Journal of Building Engineering 18 (2018) 180–194

Contents lists available at ScienceDirect

Journal of Building Engineering

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

Mitigation of wind load on tall buildings through aerodynamic modifications: Review

Ashutosh Sharma[a,*], Hemant Mittal[a], Ajay Gairola[b]

[a] Centre of Excellence in Disaster Mitigation and Management, Indian Institute of Technology Roorkee, Roorkee 247667, India
[b] Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee 247667, India

ARTICLE INFO

Keywords:
Wind Load
Aerodynamic modification
Mitigation
Response
Taper Ratio

ABSTRACT

With the advancement in construction and engineering techniques, a pragmatic shift in architectural designs of tall buildings can be observed. The buildings are going taller and unconventional shaped rather than traditional. Generally shape and orientation of the building are determined on the basis of architectural and practical considerations, but the wind-induced excitations encouraged by bluffness of the building shapes cannot be neglected also. To safeguard the functional requirement of tall flexible buildings and to mitigate the excitations, various methods are available. Among these methods, aerodynamic modification techniques are very potent, which affect the mechanism of vortex shedding phenomenon considerably and have got a lot of attention in recent years. Based on the impact of modification on the outer architecture of the building, the aerodynamic modifications are categorized in two groups i.e. minor modifications (corner cut, rounding, chamfer etc.) and major modifications (taper, set-back, twist etc.). The present study comprehensively reviews the recent/past aerodynamic modification techniques applied to high-rise buildings.

1. Introduction

Increasing demand for business and residential space, economic growth, innovation in structural systems has led to the scope of vertical expansion of the buildings thus occupying the less precious area and in the coming decades, maximum cities of developed and developing countries would be seen with the more cohesive skyline. Fig. 1 shows some of the tall buildings which are top 10 tallest buildings in the world [1].

In past decades, shapes of the tall buildings were traditional and symmetrical having square, rectangular, triangular, circular etc. cross-sections (e.g. 432 Park Avenue (New York), World Trade Centre (New York)), these shapes were less associative with torsional-vibrations by seismic loads due to eccentricity [2]. The progressive social, economic development and advancement of new engineering and construction techniques, high-grade materials, steel, welded connections and light facades (do not impart in the strength of structure) motivating architects and engineers to construct peculiar light, tall buildings to display their spirit, inventiveness and design concept. On the contrary, these advancements in heights are generally accompanied by increased flexibility, slenderness, lack of sufficient damping and low natural frequency [3,4]. As the wind-load increases with height, it raises the concern of wind-induced dynamic response and these are more expected to be in the range of wind gust. Moreover vortex shedding also plays an important role, whose frequency may reach close to the natural frequency of structure and may lead to the vibrations in structures which may be troublesome as serviceability and survivability issues are concerned [5–7].

It is well established that shape of the structure plays a significant role in resistance against wind-induced load and response of the structure in either direction. The bluff structures are more prone to excessive wind loads. Earlier records of such studies can be found in the studies by Lee [8], Irwin [9], Nakamura [10]. The rectangular cross section structures are more vulnerable to the lateral response unlike triangular, elliptical, cylindrical shapes; these shapes offer greater structural efficiency. Although wind load depends on the outer geometry of the building, the wind load for the tall buildings cannot be generalized due to wide variability in shapes and surroundings for a building which can be unique for every case [11]. So in early design stage scrutinizing of building design modification to mitigate the wind load and to deal with the serviceability issues recommended.

Nowadays, even if the safety of the structure can be confirmed by the use of advanced structural systems and high grade materials, still the vibrations caused by the wind gustiness can reach beyond the human comfort zone and may be a point of concern for fatigue life of building, excessive noise and cracks [12]. The dynamic motion of the

---

[*] Corresponding author.
E-mail address: ashukridha@gmail.com (A. Sharma).

https://doi.org/10.1016/j.jobe.2018.03.005
Received 28 September 2017; Received in revised form 16 March 2018; Accepted 17 March 2018

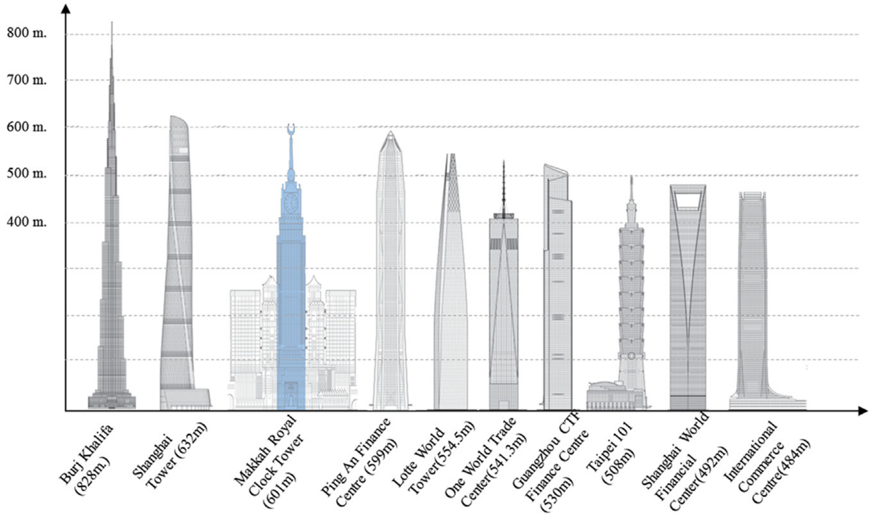

Fig. 1. World's top 10 highest buildings.

building depends on factors such as flow characteristics of wind, building surrounding, shape, and height, structural properties of the building (i.e. stiffness, damping, mass distribution, mode shape etc.) and dynamic motion of building is consists of static or sustained and the oscillatory motion. The Later parameter is considered to be significant since this motion is perceived by the occupants and can cause discomfort or nuisance to the occupants [13]. Therefore, the area of wind load and response reduction have always been a critical, interesting and explorable area among researchers and continuously gaining the attention.

The very recent review on the aerodynamic modification for mitigation of wind-induced loads is given by Moonegi et al. [14]. In this study, modification approaches for low-rise and high-rise buildings were presented in brief and the study is largely focused on optimization methods. In other review studies in past decades ([3,6]), some aspects of the aerodynamic modifications have not been covered in detail. Moreover, since year 2010, Yukio Tamura group and some other authors have dedicated a lot of research in field of aerodynamic modifications and have investigated almost all the practically possible shapes, these records have not been considered so far. The present study comprehensively reviews the recent/past work on wind resistant design modification techniques for tall buildings to mitigate wind-induced loads.

2. Wind induced Forces and responses

"The whole question of vibration in buildings from the effect of variable wind pressures is complicated by the indeterminate nature of the pressures themselves as well as by the great variation in size, shape, weight, height, and location of buildings."-Davenport [7]

A structure against wind flow experiences loads in along-wind, across-wind and torsional direction, correspondingly there are excitations in three directions (Fig. 2(a)). As the height of building increases wind load on curtain walls and sensitivity may become pronounced with increasing speed [15–17]. Excitation of the building can be suppressed either by countering the source of generation of unsteadiness (for instance the outer geometry of the building can change the organization of vortex formation) or by handling the response with some external means (addition of structural elements).

2.1. Along wind response

Along-wind excitation is primarily caused by the pressure fluctuations on windward and leeward faces of the building [3,18–20] and in general, it is followed by the oncoming wind fluctuations. In a majority of the international codes along wind response obtained by 'Gust factor approach'. Although along wind building loading dynamics can be dealt with gust factor approach, the across-wind and torsional loading do not manifest any straight relation with the fluctuations in the approaching flow, and are dealt with different practices adopted by variously available codes and standards [21,22].

2.2. Across wind / transverse response

The most common source of across wind excitation is the vortex shedding. Unlike the streamlined bodies, the tall buildings are bluff against the flow and cause the flow to separate, rather than following body contours. At low wind speeds, the vortices shed from the sides of the building in a symmetrical manner and there is no unbalanced force in the lateral direction, at comparatively high wind speeds the vortex shedding becomes unsteady and vortices shed alternatively from both the sides of the building (Fig. 2(b)). The alternate vortex shedding distributes pressure asymmetrically on the lateral or side faces of building and give rise to periodic transverse force [18,20–23], subsequently, flexible structures start oscillating in the transverse direction.

The vortices have a dominant frequency of shedding and is represented by a nondimensional number i.e. Strouhal Number (St), this number is highly dependent on the shape of the structure:

$$St = fB/U \quad (1)$$

Here 'f' is the frequency of vortex shedding, 'U' is the wind speed and 'B' is the width of the building across the wind flow direction. The frequency of vortex shedding 'f' when coincides with one of the natural frequency of building; resonance condition prevails, which consequently amplifies the transverse motion of the structure. The St value for different shapes typically varies in the range of 0.1–0.3, almost 0.14 for a square cross section and approx. 0.2 for circular sections [9,12,17].

$$f = f_r$$

$$U_c = f_r \times B/St$$

The critical velocity (Fig. 3(a)) at which resonance starts, if can be shifted to higher velocity with the help of increasing the building frequency by increasing stiffness, oscillations can be controlled but if this increase is high, it may not be tenable as far as economic point of view is concerned.

Previously a number of researchers have identified that across wind dynamic response may exceed the along wind response