

Assessment of Integrated Structural Analysis and Design Workflows for Precise Quantity Estimation in Pre-Engineered Buildings

Brajendra Singh
Department of Civil Engineering, IET
SAGE University Indore M.P. India

Prof. Vasudev Rodwal,
(Asst. Professor)
Department of Civil Engineering IET, SUI, India

Dr. Atul Bhatore, (HOD)
Department of Civil Engineering IET, SUI, India

Abstract - The increasing use of Pre-Engineered Buildings (PEBs) in industrial construction has created a need for more reliable methods of structural design and quantity estimation. In this study, titled “Assessment of Integrated Structural Analysis and Design Workflows for Precise Quantity Estimation in Pre-Engineered Buildings,” a medium-span industrial PEB structure having a length of 23.4 m, width of 9.4 m, and height of 5.5 m is analyzed and designed using STAAD.Pro

All relevant loads, including dead load, live load, wind load, and seismic load, are applied as per IS 875 and IS 1893 provisions. The analysis results, such as member forces and optimized section sizes, are used to develop a detailed 3D model in Tekla Structures.

The Tekla model includes primary members such as main frames, secondary components including purlins, bracings, sag rods, cleats, and angle braces, along with connection assemblies such as base plates (pinned and fixed), end plates, and splice joints. Based on this detailed model, a comprehensive Bill of Quantities (BOQ) is generated, covering assemblies, primary members (columns and rafters), secondary elements, accessories, and fasteners.

The developed modelling approach captured connection plates, bolts, bracings, and secondary members more effectively than conventional manual estimation methods, resulting in a more practical BOQ. It was observed that that coordination between analysis results and fabrication detailing enhanced overall quantity assessment and fabrication planning.

Keywords - Pre-Engineered Building (PEB), STAAD.Pro analysis, Tekla Structures modelling, structural design approach, quantity estimation, BOQ generation, connection detailing, steel structures)

I. INTRODUCTION

In recent years, digital engineering tools have significantly changed structural design workflows by enabling better coordination between analysis, detailing, and quantity estimation processes. In steel structures such as Pre-Engineered Buildings (PEBs), this integration is important for enhancing the accuracy of material estimation and reducing differences between design calculations and actual execution. For PEB

structures, structural optimization is necessary to achieve economical and efficient construction. In conventional workflows, analysis, detailing, and quantity take-off are often carried out separately, which can result in inconsistencies, manual errors, and variations in estimated steel quantities. In this process, structural models prepared in analysis software can be coordinated directly with 3D detailing platforms, maintaining consistency between design outputs and fabrication drawings. Using interconnected modelling and detailing software helped generate material quantities that more closely matched fabrication requirements and reduced detailing inconsistencies during project execution. The current study examines the effectiveness of combining structural analysis and BIM-based detailing for Pre-Engineered Buildings. The study evaluates how analytical modelling and 3D detailing together influence quantity estimation and fabrication coordination.

Pre-Engineered Buildings (PEBs) are steel structural systems in which the components are designed, fabricated, and assembled using built-up sections that are optimized according to the actual loading conditions. Unlike conventional steel structures, PEB systems focus on efficient material utilization by varying the sectional dimensions along the member length based on force requirements.

A typical PEB consists of primary structural members such as columns and rafters, secondary members including purlins and girts, along with roof and wall sheeting systems. In comparison with conventional steel buildings that mainly use standard hot-rolled sections, PEBs make use of built-up sections that help reduce unnecessary steel consumption while maintaining structural safety and performance. Due to this advantage, PEBs are lighter in weight, economical, and widely preferred for industrial buildings, warehouses, commercial facilities, and other infrastructure projects.

The development of structural analysis and detailing software has improved the accuracy and efficiency of PEB design practices. In this study, structural analysis is performed using STAAD.Pro, which is used to evaluate load effects, member forces, and design adequacy under different load combinations. The analysis results are further used for detailed modelling and quantity estimation. The software also assists in

checking structural stability and optimizing member sizes for safe and economical design.

For modelling and detailing, Tekla Structures is used to prepare precise 3D models, fabrication drawings, and Bill of Quantities (BOQ). The adopted software environment enables a connected workflow between analysis, detailing, and quantity estimation within a coordinated digital environment. Although BIM-based workflows are increasingly adopted in steel construction projects, differences can still occur between analytical design outputs and actual material estimation.

This work examines a connected modelling and detailing procedure for the analysis, design, and quantity estimation of Pre-Engineered Buildings using STAAD.Pro and Tekla Structures. The work demonstrates the structural efficiency of PEB systems and examines the advantages of digital modelling in minimizing manual inconsistencies, enhancing ease of fabrication and erection, and obtaining reliable quantity estimations. Special attention is given to evaluating the accuracy of quantity estimation when analytical models are directly imported into Tekla Structures for detailing and BOQ generation.

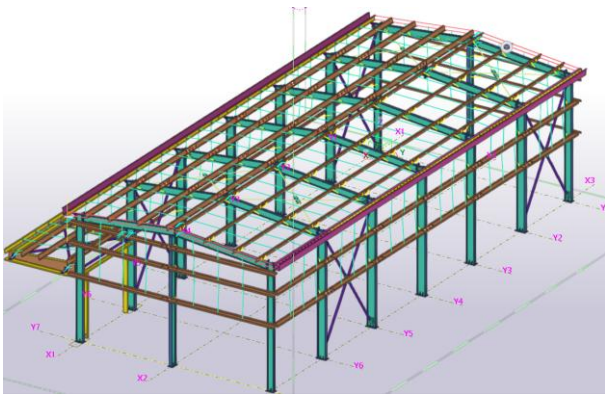


Figure 1 3D View of the Pre-Engineered Building Model (Generated from Tekla Structures)

II. OBJECTIVES

1. To perform detailed structural analysis and design of the selected Pre-Engineered Building (PEB) using STAAD.Pro by considering dead load, live load, wind load, seismic load, and suitable load combinations as per relevant steel design codes and standard provisions.
2. To study the behavior of the PEB structure under different loading conditions and examine parameters such as axial force, bending moment, shear force, displacement, deflection, and overall structural stability.
3. To prepare a precise three-dimensional model of the designed PEB in Tekla Structures including primary members, secondary members, connection details, bolts, welds, and fabrication-level assemblies.
4. To generate shop drawings, erection drawings, and detailed component drawings from the Tekla model in order to improve fabrication accuracy and reduce errors during site execution.
5. To carry out quantity estimation of structural steel members, connection materials, and related accessories directly from the Tekla model and examine the reliability of BIM-based quantity estimation methods.
6. To study the efficiency of the proposed PEB system with respect to structural performance, material optimization, ease of fabrication and erection, and reduction in unnecessary steel usage.
7. To examine the role of tapered built-up sections and secondary framing systems in achieving safe and economical design for medium-span industrial buildings.
8. To establish an integrated design process between STAAD.Pro and Tekla Structures for analysis, design, detailing, and quantity estimation so that better coordination and consistency can be achieved.
9. To study the benefits of 3D steel detailing in enhancing visualization, clash detection, fabrication coordination, and execution efficiency in steel construction projects.

III. LITERATURE REVIEW

- 4.1 **Zhou et al. (2023): Tekla-driven Quantity Assessment in PEB Projects.** The authors describe that automated quantity extraction from Tekla models provides more reliable Bills of Quantities (BOQs) compared to conventional spreadsheet-based estimation methods. Their findings indicated that Tekla-generated models include secondary structural members and connection components that are often omitted during manual quantity calculations.
- 4.2 **Kemble and Kulkarni (2022): Integration of Structural Analysis and 3D Steel Detailing.** Kemble and Kulkarni examined the effect of linking structural analysis software with 3D steel detailing platforms. Their research showed that synchronized data transfer between analytical and detailing models reduces inconsistencies in member sizing and connection detailing while improving fabrication coordination.
- 4.3 **Kothari et al. (2022): Digital Modelling Tools in PEB Projects.** Their study highlighted how digital modelling tools improve project coordination and material tracking in PEB construction. Their study indicated that automated BOQ generation and real-time model updates support improved material tracking, procurement planning, and project transparency.
- 4.4 **Liang et al. (2021): Tekla-Based Modelling of PEB Structures.** The study discussed the application of Tekla Structures for modelling tapered members, base plates, bracing systems, and steel connections in industrial buildings. The authors concluded that BIM-based models improve fabrication drawing preparation and support more realistic quantity estimation.
- 4.5 **Nagaraj and Iyer (2021): BIM Integration in Steel Building Projects.** Nagaraj and Iyer investigated the integration of structural analysis software with BIM platforms in steel construction projects. Their findings

demonstrated that coordinated modelling reduces duplication of work, improves communication between engineers and fabricators, and supports faster preparation of shop drawings.

authors suggest that proper bracing arrangements and optimized member design improve lateral stability and seismic resistance.

- 4.6 Sharma and Rao (2020): Comparative Study of PEB and Conventional Steel Frames.** Sharma and Rao carried out a comparative study between Pre-Engineered Buildings and conventional steel buildings using IS 800:2007 provisions. The results showed that PEB systems provide improved material efficiency for medium-span industrial structures through the use of optimized built-up sections.
- 4.7 Mahajan and Patil (2019): Evaluation of Steel Quantity Estimation Methods.** This study compared manual quantity estimation methods with model-based extraction procedures. The authors described that conventional methods may underestimate steel quantities because of omission of connection plates, stiffeners, and secondary framing components, whereas BIM-based extraction provides more comprehensive material estimation.
- 4.8 Verma and Singh (2019): BIM-Based Steel Detailing Using Tekla Structures.** Verma and Singh studied the application of Tekla Structures in BIM-based steel detailing and fabrication modelling. Their findings indicated that Tekla improves visualization, fabrication coordination, and automated quantity extraction for steel construction projects.
- 4.9 Srinath and Kumar (2018): Optimization of Pre-Engineered Steel Buildings.** Srinath and Kumar conducted a comparative study on optimized PEB frames and conventional hot-rolled steel frames. Their findings showed that tapered built-up sections reduce structural self-weight while maintaining required strength and serviceability performance.
- 4.10 Chaudhari and Pathak (2018): Bracing Systems in Industrial PEB Structures.** The authors evaluated different bracing arrangements in industrial PEB structures subjected to wind and seismic loading. Their study indicated that properly designed bracing systems improve lateral stiffness and help control structural drift within permissible limits.
- 4.11 Shaikh and Joshi (2018): Optimization of Steel Quantity in Industrial Buildings.** The authors investigated methods for reducing steel quantity in industrial Pre-Engineered Buildings. Their research showed that optimization of built-up sections and secondary framing systems improves structural economy without affecting stability requirements.
- 4.12 Throat and Patil (2017): Dynamic Analysis of Pre-Engineered Buildings Under Seismic Loading.** The study focused on the seismic performance of industrial PEB structures using dynamic analysis methods. The
- 4.13 Gupta and Tawari (2016): Structural Analysis of PEB Systems.** Gupta and Tawari studied the use of structural analysis software for the design of PEB systems. Their work highlighted the importance of software-based analysis in evaluating internal forces, checking structural adequacy, and improving design efficiency in steel buildings.
- 4.14 Prabhu and Babu (2016): Weight Optimization in Pre-Engineered Steel Structures.** Prabhu and Babu investigated the structural behaviour of PEB frames using computer-aided analysis methods. Their research demonstrated that tapered built-up members designed according to actual force distribution reduce steel consumption and improve overall structural economy.
- 4.15 Patel et al. (2015): Economical Design of Steel Roof Trusses Using STAAD.Pro.** Patel et al. studied the optimization of steel roof trusses using STAAD.Pro. Their research demonstrated that computer-aided structural analysis helps achieve economical member sizing and improved load distribution in steel roof systems.
- 4.16 Jayavelmurugan et al. (2015): Constructability and Economic Benefits of PEBs.** The authors concluded that standardized bolted connections in PEB systems simplify fabrication and reduce on-site erection effort when compared with conventional welded steel structures. Their study also highlighted the economic advantages of PEBs for industrial and warehouse applications.
- 4.17 Sai Kiran et al. (2014): Analysis Procedures in Pre-Engineered Buildings.** Sai Kiran and co-authors examined different procedures used in the analysis and design of Pre-Engineered Buildings. The study highlighted the importance of software-based modelling for improving design coordination and reducing manual calculation errors.
- 4.18 Charkha and Latesh (2014): Steel Economy in PEB Structures.** The authors investigated material consumption in Pre-Engineered Buildings and conventional steel buildings. Their findings showed that optimized section selection in PEB systems contributes to reduction in steel usage while maintaining structural safety.
- 4.19 Meera et al. (2013): Comparative Analysis of PEB and Conventional Steel Buildings.** Meera et al. carried out a comparative study between Pre-Engineered Buildings and conventional steel structures for industrial applications. Their analysis indicated that PEB systems reduce structural weight and construction time because

of optimized built-up sections and prefabricated components.

4.20 Zamil Steel Research Group (2010): Practical Applications of Pre-Engineered Buildings. The Zamil Steel Research Group discussed the practical aspects of designing and fabricating Pre-Engineered Buildings using optimized steel components and standardized fabrication methods. Their findings highlighted improvements in construction speed and reduction in material wastage in industrial steel projects.

Research Gap: Earlier investigations mainly concentrated on optimization of steel sections, comparative studies between PEB and conventional steel buildings, and general BIM applications. However, limited published work discusses direct coordination between STAAD.Pro analytical models and Tekla Structures for fabrication-oriented modelling and quantity extraction in industrial PEB projects. In many cases, quantity estimation did not fully consider connection details, secondary members, bolts, cleats, and fabrication components. Therefore, this research develops a coordinated STAAD.Pro–Tekla Structures workflow for structural analysis, detailing, and accurate BOQ generation for a medium-span industrial Pre-Engineered Building.

IV. METHODOLOGY

1. The present work follows an integrated approach involving structural analysis, detailing, and quantity estimation for the selected industrial PEB structure. The process is structured as follows:
2. The primary stage involved **analysis of the PEB frame** using *STAAD.Pro*. The structural model was created with the given geometry, bay spacing, and loading conditions. Loads such as dead load (DL), live load (LL), wind load (WL), and seismic load (EQ) were applied as per IS 875 2015 and IS 1893 2016. Appropriate load combinations were generated, and the structure was analysed to obtain bending moments, shear forces, and support reactions. These results were further used for the design of primary and secondary members Based on IS 800:2007 (Limit State Method).
3. The second stage focused on **detailing of connections and base plates** using *Tekla Structures*. The software enabled the visualization of column-beam connections, end plates, splice joints, and anchorage details. Though manual connection design was not performed, schematic details generated through Tekla and IDEA StatiCa were adopted to demonstrate practical feasibility and standard industry practice.
4. The third stage was **estimation of quantities** through a Bill of Quantities (BOQ). Based on the designed member sizes and connection details, quantity assessments were prepared. These included quantities of steel sections, bolts, plates, and other accessories. The BOQ provided a clear understanding of the material requirements and facilitated cost estimation for the proposed building.
5. Thus, the methodology combines **structural analysis**

(*STAAD.Pro*), **detailing (Tekla Structures), and material quantification (BOQ)** to provide a holistic representation of PEB design, covering safety, ease of fabrication and erection, and economy.

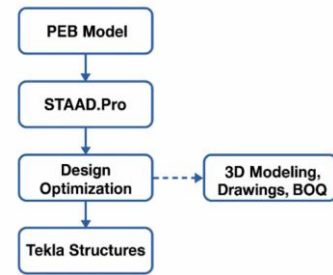


Figure 2 Combined analysis and detailing process

V. STRUCTURE CONFIGURATION

The proposed building has a ground floor plan measuring 23.40 m in length and 9.40 m in width. The column grid spacing is arranged at 3650 mm, 3900 mm, 3800 mm, 3850 mm, and 3950 mm, which provides proper alignment and spacing of structural members within the building layout. A clear height of 5.50 m is maintained inside the structure to provide adequate working space for industrial activities and installation of equipment.

1. PLAN & Elevation of PEB building

The graphical representation of the Pre-Engineered Building (PEB) through plan, elevation, and side views provides a clear understanding of the structural arrangement, geometry, and overall configuration of the building. These views are important for visualizing the structural system and maintaining coordination between analysis, detailing, fabrication, and site execution

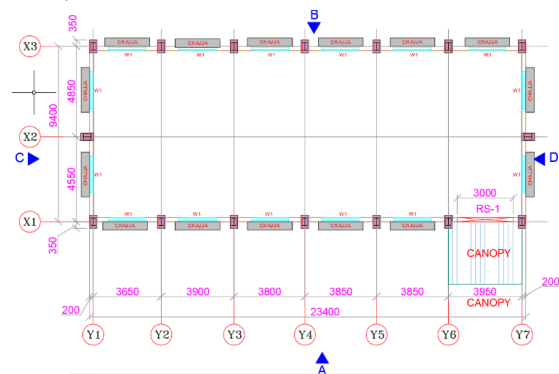


Figure 3 Plan View for PEB Warehouse

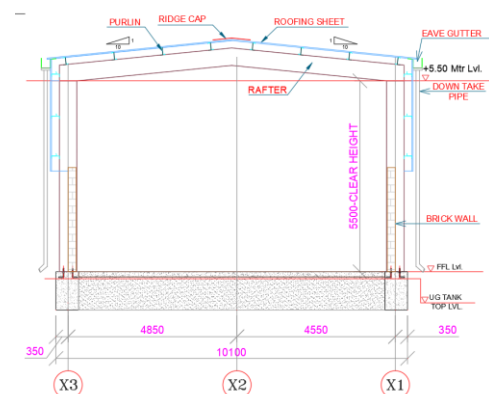


Figure 4 Cross Section for PEB Warehouse

2. Project Data and Structural Parameters

The design of a Pre-Engineered Building (PEB) requires the clear definition of basic project inputs, geometric details, and environmental conditions. These parameters form the foundation for structural modelling, load calculation, and design verification. The following summarizes the key data for this study:

Table 1 PEB Building Data

| S. No. | Details | Value |
|--------|-------------------|-------------------|
| 01 | Location | High Seismic Zone |
| 02 | No. of Bays | 6 |
| 03 | Total Bay Length | 23.4 m (c/c) |
| 04 | Spacing | Varies (c/c) |
| 05 | Width | 9.4 m (c/c) |
| 06 | Basic Wind Speed | 39 m/s |
| 07 | Clear Height | 5.5 m |
| 08 | Roof Slope | 1/10 |
| 09 | Support Condition | Pinned |

VI. LOAD APPLICATION IN STAAD PRO

The structural modelling and analysis of the Pre-Engineered Building (PEB) shed were carried out using STAAD.Pro. A three-dimensional analytical model was prepared to study the behavior of the structure under different loading conditions and to verify the adequacy of the structural members as per relevant design standards. The model was developed in such a way that it closely represented the actual structural arrangement and load transfer mechanism of the building. Defining the structural grid and node coordinates.

Assigning beam elements to represent columns, rafters, and bracings. Providing support conditions at column bases. Specifying material properties (steel grade) and sectional dimensions. Assigning truss and tension specifications to ensure correct analysis behaviour.

1. The overall modelling process included the following major steps:
2. Preparation of grid lines and generation of node coordinates in three-dimensional space.
3. Creation of beam elements representing columns, rafters, bracings, and secondary framing members.
4. Assignment of support conditions at the base of structural columns.
5. Definition of material properties and sectional dimensions for all members.
6. Application of truss and tension-only specifications to suitable structural components.

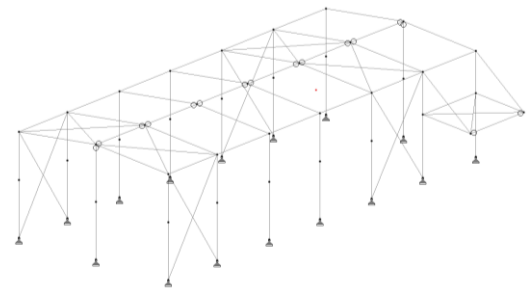


Figure 5 3D (Wire Frame) Of PEB Warehouse

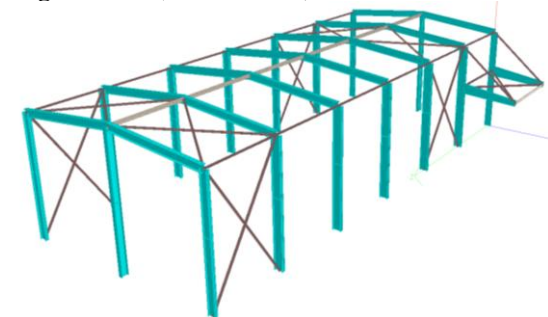


Figure 6 Isometric View of PEB Warehouse

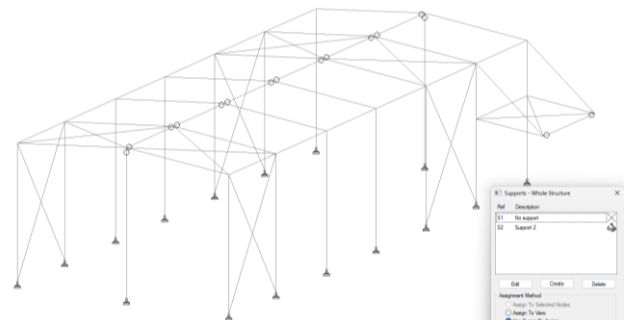


Figure 7 Specification and Releases

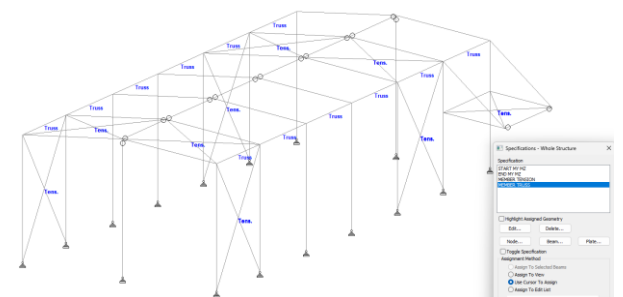


Figure 8 Pin Support Assignment

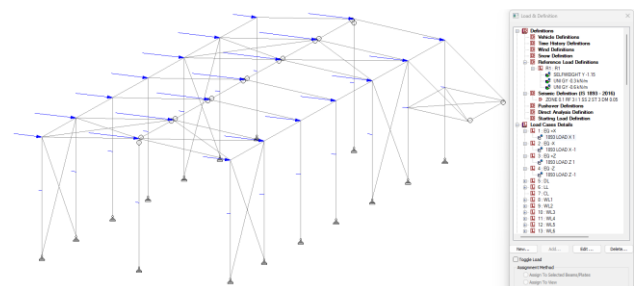


Figure 9 Application of Seismic Forces +x

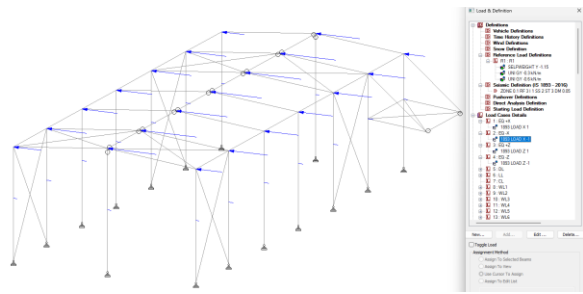


Figure 10 Application of Seismic Forces -x

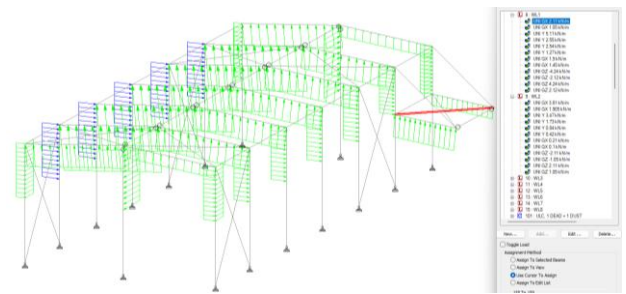


Figure 15 Wind Load Application (Wind In X+ & X- Direction with +Cpi & -Cpi)

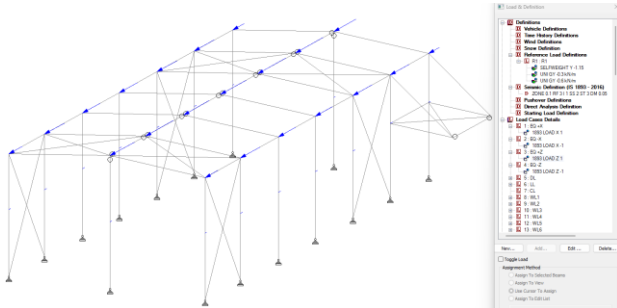


Figure 11 Application of Seismic Forces In +Z

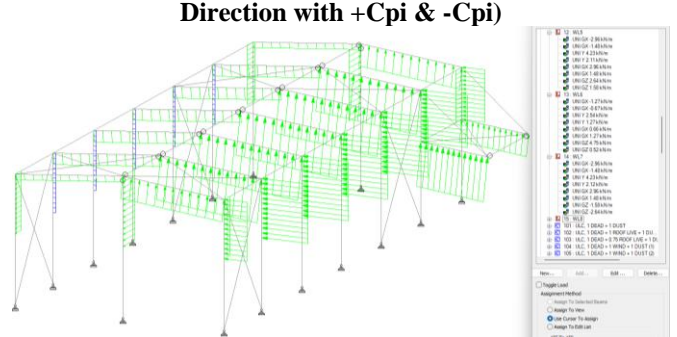


Figure 16 Wind Load Application (Wind In Z+ & Z- Direction with +Cpi & -Cpi)

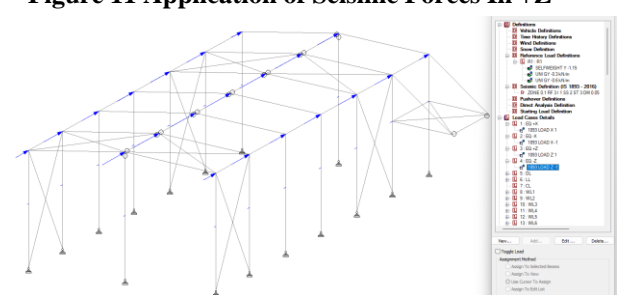


Figure 12 Application of Seismic Forces In -Z

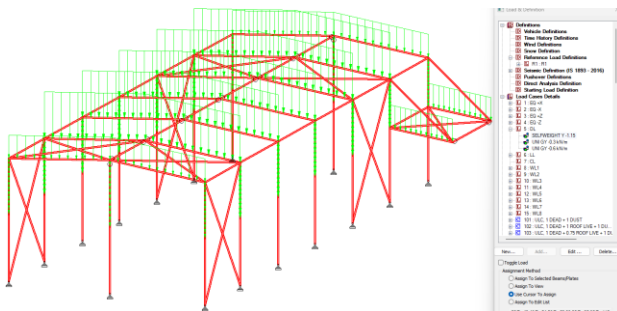


Figure 13 Application of Dead Load In Staad-Pro

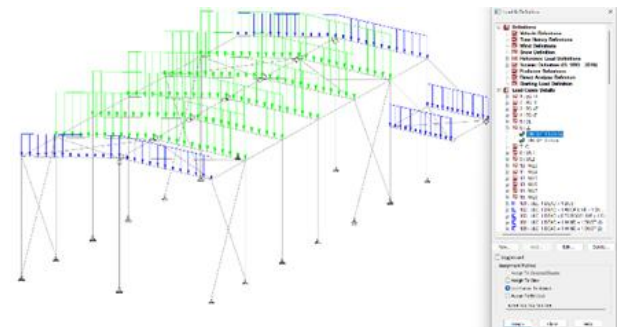


Figure 14 Application of Live Load In Staad-Pro

VII. DESIGN OF MEMBERS

The design of structural members was performed using the AISC 360-16 ASD code available in STAAD-Pro. Each member was checked for axial strength, flexural capacity, and shear resistance. Members failing to meet the criteria were optimized until they satisfied the design requirements.

Z- PURLIN - Z 200 × 60 × 20 × 2 mm

C-PURLIN - C 200 × 58 × 18 × 2 mm

| S.No. | Web | Web Thick | Flange | FlangeThick |
|-------|---------------------------------|-----------|--------|-------------|
| R1 | 382 | 5 | 165 | 6 |
| R2 | 308 | 5 | 165 | 6 |
| R3 | ROOFBRACING C RUNNER76.1X3.2CHS | | | |
| R4 | PURLIN 180ZS60X1.6 | | | |
| R5 | 382 | 5 | 165 | 6 |
| R6 | 308 | 5 | 148 | 6 |
| R7 | CLAD BRACING 88.9X3.2CHS | | | |

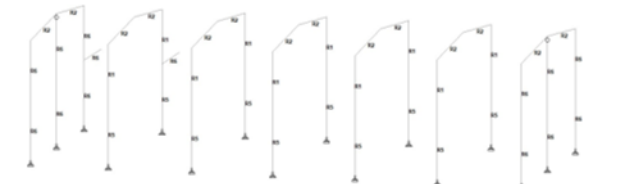


Figure 17 Size of Member for Main-Frame

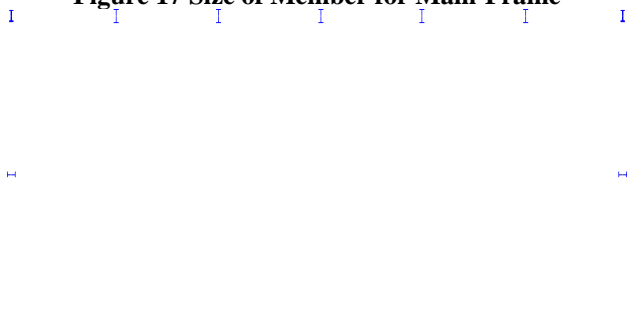


Figure 18 Column Orientation

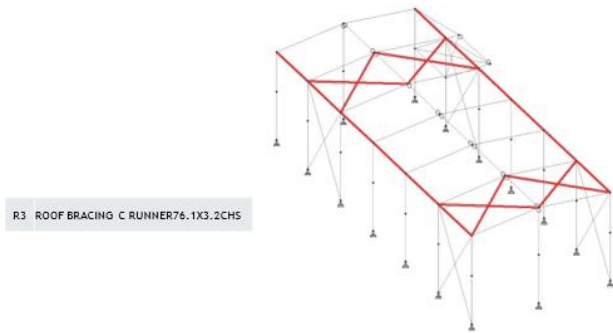


Figure 19 Size of Bracing & Runner

STAAD.Pro to Tekla Structures and developing the detailed structural model.

a. Import of STAAD File

1. The STAAD-Pro model containing member geometry, connectivity, and section properties was exported in a Tekla-compatible format.
2. The imported model maintained the exact gridlines, member orientations, and connectivity as defined in the analytical model.

b. Built-Up Section Conversion

1. Several members, including columns, rafters, and trusses, were designed as built-up sections.
2. The *Built-Up Section Converter* in Tekla was used to transform STAAD-defined sections into Tekla-compatible profiles.
3. Custom profiles were created for welded plate girders, built-up columns, and truss elements to ensure precise three-dimensional representation.

c. Generation of Fabrication and Erection Drawings

1. **Fabrication drawings:** Contain detailed part dimensions, plate cutting lengths, hole locations, and welding instructions for workshop fabrication.
2. **Erection drawings:** Indicate member positioning, erection sequence, and temporary bracing requirements for safe on-site assembly.
3. **Bill of Quantities (BOQ):** Automatically generated using Tekla reports to provide precise quantities and weights of all structural members.

| Parameter | Conventional Estimation | Tekla-Based BOQ |
|-------------------|-------------------------|-----------------|
| Primary Members | Included | Included |
| Connection Plates | Partially Included | Fully Included |
| Bolts & Fasteners | Approximate | Exact Quantity |
| Secondary Members | Sometimes Neglected | Fully Modelled |
| Quantity Accuracy | Moderate | High |
| Revision Handling | Manual | Automatic |

Figure 20 Comparison Between Conventional Estimation and Tekla-Based BOQ

d. Total Tonnage

Total Tonnage = 12.97 Metric Ton

The cumulative weight of all structural components, including fasteners, foundation bolts, sheeting, cladding, and accessories, has been computed. The overall tonnage of the structure amounts to **12.97 Metric Ton**.

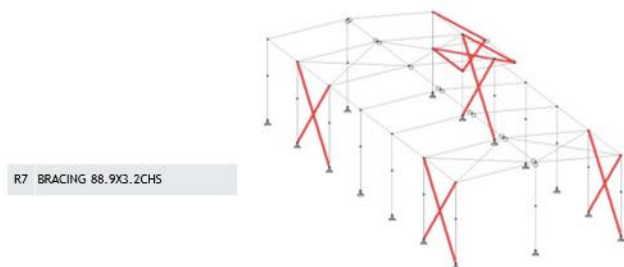


Figure 21 Size of Side Bracing
 VIII. CONNECTION DESIGN

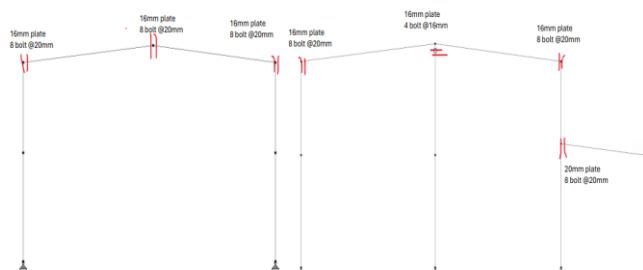


Figure 22 Connection Details

IX. TEKLA MODELLING AND DETAILING OUTPUT

The process of preparing the detailed model and drawings in *Tekla Structures* was carried out after finalizing member sizes through STAAD-Pro analysis. The following procedure was adopted for transferring the analytical model from

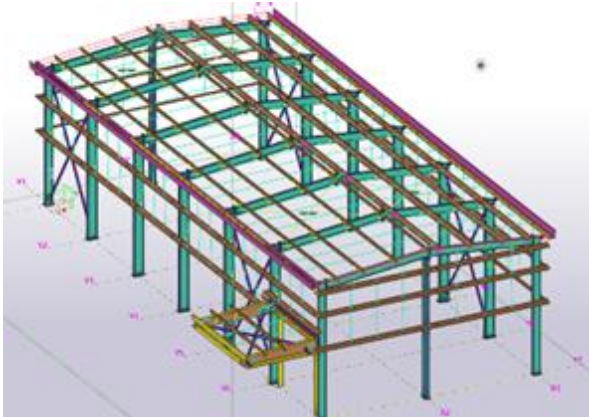


Figure 23 Isometric View in Tekla

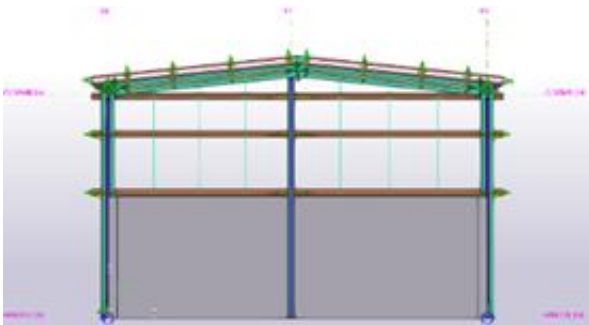


Figure 24 Plan View

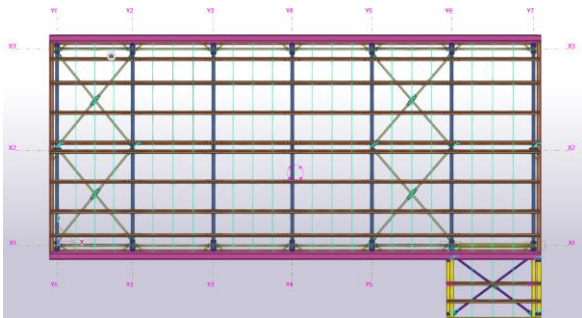


Figure 25 Elevation View (front)

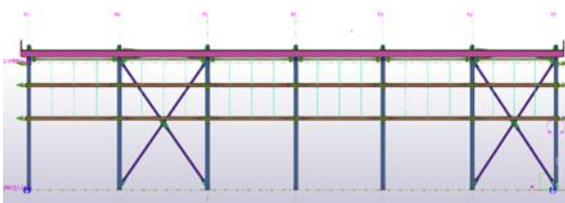


Figure 26 Elevation View (Side)

X. RESULTS & DISCUSSION

1. Maximum vertical displacement: 36.773 mm at mid-span.
2. Critical axial force: 201.736 kN in columns.
3. Maximum bending moment: 11.785 kNm at beam-column connection.
4. Maximum combined stress: 0.635 MPa (safe).
5. The analysis results from STAAD.Pro and the detailing carried out in Tekla Structures showed good consistency, confirming the structural adequacy and reliability of the integrated PEB design approach.

6. The developed Tekla model enabled identification of secondary structural components and connection elements that are generally omitted during conventional manual quantity estimation. The comparison between conventional estimation and Tekla-generated BOQ showed improved representation of bolts, cleats, bracing members, and connection plates. The developed model reduced differences in material estimation and improved fabrication-stage planning.

XI. CONCLUSIONS AND RECOMMENDATIONS

1. The present investigation successfully established a coordinated workflow for analysis, detailing, and quantity estimation of the selected PEB structure using STAAD.Pro and Tekla Structures.
2. A detailed three-dimensional model of the structure was successfully developed in Tekla Structures, including connection details, bolts, welds, and fabrication-level assemblies required for practical construction activities.
3. The serviceability study showed that the maximum roof deflection was 36.773 mm against the allowable limit of 37.6 mm. Although the variation was very small and practically acceptable, it highlighted the importance of proper member optimization and stiffness control in PEB design.
4. Detailed modelling, Shop/Erection Drawings, and BOQ extraction using Tekla Structures, and
5. The direct transfer of structural data between STAAD.Pro and Tekla Structures minimized manual rework during detailing and helped maintain consistency between analytical design and fabrication drawings.
6. The combined use of STAAD.Pro and Tekla Structures was found suitable for developing a coordinated and practically applicable workflow for analysis, detailing, and quantity estimation in PEB projects.

XII. REFERENCES

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