NINTH AUSTRALASIAN WIND ENGINEERING SOCIETY WORKSHOP, TOWNSVILLE, 2001

EFFECTS OF DISTORTION OF TURBULENCE INTENSITY AND SCALES OF TURBULENCE ON MEAN PEAK TOTAL LOADS OF A LOW RISE BUILDING MODEL

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ABSTRACT

It is found that the mean peak total loads on a low rise building are most sensitive to turbulence intensity – there is less sensitivity of the mean peak total loads to L_{uy}/W and L_{ux}/D length scale of turbulence ratios, generally. This is found by using a set of low rise building models in a set of simulated atmospheric boundary layers.

INTRODUCTION

Li and Melbourne (1995), in their study of the effects of freestream turbulence on streamwise surface pressures in separated and reattaching flows on a flat plate (D=50 mm), investigate peak pressures for length scale ratios of L_x/D greater than 2.1. For low turbulence intensity (I_u~8.0%) they find that the peak pressures increase in magnitude for length scales of turbulence ratios from 1.4 to 3.8, however, the magnitudes of peak pressures are smaller for an L_x/D of 10.20. They find, after investigating up to I_u = 15.3% and L_x/D = 8.71, that the effect of scale of turbulence on maximum magnitude of peak pressures becomes greater as the turbulence intensity increases.

Saathoff and Melbourne (1999) investigate streamwise pressures on a square cylinder (D=50 mm) in isotropic turbulence. The flows range from smooth flow up to a turbulence intensity of 24%; and having a maximum length scale of turbulence ratio, L_x/D, of 2.1. The peak pressures are located from the leading edge around 0.6D, for smooth flow, ranging to about 0.2D, for highly turbulent flow (I_u=24%), on the streamwise surface. These peak pressures are greater in magnitude for $L_x/D > 1.0$ than the peak pressures for $L_x/D < 1.0$ (small scale turbulence). They suggest that the peak pressures for turbulence intensity around 20% generally occur due to the intermittent reattachment of the separated shear layers rather than vortex shedding.

Although these results in the above references are not in boundary layer flows some understanding of the peak pressure distribution over the roof of a model in the surface layer of the atmospheric boundary layer can be gained.

Surry (1982) concludes for overall unsteady loads on structures of large or unusual geometry that together with modelling accurately mean velocity and turbulence intensity profiles scales should be maintained within better than a factor of 2, and that the most important scale being the lateral scale of the longitudinal turbulence component. Also, Roy (2000) shows data indicating that turbulence intensity dramatically affects total loads of a low rise building.

This paper investigates the sensitivity of the mean peak total loads of a low rise building to turbulence intensity, I_u, the length scale ratio, L_{uy}/W, and the length scale ratio, L_{ux}/D.

EXPERIMENTAL

Measurements were made in the James Cook University open circuit boundary layer wind tunnel which is driven by a 45 kW A.C. motor.

Four boundary layers were simulated atmospheric surface layers applicable to open country terrain. These agree with a full-scale roughness length of 10 to 30 mm. The turbulence intensity, I_u, and the length scales of turbulence, L_{ux} and L_{uy}, were measured at the long wall height of each model for each boundary layer.

A set of 4 low rise building models of a simple rectangular shape with 9° gable roofs having a ridge parallel to the longwall was constructed with 4:2:1 width to depth to height ratio, respectively. A force balance system developed by Roy (1982) was used to measure the fluctuating total loads. For a constant flow speed in the wind tunnel of about 14 ms^{-1} at mid-height and assuming a full-scale velocity of 30 ms^{-1}, an appropriate low-pass filter cut-off frequency was chosen in each case giving a constant full-scale wave number.

The load measurements were made in the xz plane on the models placed in the boundary layers at 0 degree azimuth coincident with the x direction normal to the long wall through the center of the base of the model – the z direction is vertical through the center of base.

The forces are non-dimensionalized by the freestream dynamic pressure at the height of the model, $q=1/2\rho\ \bar{u}_h^2$, and a reference area to give appropriate coefficients for the mean peak total horizontal force, C_{Fxpeak}, and the mean peak total vertical force, C_{Fzpeak}.

EFFECTS OF TURBULENCE INTENSITY ON MEAN PEAK TOTAL LOADS

It is clear from Figures 1 and 2 that C_{Fxpeak} and C_{Fzpeak} are highly sensitive to a change in turbulence intensity in the range of 20 to 23%, and more sensitive than changes in L_{uy}/W and L_{ux}/D in Figures 3, 4, 5 and 6 for the same total loads. Only a range of 1% change in turbulence intensity can be considered for a constant L_{uy}/W length scale ratio. The length scale ratio, L_{uy}/W, is plotted in Figures 1 and 2. Table 1 shows the effect of a decrease of 1% turbulence intensity, for a constant L_{uy}/W, on the mean peak total loads of horizontal force, C_{Fxpeak}, and vertical force, C_{Fzpeak}. These significant underestimations range from 12% to 9% for a 1% decrease in turbulence intensity in the region of 23 to 20%.

EFFECTS OF L_{uy}/W ON MEAN PEAK TOTAL LOADS

A least squares fit to the data for C_{Fxpeak} and C_{Fzpeak} is shown in Figures 3 and 4. As can be seen e.g. a length scale ratio decrease of L_{uy}/W from 2.4 to 1.2 includes approximately the reduction in the mean peak total loads as occurs when turbulence intensity decreases from 23% to 20%. This means that the effects of L_{uy}/W on mean peak total loads are not independent – there is an influence by turbulence intensity, I_u, because the mean peak total loads are most sensitive to turbulence intensity. Table 2 shows the effect of a decrease in L_{uy}/W by a factor of 2, for a constant h/z_o, on the mean peak total loads of horizontal force, C_{Fxpeak}, and vertical force, C_{Fzpeak}. Significant underestimations are in C_{Fzpeak} of 37% to 21%. Also, significant underestimations are in C_{Fxpeak} of 30% to 15% in Table 2. It is concluded that halving the length scale ratio, L_{uy}/W, has a significant effect upon the mean peak total loads even though the effects of turbulence intensity also contribute.

EFFECTS OF L_{ux}/D ON MEAN PEAK TOTAL LOADS

Figures 5 and 6 show the coefficients C_{Fxpeak}, C_{Fzpeak} and I_u plotted against the length scale ratio L_{ux}/D. The data do not collapse well onto the least squares fit lines and thus it is questionable whether there is any relationship between the mean peak total loads and L_{ux}/D. A halving of an L_{ux}/D value of 5 to 2.5 encompasses all the data and this includes a decrease in I_u from about 23% to 15% - thus, Iu dominates. Hence, the effect on mean peak total loads of a decrease in L_{ux}/D by a factor of 2 is not independent. Table 3 shows the underestimation in C_{Fxpeak} and C_{Fzpeak} for a decrease in L_{ux}/D by a factor of 2 – the range of L_{ux}/D is from 5 to 2.5. The underestimation for C_{Fxpeak} is 52% and for C_{Fzpeak} is 63%. Clearly, since these underestimations are large there are contributing effects by I_u and L_{uy}/W because of the large change in L_{ux}/D (from 5 to 2.5) of 2.5.

CONCLUSION

Mean peak total loads of horizontal force C_{Fxpeak} and vertical force C_{Fzpeak} are most sensitive to turbulence intensity, I_u, and less sensitive to the length scales of turbulence ratios L_{uy}/W and L_{ux}/D. Mean peak total loads, C_{Fxpeak} and C_{Fzpeak}, are significantly underestimated by about 12% for a 1% decrease in turbulence intensity over the range of turbulence intensity from 23% to 20% (L_{uy}/W

and L_{ux}/D are constant). The turbulence intensity profile as well as L_{uy} and L_{ux} have to be modelled correctly in the wind tunnel.

REFERENCES

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TABLE 1
PERCENT CHANGE IN COEFFICIENTS FOR 1 PERCENT CHANGE IN I_u

I_u range	L_{uy}/W	C_{Fxpeak}	C_{Fzpeak}
0.23 to 0.22	2.12	-11	-12
0.22 to 0.21	1.56	-10	-12
0.21 to 0.20	1.42	-9	-11

TABLE 2
PERCENT CHANGE IN COEFFICIENTS FOR FACTOR OF 2 DECREASE IN L_{uy}/W

L_{uy}/W range	h/z_o	C_{Fxpeak}	C_{Fzpeak}
2.4 to 1.2	100	-30	-37
2.0 to 1.0	185	-27	-34
1.4 to 0.7	315	-21	-28
1.1 to 0.55	565	-18	-24
0.9 to 0.45	1250	-15	-21

TABLE 3
PERCENT CHANGE IN COEFFICIENTS FOR FACTOR OF 2 DECREASE IN L_{ux}/D

L_{ux}/D range	C_{Fxpeak}	C_{Fzpeak}
5.0 to 2.5	-52	-63

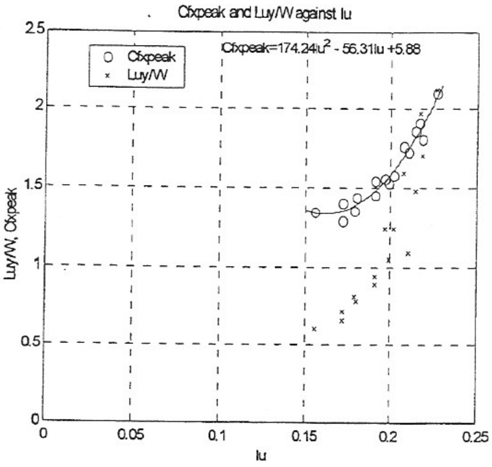

Figure 1 Cfxpeak against Iu

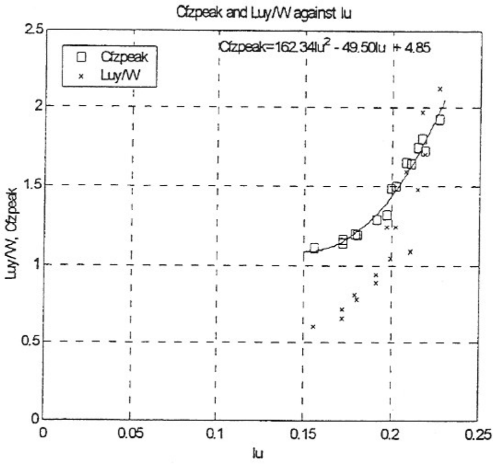

Figure 2 Cfzpeak against Iu

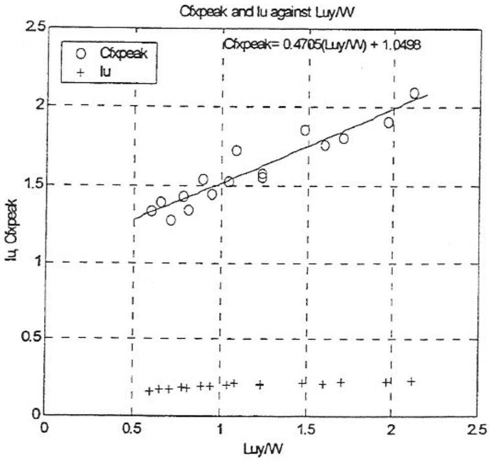

Figure 3 Cfxpeak against Luy/W

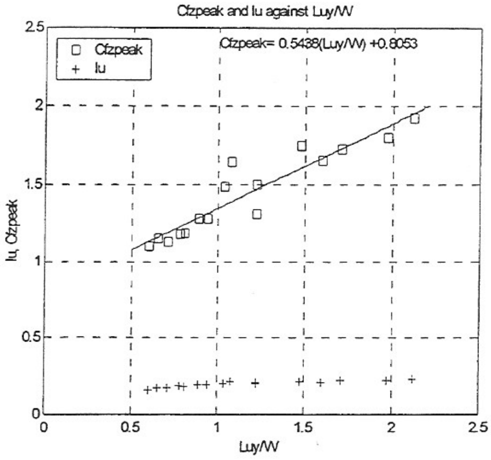

Figure 4 Cfzpeak against Luy/W

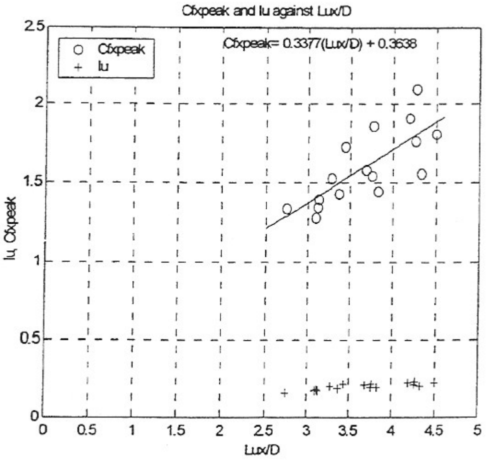

Figure 5 Cfxpeak against Lux/D

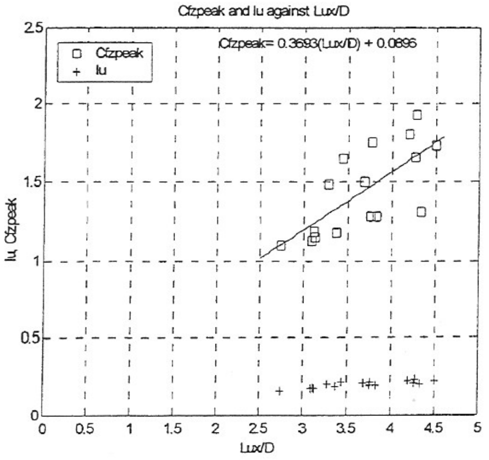

Figure 6 Cfzpeak against Lux/D