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Analyzing Efficiency of Aerodynamic Shapes of Buildings using ETABS Software

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Abstract – *Tall buildings are constructed around the world and have become an essential part of modern infrastructure. Wind load is a lateral force which affect the tall structure at all times and hence aerodynamic shapes are adopted to overcome the ill effects caused due to wind loads. Time history analysis is conducted on the aerodynamic shapes of buildings in ETABS and results are interpreted to derive conclusions about the most effective aerodynamic shape out of the analyzed shapes.*

Key Words: Aerodynamic, Wind, Time History Analysis, Accelerometer, Tall Building, Wind force, major aerodynamic modifications, QuickDAQ, Data Acquisition.

1.INTRODUCTION

Tall buildings are recurring constructions in modern infrastructure industry for past few decades. Tall buildings have long replaced low-rise buildings especially in urban developing areas and big cities which provide housing to a vast population living in a limited space. Cities are often known to have limited land space for construction yet the population that needs to be accommodated keeps increasing on a regular basis and hence tall buildings which provide housing on multiple levels in a limited land space are a necessity. But tall buildings come with their own set of problems which, if left unresolved may lead to hazardous situation either to the property itself or to the inhabitants of the building. With added levels the dead load of the structure also increases and the inhabitants occupying the structure further add to the live load of the structure. Along with the elevated gravity loads, the increased height adds to the risk of failure due to lateral loads such as seismic loads and wind loads. The additional storeys add to the seismic weight of the building and makes the structure susceptible to earthquakes, and the increased height is affected by wind loads which tend to increase with height. In this paper the effect of wind loads on tall buildings and successful mitigation of the same by virtue of major aerodynamic modifications. Major aerodynamic modifications refer to the change in shape of the plan where the actual shape of the building is altered where the area of building is kept the same as before but shape is chosen in such a way that it creates minimum drag.

1.1. Creating the time history data

1) To collect time history data and apply it on building models.
2) To analyze the model for wind time history in ETABS.
3) To observe the results obtained and discuss the results to derive conclusions to determine the most effective aerodynamic shape.

2. Creating the time history data

In this experiment the effects of wind on eight differently shaped structures of same area and height is studied. The type of analysis carried out is Time History Analysis where wind load is applied as time history for a specified location. Time history analysis is a type of analysis where the dynamic response of a structure for a specified loading which varies with time is observed. This analysis is utilized for determination of response of a building under dynamic loading for respective lateral loads. Time history data for wind is collected using accelerometer where the disturbance created due to flowing wind at different storey heights is recorded in acceleration versus time format using Data Acquisition System and QuickDAQ software. The software collects the data from accelerometer and saves it in spreadsheet and also allows us to save the plots for data as an image in jpeg format. The software allows the user to collect data in displacement versus time, acceleration versus time, velocity versus time

The design software utilizes the time history data in form of acceleration versus time. Hence the wind load is collected in form of acceleration vs time, by arranging the accelerometer on a swing and allowing it to be disturbed by wind at an elevated height. The data collected from software is saved as spreadsheet form along with the respective plot for the collected data. The design software used for this analysis is ETABS software. This software allows time history analysis for the collected data. Before using the time history data, the data from spreadsheets is saved in text document format because the software recognizes the data in text document format only. The data is further used to carry out time history analysis.

3. Determining the specifications of buildings.

The building used in this analysis is 17-storeyed having a total height of 51m having plan area of 625 m^2. The area for building is determined using norms from NBC 2016 and UDCPR 2019. The area of plot is fixed as 6280.9084 m^2, the type of building is assumed to be residential building. Marginal space at front, back and sides is left with reference to page 103, table 6-D, clause 6.2. According to UDCPR 2019 the road width for road adjoining the building with height more than 15 m should be more than 30 m, considering the same, the FSI is taken as 3, with reference to page 111, table 6-G of UDCPR. The margins to be left in front shall be 6 m, while side and rear margins shall be H/5 or 12 m. according to page 110, clause 6.2.3. Also, in case of residential buildings space should be left for amenities, page 53, clause 3.5 for UDCPR 2019, for the building under consideration for experimentation the space to be left is 5%. Before calculating the built-up area, the plot area remaining after deducting space for margins and amenities is determined. Hence after deductions the remaining area is 3532.63 m^2. Multiplying the remaining plot area with FSI 3 the determined built-up area is 10597.897 m^2. Dividing the built-up area with floor area of building, the number of stories is determined. Thus, the number of stories calculated are 17.

4. Determining the external dimensions of the aerodynamic buildings.

The aerodynamic shapes decided to be analyzed are square, rectangular, 4-side trapezoidal, 2-side trapezoidal, hexagonal, octagonal shaped buildings. By reversing the formula for area calculation, the sides of the aerodynamically shaped buildings can be calculated. The external dimensions for above mentioned buildings are given below:

Table -1: External Dimensions of Aerodynamically shaped buildings.

Calculation of side dimensions			
Sr. No.	Shape of Building	Formula for Area	Dimension of sides
	Square Building	A= S^2	S= 25 m
	Rectangular Building	A= S1 x S2	S1= 30.5 m S2= 20.5 m
	4-side Trapezoidal Building	A at bottom= 625 m^2 A at top= 531.25 m^2	S at top= 23.048 m S at bottom= 25 m
	2-side Trapezoidal Building	A at bottom= 625 m^2 A at top= 531.25 m^2	S1 at top= 25 m S2 at top= 21.25 m S1 at bottom= 25 m S2 at bottom= 25 m
	Hexagonal	A= $[(3\sqrt{3})/2] * S^2$	S= 15.5 m
	Octagonal	A= $2(1+\sqrt{2}) * S^2$	S= 11.377 m

5. Analysis of building shapes in ETABS.

Analysis in ETABS is done to obtain results of response of buildings in terms of displacement versus time, acceleration versus time, overturning moment, base shear. The gridlines of all the above-mentioned structures are established in ETABS. Further material and sectional properties like beams, columns and slabs are defined. After defining material and sectional properties, the load patterns that are affecting the structure are defined. Then the time history function is defined in which the data collected from accelerometer is imported. The load case for wind load is defined in terms of time history. In the next step, columns, beams, slabs are assigned to the building with the respective material.

The loads acting on the structures, such as dead load and live load acting on slab, super dead load acting on the beams and wind load in form of time history acting on joints of the structure are assigned. Restraints are assigned to the base of the structure. The model of structure is complete and analysis is carried out. Before analysis the load cases to be run are set and models are analyzed.

The model analysis is done and the plots are displayed in ETABS. Add pics of ETABS models.

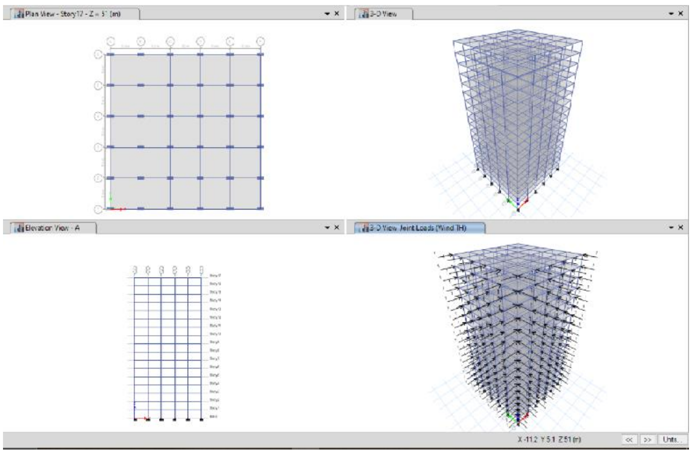

Fig - 1: Square shaped building.

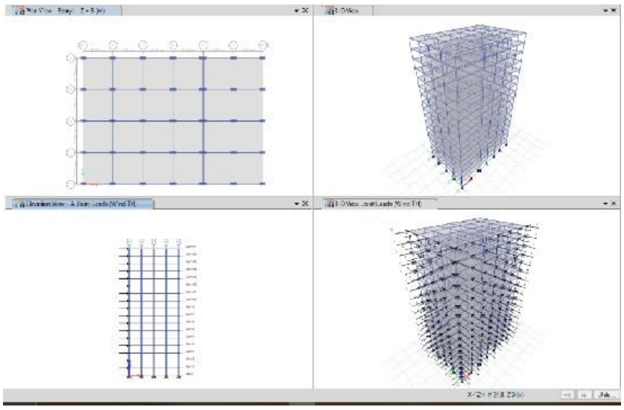

Fig - 2: Rectangular shaped building

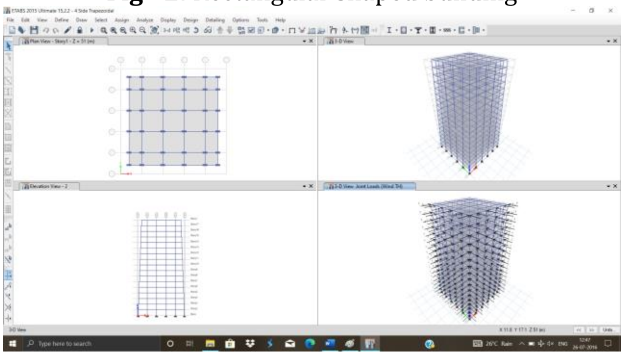

Fig - 3: 4- Side trapezoidal shaped building

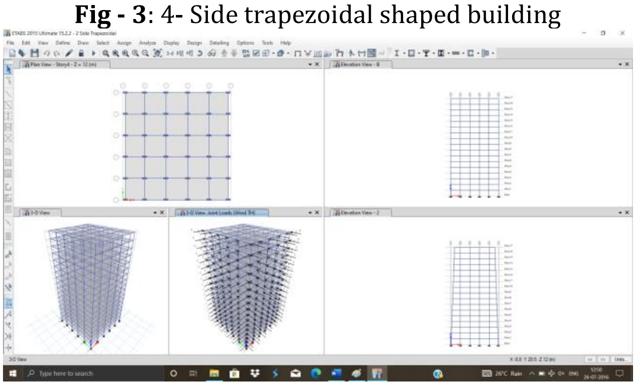

Fig - 4: 2-Side trapezoidal shaped building

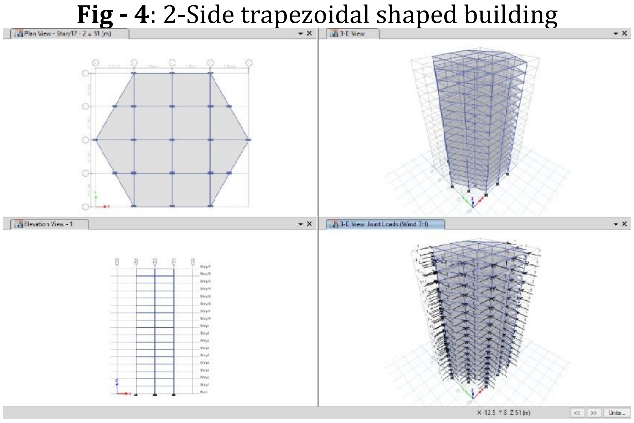

Fig - 5: Hexagon shaped building

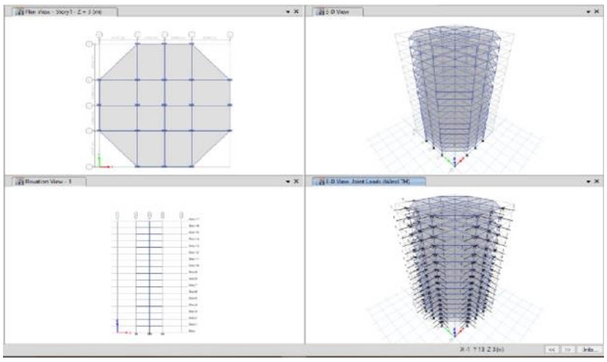

Fig - 6: Octagon shaped building

6. Results and Discussions.

The results from the time history analysis are displayed in form of tables and graphs. The results of displacement versus time, acceleration versus time, overturning moment and base shear are given below:

Table -2: Results for Time history analysis for wind in X direction.

Type of Building	Base Shear	Overturning Moment	Joint Displacement	Joint Acceleration
Square shaped	3.89 kN	38.92 kN.m	8.549 mm	3.93 mm/sec²
Rectangular shaped	-1.055 kN	35.885 kN.m	7.15 mm	3.298 mm/sec²
4-Side trapezoidal	1.2259 kN	-40.82 kN.m	8.94 mm	4.35 mm/sec²
2-Side trapezoidal	-1.149 kN	38.699 kN.m	7.488 mm	3.819 mm/sec²
Hexagon shaped	-0.574 kN	19.59 kN.m	15.57 mm	5.25 mm/sec²
Octagon Shaped	0.591 kN	-20.149 kN.m	14.99 mm	5.122 mm/sec²

Table -3: Results for Time history analysis for wind in Y direction.

Type of Building	Base Shear	Overturning Moment	Joint Displacement	Joint Acceleration
Square shaped	3.89 kN	38.92 kN.m	11.053 mm	4.51 mm/sec²
Rectangular shaped	-1.055 kN	35.885 kN.m	14.14 mm	5.526 mm/sec²
4-Side trapezoidal	1.2259 kN	-40.82 kN.m	11.133 mm	4.815 mm/sec²

2-Side trapezoidal	-1.149 kN	38.699 kN.m	11.36 mm	4.723 mm/sec^2
Hexagon shaped	-0.574 kN	19.59 kN.m	27.39 mm	8.285 mm/sec^2
Octagon Shaped	0.591 kN	-20.149 kN.m	19.027 mm	5.921 mm/sec^2

For wind loads in x- direction 4- Side trapezoidal building shows maximum base shear, whereas hexagonal and octagonal buildings show minimum base shear. 4- Side trapezoidal building shows maximum overturning moment and hexagonal and octagonal buildings show minimum overturning moments. Hexagonal and octagonal buildings show maximum displacement and rectangular building shows minimum displacement. Octagonal building followed by hexagonal building shows maximum acceleration and rectangular building shows minimum acceleration.

For wind in y- direction base shear and overturning moments remain the same for all models. Hexagonal building followed by octagonal building show maximum displacement; square building shows minimum displacement. Hexagonal building followed by octagonal building and rectangular building show maximum acceleration and square building shows minimum acceleration.

7. CONCLUSIONS

Efficient aerodynamic shape can be defined as a shape which performs consistently in all parameters of results discussion. Rectangular building performed well for wind loads in x- direction, but the results increased for load loads in y- direction, hence the building acts asymmetrically under different load conditions.

Octagonal building, square building and 2- Side trapezoidal building has symmetrical results for loads in both directions. 2- side trapezoidal building has higher base shear and overturning moment compared to octagonal building, but it also has less displacement and acceleration than octagonal and square building, and the base shear and overturning results for 2- Side trapezoidal buildings are less than square building.

Hence it can be concluded that 2- Side trapezoidal building acts most efficiently under wind loads in x and y directions aerodynamically.

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