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Effect of recessed cavities on wind-induced loading and dynamic responses of a tall building

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ABSTRACT

This paper investigates how the presence of recessed cavities modifies the wind-induced loading and dynamic responses of a tall building. The H-shaped is selected to represent a building section with two recessed cavities. Nine H-section tall buildings, with a systematic variation of breadths and depths of the recessed cavities are tested in the wind tunnel. All H-sections have the same square envelope and all buildings have a height-to-breadth ratio at 6. Fluctuating wind forces and moments on the buildings are measured with a high-frequency force balance from which wind-induced building responses are estimated. It is found that the most important effect of a recessed cavity is the significant reduction of across-wind excitations and responses of the tall building for normal wind incidence on the building face with a cavity. With an aim to understand the mechanism of this wind load modification, wind pressure on all faces of the H-section tall buildings are measured with a multi-point pressure scanning system from which time histories of wind forces on different building faces are obtained. Correlation analysis of these wind forces suggests that while the magnitudes and phase relationship of the fluctuating across-wind forces coming from the two building side faces are not largely affected by the presence of recessed cavities on the windward and leeward building faces, the contribution to the overall across-wind force from wind pressures on the inner faces of the recessed cavities acts in a slightly opposite action to the main contribution from the building side faces. This explains the reduction of overall across-wind excitation on the building.

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1. Introduction

Wind-induced dynamic response is one of the most significant factors influencing occupant comfort and structural safety of a tall building. In Hong Kong and other metropolitan cities, many residential tall buildings are designed with a planform of an irregular shape featuring wing sections extending from a central core. This architectural design aims to provide maximum views to all apartments on a floor. To provide amenity and ventilation to the bathrooms and kitchens, a recessed cavity is usually provided between two adjacent apartments where windows of bathrooms and kitchens are opened to. There have been few studies on the effect of recessed cavities on the wind engineering aspects of a tall building including wind loading and wind-induced ventilation.

For wind-induced ventilation, a recent computational fluid dynamic (CFD) study reported that there existed complex and highly three-dimensional wind-induced flow patterns inside a recessed cavity of a tall building (Cheng et al., 2011). The sizes of the cavities and the wind-incidence angles were found to govern the rates of air exchange between the cavities and the outside wind flow as well as the effectiveness of pollutant dispersion from the recessed cavities.

In wind loading calculations, the presence of these cavities is often neglected and wind flow is assumed to pass around the enveloping building planform with the space inside the cavities taken to contain stagnant air. This is largely based on the early studies of Building Research Establishment which suggested that wind flow tends to skip past a narrow recessed cavity in a square-plan building, leaving almost stagnant flow inside the cavity and thus the overall loads are likely to be the same as those on buildings of the same external envelope (Cook, 1985). While this may be true for the mean overall wind loads, a preliminary study by the present authors finds that the recessed cavities may lead to modifications of the fluctuating wind forces of a tall building (Lam et al. 2009).

This paper reports a parametric study of the effects of recessed cavities of different dimensions on wind-induced loading and dynamic responses of tall buildings. In the first part, fluctuating wind forces and moments on building models with recessed cavities are measured with the high-frequency force balance (HFFB) in the wind tunnel. Wind-induced dynamic building responses are then estimated with the HFFB technique. In the second part,

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simultaneous pressure measurement is made on all surfaces of a tall building model so as to investigate the characteristics of wind force generation by different building faces. This aims to understand the mechanism of wind load modifications caused by the presence of recessed cavities.

2. Experimental setup

The experiments were carried out in the boundary layer wind tunnel of the Department of Civil Engineering at the University of Hong Kong. The working section of the tunnel was 12 m long, 3.0 m wide and 1.8 m tall. Wind characteristics of the open sea roughness type were simulated using triangular spires and 8 m long fetch of floor roughness elements. The mean wind speed profile followed well the power law with power exponent $\alpha=0.13$. The profiles of mean wind speed and turbulence intensity are shown in Fig. 1. Another set of experiments was performed under the sub-urban roughness type ($\alpha=0.20$) but most results presented in this paper are for the open sea roughness type.

A tall building with an H-shaped planform was used to represent a building with recessed cavities. The building models being tested included a reference square-section tall building with breadth $B=0.1$ m and height $H=0.6$ m ($H/B=6$) and nine generic H-section tall buildings of the same square enveloping cross-section but with recessed cavities on two building faces. Among these nine H-shaped sections, the recessed cavities had their widths (W) or depths (D) systematically varying among three values: $W/B=\{0.25, 0.5 \text{ and } 0.75\}$ and $D/B=\{0.125, 0.25 \text{ and } 0.375\}$ (Fig. 2). The HFFB models were constructed with lightweight foam materials. Mean and fluctuating wind loads of base shear forces, F_x, F_y, base overturning moments, M_x, M_y along the x and y axes of the building and torsional moment, M_z about the central vertical axis, on each building model were measured with a HFFB (JR3 Inc.) mounted at the model base. The sampling rate was 200 Hz and the duration of measurement was 180 s.

Pressure models were also constructed for the nine H-section buildings and the reference square tall building. On each model, pressure taps were installed on five vertical levels along the building height. As an example, Fig. 3 shows the pressure tap arrangement of three selected H-section building models with cavities of different sizes. There were a total of 190, 140 and 180 pressure taps on the models A, B and C respectively. The taps were installed on all faces of the building including the faces of both recessed cavities of the H-section building. During testing of a building model, pressures at all taps were measured simultaneously with a pressure scanning system (PSI Initium) at a sampling rate of 500 Hz per port for 120 s. Tubing from the taps had the same length to the pressure scanners in order to minimize the tubing response error.

Both HFFB and pressure measurements were made at wind incidence angles at 10° or finer intervals between $\theta=0°$ and 90° (Fig. 2). In the later part of this paper, results and discussion are focused on wind incidence normal to the building face with a

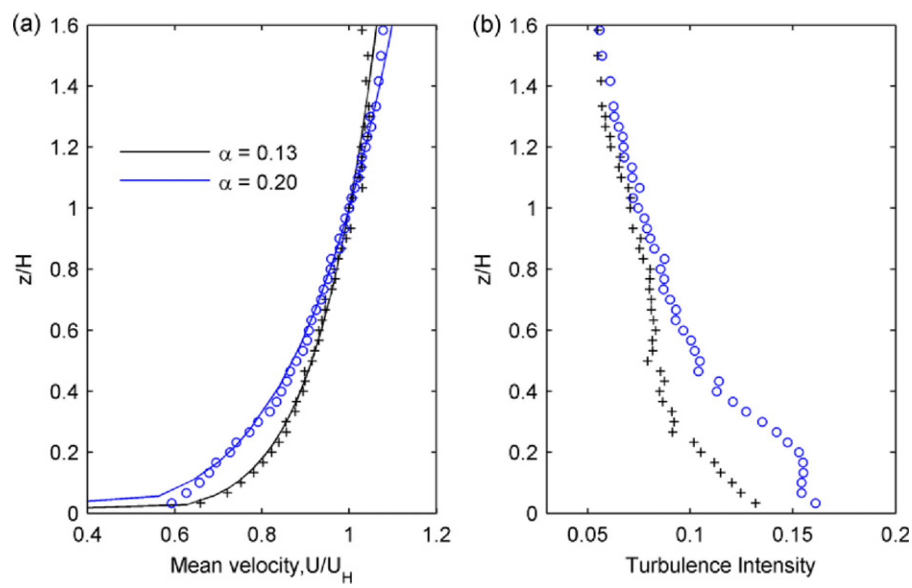

Fig. 1. Wind characteristics in wind tunnel: (a) mean wind speed profile and (b) turbulence intensity profile.

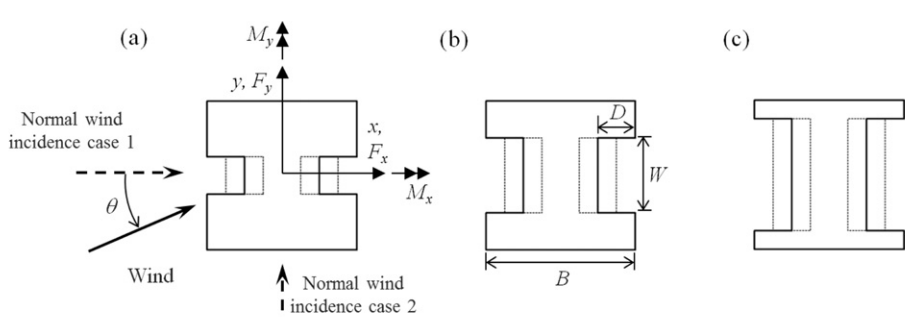

Fig. 2. Nine H-shaped building sections being tested. W/B: (a) 0.25, (b) 0.5 and (c) 0.75. For each cavity width (W), there are three depths: $D/B=\{0.125, 0.25 \text{ and } 0.375\}$.

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