Wind loads on Tall buildings with Steps
Shiva*, Ashok K. Ahuja and Pramod K. Gupta
Civil Engg. Dept., Indian Institute of Technology Roorkee, Roorkee, India
shivaprajapati08@gmail.com; ahujafce@iitr.ernet.in; pkgupfce@iitr.ernet.in; +91 9760992009

Abstract
An experimental study was carried out on the models of tall buildings with steps near its top in a wind tunnel. The aim of the study is to understand the influence of such steps on wind loads acting on buildings. Variation of base shear (Fx) in the direction of wind was measured on five models namely A, B, C, D and E as a function of wind incidence angle. Maximum values of base shear (Fx) is obtained on models D and E at angles 30° and 135°, 45° and 120° respectively and minimum values at angles 0°, 90° and 180°. The variation of maximum value to minimum value of twisting moment (Mz) is 85.80% in model A, 89.47% in B, 85.18% in C, 92.40% in D and 98.31% in E. The findings can be made use by the structural designers for safe design of such buildings under wind loads.

Keywords: Boundary layer flow, steps, tall buildings, wind incidence angles, wind loads.

Introduction
Tall buildings are generally built with square or rectangular plan shape. But sometimes the architects give special treatment to its cross-section to improve its aesthetic. These include cutting or chamfering of corners and provision of steps along height. While designing tall buildings for wind loads, relevant standards on wind loads are referred to A/S: 1170.2 (2002), ASCE: 7-02 (2002), BS: 63699 (1995), EN: 1991-1-4 (2005) and IS: 875 (part-3) 1987. However, such standards give information about wind pressure and wind force coefficients on tall buildings of simple cross-sectional shape only. In case of buildings with modification in elevation and or plan, designers are left with no other choice then going for wind tunnel testing.


However, available information is yet not complete. It is, therefore, decided to carry out wind tunnel tests on the models of tall buildings of square plan with steps near roof.

Materials and methods
Model description: The prototype building considered in this study has a plan dimensions of 30 m x 30 m (900 m²) and a height of 55 m. Five rigid models (Fig. 1-4) namely A, B, C, D and E of same cross sectional area are made of plywood at a scale of 1:100. All the models have a height of 550 mm and floor area is 90,000 mm². Detailed dimensions of these models are shown in Fig. 1 and 2.

Fig. 1. Elevation of tall building models.

MODEL A               MODEL B               MODEL C

Fig. 2. Plan view of tall building models.

MODEL D               MODEL E
**Wind tunnel:** The wind tunnel used in this study is open circuit type boundary layer wind tunnel with a cross-section of 2 m (width) x 2 m (height) and the length of the section as 15 m. The models are placed one by one on five component force balance at a distance of 11.85 m from the upstream edge of the test section and are tested under free stream wind velocity of 9.78 m/s (approx. 10 m/s) measured at 1 m height above the floor of the tunnel under the mean wind velocity profile corresponding to terrain category 2 as per Indian standard on wind loads. All five values of forces, namely two base shear (Fx and Fy), two base moments (Mx and My) and twisting moment about vertical axis (Mz) are measured on each model for wind incidence angles 0° to 180° at an interval of 15°.

**Results and discussion**
Variation of base shear (Fx) in the direction of wind, measured on five models namely A, B, C, D and E as a function of wind incidence angle is shown in Fig. 5. It is noticed from the figure that maximum value of Fx is obtained on models A, B and C at angles 45° and 135° due to maximum exposed area and minimum values at angles 0°, 90° and 180°. In case of models D and E, slight variation is noticed due to different arrangement of steps. Maximum values of Fx is obtained on models D and E at angles 30° and 135°, 45° and 120° respectively and minimum values at angles 0°, 90° and 180°.
Further, maximum values are almost 1.5 times the minimum values in all building models. Force Fx, i.e. base shear in the direction of wind on model B is smallest as compared to other models at all wind incidence angles. Variation of My i.e. base moment is identical to that of Fx (Fig. 6). Its maximum value in case of model C is about 1.4 times that of model B. Variation of twisting moment (Mz) with respect to wind incidence angle is shown in Fig. 7. Maximum value of Mz is obtained at 15° in model A at 75° in model B, at 15° in model C at 105° in model D and at 165° in model E.

The variation of maximum value to minimum value of Mz is 85.80% in model A, 89.47% in model B, 85.18% in model C, 92.40% in model D, and 98.31% in model E. Similarly, when comparing the maximum values of Mz of each model with model A, reduction in Model B by 38.23% reduction in Model C by 8.32%, increase in Model D by 6.53%, increase in Model E by 2.68% is observed.

**Conclusion**

The following conclusions are drawn from the experiment are presented here:

1. Wind force on the building is highly influenced by wind incidence angle.
2. Different arrangements of steps of the building affect the wind loads acting on the tall buildings up to great extent, even if the height of the buildings remains the same.
3. The percentage increase or decrease in the values of these forces depends upon arrangement of steps.

**Acknowledgements**

The work presented in this paper is a part of the research work being done by the first author for his M. Tech. Degree under the supervision of remaining authors.

**References**