Virtual Classroom Training Module

Cyclone Resistant Architecture

GUJARAT INSTITUTE OF DISASTER MANAGEMENT

BUILDING RESILIENCE

Message

The 2019 Very Severe Cyclonic Storm Vayu was the strongest tropical cyclone to affect the Saurashtra Peninsula of northwestern India since the 1998 cyclone. Despite not making landfall, it still caused destruction and damage to numerous buildings and structures. Many residential buildings had their roofs torn off and a large number of tin sheds were blown away. Strong wind caused the 150-year-old Bhuteshwar Mahadev temple in Porbandar to collapse and a metal shed at Somnath Temple was damaged. On the eastern front, Extremely Severe Cyclonic Storm Fani ravaged housing sector, damaging approximately 3.62 lakh units of residential dwellings during its traverse through coastal regions of Orissa.

High speed cyclonic winds teardowns the buildings which deter the wind flow and cannot bear its resulting effects leading to substantial structural losses. In order to prevent such depredation by nature it is essential to involve engineering intervention in buildings and structures to make them strong enough to withstand such natural furies.

Priority 3 of Sendai Framework 2015-30 lays importance on investing in DRR. This implies that appropriate resources need to be utilised in application of multi-hazard safety norms, including cyclone-resistant features being incorporated in planning and retrofitting of buildings. Recovery process in aftermath of a cyclonic catastrophe should synergise with Priority 4 of building back better and so the reconstruction activities should be utilised as an opportunity to incrementally replace all the prone buildings with safer structures to reduce the human and economic costs in a recurrent cyclonic interposition.

In order to address the mentioned issues GIDM has come up with Virtual Classroom Training Module on 'Cyclone Resistant Architecture' and in this regard, I appreciate the efforts of Ankur Srivastava and Prashansa Dixit for the compilation of the literature. I hope this module will benefit anyone who is interested to learn architectural techniques and methodologies to be used as a proactive measure for cyclone risk mitigation. I am sure trainings delivered using this module will complement our effort in creating a culture of disaster resilience, which in turn would lead to a disaster resilient India.

July, 2020 **P.K. Taneja**

Gandhinagar **(Director General)**

Introduction to the Module

The Virtual Classroom Training Module on Cyclone Resistant Architecture has been developed for trainers to educate the relevant participants about the architectural techniques & methodologies to stand against the wrath caused by cyclonic hazards. The module has been designed in an interesting way to avoid the use of complex scientific/ technical nomenclature. The module is divided into two sessions. First session will explain about the cyclonic activities prevalent in Arabian Sea. Any such activity is a potential threat to coastal regions of Gujarat state. The session also intends to explain hazards associated with cyclones. Knowledge of cyclonic hazards is necessary to plan appropriate architectural mitigation strategies to curb their ill effects. The second session deals with all relevant aspects of cyclone resistant architecture. This session will list out the different genre of damages caused by cyclones and relevant architectural consideration to check them.

The objective of the module is to enrich cyclone risk mitigation framework in the country. This module aims to empower a common man to take appropriate decisions while undertaking construction related commitments in cyclone vulnerable regions. Thus, in a way, the module aims to inculcate a culture of resilience.

Doing what is being taught is perhaps the best way to ensure that knowledge is retained and this forms the guiding principle of this training module. The module has been developed by the Gujarat Institute of Disaster Management (GIDM) with inputs from professionals working in this sector and by referring to several research articles.

Who shall use the Training Module?

The module has been developed in such a way that any interested individual will be able decipher the crux of the literature with relative ease. But the participants with prior knowledge of architectural complexities due to cyclonic events will find the content of the module more relatable. The module can also be used for self-study.

How to use the Training Module?

The module has two sessions which need to be read in sequence of appearance one after another for efficient understanding. As mentioned earlier, first session will explain about the cyclonic activities prevalent in Arabian Sea and hazards associated with cyclones. The second session deals with all aspects of cyclone resistant architecture.

What is mode of delivering the training?

This module is developed for delivering training through a virtual telecommunication interface. It will be like a webinar where an event held on the internet which is attended exclusively by an online audience. The trainer and participants will deal with each other remotely. Since it will be a ‘many to one’ connection, the participants should ask question and queries only when the training is completed. Trainer must allot time for Q/A and individual interaction.

Duration of Virtual Classroom Training

The virtual session is expected to be 2 hours long.

Contents

Content Design

#	Session Title	Time
1.	Introduction & About GIDM	10 min
2.	Cyclonic Activity in Arabian Sea and Hazards associated with Cyclones	30 min
3.	Aspects of Cyclone Resistant Architecture	60 min
4.	Q/A and Closing	10 min

Prologue

Reducing local vulnerability is the main and still unattended challenge that can make a difference in the immediate aftermath of a disaster, but also beforehand by preventing damage. This challenge has grown critical due to increasing climate change, natural and man-made disasters, together with rapid urbanization. These factors are also associated with the transformation of peripheral areas around cities worldwide, often with very poor construction quality.

Undertaking necessary structural measures is one of the relevant areas for DRR and enhancing resilience. These consist of various physical infrastructure and facilities required to help communities cope with disasters. The implementation of these measures is essential to enhance disaster preparedness, a component of Priority-4 of the Sendai Framework. It is also an important component of investing in disaster risk reduction for resilience, which is Priority-3 of Sendai Framework.

Disasters have demonstrated that the recovery, rehabilitation and reconstruction phase, which needs to be prepared ahead of a disaster, is a critical opportunity to "Build Back Better", including through integrating disaster risk reduction into development measures, making nations and communities resilient to disasters.

Virtual Session 1: Cyclonic Activity in Arabian Sea & Associated Hazards

Need of the session

The session elucidates about the cyclonic activities prevalent in Arabian Sea. Any such activity is a potential threat to coastal regions of Gujarat state. The session also intends to explain hazards associated with cyclones. Knowledge of cyclonic hazards is necessary to plan appropriate architectural mitigation strategies to curb its negative effects.

Objectives of the session

The primary objectives of this session would be to:

- To get an idea of cyclonic activity in Arabian Sea.
- To understand hazards associated with cyclones.

Duration

The expected duration of this session is 30 minutes.

Rationale

1.1 Cyclonic Activity in Arabian sea

Over the last few years, unusual activity in the Arabian Sea is being observed. The oceanic basin to the west of the Indian sub-continent which usually sees low-intensity cyclonic activity has suddenly turned into a hotspot of sorts, churning out severe cyclonic storms one after the other. Not only there is growing formation of cyclones in the Arabian Sea, these storms have also been increasingly severe in intensity. The cyclone pattern from the last few years suggest that the Arabian Sea also started receiving tropical cyclones of high intensity in a small time interval. For instance, in 15 years (1998 to 2013), five extremely severe cyclones originated in the Sea. Six cyclonic activities were observed in Arabian sea out of which four cyclones were of intensity VSCS and above – VSCS Vayu, VSCS Hikaa, SuCS Kyarr and ESCS Maha. While Vayu, Hikaa and Kyarr did not make landfall in India, the western coast from Kerala to Gujarat witnessed heavy rains and strong winds, affecting normal life in several areas. Officials of the India Meteorological Department (IMD) as well as climate experts are expecting more tropical cyclonic activity from the NIO in coming years. It is crucial to understand the growing cyclone activity in the region.

It is believed that among other factors, the ongoing climate emergency could be the reason for this abnormal activity in the Arabian Sea which is presumed to certainly aggravate the intensity as well as frequency of occurrence of cyclonic storms in the region. It believed that same pattern will prevail in coming future which would render Gujarat state increasingly prone to cyclonic risks.

1.2 Cyclone Hazards

The calamitous prospect of cyclone is explained by damage it unleashes on the life and life-line infrastructures during its course. A cyclonic storm is accompanied by multiple hazards resulting serious situations and enormous loss of life and property. Types of damage relevant to a tropical cyclone are flooding of coastal areas, erosion of beaches, loss of soil fertility, damage to structures, loss of power and communication, potential injuries and causalities, destruction of crops, vegetation and livestock, contamination of water supply system, land subsidence and flooding of inland area. Hazards which causes the mentioned damages are violent wind, storm surge and rain. These factors are analysed and explicated as follows:

Destructive winds

High speed winds damage residential buildings, power houses, communication towers, infirmaries, ration warehouses, bridges, conduits and vegetation owing to their violent velocities. The damage extent due to wind covers larger area than rainfall and storm surge. The impact of the passage of the cyclone eye, directly over a place is quite different from that of a cyclone that does not hit the place directly. The region lying in course of the eye passage experience frequent changes in wind direction that results in torque imposition. The torque developed can twist the building structures leading to basement failure. It causes uprooting of vegetation cover. Rest of the region bears unidirectional winds due to which leeward side is somewhat protected from action of direct winds. Violent winds also result in roof failures where roofing systems are revealed to sturdy lifting forces as shown in first snapshot of the video. Absence of roofing structure further leads to damage of walls either due to percolation of water or owing to lack of support mechanism which was initially provided by the roofing systems. It is observed that wind with speed of 44 m/s disrupts telephone lines connection and causes misalignment of microwave towers. This affects local telephone and cellular services. Wind speed more than 52 m/s demolishes microwave and radio towers including large antennas and satellite communication dishes. Winds hinders rescue and logistics attempts as roadways are blocked with uprooted trees, power poles and lines, and debris falling on roads and blocking them.

Rainfall

Cyclonic Rainfall are widespread and generally very heavy, which results in release of excessive proportions of water within very minute span of time leading to flood like situations. It has been observed that it can rain more than 300 mm in 24 hours during cyclones. Rains are worst nemesis for victims who became homeless in initial cyclonic activity and for the people involved in the rescue and relief operations. Rainfall disrupts and damages the life line infrastructures like water distribution, rail road connectivity and flood induced wrecks power transmission grids and communication systems. Rainfall induces widespread soil erosion as the water percolates down which causes it’s softening and thereby making it vulnerable to withering. This adds to fragility of embankments and similar structure.

Storm surge

Storm surge is the major cause of devastation from tropical storms. Though, the deaths and destruction are caused directly by the winds in a tropical cyclone as mentioned above, these winds also lead to massive piling of Sea water in the form of what is known as storm surge that lead to sudden inundation and flooding of coastal regions. The surge is generated due to interaction of air, sea and land. When the cyclone approaches near the coast, it provides the additional force in the form of very high horizontal atmospheric pressure gradient which leads to strong surface winds. As a result, sea level rises. It continues to rise, as the cyclone moves over shallower waters and reaches a maximum on the coast near the point of landfall.

Virtual Session 2: Aspects of Cyclone Resistant Architecture

Need of the session

The second session deals with all relevant aspects of cyclone resistant architecture. This session will list out the different genre of damages caused by cyclones and relevant architectural consideration to check them.

Objectives of the session

The primary objectives of this session would be to:

- to briefly explain the action of cyclonic wind on buildings;
- to state the general principles of planning and design;
- to suggest retrofitting considerations which could be adopted in existing buildings to minimise the damages under high winds and safety against storm surge.

Duration

The expected duration of this session is 60 minutes.

Rationale

Cyclones occurrence is a natural phenomenon on which man has no control. All that can be done is to construct buildings and structures that tend to let the winds pass with minimum obstruction and be able to resist wind pressures and suction effects without damage. During a cyclonic event, winds moving swiftly around and over the building lowers the pressure outside thus creating pressure difference. Lower pressure on the outside creates suction on the walls and roof, effectively blowing up the building.

For a building to be able to resist the effects of wind is not much dependent upon the materials that are used but on the manner in which they are used. It is a common belief that buildings made of heavy materials such as concrete block, are safer. While it is true that a well-built and properly-engineered masonry house offers a better margin of safety than other types of buildings, safe housing can be and has been provided by a variety of other materials including wood and many others.

2.1 Damages during cyclone

As a consequence of the wind pressures/suctions acting on elements obstructing the passage of wind the varied types of damage are commonly seen to occur during high wind speed. Some of them are mentioned below:

1. failures in many cantilever structures such as sign posts, electric poles etc.;
2. damage to improperly attached windows or window frames;
3. damage to roof projections, chajjas and sunshades,
4. failure of improperly attached or constructed parapets,
5. overturning failures of compound walls of various types;
6. failure of weakly built walls and consequent failure of roofs and roof covering;
7. failure of roofing elements and walls along the gable ends due to internal pressures;
8. failure of large industrial buildings with light weight roof coverings and long/tall walls;
9. brittle failure of asbestos - cement (AC) sheeting of the roofs of industrial sheds;
10. punching and blowing off of corrugated iron roofing sheets attached to steel trusses;
11. blowing off of cosmetic facade treatments done with aluminium composite panels and high pressure laminates (very common in contemporary context).

2.2 Catastrophic Failures

- ***Foundations:*** Cyclonic winds can pull off the buildings from the ground due to uplifting forces. The lighter the building the larger (or heavier) the foundation needs to be in cyclone resistant design. Ignoring this precept has led to some dramatic failure of long-span, steel-framed warehouses.

Foundation of a steel framed light weight structure completely pulled out of ground

- ***Steel Frames:*** Failure due to weakness in the connections of steel frames. Economizing on minor items (bolts) leads to the overall failure of the major items (columns, beams and rafters)
- ***Timber Houses:*** Safe construction of the timber houses depends on the connection details. Light-weight timber houses coupled with weak connections are vulnerable to high speed winds.
- ***Masonry Houses:*** These are usually regarded as being safe in cyclones. Usually the loss of roofs has triggers the total destruction of un-reinforced masonry walls.
- ***Reinforced Concrete Frames:*** The framework is often design to resist seismic forces. If seismic hazard is not an issue, then it should be ensured that concrete frames can accommodate wind forces.

2.3 Building Component Failures

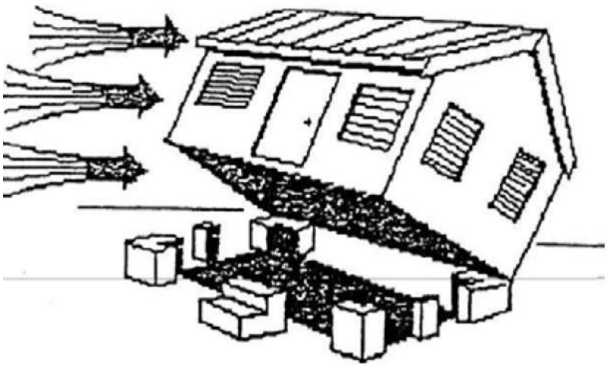
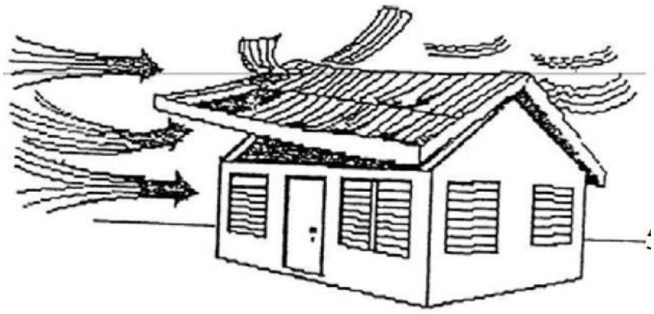
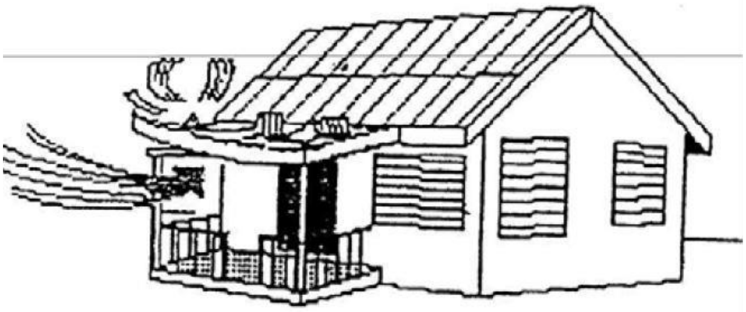
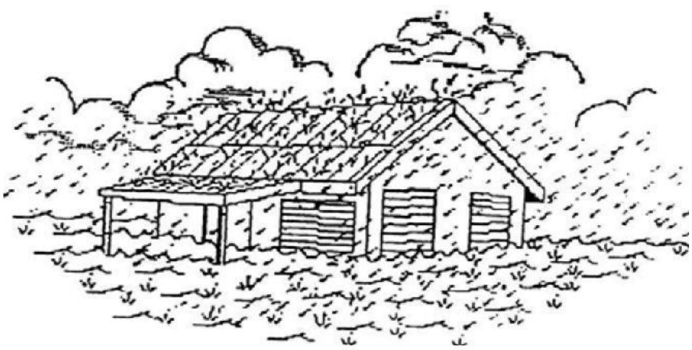
Roof Sheeting: It is the common component that fails in a cyclone. Causes being inadequate fastening devices, inadequate sheet thickness and insufficient frequencies of fasteners in the known areas of greater wind suction.

Loss of roof sheeting of Kalinga stadium in Odisha during Cyclone Fani

Windows and Doors: After roof sheeting, these are the components most frequently damaged in cyclones. Vulnerable areas are glass panes, latches, bolts and hinges.

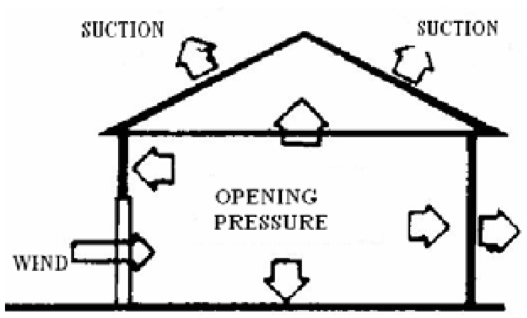
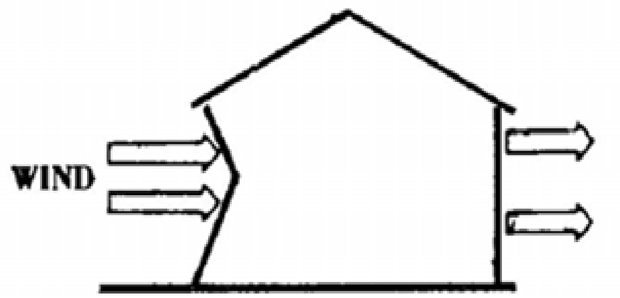
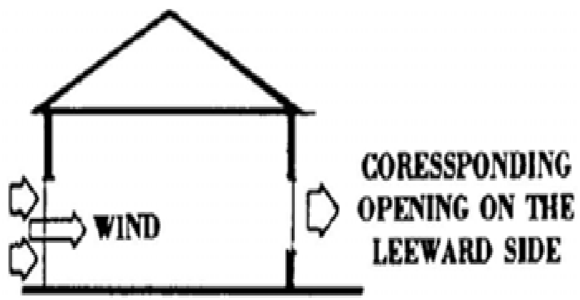
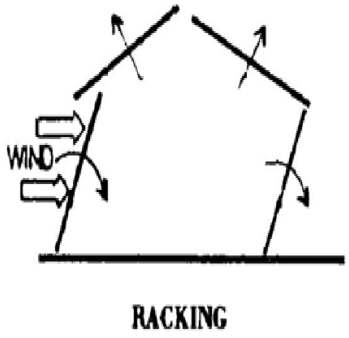
Walls: It is not uncommon for un-reinforced masonry to fail in severe cyclones. Cantilevered parapets are most at risk.

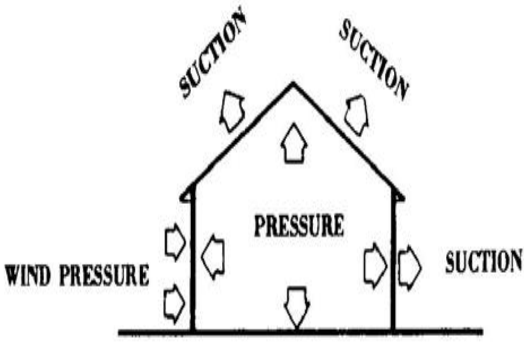
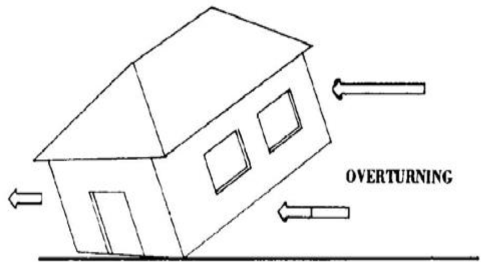
2.4 Damaging effect of cyclones on houses

Due to the high wind pressure and improper connection of the house to the footings, it can be blown away.	
Roofing materials not anchored can be blown away.	
Light weight verandah roofs are more susceptible to damage due to high wind speed.	
When cyclones are accompanied with heavy rain for a long duration, the buildings can be damaged due to flooding also. Building contents are spoiled due to rain when roofing sheets fly away.	

2.5 Design Wind Speed

General basic wind speed being 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. Given below are some typical effects of openings in the walls from the attack of winds as well as the pressure on each of the building components:

Wind generating opening on the windward side during a cyclone will increase the pressure on the internal surfaces. This pressure, in combination with the external suction, may be sufficient to cause the roof to blow off and the walls to explode.	
Another mode of failure occurs when the windward side of the house collapses under the pressure of the wind.	
During a cyclone an opening may suddenly occur on the windward side of the house. The internal pressure which builds up as a result may be relieved by providing a corresponding opening on the leeward side.	
If the building is not securely tied to its foundations, and the walls cannot resist push/pull forces the house tends to collapse starting the roof with the building leaning in the direction of the wind.	

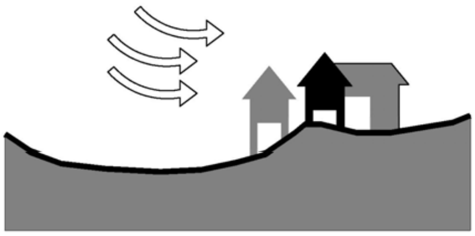
Wind forces on the walls of the house may produce failure. Wind striking a building produces pressure which pushes against the building, on the windward side, and suction which pulls the building on the leeward side and the roof. If no air enters the building, then there is pressure inside which is pushing against the walls and the roof.	
Overturning is another problem for light structures. This occurs when the weight of the house is insufficient to resist the tendency the house to be blown over.	

2.6 Site Considerations for building a house

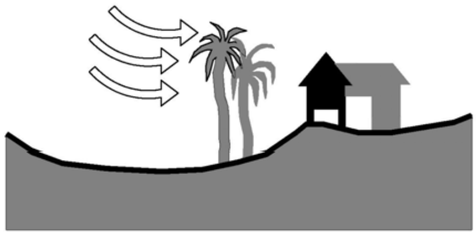
i. Though cyclonic storms always approach from the direction of the sea towards the coast, the wind velocity and direction relative to a building remain random due to the rotating motion of the high velocity winds. In non-cyclonic region where the predominant strong wind direction is well established, the area behind a mound or a hillock should be preferred to provide for natural shielding. This can also be done by creating an earthen mound intentionally.

Shielding of house by hillock

Similarly, a row of trees planted against the direction of the wind will act as a shield. The influence of such a shield will be over a limited distance, only for 8 – 10 times the height of the trees. A tree broken close to the house may damage the house also hence distance of tree from the house may be kept 1.5 times the height of the tree.



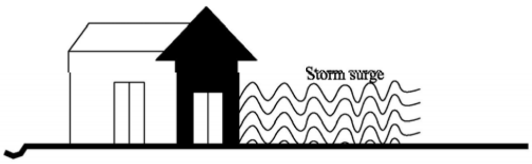
No shielding from high wind due to absence of barriers



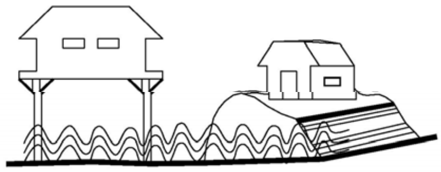
Shielding from high wind by permeable barriers such as strong trees

ii. In hilly regions, construction along ridges should be avoided since they experience an accentuation of wind velocity whereas valley experiences lower speeds in general. Though sometimes in long narrow valleys wind may gain high speed along valley. Planning should be done along the contours and not across them. Also the slope of the roof should match the slope of hills so as to minimize the impact of high wind pressures.

iii. In cyclonic regions close to the coast, a site above the likely inundation level should be chosen. In case high level natural ground is not available, construction should be done on stilts or on raised earthen mounds.



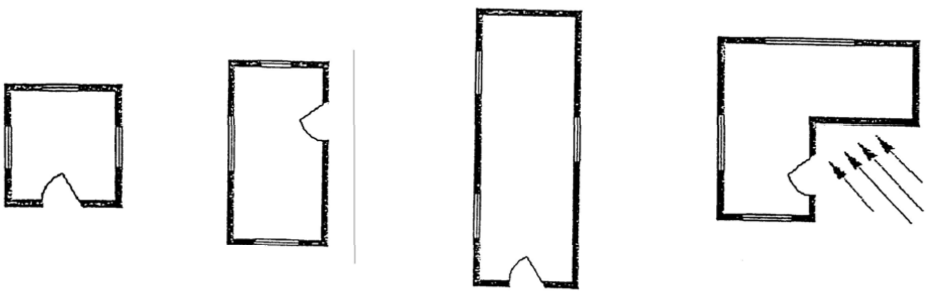
Construction at ground level risk of inundation



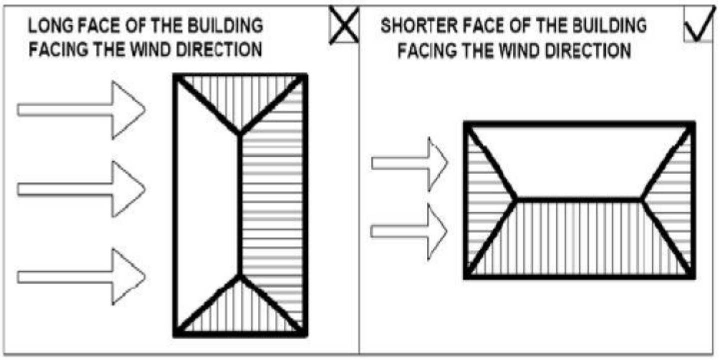
Construction on stilts or artificially raised earth mounds

2.7 House Design Consideration

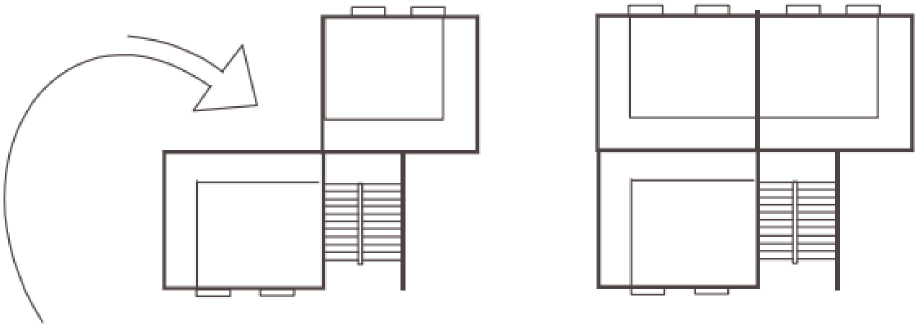
- Simple, compact, symmetrical shapes are best.
- The best shape to resist high winds is a square. Also, round or circular building shape can be considered to be the best shape. Buildings can be constructed with round facades instead of plain facades on windward direction to minimize the impact.
- Most houses are rectangular, better than L-shaped, and the best layout is when the length is not more than three times the width.
- If other shapes are desired, efforts should be made to strengthen the corners



Square (Best) Rectangle Long Rectangle L-Shape



- Reentrant corners are to be avoided. Symmetrical building with compact plan is better than an asymmetrical building with zig-zag plan, having empty pockets as the latter is more prone to wind related damage.



Asymmetric building with empty pockets are more vulnerable to damage

Symmetric buildings are more stable

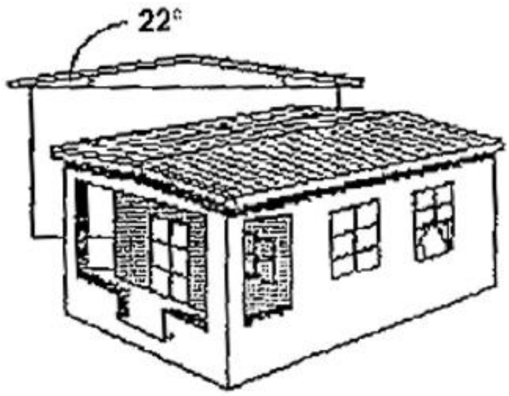
- In case of construction of group of buildings, a cluster arrangement can be followed in preference to row type.

Row planning creates wind

Zig-zag planning avoids wind

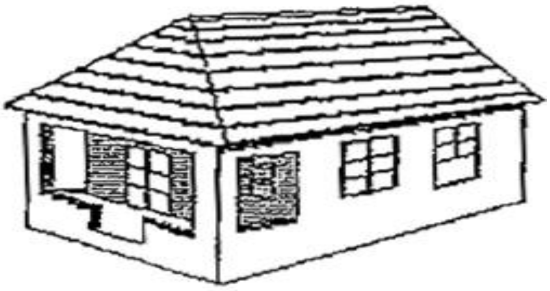
2.8 Roof Considerations

- The roof pitch should not be less than 22º. This will also facilitate quick drainage of storm water. Lightweight flat roofs are easily blown off in high winds.



Flat Roof

- Hip roofs are best as they have been found to be more cyclone resistant than gable roofs. Experience and experiment have shown that the hip roof with the pitch in 25° to 40° range has best record of wind resistance.

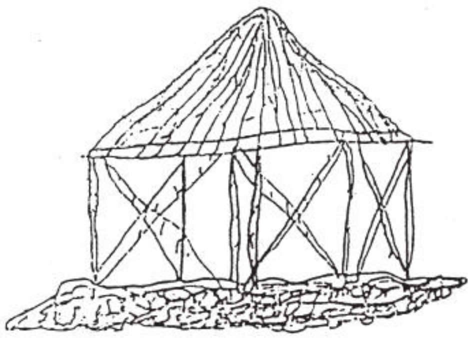


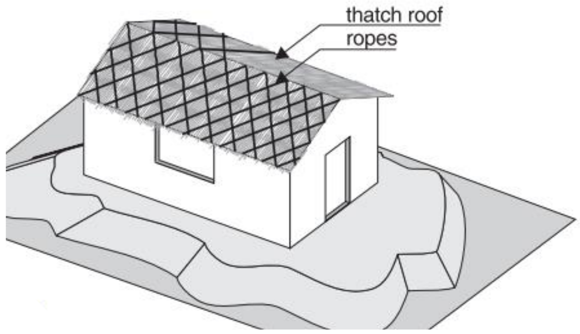
Hip roof

- Avoid a low pitched roof, use a hip roof or a high pitched gable roof.

High Gable Roof

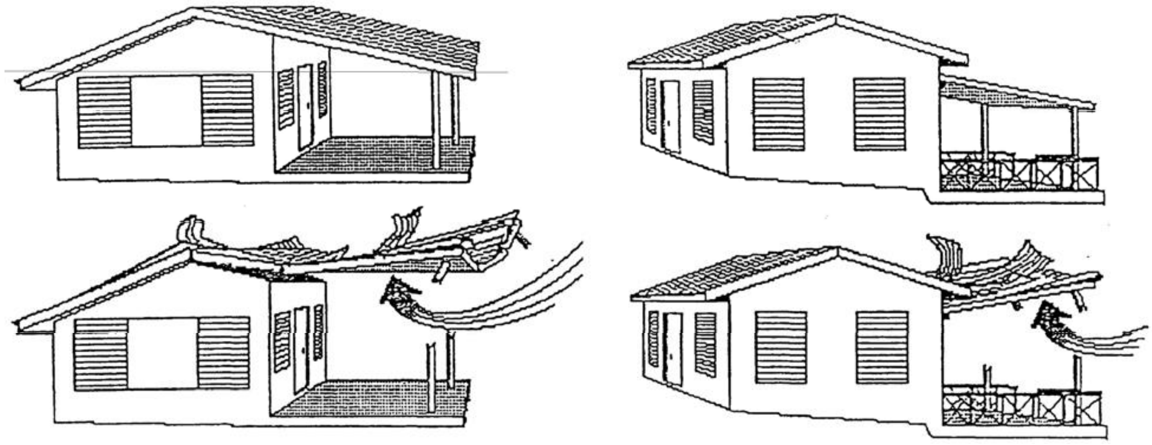
- Avoid openings which cannot be securely closed during a cyclone.
- In case of light roofs (AC or CGI sheeting) connections near the edges should be strengthened by providing additional U bolts.
- In case of thatched roof houses, properly tie the roof down to the wooden framing underneath by using organic or nylon ropes in diagonal pattern. The spacing of rope should be kept 450 mm or less so as to hold down the thatch length.





- In case of roof tiles, the overlap joint along the edges should be provided in cement mortar.
- After a cyclone warning is received, all the lighter roofs should preferably be held down by a rope net and properly anchored to ground

Overhangs, patios and verandahs



- Avoid large overhangs as high wind force build up under them.
- Overhangs should not be more than 18 inches at verges or eaves.
- Build verandah and patio roofs as separate structures rather than extensions of the main building. They may blow off without damaging the rest of the house.

2.9 Foundation Considerations

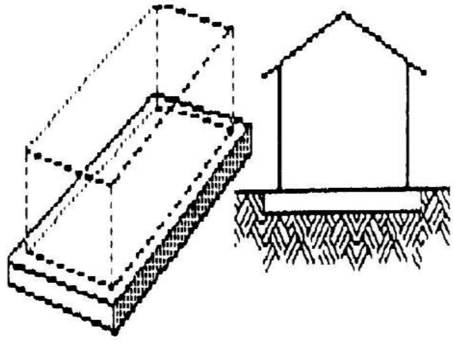
The foundation is the part of the house which transfers the weight of the building to the ground. It is essential to construct a suitable foundation for a house as the stability of a building depends primarily on its foundation. Buildings usually have shallow foundation on stiff sandy soil and deep foundations in liquefiable or expansive clayey soils. It is desirable that information about soil type be obtained and estimates 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 in the design of foundation.

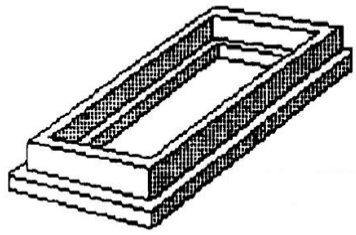
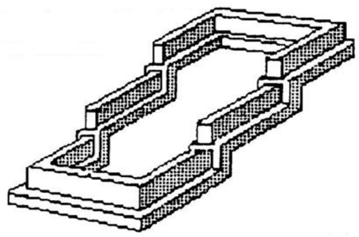
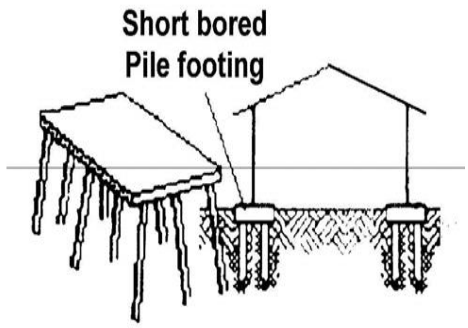
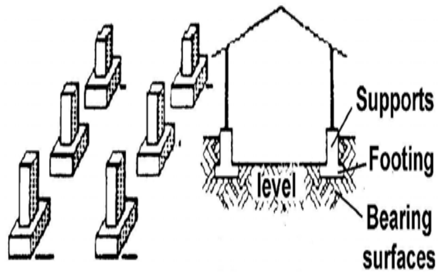
Effect of surge or flooding: Invariably a cyclonic storm is accompanied by torrential rain and tidal surge (in coastal areas) resulting into flooding of the low lying areas. The tidal surge effect diminishes as it travels on shore, which can extend even upto 10 to 15 km. Flooding causes saturation of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

Buildings 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 the complete building under lateral loads. Knee bracings will be preferable to full diagonal bracing so as not to obstruct the passage of floating debris during storm surge. The stability of a building depends primarily on its foundation. A cyclonic storm is accompanied by torrential rain and tidal surge (in coastal areas) resulting into flooding of the low lying areas. In such situation, following points should be taken into consideration:

- Estimates of soil types and soil bearing capacity should be made available.
- Likelihood of any scour due to receding tidal surge needs to be taken into account while deciding on the depth of foundation.
- Protection works around a raised ground used for locating cyclone shelters or other buildings.
- Building can be constructed on stilts on low-lying areas vulnerable to tidal surge or storm surge.
- Stilts are properly braced in both the principal directions.

Types of foundations

Slab or Raft Foundation • Used on soft soils. • Spread the weight over a wider area.	

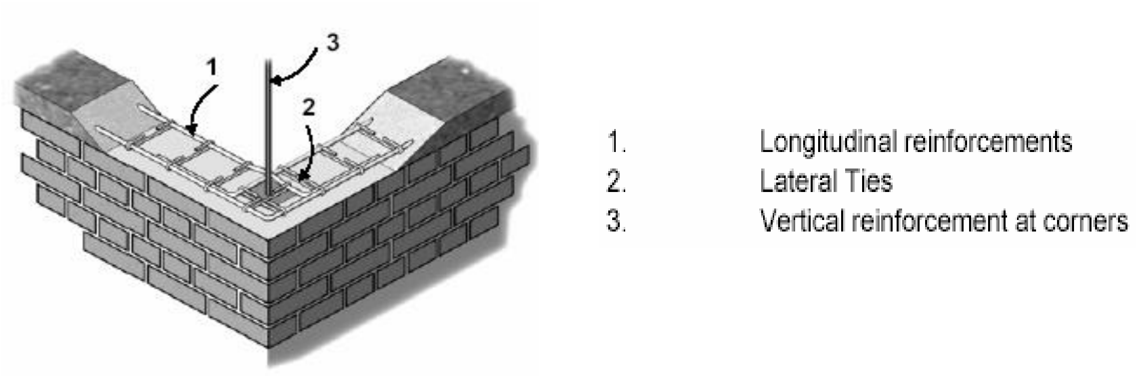
Strip Foundation • Used for areas where the soil varies. • Most common. • Supports a wall.	
Stepped Foundation • Used on sloping ground • It is a form of strip foundation	
Pile Foundation • Are deep foundations for small or large buildings. • Under reamed piles often used in expansive clay or alluvial soils.	
Pad Foundation • Used on firm soil. • Used for columns & poles.	

2.10 Walls Consideration

Masonry Construction

External Walls: All external walls or wall panels must be designed to resist the out of plane wind pressure adequately. The lateral load due to wind is finally resisted either by walls lying parallel to the lateral force direction (by shear wall action) or by RC frames to which the panel walls must be fixed using appropriate reinforcement such as seismic bands at window lintel level.

Strengthening of walls against high wind/cyclones: For high winds in cyclone prone areas it is found necessary to reinforce the walls by means of reinforced concrete bands and vertical reinforcing bars as for earthquake resistance. Also cross bracing of the walls resists out of plane wind pressure.



View showing the connection between the vertical reinforcement and the seismic band

Earthen construction

For the safety of earthen houses, appropriate precautions must be taken against the actions of rain and flood waters and high winds:

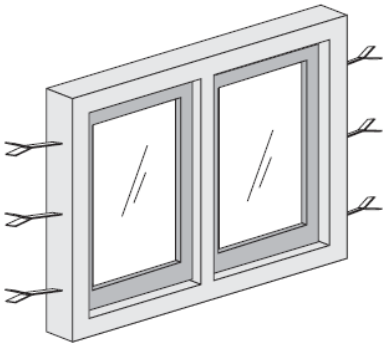
- Whereas dry clay block is hard and strong in compression and shear, water penetration will make it soft and weak, the reduction in strength could be as high as 80 percent. Hence, once built, ingress of moisture in the walls must be prevented by roof projection and waterproof plastering. External face of wall up to 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.
- 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 plastered.

2.11 Wall Openings

Wall openings are areas of weakness and stress concentration, but needed essentially for light and ventilation. The following are recommended in respect of openings.

- 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.
- Openings just below roof level can be avoided except that two small vents without shutter provided in opposite walls to prevent suffocation.

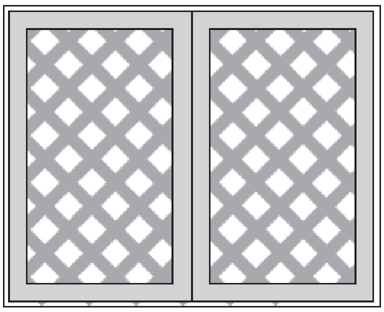
- Openings on windward side should have strong holdfasts as well as closing/locking arrangement.



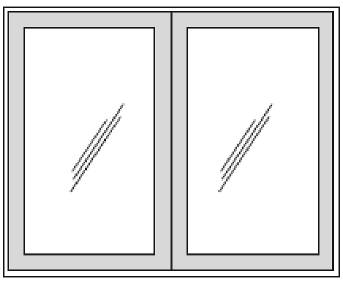
Anchorage of door and window frames with holdfasts

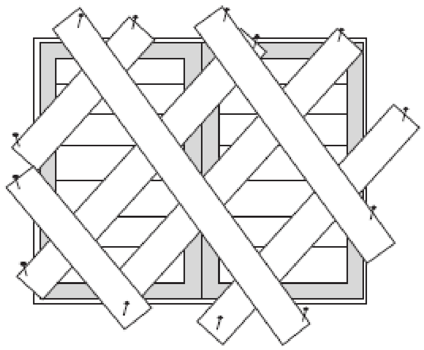
2.12 Glass panes

Glass windows and doors are very vulnerable to flying objects and there are many of these in cyclones. The way to reduce this risk is to provide well designed thicker glass panes or reduce the panel size to smaller dimensions. Also glass panes can be strengthened by pasting thin film or paper strips or using shatter free glass. 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.



Protection of Glass panes





Large & thin unprotected glass area in window (Left)

Window protected with guard bars/ tapes/ wooden batten (Right)

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