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Wind Engineering: Impact of Tornado on Low-rise building

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Abstract - The effects of wind loading on buildings due to straight line boundary layer type winds have been studied extensively in the past. Building code estimates are mainly based on these works. Little research has been, however, done to study the effect of tornado winds on built structures. Despite the destructive effects of tornadoes, limited attempts have been made to quantify tornado induced loading. This paper essentially deals with the study of the effects of tornado type wind loading on low-rise buildings. Origin of winds and wind loads on buildings as per Indian IS:875 (Part -3) have been discussed and investigated in detail. Thrusted areas of research covering the impact of tornado on low-rise buildings have been discussed.

Keywords - Wind engineering, tornado, IS:875, low rise buildings

I. INTRODUCTION

Wind has two aspects. The first - a beneficial one - its energy can be utilized to create energy, sail boats, cool down the temperature of the body. The other - a parasitic one - is that it loads any and every objects that comes in its way. The latter is the aspect an engineering is concerned with, since the load caused has to be sustained by a structure by a specified safety. Wind flow generation is on account of atmospheric pressure differential and it generates tornados, cyclones, thunderstorm etc. Tornado is violently rotating column of air (vortex) extending from a thunderstorm to the ground. It is formed when the rotating mass of air at the centre of the cloud extends downward. The tapering on the vortex funnel near the ground results in tremendous winds, due to vorticity and conservation of angular momentum. Every year, these high speed winds cause immense destruction to the life and property. Nearly 1000 tornados are reported every year in US. Annual damages can exceed over one billion dollars.

In most commonly occurring tornadoes that are EF-2 or of less intensity on the newly implemented Enhanced Fujita Scale, winds could reach 60 m/s (or 135 mph) near the ground. The importance of internal pressure inside a building in modifying the resultant uplift force on the roofing system was generally recognized, but has not been explored because of some limitations in the model geometry. It is known that the internal pressure inside a building is a function of air leakage through the building envelope because of intrinsic porosity present in the envelope and any dominant opening that could be triggered by a puncture in the envelope by wind-borne debris.

Some of the known facts about tornado are: winds can exceed 300 mph, around 1,000 occur on average each year in the U.S., can have a path up to a mile wide, can occur any time of the year, but peak during the spring (March-June), occur most frequently in the central US in a region nicknamed Tornado Alley, can occur almost anywhere in the world, duration of a few minutes, average diameter of 0.4 km, average length of path of 6 km, funnel can travel from 0 mph up to ~70 mph and usually travels at 30 mph, 99% of all tornados in Northern Hemisphere rotate counterclockwise, most likely to occur between 3 and 9 pm, but have been known to occur at all hours of the day or night, Texas is #1 for frequency of tornados per year. Few myths about tornado are: a highway overpass is a safe place to take shelter under during a tornado, opening windows during a tornado will help balance the pressure between the inside and outside of the house and may prevent destruction of the structure, one should seek shelter in the southwest corner of a house or basement etc.

Tornado Wind Speed (Fujita scale):
The intensity of the tornado is rated using Fujita scale, which is based on the damages caused by the tornado. The Fujita scale is divided in to 5 levels, the lowest being F0 (40-72 mph) and highest is F5 (261-318 mph). But 90% of the tornados are rated F2 (113-157 mph) or less. Currently, the low-rise buildings are designed for lower wind speeds based on the building codes. For example, in the region

called Tornado Alley the buildings are designed for a wind speed of 90 mph. There is little research done to estimate the wind loads on built structures due to tornados. The building code can be improved to cater for the effect of tornados; this will result in fewer losses in life and property damage. Figure 1 shows the tornado occurrence by category.

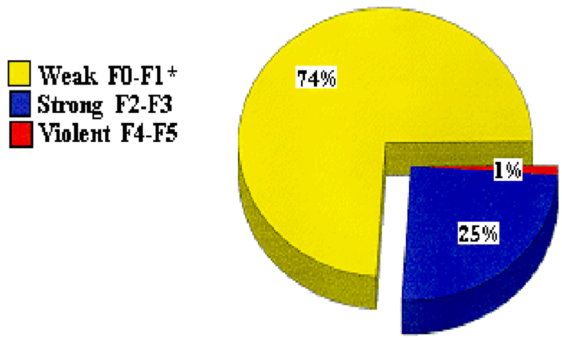

Figure 1: Tornado Occurrence by Category

Tornado Forecasting:
Meteorologists who predict tornado development analyze the current atmospheric conditions such as: air temp., barometric pressure, the locations of fronts, wind velocities, convection, etc. Probably the most useful tool a meteorologist can use to identify tornados is radar, specifically Doppler radar (WSR-88D)

Major losses all around the world due to Tornado:
In the past, large-scale damage and heavy loss of life were caused by intense tornado outbreaks in populated areas. The Tri-State Tornado of 18 March 1925 killed 695 people and the Natchez, MS tornado of 7 May 1840 claimed 317 lives. The 1965 Palm Sunday Outbreak was the second deadliest of the 20th century, killing 258 people and injuring 3,148. The Oklahoma City tornado (May, 1999) stands as the costliest tornado in US history having destroyed nearly 11,000 buildings. The damage from the May 1999 outbreak as a whole amounted to about $1.5 billion. In 2003, between May 1 and May 11, 395 tornadoes touched down in the United States.

This paper essentially deals with the study of the effects of tornado type wind loading on low-rise buildings. Origin of winds and wind loads on buildings as per Indian IS:875 (Part -3) have been discussed and investigated in detail. Thrusted areas of research covering the impact of tornado on low-rise buildings have been discussed.

Rest of the paper is organized as follows. Section 2 gives the major findings in the area of impact of tornado on low-rise buildings. Section 3 describes the tornado's impact on low-rise buildings. Origin of winds and wind loads on buildings as per Indian IS:875 (Part -3) have been discussed and investigated in detail in section 4. Section 5 makes a discussion on the thrusted areas of research covering the impact of tornado on low-rise buildings. Section 6, finally concludes the work.

II. RELATED WORK

The wind effects on structures due to straight line boundary layer flow have been studied vastly in the past. The wind design codes of various countries are giving recommendations based on these works only. However, a little research work has been done in recent years to estimate the effects of tornadoes that could occur during storm such as hurricanes and thunderstorms. The effects of vortex loading on structural projections will induce crosswind loads and torsional loads on low rise building which has severe dynamic resonant effect not only on the structural projections but also on over all structural elements of a building. So the pressure coefficients so produced could be totally different to what produced in boundary layer flow conditions [2].

Various codes of standards such as IS: 875 (Part-3)-1987, BS 6399-2:1997, ASCE-7-2010 are being used for the wind resistant design of buildings with attachment and in Japan AIJ recommends parallel information for design of buildings. The available information in these wind design codes are very limited and based on researches carried out in wind tunnels without the consideration of tornado attacks. In the situation of tornadoes, the suggested design parameters may not be sufficient for safe design of such projections. Paluch [1] presented the results of an investigation on the influence exerted by attached canopies on the static wind actions on arch roof industrial building. Six scale models of these arch roof building were tested for different dimensions and proportions. Total five types of canopies were attached to these models. All testing were done in straight line boundary layer flow conditions.

Iowa state university of USA took this important subject of research in consideration and presented good results of effects of tornadoes induced aerodynamic loads on the roofs of low- rise buildings. The study carried out by researchers was limited to the roofs of structures [3]-[4]. To quantify the interference effect on tornado-induced wind loads, systematic experiments were carried out in the Iowa state university by tornado simulator with typical configurations of a group of low-rise buildings. Wind loads on a low-rise gable-roof building model were first measured by varying the layout of surrounding buildings and compared with those of the isolated single building. Next, the flow structures in typical cases were visualized by Particle Image Velocimetry (PIV) technique. The purpose of flow study was to correlate the flow distribution around the test building model and in the street canyon surrounding the model with the resulting wind loads, and to better understand the mechanism of the interference effects.

Some of the studies involve measurements of load or surface pressure. For example, Ahmad and Kumar [5] examined interference effects of one and three similar buildings placed at upstream side of a hip roof building at fifteen locations in an atmospheric boundary layer wind tunnel. Remarkable effects on the surface pressure distribution were observed at critical roof positions of the test building.

III. TORNADO & ITS IMPACT ON LOW-RISE BUILDINGS

Tornadoes cause significant amounts of damage to buildings and most built structures are not designed to withstand these wind loads. Statistically 90% of all tornadoes are rated F2 or less on the Fujita Scale with maximum wind speeds less than 160 mph (3-sec gust). Hence it might be practical to design buildings to withstand these wind loads without escalating the building cost too significantly. The improvements in the building design must be made based on extensive wind tunnel testing. Numerical simulations are not feasible in terms of the computational resources required to capture the complex flow structure interaction. Specialized wind tunnels are required to simulate the tornado flow fields over building models.

For safe and economical design of these projections against wind forces, the wind design codes give some recommendations. In India IS: 875 (Part-3)-1987 is being used for the wind resistant design of buildings with attachment. The available information in these wind design codes is very limited and probably based on studied carried out in straight line boundary layer flow. A few researchers have taken interest in investigating the wind loads on low rise buildings with attached.

Various opinions as to whether tornado-resistant design of residential buildings is possible, let alone feasible, have been offered. These opinions have been largely motivated by experience obtained from evaluating structural failure due to strong winds and prejudiced by the awe-inspiring destructive capacity of tornadoes, but they have not been based on the comparison of pressure data obtained from either full-scale or laboratory simulated tornadoes with the capacities of the structural connections and members of typical residential construction. Modern engineering is based on the application of rational and empirical principles, but for tornado-resistant design, there has been little or no data that could be used to form engineering principles. In the past, quantification of pressures on a building envelope and forces on a building structure due to the occurrence of a tornado in its proximity has been limited to forensic investigation and engineering judgments. The reason for this limitation is threefold: the lack of research facilities capable of determining the pressures and forces on structures due to tornadoes; the absence of full-scale data to corroborate the results from laboratory experiments or field structures; and a lack of interest in pursuing tornado resistant design on the part of many as it was assumed to be cost prohibitive.

IV. WIND ENGINEERING

The wind is a movement of free air caused , on a large scale by thermal currents in the first 10 miles above the earth's surface. It is fundamentally caused by variable solar heating of the earth's atmosphere and initiated by the difference of pressure between points of equal elevation.
Origin of Wind:
Followings are the reasons of origin of wind:
- Temperature of the atmosphere
- Radiation in the atmosphere

In order to illustrate the role of the temperature distribution in the atmosphere in the production of winds, a simplified model of atmosphere circulation is being presented in figure 2. Figure 3 shows a simplified model of atmospheric circulation. Action of the model shown in figure 3 is shown in figure 4, which gives transport of heat through radiation in the atmosphere.

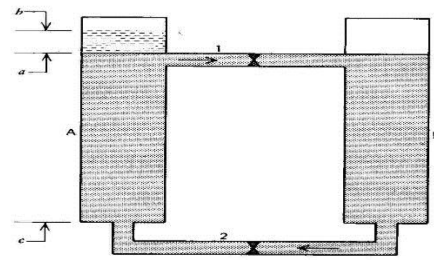

Figure 2: Circulation pattern due to temperature difference between two column of fluid

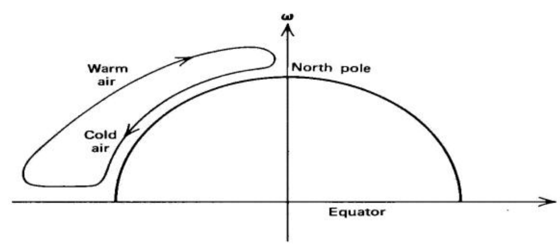

Figure 3: Simplified model of atmospheric circulation

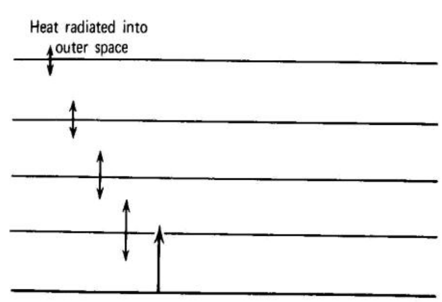

Figure 4: Transport of heat through radiation in the atmosphere

Besides these two reasons following may be the reasons of origin of wind.
- Compression and Expansion
- Molecular and Eddy conduction
- Condensation and Evaporation of water vapors

Wind loads on buildings as per IS:875 (Part -3):
In India IS:875 (Part-3) is available for calculation of wind loads on buildings. Some guidelines of IS code are:
Wind load on individual members,
F= (Cpe - Cpi).A.pd
Design Wind Pressure (pd), pd= 0.6 Vz^2
Design Wind Velocity (Vz), Vz= Vb.k1.k2.k3

External Pressure Coefficients (Cpe)
Cpe depends on various parameters like building height ratio, building plan ratio, wind angle etc. The range irrespective of these parameters are from +0.95 to –1.25. For Pitched Roofs, Cpe is influenced by slope of roof, direction of wind and height of building. Suction on windward slope first increase with roof slope up to 10° but later decrease when wind blows parallel to ridge. For Mono slope Roofs of Rectangular Buildings, the average Cpe with roof angle Φ from 5° to 30° and wind angle from 0° to 180° ranges from –1.0 to 0. Max suction will occur when θ=180°. For Canopy Roofs (with ¼< h/w <1 and 1< l/w <3),the value of pressure coefficients for mono pitched roofs are lower than that of double pitched roofs.

Internal Pressure Coefficients (Cpi)
It depends on the degree of permeability of building to the flow of air. The internal air pressure may be positive or negative depending on the direction of the flow of air in relation to opening in the building. The +ve value of Cpi is 0.2 and –ve value is 0.2. Both the design condition shall be examined i.e. +ve and –ve.

V. RESEARCH AREAS

Effects of tornado winds on particular types of low-rise buildings need to be further investigated in more depth. Majority of the work has been carried out for a smooth terrain. Different terrains can be simulated using various surface roughness and their effects on the structure of the vortex and the interaction with the building models can be studied. In most of the published work building model is tested in an isolated setup, ignoring the effects of surroundings, hence by creating an urban/sub-urban landscape, the effects of surrounding can be investigated in detail. PIV based testing can be adopted to study the flow pattern over the building model. The same can be used to understand the vortex structure. Hot wire measurements can be done to find the effects of averaging time. The internal pressure measurements should be carried out to estimate the actual uplift force.

VI. CONCLUSION

Tornado is violently rotating column of air (vortex) extending from a thunderstorm to the ground. It is formed when the rotating mass of air at the center of the cloud extends downward. The tapering on the vortex funnel near the ground results in tremendous winds, due to vorticity and conservation of angular momentum. Every year, these high speed winds cause immense destruction to the life and property. Nearly 1000 tornados are reported every year in US. Annual damages can exceed over one billion dollars. Despite the destructive effects of tornadoes, limited attempts have been made to quantify tornado induced loading. Codes of practices of various countries do not give enough information regarding pressure coefficients. Very little experimental research work has been done so far. It is required to carry out further studies to investigate the effects.

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