

Analysis of Industrial Shed with Different Bracing Configurations Resting on Sloping Ground Under Wind Load

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Abstract: Industrial sheds form the backbone of manufacturing, warehousing, processing units, and running large-scale utility operations. These buildings are usually lightweight and have a lot of space between them so that they can work as efficiently as possible. Because of their open designs and thin steel parts, industrial sheds are severely affected by lateral loads, especially wind load. The present study examines the structural performance of an industrial steel shed situated on sloped terrain under wind loading, focusing on the efficiency of various bracing designs in enhancing lateral stability. Using STAAD-PRO Software, a three-dimensional analytical model of an industrial shed in MIDC, Nagpur is generated. Staad-Pro follows the rules set down in Indian Standards, such as IS 875 (Part 3): 2015 and IS 800:2007. The shed is 48 m long, 16.5 m wide, and 11 m tall, and it is tested at a basic wind speed of 44 m/s, considering the real-world impacts of sloping terrain. For the analysis, four models are created resting on sloping ground with different bracing configurations: unbraced model, model with X-Bracing, K-Bracing and Inverted V-Bracing. We used codal provisions to manually figure out the wind loads and then used those numbers in the analytical model. Nodal displacement, column forces, bending moments, and axial forces in members are all used to measure how well the structure worked. The findings demonstrate that the inclusion of bracing markedly improves the lateral stiffness of the structure in comparison to the unbraced model. X-bracing is better at controlling lateral displacement and column moments, which showed that it had the most stiffness and could efficiently transfer forces caused by wind through axial action. K-bracing showed a larger axial force distribution than other types of bracing, which means it was better at redistributing loads but made the force more concentrated in members. Inverted V-bracing demonstrated a balanced distribution of forces and a mild response from the structure. The comparison research revealed that X-bracing is the most effective option for enhancing the wind resistance of industrial sheds built on sloped terrain. The study reveals that choosing the right bracing is very important for making sure that structures are safe, usable, and stable when wind loads are present.

IndexTerms - Industrial Shed; X-Bracing; K-Bracing; Inverted V-Bracing; Lateral Stability; Nodal Displacement; Axial Force; Bending Moment; STAAD-Pro

IJ INTRODUCTION

Industrial sheds are an important part of modern infrastructure because they provide huge, open spaces for production, storage, logistics, and other industrial activity. Steel industrial sheds are now quite popular since they are strong for their weight, easy to make, quick to build, and cost-effective. This is because industry is growing quickly and there is a growing need for efficient structural solutions. But when industrial sheds are built on sloping land, their structural behaviour becomes more complicated. This is because the different heights of the columns and the uneven shape of the building can have a big effect on how stresses are spread out and how stable the building is overall. Wind load is one of the most important lateral loads that affects the safety and performance of a structure in these kinds of situations, especially in open industrial areas. People often use bracing systems to make structures more stable in the wind, increase lateral stiffness, and lower displacement. Different bracing setups may work better or worse at stopping forces caused by wind, especially when the structure is on sloping ground that causes geometric abnormalities. Consequently, this study examines an industrial shed situated on sloped terrain with various bracing configurations subjected to wind loading, seeking to assess their structural performance regarding displacement, member forces, and overall stability, and to determine the most efficient bracing system for secure and cost-effective design. Bracing systems are often used in steel sheds to make them more stable and less likely to bend too much. Bracing makes the shed stiffer on the sides, helps it transfer loads better, and makes it work better overall against dynamic forces. Cross bracing, K-bracing, V-bracing, and portal bracing are all types of bracing that work better or worse depending on the shape and load of the structure. So, it's important to do a logical and comparative examination of various bracing techniques, especially when the shed is on sloping terrain. Asymmetry in stiffness is caused by differences in foundation levels. This makes load transfer uneven and makes the structure more likely to move sideways. Because of this, lateral load-resisting systems, especially bracing arrangements, become quite important. The current study aims to comprehend the structural behaviour of an industrial shed with diverse bracing configurations on sloping terrain, assessing its performance under wind loads according to IS 875 (Part 3): 2015, while determining the most structurally efficient and cost-effective bracing system.

II] LITERATURE REVIEW

The research conducted by Prof. Kavita. K. Ghogare, Vishakha O. Dange ^[1] compared different hot-rolled steel industrial shed configurations, including Howe truss, A-truss, and portal truss, to identify the most suitable and economical structural system. The sheds were designed as per Bureau of Indian Standards IS 800:2007 and analysed for dead load, live load, and wind loads according to IS 875 using STAAD-Pro. The comparison evaluated strength, structural efficiency, and economy to determine the optimum shed configuration. In the research by Saidi O. Olalere and Olufemi O. Alayode ^[2] presented a numerical study that analyzed wind pressure effects on low-rise buildings with flat, gable, and circular roofs using the ANSYS Fluent package under different wind speeds and terrain conditions. The results showed that drag coefficient decreases with increasing wind speed, while larger vortices form on the leeward side, increasing roof vulnerability. Based on aerodynamic performance, the circular roof was found to be the most efficient configuration. The research by Seena Somasekharan, Vasugi K ^[3] evaluated conventional steel buildings and pre-engineered buildings (PEB) for industrial construction, focusing on structural efficiency, lightweight design, and economy. Using SAP2000, wind analysis was carried out on industrial buildings with different truss sections and bracing systems such as X, diagonal, and K-bracing to identify the most optimized and economical structural configuration, which was then compared with PEB. The research conducted by Abhyuday Titiksh, Abhinav Dewangan, Ankur Khandelwal, Akshay Sharma ^[4] showed that pre-engineered structures are better than regular steel buildings in terms of cost, speed of construction, adaptability, and future possibilities. This is especially true in developing countries like India. The results revealed that pre-engineered industrial sheds are cheaper, use less energy, and may be designed in a variety of ways. The research by Shivani Meher, Ruchita Nar, Sadichha Jagadale, Gautami Kalal, Asst. Prof. Viren Chandanshive ^[5] in their study outlines the design of an industrial warehouse to accommodate the increasing demands of industrialization in India, taking into account various load impacts, including dead load, live load, and wind loads, in accordance with Bureau of Indian Standards IS 800:2007 and IS 875.

Many researchers in their research provided the study and design of truss members, columns, and connections and demonstrated that industrial warehouses can be effectively developed utilizing standard design methodologies and IS requirements. The literature analysis showed that steel and pre-engineered buildings (PEB) are good choices for industrial construction because they can span a lot of space, are light, and are cost-effective. Earlier research employing STAAD-Pro, SAP2000, and ETABS all indicate that different bracing methods, such as X, V, K, diagonal, and peripheral bracing, make structures much more stable, less prone to bending, and better able to handle wind and earthquakes. The paper also talks about how sloping land, wind zones, tubular steel sections, and optimum bracing arrangements may help make industrial sheds and warehouses that are safe, cheap, and long-lasting.

III] MODELLING AND ANALYSIS

This study employs a systematic and analytical methodology to assess the structural performance of an industrial steel shed with various bracing configurations on sloped terrain subjected to wind and seismic loads. The process entails the creation of intricate three-dimensional models with STAAD-Pro, including authentic geometric configurations, material characteristics, and diverse slope situations. We look at and compare three different bracing systems like X, Inverted V, and K configurations with a model that doesn't have any bracing to see how well they work to improve lateral stability. According to Indian Standard code of practise, loading circumstances including dead load, live load, wind load and the right load combinations are used to simulate critical situations. To see how slope and bracing systems affect the structural behaviour, we look at key response characteristics such as nodal displacement, axial forces, bending moments, and overall stability. This method guarantees a thorough and dependable evaluation, making it easier to choose the best bracing setup for industrial sheds that must deal with complicated loading situations.

The wind study of the industrial shed was done according to the rules in IS 875 (Part 3), considering that the shed is located at MIDC, Nagpur. The basic wind speed was set to 44 m/s, and the design wind speed was found by considering danger, terrain, height, and topography. The risk factor (k_1) was set to 1.0 for a building with a 50-year design life, and the terrain and height factor (k_2) was found to be 0.99 for Category 3 terrain and 11 m height. The ground slope of 1 in 10 was used to figure out the terrain factor (k_0), which gave values of 1.0 for conditions upwind and 1.03 for conditions downwind. So, the design wind speeds were found to be 43.56 m/s for upwind and 44.86 m/s for downwind. This meant that the wind pressures were 1.13 kN/m² for upwind and 1.20 kN/m² for downwind. This study looked at wind loads at the roof truss's panel points in both 0° and 90° wind directions. The leeward side had the highest loads, up to 21.5 kN per middle panel point. These loads were broken down even further into global X and Z directions and added to the STAAD-Pro model so that it could be used to study the structure and compare different brace arrangements.

For modelling of Industrial Shed first the region for proposed structure and the dimensions were fixed according to the requirements and considering different parameters. The detail of the Industrial Shed is as given below. After considering the dimensions and location for the analysis of Industrial shed, the manual calculations for the roof truss are done. Now for actual analysis, we have considered 4 models. First model will be basic model that means the model will represent an Industrial Shed without provision of any bracing configuration but resting on sloping ground. Second model represents Industrial Shed with X bracing resting on sloping ground. Third model represents Industrial Shed with K bracing resting on sloping ground, and fourth model represents Industrial Shed with inverted V bracing resting on sloping ground. The analysis is carried out in two stages, first stage is Wind Analysis, and second stage is Seismic Analysis. The results thus obtained from the models with bracing will be compared with the basic model which is without bracing. The modelling of these structures is done using Staad-Pro Software. The seismic analysis is done by equivalent static method.

| Sr. No. | Particulars | Description |
|---------|-------------------------------------|----------------------------------|
| 1 | Location | MIDC, Naggur |
| 2 | Type of Structure | Industrial Steel Structure |
| 3 | Functionality | Warehouse |
| 4 | Overall length of Industrial Shed | 48 m |
| 5 | Overall width of Industrial Shed | 16.5 m |
| 6 | Width (c/c distance of roof column) | 16 m |
| 7 | c/c spacing of Truss | 8 m |
| 8 | Rise of Truss | ¼ of span |
| 9 | Self-weight of Purlins | 318 N/m |
| 10 | Height of column | 11 m |
| 11 | Height of column on sloping side | 12.6 m |
| 12 | Roofing and side covering | AC Sheet (171 N/m ²) |
| 13 | Grade of Steel | Fe 410 |

Fig. 1: Details of Industrial Shed

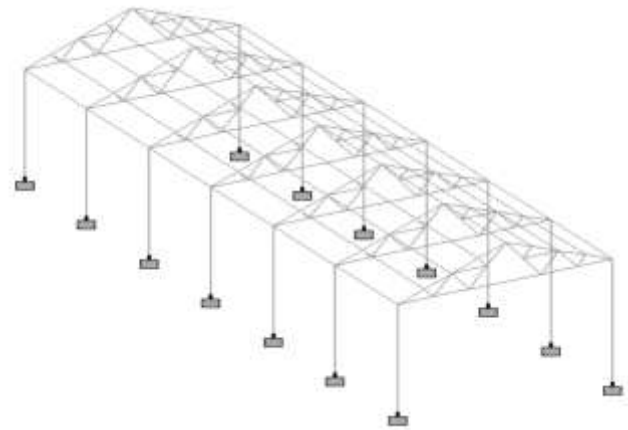


Fig. 2: Industrial Shed without Bracing

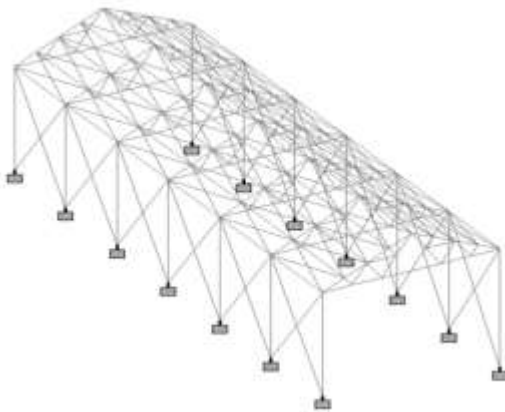


Fig. 3: Industrial Shed with X-Bracing

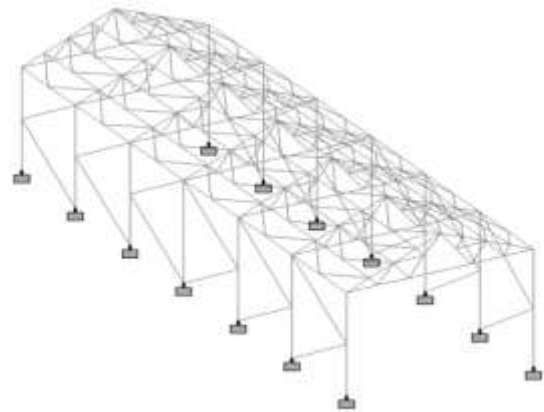


Fig. 4: Industrial Shed with K-Bracing

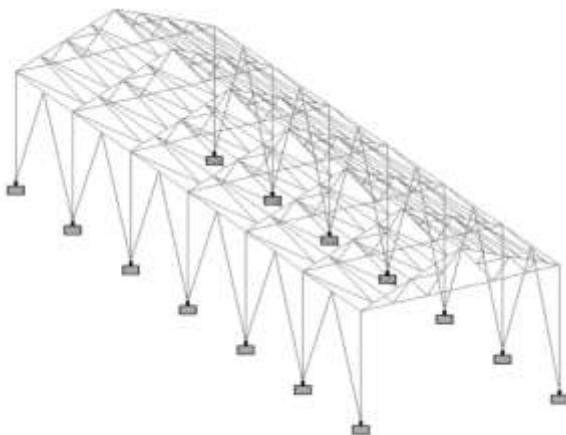


Fig. 5: Industrial Shed with Inverted V-Bracing

- i. 1.5 (D.L. + L.L)
- ii. 1.2 (D.L. + L.L + WLX)
- iii. 1.2 (D.L. + L.L - WLX)
- iv. 1.2 (D.L. + L.L + WLZ)
- v. 1.2 (D.L. + L.L - WLZ)
- vi. 0.9 D.L. + 1.5 WLX
- vii. 0.9 D.L. - 1.5 WLX
- viii. 0.9 D.L. + 1.5 WLZ
- ix. 0.9 D.L. - 1.5 WLZ

Fig. 6: Load Combinations used for Analysis

IV] ANALYSIS RESULTS

In this study, wind analysis is carried out for four models, a basic model without bracing and three models with different bracing configurations, X-Bracing, K-Bracing and Inverted V-Bracing. The three models with bracing are compared with the basic model and analysis is done using Staad-Pro Software. The results obtained from the analysis are studied and graphs are plotted. The graphs obtained are listed below.

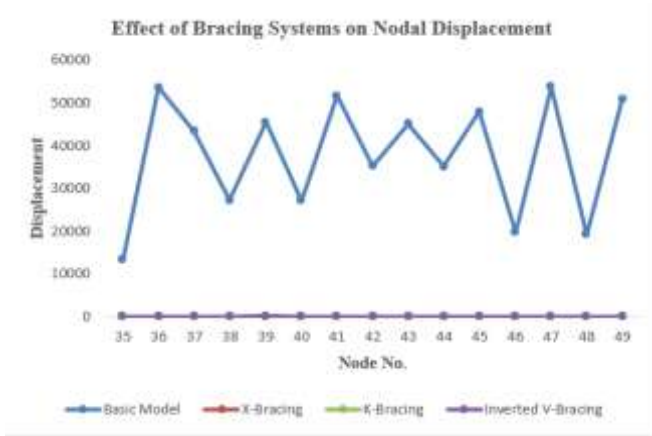


Fig.1: Displacement in Z Direction

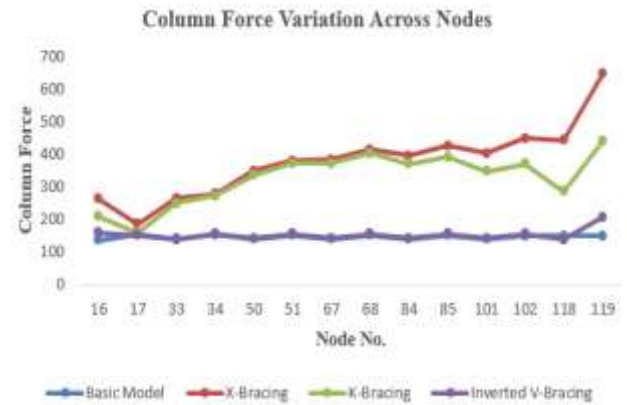


Fig. 2: Column Forces in Y Direction

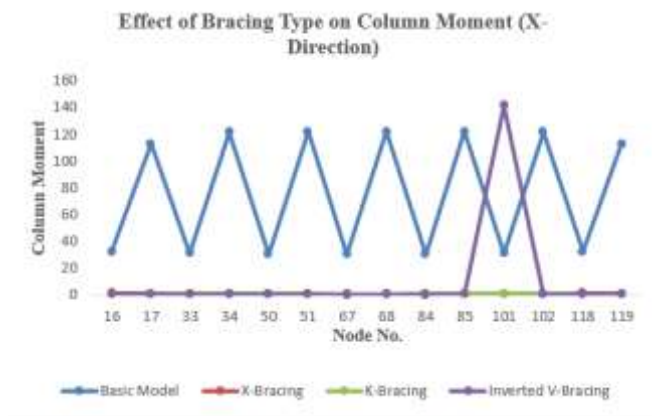


Fig. 3: Column Moment in X Direction

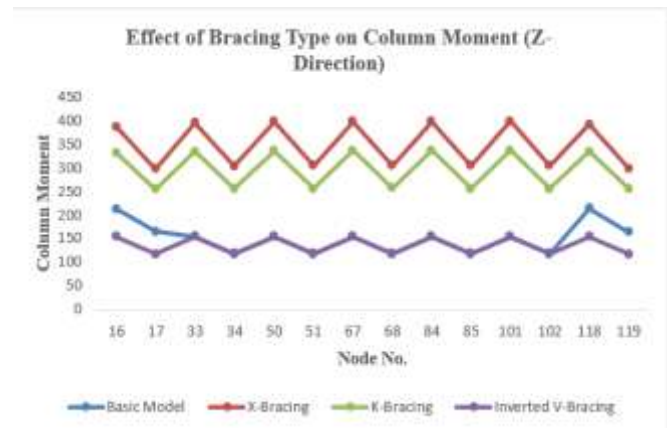


Fig. 4: Column Moment in Z Direction

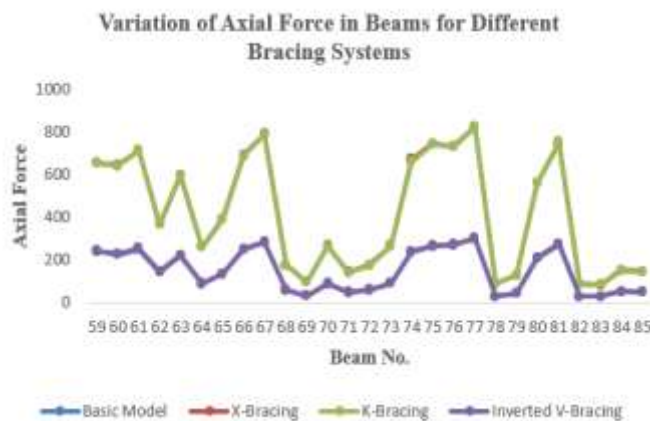


Fig. 5: Axial Forces in X Direction

VJ CONCLUSIONS

- i. The study shows that wind load has a big effect on the way industrial sheds built on sloped ground behave because the shapes and heights of the columns aren't all the same. This makes it more likely that the sheds will move side to side, and the force will be distributed unevenly.
- ii. The unbraced model had the most nodal displacement, the highest bending moments, and the least amount of horizontal stiffness. This shows that bracing systems are necessary to keep structures stable when wind blows through them.
- iii. The general performance of the structure was greatly improved by adding bracing systems, which limited lateral movement, kept member forces in check, and made the industrial shed stiffer.
- iv. X-Bracing had the best structural performance out of all the bracing designs that were looked at. It had the least amount of movement and the lowest column bending moments. This means that the structure is stiffer on the sides and can effectively pass wind-induced forces through axial action.

- v. K-Bracing had a higher concentration of axial force in its members, which meant that the load was redistributed well but that some structural parts needed more force.
- vi. The structure of the inverted V-bracing was balanced, with moderate displacement, bending moments, and axial force distribution. This meant that the total performance was stable when wind loads were applied.
- vii. A study that compares different types of sheds shows that picking the right bracing system is very important for making sheds built on sloped land safer, more useful, and more stable.
- viii. The current study shows that X-Bracing is the best and most technically reliable way to brace industrial sheds that are resting on sloped ground and being hit by wind. This makes it a good choice for real-world industrial uses in windy places.

VI] FUTURE SCOPE

The present study can be extended in several directions to enhance the accuracy and applicability of the results.

- i. In the future, we might do nonlinear analysis like pushover and time-history analysis to better understand how structures behave.
- ii. One may investigate how different soil conditions affect structures by adding soil-structure interaction, which is especially useful for buildings on sloping terrain. For higher or more flexible constructions, dynamic wind effects, such as gust variables, may also be considered.
- iii. Subsequent research may concentrate on refining bracing arrangements to attain minimal material consumption and cost-effectiveness. Also, looking at several types of structures, such as multi-bay, multi-span, and irregular industrial structures, might give a bigger picture. It may also be possible to investigate how well hybrid bracing systems, like combinations of X and V bracing, work to make them more efficient.

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