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Along- and cross-wind response of a generic tall building: Comparison of wind-tunnel data with codes and standards

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ABSTRACT

In this paper, predictions of along-wind base moments for a generic tall building from several wind tunnels from an international benchmark study, are compared with those from three codes and standards: the Hong Kong Code of Practice (2004), the Australian/New Zealand Standard, and the American Standard (ASCE 7). There are significant differences in the predictions from the codes, with two of the codes producing lower values than the average of the wind tunnel data. In the case of the Hong Kong Code, the specified drag coefficients for the building are significantly lower than the effective drag coefficients derived from the other standards, and from the measurements. The lower predictions from ASCE 7 can be partly attributed to an apparent inconsistent formulation in the numerator of the expression for the gust effect factor for dynamic structures.

Predictions of cross-wind base moments and resultant accelerations from the Australian/New Zealand Standard, have also been compared with the wind-tunnel data. The comparisons are good, with the Standard giving predictions close to the averages of the wind-tunnel data for the cross-wind moments, and close to the upper limits of the wind-tunnel data for the resultant accelerations.

1. Introduction

Calculation of the along-wind dynamic response of tall buildings, based on random process and vibration theory, was first incorporated into design codes and standards more than forty years ago, and some comparisons with boundary-layer wind tunnel data were made as early as 1967 (Vickery and Davenport, 1967). However, many detailed changes and refinements have been made to code procedures in the intervening period, and methods in various codes and standards have diverged from each other to some degree. Furthermore, new wind-tunnel methods for tall buildings have been introduced in the last thirty years – principally through the use of the high-frequency base (or 'force') balance (HFBB). In this paper, along-wind base moments calculated by three codes, are compared with consensus wind-tunnel data for a benchmark building used in a recent international comparative study based on the HFBB technique. Cross-wind base moments and resultant accelerations, from the Australian/New Zealand Standard, are also compared with the wind-tunnel data.

2. IHFBB-IAWE benchmark study

2.1. History of the study

The International HFBB Benchmark Study ran from 2008 to 2012, with the support of the International Association of Wind Engineering, (Holmes et al., 2008). Two tall buildings were defined, and various participating wind-tunnel laboratories manufactured their own models and carried out the tests, and subsequently presented results for comparison. Groups were not named explicitly in reporting of the study. The eight participating groups included four universities and four commercial wind testing companies. Geographically the groups were from Canada (two), and one from each of United States, Australia, Korea, China, Japan and Hong Kong.

The two buildings comprised:

- A 'basic' test building intended primarily for use as a benchmark for newer groups ('Building B').
- An 'advanced' building specification for more experienced groups ('Building A').

Generally the height of the 'advanced' building (240 m) puts it outside the range of applicability of wind loading codes and standards. However, the height, and relatively simple dynamic

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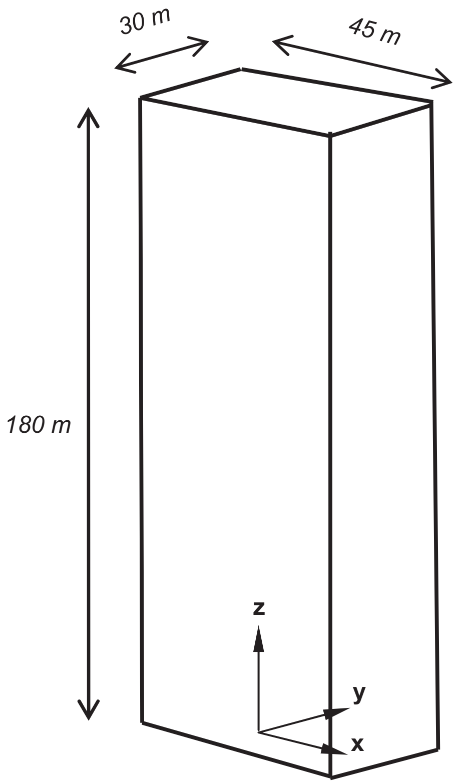

Fig. 1. Basic building used in the International HFBB Benchmark Study.

properties, of the 'basic' building make it amenable to treatment by codes and standards, at least for the along-wind response. This paper therefore focuses mainly on Building B, the dimensions of which are shown in Fig. 1. However, the effective drag coefficients derived from both Buildings A and B are compared with code and standard values in Section 5.2.

2.2. Basic building (Building B)

The building is 180 m high, and of rectangular cross section, with horizontal dimensions of 45 m by 30 m. The basic geometry is similar to that of the well-known CAARC benchmark building of the 1970s (Melbourne, 1980) – however the dynamic properties are different. Three uncoupled dynamic modes were specified, with sway frequencies of 0.20 Hz and 0.23 Hz about the two principal orthogonal axes. Participating groups were asked to produce responses (total base moments and rooftop accelerations) for hourly mean wind speeds at roof height of 20, 30 and 40 m/s, and for structural damping of 1.0% and 2.5% of critical damping, representing serviceability and ultimate limit state conditions, respectively. The original specifications and the results from this building, and from the 'advanced' Building A, are available in pdf files on the website of the International Association for Wind Engineering (〈http://www.iawe.org/committes.html〉). They have also been summarized by Holmes and Tse (2013).

2.3. Approach flow properties

The building was assumed to be located in urban terrain, in a boundary layer with a mean velocity profile described by a power-law exponent of 0.25 (approximate roughness length of 0.2 mm). The longitudinal turbulence intensity at the roof height of the building was prescribed as 0.143, with an integral length scale, at the same height, of 175 m.

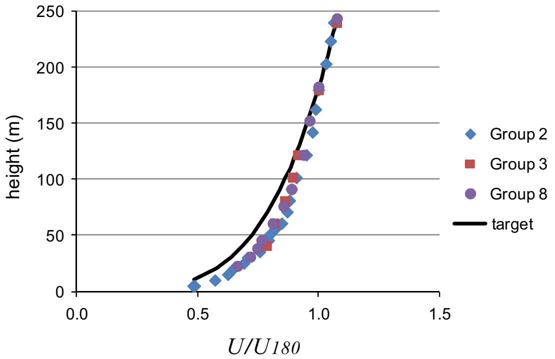

Fig. 2. Mean velocity profiles for three groups in the International HFBB Benchmark Study (the target profile was a power law with an exponent, α, of 0.25).

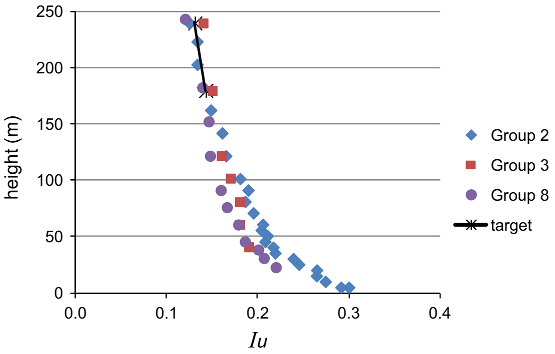

Fig. 3. Turbulence intensity profiles for three groups in the International HFBB Benchmark Study.

Figs. 2 and 3 show, respectively, the mean velocity and turbulence intensity profiles used by three of the total of eight groups in the model studies. Agreement with the target mean velocity profiles was good for all groups. The agreement with the targeted turbulence intensity at the top of the building for the three groups shown in Fig. 3 is also good. However, for one of the eight groups (not shown), the turbulence intensity was about two thirds of the target value at the top of the building. The results from another group also appeared to lie outside the general trends of the others. The results from these two groups have been removed from the comparisons of along-wind response in the present paper, which has been restricted to results from five of the original eight (one group also did not carry out tests for the 'basic' building).

3. Codes and standards

Three design codes were used for the comparison of along-wind response calculations with the combined wind-tunnel test data: (a) AS/NZS 1170.2:2011, the combined Australia/New Zealand Standard on Wind Actions (Standards Australia, 2011); (b) ASCE 7–10 (ASCE, 2010); and (c) HK CoP-2004, the Code of Practice on Wind Effects in Hong Kong, (Buildings Department Hong Kong, 2004).

Since 2002 the calculation of wind loads in AS/NZS 1170.2 has been based on a peak gust-envelope wind profile and the incorporation of correlation and dynamic resonance effects is through 'a dynamic response factor'. Holmes (2002) discussed this format and the differences between it and the original 'gust loading factor' of Davenport (1967). The maximum gust in AS/NZS 1170.2 has recently been re-defined as having an effective gust duration of 0.2 s (moving average equivalent). The logic behind