Comparative Analysis of Wind Load Effects on a G+10 RCC Building for Different Basic Wind Speeds Using STAAD.Pro

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Abstract

Wind pressure on a building varies with the square of the design wind speed, so the same building plan can attract very different lateral load demands in different wind regions of India. This study evaluates a regular G+10 reinforced cement concrete (RCC) moment-resisting framed building, 24 m × 18 m in plan on a 6 m × 6 m grid, modelled in STAAD.Pro and analysed under dead, live and wind loads according to IS 875 (Parts 1–3) and IS 456:2000. Three basic wind speeds of 39, 47 and 55 m/s were applied along both principal directions, with the geometry, sections, materials, supports and gravity loads kept identical. For the 39 m/s case, the base shear was 625.8 kN for wind along X and 834.4 kN for wind along Z, with overturning moments of 11,046 and 14,728 kN·m. Every wind-induced response, including the support reactions, base shear, overturning moment and beam end forces, increased by 45.2% at 47 m/s and by 98.9% at 55 m/s. These increases equal the ratio of the squared wind speeds, as expected for a linear static analysis. The wind-induced axial reaction of the corner column rose from 132.3 to 263.1 kN. The wind combination 1.5(DL + WL) governed the end moment of a typical 6 m beam at all three speeds, giving 140.7, 167.6 and 199.6 kN·m, compared with 97.5 kN·m under 1.5(DL + LL). For the corner column, the gravity combination governed at 39 and 47 m/s, but at 55 m/s the wind combination exceeded it by 2.9%. No uplift occurred under 0.9DL − 1.5WL. The results show that a building designed for one wind speed cannot be reused at a higher-wind site without re-checking its beams and columns.

Keywords: RCC framed building; Wind load; IS 875 (Part 3); Basic wind speed; STAAD.Pro; Base shear; Overturning moment; Load combinations

1. Introduction

Rapid urbanization and limited land have led to multistorey reinforced cement concrete (RCC) framed buildings becoming the common form of residential and commercial construction. Gravity loads produce mainly axial forces, shears and bending moments, but lateral loads from wind and earthquake also cause horizontal displacement, inter-storey drift, overturning and additional moments in beams and columns. Wind may govern the design of medium-rise and slender buildings, particularly in regions with high basic wind speeds. When wind meets a building, positive pressure develops on the windward face and suction on the leeward and side faces. These pressures pass through the façade and floor diaphragms to the frame and then to the foundations. The resulting forces depend on the wind speed, terrain, height, plan shape, stiffness and the structural system.

India has six basic wind speeds, 33, 39, 44, 47, 50 and 55 m/s, specified in IS 875 (Part 3):2015 (Fig. 1). Because the design wind pressure is proportional to the square of the design wind speed, a modest increase in wind speed causes a much larger increase in the wind forces. In practice, a standard building plan is often repeated at several locations with little modification. Such a design may be unsafe if it was prepared for a lower wind speed, or wasteful if a high-wind design is adopted everywhere. The objectives of this study are to (i) model a regular G+10 RCC framed building in STAAD.Pro, (ii) analyse it under dead, live and wind loads for basic wind speeds of 39, 47 and 55 m/s, (iii) compare the support reactions, base shear, overturning moment and member forces, and (iv) identify the load combinations that govern design as the wind speed increases.

2. Literature Review

Several studies have used STAAD.Pro to analyse RCC buildings under code-based wind loads. Amiruddin et al. analysed a G+10 residential RCC building under dead, live and wind loads according to IS 875 (Part 3):2015 and evaluated its bending moments, shear forces, axial forces and lateral displacements. They found the building to be within

permissible limits, but did not compare different wind speeds [1]. Keshav and Rajbala compared G+50 RCC and steel buildings under wind and seismic loads in STAAD.Pro V8i. They reported greater flexibility and storey drift in the steel building, showing the influence of material stiffness on lateral response [2]. Saxena et al. analysed a G+9 RCC building in three wind zones with basic wind speeds of 33, 39 and 44 m/s [3]. The maximum displacement at the 30 m level increased from 10.45 to 13.41 and 15.74 mm. The maximum shear force of a selected beam increased from 36 to 58 kN, and the axial force of a selected member from 482 to 840 kN. This is the study closest to the present work.

Siddartha et al. discussed the analysis and design of a tall RCC building under wind and earthquake loads using STAAD.Pro [4]. Yadav et al. studied a G+20 irregular RC-framed building, 24 m × 24 m in plan and about 60 m high, under basic wind speeds of 44, 47, 50 and 55 m/s together with seismic loads. They examined bending moments, shear forces, storey displacement, storey shear and drift [5]. Jain et al. demonstrated the complete STAAD.Pro workflow for the analysis and design of a G+5 RCC hostel building [6]. Shahraz et al. analysed a G+10 regular residential building for a basic wind speed of 47 m/s in STAAD.Pro V8i and ETABS 2020. They obtained maximum displacements of 9.634 and 9.121 mm and maximum axial forces of about 3090 and 3095 kN in the two programs [7]. Vinay et al. analysed a G+5 residential building in Hyderabad for a basic wind speed of 44 m/s, assigning loads according to IS 875 [8]. Most of these studies consider a single wind speed or a single response quantity. Few compare the same G+10 building across several wind speeds or examine how the governing load combination changes with wind speed, which the present study addresses.

3. Methodology

The study followed the procedure shown in Fig. 2. The same three-dimensional model was used for all wind cases, and only the basic wind speed was varied, so that the effect of wind speed could be isolated.

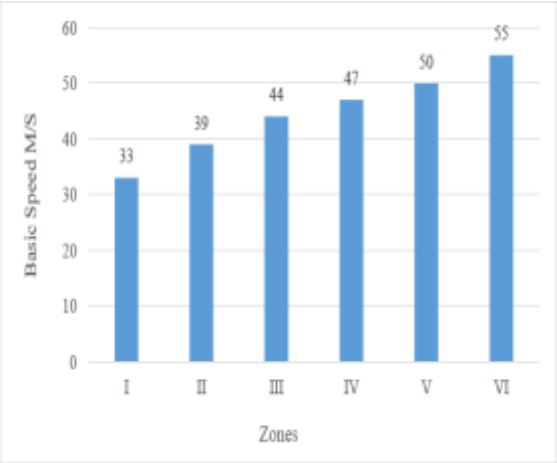


Fig. 1. Basic wind speeds for the six wind zones of India as per IS 875 (Part 3):2015

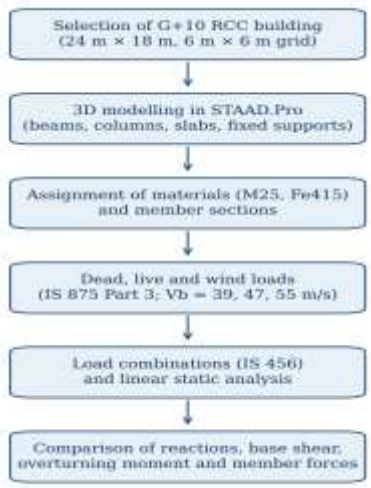


Fig. 2. Methodology of the study

3.1 Description of the building

The building is a regular RCC moment-resisting framed residential building with a ground floor and ten upper floors (G+10). It is rectangular in plan, 24.00 m × 18.00 m (432 m²), with grid lines 1–5 and A–D at a uniform spacing of 6.00 m. The typical floor has six apartments around a central lobby 3.00 m wide, with a staircase and a lift of 2.00 m × 2.00 m. The ground storey is 3.60 m high and the typical storeys are 3.00 m high, and a 1.20 m parapet is provided at the roof. The typical floor plan and front elevation are shown in Fig. 3, and the building details are given in Table 1.

Table 1. Details of the building

Parameter	Specification
Type of structure	RCC moment-resisting framed building
Occupancy	Residential
Number of storeys	G+10 (11 structural levels)
Plan dimensions	24.00 m × 18.00 m (4 bays × 3 bays of 6.00 m)
Ground-storey height / typical storey height	3.60 m / 3.00 m
Roof level above base	33.60 m (3.60 m + 10 × 3.00 m)
Parapet height	1.20 m
Column size	500 mm × 500 mm
Beam size	300 mm × 500 mm
Slab thickness	125 mm
Wall thickness	230 mm
Support condition	Fixed at column bases

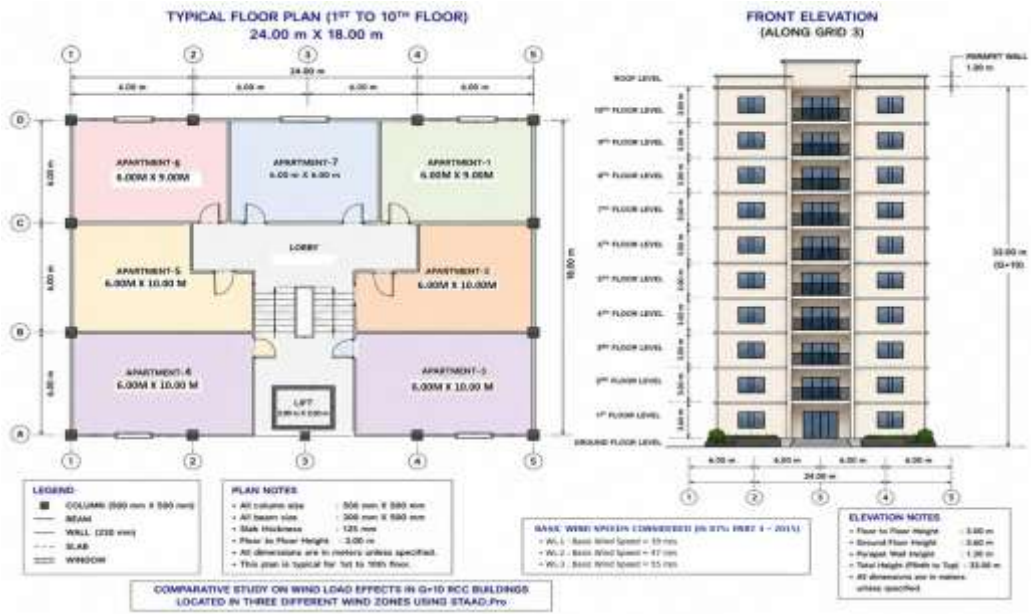
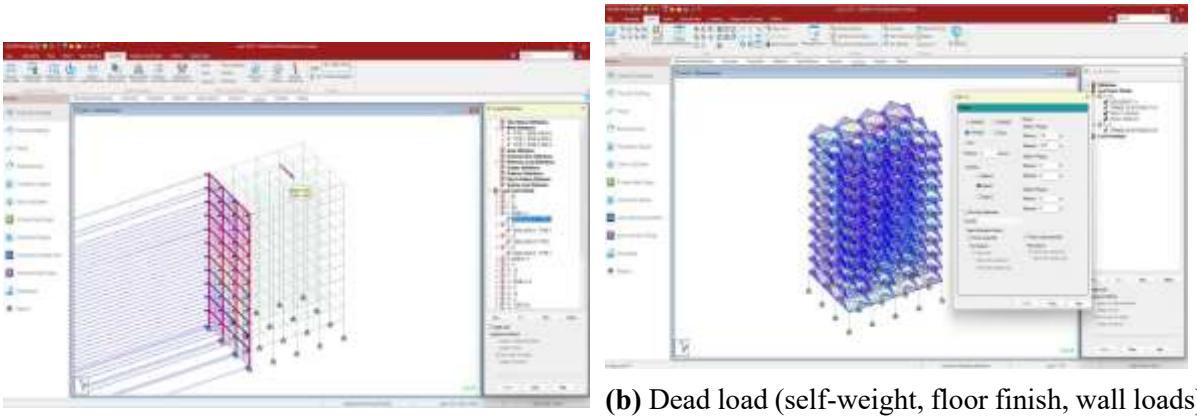


Fig. 3. Typical floor plan and front elevation of the G+10 RCC framed building

3.2 Structural modelling in STAAD.Pro

The building was modelled in STAAD.Pro as a three-dimensional frame. Columns were placed at the grid intersections, and beams connected the columns at each floor level. The nodal coordinates followed the grid spacing and storey heights of the drawings. Member sections were assigned as in Table 1, and the column bases were fixed. The same model, sections and supports were used for all three wind cases. Fig. 4(a) shows the model with the wind load definitions.



(a) Model with wind load definitions and load cases **(b)** Dead load (self-weight, floor finish, wall loads) and floor live load

Fig. 4. STAAD.Pro model of the G+10 RCC building and assignment of loads

3.3 Material properties

Concrete of grade M25 (characteristic compressive strength 25 N/mm²) and high-yield-strength deformed bars of grade Fe415 (characteristic yield strength 415 N/mm²) were used. The properties assigned in the model are listed in Table 2. They were the same in all analysis cases.

Table 2. Material properties

Property	Concrete (M25)	Steel (Fe415)
Characteristic strength (N/mm²)	25	415
Poisson's ratio	0.20	0.30
Density (kg/m³)	2500	7850
Modulus of elasticity (N/mm²)	25,000	2,00,000

3.4 Loads

Dead load (DL). The self-weight of the members was generated by STAAD.Pro. A floor finish of 1.0 kN/m² was applied to the floor slabs. Masonry wall loads of 13.2 kN/m and parapet loads of 5.52 kN/m were applied as uniformly distributed loads on the beams, corresponding to 230 mm walls. **Live load (LL).** An imposed load of 2.0 kN/m² was applied to the floors and a roof live load (RLL) of 1.5 kN/m² to the roof, according to IS 875 (Part 2) [10] (Fig. 4(b)). The totals obtained from the STAAD.Pro statics check were 54,520.7 kN for DL, 8640.0 kN for LL and 648.0 kN for RLL. These match the applied intensities (for example, 2.0 kN/m² × 432 m² × 10 floors = 8640 kN), which confirms that the gravity loads were applied correctly [9].

Wind load (WL). Wind loads were generated with the IS 875 (Part 3):2015 wind load generator of STAAD.Pro [11]. The design wind speed at height z is

$$V_z = V_b\, k_1\, k_2\, k_3\, k_4 \qquad (1)$$

where V_b is the basic wind speed and k_1, k_2, k_3 and k_4 are the risk coefficient, the terrain roughness and height factor, the topography factor and the importance factor for cyclonic regions. The design wind pressure is

$$p_z = 0.6\, V_z^2 \quad \text{and} \quad p_d = K_d\, K_a\, K_c\, p_z \qquad (2)$$

where p_z is in N/m², and K_d, K_a and K_c are the wind directionality, area averaging and combination factors. The wind force on a surface of area A is

$$F = (C_{pe} - C_{pi})\, A\, p_d \qquad (3)$$

where C_{pe} and C_{pi} are the external and internal pressure coefficients. Because every factor except V_b was kept the same, Eqs. (1)–(3) show that any wind-induced response R should scale with the square of the basic wind speed:

$$R(V_b) = R(39) \times (V_b / 39)^2 \qquad (4)$$

Three wind cases were analysed (Table 3), each applied in the +X, −X, +Z and −Z directions. Wind along X acts on the 18 m face and wind along Z on the 24 m face. In the STAAD.Pro file the cases are labelled Zone II, Zone III and Zone IV (Fig. 4(a)). In this paper they are referred to as WL-1, WL-2 and WL-3, by their basic wind speeds; with the zone numbering of Fig. 1 they correspond to the 39, 47 and 55 m/s zones.

Table 3. Wind load cases considered

Case	Basic wind speed V_b (m/s)	STAAD.Pro load cases	V_b^2 (m²/s²)	Pressure ratio $(V_b/39)^2$
WL-1	39	4 to 7	1521	1.000
WL-2	47	8 to 11	2209	1.452
WL-3	55	12 to 15	3025	1.989

3.5 Load combinations and analysis

The limit state load combinations of IS 456:2000 [12] and IS 875 [9]–[11] given in Table 4 were used, with the wind load reversed to cover both directions. A linear static analysis was carried out for each wind case. The results evaluated were the gravity and wind load totals, base shear, overturning moment, support reactions at the corner column (node 1), and the end forces of a typical 6 m beam (Beam 1, between nodes 6 and 7, spanning along X). The percentage variation of a response R between two wind speeds was calculated as

$$\text{Variation (\%)} = (R_2 - R_1) / R_1 \times 100 \quad (5)$$

Table 4. Load combinations

No.	Combination	No.	Combination
1	1.5 (DL + LL)	5	1.5 (DL − WL)
2	1.2 (DL + LL + WL)	6	0.9 DL + 1.5 WL
3	1.2 (DL + LL − WL)	7	0.9 DL − 1.5 WL
4	1.5 (DL + WL)		

4. Results and Discussion

4.1 Base shear and overturning moment

The STAAD.Pro statics check (Fig. 5) gave, for WL-1, a total lateral load (base shear) of 625.80 kN for wind along X and 834.40 kN for wind along Z. The corresponding overturning moments about the base were 11,046.3 and 14,728.4 kN·m. For every load case in the statics check the applied loads and the reactions balanced exactly. The ratio of the two base shears, 834.40/625.80 = 1.333, equals the ratio of the exposed faces, 24/18. In both directions the resultant wind force acts 17.65 m above the base (11,046.3/625.80), a little above mid-height of the 33.6 m frame, because the design wind speed increases with height.

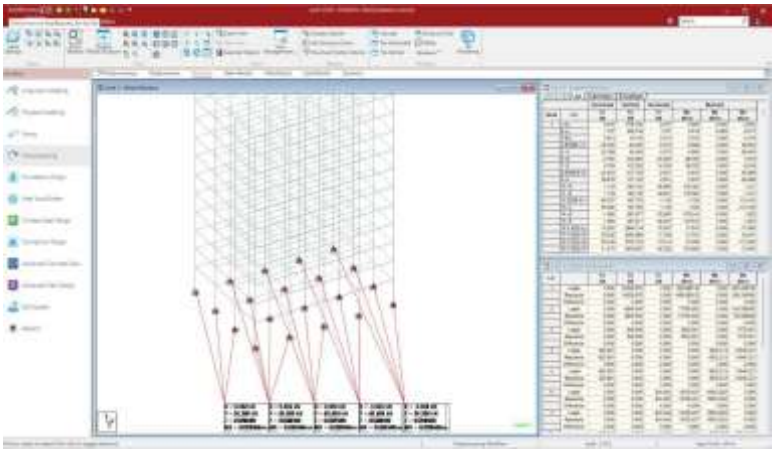


Fig. 5. Support reactions and statics check results from STAAD.Pro

Table 5 gives the base shear and overturning moment for the three wind speeds. The values for WL-2 and WL-3 were obtained from the WL-1 values with Eq. (4). This is justified by Section 4.2, where the support reactions from the STAAD.Pro analysis confirm the square-law scaling to within 0.05%. They are compared in Fig. 6. The base shear and overturning moment increased by 45.2% from 39 to 47 m/s and by 98.9% from 39 to 55 m/s. The base shear for wind along Z reached 1659.5 kN at 55 m/s, and the overturning moment reached 29,292 kN·m.

Table 5. Base shear and overturning moment for the three wind speeds

Response	WL-1 (39 m/s)	WL-2 (47 m/s)	WL-3 (55 m/s)
Base shear, wind along X (kN)	625.8	908.9	1244.6
Base shear, wind along Z (kN)	834.4	1211.8	1659.5
Overturning moment, wind along X (kN·m)	11,046.3	16,042.9	21,969.2
Overturning moment, wind along Z (kN·m)	14,728.4	21,390.6	29,292.2
Increase over WL-1 (%)	–	45.23	98.88

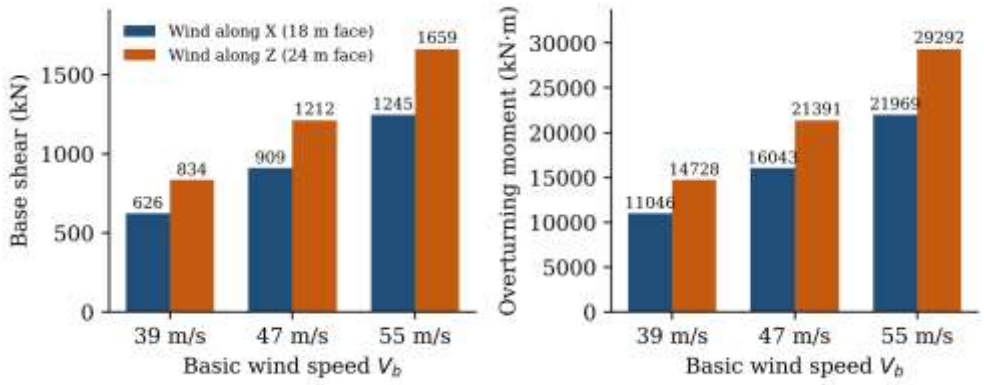


Fig. 6. Base shear and overturning moment for basic wind speeds of 39, 47 and 55 m/s

4.2 Support reactions of the corner column

Table 6 gives the reactions at the corner column (node 1) for the gravity load cases and all twelve wind load cases, as obtained from STAAD.Pro. Under DL and LL the column carries 1758.3 and 205.7 kN. Wind along Z, which acts on the wider face, produces the larger axial reaction. This reaction is 132.3 kN at 39 m/s, rising to 192.1 kN at 47 m/s and 263.1 kN at 55 m/s, or 7.5%, 10.9% and 15.0% of the dead-load reaction. Reversing the wind direction reverses the axial reaction and the moments. The horizontal reaction is larger when the corner is on the windward side (30.3 kN for +X at 39 m/s) than on the leeward side (25.4 kN for −X), because the windward wall load is delivered directly to the corner column.

Table 6. Reactions at the corner column (node 1) from STAAD.Pro

Load case	Fx (kN)	Fy (kN)	Fz (kN)	Mx (kN·m)	Mz (kN·m)
DL	8.435	1758.340	8.437	9.856	−9.853
LL	1.727	205.749	1.727	2.018	−2.017
RLL	0.014	16.140	0.014	0.016	−0.016
WL-1 +X / −X	−30.328 / 25.398	∓94.428	∓0.572	∓0.668	±66.093
WL-1 +Z / −Z	∓0.785	∓132.282	−39.256 / 34.326	∓89.782	±0.916
WL-2 +X / −X	−44.033 / 36.878	∓137.129	∓0.831	∓0.970	±95.969
WL-2 +Z / −Z	∓1.139	∓192.102	−56.996 / 49.841	∓130.365	±1.331
WL-3 +X / −X	−60.307 / 50.506	∓187.793	∓1.138	∓1.329	±131.435
WL-3 +Z / −Z	∓1.560	∓263.077	−78.062 / 68.261	∓178.543	±1.822

Dividing each wind reaction by its WL-1 value (Fig. 7) gives ratios of 1.4519–1.4522 for WL-2 and 1.9885–1.9888 for WL-3 for every component, against the theoretical $(V_b/39)^2$ values of 1.4523 and 1.9888. The wind-induced responses of the frame therefore follow Eq. (4) exactly. The building remains linear, so the wind effects scale with the wind pressure and not with the wind speed. An increase of 20.5% in basic wind speed (39 to 47 m/s) increases every wind-induced force by 45.2%, and an increase of 41.0% (39 to 55 m/s) doubles them.

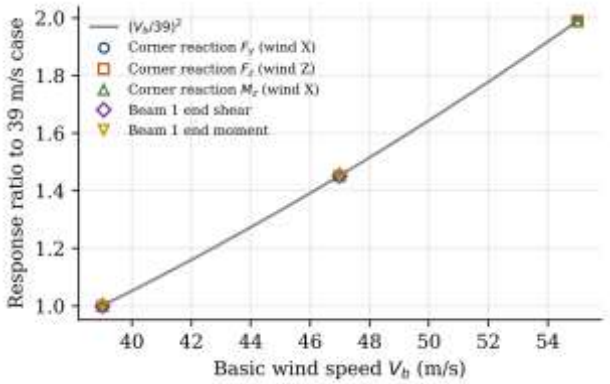


Fig. 7. Wind-induced responses from STAAD.Pro, normalised to the 39 m/s case, compared with $(V_b/39)^2$

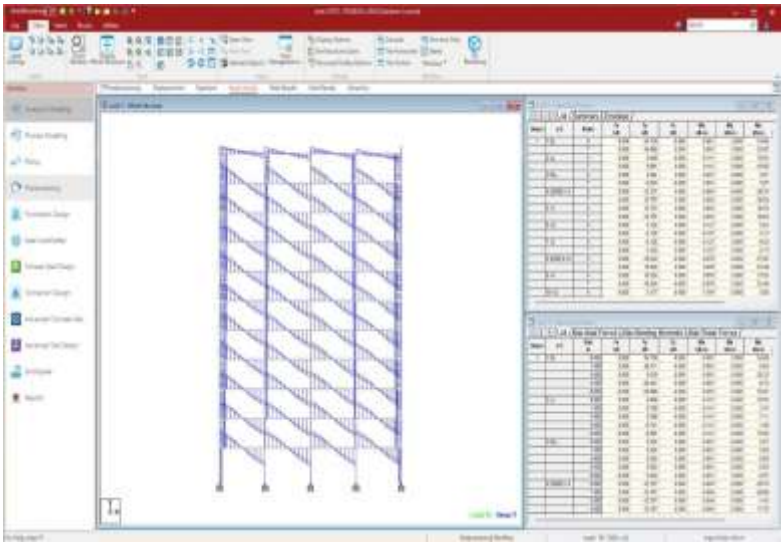
4.3 Beam forces

The end forces of Beam 1 are given in Table 7, and the shear force and bending moment diagrams of the frame are shown in Fig. 8. Under dead load the beam carries an end shear of 54.74 kN, a hogging end moment of 54.08 kN·m and a sagging midspan moment of 30.32 kN·m. Under live load it carries 9.01 kN and 10.91 kN·m. Wind along X produces an end shear that is constant along the span and antisymmetric end moments. These are 12.76 kN and 39.70 kN·m at 39 m/s and 18.52 kN and 57.65 kN·m at 47 m/s, giving ratios of 1.452. With Eq. (4), the values at 55 m/s are 25.37 kN and 78.96 kN·m. Wind along Z causes only small forces in this beam (end shear below 0.2 kN). The wind end moment at 39 m/s is already 73% of the dead-load end moment, and at 55 m/s it exceeds the dead-load moment by 46%.

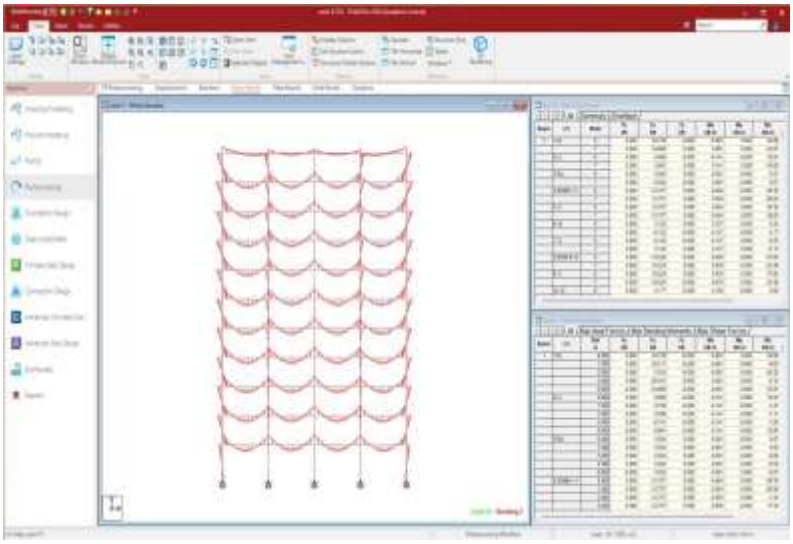
Table 7. End forces of Beam 1 (6 m span along X) at node 6

Load case	Shear Fy (kN)	Moment Mz (kN·m)	Ratio to WL-1
DL	54.738	54.08	–
LL	9.009	10.91	–
RLL	0.024	0.07	–
WL-1 ±X (39 m/s)	±12.757	∓39.70	1.000
WL-2 ±X (47 m/s)	±18.524	∓57.65	1.452
WL-3 ±X (55 m/s)*	±25.371	∓78.96	1.989
WL-1 ±Z (39 m/s)	±0.122	±0.55	–

* Obtained from the WL-1 values with Eq. (4); the ratio was verified for WL-2 in this table and for all reaction components in Table 6.



(a) Shear force diagram and beam end forces



(b) Bending moment diagram and beam force details

Fig. 8. Beam forces of the frame from STAAD.Pro

The relative deflection of Beam 1 at midspan was 1.034 mm under DL and 0.229 mm under LL, from the beam relative displacement output of STAAD.Pro. The wind load changed the beam deflection by less than 0.4 mm. These values are

far below the span/250 limit of IS 456 (24 mm for a 6 m span), so beam deflection is not affected significantly by the wind speed.

4.4 Governing load combinations

The factored forces were obtained by combining the primary load cases with the factors of Table 4. Applying these factors to the STAAD.Pro reactions reproduces the values of the STAAD.Pro combinations 16–19 exactly: 2946.13, 2495.87, 2779.15 and 2439.09 kN at node 1. The results are given in Table 8 and Fig. 9.

Table 8. Factored axial reaction of the corner column and end moment of Beam 1

Combination	WL-1 (39 m/s)	WL-2 (47 m/s)	WL-3 (55 m/s)
Corner column axial reaction (kN)			
1.5 (DL + LL)	2946.1	2946.1	2946.1
1.2 (DL + LL ± WL)	2515.6	2587.4	2672.6
1.5 (DL ± WL)	2835.9	2925.7	3032.1
0.9 DL − 1.5 WL (minimum)	1384.1	1294.4	1187.9
Beam 1 end moment (kN·m)			
1.5 (DL + LL)	97.5	97.5	97.5
1.2 (DL + LL ± WL)	125.6	147.2	172.7
1.5 (DL ± WL)	140.7	167.6	199.6
Beam 1 end shear, 1.5 (DL ± WL) (kN)	101.2	109.9	120.2

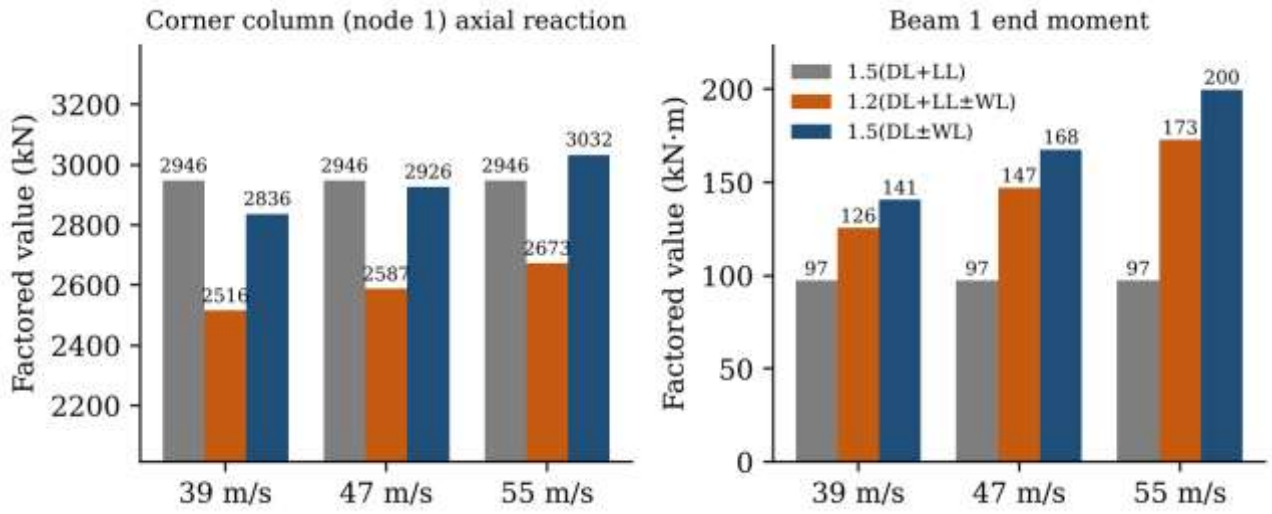


Fig. 9. Governing load combinations for the corner column axial reaction and the Beam 1 end moment

For the corner column, the gravity combination 1.5(DL + LL) gave 2946.1 kN and governed at 39 and 47 m/s, although at 47 m/s the wind combination (2925.7 kN) came within 0.7% of it. At 55 m/s, 1.5(DL + WL) gave 3032.1 kN, 2.9% more than the gravity combination, so wind then governs the column design. The minimum reaction under 0.9DL − 1.5WL fell from 1384.1 to 1187.9 kN but remained compressive, so no uplift develops at the base even at 55 m/s. For Beam 1, the wind combination 1.5(DL + WL) governed the end moment at all three wind speeds. Its value was 140.7, 167.6 and 199.6 kN·m, which is 44%, 72% and 105% above the gravity value of 97.5 kN·m. The governing end shear rose from 101.2 to 120.2 kN. The flexural and shear reinforcement of the beams, and the axial–flexural capacity of the columns, therefore depend directly on the wind speed of the site.

4.5 Comparison with earlier studies

Saxena et al. [3] reported, for a G+9 building, increases of 28.33%, 36.11% and 42.32% in maximum displacement, beam shear and member axial force from 33 to 39 m/s, and 50.62%, 61.11% and 74.27% from 33 to 44 m/s (Table 9). The corresponding increases in wind pressure are 39.67% and 77.78%. Their reported increases are of the same order but not equal to the pressure ratio. This may be because the maxima they report include gravity effects, or come from governing combinations rather than from the wind cases alone. In the present study the wind-only responses were separated from the gravity responses, and they follow the pressure ratio exactly (Fig. 7). The combined design forces, as in Table 8, increase much less than the pressure ratio for members dominated by gravity, such as columns, and much more for members dominated by wind, such as the beam end moments. The maximum displacement of 9.634 mm reported by Shahraz et al. [7] for a G+10 building at 47 m/s indicates the order of lateral deflection to be expected for a frame of this height.

Table 9. Comparison of the increase in response with wind speed

Study and response	Speed range (m/s)	Pressure increase (%)	Response increase (%)
Saxena et al. [3]: maximum displacement	33 → 39 / 33 → 44	39.67 / 77.78	28.33 / 50.62
Saxena et al. [3]: beam shear	33 → 39 / 33 → 44	39.67 / 77.78	36.11 / 61.11
Saxena et al. [3]: member axial force	33 → 39 / 33 → 44	39.67 / 77.78	42.32 / 74.27
Present study: all wind-induced responses	39 → 47 / 39 → 55	45.23 / 98.88	45.2 / 98.9
Present study: Beam 1 end moment, 1.5(DL + WL)	39 → 47 / 39 → 55	45.23 / 98.88	19.1 / 41.9
Present study: corner column, governing axial	39 → 47 / 39 → 55	45.23 / 98.88	0 / 2.9

This study has limitations. Only the output of the corner column and one beam was examined in detail. Storey displacements and inter-storey drifts should also be checked against the serviceability limit of IS 875 (Part 3), H/500 (about 67 mm for this building). Dynamic wind effects, terrain categories other than that adopted and shear walls were outside the scope of the study.

5. Conclusions

1. A G+10 RCC framed building, 24 m × 18 m in plan, was analysed in STAAD.Pro for basic wind speeds of 39, 47 and 55 m/s according to IS 875 (Part 3):2015, keeping all other parameters unchanged. The gravity loads totalled 54,520.7 kN (DL), 8640 kN (LL) and 648 kN (roof LL).
2. At 39 m/s the base shear was 625.8 kN for wind along X and 834.4 kN for wind along Z, in the ratio of the exposed faces (24/18). The overturning moments were 11,046 and 14,728 kN·m, with the resultant acting 17.65 m above the base.
3. All wind-induced responses increased by 45.2% at 47 m/s and by 98.9% at 55 m/s, exactly in proportion to the square of the basic wind speed. At 55 m/s the base shear reached 1659.5 kN and the overturning moment 29,292 kN·m.
4. The wind-induced axial reaction of the corner column increased from 132.3 to 263.1 kN (7.5% to 15.0% of its dead-load reaction). The gravity combination governed the column at 39 and 47 m/s, but at 55 m/s the combination 1.5(DL + WL) governed, at 3032.1 kN. No uplift occurred at the base.
5. Wind governed the beam design at every wind speed. The factored end moment of a 6 m beam under 1.5(DL + WL) was 140.7, 167.6 and 199.6 kN·m, which is 44% to 105% above the gravity value. Beam deflections were not significantly affected by wind speed.
6. A building plan designed for one wind speed should not be repeated at a higher-wind site without re-checking the beams and columns, particularly the end moments of beams in the lower storeys and the corner columns.

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