TOTAL LOAD MEASUREMENTS ON LOW RISE BUILDINGS:

TERRAIN CATEGORY 2

R.J. Roy[1] and G.R. Walker[1]

Introduction

Wind loads on low rise buildings are dominant in the design process for high wind regions. Knowledge of the total loads is required for global stability of a building or structure. The Australian Wind Loading Code AS1170 Pt. 2 - 1983 [1] bases design of low rise buildings on a quasi-static approach with mean pressure coefficients and a 2-3s gust dynamic pressure at eaves height to predict peak total loads. This raises the question of how representative these predictions are of the total loads?

This paper presents a set of total loads measured on four models in a simulated rural terrain, or Category 2 equivalent of the Code, in a wind tunnel, and their comparison with the Code [1] predictions.

Boundary Layer Simulation

Simulation of the boundary layer was carried out by using a plain barrier at the start of the test section and carpet over a distance of 12 m to the turntable. The boundary layer developed at the turntable was a good fit to the log-law up to a height of 25 m in full scale. Turbulence intensity agreed well with the log-law according to a full-scale roughness length of 20 mm.

Longitudinal turbulence length scales were about half of those predicted by the von Karman-Harris empirical spectrum. A lateral longitudinal integral length scale, L_{uy}, was determined from cross correlation of longitudinal turbulence fluctuations. L_{uy} was equivalent to 11.56 m at 3.75 m height in full-scale.

Models and Instrumentation

Models of 1/100 scale were constructed of balsa and polystyrene, with a rectangular plan of 14 m x 7 m in full-scale. The roof section had a central ridge over the long dimension of the model forming gable ends with verges of 0.45 m together with eaves of 1.2 m in full-scale. Four different roof pitches of 10, 15, 20 and 30 degrees were used with a common long wall height of 3 m in full-scale.

Measurements of total loads on the models were made using the balance (MkII) as described briefly by Roy [2]. Data from the transducers on the balance were digitised at 300 Hz for 18s and after digitisation weighting of the data was carried out to give the required total loads. All measurements carried out on the four models had a frequency response equivalent of up to 1.7 Hz in full-scale.

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[1] James Cook University of North Queensland

Total Load Coefficients

The total loads measured were in the vertical plane normal to the side walls (0°), designated the x-direction, and the vertical plane normal to the end walls (90°), designated the y-direction, of the model. All loads were referenced to the centre of the base of the models with the vertical direction being designated the z-direction. Overturning moments were referenced to the direction (normal) of the plane in which they act. All the coefficients were referenced to the dynamic pressure based on the mean velocity at eaves height (h = 3 m full-scale). These coefficients are:

$$C_{F_x} = \frac{F_x}{0.5\rho\bar{u}_h^{\,2}A_x}$$ A_x = area of side wall (42 m^2)

$$C_{F_y} = \frac{F_y}{0.5\rho\bar{u}_h^{\,2}A_y}$$ A_y = area of end wall (23.2, 24.3 25.5, 28.1 m^2)

$$C_{F_z} = \frac{F_z}{0.5\rho\bar{u}_h^{\,2}A_z}$$ A_z = plan area of roof (140.1 m^2)

$$C_{M_x} = \frac{M_x}{0.5\rho\bar{u}_h^{\,2}A_x h}$$

$$C_{M_y} = \frac{M_y}{0.5\rho\bar{u}_h^{\,2}A_y h}$$

The following symbols: ^,v, -, =, maximum peak, minimum peak, mean and r.m.s. respectively have been used to denote the total load value.

Results

A set of results for the four models for wind directions of 15 degree increments from 0 to 90 degrees is shown in Table 1. These results have been used to compare with predictions of total loads based on the Code [1]. For the models, wind tunnel measurements were made of the 2-3s gust velocity at an equivalent 3 m full-scale height. An average of 20 tests indicated a gust factor of 1.51.

The results for wind directions of 0 degrees and 90 degrees are shown in Figures 1 and 2. Curves are presented for the total vertical force, horizontal force and overturning moments in the x and y directions as a function of roof pitch. Four curves are presented in each graph:

(i) peak coefficients obtained from the wind tunnel measurements;

(ii) mean coefficients obtained from the wind tunnel measurements;

(iii) peak coefficients reduced by the square of the velocity gust factor - i.e. the peak coefficients expressed in terms of the dynamic pressure based on the equivalent 2-3 gust velocity at eaves height.

(iv) the predicted coefficients based on the Code coefficients - 1983 version - including area reduction factors (but not the directional reduction factor).

Discussion of Results

The Code [1] predictions compare reasonably well with the model results for both the wind directions of 0 and 90 degrees. There are however underestimates by the Code of C_{F_x}, C_{F_z} and C_{M_y}.

The horizontal force, C_{F_x}, has been underestimated by 23 and 29 percent for the 20 and 30 degree pitch models respectively at 0 degree azimuth. The Code tends to overestimate the model measurements of vertical force C_{F_z}, for the 20 and 30 degree pitch models. This overestimate is more significant for the latter model.

The overturning moments predicted by the Code generally agree well with the model values for both 0 and 90 degree azimuth. However the Code does underestimate the overturning moment C_{M_y}, about 19 percent for the 15 degree pitch model at 0 degree azimuth and overestimates this moment for the 20 and 30 degree pitch models at 0 degree azimuth.

Conclusion

A set of results from measurements of four models with different roof pitches has been presented for a Rural terrain (Category 2) boundary layer simulation and a comparison has been made with the Code [1].

Three main points are noted:

(i) The maximum peak of the total force for the model, referenced to the 2-3s velocity in the wind tunnel, resulted in a curve for the four models very near in magnitude to the corresponding mean total load coefficient of the model.

(ii) The Code appears to underestimate total vertical force for roof pitches less than 20 degrees.

(iii) The Code tends to overestimate total vertical force and overturning moment for roof pitches 20 degrees and greater.

Further model measurements need to be carried out with 0 and 5 degree roof pitches, and for different h/d ratios.

Acknowledgements

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References

1. S.A.A. 'Wind Loading Code AS1170 - Part 2 - 1983'.

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

TABLE 1

TOTAL LOAD COEFFICIENTS: RURAL TERRAIN

Pitch	Degree Azimuth	$C_{\hat{F}_x}$	$C_{\check{F}_x}$	$C_{\bar{F}_x}$	$C_{\bar{\bar{F}}_x}$	$C_{\hat{F}_z}$	$C_{\check{F}_z}$	$C_{\bar{F}_z}$	$C_{\bar{\bar{F}}_z}$	$C_{\hat{M}_y}$	$C_{\check{M}_y}$	$C_{\bar{M}_y}$	$C_{\bar{\bar{M}}_y}$	$C_{\hat{F}_y}$	$C_{\check{F}_y}$	$C_{\bar{F}_y}$	$C_{\bar{\bar{F}}_y}$	$C_{\hat{M}_x}$	$C_{\check{M}_x}$	$C_{\bar{M}_x}$	$C_{\bar{\bar{M}}_x}$
10° PITCH	0	1.86	-0.05	0.68	0.24	1.34	0.19	0.63	0.17	5.65	-0.25	2.21	0.79	1.02	-1.01	0.00	0.24	1.34	-1.22	0.03	0.27
	15	2.06	0.01	0.74	0.26	1.33	0.22	0.63	0.16	5.69	-0.36	2.23	0.80	1.42	-0.76	0.29	0.25	1.89	-0.89	0.17	0.31
	30	2.17	0.09	0.87	0.28	1.28	0.22	0.62	0.16	5.48	-0.87	1.88	0.84	1.65	-0.51	0.46	0.26	2.44	-0.55	0.53	0.37
	45	1.91	0.12	0.78	0.24	1.19	0.17	0.56	0.15	4.12	-0.65	1.42	0.63	2.18	-0.16	0.79	0.29	2.96	-0.22	0.92	0.41
	60	1.77	-0.08	0.63	0.24	1.08	0.07	0.43	0.14	3.47	-1.15	0.84	0.61	2.34	0.14	0.91	0.29	3.09	0.05	1.10	0.41
	75	1.24	-0.32	0.31	0.19	0.84	0.00	0.27	0.11	2.70	-1.54	0.37	0.59	2.51	0.14	1.01	0.32	3.61	0.18	1.43	0.47
	90	0.93	-0.83	0.00	0.21	0.72	-0.03	0.24	0.09	1.95	-1.87	-0.03	0.48	2.53	0.06	0.97	0.32	3.85	0.29	1.59	0.50
15° PITCH	0	1.72	0.09	0.68	0.22	1.24	0.21	0.57	0.15	4.78	-0.01	1.92	0.64	0.85	-0.81	0.03	0.19	1.23	-1.12	0.06	0.25
	15	1.94	0.13	0.80	0.25	1.24	0.23	0.61	0.15	4.90	-0.16	1.96	0.70	1.05	-0.56	0.21	0.20	1.67	-0.64	0.28	0.28
	30	2.00	0.24	0.89	0.25	1.29	0.26	0.64	0.16	4.45	0.02	1.74	0.58	1.37	-0.36	0.40	0.22	2.28	-0.39	0.57	0.34
	45	2.06	0.23	0.87	0.26	1.20	0.19	0.55	0.15	4.19	-0.20	1.46	0.56	1.75	-0.13	0.60	0.23	2.63	-0.20	0.83	0.37
	60	1.75	-0.02	0.66	0.24	1.02	0.10	0.43	0.13	3.29	-0.53	0.98	0.50	1.72	0.02	0.71	0.23	2.80	-0.01	1.05	0.38
	75	1.44	-0.38	0.39	0.21	0.91	0.01	0.30	0.12	2.51	-0.70	0.47	0.39	1.97	0.06	0.81	0.26	3.33	0.15	1.36	0.46
	90	0.84	-0.89	0.01	0.21	0.79	-0.01	0.25	0.10	1.54	-1.35	0.02	0.31	2.11	0.07	0.80	0.27	3.68	0.24	1.50	0.49
20° PITCH	0	2.65	0.32	1.13	0.33	0.75	0.02	0.27	0.09	3.05	-0.60	1.06	0.49	0.98	-0.87	0.02	0.23	0.89	-0.89	0.01	0.19
	15	2.69	0.31	1.15	0.35	1.00	0.04	0.34	0.13	3.04	-0.81	0.95	0.54	1.29	-0.66	0.27	0.23	1.54	-0.85	0.18	0.27
	30	2.71	0.36	1.20	0.35	1.12	0.13	0.52	0.15	2.85	-0.52	0.97	0.45	1.29	-0.53	9.33	0.22	2.29	-0.41	0.71	0.34
	45	2.43	0.22	1.00	0.31	1.21	0.19	0.56	0.15	2.71	-0.22	0.97	0.43	1.78	-0.08	0.68	0.23	2.56	-0.10	0.84	0.34
	60	2.10	0.01	0.74	0.27	1.14	0.08	0.45	0.14	2.46	-0.59	0.72	0.41	2.04	0.10	0.86	0.27	3.16	0.09	1.16	0.41
	75	1.57	-0.42	0.41	0.23	0.90	0.02	0.30	0.12	1.89	-0.87	0.31	0.36	1.97	0.10	0.81	0.26	3.26	0.24	1.31	0.43
	90	0.93	-0.91	0.01	0.21	0.69	0.00	0.22	0.09	1.21	-0.98	0.06	0.25	2.05	0.06	0.79	0.26	3.49	0.30	1.45	0.46
30° PITCH	0	3.51	0.58	1.60	0.43	0.39	-0.16	0.08	0.07	2.08	-0.13	0.82	0.29	1.15	-1.19	-0.01	0.30	0.89	-0.91	-0.01	0.23
	15	3.73	0.63	1.70	0.46	0.33	-0.13	0.06	0.05	2.31	-0.29	0.83	0.35	1.71	-0.66	0.43	0.30	1.15	-0.84	-0.12	0.24
	30	4.05	0.59	1.78	0.50	0.87	-0.01	0.32	0.12	2.46	-0.50	0.83	0.41	2.11	-0.19	0.77	0.30	2.43	-0.48	0.70	0.36
	45	3.49	0.37	1.53	0.47	0.97	0.06	0.41	0.13	2.17	-0.21	0.84	0.32	2.10	-0.23	0.75	0.29	2.49	-0.53	0.68	0.36
	60	3.04	0.10	1.10	0.42	1.06	0.13	0.47	0.13	1.93	-0.33	0.45	0.30	2.53	0.24	1.08	0.32	3.61	0.12	1.36	0.48
	75	2.22	-0.42	0.54	0.33	0.94	0.05	0.33	0.12	1.55	-0.70	0.27	0.30	2.53	0.22	1.06	0.33	4.40	0.42	1.76	0.57
	90	1.23	-1.12	0.00	0.26	0.75	0.01	0.24	0.09	0.94	-1.09	-0.15	0.23	2.48	0.13	0.98	0.32	4.44	0.43	1.90	0.59

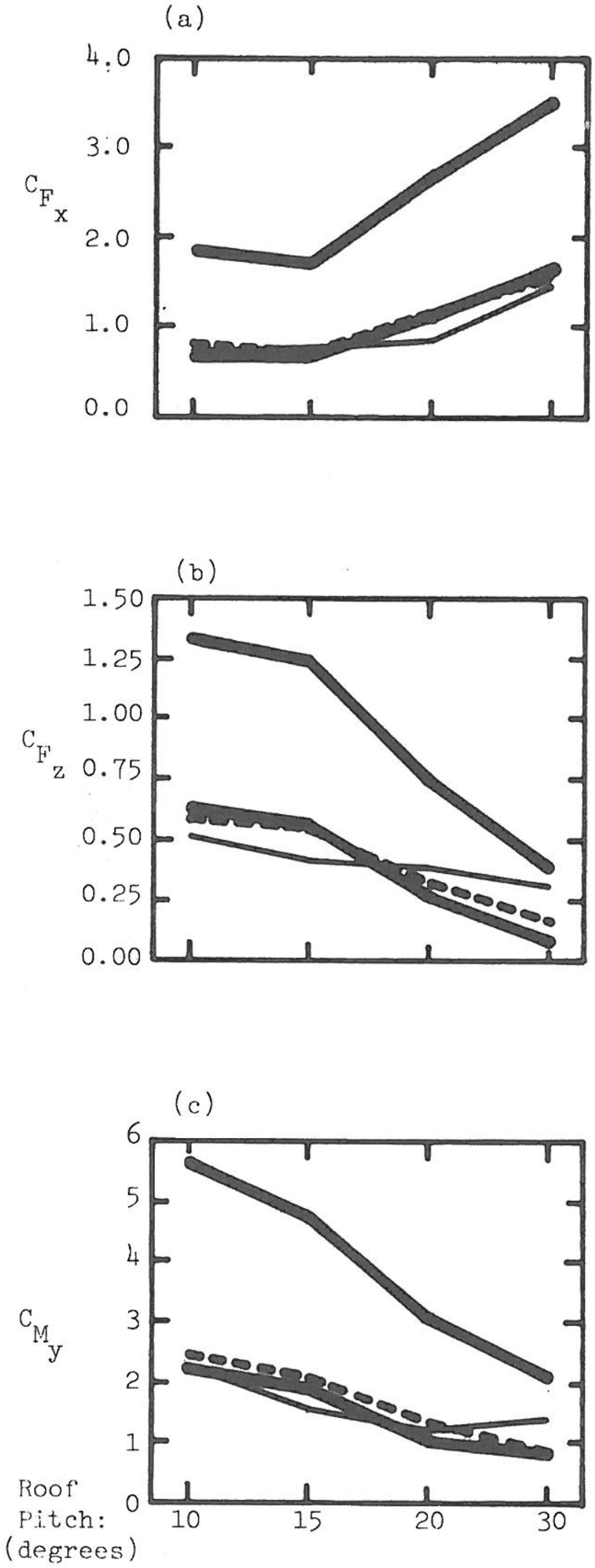

Figure 1 Total Load Coefficients (O=0°). Comparison between Model and AS1170 Pt.2-1983 Code: Rural Terrain.

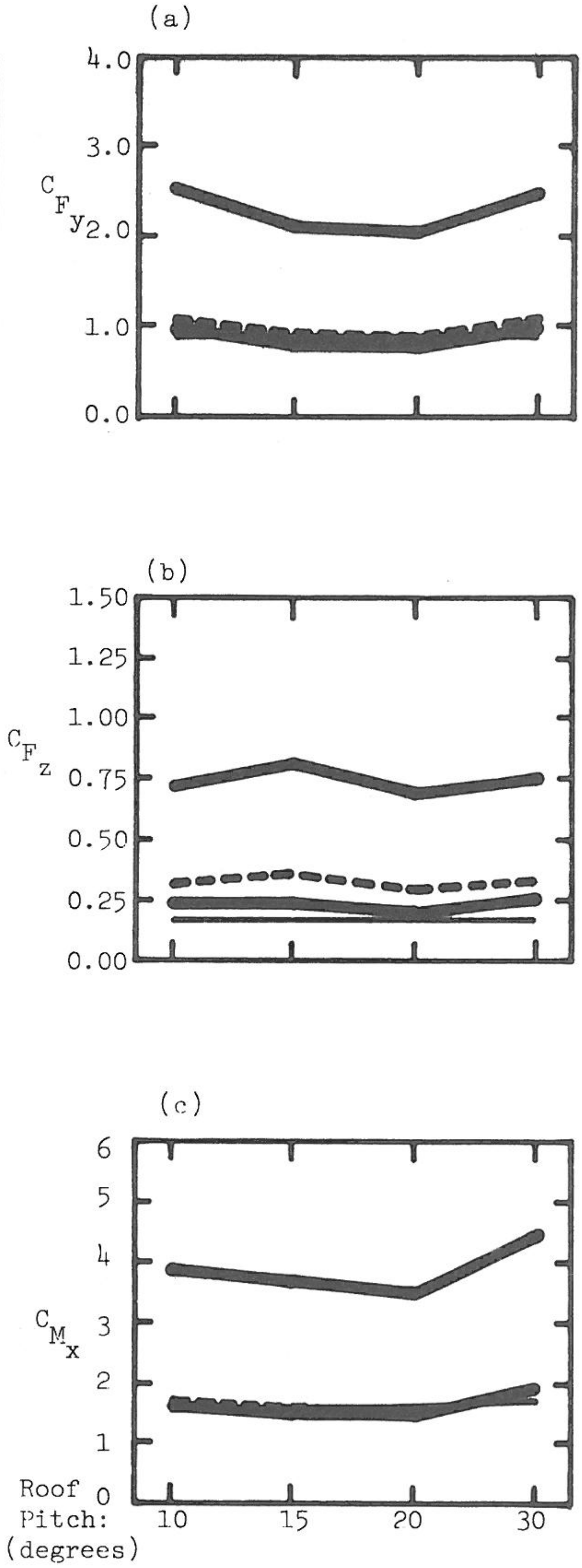

Figure 2 Total Load Coefficients (O=90°). Comparison between Model and AS1170 Pt.2-1983 Code: Rural Terrain.

Key: Model Peak and Mean; Model Pseudo Mean; Code Mean.