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Effect of Basic Wind Speed on the Structural Response and Design Requirements of an Industrial Steel Portal-Frame Building

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Abstract

This study examines the influence of basic wind speed on the structural response and preliminary member-selection requirements of a single-storey industrial steel portal-frame building. The building has a plan dimension of 30 m × 20 m, an eave height of 8 m, a ridge height of 10 m and six bays at 5 m spacing. Four wind-speed cases—33, 39, 47 and 55 m/s—are compared while the geometry and nominal non-wind loading assumptions remain unchanged. Wind pressure is estimated using $p = 0.6V^2$, with the simplifying assumption Vz = Vb. The illustrative values show an increase in pressure from 0.653 to 1.815 kN/m², maximum lateral displacement from 18.0 to 50.0 mm, maximum column moment from 185 to 512 kN·m, base shear from 110 to 306 kN and uplift reaction from 42 to 117 kN. The assumed steel quantity increases from 23.5 to 32.0 tonnes. The 55 m/s case produces the highest illustrative demand, with a maximum member utilization ratio of 0.93. The structural response values are assumed for academic parametric evaluation and are not actual STAAD.Pro analysis outputs. Accordingly, the results provide an illustrative comparative framework rather than a validated numerical analysis. A complete STAAD.Pro model, code-compliant wind-load derivation and independently checked member design are required before the findings can support engineering decisions.

Keywords—Industrial steel building; portal frame; basic wind speed; wind pressure; STAAD.Pro; structural response; member utilization; steel quantity.

I. INTRODUCTION

Industrial buildings such as factories, warehouses and workshops commonly use steel portal frames because they provide large unobstructed floor areas, relatively low self-weight and rapid construction. Their large roof and wall surfaces, together with comparatively flexible structural systems, make wind loading an important design consideration. Wind actions can influence lateral displacement, roof uplift, column and rafter moments, support reactions, bracing forces and the quantity of steel required [1]–[4].

The magnitude of wind action is strongly dependent on wind velocity. In simplified terms, wind pressure varies with the square of velocity. Consequently, even a moderate increase in basic wind speed can produce a substantial increase in pressure demand. For actual building design, however, the basic wind speed must be converted into design wind speed by considering the relevant risk, terrain, height and topography factors, and external/internal pressure coefficients in accordance with IS 875 (Part 3) [3].

Four basic wind-speed cases are compared for a single industrial portal-frame configuration to examine the potential influence of wind velocity on global response and preliminary member selection. The response values used for this comparison are illustrative assumptions for academic parametric evaluation; they are not outputs obtained from a completed STAAD.Pro analysis. This distinction governs the interpretation of all numerical results presented in this paper.

II. OBJECTIVES AND SCOPE

The objectives are to: (i) define a representative single-storey industrial portal-frame building; (ii) compare four basic wind-speed cases; (iii) examine changes in wind pressure, displacement, member forces and support reactions; (iv) compare indicative column and rafter sections, utilization ratios and steel quantity; and (v) identify the wind-speed case that produces the highest assumed demand.

The investigation is limited to one building geometry and four static wind-speed scenarios. Dead load, roof live load and wind loading are considered within the stated comparative framework. Detailed connection design, foundation design, nonlinear analysis, dynamic wind response, fatigue, cladding design and full-scale validation are beyond the scope of the present investigation.

III. BUILDING CONFIGURATION AND DESIGN BASIS

A. Structural Configuration

The model represents a single-storey pitched-roof steel shed supported on fixed column bases. Six bays at 5 m spacing provide a total building length of 30 m. The building width is 20 m, the eave height is 8 m and the ridge height is 10 m. The roof rise is therefore 2 m over a horizontal half-span of 10 m, corresponding to an approximate roof slope of 11.31°.

TABLE I. PRINCIPAL GEOMETRICAL PARAMETERS

Parameter	Adopted value
Building length	30 m
Building width	20 m
Eave height	8 m
Ridge height	10 m
Number of bays	6
Bay spacing	5 m
Roof configuration	Symmetrical pitched roof
Support condition	Fixed column bases
Structural system	Steel portal frame

B. Design Standards and Modelling Basis

IS 875 (Part 1) is considered for dead loads, IS 875 (Part 2) for imposed loads, IS 875 (Part 3) for wind loads and IS 800:2007 for steel design [1]–[4]. STAAD.Pro is the intended analysis and design platform [7]. The four cases maintain common geometry and nominal material and loading assumptions, with basic wind speed as the principal variable.

For the comparative pressure calculation, the expression $p = 0.6V^2$ is used with the simplifying assumption $Vz = Vb$. This provides a basic pressure comparison only and does not replace the complete design-wind-pressure procedure specified in IS 875 (Part 3), which requires the applicable modification factors and pressure coefficients. The resulting pressure values must therefore not be used directly for construction design.

IV. WIND-SPEED CASES AND ANALYTICAL FRAMEWORK

The four cases are M1 = 33 m/s, M2 = 39 m/s, M3 = 47 m/s and M4 = 55 m/s. The comparative analytical framework comprises definition of the building geometry, selection of trial sections, calculation of gravity and wind actions, development of a three-dimensional structural model, application of load combinations, evaluation of member forces and displacements, and iterative member design in accordance with the relevant design provisions [3], [4], [7].

TABLE II. WIND-SPEED CASES AND SIMPLIFIED PRESSURE VALUES

Model	Basic wind speed (m/s)	$p = 0.6V^2$ (kN/m²)
M1	33	0.653
M2	39	0.913
M3	47	1.325
M4	55	1.815

The pressure ratio between M4 and M1 is approximately 2.78. The increase from 0.653 to 1.815 kN/m² corresponds to approximately 177.8%. This relationship is consistent with the square-law dependence in the simplified pressure expression. The full code-based design pressure can differ after applying the relevant factors.

V. RESULTS AND DISCUSSION

The numerical values presented in this section are illustrative scenario values adopted for academic parametric comparison. They are not extracted from completed STAAD.Pro analysis output and have not been computationally validated. They are used only to examine the trends associated with the four specified wind-speed cases; they should not be interpreted as verified structural response predictions.

TABLE III. COMPARATIVE ILLUSTRATIVE STRUCTURAL RESPONSE

Parameter	33 m/s	39 m/s	47 m/s	55 m/s
Wind pressure (kN/m²)	0.653	0.913	1.325	1.815
Lateral displacement (mm)	18.0	25.1	36.5	50.0
Vertical displacement (mm)	8.5	11.9	17.2	23.6
Column moment (kN·m)	185	258	374	512
Rafter moment (kN·m)	162	226	328	449
Maximum axial force (kN)	145	202	294	403
Base shear (kN)	110	154	223	306
Uplift reaction (kN)	42	59	85	117
Maximum utilization ratio	0.62	0.71	0.84	0.93
Steel quantity (t)	23.5	25.0	28.0	32.0

A. Wind Pressure and Lateral Displacement

The illustrative pressure increases from 0.653 kN/m² at 33 m/s to 1.815 kN/m² at 55 m/s, an increase of approximately 177.8%. The corresponding illustrative maximum lateral displacement increases from 18.0 to 50.0 mm, also representing an increase of approximately 177.8%. These trends are consistent with the increase in wind action under the simplified pressure relationship when the structural configuration is held constant.

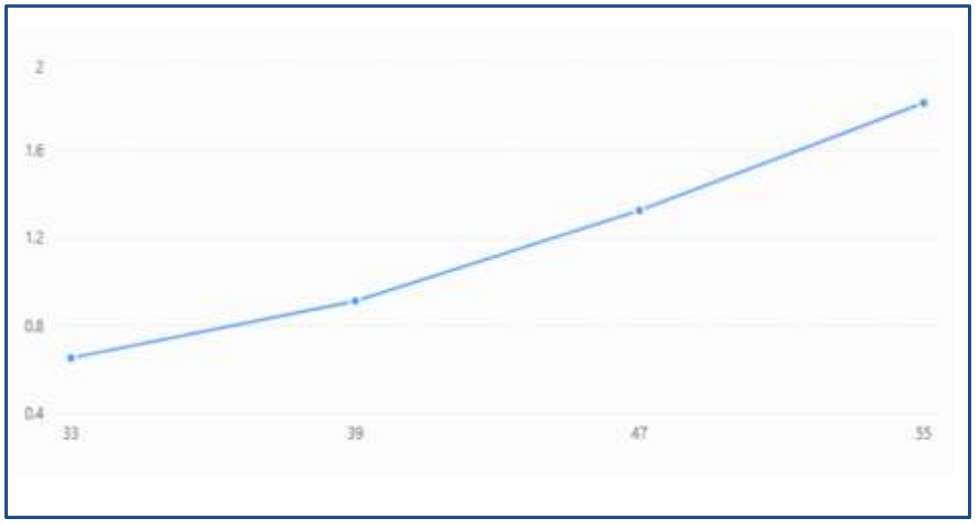


Fig. 1. Basic wind speed versus simplified wind pressure

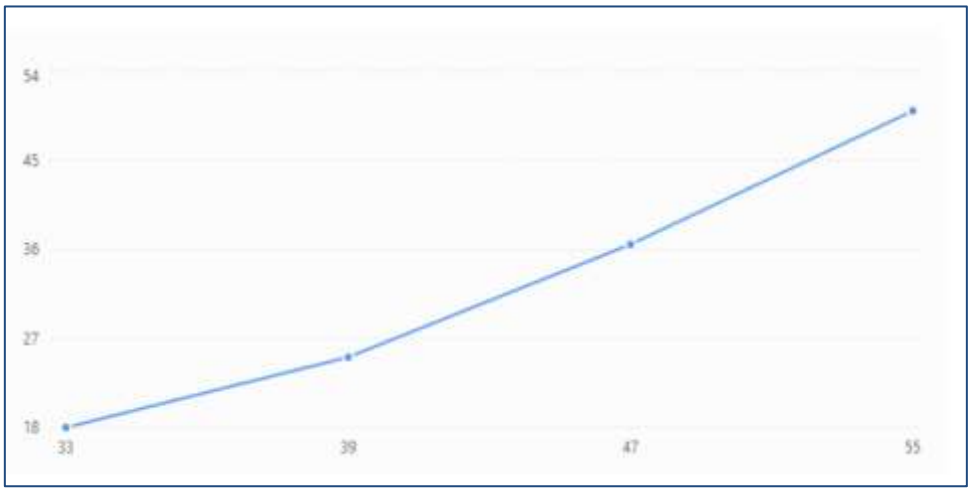


Fig. 2. Basic wind speed versus illustrative maximum lateral displacement

B. Bending Moments and Axial Force

The assumed maximum column moment increases from 185 to 512 kN·m, while the rafter moment increases from 162 to 449 kN·m. The corresponding increases are approximately 176.8% and 177.2%, respectively. Maximum axial force rises from 145 to 403 kN. These values illustrate that wind demand may increase combined axial and flexural effects in both columns and rafters. Actual member design must consider the governing load combinations and interaction checks prescribed by IS 800:2007 [4].

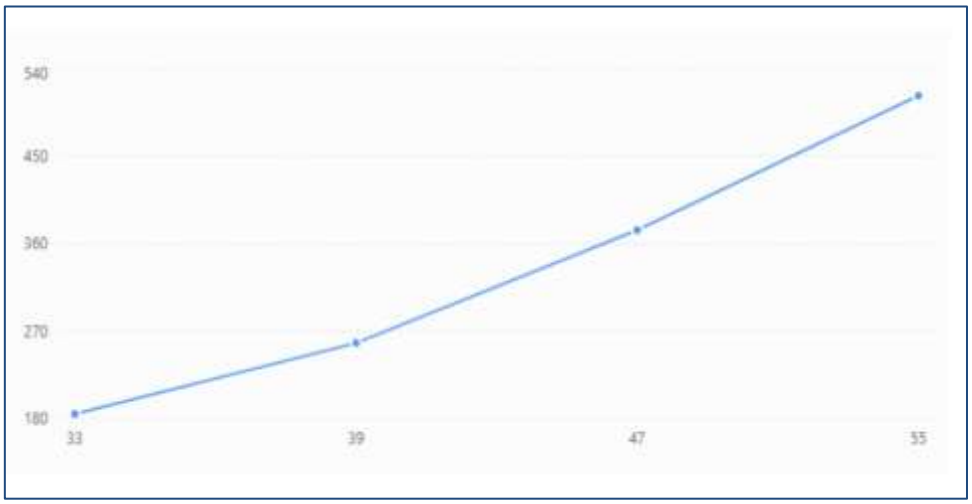


Fig. 3. Basic wind speed versus illustrative maximum column bending moment

C. Base Shear and Uplift Reaction

The illustrative base shear increases from 110 to 306 kN, while the uplift reaction rises from 42 to 117 kN between the lowest and highest wind-speed cases. These trends emphasize the importance of transmitting horizontal shear and net uplift safely through the column bases and foundations. The values are not foundation design actions until verified through a complete load model, combinations and support-reaction extraction.

D. Member Utilization and Steel Quantity

The assumed maximum utilization ratio increases from 0.62 to 0.93. The selected column sections are ISMB 400 for 33 and 39 m/s and ISMB 450 for 47 and 55 m/s. The selected rafter sections are ISMB 350, ISMB 400, ISMB 400 and ISMB 450, respectively. The associated assumed steel quantity increases from 23.5 to 32.0 tonnes, or approximately 36.2%. This increase is smaller than the pressure increase because section

sizes are discrete and the assumed design selections change only when demand reaches the next section threshold.

TABLE IV. ILLUSTRATIVE MEMBER SELECTION AND STEEL QUANTITY

Model	Wind speed	Column	Rafter	Utilization	Steel quantity
M1	33 m/s	ISMB 400	ISMB 350	0.62	23.5 t
M2	39 m/s	ISMB 400	ISMB 400	0.71	25.0 t
M3	47 m/s	ISMB 450	ISMB 400	0.84	28.0 t
M4	55 m/s	ISMB 450	ISMB 450	0.93	32.0 t

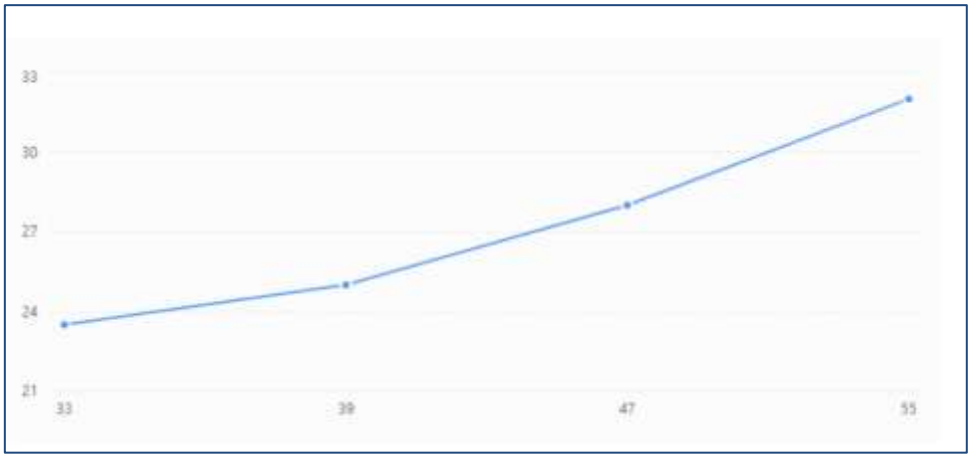


Fig. 4. Basic wind speed versus illustrative total steel quantity

VI. ENGINEERING IMPLICATIONS

The illustrative comparison indicates that wind-speed selection has implications beyond member bending. Increased lateral displacement affects serviceability; higher column and rafter moments influence section capacity and stability; increased axial force requires combined-force checks; and increased base shear and uplift affect the design of bases, anchors and foundations. Bracing and cladding load paths also require explicit verification. These observations are consistent with established steel design and wind-loading practice [3], [4], [9]–[15]. For an actual project, the basic wind speed must be selected for the site from the applicable wind map and the design wind speed calculated with the required risk, terrain, height and topography factors. Wind directions, internal pressure, external pressure, roof suction, load combinations, second-order effects and stability should be examined. A single simplified pressure value based on Vz = Vb is insufficient for final design.

VII. CONCLUSIONS

- The simplified pressure values increase from 0.653 kN/m² at 33 m/s to 1.815 kN/m² at 55 m/s, an increase of approximately 177.8%, reflecting the square-law relationship between velocity and pressure.
- In the illustrative dataset, maximum lateral displacement increases from 18.0 to 50.0 mm and maximum vertical displacement from 8.5 to 23.6 mm.
- The assumed maximum column and rafter moments increase from 185 to 512 kN·m and 162 to 449 kN·m, respectively; maximum axial force rises from 145 to 403 kN.
- The assumed base shear increases from 110 to 306 kN and uplift reaction from 42 to 117 kN, indicating the importance of foundation shear and uplift resistance in high-wind conditions.

- The assumed maximum utilization ratio rises from 0.62 to 0.93. The illustrative member schedule changes from ISMB 400 columns/ISMB 350 rafters at 33 m/s to ISMB 450 columns/ISMB 450 rafters at 55 m/s.
- The assumed steel quantity increases from 23.5 to 32.0 tonnes, corresponding to approximately 36.2%.
- The 55 m/s case is the governing case within the illustrative dataset. However, none of the assumed response values should be treated as validated STAAD.Pro output until the complete model and code checks are provided.

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