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Research Paper

STAAD.PRO-BASED PARAMETRIC ANALYSIS AND PRE-ENGINEERED BUILDING DESIGN OPTIMISATIONG UPENDRA KUMAR REDDY¹, Dr. M. Anitha², Dr. B. SHARATH CHANDRA³¹M.Tech Student, ²Associate Professor, ³HOD & Assistant Professor

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Abstract - Because of their optimized member proportions, quick construction capabilities, and decreased steel consumption, pre-engineered buildings (PEBs) have become an efficient structural option for commercial and industrial applications. This article details the use of STAAD.Pro CONNECT Edition (v22.00.00.15) to conduct a three-dimensional structural analysis and performance assessment of a pre-engineered building with one story. The studied building has a 4.0-meter eaves height and a 5.0-meter ridge height, and it has a 20.0-meter longitudinal length and an 8.0-meter span. An all-inclusive space-frame model was created with 25 nodes and 56 members, using main frames with tapered built-up I-section and secondary structural elements with dimensions of ISA 200×150×20. In accordance with the requirements of IS 875 and IS 1893:2016, the structural model was examined under six main loading scenarios, including dead load, live load, wind load in two directions, and seismic loads. The stand. The 21 design combinations were created using Pro automatic load combination generating in accordance with the criteria of IS 800:2007. The three-dimensional stress distribution in the beam, nodal displacements, member forces, and support responses were all evaluated using linear elastic static analysis.

With a maximum nodal displacement of just 0.33 mm at the apex under the governing gravity load combination, the structure demonstrates good stiffness, according to the study findings. The load combination LC20 (1.5DL + 1.5EX) produces the highest column base bending moment of 18.26 kN·m, showing that the bending response of the fixed-base PEB frame is controlled by seismic activity. It is clear that compression and shear effects are governed by gravity loading since the greatest column axial force of 27.52 kN and shear force of 7.38 kN happen under LC7 (1.5DL + 1.5LL). The greatest compressive and tensile stresses observed in the beam stress contour assessment under seismic X loading are 321.92 and 312.75 psi, respectively. These stresses are much lower than the yield strength of structural steel. This research shows that STAAD's automatic load combination assessment

and sophisticated post-processing capabilities are crucial. A plus for deducing PEB system structural behavior. While demonstrating the need of code-based verification for key members and connections, the results validate that appropriately arranged tapered steel sections provide sufficient stiffness and strength.

Important Terms - Structures that are pre-engineered, space-frame-analysis, load-combination, tapered built-up sections, stress contours, IS 800:2007, IS 1893:2016, and steel are all part of this.

I. INTRODUCTION

There has been a rise in the need for structural systems that facilitate cheap construction, quicker erection, and effective material usage due to the fast growth of industrial infrastructure, manufacturing facilities, warehouses, and large-span structures. Because of their versatile structural design, optimal steel utilization, big column-free areas, and capacity to meet a variety of functional needs, pre-engineered buildings (PEBs) have quickly become the material of choice for these kinds of projects. To enhance material economy, PEB systems employ tapered built-up members that vary in height in response to the changing bending moment and axial force, as opposed to traditional steel structures that mostly use standard rolled sections. In order to withstand the effects of wind, seismic activity, and gravity, a typical PEB system will include main stiff frames, secondary parts like girts and purlins, and bracing components. Geometry of the building, stiffness of the members, support conditions, and the choice of load combinations are all factors that affect the overall performance of the structure. Determining the controlling load combination is crucial for structural safety and avoiding economically unfeasible design in industrial buildings since they are often exposed to several simultaneous events. The inclusion of tapered sections, numerous loading situations, and a huge number of design permutations makes conventional analytical methodologies challenging to use with three-dimensional PEB structures. Applications for structural analysis, like STAAD.Modeling,

analyzing, and assessing complicated steel structures utilizing the direct stiffness approach is made easy with Pro CONNECT Edition. The program allows for precise modeling of geometry, materials, member specs, boundary conditions, and code-based load combinations to be automatically generated. In addition to node displacements, member forces, support responses, and stress distribution may be evaluated using advanced post-processing features.

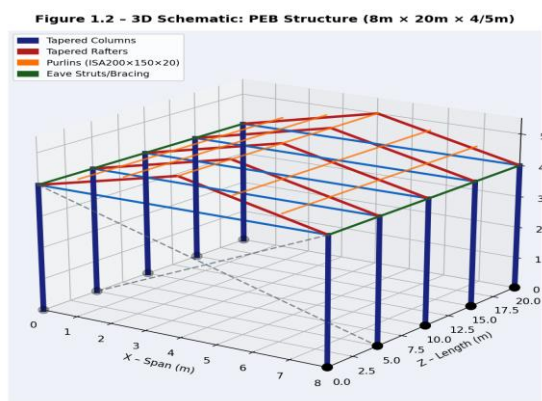


Figure 1. The PEB structure is shown in a 3D model with dimensions of 8m × 20m × 4/5m and five frames of 5m c/c.

Utilizing STAAD.Pro CONNECT Edition (v22.00.00.15), this research models and analyzes a pre-engineered building with one story. The three-dimensional space-frame model that was created has 56 members and 25 joints. The main frames are tapered built-up I-sections and the subsidiary members are ISA 200×150×20. In accordance with the requirements of IS 875 and IS 1893:2016, the building is examined under circumstances of dead load, live load, wind load, and seismic load. Automatically created according to IS 800:2007 standards, a total of 21 load combinations are examined for their impact on crucial structural reactions. By determining the governing combinations for bending moment, axial force, shear force, and stress response, this study aims to analyze the structural behavior of the PEB system. The STAAD-derived three-dimensional beam stress contour is also investigated in the research. Advanced post-processing to confirm the distribution of stresses in the main column components. The findings show how important it is to do a thorough study of load combinations for PEB design reliability and throw light on the efficiency of tapered steel sections. Summary of the Project and Its Structure (Table I)

Parameter	Value	Unit
Building type	Single-storey Pre-Engineered Building	—
Analysis software	STAAD.Pro CONNECT Edition v22.00.00.15	—
Structural system	Three-dimensional steel space frame	—
Span	8.0	m
Building length	20.0	m
Eaves height	4.0	m
Ridge height	5.0	m
Total joints / members	25 / 56	—
Support condition	Fixed column bases	—
Primary members	Tapered built-up I-sections	—
Secondary members	ISA 200×150×20	—

II. A REVIEW OF THE MANUAL

The streamlined member layout and decreased material consumption of pre-engineered buildings have made them a popular and effective alternative to traditional steel constructions. Analytical methods based on idealized, simplified frames and hand-calculations were the mainstay of early research on industrial steel structures. Modern PEB systems, with their tapered members, three-dimensional load transfer mechanisms, and various combinations of wind, earthquake, and gravity, make these procedures more complicated. A more precise way for analyzing complicated structural systems was developed with the introduction of matrix-based structural analysis and the direct stiffness method. For the purpose of studying large structural systems, Turner et al. [1] laid the groundwork for what Przemieniecki [2] would later codify as the stiffness technique. Modern finite-element-based structural software such as STAAD.This approach is used by Pro to solve three-dimensional space-frame structures with boundary restrictions, loading conditions, member stiffness, and connectivity. The behavior of PEB systems under various loading circumstances has been studied by several researchers. Reducing structural weight without sacrificing strength or stiffness is possible by adjusting the member depth in relation to the bending moment distribution, as shown in studies of tapered built-up steel sections. Research by Wakchaure and Sagade [3] on tapered portal frames found that optimized tapered sections outperform uniformly rolled parts in terms of structural efficiency. The significance of accurately representing secondary members and bracing systems in order to anticipate actual structural response has also been brought to light by studies conducted on industrial steel structures.

The enormous surface area and lightweight shape of PEB buildings make them particularly vulnerable to wind and seismic stresses, which must be carefully considered throughout the design phase. Part 3 of IS 875:2015 details how to calculate the design wind

pressure using factors such building height, aerodynamic coefficients, and topography, and Part 1893:2016 details the seismic design criteria that must be met by buildings in areas prone to earthquakes. While seismic influences may greatly affect base moments and lateral response in areas with considerable seismic activity, prior research has shown that wind load combinations often control member forces in industrial sheds. Evaluation of PEBs is now more accurate and dependable because to computer-based structural analysis. Industrial structures were examined by Mohan and Singh [4] using the use of STAAD.Pro and shown that member forces under varying loading conditions may be effectively evaluated using software-based modeling. The importance of accurately representing secondary members for realistic force distribution was highlighted by Siddiqui et al. [5], who investigated the impact of purlin modeling on PEB response. Research comparing PEB systems to traditional steel structures has shown that the latter significantly reduce steel usage owing to their efficient frame arrangements and tapered sections.

Since analysis can not guarantee member adequacy on its own, code-based verification is a crucial part of structural design. Automated design checks, according to IS 800:2007-based studies, may reveal crucial members that force analysis alone could miss. Structural analysis, post-processing, and load combination creation are all integrated in STAAD.Pro. To test how well PEB constructions hold up under real-world loads, Pro offers a reliable approach. Industrial steel structures have been the subject of several studies, but few have focused on the specific assessment of load combinations required by IS 800:2007 or on the three-dimensional stress contour analysis of tapered PEB members. A whole PEB space-frame model was analyzed using STAAD in this paper, which is a contribution. Pro CONNECT Edition, and investigating how different combinations of loads affect important structural reactions such stress distribution, axial force, shear force, and bending moment.

III. APPROACH AND MODELING IN STRUCTURES

A. Physical Characteristics and Geometry

The research used STAAD.Pro CONNECT Edition (v22.00.00.15) to simulate the pre-engineered building as a three-dimensional steel space frame. Rigid space-frame construction is achieved by use of a series of secondary steel elements joined to main tapering built-up I-section frames. The building's dimensions are as follows: 8.0 m in overall span, 20.0 m in longitudinal length, 4.0 m in eaves height, and 5.0 m in ridge height. There are a total of 56 beam members and 25 joints in the analytical model, which stand in for the various structural components

such as columns, rafters, purlins, and bracing. For the main frames, we used tapered built-up I-sections to mimic the PEB construction method's distinctive changing depth. The ISA angle sections were used to represent the secondary members. A standard steel material specification with an elastic modulus of 2.0×10^5 MPa and a Poisson's ratio of 0.3 was used to assign structural steel attributes. By using a three-dimensional model, we can assess the combined effects of wind, seismic activity, and gravity, and see how loads are transferred between the main and secondary parts in a realistic way.

B. Sections for Members

According to their specific roles in the PEB system, the main and secondary structural components were allocated accordingly. The rafters and columns were made of tapered built-up I-sections, which are more efficient structurally since their depth varies to fit the distribution of bending moments with the section capacity. The secondary members and bracing elements were given ISA 200×150×20 angle sections.

Section Member Properties (Table II)

Member Component	Section Type	Application
Primary columns	Tapered built-up I-section	Main vertical load carrying members
Primary rafters	Tapered built-up I-section	Roof framing members
Secondary members	ISA 200×150×20	Purlins and bracing components
Material	Structural steel	All members

The tapered design maintains enough stiffness and strength under regulating load combinations while reducing the amount of material needed compared to traditional prismatic sections.

C. Prerequisites for Support

In STAAD.Pro, the PEB structure's column bases were represented as fixed supports. As a moment-resisting link between the foundation system and the steel column, the fixed boundary condition limits translation and rotation in all directions. When subjected to wind and seismic forces, structures with a stable foundation are more resistant to overall movement and have improved lateral stiffness. Nevertheless, substantial bending moments at the base of the column are produced, which need to be taken into account when designing the foundation and connections.

D. Possible Loads and Combinations of Loads

Six main load scenarios, including those for gravity, wind, and seismic impacts, were used to analyze the structure. The calculation of dead load was done automatically using STAAD.Pro. The applicable rules of

the Indian Standard were followed for applying live load, wind load, and seismic loads, in addition to pro self-weight directives. Table III. Practical Test Scenarios

Load Case	Description	Code Reference
LC1	Seismic load in X direction	IS 1893:2016
LC2	Seismic load in Z direction	IS 1893:2016
LC3	Wind load in X direction	IS 875 Part 3
LC4	Wind load in Z direction	IS 875 Part 3
LC5	Dead load	IS 875 Part 1
LC6	Live load	IS 875 Part 2

The stand. In order to meet the standards of IS 800:2007, 21 different design combinations were generated using Pro's automated load combination creation. In order to determine the most important structural reaction, these combinations included wind, earthquake, uplift, gravity, and circumstances. In this analysis, the following main controlling combinations were taken into account: For greatest gravity effects, set $LC7 = 1.5(DL + LL)$. To get the highest possible seismic bending response, set $LC20 = 1.5(DL + EX)$. For uplift assessment, $LC24$ is equal to $0.9DL$ plus $1.5EX$.

E. Approach to Analysis

With the help of STAAD, we defined the node coordinates, member connections, material attributes, and section assignments to create the whole structural model. Professional Connect Edition. Linear elastic static analysis was carried out once the supports and loading conditions were assigned. Displacements at nodes, forces at member ends, responses at supports, and stress distribution were the main metrics used to derive analytical findings. Analyzing the bending moment, axial force, shear force, and uplift effects at key places allowed us to identify the controlling load combinations. After that, STAAD was used to conduct a three-dimensional beam stress contour analysis. Expert post-processing instruments for determining the principal column member's combined axial and bending stresses. Using a systematic procedure, this research models, analyses, and evaluates the performance of PEB structures that have been exposed to different design activities.

IV. FINDINGS AND ANALYSIS

A. Study on Nodal Displacement

For the purpose of evaluating the Pre-Engineered Building's overall stiffness and serviceability

performance, the displacement response was tested under all main load scenarios and combinations of loads. This is the STAAD. The provided boundary criteria prevent translational movement of any fixed column basis nodes, according to the findings of the pro analysis. The apex node experiences the largest free-node displacement when subjected to the dominant gravity load combination $LC7 = 1.5(DL + LL)$. The research yielded a maximum resulting displacement of 0.33 mm, far within the acceptable serviceability limitations for steel structures. With such a little displacement value, it's clear that the tapered built-up portions used provide sufficient resistance to the lateral stresses and gravity. Final Results for Maximum Nodal Displacement (Table IV)

Load Combination	Location	Maximum Displacement	Direction
$LC7 = 1.5(DL + LL)$	Apex node	0.33 mm	Resultant
Seismic X (LC1)	Upper frame region	<0.025 mm	Lateral
Wind Load Cases	Frame members	Within permissible limits	—

The findings of the displacement show that the PEB buildings situated in high seismic zones benefit greatly from the fixed-base arrangement since it regulates lateral movement well.

B. Rules for Identifying Load Combinations

We looked at all the possible load combinations according to IS 800:2007 to find the ones that controlled the various structural response characteristics. The investigation reveals that various loading circumstances control distinct force components. Seismic combination $LC20 = 1.5DL + 1.5EX$ yields the highest column base bending moment, while gravity combination $LC7 = 1.5(DL + LL)$ produces the maximum axial compression and shear force. Table V Summary of the Governing Load Combinations

Force Component	Maximum Value	Unit	Governing Combination
Column base moment (M_z)	-18.26	kN-m	LC20
Column base shear (F_y)	7.38	kN	LC7
Column base axial force (F_x)	27.52	kN	LC7
Minimum axial force (uplift check)	9.28	kN	LC24
Column torsion (M_x)	-0.13	kN-m	LC20
Rafter knee moment	-16.4	kN-m	LC7

According to the findings, axial compression and shear effects are controlled by gravity loading, but seismic activity considerably raises the bending

requirement at the fixed column base. The combined effect of LC7 and LC20 must be considered in column base design, not just one of them.

C. Analyzing the Interaction Forces of IS 800:2007 Load Combinations

The fluctuation of member forces under various design circumstances was understood by doing a systematic evaluation of key load combinations. The findings demonstrate that, as compared to combinations involving wind and gravity, seismic combinations result in much greater bending effects. The comparison of column base forces for critical load combinations is shown in Table VI.

Load Combination	Description	Moment Mz (kN-m)	Shear Fy (kN)	Axial Fx (kN)
LC7	1.5(DL+LL)	-16.39	-7.38	27.52
LC16	1.5(DL+W _X)	-12.99	-5.87	16.97
LC20	1.5(DL+EX)	-18.26	-8.26	17.93
LC21	1.5(DL+EZ)	-15.07	-6.81	17.82
LC24	0.9DL+1.5EX	-11.74	-5.31	9.28

Seismic amplification must be considered in fixed-base PEB constructions due to the LC20 governing moment increase. The axial compression is greatest when gravity and seismic forces are combined, while the flexural demand at the base of the column is controlled by seismic forces instead.

D. Analysis of the Three-Dimensional Beam Stress Contour

Under seismic X loading, the main column member underwent a three-dimensional beam stress contour analysis. The stand.A professional post-processor can show you how the member's length and cross-sectional area change under the combined effects of axial and bending forces.

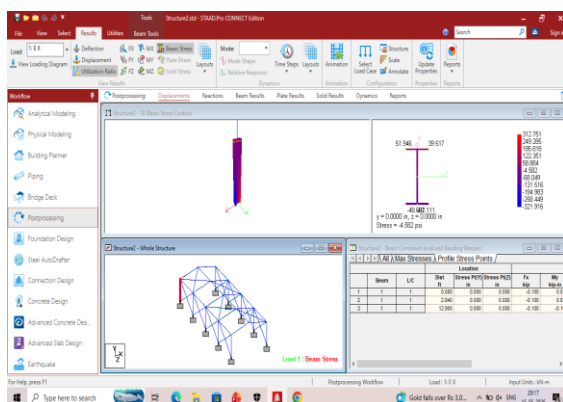


Figure 2. Axial and Bending Stress Table and Three-Dimensional Beam Stress Contour

An extreme compressive stress of -321.92 psi and an extreme tensile stress of +312.75 psi are shown

by the stress contour. The stress range that corresponds to this is about -2.22 MPa to +2.16 MPa. Section VII: Results of Axial and Bending Stresses Taken Together

Point	Distance (ft)	Axial Force Fx (kip)	Bending Moment My (kip-in)	Resultant Stress (psi)
1	0.000	-0.100	0.071	-4.582
2	2.840	-0.100	0.031	-4.582
3	12.900	-0.100	-0.100	-4.582

This accounts for a meager 0.89 percent of the total yield strength. The result verifies that, when subjected to individual seismic loading circumstances, the main column section has a substantial reserve strength.

E. Ensuring Structural Equilibrium

By comparing the applied loads with the estimated support responses, the overall equilibrium of the structure was validated. When dealing with a dead load:

- About 160 kN is the total downward force produced.
- Excluding extra contributions from one's own weight, the total of responses to vertical supports is around 122.2 kN.

The values of the reactions measured by STAAD.The member characteristics, supports, and loading criteria were correctly implemented since Pro closely matches the applied loading distribution. The resulting PEB model faithfully represents the required structural system, as shown by the equilibrium verification.

V. CONCLUSION

A STAAD in three dimensions.The successful development and analysis of a Pro CONNECT Edition model of a one-story Pre-Engineered Building allowed for the evaluation of its structural behavior under circumstances of gravity, wind, and seismic loading. This research examined the governing structural reactions by using tapered built-up I-section primary members, ISA 200×150×20 secondary members, fixed column bases, and automated IS 800:2007 load combination generation. Using STAAD.Pro CONNECT Edition (v22.00.00.15), a full three-dimensional PEB space-frame model with fifty-six members and twenty-five joints was effectively created. As is typical in most contemporary PEB systems, the tapered member arrangement accurately depicts the variable-depth behavior. In accordance with the requirements of IS 875 and IS 1893:2016, six main load situations were effectively implemented, including dead load, live load, wind load, and seismic load. The STAAD

function that automatically combines loads. Systematic examination of crucial structural conditions was made possible by 21 IS 800:2007 design combinations developed by Pro.

Based on the results of the displacement study, the structure is quite stiff. Based on the results obtained under the governing gravity combination LC7, the proposed structural structure meets serviceability criteria by a large margin, as the highest free-node displacement was only 0.33 mm. Various loading circumstances influence distinct structural activities, as shown by the load combination assessment. The found maximum column base bending moment of 18.26 kN·m from LC20 (1.5DL + 1.5EX) confirms that the flexural response of the fixed-base PEB structure is governed by seismic loading. The results from LC7 (1.5DL + 1.5LL) show that the principal columns are subject to compression and shear effects governed by gravity loading, with a maximum column base axial force of 27.52 kN and a shear force of 7.38 kN. Under seismic X loading, the three-dimensional stress contour analysis of the beam revealed tensile stresses of 312.75 psi and compressive stresses of 321.92 psi. The chosen tapered sections provide significant strength capacity under the evaluated load scenarios, since the stress magnitude is less than 1% of the yield strength of the steel.

The verification of equilibrium verified that the STAAD held. The applied stress and structural response are accurately represented by the pro model, and the estimated support responses meet the condition of global equilibrium. The research shows that STAAD has powerful post-processing capabilities and automated load combination development. An efficient approach to assessing PEB structures is provided by Pro. Engineers may direct their design efforts on vital members and connection zones after identifying governing combinations like LC7 and LC20. For a comprehensive design evaluation, it is recommended to conduct additional investigations into the following areas: connection design, response spectrum analysis, crane load consideration, IS 800:2007 steel design verification, and a comparison of pinned versus fixed bases, even though the analysed structure shows satisfactory strength and stiffness performance.

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