J. Wind Eng. Ind. Aerodyn. 133 (2014) 191–199

Contents lists available at ScienceDirect

Journal of Wind Engineering and Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Wind-induced responses of super-tall buildings with various atypical building shapes

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ARTICLE INFO

Keywords:
Time history analysis
Peak normal stress
Damping ratio
Loading condition

ABSTRACT

A wind tunnel tests were conducted on 13 super-tall building models with atypical building shapes under an urban area flow. The primary purpose of the present study was to directly compare the wind load effects on atypical super-tall buildings. Time history analyses were conducted using a frame model by inputting local wind forces at the center of each floor. The results show that the peak normal stresses on a square model are the largest among all the models tested, the setback model shows the smallest peak normal stresses of the single modification models tested, and CC+TP+360Hel shows the smallest peak normal stresses of the multiple modification models tested. The contributions of bending moments are about 20% of the total, and most of the peak normal stresses resulted from axial force. The increase in bending moment in the across-wind direction becomes significant as the damping ratio decreases, and the sensitivity of the peak normal stresses for the helical and multiple modification models to damping ratio is smaller than those of the other models. From the analyses for the various loading conditions, it was found that the contribution of bending moment in the along-wind direction is the largest and that of torsional moment is almost negligible.

1. Introduction

According to Tamura et al. (2011), more than 50% of the 100 highest super-tall buildings have been completed since 2000, and many super-tall buildings higher than 600 m are under construction, including Ping An Finance Center (660 m, China), which will be completed in 2016, and Kingdom Tower (at least 1000 m, Saudi Arabia), which will be completed in 2019. As is well-known, as buildings become higher, wind loads become more important than earthquake loads in safety design as well as in serviceability design including occupants' vibration perception. Thus, many attempts have been made to comprehensively suppress wind-induced responses by changing building shapes: so called aerodynamic modification. As wind forces largely depend on building shape regardless of structural system, studies on various aerodynamic modifications have been one of the most challenging issues in wind-resistant design. Aerodynamic modifications include taper, set-back, helical twist, openings and combinations of them, and a comprehensive study on these aerodynamic characteristics was recently made by Tanaka et al. (2012). These atypical and unconventional building shapes are a resurrection of an old characteristic, but they have the advantage of suppressing across-wind responses, which is a major factor in safety and serviceability design of super-tall buildings. The effectiveness of aerodynamic modification in reducing wind forces has been widely reported since the late 1980s (Kwok et al., 1988; Hayashida and Iwasa, 1990; Cooper et al., 1997; Kawai, 1998; Kim et al., 2011; Bandi et al., 2013; Kim and Kanda, 2013). Furthermore, Kim and Kanda (2010) reported that aerodynamic modifications such as taper and setback are also effective in suppressing mean along-wind forces, and Tanaka et al. (2013) showed high correlations between along- and across-wind forces.

Wind pressure measurements were conducted on super-tall building models, which showed superior aerodynamic characteristics. Models tested included corner modifications, taper, setback, helical, cross void, and combinations of them (Tanaka et al., 2012). Following the previous report (Tanaka et al., 2012), time history analyses were conducted in the present study using wind pressures. First, time histories of local wind forces were obtained from the wind pressures, and the time histories of local wind forces

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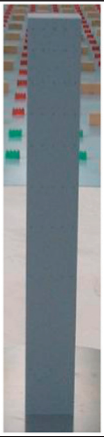
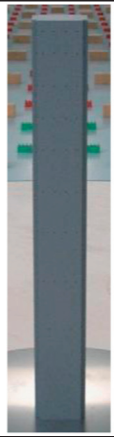
http://dx.doi.org/10.1016/j.jweia.2014.06.004
0167-6105/

Table 1
Test models for pressure measurements.

				
Square (SQ)	Chamfered (CF)	Corner cut (CC)	Taper (TP)	Setback (SB)
				
90 helical (90Hel)	180 helical (180Hel)	Cross void (CV)		
				
CC+180Hel	TP+180Hel	CC+TP+180Hel	CC+TP+360Hel	SB+45RT

were input at the center of each floor of the frame model to investigate the wind load effects. The purpose of the present study was to directly compare the wind load effects on super-tall buildings with various atypical building shapes, focusing on peak normal stresses in columns. These comparisons can advise the structural designers regarding the effectiveness of each aero-