EFFECT OF POROSITY ON NET PRESSURES ON ROOF PANEL

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Abstract
The roof panel structure is a new structure used for heat isolation on building roofs. This paper describes a parametric wind tunnel study that investigated the effects of porosity on net pressures on this structure. The propagation of pressures was studied through models to determine the effects of porosity. The mean, fluctuating (RMS), maximum peak and minimum peak distributions over the surfaces of the roof panel were measured for porosities of 0%, 5% and 10% (ratio between area of orifices and area of roof panel). The results show that the roof panel with no porosity (0%) had the highest net pressures. Those with porosities of 5% and 10% were most effective in reducing pressure fluctuations without significantly increasing mean pressures.

Key Words: Roof panel, Porosity, Wind pressure, Low-rise building

1. INTRODUCTION

Wind load on this structure depends on the difference between the pressures on the upper and lower surfaces. It is therefore important to be able to assess the effect of porosity on net pressures. Porosity allows air to flow across a roof panel tending to reduce mean pressures and to attenuate peak pressures, both of which reduce the total wind loading on the roof panel. The purpose of this study was to quantify the attenuation of wind loads on a porous roof panel as compared to that of wind loads acting on a similar non-porous roof panel with the same external flow field.

Few studies [1-2] have previously investigated the characteristics of wind loadings on porous structures while considering limit factors. This study is part of a research on this structure considering effect factors: breath/height ratio (B/H), parapet height, Reynolds number, terrain category, gap between roof panel and roof, thickness of roof panel edge, porosity, and roof type. This paper describes only results relating to porosity.

2. EXPERIMENT

A model (200mm high (H) × 470mm wide (B) × 710mm deep (D)) with roof panels was tested in a Boundary Layer Wind Tunnel, 2.2m wide by 1.8m high, in Tokyo Polytechnic University, Japan. The length and velocity scales were 1/50 and 1/4, respectively. Terrain category III in AIJ-RFLB (2004) was chosen for the tests. This category has a power law index of 0.2. The turbulence intensity at height 200mm was 0.26 and wind speed was 7m/s. There were 3 test model cases to consider the effect of porosities of roof panels (0%, 5% and 10%) with a total of 41 wind direction angles (0° to 360° in 10° steps and four wind directions angles: 45°, 135°, 225° and 315°). The model had sixteen roof panels one of which was porous with 128 holes, while four roof panels had pressure taps (A, B, C and D) (see Fig. 1). Model 1 (porosity 0%) had the roof panels without holes, while models 2 (porosity 5%) and 3 (porosity 10%) had the roof panels with holes of diameter 2.8mm and 4mm, respectively. The gap between the roof panel and the roof was 1mm (see Fig. 1).

3. DATA ANALYSIS

The net pressure coefficient on the roof panel due to the combined effect of the upper and lower roof panel surfaces is

\[ C_{p,net}(i,t) = C_{p,u}(i,t) - C_{p,l}(i,t) \] (1)

where \( C_{p,u}(i,t) \) and \( C_{p,l}(i,t) \) are wind pressure coefficients at measurement tap \( i \) at time \( t \) on the upper and lower surfaces of the roof panel, respectively; and \( C_{p,net}(i,t) \) is the net wind pressure coefficient at measurement tap \( i \) at time \( t \) of the roof panels.

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Wind pressure coefficients were defined as positive in the vertically downward direction. The time series data were moving averaged every 0.016s, corresponding to 0.2s in full scale.

The maximum peak and minimum peak pressure coefficients were calculated by the Cook & Mayne method [4].

The time history of wind force coefficients was obtained by integrating the near-simultaneous pressure signals at all tap locations over both roof panel surfaces. Following the sign convention of wind pressure in Equ. 1, the net wind force coefficients were defined as positive in the vertically downward direction.

The wind force coefficients on a roof panel were calculated from

\[ C_F(t) = \sum_{i=1}^{N} \left( (C_{p,u}(i,t) - C_{p,l}(i,t))A_i \right) / A \]  

where \( C_F(t) \) is the wind force coefficient on a roof panel at time \( t \); \( C_{p,u}(i,t) \) and \( C_{p,l}(i,t) \) are the wind pressure coefficients at point \( i \) at time \( t \) on the upper and lower roof panel surfaces, respectively, with a duration of 0.2s in full scale; \( A_i \) is the effective area on which wind pressure acts measured at point \( i \); \( N \) is the number of measurement points on roof panel \( j \); and \( A = b.d \) is the area of a roof panel (see Fig. 1).

The mean, RMS, maximum peak and minimum peak net wind force coefficients on each roof panel were calculated from \( C_F(t) \) by the above methods.

4. RESULTS AND DISCUSSION

Figures 2, 3 and 4 show the distributions of mean and RMS net wind pressure coefficients on roof panels A, B, C and D for wind directions angles 0°, 45° and 90°, respectively. Generally, the pressure coefficients of the outer roof panels are always higher than those of the inner ones. Of these four roof panels, roof panel D had the lowest values. The values of \( \bar{C}_{p,net} \) for 0% porosity were up to 71% and 140% higher than those for 5% and 10% porosities, respectively, while those of \( \bar{C}_{p,net} \) were up to 80% and 125% higher.

For wind direction angle 0°, it is observed that all the roof panels were subjected to small mean net pressure coefficients in the range of -0.16 to 0.04. The net RMS pressure coefficients varied from 0.04 to 0.32. It is also observed that the mean and RMS net pressure coefficients of roof panels A and B increased at the near windward edges of the roof panels due to the effect of flow separation.
For wind direction angle 45°, the net mean pressures varied from -0.04 to 0.62 and the RMS net pressure coefficients varied from 0.08 to 0.5. The pressures on roof panel A were positive and higher than those on roof panels B, C and D due to conical vortices. The mean values for roof panels B and C were similar and those for roof panel D were almost zero.

For wind direction angle 90°, the mean net pressure coefficients varied from -0.16 to 0.08. The RMS net pressure coefficients varied from 0.08 to 0.38. There was not much difference between the mean values for the four roof panels. It is observed that all the roof panels are subjected high RMS net pressure coefficients at their centers, and those for roof panels A and C were higher than those for roof panels B and D due to the effect of flow separation.

For porosity 0%, the highest mean pressures were on the lower surface, followed by porosities 5% and 10%, while the mean pressures on the upper surfaces were almost constant (not shown here). It is clear that the net, pC(s) for the roof panels were controlled by pressures on the lower surfaces.

The RMS coefficients of the upper surfaces also did not change with porosity while those of the lower surfaces changed slightly (not shown here). Correlation coefficients between wind upper and lower surfaces (not shown here) decreased with porosity. The lowest values were 0.65, 0.83 and 0.86 for porosities 0%, 5% and 10%, respectively. We can see that the net, pC(s) values for the roof panels were controlled by the correlation coefficients and RMS coefficients of the lower surfaces, while the correlation coefficients were most important.
Fig. 5 depicts variations of mean, RMS, maximum peak and minimum peak of net wind force coefficients ($\overline{C}_{F,net}$, $\bar{C}_{F,net}$, $\hat{C}_{F,net}$) for roof panels A, B, C and D for all wind direction angles. Generally, the net wind force coefficients for 0% porosity were the highest and those for 10% porosity were the lowest. The values of $\overline{C}_{F,net}$ were about 44% lower for 5% porosity and about 55% lower for 10% porosity than those for 0% porosity. These numbers were 55% and 72%, 62% and 77%, and 58% and 72% for $\overline{C}_{F,net}$, $\overline{C}_{F,net}$ and $\overline{C}_{F,net}$, respectively.

The difference between the mean values for the three porosities was small with the exception of those for roof panel A panels B and C were similar, ranging from -0.16 to 0.05 for roof panel B and from -0.12 to 0.1 for roof panel C. The values for roof panel D were nearly zero for all wind direction angles.

The RMS values for 10% porosity were quite small, being less than 0.05. The values for 5% porosity were higher than those for 10% porosity. For 0% porosity, there were larger changes for these values. There was a rapid change for

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**Fig 3. Distributions of $\overline{C}_{p,net}$ and $\overline{C}_{p,net}$ at wind direction angle $\theta = 45^\circ$**

The difference between the mean values for the three porosities was small with the exception of those for roof panel A for wind direction angles from 30° to 60°. Roof panel A had the highest values, ranging from -0.06 to 0.27. The values for roof panels B and C were similar, ranging from -0.16 to 0.05 for roof panel B and from -0.12 to 0.1 for roof panel C. The values for roof panel D were nearly zero for all wind direction angles.

The RMS values for 10% porosity were quite small, being less than 0.05. The values for 5% porosity were higher than those for 10% porosity. For 0% porosity, there were larger changes for these values. There was a rapid change for
wind direction angles from 0° to 180°, with values from 0.06 to 0.17. A maximum $\tilde{C}_{F,net}$ of 0.17 was found at a wind direction angle of 70°, corresponding to 0% porosity.

For the maximum peak values, the trend for $\tilde{C}_{F,net}$ was similar to that for the RMS values. There was a strong dependence between $\tilde{C}_{F,net}$ and wind direction angles with a rapid change of these values for wind direction angles from 0° to 180°. The largest values of $\hat{C}_{F,net}$ for roof panels A and D were 0.89 and 0.9, respectively, corresponding to 0% porosity. The variations of $\hat{C}_{F,net}$ for 5% and 10% porosities were smaller than those for 0% porosity. The values of $\hat{C}_{F,net}$ varied from -0.05 to 0.52 and from -0.1 to 0.31 for 5% and 10% porosities, respectively.

For the minimum peak values, the difference between the values of $C_{F,net}$ for 5% and 10% porosities was small. The ranges of values of $\tilde{C}_{F,net}$ were from -0.52 to -0.06 and from -0.39 to -0.04 for 5% and 10% porosities, respectively. The maximum peak values for 0% porosity also depended strongly on wind direction angles, ranging from -1.00 to -0.27. Values of $\hat{C}_{F,net}$ for roof panels A and C for 0% porosity changed quickly for wind directions angles from 0° to 180°.

Fig 4. Distribution of $\overline{C}_{p,net}$ and $\tilde{C}_{p,net}$ at wind direction angle $\theta = 90°$. 
5. CONCLUDING REMARKS

The effect of porosity on net pressures on a roof panel was investigated.

The mean, fluctuating (RMS), maximum peak and minimum peak distributions over the surfaces of the roof panel were measured for several wind direction angles as well as for different porosities. Four roof panels had high-pressure fluctuations at wind direction angles from 0° to 180°.

From the analysis of results obtained in the tests, the pressures on the roof panels with 0% porosity were higher than those for 5% and 10% porosities. The porosities of the roof panels were most effective in reducing wind load on them.

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