Cyclone Disaster Mitigation-Indian Scenario and Challenges for Future

Arunachalam, S. * 1,  Selvi Rajan * 2,  Prem Krishna * 3

1. INTRODUCTION
India is highly vulnerable to several natural hazards almost every year resulting in huge losses to life and property. These natural hazards which include earthquakes, severe cyclones, floods, droughts, landslides, avalanches, etc., are impediments for the economical and industrial growth of the country. Disaster mitigation and management are problems of international importance. Cyclones (or Hurricanes or Typhoons), are considered to be worst among all the natural hazards, when viewed in terms of their intensity, frequency of occurrence, and areas of destruction. A comparison of loss of people in different countries due to cyclones is discussed by Lakshmanan et al., (1997) which clearly indicates that amongst the South-Asian countries, India is highly prone to cyclone disasters [1]. Although occurrences of these hazards cannot be prevented, through proper application of science and technology, and better cooperation and exchange of information among the affected countries, the untold misery to the humankind can be minimised, both in terms of human loss and economic loss due to damage to various buildings and structures. In this context, the purpose of this special volume on “Wind related disasters and changes in regulations and practices in various countries” is a commendable step forward to bring together various researchers, administrators and implementers to share their experience and update their knowledge. India has a long coast line of about 7500 km, including island territories [2]. Among the different wind-related hazards such as cyclones, tornadoes, thunderstorms, micro-busts, etc., the Indian coastline is primarily battered by severe cyclones almost every year. Around five to six cyclones strike the Indian coasts annually, of which two or three turn into severe cyclones with an intensity exceeding about 60 m/s. The cyclones occur during months of April-May, and October-December. The east coast of India experiences higher frequency of cyclones relative to the west coast, with a ratio of about 4:1. Cyclones affect all types of buildings—viz., non-engineered buildings such as thatched roofs; semi-engineered buildings such as workshop buildings, and storage ware-houses, and even well-engineered buildings and structures such as communication towers etc. Complete collapse of some of the well-engineered structures is shown in Fig. 1. Due to concerted efforts by various stakeholders in cyclone disaster mitigation and management activities during the past few decades, and also due to public awareness, the loss of human lives after occurrence of a severe cyclone has reduced considerably, while damage/ failure of buildings and other structures continues to be on the rise. To curb this trend, a holistic approach involving scientific and reliable forecasting, better understanding of cyclone forces, quality conscious engineering design and construction practices, effective decision support systems, strict implementation of regulations is a dire need of the hour.

*1 Director, Jaypee Wind Engineering Application Centre, Jaypee University of Engineering and Technology, Guna
*2 Chief Scientist and Head, Wind Engineering Laboratory, CSIR-Structural Engineering Research Centre
*3 Professor and Head (Retd.), Department of Civil Engineering, Indian Institute Technology, Roorkee
A "well-prepared" society becomes more resilient in minimizing an inevitable natural hazard turning into a natural disaster.

2. INDIAN INITIATIVES IN CYCLONE DISASTER MITIGATION

A look at the Indian scene on initiatives for disaster mitigation would clearly reveal that the attention given to cyclone disaster mitigation is far less compared to earthquakes\(^3\). Nevertheless, there have been some significant developments over the years. The Indian Society for Wind Engineering (ISWE) has been established in 1993 and the 9th International Conference on Wind Engineering was organized in 1995. Since then, bi-annual national conferences have been regularly organized by the Wind Engineering Society, the recent being 7th NCWE in November 2014. Excellent facilities have been established for wind engineering research at the Structural Engineering Research Centre, Chennai, Indian Institute of Technology (IIT), Roorkee; IIT, Kanpur; and IIT, Delhi. These Centres have been carrying out R&D activities aimed at safe, reliable, and economical structures against wind loading. Visveswaraya National Institute of Technology, Nagpur, and IIT, Madras, have carried out several analytical investigations in the area of wind engineering. Indian Meteorological Department (IMD) monitors weather systems in India and is primarily responsible for cyclone warning bulletins. The IMD network has sophisticated equipment and facilities for this purpose.

CSIR-Structural Engineering Research Centre (CSIR-SERC) has recognized cyclone disaster mitigation as one of the thrust areas of R&D and over the years, developed expertise and state-of-the-art facilities to investigate wind-related disaster mitigation issues \(^{1,4,5}\). In India several other scientific, academic, voluntary and governmental organizations are also working towards cyclone disaster mitigation (CDM). These include CSIR-Central Road Research Institute (CSIR-CRRI), CSIR-Central Building Research Institute (CSIR-CBRI), National Disaster Management Authority (NDMA), National Institute of Disaster Management (NIDM), Bureau of Indian Standards (BIS), Building Materials Technology Promotion Council (BMTPC), Border Security Force, Orissa State Disaster Management Authority (OSDMA), Indian Red Cross Society (IRCS), etc. The CSIR-CRRI, New Delhi has brought out guidelines for protecting road infrastructure against cyclonic impact \(^{2,6}\).

3. R & D INITIATIVES TOWARDS CYCLONE DISASTER MITIGATION

Various activities involving R&D carried out at different academic/research institutions, in India in general, and at CSIR-SERC in particular, briefly can be listed as follows:

- Post-cyclone damage surveys (many surveys, since year 1977)
- Risk analysis of cyclonic wind speed data
- Recommendation of basic wind speed for cyclone regions, \((V_{bc} = 65 \text{ m/s})\)-Contributions to Indian Standards IS: 15498; 15499-2004.
- Cyclone wind characteristics based on full-scale measurements
- Cyclone Track Predictions
- Cyclone Damage Prediction model
- Construction of Demonstration Houses with cyclone resistant measures
- Full-scale Testing of typical roofs with retrofitting measures
- Design of cyclone shelter which survived the Orissa Super Cyclone in 1999, and recent ‘Phailin’ in 2013
- Simulation of cyclone wind effects in wind tunnel
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3.1 POST-CYCLONE DAMAGE SURVEYS

Damage to buildings and structures due to cyclones varies from failure of various components, viz. roofs and their supporting systems of dwellings/industrial structures, to complete collapse of these structures. Understanding of interaction between cyclonic winds and behavior of different buildings and structures is not simple. Thus, post-cyclone damage surveys serve as a useful engineering exercise to observe and identify common failures, and thereby in formulating necessary corrective measures. For example, provision of a continuous flat tie at the eaves region, and providing mortar bands to resist uplift force are found to be effective as observed in post-cyclone damage surveys (Fig.2). CSIR-SERC has been carrying out post-cyclone damage surveys, since the 1977 killer cyclone in Visakhapatnam in Andhra Pradesh, and in several cases, documented reports on structural damage to buildings and structures. Post-failure analyses of semi-engineered and well-engineered structures were also carried out in few cases. Recently (2013), a very severe cyclonic storm (‘PHAILIN’) crossed the coast near Odisha with a sustained maximum surface wind speed of 200-210 kmph gusting to 220 kmph. The post-cyclone structural damage survey conducted by the scientists of CSIR-SERC, Chennai, indicated (i) failures of engineered structures like rooftop lattice tower, ground based communication / transmission line lattice towers and steel trusses with asbestos or GI sheet roofing of industrial sheds (either mono or double sloped), (ii) total / partial collapse of semi / non-engineered structures like compound walls, roofs of dwelling units (kutchha / thatched houses) were observed and (iii) damage to roofs of fuel filling stations and façade (glass) of buildings including glass panels of windows. Similarly, a post-cyclone damage survey was also conducted after the recent Hudhud cyclone which hit Visakhapatnam in Andhra Pradesh in October 2014. These surveys point to the need for studying the effect of transient winds on the structural response and, codifying the same. The significance of conducting post-damage surveys is gaining momentum by other academic institutions as well, as can be seen form survey reported by Ramuje and Malleswara Rao [7]. Such field studies strengthen the engineering practice of “learning from failures”, leading to better techno-social awareness among students, who are the future engineers and administrators.

3.2 CYCLONE WIND SPECTRUM

The current knowledge on cyclonic wind characteristics vis-à-vis well-behaved wind is far less satisfactory, and this poses a serious scientific challenge towards design of buildings and structures in cyclone prone regions. In this regard, consequent upon full-scale experiments carried out, CSIR-SERC has proposed a cyclonic wind spectrum, which is clearly different from that specified for normal well behaved winds (Fig. 3). The findings of CSIR-SERC have led to additional scientific inputs to the existing limited knowledge on cyclonic wind characteristics, using which collapse of some of the tall lattice towers could be explained[9].

3.3 CYCLONIC WIND SPEED MAP OF INDIA

CSIR-SERC has developed cyclone wind speed map of India based on risk analysis of cyclonic wind speeds. The result of this study, in a modified form, has led to recommendation of
basic cyclonic wind speed of 65 m/s and evaluation of risk coefficients, $k_1$ for cyclonic regions. These results are incorporated in the Indian Standard IS: 15498: 2004 on “Guidelines for Improving the Cyclonic Resistance of Low-rise Houses and other Buildings / Structures” [9].

3.4 “DEMONSTRATION BUILDINGS” WITH CYCLONE- RESISTANT MEASURES

In order to demonstrate to the public the effectiveness of improvements suggested in common man’s dwellings to resist cyclonic forces four types of buildings with thatch roof, mud wall, tiled roof, A.C. sheet roof, RCC roof with brick wall have been constructed (Fig. 4). These demonstration houses have been constructed at Chennai, Nellore and Visakhapatnam which are some of the worst cyclone prone regions of east coast of India.

3.5 SIMULATION OF CYCLONE WIND EFFECTS IN BOUNDARY LAYER WIND TUNNEL

Wind tunnel testing on models of structures particularly to evaluate load effects under boundary layer flows and aspects relating to aero-elasticity and stability has served as the most effective tool over the last few decades. However, nature is not so kind as to provide boundary layer flows at all instances. There are three major wind events such as cyclones, thunderstorms and tornadoes where considerable circulatory flow is associated. These events are also non-stationary in nature. Hence it is extremely important to study the interaction of vortex flows at different scales and determine the wind characteristics for appropriate structural design. Wind tunnel experiments have been conducted on simulation of vortex flows and the interaction of terrain with models scaled to one and two orders in dimension. A novel technique has been attempted to generate a large vortex flow of diameter 1200 mm in the wind tunnel. In addition, an auxiliary device to create vortices within Boundary Layer Wind Tunnel was developed which, primarily consists of (a) a circular plate, which has a provision to rotate in yaw direction, (b) roughening elements and (c) two square plates, which has kept at right angles to each other, as paddles [9]. The device successfully demonstrated the feasibility of reproduction of increased turbulence intensities and higher energy content at low-frequency region in the turbulence spectrum. Using this device, pressure measurement studies were carried out on two different configurations of cyclone shelter models to a geometric scale of 1:100. By increasing the spacing between the device and model, the effect of location of building with reference to the eye of the cyclone was studied. These have also shown promise for use of the device as cyclone simulator. Further research studies are in progress.

3.6 CYCLONE DAMAGE PREDICTION MODEL

Damage estimation is essential for proper planning of disaster mitigation measures. Damage to buildings and structures can be considered proportional to cubic power of wind. In a developing country like India, non-engineered and semi-engineered buildings coexist with engineered buildings. The types of buildings available are also numerous. The Vulnerability Atlas of India prepared by an expert committee set-up by Government of India and published by Building Materials and Technology Promotion Board has categorized the building stock into nine categories. For the purpose of the present analysis these have been regrouped into three categories namely non-engineered, semi-engineered and engineered buildings. All buildings depending on their size, shape and
type of construction have a maximum wind velocity which they
can withstand without failure. This may be called as capacity
wind speed. However due to many factors such as inherent
deficiencies in layout, ageing, poor maintenance, improper
detailing, and poor quality of materials used and similar other
factors the capacity wind speeds get reduced. The reduced
capacity wind speeds alone are to be considered in damage
analysis. A simple empirical model has been proposed and was
verified with the actual damage that occurred during Orissa
super Cyclone (1999) \(^1\).

3.7 GUIDELINES ON CYCLONE RESISTANT DESIGN
AND CONSTRUCTION

The performance of a building under dead, live and imposed
loads depends on the prime factors like anchorage, bracing,
continuity and detailing which influence the structural integrity.
These conditions respectively imply that:

(i) Every part of a structure should be firmly tied or
anchored back to a secure point which can safely
resist all the loads acting on it.
(ii) roof and wall must be properly braced to prevent
tilting, sliding and rotation.
(iii) every part of the structure must be properly connected
to other members along the ‘strength chain’ from
cladding to foundations.
(iv) Detailing of every joint in the structure should be
made effectively so that the load is transferred through
structure without any distress.

Some of the methods/ methodologies envisaged for improving
the resistance of buildings and structures against cyclonic wind
loads are listed below:

For residential buildings,

- Lay out of low rise residential buildings is preferred to be
  rectangular in plan.
- Performance of hipped roofs is better than gable roofs.
- Performance of the pitched roof can be significantly
  improved by choosing a roof angle between 30 to 45\(^\circ\) as
  the wind load on the roof cladding is less in this range.
- Damage to tiled roofing can be reduced by increasing the
dead weight in the form concrete or masonry restraining
bands (100 mm x 50 mm) over the tiles at 1.5 m interval in
the interior region and at 1.2 m interval near gable ends.
- Performance of brick masonry walls can be improved by
  providing continuous R.C.C. bond beam over the walls
  and by anchoring the bond beam to foundation.
- Failure of glass panels of windows near edges of walls,
  which in turn increase the internal pressures causing failure
  of roofs and walls, can be minimized by properly locating
  the windows away from edges at 600 mm or more.

For industrial buildings,

- Performance of GI/AC sheet roofing can be improved by
  providing a roof pitch of not less than 10\(^\circ\), a spacing of not
  more than 1 m, galvanized 6 mm dia. ‘U’ hook bolts
  instead of ‘J’ bolts, 3 or 4 hook bolts per purlin per sheet
  over gable ends and sheet metal brackets to tie purlins to
  rafters.
- Dislocation of entire roof can be prevented by fixing the
  supports of the trusses into walls using concrete bond
  beams.
- Progressive collapse of the roof truss system can be
  arrested by providing horizontal and diagonal bracing, at
  least in the end bays.
- Performance of brick masonry walls can be improved by
  providing pilasters for reducing the panel size between the
  RC columns.
- Special/ additional bracing or supports should be provided
during construction, to cater cyclonic wind loads.

Based on the above guidelines, a book titled “Guidelines
on Design and Construction of Buildings and Structures in
Cyclone Prone Areas”, a report on Damage to Buildings
and Structures due to Kakinada Cyclone on November 6,
1996 \(^1\), and a comprehensive video cassette on R&D
activities conducted at CSIR-SERC, Chennai, in the area
of wind engineering, a typical damage survey conducted,
and explanatory visual aid on cyclone resistant construction features for buildings were widely distributed. Sample charts were prepared as part of educating the field artisans/village people (Fig.5) for creating better public awareness towards cyclone disaster mitigation.

3.8 CYCLONE SHELTER DESIGN

A novel design of cyclone shelter was developed by CSIR-SERC which was subsequently adopted by KfW Germany in constructing 23 cyclone shelters in Orissa (Fig.6). The innovativeness of the structural design includes, (i) selection of suitable aerodynamic shape, (ii) provision of stilt, and sloping ground to satisfy functional requirements against storm surges, and, (iii) selection of appropriate design wind speed based on risk analysis of cyclonic wind speeds carried out at CSIR-SERC. These shelters constructed at 23 sites in Orissa, under ODMP-1 find a mention in the World Disaster Report 2001 released in Geneva, for having been able to save more than 40,000 lives during the super cyclone of 1999 alone [11]. Cyclone shelters with alternate design configurations have also been subsequently built by Indian Red Cross Society (IRCS) in Orissa [11].

Fig.6 Cyclone shelter at 23 sites in Orissa; Structural design by CSIR-SERC; Survived Super Cyclone (1999) and Phailin Cyclone (2013).

4. WAY AHEAD - FUTURE STRATEGY

i) Continuation of post-disaster surveys

ii) Contribution to Code of Practice on design of multi-purpose cyclone shelters based on wind tunnel studies

iii) Updating of guidelines on cyclone resistant design and construction based on performance of new retrofitting measures

iv) Codal recommendations to account for the effect of transient winds on the load effects/response of buildings and structures

v) Development of vortex induced vibration (VIV) models for generic bluff bodies

vi) Wind monitoring in cyclone prone regions for structural damage mitigation

vii) Vulnerability assessment based on census of houses and buildings in coastal regions

viii) Updating of Cyclone wind speed map

ix) Computational fluid dynamics simulation of transient aerodynamics

x) Data collection through survey questionnaire proforma of IS: 15499-2004 using web service based approach and cloud environment

5. CONCLUSIONS

Disaster mitigation against natural hazards is complex and multi-disciplinary in nature. A holistic view on the entire spectrum of activities is needed. A brief account of R&D efforts being pursued in India is briefly presented in this paper. Reliable forecasting, quality construction, effective decision support systems and policy implementations are some of the future challenges for combating the fury of natural disasters.

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