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# Assessment Of Wind Effect on Tall Building of Varying Cross-Sectional Shape with Vertical Irregularity

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***Abstract***
*India's population is steadily growing, as is the amount of land required for habitation. It is essential to surviving somewhere. Because of this, multi-story structures are the greatest option for construction in metro areas with limited land. Designers are aware that multi-storey buildings offer huge floor areas in compact spaces, which is advantageous. As a result, building high-rise structures is necessary. The present study going to analyze the wind effects on the tall building where modification is provided in the vertical plane of the structure and the tall building is consisting of two types of cross-sectional shape such as square and plus shape and similar for C Shape and L Shape Cross section. High rise building mostly exposed to more environmental factor, such as wind effect, so this study investigates the effect of wind on tall buildings with along the wind direction and across the wind direction on various shape of the building under consideration, using ETABS20 software, do dynamic analysis by applying wind effect to various models in accordance with IS 875 Part III-2015. Compare regular and irregular buildings with different cross-sectional forms to determine which shape provides the least amount of story reaction.*
***Keywords:*** *Wind effect, High-rise Building, ETABS, Vertical Cross- Section, Dynamic Analysis*

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## I. Introduction

Tall buildings are thin, flexible structures, and it is necessary to do research to determine the significance of excitation or oscillations caused by wind both along and across the wind's path. The wind load on buildings and structures in India: A code of practice (IS-875 Part-3 1987)[1] gives a procedure to determine along and across the wind response of tall structures.[2]

The goal of this study is to examine how wind affects tall buildings that have modifications made to their vertical plane. These tall buildings have two different cross-sectional shapes: square and plus, which are similar to C and L shapes. Since high-rise buildings are typically more exposed to environmental factors, like wind, this study looks into how wind affects tall buildings both along and across wind directions on different building shapes. It does this by applying wind effect to different models in accordance with IS 875 Part III-2015 and using ETABS20 software to perform dynamic analysis, Comparative analysis of the receptive interference effects of wind on tall buildings in the square and +plan shapes in addition to the C and L shapes.[3]

In the high-rise building, wind is critical load and needs to be considered for safety and serviceability of structures. There is also need to understand critical effects and assess dynamic behavior of structures as per the provisions of established standards. The Indian standard IS 875(part 3) is revised in 2015[4], many modifications are carried out in sections related to dynamic wind effects, very few research papers are available in relevance to these effects. Thus, there is great need to understand dynamic wind effects in high rise structures, and prepare database for various sub sections and quantities mentioned in the standard.[5] As computing power has increased and the cost of solving complex flow problems has decreased, interest in using computational fluid dynamics (CFD) for wind-resistant building design has increased recently.[6]

A composite aerodynamic control, including the shape optimization of the cross-section (passive aerodynamic control) and air suction (active aerodynamic control[7]), is proposed to increase a tall building with a square cross-section's wind-resistance performance by obtaining a more significant reduction of the wind-induced responses.[8] When designing tall structures for wind loads, structural designers use applicable wind load standards to determine the appropriate wind force values acting on the buildings at various floor levels. While the specifications for square and rectangular plan shape structures with rectangular corners provide adequate information regarding wind pressure and force coefficients, such information is not accessible for buildings with irregular plan shapes. Indian standard on wind loads (IS: 875 (Part-3)-1987)[1] gives the external pressure coefficient values on square and rectangular plan shape clad buildings with rectangular corners for wind incidence angle perpendicular to one of the surfaces only. Whereas, it indicates the effect of height to width ratio on pressure coefficients as well as force coefficients, no information about force coefficients on buildings with varying cross- sectional shape, but having same floor area, is available.[9] The comparison is made on the basis of mean wind coefficients, pressure contours and velocity profiles at different height.[10]

Wind effects on tall buildings

Building height increases lead to a significant rise in wind loads on structures. In addition, wind pressure rises as the square of wind speed, and wind speed increases with height. As a result, the impacts of wind on tall buildings get stronger as they go taller. In addition, tall buildings have gotten lighter and more efficient due to advancements in analytical techniques, architectural treatment, and material strengths. This has made them more susceptible to deflection and even swaying under wind loads.[11]

With the development of technology, composite plan shape buildings like pentagon, hexagon, etc. have been given consideration by many architects while keeping in mind the building's aesthetics. In the current research, two structure model with the plan shapes of a square and a pentagon have been taken into consideration. On each face of the square and pentagon buildings, the average value of the coefficient of pressure Cp is computed. lever side is discovered to have negative pressure, and the pressure contours for the side faces are identical. A recirculation zone is shown by vertical flow patterns to be one-third of the building's height. While horizontal flow patterns show the development of a vortex in the building's wake.[12]

## II. Structural Modelling

To study wind effect of different shape of tall structures subjected to wind excitation. In order to evaluate lateral displacement and storey drift between different shape of buildings using static linear analysis of some samples of G+64 namely Square, 16 +, 32 +, 48 +, 64 +, 16 L, 32 L, 48 L, 64 L, 16 C, 32 C, 48 C and 64 C are analyzed on ETABS. Model 'Square' have a 192 m height with regular square cross- section and other models have a total height of 192 m built of two types of cross – sections 16 +, 32 +, 48 + and 64 + are plus and square, 16 L, 32 L, 48 L and 64 L are L shape and square and 16 C, 32 C, 48 C and 64 C are C shape and square. These models differ by the heights of the cross sections only. Plus and square cross – section heights for Model '16 +' are 48 m and 144 m respectively, for Model '48 +' are 144 m and 48 m respectively, for Model '32 +' are 96 m each, similarly for L shape and C shape. Total height and locality for all models are same as shown in Fig.1 (a)

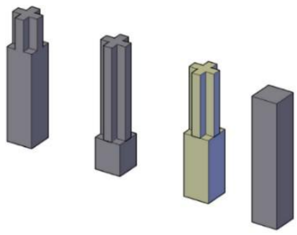

**Figure No. 1** 3D view of Model 16+, 48+, 32+ and Square

**Table no. 1** Sectional properties

| Parameters | Dimensions |
|---|---|
| No. of Storey | G+64 |
| No. of bays in X and Y direction | 3 |
| Length along X direction | 13.33 m |
| Length along Y direction | 13.33 m |
| Size of Column Storey 1-16<br>Storey 17-32<br>Storey 33-48<br>Storey 49-64 | 1800 X 900<br>1500 X 900<br>1200 X 900<br>1000 X 900 (All in mm X mm) |
| Size of Beam | 600 X 900 (mm X mm) |
| Depth of Slab | 150 mm |

| | |
|---|---|
| Storey Height | 3 m |
| Height of the Building | 192 m |
| Area of Plan | 40 X 40 (m X m) |
| Shape of Plan View | Square, + Shape, C Shape, L Shape |

**Table no.2** Material properties

| Parameters | Values |
|---|---|
| Concrete Grade | M35 |
| Young's Modulus of Concrete | 29580 Mpa |
| Concrete Density | 35 $kN/m^3$ |
| Steel Grade | Fe500 |
| Young's Modulus of Steel | $2 \times 10^5 N/mm^2$ |
| Steel Density | 76.98 $kN/m^3$ |

**Table no.3** Seismic Data

| Parameters | Factors |
|---|---|
| Location | Bangalore |
| Seismic Zone | II |
| Zone Factor (Z) | 0.24 |
| Importance Factor (I) | 1.15 |
| Response Reduction Factor (R) | 5 |
| Type of Soil | Medium (II) |

Model 'Square': G+ 64 building consisting of complete Square Cross-section shape for all stories

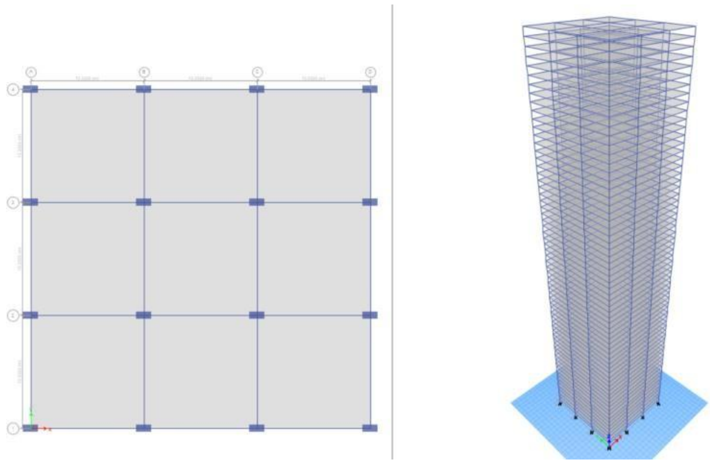

**Figure No. 2** Plan and 3D view of model Square

Model '16 +': G+64 building consisting of 48 stories square cross-section and above 16 are in '+' cross-section

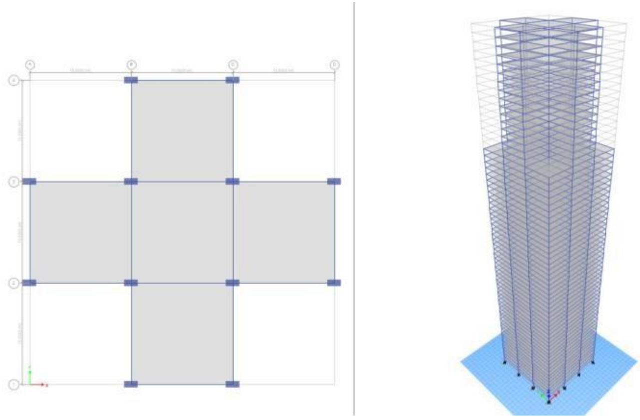

**Figure No. 3** Plan and 3D view of model 16 +

Model '32 +': G+64 building consisting of 32 stories square cross-section and above 32 are in '+' cross-section

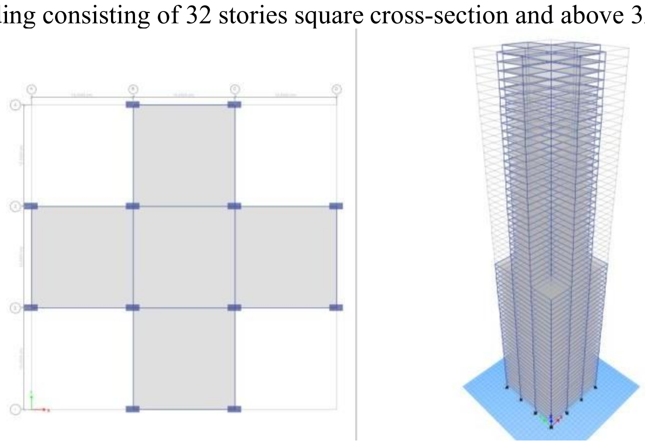

**Figure No. 5** Plan and 3D view of model 32 +

Model '48 +': G+64 building consisting of 16 stories square cross-section and above 48 are in '+' cross-section

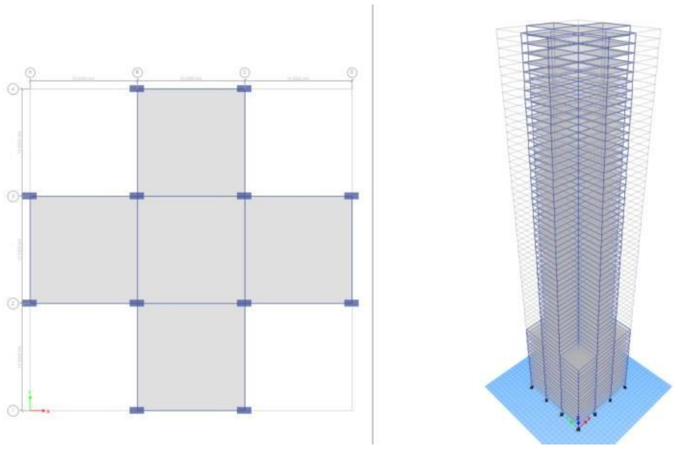

**Figure No. 4** Plan and 3D view of model 48 +

Model '64 +': G+ 64 building consisting of complete '+' cross-section shape for all stories

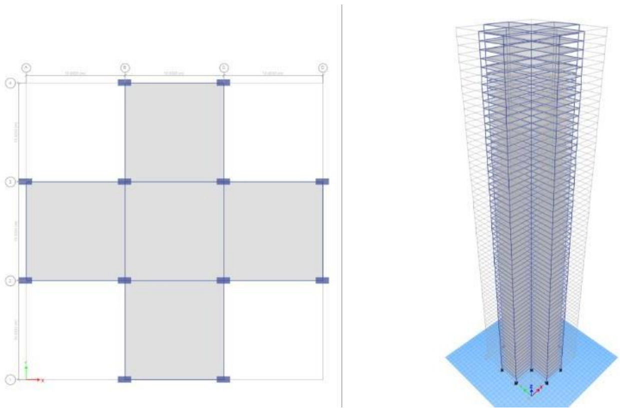

**Figure No. 6** Plan and 3D view of model 64 +

Model '16 L': G+64 building consisting of 48 stories square cross-section and above 16 are in 'L' cross-section

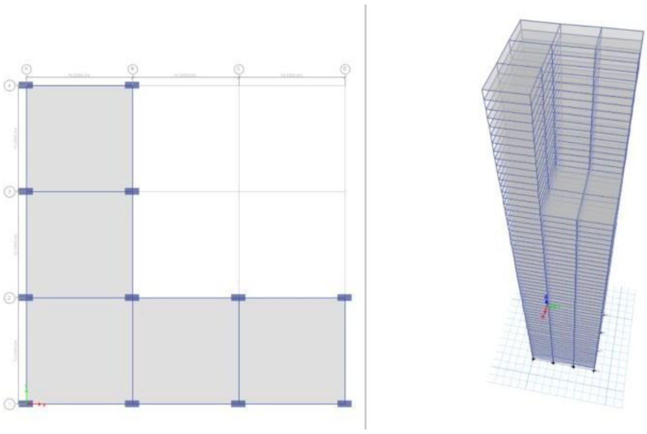

**Figure No. 7** Plan and 3D view of model 16 L

Model '32 L': G+64 building consisting of 32 stories square cross-section and above 32 are in 'L' cross-section

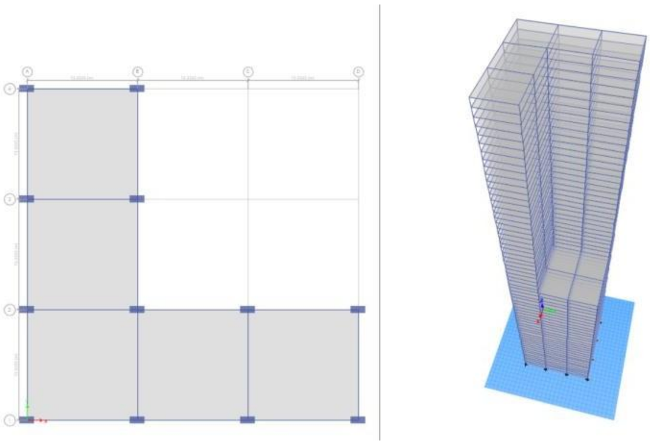

**Figure No. 8** Plan and 3D view of model 32 L

Model '48 L': G+64 building consisting of 16 stories square cross-section and above 48 are in 'L' cross-section

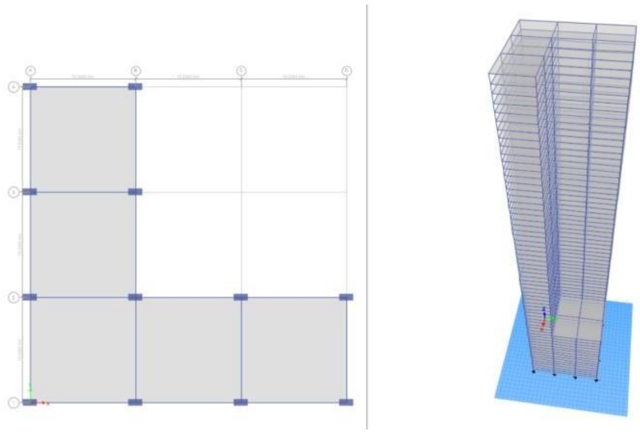

**Figure No. 9** Plan and 3D view of model 48 L

Model '64 L': G+ 64 building consisting of complete 'L' cross-section shape for all stories

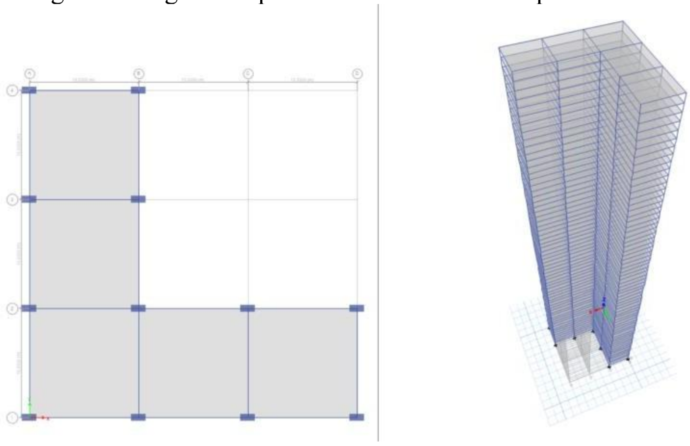

**Figure No. 10** Plan and 3D view of model 64 L

Model '16 C': G+64 building consisting of 48 stories square cross-section and above 16 are in 'c' cross-section

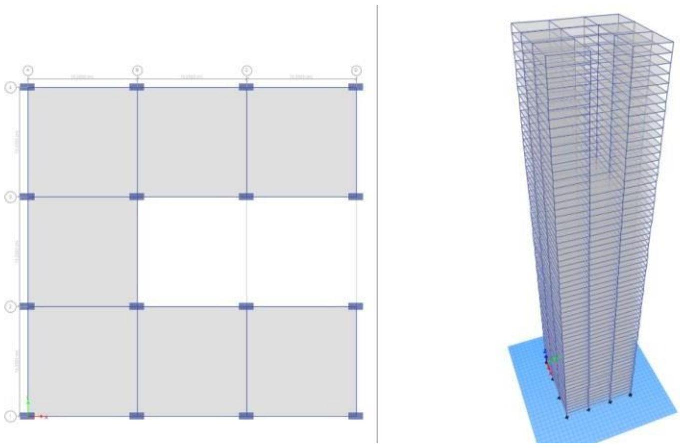

**Figure No. 11** Plan and 3D view of model 16 C

Model '32 C': G+64 building consisting of 32 stories square cross-section and above 32 are in 'C' cross-section

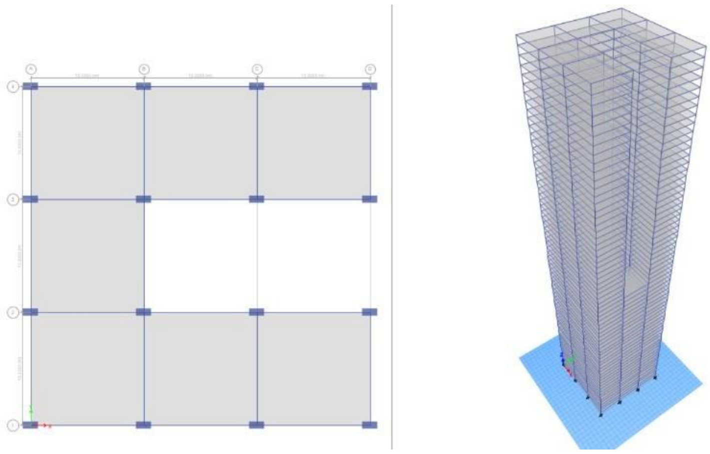

**Figure No. 12** Plan and 3D view of model 32 C

Model '48 C': G+64 building consisting of 16 stories square cross-section and above 48 are in 'C' cross-section

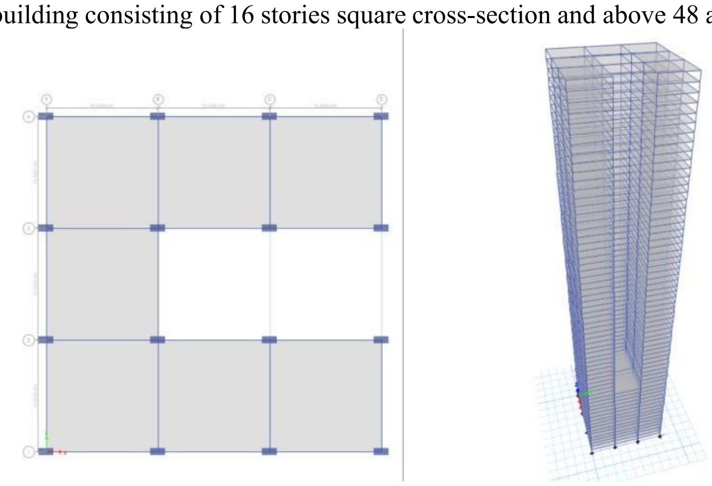

**Figure No. 13** Plan and 3D view of model 48 C

Model '64 C': G+ 64 building consisting of complete 'C' cross-section shape for all stories

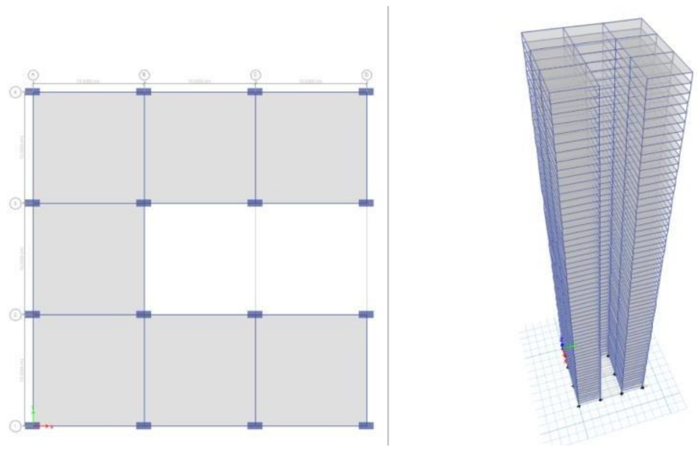

**Figure No. 14** Plan and 3D view of model 64 C

## III.Loading Details

The dead load will be considered as self-load of all structural member Live load on all floors is 3 $\boldsymbol{kN/m}$ as per IS 875 Part II- 1987
Floor finish is 1 $\boldsymbol{kN/m}$ for all floor
The wind load and wind parameters will be considered as per IS 875 Part-III -2015 are as follows,

**Table no.4** Wind Parameters

| Parameters | Factors |
|---|---|
| Location | Bangalore |
| Basic Wind Speed | 33 $m/s$ |
| Risk Coefficient Factor ($k_1$) | 1 |
| Topography Factor ($k_2$) | 1 |
| Terrain category 2 Height Factor ($k_3$) Topographical faction is less than 3° | 1 |
| Importance Factor ($k_4$) | 1.15 |

Basic wind speed ($V_b$)

Figure 15 gives basic wind speed map of India, as applicable at 10 m height above mean ground level for different zones of the country. Basic wind speed is based on peak gust speed averaged over a short time interval of about 3 seconds and corresponds to 10m height above the mean ground level in an open terrain (Category 2). Basic wind speeds presented in Fig. 15 have been worked out for a 50-year return period. The basic wind speed for some important cities/towns is also given in Appendix A.[4]

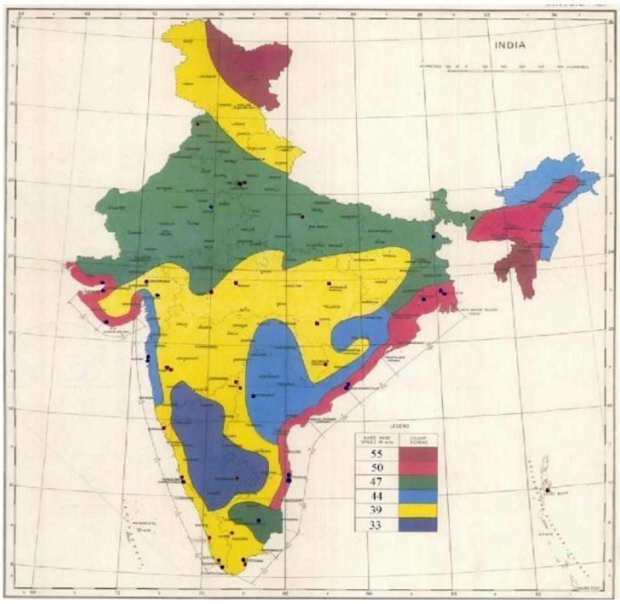


**Figure No. 15** Basic Wind Speed As per IS 875 Part III 2015

Design wind speed ($V_Z$)

The basic wind speed for any site shall be obtained from Fig. 15 and shall be modified to include the following effects to get design wind speed, ($V_Z$) at any height, Z for the chosen structure: (a) Risk level, (b) Terrain roughness and height of structure, (c) Local topography, and (d) Importance factor for the cyclonic region. It can be mathematically expressed as follows:

$$V_Z = V_b k_1 k_2 k_3 k_4$$

where,

$V_Z$ = design wind speed at any height z in m/s,

$k_1$ = probability factor (risk coefficient)

$k_2$ = terrain roughness and height factor

$k_3$ = topography factor and

$k_4$ = importance factor for the cyclonic region. [4]

Design wind pressure ($P_z$)

The wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind speed:

$$P_Z = 0.6\, V^2{}_Z$$

where
$P_z$ = wind pressure in $N/m^2$ at height z, and
$V_z$ = design wind speed in $m/s$ at height z.
The design wind pressure $P_d$ can be obtained as,

$$P_d = k_d k_a k_c P_z$$

where
$k_d$= Wind directionality factor
$k_a$ = Area averaging factor
$k_c$= Combination factor [4]

## IV.Results and Discussion

The assessment of wind load is carried out on all models using ETABS20 along the wind direction and across the wind direction and effect of wind load in the form of response of lateral displacement and story drift are as followings,
Lateral Displacement- As per IS 456-2000, the lateral sway at the top of the building shall not exceed H/500 for transient wind loads[13], where H is total height of the building is 192 m, that means lateral displacement shall not exceed than 384 mm
Story Drift – As per IS 1893-part 1-2016, the storey drift in any storey due to the minimum specified design lateral force, with partial load factor of 1.0 shall not exceed 0.004 times storey height is 3 m[14], that means story drift shall not exceed than 0.012

**Table no.5** Results of model Square, 16 +, 16 L, 16 C

| Parameters | Square Shape C/S | + Shape C/S (48 Square and 16 '+' C/S) | L Shape C/S (48 Square and 16 'L' C/S) | C Shape C/S (48 Square and 16 'C' C/S) |
|---|---|---|---|---|
| Displacement in X Direction (mm) | 208.022 | 213.671 | 211.193 | 208.337 |
| Displacement in Y Direction (mm) | 222.515 | 228.314 | 226.022 | 225.050 |
| Story Drift in X Direction | 0.000361 | 0.00041 | 0.000577 | 0.000364 |
| Story Drift in Y Direction | 0.000334 | 0.00036 | 0.000526 | 0.000453 |
| | | | | |

**Table no.6** Results of model Square, 32 +, 32 L, 32 C

| Parameters | Square Shape C/S | + Shape C/S (32 Square and 32 '+' C/S) | L Shape C/S (32 Square and 32 'L' C/S) | C Shape C/S (32 Square and 32 'C' C/S) |
|---|---|---|---|---|
| Displacement in X Direction (mm) | 208.022 | 238.835 | 222.897 | 209.212 |
| Displacement in Y Direction (mm) | 222.515 | 254.460 | 238.779 | 233.577 |
| Story Drift in X Direction | 0.000361 | 0.000499 | 0.000821 | 0.000364 |
| Story Drift in Y Direction | 0.000334 | 0.000454 | 0.000770 | 0.000614 |

**Table no.7** Results of model Square, 48 +, 48 L, 48 C

| Parameters | Square Shape C/S | + Shape C/S (16 Square and 48 '+' C/S) | L Shape C/S (16 Square and 48 'L' C/S) | C Shape C/S (16 Square and 48 'C' C/S) |
|---|---|---|---|---|
| Displacement in X Direction (mm) | 208.022 | 286.361 | 243.020 | 210.594 |

| | | | | |
|---|---|---|---|---|
| Displacement in Y Direction (mm) | 222.515 | 303.579 | 260.531 | 247.632 |
| Story Drift in X Direction | 0.000361 | 0.000618 | 0.001084 | 0.000364 |
| Story Drift in Y Direction | 0.000334 | 0.000575 | 0.001030 | 0.000796 |

**Table no.8** Results of model Square, 64 +, 64 L, 64 C

| Parameters | Square Shape C/S | + Shape C/S (64 Storey) | L Shape C/S (64 Storey) | C Shape C/S (64 Storey) |
|---|---|---|---|---|
| Displacement in X Direction (mm) | 208.022 | 333.121 | 258.961 | 211.992 |
| Displacement in Y Direction (mm) | 222.515 | 354.837 | 280.953 | 259.595 |
| Story Drift in X Direction | 0.000361 | 0.000676 | 0.001203 | 0.000364 |
| Story Drift in Y Direction | 0.000334 | 0.000633 | 0.001147 | 0.000877 |

Comparison of regular building that is square cross-sectional with all other cross-sectional shape buildings along the wind direction i.e. X and across the wind direction i.e. Y

**Observation via graphic Lateral Displacement**

Comparison of displacement of square building with another having cross-section of '+', 'L' and 'C'

- G+64 having 48 stories are square cross-section and above 16 are in different cross-section

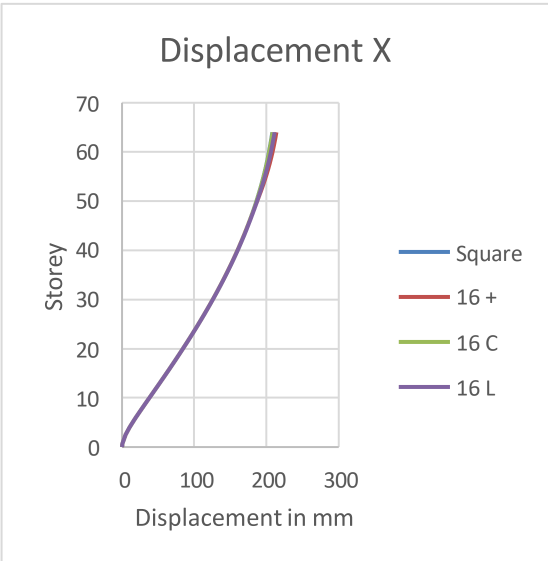


**Figure No. 16** Displacement along the wind direction 0°

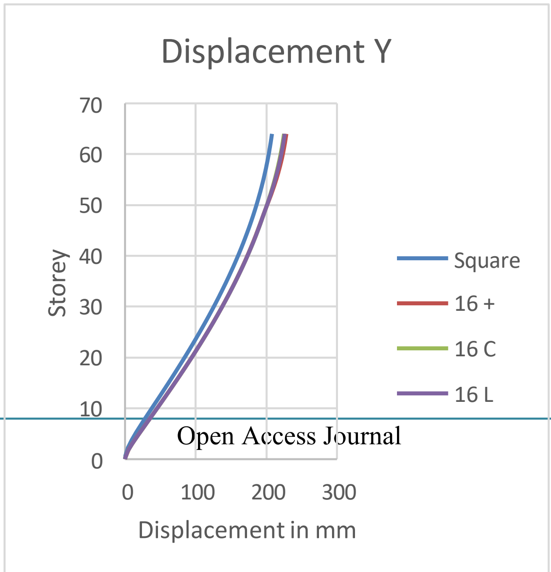

**Figure No. 17** Displacement across the wind direction 90°

- G+64 having 32 stories are square cross-section and above 32 are in different cross-section

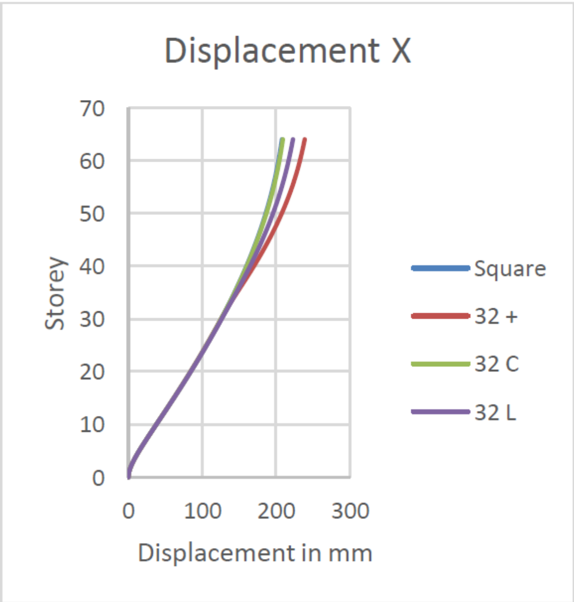


**Figure No. 18** Displacement along the wind direction 0°

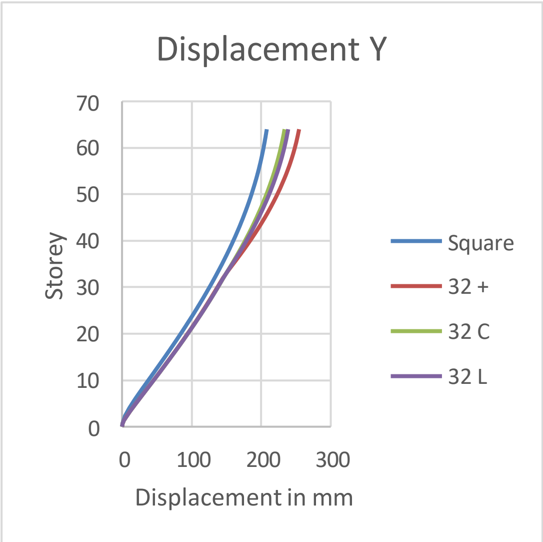


**Figure No. 19** Displacement across the wind direction 90°

- G+64 having 16 stories are square cross-section and above 48 are in different cross-section

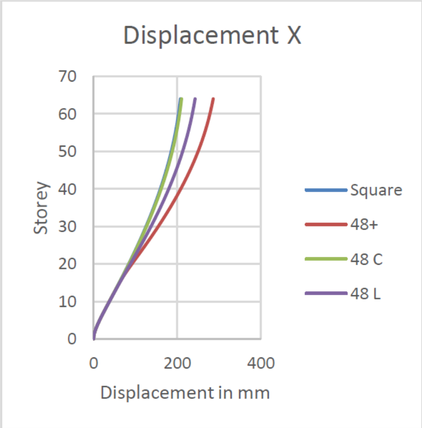


**Figure No. 20** Displacement along the wind direction 0°

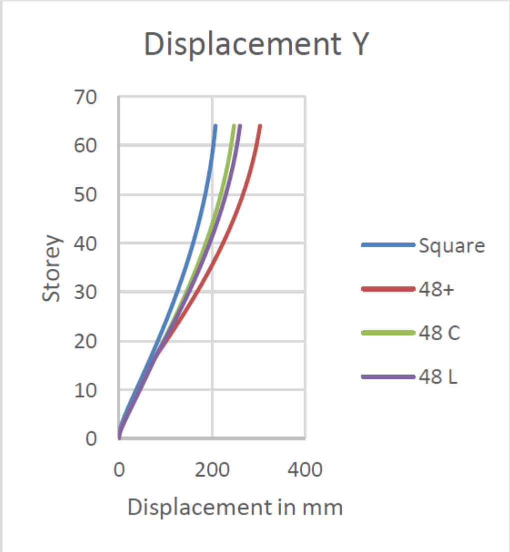


**Figure No. 21** Displacement across the wind direction 90°

- G+64 having same cross-section throughout the building.

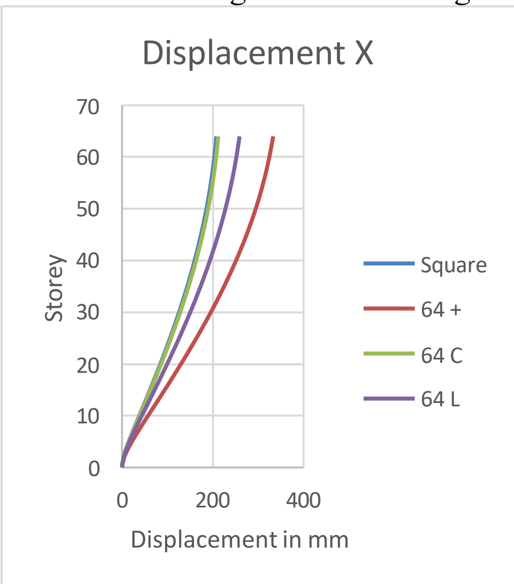


**Figure No. 22** Displacement along the wind direction 0°

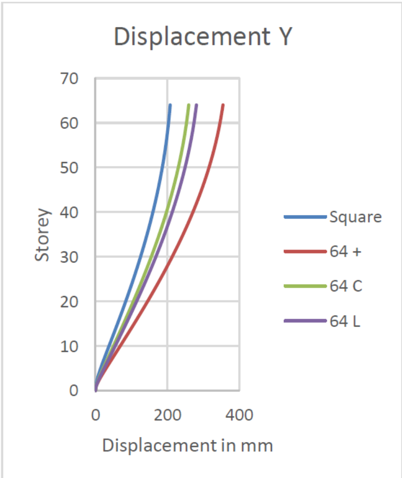


**Figure No. 23** Displacement across the wind direction 90°

**Story Drift**

Comparison of story drift of square building with another having cross-section of '+', 'L' and 'C'

- G+64 having 48 stories are square cross-section and above 16 are in different cross-section

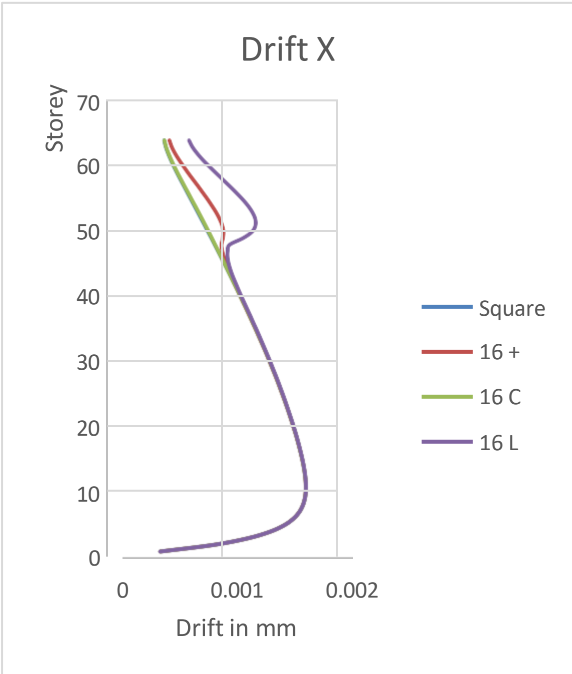


**Figure No. 24** Story Drift along the wind direction 0°

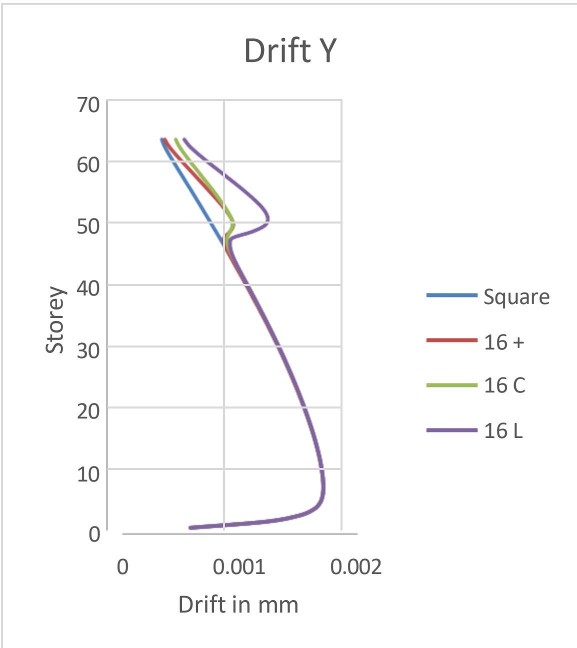


**Figure No. 25** Story Drift across the wind direction 90°

- G+64 having 16 stories are square cross-section and above 48 are in different cross-section

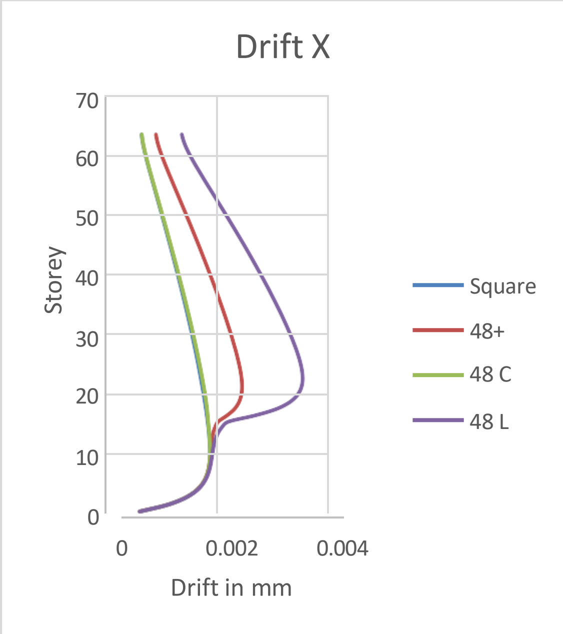


**Figure No. 26** Story Drift along the wind direction 0°

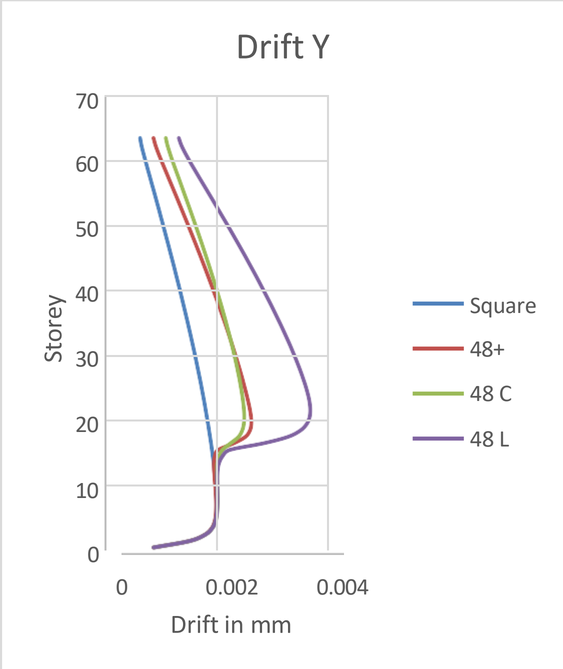


**Figure No. 27** Story Drift across the wind direction 90°

- G+64 having 32 stories are square cross-section and above 32 are in different cross-section

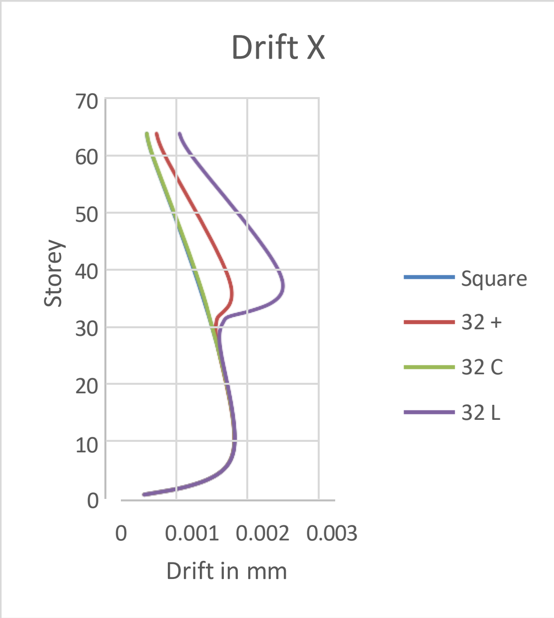


**Figure No. 28** Story Drift along the wind direction 0°

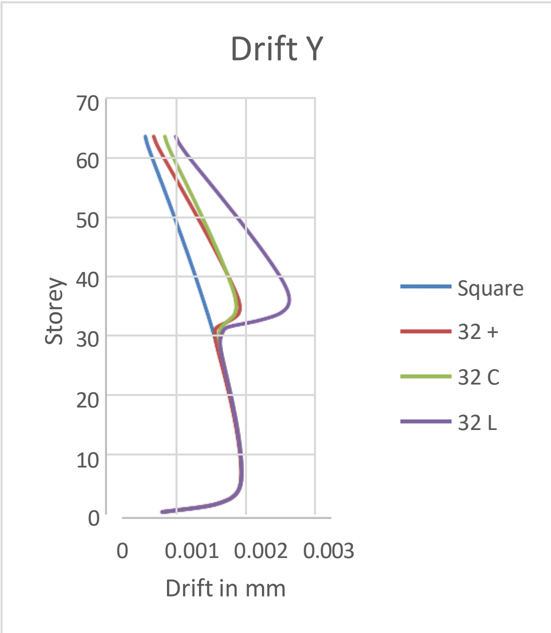


**Figure No. 29** Story Drift across the wind direction 90°

- G+64 having same cross-section throughout the building.

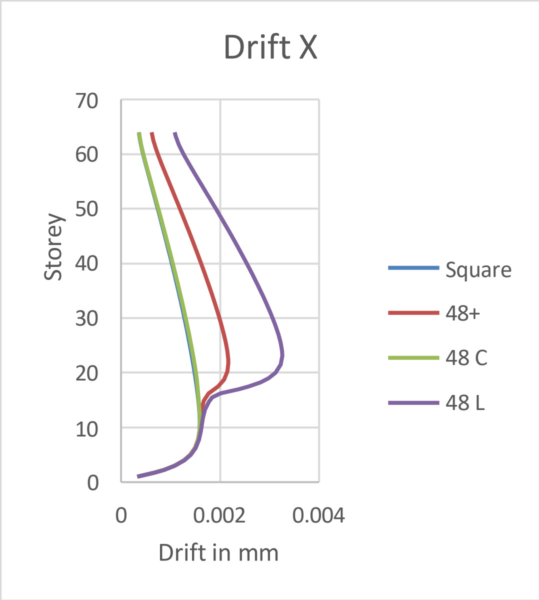


**Figure No. 30** Story Drift along the wind direction 0°

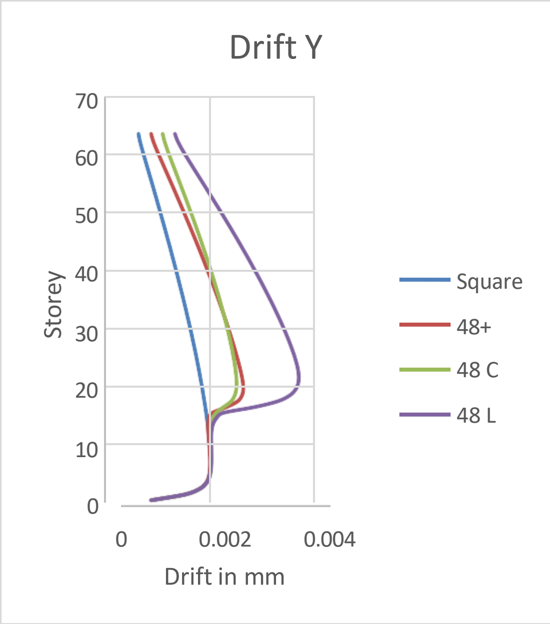


**Figure No. 31** Story Drift across the wind direction 90°

## V.Conclusion

This study for examining how wind effects on tall building with varying cross-section shape by performing dynamic analysis of different models using EATBS20 along the wind direction and across the wind direction to reveals important differences in structural behaviour like lateral displacement and story drift

a. By observations of graphs of

i. Displacement of 16 +, 16 C, 16 L are nearly differing for along the X and Y direction up to 3% with Square cross section

ii. Displacement of 32 +, 32 C, 32 L are silently differing in both the direction up to 13% with Square cross section

iii. Displacement of Square, 48 +,48 C, 48 L are having difference of 27 % that is it is increased by 27% than Square cross section

iv. Displacement of Square, 64 +, 64 C, 64 L are having difference of 37% that is it is increased by 37% than Square cross section

b. For + cross-section displacement is maximum among the all other cross section, for C cross- section displacement is similar as Square cross-section and for L cross-section the results are neutral as compare to Square and + cross-section.

c. For story drift of all models there are sudden changes in the results where cross-section of the building changes as shown in graph of figure no 24 to 31

d. Overall observation of results and graphs of all models, structure with ‘+’ cross-section gives the more lateral displacement as compare to the other cross-sectional shapes

e. On the other hand, structure with ‘L’ cross-section gives the more story drift as compare to other cross-sectional shapes

f. Structure with blunter or more asymmetrical designs are more likely to experience higher wind pressure and turbulence, which can worsen sway and possibly have an impact on the comfort of occupant and structural integrity of the building

When designing of taller buildings, safety, efficiency, and overall performance can be improved by architects and engineers by optimizing cross-sectional shapes to avoid unfavourable wind effects. In order to customize solutions to particular building forms and local wind conditions, future research and design methods should continue to concentrate on improving these tactics through the use of cutting- edge computational tools and wind tunnel testing.

**DECLARATION:**

I declare that work in the manuscript titled Assessment of wind effect on tall building of varying cross-sectional shape with vertical irregularity has been carried out by the authors in the Applied Mechanics Department Walchand College of Engineering Sangli.

The data derived from the literature is duly acknowledged in the text and a list of references provided. No part of the result and work was previously published in another journal.

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