ANALYSIS OF WIND & EARTHQUAKE LOAD FOR DIFFERENT SHAPES OF HIGH RISE BUILDING

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ABSTRACT

Modern tall buildings have efficient structural systems, and utilize high-strength materials, resulting in reduced building height, and thus, become more slender and flexible with low damping. These flexible buildings are very sensitive to wind excitation and earthquake load causing discomfort to the building occupants. Therefore, in order to mitigate such an excitation and to improve the performance of tall buildings against wind loads and earthquake loads, many researches and studies have been performed. Early integration of aerodynamic shaping, wind engineering considerations, and structural system selections play a major role in the architectural design of a tall building in order to mitigate the building response to the wind excitations. A tall building, whose shape is unsuitable, often requires a great deal of steel or a special damping mechanism to reduce its dynamic displacement within the limits of the criterion level for the design wind speed. Understandably, an appropriate choice of building shape and architectural modifications are also extremely important and effective design approaches to reduce wind and earthquake induced motion by altering the flow pattern around the building, hence for this research work four different shaped buildings are generally studied namely circular, rectangular, square and triangular. To achieve these purposes, firstly, a literature survey, which includes the definition, design parameters, and lateral load considerations of tall buildings, is presented. Then the results are interpreted for different shaped buildings and of different stories thereby concluding as to which shaped high rise building is most stable for different conditions.

Keywords: High-rise Building, Wind load Effect, Earthquake load effect.
INTRODUCTION

Tall buildings, which are usually designed for office or commercial use, are among the most distinguished space definitions in the architectural history of American urbanism in the twentieth century. They are primarily a reaction to the rapid growth of the urban population and the demand by business activities to be as close to each other as possible. Architects reinterpretations of the building type, the high cost of land in urban areas, the desire to prevent the disorganized expansion, the need to preserve agricultural production, the concept of skyscraper, influence of cultural significance and prestige, have all contributed to force buildings upward. Today, it is virtually impossible to imagine a major city without tall buildings. The importance of tall buildings in the contemporary urban development is without doubt ever increasing despite their several undeniable negative effects on the quality of urban life.

Many researches and studies have been done in order to mitigate excitations and improve the performance of tall buildings against wind loads & earthquake loads. An extremely important and effective design approach among these methods is aerodynamic modifications, including, modifications of building’s corner geometry and its cross-sectional shape. Tall buildings are gigantic projects demanding incredible logistics and management, and require enormous financial investment. A careful coordination of the structural elements and the shape of a building which minimize the lateral displacement, may offer considerable savings. Nowadays, the challenge of designing an efficient tall building has considerably changed. The conventional approach to tall building design in the past was to limit the forms of the buildings to a rectangular shape mostly, but today, much more complicated building geometries could be utilized.

OBJECTIVE & SCOPE

The main objective of this work is to contribute to the development of the design guidance for high rise buildings in relation to different shapes of building to control wind excitation and earthquake load as a reference for architects, engineers, developers, and students. In this research, the concept of high rise building, which include the definition, basic design considerations, and lateral loads; shape modifications of tall buildings, are studied. Then the results for different conditions are interpreted and conclusions are made as to which shaped buildings out of four taken in the consideration is most stable. Further work can also be done on more complicated shapes of buildings and come to conclusion as to which is most stable and economical shapes under given condition for wind and earthquake loads.

DEFINITION OF TALL BUILDING

The tall building can be described as a multistory building generally provided with high-speed elevators, constructed using a structural frame, and combining extraordinary height with ordinary room spaces such as could be found in low-buildings. In aggregate, it is a physical, economic, and technological expression of the city’s power base, representing its private and public investments.

WIND EFFECTS ON TALL BUILDINGS

The wind is the most powerful and unpredictable force affecting tall buildings. Tall building can be defined as a mast anchored in the ground, bending and swaying in the wind. This movement, known as wind drift, should be kept within acceptable limits. Moreover, for a well-designed tall building, the wind drift should not surpass the height of the building divided by 500. Wind loads on
buildings increase considerably with the increase in building heights. Furthermore, the speed of wind increases with height, and the wind pressures increase as the square of the wind speed. Thus, wind effects on a tall building are compounded as its height increases. Besides this, with innovations in architectural treatment, increase in the strengths of materials, and advances in methods of analysis, tall building have become more efficient and lighter, and so, more vulnerable to deflection, and even to swaying under wind loading. Despite all the engineering sophistication performed with computers, wind is still a complex phenomenon, mainly owing to two major problems. Unlike dead loads and live loads, wind loads change rapidly and even abruptly, creating effects much larger than when the same loads were applied gradually, and that they limit building accelerations below human perception. Although the true complexity of the wind and the acceptable human tolerance to it have just begun to be understood, there is still a need to understand more the nature of wind and its interaction with a tall building, with particular reference to allowable deflections and comfort of occupants.

**VARIATION OF WIND SPEED WITH HEIGHT**

An important characteristic of wind is the variation of its speed with height (Figure 1). The wind speed increase follows a curved line varying from zero at the ground surface to a maximum at some distance above the ground. The height at which the speed stops to increase is called the *gradient height*, and the corresponding speed, the *gradient wind speed*. This important characteristic of wind is a well understood phenomenon that higher design pressures are specified at higher elevations in most building codes. Additionally, at heights of approximately 366 m from the ground, surface friction has an almost negligible effect on the wind speed; as such the wind movement is only depend on the prevailing seasonal and local wind effects. The height through which the wind speed is affected by the topography is called *atmospheric boundary layer*. The wind speed profile within this layer is in the domain of turbulent flow and could be mathematically calculated.

![Figure 1. Variation of wind speed with height](image)

**VORTEX-SHEDDING PHENOMENON**

Along wind and across wind are two important terms, used to explain the vortex-shedding phenomenon. Along wind or simply wind is the term used to refer to drag forces. The across wind response is a motion, which happens on a plane perpendicular to the direction of wind. When a
building is subjected to a wind flow, the originally parallel wind stream lines are displaced on both transverse sides of the building (Fig 2), and the forces produced on these sides are called vortices.

![Fig 2. Simplified wind flow](image)

At quite a low wind speeds, the vortices are shed symmetrically on either transverse side of the building (Fig 2 a), and so building does not vibrate in the across wind direction.

![Fig 2. Vortices in different wind speed conditions: (a) vortices in low speed of wind (there is no vibration in the across wind direction); (b) vortices in high speed of wind – vortex-shedding phenomenon (there is vibration in the across wind direction)](image)

On the other hand, at higher wind speeds, the vortices are shed alternately first from one and then from the other side. When this occurs, there is an impulse both in the along wind and across wind directions. The across wind impulses are applied to the left and then alternatively to the right. Therefore such kind of shedding which causes structural vibrations in the flow and the across wind direction is called vortex-shedding, a phenomenon well known in fluid mechanics. This phenomenon of alternate shedding of vortices for a rectangular tall building is shown schematically in Figure 2b.

**EARTHQUAKE EFFECTS ON TALL BUILDINGS**

As earthquakes can happen almost anywhere, some measure of earthquake resistance in the form of reserve ductility and redundancy should be built into the design of all structures to prevent catastrophic failures. Moreover, during the life of a building in a seismically active zone, it is usually expected that the building will be subjected to many small earthquakes, including some moderate ones, one or more large ones, and possibly a very severe one. Building massing, shape and proportion, ground acceleration, and the dynamic response of the structure, influences the magnitude and distribution of earthquake forces. On the other hand, if irregular forms are inevitable, special design considerations are necessary to account for load transfer at abrupt changes in structural...
resistance. Therefore, two general approaches are utilized to determine the seismic loading, which take into consideration the properties of the structure, and the past record of earthquakes in the region. When compared to the wind loads, earthquake loads have stronger intensity and shorter duration.

**DESIGN CONSIDERATIONS**

Moreover, despite the advancements in earthquake engineering during the last three decades, many uncertainties still exist. The plan layout of a building plays a vital role in its resistance to lateral forces and the distribution of earthquake forces. Experience has shown that the buildings with an unsymmetrical plan have a greater vulnerability to earthquake damage than the symmetrical ones. Therefore, symmetry in both axes, not only for the building itself but also for the arrangement of wall openings, columns, and shear walls is very important. For irregular featured buildings, such as asymmetry in plan or vertical discontinuity, assumptions different from the buildings with regular features should be used in developing seismic criteria.

**TALL BUILDING BEHAVIOR DURING EARTHQUAKES**

Seismic motion response of tall buildings is to some extent generally different than low-rise buildings. The magnitude of inertia forces generated by an earthquake depends on the building mass, ground acceleration, the nature of foundation, and the dynamic characteristics of the structure (Figure 3). Although tall buildings are more flexible than low-rise buildings, and usually experience accelerations much less than low-rise ones, a tall building subjected to ground motions for a prolonged period may experience much larger forces if its natural period is near that of the ground waves.

**Figure 3.** Schematic representation of seismic force

**DAMPING AND SEISMIC SEPARATION**

The conventional approach to improving the safety and serviceability of structures is to increase the structure’s capacity by enlarging the member section and providing sufficient ductility for the structure. Utilization of damping devices is another method to mitigate the dynamic response of the building. Based on external energy requirement, damping devices used in earthquake engineering can be classified in two broad categories: active and passive devices. While in the passive devices, no external energy supply is required and the control mechanisms move along with the main structures, in the active devices, the dynamic responses of the structures are controlled with
the introduction of external energy into the structure. Besides this, the degree of damping depends on the construction materials, type of connections and the presence of non-structural elements.

SHAPE SELECTION

A tall building, whose shape is unsuitable, often requires a great deal of steel or a special damping mechanism to reduce its dynamic displacement within the limits of the criterion level for the design wind speed. Understandably, an appropriate choice of building shape and architectural modifications are also extremely important and effective design approaches to reduce wind induced motion by altering the flow pattern around the building, hence for this research work four shaped buildings are generally studied namely circular, rectangular, square and triangle as shown in (Figure 4 to Figure 7).

![Figure 4 Circular Shape](image1)

![Figure 5 Rectangular Shape](image2)

![Figure 6 Square Shape](image3)

![Figure 7 Triangular Shape](image4)
ANALYSIS PARAMETER

For analysis and comparison purpose the base area of all the four shaped building under consideration is kept same i.e. 1296 m$^2$ along with building parameters like properties of column and beam, the support condition, loading condition namely earthquake load, wind load, live and dead load and also the design parameters like grade of concrete & steel.

RESULTS

Following results were obtained by comparing the different shapes of buildings for 15, 30 and 45 storey under the parameters as mentioned above:
CONCLUSIONS

1. There is not a definite description for “tall building”, “high-rise building” and “skyscraper” in terms of height, or number of stories. Although the terms all mean the same type of building which is built extremely high, there is an implicit difference among them.

2. Many factors, such as aesthetics, functionality, and the requirements of city planning authorities, dictate the shape of a tall building.

3. Because of the enormous variety of the possible shapes in building design and their different interactions with the surrounding structures, it is difficult to develop simple general rules for the preference of shapes as a tool for reducing wind related problems. In this respect, the wind tunnel testing is usually the best way for determining project specific wind loads and building motions.

4. For 15 storied building the most stable structure is circular shape and triangular shape for maximum earthquake and maximum wind load respectively, similarly for 30 storied building, rectangular shape is most stable for maximum earthquake and wind load and for 45 storied building circular shape & rectangular shape is most stable for maximum earthquake and wind load respectively.

5. With respect to node displacement triangular shaped building is least stable for 15 & 30 storied building whereas for 45 stories building rectangular shape is least stable.

6. In terms of maximum Mz triangular Shape for 15 storey, rectangular shape for 30 storey and circular shape for 45 storey buildings are most stable respectively.

7. In terms of maximum Fy Rectangular shape for 15 storey, circular shape for 30 storey and rectangular shape for 45 storey buildings are most stable respectively.

REFERENCES


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