Interference Excitation – a Hong Kong perspective

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Introduction

A number of researchers have studied wind-induced 3DOF response and interference effects using force balances, aeroelastic modelling and MDOF aeroelastic modelling, such as Kareem (1987), Kawai (1993), Katagiri et al. (1998), Boggs et al. (2000) and Thepmongkorn and Kwok (2002). These, and other, studies have highlighted the benefits in conducting wind tunnel tests through a better knowledge of site-specific wind conditions, potential cost savings in design and construction as well as reducing the vulnerability of structures to excessive wind-induced responses.

In Hong Kong, it is only relatively recently that wind tunnel model studies have been widely undertaken for multi-tower, highrise residential developments. Such developments typically comprise several towers with heights of around 40 storeys, nearly identical external geometries and very close spacing between towers, examples of which are shown in Fig.1. Historically, structural designs of these developments, particularly those produced for low rent public housing, were often based on wind loads derived from the local wind code with little or no regard given to resonant effects. To the best of the authors' knowledge, these types of developments have not experienced adverse wind-induced responses. This is probably largely thanks to their reserve capacity, being significantly stiffer than predicted and due to material factors which are not completely accounted for in design.

With the growing awareness of the aforementioned benefits that may be gained from the wind tunnel, there is a slowly developing acceptance, if still a lack of understanding, of wind engineering in general and the role of wind tunnels in the design process. The possibility of a reduction of Hong Kong's design wind speed based on recent data, Holmes et al. (2001), and various refinements in the design process (including improving estimates of building natural frequency) all help to better define the wind hazard, but may also increase a building's vulnerability to adverse wind-induced responses.

Furthermore, building spacings in Hong Kong are typically smaller than those usually investigated in generic studies of interference effects, and may cause load increases on both upstream and downstream buildings. There is a need to conduct detailed investigations on building types and arrangements common in Hong Kong. This paper presents the initial results of a benchmarking exercise and study of 3DOF wind-induced tall building response due to various interference mechanisms. The results obtained from a high-frequency force balance study, which is the most commonly used technique in wind tunnel model studies of these developments, are compared to the recent 3DOF aeroelastic study of Tang (2002).

Experimental Configuration

A 1:400 scale model of the CAARC building (d = 30 m, b = 45 m, h = 180 m, ρ_S = 160 kg/m^3) was used in the force balance studies. The building was analysed for two linear translation modes and a torsion mode with constant mode shape, having prototype scale natural frequencies of approximately n_x = 0.20 Hz, n_y = 0.21 Hz, and n_z = 0.29 Hz. Structural damping was 1% of critical for each mode of vibration. All tests were conducted in a simulated General Terrain, defined in PNAP 150 (1994), having a mean wind speed profile with a power law exponent of 0.19 and turbulence intensity at building height of approximately 7%. Mean wind speed and turbulence intensity profiles were simulated to within 10% of values suggested in PNAP 150 and longitudinal velocity spectrum at the top of the model also compared well with the spectrum suggested in ESDU 74031 (1974).

Initial testing was undertaken with no eccentricity between centres of mass and stiffness to allow a more straightforward assessment of the excitation mechanisms. Testing has subsequently included physically offsetting the model to represent eccentricities between centres of mass and stiffness, although those results are not included here. A rigid CAARC building model was used as the interfering building at locations marked in Fig. 2, identified in the studies of Tang (2002) as being representative of different interference excitation mechanisms.

Building responses were determined through analysis in the frequency domain.

Results

Interference studies were undertaken for wind normal to the building's wide face only and data was analysed for a reduced velocity ($\bar{u}_h/n_y b$) of 6. Measurements taken initially for the isolated model exhibited characteristic along-wind and cross-wind loads and responses. Comparing force balance results to similar aeroelastic studies, Thepmongkorn and Kwok (2002) and Tang (2002) for example, it is apparent that the transfer of energy between modes due to motion dependent effects is not reproduced by the force balance, which may be significant for some eccentric cases.

Torsional loads exhibited some effects caused by wake excitation processes, the significance of which have been noted in other studies undertaken by the authors to be dependent on the nature of the approaching wind conditions, and turbulence in particular. Although approximately one order of magnitude smaller than translation responses for the CAARC building tested, significant increases in torsional response may occur close to the critical reduced velocity for cross-wind response.

With an interfering building placed directly upstream of the principal building model, at positions 1 (10d, 0b), 25 (4d, 0b) and 33 (2d, 0b), the along-wind load spectra exhibited significant shifts to higher frequency energy, indicating that responses were amplified through turbulent buffeting. This is at least in qualitative agreement with the 3DOF aeroelastic experiments reported by Tang (2002). Locating the interfering building at position 1 also caused a significant increase in cross-wind and torsional energy at a reduced frequency of 0.1.

With the interfering building offset laterally, at positions 14 (7d, 1b), 11 (8d, 2b) and 69 (9.5d, 2.5b), along-wind, cross-wind and torsional responses were all increased through the vortex shedding process of the upstream building and/or increased turbulent buffeting. For each case, the force balance was able to detect a significant increase in a relatively narrow band around a reduced frequency of 0.1 caused by vortex shedding of the upstream building.

Locating the interfering building downstream, positions 47 (-1d, 2b) and 51 (-2d, 2b), significantly increased cross-wind response by modifying the wake region of the principal building. The aeroelastic studies of Bailey and Kwok (1985) and Tang (2002) concluded that downstream interference is a function of the channel width between the two buildings and is a motion dependent phenomenon due to the fluctuating channel width. The energy peaks in the force balance cross-wind load spectra measured at positions 47 and 51 both exhibited significant broadening and shifting to higher frequencies. Interestingly, the energy peak was shifted to a range in the vicinity of the modelled building natural frequency, and would thereby give rise to response predictions significantly larger than those obtained from the 3DOF aeroelastic tests. A similar phenomenon was observed by Tang (2002) in his 3DOF aeroelastic study, although the reason behind this is not entirely clear at this stage and warrants further study.

Conclusions

- Initial tests have been undertaken using the high-frequency force balance technique to study the various mechanisms attributed to interference effects.
- Qualitatively, the force balance compared favourably with similar 3DOF aeroelastic studies, particularly with interfering buildings located upstream of a principal building.
- The mechanisms associated with downstream interference effects are not as apparent as those of upstream interference and would likely benefit from further complementary force balance and aeroelastic studies.

- Overall, the high-frequency force balance technique predicted higher responses than similar aeroelastic studies.

Acknowledgements

The authors wish to thank Dr Graeme Wood and Dr Sukit Thepmongkorn for their continuing contributions to this research project.

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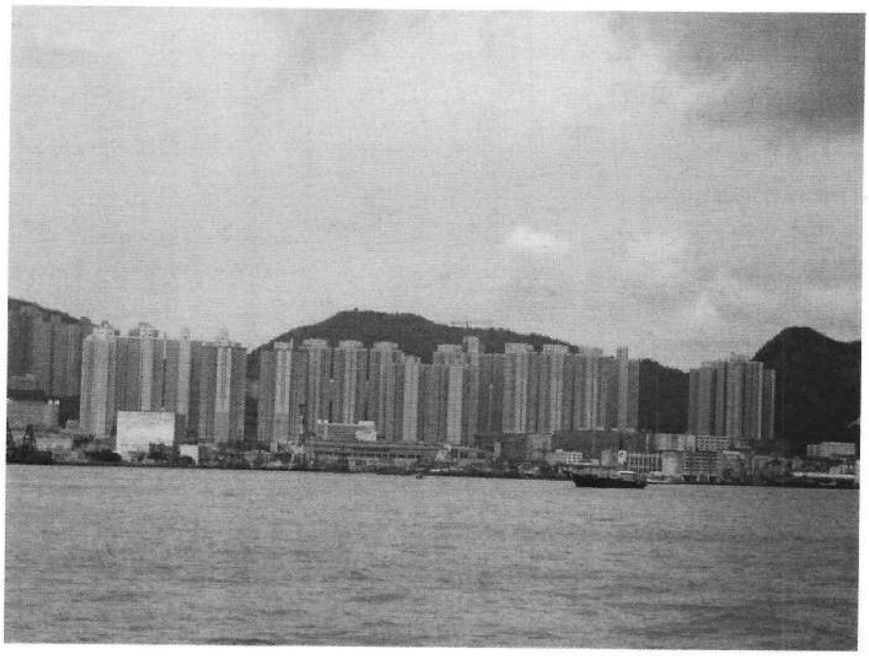

Fig. 1: Typical Public Housing in Hong Kong

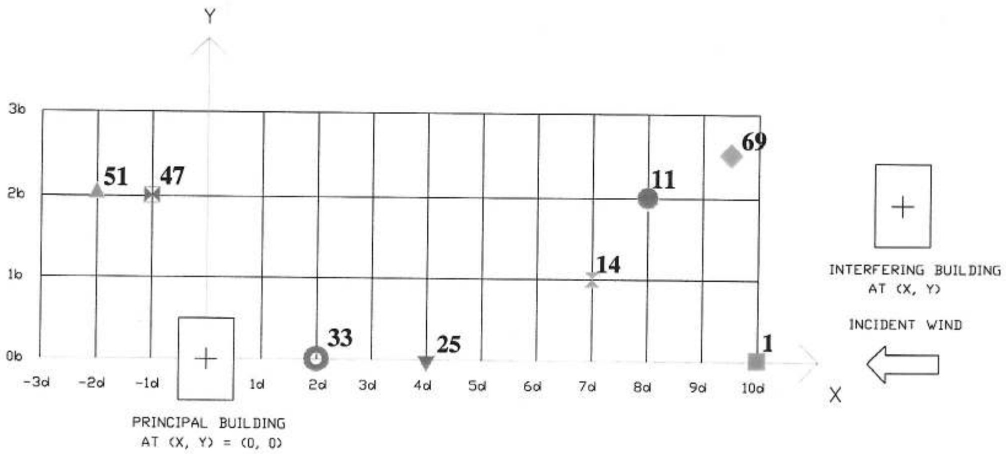

Fig. 2: Interfering building locations