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Wind Effects in Tall Buildings for Vertical Irregularity

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Abstract: In Civil Engineering, every new day rise with new and challenging task. Because requirements of people, Congested land and Modern Architectural demand arises. High-rise buildings are constructed to overcome the lack of land area. Now high rise buildings are constructed with vertical irregularities due to architectural demands. These irregularities in structure are considered as weakness of structure or cause of failure. In addition to this, in case of high rise buildings lateral forces as wind pressure are essential to take in consideration in analysis. This paper presents wind analysis of tall RC Framed (G+15) residential buildings having vertical irregularities. Three models are taken as Regular geometry and vertical irregular with setbacks at different height levels. Modeling and analysis is done by using ETABS Structural software. At the end compared the results of all models with each other in the form of axial forces, bending moment, lateral displacement and storey drift.

Keywords: Vertical Geometry, irregularity, wind analysis, stiffness, lateral forces, setbacks.

I. INTRODUCTION

Now high-rise buildings are become necessary part of urban development. In addition to height the irregularities in structure is trending due to architectural demand arise [9]. The irregularities in structure are classified into two major types namely plan irregularity and vertical irregularity [5].

This paper deals with vertical irregularity in tall multi-storied buildings. According to Indian standard code vertical irregularity is defined as when the horizontal surface dimension of lateral force resisting system in a storey is more than 125 percent of the adjacent storey is called as vertical irregular structure [4].

In the structure weakness arises due to irregularities present in the properties of structure such as mass irregularity, stiffness irregularity and geometric irregularity.

The Lateral loads such as wind loads and earthquake loads are very essential to take in consideration during analysis of multi-storied buildings [5].

It has been seen that in high-rise buildings wind loads are more critical than earthquake loads. This paper presents wind analysis of tall building, having height of 52.7 m with vertical geometric irregularity.

Three models are taken as regular, vertical irregular with one setback at 50 % of total height and vertical irregular having multiple setbacks at a different height level. For modeling and analysis ETABS structural software are used. All loadings are followed by Indian Standard codes and for wind load IS 875 (Part 3): 2015 is used.

II. LITERATURE SURVEY

- A. A. Pavan Kumar et al. (2017) performed analysis of high rise building about G+30 framed structure building situated in zone four, and zone five in soil type 2 (medium soils) and analysis is done by using ETABS software.
- B. Shashikanth et al. (2017) has worked on vertical geometric irregularity in reinforced concrete framed Structure having high wind pressure. Shows the demand of vertical irregular structure, need of lateral loads consideration in analysis of tall buildings. Clearly described the weakness in irregular structure which tends to sudden failure or rupture caused by discontinuity in mass, change in stiffness and vertical geometry of structure.
- C. K.divya et al. (2016) described different types of irregularities in structure and compared stiffness irregularity with vertical geometric irregularity. Indian codes are preferred for gravity and lateral loads. Basic wind speed was taken 50 m/sec. For structural analysis staad pro software was used. And conclude that irregularity gives maximum deformation to the structure.
- D. Md. Mahmud et al. (2015) worked on building shapes and elaborate the effects on each shape under wind and earthquake. Presents the numerical study of various effects on different shapes of buildings subjected to lateral loads.
- E. Anju Krishna et al. (2015) Performed Analysis on Vertical Geometric Irregular structure with Diagrid System and Comparison with Tubular system Structure. Explained lateral forces resisting systems in structure such as shear wall, rigid frame wall frame, braced tube system, and

diagrid system. This paper is based on diagrid system, and tubular system. The diagrid system proved efficient system to resist the worst lateral load and improves the architectural view of building.

- F. Abhay guleria et al. (2014) presents structure analysis on multi-storied buildings using Etabs for different plan configurations. Described the advantages of ETABS software using for analysis of multi-storey and different plan configuration buildings. Shows the structural behavior of multi-storied buildings with different plan configurations such as rectangular, C, L and I-shaped buildings. Prefers rectangular shaped building as the safest model.

III. OBJECTIVES OF STUDY

- A. To study the effects and response of building for vertical irregularity under high wind pressure.
- B. To observe the changes in structural behavior after applying wind loads under multiple setbacks.
- C. To create awareness about importance of wind analysis for tall and irregular buildings.
- D. To study maximum displacement and storey drift in case of vertical irregular structure at each storey.

IV. METHODOLOGY

In this study three types of RC Framed (G+15) residential structures were considered with the plan area of 32×35m and panels of 5x4m each. Ideal top height of all models is kept 52.7m. Storey height is kept 3.2m each. All the structural members designed under guidance of IS 456-2000. And for wind analysis IS 875 (Part-3) 2015 Code is followed. The short descriptions of all three models are given below.

- 1) *Model 1*: Regular Structure shown in Fig 5.1
- 2) *Model 2*: Vertical irregular structure with one setback at mid height shown in Fig 5.2
- 3) *Model 3*: Vertical irregular structure with two setbacks at 6th storey and 11th storey shown in Fig 5.3

V. SPECIFICATIONS AND REQUIRED DATA

SPECIFICATIONS	
Height of structure	52.7m
Type of structure	Residential
Floor area	1120 m ²
Live load	3 KN/m ²
Density of concrete considered	25 KN/m ³
Density of brick wall considered	20 KN/m ³
Thickness of slab	120mm
Size of beam	300 X 500 mm
Size of column	400 x 700 mm
Thickness of external wall	230mm
Thickness of internal wall	150mm
Height of each storey	3.2m
Wind speed	44 m/sec
Terrain category	3
Class of structure	C
Location	Hyderabad

Table 5.1 specifications of buildings

Fig 5.1 Model-1 (G+15) residential regular building

Fig 5.2 Model-2 (G+15) residential irregular building

With Single setback at mid height

Fig 5.3 Model-3 (G+15) residential irregular building

With multiple setback at 6th and 11th storey height

VI. LOAD CALCULATIONS

Dead weight of structural elements is automatically calculated by Etabs. No need to calculate manually.

$$\begin{aligned} \text{External wall load} &= \text{Length} \times \text{width} \times \text{height} \times \text{density} \\ &= 1 \times 0.23 \times 2.7 \times 20 \end{aligned}$$

$$= 12.42 \text{ kN/m}$$

$$\text{Internal wall load} = \text{Length} \times \text{width} \times \text{height} \times \text{density}$$

$$= 1 \times 0.115 \times 2.7 \times 20$$

$$= 6.21 \text{ kN/m}$$

$$\text{Floor finishes} = 1.5 \text{ kN/m}^2$$

$$\text{Live load} = 3 \text{ kN/m}^2$$

A. Wind Calculations

Indian Code based procedure for wind analysis:

1) Designed wind speed.

$$V_z = V_b \times k_1 \times k_2 \times k_3$$

2) Wind pressure

$$P_z = 0.6 \times V_z^2$$

3) Force coefficient.

$$F = C_f \times A_e \times p_z$$

Where,

V_z = designed speed of wind at any height in m/s.

k_1 = risk coefficient.

k_2 = Height factor and terrain roughness.

k_3 = topography factor.

P_z = wind pressure

F = Force coefficient.

A_e = Plan area

C_f = internal and external pressure coefficient..

VII. RESULTS AND SHORT DISCUSSION

This section represents the results of each model containing regular and irregular geometry in the form of following parameters.

Axial forces in columns

Lateral displacement

Storey drift

A. Model 1 (Regular)

1) **Axial Force:** Following graph Fig 6.1 shows the maximum axial forces in column for each storey. The maximum axial force of column is located at nearby center of structure in all models. In (Model-1) the maximum value of axial force is observed 12472 KN at base of the structure and linearly decreases up to 605 KN at top storey.

Fig 6.1 Maximum axial forces in Model-1

- 2) *Lateral Displacement*: The nodal displacement in lateral direction shown in Fig 6.2. The maximum displacement in regular model is observed at top 16th storey with the value of 18.75mm.

Fig 6.2 Lateral joint displacement in Model-1

- 3) *Storey Drift*: The maximum value of storey drift is located at first and second storey and gradually decreasing from bottom to top show in Fig 6.3.

Fig 6.3 Storey drift in Model-1

B. Model 2 (Irregular) Single Setback

- 1) *Axial Force*: In this model there is irregularity of geometry present due to this irregularity the amount of axial forces increases up to certain amount shown in Fig 6.4. In this model the maximum value of axial force is observed at base of the structure with the value of 14032 KN.

Fig. 6.4 Maximum axial forces in Model-2

- 2) *Lateral Displacement*: In this model there setback located at mid height of building at 8th storey. Due to change in geometry this model gives the maximum lateral displacement under wind load as about 23.45 mm. shown as follows in Fig 6.5.

Fig 6.5 Lateral joint displacement in Model-2

- 3) *Storey Drift*: The following graph Fig 6.6 shows the storey response of model-2 in the form of storey drift. The X-axis represent the storey drift whereas Y-axis represent the storey number. In this graph there is sudden increment in the value of storey drift at 8th storey due to irregularity present in this structure.

Fig 6.6 Storey drift in Model-2

Fig 6.8 Lateral joint displacement in Model-2

C. Model 3 (Irregular) Multiple Setbacks

- 1) **Axial Force:** In this model there is two setbacks are present at 6th storey and also at 11th storey. due to this irregularity little bit amount values are fluctuate at these floors. The values of axial forces are shown in Fig 6.7 The maximum value of axial force in column is observed 11788KN.

Fig 6.7 Maximum axial forces in Model-3

- 3) **Storey Drift:** In this model there is multiple setbacks are present, the first setback is at 6th storey and second setback at 11th storey. The behaviour and effect of this irregularity clearly visible in graph Fig 6.9. instant increment observed in the value of drift at 6th storey and 11th storey due to geometric irregularity.

Fig 6.9 Storey drift in Model-3

- 2) **Lateral Displacement:** The joint displacement graph Fig 6.8 highlights the displacement in lateral direction and graph indicates higher values of displacement from first setback at 6th storey. The maximum value of lateral joint displacement is observed at top storey of the building with the value of 29.62 mm.

VIII. COMPARISON

In this chapter, the comparison of all three models is done with each other to relate the effects of wind in irregular building. And to know the behavior of all the structures with the help of maximum axial forces generated in column, joint displacement, maximum bending moments in beams and maximum storey drift.

A. Maximum Axial Forces In Column

Fig 7.1 Comparison of maximum axial forces

- 1) The maximum value is observed in (Model-2) as 14032 KN at base of structure. Whereas in (Model-1) it shows 12472 KN.
- 2) Fig 7.1 shows the comparatively graph of maximum axial forces in each storey of regular model (Model-1) and irregular model (Model-2). This graph clearly represents the difference between these two models and observed that (Model-2) showing the higher value in range of 11% to 18% more as compared to (Model-1) in each storey.
- 3) (Model-2) having setback and due to irregular in vertical geometry it shows higher values than (Model-1) in the form of axial force.
- 4) (Model-3) having lesser value than both the remaining models because of mass irregularity.

B. Maximum Bending Moment In Beams

Fig 7.2 Comparison of maximum bending moment in beam

- 1) The negative bending moment in each storey of all three Models. In Model-1 the bending moment varies gradually from bottom to top. Whereas in Model-2 and Model-3 the values are suddenly fluctuate at irregular floor. Fig 7.2 represents the graph showing maximum bending moments in each model. The highest value of bending moment is observed in (Model-2) as 417.54 KN.M and the lowest value found in (Model-1) as 250.33 KN.M. Here also can conclude that irregularity present in

C. Maximum Lateral Joint Displacement

MODEL 1 JOINT DISPLACEMENT (MM)			
STOREY	UX	UY	UZ
1	1.755	1.174	-7.508
2	3.512	2.516	-12.256
3	5.32	3.964	-16.681
4	7.087	5.4	-20.784
5	8.742	6.755	-24.565
6	10.293	8.027	-28.023
7	11.742	9.215	-31.159
8	13.077	10.307	-33.973
9	14.289	11.297	-36.465
10	15.369	12.177	-38.634
11	16.31	12.942	-40.482
12	17.107	13.588	-42.008
13	17.754	14.11	-43.212
14	18.247	14.509	-44.094
15	18.583	14.782	-44.655
16	18.751	14.93	-44.893

Table 7.3 Joint displacement in all direction of model-1

MODEL 2 JOINT DISPLACEMENT (MM)			
STOREY	UX	UY	UZ
1	1.751	0.776	-8.514
2	3.502	1.662	-13.96
3	5.3	2.619	-19.079
4	7.054	3.551	-23.873
5	8.692	4.398	-28.342
6	10.224	5.162	-32.487
7	11.653	5.848	-36.31
8	12.944	6.425	-39.81
9	14.927	7.183	-42.99
10	16.955	7.926	-45.757
11	18.751	8.592	-48.114
12	20.278	9.158	-50.059
13	21.519	9.616	-51.594
14	22.464	9.962	-52.719
15	23.106	10.198	-53.434
16	23.449	10.334	-53.741

Table 7.4 Joint displacement in all direction of model-2

MODEL 3 JOINT DISPLACEMENT (MM)			
STOREY	UX	UY	UZ
1	1.748	0.567	-7.09
2	3.495	1.213	-11.557
3	5.286	1.911	-15.707
4	7.029	2.583	-19.541
5	8.661	3.173	-23.062
6	10.165	3.664	-26.272
7	12.564	4.316	-29.172
8	15.109	4.955	-31.764
9	17.456	5.524	-34.05
10	19.564	6.006	-36.03
11	21.389	6.394	-37.704
12	23.785	6.805	-39.076
13	26.059	7.166	-40.157
14	27.811	7.446	-40.947
15	28.994	7.638	-41.447
16	29.625	7.75	-41.661

Table 7.5 Joint displacement in all direction of model-3

Fig 7.3 Comparison of lateral displacement

- 1) Table 7.3 shows the maximum joint displacements in regular geometry (Model-1) at each storey. Whereas Table 7.4 and Table 7.5 shows maximum joint displacement in irregular geometry models having setbacks at different level as (Model-2) and (Model-3) respectively.
- 2) From above tables UX, UY and UZ indicates the displacement in X, Y and Z directions respectively. X and Y directions represent lateral displacement and Z direction shows the vertical displacement. In vertical displacement negative sign indicates downward.
- 3) Fig 7.3 represents the comparative graph of maximum lateral displacement in X-direction at each storey of all three models.
- 4) Table 7.3 shows the maximum joint displacements in regular geometry (Model-1) at each storey. Whereas Table 7.4 and Table 7.5 shows maximum joint displacement in irregular geometry models having setbacks at different level as (Model-2) and (Model-3) respectively.
- 5) From above tables UX, UY and UZ indicates the displacement in X, Y and Z directions respectively. X and Y directions represent lateral displacement and Z direction shows the vertical displacement. In vertical displacement negative sign indicates downward.
- 6) Fig 7.3 represents the comparative graph of maximum lateral displacement in X-direction at each storey of all three models.

D. Storey Drift

Fig 7.4 comparison of storey drift

- 1) The storey drift is very essential to take in consideration. It is the ratio of lateral displacement of two consecutive storey to its height.
- 2) Fig 7.4 shows the storey drift graph of all three models. From this graphical representation it can be easily understand the behaviour of all models under lateral loading with vertical irregularity.
- 3) For (Model-1) graph shows gradually decreasing line because there is no change in vertical geometry throughout the height of structure. But in (Model-2) there is sudden changed in drift observed at 8th storey because of setback.
- 4) Similarly in (Model-3) sudden changed in graph line noted at 6th storey and 11th storey due to irregularity present at these storey height.
- 5) With the help of tables and graph it observed that maximum lateral displacement caused by wind force is found in X-direction. Minimum value of lateral displacement is observed in (Model-1) having regular geometric structure (Model-3) shows the maximum lateral displacement as 29.625mm at top storey and gradually decreases from top to the bottom storey. In (Model-3) it has been seen that the lateral displacement value suddenly increases from 6th and 11th storey because setbacks are present at these stories.

IX. CONCLUSION

In this study three models are taken and compared regular building with two irregular buildings with setbacks at different level.

- A. Lateral Displacement is gradually increases from base to top of the storey in all models. But little bit fluctuation observed where the irregular storey starts. In (Model-2) the displacement value is obtained maximum as compare to regular model with increasing percentage range of 11% to 18%.
- B. The maximum bending moment also fluctuate at irregular floor.
- C. The maximum drift value is obtained from (Model-) as 0.0008 at 6th storey.
- 1) (Model-2) and (Model-3) gives more deformations as compare to (Model-1) because this model having setbacks and less vertical area to resist lateral forces.
- 2) (Model-1) proved safest model with minimum deformation.
- D. The Vertical irregular structure proves costly because maximum grade of material and large cross-section of structural members are required because bending moment and forces is Maximum.
- E. In these types of irregular buildings the effective and Modern lateral resisting system should be providing to avoid maximum damages like tubular system or diagrid system [11].

X. FUTURE SCOPE

This paper described the study of wind forces applied on tall structures under the critical condition of vertical geometric irregularity. In present days irregular structure becomes trending but this irregularity causes lots of damages and rupture to the structure. This study shows the analysis of tall structure with vertical irregularity under maximum wind load. And also shows the behavior of regular and irregular buildings. For structural analysis of all models ETABS software were used and for assigning the wind load the IS-875 PART 3 code has been followed. This study may extend with the work on introducing new and effective lateral resisting system for irregular structure.

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