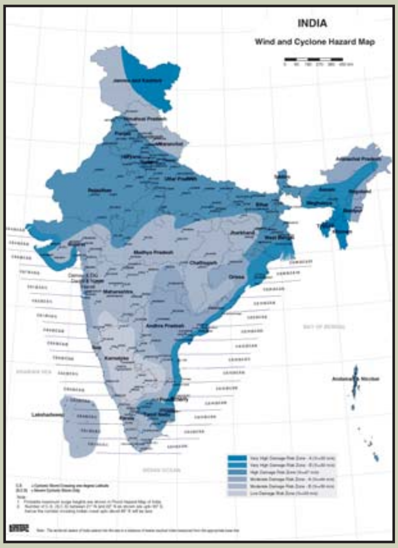
Guidelines

Improving Wind/Cyclone Resistance of Housing

2010



bmtpc

Building Materials & Technology Promotion Council
Ministry of Housing & Urban Poverty Alleviation
Government of India, New Delhi

Guidelines

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FOREWORD

Along coast line of about 7500 km of flat terrain, shallow continental shelf and high population density makes the coastal areas of India extremely vulnerable to high velocity winds, moderate to high storm surges riding over astronomical tides and very heavy rains. The vulnerability of these areas to high sea waves became evident during the 2004 Indian Ocean Tsunami which caused very heavy loss of lives in the state of Tamil Nadu and the Andaman & Nicobar Islands. In view of increased vulnerabilities of the coasted areas, BMTPC took the decision of revising and updating its earlier publication on the subject of cyclone safety of housing.

I have now great pleasure and pride in bringing out the BMTPC's revised publication entitled Guidelines for Improving Wind/Cyclone Resistance of Housing: 2010, for the benefit of all the stakeholders involved in Cyclone risk management and mitigation. The publication is the updated version of our earlier version with the same title. Since then there has been constant updation of our knowledge in the area through several failures all over the world. At the same time, codes are also being modified. Further, a lot of improvements have taken place as regards the strategy of Indian subcontinent is concerned towards combating cyclone and tsunami risk. Subsequent to the super cyclone in Orissa in 1999, our concern about safety of people and the habitations in the coastal areas has increased manifold. The 2004 Indian Ocean tsunami added to this concern. Therefore, it was felt obligatory to bring out newer version of our earlier published guidelines with an added chapter on Cyclone cum Tsunami shelters design. This document would serve as an explanatory handbook on the various clauses of Indian Standards on Wind resistant design of new buildings or improving resistance of existing building stock. Also, through these guidelines, we wish to pass on knowledge and expertise to our planners, engineers and architects and above all to the common people of India to whom we owe, what have been learnt through all these recurrent natural hazards. It has been endeavor of BMTPC to educate the masses and disseminate the knowledge in comprehensible lingo through its publication.

I place on record my deep appreciation for Dr. A. S. Arya, Prof. Emeritus, IIT, Roorkee to take up the challenge of preparing the updated version of guidelines.

Let us build India as Resilient Society to various natural hazards.

September 29, 2010

Dr. Shailesh Kr. Agrawal
Executive Director, BMTPC

PREFACE

For determining the wind forces on buildings and structures, Indian Standard 875-1987 (3) lays down the wind velocity zoning map of India, method of computing wind pressures on various surfaces, and various design factors to be taken into consideration. The cyclone affected coastal areas are also fully covered so far as wind effects are concerned. These principles and data could be used by engineers using usual methods of structural analysis and design of buildings and structures.

But there are numerous details found necessary to be adopted in construction which are not yet covered in any standard. Then there are various types of the so called non-engineered buildings particularly housing, which are traditionally built by people in cyclone prone as well as other high wind velocity areas in which severe damage occurs under wind hazard occurrences. The Expert Group constituted in 1994 by the then Ministry of Urban Development had also examined the related standards, codes and other national and international publications with a view to prepare suitable guidelines covering the general principles for safety of housing from wind hazard and detailing for minimising damage in engineered as well as non-engineered buildings. Ideas, as available, in national as well as international publications were adapted to the Indian situations and covered in the guidelines prepared by Dr.N.M.Bhandari and Dr.A.S.Arya, Professors in University of Roorkee and published by BMTPC in 1999-2000.

In this revised edition, two new chapters have been added besides editorial improvement in the document. The first chapter now gives basic information for understanding characteristics of cyclones and their classification according to Indian and U.S. scales. The number of cyclones and 'severe' cyclonesoccurred in each latitude of Indian coasts as well as storm surge heights observed at several points at the coasts are shown in maps for ready reference. The last chapter now deals with the design considerations for construction of cyclone shelters, as drafted by Dr.A.S.Arya as National Seismic Advisor under GOI-UNDP DBM Programme.

August 2010

Anand S.Arya
Professor Emeritus
IIT Roorkee

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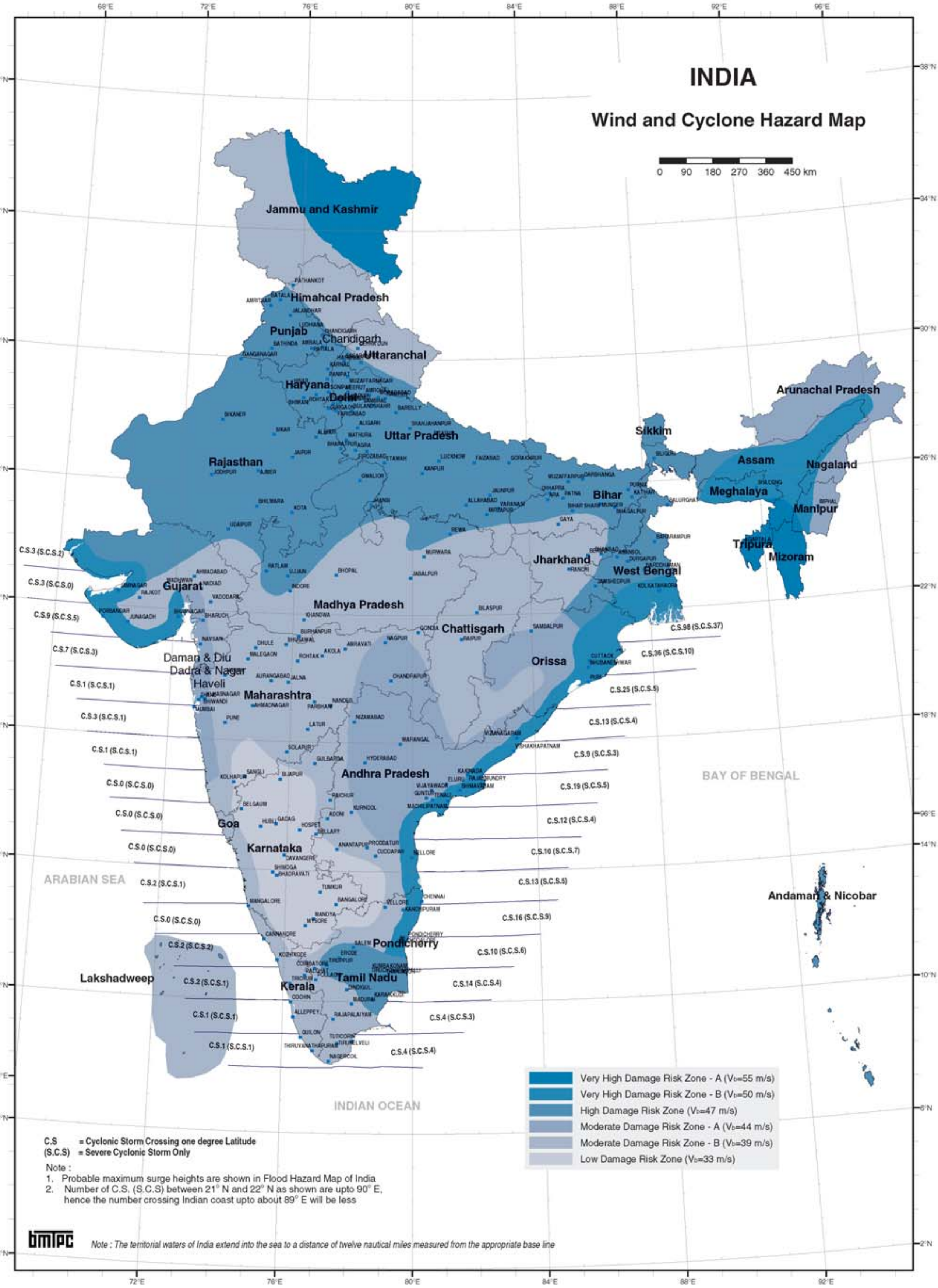


BMTPC : Vulnerability Atlas of India – 2nd Edition (2006); Peer Group, MoH&UPA; Map is based on digitised data of SOI, GOI; Basic Wind Speed Map, IS 875(3) - 1987-2005, IMD, GOI

Wind & Cyclone Hazard Map of India

IMPROVING WIND/CYCLONE RESISTANCE OF BUILDINGS: GUIDELINES

1. INTRODUCTION TO TROPICAL CYCLONES

1.1 Tropical Cyclone

1.1.1 Cyclone Characteristics

Tropical storms are severe cyclonic disturbances of the atmosphere generated over the oceans. Their characteristics depend to some extent on their life and size, and the latitude at which they occur. They are basically cyclone whirls, in which the wind near the centre form an almost circular vortex, and has a slight, inward motion toward the centre near the ocean surface. As a result of the effect of the earth's rotation, the rotation of the vortex is clockwise in the southern and counter-clockwise in the northern hemispheres. See fig. 1.1.

If the surface winds in such a cyclone exceed 120 km per hour (64 knots), this storm is called a *hurricane in the western Atlantic*, *a typhoon in the western Pacific*, or just *a cyclone or a very severe cyclonic storm in the Indian Ocean*.

All tropical storms develop over water of which the *temperature is in excess of 26.5^{o} C*, and in an area of relatively *low atmospheric pressure with other atmospheric conditions*.

1.1.2 Cyclone Season

The principal cyclone season in the northern hemisphere is between July and October. Storms may occur, although somewhat less frequently, during the rest of the year. The area covered by a cyclone with wind speeds in excess of 120 km per hour may have a diameter of only 15 km when the storm is in its early stage, 80 to 250 km when fully developed. The total area affected by a major storm may exceed 800 km across. Sustained winds in excess of 160 km/h are common near the centre and winds of upto 320 km/h have occurred. While the speed of the winds within the disturbance are high, the rate of movement of the whole disturbance is about 15 to 30 km per hour.

1.1.3 The eye of the Cyclone

Tropical storms normally lose intensity when striking land. Within 24 hours after striking land, the winds of a *severe cyclone* may reduce to approximately 50 km per hour. Within the region of cyclone winds, the wind speed rises towards the innermost portion of the whirl. Very close to the centre of mature cyclones, however, the winds drop abruptly from their extreme maximum to light breezes or even complete calm. Clear skies or only thin clouds prevail. This central circular calm area bears the name *'eye'* of the storm and the diameter of this *eye* is about 25 km on the average.

1.1.4 Rains during cyclone

Characteristically, around the eye of the tropical storm there is a great mass of cloud from which heavy rain falls. The amount of rain that falls during a mature cyclone varies widely and depends on the speed, size and intensity of the rain-producing centre and the topography of the land. Generally, rainfall from 250 to 350mm should be expected during the passage of a fully developed cyclone over coastal regions although as much as 1000 mm is possible.

1.1.5 Generation of surge

One of the characteristics of a cyclonic storm is its association with a strong reduction in atmospheric pressure. This reduction may be in the order of 60 to 100 millibars which causes a rise of the water level in the sea, called a ‘storm surge’. Although this rise of the water level is no more than one metre, the combine action of low pressure, the radius of maximum wind and direction of motion of cyclone, the maximum wind driving sea water inland (when the cyclone approaches land), hard breaking waves and coincidence with the astronomical tide may result in a rise of water level by as much as 14 metres. A rise of 3 to 4.5 meters is quite common.

1.2 Classification of Cyclones

Cyclones are known by many names the world over, as mentioned earlier *typhoon* in the North West Pacific including the South China Sea, *hurricane* in the North Atlantic including the West Indies, the Caribbean Sea and the North East Pacific, and *Tropical cyclone* (TC) over North and South Indian Ocean.

Although cyclones differ by names in different regions of the world, they are classified according to the wind speed which varies from region to region. The Indian classification of these intense low pressure systems is shown in Table 1.1.

Table 1.1 Indian Classification of Cyclone Disturbances in the North Indian Ocean (Bay of Bengal and Arabian Sea)

Type	Wind Speed in km/h	Wind Speed in Knots
Low Pressure area	Less than 31	Less than 17
Depression	31-49	17-27
Deep Depression	50-61	28-33
Cyclonic Storm	62-88	34-47
Severe Cyclonic Storm	89-118	48-63
Very Severe Cyclonic Storm	119-221	64-119
Super Cyclonic Storm	222 or more	120 or more

Source: India Meteorological Department.

1.3 Cyclones in India

The number of cyclones crossing one degree latitude in the Bay of Bengal and Arabian Sea coasts are shown in Fig. 1.2. The number of severe cyclones is also shown therein. The maximum probable storm surge (PMSS) height at some locations on the coasts are plotted in Fig. 1.3. It will become clear that the eastern coast of India in the Bay of Bengal is prone to much higher cyclone activity than the west coast wherein though Gujarat coast has a high cyclone activity. In the last about four decades, India has suffered under three very severe cyclonic storms among more than 40 severe cyclonc storms (1971 Paradip Orissa; 1977 Divi Seema in Andhra Pradesh and 1998 Kachchh Gujarat) and one super cyclonic storm in 1999 at south of Paradip in Orissa.

In the US, cyclones are classified into five different categories on the basis of their wind speed and observed effects as measured on the Saffir-Simpson scale. This classification is given in Table 1.2.

Table 1.2 Saffir-Simpson Hurricane Scale*.

Scale Number above High (Category) Tide Level	Sustained Winds Speed* Km/h	Knot	Damaging Effect	Storm Surge
1	118-152	(64-82 kt)	*Minimal:* Unanchored mobile homes, vegetation, and signs	1.2-1.5 m
2	153-176	(83-95 kt)	*Moderate:* All mobile homes, roofs, small craft; flooding	1.8-2.4 m
3	177-208	(96-113 kt)	*Extensive:* Small buildings, low lying roads cut off	2.7-3.6 m
4	209-250	(114-135 kt)	*Extreme*: Roofs destroyed, trees down, roads cut off, mobile homes destroyed, beach homes flooded	4.0-5.5 m
5	250 more	(135 kt or more)	*Catastrophic:* Most buildings destroyed, vegetation destroyed, major roads cut off, homes flooded	Greater than 5.5 m

**Converted to metric units*

Source: National Weather Services (NWS), National Oceanic and Atmospheric Administration (NOAA)

Note: Tropical Storms: winds 62-117 km/h (34-63 kt).

References:

1. *Cyclones-Resistant Primary School Construction –A Design Guide*, pub. by UNECSO Regional Office for Education in Asia, Bangalore, 1997.

2. *National Disaster Management Guidelines—Management & Cyclones* pub. by National Management Authority, Govt. of India, 2008.

3. *I.M.D., Tracks of Cyclones and Depressions in the Bay of Bengal and the Arabian Sea during 1891-2007 (Electronic Version).*

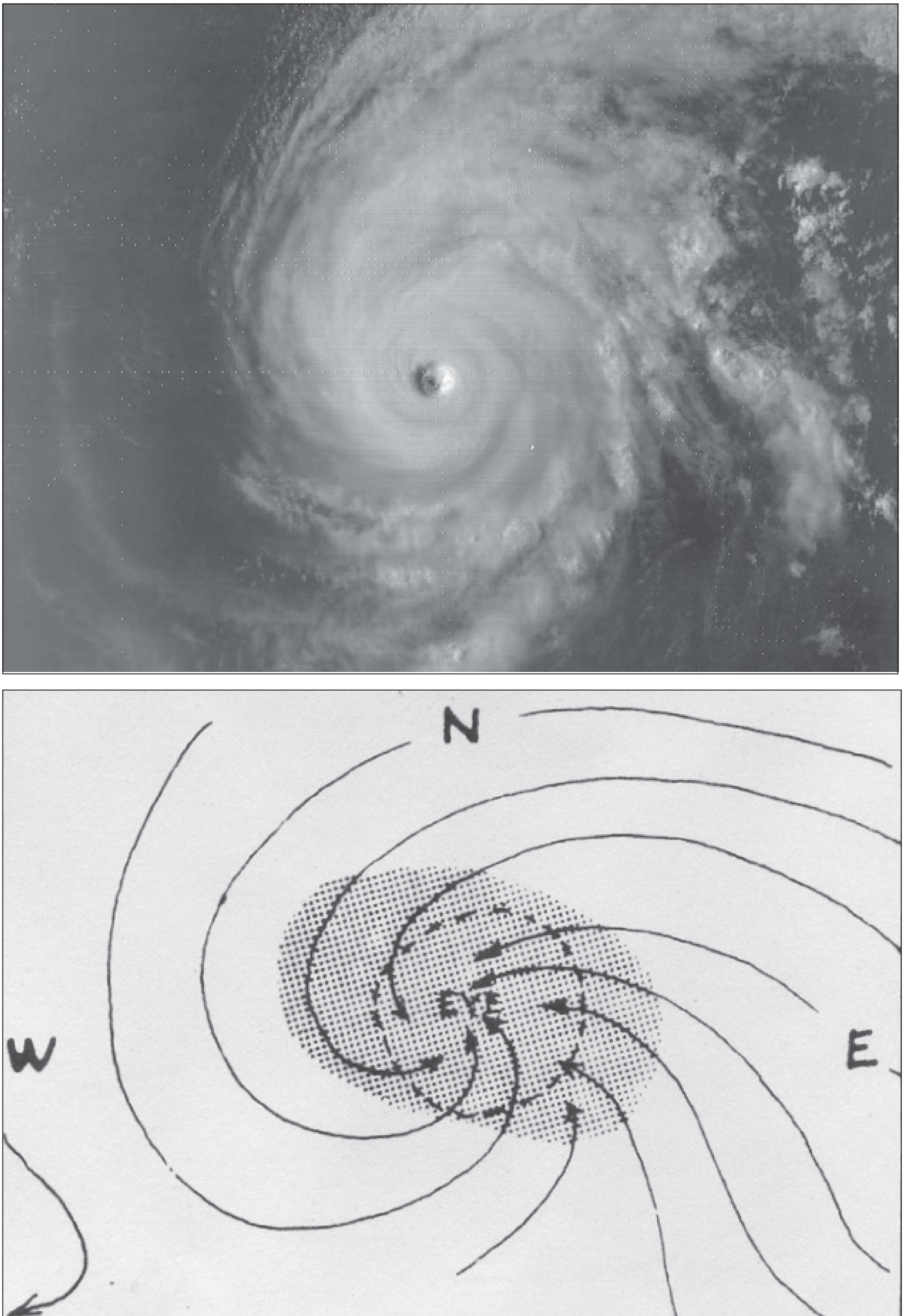


Fig. 1.1 Characteristic Features of an India Cyclone

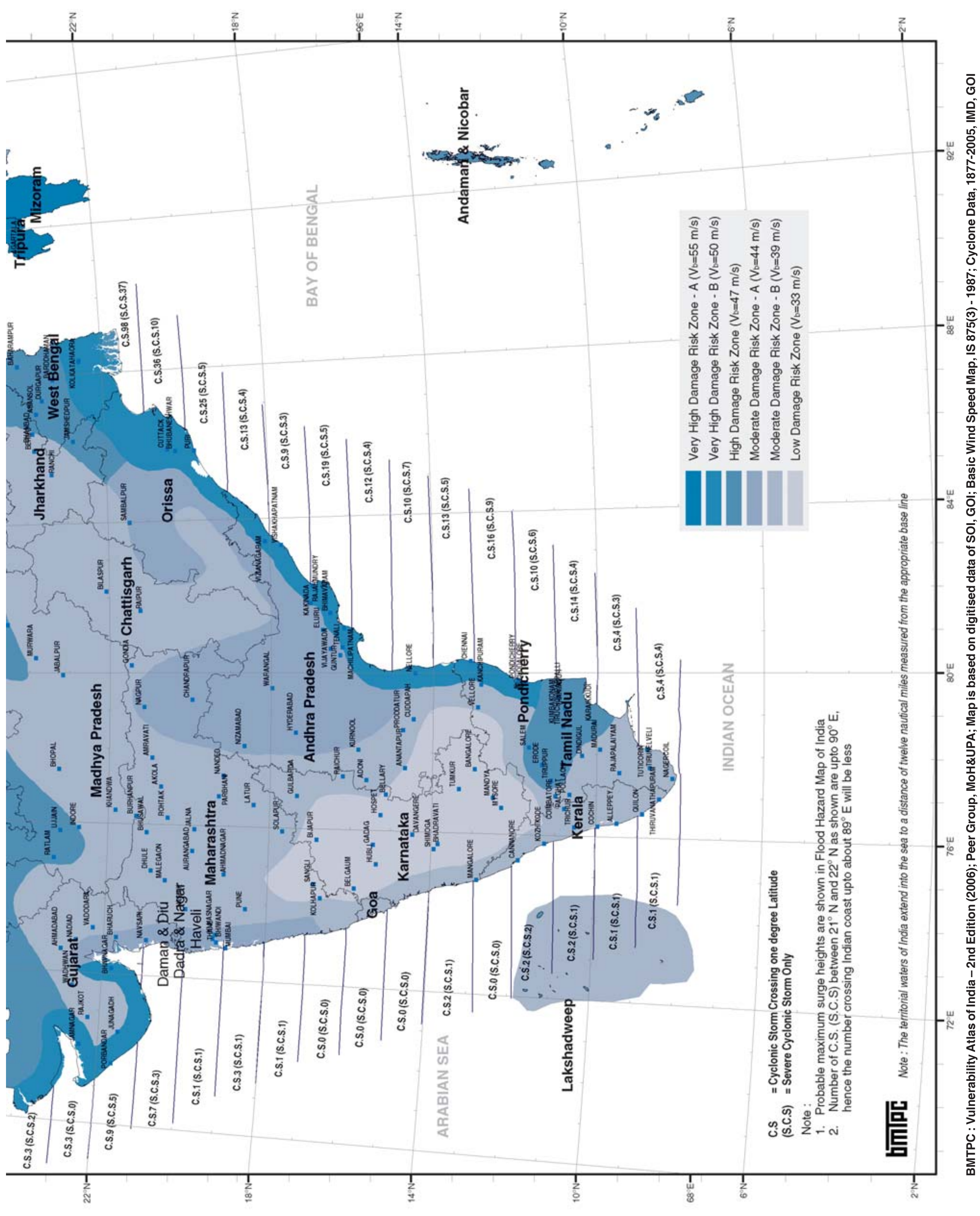


Fig. 1.2 Wind Hazard Map showing Cyclone occurrence on Indian Coasts

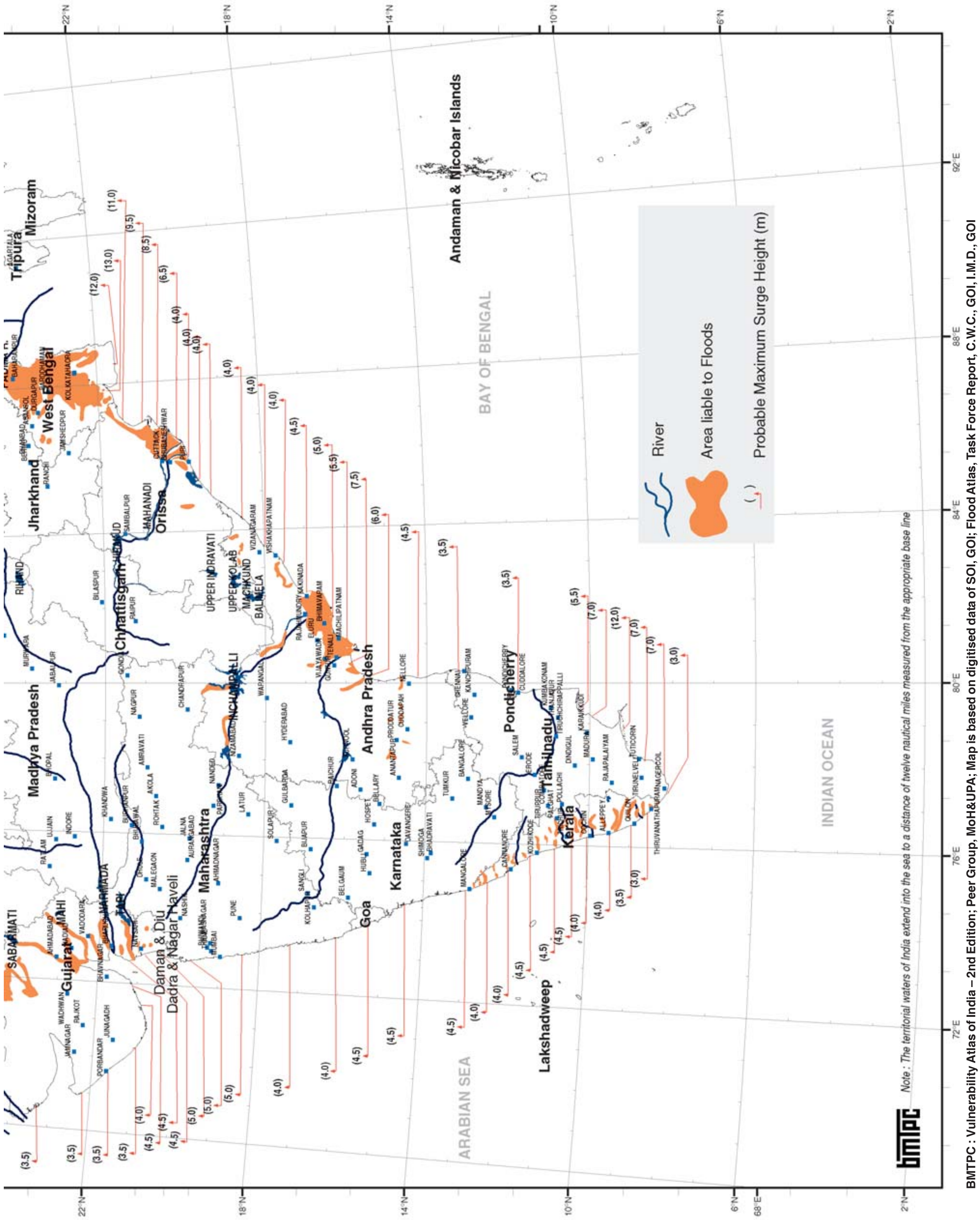


Fig. 1.3 Probable Maximum Storm Surge Heights on Some Locations on the Indian Coasts

2. OBJECTIVE AND SCOPE OF THE GUIDELINE

2.1 Impact of Cyclones

The coastal areas of India receive a number of cyclonic wind storms practically every year causing devastation over larger areas due to (i) high speed winds, which destroy traditional homes and up-root trees and electric line supports (ii) floods, caused by heavy rains, and (iii) storm surge waters, first flowing towards the land then receding back towards the sea, drowning people, destroying homes, agriculture, trees etc., whatever comes in the path of the flowing waters. HIgh speed wind storms on mainland also many times cause severe damage to buildings, particularly llight weight roofs, free standing boundary walls, etc. and lifeline infrastructure such as power and communication towers and lines. Horticultural crops suffer badly in both cases at sea coast and inland under high speed winds.

Although the amin destruction during cyclones or high winds occurs in the traditional non-engineered buildigns built using local clay, stone, Adobe or agro based materials, the engineered buildings having high sheeted roofs also suffer huge damage unless appropriate precautions are taken in design as well as construction. Even in heavy construction, substantial non-structural damage occurs to doors, windows, cladding wall panels, etc.

2.2 Objectives

The aim of these guidelines is firstly, to briefly explain the action of wind on buildings and state the general principles of planning and design; secondly, to bring out details to prevent the non-structural damage in the various buildings; thirdly, to deal with the safety aspects of traditional non-engineered buildings; and finally, to suggest retrofitting details which could be adopted in existing buildings to minimise the damages under high winds. Suggestions are also included for safety against storm surge.

2.3 Scope

These guidelines deal with the construction of wind/cyclone resistant buildings of both engineered and non - engineered types. The proposed measures are generally applicable to wind resistant construction, but have particularly been framed keeping in view the regions having wind velocity greater than or equal to 39 m/sec. Wind zoning map of India is given in IS: 875 (Part III) - 1987. The same has been redrawn for various States and Union Territories on 1:2.5 million scale in the Vulnerability Atlas of India (1997).

Such additional issues or provisions which are specifically useful and/or required for cyclone affected regions are highlighted.

To improve the wind/cyclone resistance of existing buildings, some retrofitting measures have also been presented.

Inview of the need for cyclone and tsunami shelters in the coastal areas within a belt of about 10 km adjacent to the sea costs the design aspects of the shelters are also covered in the guideline.

3. WIND PRESSURES ON BUILDINGS AND STORM SURGE HEIGHTS

3.1 Basic Wind Speed Zones

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 earthquakes) for Buildings and Structures, Part 3, Wind Loads”. There are six basic wind speeds `V_b' considered for zoning, namely 55, 50, 47, 44, 39 and 33 m/s. From wind damage view point, these could be described 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

The cyclone affected coastal areas of the country are classified in 50 and 55 m/s zones. The basic wind speeds are applicable to 10 m height above mean ground level in an open terrain with a return period of 50 years.

3.2 Design Wind Speed and Pressures

The basic wind speed is reduced or enhanced for design of buildings and structures due to factors like (i) the risk level of the structure measured in terms of adopted return period and life of structures (5,25,50 or 100 years), (ii) terrain roughness determined by the surrounding buildings or trees and, height and size of the structure. (iii) local topography like hills, valleys, cliffs, or ridges, etc. Thus general basic wind speed being the same in a given zone, structures in different site conditions could have appreciable modification and must be considered in determining design wind velocity as per IS: 875 (Part 3) - 1987.

The design wind pressure at height z above ground level on a surface normal to the wind streams 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^2

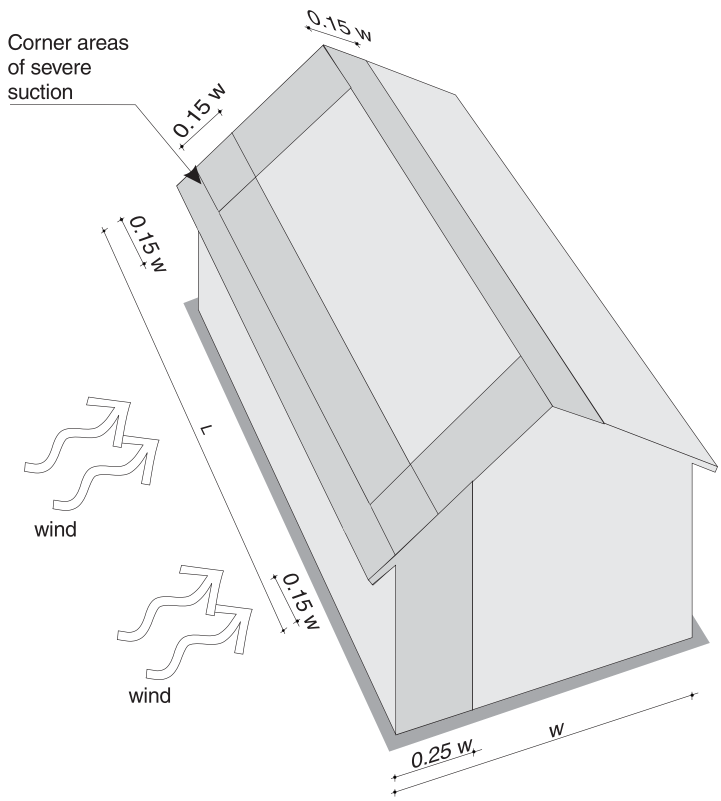


Fig. 3.1
External wind pressure areas on building faces

Areas of higher suction / pressure

General areas of normal pressure P_Z

The value of wind pressure actually to be considered on various elements depends on aerodynamics of flow around buildings the windward vertical faces being subjected to pressure, the leeward and lateral faces getting suction effects, and the sloping roofs getting pressures or suction effects depending on the slope. The projecting window shades, roof projections at eave levels are subjected to uplift pressures several times the intensity of p_z. These factors play an important role in determining the vulnerability of given building types in given wind speed zones. Refer to Tables 4 and 5 of IS:875 Part 3, 'Wind Loads' in this regard. For example, *Fig. 3.1* shows the various cladding areas of a building, which will have different pressure coefficients.

Figures 3.2 and 3.3 show typical effects of internal pressures through the openings in the walls for a given angle of attack of wind as indicated; only one large opening in a wall will cause very large internal pressure say ±0.7p_z which combined with external suction will increase the wind effects on cladding and their connections immensely. A building with all windows and doors locked, will have zero or very small internal suction or pressure <0.20 p_z. If a room has openings distributed in all walls or at least

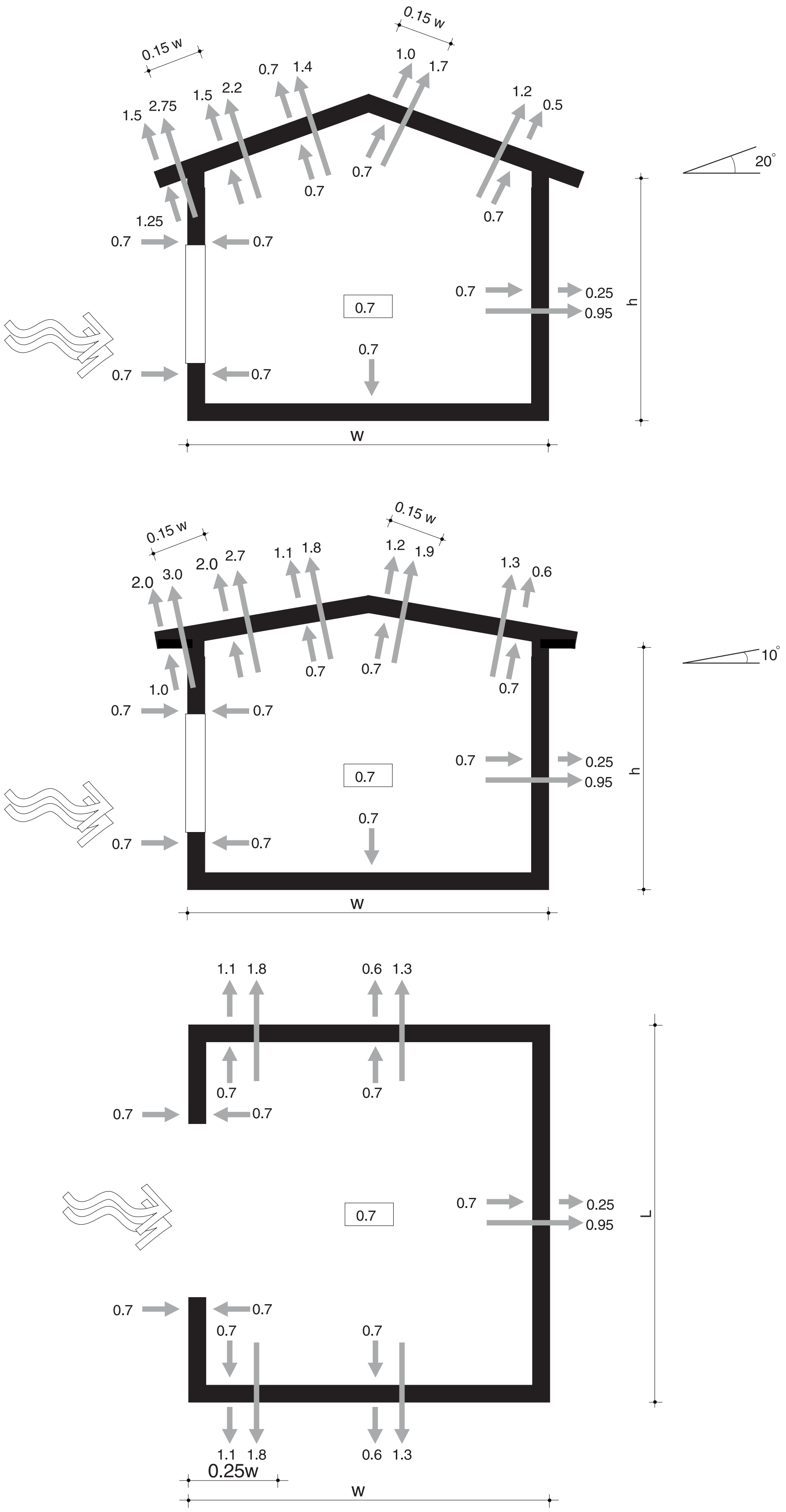


Fig. 3.2
Structural Load Coefficients, Internal and External Pressures (Openings on windward side or large permeability case, internal pressure coefficient taken as 0.7; h ≥ w/2, L ≤ 1.5w)

in opposite walls and the overall porosity is less than 5%, the passage of air will cause only low internal pressure say only 0.2 p_z. Effects of wind uplift on roof projections can also be seen in *Fig. 3.2* and *3.3.* For a design speed of 50 m/s, the basic pressure will be 1.5 kN/m^2 and the design pressures could be obtained by multiplying with the coefficients given in *Fig. 3.2* and 3.3 for the specimen cases shown. For other dimensions of length, width and height and direction of wind , reference may be made to I.S.: 875 Part 3-1987.

Areas of high local suction (negative pressure concentration) frequently occurring near the edges of walls and roofs are separately shown in the code. Coefficients for local effects should only be used for calculation of forces on these local areas affecting roof sheeting, the glass panels, individual cladding units including their fixtures, they should not be used for calculating force on entire structural elements such as roofs, walls or the structure as a whole

3.3 Coastal Areas

The coastal areas are subjected to severe wind storms 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%). But for design of structures (except

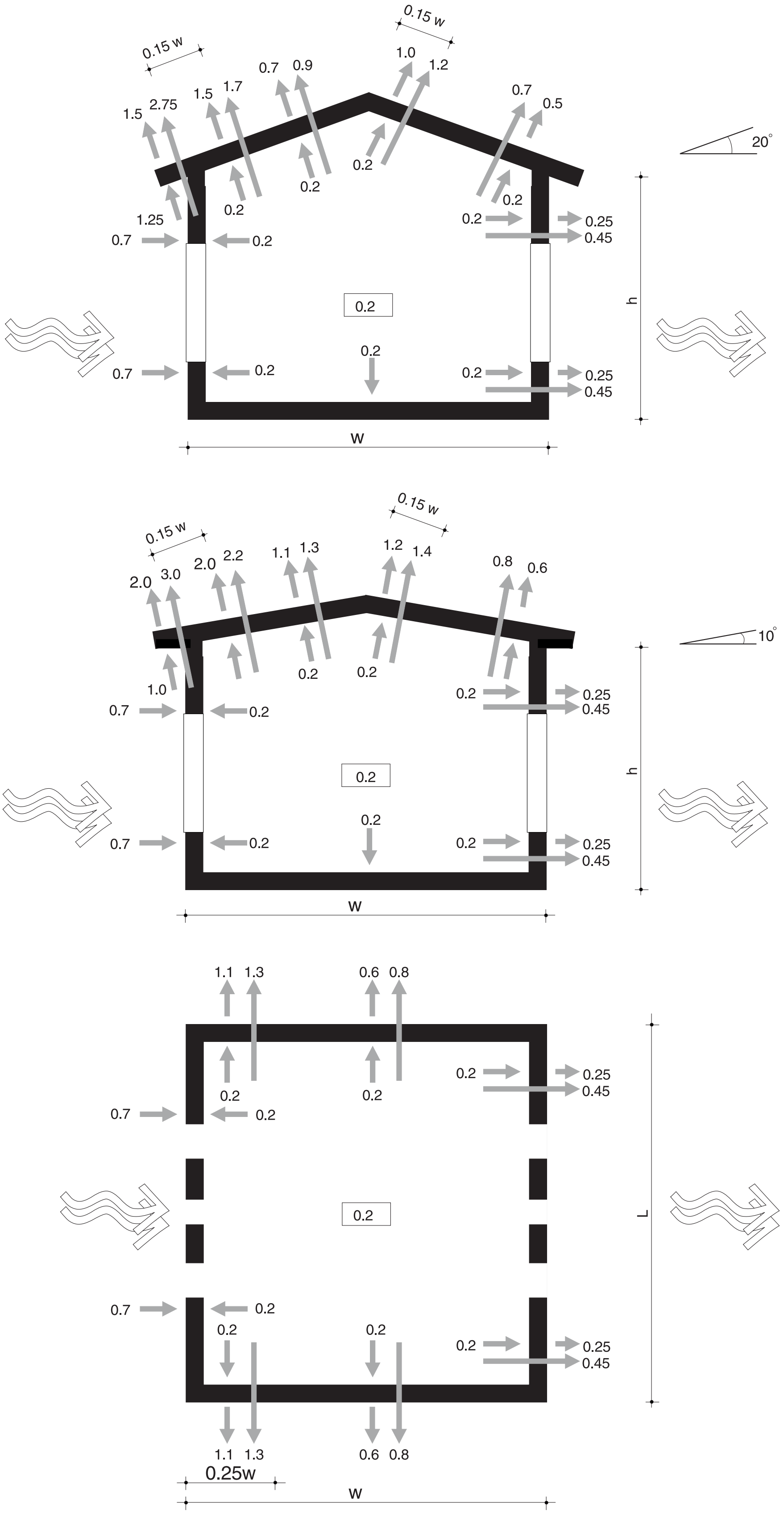


Fig. 3.3
Structural Load Coefficients, Internal and External Pressures (Openings on opposite walls or low permeability case, internal pressure coefficient taken as 0.2; h ≥ w/2, L ≤ 1.5w)

those considered very important such as cyclone shelters) the above macro-level zoning stated in 3.1 is considered as sufficient.

The frequency of occurrence of cyclones on the different portions of the coast has been different as shown in Fig. 1.1. Even for the same design wind speed in some areas, the risk of damage per year will be higher in areas subjected to more frequently cyclones.

3.4 Storm Surge

Besides the very high velocity winds, the coastal areas of India suffer from the onslaught of sea water over the coast due to the storm surge generated by cyclones, see Fig. 1.3. A storm surge is the sudden abnormal rise in sea level caused by the cyclone. As stated in 1.1.5,the surge is generated due to interaction of air, sea and land. The sea water 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. Scientists from India Meterological Department have estimated the probable maximum heights of storm surge in various sections of the sea coast. The estimated probable maximum storm surge heights are shown in the relevant state's wind hazard maps in the Vulnerability Atlas of India. The area affected due to storm surge will be more in flat terrain than in steeply rising terrain. The super cyclone of Oct. 1999 in Orissa genetared a wind speed of 250-260 km/h with a storm surge of 5-6 m close to Paradip causing an inland intandation in Distt. Jagatsingh Pur upto 35 km.

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 substantial supports. Table 4.1 shows the aerofoil effects of some wind speeds.

As a consequence of the wind pressures/suctions acting on elements obstructing the passage of wind the following types of damage are commonly seen to occur during high wind speeds (Refer to IS:15499-2004, Suvery of Housing and Building Typology in Cyclone Prone Areas for Damage Estimation):

i. uprooting of trees which disrupt transportation and relief supply missions.
ii. failures in many cantilever structures such as sign posts, electric poles, and transmission line towers;
iii. damage to improperly attached windows or window frames;
iv. damage to roof projections, chajjas and sunshades
v. failure of improperly attached or constructed parapets,
vi. overturning failures of compound walls of various types;
vii. failure of weakly built walls and consequent failure of roofs and roof covering;
viii. failure of roofing elements and walls along the gable ends particularly due to high internal pressures;
ix. failure of large industrial buildings with light weight roof coverings and long/tall walls due to combination of internal and external pressures;
x. brittle failure of asbestos - cement (AC) sheeting of the roofs of Industrial sheds; failure of AC sheets is generally along eaves, ridges, and gable ends);
xi. punching and blowing off of corrugated iron roofing sheets attached to steel trusses;
xii. though a thatch roof commonly employed in rural construction lacks durability, it provides greater permeability and attracts less forces of wind compared to an impermeable membrane.

Table 4.1:
Aerofoil Effect of Wind

Wind Speed m/sec	Typical Movement
5-10	Loose aluminium sheets fly
10-15	Loose galvanised iron sheets fly
15-20	Loose fibre cement sheets fly
25-30	Loose concrete and clay tiles fly
30-35	Roof sheets fixed to battens fly
35-40	Small aircrafts take off speed
40-45	Roof tiles nailed to battens fly
45-50	Garden walls blow over
50-55	Unreinforced brick walls fail
55-60	Major damage from flying debris
60-65	75 mm thick concrete slabs fly
65-70	100 mm thick concrete slabs fly
70-75	120 mm thick concrete slabs fly
75-80	150 mm thick concrete slabs fly

5. PLANNING ASPECTS

5.1 Site Selection

i. Though cyclonic storms always approach from the direction of the sea towards the coast, the wind velocity and direction relative to a building remain random. In non-cyclonic region where the predominant strong wind direction is well established, the area behind a mound or a hillock should be preferred to provide for natural shielding *(Fig.5.1).* Similarly a row of trees planted upwind will act as a shield (*Fig.5.2*). The influence of such a shield will be over a limited distance, generally from 8 to 10 times the height of the trees.

ii. In hilly regions, construction along ridges should be avoided since they experience an accentuation of wind velocity whereas valleys experience lower

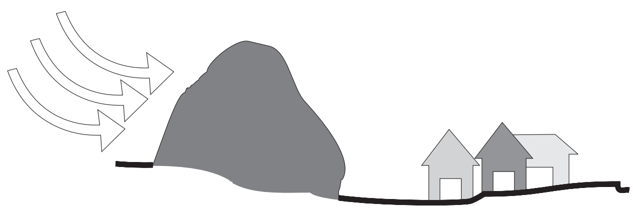


Fig. 5.1
Shielding of house by hillock

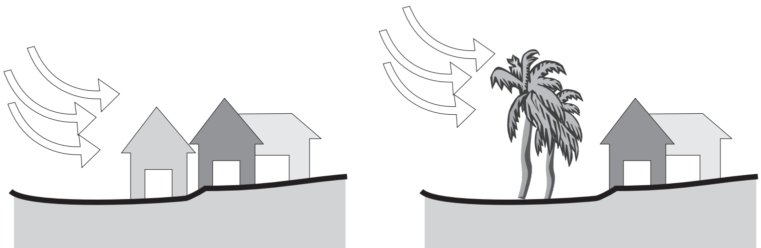


Fig. 5.2
Wind shielding of buildings

speeds in general as shown in *Fig.5.3*.

iii. Cyclonic wind storms commonly generate storm tides leading to coastal inundation. In cyclonic regions, close to the coast a site above the likely inundation level should be given preference. In case of non availability of high elevation natural ground, construction should be done on stilts with no masonry or bracings upto maximum surge level, or raised earthen mounds as shown in *Fig. 5.4* to avoid flooding/inundation.

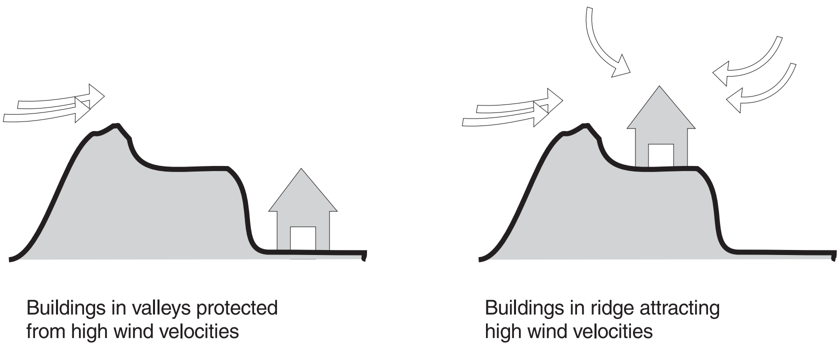


Fig. 5.3
Appropriate location of buildings in hilly terrains

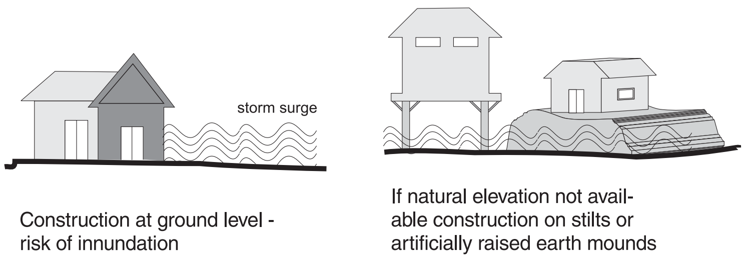


Fig. 5.4
Construction on raised ground / stilts to prevent innundation

5.2 Planforms & Orientation

i. For individual buildings, a circular or polygonal plan shape is preferred over rectangular or square plans, but from the view point of functional efficiency, often a rectangular plan is commonly used. Where most prevalent wind direction is known, a building should be so oriented, where feasible, that its smallest facade faces the wind.

ii. A symmetrical building with a compact planform is more stable than an asymmetrical building with a zig-zag plan, having empty pockets as the latter is more prone to wind/cy-

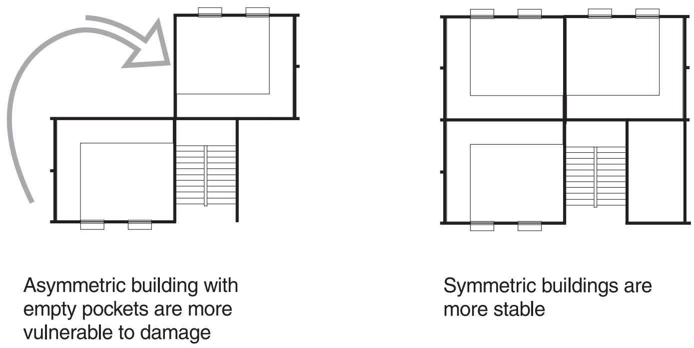


Fig. 5.5
Desirable orientation and plan form for reducing wind damage

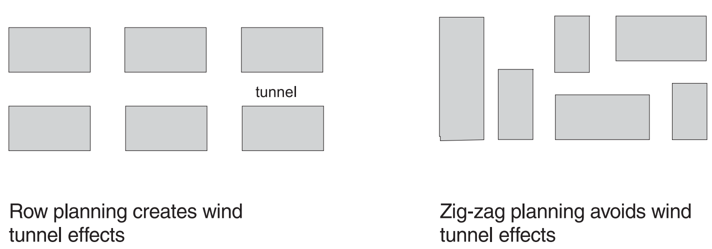


Fig. 5.6
Group planning of buildings

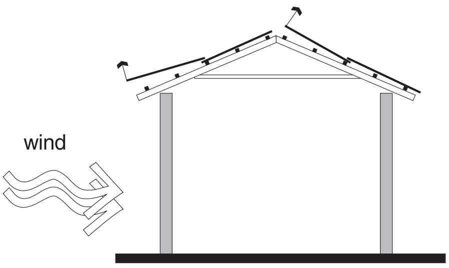


Fig. 5.7a
Roofing sheets lift

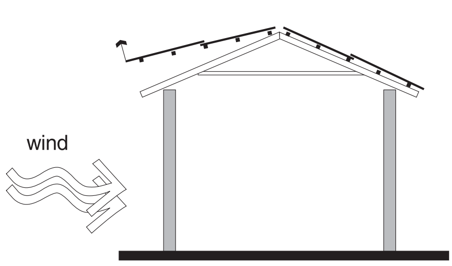


Fig. 5.7c
Reeper lifts from the rafter

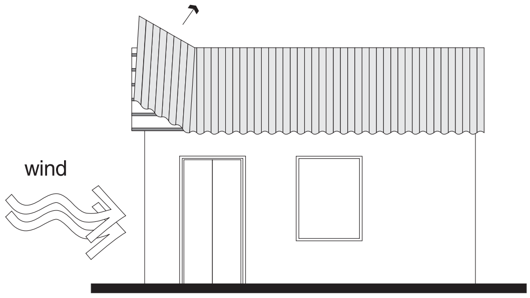


Fig. 5.7b
Roofing sheets lift at the gable end

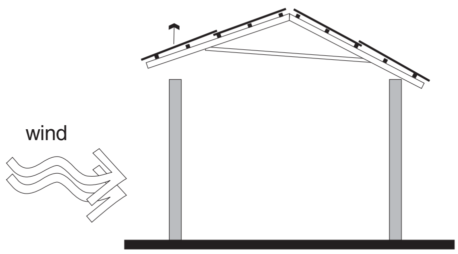


Fig. 5.7d
Holding down of rafter to wall inadequate

Fig. 5.7
Types of roof damage due to wind

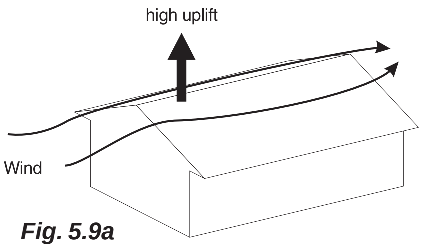


Fig. 5.9a
Gable ended roof get high uplift

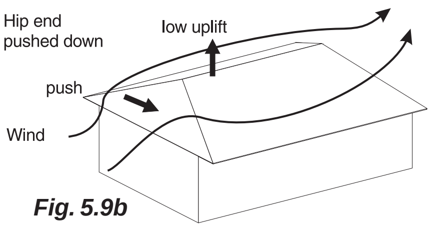


Fig. 5.9b
Hip roof get lower uplift

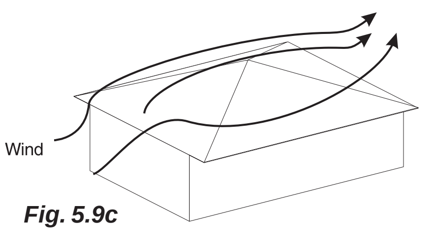
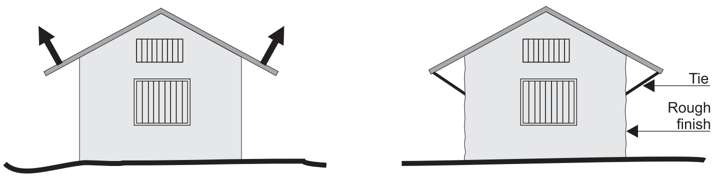


Fig. 5.9c
Pyramidal roof get lowest uplift

Fig. 5.9
Effects of roof architecture on uplift forces



Large overhangs get lifted up and broken, Smooth finish on walls undesirable

Avoid large overhangs / use ties / openings in overhangs, rough finished walls desirable

Fig. 5.8
Overhangs

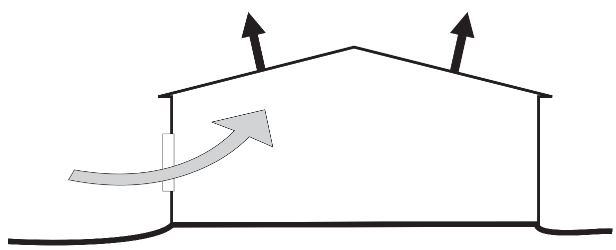


Fig. 5.10
Unclosed openings on windward side creates high positive pressure inside aiding uplift

clone related damage (see *Fig.5.5*).

iii. In case of construction of group of buildings with a row type or cluster arrangement (see *Fig.5.6*) can be followed in preference to row type. However, in certain cases, both may give rise to adverse wind pressure due to tunnel action and studies need to be conducted to look into this aspect.

5.3 Roof Architecture

i. The overall effect of wind on a pitched roof building and the critical locations are shown in *Figs.5.7 to 5.10.* It is seen that roof projections and wall and roof corners experience high suction. Accordingly places where typical failures begin are shown in *Fig. 5.7.* Therefore, the roof projections should be kept to a minimum, say not exceeding 500 mm, or else, the larger projections be tied down adequately *(Fig. 5.8)*.

   Note: *For rain protection, a minimum roof projection of 500 mm is desirable. Tying down will be very advantageous.*

ii. For the purpose of reducing wind forces on the roof, a hipped or pyramidal roof is preferable to the gable type roof *(see Fig. 5.9)*.

iii. In areas of high wind or those located in regions of high cyclonic activity, light weight (GI or AC sheet) low pitch roofs either should be avoided or strongly held down to purlins and rafters. Pitched roofs with slopes in the range 22-30^o will not only reduce suction in roofs but would also facilitate quick drainage of storm water.

5.4 Wall Openings

Openings in general are areas of weakness and stress concentration, but needed essentially for lighting and ventilation. The following norms are recommended in respect of openings.

i. 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 upto eave level.

ii. Openings just below roof level be avoided except that two small vents without shutter should be provided in opposite walls to prevent suffocation in case room gets filled with water and people may try to climb up on lofts or pegs.

iii. Since the failure of any door or window on wind-ward side may lead to adverse uplift pressures under roof *(see Fig.3.2, 3.3 and 5.10),* all the openings should have strong closing/ locking arrangement and all glass/ wooden panels be securely fixed *(Fig.5.11).*

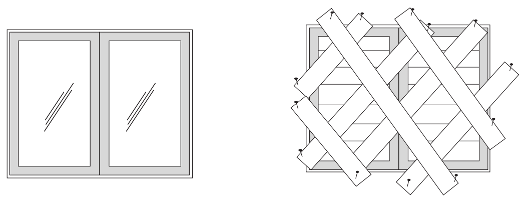


Fig. 5.11
Shutters and windows

5.5 Glass Panelling

a. One of the most damaging effect 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 door or window glass pane may shatter because they are too thin to resist the local wind pressures. A broken glass panel of a windward side opening increases internal pressures abnormally and may lead to a chain of events including a roof failure.

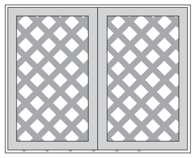


Fig. 5.12
Protection of glass panes

b. The way to reduce this problem is to provide well designed glass panels. In cyclonic regions where the exposure to high wind and gustiness is sustained, it is recommended that in designing glass panels any relief by way of increase in permissible stresses on account of the consideration of wind load be not allowed.

c. Further, recourse may be taken to reduce the panel size to smaller dimensions. Also glass panes can be strengthened by pasting thin plastic film or paper strips *(Fig 5.12).* This will help in holding the debris of glass panes from flying in case of breakage. It will also introduce some damping in the glass panels and reduce their vibrations.

d. Further, to prevent damage to the glass panels from flying wind borne missiles, a metallic fabric/ mesh be provided outside the large panels.

e. The locking arrangement of shutters should be sturdy and the door or window frames be securely fixed in the walls using hold fasts *(Fig.5.13)* so as to resist the local wind pressures.

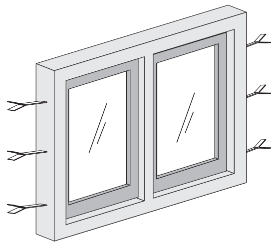


Fig. 5.13
Adequate anchorage of door and window frames with holdfasts

5.6 Foundations

Buildings usually have shallow foundation for sandy soil and deep foundations for expansive clayey soils. All shallow foundations should be designed as per IS: 1904-1978. It is desirable that information about soil type be obtained and estimate of safe bearing capacity made from the available records of past constructions in the area or by proper soil investigation.

In addition the following parameters need to be properly accounted for in the design of foundation.

i. *Effect of Surge or Flooding* - Invariably a cyclonic storm is accompanied by torrential rain and tidal surge (in coastal areas) resulting into flooding of the low lying areas. The flurry of tidal surge diminishes as it travels on shore, which can extend on flat land even upto 10 to 15 km. Flooding causes saturation of soil and thus significantly affects the safe bearing capacity of the soil. Also the likelihood of any scour due to receding tidal surge needs to be taken into account while deciding on the depth of foundation, and the protection works around a raised ground used for locating cyclone shelters or other buildings.

ii. *Building on Stilts* - Where a building is constructed on stilts it is necessary that stilts are properly braced in both the principal directions. This will provide stability to complete building under lateral loads. Knee braces will be preferable to full diagonal bracing so as not to obstruct the passage of floating debris during storm surge. The pressure loading on stilts is considerably different from buildings on ground. In case of important buildings, such as

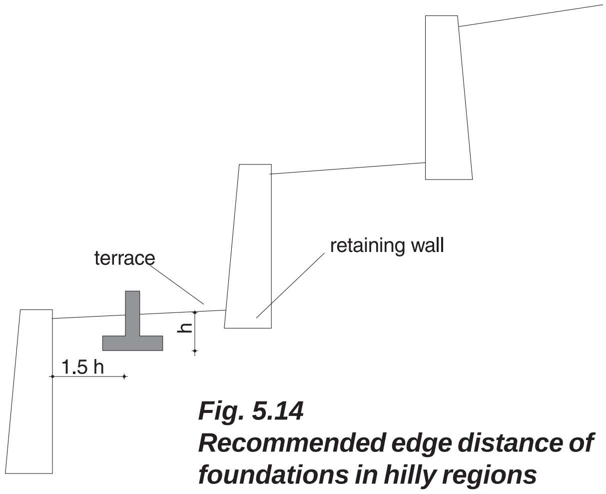


Fig. 5.14
Recommended edge distance of foundations in hilly regions

cyclone shelters, which could be repeated at various sites, it will be useful to determine the design wind pressures through wind-tunnel tests.

iii. *Building in Hilly Region-* In case of hilly regions where construction is made after cutting terraces on the hill slopes, it is essential that for the stability of slopes, a minimum edge distance of the foundation from any terrace be kept 1.5 times the depth of foundation *(Fig.5.14)* and foundation should rest on the natural firm strata. Further proper drainage of the area be ensured allowing surface water to flow unobstructed.

6. DESIGN PROCEDURE FOR WIND RESISTANT BUILDINGS

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

6.1 Fix 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 upto 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*[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 (pt.III), 1987. For buildings upto 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.

6.2 Determine the wind forces

a. Determine the design wind velocity V_z and normal design pressure p_z

$$V_z = V_b k_1 k_2 k_3 \qquad (6.1)$$

$p_z = 0.0006 V^2_z$ 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 wall, roofs and projections[(2)], as for example

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[(1) & (2)] For Detailed description and values, see Wind Code IS: 875(3)-1987 shown in *Figs. 3.1-3.3,* 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 lines 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. 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.

6.3 General Design Considerations

a. Load effects shall be determined considering all critical combinations of dead load, live load and wind load. In the design of elements, stress reversal under wind suctions should be given due consideration. Members or 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 resistance in their design.

b. Even thin reinforced concrete slabs, say 75 to 100 mm thick, may be subjected to uplift under wind speeds of 60 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 (like insulation, weathering course etc.) on such roofs to increase the effective weight to about 375 kg/m2 .

c. Since cyclonic wind could blow from any direction, building must have wind resistance along both the axes.

d. 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 minimise corrosion. In important structures, epoxy coating of reinforcing bars should be considered. The external surface should be treated with water proofing paints.

e. All dynamically sensitive structures such as chimney stacks, specially shaped water tanks, transmission line towers, etc. should be designed following the dynamic design procedures given in various IS codes.

f. 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.

It may be emphasised 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 Specifications.

6.4 Design Considerations for Roofs

Depending upon the construction material used and the geometrical aspects, the roofs can be broadly classified into two main types:

a. Flat roofs of various types
b. Pitched roofs with various covering materials

Their design considerations are stated here-below:

6.4.1 Flat Roofs

a. Flat roofs may consist of (i) R.C. slabs, (ii) wooden or R.C. joists, inverted T-irons placed closely spaced and carrying brick tiles, stone slabs or reeds with clay topping, and (iii) prefabricated R.C. elements of various designs placed side by side. Whereas R.C. slabs are rigid in their own planes, the other types will require their integration through diagonal bracing or topping R.C. screed (structural deck concrete).
b. Structural deck concrete of grade not leaner than M20 in cyclone areas shall be provided over precast components to act monolithic with them (*Fig 6.1).* Wherever, deck concrete is to be provided, the top surface of the components shall be finished rough. Cement slurry with 0.5 kg of cement per sq.m. of the surface area shall be applied over the components immediately before laying the deck concrete and the concrete shall be compacted using plate vibrators. The minimum thickness of deck concrete shall be 35 to 40 mm reinforced with 6 mm dia bars @ 150 mm apart bothways and anchored into the roof band or tie beam placed all round.
c. In view of large uplift forces, particularly if wind speed could exceed 55 m/s, the total roof weight should preferably be kept about 375 kg/m^2. Lighter roofs should be designed for net hogging forces and properly held down to supporting beams/walls, etc.
d. Ferrocement (F.C.) is an emerging construction material having many advantages. A ferrocement roof will have a reduced dead weigh compared to an R.C. roof, though it will not be so light as an AC or GI roof. Furthermore ferrocement has finer and well distributed cracks as compared to RC hence better corrosion resistance. This new material could be used for flat or sloping roofs provided that the ferro-cement sheets are adequately anchored to the supporting walls/beams against the wind-uplift forces.

6.4.2 Pitched Roofs

a. The main load bearing structural members are timber or steel trusses, purlins, and bracings. The cladding may be of GI or AC sheeting, tiles, timber planks or prefabricated R.C. or Ferrocement elements. It will be preferable to use sheeting with *adequate fixtures* than tiles in cyclone areas.

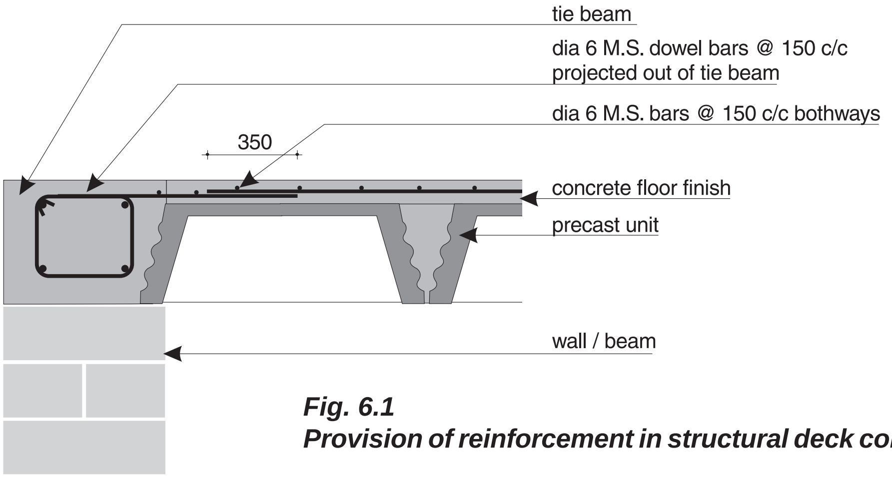


Fig. 6.1
Provision of reinforcement in structural deck concrete

b. The different design requirements for pitched roofs are as follows:

Analysis and design of pitched roof is carried out as per provisions of relevant codes of practice i.e. IS: 800-2006 for steel trusses and IS: 883-1970 for timber trusses. Under high velocity wind along the ridge of pitched roofs, the suction forces may exceed the dead load of the roof appreciably, causing compression in the bottom chord and stress reversals in all truss members in general. Buckling consideration in all members of roof trusses which are normally under tension, therefore, assumes significance. Therefore, the main ties of roof trusses may require lateral bracing and strutting against their buckling in lateral direction.

Note: Since the probable maximum wind velocities in coastal areas exceed the design velocities specified in the wind code, and the time duration for which a building is exposed to high wind velocities is much larger than in a 'passing' storm, very important buildings and structures may be designed for such probable velocities say 1.3 times those specified in IS:875(Part-3).

c. *Connections for cladding* - The corners and roof edges are zones of higher local wind suctions *(see Fig.3.1-3.3)* and the connections of cladding/sheeting to the truss need to be designed for the increased forces. As evidenced from past damage surveys (see 3), this is a vulnerable zone. The local pressure co-efficient given in IS:875-Part 3 may be used for design of connections such vulnerable areas. Further, failure at any one of these locations could lead progressively to complete roof failure. Hence, particularly in the cyclone affected zones, a reduced spacing of bolts 3/4 of that admissible as per IS: 800 is recommended. For normal connections J bolts may be used but for cyclone resistant connections U-bolts are recommended as shown in *Fig. 6.2(a).* As an alternative to the use of U-bolts, a strap may be used at least along the edges to fix the cladding with the purlins as shown in *Fig. 6.2(b)* to avoid punching through the sheet. Properly connected M.S. flat can be used as reinforcing band in high suction zones as shown in *Fig. 6.2(c)*

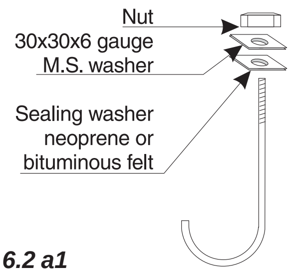


Fig. 6.2 a1

J bolt - cyclone connection for roof cladding to purlins

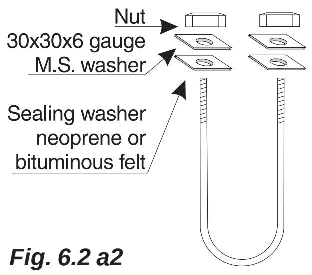


Fig. 6.2 a2

U bolt - cyclone connection for roof cladding to purlins

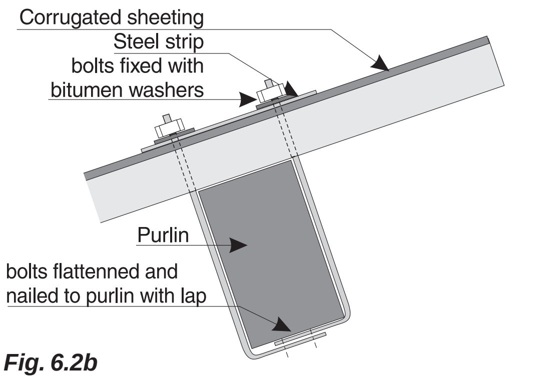


Fig. 6.2b

Fixing of corrugated sheeting to Purlins with bolts

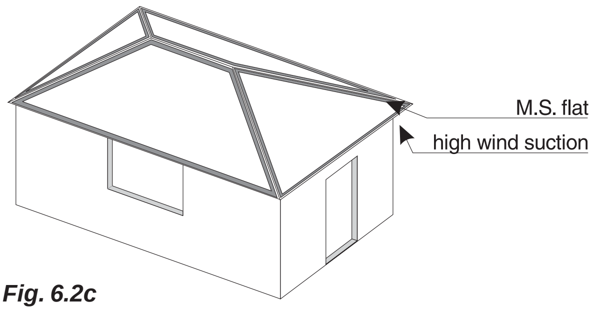


Fig. 6.2c

Using reinforcing bands in high suction zones

Fig. 6.2
Cyclone resistant connection details

In residential buildings in some areas, roof cladding may comprise of earthen tiles. 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 a R.C. strap beam along the edges is recommended for improved cyclone resistance.

d. *Anchoring of roof framing to wall/posts* - The proper connection of roof framing to the vertical load resisting elements i.e. wall or post, is equally important for overall stability of the roof. Care is particularly needed while connecting roof trusses to R.C. columns or masonry walls in cyclonic regions, by providing properly designed anchor bolts and base plates. Typical connection of wooden framing to wooden post is shown in *Fig. 6.3* through cyclone bolt or metal straps.

The anchoring of roof framing to masonry wall should be accomplished through anchor bolts properly embedded into concrete cores. The weight of participating masonry at an angle of half horizontal to 1 vertical as shown in *Fig. 6.4* should be more than the total uplift at the support. In case of large uplift forces, the anchoring bars can be taken down to the foundation level with a structural layout that could ensure the participation of filler and cross walls in resisting the uplift.

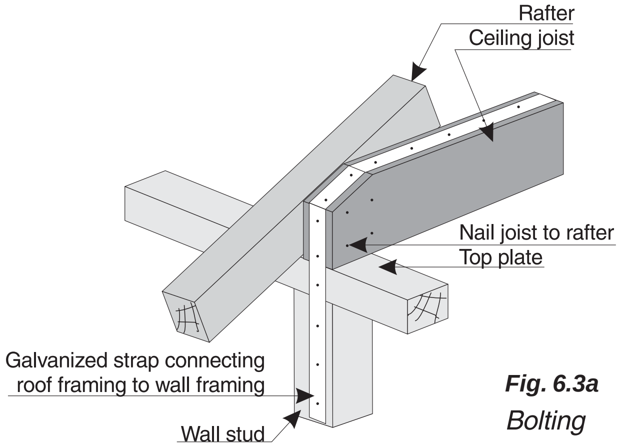


Fig. 6.3a
Bolting

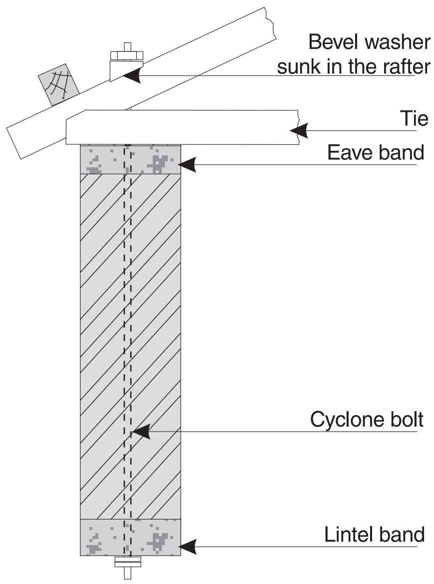


Fig. 6.3b
Connecting roof frame to wall frame

Fig. 6.3
Connection of roof framing to wall framing

e. *Bracing* - Adequate diagonal or knee bracing should be provided both at the rafter level and the eaves level in a pitched roof (see *Fig.6.5*). The purlins should be properly anchored at the gable end. It is desirable that at least two bays, one at each end, be braced both in horizontal and vertical plane to provide adequate wind resistance. Where number of bays is more than 5, use additional bracing in every fourth bay.

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 con-

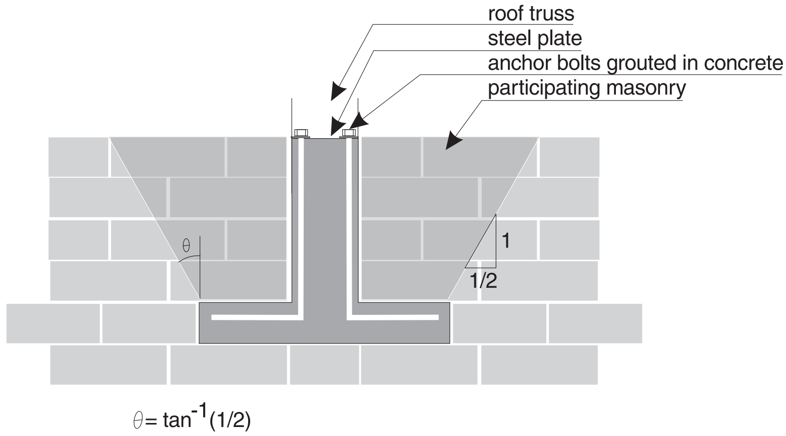


Fig. 6.4
Anchoring of roof framing in masonry

nected at the ends by at least two rivets/bolts or welds. Further the cross bracing members be welded/ connected at the crossings to reduce vibrations.

6.5 Masonry Walls of Good Design

6.5.1 General

These are usually made from rectangularised masonry units (with crushing strength not less than 5.0 MPa) bonded in cement/ cement lime mortar (not leaner than 1:6 cement-sand and 1:2:9 Cement-Lime-Sand). The commonly used masonry units are bricks, stones or concrete blocks. The stability of walls under lateral wind loads depends on their thickness, height and distance between transverse supports. Less height, larger thickness and less span make than more stable.

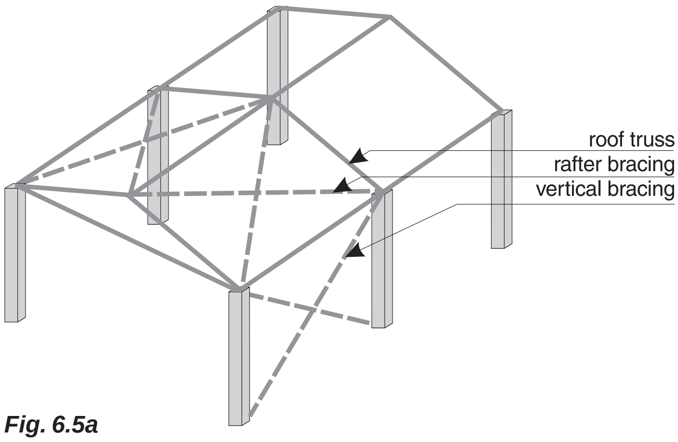


Fig. 6.5a
Bracing in planes of rafters

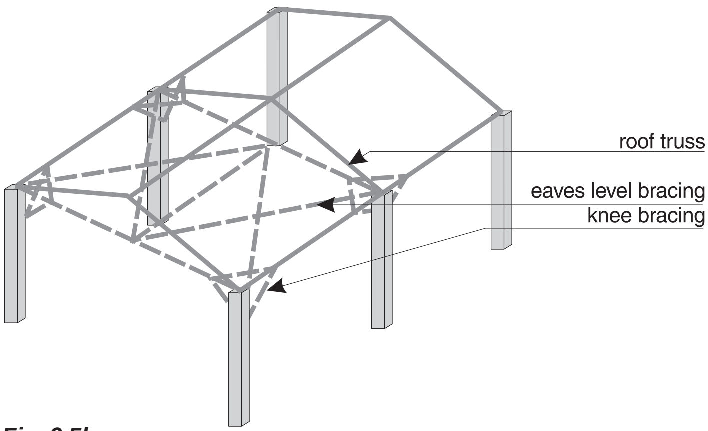


Fig. 6.5b
Eaves level knee bracing

Fig. 6.5
Typical roof bracings for industrial buildings

6.5.2 External Walls

All external walls or wall panels must be designed to resist the out of plane wind pressures adequately. The mortar used will determine the permissible tensile bending stress as per IS: 1905-1987. In case of walls of large halls or industrial buildings (more than 8 m long) adequate lateral restraint in the form of buttresses/piers should be provided.

In case of cellular plans with cast-in-situ R.C. slab, the lateral load due to wind is usually resisted by all walls lying parallel to the lateral force direction in proportion of their stiffness (by shear wall action). The walls are designed for their share of vertical and lateral load. The provisions of IS: 1905-1987 need to be complied with for the safety of the walls.

6.5.3 Strengthening of Walls Against High Winds/Cyclones

For high wind and cyclone prone areas ($V_b \geq 50$ m/s), it is found necessary to use cement - sand-mortar in the proportion of 1:4 and to reinforce the walls by means of reinforced concrete bands (equivalent to those required in masonry buildings in seismic zone V vide IS: 4326-1993) as given below to be provided at the door-window lintel level, eaves level of pitched roofs, below flexible flat roofs, and top of external gable walls. The strengthening methods suggested herein need further research using probable maximum wind speeds in cyclone prone sea coast areas, but are in the right direction and may be adopted for the time being.

a. *Lintel band* is a band provided at lintel level on all load bearing internal, external longitudinal and cross walls.
b. *Roof band* or *eave band* is a band provided immediately below the roof or floors. Such a

band need not be provided underneath reinforced concrete or brick-work slabs resting on bearing walls, provided that the slabs are continuous over the intermediate wall.

c. *Gable band* is a band provided at the top of gable masonry below the purlins. This band shall be made continuous with the roof band at the eaves level.

d. *Section and Reinforcement of Band.* See Table 6.1. The band shall be made of reinforced concrete of grade not learner than M20 or reinforced brickwork in cement mortar not leaner than 1:3, and shall cover the width of end walls, fully or at least 3/4 of the wall thickness. *See Fig. 6.6* for details of reinforcement placing and bending.

e. It is advisable that in wind velocity 50 m/s or higher velocity areas vertical reinforcing bars are provided, against uplift, between the foundation and roof band and between eave band and gable band, as follows:

• From foundation through Lintel Band into Roof/Eave Bands:	One bar of 12 mm dia. H.S.D. (High Strenghts Deformed) at each corner and junction of walls
• Between Eave and Gable Band-	One bar of 12 mm dia. H.S.D under ridge connection with gable and at every 2 m apart in between.

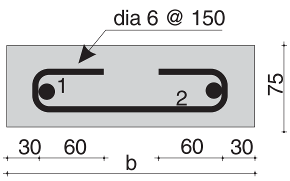


Fig. 6.6a
Section of band with 2 bars

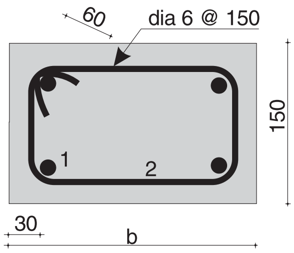


Fig. 6.6b
Section of band with 4 bars

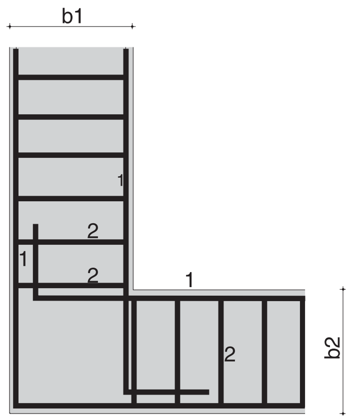


Fig. 6.6c
Structural plan at corner junction

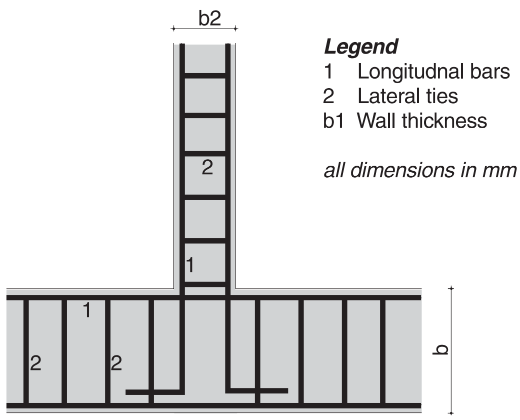


Fig. 6.6d
Section plan at T junction of walls

Fig. 6.6
Reinforcement and bending detail in R.C.band

Table 6.1: Recommended Longitudinal Steel in R.C. Bands
(High Strength Deformed Bars, Fe415)

Span	Design Wind Speed, m/s							
	>55		50-55		44-49		33-44	
m	No. of Bars	Dia. mm	No. of Bars	Dia. mm	No. of Bars	Dia. mm	No. of Bars	Dia. mm
5 or less	2	10	2	8	2	8	Nil	-
6	2	12	2	10	2	8	Nil	-
7	4	10	2	12	2	10	2	8
8	4	12	4	10	2	12	2	10

Notes:

1. *Span of wall will be the distance between centre lines of its cross walls or buttresses.For spans greater than 8 m, it will be desirable to insert pilasters or buttresses to reduce the span.*
2. *Width of R.C. band is assumed same as the thickness of the wall. Wall thickness shall be 200 mm minimum. A clear cover of 20 mm from face of wall will be maintained.*
3. *The vertical thickness of R.C. band be kept 75 mm minimum, where two longitudinal bars are specified, one on each face; and 150 mm, where four bars are specified.*
4. *Concrete mix shall be of grade M20 of IS 456: 2000 (or 1:1.5:3 by volume) in cyclone areas.*
5. *The longitudinal steel bars shall be held in position by steel links or stirrups 6 mm dia spaced at 150 mm apart.*

6.5.4 Openings

Openings in walls create stress concentrations and are thus points of weaknesses. Yet these are unavoidable. In general, large openings close to the corners, or, too many openings should be avoided. The total width of openings in a load bearing or shearing wall should not exceed 50% of the length of the wall. For taking the full advantage of return wall in the form of participating effective flange width for providing lateral load resistance, no opening should be located within a distance of 2 times the wall thickness or one twelfth of the storey height which ever is less, from the cross wall. The openings should be in a regular pattern to permit a smoother stress flow.

6.6 Framed Buildings

As an alternative to vertical load bearing walls, reinforced concrete, steel, or timber framing can be used. In R.C. constructions, 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 the horizontal planes. Stipulations for cyclonic regions as made in the foregoing section 5.5 dealing with walls are applicable to the cladding wall panels also. The recommended guidelines for the design of frames are as follows:

a. *Loading* - The different loads and load combinations to be considered for the design are as per IS: 875 (part I to IV). The dead loads, superimposed loads, wind and snow loads to be considered are given in parts I, II, III and IV respectively.
b. *Cladding* - 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. It is usual to have masonry wall panels as cladding in buildings with R.C. framing. The design of panel wall shall be carried out for out of plane local wind pressures as per IS: 1905-1987.

   In industrial buildings corrugated galvanized iron/asbestos cement (CGI/AC) sheet cladding may be used for side covering. The design should be carried out for local wind pressures. Proper attention be paid to connections specially near corners and roof edge where local pressures/suctions are very high (see fig. 3.1).

Alternatively, timber planks if available may be used for panelling particularly with timber posts. The planks and their connections with end posts shall be designed as per IS: 883-1970.

Note: In cyclone affected areas CGI sheets shall be designed for the pressures and suctions caused by cyclonic winds. AC sheeting will be vulnerable to breakage and to missile impacts, hence preferably avoided.

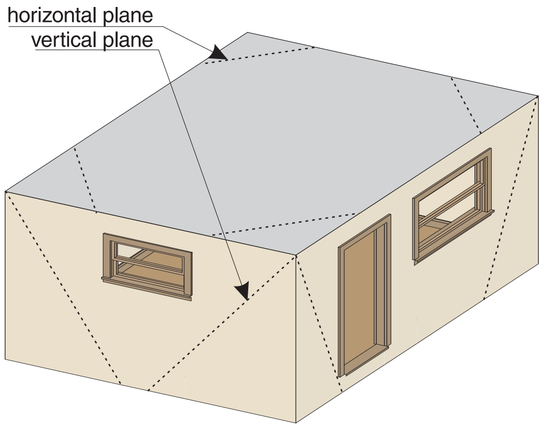


Fig. 6.7
Wind bracings in timber frames

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 their lateral load resistance. In industrial buildings employing steel framing, at least the two end bays shall be braced in the vertical and horizontal plane as per *Fig.6.5.*

In timber framing it is normal practice to brace each bay as well as to provide bracing in horizontal plane as shown in *Fig.6.7* so that complete structure is integrated.

d. *Anchoring* - The frame columns and shear wall where used shall be properly anchored in to the foundation against uplift forces, as found necessary. For R.C. frames, usually a monolithic footing is provided which provides due stability against uplift. In case of steel framing too, column posts are properly tied to steel/concrete footing through anchor bolts. For timber posts usually cross pieces are nailed at bottom end of the post and buried into the ground to provide necessary anchorage *(Fig.6.8).*

Special care is necessary for corrosion resistance of connectors used below the ground, and safety of timber by painting and /or chemical presevative treatment, particularly in cyclonic regions.

6.7 Floors

Floors usually carry no wind loads unless the building is constructed on stilts (in a cyclonic region). The design is carried out for vertical loads only. For a building on stilts, flow of wind underneath the floor is possible, thereby causing wind forces (both uplift and suction type). The forces as calculated using design wind pressures should be considered.

7 NON-ENGINEERED CONSTRUCTION

All constructions, though using the conventional building materials but made intuitively without carrying out a proper structural design, and or constructed without adequate control at site, with respect to both materials used and construction practices employed, may generally be termed as non-engineered construction. All constructions in low strength masonry or clay mud, and similar other forms of biomass, will fall under the cat-

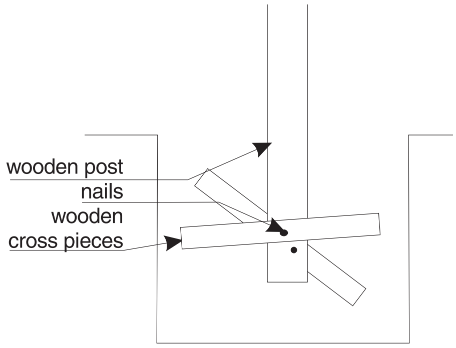


Fig. 6.8
Anchoring of wooden post using cross pieces

egory of non-engineered construction. The cyclone resistance of non- engineered construction may be improved by following suitable guidelines as given herebelow. Assistance may also be derived from IS:15498-2004, 'Guidelines for Improving the Cyclone Resistance of Low Rise Houses and other Buildings/Structures'.

7.1 Roof Covering

i. In case of thatched roof it should be properly tied down to wooden framing underneath by using organic or nylon ropes in diagonal pattern as shown in *Fig 7.1 (a)*. The spacing of rope should be kept 450 mm or less so as to hold down the thatch length. For connecting the wooden members, use of non corrodible fixtures should be made. If non-metallic elements are used, these may need frequent replacement (See *Fig. 7.1 b*).

ii. Projection of roof to be minimised, say not more than 500 mm in high wind/cyclone areas, and, larger projections be properly tied. (see *Fig.5.8*).

iii. In case of roof tiles, the overlap joint along the edges should be provided in cement mortar. In cyclones areas, tiled roofs should be provided with restraining concrete bands at a spacing not exceeding 1.2 m, and connected to rafters as shown in *Fig. 7.1 c & d.* As alternative to the bands, a cement mortar screed, reinforced with galvanised chicken mesh, may be laid in strips over the entire tiled roof, ensuring that the tile mainains its air permeability .

iv. A through and through tie of bamboo or timber, instead of m.s. flat, be provided along the edges of sheeted roofs, in addition to intermediate ties for long roofs (see *Fig. 6.2c*).

v. After a cyclone warning is received, all the lighter roofs should preferably be held down by a rope net and properly anchored to ground (see. *Fig.7.2*).

7.2 Low Strength Masonry Construction

7.2.1 General

Two types of construction are included herein, namely:

a. brick construction using weak mortar, such as clay mud or lime-sand

b. Random rubble and half-dressed stone masonry construction using different mortars such as clay mud or lime-sand.

These constructions should not be permitted for important buildings in cyclone areas and should preferably be avoided for ordinary buildings. Where used, the following precautions should be taken:

a. It will be useful to provide damp-proof course at plinth level to stop the rise of pore water into the superstructure.

b. Precautions should be taken to keep the rain water away from soaking into the wall so that the mortar is not softened due to wetness. An effective way is to take out roof projections beyond the walls by about 500 mm, which should be tied to main structure against uplift as shown in fig. 5.8.

c. Use of a water-proof plaster on outside face of walls will enhance the life of the building and maintain its strength at the time of cyclone or high wind as well (see 7.4).

d. Free standing boundary walls should be checked against overturning under the action of design wind pressures allowing for a factor of safety of 1.2.

7.2.2 Brick work in Weak Mortars

a. The fired bricks should have a compressive strength not less than 3.5 MPa. Strength of bricks and wall thickness should be selected based on the total building height.

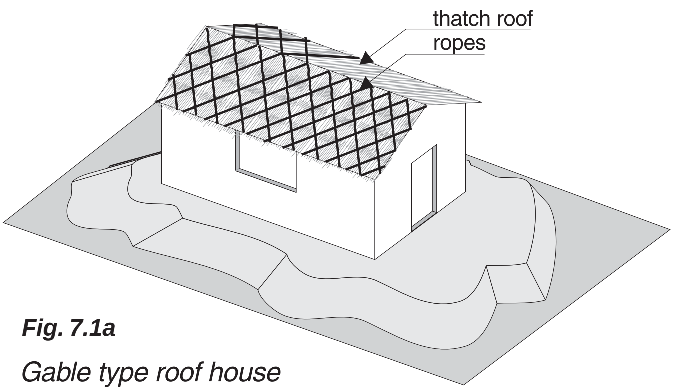


Fig. 7.1a

Gable type roof house

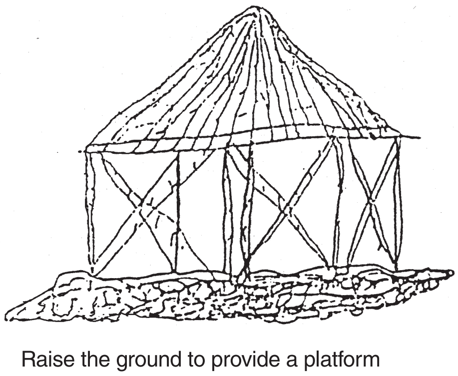


Fig. 7.1b

Conical roof house

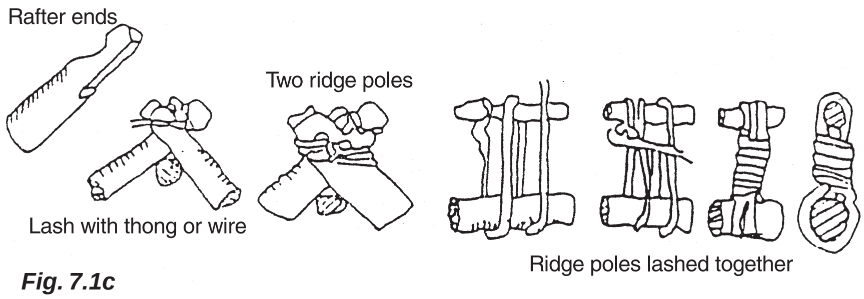
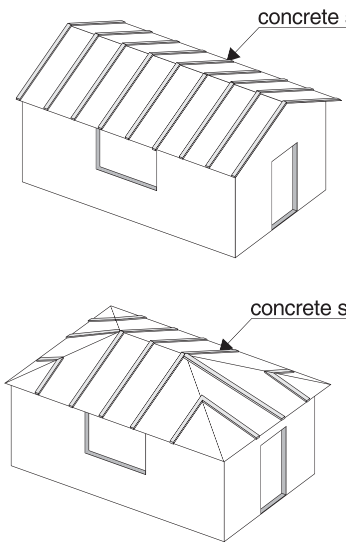


Fig. 7.1c

Wooden member connection details



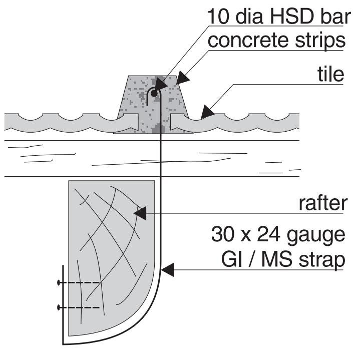


Fig. 7.1d

Connection of concrete strips to rafter

Fig. 7.1
Have a secure roof jointing

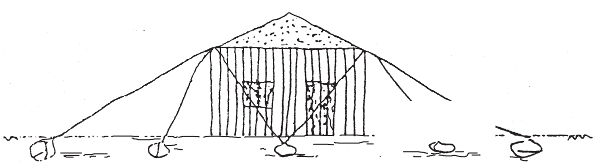


Fig. 7.2
Rope tie-backs for weak structures

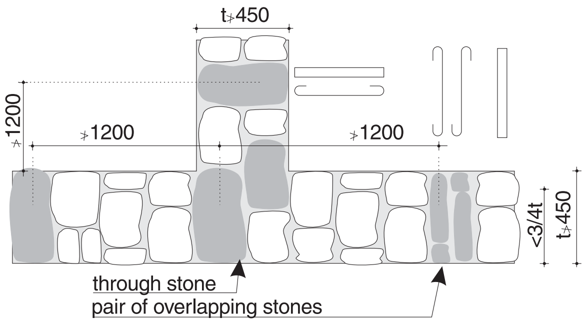


Fig. 7.3a

Sectional plan of wall

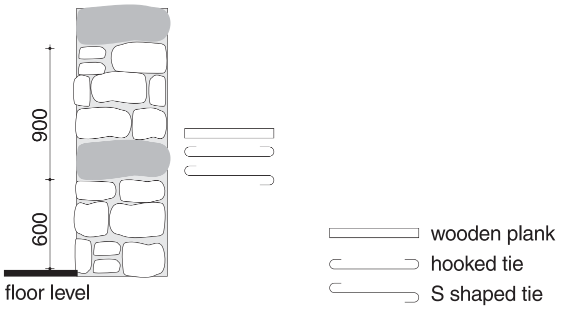


Fig. 7.3b

Cross-section of wall

Fig. 7.3
Through stone and bond elements

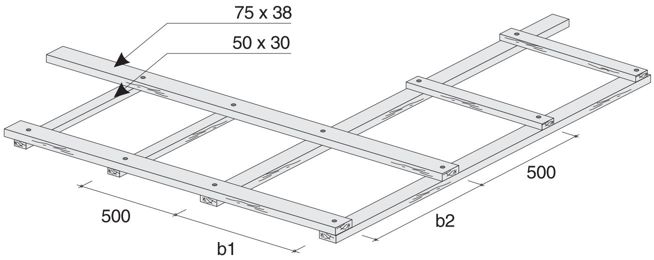


Fig. 7.4
Wooden band for low strength masonry earthern buildings

b. The mortar should be lime-sand (1:3) or clay mud of good quality.

c. The minimum wall thickness should be one brick in one storey construction and one brick in top storey and 1.5 brick in bottom storeys of upto three storey construction. It should also not be less than 1/16 of the length of wall between two consecutive perpendicular walls or buttresses.

7.2.3 Stone Masonry (Random Rubble *or Half-Dressed)*

a. The mortar should be lime-sand (1:3) or clay mud of good quality.

b. The wall thickness ‘t’ should not be larger than 450 mm. Preferably it should be about 350 mm, and the stones on the inner and outer wythes should be *interlocked* with each other.

c. The masonry should preferably be brought to courses at not more than 600 mm lift.

d. *‘Through’* stones of full length equal to wall thickness should be used in every 600 mm lift at not more than 1.2 m apart horizontally. If full length stones are not available, stones in pairs each of about 3/4 of the wall thickness may be used in place of one full length stone so as to provide an overlap between them.

e. In place of ‘through’ stones, ‘bonding elements’ of steel bars 8 to 10 mm dia bent to S-shape or as hooked links may be used with a cover of 25 mm from each face of the wall (see *Fig. 28*). Alternatively, wood bars of 38 mm x 38 mm cross section or concrete bars of 50 mm x 50 mm section with an 8 mm dia rod placed centrally may be used in place of ‘through’ stones. The wood should be well treated with preservative so that it is durable against weathering and insect action.

f. Use of ‘bonding’ elements of adequate length should also be made at corners and junctions of walls to break the vertical joints and provide bonding between perpendicular walls.

g. Height of the stone masonry walls (random rubble or half-dressed) should be restricted to 2 storeys in lime-sand mortar and one storey when clay mud mortar is used, the storey height to be kept 3.0 m maximum, and span of walls between cross walls to be limited to 5.0 m.
h. If walls longer than 5 m are needed, buttresses may be used at intermediate points not farther apart than 4.0 m. The size of the buttress be kept of uniform thickness. Top width should be equal to the thickness of main wall, and the base width equal to one sixth of wall height.

7.2.4 Openings in Bearing Walls

a. Door and window openings in walls reduce their lateral load resistance and hence should preferably, be small and more centrally located. The total width of all openings should not exceed one-third of total length of a wall.
b. Openings in any storey shall preferably have their top at the same level so that a continuous band could be provided over them including the lintels throughout the building.

7.2.5 Strengthening Arrangements for High Wind Resistance

a. *R.C. Bands.* The walls should be reinforced with reinforced concrete bands as specified in 6.5.3.
b. *Wooden Band.* As an alternative to reinforced concrete band, the band could be provided using wood beams of two parallel pieces with cross elements as shown in *Fig.7.4.*

7.3 Earthen Buildings

7.3.1 General

a. For the safety of earthen houses, appropriate precautions must be taken against the actions of rain and flood waters and high winds. Minimum precautions are recommended herein.
b. Whereas dry clay block is hard and strong in compression and shear, water penetration will make it soft and weak, the reduction in strength could be as high as 80 percent. Hence, once built, ingress of moisture in the walls must be prevented by roof projection and waterproof plastering.
c. The following recommendations are low-cost and do not include the use of stabilizers, which are rather costly though effective in increasing the strength and water-resistance of the clay units or walls. Where feasible lime-stabilized compacted clay blocks or cement-stabilized sandy soil blocks may be used with compatible stronger mortars.

7.3.2 Construction of Earthen Walls

Earthen walls may be constructed in the following four ways.

a. Hand-formed in layers using mud-lumps to form walls.
b. Built by using sun-dried blocks or *adobe* which may be cut from hardened soil, or formed in moulds, or moulded and compacted and laid in courses using clay mud as mortar.
c. Built by using rammed earth in which moist soil is filled between wall forms and compacted manually or mechanically.
d. Constructed using wood, bamboo or cane structure encased in clay mud, or wood, bamboo, cane or ikra mesh enclosures plastered with mud.

Whereas systems (a), (b), (c) depend on the strength of earthen walls for stability, the system (d) behaves like wood frame.

7.3.3 Recommendations for Cyclone Areas

a. The height of the earthen building should be restricted to one storey only in cyclone area and to two storeys in other zones. Important buildings should not be constructed with earthen walls.

b. The length of a wall, between two consecutive walls at right angles to it, should not be greater than 10 times the wall thickness t nor greater than 64 t^2/h where h is the height of wall.

c. When a longer wall is required, the walls should be strengthened by intermediate vertical buttresses.

d. The height of wall should not be greater than 8 times its thickness.

e. The width of an opening should not be greater than 1.20 m.

f. The distance between an outside corner and the opening should be not less than 1.20 m.

g. The sum of the widths of openings in a wall should not exceed one third the total wall length in cyclone areas and 40 percent in other areas.

h. The bearing length (embedment) of lintels on each side of an opening should not be less than 300 mm.

i. Hand-formed walls should preferably be made tapering upwards keeping the minimum thickness 300 mm at top and increasing it with a batter of 1:12 at bottom.

j. The footing should preferably be built by using stone or fired brick laid with lime mortar. Alternatively, it may be made in lean cement concrete with plums (cement : sand : gravel : stones as 1:4:6:10) or without plums as 1:5:10. Lime could be used in place of cement in the ratio lime: sand : gravel as 1:4: 8.

k. *Plinth Masonry.* The wall above foundation up to plinth level should preferably be constructed using stone or burnt bricks laid in cement or lime mortar. Clay mud mortar may be used only as a last resort.

The height of plinth should be above the flood water line or a minimum of 300 mm above ground level. It will be preferable to use a waterproofing layer in the form of waterproof mud (see 7.4) or heavy black polythene sheet at the plinth level before starting the construction of superstructure wall. If adobe itself is used for plinth construction, the outside face of plinth should be protected against damage by water by suitable facia or plaster. A water drain should be made slightly away from the wall to save it from seepage.

7.3.4 Strengthening of Earthen Buildings Against High Wind/Cyclones

a. *Collar Beam or Horizontal Band.* Two horizontal continuous reinforcing and binding beams or bands should be placed, one coinciding with lintels of door and window openings, and the other just below the roof in all walls in cyclone areas. Where the height of wall is not more than 2.5 m, the lintel band may be omitted. Also only the band below the roof may be used in other zones. Proper connection of ties placed at right angles at the corners and junctions of walls should be ensured. The bands could be in the following forms:

i. Unfinished rough cut or sawn (70 x 150 mm in section) lumber in single pieces diagonal members provided for bracing at corners (see *Fig.7.5a*)

ii. Unfinished rough cut or sawn (50 x 100 mm or 70 x 70 mm in section) lumber two pieces in parallel with halved joints at corners and junctions of walls placed in parallel (See *Fig.7.5b*).

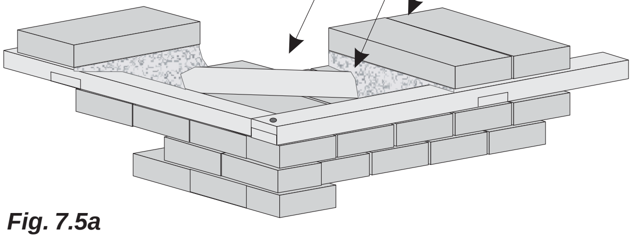


Fig. 7.5a

Band with single timber and diagonal brace at corner

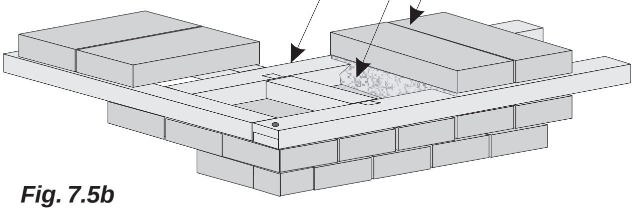
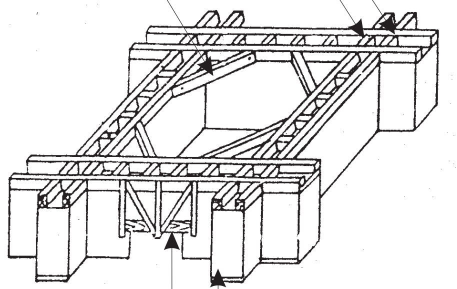


Fig. 7.5b

Band with two timbers in parallel

Fig. 7.5
Wooden band in walls at lintel and roof levels



Where pillasters or buttresses are used at corner or T junctions, the collar beam should cover the buttresses as well. Use of diagonal struts at corners willl further stiffen the collar beam

Fig. 7.6
Roof band on pillastered walls

In each case, the lengthening joint in the elements shall be made using iron-straps with sufficient nails/screws to ensure the strength of the original lumber at the joint.

b. Pilasters and Buttresses
Where pilasters or buttresses are used, at corner or T-junctions, the collar beam should cover the buttresses as well, as shown in *Fig. 7.6*. Use of diagonal struts at corners will further stiffen the collar beam.

7.3.5 Earthen Constructions with Wood or Cane Structures

The scheme of earthen construction using structural framework of wood or cane, as shown in *Fig.7.7*, consists of vertical posts and horizontal blocking members of wood or large diameter canes or bamboo, the panels being filled with cane, bamboo or some kind of reed matting plastered over both sides with mud.

7.4 Plastering and Painting

The purpose of plastering and painting is to give protection and durability to the low strength masonry walls (6.2) and earthen walls (7) and thatch roof, in addition to obvious aesthetic reasons.

a. In dry areas, plastering based on natural additives could be formed in two layers. The first one of about 12 to 15 mm, is a mixture of mud and straw (1:1 in volume), plus a natural additive like cowdung used to increase the moisture resistance of the mud, thus preventing the occurrence of fissures during the drying process. The second and last layer is made

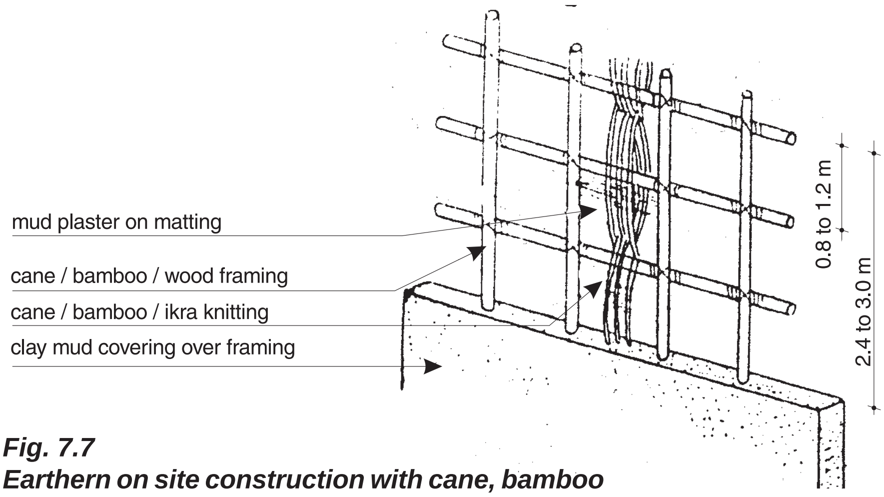


Fig. 7.7
Earthern on site construction with cane, bamboo or wooden structure

with fine mud which when dried, should be rubbed with small, hard, rounded pebbles.

b. In cyclone prone and other wet areas, the walls should be covered with waterproof mud plaster. To obtain this, the following procedure may be followed:

   "Cut-back should be prepared by mixing bitumen 80/100 grade and kerosene oil in the ratio 5:1. For 1.8 kg cut-back, 1.5 kg bitumen is melted and is poured in a container having 300 millilitres kerosene oil, with constant stirring, till complete mixing. This mixture can now be mixed with 30 litres of mud mortar to make it both, water repellent and fire resistant.

c. For improving water and fire resistance of thatch roof, the water proof plaster may be applied on top surfaces of the thatch, 20 to 25 mm thick, and allowed to dry. It may then be coated twice with a wet mixture of cowdung and waterproof plaster in the ratio of 1:1, and allowed to dry again.

d. The exterior of walls after plastering and thatch roof after treatment as explained above may be suitably painted using a water-insoluble paint or washed with water solutions of lime or cement or gypsum.

7.5 Framed Houses

7.5.1 General

The following guidelines should be used in building framed houses:

a. The main framing should be made with timber posts, bamboos or hollow pipes, and, ensuring proper connections of post with eaves level beam and rafters. (see *Fig.7.8).*

b. Frames should be properly braced in both horizontal and vertical

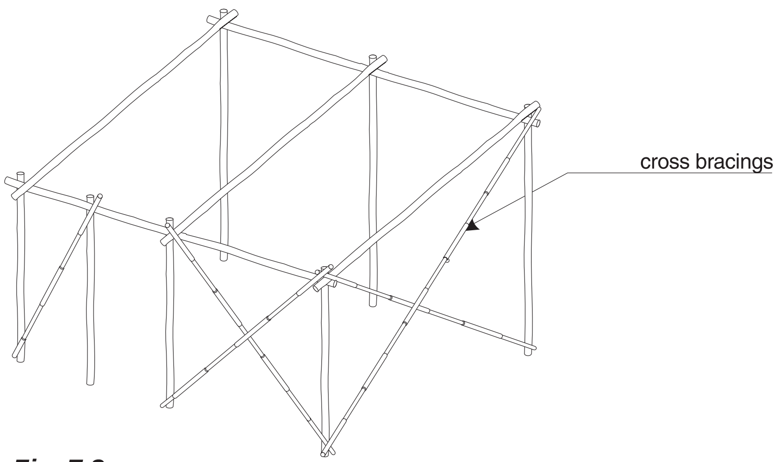


Fig. 7.8
Wind fracing of frame

planes using knee braces or using cross ties *(Fig.6.7).*

c. Cladding panels may be made using meshes of bamboo strips, cane or Ikra or other suitable fibrous agro waste, and plastering insitu.

d. Openings in the walls should be small and located away from the edges and not immediately below the roof. In case openings are non closable (without shutters) these should be less than 5% of wall area each and in pairs on the opposite walls to prevent high suction on the roof from inside.

7.5.2 Foundation

a. The drainage around the building be improved to prevent water collection for the durability of walls and foundations.

b. All posts be properly anchored into the ground or reinforced cement footing. Alternatively, the posts with cross members connected at the lower end be embedded in ground (see *Fig.7.9*) by a minimum depth of 750 mm.

c. Walls be raised from a well compacted lean concrete bed or well compacted ground, from a minimum depth of 450 mm below the ground level (see *Fig.7.10*).

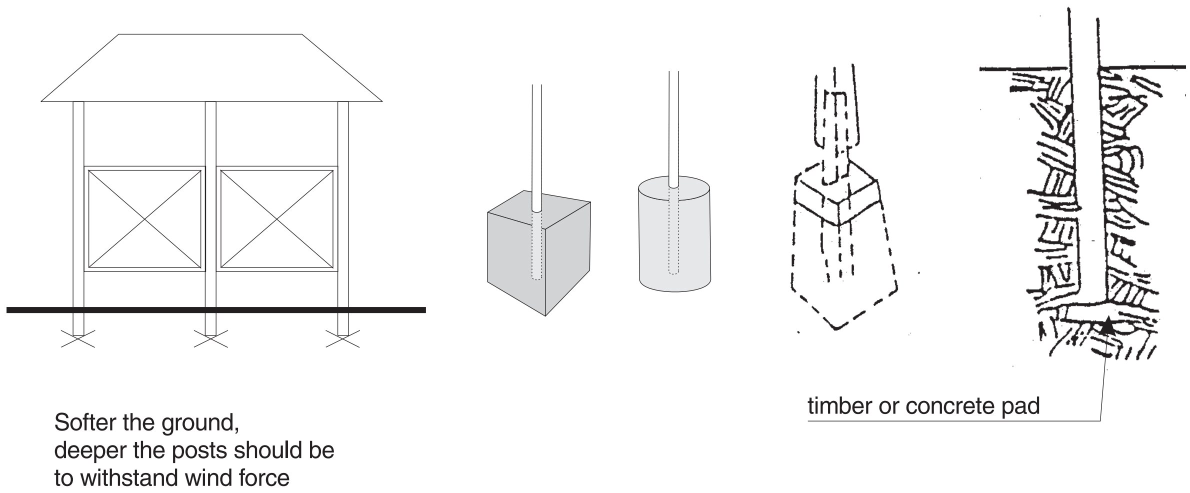


Fig. 7.9
Proper footings for timber post

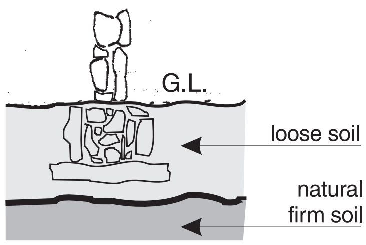


Fig. 7.10a
Shallow foundation over loose soil

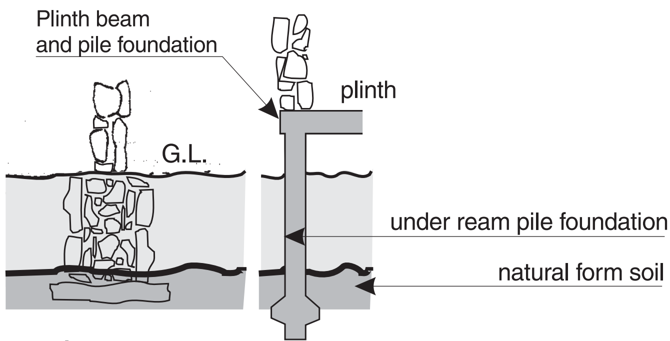


Fig. 7.10b
Adequate depth of foundations to reach natural firm soil or pile foundations more desirable

Fig. 7.10
Shallow foundation for walls

8 RETROFITTING OF EXISTING BUILDINGS AGAINST CYCLONES

For all the existing structures not having adequate cyclone resistance, appropriate to the zone in which located, retrofitting measures are advocated to reduce the risk of damage or failure. Some measures along with approximate cost as a proportion of the cost of the building are given in Table 8.1 for preliminary guidance. These measures are based on the lessons learnt from the post-cyclone damage surveys conducted in the past. While the recommendations can be more specific for engineered constructions, for non engineered constructions the recommendations would depend upon building typology, construction material and practices prevalent in the region. The retrofitting guidelines will generally arise from the guidelines already given for new constructions. Some measures are indicated herebelow. It is however recommended that for cyclone affected zones of the country, the retrofit measures be evolved through a detailed study based upon building typology.

8.1 Engineered Constructions

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 points for special attention are indicated in following paras:

8.1.1 Roof

a. In case of light roofs (AC or CGI sheeting) connections near the edges should be strengthened by providing additional U bolts. M.S. flat ties may be provided to hold down the roof in cyclonic regions. J-bolts if used earlier may be replaced by U-bolts.

b. All projections in roofs be properly checked for strength against uplift and tied down if found necessary, particularly, if longer than 500 mm, *(see Fig. 5.8).*

c. All metallic connectors for different components of roof should preferably be of non-corrosive material, or else must be painted and checked before each cyclone season and doubtful ones be replaced immediately.

d. There must be proper bracings (i) in the plane of rafters, in plan at eaves level, and, in the vertical plane of columns along both axes of the building in sufficient number of panels determined by recalculation *(see Fig. 6.5).*

e. Flat roofs may be integrated to behave as *horizontal diaphragms* and either weighted down by dead weights or held down against uplift forces.

8.1.2 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 be provided to improve the overall stability.

b. All roof trusses be properly connected to posts. Particularly in a cyclonic region this should be done with the help of anchor bolts or metallic straps.

c. Undesirable openings in the walls specially near the corners or edges be closed permanently to improve the lateral support to the cross walls particularly in a cyclonic region.

8.1.3 Load Bearing Walls

a. Buttresses be provided to improve the lateral load resistance of long walls, achieving cross wall spacings to less than 5m, thus reducing the unsupported lengths.

b. The exterior perimeter may be *belted* all round by using ferro-cement plating in the spandrel wall portion between lintel and eave/roof levels.

Table 8.1:
Retrofitting Measures for Buildings and Structures to Increase Cyclonic Resistance

S.No.	Type	Retrofit/Maintenance Measures	Approximate cost as a proportion of cost of building
1.	Non Engineered Building Thatched House	• Provisions of metal straps and nails at joints • Holding down coiror nylon ropes • Replacement of worn out fibre ropes	Retrofit - 4.5% Maintenance - 1%
2.	Tiled Building	• Use Concrete strips (fig. 7.1) • Holding down rods • Metal straps for connection to trusses • Provision of eaves holding down angle/metal strap • Maintenance replacement of broken tiles, worn out bolts, metal straps, etc. • R.C.C. holding down rafters	Retrofit - 8% Maintenance - 1%
3.	Compound Wall	Checking the available capacity and detailing retrofit measures consisting of reinforced concrete vertical and horizontal bands to obtain the required strength	Additional cost varies in the range of 25 to 60% of new construction satisfying the design requirements. Retrofitting cost + existing structure cost approximately equals the cost of new construction.
4.	Lamp Masts	• Provision of a foundation block and extending it upto a certain height above ground level to ensure natural frequency is greater than 1.5 Hz. • Underground cables to reduce load on lamp mast/failure of masts by falling branches of tress.	Cost of individual lamp mast with foundation will be increased by 40 to 50%
5.	Water Tanks Ferrocement/ Other Lightweight Tanks	Provision of holding down/preventing sliding etc.	Marginal

8.1.4 Glass Panelling

a. The size of large glass panes be reduced by adding battens at appropriate spacing. Large glass panes be strengthened by fixing adhesive tapes, along and parallel to diagonals, at 100-150 mm spacings prior to each cyclone season. Alternatively, thin plastic film be pasted on both faces of the panes to prevent shattering.

b. Protective cover in the form of mesh or iron grill be provided to prevent breakage of glass panels by flying missiles.

8.1.5 Door and Window Shutters

The locking arrangements for door and window shutters be strengthened to prevent opening of doors/windows during cyclone/gust causing failure of glass panels as well as adverse suction on roofs.

8.1.6 Foundations

a. While checking the safety of a foundation, an allowance should be made for likely submergence of the foundation in a cyclone region by appropriately reducing the safe bearing capacity of soil.

b. Proper drainage around the building should be provided to prevent pooling of water in its vicinity.

c. The plinth should be protected against erosion by using pitching of suitable type.

8.2 Non Engineered Construction

a. In case of thatched roof, it should be properly tied to timber framing on underside. Use of metallic/synthetic connectors is desirable. Use of water proof mud plaster may be made to make it leak proof.

b. In case of tiled roofs, the overlaps be jointed through use of cement mortar to provide more stability.

c. While relaying of roofs, its slope be changed to about 22 to 30^o to reduce the wind suction on roof and thus reducing the damage potential. At the same time, eave level wooden band should be introduced on top of walls *(Fig. 7.4-7.6)*.

d. The wooden frame where used should be properly braced in both horizontal and vertical planes by using knee braces or ties.

e. All mud walls have a limited life after which they need to be rebuilt and the suggested strengthening by bamboo mesh placed at the middle can be affected only then. However, for the existing walls such mesh may be provided on the inner face and the wall replastered.

f. For greater durability of wall against rain and water etc., external face of wall upto 1.0 to 1.5 m height above plinth level should be covered with burnt clay tiles laid in cement mortar of 1:6 mix.

g. The roof rafters be properly tied to posts using metallic strap connectors.

h. All openings very close to wall edges be closed. All asymmetric non-closable openings be filled up to eliminate any unfavourable roof pressure from within. Two small vents in opposite walls close to the roof may be left open.

i. If the foundations of the posts are not made heavy enough to prevent uprooting of the building, 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 away of roof/building.

9. DESIGN OF CYCLONE-CUM-TSUNAMI SHELTERS

9.1 Location of cyclone shelters

The number of cyclone shelters to be built largely depends on the number of vulnerable populations to be sheltered during emergencies. The effectiveness of a cyclone shelter, thus, depends on the assessment for the number of likely users and considerations in design and structural aspects of the shelter.

9.2 Multi-hazard resistance of shelters

It is necessary that the cyclone shelters are multi-hazard resistant for the reason that the coastal areas are multi-hazard prone with cyclones, moderate earthquake, floods and tsunamis occurrences. This will significantly increase the life of the structure, its utility, and hence the economic efficiency of the investment made.

9.3. The Design Recommendations

Based on the experiences of construction and maintenance of cyclone shelters, a common strategy has been evolved for sustainable use of the shelters. It is suggested that the local bodies such as Panchayat Raj Institutions and Urban Local Bodies should participate in selection process of its *location* and *use*. The recommendations for construction of cyclone shelters deal with the following design and construction aspects of cyclone shelters:

- Sustainable Use
- Building
- Accommodation Capacity
- Location
- Height of the Cyclone Shelter
- Inner Design
- Structural Specifications
- Staircases
- Material Selection
- Water Supply
- Toilets and Sewerage
- Other Considerations
- Provision for Helipads

9.4. Sustainable Use

The more a shelter is used in normal time, the better it is maintained, and the more successfully it serves in emergencies. Regular use also provides economic justification for the investment. Among a number of alternatives suggested, primary schools have been found most suitable and compatible for normal time use of shelters. These could also be used temporarily for community gatherings, health camps, election booths, etc. The following guidelines would help in sustainable use of the shelters.

1. It should be noted that the *primary use* of the shelter is for protecting people from the vagaries of nature such as flood, cyclone and tsunami and act as relief camp during other disasters.
2. The shelter should always be made and protected keeping all concerns pertinent to its *primary* use.
3. The features pertinent to other uses should then be overlapped with those of the primary use of the shelter with *no compromise on its primary use*.
4. Broadly, the State Government will have maximum say on the kind of sustainable use the shelters be put to, it should encourage local innovations based on local needs and necessities as identified by the village communities to be fitted in.
5. The use of cyclone shelters for housing the offices which are of the *permanent occupation nature* (e.g. Panchayat offices, hospitals etc) must be discouraged, since these offices cannot be relocated during the periods of occurrence of natural disasters, which occur without prior notice, hence will hinder the usability of the shelter for its *primary purpose*.

6. The shelter should ultimately become a “Community asset/resource” such that it will have a broader impact on the livelihood of the villages. Hence, it is appropriate to locate the shelters inside or near the villages.
7. Using the shelter as primary school on regular basis will not come in the way of sheltering since most rural primary schools use mats for seating the children and where low height desks/benches may be used, they could be stored in a small space or used for people sitting or standing on them.
8. Other temporary uses may be for village gatherings, camps, marriages, and other community activities. Such a sustainable use should also generate required finances to supplement proper maintenance of the structure.

9.5 Accommodation Capacity

1. Capacity should be decided based on the local assessment of vulnerable populations and availability of any multi-storied buildings and buildings located on elevated grounds which can accommodate some of the vulnerable people during the times of cyclone, tsunami and flood.
2. Experience on capacity assessment of cyclone shelter indicates that, on an average, about 50-60% of total population of vulnerable locations may be using the cyclone shelter during emergencies.
3. As Stated earlier, planning of the shelter should take into account the sustainable utility aspect of the shelter. For example, a 4-room [6 m x 5.4 m + verandah (1.8 m)] school will have a clear floor area of about 172 m^2 (1850 sft) and a similar floor area on the terrace. Such a school will accommodate about 200 students and will provide around 0.65 m^2 (7 sq.ft.) per student. From the past experience, in our country as well as in other Asian countries, it is observed that an area of 0.186 m^2 (2 sq ft)/person has generally been provided for sheltering purposes. Such a density may lead to suffocation and inhuman environment. The area of the four room school could accommodate about 500 persons counting the area on the verandah floor at a rate of 0.344 m^2 (3.7 sq.ft). per person. Counting the available open area on the terrace another 500 persons can be accommodated. Hence, *a four room school could be assumed to accommodate easily upto 1000 persons*.

9.6 Location

1. Emphasis should be given such that the shelters are located on the available high elevated land. Guidance on the levels can be taken from large scale district maps or from Survey of India. Exact location within the broad contour is left to the decision making mechanism adopted locally involving communities & local authorities.
2. In absence of available elevated area, the structure may be elevated through construction of a mound ,or the shelter be built on *stilt*.
3. It will be necessary to carry out a survey within 10 km band width from the coast and identify all villages therein and submit the list to the Survey of India which should provide the information on astronomical high-tide levels and ground levels within a level range of + 0.5 m.

Note:- High tide line on the coast may be found from the people/fishermen living in the village.

4. Regenerating mangroves and raising shelter belt plantations will help reducing the fury of the storm surge and tsunamis. Suitable isolation distance must be provided between the shelter belt and the cyclone shelter to avoid damage to the foundation of the building by the roots of the shelter belt.

9.7 The Shelter Building

1. RCC or brick masonry two storeyed building *with* or *without stilt* depending on the storm tide levels is considered suitable. Height depends on the storm tide levels. In view of general soft top soil in coastal areas, pile foundations may be preferable. However, suitable type of foundations should be considered based on local geotechnical conditions revealed by soil investigations.
2. *Shape*: Any shape (circular, hexagonal, octagonal) is suitable. However, square or rectangular may be used provided the peripheral corners are rounded for improving the aerodynamics of the structure. Fig. 9.1 shows a typical plan of a shelter –cum-school.
3. *Doors*: Should be opened outwards into a box having four heavy duty stainless steel hinges fixed firmly to the holding medium.
4. *Windows*: Louver type of window is suggested with non-breakable and non-brittle items made of Fiber Reinforced Plastics (FRP).
5. *Parapet:*
   a. For RCC buildings, the height of the RCC parapet over the first floor roof will depend upon design storm surge height and may be taken from 0.8m to 1.35 m having holding-pipes on top or inside of the parapet depending on the design surge levels.
   b. For masonry buildings: The parapet may be made of brick masonry up to a height of 0.8 m with pipe railing at top.

9.8 Height of the Cyclone Shelter

The total height of the shelter above *high tide line* should meet the requirement of the design height of the storm surge*. The height of the structure may be worked out as follows:

1. A height of ground level of 1 m is assumed above the high-tide level.
2. Raise the plinth about 1.2- 1.5 m above the ground level.
3. Where needed, add 3.0-4.5 m high stilt up to the first floor of the building. This will take care of surge height of 5.2 to 6.7 m above the high tide.
4. Add one livable storey of 3.5 m height to the above level. This will be sufficient for most surge heights up to 8.7 to 10.2 m upto the roof of the shelter.
5. Design the roof to act as shelter space with parapet all around in case of larger storm surge in the area.

9.9 Inner Design

1. Provide bunkers with resting facility for small children, elderly/sick persons.
2. Provide storage shelf facilities in every room and verandah for accommodating the personal belongings of the occupants.
   Figures 9.1 and 9.2 show these details.

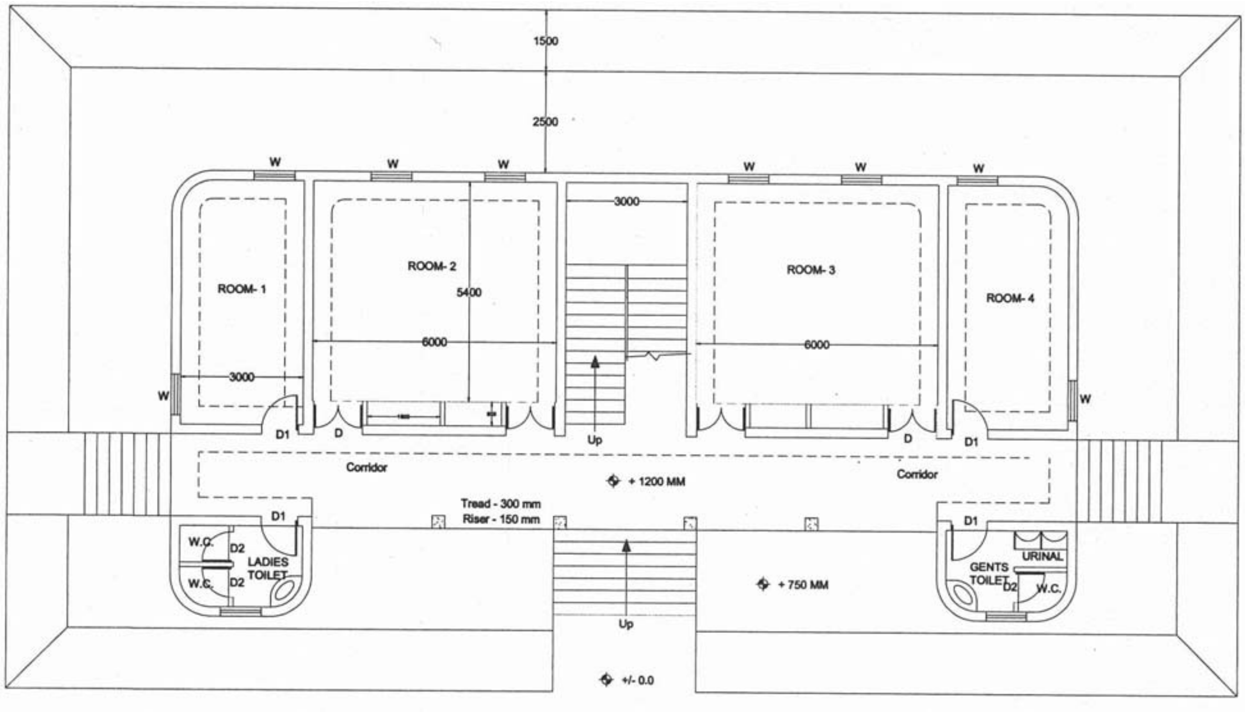


Fig. 9.1 Plan of shelter building on raised platform.

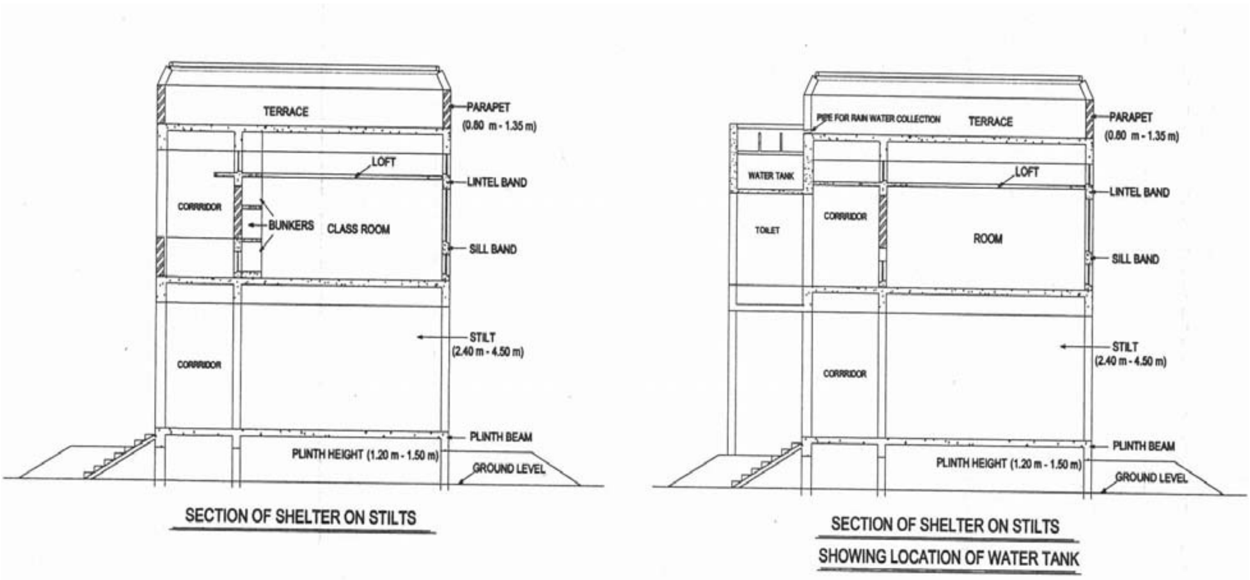


Fig. 9.2 Section of Shelter on Stilts showing location of water tanks

9.10 Structural Specifications

1. Imposed Load for design of floor slab and beams: 500 kg/ m^2.
2. *Wind velocity for East Coast of India and Gujarat coast*: Basic wind speed 65 m/sec with modification factors K1=1.08, K2=1.05, and K3=1.0 as per IS 875 – (Part III) with specified normal load factors.
3. *Wind velocity for West Coast (excepting Gujarat) and Andaman & Nicobar Islands*: Basic wind speed 50 m/sec with modification factors K1= 1.08, K2= 1.05, K3 = 1.0 as per IS 875(Part III)
4. *Roof Terrace*: Design for same imposed load as that of the first floor in case of larger than 7 m storm surge height; for lower surges, design for 250 kg/m^2.
5. Earthquake load will not be considered simultaneously with that of wind loading. EQ Importance Factor is to be taken as 1.8 for the shelter design. Rest of the norms should be followed from the relevant IS codes IS:1893 and IS:13920. The floor live load will be taken as for secondary uses (say school, community gathering etc) as per IS:875 (Part II).
6. *Vents*: Provide as per the norms for adequate ventilation. Louvered vents to be used in shelter in various walls just above floor level to drain water flowing in and out in case of higher than first floor surge height.
7. *Shelves*: Provide at door-window lintel level in line with seismic band at that level.

**The maximum surge height vary on the long sea coasts of India : West Bengal (12-12.5m), Orrisa (2.7-9.8m), Andhra Pradesh (3-6.0m), Pondicherry (3-4.5m), Tamil Nadu (2.7-7.0m, except 11m near Tondi), Kerala (2.3-3.5m), Karnataka (3.4-3.7), Goa (3.4m), Maharashtra (2.9-4.2), Daman, Diu, Dadra Nagar Haveli (5.0m), and Gujarat (2.5-5.0m).*

9.11 Staircases

1. Need to be located up to first floor level clearly and spacious enough for the movement of the people. The staircases should have a width of 1.5 to 2 m depending on shelter capacity with multi-entry possibilities.
2. Alternatively, a ramp with a slope of 1:8 to 1:10 may be considered upto the first floor for carrying physically disabled and elderly people.
3. A staircase of minimum 1.2 m width may be provided from the first floor to the terrace level.

9.12 Material Selection

1. Load bearing brick masonry structure may be adopted where no requirement of stilt. All stilted shelters should be raised on RCC frame and upper portion (first floor and above) could be constructed with load bearing brick masonry structure as an alternative to continuing the RCC framed structure.
2. Light weight pre-cast concrete blocks (aerated flyash mixed concrete or hollow concrete) can be considered as an alternative for non-load bearing filler and partition walls so as to reduce weight on foundations. When using solid bricks, rat-trap bond may be adopted to save about 25% of bricks as well as weight.

3. Corrosion resistant steel must be used as there would be considerable improvement in the service life of the structure (say TMT-HCR 500 of SAIL or TATA make).
4. Good concrete with proper cover (5 mm extra to that used for buildings in coastal areas) to corrosion resistant steel results in a durable structure. The use of blended cements is to be encouraged as it enhances the durability of the structure. All the materials should conform to the relevant IS Codes.

9.12 Water Supply

1. *Number of tanks*: Minimum two tanks should be provided to cater for drinking as well as for the toilets.
2. *Capacity for water requirements*: According to the National Building Code of India, for schools a water supply of 45 liters per day per person is required. Assuming a storage capacity of 50% of the water supply requirement, the two tanks should have an overall capacity of 4500 lts. Therefore, each tank should have a minimum capacity of 2000 lts (For each additional 500 persons or additional 100 students, the capacity of the each water tank should be increased by 1000 lts.)
3. Provision shall be made for rainwater harvesting from roof to the tanks.
4. Sedimentation-based water filters may be adapted for rainwater harvesting structures for purifying the water for drinking purposes.
5. Provide a hand-pump at the first floor level in stilt structures and at the ground floor for non-stilt structures for drawing ground water during normal use as well as emergencies.
6. Arrange cleaning of the terrace at least during the rainy and cyclonic season (April- May and Oct-Dec) such that the harvested water from roof is clean. Clean the water harvesting system (including the tank) once in a month in all seasons and adopt water purification system as found necessary.

9.13 Toilets and Sewerage

1. *Criteria for toilets*: To serve the requirements of school with 200 students, minimum 2 toilets for boys and 2 toilets for girls need to be provided. In addition 6 urinals may be provided for boys. These will also serve the needs of the shelter in emergencies. (For each additional 500 persons or additional 100 students, one additional toilet each for men and women should be provided.)
2. *Size of each toilet* should be minimum 0.836 m^2 (9 sq ft), preferably 1.12 m^2 (12 sq ft).
3. *Septic tanks:* Tanks should be properly sealed and roof sufficiently elevated so as to prevent inundation during flooding.

9.14 Other Considerations

1. Elevated approach road may be laid up to the shelter with gravel/cement top.
2. Provision for appropriate power back-up facilities such as generator/solar power cells may be made. These should be located above the design surge level.
3. Communication facilities such as wireless radios/walkie-talkies may be provided.
4. Community participated Maintenance and Management Committees may be formed for the regular maintenance of the shelter.

9.15 Provision for Helipads

Heavy cyclones often inundate large areas and situation may arise that helicopters may have to be used to access the affected areas. The terraces of cyclone shelters may be used to provide space to land helicopters as they are high rise and sturdy structures. The design parameters have to be ascertained and the cost implications worked out on the structural design of the shelter. Identify critical areas where cyclone shelters need to accommodate helipads. These areas include:

- Large stretch of low-lying areas which are difficult to reach quickly with the available means of water based transport.
- Areas with higher density of vulnerable populations with high frequency of cyclones.
- Areas with critical/strategic installations that could prove fatal when a secondary disaster is triggered due to floods and cyclones.

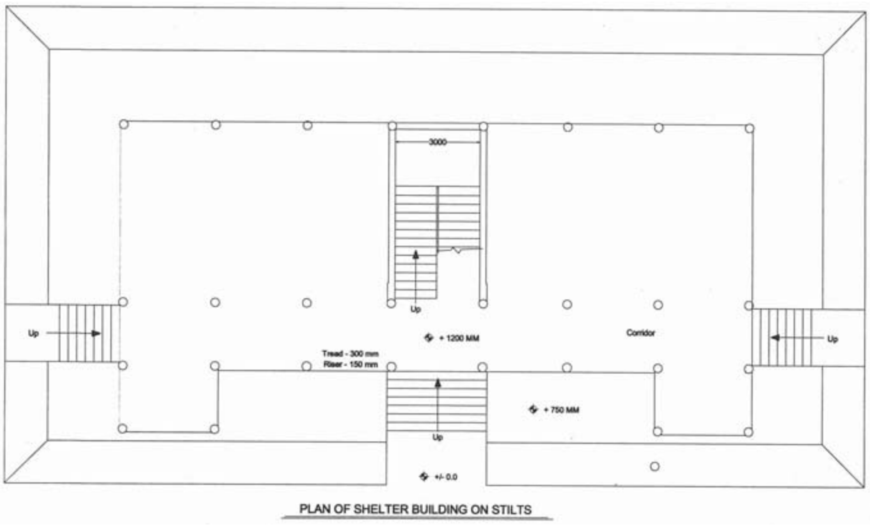


Fig. 9.3 Plan of shelter building on stilts

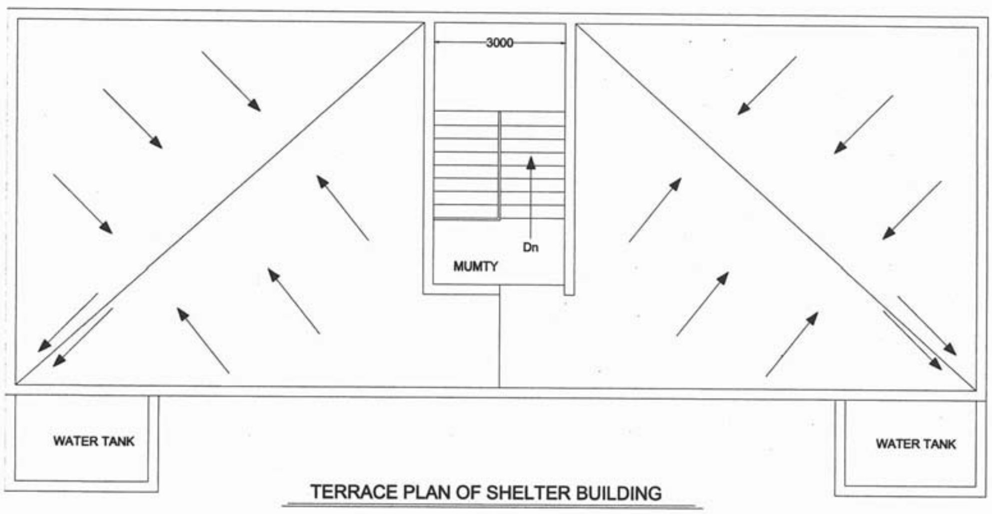


Fig. 9.4 Terrace Plan showing slopes for water water flow to tanks.

ABOUT BMTPC

Building Materials & Technology Promotion Council under the auspices of Ministry of Housing & Urban Poverty Alleviation is an autonomous organization dedicated to promote and popularize cost effective, eco-friendly and energy efficient building materials and disaster resistant construction technology. BMTPC works as a technology transfer council and helps various stake holders involved in the construction industry for technology development, production, mechanization, implementation, standardization, certification & evaluation, training & capacity building and entrepreneur development. Over the last two decades, BMTPC has expanded its activities and made commendable efforts in the area of disaster mitigation and management.

Ever since 1991 Uttarkashi earthquake, BMTPC has been pro-actively involved not only in seismic rehabilitation but also in the area of prevention, mitigation & preparedness as regards earthquake safety is concerned. The widely popularized publication of BMTPC entitled 'Vulnerability Atlas of India' is one of its kind which depicts the vulnerability of various man made constructions in different districts of India not only from earthquake hazards but also from Wind/Cyclone and Flood hazards. Efforts of BMTPC were applauded well and in the process UN Habitat selected the same as one of the Best Practices. It is being BMTPC's endeavour to constantly publish guidelines, brochures, pamphlets on natural hazards so as to educate the common man and create capacities within India to handle any disaster. BMTPC has recently published the following documents:-

1. Guidelines : Improving Earthquake Resistance of Housing
2. Guidelines : Improving Flood Resistance of Housing
3. Manual on Basics of Ductile Detailing
4. Building a Hazard Resistant House, a Common Man's Guide
5. Manual for Restoration and Retrofitting of Buildings in Uttarakhand & Himachal Pradesh.

These documents are important tools for safety against natural hazards for various stake holders involved in disaster mitigation and management. Apart from publications, the council is also involved in construction of disaster resistant model houses and retrofitting of existing life line buildings such as Schools/Hospitals to showcase different disaster resistant technologies and also spread awareness amongst artisans and professionals regarding retrofitting and disaster resistant construction.

BMTPC joined hands with Ministry of Home Affairs to draft Model Building Bye-laws incorporating disaster resistance features so that State/UT Governments incorporate them into their municipal regulations and prepare themselves against natural hazards. One of the very basic publications of BMTPC with IIT, Kanpur has been 'Earthquake Tips' which was specially designed and published to spread awareness regarding earthquake amongst citizens of India in a simple, easy to comprehend language. The tips are being published in other languages also so that there is greater advocacy and public out reach regarding earthquake safety.

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