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Analysis of Wind Load Factors and Stability on Sensitive Structures

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Abstract - *The roofs of low-rise structures are usually flat, pitched / gabled, hipped, or curved. Structures with curved roof are being constructed to achieve large unobstructed spans like entertainment centres, exhibition centres, sports arenas, airport hangers, etc. which are essential for various functional requirements. These structures are generally constructed either at ground level or at an elevated level. Wind loads are considered to be one of the most important load criteria for the structural design of such structures. The aerodynamic behaviour and wind induced pressures over the curved roofsare being affected by major factors such as inflow characteristics such as mean velocity and turbulence intensity profiles, Reynolds number, surface roughness, angle of wind incidence, neighboring structures, size of tributary area and geometric proportions such as rise to span ratio, wall height to span ratio, length to span ratio and wall height to rise ratio. Based on the wind induced pressure information, database assisted design and equivalent static wind loading are used to establish wind loading for their structural design. Studies on the characteristics of wind pressure over curved roofs were reported over the last three decades. Based on the earlier studies, the rise to span ratio is observed to be significantly affecting the wind pressure on curved roofs. The side wall height to span ratio and building length to span ratio are the two other geometric proportions, which also influence the wind induced pressure on curved roofs, as reported in the literature. Further, most of the studies reported in the literature were conducted under any one type of flow conditions, viz. uniform flow, open and suburban terrain conditions*.

Key Words: ABLWT, CFD, fabrication of curved roof, models curved roofs, Under uniform flow 2d and 3d pressures coefficients.

1.INTRODUCTION

'Wind' or 'air in motion' usually creates a natural movement of air parallel to the earth surface creating a fast-moving current. It is caused due to the variation of temperature in the earth's atmosphere which in turn creates pressure differences, making the air or 'wind' to move from the high pressure region to the low pressure region. Further, due to the roughness of the earth's surface, turbulent boundary layer air flows take place with a varying gradient height depending upon the length of the fetch and the magnitude of the surface roughness. These turbulent boundary layer flows are characterized by randomly varying wind velocities and the presence of buildings in its way make the wind flow to deviate from its usual path. In the case of high-rise buildings, the wind will predominantly flow on both sides of the building, whereas, in the case of low-rise buildings, the wind will predominantly flow over the roof of the building. Since, low-rise structures top the list of civil engineering constructions a study on the effect of wind pressure on the roofs of these structures becomes mandatory.

1.1 Scope of the present study

- To study the wind induced pressure over a curved roof with specific rise to span ratio and length to span ratio.
- To study the effect of change in sidewall height to span ratios on wind induced pressure over the curved roof.
- To study the effect of flow conditions, viz. uniform or open and suburban terrains, on wind induced pressure over the curved roof.
- To study the effect of the angle of wind incidence, in the range between wind normal to the axis of the roof and wind parallel to the axis of roof, on wind induced pressures over the curved roof.

2. EXPERIMENTAL INVESTIGATION

2.1 Fabrication of curved roof models

In the present study, a wind tunnel pressure measurement on a curved roof structure with full-scale dimensions of length 135 m, span110.1 m and rise 32.1 m was considered. A scaled down ratio of 1:300 was considered in order to achieve the blockage ratio less than 5 %. The details of dimensions of 2-Dimensional '2-D' and 3-Dimensional '3-D' curved roof models (with and without walls) considered for wind tunnel experiments are given in Table-1. The curvature of the curved roof model considered in the present study is a circular arch with a radius of 0.21085 m and the subtended angle is 121 degree.

Table -1: Dimensions of curved roof models for experiments

Sl. No	Model code no.	Dimensions				Geometric ratios			
		Rise, f (m)	Span, d (m)	Length, L (m)	Wall height, h (m)	f/d	L/d	h/d	h/f
1	AA0-3D				0			0	0
2	SP0-3D				0			0	0
3	SP1-3D				0.0535			0.2	0.5
4	SP2-3D	0.107	0.367	0.45	0.107	0.3	1.2	0.3	1
5	SP0-2D				0			0	0
6	SP1-2D				0.0535			0.2	0.5
7	SP2-2D				0.107			0.3	1

2.2 Fabrication of curved roof models

A 3 mm thick acrylic sheet was chosen for the fabrication of the curved roof model. The sheet with required dimensions was placed in a thermal cyclic chamber for heating. After heating to the required level of flexibility, the acrylic sheet was placed on the cement mortar surface of the bottom mould. The heated sheet was loaded with the top mould and, allowed it to cool under ambient conditions in order to get the required curvature. Totally, two numbers of curved roof models without the presence of walls were fabricated with the required dimensions of length, span and rise.

2.3 Fabrication of curved roof models

Piezoelectric type differential pressure transducers were used in the wind tunnel investigations to measure the wind induced pressure fluctuations at high speed. These transducers measure the upstream dynamic pressure by measuring the pressure difference between the total pressure and static pressure from a pitot-static probe. Two commercial makes of pressure transducers were used i.e., PSI pressure transducers with 32 channels and Scanivalve pressure transducers with 32 / 64 channels. The PSI and Scanivalve pressure transducers are capable of capturing the pressures with sampling rate of 625 Hz and 500 Hz, respectively. The curved roof model AA0-3D was instrumented with area- averaged pressure ports using manifolds of 10 numbers along the arch direction at two different locations, (i.e.,) at mid-length and at half-way between mid-length and edge of the roof.

The 3-D curved roof models were instrumented with single point pressure ports and the pressure measurements were made under uniform, open terrain and suburban terrain conditions. For different wall height to spanratios and under each terrain condition, simultaneous pressures over the roof and wall were measured for angles of wind incidence, between 0° and 360° at 30° intervals. Pressure data sets were acquired for a duration of 15 seconds with sampling frequencies of 625 Hz by PSI pressure transducers and 500 Hz by Scanivalve pressure transducers.

3. EXPERIMENTAL RESULTS AND DISCUSSION

This chapter presents the results of mean / standard deviation of pressure coefficients of the 2-D / 3-D curved roof models of with height to spanratio of 0, 0.15 and 0.29 at two / three different locations for various angles of wind incidence under different terrain conditions. Further, comparison of the following results are also made and presented in the following sections.

- Variation of mean Cp values obtained using area-averaged pressure ports and single point pressure ports over 3-D curved roofs under open and suburban terrain conditions.
- Comparison of mean Cp values obtained from the wind tunnelexperiments and codes of practice over 3-D curved roofs for wind direction normal and parallel to the axis of roof cases.
- Pressure measurements on curved roof models were carried out using Atmospheric Boundary Layer Wind Tunnel (ABLWT) facility available at CSIR-Structural Engineering Research Centre (SERC), Chennai, India,which is an open circuit and blower type wind tunnel.
- The total length of the ABLWT is 52 m, with a long test section of 18 m. The test section has a width of 2.5 m and height of 1.8 m.
- The specifications of the ABLWT are given in Table-2.
- The wire-line diagram and the side view of the ABLWT are shown in Figures 3.12 (a) and (b).
- The wind tunnel has two turn tables,one on the upstream side and another on the downstream side of the test section, which can rotate at 360° in the azimuth direction to achieve different angles of wind incidence.
- A uniform flow condition was achieved on the upstream side of the test section, whereas, a turbulent boundary layer flow conditions (open and suburban terrains) were achieved.
- The downstream side of the test section, by blowing the wind over a trip board followed by a set of roughness boards, which were placed along the length of the test section.

Table -2: Specifications of ABLWT

Type	Open circuit blower
Fan	Axial flow
Variable speed	0.5 m/s to 55 m/s
Power for fan motor assembly	600 HP
Test section	18 m (L) × 2.5 m (W) × 1.8 m (H)
Contraction ratio	1:5
Exit velocity	11 m/s (maximum)
Ceiling	Adjustable

Fig-1 Side view of ABLWT

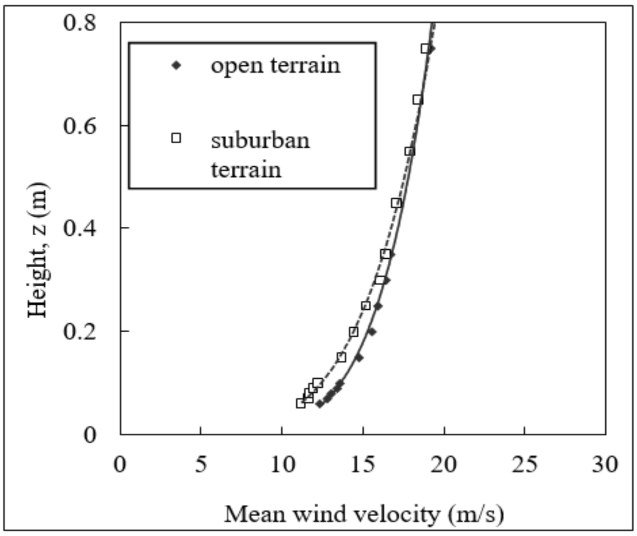

Chart-1 Simulated mean velocity profiles for two terrain conditions

Table -3: Details on instrumentation scheme, angles of wind incidenceand terrain conditions

Sl.no.	Model code no.	Type of pressure port adopted	Angle of wind incidence	Flow / terrain conditions	Transducers engaged	3-D/2-D
1	AA0-3D	Area-averaged using manifolds	0° to 360° in azimuth direction with 30° intervals including diagonal winds	Open and suburban	2 nos. of PSI	3-D
2	SP0-3D	Single point	0° to 360° inazimuth direction with 30° intervals including diagonal winds	Uniform, open and suburban	5 nos. (2 nos. of PSI + 3 nos. of Scanivalve)	3-D
3	SP1-3D					
4	SP2-3D					
5	SP0-2D	Single point	0° only	Uniform flow	12 nos. of PSI	2-D
6	SP1-2D					
7	SP2-2D					

Fig-2 Uniform flow

Fig-3 Open terrain

Fig-4 Suburban terrain

In the case of 2-D curved roof models, the instrumented 3-D curvedroof model was used for pressure measurements by extending it on either side to a length of 2.5 m, which is equal to the width of the wind tunnel testsection. These models were instrumented with single point pressure ports at central region of the roof over a length of 0.450 m and no instrumentation wasmade in the extended portion. Pressure data sets were acquired for a duration of 18 seconds with sampling frequency of 650 Hz by PSI pressure transducers and for a mean wind velocity of 16 m/s under uniform flow, measured at a level of the crown height of the models SP0-2D, SP1-2D and SP2-2D, respectively. Pressures were measured for only one angle of wind incidence i.e., wind normal to axis of the roof under uniform flow.

4. CONCLUSIONS

- The significance of wind induced pressures and their effects on cylindrical roofs under boundary layer flows were studied by various researchers using Atmospheric boundary layer wind tunnel (ABLWT).
- Based on the literature on the wind induced pressures and its effects on curved roofs, important issue to be studied were identified.
- In the present study, wind tunnel pressure measurements on 2-D and 3-D models of curved roof were carried out under uniform flow, open andsuburban terrain conditions.
- The curved roof has a rise to span ratio of 0.29, a length to span ratio of 1.23 and wall height to span ratios of 0, 0.15 and 0.29.
- The effect of wall height and flow conditions on the distributions of mean and standard deviation of pressure coefficients at edge and mid-length arches of the curved roof for various angles of wind incidence were investigated.
- The values of mean pressures coefficients obtained from the experiment were compared with the values given in various codes of practice. Further, a patch load method has been formulated for computation of peak loads by using the distributions of mean and standard deviation of pressure coefficients obtained from the wind tunnel pressure measurements.
- 2-D and 3-D numerical simulations on curved roofs were carried out using Realizable k-□ and Shear Stress Transport k-□ turbulence models to obtain the pressures exerted over the roof under uniform flow.
- The values of mean pressures coefficients obtained from the numerical simulations were compared with the experimental values for validation.
- Based on the wind tunnel experiments / Computational fluid dynamics (CFD) simulations carried out on 2-D and 3-D models of curved roof with different wall height to span ratio of 0, 0.15 and 0.29 under uniform flow, open and suburban terrain conditions, the following observations and conclusions are made.
- The effect of wall height to span ratio over 2-D curved roofs is observed to be significantly pronounced with the magnitudes of mean pressure coefficients in the windward quarter region reduced with increase in wall height to span ratio.
- The magnitudes of negative mean pressure coefficients in the center half and leeward quarter increased with increase in wall height to span ratio. On the leeward side the mean Cp values remain constant irrespective of wall height to span ratio.

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