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On

SCOPE AND CURRENT STATUS OF WIND ENGINEERING - INDIAN SCENARIO

(a) Structural Safety and Wind Engineering

Submitted

By

Dr. Ajay Gairola
Associate Professor
Department of Civil Engineering
Indian Institute of Technology Roorkee
ROORKEE – 247667, INDIA
e-mail: garryfce@iitr.ernet.in

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GAIROLA, AJAY

Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, India
E-mail : garryfce@iitr.ernet.in

ABSTRACT

India is affected by cyclones which are violent during pre and post monsoon storms compared to the storms of the monsoon season. These cyclones are associated with high pressure gradients and consequent strong winds. These winds damage installations, dwellings, communication systems, trees etc. resulting in loss of life & property. Vulnerability to storm surges is not uniform along Indian coasts. In the present paper an attempt has been made to illustrate an account of damage caused by cyclones in India. The paper covers the major concerning issues affected by wind movement in India.

KEY WORD : *Indian cyclones, wind induced disasters. mitigation, computational fluid dynamics*

INTRODUCTION

The main land of India roughly extends between 8^{o}N to 37^{o}N latitudes and 69^{o} E to 97^{o} E longitudes. This does not include the islands group of Lakshdweep in Arabian sea and the Andman and Nicobar islands in the Bay of Bengal. India is surrounded by large oceans from the three sides south, west, and east, however the northern part has high mountains. The north-south extent of India is about 3,200 kms and east-west extent is about 2,900 kms. The length of the Indian Coastline including that of group is about 7,500 kms. The land frontier is about 15,200 kms long. India has total area of about 3.28 million square kms, which accounts nearly two percent total area of the world. The average temperature is reasonably high to produce large thermal gradients allowing conducive conditions for high speed of wind. Also, there exists a large variation in the terrain conditions, which influence the wind movement significantly.

All these put together have a high potential for detailed study and analysis of wind and it's flow characteristics. Climatic and Geographic conditions have a distinct role in adversely affecting wind sensitive structures, built environment influencing the pollutant transport through air and wind energy potential. A large number of government, semi government and private agencies are involved in preparing suitable guidelines and methodologies to tackle such problems of societal importance. A strong need has been rightly felt in the country to propagate Wind Engineering as an important branch of engineering, dealing with issues of disaster and it's mitigation. Institutes of excellence in the country have been entrusted with the responsibility of developing relevant National facilities and trained human resources. Substantial in house research activities are being conducted by the educational institutes and research centers. Indian Society for Wind Engineering is playing a vital role in co-ordinating the research/ extension activities in bringing together the service providers and the user agencies in providing solutions for the problems affected by Wind and related Engineering.

1.1 SCOPE

Cyclones are intense low pressure areas - from the centre of which pressure increases outwards- The amount of the pressure drop in the centre and the rate at which it increases outwards gives the intensity of the cyclones and the strength of winds.

The criteria followed by the Meteorological Department of India to classify the low pressure systems in the Bay of Bengal and in the Arabian Sea as adopted by the World Meteorological Organisation (W.M.O.) are:

Types of Disturbances	*Associated wind speed in the Circulation*
1. Low Pressure Area	(< 31 kmph)
2. Depression	(31 to 49 kmph)
3. Deep Depression	(50 to 61 kmph)
4. Cyclonic Storm	(62 to 88 kmph)
5. Severe Cyclonic Storm	(89 to 118 kmph)
6. Very Severe Cyclonic Storm	(119 to 221 kmph)
7. Super Cyclonic Storm	(222 kmph and above)

Cyclones affect both the Bay of Bengal and the Arabian Sea. They are rare in Bay of Bengal from January to March. Isolated ones forming in the South Bay of Bengal move west north westwards and hit Tamil Nadu and Sri Lanka coasts. In April and May, these form in the South and adjoining Central Bay and move initially northwest, north and then recurve to the northeast striking the Arakan coasts in April and Andhra-Orissa-West Bengal-Bangla Desh coasts in May. Most of the monsoon (June - September) storms develop in the central and in the North Bay and move west-north-westwards affecting Andhra-Orissa-West Bengal coasts. Post monsoon (October-December) storms form mostly in the south and the central Bay, recurve between 15^0 and 18^O N affecting Tamil Nadu-Andhra Orissa-West Bengal-Bangla Desh coasts.

Cyclones do not form in Arabian sea during the months of January, February and March and are rare in April, July, August and September. They generally form in southeast Arabian Sea and adjoining central Arabian Sea in the months of May, October, November and December and in east central Arabian Sea in the month of June. Some of the cyclones that originate in the Bay of Bengal travel across the peninsula, weaken and emerge into Arabian Sea as low pressure areas. These may again intensify into cyclonic storms. Most of the storms in Arabian Sea move in west-north-westerly direction towards Arabian Coast in the month of May and in a northerly direction towards Gujarat Coast in the month of June. In other months, they generally move northwest north and then recurve northeast affecting Gujarat-Maharashtra coasts; a few, however, also move west north westwards towards Arabian coast.

Pre and Post-monsoon storms are more violent than the storms of the monsoon season. Life span of a severe cyclonic storm in the Indian seas averages about 4 days from the time it forms until the time it enters the land.

1.2 Destruction caused by Cyclones

There are three elements associated with a cyclone, which cause destruction. They are explained in the following paragraphs:

1. Cyclones are associated with high-pressure gradients and consequent strong winds. These, in turn, generate storm surges. A storm surge is an abnormal rise of sea level near the coast caused by a severe tropical cyclone; as a result, sea water inundates low lying areas of coastal regions drowning human beings and live- stock, eroding beaches and embankments, destroying vegetation and reducing soil fertility.
2. Very strong winds may damage installations, dwellings, communication systems, trees., etc. resulting in loss of life and property.
3. Heavy and prolonged rains due to cyclones may cause river floods and submergence of low lying areas by rain causing loss of life and property. Floods and coastal inundation due to storm surges pollute drinking water sources causing outbreak of epidemics.

It may be mentioned that all the three factors mentioned above occur simultaneously and, therefore, relief operations for distress mitigation become difficult. So it is imperative that advance action is taken for relief measures before the commencement of adverse weather conditions due to cyclones.

The most destructive element associated with an intense cyclone is storm surge. Past history indicates that loss of life is significant when surge magnitude is 3 metres or more and catastrophic when 5 metres and above.

1.3 Surge prone coasts of India

Storm surge heights depend on the intensity of the cyclone, i.e., very high-pressure gradient and consequent very strong winds and the topography of seabed near the point where a cyclone crosses the coast. Sea level also rises due to astronomical high tide. Elevation of the total sea level increases when peak surge occurs at the time of high tide.

Vulnerability to storm surges is not uniform along Indian coasts. The following segments of the east coast of India are most vulnerable to high surges

i) North Orissa, and West Bengal coasts.
ii) Andhra Pradesh coast between Ongole and Machilipatnam.
iii) Tamil Nadu coast, south of Nagapatnam.

The West coast of India is less vulnerable to storm surges than the east coast of India in terms of both the height of storm surge as well as frequency of occurrence. However, the following segments are vulnerable to significant surges :

i) Maharashtra coast, north of Harnai and adjoining south Gujarat coast and the coastal belt around the Gulf of Bombay.
ii) The coastal belt around the Gulf of Kutch.

Wind Engineering in India for the past three decades has been drawing the attention of Engineering community for need based research/extension services in the country. The prime focus for a long time continued towards the structural safety, but lately the focus has been diversified for computational wind engineering, environmental hazards and wind energy.

The Government of India and the decision makers, realizing the scope and utility of wind engineering have identified two major sectors of concern.

- Wind induced Disaster and its Mitigation
- Wind Energy

The material for part presentation subsequently has been taken from the paper presented in the International Workshop on Wind Engineering and Science (WES-04) by Dr. Prem Krishna, Emeritus Fellow, Department of Civil Engineering, Indian Institute of Technology Roorkee, India.

2 WIND INDUCED DISASTERS IN INDIA

It has been seen through literature that the Indian region is the worst to suffer from cyclonic storms in terms of loss of life. Typical images of cyclones and tornadoes are shown in Fig. 1. These storms are the major cause for Wind induced Disasters. Typical scenes of destruction can be seen in Fig. 2. The order of magnitude of these losses is similar to ones due to earthquakes & floods as shown in Table. 1.

Figure 1 : Typical images of Cyclones & Tornados

Figure 2 : Damage or Destruction of Structures

Table – 1 : Losses due to Different natural Hazards, Worldwide (1900 – 1976) [1].

	Gross	**Landslides, Avalanches, Volcanic Eruptions (%)**	**Cyclonic and other wind storms (%)**	**Floods (%)**	**Earthquakes (%)**
Deaths	4.58 m	2.93	10.83	28.10	58.14
People rendered homeless	2.32 m	-	12.07	75.45	42.45
Economic Losses	131200 m US $	7.62	36.43	18.37	37.58

It may be noted that Asia-Pacific region suffers the bulk of the natural disaster losses as shown in Table 2.

Table – 2: The losses from all Disasters (1985 – 2000) [2].

	Worldwide	**Asia-pacific**
Lives Lost	536,250	443,480 (82.7%)
Economic Losses US $	895,800	426,270 (47.5%)

It is seen that more lives have been lost in cyclones in the Indian region, as compared to the other regions of the world prone to cyclones – see Table 3.

Table – 3 : Deaths Associated with Noteworthy Tropical Cyclones [3].

India & Bangladesh	
Year	**Deaths**
1737	300,000
1787	10,000
1789	20,000
1822	50,000
1864	50,000
1876	215,000
1882	100,000
1941	5,000
1942	61,000
1955	1,700
1959	14,000
1960	10,000
1963	22,000
1965	15,000
1970	300,000
1971	9,658
1977	14,000
1985	10,000
1991	1,39,000
1999	10,000

China & Hong Kong	
Year	**Deaths**
1874	6,000
1881	300,000
1906	10,000
1912	50,000
1922	60,000
1927	5,000

Other Countries		
Country	**Year**	**Deaths**
Japan	1959	5,098
	1987	10,000
United Kingdom	1588	20,000
	1780	24,000
Haiti	1963	5,000
Honduras	1974	9,000
Puerto Rico	1899	6,000
United States	1900	6,000

It is also to be noted that loss of lives in India due to cyclones is more than that due to earthquakes (See Table 4). Losses due to cyclones are not surprising because the kinetic energy in a mature cyclone for maintaining the swirling motion (the horizontal wind) is estimated to be about half the world's electricity generating capacity [6]. This is an amazing amount of energy.

Table – 4 : Lives Lost in India (1900 – 1993) [5, 6]

Cyclones	82,234
Earthquakes	30,200
Floods	22,291

Data are often not consistent but the important fact is that losses on account of natural hazards are enormous. Furthermore, over the last few decades, there is an increasing trend of occurrences of hazardous events. (See Table 5). Whereas the loss of life may have reduced compared to earlier cyclonic events, the economic losses and insured loses have been increasing. Reduction in loss of life has occurred because of improved measures of crisis management – better prediction capability, more shelters, more organised management machinery. However there is as yet not enough thrust towards preventive measures which can not only save more lives but also economic losses. Although it is true to say that almost all the wind engineering activity in the country is geared towards disaster reduction, it is highly inadequate and a much greater coordinated thrust is required.

Table – 5 : Comparison of great Natural Disasters Decade-wise [2]

Decades	1960s	1970s	1980s	1990s
Numbers	27	47	63	84
Economic losses (US $ billion)	73.1	131.5	204.2	591

2.1 Mitigation measures in India

Wind engineering has developed in India to a good extent over the last 2-3 decades. The text below lists the major features of this development.

2.1.1 Organisational Effort

In order to provide a platform for exchange of ideas, fostering of interaction and increasing awareness amongst the wind engineering community, the Indian Society of Wind Engineering was established in 1993. As its first major activity the 9th International Conference on Wind Engineering was organised in 1995 at New Delhi, India, and there has been no looking back since. The society is now a member of the International Association of Wind Engineering which has created a more organised structure for itself in recent years.

Further, forced by frequent occurrence of disastrous natural hazards, several states have set up disaster management agencies, which have taken up varying degrees of extensional activity.

2.1.2 Codes & Standards

The latest revision to the major wind loading code, the IS:875 – part 3 was brought about in its 1987 version. This is a document prepared on contemporary lines. However, keeping in view the wind engineering developments of the period since, an academic exercise is in progress to produce a revision of the code.

2.1.3 Research and Development

Good facilities for industrial wind engineering have developed during the last two decades at IIT Kanpur, IIT Roorkee, SERC Chennai and IIT Delhi. Work at these centers includes research and studies related to field problems, which in broad terms is leading to greater safety, rationality and economy in wind-resistant design of structures and thus to disaster reduction.

An invaluable addition to current literature on Disaster Mitigation came in the form of the 'Vulnerability Atlas of India' in 1997. This document includes data on housing typology based upon the 1991 census and their vulnerability under various levels of wind, guidelines for enhanced wind resistance of buildings, and, other measures for greater safety against wind. The atlas is now under revision and will take account of the 2001 census as well as other technical developments in the intervening period.

2.1.4 Resulting Status

The aforesaid efforts have created, in reference to the Indian context, a strong base of personnel, documents, and know how which are being continually updated through ongoing research and developmental effort. Nevertheless the country continues to lose civil engineering structures – primarily dwellings – due to the wind hazard, thus inflicting a recurring loss on the population of the region and the National economy. The reason for this is the inadequacy of extensional activity and therefore the lack of awareness about the existing know how and its application.

In order to understand what needs to be done, the scenario requires further scrutiny. In this respect it will be appropriate to divide the affected structures into two parts – (i) dwellings and (ii) other structures. Bulk of the dwelling units are non-engineered and the majority of other structures are engineered. Also the major proportion of loss of life is due to the damage or destruction of housing. While in no way deteracting from the importance of the safety of other structures, let us focus on dwellings. The position vis-à-vis dwellings is as given below:

Considering the five coastal states of Andhra Pradesh, Orrisa, West Bengal, Tamil Nadu and Gujarat which are affected by cyclones, it is seen that a very large number of dwelling units are in the category of being "Very highly" vulnerable. The data is given in Table 6 is based on the 1991 census. In order to estimate the number for the year 2004, multiply by a factor 1.2 based on an annual incremental increase of 1.5%. Thus the number is of the order of 13.68 million, and this is only the very highly vulnerable ones, not to speak of those with lower levels of vulnerability. There will be a large number of such houses in other states too, but the situation is more serious in these five states.

Table – 6 : Numbers of Houses Very Vulnerable to Wind in Five Coastal States of India Affected by cyclones.

State	No. of Highly Vulnerable Houses*	% of Total no. in the State
Andhra Pradesh	1738000	10.45
Gujarat	1559800	15.12
Orissa	1446000	18.95
Tamil Nadu	899000	6.18
West Bengal	5754500	35.76

* Rounded off to the nearest hundred

2.2 Proposed Course of Action

A huge population of dwelling units such as the one identified in the earlier section can not be 'wished away' or replaced for obvious reasons. Effort has therefore to be made to strengthen / retrofit and salvage as many such units as possible, using the existing knowhow and techniques (and developing the same further). The other facet of the task is to ensure that new construction for both housing as well as other structures utilizes the latest engineering knowledge and technology as suited to the Indian Scenario.

2.3 Suggested Action Plan

- Continued improvement / development of the existing scientific / technical knowledge related to wind disaster prevention / reduction is imperative. This is already happening both at the International level as well as Nationally, but needs a further push in the Indian context. This will require involvement of such organizations as the BIS and selected R&D institutions.
- Awareness drive to acquaint the population in the effected region, who have stakes in ensuring greater safety against wind storms, with the existing relevant information mentioned in the previous paragraph. It will be more effective if the information is available in the local language.
- Training of technical hands, more specifically at the operational level, to enhance their capability in applying wind-resistant measures, as known at the present.
- Microzonation of affected regions to identify vulnerable housing stock and structures of post-cyclone importance and launching of a programme to increase their wind resistance, whether it implies repair, restoration or retrofitting.
- Testing of typical units treated be carried out 'on site' or by modeling in a laboratory to determine their capacity for resisting wind loading.

In order to sustain the above development there are two steps that are recommended –

1. To set up a closely spaced network of extension centers in both the affected coastal belts to coordinate the localized activity, functioning under the overall umbrella of a central agency.
2. As a parallel exercise to launch an awareness program amongst technical teachers, in order that students can be exposed to the subject.

3.0 Computational Wind Engineering

Computational method used in solving wind engineering problems mainly related to wind flow over bluff bodies such as square buildings. The research work on application of computational method in wind engineering began about two decades back and was pioneered by Prof Murakami's group in Japan. The computational method involves solution of unsteady Navier-Stokes equation with appropriate boundary conditions and use of suitable turbulence model. At present the main challenge before the researchers is development of suitable model for simulation of small scale eddies (Kolmogorov's scale). It appears that with the present computer facilities it is difficult to meet this challenge particularly for complex problems at high Reynolds Number usually encountered in wind engineering.

Rapid advance of computer technology, computational methods have become a powerful tool for solving diverse engineering problems of complex nature. The popularity of computational method is due to the fact that experimental techniques are quite time consuming, costly and expensive. This is particularly true in problems related to wind engineering. In cases where parametric variations need to be done experimental methods are quite laborious and time consuming. Further it is sometimes possible to simulate full scale boundary conditions in numerical method.

Computational methods have been applied in wind engineering to study wind flow pattern around buildings or a group of buildings with a view to understand flow interference effects and its relation to pollution dispersion, pedestrian comfort, ventilation in the building etc. Aerodynamic forces on the buildings have also been predicted through numerical simulation. The main complications of using numerical method arise due to bluff body shape of the structures with sharp corners in contrast with streamline bodies used in aerospace applications. Complicated flow fields around buildings consisting of impingement, flow separation, streamline curvature, reattachment and vortex formation remains the most challenging problem for computational specialists to tackle. Further complications arise due to the presence of turbulence. Anisotropic strain rates that develop on the body lead to complicated turbulence characteristics which has put a question mark on kind of modeling to be used for turbulence simulation.

Numerical predictions of flow around building are based on solution of Navier-Stokes equations with appropriate boundary conditions and turbulence simulation. The accuracy of predictions depends primarily on proper choice of boundary conditions, accuracy of discretisation methods and most important of all the proper choice of turbulence model. Literature shows that many researchers particularly a group headed by Prof Murakami in Japan have made significant contributions in the field of computational wind engineering in the past two decades.

4.0 CONCLUDING REMARKS

It is seen that wind and cyclonic storms cause as much (or even more) distress and loss in the country as compared to other natural hazards such as earthquakes and floods. Nevertheless, while fairly well organised activity has been initiated in respect of earthquakes, there is much less effort with respect to wind-induced disasters. In a way the latter can be taken up with comparatively less difficulty, the wind hazard being not so wide-spread as the regions that can be affected by earthquakes.

The chronological developments in research on computational wind engineering show that it has been the aim of researchers to obtain as accurate predictions as possible by using improved discretisation schemes and turbulence modeling. While the issue of discretisation schemes have been adequately addressed and standardized, the issue of turbulence modeling still poses a challenge to the researchers working in this field. The problem of resolving small scale eddies of Kolmogorov's scale is a problem still to be tackled. The three-dimensional LES model looks quite attractive but it requires very high computational space, time and cost particularly for flows with high Reynolds number over bodies of complicated shapes. The DNS model is still in its infancy. It has been used for solving flows at low Reynolds number over simple body shapes. LES will continue to engage the researchers for some more time. The use of DNS for solving wind engineering problems must wait till computers with much higher speed of computation and storage space are available.

Furthermore, it is noteworthy that scientific and technical knowhow is available in good measure to combat the problem arising from wind storms, though continued effort is necessary to improve upon the same, and this should be encouraged. On the other hand extensional activity is as yet very limited and this is an area requiring urgent and intense effort.

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