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AERODYNAMIC MODIFICATION AND SHAPE OPTIMIZATION ON HIGH-RISE BUILDING TO WIND-INDUCED LOAD (REVIEW)

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Abstract*— In construction and engineering techniques, a realistic shift in architectural designs of high-rise buildings can be perceived. This kind of buildings are most frequently taller and distinctive shaped rather than normal. Predominantly, shape and orientation of the building are determined on the premises of architectural and empirical deliberations, but the wind-induced excitations are stimulated by irregularity of the building shapes can not be neglected also. To protect the functional necessity of high-rise flexible buildings and to mitigate the excitations, miscellaneous methods are accessible. Between these methods, aerodynamic modifications techniques are very influence which affect the structure of tall-buildings significantly and have obtained a lot of awareness in recent years. For investigations of the effects of building modification on reduction of wind load on high-rise buildings. A benchmark models can be tested by pressure measurements. Based on the preliminary results, mean wind pressure co-efficient, base moment co-efficient and local wind force co-efficient of the modified models are discussed to provide comprehensive evaluations of the effects through aerodynamic modification. This paper aims a review on various aerodynamic modification techniques applied to high-rise buildings.

Keywords*— Wind load, Effects on high-rise building, Aerodynamic modification, Shape optimization, Response of building

I. INTRODUCTION

Increasing demand for commercial 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 scenario, maximum cities of developed and developing countries would be seen with the more cohesive skyline [1]. In recent era, many tall buildings and structures have been or are being constructed, and more are being planned in the world. These tall buildings such as more flexible structures undergo a dynamic response to the gustiness of wind. As it is well-known, as buildings become higher, wind loads become more important than earthquake loads in safety design as well as in serviceability design including occupants' vibration perception.

Some researches and studies have been done in order to mitigate excitations and improve the performance of tall buildings against wind loads. But, to suppress wind-induced responses by changing building shapes: so, called aerodynamic modification. These methods effectively use innovative architectural features to modify the aerodynamic shape of the buildings in order to reduce the wind loads. In aerodynamic shape optimization, the optimization of a performance criterion depends on the shape of a boundary. The creativity and insight of an experienced designer is required to reduce the design problem to a well-posed optimization problem. This involves the definition of objective functions that specify the goals of the optimization, design variables that determine the aerodynamic shape, as well as constraints that define a feasible region of the design space. As wind forces largely depend on building shape regardless of structural system, aerodynamic modifications include taper, set-back, helical twist, openings and combinations of them [10]. The analysis of a high-Rise building involves the development of the physical description of an artifact subject to a set of given constraints and specifications. There are three steps in the design of a high-Rise building; 1) conceptual, 2) preliminary, and 3) detailed design. These 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.

II. LITERATURE REVIEW

Following few researches of previous works which are based on, *A. Wind load and Response*

A. Sharma, H. Mittal [1] had defined that a structure against wind flow experiences loads in along-wind, across-wind and torsional direction, correspondingly there are excitation in three directions.

i. Along-wind excitation is primarily caused by the pressure fluctuations on windward and leeward faces of the building 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'.
ii. The most common source of across wind excitation is the vortex shedding. Previously a number of researchers have identified that across wind dynamic response may exceed the along wind response and motion in the transverse direction can be a severe issue not only for the structural fatigue but also for serviceability design.
iii. Torsional response emerges due to the imbalance in pressure fluctuation on the surfaces and so the force imbalance on the building. The torsional dynamic response of a building becomes significant if the centre of mass does not coincide with the centre of reaction forces/ centre of stiffness/ centre of rigidity.

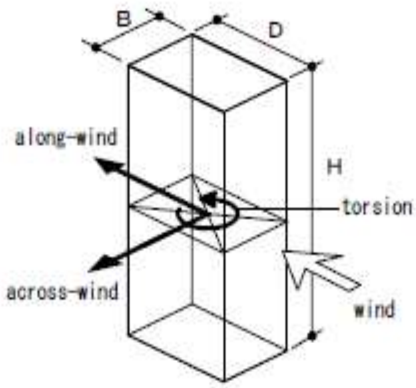

Fig. (1) Force Directions [4]

B. Effect of building shape on wind load

In this research, **A. Rajmani, Priyabrata Gupta** [2] have given the concept of high rise building, which include the definition, basic design considerations, and lateral loads; shape modifications of tall buildings, are studied. 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.

Md. Mahmud Sazzad, Md. Samdani Azad [9] had aim of the present study is to compare the effect of building shape on the displacement characteristics of building. The aim includes showing the effect of eccentricity, irregularity and diaphragm discontinuity; making a comparison due to both wind and seismic force and showing the variation of point displacement and story drift. Three different shaped buildings: Rectangular with hollow space, modified cross shaped & L-shaped have been considered. They have analysed the high-rise building for wind force by Surface-area method and Projected area method.

C. Aerodynamic treatment by shape optimization

H. Tanaka, Y. Tamura, K. Ohtake [4] have observed tall building models for the experiment which had the area of 10^6 m^3 and for 80 storeys. The aspect ratio H/B was 8 and the geometric scale of wind tunnel test was 1/1000. In this paper, they have analysed for various kinds of models e.g. square, circular, elliptic, corner, chamfered, etc. A series of wind tunnel experiments were conducted to investigate the aerodynamic characteristics and to evaluate the most effective structural shape in wind-resistant design for tall buildings with various aerodynamic modifications.

M. Ashgani Moonegi, R. Kargarmoakhar [6] have studied that for typical tall buildings, aerodynamic forces are drag force (along wind), lift force (across wind) and torsional moment. The wind-induced response of tall buildings is usually dominated by dynamic across wind loading resulting from wind vortex shedding. When wind blows over a bluff structure, flow separates and causes periodic shedding of vortices. Optimization is to find the best solution to a certain designated problem. For optimization of an objective, different categories of optimization techniques namely "Gradient based" methods and "Non- gradient based" methods can be used. In this Computational Fluid Dynamics (CFD) for wind tunnel test on the building.

In this paper, **Yi Li, X. Tian** [11] have discussed different kinds of co-efficient of three corner models. Based on extensive wind tunnel test on four models at subcritical Reynold's number, corner cut was applied by 10%. They have provided useful information about the wind resistant design of the high-rise building. Wind tunnel test was carried out in a boundary layer wind tunnel at Hunan University of Science and Technology, China. The cross-section of the wind tunnel is 4.0 m wide by 3.0 m high.

D. Mitigation of wind load

H. Mittal, A. Gairola [1] have analysed that the aerodynamic treatment can reduce the wind-induced excitations, it can not be eliminated completely. Thus, based on the impact of modifications on the outer architecture of the building, the aerodynamic modifications are categorised in two groups i.e. minor modifications (corner cut, rounding, chamfer, etc.) and major modifications (taper, setback, twist, etc.) The response of building majorly influenced by the aerodynamic characteristics of wind (Design wind speed, turbulence) and the mechanical properties of the building (Mass, stiffness, and damping). Considering the safety of the structure, human perception to vibration and serviceability measures, numerous techniques have been presented so far to alleviate the discomforting motion induced.

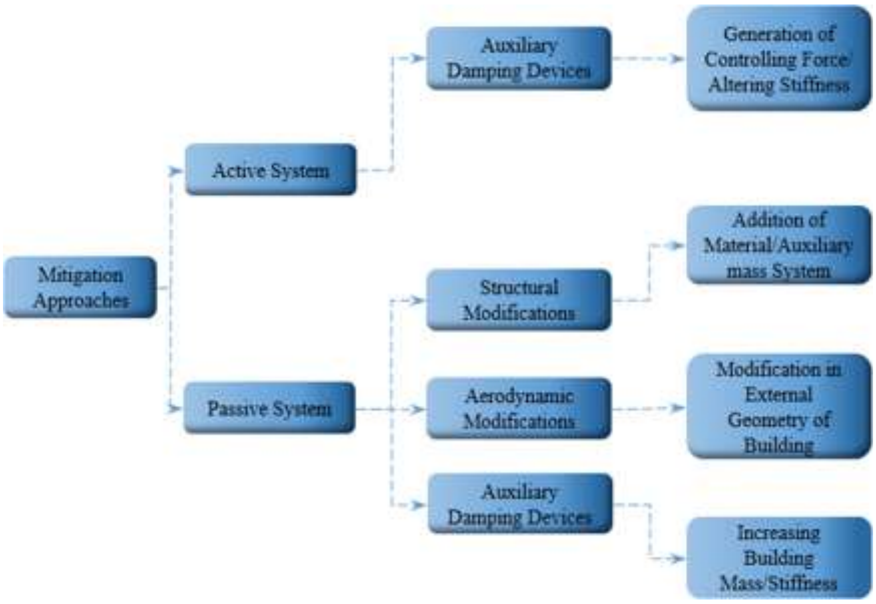

Fig. (2) Mitigation approaches [1]

Y. C. Kim, Y. Tamura [10] had the purpose of to directly compare the peak normal stress in columns of Super-tall buildings. A wind tunnel tests were conducted for 10^6 m^3 area of 13 super-tall building models with a typical building shapes under an urban area flow. The taper ratio was 10% and top to bottom area ratio was 1/6. Time history analyses were conducted using a frame model by inputting local wind force sat the centre of each floor. The results show that the peak normal stresses on a square model are the largest among all the models tested, the setback model shows the smallest peak normal stresses of the single modification models tested, and CC+TP+360Hel shows the smallest peak normal stresses of the multiple modification models tested.

III. SUMMARY

1. As per literature survey, the aerodynamic modifications are efficient in improving building aerodynamics, the efficiency may come at the cost of usable floor area of the building. The economical perspective of the modifications is still a grey area and needs attention of the researchers.
2. The main objective of the work was to contribute to the development of the design guidance for high rise buildings in relation to different shapes of building to control wind excitation.
3. Fluctuating aerodynamic forces on tall building models with the same volume were firstly measured, and wind pressure measurements were conducted on building models, showing excellent aerodynamic characteristics. They presented comprehensive and detailed discussions on the aerodynamic characteristics of the shapes tested.
4. They have summarised that the stability of shaped high-rise building for different conditions and in this, they have clarified that the wind tunnel test is the best way for determining project specific wind loads and building motions.
5. The aerodynamic modifications of a building's cross-sectional shape, variation of the cross-section shape and/or its size along the height of building, twisting the building, porosity and openings, etc. can significantly reduce building

response in along wind (drag force) as well as across wind (across wind force due to vortex shedding) directions by altering the wind flow characteristics around the building.

6. Some authors have introduced wind-resistant studies of our research team on tall buildings and structures, including some issues of basic researches and applied researches. While dealing with high-rise buildings over 1km in height, wind engineering researchers will be faced with more new challenges, even problems currently not aware of.
7. A numerical investigation is carried out to evaluate the effect of shape of building on the drift and displacement due to wind and earthquake loads.
8. Comparison of the buildings is done with different modifications based on the subcritical Reynold's number for reducing wind load.

IV. CONCLUSIONS

In this present research, it has been concluded that bluff shaped structures are more vulnerable to forceful wind-induced excitations and can be controlled either by structural or aerodynamic modifications. Minor modifications promote the shear layer reattachment and can result into a reduction of 30–60% in wind-induced loads. The impact of aerodynamic modifications cannot be disregarded but these modifications may sometimes give adverse results too depending on the local environment conditions. So, these methods should be established considering all the associated constraints i.e. wind flow characteristics, surrounding environment of the concerned building, geometrical and economic constraints, functional requirements etc. For these building models, it is observed that the correlations between maximum mean coefficients and maximum fluctuating coefficients are high for both along-wind and across-wind directions.

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