Engineering Structures 136 (2017) 133–148

Contents lists available at ScienceDirect

Engineering Structures

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

Enhancing wind performance of tall buildings using corner aerodynamic optimization

Ahmed Elshaer, Girma Bitsuamlak *, Ashraf El Damatty

Department of Civil & Environmental Eng./WindEEE Research Institute, University of Western Ontario, ON, Canada

ARTICLE INFO

Article history:
Received 14 May 2016
Revised 4 November 2016
Accepted 9 January 2017

Keywords:
Tall building
Wind load
Vibration
Wind direction
Turbulence, aerodynamics, optimization
LES
Genetic algorithm
Artificial neural network

ABSTRACT

Wind-induced loads and motions of tall buildings usually govern the design of the lateral load resisting systems. The outer shape of the building is one of the many parameters that affect these design wind loads and responses. This study presents building corner aerodynamic optimization procedure (AOP) to reduce the wind load, by coupling an optimization algorithm, large eddy simulation (LES) and an artificial neural network (ANN) based surrogate model. As an illustration, corner mitigation that has limited effect on both the structural and the architectural design is presented. Two aerodynamic optimization examples focusing on drag and lift minimization that consider wind directionality and turbulence are presented. For example, reductions in the order of more than 30% both in along- and across-wind responses are obtained through a two-surface chamfering that was constrained to 20% of the building width.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

New generations of tall buildings are becoming increasingly taller, flexible and slender primarily driven by novel developments in design methods and new construction materials and techniques. This in turn makes tall buildings more sensitive to lateral loads such as wind. In addition, there is a need to lower the building weight in order to decrease the gravity loads to control the inertial forces developed by earthquake. This further contributes to an increase in the wind-induced forces and motions. As a result, wind-induced loads and motions typically govern the design of the lateral load resisting systems in tall buildings. The outer shape of the building is one of the main parameters that affect these loads and responses. The dependence of the wind load on the building shape makes the generalizations of wind load for tall buildings almost impossible, because every complex shape and surroundings produce a unique set of design wind loads. On the other hand, this dependency on the shape provides a unique opportunity to reduce the wind load through outer shape modifications either globally or locally. In that context, global modification involves major changes on the form of the building, which has a considerable effect on the overall architectural and structural design. This includes large openings, tapering, twisting, set-backing, etc. The architects can implement global modifications at the early conceptual design of the building if the modifications fit with the major functionalities of the building. On the other hand, local modifications result in minor changes on the building shape that have limited effects on the structural and architectural designs. Thus, the architects can introduce the local mitigations at a later stage of the conceptual design. One such local mitigation is corner modification; whish is the focus of the present study.

The outer shape of tall buildings is typically aerodynamically "bluff" and characterized with sharp corners. Wind loads for tall buildings with various shapes have been widely investigated in many numerical and experimental wind engineering studies, few examples include Vickery [1], Lee [2], Okajima [3], Igarashi [4], Nakamura and Ohya [5], and Merrick and Bitsuamlak [6]. Many researchers have reported that careful modification of the shape of the corners can provide better aerodynamic performance [7–10]. Fig. 1 summarizes the widely used corner modifications in literature. Boundary Layer Wind Tunnel (BLWT) based studies [11–13,10] reported chamfered, recessed and rounded corners to be effective in reducing the along- and across-wind forces. Kwok and Bailey [14] reported that finned corners increase the along-wind and decrease the across-wind responses, while slotted corners reduce responses in both directions. Tamura and Miyagi [9] reported that 2D flow BLWT tests were sufficient to indicate the aerodynamic improvements by corner modifications similar to

---

* Corresponding author.
E-mail address: gbitsuam@uwo.ca (G. Bitsuamlak).

http://dx.doi.org/10.1016/j.engstruct.2017.01.019
0141-0296/© 2017 Elsevier Ltd. All rights reserved.

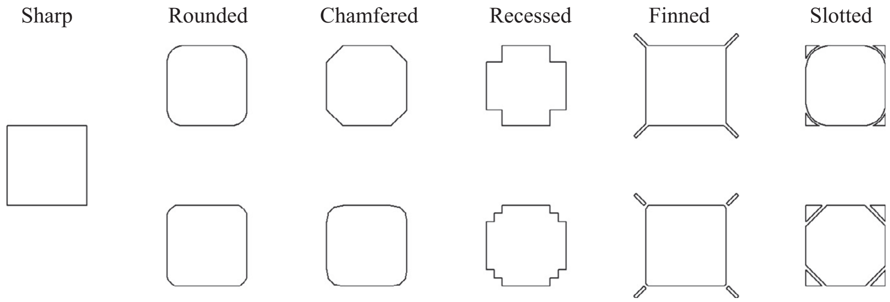

Fig. 1. Examples of tall building corner mitigations.

ABL flow tests. Table 1 summarizes the scope and main findings of previous experimental and computational studies focusing on aerodynamic modifications of tall building corners.

As summarized in Table 1, BLWT has been widely used for studying building aerodynamic mitigations. This approach is reliable but only useful to compare limited number of feasible building shapes in addition to being costly for repetitive investigation. A wide portion of the search space remains unexplored as the search space is only limited to the tested options [19]. On the other hand, integrating CFD with an optimization algorithm can be more useful to explore wider geometric alternatives to find near optimal shapes. This is inspiring an increased number of researchers to work on building aerodynamic optimization applications. For example, Kareem et al. [20–22] introduced an approach for tall building corner optimization to reduce drag and lift by adopting low-dimensional CFD models. This approach is useful to overcome the computational cost associated with the iterative procedure required for optimization. Bernardini et al. [19] investigated the efficiency of utilizing Kriging model as a surrogate model for the objective function evaluation. The utilization of a surrogate model reduced the computational time. In these studies, Unsteady Reynolds-Averaged Navier–Stokes (URANS) equations were used. Although these studies developed a very promising and useful approach for building aerodynamic optimizations, some limitations are observed. For example, (i) wind directionality effect is not considered, (ii) low-order CFD models are used to evaluate shape alternatives, although wind performance assessment usually requires the use of high accuracy CFD- or BLWT-based evaluations. Using these novel approaches, it is possible to infer the relative performance of the various geometric alternatives (i.e. comparing alternatives) adopting the reduced order 2D simulations. A similar conclusion was also reported by Tamura and Miyagi [9]. However, adopting a simplified low order simulation can significantly reduce the analysis accuracy that may affect the conclusions observed under such simplified scenarios. Particularly when simulating the turbulent atmospheric boundary layer (ABL) flow and its interaction with a tall building. In the author's opinion, the CFD simulations used to assess wind loads on buildings shall be commensurate with the complexity encountered in urban flows. These complex interactions can be realistically captured through LES as reported by Nozawa and Tamura [23], Dagnew and Bitsuamlak [24,25], Aboshosha et al. [26] and Elshaer et al. [27]. It is to be noted that the accuracy of LES depends on the proper selection of the inflow boundary conditions and the adopted grid resolution.

Table 1
Scope and main findings of previous studies focused on local aerodynamic mitigations.

Reference	Method	Scope	Findings/comments
Kwok and Bailey [14] Kwok et al. [15]	BLWT	Square sections with fins, vented fins and slotted corners	Fins and slotted fins increase the along-wind responses and reduce the across-wind responses. While slotted corners reduce both along- and across-wind responses
Kawai [11]	BLWT	Square and rectangular sections with rounded, chamfered and recessed corners	Small chamfers and recessions are effective in preventing aeroelastic instability. Rounded corners increase the aerodynamic damping
Tamura et al. [16]	CFD	Square sections with rounded and chamfered corners using smooth uniform flows	CFD is very reliable in predicting wind loads and basic flow statistics and is able to capture the aerodynamic improvement resulted from corner modifications
Tamura and Miyagi [9]	BLWT	Square sections with rounded and chamfered corners using smooth uniform and turbulent flows	Chamfered and rounded corners decrease drag forces. Fluctuating lift coefficients for the 3D turbulent models are lower by 10% compared with those obtained from 2D models
Gu and Guan [12]	BLWT	Square and rectangular sections with chamfered and recessed corners	The effects of terrain condition, aspect ratio and side ratio of cross section are investigated for different cross-sections. In addition, formulas for the power spectra of the across-wind dynamic forces, the coefficients of base moment and shear force are derived
Tse et al. [13]	BLWT	Square and rectangular sections with chamfered and recessed corners	The effects of aspect ratio of recessed corners are pronounced compared to chamfered corners. Empirical formulae are proposed to relate the cross-wind responses to the building dimensions and dynamic properties
Tanaka et al. [17]	BLWT	Square sections with recessed and chamfered corners in addition to other global modifications such as twisting, openings, tapering and set-backing	Base moments and moment coefficients of tall buildings with various configurations are reported
Carassale et al. [10]	BLWT	Square sections with rounded corners of different modification length	Critical angle of incidence decreases with the increase in the modification length. Supercritical Re regime observed only for larger modification lengths
Elshaer et al. [18]	CFD	Square sections with rounded chamfered and recessed corners using 2D flow and different inflow velocities	2D models can provide sufficient accuracy for comparing the effect of aerodynamic modifications. Round corners are effective in reducing drag followed by chamfered and then recessed shapes

Download English Version:

https://daneshyari.com/en/article/4920490

Download Persian Version:

https://daneshyari.com/article/4920490

Daneshyari.com