Wind Tunnel Pressure and Acceleration Measurement studies on Tall Building Models Subjected to Different Wind Speeds

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***Abstract*: It is evident that due to rapid growth in population tall buildings are being raised in urban areas. The factors which mainly determines the need for tall buildings are limited space and significant cost of land in developing countries like India. In general, the tall buildings are of symmetric and regular in plan. These days tall buildings with different plan and shapes are being regarded and hence irregular plan shapes are also in place in the architectural design. The main objective of this paper is to study and analyze a tall building model of 232m (full height) subjected to different wind pressure and to measure its acceleration using ADLX-335 sensors to the applied wind load on various models on a 1:500 scale with conventional plan rectangular shape under isolated condition. to evaluate pressure co-efficient. This study is being conducted on a low-speed subsonic wind tunnel set up. The building model is of 10cmx20cmx47cm (lxbxh) The said test was conducted on three different models viz., Control Model, Wood Framed model, and Wood-Steel model. The pressure co-efficient are measured along 0-, 90- and 45-degrees angle of wind attack. Further, based on the variation of mean pressure co-efficient, critical angle of wind incidence and corresponding accelerations have been identified. The wind speed replicated different wind velocities for cities mentioned in IS 375 Part III The results showed that solid acrylic model showed considerably high vibration whereas due to low circumferential surface area wood framed and wood with steel ties showed low vibration levels.**

***Keywords*: Tall Buildings, Acceleration, Pressure co-efficient, ADLX-335 triaxial-accelerometers sensors, wind load, Building models**

1. Introduction:

In recent years, tall buildings with conventional plan and shapes are being common and are considered to have its own identity. Design of tall building, in general governed by either wind or earthquake load. The factors which govern the design of tall buildings are terrain conditions, height, aspect ratio etc. For tall buildings with convectional plan shapes appropriate wind loading co-efficient are generally available in the code of practice (IS: 875-Part3). However, IS:16700-2017 and IS:875 (Part3) standard gives guidelines for estimating the design wind load for tall buildings whose height greater than or equal to 252m.Further, these coefficients are available for only selected geometrics and selected wind speed incidence. The current code specifies only provision for calculating wind load by pressure/force coefficients for specified wind flow speed and specified terrain conditions flow conditions reported by Babitha, and Rajagopalan (2016)

Priyanga et al (2014) observed the characteristics of wind pressure on 1:2:7 rectangular modal under uniform flow using scan valve pressure transducers. In her study the mean pressure coefficients on the wind ward face was found to be comparable at all levels except for level 5. It was concluded that the edge effect on the average Cp values on the wind ward face were extended up to a region from the top of the building which was proportional to the projected width rather than proportional to the overall height of building. Katageri et al (2001) observed that the characteristics of motion induced modal wind force acting on tall buildings with irregular plan shapes that were conducted in boundary layer flows and the same was reported by Lakshmanan et al (2004), Harikrishna et al (2009) and Abraham et al (2012).

In the present study, wind tunnel experiment on a tall building model with conventional plan shape under isolated condition is conducted and the pressure measurement studies on a 1:2:8 rectangular building model has been carried out under uniform flow conditions. This paper also presents the variation of evaluated mean pressure/ force co-efficient for different angles of wind incidence along height of 1:2:8 building models. Further, the acceleration measurements were recorded using ADLX-335 triaxial-accelerometers sensors with the aid of NI-myRIO hardware for three types of models categorized based on material properties namely Control (Wood), Solid (Acrylic) and Wood framed with Steel model.

Surface wind pressure on tall building models was determined in low-speed subsonic wind tunnel. Pressure tapings were made along the periphery of the acrylic model five along the length and three numbers along breadth. These pressure tapings were in turn connected to u-tube manometers. Further, accelerations using tri axial accelerometers for tall building acrylic and wood framed models were recorded by fixing three tri-axial accelerometers on free end mid span of the model and fixed end. To record the accelerations a program was coded using LabVIEW. The signals obtained is later analyzed for FFT to obtain high frequency for respective wind speeds.

2. Experimental Work

2.1 Details of Models

A model (scale: 1:500) with a height of 47 cm and plan dimensions of 10cmx20cm of building with conventional plan shape as shown in the fig.1has been fabricated using 6mm thick acrylic sheet. The fabricated model gas 8 segments using 8 different levels. Pressure ports of each 0.5mm were drilled along the circumference of the rectangular building model at 4intermediate levels (Floor A to Floor D) 5.8, 17.4, 29, and 40.6cm of height respectively.

Below fig shows the schematic diagram of the model with locations of the pressure ports. It can be seen that a total number of 16 pressure ports (5 ports along the length for each side and 3 ports along with for each face) are provided at each level.

In this study uniform pressure on the building model surface have been measured using multi-tube manometer and restrictor-based tubing system which includes PVC tubes of 2mm outer diameter with lengths up to 20cm, which are in turn connected to multi-tube manometer.

2.2 Wind Tunnel Facility

The present study has been conducted in the low-speed subsonic wind tunnel available at wind tunnel lab, Dayananda Sagar College of Engineering. The wind tunnel was 6m long with a dimension of 600mm x 600mm cross section. Length of the test section is 2000mm. The building model was fixed firmly to the base of the test section at its center with help of fasteners. The plastic tubes from the tapping's were taken out and connected with multitude manometer, which contained water as the manometer liquid.

2.3 Pressure Measurements

In the present study, the fabricated building model was mounted in the upstream side of test section of the wind tunnel to measure the wind induced pressure under uniform flow conditions. The pressure measurements studies were conducted at different wind speed for different cities like Bengaluru, Pune and Hyderabad. The pressure measurements were made for three different angle of incidence 0, 90 and 45 degrees.

2.4 Tri-Axial Accelerometer

Table 1: Specifications of ADLX-335 Tri-Axial Accelerometer Sensor

Supply Voltage	3to 6
Each Axis Band Width	50Hz
Operating Temperature(̊C)	40to -90
Length(mm)	20
Width (mm)	17
Weight(gm)	0.6
Dimension (Cm)	4x3x1

Acceleration measuring code is programmed using LabVIEW and NI-myRio interface is used to record the acceleration, further three tri axial accelerometer is fixed to model at three different locations, viz., free end, mid span and fixed end.

Building model is fixed firmly to the rotating base with the help of nuts and bolts. Further the wind load, with necessary calculations is scaled down and applied over the model. Due to the applied load the model vibrates and hence the vibrations are recorded directly to the PC. In order to produce the reproducibility, three sets of readings were recorded.

Below figures shows three different types of models used for present work. Fig2 shows wood framed model with steel ties while wood framed alone without steel is considered as control model (wood framed model). Fig 3 Shows solid model made of acrylic material.

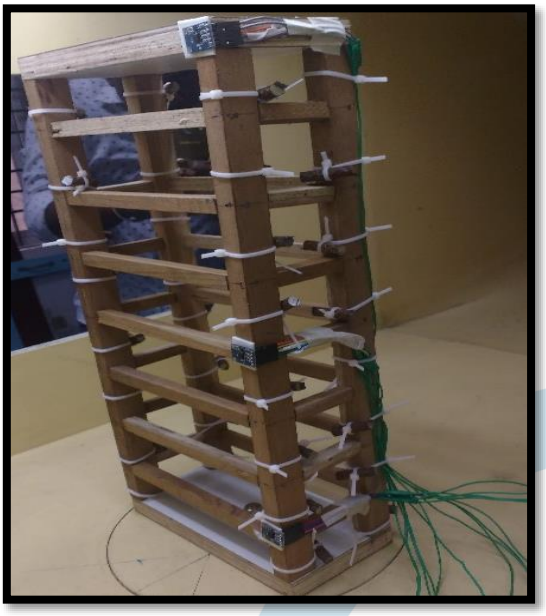


Fig.2.4.1: Wood-Framed Model with steel with accelerometers in place

Fig.2.4.2: Solid (Acrylic) Model with pressure tapings

3. Results and Discussions

3.1 Co-efficient of Pressure

The measured pressures on the building model have been analyzed to obtain mean and standard deviation values of pressure coefficient, lift coefficient, and drag coefficient. The co-efficient of pressure (Cp) is calculated for all the considered floor levels (ABCD) at angles 0^0,45^0 and 90^0 for three different locations i.e, Bengaluru, Pune and Hyderabad. As the manometer reading fluctuates both upper and lower reading in the multitude manometer is recorded. The co-efficient of pressure is calculated by applying below formula.

$$Cp=\frac{P-Pinf}{P0-Pinf} \qquad (1)$$

Where,

Cp= Co-efficient of Pressure

P= Monometer reading

P_{inf}= Free stream pressure

P_0= Stagnation Pressure

After calculating the co-efficient of pressure(Cp) for every face, there are four faces to model one which is against the direction of wind flow is considered as front face, opposite to it is a Rear face and the other two are Side faces (this will give two side faces at θ = 0°& 90° and zero side faces at θ = 45°).The graph ofCp is plotted against the distance which means x-axis is the distance from one corner to each different pressure ports and y-axis is co-efficient of pressure. Following are the Superimposed graphs showing the variation of mean Cp plotted against chord length i.e., circumferential distance of model showing pressure measuring points. The graphs are plotted for different wind conditions considering three different cities namely Bengaluru, Pune, and Hyderabad.

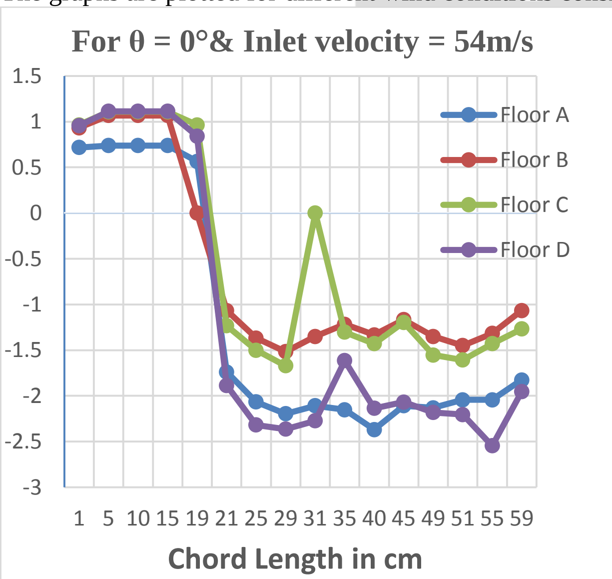


Fig.3.1.1: Mean Cp variation for θ = 0°&v = 54m/s

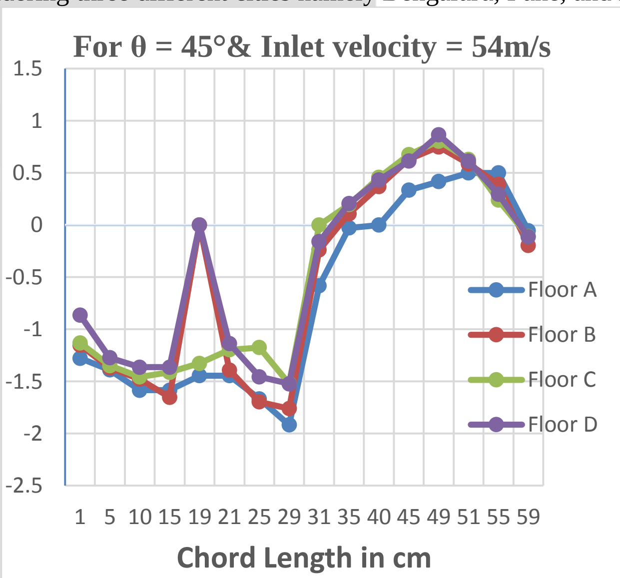


Fig.3.1.2: Mean Cp variation for θ = 45°&v = 54m/s

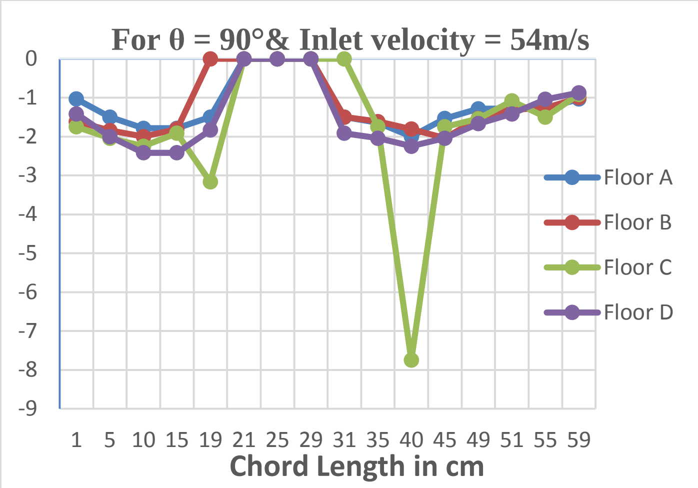


Fig.5: Mean Cp variation for θ = 90°&v = 54m/s

The above figures show the variation of mean Cp along the chord length for a wind velocity of 54m/s considering city Bangalore and angle of incidence of 0,45 and 90 degrees. It can be seen that the wind load acting on building at 0^0 angle gives the positive Cp on the front face and negative values of the same are obtained for other faces and its vice versa for θ = 45^0at all floor levels. Cp is negative at 90^0 angle of incidence for all the faces at deferent levels. For θ = 90^0, the front face pressure reading were negligible and nearer to zero.

The same is the case for two more Inlet velocities that is 72m/s for Pune city condition and 85m/s for Hyderabad city. This clearly indicates that Inlet Velocity of wind has least effect on Cp. In all the three angle of incidence, it was the intermediate level Floor C which shows abrupt change in the pressure readings, while it has to be the Floor D in practical.

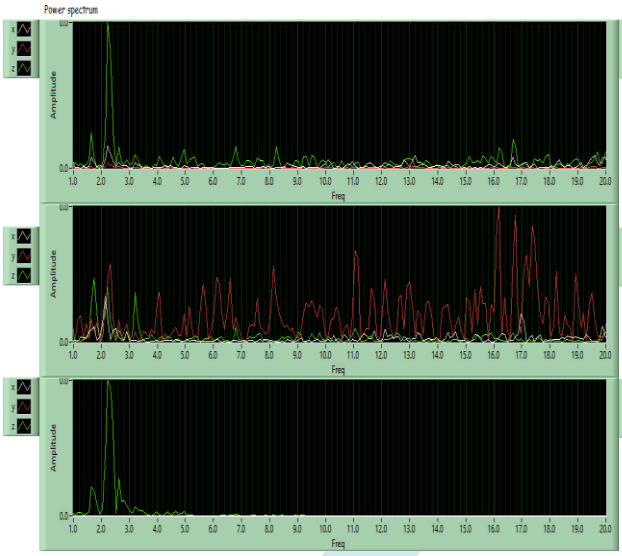
3.2 Acceleration Measurements

Accelerometer reading were recorded using ADLX-335 triaxial-accelerometers sensors with the aid of NI-myRIO hardware for three types of models were recorded. Table 2 shows the acceleration values of three models at wind velocity of 15 and 33m/s along x, y and z axes at three different faces. The obtained recordings were later incorporated to lab view and FFT analysis was performed for each set of readings which were shown in below figures. In order to produce the reproducibility, three sets of readings were recorded and the best suitable FFT analysis among the three is presented in the work below

Table 2: Acceleration measurements obtained from ADLX-335

Model Type	Wind Velocity (m/sec)	X1	Y1	Z1	X2	Y2	Z2	X3	Y3	Z3
Control	15	2.0	2.0	2.0	1.3	16.8	3.2	0	0	2.0
		2.1	2.1	2.1	1.9	16.1	1.8	0	0	2.1
		1.2	1.2	1.2	1.0	16.3	2.9	0	0	2.0
Control	33	17.6	17.5	16.1	0.01	5.3	6.3	0.01	5.3	1.3
		18.4	0.01	1.3	0	2.2	4.1	0	19	1.3
		19.1	19.1	19.3	1.0	19.0	1.3	0	19.0	1.3
Solid (Acrylic)	15	0	1.9	0	1.5	1.9	1.9	0	0	1.9
		0	1.8	0	1.9	1.7	1.5	0	0	1.5
		0	1.8	0	1.8	1.6	1.5	0	0	1.6
Solid (Acrylic)	33	0	2.5	0	1.8	1.8	1.8	0	0	1.6
		0	2.5	0	1.6	2.5	1.8	0	0	1.8
		0	1.8	0	2.0	1.8	1.8	0	0	1.8
Wood Framed+Steel	15	1.8	2.0	19.4	2.1	14.8	19.4	0	0	19.8
		2.0	2.0	2.0	2.0	2.0	2.0	0	0	2.0
		2.0	2.0	20.0	2.0	2.0	20.0	0	0	2.0
Wood Framed+Steel	33	1.8	1.8	19.4	2.4	1.8	19.2	0	0	1.9
		19.2	0	19.4	0	14.8	19.6	0	0	2.6
		18.6	0	19.4	14.2	14.8	19.4	0	0	2.6

Control Model



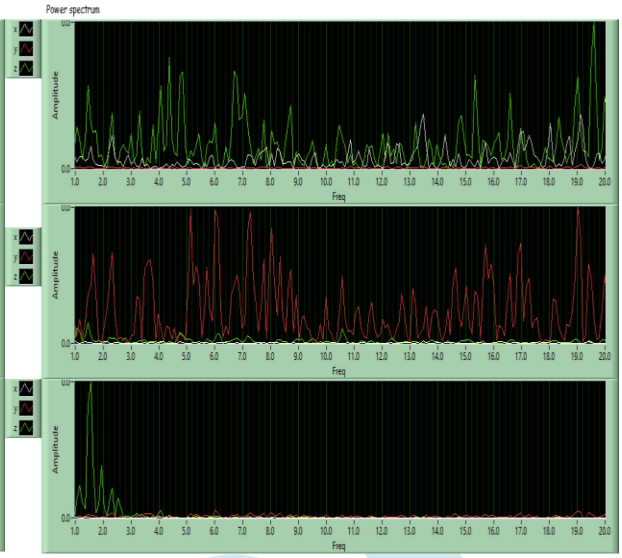
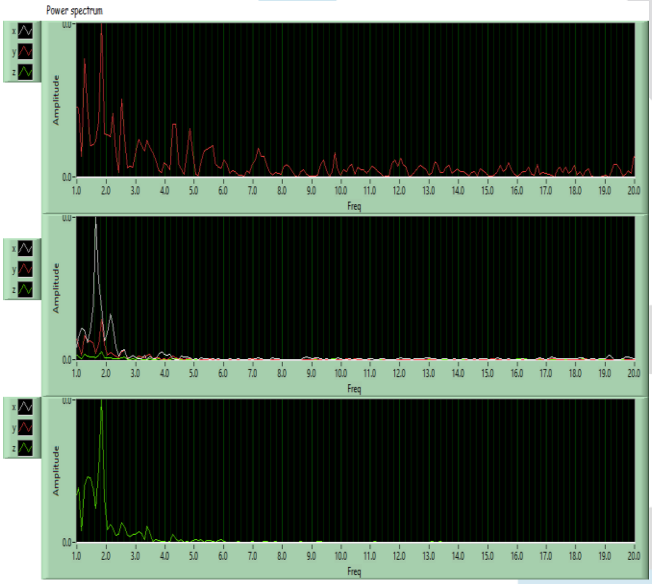


Fig.6: FFT for Wind Speed: 15 m/s

Fig.7: FFT for Wind Speed: 33 m/s

The above figures show the FFT analysis of accelerometer readings of Control model at wind speed of 15 and 33m/s, which clearly shows the increase of frequency levels all along the length in the top accelerometer compared to the other two as the wind speed increases.

Acrylic Model



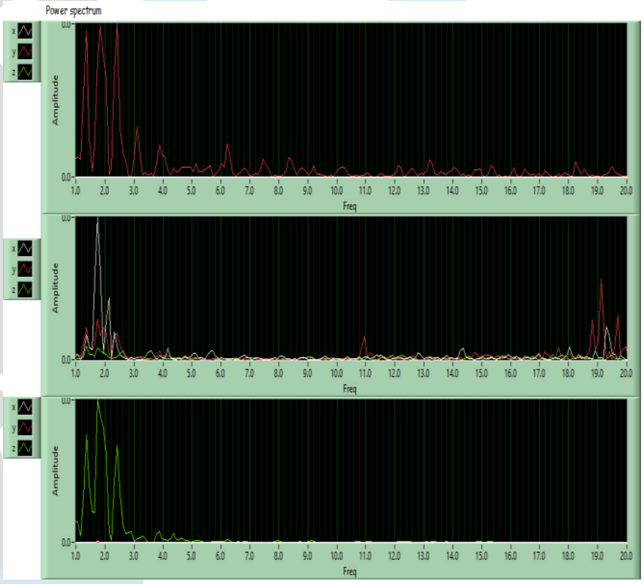


Fig.8: FFT for Wind Speed: 15m/s

Fig.9: FFT for Wind Speed: 33m/s

The above figures show the FFT analysis of accelerometer readings of acrylic model at wind speed of 15 and 33m/s, which shows that appreciable vibrations were not recorded compare to that of solid controlled model and also the there is no increase of frequency as the wind speed increases.

Wood with Steel ties Framed Model

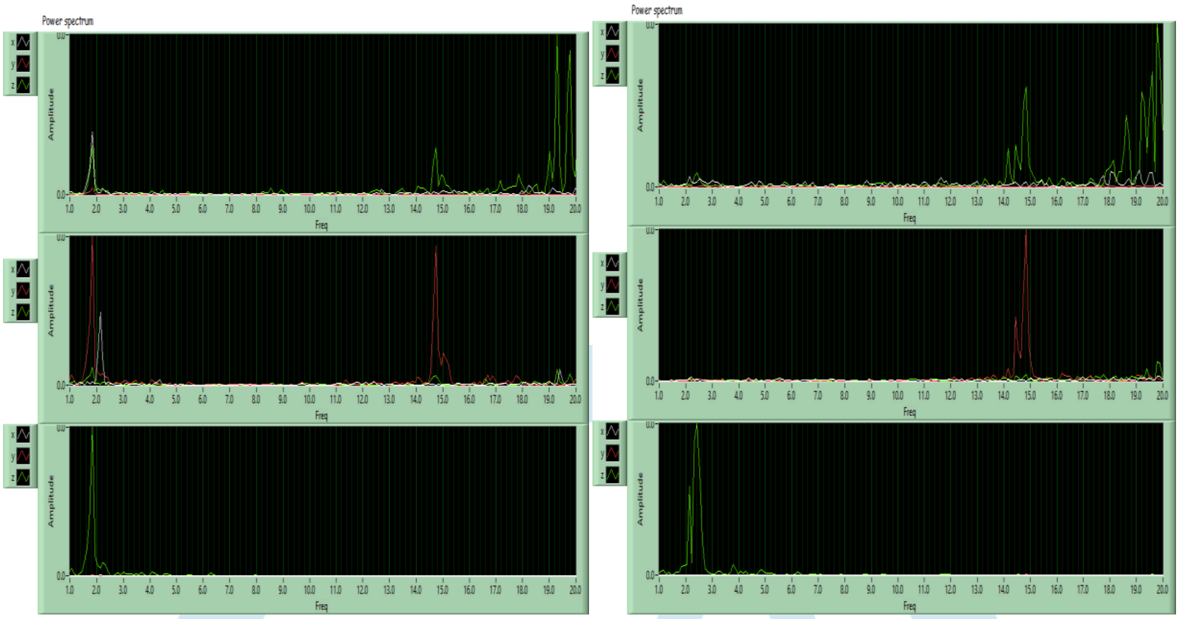


Fig.10: FFT for Wind Speed: 15m/s Wind Speed: 33m/s

The above figures show the FFT analysis of accelerometer readings of Wood +Steel Framed Model at wind speed of 15 and 33m/s, which shows that appreciable vibrations were recorded only in the top accelerometer and the increase of frequency with increase in wind speed is very minimum.

4. Conclusions

The following conclusions were drawn from the present work.

The value Cp and its variation at different angles shows that.

1. Control model, i.e., wood framed model showed considerably less frequency level when compared with the other two models. This may be because of lesser surface area exposed to wind attack
2. Solid acrylic model showed highest vibration level, this may be due to higher surface area of model, the drag coefficient was found to be high and hence the vibration level was high.
3. Wood framed along with steel model showed slightly higher amplitude at 33m/sec wind velocity.
4. It is observed that, due to constraints on placing models, at fixed end sensor few accelerations were recorded. However, it is considered as null.

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