Along-wind response of a generic tall building – comparison of consensus wind-tunnel data with codes and standards

John Holmes[1]

[1]*Director, JDH Consulting, Mentone, Victoria, Australia,* john.holmes@jdhconsult,com

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. 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 study.

IHFBB-IAWE BENCHMARK BUILDING B

The 'basic' building used in the recent International High-Frequency Base-Balance Benchmark study (IHFBB) was 180 metres high, and of rectangular cross section, with dimensions of 45 metres by 30 metres. Three uncoupled dynamic modes were specified, with sway frequencies of 0.20 Hertz and 0.23 Hertz about the two principal orthogonal axes. The building was assumed to be located in urban terrain with a boundary layer with a mean velocity profile with a power-law exponent of 0.30 (approximate roughness length of 0.5 mm). The longitudinal turbulence intensity at the roof height of the building was prescribed as 0.15, with an integral length scale at the same height of 175m. 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. 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 (2012).

CODES AND STANDARDS

Three design codes were used for a 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 Action; b) ASCE 7-05; and c) HK CoP-2004, the Code of Practice on Wind Effects in Hong Kong.

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. It should be noted that the maximum gust in AS/NZS 1170.2 has recently been re-defined as an effective gust duration of 0.2 seconds (moving average equivalent).

ASCE 7 converted to a peak gust format in 1995, and a new 'gust effect factor' introduced based on this format, as described by Solari and Kareem (1998); this is similar to the 'dynamic response factor' format of AS/NZS 1170.2. This re-formulation assumed that ASCE 7 is based on a moving average 3-second gust, and this is also assumed for the present paper. The along-wind 'dynamic analysis' in Appendix F of the 2004 Hong Kong Code of Practice is based on an hourly mean wind speed and a 'gust response factor'. The method is derived from the 1989 version of the Australian Standard.

RESULTS AND DISCUSSION

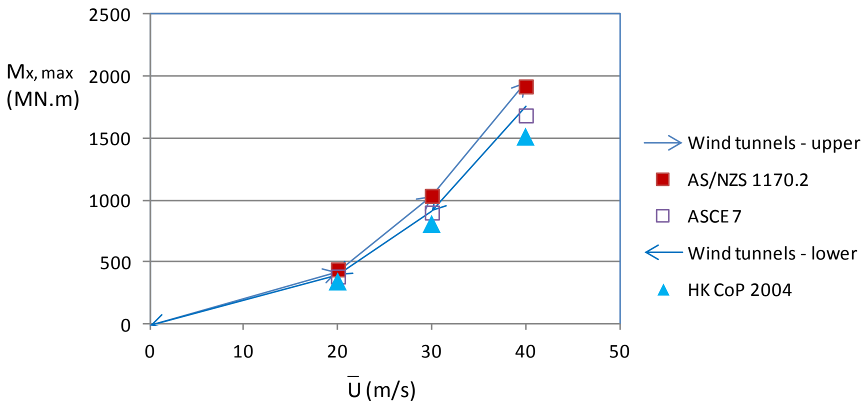

Figure 1. Comparison of maximum M_x base moments for 2½% structural damping

Some comparisons for the maximum sway base moments for the wind direction normal to the wide (45m) face of the building are shown in Figure 1. It should be noted that for these comparisons, the stipulated wind profiles for urban terrain by each code or standard have been used, rather than adjusting them to suit the specified IHFBB profiles; however the assumed turbulence intensities and length scales are similar to those specified.

The upper and lower limits of the seven sets of wind-tunnel data are shown. The results from AS/NZS 1170.2 closely follow the upper limit of the wind tunnel data, and are 2-9% above the average of the seven wind-tunnel data sets. ASCE 7 produces predictions close to the *lower* limit of the wind-tunnel data and 5-10% below the average. Predictions from the Hong Kong Code of Practice are 15-20% below the average of the wind-tunnel data. The lower values from ASCE 7 are mainly due to the use of a 3-second moving average gust, and over-reduction of the background response for correlation effects, since this gust duration already has an effective averaging area equal to that of a large building, as discussed elsewhere (Holmes and Allsop, 2013). The low values in the HK CoP are not related to the gust response factor, but are due to the use of a too-low drag coefficient for the cross section. It should be noted that the HK CoP is presently being revised, and this flaw will be rectified.

REFERENCES

American Society of Civil Engineers, 2006. *Minimum design loads for buildings and other structures*. ASCE/SEI 7-05. Structural Engineering Institute, ASCE, Reston, Virginia, U.S.A.

Buildings Department, Hong Kong, 2004. *Code of practice on wind effects in Hong Kong*. Government of the Hong Kong Special Administrative Region, Buildings Department, Mongkok, Hong Kong, China.

Holmes, J.D., 2002. Gust loading factor to dynamic response factor (1967-2002). *Engineering Symposium to honour A.G.Davenport*, London, Ontario, Canada, June 20-22.

Holmes, J.D. and Allsop, A., 2013. Gust factors and effective frontal areas, with applications to codes and standards. submitted to *12th Americas Conf. Wind Engg.*, Seattle, Washington, June 16-20.

Holmes, J.D. and Tse, T.K.T, 2012. International high-frequency base balance benchmark study. *2012 World Congress on Advances in Civil, Environmental and Materials Research*, Seoul, Korea, Aug. 26-30.

Solari, G. and Kareem, A., 1998. On the formulation of the ASCE 7-95 gust effect factor. J. Wind Engg & Ind. Aerodyn. 77-78, 673-684.

Standards Australia, 2011. *Structural design actions. Part 2: Wind actions*. Australian/New Zealand Standard AS/NZS 1170.2:2011. Standards Australia, Sydney, N.S.W., Australia.

Vickery, B.J. and Davenport, A.G., 1967. A comparison of theoretical and experimental determination of the response of elastic structures to turbulent flow. *International Research Seminar on Wind Effects on Buildings and Structures*, Ottawa, Canada, Sept. 11-15, Proceedings pp 705-738.