WIND LOADS ON GRANDSTAND ROOFS

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Introduction

Melbourne [1] speculated on the cause of high negative peak pressures which occur under the separation bubble near the leading edge of flat roofs or near streamwise surfaces generally, in turbulent flow. In further study, Melbourne [2] illustrated the strong dependence on turbulence and in particular showed that by venting the leading edge (to prevent the very early reattachment phenomenon which was seen to be correlated with the occurrence of the highest negative pressures), the pressures and overall wind loading on the roof could be substantially reduced. One of the most relevant applications of a vented leading edge was seen to be on grandstand roofs, which are very wind sensitive structures. Cook [3] used this approach on a cantilevered grandstand roof, and in model measurements showed that a 25% reduction in mean pressures could be achieved by using a slotted leading edge. It remained still to show that a slotted leading edge could substantially reduce the dynamic response of such a cantilevered grandstand roof. In 1985 the opportunity arose to put the idea into action on a roof for the new Parramatta Oval Grandstand, and accordingly an aeroelastic model of this roof system was built and tested in the 450 kW Boundary Layer Wind Tunnel at Monash University. Subsequently, the model was used to explore a number of configurations to optimise the slot configuration and to determine generalised equivalent static loads on a cantilevered roof system, which is the subject of this paper.

The Grandstand Roof Model

The aeroelastic model was built to a scale of 1/100 and was tested in a 1/100 scale model of the natural wind boundary layer over suburban terrain (z_o=0.020). The basic dimensions of the cantilvered roof are given in Figure 1, along with definitions of the leading edge slot configuration. The model beams were made of Sugar Pine, and the roof deck was made of Balsa, and discrete masses were added to bring up the required mass distribution.

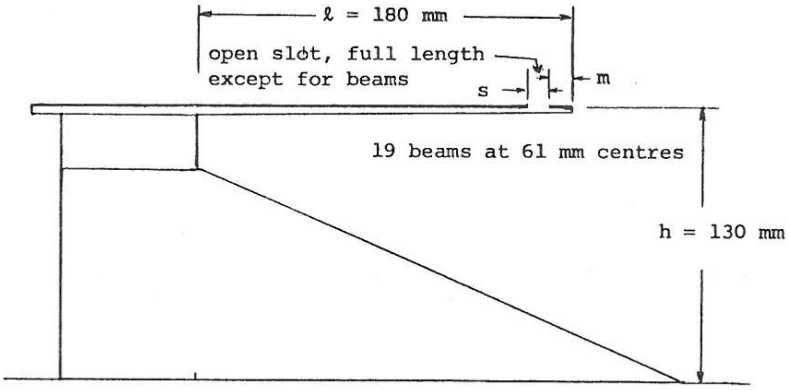

Figure 1. Dimension of 1/100 scale aeroelastic model of the grandstand cantilevered roof.

The aeroelastic scaling of the beams was based on keeping $\rho \bar{V}^2 L^4 / EI$ constant in model and full scale and in which the model/full scale ratios (subscript r) were

length	$L_r = 1/100$	density	$\rho_r = 1$
velocity	$V_r \approx 0.7$	Youngs modulus	$E_r \approx 0.040$
time	$T_r = L_r/V_r \approx 0.014$	Second moment of area	$I_r \approx 12 \times 10^{-8}$

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The deflection, in full scale terms, of the tip of the beams under a triangular load distribution, i.e. starting at a load of F Nm^{-1} at the leading edge reducing linearly to zero at the cantilever root, was 78×10^{-6} m per unit F Nm^{-1}. The use of a triangular load distribution will be discussed later. The stiffness of the edge beam was such that the influence of a triangular load distribution of one beam on the adjacent beams was as follows.

				load ↓			
tip displacement (ratio)	0.02	0.12	0.50	1.00	0.50	0.12	0.02

Measurements of the displacement of the leading edge of the roof were made directly through small calibrated strain gauged links which added negligble stiffness to the canopy system.

The model roof was also fitted with pressure tappings to permit the measurement of pressures above and below the roof with reference to freestream static pressure, and to measure pressures above the roof with reference to the pressure below the roof at the same location.

The Loading Process

The response of a cantilevered roof to wind action is complex as can be seen by a trace of the leading edge displacement given in Figure 2. The response is a combination of low frequency response, which can be observed, even at model scale, as being like a wave, often running along the leading edge from one end to the other, and on which a beam resonant component is superimposed. The low frequency response is driven in a quasi-steady manner by the pressure distribution which might typically vary from $\hat{C}_p = -6$ at the leading edge to $\hat{C}_p = -3$ at the trailing edge (Peak C_F based on V_h). The load from the resonant response is from the inertial load distribution; for a constant mass per unit length and linear mode the load distribution is triangular, but as the mode is very much that of a cantilever, (exponent could even be 2.0), and even with a reducing mass per unit length approaching the leading edge, the inertial load distribution is likely to be very much more peaked than triangular. Overall, for the purposes of determining an equivalent static load, it is suggested that a triangular load distribution is likely to be the best simple approximation of the effective load from the combined effects of the pressure driven low frequency response and the high frequency resonant response.

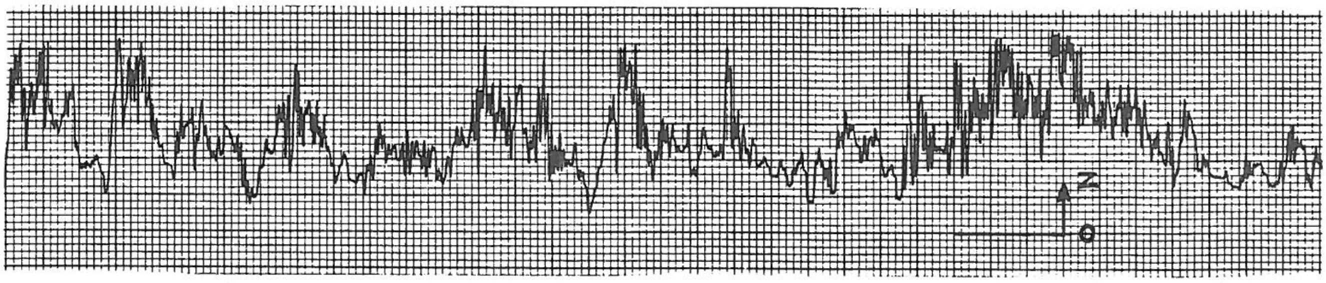

Figure 2. Trace of vertical displacement of the leading edge showing the skewed distribution, low frequency wake pressure components, and high frequency first mode beam resonance component.

Model Measurements

Tip displacements as a function of wind speed and direction were measured on a number of beams for various canopy configurations. The results are plotted in non-dimensional form as C_F versus $\bar{V}_h/n\,\ell$ where

$C_F = F / \tfrac{1}{2} \rho \bar{V}_h^2 b$

ℓ is length of cantilever beam

F is force per unit length of beam at the leading edge of a triangular load distribution which would give a displacementa z.

b is width of roof per beam (i.e. defining tributory area)

$\bar{V}_h$ is mean wind speed at the top of the beam

ρ is air density

s is the first model frequency of the beam

C_F is numerically equal to the leading edge pressure coefficient defining the triangular load distribution which, if applied statically, would give the same leading edge displacement.

These effective pressure coefficients may be converted to those based on a 3-second mean maximum gust wind speed by multiplying by $\bar{V}^2/\hat{V}^2$. These tests were conducted in a model wind turbulent boundary layer where at the height of the roof $\sigma_V/\bar{V} = 0.25$,

$$\text{which from } \hat{V} = \bar{V}\left(1 + g \frac{\sigma_V}{\bar{V}}\right) \text{ for } g = 3.7 \text{ gives } \left(\frac{\bar{V}^2}{\hat{V}^2}\right) = 0.27 .$$

For example, a peak coefficient of $C_{\hat{p}} = 7.0$ is equivalent to using $C_p = 7.0 \times 0.27 = 1.9$ in a quasi-steady code such as the Australian Wind Loading Code AS1170.

Examples of mean, standard deviation and peak effective pressure coefficients are given in Figures 3 and 4 for a range of slot configurations. These measurements were made over a full scale equivalent time of one hour.

Conclusions

Design loads for large cantilevered roofs are significantly greater than specified by AS1170. Incorporation of a slot along the leading edge was shown to reduce response, and hence design loads, by up to 30%.

References

1. W.H. Melbourne, 'The relevance of codification to design', Proc. 4th Int. Conf. on Wind Effects on Buildings and Structures, 785-790, 1975.

2. W.H. Melbourne, 'Turbulence effects on maximum surface pressures - a mechanism and possibility of reduction', Proc. 5th Int. Conf. on Wind Engineering, 541-552, 1979.

3. N.J. Cook, 'Reduction of wind loads on a grandstand roof', Jnl. Wind. Eng. and Industrial Aerodynamics, <u>10</u>, 373-380, 1982.

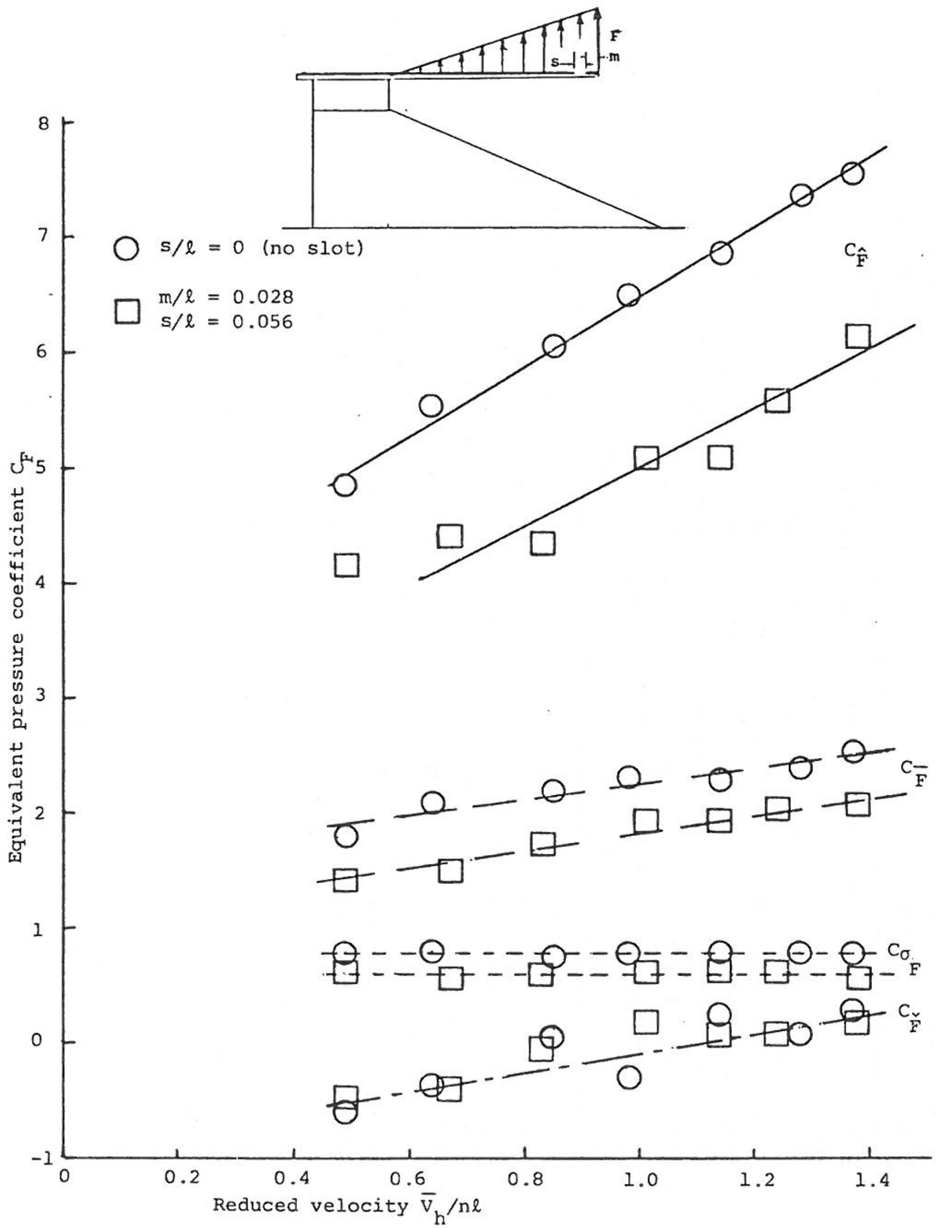

Figure 3. Leading edge response in terms of the equivalent pressure coefficient at the leading edge of a triangular distribution.

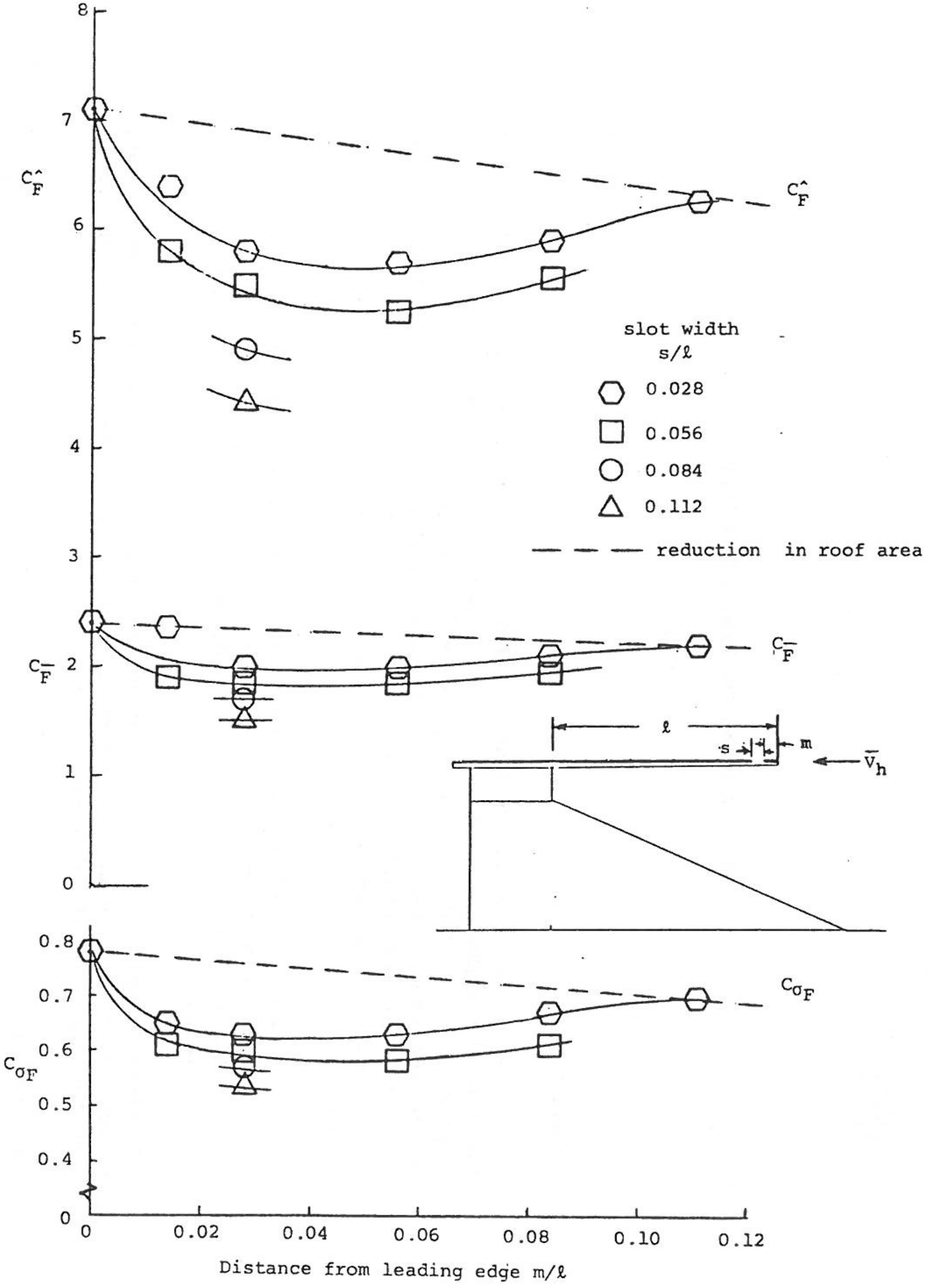

Figure 4. Effect of varying slot width and distance from the leading edge at $\bar{V}_h/n\ell = 1.2$