MODIFICATION OF SKYSCRAPER BUILDING AGAINST WIND EXCITATION

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ABSTRACT

The evolution of high-strength concrete, higher-grade steel, modern design methods, and advanced computational techniques has resulted in the development of a new generation of tall structures that are lightweight, damping-free, slim, and convenient. Dynamic wind loads are a concern for these tall structures. Super-tall buildings are vulnerable to wind excitations, especially vortex-induced oscillations, due to their slenderness, low natural frequencies, low inherent damping levels, and high wind speeds at upper levels. Not only the wind loads, but also the wind-induced building motions are included in the design to ensure the building's serviceability. The action of wind response is well known to be primarily dictated by building shapes. Buildings may benefit from aerodynamic modifications to improve their performance. The main goal of this research is to see how corner modification, setback, and stepping affect tall buildings. Aerodynamic modifications are divided into two categories based on their effect on the building's outer architecture: minor modifications (corner cut, rounding, chamfer, etc.) and major modifications (corner cut, rounding, chamfer, etc.). (Taper, set-back, twist etc.). The current research discusses high-rise building aerodynamic modification techniques that have been used recently and in the past.

Key Words: *Tall building, wind excitation, aerodynamic modification, wind safe design, Corner modification, setback, stepping, taper.*

1. INTRODUCTION

Growing demand for office and residential space, economic development, and structural system innovation have led to the possibility of vertical building expansion, occupying less valuable land, and in the coming decades, most cities in developed and developing countries will have a more unified skyline. The figure 01 depicts some of the world's top ten tallest buildings. Tall building forms used to be conventional and symmetrical, with square, rectangular, triangular, circular, and other cross-sections (e.g. 432 Park Avenue (New York), World Trade Centre (New York)), and these shapes were less associated with torsional-vibrations caused by seismic loads due to eccentricity. The advancement of modern engineering and construction methods, high-grade materials, steel, welded ties, and light facades, as well as the revolutionary social and economic growth, encourage architects and engineers to create unusual light, tall buildings to show their spirit, inventiveness, and design concept. On the other hand, these height gains are often followed by increased stability, slenderness, a lack of adequate damping, and a low natural frequency.

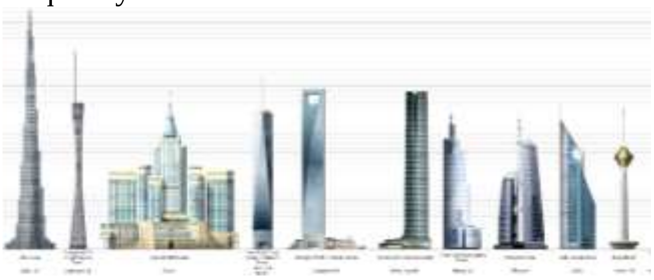

Figure 01- world top skyscrapers

As the height of the wind-load increases, the risk of wind-induced dynamic response increases, and these are more likely to be in the range of wind gusts. Furthermore, vortex shedding plays an important role, as its frequency may approach that of the system's natural frequency, causing vibrations throughout the structure that can be problematic as serviceability and survivability problems are intertwined. Excessive wind loads are more likely to damage structures. In comparison to triangular, elliptical, and cylindrical forms, rectangular cross section structures are more susceptible to lateral response; these shapes provide greater structural performance. While wind load is determined by the building's outer geometry, the wind load for tall buildings cannot be standardised due to the wide range of shapes and environments for each building, which can be special in each case. As a result, it is recommended that building design changes be scrutinised during the early stages of the design process in order to reduce wind loads and resolve serviceability issues.

The main objective are:

- To evaluate the effect of Minor and major modification on a building design to resist the wind load.
- Evaluation and comparison of results within the studies, to know the effective shape for a tall building.

2. NEED AND IMPORTANCE

A tall building's wind-induced motion can be regulated by lowering the wind loads or lowering the response. By altering the flow pattern around the structure, a proper choice of building form and architectural modifications will result in a reduction of motion. As a result, aerodynamic modifications, such as improvements to the building's cross-sectional form, corner geometry, sculptured building tops, and openings through the building, are an extremely significant and efficient design method for minimising wind-induced motion.

Despite all of the computer-assisted engineering sophistication, wind remains a dynamic phenomenon, owing to two major issues. Wind loads, unlike dead and live loads, shift quickly and sometimes suddenly, producing much greater effects than when the same loads are applied gradually, and they restrict building accelerations below human experience. Despite the fact that the true complexity of the wind and the appropriate human tolerance for it has only recently begun to be understood, there is still a need to learn more about the nature of wind and its interaction with a tall building, especially in terms of allowable defections and occupant comfort.

3. CAUSE

Wind load on curtain walls increases with building height, and sensitivity can become more pronounced with increasing speed. The building's excitation can be suppressed by either removing the cause of unsteadiness or controlling the reaction by some external means.

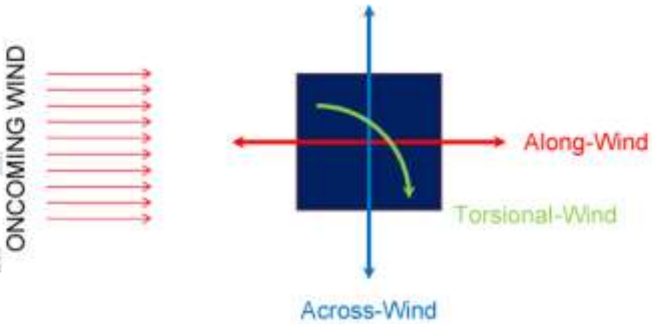

Figure 02- different types of wind effect

i. ALONG WIND RESPONSE

Along-wind excitation is caused mainly by pressure variations on the building's windward and leeward sides, and it is generally accompanied by oncoming wind fluctuations. The 'Gust factor method' is used in the majority of international codes to calculate wind response.

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.

ii. ACROSS WIND RESPONSE

Vortex shedding is the most common cause of across-wind excitation. Tall buildings, in contrast to streamlined bodies, are uncertain against the flow and cause the flow to separate rather than meet body contours. At low wind speeds, vortices shed in a symmetrical fashion from the building's sides, and there is no unbalanced force in the lateral direction; however, at higher wind speeds, vortex shedding becomes unsteady, and vortices shed alternately from both sides of the building.

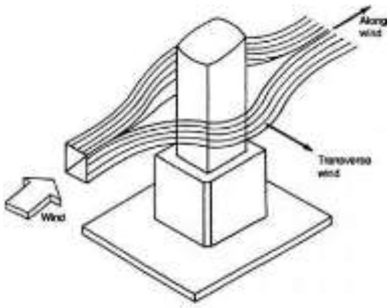

Figure 03- across wind and along wind flow

The vortices have a dominant shedding frequency that is represented by a non-dimensional number called the Strouhal Number (St), which is highly dependent on the structure's shape:

St= fB/U

'f' is the frequency of vortex shedding

'U' is the wind speed

'B' is the width of the building across the wind flow direction.

iii. TORSIONAL RESPONSE

The imbalance in pressure fluctuations on the surfaces, and thus the force imbalance on the building, causes torsion. If the centre of mass does not align with the centre of reaction forces, the building's torsional dynamic response becomes important like the Center of rigidity/center of stiffness. This condition can occur as a result of the structure's geometric form, geometrical eccentricity, or an uneven load pattern caused by dynamic wind.

4. METHODS AND APROACHES FOR MITIGATION

The aerodynamic characteristics of the wind (design wind speed, turbulence) and the mechanical properties of the building have a significant impact on the building's response (Mass, stiffness, and damping) some of the methods for reducing wind loads and responses include:

i. INCREASING STIFFNESS

The stiffness of a structure is a significant factor in its stability and reaction. The structure is more susceptible to vortex caused across wind vibrations when the wind speed is high and the stiffness is low. The building's stiffness will be improved (which raises the building's natural frequency) and has been shown to be one of the most effective methods for reducing structure motion without impacting the structure's exterior. However, increasing stiffness may be ineffective and may result in an increase in construction costs, as well as a reduction in the interior deployable area (as the size of the columns has to be increased).

ii. INCREASING BUILDIND MASS

The mass and stiffness of the structure have a direct impact on the frequency of the structure's sway motion. The effect of increased building mass on response can be understood using the Scruton number:

$Sc = (2m\delta/\rho B^2)$

Where m is the generalised mass per unit length, is the logarithmic decline in damping, is air density, and B is the width of the building. The amplitude of vibrations is inversely proportional to this number. As a result, it is clear that as mass increases, the amplitude of vibration decreases. However, after a certain point, rising mass is not a good practise and is not preferred due to the increase in seismic forces and expense. Structural steps cannot always be sufficient to minimise building motions, so additional options such as dampers are used to reduce motions.

iii. ADDITION OF DAMPING DEVICE

Damping refers to a structure's ability to dissipate steam. A higher damping ratio ensures greater efficiency, and any structure's dissipation capacity must be greater than the rate at which the wind imparts energy to it.

$Sc = (2m\delta/\rho B^2)$

From above equation on increasing δ value, It may make additional damping to dampen down the amplitude of motion by increasing the value with some kind of supplementary mechanism. Auxiliary damping devices, such as TMD (tuned mass damper), TLD (tuned liquid damper), and TLCD (tuned liquid column damper), are effective mechanisms for controlling the building's across wind motion. There are many types of damping devices, such as active, passive, hybrid, and semi-active control, and numerous studies on response reduction by auxiliary devices are available. However, in addition to minimising response time, these systems necessitate routine inspection and repair, making this activity less desirable. The damping device is effective for region where there is also the risk of earthquake along with wind pressure.

iv. AERODYNAMIC MODIFICATIONS

Despite the fact that auxiliary damping devices can minimise the effects of vortex shedding-induced oscillatory motions, approaches other than shape alteration do not alter the cause or source of vortex shedding. The cause of shedding is the form of the building itself, as well as changes in the exterior design of the building such that the movement of wind through the building is smooth, as in the case of the building. It is preferable to have a streamlined body, and the physical process of vortex formation can be customised. The aerodynamic shapes block the creation of alternate vortices on the building's windward sides and stifle the formation of coherent vortices. Aerodynamic modifications can be classified into two categories based on their effect on the exterior architecture of the main structure: major modifications and minor modifications.

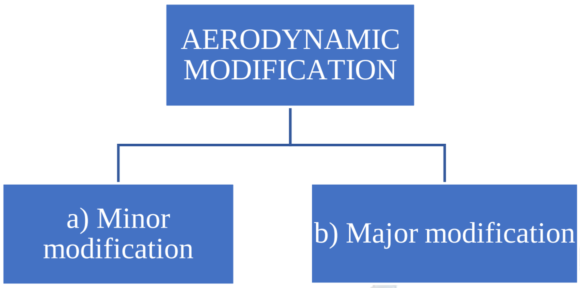

Table 01- types of aerodynamic modification.

a) Minor modification

Buildings with square and rectangular bluff shapes are very common, and they are more vulnerable to vortex shedding induced vibrations and galloping oscillations during strong winds. One of the governing features for aerodynamic characteristics is shear layer separation. Corner modifications facilitate shear layer reattachment and narrow the wake area behind the leeward face, resulting in a reduction in both along and through wind fluctuating forces.

Chamfering, rounding, recession, and slotted corners, for example, are effective techniques for reducing wake-excited motions by up to 30%, and Tamura et al. say that a substantial amount of along-wind load can be reduced by up to 60%. The strongest mitigation results can be seen when the adjustment duration is about 10% of the building's width. Figure depicts the flow field structure in vertical and horizontal planes around selected corner modification models.

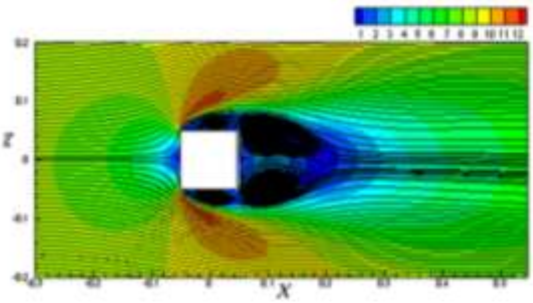

Figure 04- wind flow around plain or square structure

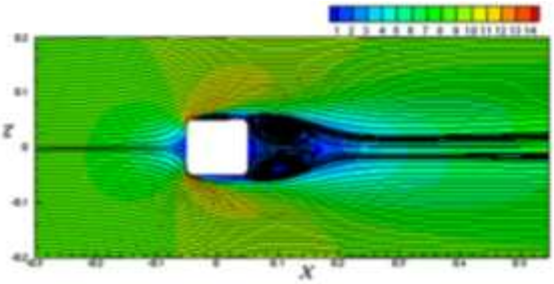

Figure 05- wind flow around corner rounded structure

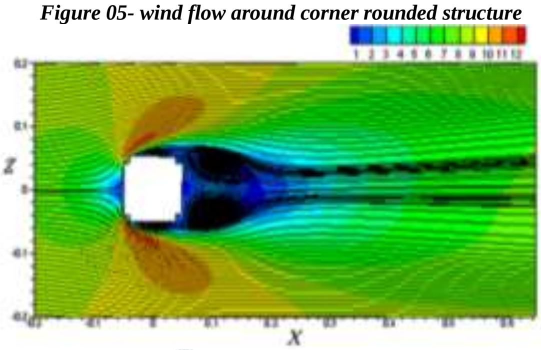

Figure 06- wind flow around corner chamfering structure

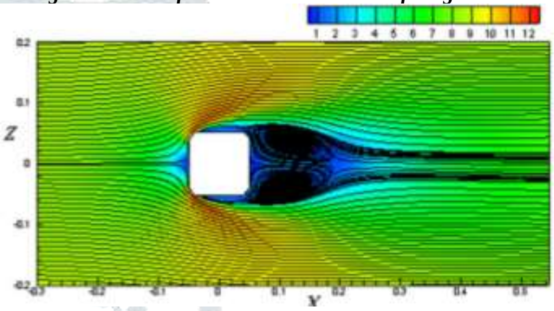

Figure 07- wind flow around corner cut structure

The form and degree of modifications influence the flow structure. As shown in Fig. corner modifications change the flow structure three-dimensionally and affect the width/length of the wave shaped on the body's leeward side In contrast to the square model, the isolation of the shear layer from the building's sides is increased.

For corner adjusted models, the wake width is narrowed, causing an increase in negative pressure on the leeward side of the building model and, as a result, a reduction in wind induced drag. The mean across-wind load is found to be substantially reduced due to the shape's symmetry.

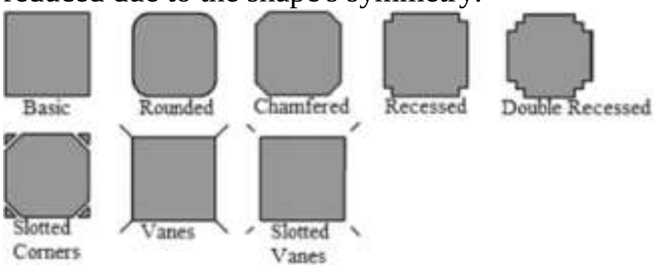

Figure 08- types of minor modification

b) Major modification

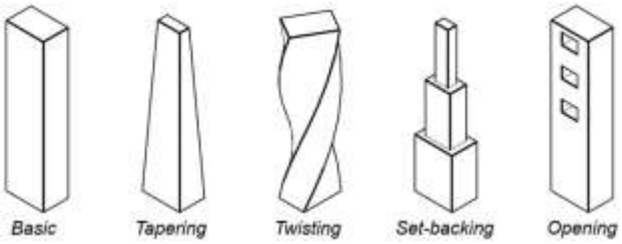

Figure 09- types of major modification

- SETBACKS AND TAPERING

The frequency of vortex shedding is proportional to the building width. As a result of the tapering and setback that spread the vortex-shedding over a wide frequency spectrum, vortices shed at different frequencies across the height. The distribution and variation of shedding frequency with elevation suppresses the coherency and excitation induced by vortex shedding, as well as the resulting fluctuating forces and responses. The flow pattern around a tapered building in vertical and horizontal planes (at 2/3rd height) is depicted in Fig.

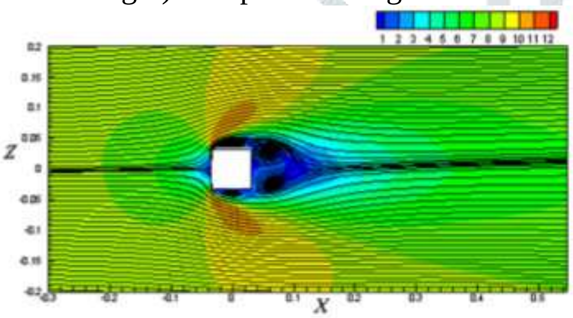

Figure 010- wind flow around taper structure

Because of their geometrical features, tapered and set-back versions minimise drag. Due to the rising dimension in the downward direction, the down-wash phenomenon slows down with lower velocity, while the upward flow accelerates with higher velocity due to the narrower distance, resulting in a lower pressure coefficient at the bottom and a higher pressure coefficient at the top level.

- HELIX AND TWISTING

A "twisting" building is one that rotates its floor plates or facade as it rises in height, according to the CTBUH (Council on Tall Buildings and Urban Habitat). A twisted form of architecture is the latest design trend that has been used in recent years for buildings and has piqued the interest of some architects. The first such twisted structure was Turning Torso in Sweden, which was completed in 2005 with a 90° clockwise twist. Following the completion of this structure, several other similar structures were proposed and built. Twisting type suppresses the dynamic response of tall buildings by breaking the coherency of vortex shedding, preventing simultaneous shedding across the height. It is also efficient for prevailing wind directions because it dodges the orientation of the building so that its least favourable aspect does not align with the strongest wind direction. This structure is effective not only in terms of wind load, but also in terms of improved indoor comfort.

- OPENINGS

The opening allows air to flow into the system, weakening and disrupting the vortex formation. It also affects the formation of the wake area by decreasing the negative peak pressure on the leewar side.

At mid-height, a flow pattern around the building with varying cross sections. The structure decreases the association between the forces acting on the building's side faces. The design should be provided along wind and cross wind gaps at three levels along the height, finding that providing an across wind gap alone is not as efficient as providing an along wind gap, and that providing both along wind and cross wind gaps at the same time suppresses responses more effectively.

5. DISCUSSION

Tall buildings are major projects that necessitate exceptional logistics and management. They have an impact on the construction industry and the national economy, and they necessitate a significant financial investment. A careful alignment of structural elements and the shape of a tall building that minimises lateral displacement could result in significant cost savings. In the case of very tall and slender buildings, the issue of excessive building motions and their effect on occupant comfort can be more difficult to solve. In certain cases, structural steps alone are insufficient to find a realistic solution to motion problems, and other methods, such as special damping devices, must be used. As a result, by altering the flow pattern around the structure, an acceptable choice of building form will result in a substantial reduction of aerodynamic forces. When compared to the original building shape, this form of treatment will help to moderate wind responses. Aerodynamic modifications such as setback, tapering, sculptured building tops, corner modifications, and installation of openings completely across the building are very efficient architectural methods of regulating wind excitation from the viewpoint of a wind engineer. Aerodynamic modifications may substantially reduce wind excitation in tall buildings, but they cannot fully eradicate it, so additional measures such as a "tuned mass damper" may be needed.

6. CONCLUSION

The optimization of building forms for aerodynamics is a significant part of supertall building design. The paper discusses many types of optimization: aerodynamic improvements, which are typically used as corrective steps, and aerodynamic designs, which combine architectural design with aerodynamic analysis early in the design process. Aerodynamic designs have more choices in building forms, including overall elevation optimizations such as tapering, turning, stepping, opening, top sculpturing, and so on, while aerodynamic modifications often include building corner treatments. This paper shows a few examples of aerodynamic optimization systems that have been successfully applied in building designs. The most difficult aspects of building aerodynamic optimization are balancing aerodynamic solutions with other architectural design elements and balancing advantages and costs. As a result, it's important to provide a fair evaluation of the efficacy of different aerodynamic solutions early in the design process, so that the possible benefits and disadvantages can be weighed in the decision-making process. This is something that the approach suggested in this paper will help with.

Minimum wind tunnel experiments can be used to measure the aerodynamic efficacy of tapering, stepping, and twisting at a low cost. The study and findings show a variety of major phenomena:

- Tapering and stepping, in general, will minimise across-wind responses. However, for a short-return period response, such as a building's output in common winds, where the associated reduced velocity is poor, tapering or stepping can actually increase accelerations, affecting occupant comfort.
- Although twisting can reduce maximum across-wind responses, it can also result in a more balanced response across wind directions. As a result, a possible mutual effect between the two traditional optimization methods, twisting and building orientation, should be considered.
- For a square house, corner roundness is the most efficient way to reduce aero-elastic instability. As the radius of the corner roundness increases, the amplitude of the wind-induced vibration decreases.
- Although the aerodynamic effectiveness of twisting increases as the twisting amount increases, the increment of effectiveness appears to diminish after a certain stage.
- In the crosswind direction, the tapering effect is more apparent than in the upwind direction. The through building opening along the alongwind and crosswind directions, particularly at the top, significantly reduces the building's wind excitation.

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9. LIST OF FIGURE