

# Cyclone-Resistant Design of Buildings as Per Indian Standards

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**Abstract:** *Cyclonic storms subject buildings to extreme winds which if the buildings are not able to withstand, they collapse leading to huge losses during cyclones. Hence the wind load codes of every country provide guidelines for the design of cyclone-resistant structures. In India, IS 875-3(1987) & IS15948-2004 describes the wind loads acting on each and every element of the building individually. For a building to be safe during wind-induced disasters, the foundation, the walls as well as each connection have to be well-built. Hence in this paper the main area of concern will be to tackle the vulnerable areas and design of the elements in order to make them less vulnerable to the high-speed winds.*

**Keywords:** *Cyclones; Wind; Pressure; Suction; Disaster*

## 1. Introduction

Cyclone is basically a violent storm characterized by high winds rotating about a centre of low atmospheric pressure. Around 32% of loss per year in the Asia-Pacific region by the natural disasters is solely due to cyclones and other wind-induced disasters. Hence wind becomes the primary force of concern which governs the design of buildings in cyclone-prone areas. And the cyclone-prone areas are vulnerable to high speed winds that can go as high as 200kmph. That is why there has to be proper estimation on the amount of load that the building has to withstand due to the wind around it. Every country has its provision for the estimation of the wind loads acting on a building as a whole as well as the load acting on individual elements of the building. In India as well there are standard code for the calculation of wind load as IS875-Pt.3(1987) & IS15948-2004. These codes give the pressure acting on various shaped buildings and on different parts of buildings at different locations and topographical conditions. Based on extensive research, there have been many other suggestions in IS 15498 (2004) that can help make a building less vulnerable to extreme winds. All these architectural suggestions, the engineering solutions and the calculations will be dealt in detail further.

## 2. General Guidelines as per Indian Standards

A building is at risk if it cannot withstand high winds. When subjected to extreme wind pressure, the building and its foundation must be strong enough to withstand the force. But there is a general notion that during cyclonic storm, high winds blow away the building from its foundation. But in actual case, the wind pulls apart the building. The pressure on the windward side creates a negative pressure (suction) over all the other side as well as the roofs (leeward side) and as well increases the internal pressures. This increase in the internal pressure and the external suction together is instrumental in pulling the walls and the roofs of the building apart. The general suggestions on the planning aspects, as per the provisions in the Indian Standard code IS 15498 (2004) [2], which must be followed to decrease the vulnerability of a building to collapse during cyclone are:

- Site selection: The buildings in cyclone-prone areas need to be built on good ground. And part construction on good ground and part construction on made-up ground must be avoided. Though the wind direction during cyclones is random, still effort should be taken to have a natural shielding from the wind either in the form of a hillock or a group of trees. Also cyclones are followed by floods; hence construction on low-lying areas should be avoided. In hilly regions, construction along ridges should be avoided as at the ridges there is sudden increase of wind velocity. Buildings should not also be constructed within the inundation level in the cyclonic regions. If constructed, they must be on naturally occurring high ground or on stilts with bracings provided.

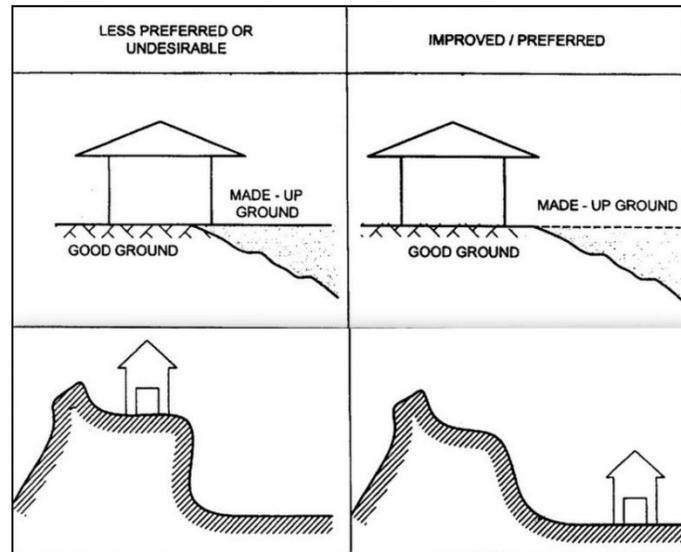


Fig 1: Site selection criteria

- Plan of building: Simple and symmetrical structures are the best in performance during cyclones. Square shaped buildings are more cyclone-resistant than rectangular buildings or L-shaped buildings. Especially efforts have to be taken to reduce the local excess pressure at the corners and edges. Design should be such that the smallest facade of the building should be on the windward side. Long walls should be avoided. In case where the wall length exceeds 3.5m, it should be divided using either cross walls or integrated pilasters. In case of group of buildings, a clustered arrangement is more efficient than a linear arrangement as it breaks the flow of the wind and hence reduces the velocity.

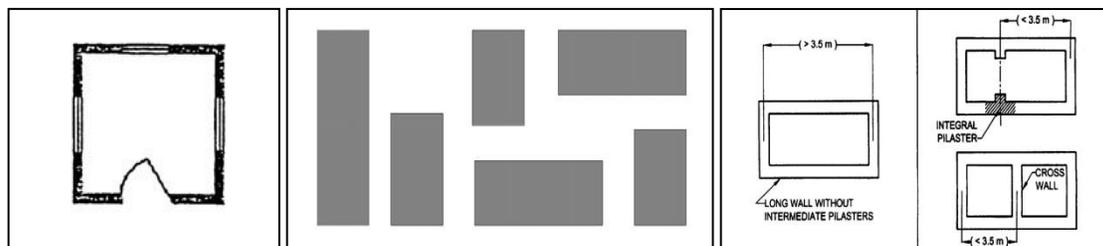


Fig 2: Plan and arrangement of buildings

- Roofs: Flat roofs should be avoided. Pitched roof with a slope between  $25^\circ$  to  $40^\circ$  is acceptable. The best roofs which have proved to be cyclone-resistant are the hip roofs. The suction pressure pulling the roof apart from the building is about 80% less in the case of hip roofs than gabled roofs. [3] Hence their performance during cyclones is the best as compared to others. Moreover, the corners of buildings and the edges of the roofs are subjected to excess local suction pressure. Hence the connections of the roof cladding to the trusses of the roof should be properly designed such that they can withstand the excess pressure they are subjected to. In case of galvanized sheeted roofs, the spacing between bolts should be reduced and U-

bolts should be used instead of the regular J-bolts. The roof also needs to be properly anchored to the walls for its overall stability by the proper design of anchor bolts. Thatched roofs are the most vulnerable type of roofs to cyclone as they can be blown away easily. So to make them less vulnerable, organic ropes should be used to tie them together. It is even better if the ropes are tied diagonally as it adds more strength.

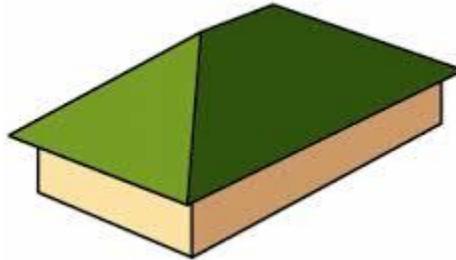


Fig 3: Hip roof

High wind forces are built under overhangs and projections of roofs. Hence long projections should be avoided. It is restricted to 450mm. If it exceeds 450mm, then the projected portion should be tied properly to the wall framework. [6]

- Doors, windows and other openings: Any opening in the building is the main area of weakness as they let in the pressure inside the building and increase the pressure inside the building thus pushing the walls and the roofs outward more forcefully. Hence the openings must be avoided near to the corners of the walls as well as just below the roofs as these are the areas subjected to excess local pressures. The openings must be provided at a minimum distance of  $h/6$  from the corners of walls, 'h' being the height of each storey in the building. [4] Also the total width of the opening on the load bearing façade should be less than half of the total width of that wall. Doors and windows have glass panels which are the most vulnerable because of its brittle nature. So properly designed thicker glass panes with smaller dimensions are preferred to be used. Also some adhesive tapes are used with the glass which increases its dampness thereby reducing the vibration. Proper connections and anchoring can also protect the glass. Also cross bracings are used behind the glass facades to decrease the probability of its breakage.
- Foundations: Foundation is the part of the building through which the weight of the building is transferred to the ground. For sandy soil, buildings usually have shallow foundation whereas for clayey soil, they have deep foundation. Apart from that, effect of surge on the foundation needs to be examined. [7]

## 2.1. Governing Equations according to IS 875 Part 3 (1987)

IS 875-3 defines the wind loads acting on a building as a whole as well as on the connections and claddings and individual elements. For that, it is basically needed to know the wind velocity at the particular location under study. According to the Indian Standard code, India is divided into six different zones with each zone assigned a basic wind speed for that zone. But the wind speed also depends on the risk and probability of occurrence of cyclone in that area, the terrain and the height of the structure and the topography of the location and also on a cyclone importance factor. All these corrections need to be included to get the final design wind speed. [1]

Hence, according to the draft code IS 875-3 [11],

$$V_z = V_B * k_1 * k_2 * k_3 * k_4 \quad (1)$$

[  $V_z$  is the design wind speed at any height 'z', in m/s;

$V_B$  is the basic wind speed for the zone;

$k_1$  is the probability factor whose value is taken from Table 1 of the code;

$k_2$  is the terrain, height and size of structure factor taken from Table 2 of the code;

$k_3$  is topography factor, whose value is taken 1.0 for flat terrain and for slopes greater than  $3^\circ$ , its value varies between 1.0 and 1.36;

$k_4$  is the importance factor for the cyclonic region whose value is 1.0 for non-cyclonic regions and for cyclonic regions and different types of buildings, its value has to be taken from the code. ]

After having found the design wind speed, the pressure due to wind at that point is found out.

$$P_z = 0.6 * V_z^2 \quad (2)$$

$$P_d = K_D * K_A * K_C * P_z \quad (3)$$

Here,  $P_z$  is the wind pressure at a height 'z', in  $N/m^2$

$P_d$  is the design wind pressure at a height 'z', in  $N/m^2$

$K_D$  is the wind directionality factor

$K_A$  is the area averaging factor

$K_C$  is the combination factor

The values of these factors are as per the code.

And now, this wind pressure exerts a force individually on the roofs, walls and other connections as well which are evaluated separately. And due to this pressure, apart from the pressure developed on the external sides of the building, there is also an internal pressure developed inside the building whose combined effect gives the final total force acting on the building. Hence to calculate the forces, there is an inclusion of external coefficients as well as internal pressures.

Thus the force 
$$F = (C_{pe} - C_{pi}) * A * P_z \quad (4)$$

[ $C_{pe}$  : external pressure coefficient;  $C_{pi}$  : Internal pressure coefficient; A : Area on which the lateral wind force acts; ]

The value of the external pressure coefficients for individual elements of building and different types of buildings is given in different tables in the code. Depending on wind direction, the ratio between different dimensions and the slope of the roof, values of the external pressure coefficients are decided.

The values of the internal pressure coefficients depends on the openings in the building which is decided by finding out the permeability of the building, i.e the percentage of openings in the buildings. And as per the code, if the permeability is less than 5%, it is a case of low permeability and the internal pressure coefficient equals 0.2. Two cases are evaluated, one with pressure value on the internal side and the next case with the negative pressure (suction) acting on the internal side. Thus, the value of internal pressure coefficient taken is +0.2 and -0.2. Similarly if the permeability is medium, i.e from 5% to 20%, the internal coefficient taken is +0.5 and -0.5. And if the permeability is high, i.e more than 20%,  $\pm 0.7$  value is used as the internal pressure coefficient. [5]

Having known the values of the external pressure coefficients and the internal coefficients, and the affected area as well as design pressure value, the force acting can be calculated. This completes the wind load analysis of a building which gives the idea about the maximum lateral wind force a particular building can withstand.

### 3. Performance of Buildings during Cyclones

There have been many researches carried out all over the world to study the performance of different types of building during cyclones. This makes construction post-cyclone easier. According to a case study of the Karaikal cyclone of December, 1993 [8], the best performance was by steel trusses and industrial sheds. In case of walls, brick walls performed better than thatched roofs. Even some brick walls collapsed due to lack of lateral strength. Roofs had damage in specific locations as eaves, ridges and hips. Roofs with higher dead load were found to be safer during cyclones. Yet another study conducted by SERC Chennai on the buildings after cyclones in Gujarat and Andhra Pradesh [9] showed similar result. Thatched roofs were completely blown away. Even AC sheeting of roofs were blown away due to improper cladding connections. But the trusses remained intact. Also the fully-engineered houses with RCC roofs performed well during the cyclones and had less damage. Another paper on Hurricanes and their effects on buildings and structures in the Caribbean [10] come up with the conclusion that steel structures perform better due to their flexibility, but as they are light weight structures there is probability

of them being completely uprooted. Hence heavier foundations need to be constructed. And the most vulnerable portions in the steel buildings are the connections, hence the requirement to properly design the bolts and all the minor items. In case of masonry houses, the loss of roofs triggers the complete destruction of the unreinforced masonry walls. Timber houses are most vulnerable to damage during cyclones due to their light weight. Fully-engineered RCC houses are mostly safe during cyclones.

As suggested by all the literatures gone through, fully-engineered buildings are the best performers at the time of cyclones. Especially steel structures perform better. A 3D model created on StaadPro gives an example of the typical building which can resist the lateral wind forces and can act as a cyclone-resistant structure.



Fig 4: 3D model of a steel frame shelter

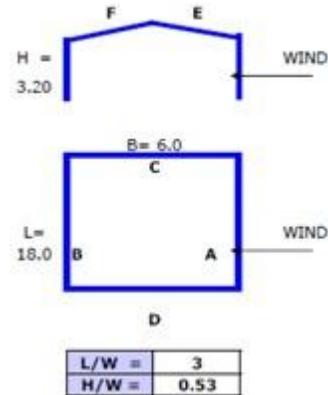


Fig 5: Dimensions

This model was tested was acted upon by dead load, live load and wind load and the analysis was done with the load combination as suggested by Indian Standard codes. After all the analysis, it was seen that all the columns and beams passed the test and were capable of taking up the load.

Hence it would be a suggestion to construct engineered buildings in cyclone-prone areas, with all the guidelines taken into consideration, strict compliance with the standard code and proper estimation of the wind load. The most vulnerable area for all types of buildings is the connection. Any failure in the connections leads to total destruction of the entire structure. Hence in cyclonic areas, the connections need to be designed with much precision.

#### 4. Conclusion

For making a building cyclone-resistant, it has to withstand the amount of force that the wind casts over it during the cyclonic storm. And hence, it should be accordingly designed. For proper estimation of wind loads and subsequent design, wind load code should be followed properly for the analysis which will then lead to appropriate design with the correct amount of reinforcements, the correct inclination of the roofs etc. Beyond the scope of the code lies the ‘Interference effect’ which is due to the presence of other buildings in the vicinity of the building we are studying about. The wind pattern is highly changed due to interaction with other buildings as well. But this effect can be accounted only by conducting wind tunnel tests. This is a limitation in using the wind load codes. Wind load code even accounts for the dynamic effects of the wind for high rise buildings whose natural frequency is less than 0.1Hz. The code extends its scope to different building types, different terrains and different topographical conditions. Thus even with a few limitations, it is highly helpful in the proper analysis and design of cyclone-resistant structures.

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