High frequency force balance model tests

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Summary

High frequency force balance model test techniques for wind–induced response predictions of tall buildings were developed. A lightweight rigid model of a tall building mounted on an ultra-sensitive force transducer allows the measurement of the wind-induced base shears, overturning moments, and torsional moments. Generalised forces on the building are estimated and the building responses are calculated using the dynamic properties of the prototype building. Along-wind, cross-wind, and torsional responses of the CAARC standard tall building were estimated for both the incident wind normal to the wide and narrow faces of the building model. The results obtained from a high frequency force balance test technique are consistent with the results obtained from aeroelastic model test techniques reported by other researchers.

1. Introduction

A high frequency force balance (HFFB) test technique is a fast and cost effective method to measure the mean and quasi-steady dynamic forces and responses of structures, in particular tall buildings. The technique involves the use of a lightweight rigid model, correctly scaled to the prototype geometrical shape, made from high-density structural foam materials, and mounted on an ultra sensitive force transducer. Wind-induced base shears, overturning moments, and torsional moments are measured. Generalised forces on the building are estimated and the responses of the building are calculated using the dynamic properties of the prototype building. This wind tunnel test technique was first developed in early eighties (Tschanz 1982, and Tschanz & Davenport 1983). Since the dynamic structural properties are introduced at the data analysis stage, the wind tunnel test data can be used effectively to carry out parametric studies on the variation of dynamic properties such as natural frequency, damping value, and mass. This allows a greater flexibility to the analysis of results as well as provides the engineers with useful information at an early design stage.

The high frequency force balance test technique also has major limitations, i.e. aeroelastic effects are ignored, and peak loads and responses are predicted using a peak factor approach. These limitations have been documented by Yip et al. (1995). However, for tall buildings that have uniform geometrical shapes and structural systems constructed from concrete core and frame structures, modes of vibration are relatively uncoupled and the sway modes of vibration can be approximately represented by linear mode shapes. Therefore, the aim of this research is to develop the high frequency force balance test technique for determinations of the overall wind-induced loads and responses of tall buildings with linear and uncoupled modes of vibration. The development of the high frequency force balance test technique to take into account the effects of coupled modes and higher modes of vibration are the subject of ongoing research.

2. Experimental programme

A commercially available six component force balance JR3 was used for this study. The JR3 sensor is a monolithic design containing no electronic components, stiff, resulting in minimal degradation of system dynamics and positioning accuracy. The CAARC standard tall building model (Melbourne 1980) was selected for a detailed study. The building is flat-topped, without parapets, and the exterior walls are flat without millions or other geometric disturbances. The building is 180 m high with side lengths of 45 m and 30 m. Only the fundamental modes of vibration were considered in this study. The sway mode shapes were assumed to be linear, rotating about a point analogous to ground level of the model, and the torsional mode shape was assumed to be constant throughout the entire height of the building. The corresponding fundamental natural frequencies were taken as 0.20 Hz for both translational motions, and 0.36 Hz for torsional motion. Structural damping was taken as 1% of critical for translational motions and about 1.4% of critical for torsional motion. Building density was taken as 160 kg/m^3.

An open terrain wind model with a power law exponent of the mean wind speed profile $\alpha \cong 0.15$ and a turbulence intensity at top of the building model $I_u \cong 0.10$ was simulated. Wind tunnel model tests were conducted for the incident wind normal to the wide and narrow faces of the building model. Measurements were taken at a single mean wind speed of approximately 9.8 m/s at top of the building model. The analogue output signals from the force balance sensor were suitably amplified and low pass filtered to maximise the output signals and minimise the electrical noise respectively. The analogue signals were then digitised by an analogue-to-digital converter at a sampling frequency of 400 Hz, for approximately 11 minutes to yield a sample size of 262144 (2^{18}).

3. Wind-induced responses of the CAARC building

Spectra of the generalised along-wind and cross-wind forces, and generalised torsional moment were determined from the spectra of the measured along-wind, cross-wind, and torsional moments respectively. Mean and standard deviation of the along-wind and cross-wind deflections, and twisting angles for the CAARC building model were determined. In this paper, only the results of standard deviation twisting angles at top of the building model are presented.

Torsional responses in terms of standard deviation angles of twist for the CAARC building model, for incident wind normal to the wide face, are presented as a function of reduced wind velocity, $\overline{U}_h / n_{z-z} D_y$, as shown in Figure 1. Results obtained from aeroelastic model tests of the CAARC building with coupled translational/torsional motion using a base hinge assembly (BHA) model (Thepmongkorn & Kwok 1999) are also presented for comparison. It can be seen that the torsional responses predicted by HFFB model obtained from this study are in good agreement with, but generally higher than, the results obtained from a BHA model. However, for reduced wind velocities close to 5, the results from the BHA model indicated a peak in the torsional response due to an enhanced transferred energy from cross-wind resonance. The variation between the results obtained from the HFFB and BHA models are evident due to significant aeroelastic effects, which are not modelled by the HFFB test technique. The torsional responses obtained from pure torsional aeroelastic model tests for buildings with side ratios of 1:1 and 1:2, reported by Zhang et al. (1993) and Xu (1991) respectively, are also presented in Figure 1. It is evident that the torsional responses for the CAARC building, representative of a rectangular building with side ratio of 1:1.5, lie between those two responses due to the different frontal widths of the building models. These results confirm the ability of the HFFB model for torsional response predictions when aeroelastic effects are not significant.

Similar results are presented in Figure 2 for the incident wind normal to the narrow face of the building model. The results from the HFFB model are in good agreement with the results obtained from a BHA model for reduced wind velocities, $\overline{U}_h / n_{z-z} D_x$, ranging from 3 to 10. The torsional response for this incident wind angle are caused by twisting moments resulting from the non-uniform pressure distributions along the side faces of the building model. This is due to the separation of the wind at upstream corners and the reattachment process of the separated shear layers. Consequently, the torsional responses for a rectangular building are expected to be higher than those for the square building. The higher responses for the CAARC building and the rectangular building with a side ratio of 1:2 compared to the square building confirm this wind excitation mechanism.

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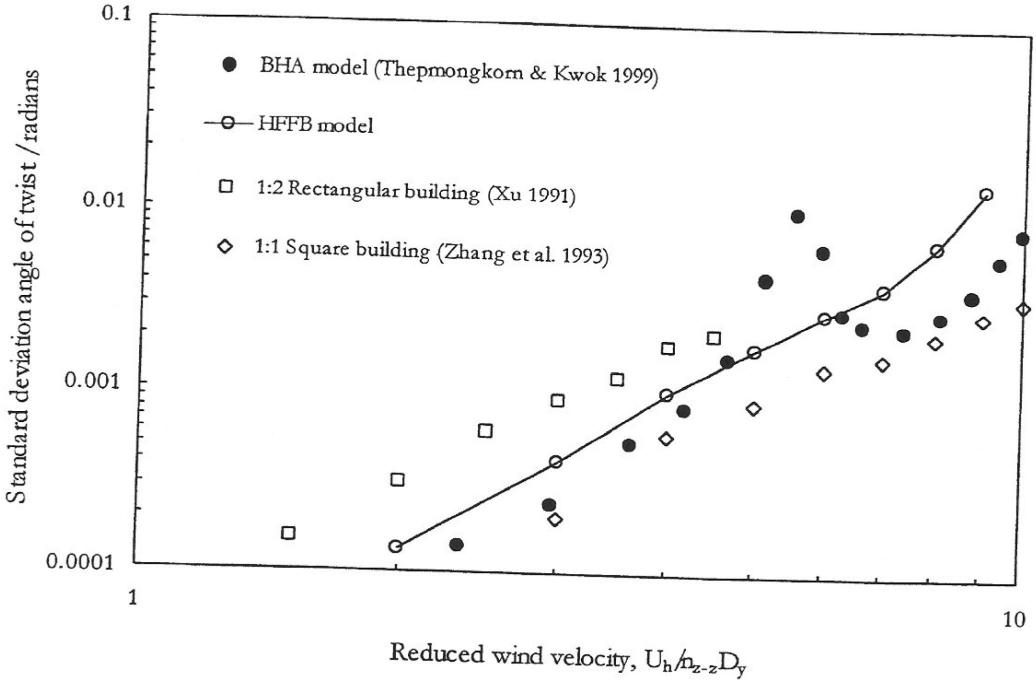

Figure 1: Standard deviation angles of twist at top of the CAARC building model as a function of reduced wind velocity for the incident wind normal to the wide face of the building model.

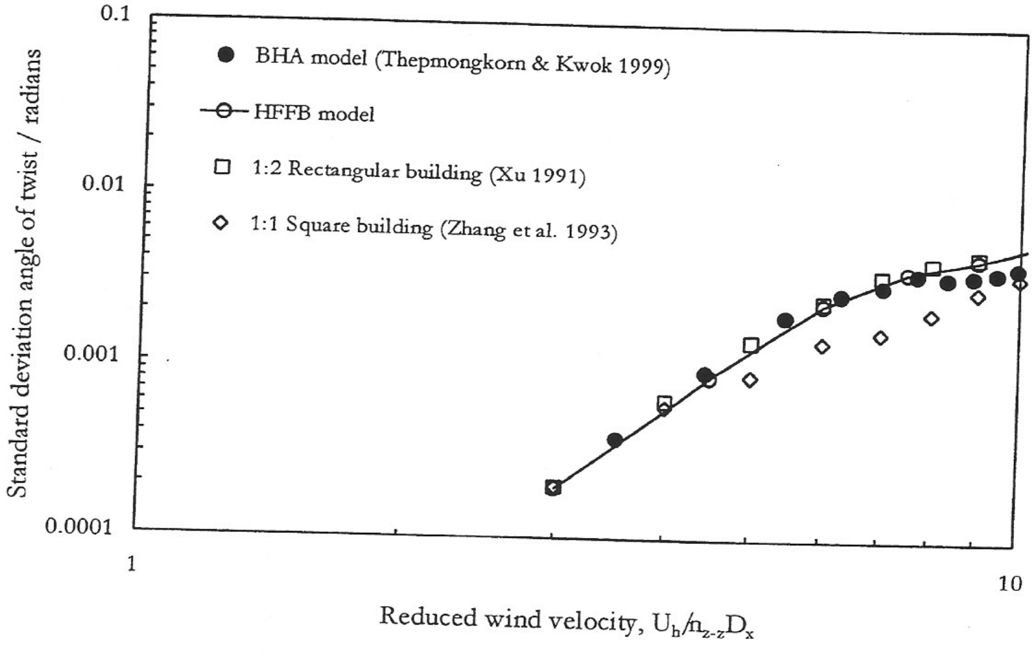

Figure 2 Standard deviation angles of twist at top of the CAARC building model as a function of reduced wind velocity for the incident wind normal to the narrow face of the building model.