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AWES QUALITY ASSURANCE MANUAL

Part D: Study of dynamic loading on tall buildings

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PART D: STUDY OF DYNAMIC LOADING ON TALL BUILDINGS

1.1 WIND TUNNEL MODELLING REQUIREMENTS

1.1.1 Methodology.

The use of a boundary-layer wind-tunnel with acceptable methods of simulation (see Section A2), is currently regarded as the only acceptable method for predicting the dynamic response of buildings.

Finite Element Modelling techniques are capable of providing acceptable estimations of the dynamic response of a building in isolation, but cannot predict with the same accuracy the response of a building when interaction with its surrounds are included.

A general reference for boundary-layer wind-tunnel techniques is that due to Reinhold (ed) (1982).

1.1.2 Boundary-layer Simulation.

Refer to Sections A3 to A7 for Boundary Layer Flow Simulation.

1.1.3 Accuracy of the model.

10%

The overall dimensions of the test building model (height, plan shape, etc.) should be accurate to within 2%. Architectural details, such as balconies, mullions, sunshades, etc. should be included on the building model when their smallest dimension is 1 metre of greater.

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Surrounding buildings should be modelled with overall dimensions accurate to within at least 10%. Architectural details need not be included on the surrounding buildings.

Immediately surrounding buildings need to be modelled reasonably accurately so that important features such as the sizes of gaps between buildings are correct. Buildings further away from the test model can be modelled by approximate block shapes.

If there is a significant amount of vegetation in the vicinity (for example, being adjacent to a large reserve) then vegetation modelling is important to ensure equivalence of the flow.

1.1.4 Meteorological data.

Wind speed data (and direction data if available), properly corrected for siting and shielding effects and for instrumentation response, for a period not less than ten years shall be used.

Wind speeds and directions given in Australian Standard AS 1170.2 (SAA 1989) for capital cities and defined regions in Australia can be considered to satisfy the above criterion. For locations not covered in AS 1170.2, or for other countries, the user should satisfy himself that appropriate corrections have been made and that the record length is long enough.

Either gust or mean wind speed data may be used provided appropriate corrections are made to relate to the reference wind speed in the wind tunnel.

1.2 WIND-INDUCED LOAD AND VIBRATION STUDIES REQUIREMENTS

1.2.1 General.

Sufficient information regarding the building's dynamic characteristics should be obtained. These must include the mode shapes and natural frequencies of the first three modes of vibration of the prototype building. If this information cannot be provided by the structural engineer then a Finite Element Model can be set up. In such a situation, reference to the Structural Engineer is essential to confirm any assumptions made in the preparation of the Finite Element Model. Alternatively, if the tower of the building is of a regular plan form and does not vary significantly with height then an approximation of the natural frequency and mode shape for the first two modes can be obtained from AS1170.2-1989. If the tower is situated on a significantly wider podium then the height of the tower is deemed to be the height above the podium when using AS1170.2-1989.

In addition, the mass distribution of the building with height is required. The structural damping ratio of the building can be based on the estimates provided in AS1170.2-1989 but these should be determined in consultation with other relevant literature.

Adequate assessment of human comfort in situations of wind-induced vibration of building developments with respect to occupant comfort criteria should be made. The interference effects of nearby buildings should be identifiable and remedies proposed to alleviate problems.

identified

1.2.2 Modelling requirements.

If the aeroelastic model technique is used then the rig must be set up so as to replicate the dynamic behaviour of the prototype building as closely as possible. This includes care in ensuring that coupling effects in the prototype due to similar natural frequencies in the two translational modes in the model should also have similar natural frequencies and vice versa. If the torsional mode has a natural frequency clearly within 1Hz and is not greater than twice the lowest natural frequency of the building then the rig will need to be set-up to be able to measure the torsional loads.

Also, in the case of an aeroelastic model, care should be taken to ensure a similarity between the mass moment of inertia of the model and that of the prototype building. Similarity should be within a factor of 2.

Where the elastic centre does not match with the geometric centre of the building, care should be taken to mount the building model from the position representing the elastic centre of the prototype building.

The adequacy of the modelling technique should be checked against results from other laboratories (eg. Melbourne, 1980, and for torsion; Beneke & Kwok, 1993)

Building surface roughness elements can be important in governing separation and reattachment of the wind flow, and hence special care should be taken at edges. However, the physical size and the practicality of incorporating small details into the building model limit the modelling of the architectural details. A suggested limit to the detail of these elements would be all features that have a maximum sectional dimension of less than 2m.

For the large majority of cases, a full aeroelastic model is not required and a force balance can be used to obtain the wind force spectrum which is can be modified to obtain the response spectrum through the application of a mechanical admittance function. However, the use of a force balance is not appropriate in cases in which negative aerodynamic damping is known to be significant or approaches the level of structural damping. High negative aerodynamic damping in tall buildings can occur in a low-turbulence environment (for example, facing the ocean) and where the prototype building is exposed to design reduced velocities that are more than 80 percent of the critical velocity for the tower section concerned. For most tall buildings having a rectangular plan, this implies a limiting reduced velocity of 8 [Steckley, 1989]. However, the recommended limiting velocity would differ for other shapes. For example for tall buildings with chamfered rectangular, triangular (with or without chamfer), hexagonal or octagonal plans, which are located in low turbulence environments, the force balance technique is not appropriate where the maximum design reduced velocity exceeds 6 [WEC Notes, 1997].

A lumped mass aeroelastic model should be used in the case of a very tall/slender or complex-shaped building, where loading from higher modes are likely to be critical.

1.2.3 Measurement of wind-induced loads and vibrations.

Wind-tunnel wind-induced load and vibration measurements should be made with instrumentation, which is accurately calibrated and set to appropriate channels for various measurement. All components of the test rig are to be calibrated prior to each test.

Strain-gauged test rigs must provide a sufficiently high signal to noise ratio (a minimum of 1:50 in the RMS for a typical maximum RMS signal). Other methods, including non-contact displacement sensors are to maintain a similar signal to noise ratio. Filters can be applied, provided that they produce an output that is equivalent to 0.7 of the input signal at 1.5 times the natural frequency of the model.

In the case where an aeroelastic rig is used, which provides a straight-line approximation to the mode shape, the position of the pivot point should be such that the straight line matches as close as possible to the line of best fit to the mode shape of the fist two modes (with emphasis on the upper sections of the tower).

A calibration must be performed prior to each test. Care must be made to ensure that the setup is not altered between calibration and measurement (eg. The model must be attached and the pivot point already placed at the determined height.

Minimum sample time is 30 minutes in full-scale. The sample rate should be at least 10 times the highest natural frequency of the model. In the case of force balance tests, it is recommended that the number of samples be not less than 4000 per measurement.

1.2.4 Permissible stress design wind speeds.

In the case of aeroelastic model studies, a minimum of three wind speeds are to be used and are to correspond to the permissible stress design wind speeds for return periods of 1 year, 50 years, and 1000 years, as defined in Appendix E of AS1170.2-1989.

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Damping characteristics of the model should be noted and corrections applied to match the prototype values for serviceability and permissible stress loads. For a typical tall building, the damping ratios would be approximately 1%, 3% and 5% for 1 year, 50 year and 1000 year return wind speeds, respectively. The results for the directional design wind speeds can be obtained by interpolation using a regression of the results obtained from the three or more different wind speeds.

1.2.5 Assessment criteria.

A set of criteria for the assessment of the Acceleration and Occupant Comfort has been recommended in the Commentary to AS1170.2-1989 (Holmes et al, 1990). The criteria express the limiting annual maximum combined standard deviation acceleration with a 5-year return period as a function of the natural frequency. In addition, the same reference provides a set of peak acceleration criteria. Peak acceleration criteria are considered more appropriate for residential buildings.

When combining the three components of acceleration, a correction may need to be applied to the torsional component to account for the lower correlation of the peak accelerations.

1.2.6 Reporting.

The assessment of the wind-induced loads and vibrations for a development should be presented in a way that simplifies the interpretation for the client. In addition, the maximum total standard deviation and peak combined horizontal accelerations are to be presented and compared to the criteria.

The report should present a summary of results, which indicate the overall design base moments and corresponding maximum displacements. In addition, the corresponding point load and shear force distribution with height should be provided. The distribution of the mean component with height should be based on the distribution of the mean pressure coefficients with height along the windward and leeward faces for the most critical wind direction. The distribution of the dynamic component with height should be based on either a linear variation from pivot point to roof level (adjusted to account for the effect of variations in the width of the tower) or based on the mass distribution of the tower.

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If the mode shape presents a significant departure from the straight-line mode shape then a mode shape correction factor should be applied.

The maximum total standard deviation and peak combined accelerations can be compared to criteria such as those recommended in the Commentary on the Australian Wind Loading Code. It is recommended that the torsional acceleration be converted into an equivalent translational acceleration and added into the combined acceleration. In the case of the combined peak acceleration, a correction factor in the range of 0.7 to 1.0 should be applied to compensate for the effect of the degree of correlation between the accelerations along the three principal axes. Alternatively, a cross-correlation between the torsional and translational accelerations can be determined from the wind tunnel test [Yip, 1996]. 1.0 !?

In addition to the results, the report should also include sections relating to the requirements of this manual, i.e.:

(a) A general description of the model construction, properties of the model and the prototype (eg. Natural frequencies and mode shapes of the first three modes, mass distribution/mass moment of inertia, damping characteristic, position of the elastic centre, pivot point), wind tunnel and atmospheric boundary-layer simulation and the test procedure.

(b) A description of the method of analysis for the determination of the design loads and the maximum accelerations, including analysis of directionality effects.

(c) Specification of the wind directions tested, measurement sample size, sample rate and bandwidth.

(d) Analysis of Base Moments, Load Distribution with Height and Load Combinations, Displacements and Acceleration.

(e) A full listing of the tabulated results of the full scale moments (mean, rms, maximum, minimum), the base moment results in coefficient form (mean, rms, maximum, minimum), rms prototype accelerations for appropriate structural damping ratio and combined standard deviation acceleration. These are to be provided for each of the three components.

(f) A full listing of the plots of the full scale moments (mean, rms, maximum, minimum), the base moment results in coefficient form (mean, rms, maximum, minimum), rms prototype accelerations for appropriate structural damping ratio and combined standard deviation acceleration. These are to be provided for each of the three components.

Finally, any unusual details of the study should be described. This is in addition to the identification of any potential interference excitation (eg Bailey and Kwok, 1985). Where accelerations exceed the recommended criteria then in-principal recommendations for treatments should be made.

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