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Interaction of Across-Wind and Along-Wind with Tall Buildings

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ABSTRACT

In our modern society, tall structures are an essential component of new civilization. These kinds of structures are sensitive to wind excitations due to their low damping and stiffness, and therefore large amplitude vibrations often happen under strong wind excitation. Focus of this study is a review of the research development on interaction between wind excitations and tall buildings. Wind motions occur simultaneously in along-wind mode, across-wind mode and torsional mode. The dynamic behavior and characteristics of the tall buildings are determined based on the field measurements and comparisons between across-winds and along-winds. Across-wind dynamic responses are greater than along-wind ones caused by vortex shedding. Aerodynamic modifications of the form of the tall buildings are considered to reduce the wind loads.

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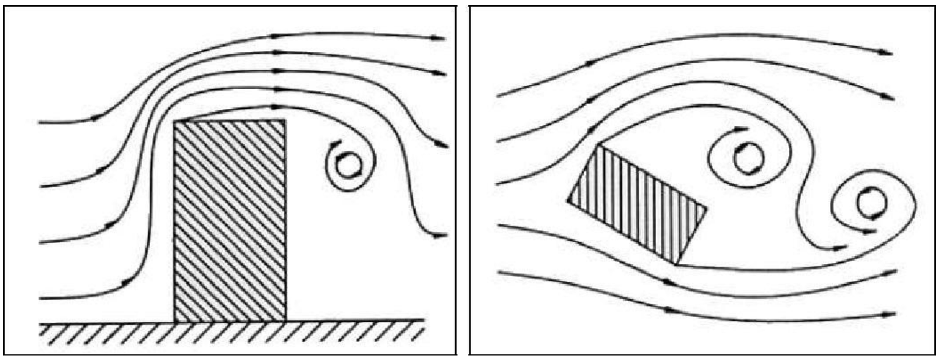
INTRODUCTION

In last decades a large number of tall structures have been proposed and these days, more and more tall buildings are being built worldwide. In our modern society, tall structures are an essential component of new civilization. Generally, these structures are designed to resist static loads. On the other hand, they may be subjected to dynamic loads like earthquake, wind, wave and traffic. These loads can cause intensive and stable vibrational motions, which can be damaging to the structure and human inhabitants. Because of this, safer tall buildings should be designed (MousaadAly, 2011).

Wind loads in tall buildings are one of the most significant forces which are responsible for the terrible disasters. Hence, correct assessment and estimation of wind loads are necessary to reduce the destructive effects of wind excitations in the built environment (Dagnew, 2009).

This study presents a review of the research development on interaction between wind excitations and high-rise buildings, wind loads effects on these kinds of structures and aerodynamic modification of tall buildings against wind excitations.



(a) (b)

Fig. 1: Flow around a tall building (a) Elevation and (b) Plan (Mendis *et al*., 2007).

Wind and flow around a tall building:

Wind is a phenomenon of big intricacy because of the numerous flow situations arising from the interaction between wind and structures (Mendis, 2007). The difficulties related to the wind-induced vibrations of tall

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buildings are acquainted. Wind-induced vibrations in tall buildings may cause many problems like displeasure of inhabitants, structural damage or weakened function of tools. Actually displeasure of residents is more tangible in higher floors (MousaadAly, 2011). Figure 1 shows flow around a tall building in elevation and plan.

Directions of wind:

Effects of wind on tall buildings depend on two main factors: the magnitude of wind speeds and directions of wind (Khanduri, 1998). Wind-induced fluctuations in high-rise buildings with one face perpendicular to the mean flow take place mostly in three different modes of action: along-wind, across-wind, and torsional modes (ILGIN, 2007). According to Solari (1985) a mathematical model of dynamic wind loads can be considered which wind induced dynamic force on tall buildings is determined by three independent contributions: force due to along-wind turbulence, force due to across-wind turbulence and force due to wake excitation.

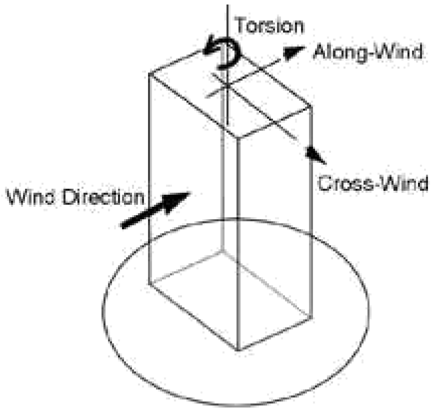

Fig. 2: Wind response directions (Mendis *et al*., 2007).

Wind effects on structures:

Modern tall buildings move toward taller and more bendable designs, hence the problems of wind effects on these types of structures endanger structural integrity as well as increase human discomfort (Kijewski, 2000). As a result, a various group of contributions should be considered, as shown in figure 3. In high-rise buildings across-wind load can be divided into three mechanisms which include vortex shedding, incident turbulence and higher derivatives of across-wind displacement (galloping and flutter). The fluctuating along-wind loads are various accidental blends of gusts or eddy (Mendis, 2007).

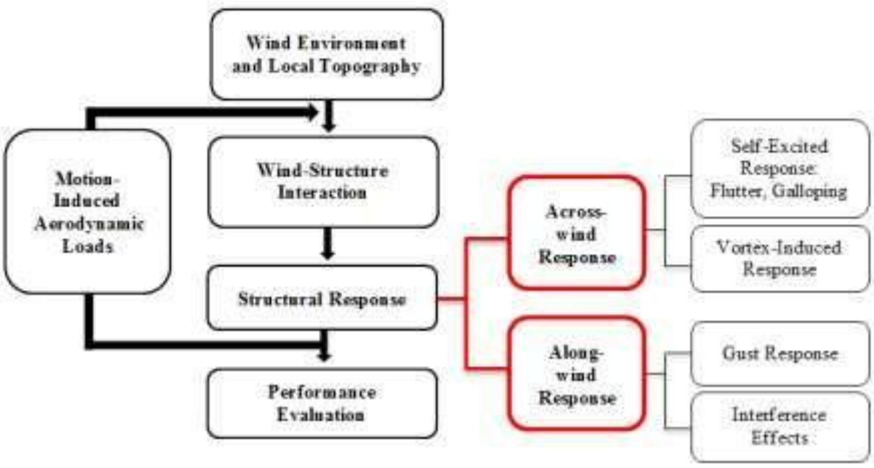

Fig. 3: Overview of scheme to determine wind effects on structures (Kijewski *et al*., 2000).

RESULT AND DISCUSSIONS

Across-wind load:

Across-wind response is a perpendicular fluctuation response of wind excitation (ILGIN, 2007). In tall buildings across-wind excitation is divided into three mechanisms: vortex shedding, incident turbulence, higher derivatives of across-wind displacement (galloping, flutter and lock-in) (Mendis, 2007). In recent years there have been vast theoretical and experimental investigations about the across-wind effects on tall buildings (Liang, 2004).

Along-wind load:

Along-wind is the term which refers to drag forces. Pressure fluctuations on windward face (building's frontal face that wind hits) and leeward face (back face of the building) as well as wind load interaction with buildings causes along-wind load (Dagnew, 2009; ILGIN, 2007).

Some techniques, such as the ''gust loading factor'' approach, are developed to predict forces and response in the along-wind direction [9]. The gust factor approach is used in international standards and codes to evaluate the dynamic along-wind forces and their effects on tall buildings (Zhou, 2003).

Comparison of evaluation of the across-wind and along-wind response:

Tall buildings are very sensitive to across-wind motion. This sensitivity will be become visible with wind speed rises. In the design of tall buildings, the across-wind response usually controls over the along-wind response (ILGIN, 2007). The wind tunnel test of tall Buildings demonstrates that maximum acceleration in across-wind direction at design wind speed is more than along-wind direction (Gu, 2004). When the building vibrates in along-wind direction (e.g., in Y-direction), across-wind motion also happens simultaneously (in X-direction). For the same wind speed, actions responses of across-wind (in X-direction) are more than the along-wind responses (in X-direction) and are less than the along-wind responses (in Y-direction). This obviously shows that response of across-wind is comparable to the along-wind responses (Wu, 2007).

Studies in the literature (Zhou, 2012; Kijewski, 2000; Boggs, 2009) demonstrate that in measured aerodynamic load spectra for the along-wind and across-wind load components of a tall building on the wind tunnel, the response of along-wind component will always reduce with a growth in natural frequency. On the other hand, vortex shedding causes a medium peak in the spectrum of the across-wind component. However, vortex shedding can greatly affect the resonant response of across-wind load; along-wind response is more significant in design than across-wind load.

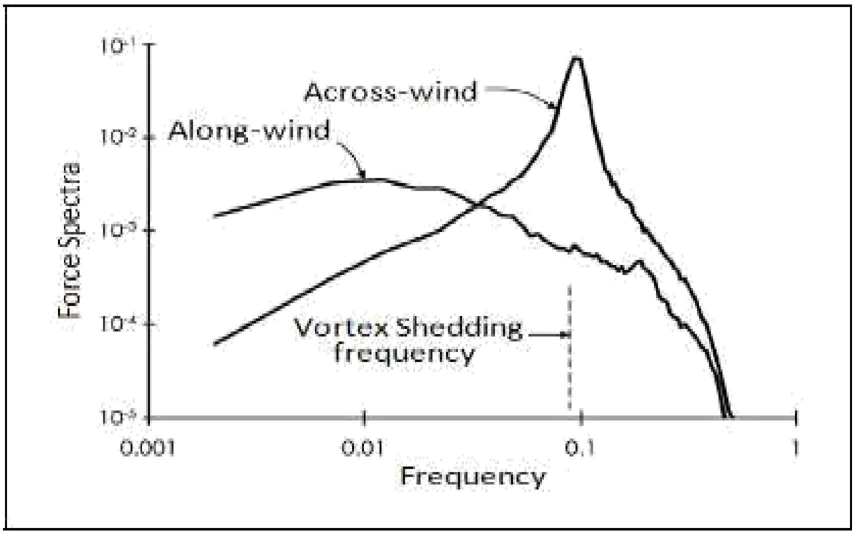

Fig. 3: Aerodynamic load spectra in a wind tunnel (Boggs & Dragovich, 2008)

Aerodynamic modification in tall building's form against wind loads:

From the wind engineer's view point, aerodynamic modifications of the form and cross sectional shape of the tall buildings such as corner modifications, additional openings, changing the shape, tapering and setbacks should be considered to reduce wind loads by changing the flow schema around the tall building. In many of the most well-designed and famous high-rise buildings (e.g. The Petronas Towers, The Burj Dubai, The Sears Tower, The Jin Mao Building, The Millennium Tower, Toronto City Hall, etc.) have been used this method. Although this method can moderate wind excitations of tall buildings, cannot omit them completely. Therefore, extra damping devices such as 'Tuned Mass Damper', 'Tuned Liquid damper', 'Friction damper' and 'Fluid Viscous Damper' may be needed, as an illustration, using Tuned Mass Damper (TMD) in Taipei 101(ILGIN & GÜNEL, 2007).

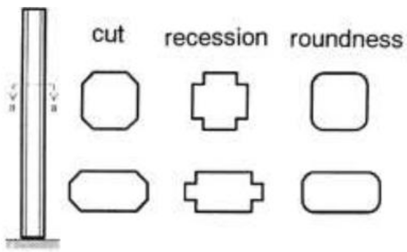

Fig. 4: Corner modifications (Kawai, 1998) [15]

Fig. 5: Taipei 101, Corner modification (ILGIN & GÜNEL,2007)

Fig. 6: Additional opening, Financial Center, (ILG IN & GÜNEL, 2007)

Fig. 7: Setback, The Petronas Towers, (ILGIN & GÜNEL, 2007)

Fig. 8: Changing the shape, The Burj Dubai (ILGIN & GÜNEL, 2007)

Conclusion:

Tall buildings are sensitive to wind excitations. Wind motions occur in along-wind mode, across-wind mode and torsional mode. Because of vortex shedding across-wind load is more than along-wind load. Therefore, the lateral displacement in across-wind direction is greater than along-wind direction. Aerodynamic modifications of the form of the tall buildings should be considered to minimize the lateral displacements of tall buildings due to wind excitations.

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