Wind tunnel analysis on the influence of cantilever parapets on the wind loads on curved roofs

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Abstract

Different methods to reduce the high suction caused by conical vortices have been reported in the literature: vertical parapets, either solids or porous, placed at the roof edges being the most analysed configuration. Other method for alleviating the high suction peaks due to conical vortices is to round the roof edges. Very recently, the use of some non-standard parapet configuration like cantilever parapets has been suggested. In this paper, its efficiency to reduce suction loads on curved roofs is experimentally checked by testing the pressure distribution on the curved roof of a low-rise building model in a wind tunnel. Very high suction loads have been measured on this model, the magnitude of these high suction loads being significantly decreased when cantilever parapets are used, thus the suitability of these parapets to reduce wind pressure loads on curved roofs is demonstrated.

Keywods: conical cortices, wind-tunnel test, wind-loads on roofs, low-rise buildings, cantilever parapets

1 Introduction

In the sharp edges on bluff bodies like low rise buildings, the severe adverse pressure gradients appearing downstream the roof edges cause the boundary layer separation. This boundary layer separation generates a vortex flow pattern which produces severe suction loads in the separated flow region. This phenomenon becomes remarkable in the case low rise buildings with incident wind at oblique angles to the edges, where the existence of such vortex pattern in the region of the windward facing corner of the roof is well established at both model scale and full scale. The structure of these roof-edge vortices, also known as conical vortices, is a matter of great concern because of their potentially damaging effects on roof buildings, and considerable efforts are being devoted to analyse the nature of such conical vortices, mainly through measurements made on wind tunnel models [1-9] and through measurements made on full scale buildings [10-12]. In all mentioned papers very high values of mean suction peaks are reported. These severe mean suction peaks, which can produce cladding failures, usually only affect a small roof area near the windward corner, the reason being that the absolute value of the pressure coefficient seems to increase as the inverse of the root of the distance to the roof corner [4, 6].

Different ways to reduce the high suction loads caused by the conical vortices have been studied in the past. The most common solution suggested by investigators being the installation of vertical parapets at the roof edges [13-17]. The presence of parapets modify the air flow on the roof, changing the position of the conical vortices and rising them from the surface of the roof [18]. This change in the position of the vortices produces a reduction of the suction on the roof. Recently, some results concerning the effectiveness of porous and cantilever parapets to reduce the roof suction have been published [19]. Finally, other method studied for alleviating the high suction peaks due to the conical vortices is to round the edge profiles [20].

It is also well known that the shape of the roofs modify the wind-induced pressure distribution on their surfaces, being the suction higher on flats roofs than on gable roofs or hipped roofs [21]. On the contrary, curved roofs do not seem to alleviate the wind loads when compared with flat roofs. In a wind-tunnel study of the aerodynamic loads on the buildings of the new control tower of Tenerife-Norte airport [22], see figure 1, the highest mean suction measured on the low-rise building curved roof was considerably high, $-c_{p\ \min} = 3.64$, such suction peak being located far from the windward corner of the roof. This position of the higher wind load, was an unexpected result taking into account that the highest wind loads on roofs (flat, gable,…) are located at the corners. In this paper some efforts to clarify this phenomenon are presented. Thus, to study the effectiveness of cantilever parapets on curved roofs in terms of wind-load reduction, the wind loads on a curved roof have been experimentally analysed.

2 Experimental procedures

The test model represents a low-rise building with a curved roof, see figure 2. One hundred and forty-eight pressure taps are installed on the surface of the test model roof, see figure 3. These pressure taps are located in a reduced area of the roof (shaded area in figure 2), taking into account that, as it was previously explained, the highest wind loads are produced around the windward corner of the roof. Each pressure tap consists of a brass tube, 1 mm inner diameter, which is connected to the pressure measurement instrument by a plastic tube with 1 mm inner diameter. Plastic tubes are connected to pressure scanners from Scanivalve Corp., each one equipped with a Druck PDCR22 differential pressure transducer. Transducer outputs were sampled at 20 Hz during 12.5 seconds for each measurement.

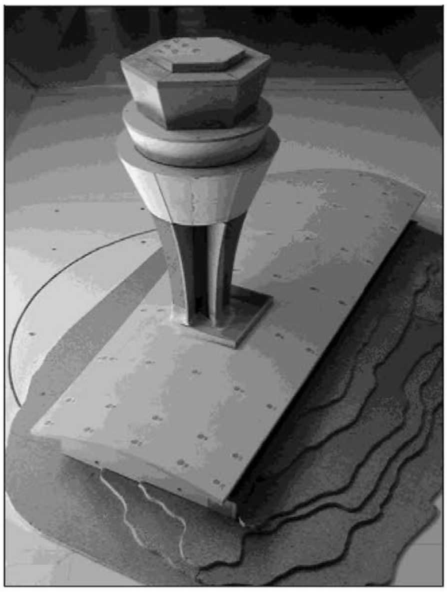


Figure 1: Test model used in the wind tunnel study of the aerodynamic loads on the new control tower buildings of Tenerife-Norte airport.

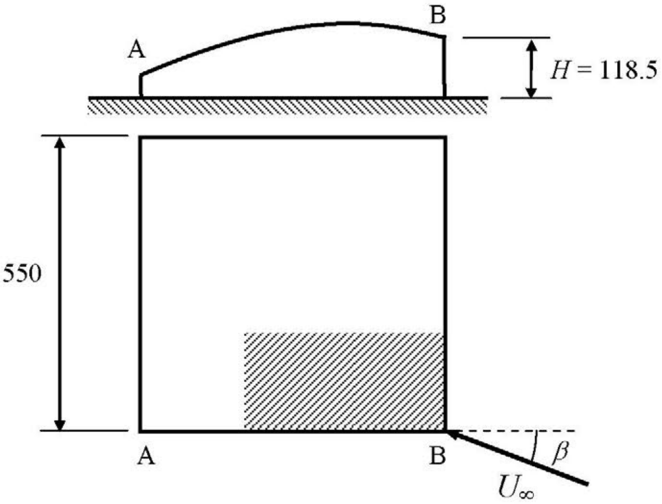


Figure 2: Sketch of the test model. The shaded area indicates the location of the pressure taps on the model roof. The wind direction angle, β, is also indicated. The curvature of the roof is defined with two circumference arcs (the exact definition of the curve is available at request to the authors). The cantilever parapet to be studied is located on edge AB. All dimensions are in millimetres.

Pressure measurements have been made dimensionless by using the values of both the static pressure and the dynamic pressure of the incident wind at the model roof height (H, defined in figure 2), the pressure coefficient being defined as usual, $c_p = (p - p_\infty)/q_\infty$, where p is the mean pressure measured on each tap, and p_∞ and q_∞ are the static and dynamic pressures upstream the test model, respectively. Measurements have been carried out in a low velocity wind tunnel at IDR/UPM. The test section is 1.5 m wide and 1.8 m high. Taking a 1:100 scale for the test model the wind velocity profile at the model test section was similar to type I atmospheric boundary layer distribution [21]. The wind velocity of the stream at the test section of the wind tunnel, at model roof height, H, was 22 $\mathrm{m{\cdot}s^{-1}}$. Additional details on the measurement conditions are available at request to the authors.

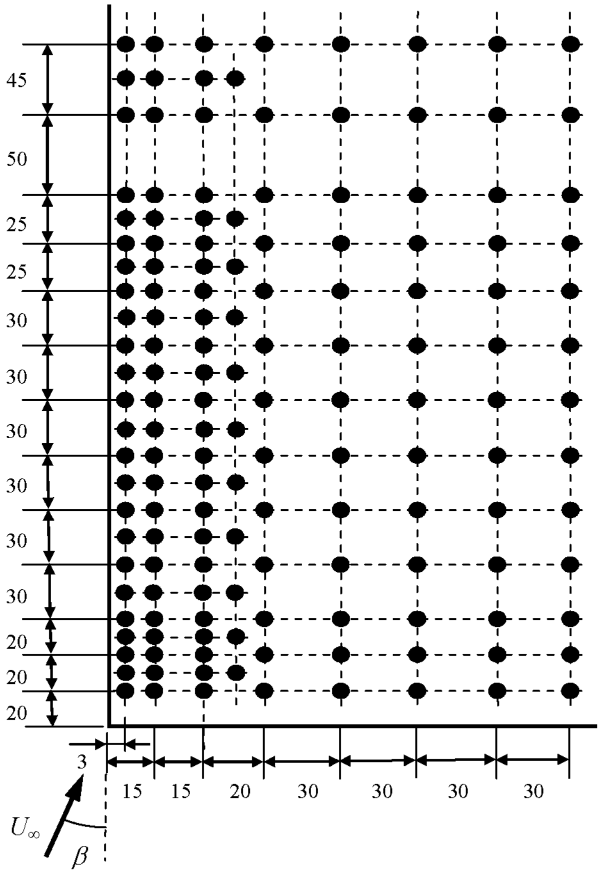


Figure 3: Arrangement of the pressure taps on the model roof (shaded area in figure 2). All dimensions are in millimetres. Dimensions are measured on the surface of the roof.

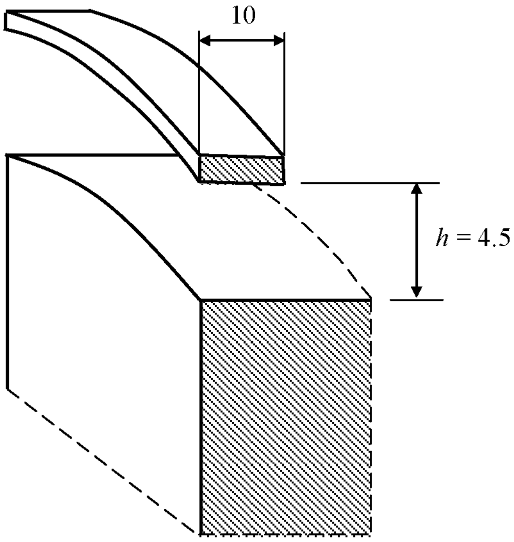


Figure 4: Sketch of the cantilever parapet tested. Dimensions are in millimetres.

3 Results and discussion

In figure 5 the variation of the higher mean suction measured on the model roof, $-c_{p\ \mathrm{min}}$, with the wind direction angle, β, is shown. Both cases, roof with and without cantilever parapet are shown in this plot. As it was expected, high wind-induced suction has been measured in the present experiments on the curved roof without parapet, the maximum being $-c_{p\ \mathrm{min}} = 5.25$ at $\beta = 60^{\circ}$. Two peaks of suction, Peak A and Peak B, can be observed in the pressure coefficient distributions measured with no cantilever parapet (figures 6-7). Both peaks are located along the axis of the conical vortex projection, the second one, Peak B, being more separated from the edge of the roof (that is, the origin of the conical vortex). Experimental results show that Peak A suction is higher than Peak B one for wind angles $\beta > 45^{\circ}$, whereas the contrary occurs for $\beta \leq 45^{\circ}$. The existence of a detachment and reattachment of the conical vortex is suggested in order to explain the presence of Peak B. Then, the first peak would be produced by the conical vortex before the detachment and the second one after its reattachment. In order to demonstrate this suggestion new experiments should be done, this work being out of the scope of the present paper.

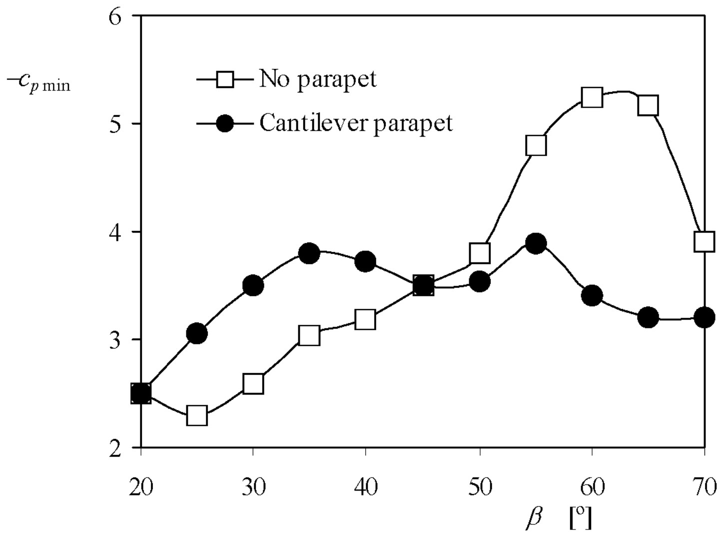
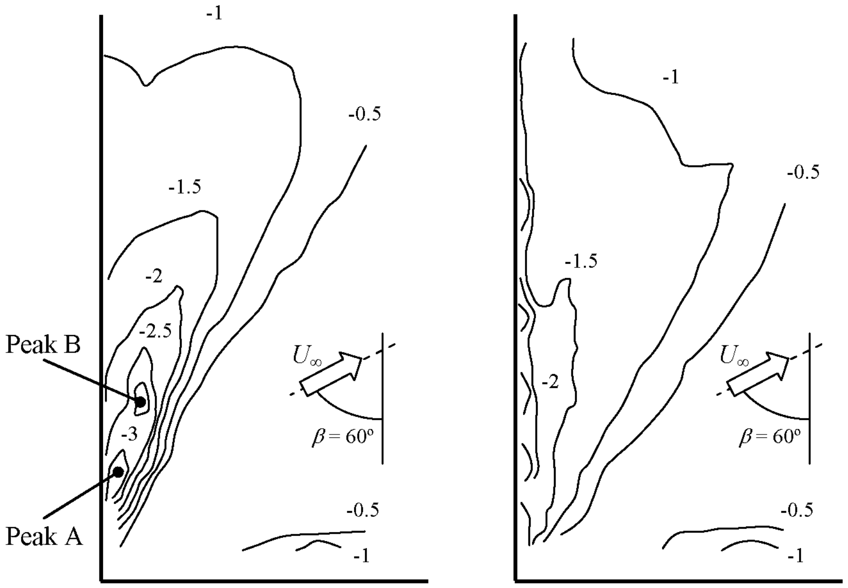


Figure 5: Variation of the higher mean suction measured on the model roof, $-c_{p\,\mathrm{min}}$, with the wind direction angle respect the model, β.

As it can be observed in figure 5 the maximum suction measured at $\beta = 60°$ ($-c_{p\,\mathrm{min}} = 5.25$) is highly decreased when the cantilever parapet is installed on the roof. Comparing the contours of constant c_p in figures 6 ($\beta = 60°$) and 7 ($\beta = 40°$), it is clear that parapets decrease the global wind-load on the roof. However when parapets are used high suction appears locally at the edge of the roof, this local effect being produced by the jet between the roof and the parapet. Because of this jet, in the case of cantilever parapet suction loads are almost constant irrespective the value of the wind angle of incidence (figure 5).

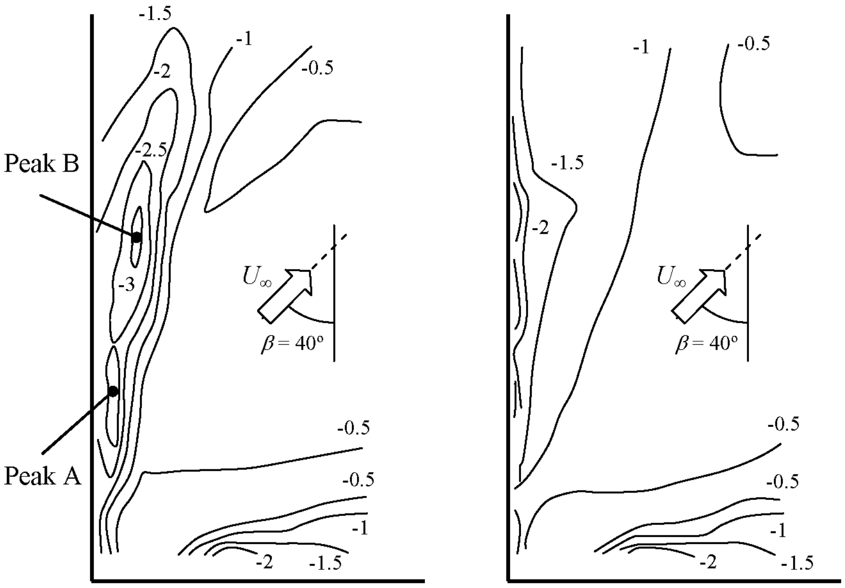
At wind angles $\beta > 45^\circ$ the interaction between the plane jet created under the cantilever parapet and the conical vortex, reduces both the higher suction, $c_{p\,\mathrm{min}}$, and the global wind load on the roof. The situation is different at wind angles $\beta < 45^\circ$, where the maximum suction measured on the roof, $c_{p\,\mathrm{min}}$, is higher at the roof edge due to the mentioned jet created by the cantilever (figure 5).



No parapet

Cantilever parapet

Figure 6: Contours of the pressure coefficient distribution, c_p, measured on the roof model at wind direction $\beta = 60^\circ$.



No parapet

Cantilever parapet

Figure 7: Contours of the pressure coefficient distribution, c_p, measured on the roof model at wind direction $\beta = 40°$.

4 Conclusions

Experimental data indicate that the use of cantilever parapets reduces the global wind-loads on curved roofs, although high suction is produced at the windward edge of the roof due to the plane jet that exists between the roof and the parapet.

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