depends on the quality of the formwork and its imperviousness to the leakage or oozing out of the water and cement through the joints. Wooden or steel sheet formwork with well-formed surface and joints between planks or sheets should be used. Use of water resistant plywood for the skin of the formwork will give very good surface for the concrete.

## d) Placing of Reinforcement

While placing reinforcing bars, the following points must be taken care of otherwise the structure will get into undefined weakness. Minimum clear cover to the reinforcement: 20mm to the bars in slabs, 25mm to bars in beams and 40mm to the bars columns. In large columns, say 450mm in thickness, the cover should be 40mm. For achieving proper cover mortar bricks of required size should be made. They should be properly installed between the bars and formwork. Tying with bars with thin soft binding wire will ensure the proper placement of bar. Mortar bricks should be of good quality so that they do not introduce local weakness below the rebar's

The following precautions are necessary while tying the reinforcement cage:

- Tying of longitudinal bars with transverse bars and stirrups and links at each crossing with soft binding wire.
- Minimum overlap in bars: 45 times the diameter of the bar for plain mild steel and 60 times the diameter for high strength deformed bar. The overlapping portion should preferably be wound with binding wire through the lap length.

- Shape of links and stirrups: the ends of bars should be hooked by bending through  $180^\circ$  in mild-steel bars and  $135^\circ$  in deformed bars.
- The binding wire should be turned inward after binding so that they do not touch the erected formwork.

#### e) Casting and compacting Concrete

The concrete should normally be cast in one continuous operation so as to avoid discontinuity of more than one hour. Mixed concrete should not be allowed to stay on the platform by more than 45 minutes and must be placed in the forms and compacted continually. Hand compaction must be done by rodding through the freshly placed concrete. Simply leveling the surface with trowels will leave voids in the mass. It may be mentioned that lack of compaction results in large reduction in concrete strength, hence utmost attention should be given to this factor. For rodding, good results will be obtained by using 16mm diameter rods about 50cm long. When vibrators are used, form work should be checked to ensure proper water tightness and to withstand vibration effects of wet concrete.

#### f) Curing of Concrete

Concrete work requires water curing for a minimum of 14 days so as to gain strength, otherwise the gain in strength is low and concrete becomes brittle. Concrete slabs may be kept under water by ponding of water over it by making barriers around the edges. Columns should be kept covered with wet empty gunny bags. Keeping the side forms intact on the beam webs and column sides will prevent the evaporation of water from the concrete surface and help in curing. Covering any concrete surface with polythene sheets after wetting the surface will help retain the moisture for longer period of time. Curing should be continuous and not intermittent.

#### g) Construction Joints

Where a joint is to be made, the surface of the concrete shall be thoroughly cleaned and all laitance removed. The surface shall be thoroughly wetted, and covered with a coat of neat cement slurry immediately before placing of new concrete. Construction joints in floors shall be located near the middle of the spans of slabs, beams or girders, unless a beam intersects a girder at this point, in which case the joints in the girder shall be offset a distance equal to twice the width of the beam. Provision of keys should be made for transfer of shear through the construction joint. Polymer bonding agent between old and new concrete can be used for good performance of construction joints.

### 4.7.3 Typical Material Properties required

Concrete is made to have the desired strength for the required use. The strength is defined on the basis of 28 day cube crushing strength. For use in buildings the cube strength  $F_c$  between 20 to 30N/mm<sup>2</sup> will be adequate for RC work.

The concrete mix is accordingly designed for M20 or M30 grade concrete. It is preferable to use M30 grade concrete in costal areas. The mass density of RC is about 24 kN/m<sup>3</sup> and modulus of elasticity is related with the concrete strength. Since the stress-strain characteristics are non-linear, the value of modulus of elasticity is ambiguous.

It is important to know that the tensile strength of concrete is only about one-tenth of the compressive strength. The diagonal tension caused by seismic shear forces, if not thoroughly protected by well-designed stirrups or ties, can lead to wide cracking and failure.

Concrete is a brittle material and weak against impact shock and vibrations. The reinforcing steel imparts ductility to it. The compressive strength as well as straining capacity can be greatly increased by using closely spaced lateral stirrup ties or spiral reinforcement. This is an important method for improving the earthquake resistance of reinforced columns and frames.

The critical zones in reinforced concrete frames where ductility of sections and confinement of concrete by closely spaced stirrups or spiral is essential are:

1. Ends of beam upto a length of about twice the depth of the beam where large negative moments and shears develop are likely locations for plastic hinges. Here shear and moment reversal is possible under large lateral forces.
2. Ends of columns where maximum moments develop due to lateral forces. Values of maximum column moments closely approaching plastic moment capacity can be expected and these moments are likely to undergo full reversal. High lateral shears can be developed based on moments of opposite sign at the column ends and these shears can undergo full reversal. The length of such zones is about one-sixth of the clear height of the column between floors or the dimension of the column section in the plane of the frame.
3. Joint regions between beams and columns undergo very high local shears, there full reversal is likely, diagonal cracking and local deformation may cause significant part of rotation at joint increasing the lateral displacement of frame.

#### 4.7.4 Detailing of Beams

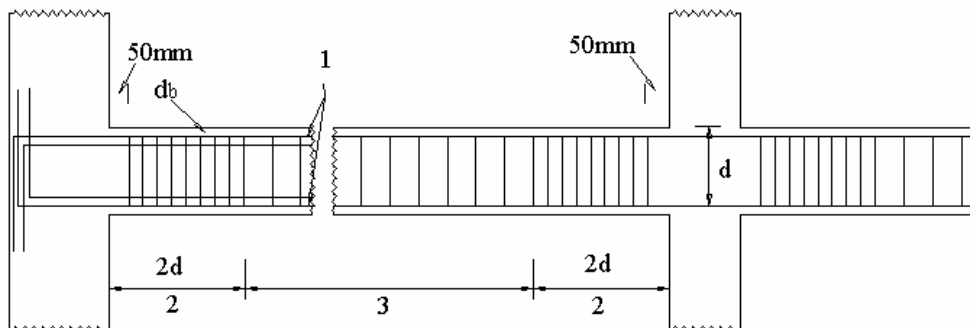
##### a) Longitudinal Steel

Beams should be reinforced on both top and bottom face throughout. Where reinforcement is required by calculation, the percentage should correspond to that required for ductile behavior. The recommended limits on steel area are shown in Table.8. Minimum steel should consist of two bars of 12mm diameter in case of mild steel (MS) and 10mm diameter when high strength deformed bars (HSD) are used .Detailing of beam reinforcement is shown in Fig.21.

**Table8: Recommended Limits on Steel Area Ratio in Beam**

Concrete	Steel	$P_{max}$	$P_{min}$
M20	M.S ( $F_y=250$ Mpa)	0.011	0.0035
	HSD ( $F_y=415$ Mpa)	0.007	0.0022
M30	M.S ( $F_y=250$ Mpa)	0.015	0.0048
	HSD ( $F_y=415$ Mpa)	0.009	0.0029

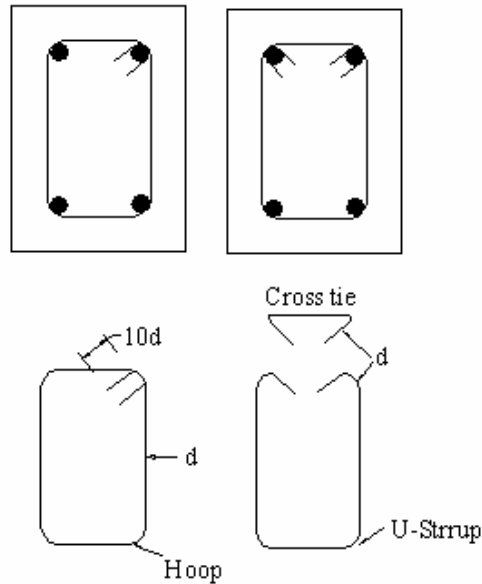
Notes:  $f_{ck}$  = 28 days crushing strength of 150mm cubes,  
 $f_y$  = Yield strength of reinforcement,  
 MS = Mild Steel, HSD = High-strength deformed bars  
 $p = A_s/bh$ ,  
 $A_{smax} bh = P_{max} bh$ ,  
 $A_{smin} = P_{min} bh$



##### Note:

- 1- Minimum 2 bars for full length along top and bottom face,  
 $A_s \geq \rho_{min} Bd$   
 $A_s \leq \rho_{max} Bd$
- 2- Hoop spacing,  $\leq d/4$  and  $8d_b$
- 3- Hoop spacing, not greater than  $d/2$
- $d_b$ - Dia of longitudinal bar



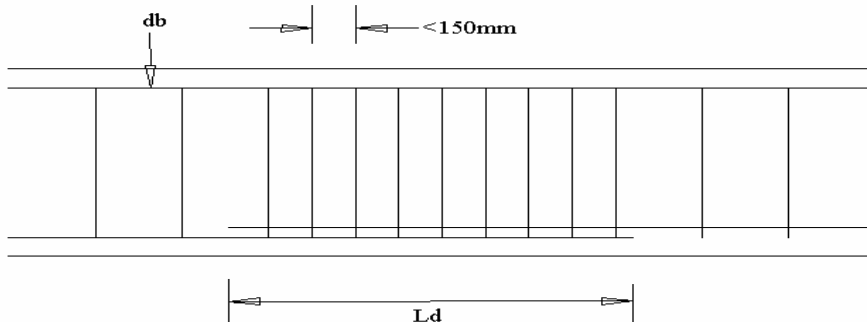


Beam Web Reinforcement

**Fig.21. Detailing of beam reinforcement**

b) Splicing of Steel

All longitudinal bars should be anchored or spliced for full strength development. All splices should be contained within at least three stirrups at each end and one in the middle of the splice so as to avoid spalling of cover concrete (fig.22).



**Fig.22.Splicing in Beam**

c) Transverse Stirrups

The ultimate shear strength of the beam should be designed to be more than its ultimate flexural strength. Vertical shear stirrups should be closely spaced at not more than one-fourth of effective depth in end  $2h$ -length of spans of the beams. In the remaining length spacing should not exceed  $h/2$ .

#### 4.7.5 Detailing of Columns

##### a) Column Section

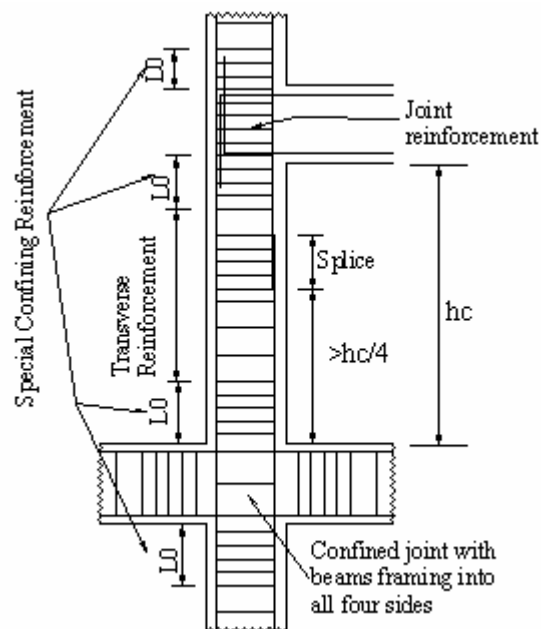
In view of earthquake force acting in all directions, square section of columns is better than rectangular (Fig.23).

##### b) Longitudinal Steel

Vertical reinforcement should be distributed on all the faces of the columns. Use of eight vertical bars is preferable to four bars of equal area; minimum diameter of bars should be 12mm.

##### c) Lateral Reinforcement

Concrete confined within the spirals is stronger as well as much more ductile as compared with plain concrete or that containing widely spaced stirrups. The behavior of columns can be much improved by using closely spaced ties with adequate anchorage at ends in the form of suitable hooks. In a length of about 450mm near the ends of columns, a spacing not more than 100mm may be adopted for achieving adequate ductility.



**Fig.23. Column and Joint Detail**

#### d) Corner Column

The corner columns of buildings are stressed more than any other column due to biaxial bending and must therefore have steel distributed on all faces and have closely spaced lateral ties.

#### 4.7.6 Connection

In the connections, the beam and column bars must be well anchored in tie compression zone so as to achieve their full strength. Where beams on all four sides do not confine the joint, it will be necessary to place the closely spaced ties in the column throughout the height of the joint as well.

#### **Illustrate Sketches**

Typical recommended details of connections in earthquake resistant frames are shown in Fig.24 to Fig.29.

The following abbreviations are used in the illustrative sketches.

S2: maximum value =  $h/4$  or  $16d$  whichever smaller where  $d$  = bar diameter of beam reinforcement

S3: maximum value =  $h/2$

S4: value 75mm to 100mm

S5: maximum value =  $bk/2$  or 200mm whichever smaller.

S6: optimum value 50mm

$L_0$ : length of overlap to develop full tensile strength  $\sim 55d$  including bends or hooks

$L_d$ : anchorage length to develop full tensile strength  $\sim 55d$  including bends or hooks

Use diameter of stirrup bar in beam and column:

Minimum = 6mm, preferable = 8mm

Fig.24 shows Connection between roof beam and exterior column.

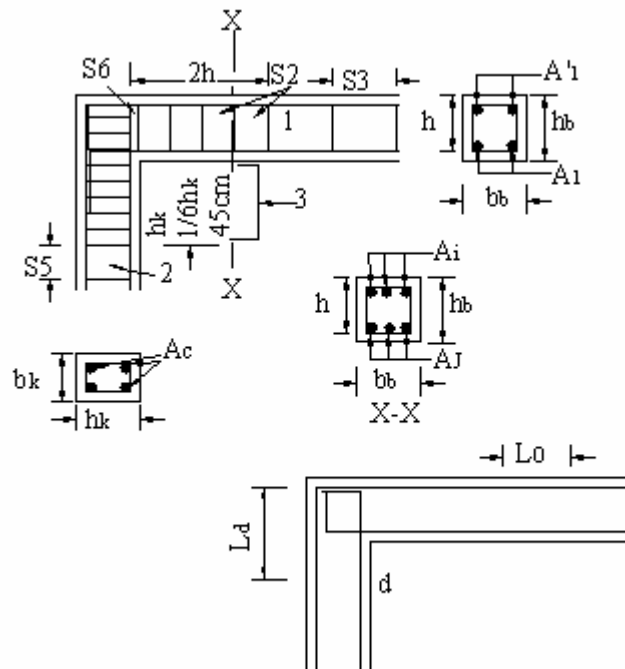
Fig.25 shows Connection between floor beam and interior column.

Fig.26 shows Interior joint between Haunched beam and column.

Fig.27 shows Connection between Floor beam and exterior.

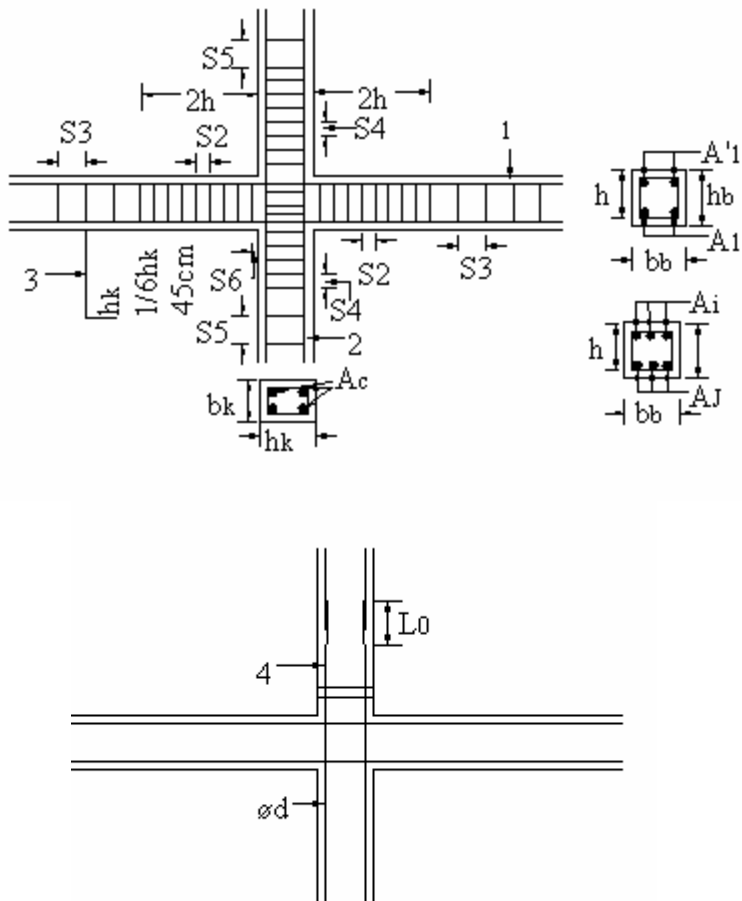
Fig.28 shows Column footing and foundation- Plinth beam

Fig.29. Provision for Confining Reinforcement in Footing

**Note:**

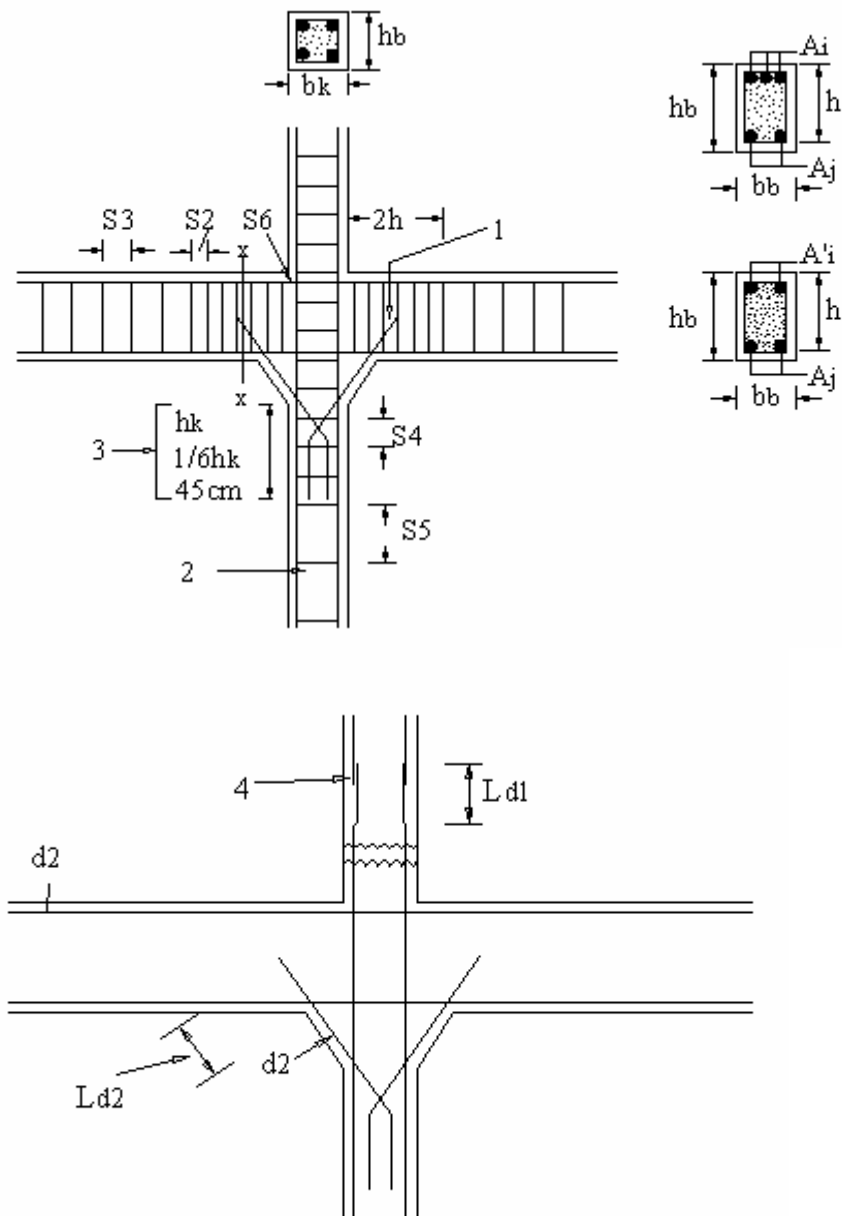
- 1-Roof beam
- 2-Exterior column
- 3-Take largest of three values

**Fig.24.Connection between roof beam and exterior column**

**Note:**

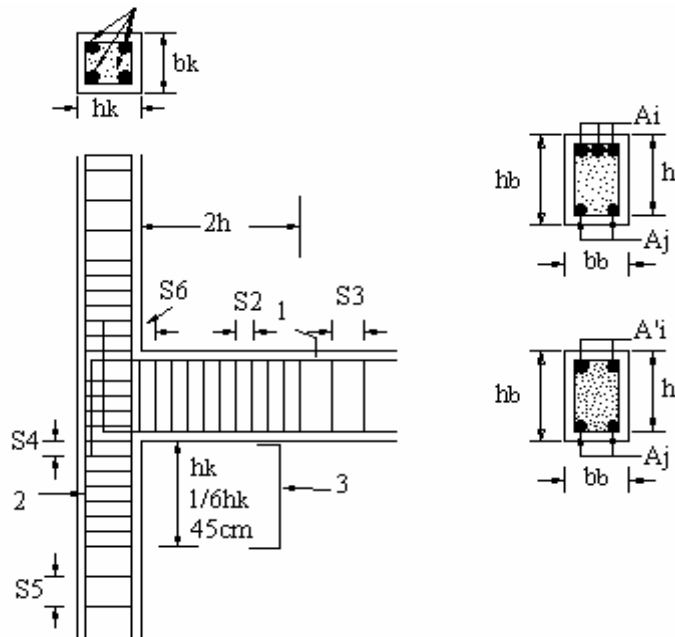
- 1-Floor beam
- 2-Interior column
- 3-Take largest of three
- 4-Lap splice of column bars in mid-height of column

**Fig.25.Connection between floor beam and interior column**

**Note:**

- 1-Floor beam
- 2-Interior column
- 3-Take largest of three
- 4-Lap splice of column bars in mid-height of column

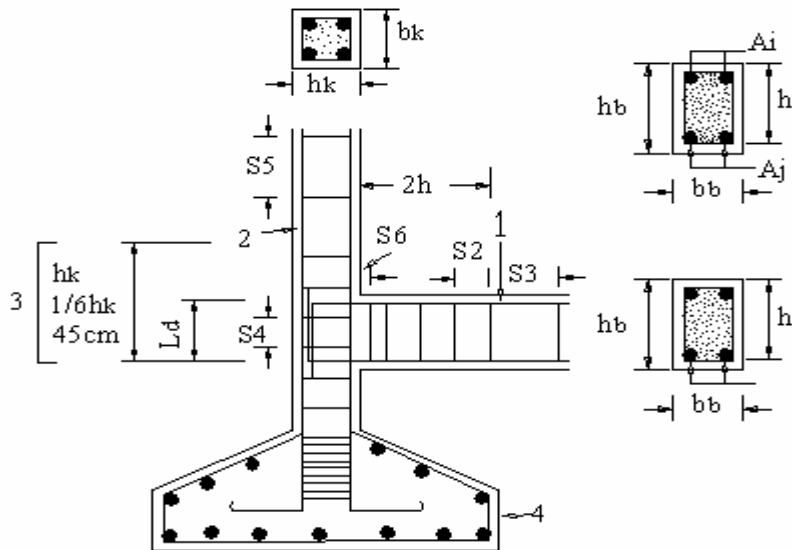
**Fig.26. Interior joint between Haunched beam and column**



**Note:**

- 1-Floor beam
- 2-Interior column
- 3-Take largest of three

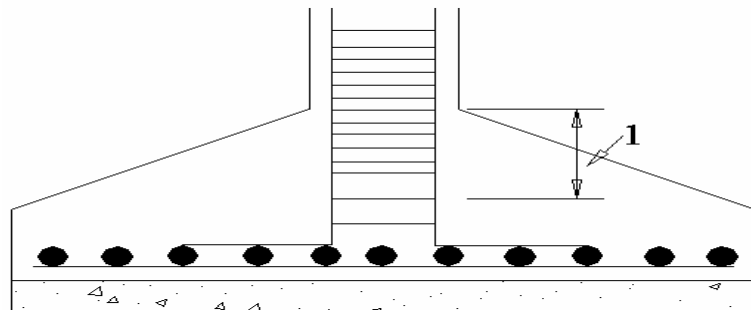
**Fig.27.Connection between Floor beam and exterior**



**Note:**

- 1-Floor beam, 2-Interior column
- 3-Take largest of three, 4-Individual footing in soft soil
- Reinforcement in top face of footing is necessary when foundation is in tension.

**Fig.28.Column footing and foundation-  
Plinth beam**

**Note:**

- 1- Special confining Reinforcement  $\geq 300\text{mm}$

**Fig.29. Provision for Confining Reinforcement in Footing**

#### **4.8 Construction and Planning Aspects for Cyclones**

##### General consideration for preventing Wind Damages:

The following constructional and planning aspects will help in reducing damages during cyclones and heavy winds.

##### 4.8.1 Overhangs

1. For the purpose of reducing wind forces on the roof, a hipped or pyramidal roof is preferable to the gable type roof.
2. In the areas of high wind or those located in regions of high cyclonic activity, light weight( GI or AC sheets) low pitch roofs should either be avoided or strongly held down to purlins. Pitched roofs with slopes in the range 22-30 degree i.e. pitch of 1/5 to 1/ 3.5 of span will not only reduce suction on roofs but would also facilitate quick drainage of rain water.

##### 4.8.2 Wall Opening

Openings in general are areas of weakness and stress concentration, but needed essentially for lightning and ventilation. The Openings in load-bearing walls should not be within a distance of  $h/6$  from inner corner for the purpose of providing lateral support to cross walls, where 'h' is the storey height up to eave level.

The Opening just below roof level should be avoided except that of two small vents without shutter. These should be provided in opposite walls to prevent suffocation.



The failure of any door or window on wind-ward side may lead to adverse uplift pressures under roof. Hence the openings should have strong holdfasts as well as closing/Locking arrangement.

#### 4.8.3 Glass Paneling

1. One of the most damaging effects of strong winds or cyclones is the extensive breakage of glass panes caused by high local wind pressure or impact of flying objects in air. The large size glass panes may shatter because they are too thin to resist the local wind pressure.
2. The way to reduce this problem is to provide well-designed thicker glass panes.
3. Pasting thin plastic film or paper strips can strengthen the glass panes during cyclone seasons.

#### 4.8.4 Foundations

Buildings usually have shallow foundations on stiff sandy soil and deep foundations in liquefiable or expansive clayey soils. It is desirable that information about soil types be obtained and estimates of safe bearing capacity made from the available records of past constructions in the area and by proper soil investigation. The tidal surge effect diminishes as it travels on shore, which can extend even up to 10 to 15 km. Flooding causes saturation of soil and this significantly affects the safe bearing capacity of the soil. In flood prone areas, the safe bearing capacity should be taken as half of that for the dry ground. Also the likelihood of any scour due to receding tidal surge needs to be taken into account while deciding on the depth of foundations and the protection works around a raised mound be used for locating cyclone shelters or other community buildings.

#### 4.8.5 Building on Stilts

Where a building is constructed on stilts it should be properly braced in both the principal directions. This will provide stability to the complete building under lateral loads. Knee braces will be preferable to full diagonal bracing so as not obstruct the passage of floating debris during the storm surge.

#### 4.8.6 Masonry walls -External Walls

All the external walls or wall panels must be designed to resist the out of plane wind pressures adequately. The lateral load due to wind is finally resisted either by all walls lying parallel to the lateral force direction or by RC frames to which the panel walls are fixed using appropriate reinforcement such as 'seismic' bands at plinth and lintel levels.

#### 4.8.7 Strengthening of walls against High winds/Cyclones

For high winds in cyclones prone areas it is found necessary to reinforce the walls by means of reinforced concrete bands and vertical reinforcing bars as for earthquake resistance.

#### 4.8.8 Framed Buildings

RC framed construction, the frame comprises of rigidly connected beams and columns or posts. In steel and timber constructions, complete structural framing should be adequately braced both in the vertical and in the horizontal planes.

- a) Loading – the different loads and load combinations to be considered for the design are given in IS: 875 (Parts 1 to 4). The dead loads, superimposed loads, wind and snow loads to be considered are given in parts 1, 2, 3, and 4 respectively.
- b) For enclosing the space it is necessary that cladding be provided, firmly secured to columns or posts, on all the external faces and where partitioning is required. The design of these panel walls should be made for out of plane forces.
- c) Bracing – Adequate diagonal bracings with strong end connections shall be provided in steel/ timber framing in both the horizontal and vertical planes to improve the lateral load resistance. At least two end bays shall be braced in the vertical and horizontal plane.
- d) Anchoring – the frame columns and shear wall where used shall be properly anchored to the foundation against uplift forces. Usually a monolithic footing is provided which provides due stability against uplift. In case of steel framing the columns should be properly tied to flooring through anchor bolts. For timber posts usually cross pieces are nailed at the bottom end of the post and buried into the ground to provide necessary anchorage.

#### 4.8.9 Foundations

- a) The drainage around the building must be improved to prevent water stagnation.
- b) All the posts should be properly anchored into the ground or in reinforced cement concrete footing. Alternatively, the posts with cross members connected at the lower ends should be embedded in ground for a minimum depth of 750 mm.
- c) Walls are raised from a well compacted lean concrete bed or well-compacted ground from a minimum depth 450 mm below the firm foundation or footing.

#### 4.8.10 Floors

Floors may consists of the following

1. RC slabs
2. Wooden or R C joists carrying brick tiles, stones slabs or reeds with clay topping.
3. Prefabricated R C elements of various designs placed side by side.

#### 4.8.11 Construction of Roofs

Depending Upon the construction materials used and the geometrical aspects, the roofs can be broadly classified into two main types.

1. flat roofs of various types
2. Pitched roofs with various covering materials

##### a) Flat Roofs

In the view of large uplift forces, particularly if the wind speed could exceed 55 m/s, the total roof weight should preferably be kept around 375 kg/m<sup>2</sup>. Lighter roofs should be designed for net uplift forces and properly held down to supporting beams/walls etc.

##### b) Pitched roofs

- I. The main load bearing structural members are timber or steel trusses, purlins, and bracings. It will be safer to use sheeting with adequate fixtures and U bolts are recommended in place of J belt for anchoring the sheeting's.
- II. Under high velocity wind along the ridge of pitched roofs, the suction forces may exceed the dead loads of the roof appreciably, causing compression in the bottom chord and stress reversal in all truss members in general. Buckling consideration in all the members of roof trusses, which are normally under tension, therefore, assumes significance. Therefore, the main ties of root trusses also require lateral bracing and strutting against their buckling in lateral direction.

#### 4.9.12 Ferro-Cement as Roofing material

Ferro-cement has the advantage of reduced dead weight compared to an RC roof, as well as better corrosion resistance. These new material could be used for flat roof or supporting walls/beams against the wind-uplift forces

#### 4.8.13 Roof Covering

##### a) Clay tile roofs

Because of lower dead weight, these may be unable to resist the uplifting force and thus experience heavy damage, particularly during cyclones. Anchoring of roof tiles into R.C. strap beam is recommended for improved cyclone resistance. As alternative to the bands, a cement mortar screed, reinforced with galvanized chicken mesh, may be laid over the entire tiled roof.

##### b) Thatch roof

The thatched roof should be properly tied down to wooden framing underneath by using organic or nylon ropes in diagonal pattern. After a cyclone warning is received, a rope net properly anchored to ground should preferably hold down all lighter roofs. The fire hazard to thatch should be reduced by spraying fire retardant coating at periodic intervals.

##### c) Anchoring of roof framing to wall/posts

The connection of roof framing to the vertical load resisting elements i.e., wall or post, by providing properly designed anchor bolts and base plates are equally important for overall stability of the roof. The anchoring of roof framing to masonry wall should be accomplished through anchor bolts embedded into concrete bed blocks.

##### d) Flutter

In order to reduce wind induced flutter/ vibration of the roof in cyclonic regions, it is recommended that all members of the truss and the bracings be connected at the ends by at least two rivets/bolts or proper welds. Further the cross bracing members be welded/connected at the crossings to reduce vibrations.

## **5. Retrofitting of existing buildings**

In engineered constructions, the maximum wind forces should be evaluated as per the wind code and various elements checked for the worst combination of dead and live loads to identify the points of weakness requiring retrofitting. Some of the vulnerable parts may need special attention. They are indicated below:

### **5.1 Lighter Roof**

- a) In case of light roofs (AC or CGI sheeting) connections near the edges should be strengthened by providing additional U bolts. Mild steel flat may be provided to hold down the roof. J- bolts used earlier may be replaced by U- bolts.
- b) All projections in roofs should be properly checked for strength against uplift and tied down if found necessary, particularly, if projection is longer than 500 mm.
- c) All metallic connectors for different components of roof should preferably be of non-corrosive material, or else must be galvanized or painted and checked before each cyclone season and doubtful ones should be replaced.
- d) There must be proper bracings in the plane of rafters, in plan at eaves level, and, in the vertical plane of columns along the both axes of the buildings in sufficient number of panels determined by proper calculations.
- e) Flat roofs may be integrated to behave as horizontal diaphragms and either weighted down by dead weights or held down against uplift forces.

### **5.2 Framed Buildings**

- a) In case of a framed structure, the total system requires to be properly braced. If existing lateral strength or bracing is inadequate, braces are added to improve the overall stability.
- b) Beam column junction should be inspected and repaired.
- c) Undesirable openings in the walls especially near the corners or edges should be closed permanently to improve the stability.
- d) Wherever, corrosion is detected, it should be attended by going for proper rehabilitation if necessary.

### 5.3 Load bearing walls

- a) Weak wall may be identified and buttressed be provided to improve the lateral load resistance of long walls, achieving cross wall spacing to be less than  $a/t < 40$ , thus reducing the unsupported lengths.
- b) If the horizontal bands are not provided during the original construction, the exterior perimeter maybe belted all around by using Ferro-cement or steel belts in the spandrel wall portion between lintel and eave/roof levels. This will prevent diagonal cracking of piers.

### 5.4 Glass Paneling

- a) Adding battens at appropriate spacing reduces the size of the large glass panes. Fixing adhesive tapes, along and parallel to diagonals, at 100-150 mm spacing prior to each cyclone season, strengthen large glass panes. Alternatively, thin plastic film can be pasted on both faces of the panes to prevent shattering of glass in case of damages.
- b) Protective cover in the form of mesh or iron grill can be provided to prevent breakage of glass panes by flying debris which act like missiles.

### 5.5 Foundations

- a) Proper drainage around the building should be provided to prevent pooling of water in its vicinity.
- b) The plinth should be protected against erosion by using pitching of suitable type.

### 5.6 Non-Engineered constructions

- a) In case of thatched roof it should be properly tied to timber framing underneath. Use of metallic/synthetic connectors is desirable. Use of waterproof mud plaster may be made to make the roof leak proof.
- b) In case of tiled roofs, the overlaps are joined through use of cement mortar to provide additional stability.
- c) While relaying of roofs, its slope be changed to about 20degrees to 30 degrees to reduce the wind suction on roof and thus reducing the damage vulnerability. At the same time, eaves level wooden band should be introduced and integrated with the wall.
- d) The wooden frame when used for the structure of the building should be properly braced in both horizontal and vertical planes by installing knee braces or cross ties.

- e) For greater durability of a mud wall, against rain and water etc., external face of the wall upto 1.0 to 1.5 m height above plinth level should be covered with burnt clay tiles laid in cement mortar 1:6 mix.
- f) The roof rafters should be properly tied to the posts using metallic strap connectors.
- g) All openings very close to wall edges should be closed. All asymmetric non-closeable openings should be filled up to eliminate any un-favorable roof pressure from within. Two small vents in opposite walls close to the roof may be left open.
- h) It is advisable that before the cyclone season, a protective net be provided on the roof and securely tied to the ground to prevent flying of very light roof.

## **6. Repairs and Strengthening of buildings**

The problems of repairs, restoration and seismic strengthening of buildings are briefly stated below:

- a) Before the occurrence of a probable disaster, the required strengthening of weak buildings is to be determined by a survey and analysis of the structures.
- b) Just after a damaging disaster, temporary supports and emergency repairs are to be carried out so that precariously standing buildings may not collapse during aftershocks and the less damaged ones could be quickly brought back into use.
- c) The real repair and strengthening problems are faced at the stage after the disaster when things start settling down. At this stage distinction has to be made in the type of action required, that is, whether to repairs, restore and strengthen. The cost, time and skill required in each of the three are quite different.

The method of repair and strengthening would naturally depend very largely on the structural scheme and materials used for the construction of the original building in the first instance, the technology that is feasible to be adopted quickly and on the amount of funds that can be mobilized for the task. Some methods like “splints and bandages”, “wire mesh with gunite”, “epoxy injection” etc., enables repairing as well as strengthening the buildings.

### **6.1 Repair**

Simple repair does not intend to improve the structural strength of the building and can be very deceptive for meeting the strength requirements of the next disaster. The actions in this category will include the following:

- a) Patching up of defects such as cracks and fall of plaster.
- b) Repairing doors, windows, and 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.



## **6.2 Restoration**

Restoration is a procedure adapted to regain the strength the building had before the damage occurred. This type of action must be undertaken when there is evidence that the structural damage can be attributed to exceptional phenomena that are not likely to happen again and that the original strength provides an adequate level of safety.

The main purpose of restoration is to carry out structural repairs to load bearing elements. 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. Some of the approaches are stated below:

- a) Removal of portions of cracked masonry wall and piers and rebuilding them in richer mortar. Use of non-shrinking mortar will be preferable.
- 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 for this have been used.
- c) Injecting epoxy like material, into the cracks in walls, columns, beams etc.

## **6.3 Strengthening of existing Buildings**

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

Strengthening is an improvement over the original strength where the evaluation of the building indicates that the strength available is insufficient and restoration alone will not be adequate for resisting future disasters.

## **6.4 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 admixture like aluminum powder and ordinary Portland cement will be suitable. Steel may be required in many forms, like bolts, rods, angles, channels, the expanded metal and welded wire fabric. Wood and bamboo are the most common material for providing temporary supports and scaffolding etc., and will be required in the form of rounds, sleepers, planks, etc.

#### 6.4.1 Shotcrete

Shotcrete is a method of applying a combination of sand and Portland cement 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 or concrete. Its versatility of application to curved or irregular surfaces, its high strength after application and good physical characteristics, make this technique an ideal means to achieve better structural capability for walls and other elements.

#### 6.4.2 Epoxy Resins

Epoxy resins are excellent binding agents with high tensile strength. These are chemical preparations, the compositions of which can be changed as per requirements. The epoxy components are mixed just prior to application. The low viscosity product can be injected in to small cracks. 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 in associated with higher temp.) and method of application.

#### 6.4.3 Epoxy Mortar

For larger void spaces, it is possible to combine the epoxy resins of either low viscosity with sand to form epoxy mortar. Epoxy mortar mixture has higher compressive strength, higher tensile strength and a lower modulus of elasticity than cement mortar. Thus the mortar can be used for repair in rcc works.

#### 6.4.4 Quick – Setting cement Mortar

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

#### 6.4.5 Gypsum cement Mortar

It has very low strength. It is a workable mortar and is used for finishing and plastering cracks.

#### 6.4.6 Mechanical Anchors

Mechanical type of anchors employ wedging action to provide anchorage. Some of the anchors provide both shear and tension resistance. Alternatively chemical anchors using polymer in drilled holes can also be used.

#### 6.4.7 Small Cracks

If the crack are reasonably small (opening width = 0.075cm) the technique to restore the original tensile strength of the cracked element is by pressure injection of epoxy (see Fig.30(a)). The procedure is as follows:

The external surfaces are cleaned of non-structural materials and plastic injections ports are placed along the cracks on both sides of the member and are secured in place with an epoxy sealant. The center to center 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 port of the crack in case it is vertical or at one end of the crack in case crack is horizontal.

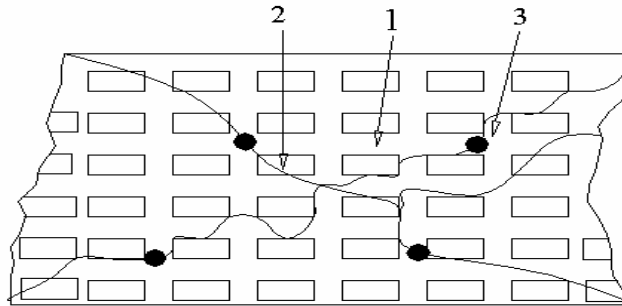
The smaller the crack, higher is the pressure or more closely spaced should be the ports so as to obtain complete penetration of the epoxy material throughout the depth and width of crack. Larger cracks will permit, larger port spacing depending upon the width of the member. This technique is the appropriate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

#### 6.4.8 Large cracks and crushed concrete

For cracks wider than about 6mm or for regions in which the concrete or masonry has crushed, a treatment other than injection is needed. The following procedure is 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 gypsum cement mortar, (Fig.30(b)).
- b) Where found necessary, additional shear or flexural reinforcement could be covered by mortar to give further strength as well as protection to the reinforcement.
- c) In areas of very severe damage, replacement of the member or portion of member can be carried out.

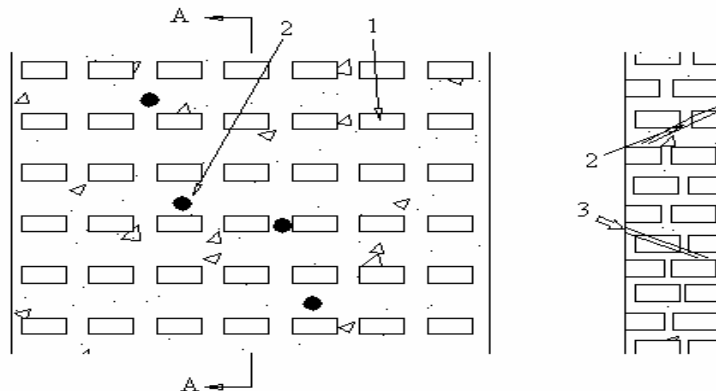
- d) In the case of damage to walls and floor diaphragms steel mesh could be provided on the outside surface and nailed or bolted to the wall. Then it may be covered with plaster or micro-concrete (Fig.30(c)).



**Note:**

- 1-Plaster removed
- 2-Crack sealed after cleaning
- 3-Grout ports

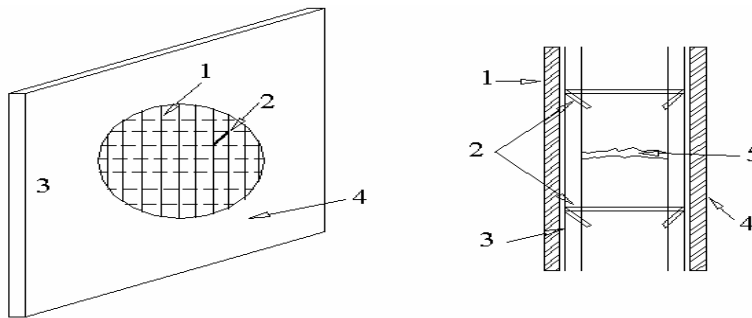
(a) Grout or epoxy injection in cracks.



**Note:**

- 1- Brick or block wall
- 2-Injection holes
- 3-Grout mixture

(b) Grout or epoxy injection in existing weak walls.

**Note:**

- 1-Wire mesh on front face
- 2-Clamps
- 3- Wire mesh on back face
- 4-Cement plaster
- 5-Crack in wall

(c) Providing Mesh Reinforcement

**Fig.30.Strengthening of existing masonry****6.4.9 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. Replacing the old portion of steel with new steel using butt welding or lap welding can repair such an element.

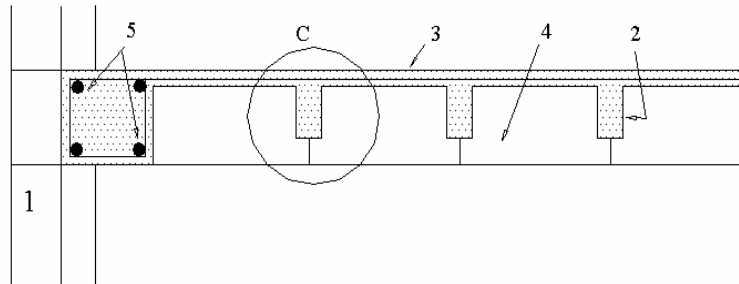
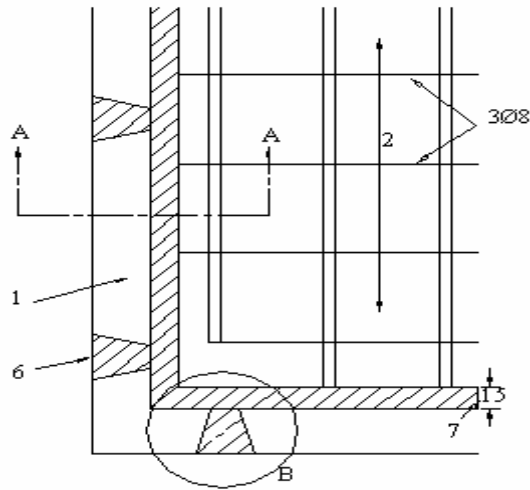
If repair has to be made without removal of the existing steel, the best approach would depend upon the space available in the damaged portion before concreting so as to confine the concrete and enclose the longitudinal bars to prevent their buckling in future.

In some cases it may be necessary to anchor additional steel into existing concrete.

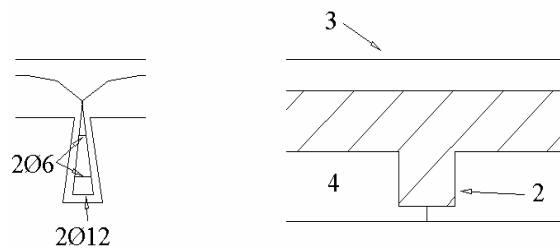
A hole larger than the bar is drilled. The hole is filled with epoxy, expanding cement, or other high strength grouting material. The bar is pushed into place and held there until the grout has set. This will give anchorage to the steel that is being added longitudinally.

**6.4.10 Fractured wooden Members and joints**

Since wood is an easily workable material, it will be easy to restore the strength of wooden members, beams columns structures and ties by splicing additional material. It will be advisable to use steel straps to cover all such splices and joints so as to keep them tight and stiff.



Section A-A

**Note:**

1-Existing wall

2-New floor

3-Prefab slab units

5-RCband

6-Keys connecting new floor to existing wall

7-Groove connected in wall

**Fig.31. Integrated and Stiffening of an Existing Floor**

## 6.5 Modification of roofs

- a) The roofing tiles are brittle and easily dislodged. Where possible they should be replaced with corrugated iron sheeting.
- b) False ceilings of brittle material are dangerous. Non brittle material like hessian cloth, bamboo matting, or light foam substances may be used for false ceiling.
- c) Welding or clamping suitable diagonal bracing members in the vertical as well as horizontal planes can be used to brace roof trusses and frames.
- d) Anchors of roof trusses to supporting walls could be improved.
- e) Where roof or floor consists of prefabricated units like RC rectangular, T or channel units or wooden poles and joists carrying brick tiles, integration of such units is necessary. Timber elements could be connected to diagonal planks nailed to them and spiked to an all round wooden frame at the ends. RC elements may either have 40mm cast-in-site-concrete topping with 6mm dia bar 150mm/c both way or a horizontal cast in suit RC ring beam all round into which the ends of RC elements are embedded (Fig.31 shows one such details).
- f) Roofs or floors consisting of steel joists and flat or segmental arches must have horizontal ties holding the joists horizontally in each arch span so as to prevent the spreading of joists. If such ties do not exist, these could be installed by welding or clamping.

## 6.6 Substitution or strengthening of slabs

- a) Insertion of a new slab

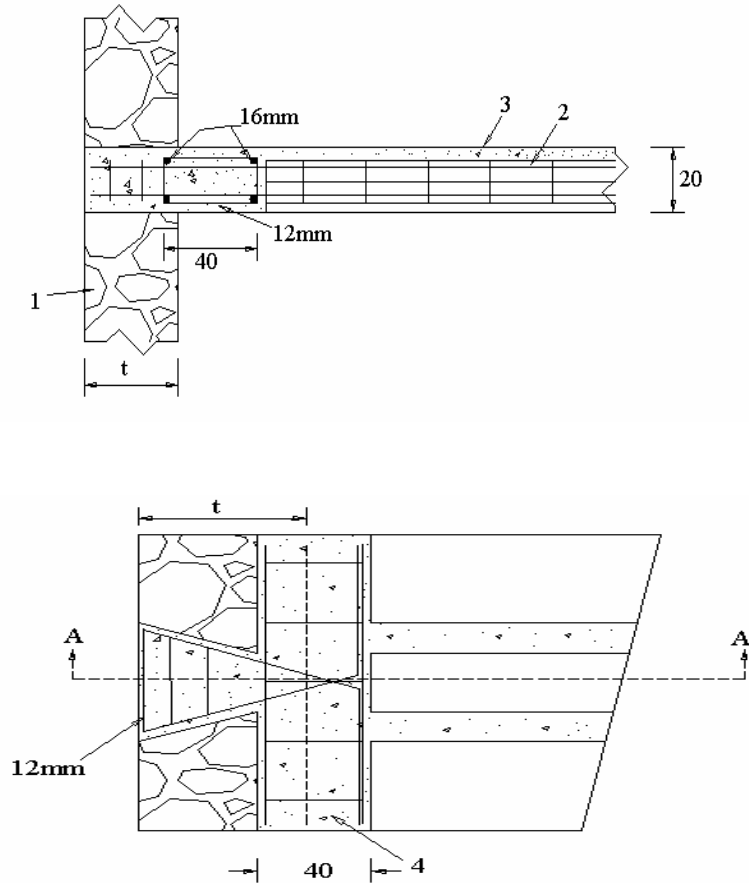
A rigid slab inserted into existing walls plays an important role in the resisting mechanism of the building in keeping the walls together and distributing seismic forces among the walls. The slab has to be properly connected to the walls through appropriate key arrangement as shown in Fig.32.

## 6.7 Modifications and strengthening of walls

### 6.7.1 Inserting New Walls

In the case the existing buildings show asymmetry which may produce dangerous torsional effects during earthquakes, the center of masses can be made coincident with the center of stiffness by separating parts of buildings thus achieving individual symmetric units and / or, inserting new vertical resisting elements such as new masonry or reinforced concrete walls either internally as shear walls or externally as buttresses. Insertion of cross wall will be necessary for providing transverse supports to longitudinal walls of long barrack type buildings used for various purposes such as schools and

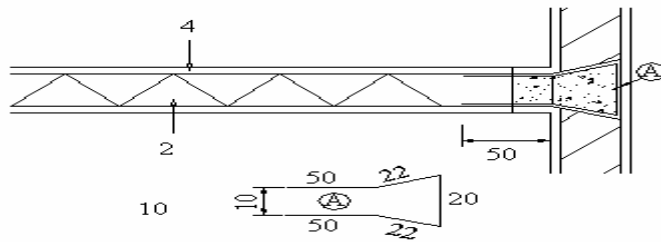
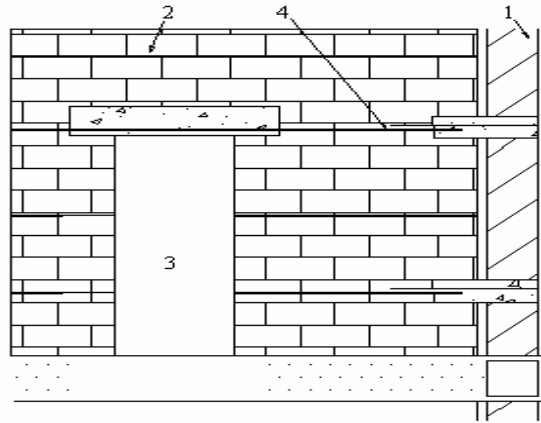
dormitories. The main problem in such modification is the connection of new wall with old wall, Fig.33 shows one example.



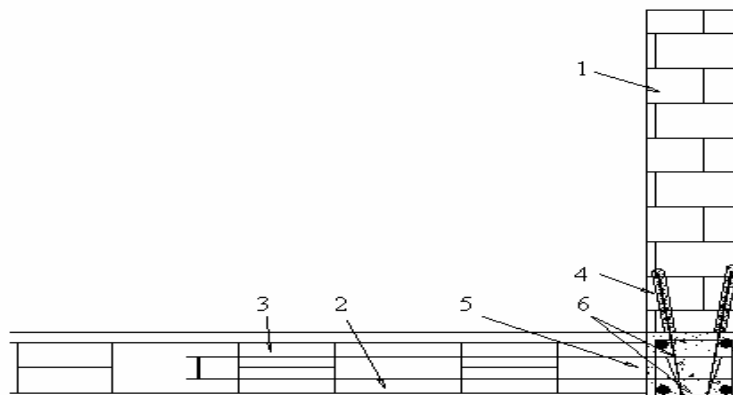
- Note:**  
 1-Existing wall  
 2-New floor  
 3-Topping slab Concrete  
 4-R.C.band

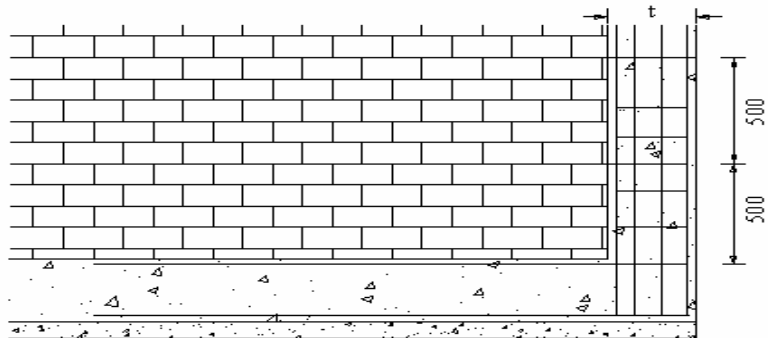
**Fig.32. Details of inserted slab.**



**Note:**

- 1-Existing wall
- 2-New wall
- 3-Door opening
- 4-Horizontal reinforcement

**(a) T-junction**

**Note:**

- 1-Existing wall
- 2-New wall
- 3-Horizontal reinforcement with links
- 4-Connection steel grouted in drilled holes
- 5-Concrete in column or footing
- 6-Stirrups

**(b) Corner junction****Fig.33. Connection of New and Old Brick Walls****6.7.2 Strengthening Existing Walls**

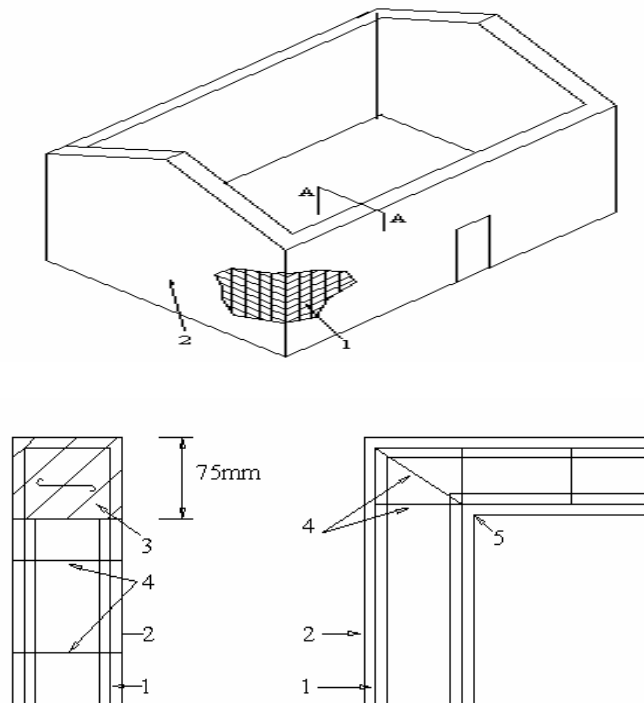
The lateral strength of buildings can be improved by increasing the strength and stiffness of existing individual walls whether they are cracked or uncracked. This can be achieved (a) by grouting; (b) by addition of vertical reinforced concrete coverings on two sides of the wall (c) by prestressing the walls

**a) Grouting:**

A number of holes are drilled in the wall, (2 to 4 each square meter). First water is injected in order to wash the wall inside and to improve the cohesion between the grout mixture and the wall elements. Secondly a cement water mixture (1:1) is grouted at low pressure (0.1 to 0.25 MPa) in the holes starting from the lower holes and going up. Alternatively, polymeric mortars may be used for grouting. The increase of shear strength which can be achieved in this way is considerable.

### b) Strengthening with wire mesh

Two steel meshes (welded wire fabric with a mesh of approximately 50x50mm) are placed on the two sides of the wall, they are connected by passing steel (each 500 to 750mm apart), Fig.30. A 20 to 40mm thick cement mortar or micro-concrete layer is then applied on the two sides. The two are clamped to form a network. This gives rise to two interconnected vertical plates. This system can also be used to improve connection of orthogonal walls (Fig.34).



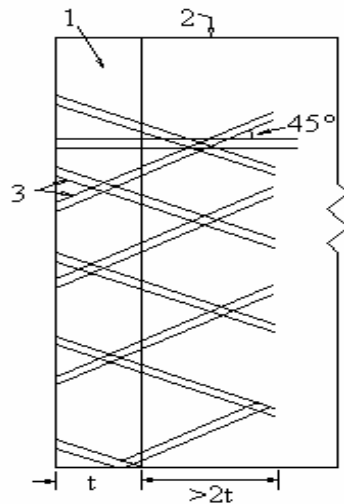
**Note:**

- 1-Welded wire mesh, 50X50mm
- 2-Mortar or micro concrete rendering
- 3- Concrete roof band
- 4-Cross ties, 500 to 750 mm apart
- 5-Corner bar,  $\phi$  8mm

**Fig.34. Strengthening with wire mesh and Mortar**

### c) Connection between existing stone walls

In stone buildings consisting of fully dressed stone masonry in good mortar, effective sewing of perpendicular walls can be done by drilling inclined holes through them and inserting steel rods and injecting cement grout (Fig.35)

**Note:**

1-Transverse wall

2-Longitudinal wall

3-10mm dia bar in 20 mm hole filled with cement grout

**Fig.35. Sewing Transverse Walls with Inclined Bars**

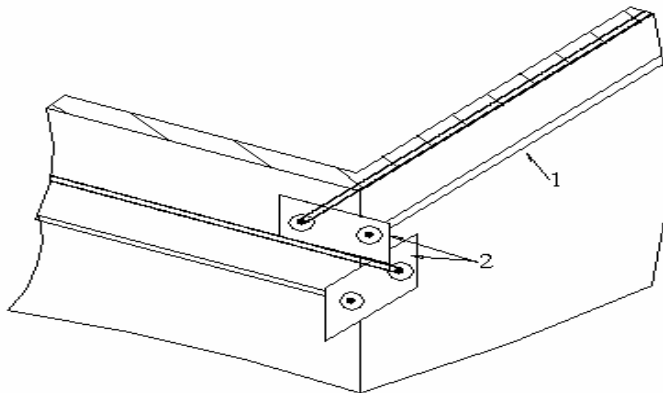
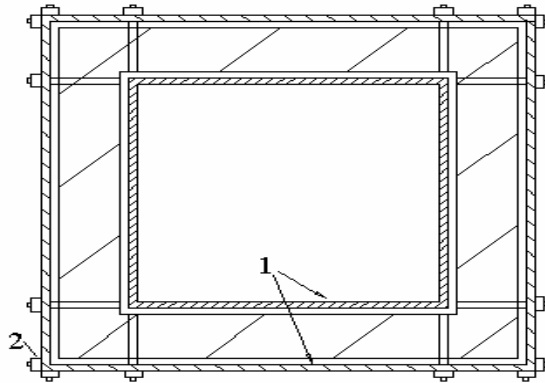
## d) Prestressing

A Horizontal compression state induced by horizontal tendons can be used to increase the shear strength of walls. Moreover this wall also improves considerably the connections of orthogonal walls (Fig.36). The easiest way of effecting the precompression is to place two steel rods on the two sides of the wall and strengthening them by turnbuckles. Note that good effects can be obtained by slight horizontal prestressing (about 0.1MPa) on the vertical section of the wall. Prestressing is also useful to strengthen spandrel beam between two rows of openings in the case no rigid slab exists.

## e) External Binding

Opposite parallel walls can be held to internal cross walls by prestressing bars as explained above, the anchorage 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.

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. This would strengthen the walls as well as bind them together. As a variation and for economy in the use of materials, the covering may be in the form of vertical splints between opening and horizontal bandages over spandrel walls at suitable number of points only (Fig.37).

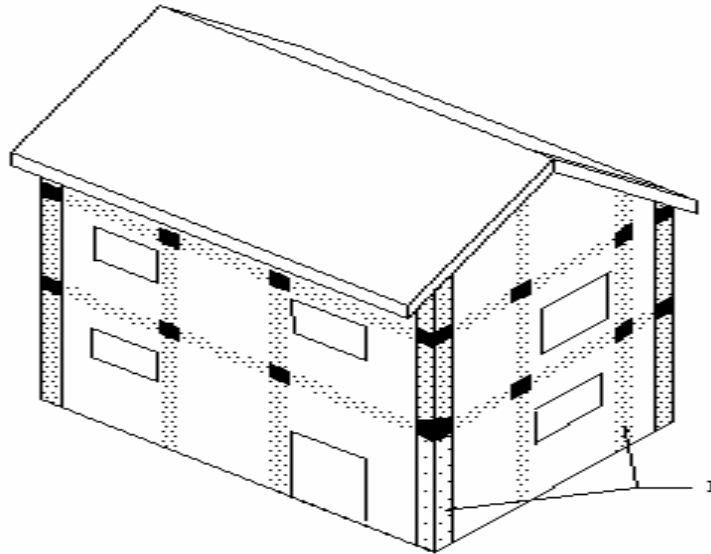


**Note:**

1-Steel rod for prestressing

2-Anchor plates

**Fig.36. Strengthening of Wall by Prestressing**

**Note:**

1-Wire mesh with width  $\geq 400\text{mm}$

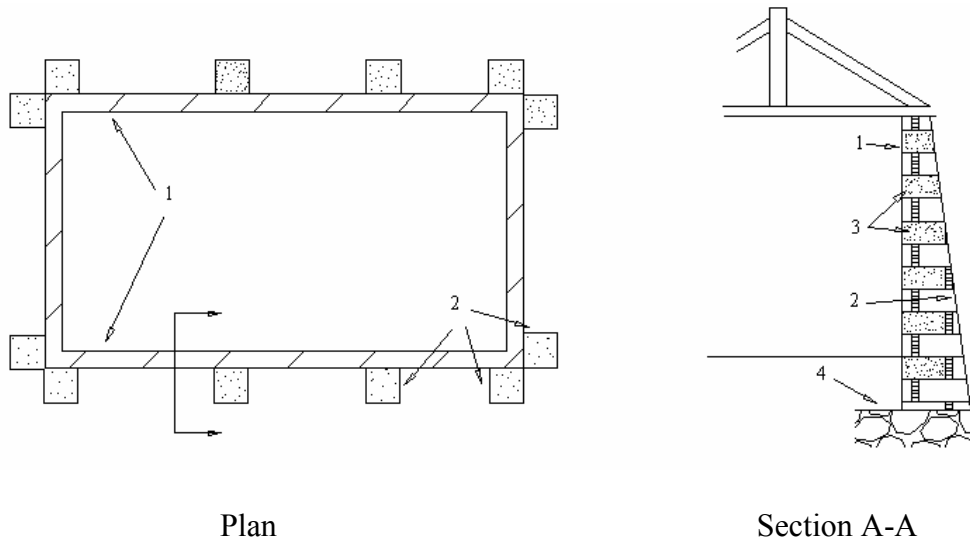
**Fig.37.Splint and Bandage Strengthening Technique**

f) Other Strengthening measures

I. Masonry Arches

If the walls have large arched openings in them, it will be necessary to install tie rods across them at springing levels or slightly above it by drilling holes on both sides and grouting steel rods in them. Alternatively, a lintel consisting of steel channels or I-sections could be inserted just above the arch. In Jack-arch roofs, flat iron bars or rods may be provided to connect the bottom flanges of I-beams, connected by bolting or welding.

- II. Random rubble masonry walls are most vulnerable to complete collapse and must be strengthened by internal impregnation by rich cement mortar grout in the ratio of 1:1 or better still covered with steel mesh and mortar. Damaged portions of the wall, if any, should be reconstructed using richer mortar.
- III. For bracing the longitudinal walls of long barrack type buildings, a portal type framework can be inserted transverse to the walls and connected to them. Alternatively, masonry buttresses or pilasters may be added externally (Fig.38).
- IV. In framed buildings, the lateral resistance can be improved by inserting knee braces or full diagonal braces or inserting infill walls.

**Note:**

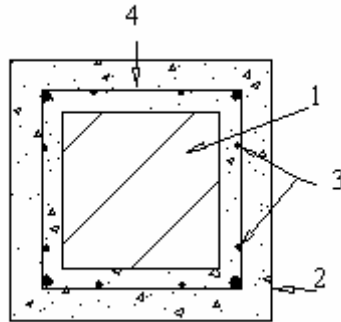
- 1-Existing wall
- 2-Buttress or pilaster
- 3-Key stone
- 4-Foundation

**Fig.38. Strengthening of Long Walls by Buttresses**

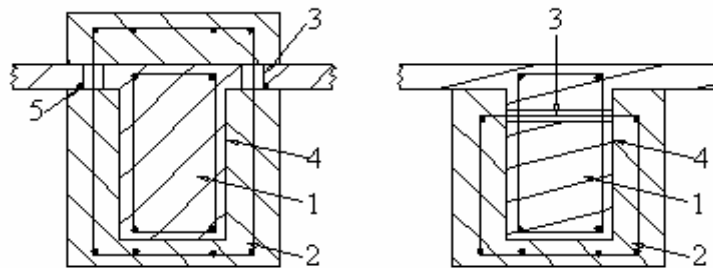
### 6.8 Strengthening R.C.Members

The strengthening of reinforced concrete members is a task that should be carried out by a structural engineer according to calculations. Here only a few suggestions are included to illustrate the ways in which the strengthening could be done.

- a) R.C columns can best be strengthened by jacketing, and by providing additional cage of longitudinal and lateral tie reinforcement around the columns and casting concrete jacket (Fig.39) .The desired strength and ductility can thus be built-up.
- b) Jacketing a reinforced concrete beam can also be done in the above manner. For holding the stirrup in this case, holes will have to be drilled through the slab (fig.40) or through the web.
- c) Similar technique could be used for strengthening R.C. Shear walls.
- d) Inadequate section of RC columns and beams can also strengthened by removing the cover to old steel, welding new steel to old steel and replacing. In all cases of adding new concrete to old concrete the original surface should be roughened, groves made in the appropriate direction for providing shear transfer. The ends of the additional steel are to be anchored in the adjacent beams or columns as the case may be. The old concrete can be effectively bonded to the new concrete using polymer bonding agents.

**Note:**

- 1-Existing column section
- 2-Added section
- 3-New longitudinal bar
- 4-New Tie bars

**Fig.39. Jacketing of Concrete Column****Note:**

- 1-Old Concrete
- 2-New Concrete
- 3-Holes for passing Stirrup
- 4- Chipped old surface
- 5-Groove for new slab

**Fig.40. Increasing the section and Reinforcement of Existing Beam**

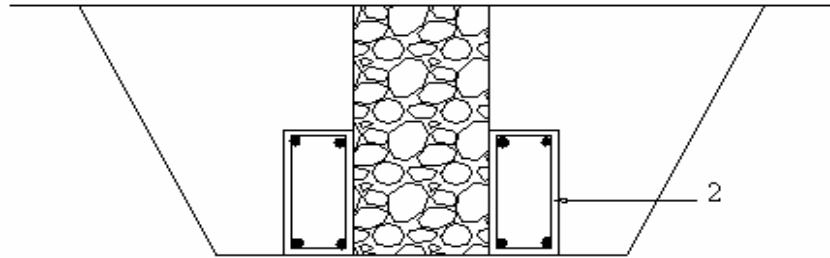


## 6.9 Strengthening of Foundations

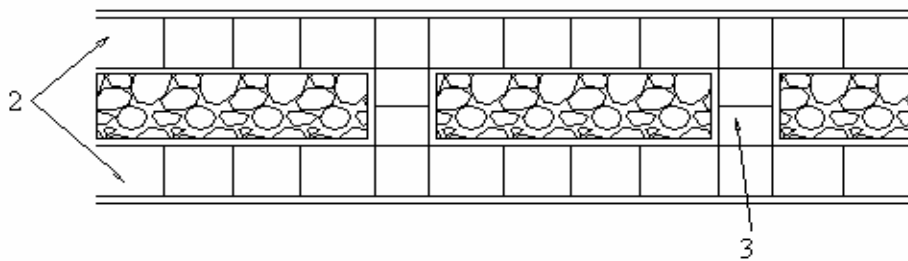
Seismic strengthening of foundations before or after the Tsunami is the most involved task since it may require careful underpinning operations. Some alternatives are given below for preliminary consideration of the strengthening scheme.

- a) Introducing new load bearing members including foundations to relieve the already loaded members. Jacking operations may be needed in this process.
- b) Improving the drainage of the area to prevent saturation of foundation soil to obviate any problems of liquefaction which may occur because of poor drainage.
- c) Providing apron around the building to prevent soaking of foundation directly and draining off the water.
- d) Adding strong elements in the form of reinforced concrete strips attached to the existing foundation. These will also bind the various wall footings and may be provided on both sides of the wall. To avoid digging the floor inside the building, the extra width could be provided only on the outside of the external walls. The extra width may be provided above the existing footing at the level of the existing footing. In any case the reinforced concrete strips and the walls have to be linked by a number of keys inserted into the existing footing (Fig.41).

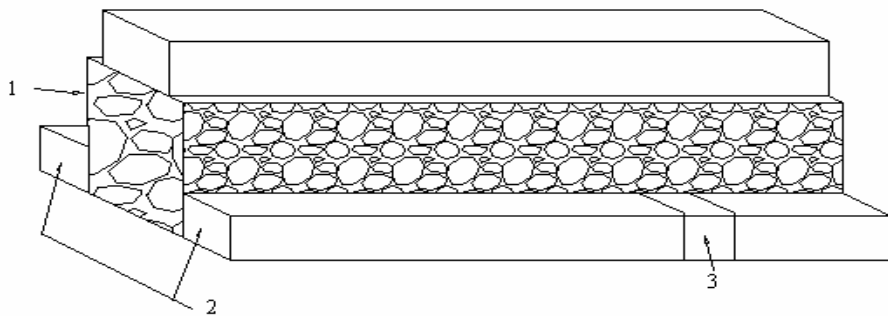
**Note:** To avoid disturbance to the integrity of the existing wall during the foundation strengthening process, proper investigation and design is called for.



(a) Vertical section of wall



(b) Horizontal section of wall through new R.C. Beams

**Note:**

1-Old foundation

2-New concrete beam

3-Connecting lateral concrete beams

**Fig.41. Improving a foundation by inserting lateral concrete beams.**

## Appendix 1

### Categories of Earthquake damages

<b>Damage Category</b>	<b>Extent of Damage In General</b>	<b>Suggested Post-Disaster Actions</b>
No damage	No damage	No action required
Slight Non-Structural Damage	Thin cracks in plaster and falling of plaster bits in limited parts	Building need not be vacated. Only architectural repairs are needed.
Slight Structural Damage	Small cracks in walls, falling of plaster in large bits over large areas; damage to non-structural parts like chimneys, projecting cornices, etc. The load carrying capacity of the structure is not reduced appreciably.	Building need not be vacated. Architectural repairs required to achieve durability.
Moderate Structural Damage	Large and deep cracks in walls; widespread cracking of walls, columns, piers and titling or falling of chimneys. The load carrying capacity of the structure is partially reduced.	Building needs to be vacated. It can be reoccupied after restoration and strengthening. Structural restoration and strengthening are necessary after which architectural treatment may be carried out.
Several Structural Damage	Gaps occur in walls; inner and outer walls collapse; failure of ties separating parts of buildings. Approx 50% of the main structural elements fail. The building is in a dangerous state.	Building has to be vacated. Either the building has to be demolished or extensive restoration and strengthening work has to be carried out before reoccupation.
Collapse	A large part or whole of the building collapses.	Clearing the site and reconstruction.

## Appendix 2

### Building Categories for Various Multihazard Resisting Features

In this guideline, it is intended to cover specified features of design and construction for multihazard resistance of building of conventional type. In cases of other special buildings, detail analysis of earthquake/wind forces will be necessary.

For the purpose of specifying the earthquake resisting features in conventional buildings, the buildings have categorized into four categories based on multihazard forces, they are intended to resist as shown in table below:

### Building Categories for Various Multihazard Resisting Features

Building Category	Soil type	Seismic Zone	Wind zone (Basic wind speed)	Importance Factor
IV	Type I	II	$V_b \leq 33\text{m/s}$	1
III	Type III	III	$34 \geq V_b \geq 39\text{m/s}$	1
II	Type IV	IV	$40 \geq V_b \geq 49\text{m/s}$	1.5
I	Type V	V	$V_b \geq 50\text{m/s}$	1.5

The building categories is fixed based on maximum vulnerability level if soil type/seismic zone/wind zone/Importance factor/ as per the above table.

## **Appendix 3**

### **Information on Coastal Regulation Zone**

#### **Classification of Coastal Regulation Zone:**

**For regulating development activities, the coastal stretches within 500 meters of High Tide Line on the landward side are classified into four categories, namely:**

##### **Category I (CRZ-I):**

1. Areas that are ecologically sensitive and important, such as national parks/marine parks, sanctuaries, reserve forests, wildlife habitats, mangroves, corals/coral reefs, areas close to breeding and spawning grounds of fish and other marine life, areas of outstanding natural beauty/historically/heritage areas, areas rich in genetic diversity, areas likely to be inundated due to rise in sea level consequent upon global warming and such other areas as may be declared by the Central Government or the concerned authorities at the State/Union Territory level from time to time.
2. Area between Low Tide Line and the High Tide Line.

##### **Category – II (CRZ – II)**

1. The areas that have already been developed upto or close to the shoreline. For this purpose, “developed area” is referred to as that area within the municipal limits or in other legally designated urban areas which is already substantially built up and which has been provided with drainage and approach roads and other infrastructural facilities, such as water supply and sewerage mains.

##### **Category – III(CRZ – III):**

1. Areas that are relatively undisturbed and those which do not belong to either Category – I or II. These will include coastal zone in the rural areas (developed and undeveloped) and also areas within Municipal limits or in other legally designated urban areas which are not substantially built up.

##### **Category – IV (CRZ – IV):**

- a Coastal stretches in the Andaman & Nicobar, Lakshadweep and small islands, except those designated as CRZ – I, CRZ – II or CRZ – III.

## Appendix 4

### MSK Intensity Scale

The following definitions are used in the scale:

#### 1. Type of Structures (Buildings)

Structure A	Buildings in field-stone, rural structures, un burnt brick houses, clay houses
Structure B	Ordinary brick buildings, buildings of the large block and prefabricated type, half timbered structures, buildings in natural hewn stone
Structure C	Reinforced buildings, well built wooden structures

#### a Definition of Quantity

Single, few	About 5 percent
Many	About 50 percent
Most	About 75 percent

#### a Classification of Damage 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; and inner walls collapse.
Grade 5 Total damage	Total collapse of buildings

#### 4. Intensity Scale

- I. Not noticeable
- II. Scarcely noticeable (very slight)
- III. Weak, partially observed only
- IV. Largely observed
- V. Awakening
- VI. Frightening

Damage for 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 landslips 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 suffer of Grade 3, and 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. Memories 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. and a few of Grade 4, many buildings of Type B show damage of Grade 4, and 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 and 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. Road paving and asphalt show waves.

XI. Destruction

Severe damages even to well built buildings, bridges, water cams and railway lines, highways become useless; underground pipes destroyed.

XII. Landscape changes

Practically all structures above and below ground are greatly damaged or destroyed.

## Appendix -5

### Design Procedure for wind resistance in buildings

The following procedure may be followed to design a building that will be resistant to damages during high winds/cyclones.

#### Fix the Design Data

- a) Identify the national wind zone in which the building is situated. This can be seen from wind code (IS: 875 Part 3-1987) or the Vulnerability Atlas of India (1997)
- b) Corresponding to the zone, fix the basic design wind speed,  $v_b$  which can be treated as constant up to the height of 10m.
- c) Choose the risk co-efficient or the importance factor  $k_1$ , for the building, as for example given below:

Building type	Coefficient $k_1$
i Ordinary residential building	1.0
ii. Important building (e.g. hospital, police station, telecommunication, school, community and religious buildings, cyclone shelters, etc.)	1.08

- d) Choose appropriate value of  $k_2$  corresponding to building height, type of terrain and size of building structure, as per IS: 875 (part 3) 1987. For buildings up to 10m height and category –A, which will cover the majority of housing, the values are:

Terrain	Coefficient $k_2$
I. Flat sea-coastal area	1.05
II. Level open ground	1.00
III. Built-up suburban area	0.91
IV. Built-up city area	0.80

- e) The factor  $k_3$  depends upon the topography of the area and its location above sea level. It accounts for the acceleration of wind near crest of cliffs or along ridge lines and deceleration in valleys etc.

#### Determine the wind forces

- a) Determine the design wind velocity  $V_z$  and normal design pressure  $P_z$

$$V_z = V_b k_1 k_2 k_3$$

$$p_z = 0.0006 V_z^2$$

$p_z$  will be in  $\text{kN/m}^2$  for  $V_z$  in m/s.



- b) Corresponding to the building dimensions (length, height, width) the shape in plan and elevation, the roof type and its slopes as well as projections beyond the walls, determine the coefficients for loads on all walls, roofs and projections, taking into consideration the internal pressures based on size and location of openings. Hence calculate the wind loads on the various elements normal to their surface.
- c) Decide on the line of resistance, which will indicate the bracing requirements in the planes of roof slopes, at eave level in horizontal plane, and in the plane of walls. Then, determine the loads generated on the following connections;
- Roof cladding to Purlins
  - Purlins to rafters/ trusses
  - Rafters/trusses to wall elements
  - Between long and cross walls
  - Walls to footings.

**Design of the elements:**

- a) Load effect shall be determined considering all critical combinations of dead load, live load and wind load in the design of elements, stresses reversal under the wind suction should be given due consideration. Members are flanges, which are usually in tension under dead and live loads, may be subjected to compression under dead load and wind, requiring consideration of buckling in their design.
- b) Even thin reinforced concrete slabs, say 75 mm thick may be subjected to uplift under wind speeds of 55 m/s and larger, requiring holding down by anchors at the edges and reinforcement on top face! As a guide there should be extra dead load (insulation, weathering course, etc.). On such roofs to increase the effective weights to about 375 Kg/ m<sup>2</sup>.
- c) Resistance to corrosion is a definite requirement in cyclone prone sea coastal areas. Painting of steel structures by corrosion-resistant paints must be adopted. In reinforced concrete construction, a mix of M20 grade with increased cover to the reinforcement has to be adopted. Low water cement ratio with densification by means of vibrators will minimize corrosion.
- d) All dynamically sensitive structures such as chimney stacks, specially shaped water tanks, transmission line towers, etc. should be designed following the dynamic design procedures in various IS codes.

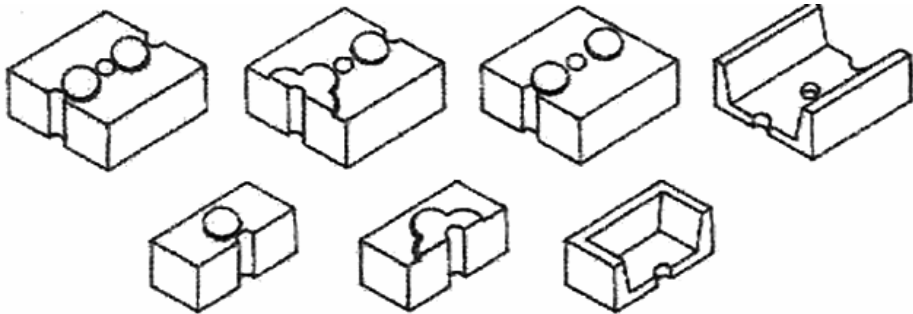
- e) The minimum dimensions of electrical poles and their foundations can be chosen to achieve their fundamental frequency above 1.25 Hz so as to avoid large amplitude vibrations and consequent structural failure.

**Conclusion:**

It may be emphasized that good quality of design and construction is the single factor ensuring safety as well as durability in the cyclone hazard prone areas. Hence all building materials and building techniques must follow the applicable Indian Standard Specification.

## Appendix -6

### Basic Design Guidelines for CSEB



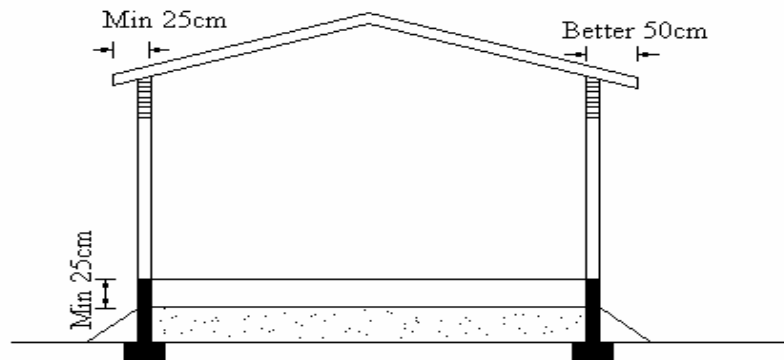
**Fig.42. Varsity of Auram Block 245**

### General principles for a good design

”Good boots and a good hat”

That means built a good basement:  
(Minimum 25-cm high, See Fig.43)

Good over hangs:  
(Minimum 25cm wide or better 50cm, See Fig.43)



**Fig.43. Good Basement and Overhanging**

### Compressive strength for earth quake resistant CSEB

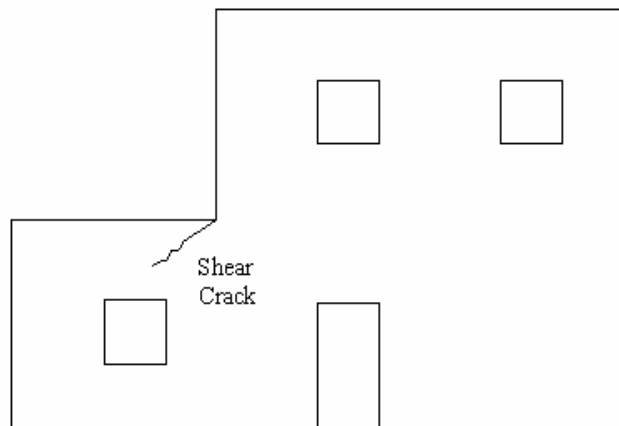
- Design the walls (thickness + stability) according to the weight bearing capacity of wet CSEB.
- The minimum admissible crushing load of HI CSEB should be 25 Kg/cm<sup>2</sup> under wet conditions. (After 3 days immersion)
- Keep at least safety factor of 10 from the wet crushing strength ( $\sigma_c$ ) for hi CSEB.

Example: A hi CSEB has a  $\sigma_c$  wet of 25kg/cm<sup>2</sup>; the maximum load bearing for the basement will be

$$25/10 = 2.5\text{kg/cm}^2$$

### Shear strength

- Avoid any major difference of load bearing in CSEB walls: especially with a different floor height.



**Fig.44. Shear Crack in Building with Different Floor Height**

**Water Absorption and Erosion.**

- Avoid any concentration or accumulation of water in any part or surrounding of the building.
- Avoid any run of water in any part of the building (i.e. leakage)

**Module of Blocks**

- Design the building according to the module of blocks.  
The module of the block is its nominal size + the mortar thickness

## Appendix -7

### Dead Weights of Construction Materials

S.no	Description of Construction Materials	Weight in kg/m <sup>3</sup>
1	Brick, in mud lime or cement mortar	1920
2	Coarsed rubble in lime or cement mortar	2240
3	Laterite in lime mortar	2000
4	Concrete in lime or cement mortar	19.2 (Brick jelly) or 2240 (Hard broken stone)
5	Random rubble in lime or cement mortar	2240
6	Lime stone	2240 to 2640
7	Sand-stone	2240 to 2400
8	Cuddapha slabs	2720
9	Ashlar	2720
10	Granite stone	2620 to 2800
11	Reinforced concrete	2400
12	Cast iron	7030 to 7130
13	Wrought iron	7700
14	Steel	7850
15	Teak	625
16	Pine	610
17	Oak	865
18	Fir	430 to 460
<b>Description of roof materials and roofs</b>		
19	Corrugated iron sheet (1.25mm)	10.56
20	Corrugated iron sheet (1mm)	8.6
21	Brick, in mud lime or cement mortar	1,920
22	Coarsed rubble in lime or cement mortar	2,240
23	Laterite in lime mortar	2000
24	Concrete in lime or cement mortar	19.2 (Brick jelly) or 2240 (Hard broken stone)
25	Random rubble in lime or cement mortar	2,240
26	Lime stone	2400 to 2640
27	Sand stone	2240 to 2400

## Imposed Floor Loads for Different Occupancies

### a) Residential Building:

S.no	Occupancy Classification	Uniformly Distributed Load (kN/m <sup>2</sup> )	Concentrated Load (kN)
1	All rooms and kitchen	2.0	1.8
2	Toilet and bathrooms	2.0	-
3	Corridor, passage, staircases including fire escape and store room	3.0	4.5
4	Balconies	3.0	1.5m/run concentrated at the outer edge

### b) Hotels, hostel, boarding/lodging houses, dormitories, residential clubs:

S.no	Occupancy Classification	Uniformly Distributed Load (kN/m <sup>2</sup> )	Concentrated Load (kN)
1	Living room, bedroom and dormitories	2.0	1.8
2	Kitchen and laundries	3.0	4.5
3	Billiards room and public lounges	3.0	2.7
4	Store room	5.0	4.5
5	Dining rooms and restaurants	4.0	2.7
6	Office rooms	2.5	2.7
7	Baths and toilet	2.0	-

**c) Educational buildings:**

<b>S.no</b>	<b>Occupancy Classification</b>	<b>Uniformly Distributed Load (kN/m<sup>2</sup>)</b>	<b>Concentrated Load (kN)</b>
1	Class rooms	3.0	2.7
2	Dining rooms, cafeterias and restaurants	3.0	2.7
3	Office, lounges and staff rooms	2.5	2.7
4	Dormitories	2.0	2.7
5	Projection room	5.0	-
6	Kitchen	3.0	4.5
7	Toilet and bathrooms	2.0	-
8	Store rooms	5.0	4.5
9	Libraries and archives		
9.a	Stack room	6.0kNm <sup>2</sup> for a minimum height of 2.2m and 2kN/m <sup>2</sup> beyond 2.2m	4.5
9.b	Reading room	4.0	4.5
10	Corridors, lobbies. Staircase including fire escape	4.0	4.5
11	Balconies	4.0	1.5/meter run

**d) Office buildings:**

<b>S.no</b>	<b>Occupancy Classification</b>	<b>Uniformly Distributed Load (kN/m<sup>2</sup>)</b>	<b>Concentrated Load (kN)</b>
1	Rooms for general use with separate storage	2.5	2.7
2	Rooms for general use without separate storage	4.0	4.5
3	Store rooms	5.0	4.5
4	Dining rooms and cafeterias	3.0	2.7
5	Corridors, passage and lobbies	4.0	4.5
6	Bathroom and toilets	2.0	-



### Live Loads on Roofs

Type of roof	Live load	Minimum live load measured on plan
Flat, sloping roof or cured roof with slope upto 10degree (access provided)	150kg/m <sup>2</sup>	375kg uniformly distributed over any span of one meter width of roof slab and 900kg uniformly distributed over the span in case of beam
Flat, sloping roof or cured roof with slope upto 10degree (access not provided)	75kg/m <sup>2</sup>	190kg uniformly distributed over any span of one meter width of roof slab and 450kg uniformly distributed over the span in case of beam
Sloping roof with slope degree greater than 10 degree	For roof members sheets or purlins 75kg/m <sup>2</sup> for every degree increase in slope over 10 degree	
	For member supporting the roof membrane and roof purlins, such as trusses, beam girders, etc-2/3 of load described above	

**Note:** For special type of roof with highly permeable material and absorbent material, the contingency of roof material increasing in weight due to absorption of moisture shall be provided.

### Live Load on Structures Affected by Impact and Vibration

Impact of live load for structure carrying live load which induce impact to vibrations, the live load shall be increased as follows:

- a) For frame supports lifts and hoists – 100%
- b) For foundation, footing and piers supporting lifts and hoisting apparatus – 40%
- c) For light machinery, shaft or motor units – 20% minimum
- d) For reciprocating machinery or power units – 50% minimum

## Appendix -8

### Design for Physically Challenged and Aged

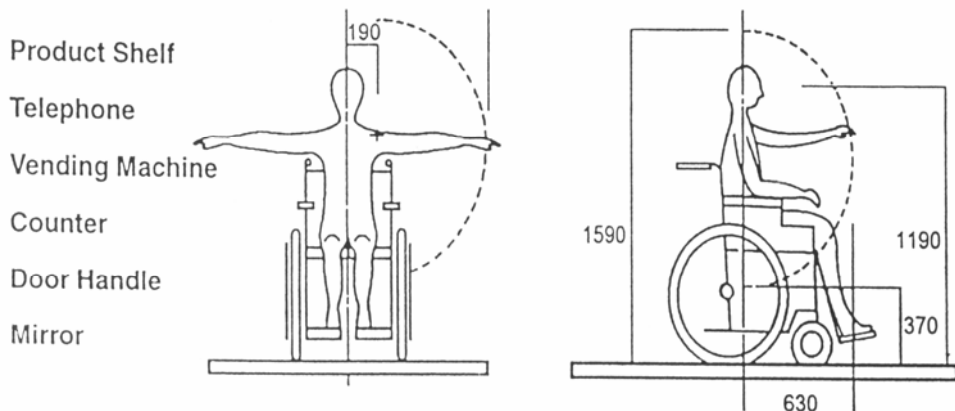
#### Recommended Minimum Access provision for the Physically challenged:

S.no	Type of building	Minimum Provision
1	Single detached, single dwelling units	A minimum of 2% of the total number of units to be constructed with barrier-free feature
2	Staff housing, Multiple dwellings and high residential units	A minimum of 1 unit for every 25, plus 1 additional unit for every 100 units thereafter. Entrance and exit to be accessible
3	Tenement house, row houses and town houses	A minimum of 1 unit for every 150, plus 1 additional unit for every 100 units thereafter to be accessible
4	Post office, banks and financial service institutions	A minimum of 1 lowered service counter on the premises
5	Shops and single stories	Accessible shopping area
6	Food center	A minimum of 1 table without stool or seats attached to the floor for every 10 tables.
7	Community centers, village halls, concert halls, theaters and place for public assembly	Accessible entrance, exit and toilet should be provided. A minimum of 4 wheel chair spaces for seating capacity from over 100 to 400 seats.

#### Anthropometrics and Ergonomics of Physically Challenged and Aged:

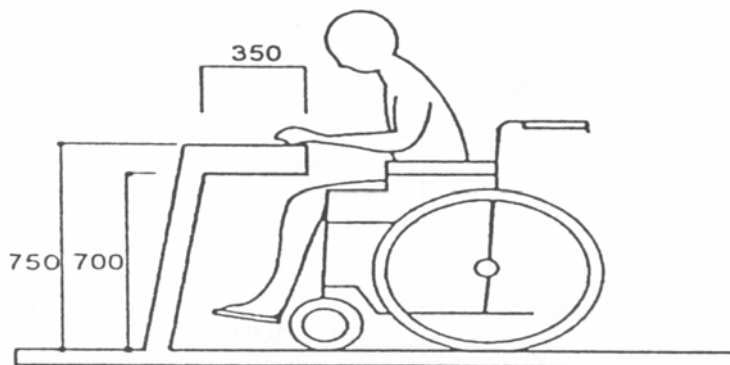
##### Range of Reach:

- A wheelchair user's movement pivots around his or her shoulders. Therefore, the range of reach is limited, approximately 630mm for an adult male
- While sitting in a wheel chair, the height of the eye from the floor is about 1190mm for an adult male.

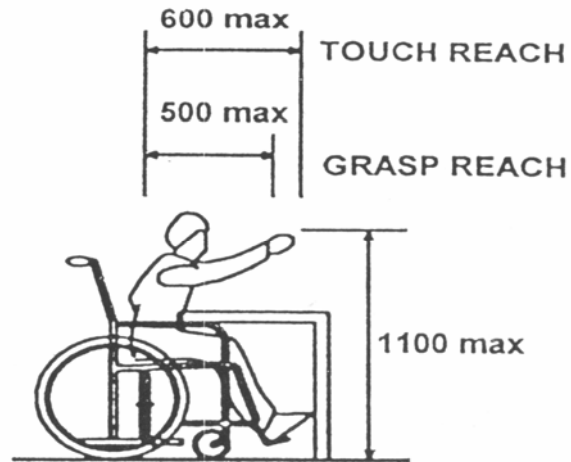


**Fig.45. Range of Reach**

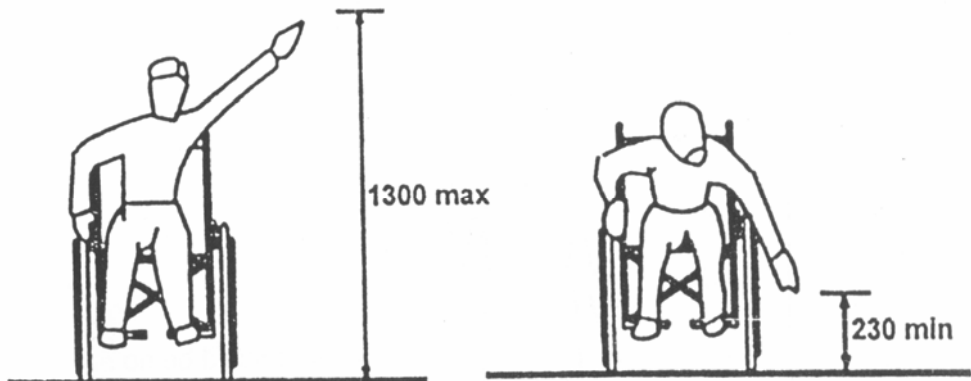
- A wheelchair has a footplate and leg rest attached in front seat (the footplate extends about 350mm in front of the knee). The footplate may prevent a wheel chair user from getting close enough to an object.
  - a) Manually operated equipment must be designed to be easily accessible from wheel chair.
  - b) Make sure that the coin slots of vending machines etc are located no higher than 1200mm.
  - c) Allow a space at least 350mm deep and 700mm high under a counter, stand etc.



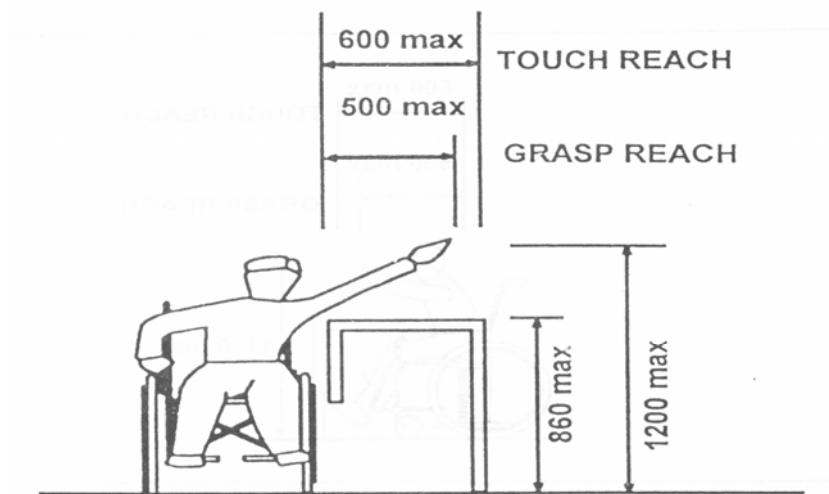
**Fig.46. Space Required for Wheelchair Footplate**



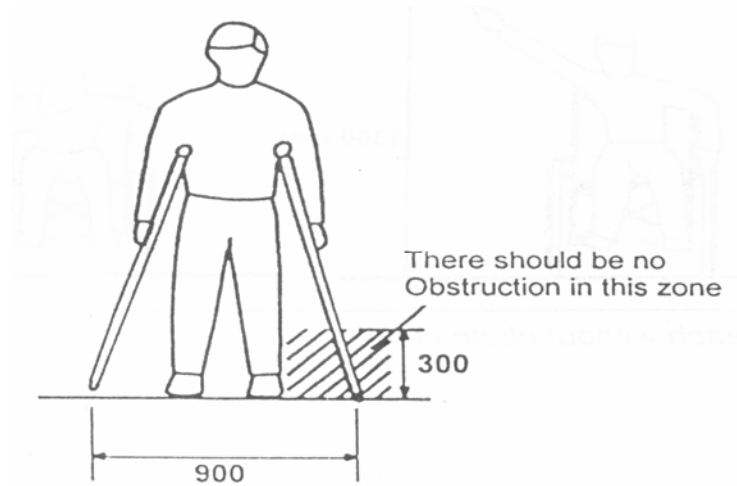
**Fig.47.Forward Reach over Obstruction**



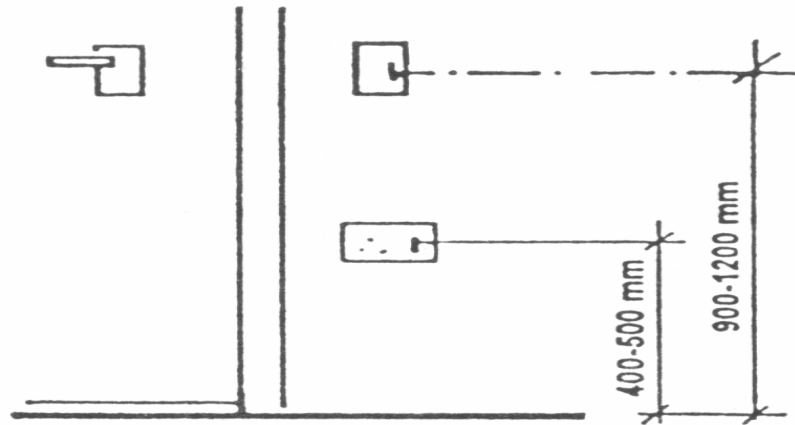
**Fig.48.Side Reach without Obstruction**



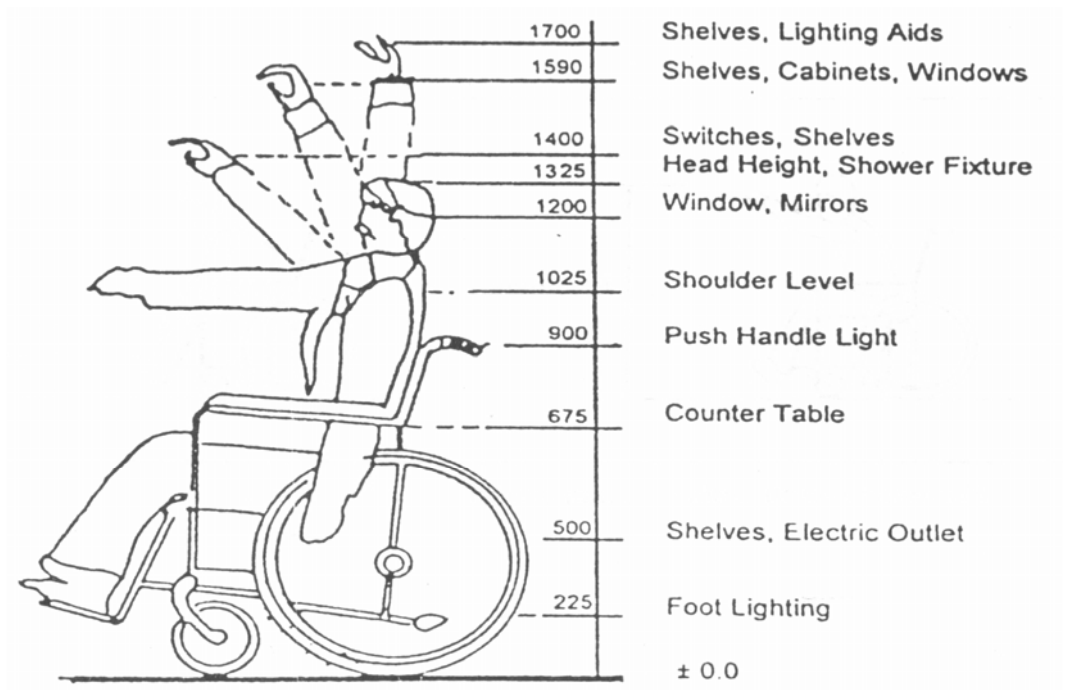
**Fig.49.Side Reach over Obstruction**



**Fig.50. Space Allowance**



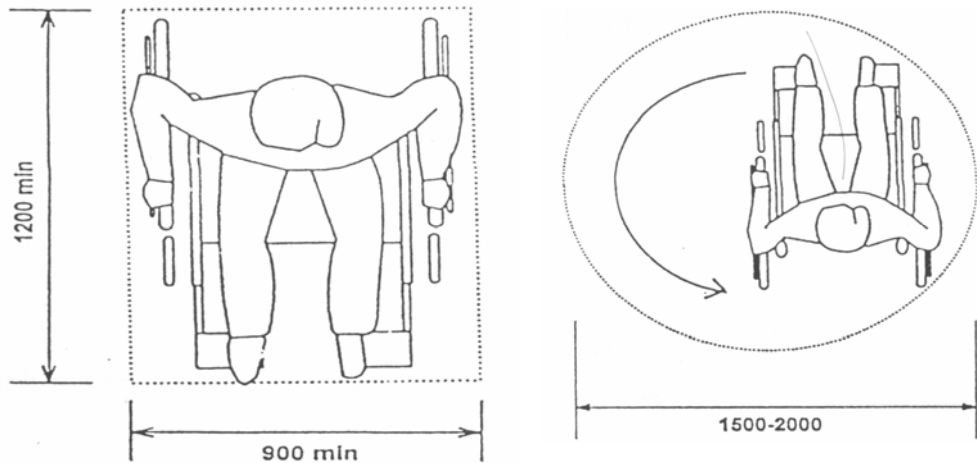
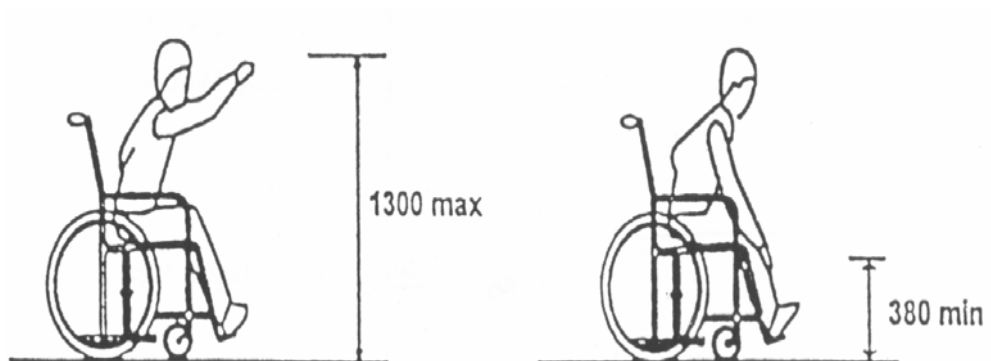
**Fig.51. Height of Switches, Doors, Handrails**



**Fig.52. Typical Dimensions for Essential uses with in Easy Reach**

**Controls:**

- For locking and opening controls for windows and doors should not be more than 1400mm from finished floors usable by one hand.
- Switches for electric light and power as well as door handles and other fixtures and fitting should be between 900mm to 1200mm from finished floor.
- Power points for general purposes should be fixed between 400 to 500mm from the finished floor.

**Reference Figures:****Fig.53. Space Allowance****Fig.54. Forward Reach without Obstruction**

## Appendix -9

### List of IS Codes and further references

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  - a) IS:1893-2002: Criteria for Earthquake Resistance Design of Structures, Part1: General Provision and Buildings.
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3. Produced by ‘Building Material and Technology Promotion Council’, Core 5-A, First Floor, India Habitat Center, Lodi Road, New Delhi-110 003. Tel: +91 11 24638096, Fax: +91 11 24642849, email: info@bmtpc.org, Web: <http://www.bmtpc.org/>
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  - c) Building with Arches, Vaults and Domes, 1996, Revised 2005-38p.
  - d) Production and Use of Hollow Interlocking CSEB for Disaster Resistance, 2005-25p.