Aerodynamic profiling of terminal building using computational fluid dynamics approach

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Abstract. A case study of isolated building is studied using ANSYS CFX and SAP2000. The plan idea of 30m by 60m is chosen for terminal building. The model is subjected to different wind incidence from 0° to 90° and 45° with 30° interval for 55m/s wind speed. By using tributary area method, the forces at the each mesh node are summed up to get corresponding wind force at that joint within that area. The best effective structural system is determined by designing the structure for each wind incidence. Wind analysis and design is carried out for increasing wind speed above 55m/s to identify the collapse pattern of structure. External supporting members are suggested to withstand that maximum wind speed.

1. Introduction

Wind is an important parameter to be considered for tall buildings. Buildings near to coastal areas are more prone to tropical cyclone. Recent cyclone reaches Very Severe and Extremely Severe Cyclonic storm category in Tropical Cyclone intensity scale. Also due to Cyclone Hudhud, Vizag terminal building has been damaged severely. Wind code IS875 (Part-3):1987 provides the wind load calculation for structure at orthogonal wind incidence. For skew wind incidence angles, there is no provision. And the maximum wind speed in IS code is 55m/s. There is no provision for cyclonic wind speed above 55m/s and also dynamic wind effects are not fully addressed. Recent Hudhud cyclone reached wind speed of 68 m/s. From this, it is clear that there is a necessity for alternate approach for more structural details. Wind tunnel experiments and CFD technique can be used as an alternative approach. Therefore, understanding the wind effects and pressure on the building is necessary to get more structural details. Proper wind loads determination helps us to avoid excess wind loads as well as unsafe structures.

2. Literature Review

Blocken.B and Carmeliet.J[1] had discussed the wind tunnel experiment and CFD validation for pedestrian wind conditions in passage between the two long narrow building. From this study, it is found that CFD validation shows better results. Aly Mousaad Alya and Joseph Bresowar [2] investigated mitigation features to reduce the uplift forces on the roof by CFD simulations. It is observed that roof with airfoil edges reduces significant uplift forces. Mohamed I. Farouk [3] conducted an investigation on occupants comfort in high rise buildings. Comparison is made for

standard equation and CFD result. It is observed that CFD result shows good accuracy. Souvik Chakraborty and Ashok Kumar Ahuja[4] conducted an experimental investigation of plus shape building. The flow pattern is observed using CFD analysis. The pressure contour and velocity flow is observed for that building.

3. Methodology

Wind analysis of structure for different wind incidence is carried out using ANSYS CFX. By tributary area method, the critical wind force at each joint is determined. Gravity loads are calculated as per IS 875(part 1 &2) 1987. Load combinations are considered as per IS800: 2007. By using SAP2000, analysis and design of the structure is done.

4. Analysis and Design

4.1. Model

A pitched roof model is taken as case study. The structure along with wind tunnel is modeled for the CFD analysis. The plan area is taken as 30 m x 60 m, eave and truss height of the model is 24m and 6m respectively. The wind tunnel dimension is taken in such a way that it should not disturb the velocity flow. The wind tunnel is rotated to get different wind incidence flow on the structure.
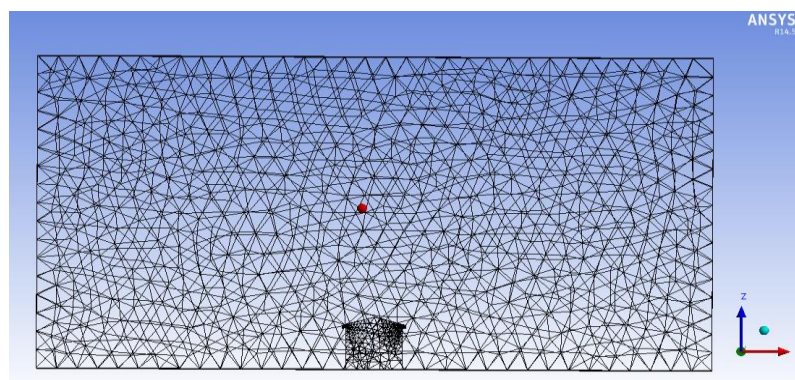
From the previous study, the wind tunnel model dimensions are chosen as the following boundary dimensions. The inlet and outlet boundaries have been extended to 5H and 15H respectively, where H is the height of the building.
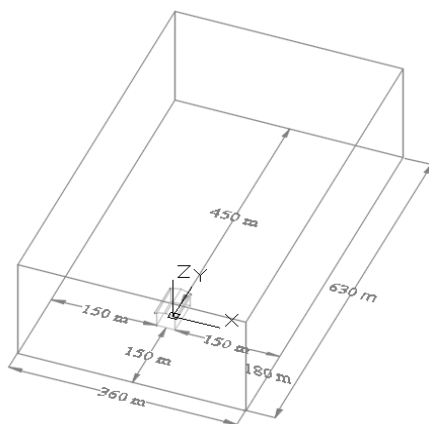
Figure 1. Structure with wind tunnel
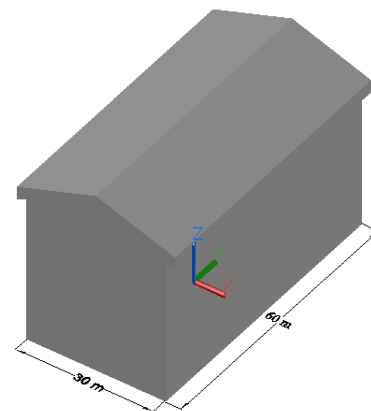
Figure 2. Structure

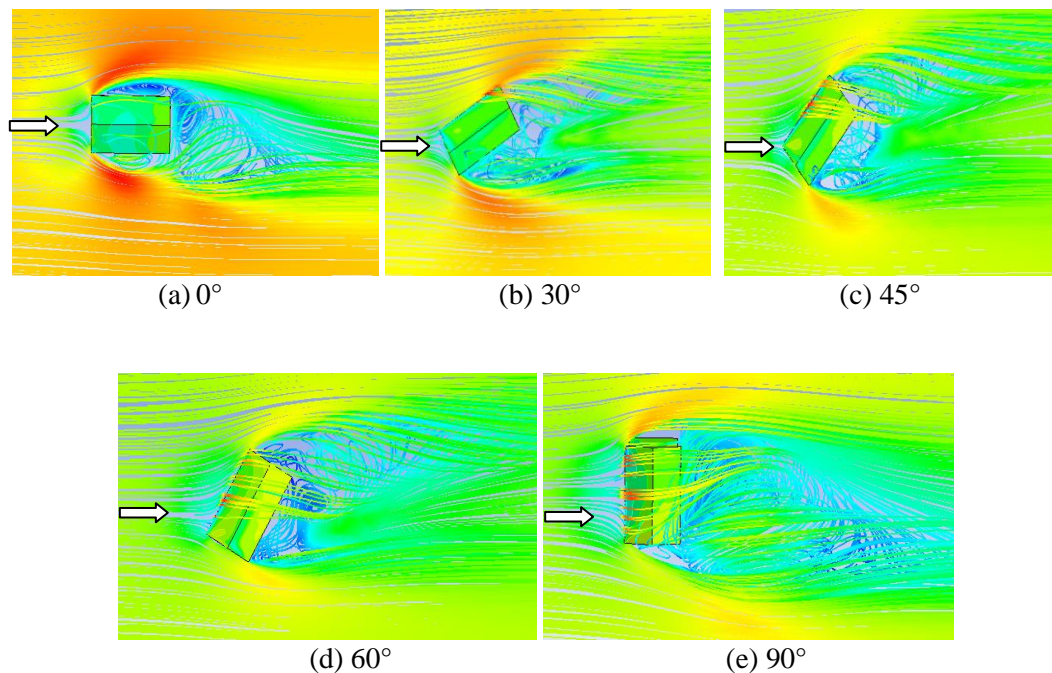**Figure 3.** Effect of soil stiffness on time period

(a) 0°   (b) 30°   (c) 45°

(d) 60°   (e) 90°

Figure 4. (a), (b), (c), (d) and (e) Velocity streamline for different wind incidence

4.2. Wind Analysis in ANSYS CFX
Tetrahedron meshing is done for the model in ANSYS CFX. Boundary conditions such as inlet, outlet and walls are assigned for the wind tunnel. At inlet, velocity of 55m/s wind speed is considered. To provide open atmospheric conditions, the surface of the tunnel is considered as free slip walls. No slip wall is considered for surface adjacent to the structure and the structure surface.

The velocity streamline of the structure are obtained from the analysis are shown in Fig.4. The wind flow around the buildings is clearly visualized above.

Figure 5 sows the pressure contour for different wind incidence. For orthogonal wind incidence, the surface subjected to direct wind incidence gets positive pressure at the surface and suction at the edges due to flow separation. For skew angles, pressure and suction on the surface depends up on the wind flow angle.

The parameters, pressure/ force at each mesh nodes are extracted from ANSYS CFD Post. By using tributary area method, the wind force at the each joint are determined.

4.3. Analysis and Design in SAP2000

   As per IS 800-2007, analysis and design are carried out. If the demand / capacity ratio is less than 1, then that member is considered as safe.

Table 1. Structural Specification

Length	60 m
Breadth	30 m
Height	30 m
Eave Height	24 m
No of bays in Y direction	10
No of bays in X direction	4

Table 2. Type of Section

Column	Pipe Section
Beam(Girt)	Tube Section
Purlin	Tube Section
Truss Elements	Pipe Section
Bracing	Pipe Section
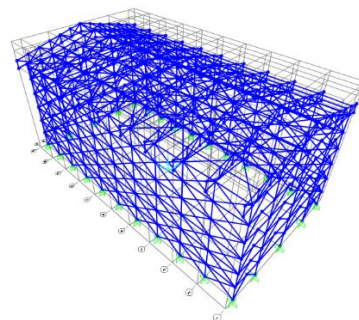
Figure 5. Effect of soil stiffness on time period
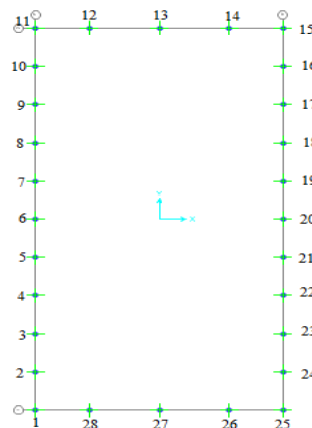
Figure 6. Column base node numbers

5. Results and Discussions

Table 3. Column Node Reactions for Different Wind Incidence Angle

Column Nodes Number	Wind Incidence Angle				
	0°	30°	45°	60°	90°
1	127.25	406.82	609.19	512.01	465.75
2	116.75	165.8	234.99	243.94	177.52
3	120.26	113.18	178.24	255.85	195.37
4	119.54	83.31	129.31	214.89	180.42
5	127.28	94.48	140.36	241.28	217.42
6	125.98	86.67	137.71	204.14	203.75
7	119.44	98.73	155.7	208.96	224.45
8	106.46	91.63	137.86	163.93	211.4
9	78.63	125.41	160.77	185.76	246.36
10	74.70	220.79	161.1	169.64	235.83
11	75.83	106.66	300.63	299.34	447.03
12	42.17	51.27	101.16	90.52	189.18
13	57.93	82.45	82.31	73.73	152.92
14	26.64	65.70	399.56	406.39	672.3
15	50.09	301.52	109.20	102.21	187.25
16	43.70	75.18	70.70	68.56	102.67
17	62.27	133.36	158.63	136.72	201.83
18	79.45	154.68	183.26	156.26	209.18
19	108.35	151.62	184.92	179.56	210.23
20	136.19	141.89	175.82	192.38	192.68
21	140.63	150.31	191.12	208.11	181.29
22	137.54	150.29	191.94	203.85	151.12
23	124.31	132.46	170.55	190.98	111.29
24	112.19	90.19	92.68	78.65	53.31
25	166.35	174.79	467.46	538.68	535.9
26	96.82	109.13	254.28	255.64	158.04
27	212.82	146.34	88.03	64.14	75.01
28	101.63	119.45	138.21	127.81	126.9

The column base node reactions are tabulated below. From the table 1, it is observed that for 0° wind incidence C27 need to bear highest load. Similarly, C12 for 30°, C1 for 45°, C25 for 60° and C14 for 90° wind incidence are bearing highest loads. And the lowest load bearing column for 0°, 30°, 45°, 60° and 90° wind incidence are C14,C12,C16,C27and C24 respectively.

Table 4 shows the average base reactions of the structure for critical load combination. The 0° wind incidence shows lowest reaction (4110kN) and highest reaction (5100kN) for 90° wind incidence. This shows that the building should withstand lower pressure when it oriented to 0° rather than 90°. Nearly 15 – 20 % average base reactions increases for 45° to 60° wind incidence.

Table 4. Average Base Reaction for Different Wind Incidence

Wind Incidence Angle	Average Base Reaction (kN)
0°	4755
30°	4780
45°	5355
60°	5585
90°	6560

Table 5 shows the quantity of required steel is minimum for 0° and maximum for 90° wind incidence. As compared to 0° wind incidence, nearly 20 - 25% increase in total weight for 45° to 90°. And there is only 2% increase for 30° wind incidence.

**Table 5.** Total Weight for Different Wind Incidence Angle

Wind Incidence Angle	Total Weight (Ton)
0°	411
30°	420
45°	490
60°	509
90°	510

From this it is observed that orienting the shorter dimension of the structure to wind incidence needs to sustain lower pressure thereby requires less quantity of steel.

Therefore 0° wind incidence is analysed for increasing wind speed, to find the collapse pattern of the structure. From the analysis and design, it is determined that up to 80m/s there is no failure in the structural member. At 90 – 100 m/s, the structure becomes unstable. From 85m/s, the some beams

provided at the eave height are failing. Later for the increasing wind speed along with those beams, the columns at the Face A are started to fail. Solutions are studied to make those members safe by providing external supports to the structure. Inclined members are chosen as supporting members with intermediate beams and bracings. With several trials, the required supports and the location are determined. The length of the inclined member is 20.8 m and is supported at 20 m height. It is determined that inclined members with 75° - 80° angle shows good results as supporting members.

By providing inclined external supports, the section members are passing for 85 – 90m/s without any failure.
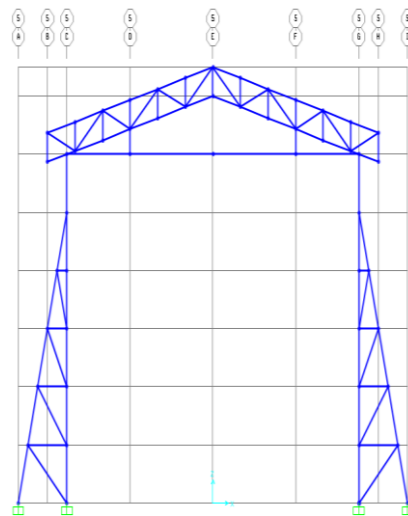
Figure 7. Model with External Support

6. Conclusion

Wind force provisions in IS875 (Part-3)1987 code are limited to 55m/s wind speed. CFD analysis shows better results, for more precise information of structure for wind speed in standard code as well as increasing wind speed. From the results, it is observed that orienting the shorter dimension of the structure to the wind direction needs to bear less pressure when compared to orienting the larger dimension of the structure to the wind direction.

References

[1] Blocken.B, Carmeliet.J and Stathopoulos.T 2008 . *J. Aerospace Engineering*, **vol. 21**, pp. 280-887.
[2] Aly Mousaad Alya and Joseph Bresowar 2016. *J. Building Engineering*, **vol. 5**, pp. 267-276.
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