GOVERNMENT OF TAMILNADU

GUIDELINES FOR RECONSTRUCTION OF HOUSES AFFECTED BY TSUNAMI

GENERAL AND PUBLIC BUILDINGS (MASONRY)

BUILD FOR SAFETY...

UNDP India

A5/-

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FOREWORD

The Government of Tamil Nadu initiated a number of steps in consultation with experts, research institutions, technical universities and civil society organizations for formulating comprehensive guidelines for the reconstruction programme of houses damaged by the tsunami of 2004. More than 54,000 houses are being constructed in the first phase by various organizations including the Tamil Nadu Slum Clearance Board for providing disaster resistant houses to the tsunami affected families. Government also announced a comprehensive housing reconstruction policy to provide safe buildings resistant to different disasters like floods, cyclones, earthquakes, tsunami, etc in areas which are vulnerable to such disasters.

A number of training programmes were organized for the Engineers and Building Supervisors of various Non Governmental Organizations to sensitize them to follow good construction practices while building the structures with masonry. The study undertaken as a follow up on the supervision of the quality of such masonry structures, indicated areas of concern with respect to quality of such masonry structures, indicated areas of concern with respect to quality of construction. The findings of this study were also discussed with the District Collectors concerned. One of the major findings of this study was the need for comprehensive guidelines for masonry and traditional structures. The State Government with the advice and guidance of Prof. A R Santhakumar has prepared this guideline based on various practices in the districts and national codes. The guidelines were circulated to the following team of experts for suggestions and modifications:-

1. Dr. N Lakshmanan, Director, Structural Engineering Research Centre.
2. Thiru R Jayaram, Chief Engineer, Tamil Nadu Slum Clearance Board.
3. Thiru S Nagarajan, Deputy Chief Engineer (Buildings), Public Works Department.
4. Dr. K.P. Jaya, Assistant Professor, Structural Engineering Division, Anna University.
5. Thiru M Syed Mohamed Abuthalib, Executive Engineer (Tsunami), O/C SC & CRA.
6. Thiru Hariharasubramanian, Engineering Specialist, Tsunami PIU, RD & PR Department.
7. Thiru Alok Patnaik, Shelter Specialist, UNDP, Chennai.

These guidelines will not only be of use to the tsunami reconstruction programme but also in the construction of masonry structures throughout the various districts of Tamil Nadu.

Many Public masonry buildings such as schools, hospitals etc. are planned and constructed in the districts. For such buildings, analysis and design can be carried out as per this guideline. These guidelines are applicable for buildings which are partly RCC and partly brick work. It becomes mandatory to follow these guidelines in order to ensure prevention of loss of precious lives during future disasters.

I compliment the team of experts who have brought out these guidelines for dissemination to all the stakeholders. I thank UNDP particularly Prof. A R Santhakumar and Er. Alok Patnaik for taking the responsibility of bringing out this document at an appropriate time. All the organizations concerned including UNDP are requested to organize IEC campaigns as well as training programmes for communicating these guidelines to the widest audience possible.

(C.V. SANKAR)

CONTENTS

MASONRY GUIDELINES

1. INTRODUCTION

A very severe earthquake measuring magnitude of 8.9 on Richter Scale struck northern Sumatra, Indonesia at 00:58:50 UTC or 06:28 AM IST. The earthquake driven tsunami was felt widely along the east coast of India. The calamity which struck the Tamil Nadu coast was unprecedented in its suddenness and ferocity. It was also widespread in scale affecting villages and towns all along the coastline. A calamity of this nature has never been known.

Cyclones:

Tamil Nadu being located in a highly vulnerable part of Peninsular India - the Deccan Plateau and flanked by the Bay of Bengal and the Arabian Sea, is frequently subjected to overwhelming devastation by natural calamities due to cyclonic storms and flooding in its coastal districts. Records of the past occurrences of cyclonic storms highlight the alarming fact that severe cyclonic storms are more frequent in the Bay of Bengal than in the Arabian Sea and records indicate that from the beginning of this century about 400 cyclonic storms formed in the Bay of Bengal as compared to just 80 in the Arabian Sea. Almost every year on an average, one severe cyclone in the pre-monsoon period and one or two in the post-monsoon period are expected during the Northeast monsoon period in the Bay of Bengal. The area normally affected by cyclones is the entire first line coastal taluks right from Chennai district to Ramanathapuram district. Tamil Nadu is one of the most vulnerable States in the country affected by cyclones.

As per the Wind & Cyclone zoning map as given in IS 875(Part-3) - 1987 and Vulnerability Atlas of India, brought out by BMTPC, there are six basic wind speeds considered for zoning, i.e. 55, 50, 47, 44, 39 and 33 m/sec. These peak wind speeds represent the peak gust velocity averaged over a short duration of 3 sec., at a height of 10 m above the ground level in an open terrain with a return period of 50 years. From wind damage point of view, these are categorized as follows:

55 m/sec- Very high damage risk zone- A

50 m/sec- Very high damage risk zone- B

47 m/sec- High damage risk zone

44 m/sec- Moderate damage risk zone- A

39 m/sec- Moderate damage risk zone- B

33 m/sec-Low damage risk zone

The wind speed zoning map of Tamil Nadu as per the Vulnerability Atlas of India is shown on inside back wrapper, Tamil Nadu falls in three categories of the wind zones :

50 m/sec- Very high damage risk zone -B

47 m/sec- High damage risk zone

44 m/sec- Moderate damage risk zone –A

Importance factor (f) to be considered for the following types of buildings is:

Special Buildings including Societal buildings, Schools, Hospitals involving post-cyclone importance $f = 1.3$

Industrial structures $f = 1.15$

Normal buildings $f = 1.0$ (1)

1.1 Wind Induced Loads

Wind force is basically random and dynamic in nature, and it is treated as stationary for simplicity in the analysis and design of structures. As per IS 875 (Part 3) Code, the wind load on a building/ structure shall be calculated for (i) the building as a whole and (ii) individual elements/ members. Wind loads on individual elements/ members are calculated as given below:

$$F = \left(C_{pe} - C_{pi}\right)A\left(\frac{1}{2}\rho V_z^2\right) \quad (2)$$

where C_{pe} and C_{pi} = external and internal pressure coefficients, respectively; A = surface area of structural element/ member; ρ = air density; and V_z = design wind speed at height z.

The total wind load on the building/ structure is calculated as given below:

$$F = C_f A_e \left(\frac{1}{2}\rho V_z^2\right) \quad (3)$$

where C_f = force coefficient for the building; A_e = effective frontal area of the building or structure.

When the fundamental frequency of the structure is less than 1Hz or the aspect ratio (height/ width) of the structure is very high (>5), the structure is considered as dynamically sensitive to wind. The equivalent steady state wind load on such building/ structure based on gust effectiveness factor approach is given as,

$$F = GC_f \left(\frac{1}{2}\rho \bar{V}_z^2\right) A_e \quad (4)$$

where, $\bar{V}_z$ = hourly mean wind speed at height z;

G = Gust Effectiveness Factor (GEF)

IS 875 (Part 3) code suggests the following expression for the estimation of the gust effectiveness factor,

$$G = 1 + g_f r \sqrt{B(1+\phi)^2 + \frac{SE}{\beta}} \quad (5)$$

where, g_f = peak factor; r = roughness factor (twice the value of intensity of turbulence, $\sigma_v / \bar{V}$); B = background factor; S = size reduction factor; E = measure of available energy in the wind stream at the natural frequency of the structure; β = damping coefficient of the structure.

The parameters g_f, r, B, S, E and B can be obtained from the IS 875 (Part 3) code using different graphs. The parameter ϕ in Eq.(5) can be calculated as $(g_f r\sqrt{B})/4$. The parameter ϕ is to be accounted only for buildings less than 75m high in terrain category 4 and for buildings less than 25m high in terrain category 3 and is to be taken as zero in all other cases.

Even though the Indian code specifies that the cyclonic wind speeds have been included in estimating the basic wind speed, the extreme value analysis carried out at SERC, Chennai, clearly reveals that the cyclonic wind speeds are far in excess of the wind speeds recommended in IS 875 (Part 3) . The possible reason may be the use of non-cyclonic and cyclonic winds as belonging to one parent distribution. Based on the evaluated characteristic cyclonic wind speeds for different coastal regions a common basic cyclonic wind speed of 65 m/s has been recommended for adoption in cyclone-prone regions. To obtain the corresponding risk coefficient, k_1, the values of the parameters A and B defined in IS:875 (Part 3) code were suggested as 95 and 35 kmph, respectively.IS 15498 code (2004) has slightly modified the above mentioned basic cyclonic wind speed by including an enhancement factor for cyclonic risk as given below,

$$V_z = f\, k_1\ k_2\ k_3\ V_b \qquad (6)$$

where k_1, k_2, *and* k_3 are defined as per IS 875 (Part 3) code

f = enhancement factor for cyclonic risk (same as importance factor Eq.(1))

1.2 Earthquakes:

Though not as seismically active as States in the northern and western parts of the country, small to moderate earthquakes have occurred in the state of Tamil Nadu.

Earthquakes in the state of Tamil Nadu are mid-plate in nature and the frequency of earthquakes is low i.e. the gap between moderate sized events is fairly long. Tremors have been felt in almost every corner of the state, mostly from distant earthquakes in adjoining States or from the Indian Ocean. Historically however, most earthquakes have originated in western and northeastern regions. Seismic activity in the recent past has occurred in clusters along the borders with Andhra Pradesh, Karnataka and Kerala.

Several faults have been identified in this region out of which many show evidence of movement during the Holocene period. The east-west trending Cauvery Fault, Tirukkovilur - Pondicherry Fault and Vaigai River Fault and the north-south trending Comorin-Point Calimere Fault and Rajapatnam-Devipatnam Fault are some of them and run close to major urban centres like Coimbatore, Madurai, Nagapattinam, Thanjavur and Pondicherry.

Latest Seismic zoning map of Bureau of Indian Standards classifies Tamil Nadu into two categories - Zone II and Zone III which are under low risk and Moderate risk respectively (as shown on map on back wrapper).

Summary:

These guidelines have been specifically framed for the reconstruction of public buildings considering multi hazard perspective, for the communities which have been affected by the tsunami of 26 th December 2004 in coastal districts of Tamil Nadu. These guidelines will also be helpful for the construction of houses in other districts apart from the coastal districts, which are prone to cyclones and earthquakes.

Public buildings such as schools, hospitals etc. should be suitably planned and designed. For such buildings, analysis and design can be carried out as per this guidelines. These guidelines are also applicable for buildings which are partly RCC and partly brick work.

2. DETERMINATION OF LATERAL LOADS DUE TO EARTHQUAKE

The procedure recommended is either equivalent static approach or based on dynamic analysis. The main difference between the equivalent lateral load procedure and dynamic analysis procedure lies in the magnitude and distribution of the forces along the height of the building. In the dynamic analysis procedure the lateral forces are based on properties of natural modes of vibration which depend on distribution of mass and stiffness along the height. In the equivalent lateral force procedure, the magnitude of forces is based on fundamental period and the distribution of forces is given based on simple formula applicable for regular buildings.

Regular and Irregular Configuration

To perform well in an earthquake, a building should possess four main attributes, namely simple and regular configuration, and adequate lateral strength, stiffness and ductility. Buildings having simple regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation, suffer much less damage than buildings with irregular configurations.

Equivalent lateral force procedure

The design base shear is first computed for the whole structure and then distributed along the height of the building based on simple formula. The design lateral load obtained at each floor level is then distributed to individual lateral load resisting elements based on floor diaphragm action. In RCC buildings with rigid floors the shear in that floor is distributed based on their relative rigidity.

Design Seismic Base Shear

The total design lateral force or design seismic base shear (V_B)along any principal direction shall be determined by the following expression:

Where

$$\mathbf{V_B = A_h W}$$

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

$$A_h = \frac{ZIS_n}{2Rg}$$

Z=Zone factor given in Table 2 of IS 1893: 2002, is for the Maximum Considered.

Earthquake (MCE) for the service life of structure in a zone. The factor 2 in the denominator of Z is used so as to reduce the Maximum Considered Earthquake (MCE) to the Design Basis Earthquake (DBE).

I=Importance factor, depending upon the functional use of the structures, characterized by hazardous consequences of its failure, post-earthquake functional needs, historical value, or economic importance (Table 6 of IS 1893:2002). The table is reproduced below as Table 1

R=Response reduction factor, depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations. However, the ratio (I/R) shall not be greater than 1.0.The values of **R** for buildings are given in Table 7 of IS 1893:2002.

Average response acceleration coefficient **Sa/g** is determined based on period of the building and damping.

Table 1 Importance Factors, I

Table 1 Importance Factors, I

(Clause 6.4.2)

Sl No.	Structure	Importance Factor
(1)	(2)	(3)
i)	Important service and community buildings, such as hospitals; schools; monumental structures; emergency buildings like telephone exchange, television stations, radio stations, railway stations, fire station buildings; large community halls like cinema halls, assembly halls and subway stations, power stations, etc.	1.5
ii)	All other buildings	1.0

NOTES

1. The design engineer may choose values of importance factor / greater than those mentioned above.

2. Buildings not covered in Sl No. (i) and (ii) above may be designed for higher value of I, depending on economy, strategy considerations like multi-storey buildings having several residential units.

3. This does not apply to temporary structures like excavations, scaffolding etc of short duration.

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 Earthquake

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

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.

This special guidelines deals with the design of structures located on coastal sites to resist the forces induced due to tsunami impact and is applicable to concrete and masonry buildings, earth dams, embankments, dykes , retaining walls , tsunami shelters and engineered multistory buildings that may be used for vertical evacuation.

Lateral Loads due to tsunami impact

Hydrodynamic Loads

The hydrodynamic loads due to tsunami and storm surge on coastal structures include hydrostatic pressure, buoyancy force, fluid flow drag and surge impingement.

Hydrostatic Force (F_h)

Hydrostatic force occurs when standing or slow moving water encounters a building or building component. The lateral hydrostatic force is given by:

$$F_h = \frac{1}{2} \rho g \left(h + u_p^2 / 2g \right)^2 \quad (7)$$

Where,

F_h : Hydrostatic force

ρ : Density of water

g: Accleration due to gravity

h: water depth

u_p : Water velocity normal to the wall (as obtained from simulation)

The resultant force will act horizontally at a distance of h_R above the base of the wall where:

$$h_R = 1/3(h+ u_p^2 / 2g) \quad (8)$$

Hydrostatic force is usually important for 2-D structures such as seawalls and dikes or for evaluation of an individual wall panel where the water level outsides differ substantially from the level inside.

Buoyant Force (F_b)

The buoyant or vertical hydrostatic forces on a structure or structural member subjected to partial or total submergence will act vertically through the center of mass of the displaced volume. Buoyant forces are a concern for basement, empty above ground and below ground tanks, and for swimming pools. The buoyant force is given by:

$$F_b = \rho g V \quad (9)$$

Where, V is the volume of water displaced by the structure considered. This force is significant in tsunami and storm surge situation.

Hydrodynamic Drag Force (F_d)

The hydrodynamic drag force on a structure component in the direction of a steady flow can be expressed as:

$$F_d = \frac{1}{2} \rho C_D A u_p^2 \qquad (10)$$

Where,

C_D : Drag coefficient , the value is taken as 1.0 for circular piles, 2.0 for square piles and 1.5 for wall sections. A : Projected Area normal to the direction of the flow.

Surge Impingement (F_s)

Surge forces are caused by the leading edge of a surge of water impinging on a structure. The hydrodynamic force of the leading edge of the fluid flow acting per unit area of a structure due to tsunami surge is given by:

$$F_s = 4.5 \rho g h^2 \qquad (11)$$

Where, h is the height of surging flow. The resultant acts at a distance of approximately h above the base of the wall. This equation is applicable for walls within heights equal to or greater than 3h. Walls whose heights are less than 3h require surge force to be calculated appropriate combination of hydrostatic and hydrodynamic force equations for based on the given situation.

Impact Force (F_i)

During the tsunami or storm surge, water-borne objects (e.g. boats, oil rigs, vehicles, drift wood etc.) may hit a coastal structure with tremendous impact force.. The generalized expression for impact force F_i is give by following equation:

$$F_i = m (u_I / \Delta t) \qquad (12)$$

Where, u_I is the approach velocity that is assumed equal to the flow velocity, m is the mass of the body, Δt is the impact duration that is equal to the time between the initial contact of the body with the building and the maximum impact force.

Breaking Wave Force(F_{brkw})

Following expression for wave breaking force may be used:

$$F_{brkw} = \frac{1}{2} \rho C_{db} H_b D \qquad (13)$$

Where, C_{db} is a shape coefficient (value = 2.25 for square or rectangular piles and 1.75 for round piles), D is the pile diameter, and H_b is the wave breaking height ($H_b = 0.78\ d_s$, where d_s is the design still water depth).

Tsunami and Storm Surge Scour

The behavior of tsunami and storm surge scour is very complex and dependent on the geometric properties of the bridge columns as well and the material properties of the surrounding soil at the base. Currently, no simple formula exists for scour prediction. In the absence of site specific data a footing depth

$$d_s = (wh+1)^{0.65} \qquad (14)$$

is suggested for a depth of 'd_s' from the corners of buildings, with a minimum depth of 1m in any case. w is the footing width in 'metres' and 'h' the inundation depth of Tsunami run-up on land.

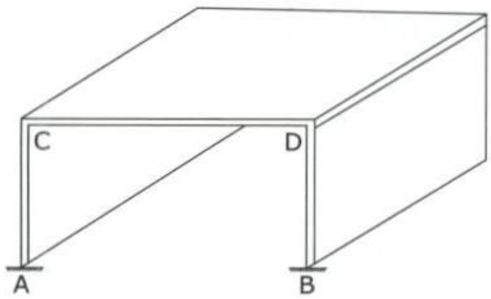
3.1.4 Fire

When the fire starts, it becomes difficult to extinguish it. 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.

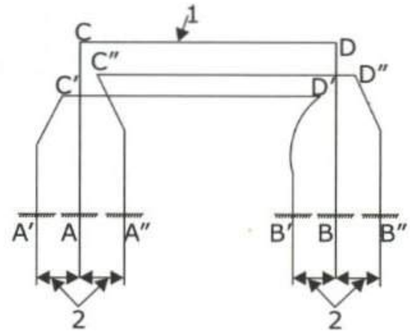
3.1.5 Ground Shaking Effect on Structures

a) Inertia Force

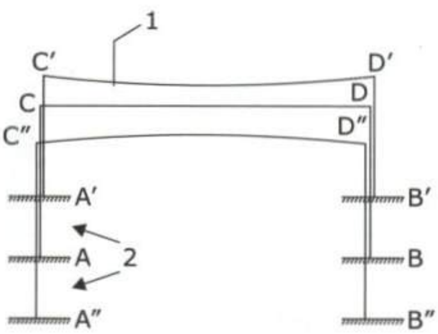
Buildings are fixed to the ground as shown in Fig.1 (a). As the base of building moves the superstructure including its contents tends to shake and vibrate from the position of rest, in a very irregular manner due to the inertia of the masses. When the base of the building suddenly moves to the right,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



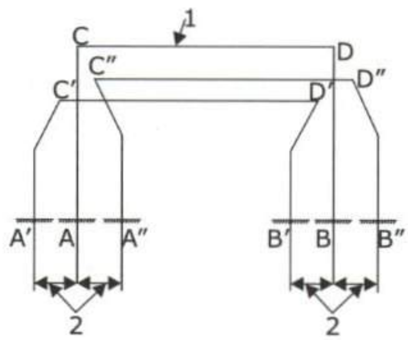
(a) Section of Building



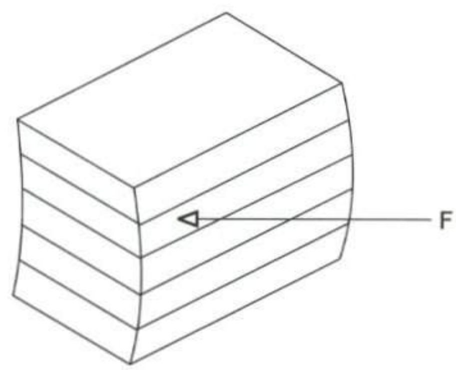
(b) Transverse Vibration



(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

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 loose 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 loose 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 $10t/m^2$
- Soft – Those soils, which have allowable bearing capacity less than or equal to $10t/m^2$
- 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.

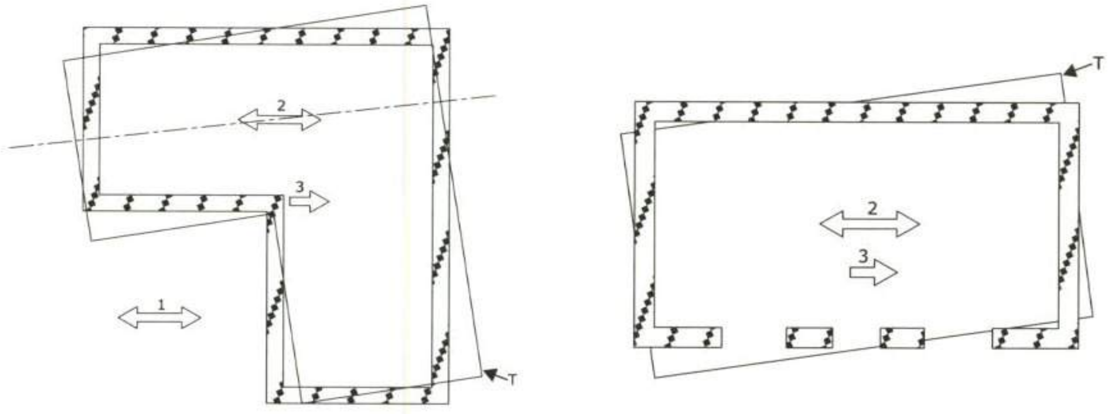
4.2.3 Selection of Foundations type

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 used either as shallow or deep foundation (Table.2).

Table 2: 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

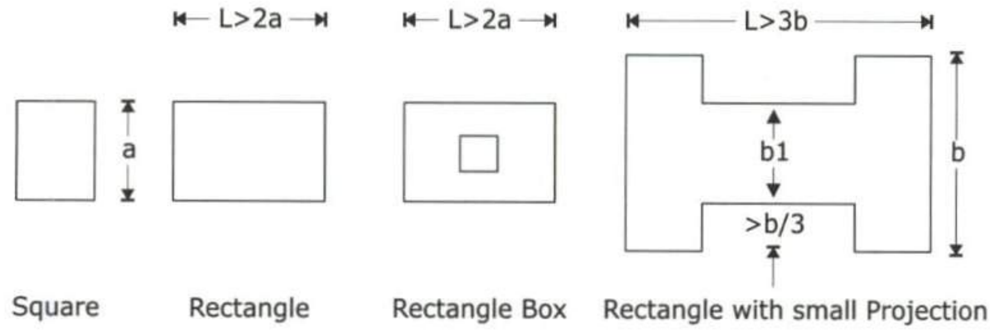
3- Center of Gravity or the Applied Inertia Force

T- Twisted Building

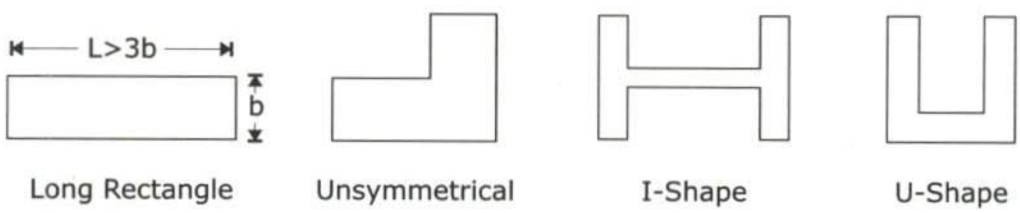
Fig.2. Torsion of Unsymmetrical Building

4.3.1 Symmetry

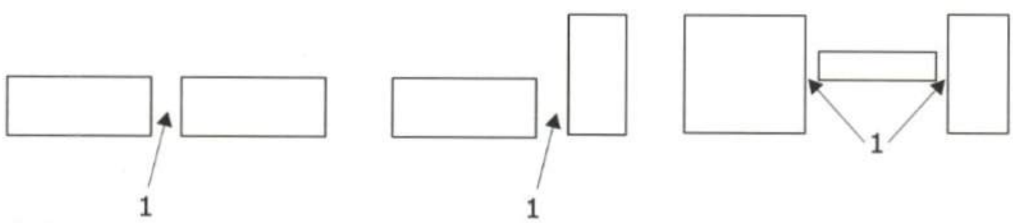
The building as a whole or its various blocks should be kept symmetrical about both the axes. Asymmetry leads to torsion during earthquakes and is dangerous. Torsion due to asymmetric loading is shown in Fig.2. Symmetry is also desirable in the placing and sizing of door and window openings as far as possible.



(a) Symmetrical desirable plans



(b) Long or Unsymmetrical Undesirable plans



Note:

1-Separations

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

(c) Use of Separation for improving behaviour of building

Fig.3.Plan of Building Block

4.3.2 Regularity

Simple rectangular shapes (Fig.3(a)) behave better in an earthquake than shapes with projections (Fig.3(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.3(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

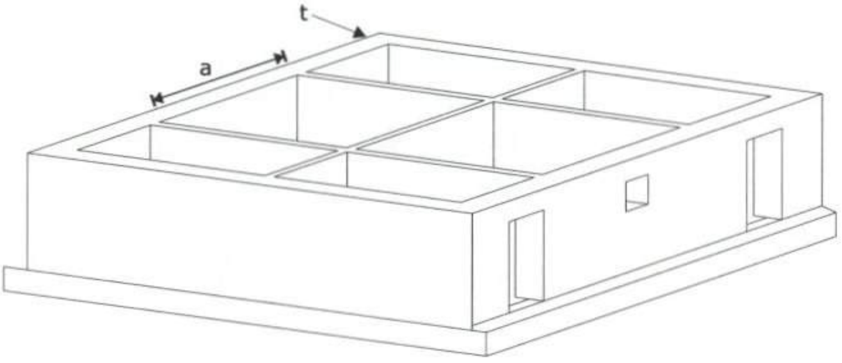
Ornamentation involving large cornices, vertical or horizontal cantilever projections, facia stones and the like are dangerous and undesirable from disaster resistance viewpoint. Simplicity is the best approach. Where ornamentation is insisted upon, it must be reinforced with steel, which should be properly 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.4(a) rather than one long room,Fig.4(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 4(c).

4.3.6 Separate Buildings for Different Functions

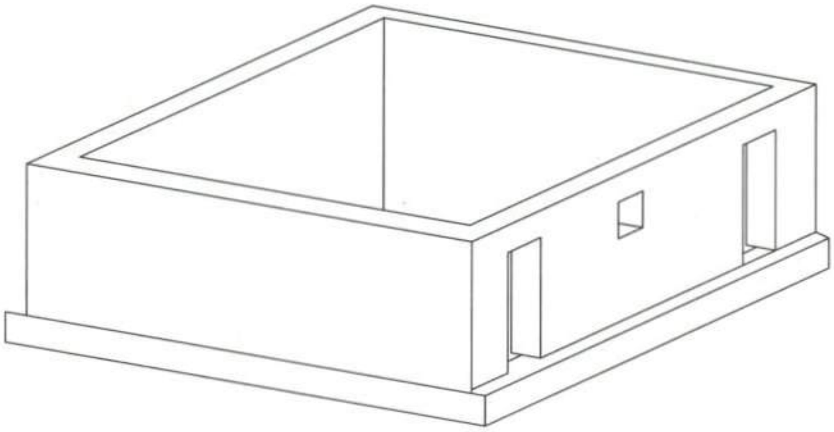
In view of the difference in importance of hospitals, schools, assembly halls residences, communication and security buildings, etc., it may be economical to plan separate blocks for different functions so as to effect economy in strengthening costs.



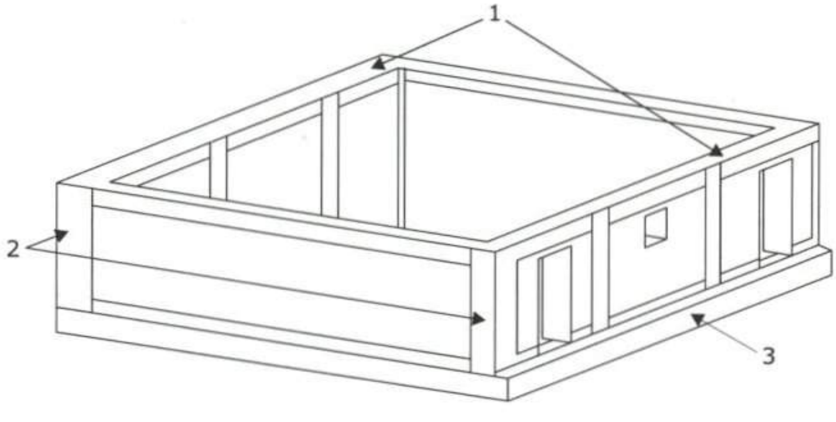
Note:

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

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



(b) No cross walls- long walls are seismically weak



Note:

1-Collar beam,

2-Column (or) Buttress,

3-Foundation.

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

Fig.4.Enclosed area forming box units

For various types of occupancies the dead load and live load are to be considered as given in IS 875.

The institutional building such as hospital, dispensaries and educational institutions should have provisions for physically challenged and aged. (Appendix 3)

4.4 Building with Fired Brick Masonry Units

The masonry wall fails in a brittle manner during disaster. Herein we discuss the causes of failure of masonry units, its strength and reinforcement requirement in masonry 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 is the, 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.

Table 3: 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 modules 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^3 and dressed stone masonry 24 kN/m^3.

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.

Table 4: 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 Appendix 2	

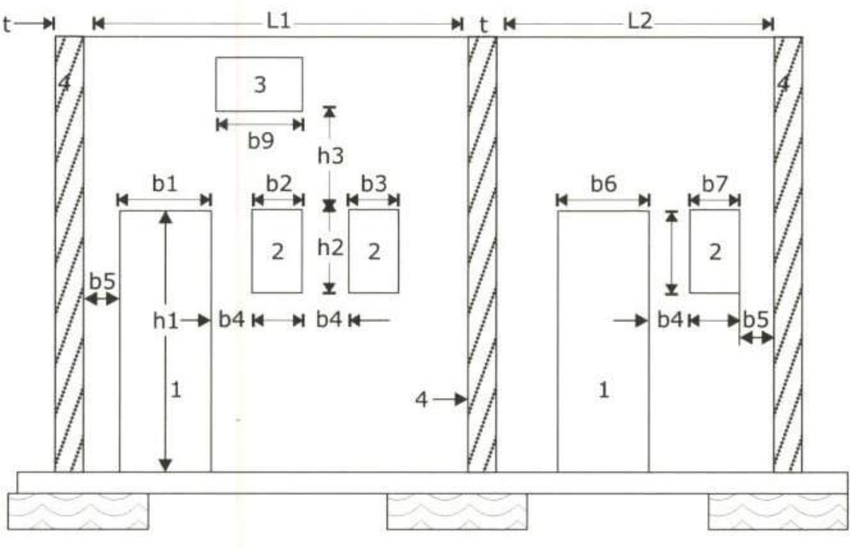
4.4.4 Wall Enclosure

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.5).

1. Openings to be located away from the inside corner by a clear distance b_5 equal to at least ¼ 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 ½ 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 ½ 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.6).



Note:

1-Door, 2-Window

3-Ventilator, 4-Cross wall

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

$\leq 0.42L_1$ for two storey

$\leq 0.33L_1$ for three storey

$b6+b7 \leq 0.5L_2$ for one storey

$\leq 0.42L_2$ for two storey

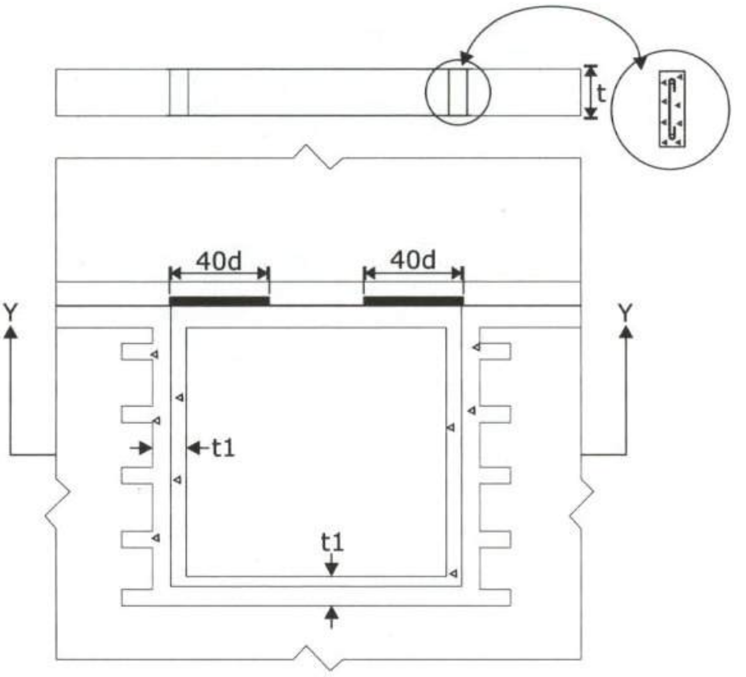
$\leq 0.33L_2$ for three storey

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

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

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

Fig.5. Recommendations regarding opening in bearing wall.



Note:

t-thickness of wall

t_1-thickness of R.C band

d-dia of reinforcing bar

Fig.6. Strengthening masonry around opening (window)

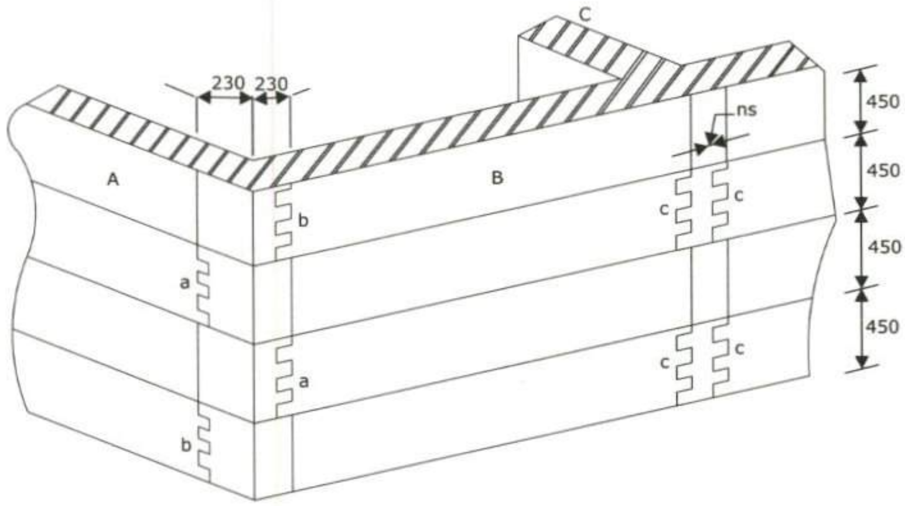
4.4.6 Masonry Bonds

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.7) 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.7. 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 board:

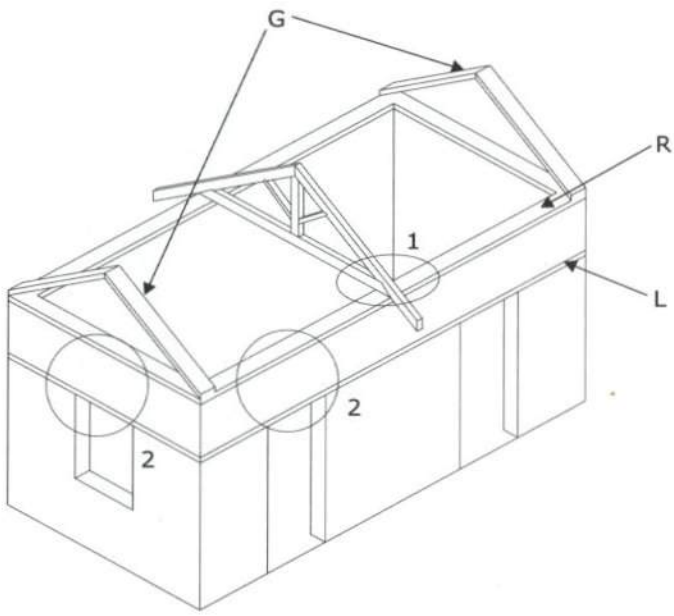
This is the most important band and will incorporate in itself all door and window lintels the reinforcement required for lintel for bridging the door/window opening should be extra to the lintel band steel. It must be provided on all walls in a storey and in all storeys.

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 gabble 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.8.



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.

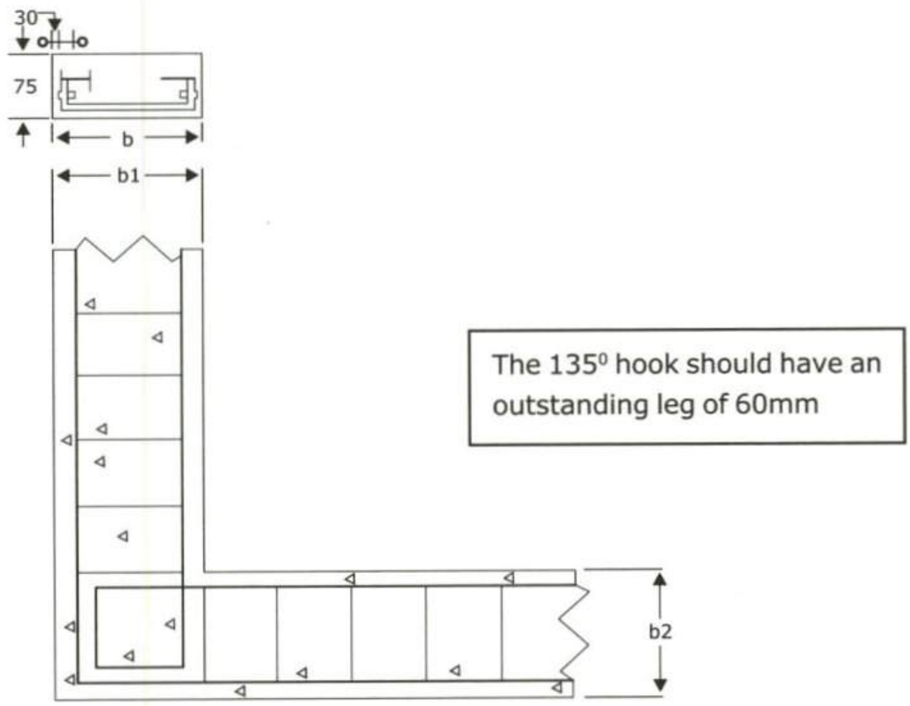
Fig.8. Gable band and Roof band in building

b) Selection of Bands or Ring Beams

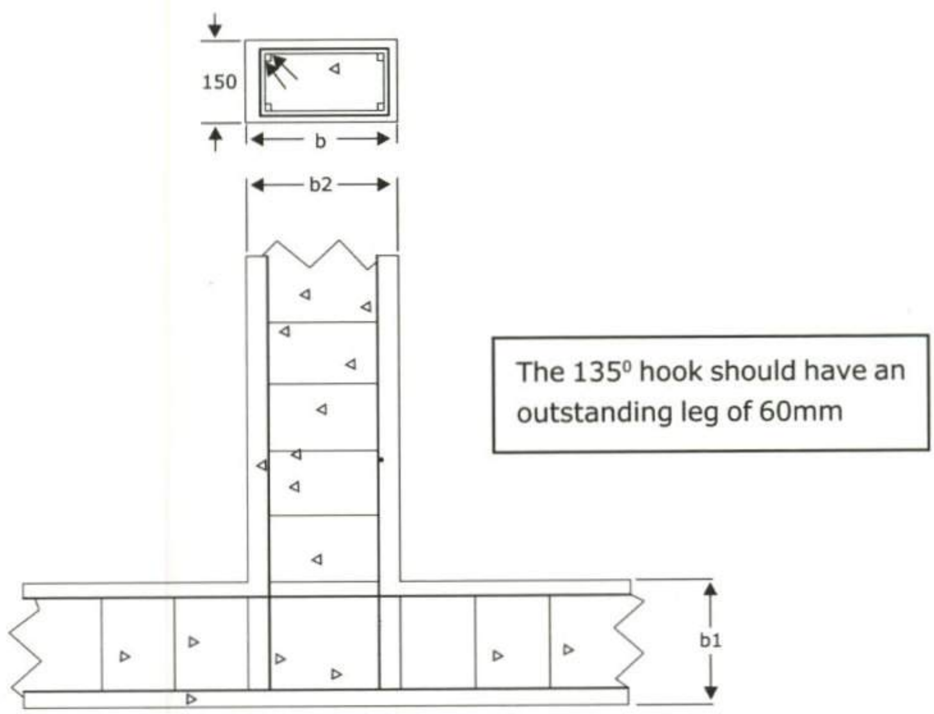
The reinforcement and dimensions of these bands may be kept as follows for wall spans upto 9m between the cross walls or buttresses. For longer spans, the size of band must be specially designed.

A band consists of two (or four) longitudinal steel bars with links or stirrups embedded in 75mm (or 150mm), thick concrete (Fig.9). 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.9).



(a) R.C Band Reinforcement at corner



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

Fig.9. Reinforcement detail in R.C.Band

Table 5: Recommendation for steel in RC Band

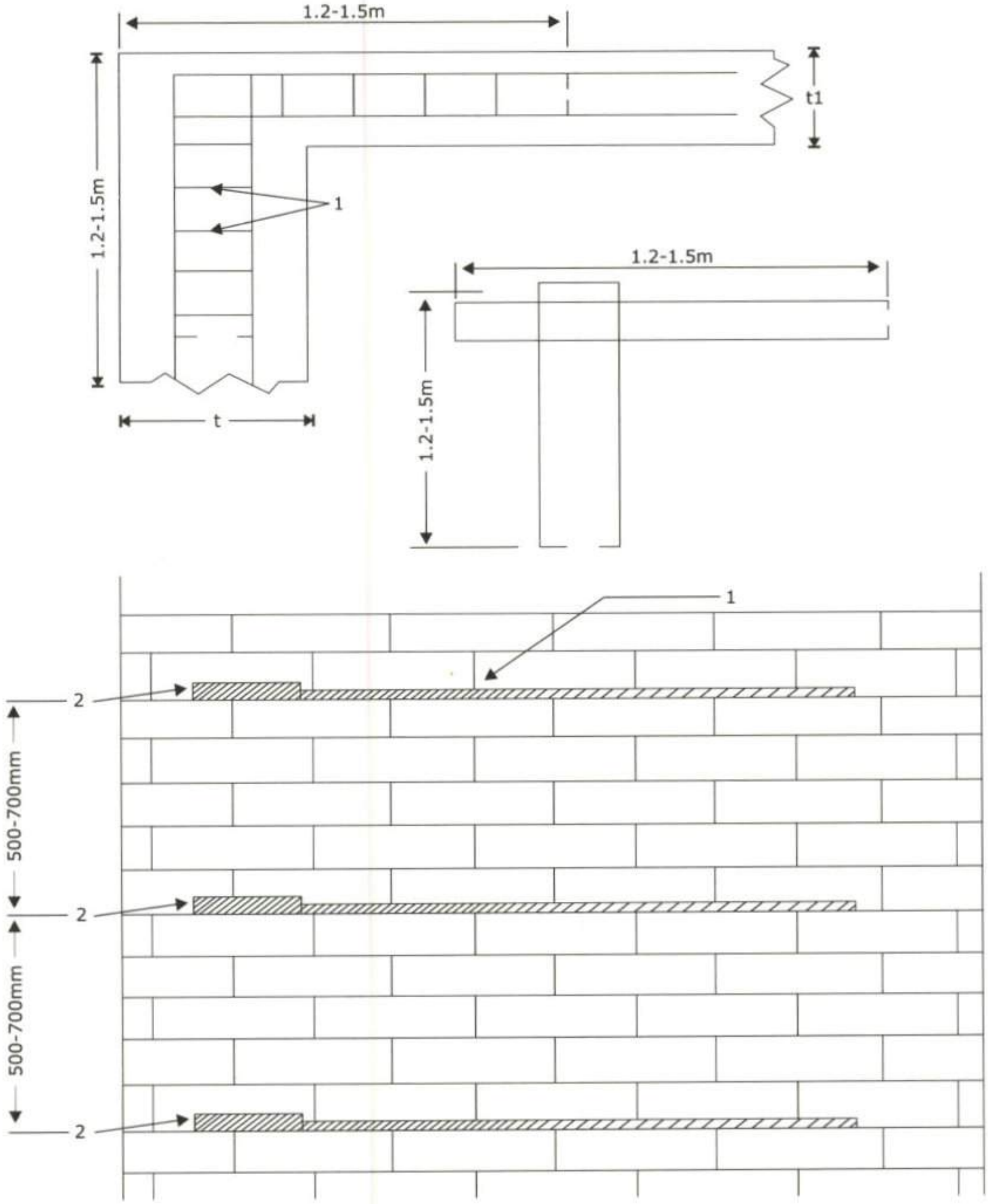
Span (m)	Category I		Category II		Category III		Category IV	
	No.of Bars	Dia.of Bars (mm)	No.of Bars	Dia.of Bars (mm)	No.of Bars	Dia.of Bars (mm)	No.of Bars	Dia.of Bars (mm)
5	2	12	2	10	2	10	2	10
6	2	16	2	12	2	10	2	10
7	2	16	2	16	2	12	2	10
8	4	12	2	16	2	16	2	12
9	4	16	4	12	2	16	2	12

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 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.10) 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

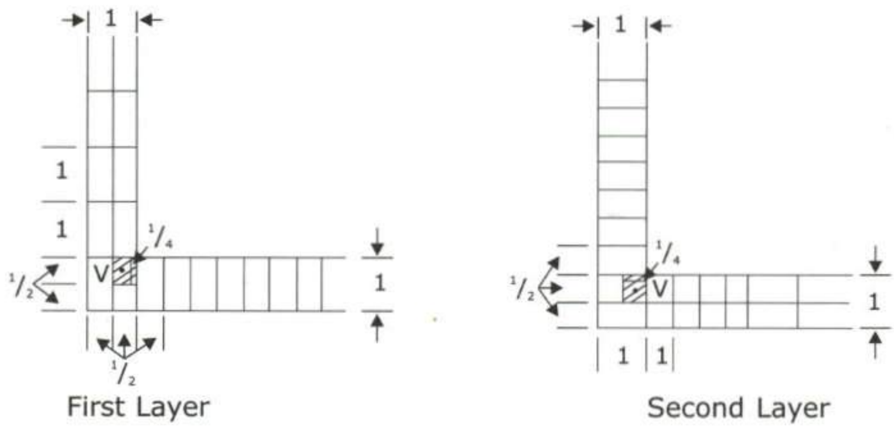
1-Cross links

2-Thicker joints to receive bars

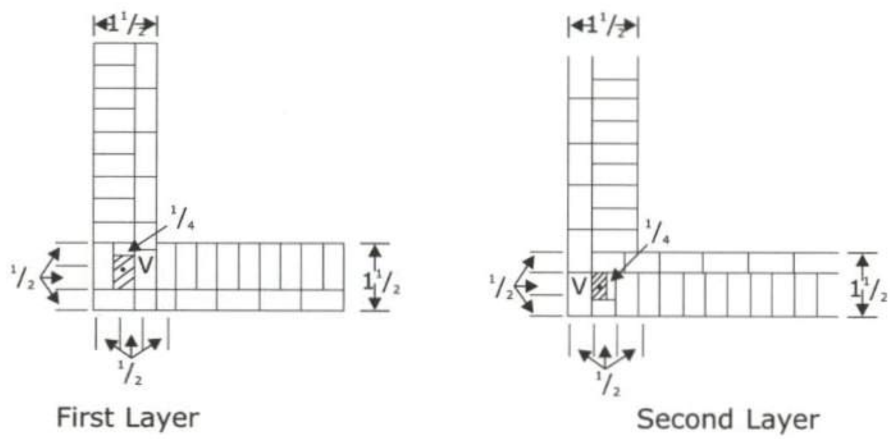
Fig.10. Corner strengthening by Dowel Reinforcement

4.4.9 Vertical Reinforcement in Walls

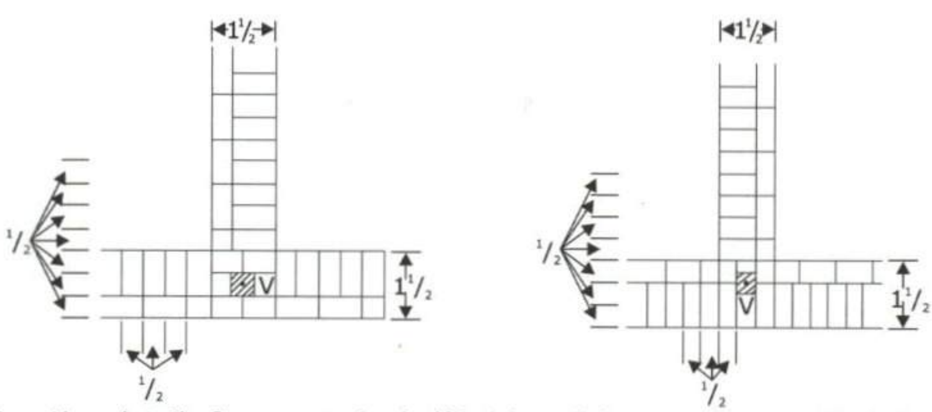
The critical sections are the jambs of openings and the corners of walls. The amount of vertical reinforcing steel will depend upon several factors like the number of storey, storey heights, the effective seismic force based on seismic zone, importance of building and soil foundation type. Values based 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.11. 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.11.Vertical Reinforcement in walls

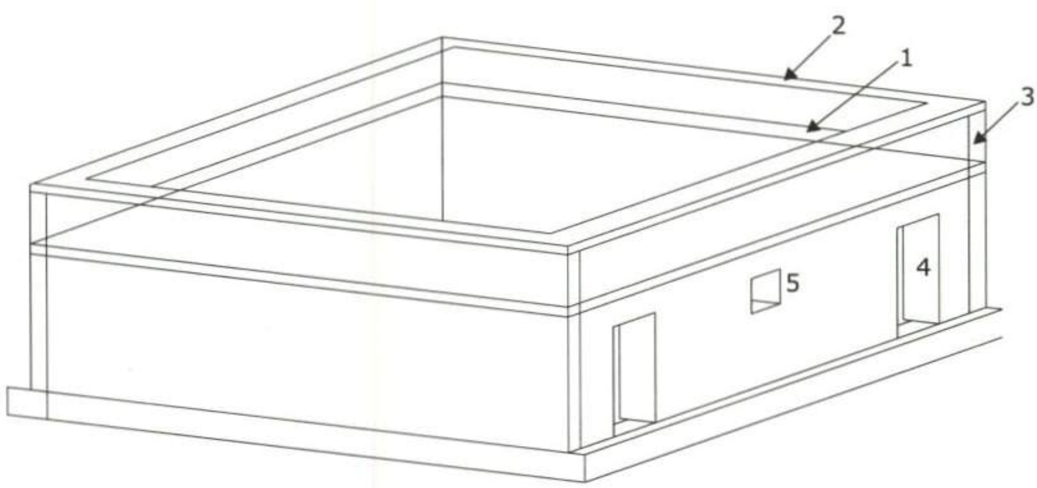
Table 6: Diameter of steel bar to be provided at critical section

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			12	12
	Third			12	12
	Second	(2)	(2)	16	12
	Bottom			16	12

(1) Category of construction is defined in Appendix 2.

(2) Four storied load bearing wall construction should not be used for categories I and II buildings.

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.12).



Note:

1-Lintel band, 2-Roof band

3-Vertical steel, 4-Door, 5-Window

Fig.12.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.13.The amount of horizontal reinforcement may be taken 25% more than that given in Table.5 and provide by using 4 main bars and 6mm dia stirrups. Other details shall be followed as shown in Fig.9.

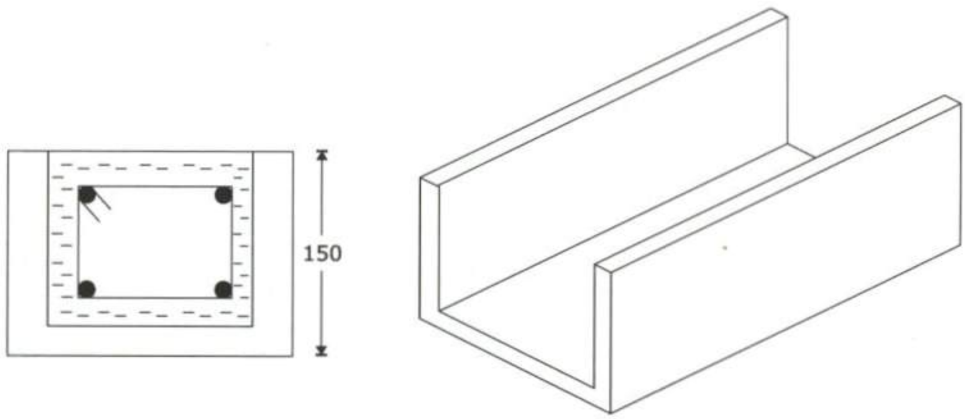


Fig.13. U-Block for Horizontal Bands

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 placed in 2 or 3 consecutive cavities as shown in Fig.14. 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.

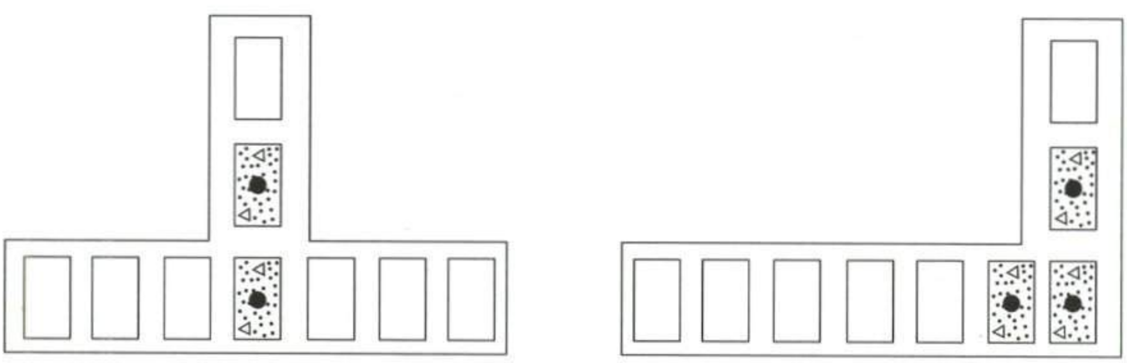


Fig.14. Vertical Reinforcement in Cavities for Hollow Block Masonry

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 increase the strength of the wall against lateral forces. The interlocking blocks can be suitably reinforced for disaster resistance.

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.

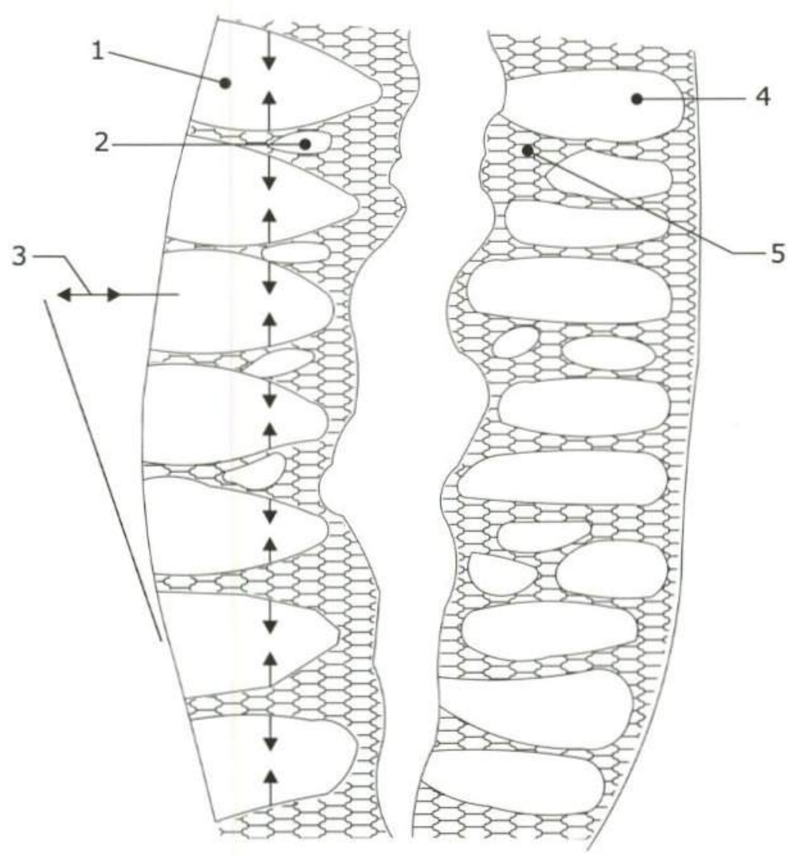
4.6. Construction Guidelines for Building with Stone Masonry

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. These guidelines 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.15) have suffered extensive damage and complete collapse during past earthquakes and other disasters.



Note:

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

Fig.15.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 4m.
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.

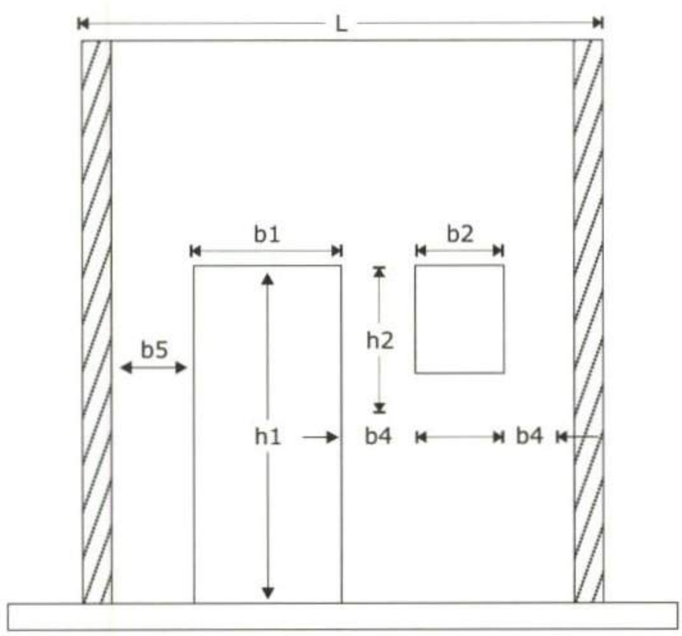
The recommended opening limitations are shown in Fig.16.

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 ¾ of the wall thickness may be used in place of one full length stone so as to provide an overlap between them.



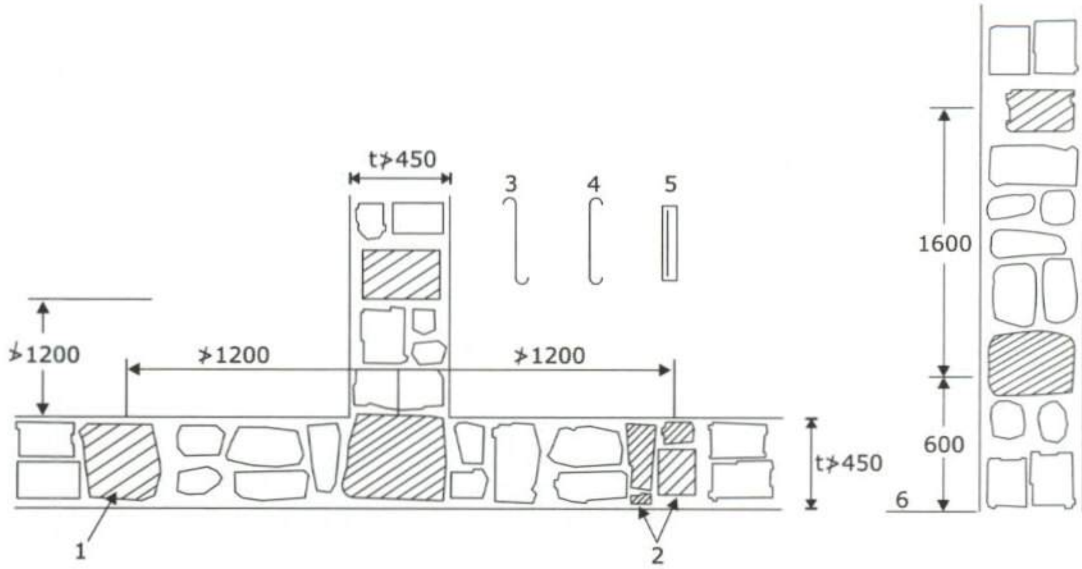
Notes:

$b_1+b_2<0.3L$

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

$b_5 \geq 0.25h_1$ but not less than600mm

Fig.16.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.17.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.17)

Alternatively, wood elements 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.17). 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.18.

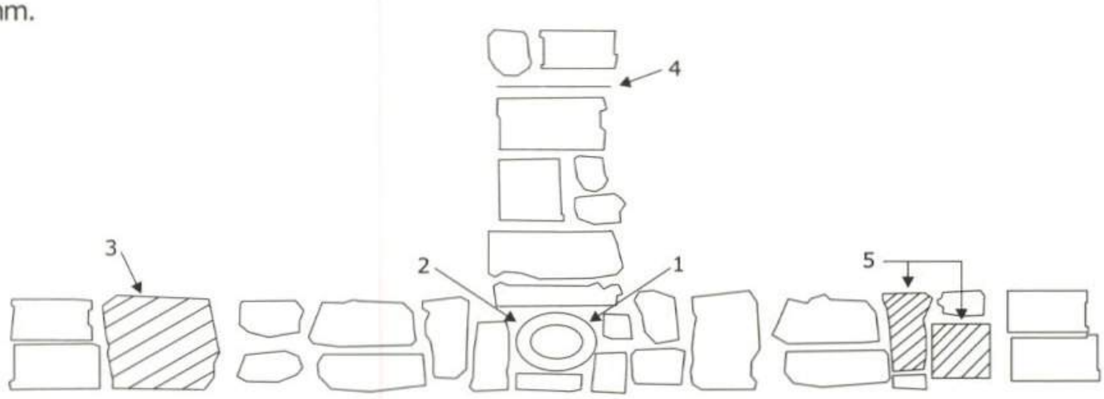
Table7: Recommended Vertical Steel at Critical Sections

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.18.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 costal 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).

APPENDIX 1

LIST OF IS CODES AND FURTHER REFERENCES

1. Published by Bureau of Indian Standards, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110 002, Tel: +91 11 23234062.

   email: info@bis.org.in, Web:www.bis.org.in/

   a) IS:1893-2002: Criteria for Earthquake Resistance Design of Structures, Part1: General Provision and Buildings.

   b) IS:4326-1993: Earthquake Resistance Design and Construction of Buildings- Code of Practice.

   c) IS:13827-1993: Improving Earthquake Resistance of Earthen Buildings-Guidelines.

   d) IS:13828-1993: Improving Earthquake Resistance of Low Strength Masonry Buildings-Guidelines.

   e) IS:13920-1993: Ductility Detailing of Reinforced Concrete Structures Subjected to Seismic Forces-Code of Practice.

   f) IS:13935-1993: Repair and Seismic Strengthening of Buildings - Guidelines.

   g) IS 15498 : 2004, "Indian Standard – Guidelines for Improving the Cyclonic Resistance of Low Rise Houses and Other Buildings/ Structures", Bureau of Indian Standards, New Delhi, 2004.

   h) IS:456-2000: Code of Practice for plain and Reinforced Concrete.

2. Produced by 'The International Association for Earthquake Engineering, Tokyo'; "The Guidelines for Earthquake Resistant Non-Engineered Construction" A.S.ARYA, et al, oct.1986, Reprint by Indian Society of Earthquake Technology, Roorkee-247667.

3. Lakshmanan, N., and Shanmugasundaram, J., "Guidelines for Design and Construction of Buildings and Structures in Cyclone Prone Areas", Report of SERC-UNDP Project on "Engineering of Structures for Mitigation of Damage due to Cyclones" , SERC, Madras, January 1995.

4. Published 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: htpp://www.bmtpc.org/

   a) Improving Earthquake Resistant Buildings-Guidelines by Arya A.S. et al -1999.

   b) Improving Wind/Cyclone Resistant Buildings-Guidelines by Arya A.S. et al -1999.

   c) "Reconstruction and New Construction of Building in Chamoli Earthquake affected areas of Uttar Pradesh" by Arya.A.S. January 2000.

5. Earthquake Resistant Construction and Seismic Strengthening, Govt. of India, Maharastra Emergency Rehabilitation Program. Revenue and Forest Department, Mumbai, India.

6. General Guidelines Part I and Technical Guidelines Part II for reconstruction of Houses affected by Tsunami in Tamilnadu- Revenue Administration – Govt. of Tamilnadu.

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 necessary.

For the purpose of specifying the earthquake resisting features in conventional buildings; the buildings have been 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_bd"33m/s	1
III	Type III	III	34e"V_b3"39m/s	1
II	Type IV	IV	40e"V_be"49m/s	1.5
I	Type V	V	V_be"50m/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

Design for Physically Challenged and Aged

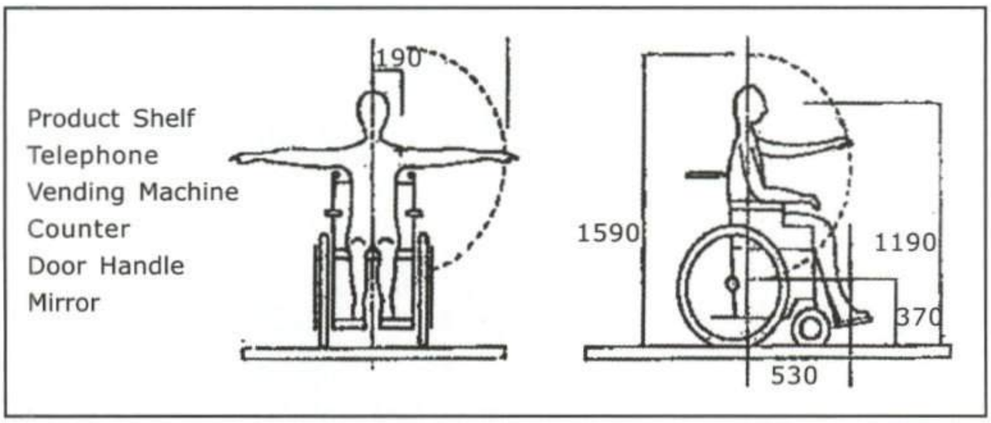
Recommended Minimum Access provision for the Physically challenged :

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



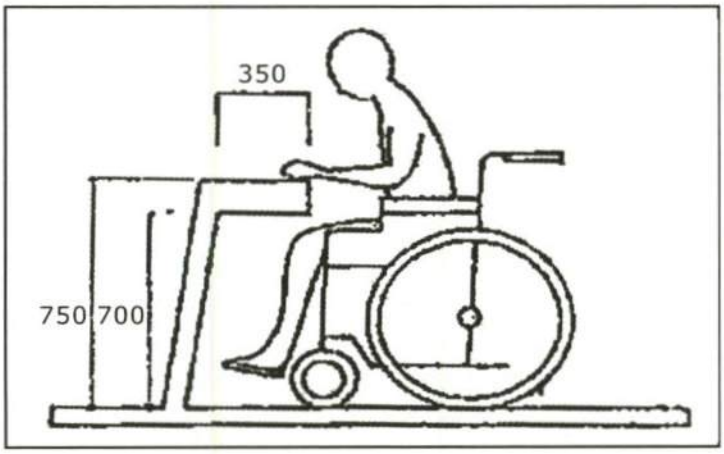
Range of Reach

- 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 wheelchair user from getting close enough to an object.

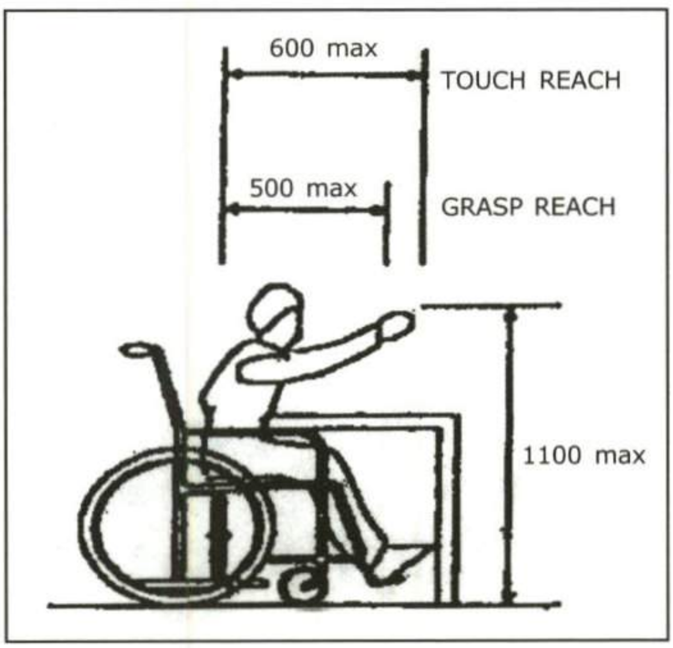
a) Manually operated equipment must be designed to be easily accessible from wheel chair.

b) Make sure that the coin slots of vending machines etc are located no higher than 1200 mm.

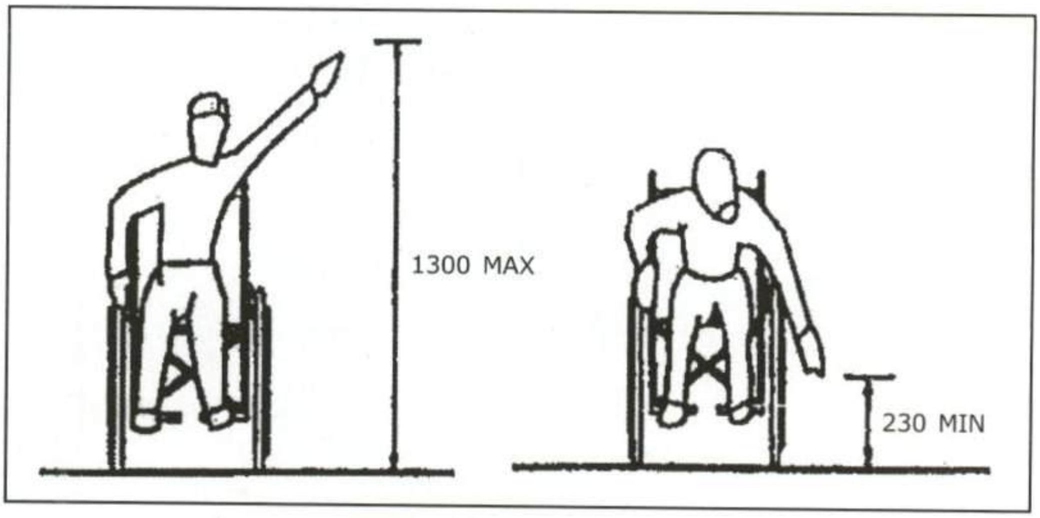
c) Allow a space at least 350mm deep and 700mm high under a counter, stand etc.



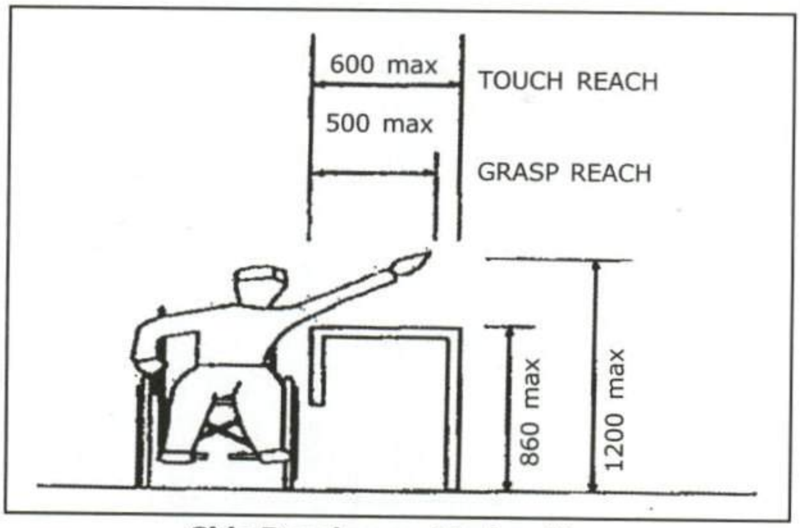
Space Required for Wheelchair Footplate



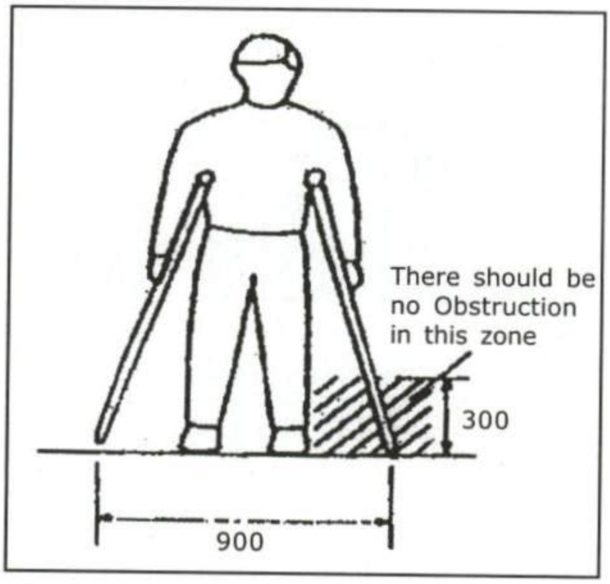
Forward Reach over Obstruction



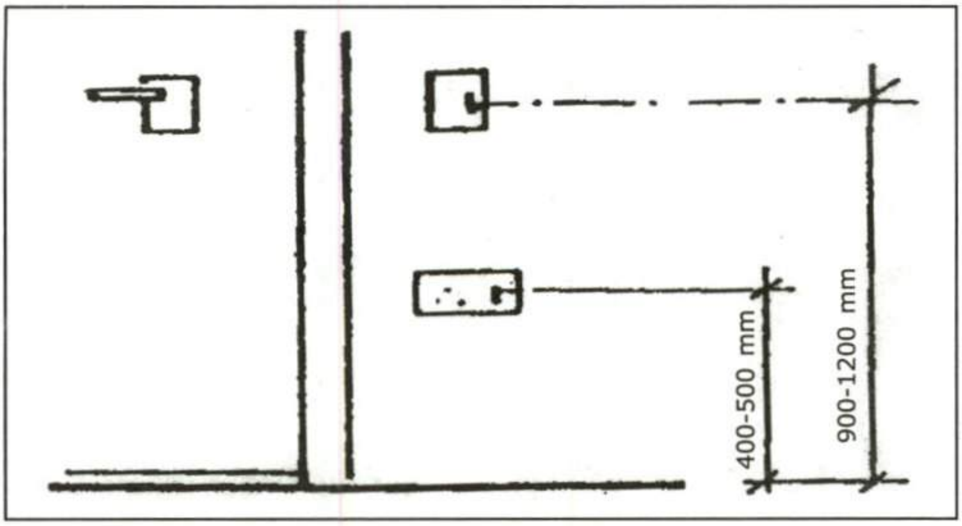
Side Reach without Obstruction



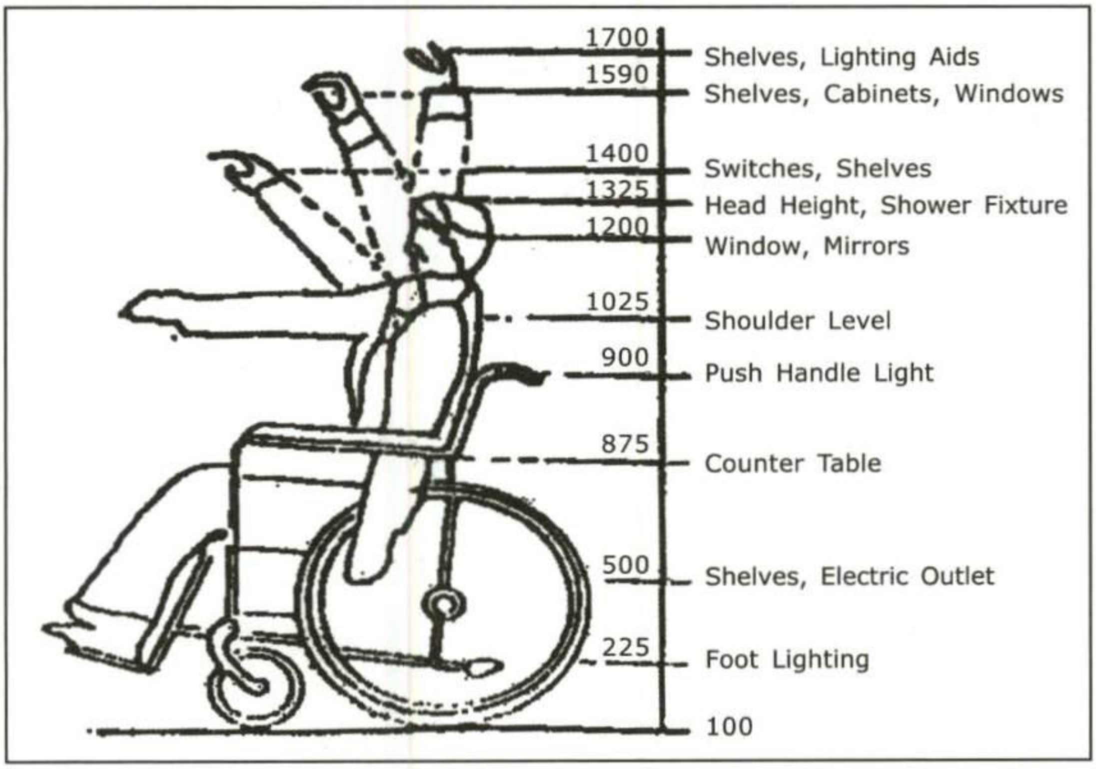
Side Reach over Obstruction



Space Allowance



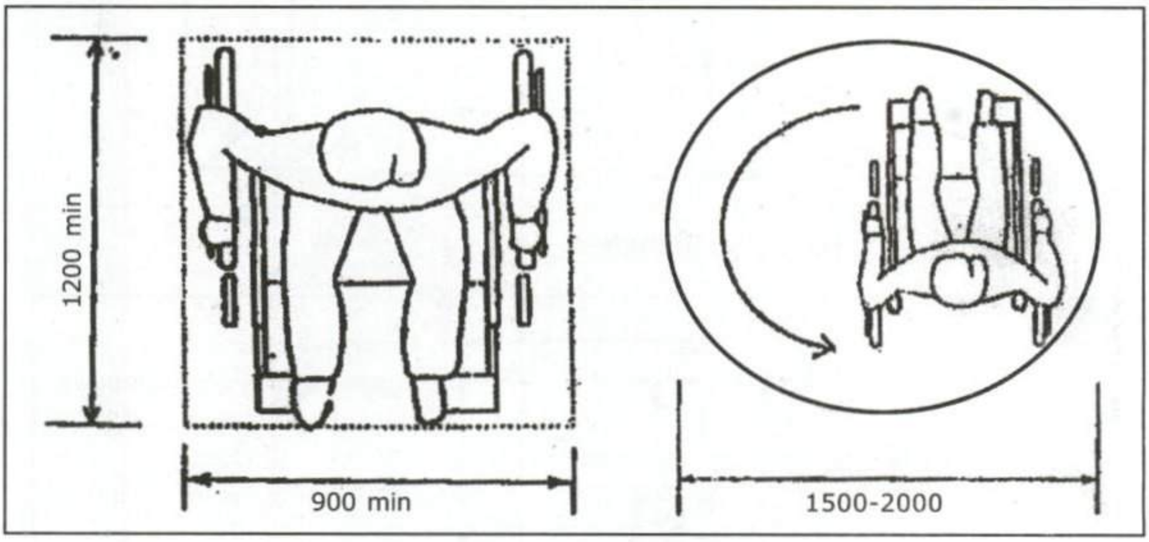
Height of Switches, Doors, Handrails



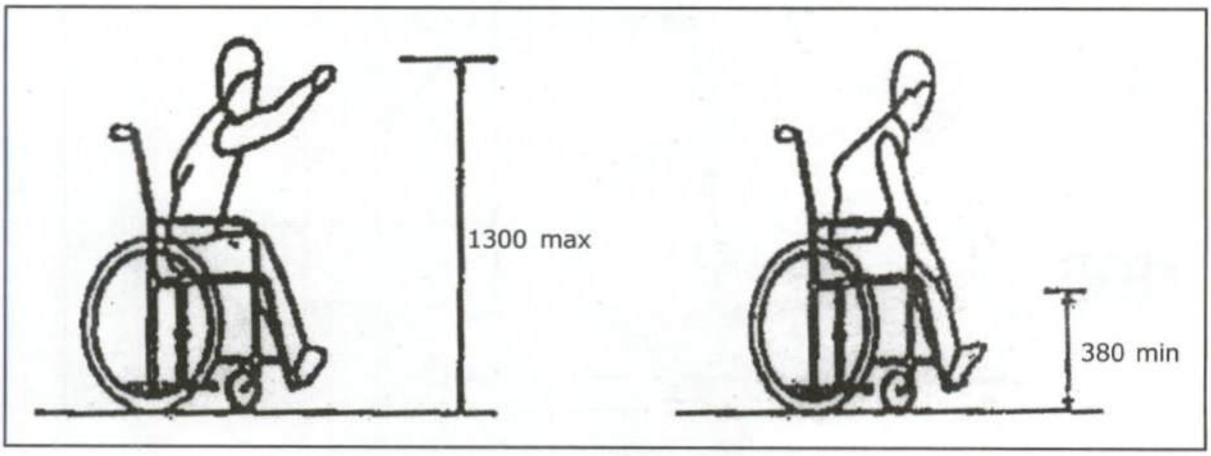
Typical Dimensions for Essential uses with in Easy Reach

Controls:

- For locking and opening controls for windows and doors should no 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.

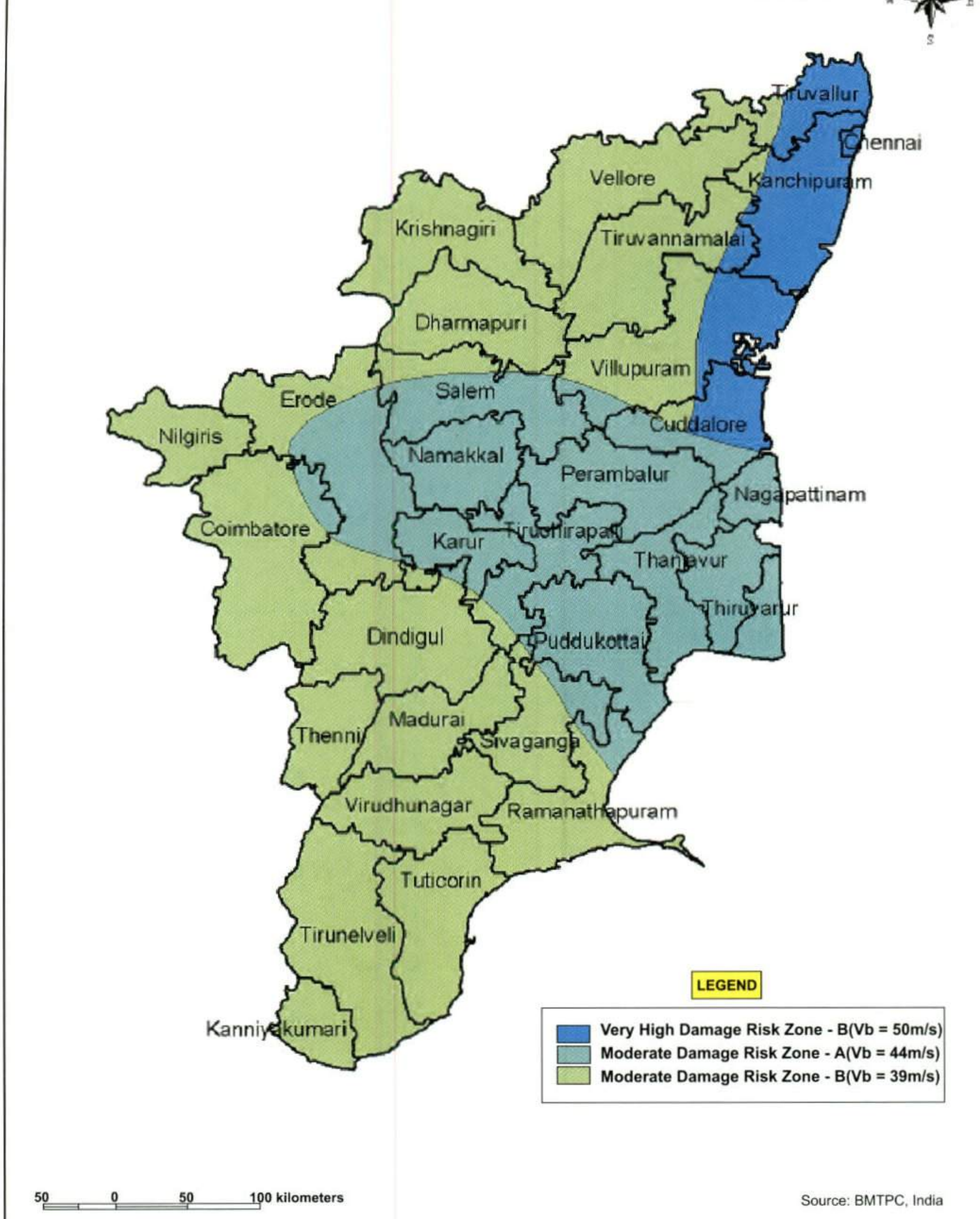


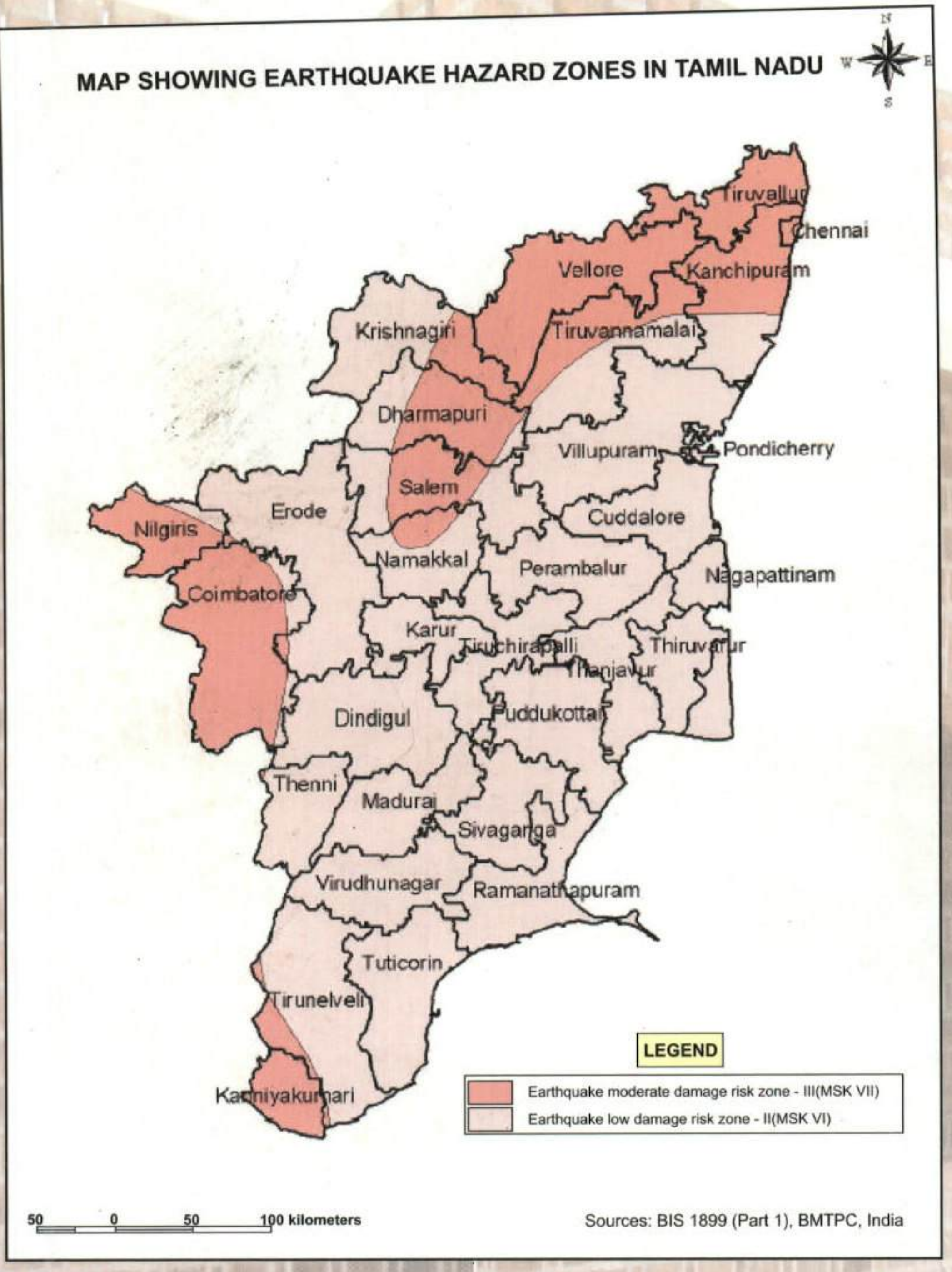
Space Allowance



Forward Reach without Obstruction

MAP SHOWING WIND & CYCLONE ZONES IN TAMIL NADU





These guidelines have been prepared by the Disaster Management and Mitigation Department, Revenue Administration, Gover
Tamil Nadu with support from UNDP. Technical inputs were provided by Prof. A.R. Santhakumar and the Expert Committee.

For more information please contact :

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600 005; Email : relief@tn.nic.in. Soft copy of the same can be accessed at www.tn.gov.in/tsunami or www.un.org.in/untrs

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