STUDY ON EFFECT OF WIND FOR DIFFERENT STRUCTURAL CONFIGURATION USING E-TABS SOFTWARE

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Abstract –Increase in vertical growth of urban cities, high rise structures are being constructed enormously in recent years. This study elucidates the effect of wind on multi-storied structures for different structural configuration i.e. Rectangualr,L-shape,C-shape, T-shape. Analytical investigation and various analytical approaches are performed on the structures.Wind loads are determined as per IS: 875(part 3)-2015. These plans are modeled and analysed in ETABS 2016 software. Different load combinations are considered and the models are compared in different aspects such as storey displacement, storey drift etc. The results conclude, which shape of the building provide sound wind loading to the structure.

***Key Words*:**Wind load, Storey displacement, Storey drift, lateral load and ETABS 2016

1. INTRODUCTION

In this modern era, high rise building shows the potential of the country in the development of Infrastructure. Due to rapid growth in metropolitan, the land has become very scarcer, and the only alternative is to provide vertical occupancy by constructing tall buildings. Today, it is impossible to imagine a major city without tall buildings. High rise structures pose particular design challenges for structural engineers where they consider a different aspect such as safety, aesthetics and functionality of the structures. As the height increases the lateral loads play a crucial role. Wind is natural movement of air with certain velocity and these wind speeds are vulnerable and usually varies with time across different places. As these wind acting against the building structures from a lateral direction, it results in a force acting upon the elevation, called as wind force. These wind force directly depends on the wind speed at an particular location. As per IS 875: part 3, India is classified into different zones according to different wind speeds, called as basic wind speed map. The map consists of 6 zones of wind speeds 55, 50, 47, 44, 39 and 33 m/s. This project work deals with a building located in Bengaluru that has a basic wind speed of 33 m/s. Movement of wind is always lateral in nature, compared to other loads such as dead loads, live load and snow loads. And wind forces are also one of the most dominant horizontal force similar to earthquake loads. Another characteristic of wind loads are increase with the height of the structure. Due to this immense wind load acting on the large surface, the tall building usually sway in both X and Y direction. Wind force acting in lateral direction can cause disruption in the load path of the building, which leads to formation of cracks around the corners and walls of the structure. A larger wind speed acting on tall structure can cause movement in its foundation and also leads to overturn. Whenever wind acts on the surface of the structure, a large pocket of air is formed on the other side of the building which are low pressured zones producing large vibrational force which affects the resonance frequency of the structure and also causes huge turbulence. This phenomenon of formation of vortexes is known as vortex shedding. Since wind load leads to lateral displacement that causes discomfort to the occupant it poses as a main concerning problem in tall structures. Sometimes the actual force of high winds can cause a door or window to break open.

1.1. Objectives

The main objective of this project work is to contribute to the establishment of the design guidance for high rise buildings in reference to different shapes of building to control wind excitation load. In this project work, the concept of high-rise building, which include the definition, basic design considerations, and lateral loads; shape modifications of tall buildings, are studied. The results for different conditions are considered and conclusions are made as to which building's configuration out of four taken in the consideration, is most stable and optimal design.

1. To analyse four models having different structural shape (L, T, C, Rectangular) for displacement and story drift for G+25 floors considered in wind zone 2 (Bangalore).

2. To compare the lateral displacement and storey drift of different shaped structure against wind force using E-TABS software.

3. To verify the proposed design by comparison with those developed by other researchers and IS: 875 (part 3)-2015 provisions.

2. METHODOLOGY

The current study is limited to wind analysis for four different structural configurations (i.e. Rectangular, L-shape, C-shape, T-shape). All the tall buildings are of G+25 stories considered at Bengaluru within wind zone - II. The analytical calculations are made as per Indian Standard IS: 875 (part 3)-2015.

PROBLEM DEFINITION

A. General specifications of the buildings:

- Plan dimension: 60m x 40m
- Building dimension: 54m x 32m
- Number of stories: G+25

- Height of the building: 78m
- Type of soil: Hard soil

B. Member properties:

- Column size: 750mm x 750mm
- Beam size: 450mm x 450mm
- Slab thickness: 125mm
- Support condition: Fixed
- Storey height: 3000mm
- Wall thickness: 200mm
- Grade of concrete: For columns – M40 N/mm^2

: For beams and slabs – M25 N/mm^2

- Grade of steel: Fe500
- Density of cement blocks for wall: 11 kN/m^3
- Density of steel: 78.5 kN/m^3

C. Load specifications:

- Live load: Typical floors live load – 3 kN/m^2

: Terrace floor live load – 1.5 kN/m^2

- Dead load: Self weight of the elements

: Floor finish – 1.5kN/m^2

: Wall load - 5.61 kN/m^2

- Basic wind speed – 33m/s

As per IS :875(part 3)-2015,

- Wind speed : 33m/s
- Terrain category: 3
- Class: C
- Life of structure : 50 years

D. Building models

From ETABS:

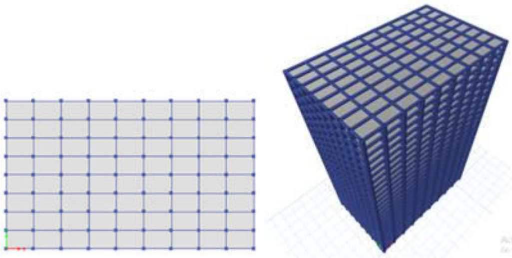

Fig-1 Plan and 3D-view of rectangular building

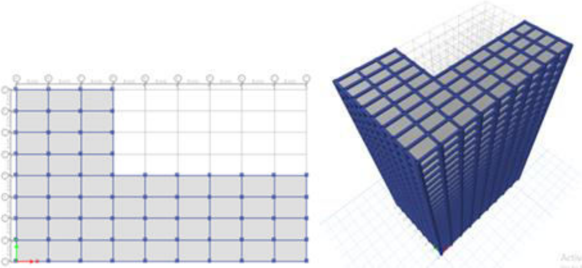

Fig-2 Plan and 3D-view L-shape building

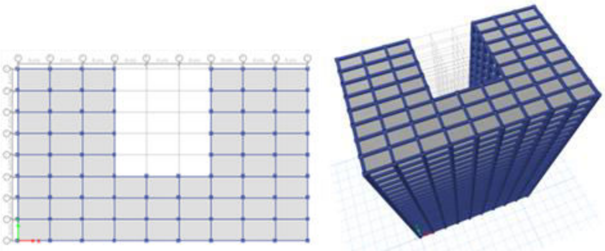

Fig-3 Plan and 3D-view C-shape building

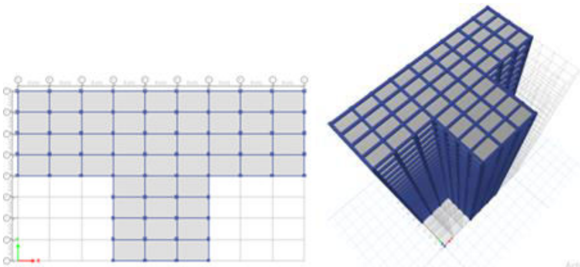

Fig-4 Plan and 3D-view T-shape building

AUTOCAD 2020 drawings:

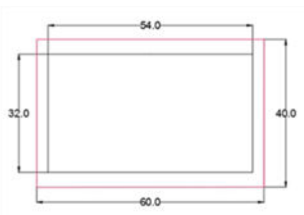

Fig-5 Rectangular plan

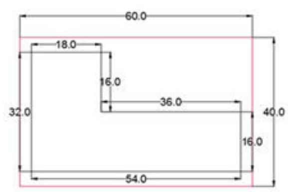

Fig-6 L-shape plan

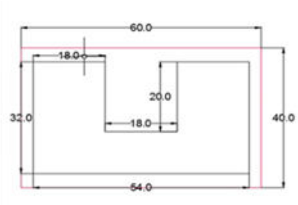

Fig-7 C-shape plan

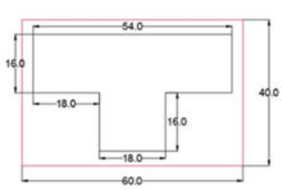

Fig-8 T-shape plan

3.ANALYSIS

3.1.Analytical

Design wind speed (Vz):
Vz = Vb .k1 .k2 .k3 .k4
Where, Vb = 33m/s
k1 = 1.0 (clause 6.3.1, table 1)
k2 = 1.164 (clause 6.3.2, table 2)
k3 = 1.0 (clause 6.3.3)
k4 = 1.0 (clause 6.3.4)
Vz = 38.412 m/s
Therefore, the wind speed is 38.412 m/s.
Design wind pressure (Pd):
Pd = Kd. Ka. Kc. Pz
Where, kd = 0.90 (clause 7.2.1)
ka = 0.8 (clause 7.2.2)
kc = 0.90 (clause 7.3.3.13)
And, Pz = 0.6 x Vz^2
= 885.29 N/m^2
Hence, Pd = 573.66 N/m^2
The value of pd, however shall not be taken as less than 0.70 X pz – (IS: 875 (part 3) – 2015, clause 7.2 and page number 9.)
573.66 N/m^2< 619.70 N/m^2
∴ Pd = 619.70 N/m^2
Now, Wind load on individual members (F) is calculated
F = (Cpe – Cpi)A.Pd

The percentage of openings is around 20 % (assumed). The lighting and ventilation is a must to the structure. The amount of natural ventilation required is exactly half that of the natural light requirement. In this paper, a building with medium openings is considered. The percentage of opening area to the wall area is less than or around 20% as per IS: 875 (part 3)-2015 for buildings with medium openings. The wall area is 9m2 and 2 window's area is 1.92m2. Approximately the percentage of openings is 20%. Hence, the Cpi value is considered as +0.5 and -0.5 (clause 7.3.2.2)
Now,

- Building height ratio i.e. H/W = 2.43
- Building plan ratio i.e. L/W =1.70

Based on these ratio's the external pressure coefficients (cpe) value are (+0.7, -0.4, -0.7, 0.7) for wind angle 0○ and for wind angle 90○ the values are (-0.5, -0.5, +0.8, -0.1).
The wind load is calculated in 8 ways with the coefficients obtained. In many practices the wind load is consisdered in two directions only which does not meet the accuracy or the standards. Therefore, according to the industrial based the wind load is analysed in 8 ways for effective results. They are listed below:

1. WIND(X+Cpi)
2. WIND(X-Cpi)
3. WIND(-X+Cpi)
4. WIND(-X-Cpi)
5. WIND(Y+Cpi)
6. WIND(Y-Cpi)
7. WIND(-Y+Cpi)
8. WIND(-Y-Cpi)

Wind load on individual members are determined.

3.2Software

ETABS that stands for Extended 3D Analysis of building System developed by CSI America is an ultimate integrated software package for the structural analysis and design of buildings.

Step by step procedure followed for the analysis and design of the building:

Step 1: Model creation
After launching the program, a new model was selected and SI units were assigned. Through grid system the models were generated in 2D and 3D view.

Step 2: Definition of properties
Member properites (i.e. M25, M40 and Fe500) were defined.

Step 3: Assining of members
Members are assigned as per the geometry of the building.
'Draw' → Draw Beam/Column/Brace objects → Quick draw Columns. Similarly, the beams and slabs have been assigned.
And the support is assigned as FIXED condition support.

Step 4: Definition of loads
The various considered loads were defined.
Eg. Self weight, floor finish, wall load, WIND(X+Cpi) so on.

Step 5: Assinging of loads
The defined loads are assigned to the structure. Dead loads, live loads and wind loads are seperately.

Step 6: Definition of load combinations
The various load combinatons mentioned below were defined:

- 1.5DL+1.5LL
- 1.5DL+1.5LL+1.5WIND(X+Cpi)
- 1.5DL+1.5LL+1.5WIND(X-Cpi)
- 1.5DL+1.5LL+1.5WIND(-X+Cpi)
- 1.5DL+1.5LL+1.5WIND(-X-Cpi)
- 1.5DL+1.5LL+1.5WIND(Y+Cpi)
- 1.5DL+1.5LL+1.5WIND(Y-Cpi)
- 1.5DL+1.5LL+1.5WIND(-Y+Cpi)
- 1.5DL+1.5LL+1.5WIND(-Y-Cpi)

Step 7: Diaphragm and Torsional constant
Diaphragm constraint is planar constraint connecting joints in a plane. Semi rigid diaphragm imitates actual in-plane stiffness properties and behaviour. Semi rigid diaphragms are more realistic than rigid diaphragms. Modified semi rigid Diaphragm is defined and assigned to each floor by using assign command.
'Assign' → Shell Diaphragm.
Torsional in beams are minimized with torsional constant as 0.01. To redistribute the torsional stresses from one member to another member a very low torsional modification factor value 0.01 is assigned. This set the torsional stiffness to almost zero which means it will not be able to take any torsional stresses. Therefore, the member need not be designed for torsion. 'Select' command → torsional constant is set to 0.01

Step 8: Analysis

Analysis check is performed for any errors to be rectified.
'Analyze'→ check model.
Further proceeded to 'Run analysis' command to observe the movement of the building.

Step 9: Design check
Concrete design check on every structural element is performed as per IS 456:2000.
'Design'→ concrete design.

Step 10: Results extraction
ETABS Software has a provision to display all the results in tabular form and can indicate the parameters required graphically.

4. RESULT AND DISCUSSION

4.1 Storey Displacement: This indicates the total displacement of any storey considering the ground as base/origin. According to Indian standards IS: 456 2000 the maximum storey displacement is limited to H/500, where H is total height of the building. The following are the storey displacement in X- direction of different structural configuration:

Table-1Maximumstoreydisplacement (1.5DL+1.5LL+WIND(X+Cpi))

Storey	Rectangular shape	L shape	C shape	T shape
0	0	0	0	0
1	1.299	0.325	0.426	0.384
2	3.117	1.678	1.521	1.884
3	4.835	3.502	3.119	3.951
4	6.46	5.532	4.882	6.243
5	8.017	7.606	6.684	8.592
6	9.505	9.653	8.464	10.917
7	10.925	11.638	10.19	13.179
8	12.278	13.546	11.846	15.357
9	13.565	15.366	13.423	17.441
10	14.784	17.096	14.918	19.424
11	15.936	18.733	16.327	21.305
12	17.021	20.275	17.651	23.082
13	18.039	21.722	18.887	24.753
14	18.99	23.073	20.036	26.317
15	19.873	24.328	21.109	27.775
16	20.688	25.486	22.175	29.125
17	21.436	26.547	23.163	30.368
18	22.116	27.511	24.074	31.502
19	22.728	28.378	24.907	32.529
20	23.272	29.148	25.663	33.446
21	23.748	29.821	26.34	34.256
22	24.156	30.396	26.94	34.957
23	24.498	30.877	27.463	35.552
24	24.778	31.267	27.91	36.042
25	25.008	31.586	28.284	36.433
26	25.17	31.879	28.594	36.735
27	25.475	32.195	28.853	36.97

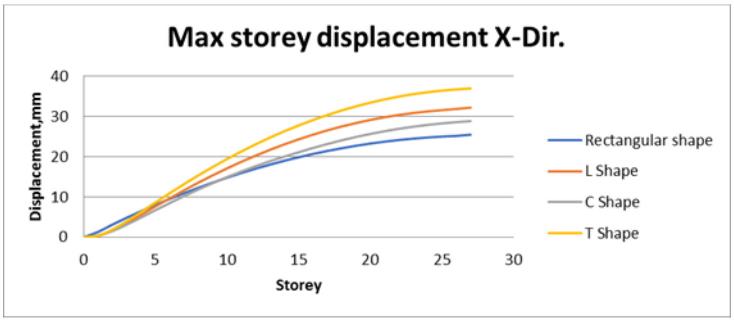

Fig-9 Maximum storey displacement X direction

From the above table and its related graph, it is observed that as the building height increases the storey displacement also increases and the maximum storey displacement is achieved at the top most (27th) storey of the building. It has been observed that for the load combination of (1.5DL+1.5LL+WIND(X+Cpi) in X direction the maximum impact of the displacement is found in T shape structural configuration of 36.97mm due to irregularity in geometry layout.

The following table represents the storey displacement in Y-direction.

Table-2 Maximum storey displacement (1.5DL+1.5LL+WIND(Y+Cpi))

Storey	Rectangular shape	L shape	C shape	T shape
0	0	0	0	0
1	1.343	0.533	0.534	0.356
2	3.191	2.609	1.67	1.69
3	4.91	5.39	3.395	3.461
4	6.533	8.435	5.282	5.366
5	8.083	11.54	7.217	7.279
6	9.567	14.616	9.151	9.146
7	10.989	17.622	11.059	10.943
8	12.349	20.537	12.93	12.657
9	13.649	23.35	14.759	14.285
10	14.886	26.056	16.541	15.824
11	16.062	28.65	18.273	17.272
12	17.174	31.129	19.953	18.629
13	18.224	33.49	21.58	19.894
14	19.209	35.731	23.15	21.066
15	20.13	37.85	24.663	22.147
16	30.987	39.845	26.116	23.134
17	21.778	41.714	27.508	24.029
18	22.504	43.456	28.837	24.831
19	23.165	45.069	30.102	25.54
20	23.759	46.553	31.301	26.158
21	24.288	47.906	32.434	26.683
22	24.751	49.128	33.498	27.117
23	25.147	50.218	34.492	27.461
24	25.479	51.175	35.417	27.717
25	25.754	52	36.273	27.888
26	25.978	52.712	37.062	27.982
27	26.217	53.338	37.794	28.016

From the analysis with respect to Y-direction the maximum impact of the storey displacement with the load combination of (1.5DL+1.5LL+WIND(Y+Cpi)) have been considered. It is observed that L shape structure is more prone to displace by 53.338mm when its analysed from Y direction. This is due to the structural shape of the building.

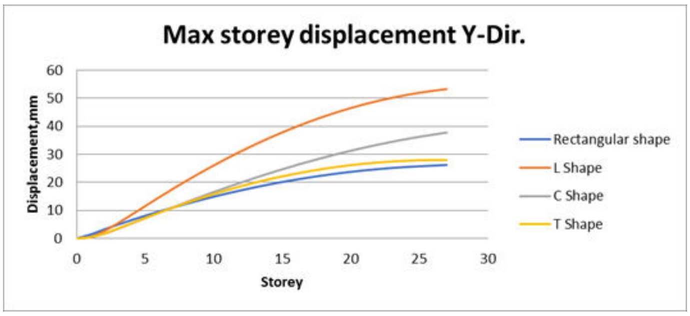

Fig-10 Maximum storey displacement Y-direction

4.2 Storey Drift: It is the lateral displacement of one storey with respective to other storey. As per the code IS: 1893-2002 the maximum storey drift is limited to 0.004h, where h is storey height of the building. The maximum storey drift for rectangular, L, C, T shape are compared and it is graphically represented below:

The following table represents the storey drift in X-direction. for the load combinations of (1.5DL+1.5LL+WIND(X+Cpi)).

Table-3 Maximum storey drift (1.5DL+1.5LL+WIND(X+Cpi))

Storey	Rectangular shape	L shape	C shape	T shape
0	0	0	0	0
1	0.00065	0.000176	0.000213	0.000192
2	0.000606	0.000447	0.000406	0.000507
3	0.000573	0.000617	0.000533	0.000689
4	0.000547	0.000678	0.000587	0.000764
5	0.00052	0.000691	0.000601	0.000783
6	0.000496	0.000682	0.000593	0.000775
7	0.000476	0.000662	0.000575	0.000754
8	0.000451	0.000636	0.000552	0.000726
9	0.000429	0.000607	0.000528	0.000694
10	0.000407	0.000577	0.000505	0.000661
11	0.000384	0.000546	0.000481	0.000627
12	0.000362	0.000514	0.000456	0.000592
13	0.000339	0.000482	0.000431	0.000557
14	0.000317	0.00045	0.000406	0.000522
15	0.000295	0.000418	0.000381	0.000486
16	0.000272	0.000386	0.000355	0.00045
17	0.000249	0.000354	0.000329	0.000414
18	0.000227	0.000321	0.000304	0.000378
19	0.000204	0.000289	0.000278	0.000342
20	0.000182	0.000257	0.000252	0.000306
21	0.000159	0.000224	0.00026	0.00027
22	0.000137	0.000192	0.0002	0.000234
23	0.000114	0.00016	0.000174	0.000198
24	9.30E-05	0.000131	0.000149	0.000163
25	7.70E-05	0.000106	0.000125	0.00013
26	5.60E-05	9.80E-05	0.000103	0.000101
27	0.000118	0.000116	8.06E-05	7.80E-05

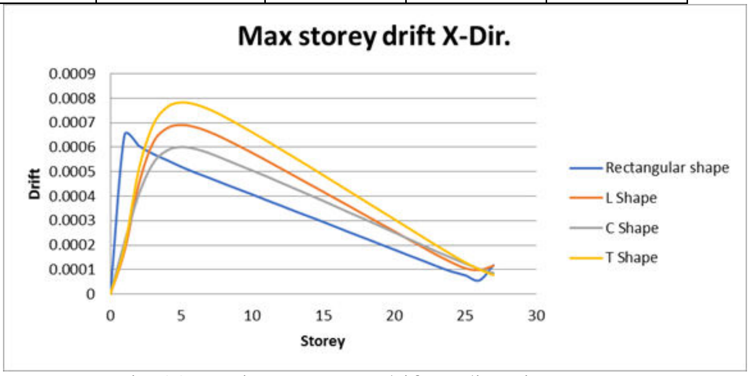

Fig-11 Maximum storey drift X-direction.

From the Fig. i.e. Storey vs Drift the maximum storey drift is observed at the 5th storey of L, C, and T shape structure. And for the rectangular shape the maximum storey drift is observed at the 1st storey of the structure due to stiffness irregularity. From the above data it is observed that, all storey drifts are within the permissible limit (0.004x3=0.012mm). The below obtained result is for the load combination of (1.5DL+1.5LL+ WIND(Y+Cpi)).

Table-4 Maximum storey drift (1.5DL+1.5LL+WIND(Y+Cpi))

Storey	Rectangular shape	L shape	C shape	T shape
0	0	0	0	0
1	0.000671	0.000267	0.000267	0.000178
2	0.000616	0.000643	0.000445	0.000451
3	0.000573	0.00093	0.000575	0.00059
4	0.000542	0.001015	0.000629	0.000635
5	0.000517	0.001035	0.000645	0.000638
6	0.000495	0.001025	0.000644	0.000622
7	0.000474	0.001002	0.000636	0.000599
8	0.000454	0.000972	0.000624	0.000572
9	0.000433	0.000938	0.00061	0.000543
10	0.000413	0.000902	0.000594	0.000513
11	0.000392	0.000865	0.000577	0.000483
12	0.000371	0.000826	0.00056	0.000452
13	0.00035	0.000787	0.000542	0.000422
14	0.000329	0.000747	0.000523	0.000391
15	0.000307	0.000706	0.000504	0.00036
16	0.000286	0.000665	0.000484	0.000329
17	0.000264	0.000623	0.000464	0.000298
18	0.000242	0.000581	0.000443	0.000267
19	0.00022	0.000538	0.000422	0.000237
20	0.000198	0.000495	0.0004	0.000206
21	0.000176	0.000451	0.000377	0.000175
22	0.000154	0.000407	0.000355	0.000145
23	0.000133	0.000363	0.000332	0.000115
24	0.000111	0.000319	0.000308	8.50E-05
25	9.20E-05	0.000275	0.000285	5.70E-05
26	7.70E-05	0.000237	0.000263	3.10E-05
27	9.20E-05	0.000216	0.000244	1.20E-05

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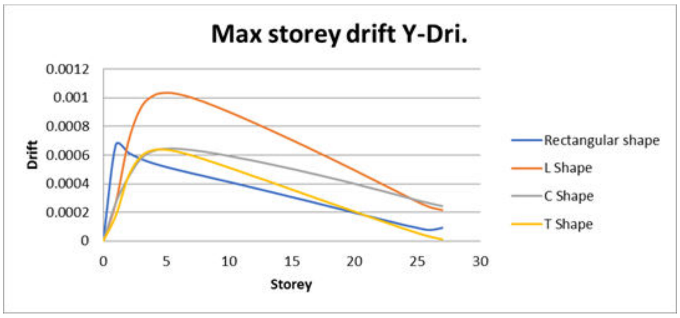


Fig-12 Maximum storey drift Y-direction.

In Y-direction, it has been observed that the impact of maximum storey drift is obtained at the 5th storey of L, C, and T shape structural configuration. In rectangular shape building the maximum storey drift is obtained at the 1st storey by 0.000671. According to the above data the maximum storey drift is observed in the lower storeys because of stiffness irregularity.

4.3 Time period: The time taken by a building to undergo one complete cycle of oscillation. In order to understand the performance of the building under the effect of lateral loads, it is necessary to evaluate the time period of a structure. The time period plays a major role in determines the base shear. The following table represents the time period that has been evaluated for different number of modes from ETABS.

Table-5 Natural time period

Mode	Rectangular shape	L shape	C shape	T shape
Mode 1	4.259	3.945	4.028	3.947
Mode 2	3.644	3.541	3.394	3.468
Mode 3	3.482	3.293	3.298	3.398
Mode 4	1.368	1.28	1.304	1.28
Mode 5	1.191	1.143	1.103	1.123
Mode 6	1.139	1.072	1.075	1.101
Mode 7	0.79	0.728	0.738	0.729
Mode 8	0.678	0.642	0.628	0.635
Mode 9	0.654	0.613	0.616	0.623
Mode 10	0.532	0.49	0.496	0.49
Mode 11	0.462	0.436	0.428	0.432
Mode 12	0.445	0.418	0.419	0.423

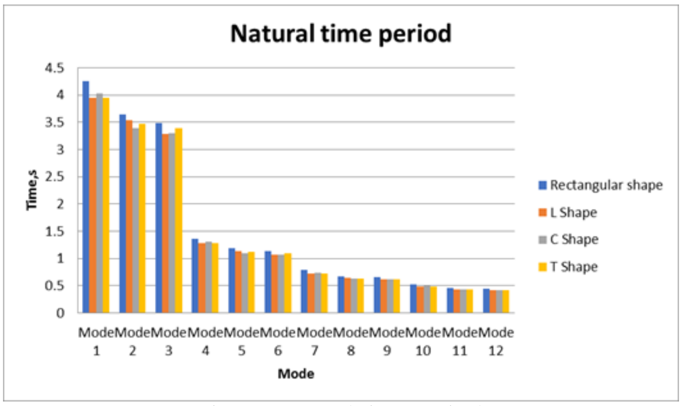
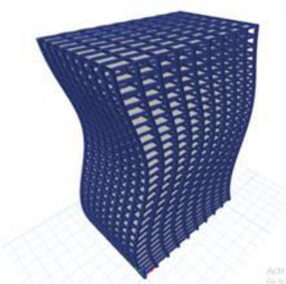


Fig-13 Natural time period

From the result it has been observed that the time period of rectangular shape structure is greater than the other structural configuration considered. The maximum value of time period is achieved in mode one.

The following are the deformed shape of the structure (Mode 7):



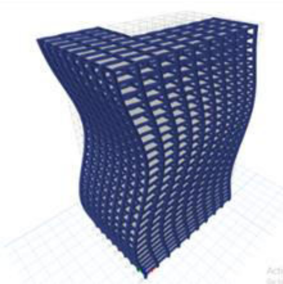
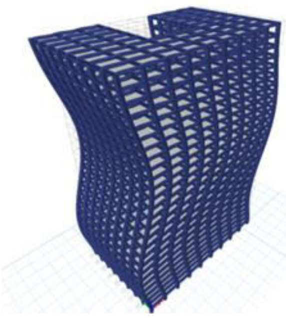


Fig-14 Rectangular shape Fig-15 L shape



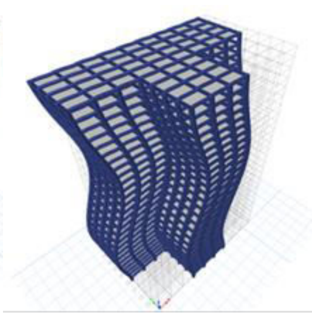


Fig-16 C-shape Fig-17 T-shape

4.4 Base Reaction/Moment:

The maximum lateral force that will occur at the base of the structure. The base reactions for the load combination of (1.5DL+1.5LL+WIND(X+Cpi) is observed below. The following table and the figure show the comparison of base reaction of different structural configuration under consideration. It is observed that the base reaction is maximum in FZ direction.

Table-6 Base reactions

Base Reaction	Rectangular shape	L shape	C shape	T shape
FX	-2611.2	-2180.64	-2611.2	-2448
FY	0	267.48	534.96	-534.96
FZ	1014507	678183.7	805745.1	673915.7

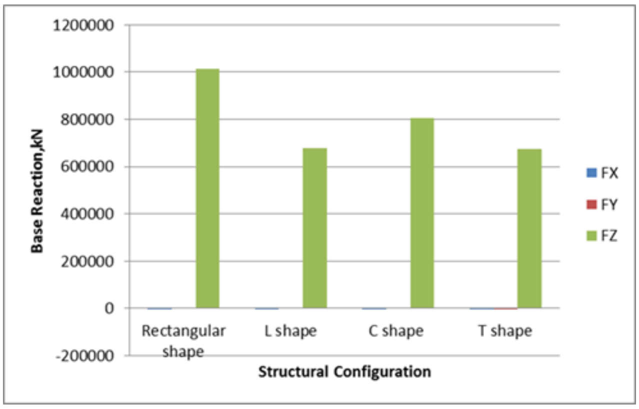


Fig-18 Base reactions

It is observed that the base moment is maximum in rectangular shape structure compared to other structures in MX direction.

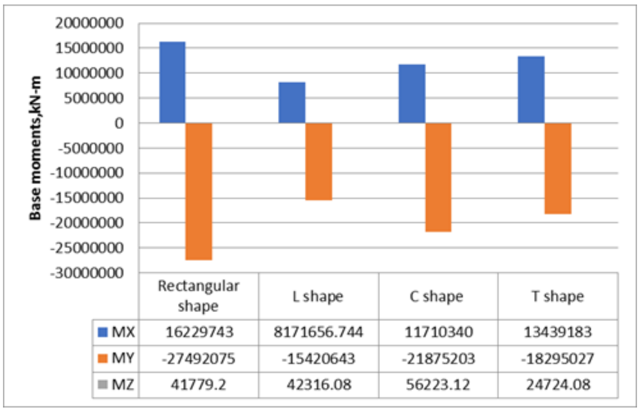


Fig-19 Base moments

5. CONCLUSIONS

The strength of the multi-storey building mainly depends on the plan, vertical orientation and dynamic effects. G+25 storied building of different shapes such as rectangular, L, T and C shaped were undertaken for the present study. The following are the conclusions derived from the analysis results.

1. The irregular shaped buildings show poor performance when subjected greater wind force.
2. The results obtained by E-tabs software are comparable with the results obtained by IS codal provision and hence the software can be conveniently used for the analysis of high-rise building.
3. T-shaped structural configuration has been found to be 31.09% higher for storey displacement in X direction, and L-shaped structural configuration has been found to be 50.84% higher for storey displacement in Y direction than the Rectangular structural configuration respectively against the wind forces.
4. In the same manner, T-shaped structural configuration proved to be 24.74% larger having maximum storey drift in X direction, and L-shaped structural configuration has been found to be having 50.04% larger storey drift in Y direction than the Rectangular structural configuration respectively against wind forces.
5. The natural time period of L-shaped structural configuration is found to be minimum among the considered configurations with 7.95% lesser than Rectangular structural configuration.
6. Rectangular structural configuration has the minimum base shear and moment values as compared to T-shaped structural configuration followed by C-shaped structural configuration.
7. From the above obtained results by the software, the rectangular structural configuration can be considered as the most feasible configurations under consideration for wind forces.
8. T-shaped buildings shall not be preferable in wind prone zone due to large displacement and less stiffness against wind force. Whereas C-shaped and T-shaped configuration structure with additional frames and bracing system considered are appreciable. The study shows that the effect of wind load on multi storey structure is accountable for high rise structure and also depends on shape of buildings.

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