Wind analysis of tall structures by soft computing technique

Introduction, model parameters, stress distribution, analysis results

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***Abstract*—This paper deals with the study of behavior of a tall structure for a maximum expectancy of wind forces. The details how a finite element analysis software considers a wind force and the response of a structure to it.**

***Index Terms*— wind resisting system, model parameters, wind intensity, stress distribution, base shear, moment, axial force.**

I. INTRODUCTION

A rapid growth in population and infrastructure has led to the population concentration in a developed cities, forcing a city grow vertically instead of horizontally. In recent years a skyscraper has satisfied the present needs of economy both in Luxury and Aesthetic appearance. When an economic growth is concentrated in a coastal strip, the structure is subjected to an enormous wind force, which it has to withstand for safety and serviceability requirement.

If a structure surface is of zero friction and a shape of the structure is very sharp along the wind, then its effect is less and can be neglected for analysis. But in practical case it is impossible since the exact direction of the wind is unpredictable at a given location and situation. Even though the density of air is 1.2kg/m^3, with some velocity it can be devastating and the whirlpool action due to wind can cause a major problems and situation where a structure is subjected to a force for which it's not designed. In the normal conventional framed structure, which is built for gravity loading the loading on a members are not applied until the member gains its required strength, but in case of structure resisting wind force it's not true since the wind forces are unpredictable and it is acted instantly as the member is placed or casted. The panel in between the vertical frames is placed after the frame structure is completely executed. There are various methods to overcome the wind forced but to improve the structure behavior one can install dampers for a building by studying its mass and the sway to the direction of the wind force. The question is the economy the method to be chosen for execution and minimize the time and manpower required.

II. TYPES OF WIND RESISTING SYSTEM

A structural engineer who has encountered an enormous wind load in a structural system has a three ways to proceed; one is to change the building geometric properties or to install dampers to structural system and many more to overcome the excessive sway. The types elaborated are as follows;-

I. Altering the building geometrical properties.
II. Installing dampers.
III. Change of surrounding parameters.

I. ALTERING THE BUILDING PARAMETERS

A structural engineer will have a full control on building geometrical properties while modeling the structure. Hence when a cost and safety is concerned he might opt to reduce the storey height but it will ruin the elevation and the exoskeleton elevation. Hence the structural engineer will for the following methods for storey relaxation.

I. Increasing the vertical stiffness and reducing the horizontal stiffness will help, but for more number of stories it won't, hence the structure has to be made flexible in some cases to attract less wind forces.
II. By providing the stiffer outer cores the structure's moment of inertia will be increased which helps in storey relaxation.
III. By adopting the smart structural systems like Digrid system or tensegrity structures etc.
IV. It is a basic understanding that if the base dimension is more it will help in storey relaxation like a pyramid, but it is important to build a structure in a limited area for a greater heights.

II. INSTALLING DAMPERS

Installation of dampers in a system is one of the most efficient and effective way of overcoming the sway of the building. The rapid growth in the damper science has helped not only in controlling structural vibrations but also to overcome various problems caused by undesirable vibrations in Aircrafts, ships, submarines and rockets etc. There are various types but some are listed below.

- Active dampers.
- Passive dampers.

III. CHANGING THE SURROUNDING PARAMETERS

This is a hypothetical case or a next to hypothetical, which means it is practically uneconomical to change the surrounding layout just for structural system. For example in a wind tunnel test a behavior of a model under wind is determined by roughly modeling the adjacent building in the tunnel and keeping the surface rough before the impact but if the change of the topography or the surrounding parameter is possible then the effect of wind on a structure can be changed and brought down. But a good wind engineer can reduce the wind impact on a structure by vegetation at a high level area in the direction of wind before striking the structure.

III. MODEL PARAMETERS

The modeling is done in STADD PRO V8i using coordinating system. The further in detail properties of model is shown below.

IV. GEOMETRIC PARAMETERS

The model consists of 16 columns and 24 beams connecting columns orthogonally as shown in figure. The cross section of columns and beams is kept similar to reduce the complexity of analysis. The height of the column is kept as 3meters and number of stories is kept flexible to attain a required deflection on top.

The reason behind it is to attain the larger deflection on top is to observe the building full scale response against the very slight change in the deformation of the structure to a larger figure due to installation of dampers.

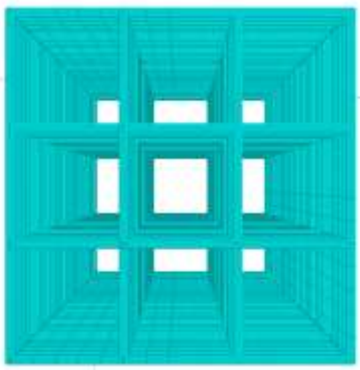

Fig 1 top plan of frame

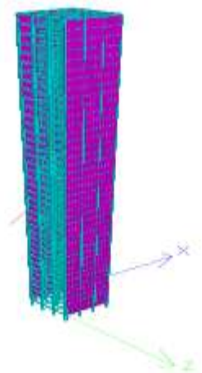

Fig 2 rendering view of frame

The sectional properties of the members are shown below.

Table 4.1 Details of members to be assigned

Structural elements	Sectional Property in mm	Material Property
Beams	300 X 300	Concrete
Columns	300 X 300	Concrete
Plates	200 thick	Concrete

The sectional properties of the beam and column are kept same to reduce the complexity regarding manual check. The structural rendering view is shown below.

V. PLATE ELEMENT PARAMETERS

Initially the structural engineer has to determine that how the software works for good of the structural system and then and then only he can analyze the structural system. He has many ways to determine the software check, but a good structural engineer will either compare a analysis results for a small frame or grid with manual method or determine the forces obtained ins within the range by experience.

In this project I have made a plate of uniform thickness surrounding in U shape as shown above. The reason behind this plate assigning is to observe weather the software is considering any leeward effects due to vortex shedding but by observation is proved to be negative hence the software simply considers as the horizontal varying surface load. Now with a horizontal wind load if a vortex shedding is taken into account then the side faces of the structures i.e. even Lee ward face will also develop a stress with a stress distribution contours which will be almost as same as that of front face. But the stress contour which is obtained is shown below which simply resembles a stress distribution of a hollow square tube with a fixed base and a horizontal loading. Hence we can independently check the results obtained by 2-D manual analysis, since the loading is normal to the direction x.

Fig 3 Stress distribution (Front)

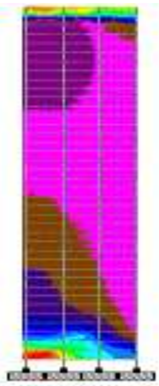

Fig 4 Stress distribution (Side)

Now with a horizontal wind load if a vortex shedding is taken into account then the side faces of the structures i.e. even Lee ward face will also develop a stress with a stress distribution contours which will be almost as same as that of front face. But the stress contour which is obtained is shown below which simply resembles a stress distribution of a hollow square tube with a fixed base and a horizontal loading. Hence we can independently check the results obtained by 2-D manual analysis, since the loading is normal to the direction x.

VI. LOADING PARAMETERS

Loading and Load combinations on a structural system is calculated on the basis of Bureau of Indian standard, code IS 875 (part -3) and a severe case is considered in all parameters to enlarge its availability for all users from the nation. Simple horizontal varying load is applied after the calculation of wind velocity and intensity manually by Excel programming for different height.

The design wind speed is calculated by following formula.

$V_z = V_b * k_1 * k_2 * k_3$

Vz = Design wind speed in m/s

Vb =Basic wind speed for the structure and it is 55m/s (max).

k_1 =Factor of life span of the structure and its 1 for 50 years.

k_2 =Factor of geometric properties like height, size of structure (Varies).

k_3 =Factor of topography in structure vicinity which is 1.

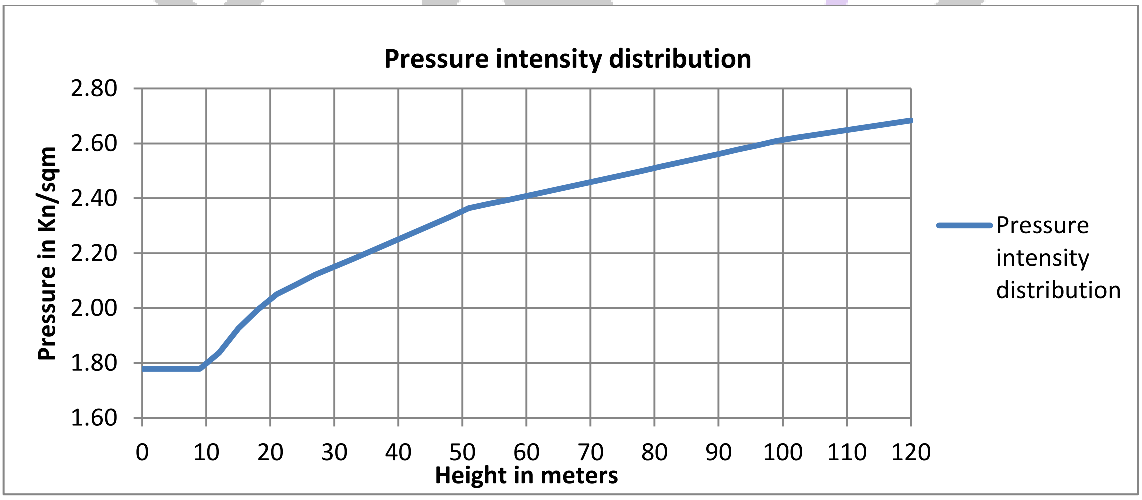

Fig 5 Storey v/s pressure intensity

Above chart clearly defines the wind pressure distribution along the height of the structure. One can note that initially up to 10 meter height the buildings pressure remains same and it increases with height till the top. This intensity is used as a wind load for the structure and it is studied.

VII. STRESS DISTRIBUTION IN PLATES

This is one of the important criteria as such a stress distribution is important in every structural element. In this project I have assigned a concrete plate of about 200mm thick facing the direction of wind to determine the stress distribution on the surface of the structure. We have a liberty to go to a plate facing in x direction only since it is clear the software won't consider the vortex shedding effect on orthogonal direction.

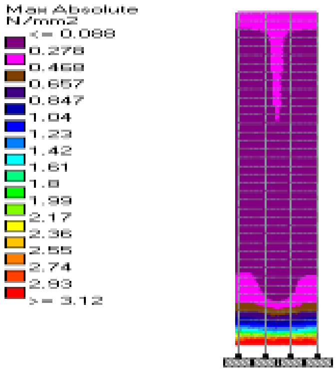

Fig 6 Stress distribution at the face of the structure

The structural unit is fixed at bottom and free on top henceforth the stress on top is less compared to that of bottom and hence we can say that whatever the values that we obtain after analysis is reliable. The stress observed at bottom is above 2.93N/mm^2 hence the design of plates as a panel at bottom is very crucial and requires an importance. And the top is free to deform hence the structural panels will have to deal with the less number of casualties or the wind intensities its stress lies at 0.278N/mm^2. If we observe the structure is free in lateral condition and hence we can confirm that the stress at those corner panels is much more less than that of the any adjacent ones and they are very clear in the figure with stress less than 0.088N/mm^2. We can clearly observe that there is a stress contour intrusion in the face of wall in between, longitudinally in downward direction. By observing this stress intrusion one can conclude that the stress is developed in this face due to the stiffness of the columns and it is inversely proportional which means as the stiffness of the column increases the stress in the plate increases due to unyielding of the structure. If the plate stiffness is increases the stress intensity will obviously decrease inversely. The formation of the U shaped stress contour is proof for this.

VIII. BASE SHEAR

The total base shear is the sum of all the horizontal wind forces acting on a structure due to wind intensity. The base shear remains unchanged in load combinations which includes wind load along X directions for X direction and for Y along Y directions. The storey shear of different columns and at different height is mentioned below. Many load combination is considered among which only one combination is selected for all the analysis it is sum of dead load, Live load and wind load along respective dimensions. The observation is made below. The storey shear is shown in figure, it is clear that the values are symmetric along X axis. The Axial force in the columns are shown below, we can see that columns facing x direction owes a tension and the far most column will be of compression. In the project if we install a plate facing x direction it will affect the stiffness of the structure which intern affects the results of the structure. We have analyzed a building with a plate and without a plate to make sure that the full wind is captured in an effect but, and it is to be seen that the results have not made any considerable change, hence for manual check it will not be a problem.

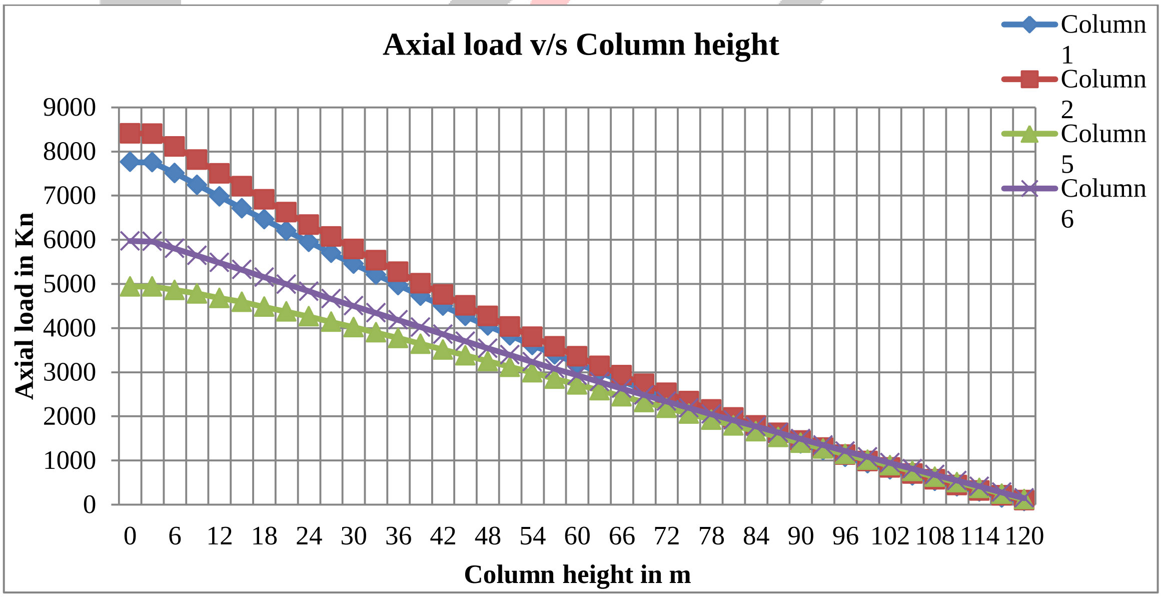

Fig 7 Graph showing axial load variation with height.

The column axial force and v/s storey height is drawn above. It clearly states the following points. The axial force on a column decreases with respect to a storey height in Y-direction. The axial force on a column is a product of structural weight and loading along Y-direction and it is least affected by the load along any other direction. The isolated column will have greater axial force compared to that of edge columns. Edge columns will have a greater axial force compared to that of cornered column. The axial load plays a very crucial role in designing the foundation, since the moment at the base is least for a building with greater height. The axial load on a column is affected by other parameters also like discontinuity in columns and change in beam layout in successive stories. In the graph it is clear that column2 has a greater axial force, since it is isolated column and column 1 has axial load greater than that of column 5 since it is at the edge and column5 has a axial load very less since it is at the corner. One can see the variation of the axial load, at the level of ground floor to first floor the axial load is almost constant except the self weight of column which is least and after that the summation of slab loads comes into picture where as the height increases the slab loads summation decreases leading to the reduction in the axial load.

IX. BENDING MOMENT

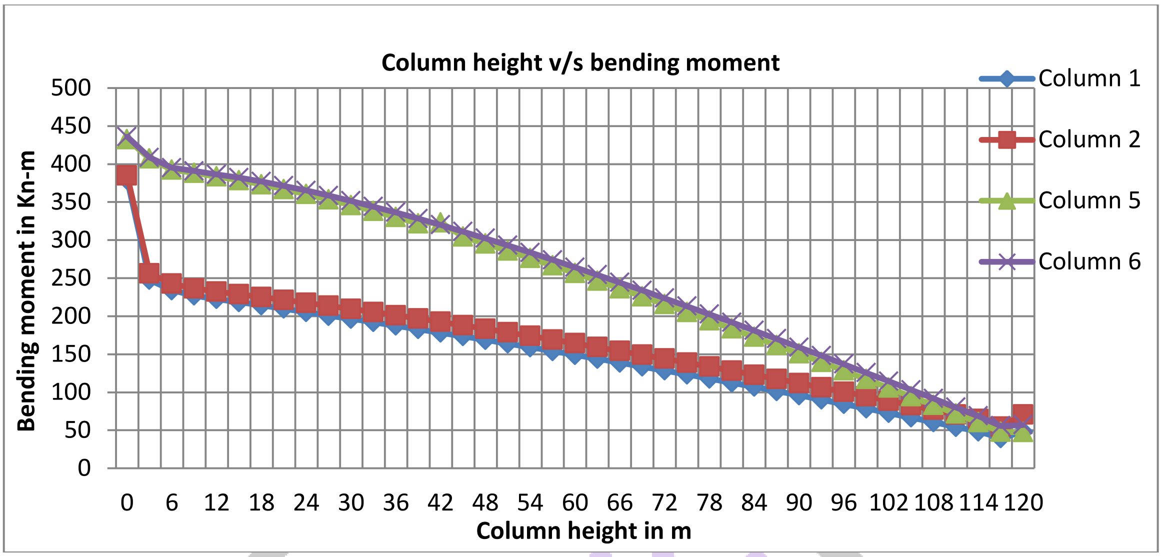

Fig 8 Graph showing Bending moment variation with height.

The outer columns will have to resist more moments, it follows a same principle as that of beam subjected to flexure where top and bottom fibers encounter more stresses compared to that of central fibers. The above results mirrors the same type of results as that the column 5 and 6 are in the outer face of the building. By above results we can conclude that if the horizontal loading is applied on a structure, either it may be due to earthquake o wind the corner and peripheral columns suffer more damage and hence if the structure needs to be strengthened it has to be done by outer columns. In case of building subjected to eccentricity and torsion same principle follows. The column 5 and 6 follows the same path and same moment.

The bending moment has decreased as the storey height is increased, this is due to reason that the structure acts as a cantilever I, e the bottom is fixed and the top is free. The bending moment of a member is a moment resisted by the member under a external loading, In a cantilever beam the free end is free to move and hence when the load is applied on it, it will simply move along its degree of freedom without developing a strain energy or any kinds of stresses in it.

This is one of the important criteria which should be observed I, e if a member is free to move along any axis it will no longer resists any force along that direction, in same manner it will not develop any kinds of forces or moment in that direction. So if continues girder is running along various spans and subjected to large loadings, there will be a hogging moment at the supports and a sagging moment at the center. Hence a structural engineer can eliminate either sagging moment and keep the hogging moment through the member and vice versa. This can be done either by making the supports simply supported so eliminating the hogging at the support, in such case the cross section will be more at the center due to moment and same at the supports due to shear, in other case if we want to eliminate the sagging moment and keep only hogging one we can place the supports as close as possible. This will help in reduction of cross section at the desired point for a desired purpose. For example reducing the central cross section in a sail by bridges, or for roof of hanger bays.

In the graph the column 1and 2 follows the same path since there are at a same distance from the point of application of force, but we can see a little variation due to the difference in the perpendicular distance from the centroid to the direction of force. We can observe at the base there is a hike in the bending moment this is due to a reason that a cantilever beam carrying uniformly varying load (maximum at the tip and minimum at the fixed end) will have a greater bending moment than that of a cantilever carrying a uniformly varying load. There are columns in four rows and if we draw a bending moment graph as that of above we will get a lines following the above 4 paths in a same manner. If we install a masonry wall or shear wall at the face of wind impact we will not only be affecting the structural stiffness but we will also be loading the structure at one face which is not uniform for all the faces and it makes the structure non-uniform in the horizontal and vertical axis.

Hence finally we can conclude that the results which we obtain will be feasible for the above model.

X. SHEAR FORCE

The shear force diagram of critical columns is shown above. The salient features are tabulated below.

The column 5 and 6 has encountered a greater shear force compared to the column 1 & 2, as seen on the graph. This effect is due to a fact that in any type of flexural behavior of a member the shear stress will be maximum at top and bottom fibers. The sudden rise and fall in the shear force at the bottom storey is clearly observed in the above graph is due to the fact that the load applied is less at bottom and more at top.

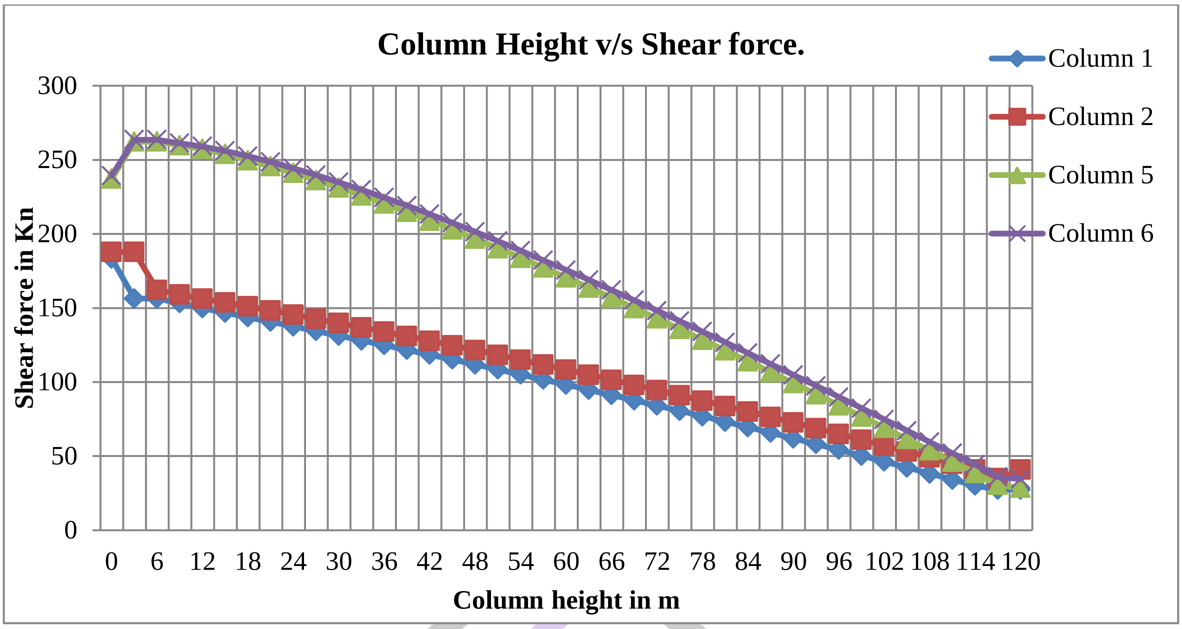

Fig 9Graph showing shear force variation with height.

XI. DISPLACEMENT

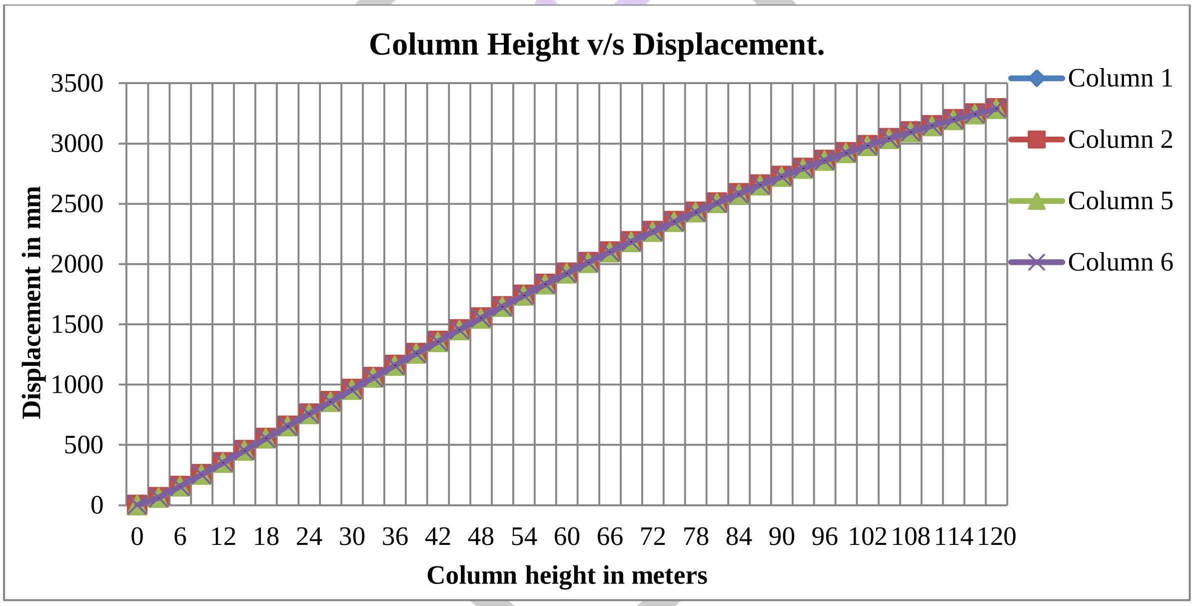

Fig 10 Graph showing displacement variation with height.

In the above diagram we can observe the displacement of the structure. The salient features of the graph are discussed below. All four columns have yielded almost same displacements, except that they vary in a couple of mm.The reasons behind this symmetric results is that the building is behaving as whole single unit and the displacement of columns varied less which is almost eliminated in the above graph. One can observe the graph that the displacement curve was linear till an extent of 75meters and it has become non-linear. The reason for this is same as that of previous one that is the wind pressure on a structure has varied from bottom to top, increasing. The yielded results are reliable since the displacement is similar along the column length. This clearly explains the state of super positioning I.e. the structural elements are axially rigid (no yielding has occurred along its length) but at the nodes there is a rotation which is responsible for yielding. If a member has to yield it will only yield at the nodes, which are at the face of junctions, the difference in the displacement may be due to variation in the load along the direction perpendicular to the direction of wind. This variation is reasonable if one looks at the stress distribution on a plate facing the wind.

XII. ACKNOWLEDGMENT

I would take this opportunity to express my gratitude for my guide Arjun B for enlightening the path of my research and, I am grateful for my friends without whose help the success of this project wouldn't be achieved. I would like to thank all the great personalities who has helped me to enlarged the knowledge domain within me.

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