The Mitigation of Vortex Induced Rooftop Suction

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Abstract

The worst wind-induced suction on a low-rise building's surface are known to occur beneath the separated flow along the edges of the roof. This study examines two techniques for the mitigation of these suctions by performing wind tunnel pressure and visualization tests on scale models of the TTU WERFL field site. One of these techniques has also been studied at full scale. The results indicate that the vortices which cause the worst case suctions can be eliminated with simple additions to the roof edge. The effectiveness of each technique is evaluated using a new parameter which attempts to indicate how close each method comes to eliminating all suction beyond that which is inherent in the flow acceleration around a surface mounted bluff body.

Introduction

Many studies have shown that the worst mean and peak suctions on low rise building roofs, whether flat, gabled, hipped, or mono-sloped, occur beneath the separated flow along the leading edges [1-3]. It is anticipated that the mitigation devices developed in this study will be of use for any roof shape.

The worst peak suctions of all are associated with the dual conical vortices which form on flat roofs during cornering winds, but studies of flow normal to a wall show that vortices are responsible for peak suctions for these wind directions as well [4]. These vortices are much less stable than the conical "delta-wing" vortices. They tend to be convected away from the leading edge, causing a wave of increased surface suction to follow them.

By introducing a means of disrupting these vortices and preventing early flow reattachment, a significant suction reduction can be achieved. This has been reported for a variety of roof corner modifications [5]. Similar reductions in suction have been reported for curved eaves, which effectively prevents the flow separation from occurring at all [6].

Experimental procedures

This study has attempted to devise a means of passively venting the flow separation to prevent vortex formation and early flow reattachment with a minimal impact on the visual appearance of the roof edge. The most effective means of reducing suction tested in Ref [5] was the porous parapet, which operates on this principle of re-routing the flow to disrupt reattachment. Several porous parapet parameters were modified, to determine a most effective configuration. The most

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effective porous parapet was then compared to two new venting techniques: direct venting through flow holes, and the use of a leading edge spoiler.

The model scale experiments were conducted in the Meteorological boundary layer wind tunnel at Colorado State University (CSU), using the BII boundary layer developed by Ham [7]. A solid parapet was also tested for comparison. All of the initial tests were conducted on a 1:50 scale model of the TTU WERFL site [8] (Note that additional taps have been installed near the roof corner since 1992). Pressure taps were drilled in the 1:50 model in 5 rows along the longer (13.8m) wall at x = 1.5m, 3m, 4.3m, 5.6m, and 6.9m. Pressures were recorded nearly simultaneously using sequential sampling frequencies of over 21 000Hz, for a return time at each tap of over 450 Hz. Some velocity measurements were also taken above the roof using a hot-wire probe. Flow visualization was also performed using glycerin fog and a laser light sheet. (Figure 1 shows how flow passing through the porous parapet curls upward to join the weakened shear layer coming off of the top of the parapet.)

Initial tests attempted to directly vent into the separated flow using holes in the roof surface, located beneath the worst case vortex position. By keeping the inside of the model at the stagnation pressure, the effect of connecting these holes to a steady supply of higher pressure air through an opening on the windward face was tested. However, the holes had to be quite large (0.5m full scale) for the vortices to be significantly disrupted, and this technique was abandoned.

Conversely, the use of a spoiler along the roof's edge proved more effective than the porous parapet. Because of the small size of the opening between the spoiler and the roof surface, a 1:25 scale model of the TTU WERFL site was used for these tests. In this case, pressure tap locations matched those currently in place at the full scale site, with some variations for taps far from the leading edge corner. Further testing of the porous parapet was also conducted on the 1:25 model. Only the spoiler has been tested at full scale.

Sample results

Figure 2 shows mean and peak pressure coefficients for a row of taps 1.4m (~5 ft.) from the roof corner. The parapet used in this case was 25 cm high at full scale, and consisted of a 70% porous fence of long flat horizontal bars, angled slightly toward the roof surface. Both the parapet and the spoiler extended along the full length of the building for these tests. The data is from 36-second long runs, which correspond to 15 minutes at full scale.

Discussion: measuring mitigation

The mean pressure profile in Figure 2 might lead one to believe that the porous parapet is of little use for reducing the net uplift on the roof, since the suction is actually greater for $y>0.5$m. However, it is the reduction of worst case loads which is of interest, and the peak profiles show a significant decrease in suction for $y<1$m for the porous parapet, and for all y values for the spoiler. The use of single peaks as an indicator of peak reduction is statistically weak, however, so the full report will make use of pressure histograms to assess peak trend behaviour.

It is somewhat misleading to assess a percentage peak pressure reduction by comparing the ratio of Cp values with and without the mitigation device in place, since Cp = 0 cannot be achieved. The flow curvature and acceleration induced by the building provide a definite limit to the possible reduction in roof-top suction. One possible simple estimate of the magnitude of this limit can be made by using the pressures measured at taps in the middle of the roof. These taps tend to measure similar mean and peak values with or without mitigation devices in place, and they can, on average, be expected to reflect the effect of flow acceleration over top of the building. If we define the mean value of several mid-roof taps as the mitigation limit (Cp_0), then a Mitigation Effectiveness Parameter can be defined as

$$\mathrm{MEP} = 1 - \frac{\iint_A \left(Cp_m - Cp_0\right) dA}{\iint_A \left(Cp_b - Cp_0\right) dA} \qquad (1)$$

where Cp_m is the Cp value with mitigation, and Cp_b is the pressure coefficient when the roof is bare. The area of integration (A) depends upon the structural element in question. For a 1m x 1m roof paver or roof-mounted solar panel located at the roof edge beneath the profile shown in Figure 1, the MEP for the spoiler is .67, meaning that 67% of the possible mitigation has been achieved.

Conclusions

Two methods of reducing the high peak suctions experienced beneath separated flows on roof tops have been investigated through a wind tunnel and full-scale study of pressures on the TTU WERFL building. Both methods offer significant reductions in peak surface pressures by venting the separated flow zone. The resulting pressures approach the minimum suction which is considered attainable.

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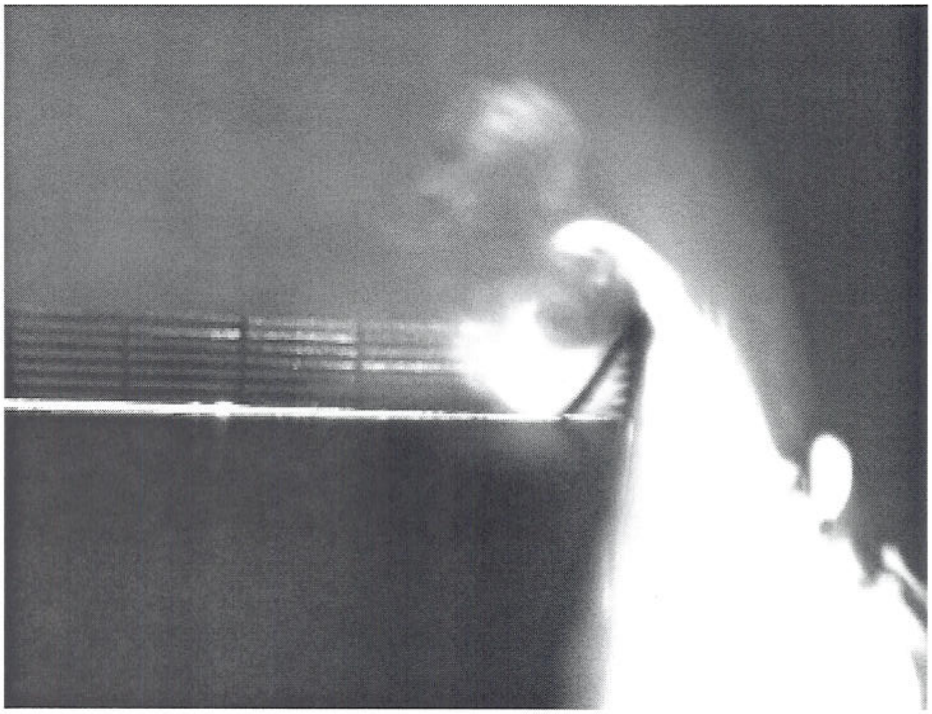

Figure 1: Visualization of flow over a porous parapet. Flow is from right to left. Building corner is dark rectangle in the lower left. Horizontal black lines are the parapet bars.

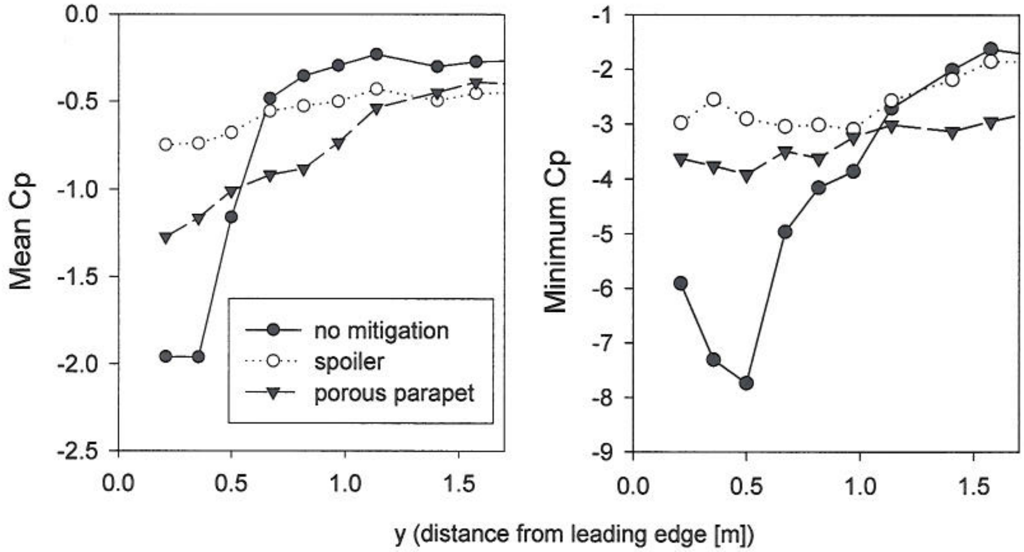

Figure 2: Pressure profiles at 1.6 m from the roof corner. Wind angle is 50°, where 90° is normal to the leading edge. ($\theta = 220°$ in TTU co-ordinates).