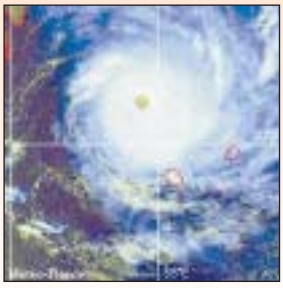
5. Safe Construction Practices

FOCUS

*A powerful earthquake measuring 6.6 at the Richter scale struck **SOUTHEASTERN IRAN** on **26th December, 2003** at **5:26:52 AM** (local time) and caused enormous loss of life, and near total destruction of physical assets, killing 30,000 people and injured another 30,000. The health and education infrastructure was severely damaged and over 85% houses collapsed.*



A super cyclone slammed the state of Orissa on October 29, 1999 with a wind speed of 270-300 kmph, accompanied by torrential rains ranging from 400 mm to 867 mm continuously for three days. Over 7 lakh buildings were completely damaged and 13 lakh buildings were partially damaged.

In Class VIII and Class IX textbooks we have studied about causes, effects and mitigation strategies of natural and manmade hazards. In this chapter we will discuss about some of the important factors to be considered to construct a building resistant to four natural hazards: **earthquake, landslide, cyclone and flood**. The cost of natural disasters to lives, property, livelihood and infrastructure have skyrocketed in last few decades, as the world's population has grown and people have started residing in areas that are vulnerable to natural hazards. The most successful way to mitigate loss of life and property, is to construct buildings that are **disaster resistant**. This chapter outlines some of the structural safety measures that need to be taken up for constructing desaster resistant buildings.

Earthquakes

On December 23, 1972, a series of earthquakes shook the Central American nation of Nicaragua. The largest earthquake registered 6.2 on the Richter scale. The earthquake's epicenter was located precisely at the capital city of Managua. The earthquake resulted in the destruction of the heavily populated central zone and damage to a total area of about 27 square kilometers (10 square miles). Subsequent fires blazed throughout the city, compounding the damages. In the wake of the disaster, at least 8,000 of Managua's total population of 430,000 had died, 20,000 were injured, over 260,000 had fled the city, 50 percent of the employed were jobless, and 70 percent were left temporarily homeless. At least 10 percent of the nation's industrial capacity, 50 percent of commercial property, and 70 percent of government facilities were rendered inoperative. Overall, the damage estimated in US dollars was $845 million.

The building has tilted as a result of column failure & has partly damaged the nearby building (Taiwan 1999). (By Bachmann H., Sesimic Conceptual Design of Buildings)

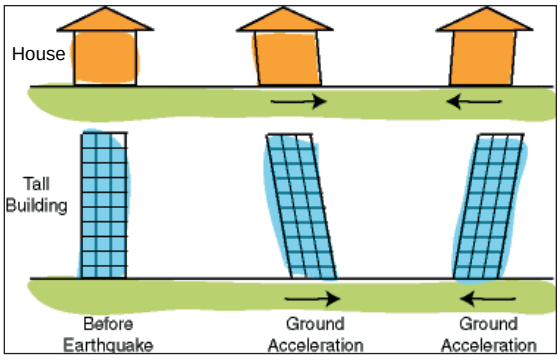
GROUND MOVEMENTS

The ground movements caused by earthquakes can have several types of damaging effects. Some of the major effects are:

1. Ground shaking, i.e. back-and-forth motion of the ground, caused by the passing vibratory waves through the ground.
2. Soil failures, such as liquefaction and landslides, caused by shaking;
3. Surface fault ruptures, such as cracks, vertical shifts, etc.
4. Tidal waves (tsunamis), i.e. large waves on the surface of bodies of water that can cause major damage to shoreline areas.

EFFECT ON BUILDINGS

As the vibrations and waves continue to move through the earth, buildings on the earth's surface are set in motion. Each building responds differently, depending on its construction. When the waves strike, the earth begins to move backward and forward along the same line. The lower part of a building on the earth's surface immediately moves with the earth. The upper portion, however, initially remains at rest; thus the building is stretched out of shape. Gradually the upper portion tries to catch up with the bottom, but as it does so, the earth moves in the other direction, causing a "whiplash" effect. The vibration can cause structural failure in the building itself,



Shaking of short and tall building due to ground acceleration

or to an adjacent building having different response characteristics.

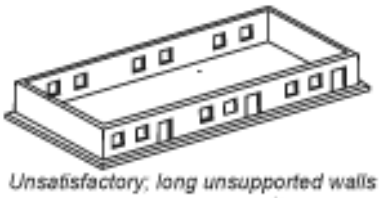
Taller buildings also tend to shake longer than short buildings, which can make them relatively more susceptible to damage.

PROTECTION MEASURES

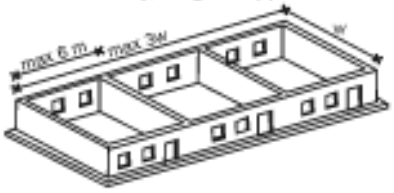
The primary objective of earthquake resistant design is to prevent collapse during earthquakes thus minimising the risk of death or injury to people in or around the buildings. There are certain features which if taken into consideration at the stage of architectural planning and structural design of buildings, their performance during earthquakes will be appreciably improved. Some of these are stated below :

Building configuration

- ★ The building should have a simple rectangular plan.
- ★ Long walls should be supported by Reinforced Concrete columns as shown on the right side.
- ★ Large buildings having plans with shapes like T, L, U and X should preferably be separated into rectangular blocks by providing gaps in between.



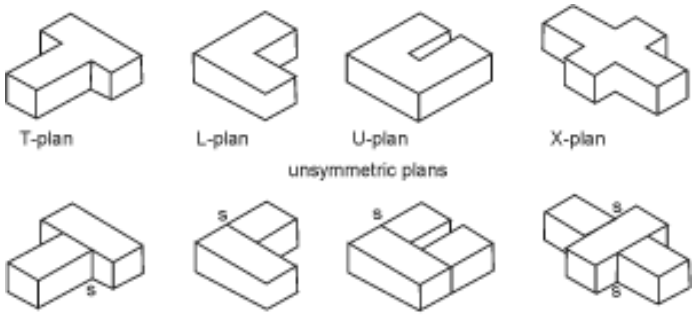
Unsatisfactory; long unsupported walls



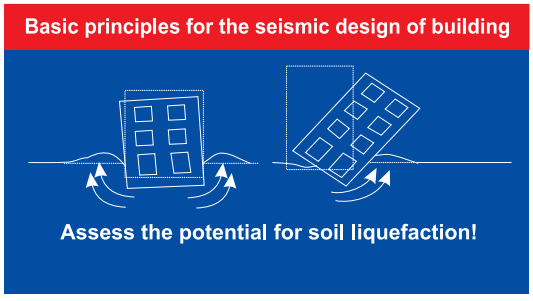
Satisfactory; cellular enclosure

Foundation

Buildings which are structurally strong to withstand earthquakes sometimes fail due to inadequate foundation design. Tilting, cracking and failure of structure may result from soil liquefaction. *Soil liquefaction refers to transformation of soil from a solid state to a liquid state as a consequence of increased* pressure.



Use of seperation gaps

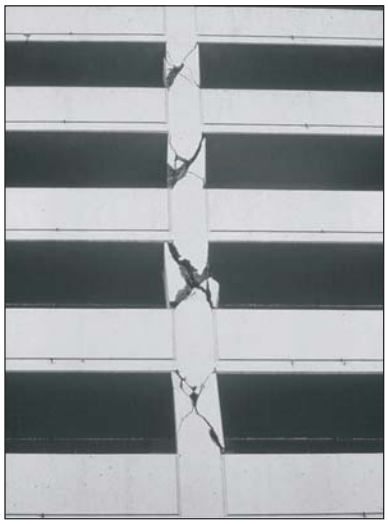


Tilting of building due to liquefaction (Adapazari, Turkey 1999)
By Bachmann H., Sesimic Conceptual Design of Buildings

Depending on the type of soil conditions the depth of the foundation has to be decided.

Control on openings in walls

Door and window openings in walls should preferably be small and more centrally located. Too many or large openings will make the wall vulnerable to collapse during earthquakes. The location of openings should not be too close to the edge of the wall.

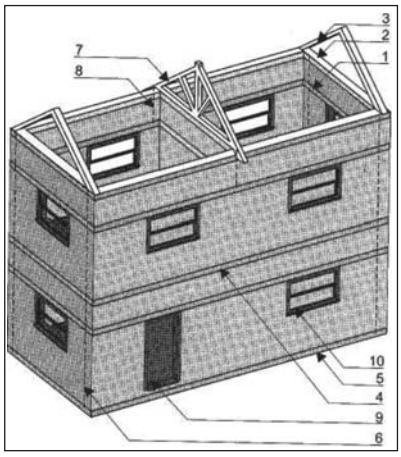


RIGHT: Damage to columns due to long openings & windows located at the edge of the column (Northridge, California 1994)

LEFT: Long window opening caused additional shear stress & column failure (Izmit, Turkey 1999) By Bachmann H., Sesimic Conceptual Design of Buildings

Reinforced concrete bands in masonry buildings

For integrating the walls of an enclosure to perform together like a rigid box reinforced concrete bands are provided which *run continuously on all external and internal walls including fixed partition walls.* One or more of the following bands may be necessary in a building. Plinth band, lintel band, roof band, and gable band are names used for the band depending on the level of the building where the band is provided.



Overall arrangement of reinforcing in masonry double storey building having pitched roof

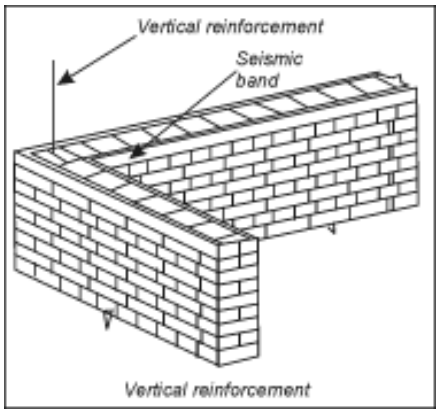
Legend

1 Lintel band
2 Eave level (Roof) band
3 Gable band
4 Floor band
5 Plinth band
6 Vertical band
7 Rafter
8 Holding Down bolt
9 Door
10 window

Vertical reinforcement

Vertical reinforcement should be provided at corners and junction of walls. It shall be passing through the lintel bands and floor slabs or floor level bands in all storeys.

Earthquake doesn't kill people. It is the badly designed buildings that kill the people. So to prevent an earthquake hazard from becoming a disaster our buildings should be properly designed incorporating the earthquake resistant design features into it.



Landslides

Landslides are among the major natural disasters or calamities in the world. In hilly terrains of India, including Himalayan mountains landslides have been a major and widely spread natural disasters that strike life and property almost perennially and occupy a position of major concern. These landslides, year after year, bring about untold misery to human settlements apart from causing devastating damages to transportation and communication network.

Landslides, debris fall, debris slide, debris flow, rock toppling etc. cause destruction of slope and ground surface, initiating the change of uncontrolled erosion in the mountain terrains.

On 21st August, 2002, heavy monsoon in eastern Nepal triggered landslides and flashfloods which killed 419 people and injuring 105 people. More than 53,152 families were affected and about 19,485 houses were destroyed. A total of 47 districts were affected.

FACTORS THAT CAUSE LANDSLIDES

Landslides occur because of the interplay of several factors.

Natural factors

- ★ Intensity of rainfall
- ★ Steep slopes
- ★ Stiffness of slopes
- ★ Highly weathered rock layers
- ★ Soil layers formed under gravity
- ★ Seismic activity
- ★ Poor drainage

Man made factors

- ★ Deforestation leading to soil erosion
- ★ Non-engineered excavation
- ★ Mining and quarrying
- ★ Non-engineered construction
- ★ Land use pattern

Normal life disrupted in the hilly terrains of Uttaranchal

Large volume of sediments, rudiments of buildings and other debris were transported by debris flows and high flood water

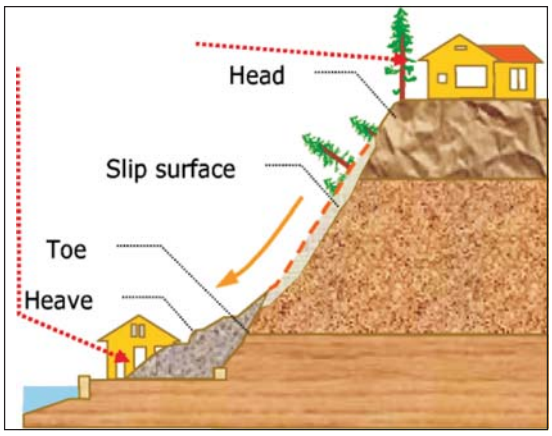
MOST VULNERABLE HOMES

Vulnerable houses are those which are situated on:

- ★ Existing landslides area.
- ★ Steep natural slopes.
- ★ Areas in or at the mouths of drainages (such as canyons).
- ★ Houses constructed near foothills.

PROTECTION MEASURES FROM DAMAGE TO BUILDINGS

Site Selection



Landslides generally happen where they have occurred in the past, and in identifiable hazard locations. Areas that are typically considered safe from landslides include areas that have not moved in the past; relatively flat areas away from sudden changes in slope; and areas at the top of or along ridges. Houses built at the toe of steep slopes are often vulnerable to slides and debri flows.

Signs and Warnings

If your house is on a hill, you can detect possible slope failure if you watch for these signs:

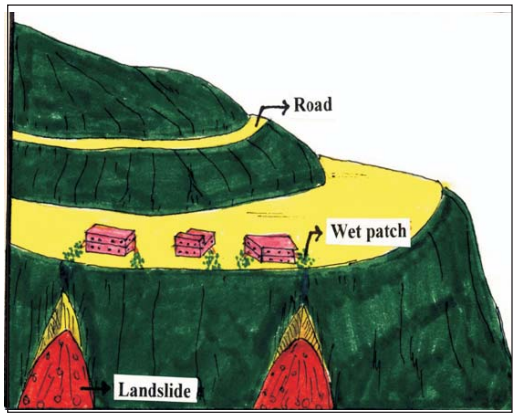
- ★ Doors or windows stick or jam for the first time.
- ★ New Cracks appear on plaster, tile, brick or foundations.
- ★ Outside walls, walks or stairs begin pulling away from the building.
- ★ Slowly developing, widening cracks appear on the ground or on paved areas such as streets or driveways.
- ★ Underground utility lines break.
- ★ Fences, retaining walls, utility poles or trees tilt or move.
- ★ Water or bulging ground appears at the base of a slope.

Take Preventive Action

The potential for landslides and destructive erosion can be greatly reduced or prevented with proper development, sound construction techniques, seasonal inspections and regular maintenance of drainage facilities.

Protect Vulnerable Areas

Keep surface drainage water away from vulnerable areas, such as steep slopes, loose soils and non-vegetated surfaces.



Collect Runoff

Collect and direct water from patios, driveways, non-vegetated surfaces, into catch basins; and confine water flow in drainpipe such as a drainage ditch, drywell, gutter, natural drainage or holding pond. Roof water may go directly to the drainpipe.

Intercept Surface Water

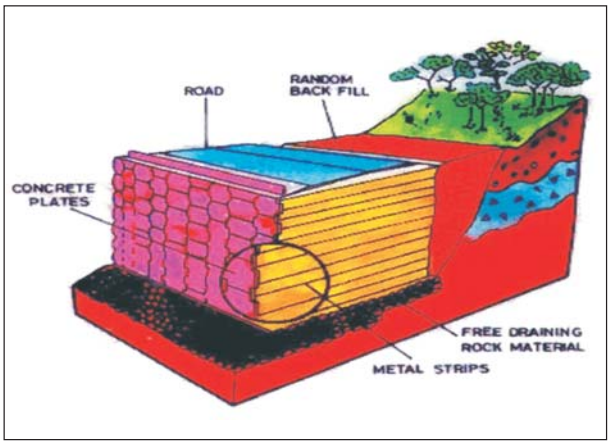
When surface water flows onto your property, and where a discharge point is available, dig a shallow, gently sloping ditch to intercept the water and direct it into a natural water course, vegetated drainage area, street pavement, or road drainage ditch. Your intercepting ditch should be nearly horizontal, with a minimum slope, sufficient to allow water to flow slowly. Smoothen the sides of the ditch and grow vegetation ; keep all ditches free of debris.

Stabilize Slopes

- ★ Improve your soil's ability to resist erosion by stabilizing slopes by increasing vegetation and trees.
- ★ Straw, woodchips, or bark applied to a depth of at least one inch are effective in holding soil in place on slopes.

BARRIERS

Property owners at the toe of steep slopes may be able, in some situations, to create barriers or catchments that trap smaller landslides. Such structures must be designed to withstand the volumes and velocities of material in any potential slide. In addition, designs must allow removal of trapped material. Barriers may consist of reinforced walls on the side of a building facing the slope.



Floods

Bangladesh is a riverine country where recurrent flooding is both common and necessary. Every year large areas are submerged during the monsoon season and fertilized by deposits of fresh alluvium, i.e., the soil deposited by moving water. However, if the waters remain stagnant for too long, these beneficial floods become major disasters. Such was the case in the summer and fall of 1974 when flooding extended over nearly one-half of the country and stagnated for more than a month. At least 1,200 people died in the floods and another 27,500 died from subsequent disease and starvation. Approximately 425,000 houses were destroyed or severely damaged. A total of 36 million people suffered severe hardship and losses due to the disaster.

Water is a source for all life forms. Without water no life is sustainable. How tragic it is, when water in the form of floods takes away thousand of human and cattle lives. More than one million huts and poor houses are lost every year in floods in India. Can we prevent this loss?

MOST VULNERABLE HOMES

1. Buildings, which are constructed with earth-based materials or using stone and brick in mud mortar are highly vulnerable to damage in heavy rains and/or floods.
2. The huts made from biomass materials like bamboo, leaves, thatch or light construction using metal sheets are easily destroyed in floods and washed away.
3. The occupation of areas within the flood plain of rivers has increased the vulnerability, especially in areas of high population concentration. Flood plains attract poor people because of inexpensive land values.

EFFECT ON BUILDINGS

The damage to buildings due to floods are as follows:

Flood disrupting normal life

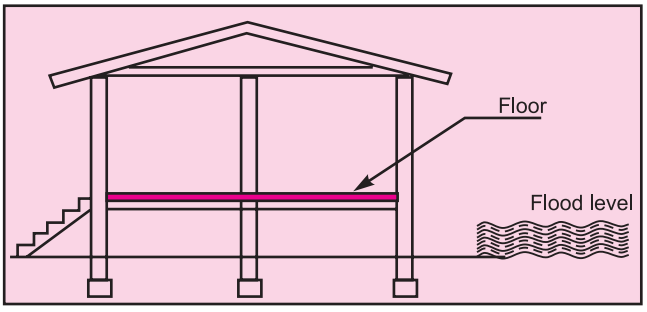
1) Houses are washed away due to the impact of the water under high stream velocity. The houses are commonly destroyed or dislocated so severely that their reconstruction is not feasible.
2) Houses constructed out of light weight materials like wood float when they are not anchored properly.
3) Damage caused by inundation of house. The house may remain intact on its foundation, but damage to materials may be severe. Repair is often feasible but may require special procedures to dry out properly.
4) Undercutting of houses. The velocity of the water may scour and erode the foundation of the house or the earth under the foundation. This may result in the collapse of the house or require substantial repair.
5) Damage caused by debris. Massive floating objects like trees, electric poles, etc. may damage the standing houses.

Roof tops being used as shelter places during floods

PROTECTION MEASURES FROM DAMAGE TO BUILDINGS

The most effective measures for prevention against inundation are:

1. to avoid residing on river banks and slopes on river sides and the sides of gorges.
2. to build at least 250 meters away from the sea coast/river banks
3. to build proper drainage system in all flood prone areas, so that the water can be drained off quickly to prevent accumulation.
4. to construct the building with a plinth level higher than the known high flood level.
5. to construct the whole village *or* settlement on a raised platform higher than the high flood level.
6. to construct buildings on stilts or columns with wall-free space at ground level permitting free flow of water (inundation or flowing), provided that columns are circular and strong. In dry weather condition the ground area could be fenced and used for cattle, sheep poultry farming, or storage etc.



Use of stilts for raised floor above flood level

Not only do we contribute to the causes of floods, but reckless building in vulnerable areas, poor watershed management, and failure to control the flooding also help create the disaster condition. Therefore there is an urgent need to mitigate the flood hazard by proper habitat management, watershed management and incorporating flood resistant features in our buildings.

Cyclones

Cyclones pose a major threat to life and property in many parts of the world. Every year these sudden, violent cyclones bring widespread devastation to coastlines and islands lying in their erratic paths. A windstorm's destructive work is done by the high wind; flood producing rains and associated storm surges.

On November 19, 1977, a cyclone, which had been expected to hit Tamil Nadu, instead struck the central coast of Andhra Pradesh State in the Krishna Godavari Delta. Many people perished because advance warning was either too slowly or too narrowly disseminated. Damage in Andhra Pradesh was caused primarily by a storm surge that devastated some 65 villages, about 21 of which were completely washed away. The storm surge was reported to have been 5.7 meters (19 feet) high, 80 kilometers (50 miles) long, 16 kilometers (10 miles) wide, with a speed of 190 kilometers per hour (120 miles per hour). Many of the victims of the Andhra Pradesh cyclone were migrant laborers. This made identification of the dead difficult.

Pictures showing the effect of cyclone on structures

MOST VULNERABLE HOMES

The vulnerability of a human settlement to a cyclone is determined by its location, the probability that a cyclone will occur, and the degree to which its structures can be damaged by it. Buildings are considered vulnerable if they cannot withstand the forces of high winds and storm surge. Generally those most vulnerable to cyclones are lightweight structures with wooden frames, especially older buildings where wood has deteriorated and weakened the walls. Houses made of poorly constructed concrete blocks are also vulnerable.

Urban and rural communities on low islands or in unprotected low-lying coastal areas or river floodplains are considered vulnerable to cyclones. Furthermore, the degree of exposure of land and buildings will be affected by the velocity of the cyclone wind at ground level.

EFFECTS ON BUILDINGS

As a consequence of the storm surge and high wind speed following types of damage are commonly seen :

- ★ Uprooting of trees which disrupt transportation and relief supply missions.
- ★ Damage to signposts, electric poles and transmission line towers.
- ★ Damage to improperly attached windows or window frames.
- ★ Damage to roof/lintel projections.
- ★ Failure of improperly attached or constructed parapets.
- ★ Overturning failures of compound walls of various types.
- ★ Failure of roofing elements and walls along the gable ends particularly due to high internal pressures.
- ★ Failure of large industrial buildings with lightweight roof coverings and long/tall walls due to combination of internal & external pressures.
- ★ Brittle failure of asbestos.
- ★ Punching and blowing off of corrugated iron roofing sheets attached to steel trusses

PROTECTION MEASURES FOR DAMAGE TO BUILDINGS

1. Site selection

Cyclonic windstorms 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 to avoid flooding/inundation.

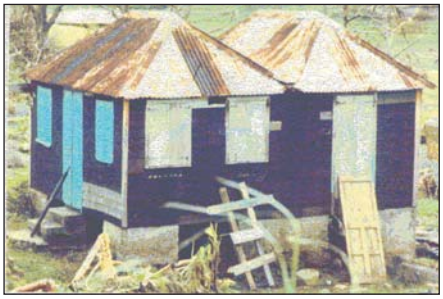


Fig 1. ***If natural elevation is not available construction on stilts or on artificially raised earth mounds***

2. Platforms and Orientation

(a) For individual buildings, a circular or polygonal plan shape is preferred over rectangular or square plans.

(b) A symmetrical building with a compact plan-form is more stable than an asymmetrical building with a zig-zag plan, having empty pockets as the latter is more prone to wind/cyclone related damage.

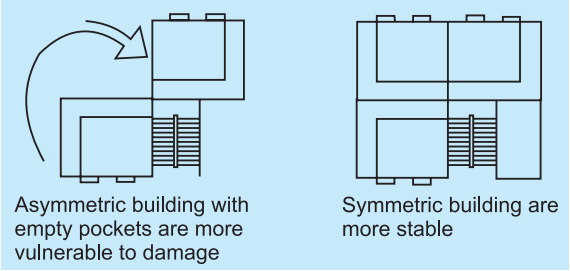


Fig. 2 Desirable orientation & plan form for reducing wind damage.

3. Foundations

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

(a) *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 even upto 10 to 15 km.

(b) *Building on Stilts:* Where building is constructed on stilts, it is necessary that stilts are properly braced on both the directions.

4. Wall Openings

(a) Openings just below roof level are avoided except that two small vents without shutters are provided in opposite walls to prevent suffocation in case room gets filled with water if people try to climb up on lofts.

(b) Doors and windows should have strong closing/ locking arrangements and glass/wooden panels be securely fixed.

5. Glass Panelling

(a) One of the most damaging effects is the extensive breakage of glass panes caused by high wind pressure or impact of flying objects in air. The large size door or window glass panes may shatter because they are too thin to resist the wind pressures.

(b) Reduce the panel size to smaller dimensions. Pasting thin plastic film or paper strips can strengthen Glass panes.

(c) Provide a metallic fabric/mesh outside the panels.

(d) Provide proper locking arrangement of shutters. Securely fix the frames to walls.

6. Roof Architecture

(a) The overall effect of wind on a pitched roof building and the critical locations are shown in figures. Therefore, the roof projections should be kept minimum, say not exceeding 500 mm, or else, are tied down adequately.

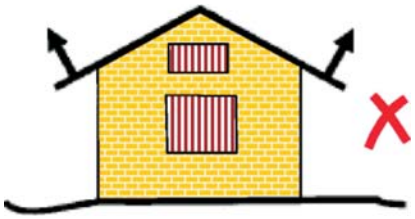


Fig. 4 LEFT: Large overhangs get lifted and broken

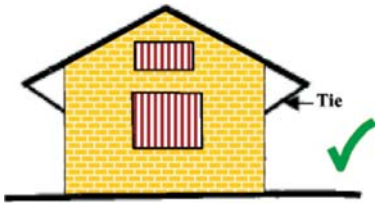


Fig. 5 RIGHT: Avoid large overhangs and use ties

(b) For the purpose of reducing wind forces on the roof, a hipped or pyramidal roof is preferable to the gable type roof as shown in figure 6.

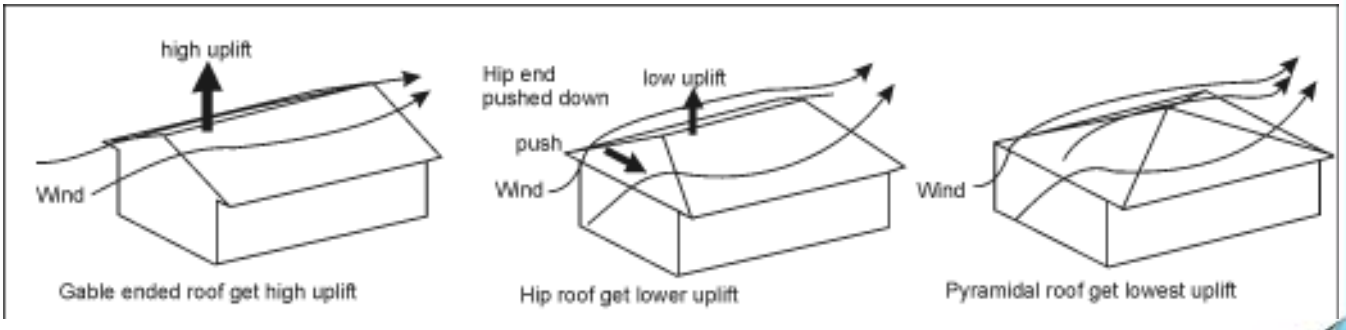


Fig. 6 ***Effects of roof architecture on uplift force***

The damage due to cyclones can be minimised by adopting the technologies and procedures mentioned above. It is advisable to have shelterbelts plantation across the wind direction, in coastal areas and in all large establishments to check the wind speed and reduce damage.

A shelter with special feature to withstand cyclones and floods. Traditional homes can be improved by building in disaster resistant features. Such homes could withstand cyclones with moderate speeds.

Reference for further reading:

- http://www.bte.gov.au/docs/r103/chapter1.htm
- http://gujarat-earthquake.gov.in/
- http://www.benfieldhrc.org/SiteRoot/activities/misc_papers/DEVRISK/BENSON.HTM
- http://www.adrc.or.jp/countryreport/IND/INDeng02/India07.htm
- http://eqseis.geosc.psu.edu/~cammon/HTML/Classes/IntroQuakes/Notes/earthquake_effects.html
- Guidelines For Improving Earthquake Resistance Of Housing – BMTPC
- Guidelines For Improving Flood Resistance Of Housing – BMTPC
- Guidelines For Improving Wind/Cyclone Resistance Of Housing – BMTPC
- http://quake.ualr.edu/HazardMitigation/claymitg-plan/Landslides.htm

Exercise

1. What should be the configuration of an earthquake resistant building?
2. How should the foundation be constructed in soft and firm soil?
3. Which are the most vulnerable homes due to flood?
4. What are the general protection measures for buildings against flood damage?
5. What are the considerations for selecting the site in area prone to landslides?
6. Write about the slope stabilization methods by drainage?
7. What are the desirable plan forms and orientations for cyclone resistant buildings?
8. What kind of roof designs should be used in cyclone prone areas and why?