

Comparative Design Utilization Sensitivity of Industrial Steel Buildings under Increased Roof and Wind Actions

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Research Article

Keywords: industrial steel building, portal frame, pre-engineered building, wind sensitivity, roof collateral load, utilization ratio

Posted Date: October 27th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11486627/v1>

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Additional Declarations: The authors declare no competing interests.

Abstract

Industrial steel buildings are frequently subjected to revised roof-service demands and uncertain wind actions during their service life. This study compares the governing member design utilization of three named professional-practice industrial steel-building models under controlled changes to roof collateral load and wind load. The verified baseline models span transverse extents of 52.92–105.20 m, longitudinal extents of 67.50–150.00 m and maximum heights of 9.98–15.87 m. Member checks were retained in their original Indian steel-design configuration, while only the relevant primary uniform load records were scaled. The six scenarios comprised the baseline, roof-load factors of 1.25 and 1.50, wind-load factors of 1.10 and 1.20, and a combined roof/wind factor of 1.25/1.10. The cases correspond to a Bansal Steel & Power Limited shed, the Tata Motors Body Solutions Limited facility at Dharwad, and a LIBGEM Solutions/Gravita industrial-shed assignment. All baselines passed, with governing utilization ratios of 0.897, 0.917 and 0.977. Wind amplification governed Cases A and C, whereas Case B showed comparable sensitivity to roof and wind actions. At wind factor 1.20 the utilization ratios reached 1.073, 1.064 and 1.235, respectively. The results demonstrate that a common percentage load increase does not produce a common utilization response, and that governing-member migration must be tracked when screening existing industrial steel buildings for additional roof loads or altered wind demand.

1 Introduction

Low-rise industrial steel buildings commonly use rigid portal frames, tapered welded members, hot-rolled secondary members and braced bays. Their structural economy also means that modest changes in load can move a different member or load combination to the governing position. This issue is relevant when photovoltaic systems, services, suspended utilities or maintenance loads are added after the original design, and when revised wind information is considered during assessment.

Full-scale measurements on portal-framed buildings have shown that external and internal pressure interaction can materially affect frame response [5]. Database-assisted wind studies have also reported differences between code-based and pressure-database estimates of portal-frame bending demand [6], while demand-to-capacity formulations provide a direct means of connecting wind effects with member design checks [7]. Research on tapered portal frames has further identified wind-induced drift and connection restraint as important optimization variables [8]. At a broader level, system-based studies show that gravity-to-wind proportion, redistribution and model assumptions influence structural reliability beyond an isolated member check [9, 10].

The present work is a comparative screening study rather than a nonlinear collapse or reliability analysis. It evaluates how the governing code-check utilization changes when identical relative load perturbations are applied to three different professional-practice models. The objective is to identify whether roof or wind action controls each model, to record the first tested unity exceedance and to examine changes in the governing member.

2 Models and Method

2.1 Study models

Three three-dimensional STAAD.Pro models from completed professional assignments were adopted as named Cases A-C. Case A is Bansal Steel & Power Limited, Shed B; Case B is the Tata Motors Body Solutions Limited industrial shed at Dharwad; and Case C is the plastic-paint and smelting industrial shed associated with LIBGEM Solutions and the Gravita project. The project identities are retained to provide traceability to the corresponding engineering assignments, while client drawings, commercial terms and identifiable analytical model files are not reproduced. Each research baseline was reanalysed and required to complete without analysis errors and without failed member checks. The models retained their geometry, supports, member releases, material properties, section assignments, load combinations and Indian steel code-check parameters. Table 1 summarizes their scale, and Fig. 1 compares their principal extents.

Table 1
Characteristics of the verified research models

Model and project	Transverse extent m	Length m	Maximum height m	Joints	Members	Load cases and combinations
A - Bansal Steel & Power, Shed B	52.92	90.00	9.98	4,030	7,584	21
B - Tata Motors Body Solutions, Dharwad	105.20	150.00	14.90	541	816	32
C - LIBGEM/Gravita plastic-paint and smelting shed	65.00	67.50	15.87	3,107	5,733	21

2.2 Analysis basis

Loads were represented in kN and m. Cases A and C contained dead, collateral and six directional wind primary load cases followed by combinations. Case B additionally contained two seismic primary cases; these were retained but were not scaled in the present investigation. The member design checks used the Indian code implementation corresponding to IS 800:1984 [1] in the archived model configuration. Dead and imposed loading concepts were consistent with the Indian loading framework [2, 3], and the directional wind cases reflected the treatment of wind action under IS 875 Part 3 [4].

For every analysis, the governing utilization ratio was taken as the largest reported demand-to-capacity value among all checked steel members. A ratio not exceeding 1.000 was treated as passing the retained member check. The number of result rows above unity and the identity of the governing

member were recorded. Because this metric comes from code-based elastic analysis and member verification, it is not interpreted as a system collapse load factor.

2.3 Controlled sensitivity scenarios

Only the numerical magnitudes in the relevant primary STAAD uniform-load records were changed. Combination factors and all non-targeted actions were retained. The six scenarios were: baseline; roof collateral load multiplied by 1.25; roof collateral load multiplied by 1.50; wind load multiplied by 1.10; wind load multiplied by 1.20; and roof/wind loads multiplied simultaneously by 1.25/1.10. This approach preserves each model's original load-distribution pattern while enabling an internally consistent relative comparison.

The study intentionally compares relative sensitivity rather than equal absolute pressure or equal added roof load. The cases differ in geometry, framing density, section distribution, load combinations and baseline demand. Consequently, direct ranking by utilization is restricted to the tested model configurations.

2.4 Use of generative artificial intelligence tools

A generative artificial intelligence tool assisted with manuscript structuring, language drafting and document formatting. The author independently reviewed the model inputs, numerical outputs, technical interpretation, citations and final text and accepts responsibility for the submitted work.

3 Results

Table 2
Governing utilization ratios and failed member-check rows

Model	Baseline	Roof 1.25	Roof 1.50	Wind 1.10	Wind 1.20	Roof 1.25 wind 1.10
Case A UR	0.897	0.899	0.954	0.984	1.073	0.986
Failed rows	0	0	0	0	1	0
Case B UR	0.917	0.969	1.073	0.990	1.064	1.009
Failed rows	0	0	14	0	2	1
Case C UR	0.977	0.981	1.011	1.101	1.235	1.101
Failed rows	0	0	1	5	10	5

All three baseline models passed. Case A had the largest baseline margin, while Case C began closest to unity. Under a 25% roof-load increase, all cases remained below unity. A 50% roof-load increase raised Case A to 0.954 but produced first tested exceedances in Cases B and C at 1.073 and 1.011. Thus the

tested roof-load interval containing unity was 1.25–1.50 for Cases B and C; Case A did not reach unity within the investigated roof range.

Wind scaling produced the clearest separation. At a wind factor of 1.10, Cases A and B remained below unity at 0.984 and 0.990, whereas Case C reached 1.101. At a wind factor of 1.20, all three exceeded unity, reaching 1.073, 1.064 and 1.235. Relative to baseline, these values represent increases of approximately 19.6%, 16.0% and 26.4%. Figure 2 shows that the response is model-specific and not proportional to baseline utilization alone.

The combined roof/wind scenario remained below unity for Case A at 0.986, while Cases B and C reached 1.009 and 1.101. Case C's combined result equalled its wind 1.10 result to three decimal places, showing that wind-controlled members governed that scenario. The number of above-unity rows also differed: Case B produced fourteen failed rows under roof 1.50 but two under wind 1.20, whereas Case C produced one and ten, respectively. A single governing ratio therefore does not describe how widely demand is distributed through the model.

4 Governing Member Migration

The identity of the critical member changed in several scenarios. In Case A, the baseline and wind scenarios were governed by a short ISMB300 segment, but the roof 1.50 scenario shifted to an angle bracing member. In Case B, the baseline and wind scenarios were governed by a tapered column, whereas both amplified roof scenarios were governed by a tapered rafter. In Case C, the baseline and roof 1.25 scenarios were governed by one tapered column segment, while higher roof and wind scenarios shifted to another full-height tapered column.

This migration is important for assessment practice. Scaling a previously governing member's baseline ratio would not reproduce the model results because a different member, resistance mode or load combination can become critical. A defensible screening process must therefore rerun the complete analysis and code-check set after each load change rather than applying a global multiplier to the baseline utilization.

5 Discussion

Case A was comparatively insensitive to added roof load over the tested range but crossed unity between wind factors 1.10 and 1.20. Case B showed material sensitivity to both load families: the roof factor 1.50 and wind factor 1.20 produced similar governing ratios, although many more members exceeded unity in the roof scenario. Case C was the most wind-sensitive model and crossed unity by wind factor 1.10. Its roof response remained modest until factor 1.50, when a different column became critical.

These findings agree with the broader observation that wind response in portal and low-rise metal buildings depends on geometry, pressure distribution, restraint and structural interaction [5–8]. They also

support the system-oriented view that demand distribution and governing locations may change with the wind-to-gravity proportion [9, 10]. However, the present elastic member-check method does not capture yielding redistribution, connection flexibility, geometric imperfections beyond the retained model assumptions, cladding stressed-skin action or probabilistic uncertainty.

For engineering screening, the tested unity brackets identify where a refined analysis should concentrate. A smaller increment sweep should be run between the last passing and first exceeding factors, followed by serviceability, connection, foundation and local stability checks. The results should not be used as authorization for additional rooftop loading or revised wind demand without project-specific verification of the physical structure and the adopted model.

6 Limitations

The sample contains only three models and is not statistically representative of all industrial steel buildings. Relative load factors were applied to existing uniform-load records; no attempt was made to impose a common absolute wind pressure or roof load. The retained member checks use IS 800:1984 because that configuration is common to the three research models; redesign under current requirements may produce different results. The study addresses strength utilization only and does not report drift, deflection, fatigue, connection capacity, foundation response, corrosion, construction deviations or as-built condition. Project names are retained only for professional traceability; the underlying client drawings, model files, commercial data and plant-sensitive information are not publicly distributed.

7 Conclusions

1. All verified baselines passed, with governing utilization ratios of 0.897, 0.917 and 0.977.
2. A 25% roof-load increase remained below unity in all cases; at 50%, Cases B and C exceeded unity while Case A remained at 0.954.
3. Wind factor 1.20 produced utilization ratios of 1.073, 1.064 and 1.235, making wind the strongest tested driver in Cases A and C.
4. The governing member migrated with load type and magnitude, so baseline-ratio scaling cannot replace complete model reanalysis.
5. The proposed workflow provides a compact screening method for prioritizing detailed reassessment when roof services or wind demand change.

References

1. Bureau of Indian Standards (1984) IS 800:1984 Code of Practice for General Construction in Steel. BIS, New Delhi
2. Bureau of Indian Standards (1987) IS 875 Part 1:1987 Code of Practice for Design Loads Other Than Earthquake for Buildings and Structures Dead Loads. BIS, New Delhi

3. Bureau of Indian Standards (1987) IS 875 Part 2:1987 Code of Practice for Design Loads Other Than Earthquake for Buildings and Structures Imposed Loads. BIS, New Delhi
4. Bureau of Indian Standards (2015) IS 875 Part 3:2015 Design Loads Other Than Earthquake for Buildings and Structures Wind Loads. BIS, New Delhi
5. Robertson AP, Wind Eng J (1992) Ind Aerodyn 41–44. [https://doi.org/10.1016/0167-6105\(92\)90577-W](https://doi.org/10.1016/0167-6105(92)90577-W)
6. Coffman BF, Main JA, Duthinh D, Simiu E (2010) J Struct Eng 136:744. [https://doi.org/10.1061/\(ASCE\)ST.1943-541X.0000140](https://doi.org/10.1061/(ASCE)ST.1943-541X.0000140)
7. Habte F, Chowdhury AG, Yeo D, Simiu E (2017) Eng Struct 131:428. <https://doi.org/10.1016/j.engstruct.2016.11.024>
8. Fu JY, Wu JR, Dong CC, Xu A, Pi YL (2019) Eng Struct 194:396. <https://doi.org/10.1016/j.engstruct.2019.04.090>
9. Liu W, Zhang H, Rasmussen KJR, Yan S (2019) J Constr Steel Res 157:440. <https://doi.org/10.1016/j.jcsr.2019.02.015>
10. Arrayago I, Rasmussen KJR, Zhang H (2022) Struct Saf 97:102211. <https://doi.org/10.1016/j.strusafe.2022.102211>

Figures

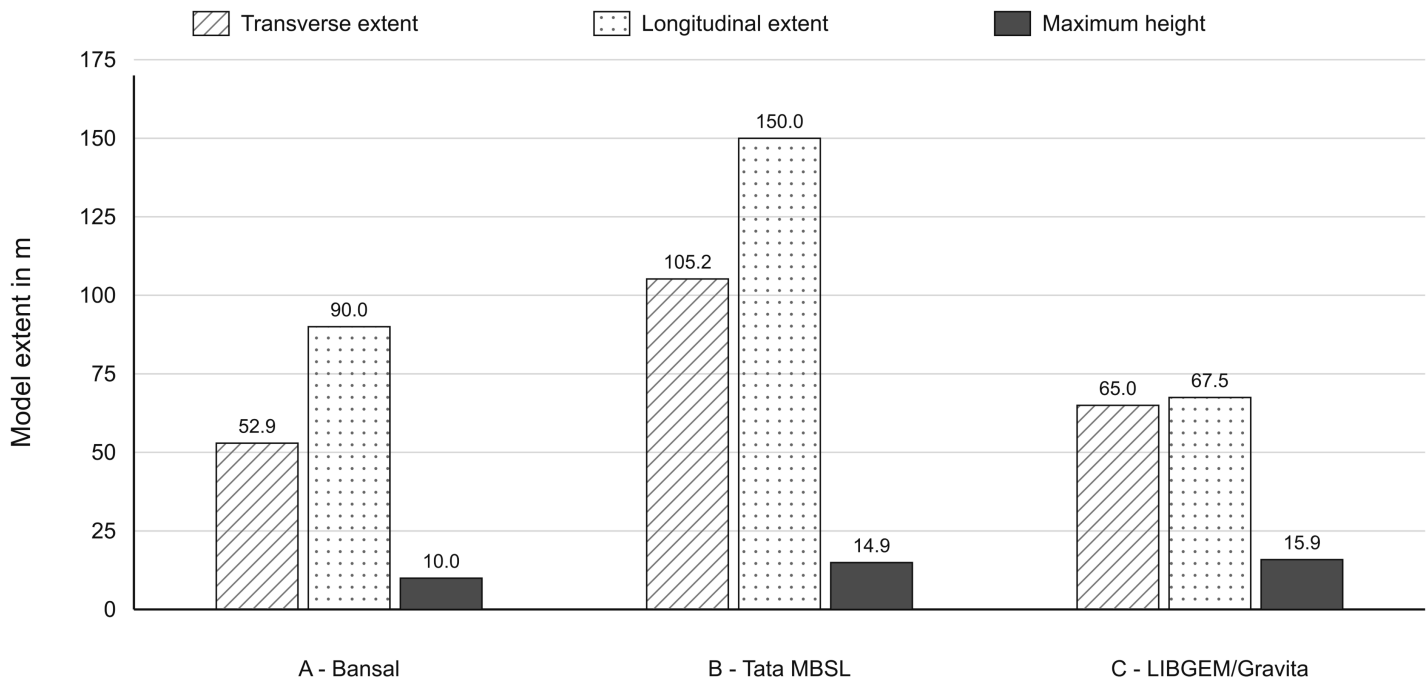


Figure 1

Comparative geometric extents of the Bansal, Tata Motors Body Solutions and LIBGEM/Gravita research models

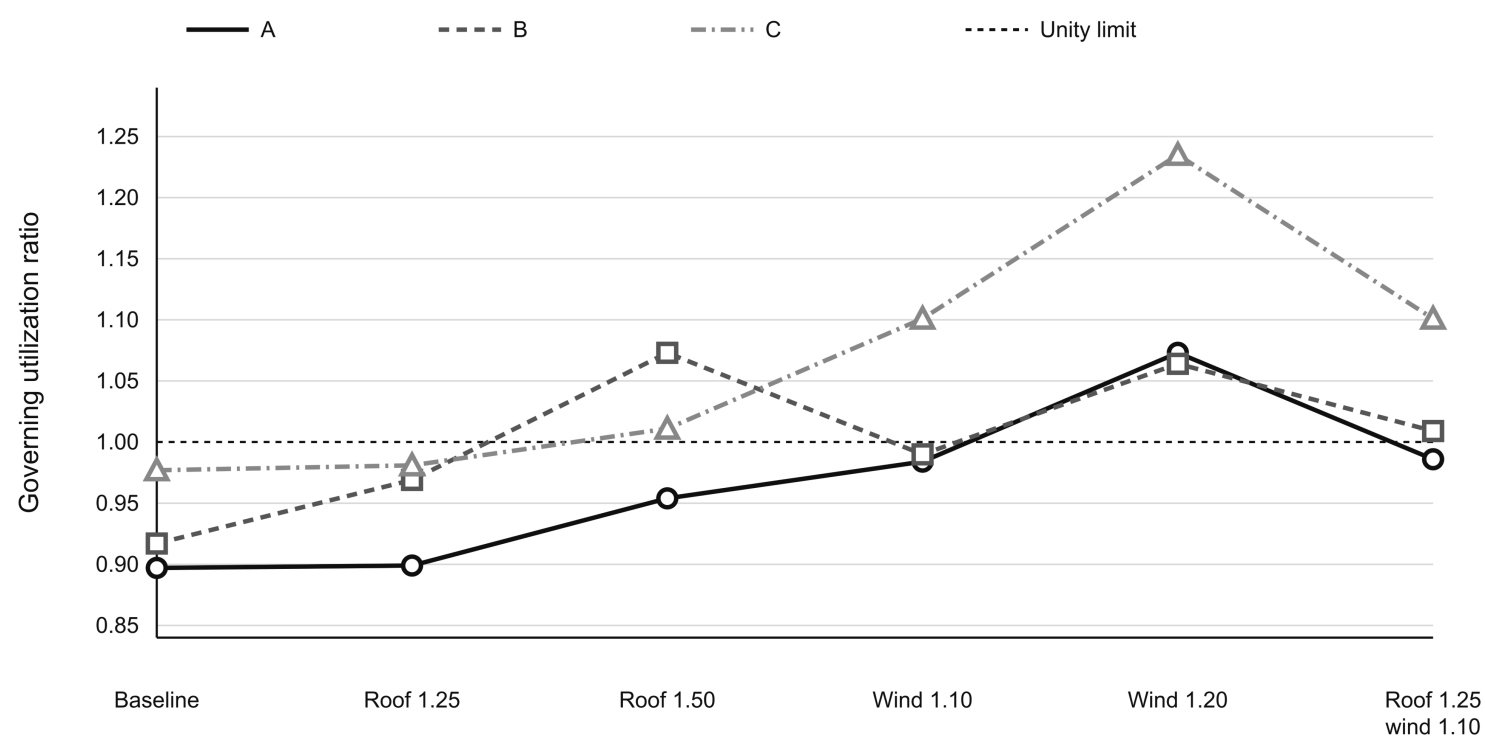


Figure 2

Governing utilization ratios under the six controlled loading scenarios; A denotes Bansal Steel & Power, B denotes Tata Motors Body Solutions, and C denotes LIBGEM/Gravita