NUMERICAL AND EXPERIMENTAL INVESTIGATION OF AERODYNAMIC LOADS FOR TALL BUILDINGS WITH PRISMATIC AND TWISTED FORMS

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ABSTRACT

Cantilevered from the ground, tall buildings reaching exceptional heights are inevitably exposed to severe lateral effects, particularly wind loads. As the structures get higher, slenderer and have larger strength-to-weight ratios, their design, both structural and architectural, is principally based on wind rather than gravity or seismic demands. Wind forces acting on this type of structures primarily depends on wind characteristics and the building form. Thus, creating distinctive forms that attract public interest and are aerodynamically efficient is an ambition of architects and engineers for decades. Recently, twisting tall buildings emerged by virtue of such a motivation. This study investigates wind effects on these complex forms through a case study research. Comparisons between wind loads on a twisted building model and those on its conventional prismatic counterpart were performed by making use of both numerical analyses and experimental measurements. The influences of facade texture, wind speed, and wind direction on separated turbulent flow around the model buildings and the aerodynamic loads acting on the buildings have been investigated. Comparisons highlighted that, wind loads around the bluff body of twisting structure is on a lower grade compared to the prismatic counterpart which is valid for both along wind and across wind directions.

INTRODUCTION

There is not a constant definition for the term ‘‘tall building’’ from architectural or technological views. However, when the structural aspect is the subject, the definition particularly comes from the wind loads. In other words, when the design of a building is governed by aerodynamic loads rather than gravity or seismic loads, building can be identified as tall building or high-rise building [1]. Effects of the aerodynamic loads on the tall buildings like towers are focus of researchers in the recent literature [1-9] as the number of tall buildings has been rapidly increasing [2]. Unsteady, 3-D, separated and turbulent flow around the structure creates the wind loads which are the primary design parameter for this kind of structures in terms of occupancy comfort and structural stability [7]. In order to investigate this complex problem, wind tunnel experiments are conducted [4-5, 8] and CFD analyses are performed [6-9] in the recent literature. The wind loads on the 38-storey high-rise building was investigated by Vafaeihosseini in 2011 [6]. Mohotti et al. [7] solved the flow around tall buildings

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by using k-epsilon turbulence model with a constant velocity profile. Also, he considered the effect of atmospheric boundary layer on the structures. Yılmaztürk and Sezer-Uzol [8-9] performed CFD analyses of a model tall building and also conducted wind tunnel tests to investigate the flow field characteristics and wind loads. Atmospheric boundary layer effects in a short tunnel are also investigated experimentally for the same building [8] by Shojaee et al. [9].

METHODOLOGY

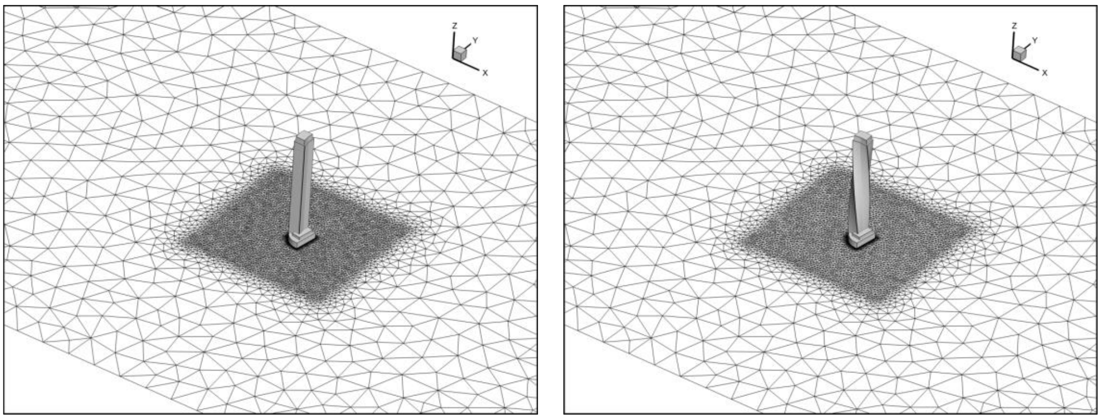
Aerodynamic effects have been analyzed by both wind tunnel tests and numerical analyses. High frequency base balance (HFBB) tests on 3-D building models are performed to evaluate wind load effects on a global scale via wind tunnel tests which is accepted as the most confidential tool all over the world. Moreover, mathematically complex but another confident discipline, named Computational Fluid Dynamics (CFD) is used and comparisons of the results of the CFD simulations are made with the wind tunnel test results.

For wind tunnel tests, experimental models are produced by 3-D printers. In HFBB tests, models are required to have low mass and high rigidity [4], therefore, polyactic acid (PLA) material is preferred to satisfy this necessity. 3-D models can be seen in Figure 1. The scale of the models comes from the dimensions of wind tunnel's test section. Blockage ratio is the maximum cross-sectional area of the model at any cross-section divided by the area of the wind tunnel cross-section [3]. 1/750 scale was used to keep the blockage ratio small enough so that the error introduced is small and no correction is required. Two different design wind speeds of 6.85 m/s and 13 m/s are considered. Influence of angle of attack was investigated for each 15 degrees for each model. Although 10000 Hz is used for data acquisition through the tests, 1000, 100 and 10 Hz of data is also analyzed during post process of data. Data acquisition is implemented for a period of 2 minutes.

(a) (b)

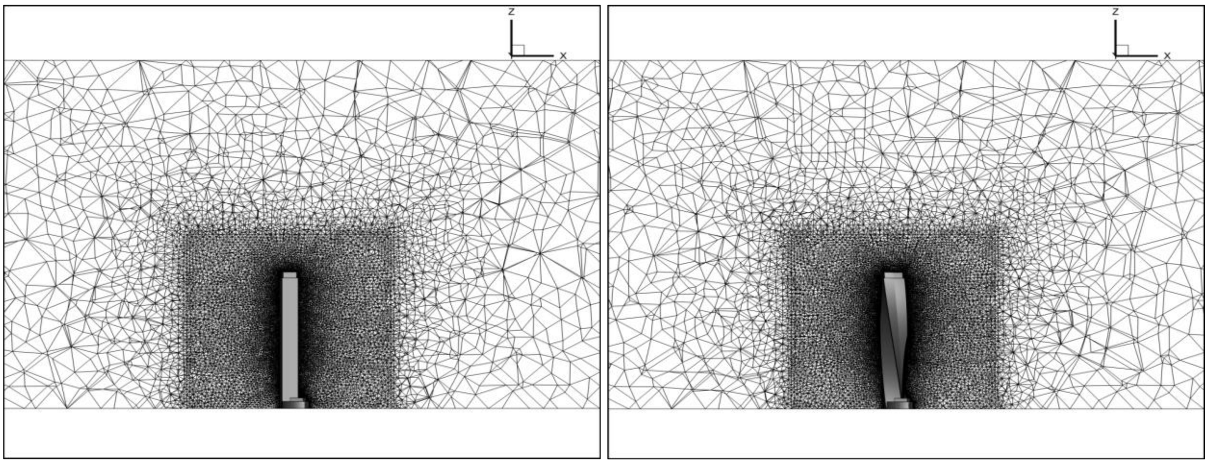
Figure 1. Experimental models during the tests: a) Prismatic b) Twisted

For CFD simulations, unstructured mesh is generated for model scales of prismatic and twisted buildings, since unstructured grids are easy to generate in complex geometries such as twisted towers. The commercial software, Pointwise, is used to generate the computational grid around the towers. In Figure 2, the computational mesh for both cases can be seen. The computational domain of prismatic building and twisted building cases consist of approximately 2600 K cells. In this figure, building positions are according to head wind direction (yaw angle of 0 degree). In Figure 3, mesh around buildings can be seen along the slice at centerline of the domain, which represents zoomed views of the meshes.



(a) (b)

Figure 2. Computational mesh around a) prismatic building b) twisted building



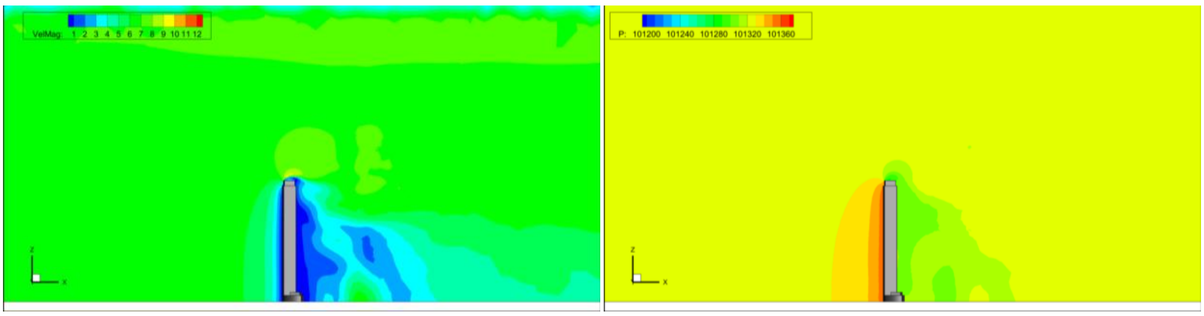
(a) (b)

Figure 3. Unstructured mesh around a) prismatic building b) twisted building

In order to solve the flow field through the computational domain, RANS equations are solved in the computational domain by using the commercial CFD flow solver, CFD++. In CFD analysis, different yaw angles of upcoming wind of ±15, ±75 and ±255 degrees and two different freestream velocities of 6.85 m/s and 13 m/s are considered. Uniform freestream is considered for this study by considering the short wind tunnel used in the tests, while neglecting the atmospheric boundary layer (ABL) effect. For two types of buildings, prismatic and twisted, flow analyses are performed. In the computations, characteristics farfield boundary condition is used in inlet and outlet face of the outer domain. No-slip wall boundary condition is applied at both building and wind tunnel walls. At first, steady-state computations are performed and the forces and moments acting on the building due to aerodynamic loads are compared with the wind tunnel experimental results. Then, unsteady simulations are performed in order to obtain time history of velocities around the building and load fluctuations. The comparison between the computational results and experimental data are also done and discussed.

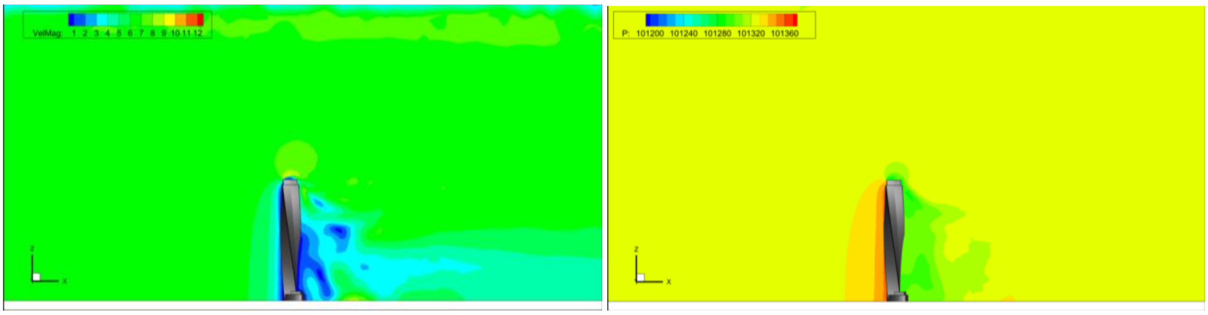
PRELIMINARY RESULTS

Wind loads obtained from the experimental measurements are presented for the selected wind conditions for both buildings. In CFD analysis, preliminary results are obtained. During the computations, flowfield around the buildings are investigated in terms of velocity and pressure distributions which cause aerodynamic loading at structures. In Figure 4, flow around the prismatic building can be seen showing the pressure variation on the left and velocity magnitude changes on the right. In Figure 5, the preliminary results of the twisted building case are presented.



(a) (b)

Figure 4. Flowfield around the prismatic building a) Pressure variation b) Velocity magnitude change



(a) (b)

Figure 5. Flowfield around the twisted building a) Pressure variation b) Velocity magnitude change

CONCLUSIONS

Aerodynamic loads are the primary factors affecting tall building design in terms of structural stability and occupancy comfort. This study mainly investigates aerodynamic effects on the twisting building and on its conventional prismatic counterpart by making use of wind tunnel tests and CFD. The effects of wind characteristics as speed and direction have been analyzed on these forms of building models. Further analyses on the unsteady flow field characteristics will be discussed in the final paper. Comparisons on preliminary results showed that wind loads around the bluff body of twisting structure is on a lower grade compared to the prismatic counterpart which is valid for both along wind and across wind directions.

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