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Comparative Study of Tall Structures with Plan Irregularity Subjected to Wind Load

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***Abstract*— Wind is a perceptible natural motion of air relative to earth surface, especially in the form of air current blowing in a particular direction. Wind loads is caused by difference in pressure. In this discussion calculation of wind response of structure for various parameters by static method by considering the effect of change in terrain category as described by the code (IS 875:1987 PART III). manually and by user SAP-2000 program. Typical results of variation of Displacement, Storey drift, Time period and Base shear have been included. The analysis of these building using present code indicates that for Terrain category 1,2,3 and 4 by static method. Then beam with normal slab is compared with flat slab in terrain category 1 for different shape of building in static method.**

Keywords*— *Wind loads; Terrain category; static method; normal slab; flat slab; SAP-2000

I. INTRODUCTION

Now a day's world is behind modernization and the new technics in construction. Due to this there is an increase in traffic and less availability of land which necessitate the construction of tall building. Such structure generally exhibits an increase susceptibility to the action of wind. Wind is the phenomenon of great complicity because of many flow arising from the interaction of wind with the structure. Wind is caused by difference in temperature over the earth surface. As per the national building code 2015 of INDIA building height more than 15m is considered as tall building. Generally, such structure is more affected by the action of wind. The structure engineer should ensure that the structure should be safe and serviceable during its anticipated life even if it is subjected to wind load on tall structures. Wind impacts on structure can be named as:

1) Static Impact
2) Dynamic Impact

1. Static Impact

Static wind impact basically causes elastic bending and twisting of structure. This method is used for analysis of low rise structure.

2. Dynamic Impact

For high rise, long traverse and thin buildings a dynamic analysis of the buildings is vital, Wind gusts cause unstable wave forces on building which induce huge dynamic movements, as well as oscillations.

A. Parabolistic Approach

In several engineering sciences intensity of definite procedure in taken to function of period repetition interval. For example, in hydrology the rain fall intensity predicable one time in an area is taken in terms of return period for the reason that that rain predictable one time in 10 years is lesser than the one predictable once in 50 years. Likewise, in wind engineering wind speed is taken to contrast with return periods.

B. Wind turbulence

Turbulence is nothing but motion of wind. The exact meaning for turbulence is little hard to define excepting to express that it will occurs due to wind flow for the reason that viscosity of air is very low nearly one sixteenth of water. If the speed of the air is more than 2-3miles per hour, then it is called wind is in turbulence.it will cause random movement of air particles in all section.

C. Vortex Shedding

Generally, wind buffeting in contrast to a bluff form will get diverted in three mutually perpendicular directions, resulting to the forces and moments about three directions. Though all six components are important in the aeronautical engineering, in civil and structural engineering, forces and moments corresponding to the vertical axis (lift and yawing moment) are of less important. Thus, sidewise from uplift forces on large roof parts, the motion of wind is made easy and taken in two dimensional consisting of along wind and traverse wind.

D. Response parameters

Induced wind response of a high rise structure is a function of many parameters. These include the dynamic and geometric properties of structure and turbulence characteristic of the flow. Some of analytical approaches can be used for the calculation of the wind induced response of the tall structures in along and across wind direction.

E. Torsional Wind Load

The twisting motion of a bluff body subjected to air flow results from the non-uniform pressure distribution around the wall face of the body. This mechanism was generally studied through measuring aerodynamic loads in wind tunnel tests on bluff bodies with varying shapes, presence of other interfering bodies and various angle of the approaching flow. Codes and standards do not give appropriate procedure for computing the torsional wind response.

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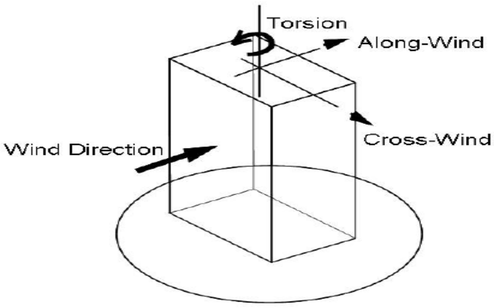


Fig 1. Wind Response direction

F. Terrain Catagories

Selection of terrain categories shall be made with due regard to the effect of obstructions which constitute the ground surface roughness. The terrain category used in the design of structure may vary depending on the direction of wind under consideration.

Category 1 - Exposed open terrain with rare or no obstructions and in which the average height of any object surrounding the structure is less than 1.5 m.

Category 2 - Open territory with well scattered obstructions having heights generally between 1.5 to 10 m.

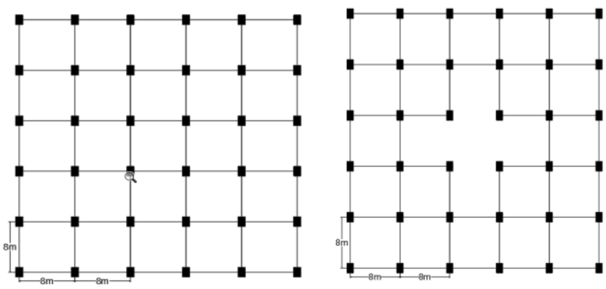
Category 3 - Territory with several closely spaced obstructions having the size of building-structures up to 10 m in height with or without a few isolated tall structures.

Category 4 - Terrain with several large high closely spaced obstructions. This category includes large city centres, usually with obstructions above 25m and well developed industrial complexes.

II. METHODLOGY

In this paper, the buildings have been analyzed under wind analysis in SAP 2000 (V19). SAP 2000is software used for analysis and design of building. Both linear and nonlinear analysis can be done by SAP 2000.

Here, linear static analysis has been used for analyzing the building. For the study, compare the flat slab and beam column, Variation of stiffness and different shapes of building under the action of wind load is considered. There are 5 number of bays in the study of flat slab and 6 bays in shape effect in both X and Y directions and each bay is 8m. The typical storey height is 3m. The RC structural members are designed as per code provisions. The slab thickness is 150mm. The total height of building in 75m(G+24).



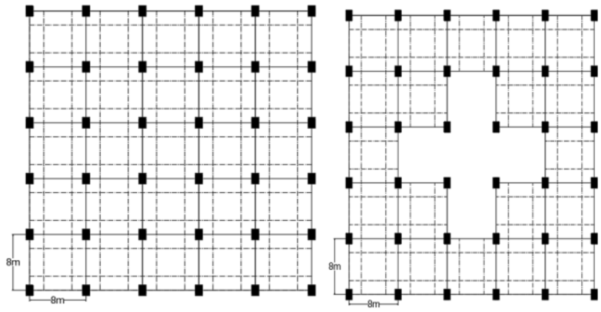


Fig 2. Plan of flat slab with drop and beam column model

Fig 2. Shows the plan of flat slab with drop and beam column model used in analysis.

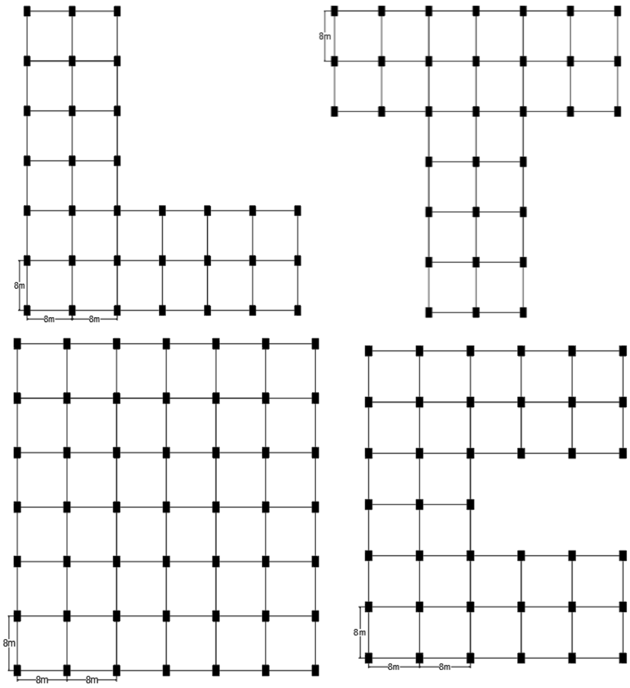


Fig 3. Plan of different shapes of model

Fig 3. Shows the plan of different shapes model used in analysis.

A. Design of wind loads

The Indian wind code suggests two methods for computation of wind loads on buildings and other structures, viz., force co-efficient or static method and dynamic or gust factor method.

a. Static Method

As per Force co-efficient process or static method the structural design wind loads are estimated by considering following equations:

$Vz = V_b*k1*k2*k3$

$p_z = 0.6\ Vz^2$

Where p_z-design wind pressure in N/m^2 at height z

V_b-basic wind speed

Vz- design wind speed at any height in m/s

k1- probability factor

k2- terrain, height and structure size factor

k3- topography factor

The topography factor k3 is given by the following:

ks = 1+ Cs

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s is a consider determined understanding with C-2.1 (IS 875 Part 3) fitting to the stature, H above mean ground level and the separation, X, from the summit or peak in respect to the powerful length, Le. Table 1 shows k3 factor for different angle of slope.

TABLE 1. TOPOGRAPHY FACTOR K3

Slope	**C**
3˚ < ϴ ≤ 17˚	1.2 (z/L)
> 17 ˚	0.36

III. ANALYSIS

The buildings were modelled in SAP 2000with the parameters from table 1. The buildings were analyzed and designed by applying dead loads and live loads before applying the lateral loads to check the safety of the structure. Once the building is safe, lateral loads were applied.

Table below shows the parameters that are considered in this study.

TABLE 2. PARAMETER CONSIDER FOR ANALYSIS OF STRUCTURE

No of storey	G+24
Typical storey height	3m
Material properties	
Grade of concrete	M30 for beam and slab
	M50 for column
Grade of steel	Fe500
Density of concrete	25kN/m^3
Member properties	
Slab thickness	0.2m
Beam size	0.3X0.6m
Column Size	0.45X0.95m
Loads considered	
Live loads	4kN/m^2 for floor
	2kN/m^2 for roof
Floor finish	1.2kN/m^2

A. Wind load Calculation

Wind Speed -55kmph (worst condition)
Design life of Structures -50 years
Risk coefficient factor(k1) =1

Terrain, height and structure size factor(k2) =Its variable with respect to height of the building (Terrain category 1 Class A building for a height of 75m) =1.23

Topography factor(k3) =1.36(taking slope >17 ˚)

Vz=55*1*1.23*1.36=92m/s

Pz=0.6*92*92=5.078kN/m^2

For face of building

A=5.078*0.8*3=12.2 kN/m^2

B=5.078*0.28*3=3.8 kN/m^2

IV. RESULTS AND DISCUSSIONS

The obtained results from the analysis were tabulated and lateral displacements, storey drift and base shear at the end of Projections were noted down.

Graphs of lateral displacement v/s Number of storeys were plotted for wind X at end of corner for comparison of flat slab, different shapes and variation of stiffness for buildings is shown below.

A. Comparision between flat slab and beam column slab

The comparison between beam column and flat slab is checked in terrain category 1 to 4 for joint displacement, storey drift, base shear.

a. Joint displacement

From the analysis the results of joint displacement as shown in below table for terrain category 1. Joint displacement for other categories are varied linearly with terrain category 1, so the multification factors with terrain category 1 shown below.

TABLE 3. MULTIFICATION FACTOR FOR DIFFERENT TERRAIN CATEGORY.

TERRAIN CATEGORY	**MULTIFICATION FACTOR**
TERRAIN CATEGORY 1	1
TERRAIN CATEGORY 2	0.96
TERRAIN CATEGORY 3	0.89
TERRAIN CATEGORY 4	0.86

The below table shows joint displacement for beam column and flat slab with drop with both solid and open structures.

TABLE 4. FULL FORM OF HEADING IN TABLE 6 AND 7.

BC S	BEAM COLUMN WITH SOLID
BC O	BEAM COLUMN WITH OPEN
FS S	FLAT SLAB WITH SOLID
FS O	FLAT SLAB WIEH OPEN

TABLE 5. DISPLACEMENT FOR FLAT SLAB AND BEAM COLUMN

STOREY HEIGHT	**JOINT DISPLACEMENT**			
	BC S	***BC O***	***FS S***	***FS O***
0	0	0	0	0
3	4.9	5.3	6.3	7.3
6	14.9	16.3	19.2	22.5
9	26.6	29.5	34.3	41.0
12	38.8	43.3	50.0	60.5
15	51.0	57.1	65.6	80.2
18	62.8	70.6	80.8	99.5
21	74.2	83.7	95.5	118.3
24	85.1	96.3	109.6	136.3
27	95.6	108.4	123.0	153.7
30	105.5	119.9	135.8	170.2
33	114.9	130.8	147.9	185.9
36	123.7	141.1	159.3	200.7
39	132.0	150.8	170.0	214.7
42	139.7	159.9	180.0	227.8
45	146.9	168.3	189.2	239.9
48	153.5	176.0	197.7	251.1
51	159.4	183.1	205.4	261.4
54	164.8	189.5	212.3	270.6
57	169.5	195.2	218.4	278.9
60	173.7	200.2	223.7	286.2
63	177.2	204.5	228.3	292.6
66	180.1	208.2	232.1	297.9
69	182.4	211.1	235.0	302.3
72	184.2	213.5	237.3	305.8
75	185.5	215.3	239.0	308.7

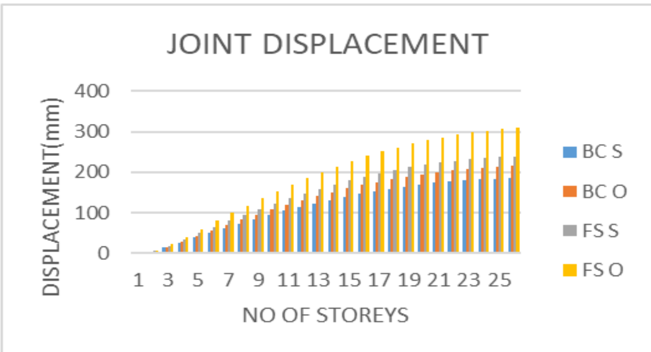

Fig 4. Storey displacement for flat slab and beam column

From the above graph it shows that flat slab with hollow structure is more displacement compare to other structure in all 4 categories.

b. Storey Drift

From the analysis the results of storey drift as shown in below table for terrain category 1. Storey drift for other categories are varied linearly with terrain category 1. The below table shows storey drift for beam column and flat slab with drop with both solid and open structures.

TABLE 6. STOREY DRIFT FOR FLAT SLAB AND BEAM COLUMN

STOREY HEIGHT	STOREY DRIFT			
	BC S	*BC O*	*FS S*	*FS O*
0	0	0	0	0
3	4.9	5.3	6.3	7.3
6	10.0	11.0	12.8	15.3
9	11.7	13.2	15.1	18.5
12	12.2	13.8	15.7	19.6
15	12.1	13.8	15.6	19.7
18	11.8	13.5	15.2	19.3
21	11.4	13.1	14.7	18.8
24	10.9	12.6	14.1	18.1
27	10.4	12.1	13.4	17.3
30	9.9	11.5	12.8	16.5
33	9.4	10.9	12.1	15.7
36	8.8	10.3	11.4	14.8
39	8.3	9.7	10.7	14.0
42	7.7	9.1	10.0	13.1
45	7.1	8.4	9.2	12.1
48	6.6	7.7	8.5	11.2
51	6.0	7.1	7.7	10.3
54	5.4	6.4	6.9	9.3
57	4.8	5.7	6.1	8.3
60	4.1	5.0	5.3	7.3
63	3.5	4.3	4.5	6.3
66	2.9	3.6	3.8	5.3
69	2.3	3.0	3.0	4.4
72	1.8	2.3	2.3	3.5
75	1.3	1.9	1.7	2.9

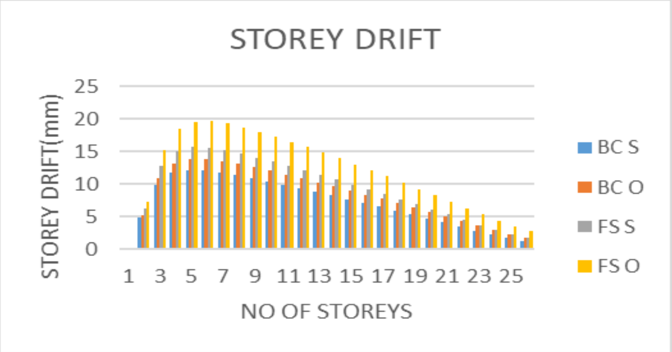

Fig 5. Storey drift for flat slab and beam column

From the Fig5 shows that flat slab with hollow structure is more displacement compare to other structure in all 4 categories. The storey drift is maximum at 5th floor(15m) in all structures.

c. *Base Shear*

After analysis of building with beam column and flat slab in four terrain categories with both solid and hollow structures. Base shear in KN. The below table shows the base shaer for different terrain categories.

TABLE 7. BASE SHEAR FOR DIFFERENT CATEGORY

CATEGORY 1	CATEGORY 2	CATEGORY 3	CATEGORY 4
17215	16211	14550	12711

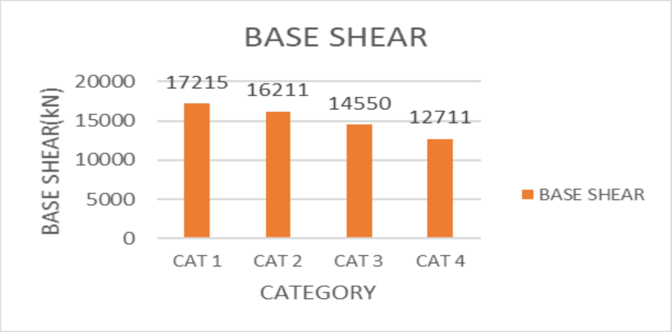

Fig 6. Base shear for structure

From the Fig 6. clearly shows that base shear is more in terrain category I compare to other three categories.

B. Compare with different Shapes of structure

In this study structure is analyzed for wind force in different terrain categories for solid, T, U and L shapes. The joint displacement for different shapes as tabulated below.

TABLE 8. DISPLACEMENT FOR DIFFERENT SHAPE OF STRUCTURES

STOREY HEIGHT	DIFFERENT SHAPE OF STRUCTURE			
	SOLID	*L SHAPE*	*T SHAPE*	*U SHAPE*
0	0	0	0	0
3	4.2	10.7	11.1	4.8
6	12.8	32.6	34.1	14.7
9	22.8	58.8	61.5	26.3
12	33.1	86.2	90.3	38.4
15	43.4	113.7	119.3	50.4
18	53.4	140.6	147.6	62.2
21	63.0	166.8	175.2	73.5
24	72.2	192.0	201.7	84.3
27	81.0	216.2	227.2	94.7
30	89.3	239.4	251.6	104.6
33	97.2	261.5	274.8	113.9
36	104.6	282.4	296.8	122.6
39	111.6	302.1	317.6	130.8
42	118.1	320.7	337.0	138.5
45	124.0	338.0	355.2	145.6
48	129.5	354.0	372.0	152.0
51	134.5	368.8	387.5	157.9
54	138.9	382.2	401.5	163.2
57	142.9	394.3	414.2	167.9
60	146.3	405.0	425.4	171.9
63	149.2	414.4	435.2	175.4
66	151.6	422.4	443.6	178.2
69	153.4	429.1	450.6	180.5
72	154.8	434.6	456.3	182.2
75	155.8	439.2	461.1	183.4

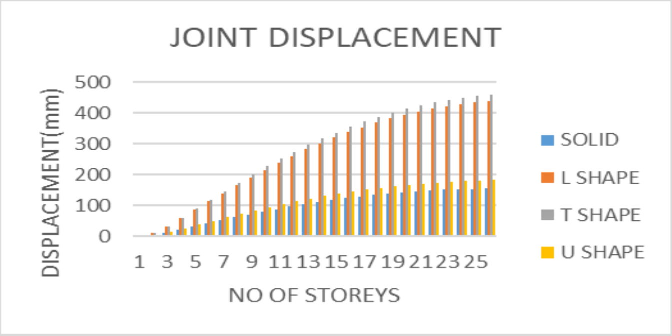

Fig 7. Storey displacement for different shape of structures

From the Fig 7. shows that T shaped structure has more displacement compare to other structure in all 4 categories.

C. *Variation of Stiffness*

For the variation of stiffness, the column sizes are changed for structure but the size of the beam kept constant for whole structure. The beam size will be 300X600mm and slab dimension will be 200mm. Column size 300X450mm, 450X600mm, 450X750mm.

The below table shows the displacement for the variation of stiffness.

TABLE 9. DISPLACEMENT FOR CHANGE OF STIFFNESS

STOREY HEIGHT	VARIATION OF STIFFNESS		
	300X450	*450X600*	*450X750*
0	0	0	0
3	4.9	4.9	4.9
6	14.9	14.9	14.9
9	26.6	26.6	26.6
12	38.9	38.8	38.8
15	51.0	51.0	51.0
18	62.8	62.8	62.8
21	74.3	74.2	74.2
24	85.2	85.2	85.1
27	95.7	95.6	95.6
30	105.8	105.6	105.6
33	115.4	115.2	115.1
36	132.5	126.1	124.7
39	148.6	136.2	133.6
42	163.6	145.6	142.0
45	177.5	154.4	149.7
48	190.2	162.4	156.8
51	201.8	169.7	163.2
54	212.1	176.2	169.0
57	221.3	182.0	174.1
60	229.2	187.0	178.6
63	235.9	191.3	182.4
66	241.4	194.7	185.5
69	245.6	197.5	187.9
72	248.5	199.4	189.7
75	250.3	200.7	191.0

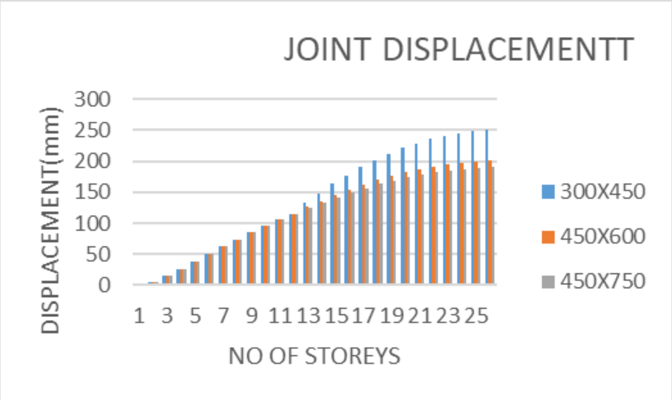

Fig 8. Storey displacement for change of stiffness

From the Fig 8 shows that column size 300X450mm has more displacement compare to other structure.

V. CONCLUSION

The different cases studied that are presented in this report led to following conclusions:

1. Displacement is maximum at top story and it reduce to zero at the base. Displacement will increase by increase in story height in static method.
2. Displacement is higher for Category 1 compared to all other categories, as the category increase displacement will decrease for all shape.
3. Joint displacement in beam column model is more than flat slab in both solid model and open model.
4. Displacement in different shapes of structures, T shape having more displacement.
5. For the variation of stiffness smaller size of column having more displacement compare to larger size of column.
6. Storey drift is increasing from 1st storey to 5th (15m) storey, then its starts to decrease from 5th to top storey in all types of structures in static method.

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