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Effect of Steep Escarpment on the Wind Pressure Distribution on a Rectangular Shape Building

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SUMMARY:
This paper presents a wind tunnel investigation of turbulent flow over a steep escarpment and the subsequent wind pressure distribution on a rectangular plan building located near and on top of the steep escarpment. Results measured include longitudinal mean wind velocities and wind pressure distribution on the building over 17 successive measuring points between far upstream and downstream of the top edge (crest) of the steep escarpment. It is observed that when the building is at far upstream locations of the escarpment, the wind pressure distribution greatly resembles with that of the isolated case (when the building is placed inside the wind tunnel with no escarpment). A reversed flow is observed just upstream of the crest which is reflected in the pressure values of the leeward face of the building when it is at a distance equal to one height of the escarpment from its crest. Contour plots for mean wind pressure coefficient are plotted for every location of the building considered. A separation bubble extending downstream of the crest is seen which results in suction values on the windward face of the building. The work presented in this paper is expected to greatly assist the structural designers designing buildings in such steep terrains.

Keywords: wind tunnel, rectangular building, wind pressure

1. INTRODUCTION

The appropriate calculation of wind loads on buildings and structures located on exposed hill sites is one of the most important applications of the proper understanding and knowledge of topographical effects. Studies on wind flow over escarpments include the prominent work of Bowen and Lindley, (1977) where they carried out wind tunnel investigation of flow and turbulence characteristics over various escarpment shapes. Notable field studies on wind flow over escarpments include the work of Emeis et al., (1995) and Holmes et al., (1997). Other studies on wind flow over escarpments lately include the work of Sherry et al., (2010), Tsai and Shiau, (2011), and Kilpatrick et al., (2021). Almost all of the above-mentioned studies address the phenomenon which are not related to structural engineering field. There has perhaps not been any study completely carried out from the perspective of structural loading of buildings. The flow over a steep slope escarpment (representative of a bluff body) is of significant practical interest for design of buildings or structures in general. This study is an attempt to understand and evaluate the effect that the steep escarpment has on a rectangular plan building located in its vicinity.

The primary objective of this paper is to evaluate the wind pressure distribution on the building model placed successively at a total of 17 locations between the upstream and downstream measuring points over the escarpment model. The work described in this paper should greatly assist in the prognosis of design wind loads of rectangular plan buildings which are mostly calculated using standard wind loading codes of practice.

2. MATERIALS AND METHODS

2.1. Characteristics of wind flow

The experiments were conducted in an open-circuit boundary layer wind tunnel at IIT Roorkee, India. The tunnel was 2 m wide and 2 m high and had a test section length of 15 m. The simulated atmospheric boundary layer is about 0.9 m deep and is characterised by a power-law exponent of 0.2 for the approach flow.

2.2. Model description

A two-dimensional model of a steep escarpment having slope 75° is machined from plywood and is used for measuring the wind flow characteristics inside the wind tunnel (Fig. 1). The height of the escarpment is kept fixed at 300 mm. Next, a model of a rectangular plan building made from Perspex sheet is used for the pressure measurement study. The building has plan dimensions of 200 mm × 100 mm and height equal to 300 mm. The building has a cumulative of 112 pressure points, with 35 each on windward face (Face A) and leeward face (Face C), and 21 each on Face B and Face D (Fig. 2). A geometric length scale of 1:100 is adopted throughout the present study.

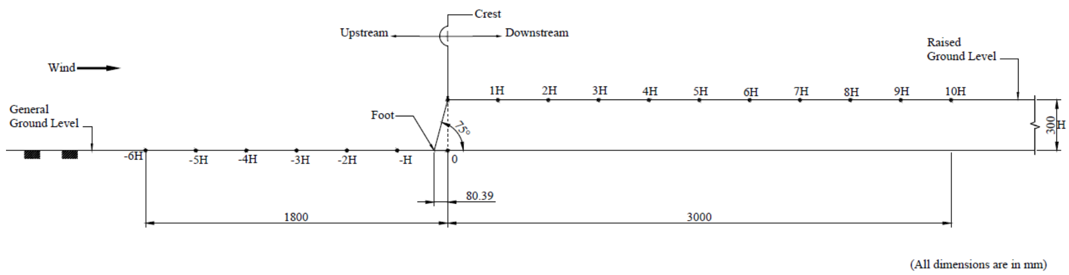
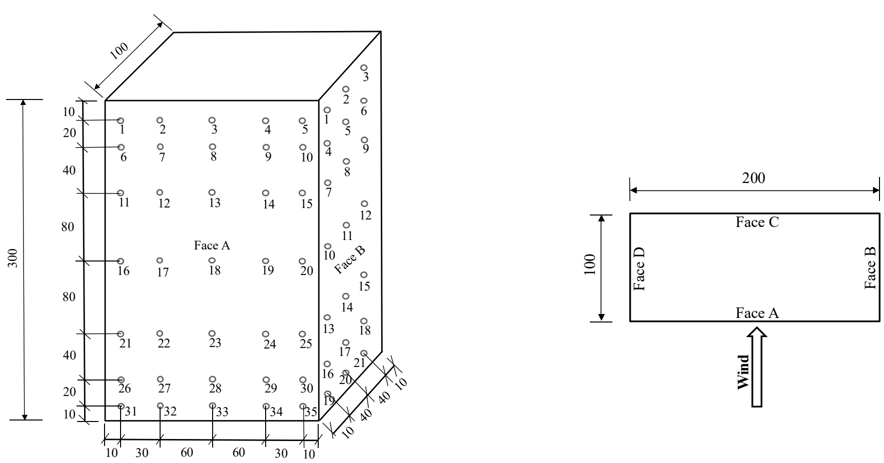


Figure 1. Geometric representative sketch of the cross-section of escarpment model with 75° slope showing different strategic measuring locations



(a) (b)

Figure 2. Building model made of Perspex sheet with different pressure tap locations; (a)-Isometric view, and (b)-Plan (All dimensions are in mm)

3. RESULTS AND DISCUSSIONS

Mean wind flow is measured over the steep escarpment at successive locations between 6H upstream (u/s) and 10H downstream (d/s) (Fig. 1). The resultant graphs at a few selected locations are shown in Fig. 3. It is observed that there is not any significant difference between mean wind velocity profiles at 6H u/s, 5H u/s, 4H u/s and 3H u/s. A small region of reversed flow with approximate height equal to H/8 is seen at 1H u/s.

Variation of wind pressures on the surfaces of buildings can be well represented by contours of dimensionless parameter mean wind pressure coefficients C_p. To get an accurate idea of the wind pressure distribution on the building model, contour plots for mean wind pressure coefficients C_p are drawn. Contour plots at 1H u/s are shown in Fig. 4.

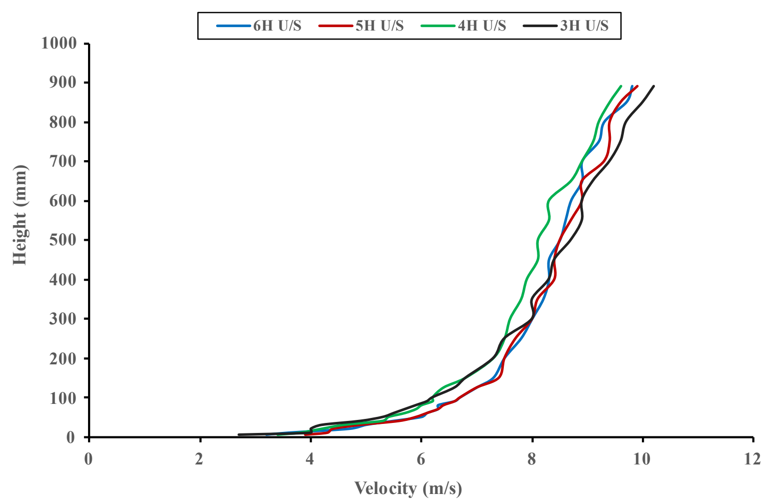


Figure 3. Mean wind velocity profiles at a few locations out of the total 17 locations

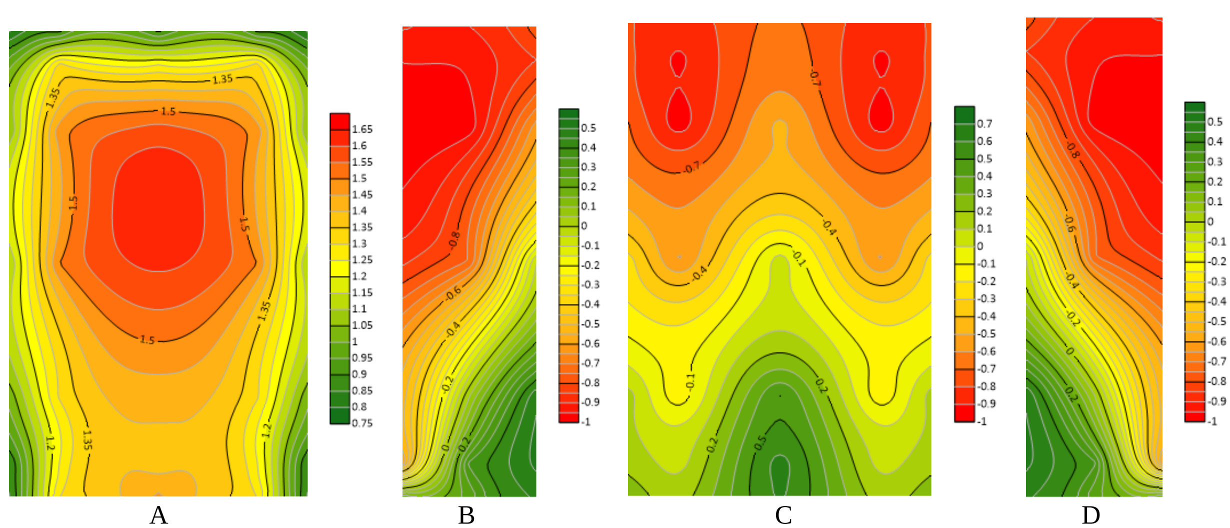


Figure 4. Contour plots for C_p at 1H u/s location

4. CONCLUSIONS

The present study investigates experimentally the wind pressure distribution on a rectangular plan building located in vicinity of a steep slope escarpment. Following conclusions can be drawn from this study:

- The wind flow does not change significantly until it reaches 2H u/s, where from flow starts to separate. Maximum increase in the mean wind velocity is observed at the crest.
- Beyond the crest, in the downwind direction, there is a region of high turbulence extending till 6H d/s owing to the formation of separation bubble. The downstream recovery of the mean wind velocity profile does not take place even at 10H d/s which is the last measuring point in this study.
- The leeward face of the building experiences pressure in its lower middle part when it is at 1H u/s (very close to the steep slope). This phenomenon happens due to the flow reversal which occurs due to separation of flow just upstream of the crest.
- Contour plots of C_p illustrate that at crest, there is highest suction observed on the leeward face of the building among all the locations. The suction on part of the windward face of the building beyond the crest continues till 6H d/s owing to the reversed flow in the separation bubble.
- The results presented in this study clearly confirm that structural engineers would be well advised to consider flow separation and behaviour of the buildings, or any other structures immersed in the separation bubble or beyond the reattachment point on the downstream side, in order to accurately predict the wind loads on buildings or other structures in complex terrains like an escarpment.

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