Wind Tunnel Investigation of Crosswind Generalised Force Spectra for Slender Shapes

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1 INTRODUCTION

The consideration of potential occupant discomfort through wind induced acceleration is a major concern during the design phase for slender buildings. In recent years, New Zealand architects have been designing buildings of high aspect ratio for small sites. These buildings are often less than 100 m tall, and are located in highly turbulent city environments. They are built with modern lightweight materials and have low structural damping. In many cases the information required to estimate accelerations for comfort levels is not available in the wind loading standard [1], for the associated low reduced velocities, or the desired aspect ratio is not available due to the limited shapes available in the standard. This lack of clarity causes problems for the structural engineer, who has to decide whether the performance of the building will be adequate, or whether perhaps provision should be made for adding a damper to the design at or near the top floor. This necessarily has an important economic impact on the project. The present research is aimed at providing generalised force spectra at low reduced velocities, and for more cross-sectional shapes than currently available in the standard.

The current method used in New Zealand to determine the cross-wind excitation and response is described in AS/NZS1170.2:2002 [1]. One determines the reduced velocity, $V_r = V_h/(Bn_c)$ (where V_h is the wind speed at the top of the building, B is the building width normal to the wind, and n_c is the first mode cross-wind natural frequency) and then reads off the generalised force coefficient C_{fs} from an appropriate graph.

C_{fs} is a function of aspect ratio and only a few aspect ratios are available. Often the aspect ratios required are more 'slab-like' than those provided, such as the 51m:23.5m:7.4m (6.9:3.2:1) shape proposed for Auckland's CBD. This causes problems as the most common method for getting C_{fs} information uses the High Frequency Force Balance method which requires models to be as light and stiff as possible so that the model/balance natural frequency is well above the frequencies of interest. 'Slab-like' models are generally less stiff than conventional more compact shapes and thus can have first mode natural frequencies that lie within the region of interest of reduced velocities. Determining C_{fs} from multi-channel pressure measurements offers an advantage for investigating the generalised force spectrum for 'slab-like' aspect ratio buildings because the upper frequency range is not dependent on model stiffness, but on the frequency response of the tubing system. Thus potentially, high frequencies, corresponding to low reduced velocities are obtainable.

Thus the aim of this investigation was to measure C_{fs} for lower reduced velocities for aspect ratios available in the standard, as well as for more 'slab-like' shapes, and also to compare the spectra measured from the HFFB method with those obtained from multi-channel pressure measurements.

2 EXPEREMENTAL PROCEDURE

2.1 Wind Tunnel

All the testing carried out for this project used the de Bray wind tunnel, located in the Faculty of Engineering at the University of Auckland. The wind tunnel tests were carried out at a model scale of 1/400 using a reference model height of 240mm which represents a 96m tall building, as previous studies ([2], [3], [4] and [5]) have had success using models with heights between 240mm and 187mm.

Much work went into the placement of blocks and trip barriers in the upstream region of the wind tunnel to get a Terrain Category 3 boundary layer. Ideally the boundary layer would be allowed to grow naturally using minimal blocks over a large fetch [6], but for this small wind tunnel large grids and blocks had to be used. The velocity and turbulent intensity profiles necessary to validate the boundary layer set up were measured using a Cobra Probe manufactured by Turbulent Flow Instrumentation. Along-wind and cross-wind spectra were also measured and compared to published results (Cook [7]). The length scales for the longitudinal directions showed very good agreement with Cook. However the lateral length scales were smaller, as expected, due to the relatively small tunnel cross section restricting the maximum eddy size. For all tests the flow velocity was kept fairly low at around 5m/s in order to get information at low reduced velocities. Reference pitot-static tubes were used during each run to get an accurate velocity from which reduced velocities could be calculated.

2.2 High Frequency Force Balance

The High Frequency Force Balance (HFFB) method involves measuring forces and moments at the base of the models at high frequencies. From these force spectra were derived for the across- and along-wind directions. Six aspect ratios, namely 3:1:1, 6:1:1, 6:2:1 and 6:3:1 (height: breadth: width) were tested using the HFFB. Careful calibration checks of the JR3 force balance used for all HFFB testing proved that the factory calibration matrix was very good. Data were recorded at a sample rate of 5000Hz for a period of 60 s, and a block size of 8192 was chosen. All models were constructed of foam covered in fibreglass reinforced tape and measured 240mm in height. Different aluminium inserts for the high aspect and low aspect ratio models were used to rigidly attach them to the force balance.

2.3 Electronically Scanned Pressure System Testing

The Electronically Scanned Pressure System (ESPS) testing method involves getting time history information from a large number of pressure transducers connected to the walls of hollow models via thin tubing (see reference [8] for greater detail on the system developed at the University of Auckland). Two groups of models were tested, one low aspect ratio group (3:1:1, 3:1:2, 3:2:1, 3:1:3 and 3:3:1) and one high aspect ratio group (6:1:1, 6:2:1 and 6:3:1). The models were constructed from 6mm acrylic sheet as it is stiff, transparent and relatively easy to work with. The large amount of labour involved in inserting pressure tubes lead to panels being reused for different aspect ratios as much as possible. A sample rate of 800Hz was chosen to adhere to the recommendations made in the quality assurance manual produced by the Australasian Wind Engineering Society [9]. A block size of 1024 was chosen for calculating spectra as it gave sufficient bandwidth as well as allowing a large number of blocks to be available for averaging to reduce the noise in the spectra. A digital recursive filter of order 24 (25 coefficients) was implemented with the expertise of Dr Roger Halkyard and Dr Nick Velychko as it gave the required amount correction from resonant effects and energy dispersion (as outlined by the Australasian Wind Engineering Society [9]). More information can be gathered regarding the recursive filter method in references [10] and [11].

3 RESULTS

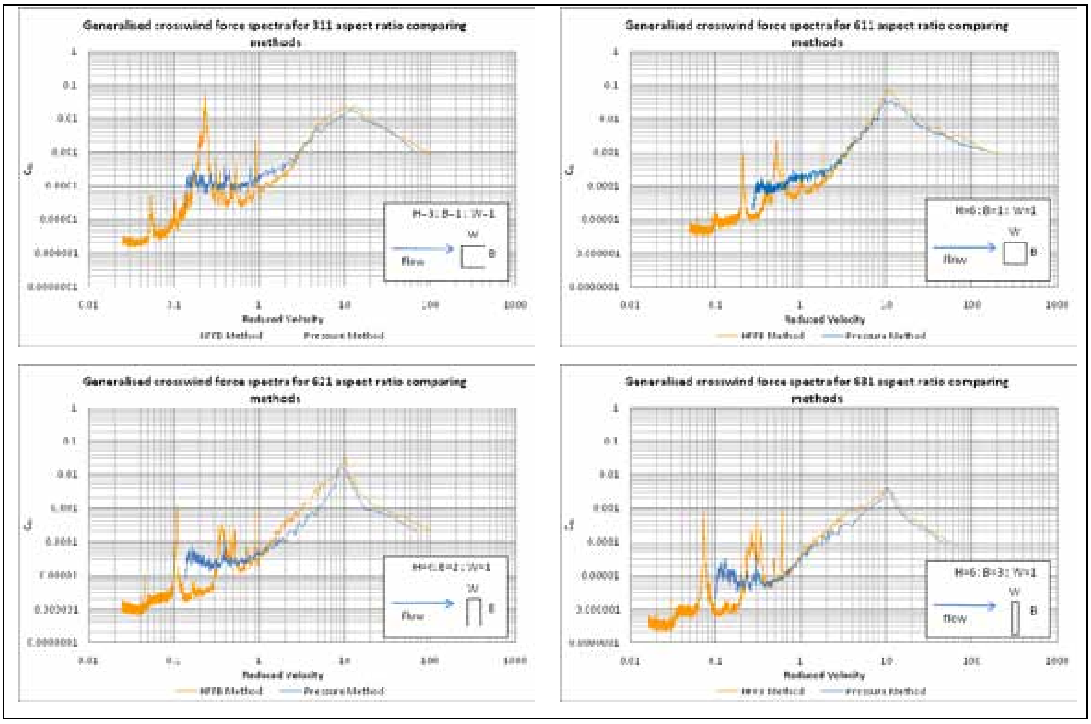

Fig. 1: Plots showing comparison between HFFB method and ESPS for identical aspect ratios

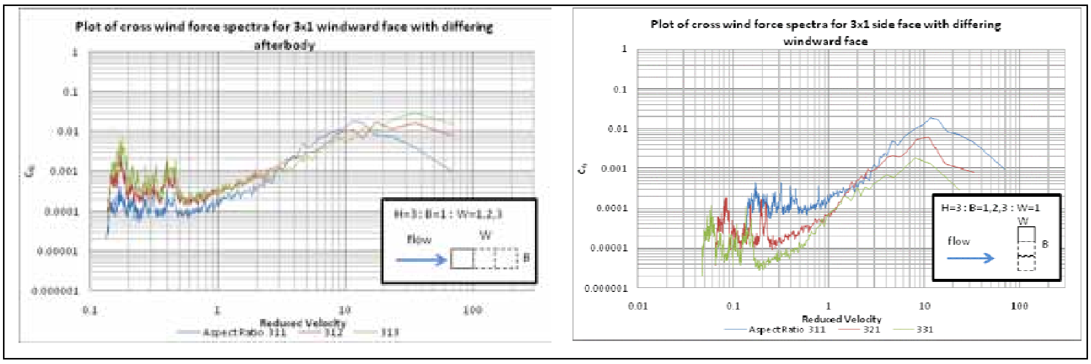

Fig. 2: Plots showing 'slab like' aspect ratios not currently covered in the wind loading standard [1] (3:1:2, 3:2:1, 3:1:3, 3:3:1)

The spectra calculated using the Electronically Scanned Pressure System (ESPS) appeared to match well with the spectra calculated using the HFFB method for reduced velocities above 2.

It was expected that spectra would be able to be calculated to very low reduced velocities (frequencies above the vortex shedding frequency) using the pressure measurements. However, this was not the case as all the spectra flattened off at a reduced velocity corresponding to a frequency of approximately 60Hz (see Fig. 1 and Fig. 2). This may be due to electronic noise, and is still being investigated. Unfortunately it is very near the spectral peaks at 70Hz measured using the HFFB method (see Fig. 1) corresponding to reduced velocities of between 0.6 and 1.8 depending on aspect ratio. This peak was not a function of model moment of inertia, and is possibly a result of an acoustic phenomenon in the wind tunnel as it appears to be a characteristic of the de Bray wind tunnel with previous studies showing spectral peaks corresponding to the same frequency regardless of aspect ratio (Bhatt 2005 [2]).

4 CONCLUSIONS

The spectra calculated using the Pressure System appeared to match well with those obtained though the use of the High Frequency Force Balance System. This confirms the suitability of the pressure method for calculating crosswind force spectra.

Unfortunately an as yet undefined wind tunnel characteristic, whether it is acoustic or electronic, has resulted in spectral information recorded at low reduced velocities to be distorted. Aspect ratio 6:1:1 has a spike in the spectra at a reduced velocity of approximately 1.8 thus not providing much more information than the AS/NZS1170.2:2002 wind loading standard [1], that currently provides information down to a reduced velocity of 2.0. For aspect ratios 3:1:1 and 6:2:1 the spectrum was extended down to a reduced velocity of approximately 0.9. The aspect ratio 6:3:1, not included in the current AS/NZS1170.2:2002 wind loading standard [1], was also calculated down to a reduced velocity of approximately 0.6.

Crosswind spectra for 'slab like' aspect ratios 3:1:2, 3:2:1, 3:1:3 and 3:3:1 not included in the current AS/NZS1170.2:2002 wind loading standard [1] were tested using the pressure method and gave reliable data to reduced velocities 1.0, 0.5, 1.0 and 0.35 respectively. These will be included in the oral presentation.

5 REFERENCES

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