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OPTIMIZING STRUCTURAL DESIGN PARAMETERS FOR TALL BUILDING IN HIGH WIND ZONE

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ABSTRACT

The crucial challenge of optimising structural design parameters for tall structures located in high wind zones is addressed in this work. Regions with high wind speeds provide particular difficulties for tall structures, requiring careful attention to structural details to guarantee efficiency and safety. This study intends to give insights into the optimisation of important factors including form, height, and materials by a thorough examination of the current literature, wind engineering concepts, and structural design approaches. The influence of various design configurations on the structural integrity and performance of tall buildings in high wind settings is studied in this research using sophisticated computer simulations and modelling tools. The study aims to determine the most efficient set of design characteristics that may improve the durability and sustainability of tall buildings while reducing construction costs. These elements include aerodynamics, load distribution, and material qualities. The study investigates how to combine cutting-edge technology, such as adaptable facades and tuned mass dampers, to lessen the impact of wind-induced vibrations and enhance occupant comfort in general. In order to help construct more durable and financially feasible structures in the face of ever-changing environmental conditions, the study's conclusions are intended to be of great use to structural engineers, architects, and urban planners engaged in the design and construction of tall buildings in high wind zones.

Keywords: Structural design, Tall buildings, High wind zone, Wind engineering, Optimization, Structural parameters, Computational simulations, Aerodynamics, Load distribution.

I. INTRODUCTION

The last two decades have seen a remarkable increase in construction of tall buildings in excess of 150m in height, and an almost exponential rate of growth. A significant number of these buildings have been constructed in the Middle East and Asia, and many more are either planned or already under construction. "Super-tall" buildings in excess of 300m in height are presenting new challenges to engineers, particularly in relation to structural and geotechnical design. Many of the traditional design methods cannot be applied with any confidence since they require extrapolation well beyond the realms of prior experience, and accordingly, structural and geotechnical designers are being forced to utilize more sophisticated methods of analysis and design. In particular, geotechnical engineers involved in the design of foundations for super-tall buildings are increasingly leaving behind empirical methods and are employing state-of-the art methods. There are a number of characteristics of tall buildings that can have a significant influence on foundation design, including the following:

1. The building weight increases non-linearly with increasing height, and thus the vertical load to be supported by the foundation, can be substantial.

2. High-rise buildings are often surrounded by low-rise podium structures which are subjected to much smaller loadings. Thus, differential settlements between the high and low-rise portions need to be controlled.
3. The lateral forces imposed by wind loading, and the consequent moments on the foundation system, can be very high. These moments can impose increased vertical loads on the foundation, especially on the outer piles within the foundation system.
4. The wind-induced lateral loads and moments are cyclic in nature. Thus, consideration needs to be given to the influence of cyclic vertical and lateral loading on the foundation system, as cyclic loading has the potential to degrade foundation capacity and cause increased settlements.
5. Seismic action will induce additional lateral forces in the structure and also induce lateral motions in the ground supporting the structure. Thus, additional lateral forces and moments can be induced in the foundation system via two mechanisms: a. Inertial forces and moments developed by the lateral excitation of the structure; b. Kinematic forces and moments induced
1. in the foundation piles by the action of ground movements acting against the piles.
6. The wind-induced and seismically-induced loads are dynamic in nature, and as such, their potential to give rise to resonance within the structure needs to be assessed. The fundamental period of vibration of a very tall structure can be very high, and since conventional dynamic loading sources such as wind and earthquakes have a much lower predominant period, they will generally not excite the structure via the fundamental mode of vibration. However, some of the higher modes of vibration will have significantly lower natural periods and may well be excited by wind or seismic action.

1.2 Tall Buildings

The last two decades have seen a remarkable increase in construction of tall buildings in excess of 150m in height, and an almost exponential rate of growth. A significant number of these buildings have been constructed in the Middle East and Asia, and many more are either planned or already under construction. “Super-tall” buildings in excess of 300m in height are presenting new challenges to engineers, particularly in relation to structural and geotechnical design. Wind analysis is important in case of tall buildings. Figure 1 shows the significant growth in the number of such buildings either constructed. Many of the traditional design methods cannot be applied with any confidence since they require extrapolation well beyond the realms of prior experience, and accordingly, structural and geotechnical designers are being forced to utilize more sophisticated methods of analysis and design. In particular, geotechnical engineers involved in the design of foundations for super-tall buildings are increasingly leaving behind empirical methods and are employing state-of-the art methods.

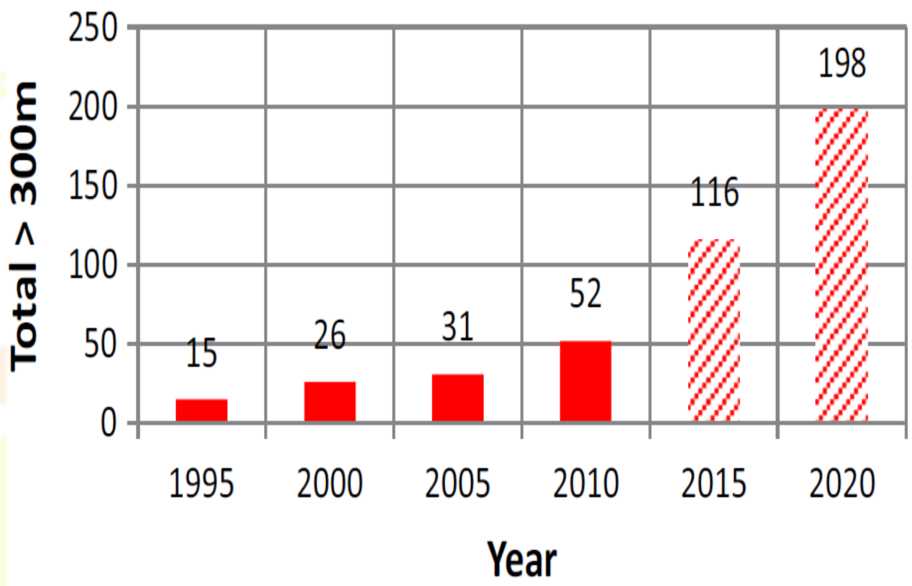

Figure No.1 Total Number of Buildings in Excess of 300 M Tall

The investigations have been carried out by many researchers on the structural behavior of tall buildings with SSI (Soil Structure Interaction) by considering many parameters like foundation type, soil conditions, lateral forces, ratio of flexural stiffness of beam and column etc. Very few investigations have been carried out on soil-structure interaction of tall buildings under clayey soil conditions, particularly in Indian seismic zones. There are a number of characteristics of tall buildings that can have a significant influence on foundation design, including the following: -

- The building weight increases non-linearly with increasing height, and thus the vertical load to be supported by the foundation, can be substantial.
- High-rise buildings are often surrounded by low-rise podium structures which are subjected to much smaller loadings. Thus, differential settlements between the high and low-rise portions need to be controlled.
- The lateral forces imposed by wind loading, and the consequent moments on the foundation system, can be very high. These moments can impose increased vertical loads on the foundation, especially on the outer piles within the foundation system.
- The wind-induced lateral loads and moments are cyclic in nature. Thus, consideration needs to be given to the influence of cyclic vertical and lateral loading on the foundation system, as cyclic loading has the potential to degrade foundation capacity and cause increased settlements.
- Seismic action will induce additional lateral forces in the structure and also induce lateral motions in the ground supporting the structure. Thus, additional lateral forces and moments can be induced in the foundation system via two mechanisms:

a. Inertial forces and moments developed by the lateral excitation of the structure;
b. Kinematic forces and moments induced in the foundation piles by the action of ground movements acting against the piles.

- The wind-induced and seismically-induced loads are dynamic in nature, and as such, their potential to give rise to resonance within the structure needs to be assessed. The fundamental period of vibration of a very tall structure can be very high, and since conv entional dynamic loading sources such as wind and earthquakes have a much lower predominant period, they will generall y not excite the structure via the fundamental mode of vibration. However, some of the higher modes of vibration will have significantly lower natural periods and may well be excited by wind or seismic action.
- The dynamic response of tall buildings poses some interesting structural and foundation design challenges. In particular, the fundamental period of vibration of a very tall structure can be very high (10 s or more), and conventional dynamic loading sources such as wind and earthquakes have a much lower predominant period and will generally not excite the structure via the fundamental mode of vibration. However, some of the higher modes of vibration will have significantly lower natural periods and may well be excited by wind or seismic action. These higher periods will depend primarily on the structural characteristics but may also be influenced by the foundation response characteristics.
- The connection between High-rise construction and deployment and environmental protection. Using Sustainability as a guiding framework to organize the many issues related to tall building developments.

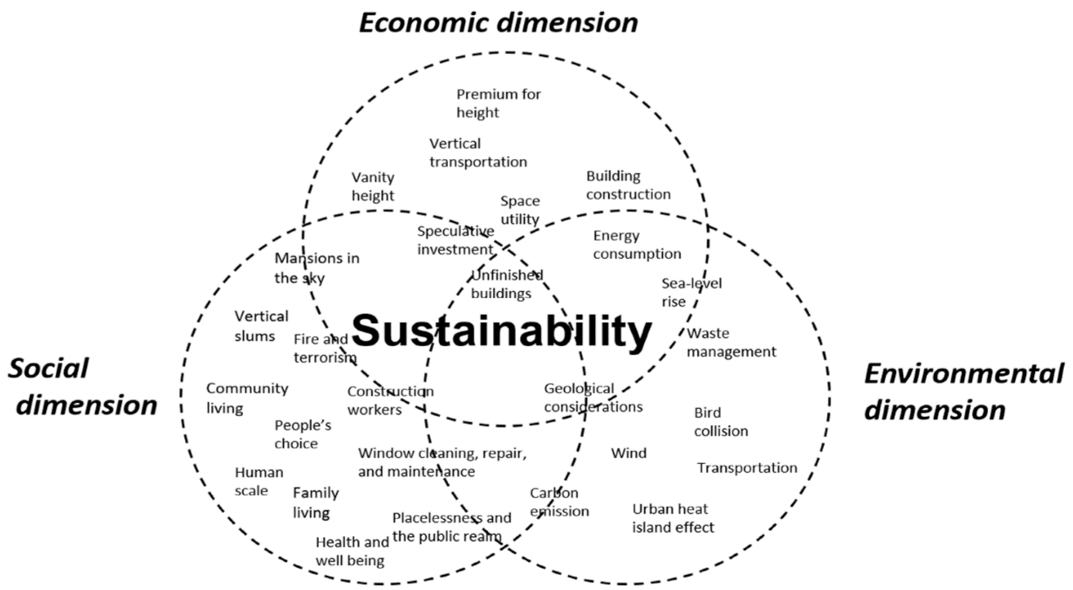

Figure No.2 Development of Tall buildings

1.3 Structure of wind

Wind is randomly varying dynamic phenomenon and a trace of velocity verses time for wind will be typically as shown in figure 1.1. The wind velocity V can be seen as a mean plus a fluctuating component responsible for creating 'gustiness. Within the earth's boundary layer, both components not only vary with height, but also depend upon the approach terrain and topography, as seen from figure 1.2. While dealing with rigid structures, the consideration of the equivalent static' wind is adequate. However, in dealing with wind-sensitive flexible structures, the considerationof wind-energy spectrum, integral length scale, averaging time and the frequencies of the structure become important. The determination of wind velocity for a certain geographical location is essentially a matter of statisticalreduction of a given measured data. On this depend the various wind zones. Another important decision involved is the averaging time is concerned, it may be anywhere from 2-3 seconds to 10 minutes to an hour. The influenceof averaging time on velocity is seen in figure 1.3

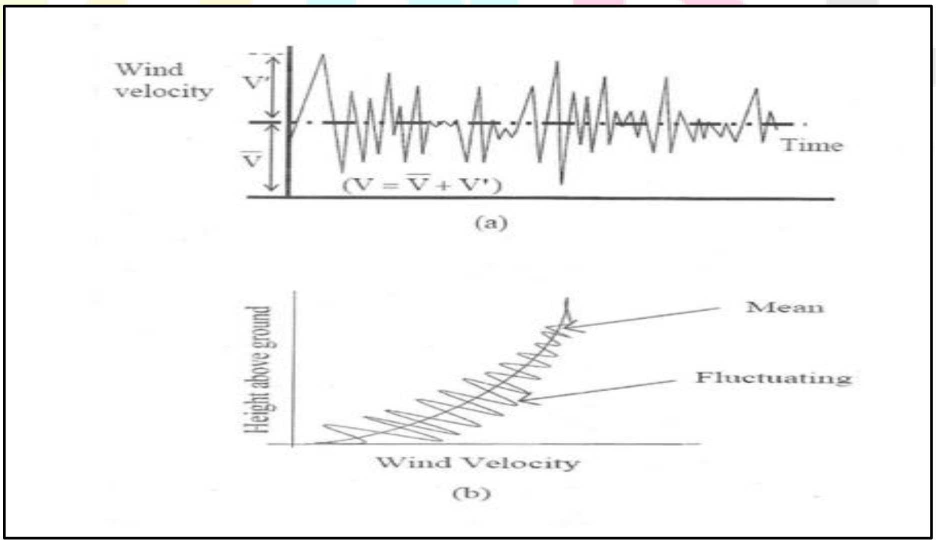

Figure No.3 Variation of wind velocity with (a) Time (b) Height

(Source: An Explanatory handbook on proposed IS 875 (Part 3) wind loadson buildings and structures)

Influence of Terrain and Topography

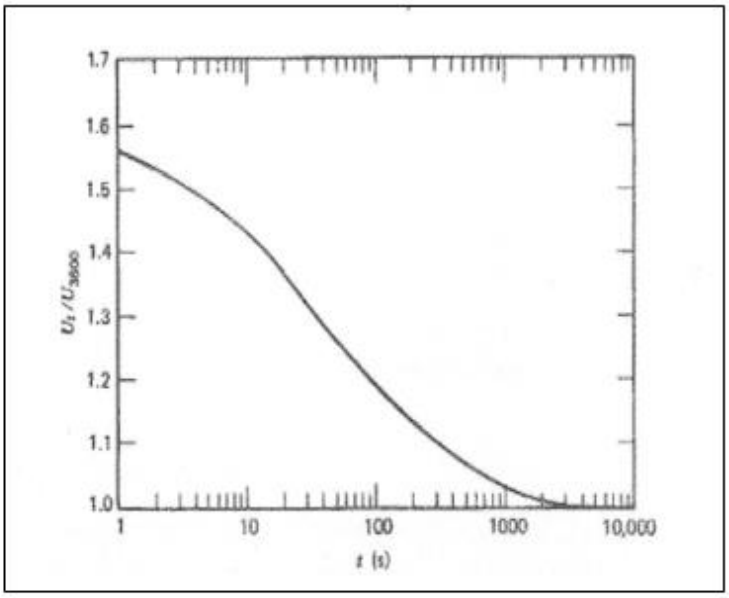

Figure No.4 Ratio of probable maximum speed averaged over period 't' tothat averaged over one hour (Source: An Explanatory handbook on proposed IS 875 (Part 3) wind loads on buildings and structures)

II. LITERATURE REVIEW

A state of the art literature review is carried out as part of the presentstudy. The extensive literature review was carried out by referring standard journals, reference books and conference proceedings. The major work carried out by different researchers is summarized in this chapter. It deals with the previous work carried out on behavior of tall buildings havingdifferent shapes subjected to wind loads and the gust effectiveness factor approach for estimating dynamic effect on high-rise structures. Ji-Yang Fu [1] Tall buildings are usually sensitive to wind loads, and effective and accurate methods for the wind-resistant structural optimal design of tall buildings have become a widely concerned problem. Conventionally, the frequency constraint for the structural optimal design of a tall building is formulated through the strain energy method, and with the objective functions and constraint functions being established, the structural optimization problem is mathematically modelled, and the corresponding solution is solved using the optimal criteria (OC) method. This procedure has two disadvantages. First, the strain energy usually does not consider the gradient of the structural internal forces to the design variables, and so the computed sensitivity of the frequency constraint is inaccurate. Fadi Alkhatib [2] A computational optimization methodology consisting of a computational fluid dynamic coupled with finite element analysis and embedded within a radial basis function surrogate model is proposed to mitigate wind-induced loads on tall buildings. In addition, a numerical example implementing the proposed methodology on selected case study is presented and discussed. The proposed approach was able to achieve a minimization of 13.83% and 23.12% for a long-wind and across-wind loads, respectively, which is translated to a reduction in structural response by 12.95% and 14.31% in maximum deflection for a long-wind and across-wind directions, respectively. Mohamed Khallaf [3] This paper investigates performance-based tall building design and the development of a combined architectural-urban design method focusing on the effects of wind loads on- and wind flows around tall buildings. The paper provides an overview of related buildings codes and city development design guidelines that define requirements for structural façade wind loading and urban ventilation. A review of performance-based design methods for the generation, analysis and optimization of buildings is also presented. Within this frame, an approach to performance-based tall building envelope design is proposed. Xiao-Wei Zheng [4] In this paper, a reliability-based approach is presented to compute the load modification factor for designing high-rise buildings in regions prone to earthquake and strong wind events. The paper illustrates the proposed procedure from the construction of hazard models to load modification calculations, which is implemented in a 42-story steel frame-reinforced concrete (RC) core tube building located in the Dali region, southwest of China. The uncertainties associated with hazard models, material properties, input loads, demand models and structural capacity are considered to improve the accuracy of failure probability estimations. Prasenjit Sanyal [5] In this Paper, Wind load and response are the major factors that govern the most critical condition for designing tall buildings. This study discusses the variability of wind load and pressure on a Y plan shaped tall building due to the change in the building side ratio. The length to width ratio is changed keeping the total plan area same. The numerical study is done by ANSYS CFX. Two turbulence models, k-epsilon and shear stress transport (SST), are used for doing the numerical simulation and the results are compared with the previous wind tunnel results in a similar flow condition. Sample points were selected based on Audze–Eglais Uniform Latin Hypercube (AELH) method and the analytical expressions of force, moment and torsional coefficients of Y plan shaped tall building are proposed.

Yi Li [6] Modern tall buildings are likely sensitive to wind excitations due to their increasing height and structural flexibility. Proper or optimal wind-resistant structural design of such high-rise buildings is required or sometimes necessary to meet the requirement of safety and serviceability. Combining a genetic algorithm (GA) with im- proved penalty function and calculation method for equivalent static wind loads (ESWLs), this paper presents an optimal procedure for the wind-resistant design of tall buildings, which aims to minimize the total weight of the designed building subject to the constraints of top acceleration and lateral drifts. A penalty function is utilized to deal with the implicit expressed constraints of optimization. H.P. Lou [7] It was acceptable that construction industry was reaching to new bench marks by constructing certain Tall Buildings, includes of significant engineering. Construction of Tall buildings might be a complicated affair with the lateral loads playing a dominant role in design of the certain structures, where buildings need certain lateral load resisting structural system. With the evolution of technology numerous structural systems came out such as Shear Wall System, Tube in Tube, Core Out-trigger System etc. Aydin Shishegaran [8] The main target of this study is related to the sustainability evaluation of the optimized structural designs by the various lateral force-resisting system to select the best structural system for a tall building. According to interviews with 28 experts, condition and location of the study area, and intensive observation, 12 lateral force resisting systems were proposed to design a 17-storey five-bay structure. Each structural design was optimized by the optimization modules of SAP2000. Eleven indicators were selected based on data availability, experts' opinions, and authors' opinions. Ahmed Elshaer [9] This study presents building corner aerodynamic optimization procedure (AOP) to reduce the wind load, by coupling an optimization algorithm, large eddy simulation (LES) and an artificial neural network (ANN) based surrogate model. As an illustration, corner mitigation that has limited effect on both the structural and the architectural design is presented. Two aerodynamic optimization examples focusing on drag and lift minimization that consider wind directionality and turbulence are presented. Maryam Asghari Mooneghi [10] This paper reviews the past/recent work on various aerodynamic mitigation techniques developed for reducing wind loads on buildings by modifying their shapes and/or adding simple architectural elements. Aerodynamic mitigation techniques applicable to low-rise and high-rise buildings have been reviewed. In addition, aerodynamic shape op- timization techniques for reducing wind loads on tall buildings are presented and the suitability and challenges of using Computational Fluids Dynamics (CFD) for this application are discussed.

III. METHODOLOGY

At the starting of any project some preliminary study is required. These preliminary studies are required to know the exact behavior of the structure,to know the property of the structure and various load conditions of the structure. Analyzing the small structure concern to respective project study does these types of studies. In this Paper software modeling, wind load calculations by static and dynamic methods for various shapes of buildings as per IS 875 (part 3)-1987 has been done. Then application to calculated wind loads to software models and analysis is studied.

Following is flowchart of work for Project: -

Figure No.5 Methodology Flowchart

Parameters considered for the study

A 50 storied building of different shapes- Square, Rectangular, Circular and Elliptical, having equal plan area and equal stiffness of the columns has been analyzed.

Buildings Description

Table 1. Building components and details

Name of parameter	**Value**	**Unit**
No. of storey	50	Nos.
Bottom storey height	3	m
Storey height	3	m
Soil type	Medium	
Wind zone	I	
Design wind speed	33	m/sec
Shape of buildings	Rectangular, square,circular, elliptical	
Plan area	2500	m^2
Grid size	5x5	m
Thickness of slab	125	mm
Size of beam	300 X 600	mm
Size of column	1000 X 1000	mm
Material properties		
Grade of concrete	M40	N/mm^2
Grade of steel	Fe500	N/mm^2
Dead load intensities		
FF on floors	1.75	kN/m^2
FF on roof	2	kN/m^2
Live load intensities		
LL on floors	2	kN/m^2
LL on roof	1	kN/m^2

In general, for design of tall buildings wind load need to be considered. Governing criteria for carrying out dynamic analyses for wind loads as per IS 875(Part 3): 2015.When wind interacts with a building; both positive and negative pressures occur simultaneously. The building must have sufficient strength to resist the applied loads from these pressures to prevent wind induced building failure. Load exerted on the building envelope are transferred to the structural system and they in turn must be transferred through the foundation into the ground. The magnitude of the wind pressure is a function of exposed basic wind speed, topography, building height, internal pressure, and building shape. The main objective of this study is to carry out the analysis of tall residential building against wind loads as per Indian standard codes of practice IS 875(Part 3):2015 and to compare the results with the results obtained by E-Tabs software. First, the sensitivity of base shear of the building with respect to the location of the building at the wind zones in Pune (India) is to be investigated. The wind load on the building are calculated assuming the building to be located at Pune. Lateral load on tall buildings is most critical one to consider for the design. In order to observe the wind effect on tall building, a study on G + 18 storey's are taken for analysis. The structural response due to lateral loads with load combinations is extracted. Effect of lateral load on moments, displacements, base shear, maximum storey drift and tensile forces on structural system are studied. The ETABS stands for extended 3D (Three Dimensional) Analysis of Building Systems. This is based on the stiffness matrix and finite element-based software.

Building Models

Modeling a building involves the modeling and assemblage of its various load carrying elements. The model must ideally represent the mass distribution, strength, stiffness and deformability. Plan and 3-D view of building of various shapes are shown below.

Models

Model 1: Square shape building used for linear analysis Model 2: Rectangular shape building used for linear analysis
Model 3: C shape building used for linear analysis
Model 4: T shape building used for linear analysis

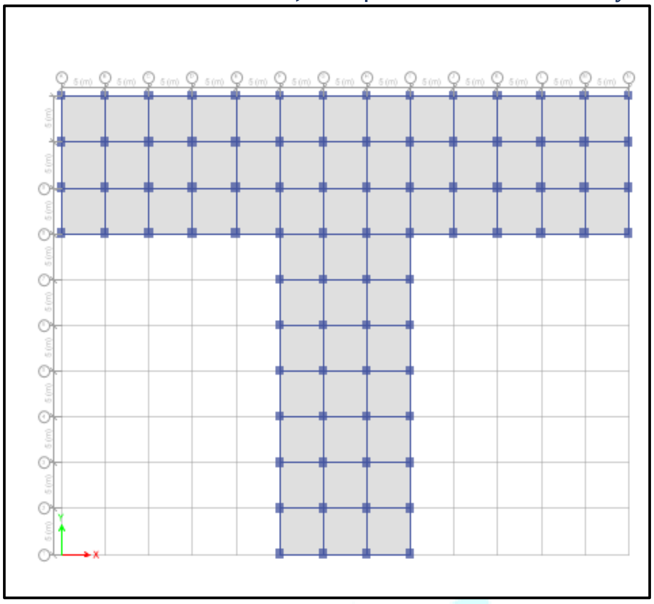

Figure No.6 T shape plan view

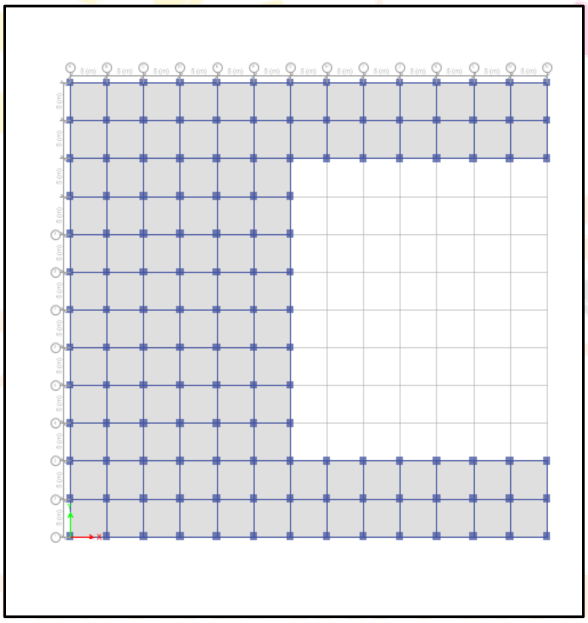

Figure No.7 C shape plan view

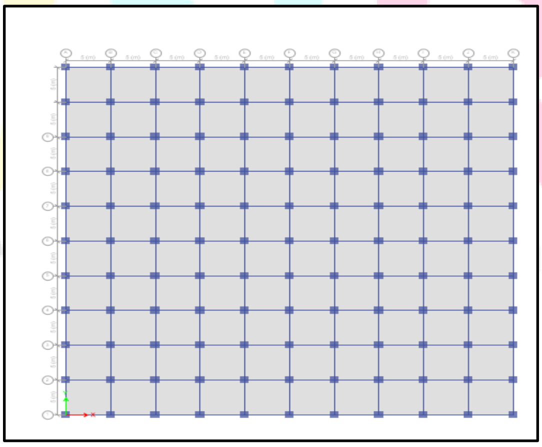

Figure No.8 square shape plan view

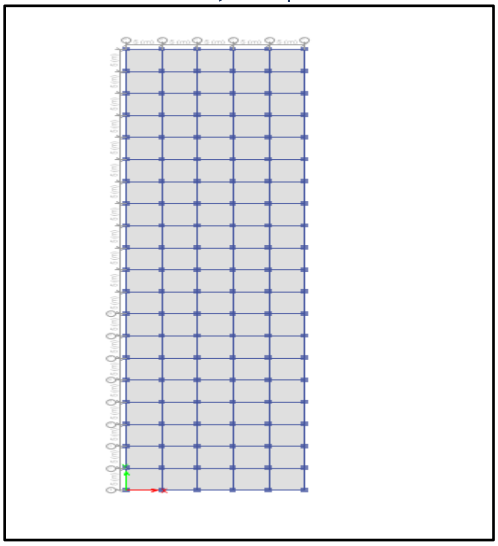

Figure No.9 Rectangle shape plan view

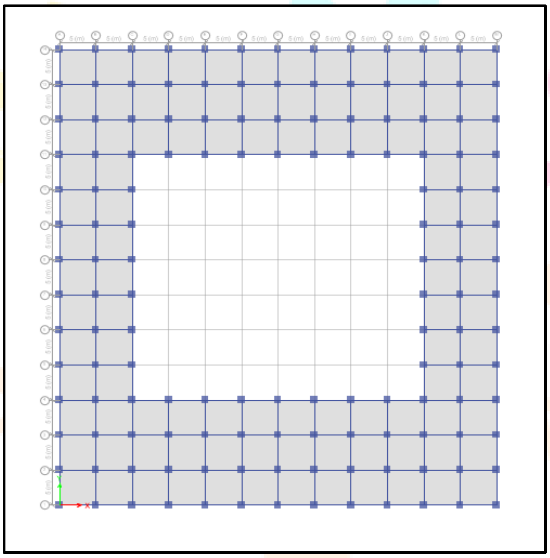

Figure No.10 Hollow shape plan view

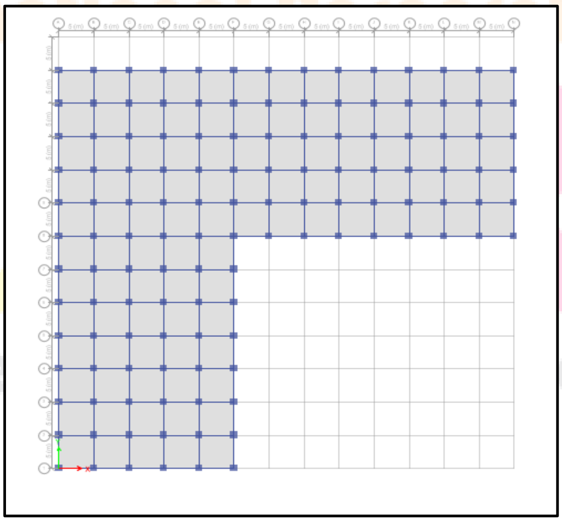

Figure No.11 L shape plan view

IV. RESULTS & DISCUSSION

This Paper contains the results taken from software after application of loads to the models. After running the models, software shows the table of results. This chapter is divided into three parts i.e. results from linear analysis, and results which shows the effects of shape of buildings. It also contains graphical representation of the comparison of results of various shapes of buildings methods.

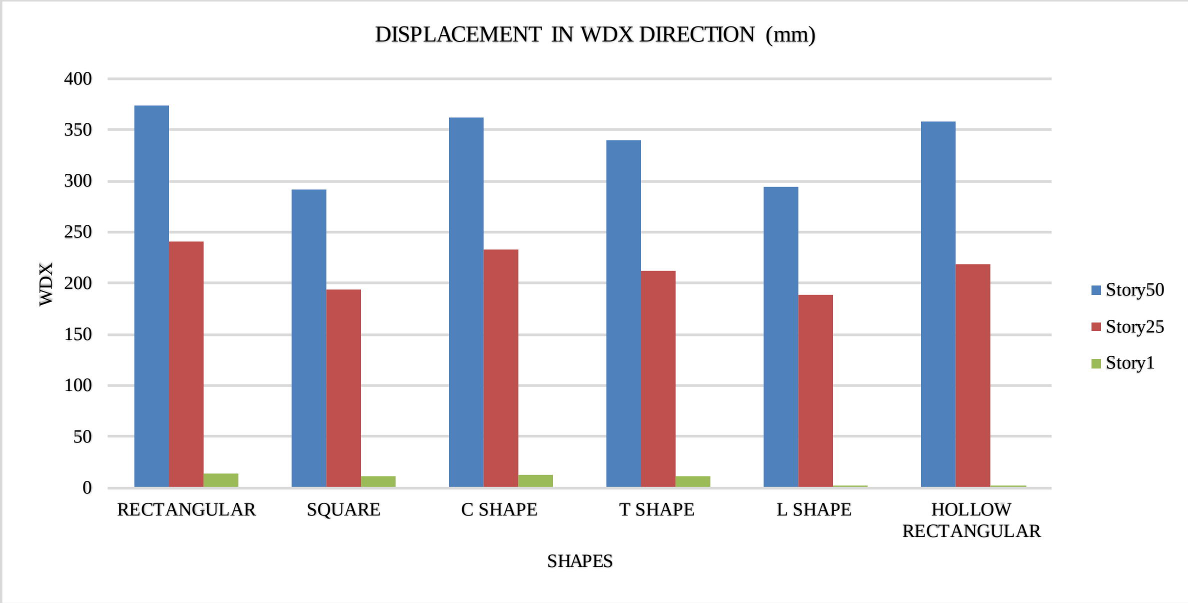

Figure No.12 Displacement In X –Direction

Terminologies
1. rectangular shape
2. square shape
3. C shape
4. T shape
5. L shape
6. Hollow rectangular shape

The above graph shows displacement in X –direction for square ,Rectangular ,C shape,T shape ,L shape, hollow rectangular building. square shape building has lower displacement than the rectangular shape building by 21.88%, C shape 19.36 % building and T shape building by 14.23%. L shape by 0.95 %, hollow rectangular by 18.71 %.

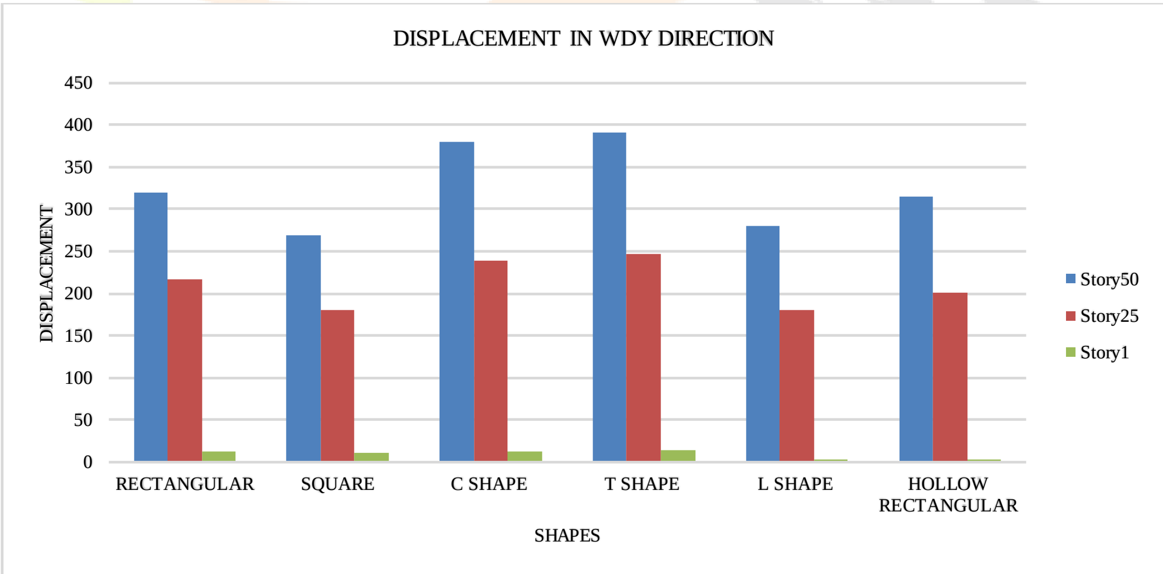

Figure No.13 Displacement In Y –Direction

The above graph shows displacement in Y –direction for square ,Rectangular ,C shape,T shape ,L shape, hollow rectangular building. square shape building has lower defirmation than the rectangular shape building by 15.60 %, C shape 28.94 % building and T shape building by 31.11 %, ,L shape by 3.87 % , hollow rectangular by 14.16 %

Figure No.14 Storey Drift In X –Direction

The above graph shows storey drift in X –direction for square ,Rectangular ,C shape,T shape ,L shape, hollow rectangular building. square shape building has lower storey drift than the rectangular shape building by 25.83 %, C shape 25.14 % building and T shape building by 57.72 % L shape by 30.53 % , hollow rectangular 43.38 by %.

Figure No.15 Storey Drift In Y –Direction

The above graph shows storey drift in Y –direction for square ,Rectangular ,C shape,T shape , L shape, hollow rectangular building. square shape building has lower storey drift than the rectangular shape building by 2.02 %, C shape 54.90 % building and T shape building by 50.66 % , L shape by 49.44 % , hollow rectangular by 25.70 %.

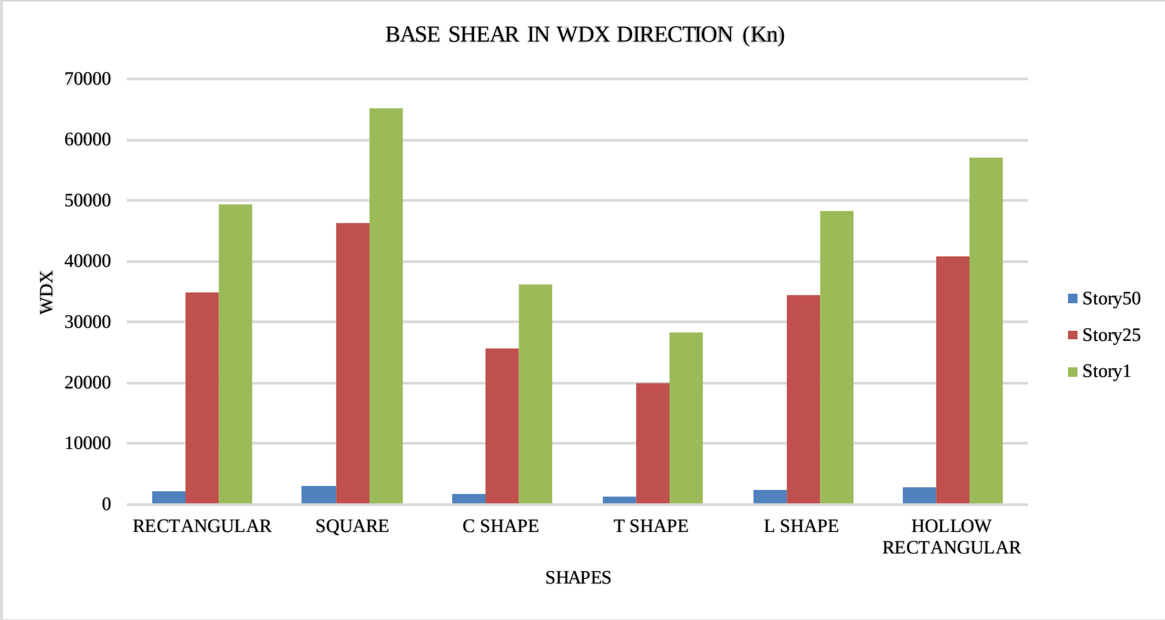

Figure No.16 Base Shear In X –Direction

The above graph shows Base shear in X –direction for square ,Rectangular ,C shape,T shape, L shape, hollow rectangular building. square shape building has higher Base shear than the rectangular shape building by 23.80 %, C shape 44.26 % building and T shape building by 54.77 %, L shape by 17.78 % , hollow rectangular by 3.60 %.

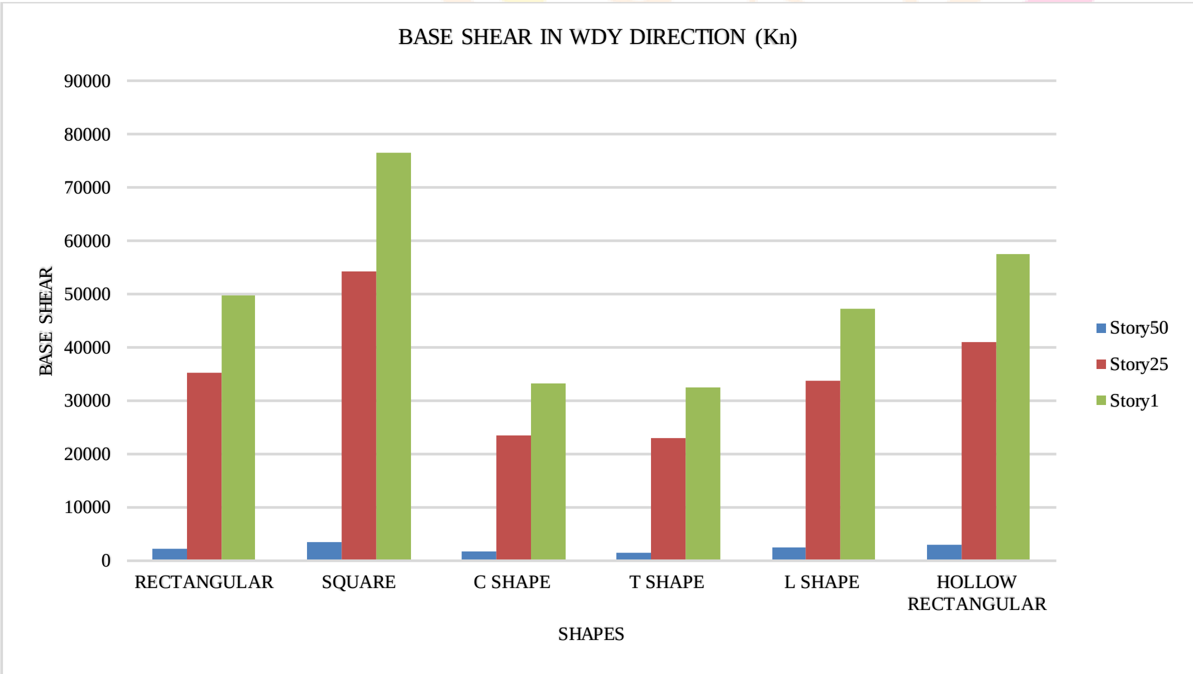

Figure No.17 Base Shear In Y –Direction

The above graph shows Base shear in Y –direction for square ,Rectangular ,C shape,T shape, L shape, hollow rectangular building. square shape building has higher Base shear t than the rectangular shape building by 35.62%, C shape 54.98 % building and T shape building by 57.28 %, L shape by 30.67 % , hollow rectangular by 18.35 %.

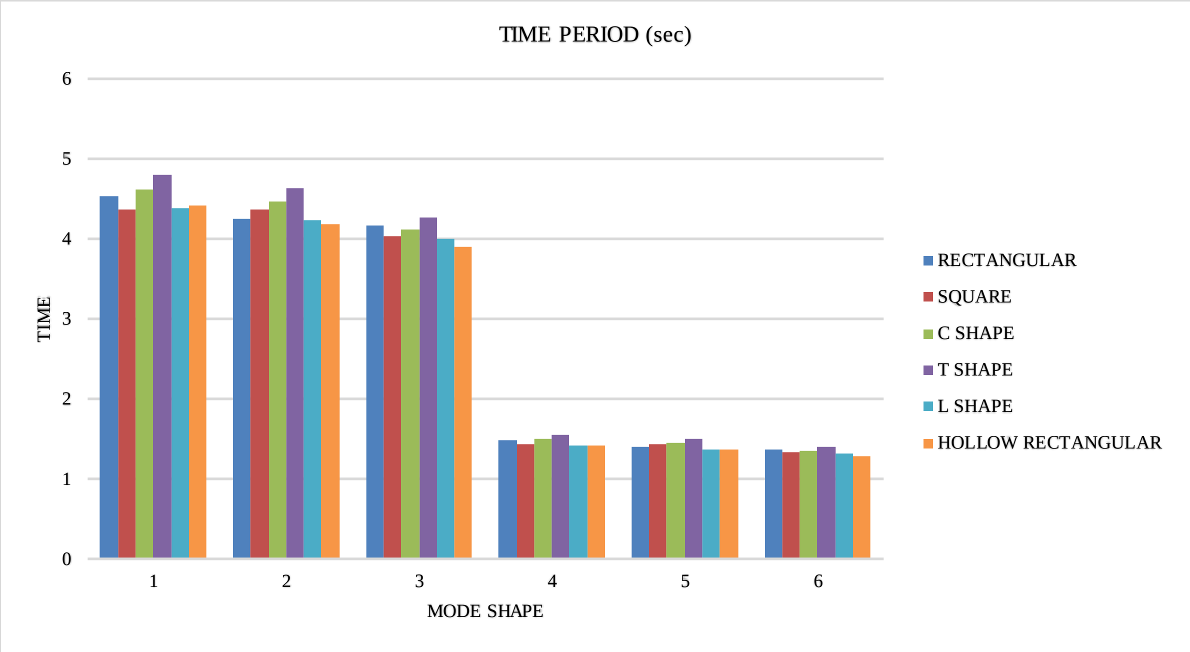

Figure No.18 Time Period

The above graph shows Time period in direction for square ,Rectangular ,C shape,T shape , L shape, hollow rectangular building. square shape building has lower Time period t than the rectangular shape building by 3.74 %, C shape 5.26 % building and T shape building by 8.85 % ,L shape by 0.41 % , hollow rectangular by 1.22 %.

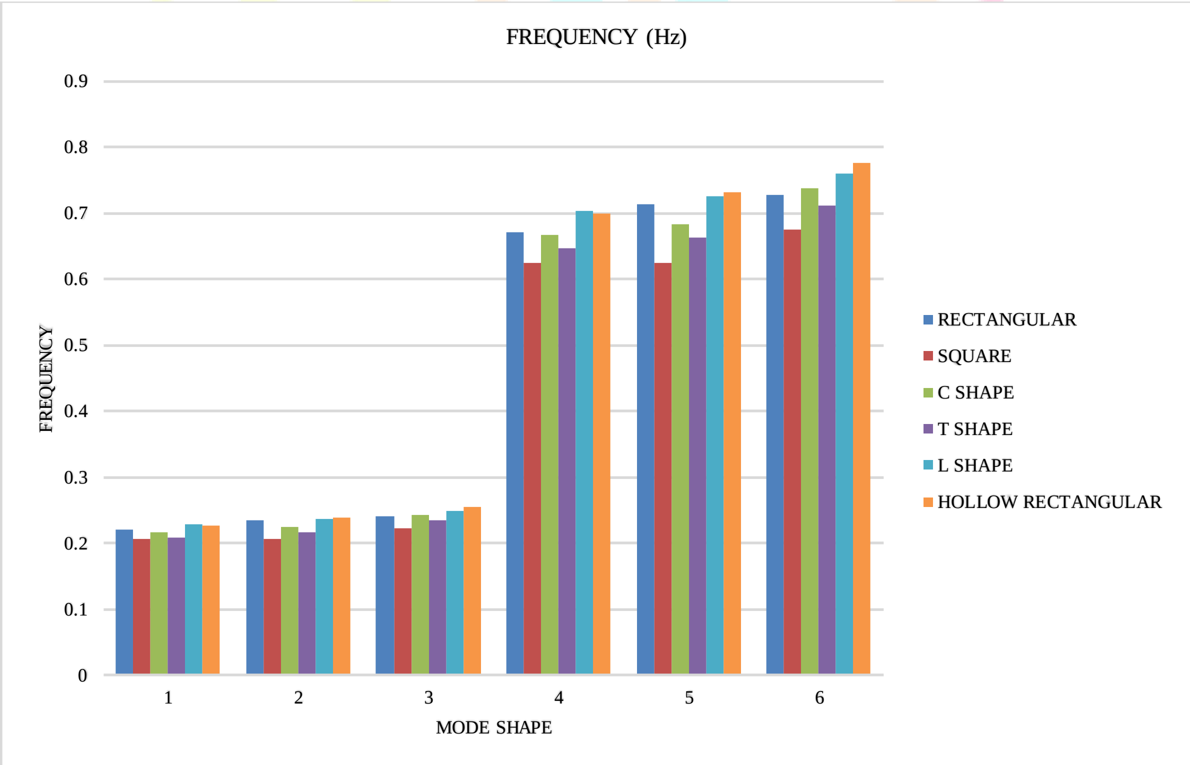

Figure No.19 Frequency

The above graph shows Frequency in direction for square ,Rectangular ,C shape,T shape, L shape, hollow rectangular building. square shape building has lower frequency t than the rectangular shape building by 6.31 %, C shape 5.02 % building and T shape building by 0.91% ,L shape by 9.60 % , hollow rectangular by 8.72 %.

V. CONCLUSION

Each tall building is unique and based on many situations which influence the choice made in the design of high rise buildings. It was concluded that, before constructing tall buildings an alternate design method should be introduced by creating innovative computational workbench in order to design efficient high rise building to withstand wind load influences. High rise buildings are affected by wind load through deferent parameters such as storey drift, shear force, displacement, bending moment, axial force etc. The wind load affects increases with increasing the height of the building. Many researchers carried out papers to study the effect of lateral load on tall building and find a proper solution to avoid instability of structure. In order to reduce those effects the suitable structural system and the frontage of the building should be well chosen. Also, the appropriate choice of building shape and architectural modifications are frequently effective to reduce wind load by changing the flow patternin surrounding of the building. In addition, the geometry and aerodynamic modification contribute to make the building having more stability and strength. At the end, the structures must be designed for forces obtained in different directions for critical forces of earthquake or wind to prevent damage in building which leads to collapse. Modern buildings having high efficient structural system depending on the number of storey designed. In addition, these advanced buildings provided by qualifiedmaterials due to the sensitivity of the building when exposed to the lateral loads effects.Therefore, developing the criteria of the building through providing the appropriate structural system will contribute in reducing the impact of wind load on high rise building. The objectives of this project has been achieved through studying the behavior of different shapes of building when subjected to wind load. As well as, the comparison of all shapes carried out to choose the most stable building.

- The shape of the tall buildings playing a major role in reducing the wind load effect in terms of different design parameters that should be taken into consideration before designing any building.
- If the building height increased, the lateral load comes from wind load will increased aswell causing the increasing in wind pressure. This is will generate additional stress to the building members. In addition, the storey displacement increased so the structure will have less stability and stiffness.
- The square shape building is more effective and less affected by wind load because ofsmooth surface that create a less friction between the wind load and the surface itself due to the wind excitation.
- By changing the shape from triangular to circular shape, the storey displacement and drift will reduced by maximum percentage due to reducing the wind pressure affecting the building.
- The building shapes that highly influenced by wind load can be reduced the impact by taking the efficient structural system, lateral bracing and increasing the dimension of beam and columns to have enough stiffness as well as usually shear wall has been usedin order to reduce wind load.

This study is connected to the scholars studies through result getting from this report is matched with the journals and the result of literature review chapter. At the end, I hope myfindings in this project are expanded the knowledge in this field as well as contributes to all of us in future and done in required manner.

VI. SCOPE FOR FUTURE WORK

1. The proposed results need to be validated by further case studies. Further study could be on another aerodynamic shapes which can reduce the wind pressures.
2. Another field of wide study could be the addition of maximum openings to irregular shaped high rise buildings to reduce the effects of wind on the structures.
3. Another field of wide study could be the reduction in plan area after certain height to evaluate the wind effects. Future study could be on the modifications in comer geometry of various shaped high rise buildings.

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