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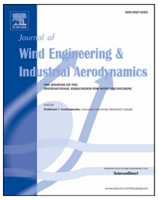

Wind-induced responses of a tall building with a double-skin façade system

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ABSTRACT

To date the engineering community has seen double-skin façade systems as non-structural elements on buildings for the aesthetic desire, improving the indoor environment, reducing the energy use, and even improving acoustics in buildings. In this study, the effects of a double-skin façade system on the wind-induced responses of a tall building were investigated via a program of wind tunnel tests. Two types of wind tunnel tests, i.e. aeroelastic test and pressure test, were performed. It was found that a double-skin façade with/without vertical openings installed in front of the windward face of the building model results in very different effects on the wind-induced responses in alongwind and crosswind directions. In the alongwind direction, the façade with/without openings induces negligible effects on the wind-induced response. However, in the crosswind direction, the façade with opening(s) reduces the wind-induced response significantly, whereas the façade without any opening increases the response, compared to the bare tall building model. Therefore, in addition to achieve the purposes of the aesthetic desire, improving indoor environment and reducing energy use, the double-skin façade system with vertical opening(s) can also be used to effectively reduce crosswind responses without inducing larger alongwind responses.

1. Introduction

To date the engineering community has seen structural façade systems as non-structural elements with high aesthetic value and a barrier between the outdoor and indoor environments (Haase et al., 2007; Manz and Frank, 2005; Poirazis, 2004; Streicher, 2005). One example is the Kingtown International Center in Nanjing, China, as shown in Fig. 1. The role of facades in energy use in a building has been recognized and the industry is witnessing the emergence of many energy efficient façade systems (Chan et al., 2009; Gratia and De Herde, 2004a, b; Shameri et al., 2011). It has also been recognized that the façade system is capable of adding some stiffness and damping to the overall building (Barone et al., 2015; Moon, 2009, 2011).

A number of studies have been concentrated on using a double skin façade to reduce vibrations of tall buildings. Samali et al. (2014) studied the potential of utilising a moveable exterior façade in a double-skin façade system. The investigations have shown that with optimal choices of materials for enhancing the stiffness and damping of the brackets connecting the two skins, a substantial portion of wind-induced vibration energy can be dissipated, which leads to inexpensive lateral stiffening systems and/or space-consuming damper systems such as massive tuned mass or liquid dampers. Azad et al. (2013) demonstrated that up to 50% of wind-induced accelerations and displacements can be reduced by a smart and efficient façade design, including purely passive systems with constant stiffness and damping or better, by a smart system possessing variable stiffness for different phases of façade movement. In addition, the same concept was also adopted by Abtahi et al. (2013) to dissipate a large proportion of seismic energy when dealing with earthquake loads. A proper choice of similar and optimal stiffness and damping of brackets connecting the two skins can lead to an energy dissipating façade system and hence reduce the reliance on large ductility of the main structural framing system to dissipate seismic energy. This will lead to smaller ductility demand and hence a more efficient, easier and faster-to-build and a more economical structural system.

Despite these efforts on better applications of the façade in buildings, the façade has been rarely considered or designed from an aerodynamic perspective to control wind-induced vibration of tall buildings. In past decades, aerodynamic treatments, such as tapering, corner shaping and modification, sculpturing and through building openings, has increasingly been adopted in the design of tall buildings due to aesthetic appeals and the ability to reduce wind loads and wind-induced dynamic responses. Numerous studies (Bandi et al., 2013; Dutton and Isyumov, 1990; Kareem et al., 1999; Kawai, 1998; Kim et al., 2014, 2015; Kwok, 1988; Kwok and Bailey, 1987; Kwok and Isyumov, 1998; Kwok et al.,

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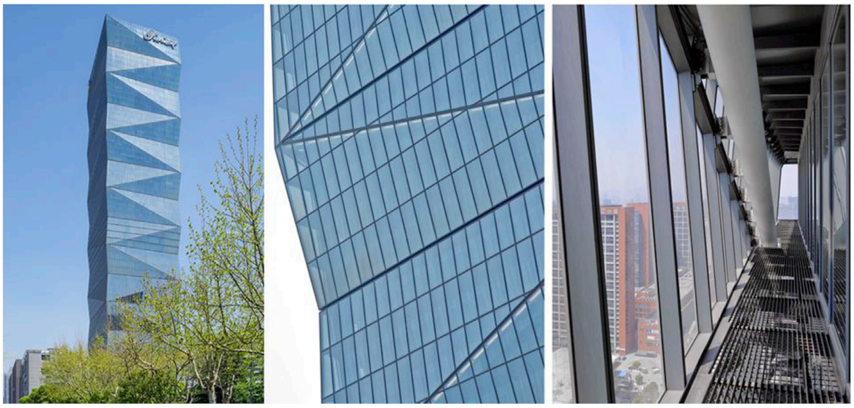

Fig. 1. Kingtown international center in Nanjing, China (SOM).

1988; Tse et al., 2009) have concentrated on the effects of the aerodynamic treatments on wind induced vibrations of tall buildings. With chamfered corners, there was up to a 40% reduction in the alongwind response within a reduced wind velocity range of 3–20 compared with that for the plain building. With wind normal to the wide face of the building, the dynamic crosswind response of the modified buildings were found to be up to 30% smaller than that of the plain building at the low range of reduced wind velocities. Other modifications such as horizontal slots, slotted corners and chamfered corners were also found to result in a 30% or more reduction in the crosswind response. Another type of effective aerodynamic modification termed 'base-bleed' technique was investigated by Isyumov et al. (1989) and Dutton and Isyumov (1990), which produced similar magnitude reduction in responses of a tall building.

This paper aims to explore the reduction of wind-induced tall building motions through an innovative double-skin façade system. The potential of creating intentional and optimal porosity in the external skin of a double-skin façade system, created by vertically aligned openings, was investigated. Both aeroelastic tests and pressure tests were performed. Based on the aeroelastic tests, the influence of the façade system on wind-induced vibrations of tall buildings was evaluated. Aerodynamic properties of the building with the façade system were studied by analysing pressure data obtained from the pressure tests to study the mechanism related to the influence of the façade system. The results clearly demonstrate that the façade with the vertically opening(s) can significantly reduce the wind-induced responses of tall buildings, in particular vortex-induced responses. This will potentially eliminate the need for installing large and space-consuming mechanical damper systems and therefore increase the prime leasable space available to the building owner with significant economic benefits.

2. Wind tunnel model tests

2.1. Wind tunnel facility and flow field

The building model was tested in the high-speed test section of the boundary layer wind tunnel at CLP Power Wind/Wave Tunnel Facility at Hong Kong University of Science and Technology. The tests were conducted in an open terrain wind model (i.e. AS1170.2:2002 open terrain category 2), as shown in Fig. 2, with a longitudinal mean velocity profile power exponent of 0.15 and a longitudinal turbulence intensity of 0.10 at the top of the building model.

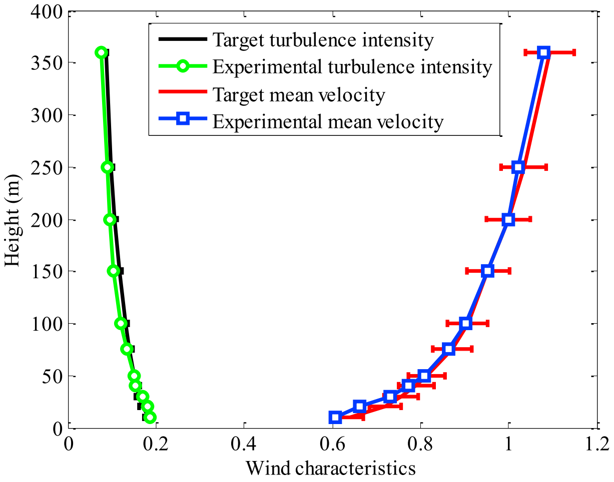

Fig. 2. Wind flow condition for wind tunnel tests.

2.2. Aeroelastic tests

A 1:400 linear scale model of the CAARC Standard Tall Building (prototype: Height (H) 180 m, Breadth (B) 45 m, Depth (D) 30 m; model: $H = 450$ mm, $B = 112.5$ mm, $D = 75$ mm) was tested. The test building was mounted on a two degree-of-freedom aeroelastic "stick model" test rig that modelled a linear mode shape in alongwind (x) and crosswind (y) directions pivoted at the base of the building, as depicted in Fig. 3. The equivalent mass of the aeroelastic system can be adjusted by the adjustable weight, which can be moved up and down. The density of the test building was set to a reasonable value of approximately 160 kg/m^3. The building model stiffness was provided by two sets of linear springs, which were linked to two strain gauge bridges calibrated to measure the alongwind and crosswind deflections at the top of the test building.

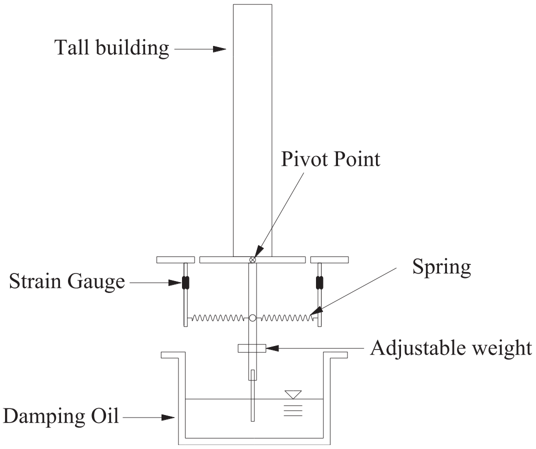

Fig. 3. Schematic of the aeroelastic test system used in the wind tunnel tests.