EFFECT OF SCALE ON TOTAL LOADS ON LOW RISE BUILDINGS

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Introduction

Measurements have been and are being carried out in wind tunnels on models of low rise buildings in boundary layers which are incorrectly simulated, in terms of scales. This generally arises due to relaxation of length scales' simulation and particularly the longitudinal length scales which indicate the low and high frequency parts of the longitudinal spectrum of turbulence. Another distortion of scale is the mismatching of the geometrical scale model in the scaled boundary layer. Some investigations have been carried out by Hunt [1] with emphasis on these effects, however the work was carried out using point pressures on cubic models in boundary layer flows which were simulated, in some cases, only over the height of the models.

The paper presents results of some measurements of the effect of scale on total loads on models in a wind tunnel.

Boundary Layer Data and Model Measurements

The three boundary layers simulated in the wind tunnel were 1/50, 1/100 and 1/200. Each boundary layer (B.L.) was generated using a plain barrier at the start of a 12 m long floor section, covered with carpet. The corresponding mean velocity profiles were similar at the height of the 1/50, 1/100 and 1/200 models in the respective B.L. and they compared well with the log-law profile. The roughness lengths, z_o, of the B.L. were intermediate between rural and urban terrain in full-scale. The turbulence intensities at the height of the models in the corresponding B.L. were very near the same. These are shown in Table 1.

The scales of longitudinal turbulence have been considered in two ways: firstly the lateral integral length scale, L_{u_y}, representing the low frequency end of the spectrum and secondly a measure of the integral length scale, L_{u_x}, representing the flow around the model and thus the high frequency end or the inertial subrange of the spectrum. The ratio of the mean velocity and the average cycling rate gave a length which is proportional to L_{u_x} and hence a length, l_n, such that

$$l_n = l_x \frac{X_{pk}}{X} \qquad X = \frac{\nu\, l_x}{\bar{u}}$$

$$= X_{pk} \frac{\bar{u}}{\nu} \qquad X_{pk} = \frac{n_{pk}\, l_x}{\bar{u}}$$

where X_{pk} is the peak dimensionless frequency in terms of a characteristic length l_x. Generally X_{pk} is invariant with height thus $\bar{u}/\nu$ is proportional to l_n representing a length scale in the inertial subrange of the velocity spectrum.

The models were of a rectangular plan 30 m x 7.5 m in full-scale with a gable roof section of 10° pitch and a central ridge over the long dimension. The total load measurements were made using a total load balance (Mk II) described briefly by Roy [2]. Low pass filtering, digitising and sampling times were set in accordance with dimensional analysis for the models. The total forces and overturning moments were non-dimensionalised by the free-stream dynamic pressure based on the mean velocity at the long wall height (h=3.75 m full-scale) of the model.

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$$C_{F_x} = \frac{F_x}{0.5\rho\bar{u}_h^2\ A_x}$$

A_x = area of long wall ($112.5\ m^2$)

$$C_{F_z} = \frac{F_z}{0.5\rho\bar{u}_h^2\ A_z}$$

A_y = area of end wall ($30.6\ m^2$)

$$C_{M_y} = \frac{M_y}{0.5\rho u_h^2\ A_y\ h}$$

A_z = plan area of roof ($225\ m^2$)

The direction normal to the long wall of the models denotes the x-direction. The y-direction is at 90° to the x-direction and the moment M_y is defined as that acting about this direction axis y. All measurements were made with reference to the center of base of the models and the vertical direction was designated the z-direction. Measurements were carried out for the wind direction in the x-direction on the models: a 1/50 model in 1/50 simulated B.L.; a 1/100 model in a 1/100 B.L.; and a 1/200 model in a 1/200 B.L.

Discussion of Results

The ratio of the measure of the longitudinal length scale, $\bar{u}/\nu$, and the lateral longitudinal length scale, L_{u_y}, are shown in Table 2. The total load measurements, for the three models, of maximum peak, mean, minimum peak and r.m.s. coefficients are shown in Figure 1 and 2. The results show definite differences in the total loads measured on the models however the turbulence intensity and the mean velocity profiles were similar at the height of the models.

It is clear from Table 2 and Figures 1 and 2 that with an increase in dominance of the scale $\bar{u}/\nu$ in the flow, the total loads tend to decrease. However, for the overturning moment the mean follows this trend but the r.m.s. is high and contrary to the r.m.s. horizontal and r.m.s. vertical force trend. Complexities in the correlation of the horizontal and vertical forces in terms of contribution to the overturning moment on the 1/200 model maybe a contributing effect.

There is generally an increase in the response of horizontal and vertical force and overturning moment for the 1/100 model (Figures 1 and 2). A similarity analysis was carried out and examined to determine the equivalent full-scale frequency response for the three models. The equivalent full-scale responses were up to 1.35 Hz, 1.50 Hz and 1.08 Hz for the 1/50, 1/100 and 1/200 model respectively. The 1/100 model has the highest response which would tend to relate to the high peak and r.m.s. coefficients shown in Figures 1 and 2. However this is not conclusive since there maybe an effect due to Reynolds number or a combination of Reynolds number and the maximum frequency response.

Conclusions

A set of results of total load measurements of 1/50, 1/100 and 1/200 models in 1/50, 1/100 and 1/200 boundary layers respectively has been presented. Generally the total horizontal and vertical forces increase as the turbulence scale ratio ($\bar{u}/\nu/L_{u_y}$) decreases. The equivalent full-scale frequency response was greatest for 1/100 model compared with the frequency response of the 1/50 and 1/200 models, and it is thought that the high loads on the 1/100 model may also be due to Reynolds number effects in the flow.

A frequency response of up to a set constant value for all the models is required to be investigated for any effect on total loads. Furthermore, measurements on models of 1/75 and 1/150 scale in the corresponding boundary layers need to be carried out for the investigation of possible Reynolds number effects on the total loads.

References

1. A. Hunt, 'Wind-Tunnel Measurements of Surface Pressures on Cubic Building Models at Several Scales', Journal of Wind Engineering and Industrial Aerodynamics, 10, pp. 137-163, 1982.

2. R.J. Roy, 'Total Force and Moment Measurement on Wind Tunnel Models of Low Rise Buildings', MEngSc. Thesis, J.C.U., 1982.

TABLE 1

TURBULENCE INTENSITIES AT MODEL HEIGHT

Boundary Layer Scale	1/50	1/100	1/200
I_u	0.21	0.21	0.20

TABLE 2

LENGTH SCALE RATIO

Boundary Layer Scale	1/50	1/100	1/200
$\frac{\bar{u}/\nu}{L_{u_y}}$	2.65	2.59	3.43

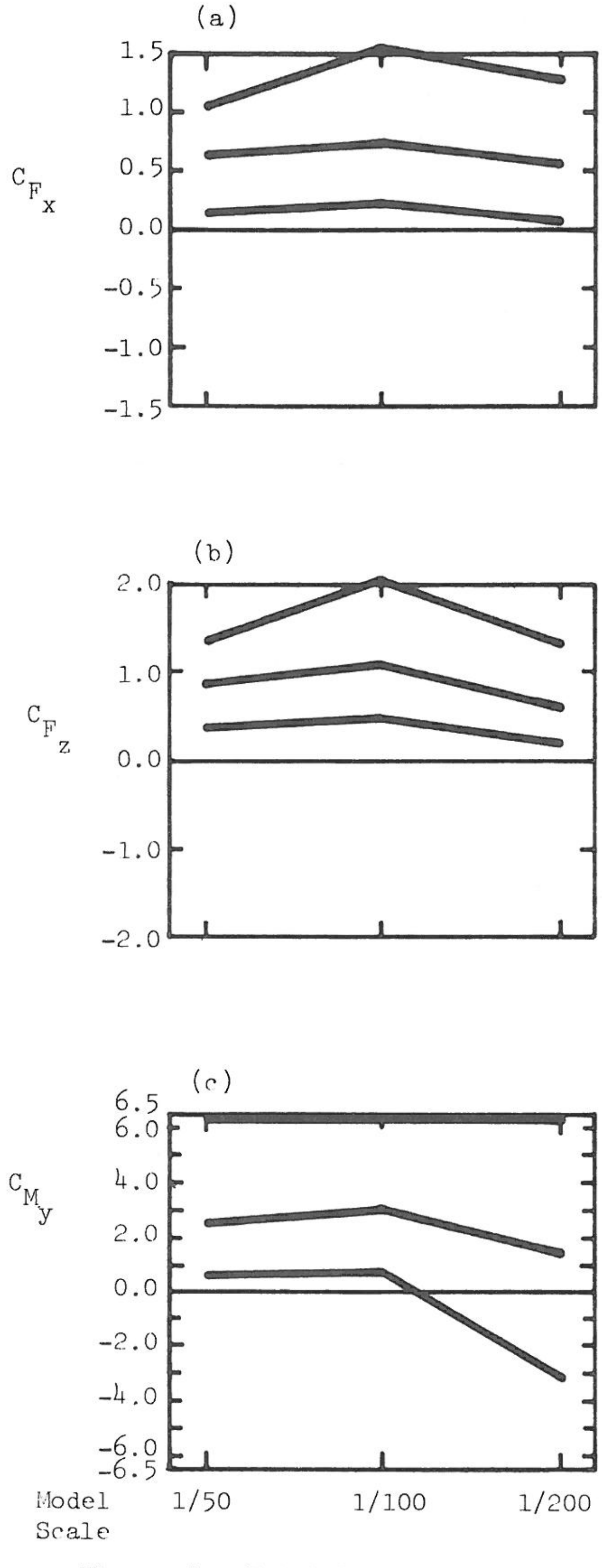

Figure 1. Total Load Measurements; Maximum peak, mean, minimum peak.

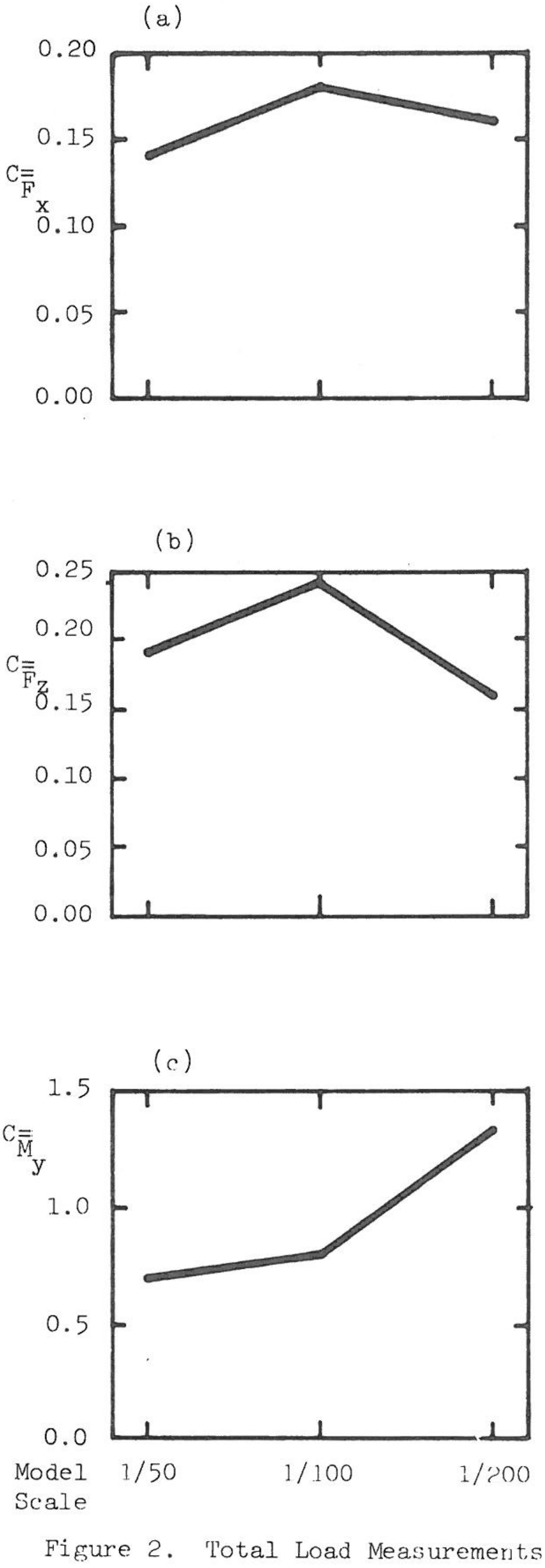

Figure 2. Total Load Measurements; r.m.s.