# PRE-ENGINEERED BUILDING DESIGN OF AN INDUSTRIAL WAREHOUSE

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***ABSTRACT***

*Pre-Engineered Building (PEB) concept is a new conception of single storey industrial building construction. This methodology is versatile not only due to its quality pre-designing and prefabrication, but also due to its light weight and economical construction. The concept includes the technique of providing the best possible section according to the optimum requirement. This concept has many advantages over the Conventional Steel Building (CSB) concept of buildings with roof truss. This paper is a comparative study of PEB concept and CSB concept. The study is achieved by deigning a typical frame of a proposed Industrial Warehouse building using both the concepts and analyzing the designed frames using the structural analysis and design software Staad.Pro.*

***KEYWORDS:*** *Conventional Steel Building, Pre-Engineered Building, Staad.Pro, Tapered I section.*

## I. INTRODUCTION

Steel is a material which has high strength per unit mass. Hence it is used in construction of structures with large column-free space. Most of the Industrial Structures require this criterion. An Industrial Warehouse is a storage building and is usually characterized as single storey steel structures with or without mezzanine floors. The enclosures of these structures may be brick masonry, concrete walls or GI sheet coverings. The walls are generally non-bearing but sufficiently strong enough to withstand lateral forces caused by wind or earthquake. The designing of industrial warehouse includes designing of the structural elements including principal rater or roof truss, column and column base, purlins, sag rods, tie rods, gantry girder, bracings, etc. A combination of standard hot-rolled sections, cold-formed sections, profiled sheets, steel rods, etc. are used for the construction of industrial steel structures. Industrial buildings can be categorized as Pre-Engineered Buildings (PEB) and Conventional Steel Buildings (CSB), according to the design concepts. The paper starts with the discussion of methods adopted in the study. Introduction to PEB systems and CSB systems are then described followed by the details of case study. Loads and the load combinations adopted for carrying out the analysis of the structure is well defined in the further portions. A section depicting the importance of the software used and the software procedure followed is included. Final portion explains the results obtained from the software analysis of the case study and the inferences from the literature studies. The paper aims at developing a perception of the design concepts of PEB structures and its advantages over CSB structures.

## II. METHODOLOGY

The present study is included in the design of an Industrial Warehouse structure located at Ernakulam. The structure is a container warehouse of Vallarpadam Container Terminal. The actual structure is proposed as a Pre-Engineered Building with four spans each of 30 meters width, 16 bays each of 12 meters length and an eave height of 12 meters. In this study, a typical PEB frame of 30 meter span is taken into account and the design is carried out by considering wind load as the critical load for the structure. CSB frame is also designed for the same span considering an economical roof truss configuration. Both the designs are then compared to find out the economical output. The designs are carried out in accordance with the Indian Standards and by the help of the structural analysis and design software Staad.Pro.

## III. PRE-ENGINEERED BUILDINGS

Pre-Engineered Building concept involves the steel building systems which are predesigned and prefabricated. As the name indicates, this concept involves pre-engineering of structural elements using a predetermined registry of building materials and manufacturing techniques that can be proficiently complied with a wide range of structural and aesthetic design requirements, as in [3]. The basis of the PEB concept lies in providing the section at a location only according to the requirement at that spot. The sections can be varying throughout the length according to the bending moment diagram. This leads to the utilization of non-prismatic rigid frames with slender elements. Tapered I sections made with built-up thin plates are used to achieve this configuration. Standard hot-rolled sections, cold-formed sections, profiled roofing sheets, etc. is also used along with the tapered sections, as in [3]. The use of optimal least section leads to effective saving of steel and cost reduction. The typical PEB frame of the structure considered for the study is as shown in Figure 1.

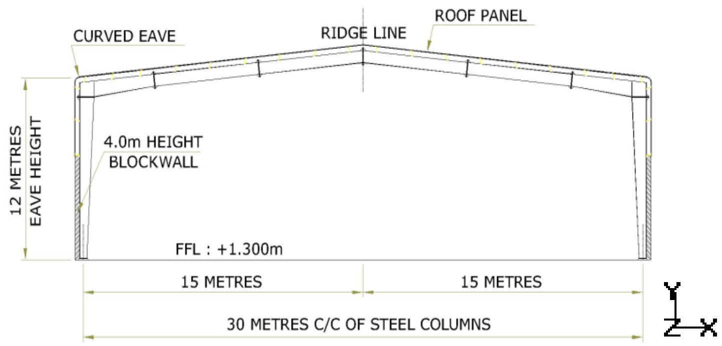


**Figure 1:** PEB Frame

## IV. CONVENTIONAL STEEL BUILDINGS

Conventional steel buildings (CSB) are low rise steel structures with roofing systems of truss with roof coverings, as in [3]. Various types of roof trusses can be used for these structures depending upon the pitch of the truss. For large pitch, Fink type truss can be used; for medium pitch, Pratt type truss can be used and for small pitch, Howe type truss can be used, as in [1]. Skylight can be provided for day lighting and for more day lighting, North light type truss can be used, as in [1] The selection criterion of roof truss also includes the slope of the roof, fabrication and transportation methods, aesthetics, climatic conditions, etc, as in [1]. Several compound and combination type of economical roof trusses can also be selected depending upon the utility. Standard hot-rolled sections are usually used for the truss elements along with gusset plates, in passing [2]. The CSB frame of the structure considered in the study is as shown in Figure 2.

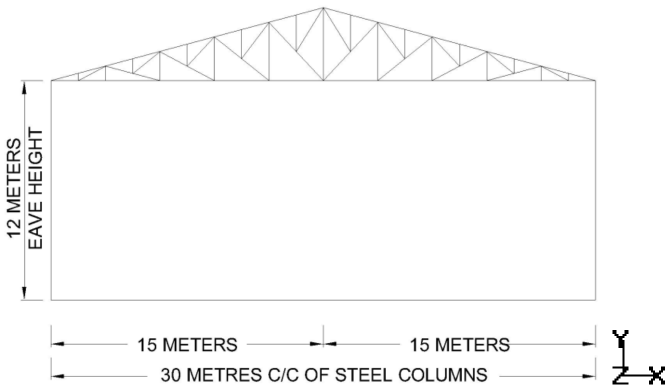


**Figure 2:** CSB Frame

## V. WAREHOUSE PARTICULARS

Type of building : Container Warehouse
Type of structure: Single Storey Industrial Structure
Location : Ernakulam
Area of site : 43348 $m^2$ (466597.872 *sq.ft.*)
Type of building : Industrial Warehouse
Area of building : 22979 $m^2$ (247343.900 *sq.ft.*)
Eave height : 12.00 *m*
Number of spans: 4 *Nos*
Single span width : 30.00 *m*
Total span width : 120.00 *m*
Number of bays : 16 *Nos*
Single bay length : 12.00 *m*
Total bay length : 192.00 *m*
Support condition : Pinned
PEB roof slope : 5 degree
CSB roof slope : 15 degree

The building plan of the proposed Industrial Warehouse structure considered for the study is as shown in Figure 2.

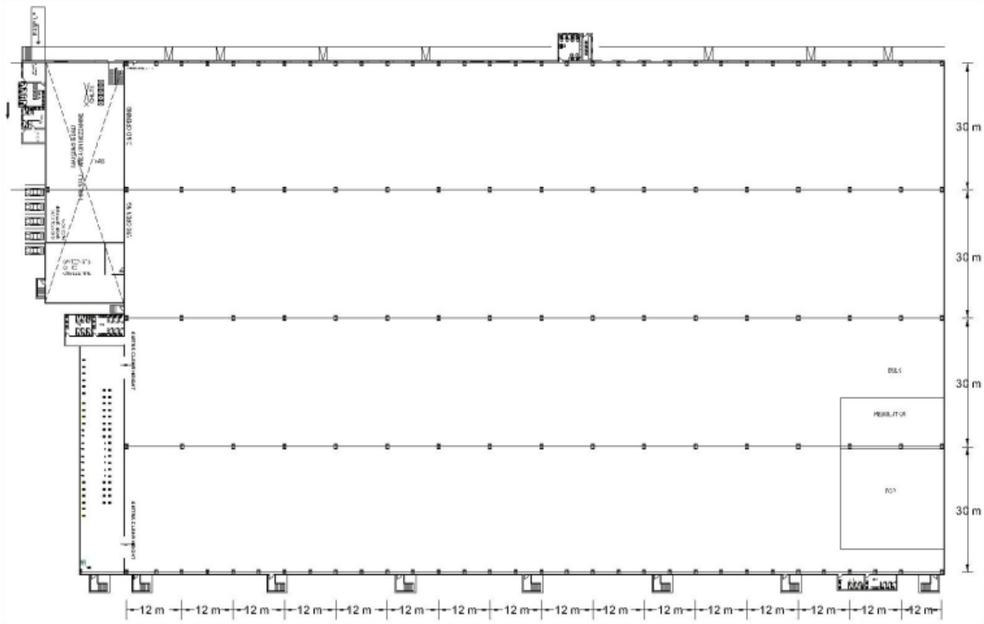


**Figure 3:** Building Plan

# VI. LOADS

The loads acting on the structure includes dead load, live load, snow load, wind load, earthquake load, crane load, erection load, accidental load, etc., as in [4]. The load calculation for the structure can be carried out in accordance with IS : 875 – 1987 and IS : 1893 - 2000. For this structure wind load is critical than earthquake load, as in [8]. Hence, load combinations of dead load, live load, crane load and wind load are incorporated for design.

## 6.1. Dead Load

Dead load comprises of self-weight of the structure, weights of roofing, G.I. sheets, gantry girder, crane girder, purlins, sag rods, bracings and other accessories, in passing [5]. The dead load distributed over the roof is found to be 0.438 kN/m excluding the self weight. This load is applied as uniformly distributed load over the rafter while designing the structure by PEB concept. For CSB concept the load is applied as equivalent point load of 0.657 kN at intermediate panel points and half the value at end panel points over the roof truss. Reference [5] shows the procedure for dead load calculation.

## 6.2. Live Load

According to IS : 875 (Part 2) – 1987, for roof with no access provided, the live load can be taken as 0.75 $kN/m^2$ with a reduction of 0.02 $kN/m^2$ for every one degree above 10 degrees of roof slope, explicitly as in [6]. Total uniformly live load acting on the rafter of the PEB structure is found to be 4.5 kN/m. Similar to dead load, live load is also applied as point loads at panel points for CSB structure and is found to be 6.75 kN at intermediate panel points and half this value at end points. Reference [6] shows the procedure for live load calculation.

## 6.3. Crane Load

Cranes are used in warehouse for lifting heavy materials from one point to another. The cranes are supported by crane bridge end trucks bearing on rails that are supported on the top of the crane beams, as in [14]. The crane bridge itself moves over the rails on the gantry girder which is in turn supported on the column brackets, in passing [14]. The crane load is calculated by positioning the moving load for maximum effects of shear force and bending moment.

The dead load contribution of crane system along with the gantry girder is found out to be 7 kN acting over the column brackets. The horizontal and vertical crane live loads come in four different combinations as in Table 1.

**Table 1:** Crane Live Load Cases

| Case | Vertical Crane Live Load (kN) | | Horizontal Crane Live Load (kN) |
|---|---|---|---|
| | Left corbel | Right corbel | |
| CL1 | 124.33 | 47.61 | 16.50 |
| CL2 | 47.61 | 124.33 | 16.50 |
| CL3 | 124.33 | 47.61 | -16.50 |
| CL4 | 47.61 | 124.33 | -16.50 |

## 6.4. Wind Load

Wind load is calculated as per IS : 875 (Part 3) – 1987. The basic wind speed for the location of the building is found to be 39 m/s from the code, in passing [8]. The wind load over the roof can be provided as uniformly distributed load acting outward over the PEB rafter, as in [10], and as point loads acting outward over the CSB panel points. For side walls, the wind load is applied as uniformly distributed loads acting inward or outward to the walls according to the wind case. The wind loads over the roof and side walls comes in four different combinations as in Table 2.

**Table 2:** Wind Load Cases

| Case | Side wall (kN/m) | | PEB Rafter (kN/m) | CSB panel points (kN) | |
|---|---|---|---|---|---|
| | **Left** | **Right** | | **Intermediate** | **End** |
| θ=0+ | 2.61 | -2.35 | 5.74 | 8.61 | 4.31 |
| θ=90+ | -3.65 | -3.65 | 5.74 | 8.61 | 4.31 |
| θ=0- | 4.70 | -0.26 | 3.65 | 5.48 | 2.74 |
| θ=90- | -1.57 | -1.57 | 3.65 | 5.48 | 2.74 |

### 6.5. Load Combinations

Load combinations can be adopted according to IS : 800 – 2007. Sixteen different load combinations adopted for the analysis of the frame in both the concepts, as in [4], and are listed as follows:

1) 1.5DL+1.5LL+1.5CL1
2) 1.5DL+1.5LL+1.5CL2
3) 1.5DL+1.5LL+1.5CL3
4) 1.5DL+1.5LL+1.5CL4
5) 1.5DL+1.5WL(θ=0+)
6) 1.5DL+1.5WL(θ=90+)
7) 1.5DL+1.5WL(θ=0-)
8) 1.5DL+1.5WL(θ=90-)
9) DL+LL+CL1
10) DL+LL+CL2
11) DL+LL+CL3
12) DL+LL+CL4
13) DL+WL(θ=0+)
14) DL+WL(θ=90+)
15) DL+WL(θ=0-)
16) DL+WL(θ=90-)

Note:
DL – Dead Load
LL – Live load
CL – Crane Load
WL – Wind load

## VII. STAAD.PRO PROCEDURE

The Staad.Pro software package is a structural analysis and design software which helps in modeling, analyzing and designing the structure. The software supports standards of several countries, including Indian standard. The procedure includes modeling the structure, applying properties, specifications, loads and load combinations, analyzing and designing the structure. This software is an effective and user-friendly tool for three dimensional model generation, analysis and multi-material designs, explicitly as in [15].

## VIII. RESULTS & DISCUSSION

The structural analysis and design of the structural frame considered was done using the Staad.Pro software which is very user friendly and effective. First a typical frame is selected from the structure. First the frame was analysed and designed according to the PEB concept and then by the CSB concepts. On comparing the results of both the analysis, the following results were obtained as in Table 3.

**Table 3:** Software Analysis Results Summary

| Sl. No. | Description | PEB | CSB |
|---|---|---|---|
| 1 | Steel Take Off (kN) | 53.221 | 84.595 |
| 2 | Support Reaction (kN) | 355.475 | 375.582 |
| 3 | Maximum deflection (mm) | 1.862 | 8.611 |
| 4 | Maximum Shear Force (kN) | 340.940 | 453.981 |
| 5 | Maximum Moment (kNm) | 888.97 | 908.577 |

### 8.1. Discussion

Pre-Engineered Buildings have vast advantages over the Conventional Steel Buildings. The results of the software analysis and literature studies conducted for both the concepts suggest the same. The various inferences made from the studies are described below.

#### 8.1.1. Material Take off

PEB structures are lighter than CSB structures, as in [12]. From the software analysis it was found that the PEB roof structure is almost 30% lighter than the CSB structure. Regarding the secondary members, light weight Z purlins are used for PEB structure whereas heavier hot-rolled sections are used for CSB structure, explicitly as in [13].

#### 8.1.2. Design

PEB design is rapid and efficient compared CSB design. Basic design steps are followed and optimization of materials while software analysis is possible for PEB, increasing the quality of design, in passing [11]. CSB design is done with fewer design aids and each project needs to develop the designs which require more time, as in [3]. Connection design is also lesser for PEB when measured up to CSB

#### 8.1.3. Foundation

Support reaction for PEB is much lesser than CSB as per the analysis. Hence, light weight foundation can be adopted for PEB which leads to simplicity in design and reduction is cost of construction of foundation, as in [11]. Heavy foundation will be required for CSB structure.

#### 8.1.4. Delivery of materials

For PEB, delivery is done in around 6 to 8 weeks and for CSB it is 20 to 26 weeks, in passing [13].

#### 8.1.5. Erection

Erection procedure is standard for all the projects and it is done free of cost by the manufacturer which results in faster and cost effective erection for PEB, in passing [10]. Erection of CSB differs from project to project and separate labour has to be allocated, leading to 20 percent more expense than PEB.

#### 8.1.6. Earthquake resistance

Low weight flexible frames of PEB offer higher resistance to earthquake loads than rigid heavy frames of CSB, as in [8].

#### 8.1.7. Cost

PEB costs 30% lesser than cost for CSB, in passing [13]. Outstanding architecture can be achieved at low cost for PEB. Single sourcing and co-ordination of PEB is highly cost effective than multiple sourcing system of CSB. Building accessories are mass produced for PEB which also leads to economy, explicitly in [3].

### 8.1.8. Change of order

Due to standardized design, PEB manufacturers are able to stock large amount of elements and accessories which can be flexibly used in many types of PEB construction. Hence change of order can be fulfilled easily at any stage of construction, explicitly as in [15]. Cost for change of order is also lesser in this case. In case of CSB, change of order is expensive and time consuming as substitute sections are infrequently rolled by mills, in passing [12].

### 8.1.9. Future expansion

Single sourcing of PEB is advantageous for future expansion whereas multiple sourcing of CSB poses difficulty, as in [13]. Future expansion is easy and simple for PEB whereas it is most tedious and costly for CSB.

### 8.1.10. Performance

All components of the PEB system are specially designed to act together as a system for highest efficiency. PEB designs are revised regularly with respect to the actual field conditions and in accordance with various country codes, which resulted in improved standardized designs leading to high performance of the structure, as in [11]. CSB system components are conventionally designed for a specific project and the performance depends on how the individual project is designed.

### 8.2. Advantages of PEB

The concept of Pre-Engineered Buildings is extensively used for the construction single storey industrial steel buildings. This system has many benefits than the conventional construction concepts that have been using. PEB systems have numerous advantages including cost effectiveness, quality control, speed in construction, ease in expansion, achievement of large span, long durability, exceptional architecture, standardization of materials, standardization of design, single sourcing and co-ordination, speed in delivery, etc, in passing [3]. By understanding the preliminary design concepts, it is easy to achieve the design of PEB system.

### 8.3. Applications

Pre-Engineered Building concept have wide applications including warehouses, factories, offices, workshops, gas stations, showrooms, vehicle parking sheds, aircraft hangars, metro stations, schools, recreational buildings, indoor stadium roofs, outdoor stadium canopies, railway platform shelters, bridges, auditoriums, etc, explicitly as in [13]. PEB structures can also be designed as re-locatable structures.

## IX. CONCLUSION

This paper effectively conveys that PEB structures can be easily designed by simple design procedures in accordance with country standards. In light of the study, it can be concluded that PEB structures are more advantageous than CSB structures in terms of cost effectiveness, quality control speed in construction and simplicity in erection. The paper also imparts simple and economical ideas on preliminary design concepts of PEBs. The concept depicted is helpful in understanding the design procedure of PEB concept.

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