Chapter 1

INTRODUCTION

1.1 General overview

World Urbanization Prospect (2018) reports that 55.28 percent of the world's population lives in urban areas. According to the United Nations, 68.4% of the world's population will live in urban areas by 2050. Urbanization is increasing the number of high-rise buildings in many cities, which are replacing vast areas of traditional housing. Construction in the real estate industry continues to expand vertically due to population growth and limited land resources. With limited landmass as the buildings become taller, their height ratio increases eventually. According to the Council of Tall Buildings and Urban Habitat (CTBUH), the number of tall buildings is growing each year as shown in Figure 1.1.

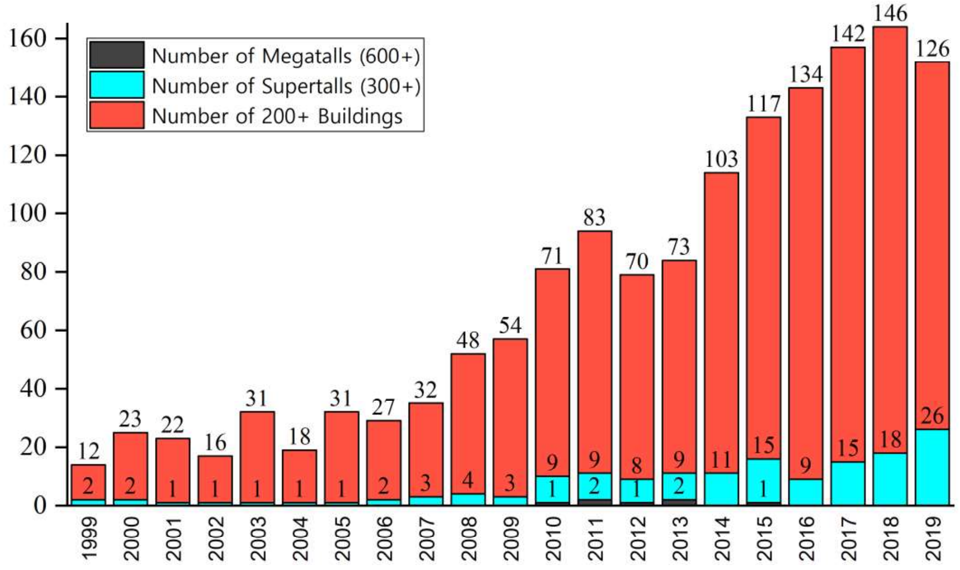


Figure 1.1 Number of tall buildings completed by year (CTBUH 2020).

Wind load is a critical consideration in the design of tall buildings because of its potential impact on the structural stability and performance of tall buildings. When wind flows around a tall building, it creates pressure variations on the building's surfaces, resulting in wind loads that can affect the building's structural behaviour. The magnitude and direction of wind loads vary depending on a range of factors, including the building's height, shape, location, and surrounding terrain (Davenport 1971). Tall buildings are particularly susceptible to high wind loads because they have a large surface area exposed to wind and are subject to significant wind-induced vibrations.

1.2 Wind induced load and responses

Wind forces that fluctuate can cause significant dynamic motion in high-rise buildings. Tall buildings are bound to oscillate in three ways, *viz*., two linear (along-wind and across wind directions), and one rotational (torsional mode). The wind-induced loads and their components are represented in Figure. 1.2.

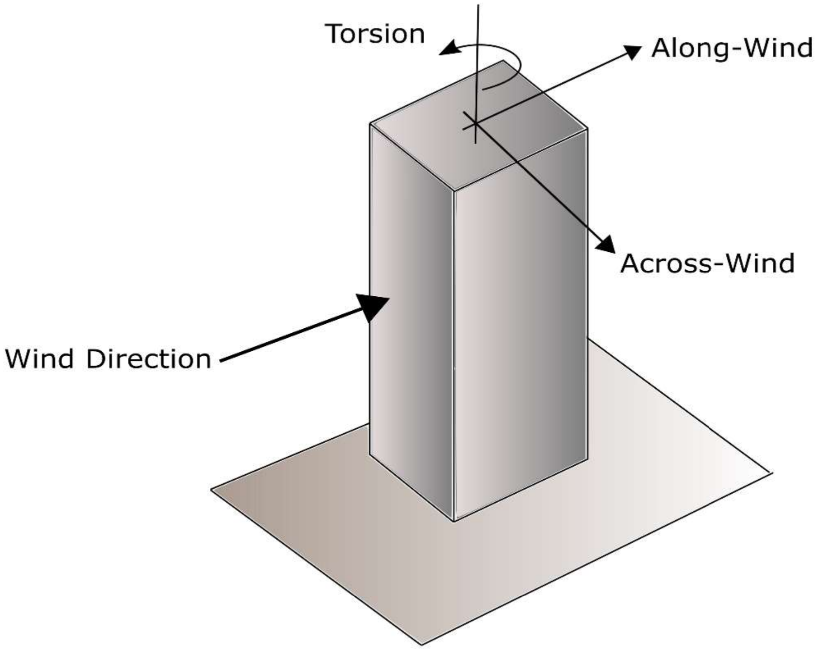


Figure 1.2 Direction of wind loading and its component.

1.2.1 Along wind loading

When wind approaches a building, the resulting loading or response can be separated into a mean component caused by the mean wind speed and a fluctuating component caused by wind speed variations from the mean. The fluctuating wind is a mixture of gusts or eddies of different sizes, with larger eddies occurring less frequently than smaller ones. The larger gusts do not force the structure to respond dynamically because they occur less frequently than any of the structure's natural frequencies of vibration. The smaller eddies, on the other hand, occur more frequently and may induce significant dynamic load effects in the structure. This distinction between mean and fluctuating wind loading is the basis for the “gust-factor” approach used in almost every design code. The approach evaluates the mean load component using pressure and load coefficients, while the fluctuating loads are determined separately by taking into account the turbulence intensity, size reduction effects, and dynamic amplification (Davenport 1967). The gust factor approach can accurately predict the dynamic response of buildings in the along-wind direction as long as the wind flow is not significantly affected by nearby tall buildings or terrain.

1.2.2 Across-wind loading

The across wind forces are also termed as lift or transverse forces which arise, mainly due to wake excitation, *i.e.*, flow separation from the cross section of the structure causing vortices to shed at varying frequencies. Vortex shedding is the primary source of across wind excitation. Tall buildings have a different effect on wind flow compared to streamlined bodies because they create bluff surfaces that cause the flow to separate instead of following the contours of the building. When wind speeds are low, the vortices shed from the sides of the building symmetrically, resulting in no unbalanced force in the lateral direction. However, at higher wind speeds, the vortex shedding becomes unsteady, and vortices are shed alternately from both sides of the building. This alternating shedding of vortices causes an asymmetrical distribution of pressure on the lateral faces of the building and results in periodic transverse force (Kwok 1982). Consequently, this force causes flexible structures to oscillate in the transverse direction.

1.2.3 Torsional wind loading

The torsional loads are predominantly dynamic in nature. A tall building can be subjected to wind-induced torsional load in three ways:

(i) Due to its structural and architectural characteristics (*e.g.*, unsymmetric cross-section, non-symmetrical mass & stiffness distribution) assuming wind load on building is uniformly distributed across its faces.

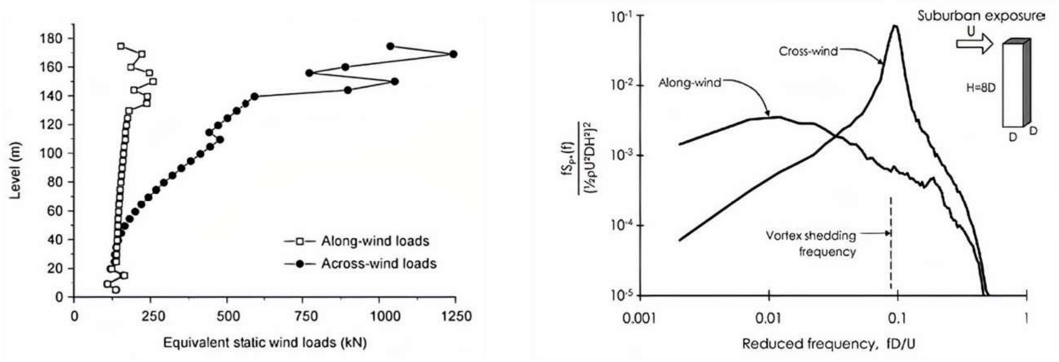
(ii) Due to the flow characteristics of the wind (*e.g.*, uneven pressure distribution across the face, flow approaching at oblique angle to the face) regardless of plan & shape of the building.

(iii) Due to dynamic responses resulting into torsion of building.

Torsional motions are particularly problematic since, unlike the other components of wind loads as they offer occupants with an additional motion due to an apparent rotating horizon. Residents of high-rise buildings are more likely to get disturbed due to torsional motion than that of translational motion (Tallin 1984). According to Kwok (2009), prolonged exposure to large-amplitude vibrations can cause dizziness, migraines, and nausea in the tall building occupants.

1.3 Importance of across wind load in tall buildings

Several studies have noted that the across-wind dynamic responses of super high-rise buildings (the term ‘super high-rise building’ refers to buildings that are 300 meters or higher in height) tend to be larger than those in the along-wind direction. For instance, Gu and Quan (2011) stated that across-wind loading is 1.2 times greater than along-wind loading for a tall building at its design wind speed (Figure 1.3.(a)). This finding was also supported by Zhou *et al.* (2003). Boggs and Dragovich (2006) mentioned specific situations where the across-wind load may be 40% higher than the along-wind load (Figure 1.3.(b)). Li *et al.* (2007) observed from measurements taken on the Jin Mao building (height 420.5 m) that the acceleration response was larger in the across-wind direction compared to the along-wind direction. Zhang and To (2016) concluded that across-wind loads exceed twice the along-wind loads for basic wind pressures greater than 0.8 kPa in tall buildings. Chen and Kareem (2005) noted that certain high-rise buildings exhibit more severe coupled responses than currently estimated due to variable wind pressure fluctuations in the along-wind, across-wind, and torsional directions.



(a) (b)

Figure 1.3. (a) Equivalent static wind load distribution of the building (Gu and Quan 2011). **(b)** Aerodynamic load spectra measured on wind- tunnel model (Boggs and Dragovich 2006).

1.4 Motivation of thesis

The introductory section of this chapter highlights the significance of wind load as a primary factor influencing the design of tall buildings. Specifically, the across wind load is identified as a crucial component that plays a critical role in this process. The magnitude of the across wind load is contingent upon various parameters, including the building's geometrical characteristics, structural properties, and the prevailing wind conditions. However, the precise impact of these parameters on across wind load is still an area of active research. Understanding how these parameters impact the across wind load is of paramount importance as it enables accurate estimation and facilitates the creation of more realistic building designs. Therefore, this thesis work focuses on investigating the effects of geometrical, structural, and wind parameters on across wind loading specifically in the context of super high-rise buildings. This thesis work aims to advance our understanding of the factors influencing across wind loading in super high-rise buildings by investigating the effects of geometrical, structural, and wind parameters. Such insights are invaluable for engineers and designers as they strive to improve their ability to predict and quantify the across wind load accurately. Moreover, by gaining a deeper understanding of the influence of these parameters, it becomes possible to develop more realistic and reliable designs for super high-rise buildings.

During our investigation into the effect of geometrical parameters, the study revealed that square-shaped buildings exhibit a heightened susceptibility to crosswind loads. This finding not only piqued our curiosity but also served as a catalyst for delving deeper into the subject. It inspired us to embark on a study focused on mitigating crosswind loads through corner modifications of a square plan buildings.

To the author's best knowledge, prior research has not explored the influence of torsional wind loading on framed-tube buildings. This knowledge gap serves as a compelling motivation for the author to delve into this uncharted territory in the thesis work.

1.5 Organization of thesis

The content of the present thesis work is organized according to the following chapters:

Chapter 1 presents the potential significance of tall buildings in the near future, focusing on their pivotal role in urban development and architectural advancement. Additionally, this chapter explores the intricate components of wind load, namely along wind load, across wind load, and torsional wind load, with particular emphasis on the significance of across wind load in tall buildings. Further, this chapter outlines the underlying motivation and organizational structure of this thesis.

Chapter 2 provides a comprehensive literature review that encompasses the current state-of-the-art research on the along, across, and torsional wind load. Additionally, it explores various strategies for mitigating the across wind load. The literature review further identifies gaps in the existing research, highlighting areas that require further investigation and exploration. Finally, the chapter concludes by clearly stating the specific objectives of the current study.

Chapter 3 of the thesis initially describes the procedure followed by the Indian standard to calculate along wind loads. Subsequently, it explores the Quan and Gu (2012) formulation, specifically designed for computing the across-wind Equivalent Static Wind Load (ESWL). Furthermore, the chapter delves into how geometrical parameters, such as plan and height aspect ratios, affect the across wind ESWL. By examining these aspects, we aim to understand better how the geometrical parameters affect the across-wind ESWL.

In **Chapter 4** of the thesis, we explore how various wind and structural parameters affect the across wind ESWL. The wind parameters that we take into account are the Exponent of mean velocity profile (α), turbulence intensity (I_H), peak factor for resonant response (g_R), and the background peak factor (g_B). Additionally, we also consider specific structural parameters, namely the Natural frequency of the structure (f) and the structural damping ratio (ζ_s). By analysing these factors, we aim to better understand their influence on the ESWL and its implications for the structural behaviour under across wind load.

Chapter 5 of the thesis extensively investigated the impact of corner modifications on both along and across wind loads. Four corner modification strategies were studied, including chamfering, rounding, recessing, and double-recessing. Each corner modification strategy involved creating four models with reductions of 5%, 10%, 15%, and 20% in the length of each side of the square. Using CFD analysis and comparisons with the original square model, results revealed that corner modification is an efficient strategy for reducing wind loads on square-plan tall buildings.

Chapter 6 investigates the impact of torsional wind loads on a 40-story tubular building. Six different load cases from American and Canadian codes were analysed. The results reveal significant changes in axial force distribution based on loading patterns, with notable differences between torsional and non-torsional load cases.

Chapter 7 of the thesis sums up the conclusions of the work. It also provides for the recommendations for future work.