

Analysis and Comparative Study of Conventional Steel Structure with PEB Structure

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Abstract: Cost of steel is increasing day by day and use of steel has become inevitable in the construction industry in general and in industrial building in particular. Hence to achieve economic sustainability it is necessary to use steel to its optimum quantity. Long span, Column free structures are the most essential in any type of industrial structures and Pre Engineered Buildings (PEB) fulfil this requirement along with reduced time and cost as compared to conventional structures. This methodology is versatile not only due to its quality pre-designing and prefabrication, but also due to its light weight and economical construction. In this paper an attempt has been to present comparative study of conventional and Pre-engineered steel structures which is a truss of span 30m carrying a crane of 10tonne, 15t and 20t. It has shown considerable reduction in the quantity of material.

Keywords: Pre-engineered Building; Pre-Engineered Building Systems; Pre-Engineered Technology; Prefabricated Buildings; Metal Building Systems; Eco-Friendly Construction, Staad.Pro

1. Introduction

Pre-engineered buildings are those which are fully fabricated in the factory after designing, shipped to site in CKD (completely knocked down) condition; and all components are assembled and erected at site with nut-bolts, thereby reducing the time of completion.

The designs were ready-made but the building components were either ready-made or manufactured against specific orders. These buildings were pre-designed or 'pre-engineered' into standard sizes, spans, bays and heights, and use standard details for fixing cladding, roofing, gutters, flashing, windows, doors etc. taking advantage of industrial practices of mass production of components economically.

2. Pre Engineered Buildings

Pre-Engineered Building concept involves the steel building systems which are pre-designed 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. 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.

The scientific-sounding term pre-engineered buildings came into being in the 1960s. The buildings were —pre-engineered because, like their ancestors, they relied upon standard engineering designs for a limited number of off-the-shelf configurations. Several factors made this period significant for the history of metal buildings.

First, the improving technology was constantly expanding the maximum clear-span capabilities of metal buildings. The first rigid-frame buildings introduced in the late 1940s could span only 40ft. In a few years, 50, 60, and 70-ft buildings

became possible. By the late 1950s, rigid frames with 100-ft spans were made.

3. Framing System

3.1 Conventional Steel frame

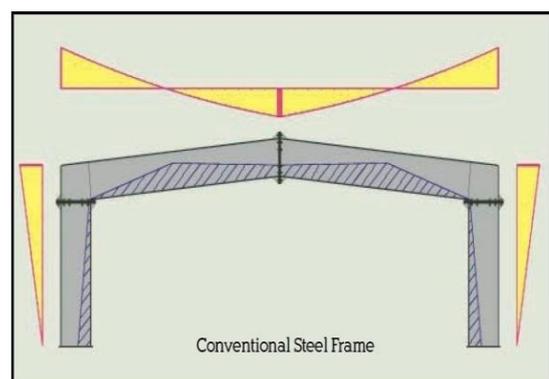


Figure 1: Conventional Steel Frame

In conventional steel buildings, mill-produced hot rolled sections (beams and columns) are used. The size of each member is selected on the basis of the maximum internal stress in the member. Since a hot rolled section has a constant depth, many parts of the member (represented by the hatched area), in areas of low internal stresses, are in excess of design requirements.

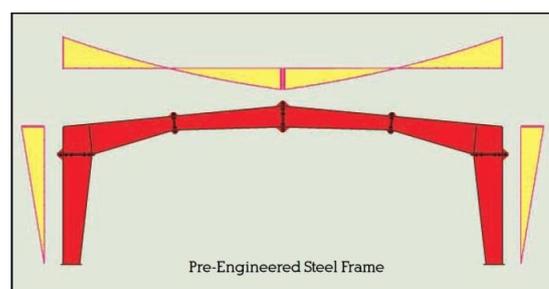


Figure 2: Pre – Engineered Steel Frame Secondary Framing System

3.2 PEB Steel Frame

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Frames of pre-engineered buildings are made from an extensive inventory of standard steel plates stocked by the PEB manufacturer. PEB frames are normally tapered and often have flanges and webs of variable thicknesses along the individual members. The frame geometry matches the shape of the internal stress (bending moment) diagram thus optimizing material usage and reducing the total weight of the structure.

“Z” shaped roof purlins and wall girts are used for the secondary framing. They are lighter than the conventional hot-rolled “I” or “C” shaped sections in conventional steel buildings. Nesting of the “Z” shaped members at the frames allows them to act as continuous members along the length of the building. This doubles the strength capacity of the “Z” shaped members at the laps where the maximum internal stresses normally occur.

4. Advantages of Pre-Engineered Steel Building

1) Ability to span long distances. There are not many other types of gabled structures than can span 100 ft or more in a cost-effective manner. The competition consists mainly of trusses, which require substantial design and fabricating time. (Special tensioned fabrics could also span the distance, but are in a class by themselves.)

2) Faster project construction. Anchor bolt setting plans and anchor bolts can be delivered earlier than the building supply to enable the construction of foundations prior to delivery of the steel buildings. Standard buildings delivery is only 8 weeks (including engineering time) and may be reduced to as low as 6 weeks for special “fast track” projects. Fast erection of the steel buildings because all structural members are field bolted using clear user-friendly erection drawings.

3) Cost and Load efficiency. The use of tapered built-up primary structural members (columns and rafters) usually results in up to a 40% weight advantage for the main rigid frames when compared to the use of conventional hot rolled sections as primary members. The use of “z” shaped secondary structural members (roof purlins and wall girts), particularly the overlapping of the “Z” shaped purlins at the frames, results in up to a 30% weight saving for the secondary members when compared to the use of hot rolled channels a purlins and girts. The manufacturing scrap from the production processes of built-up plate members and cold formed Z sections is typically 75% less than the scrap costs generated from the fabrication of hot rolled members. The foundation requirements of pre-engineered steel buildings are fewer and lighter. This is due to wider clear span capability of main frames, longer economic bay lengths and lower weight of the overall PEB steel structure. The cost of initial engineering of the structure, as well as later design revisions, is substantially reduced due to the inclusion of the engineering costs within the supply price of the pre-engineered building.

4) Flexibility of expansion. Metal buildings are relatively easy to expand by lengthening, which involves

disassembling bolted connections in the end wall, removing the wall, and installing an additional clear-spanning frame in its place. The removed end wall framing can often be reused in the new location. Matching roof and wall panels are then added to complete the expanded building envelope.

5) Low maintenance. A typical metal building system, with prefinished metal panels and standing seam roof, is easy to maintain: metal surfaces are easy to clean, and the modern metal finishes offer a superb resistance against corrosion, fading, and discoloration.

6) Single-source responsibility. The fact that a single party is responsible for the entire building envelope is among the main benefits of metal building systems. At least in theory, everything is compatible and thought through. The building owner or the construction manager does not have to keep track of many different suppliers or worry about one of them failing in the middle of construction. Busy small building owners especially appreciate the convenience of dealing with one entity if anything goes wrong during the occupancy. This convenience is a major selling point of the systems.

4.1 Application of Pre-Engineered Steel Buildings

In the USA, where the PEB concept was originally conceived during the early years of this century, nearly 70% of all single storey non-residential construction now utilizes pre-engineered buildings. Applications range from small car parking sheds to 90 m (+), wide clear span aircraft hangars to low-rise multi-storey buildings.

The most common applications of pre-engineered buildings are:

- 1) **Industrial:** Factories, Workshops, Warehouses, Cold stores, Car parking sheds, Slaughter houses, Bulk product storage.
- 2) **Commercial:** Showrooms, Distribution centers, Supermarkets, Fast food restaurants, Offices, Labor camps, Service station, Shopping centers.
- 3) **Institutional:** Schools, Exhibition halls, Hospitals, Theatres/auditoriums, Sports halls.
- 4) **Recreational:** Gymnasiums, swimming pool enclosures, Indoor tennis courts.
- 5) **Aviation & Military:** Aircraft hangars, Administration buildings, Residential barracks.
- 6) **Agricultural:** Poultry buildings, Dairy farms, Greenhouses, Grain storage, Animal confinement



Figure 3.1: Application of PEB



Figure 5.1: Components of PEB building

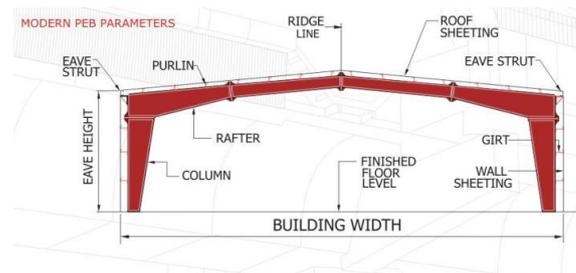


Figure 5.2: Modern PEB parameters



Figure 3.2: Diversified Application of PEB

5. Components of PEB

5.1 Main Components

There are following major components in a pre-engineered building:

- Primary or Main frame
- Gable End framing or Wind columns
- Secondary frame or Purlins, girts etc.
- Roof & Wall Sheeting
- Bracing system
- Crane system
- Mezzanine system
- Insulations
- Attachments like canopies, fascia etc.
- Doors, Windows, Ventilators
- Accessories like Turbo vents, Ridge Vents, Skylights etc.

5.1.1 Main Framing

Main framing basically includes the rigid steel frames of the building. The PEB rigid frame comprises tapered/straight columns and tapered rafters (steel plate fabricated 'T' or 'H' sections are referred to as built-up members). The frame is erected by bolting the end plates of connecting sections together.

5.1.2 Secondary frame or Purlins, girts etc.

Purlins, girts and eave struts are also known as secondary cold-formed members. There is no welding involved in their preparation. They are prepared by press bending the HR steel coil giving it the desired shape (Z- or C-shape).

5.1.3 Roof & Wall Panels

Metallic plain or colour coated profiled steel sheets are used as roof and wall sheeting. The steel sheets are generally made from Zinalume or Galvalume coils in thickness range of 0.47mm to 0.55mm. The base steel is either galvanized having a zinc coating varying from a minimum Mass of 120 gsm./m² to a maximum of 275 gsm./m² (total of both sides) or a base steel coating of zinc – aluminum (zinc 45%, aluminum 55%) of total Mass of 150 gsm./m² (total of both sides) are available with permanent colour coating. The colour coating is also available in various options in polyester paint coating like regular modified polyester, silicon modified polyester and super polyester coatings. Special organic coatings like PVF2 (Poly Vinyl Fluoride) are also made available. These various colour coatings on the base steel with galvanized or zinc aluminium coating provides suitable resistance for various kinds of environment hazards. Metal roofing and siding profiles can be manufactured to any length – limited only by transportation constraints (usually to 12 meters). To eliminate water ingress, general overlap joint considered is 15 cm to 20 cm.

It also has a major advantage for the designers as it allows roofing with minimum pitch which is a rare case in conventional buildings. This happens due to joint-less run of roofing as it has flexibility in cutting of lengths. Slopes as shallow as 1:20 are possible which allows sufficient drainage of water thereby improving long term performance of the panels. These profile steel sheets are conventionally categorized into two types depending upon the type of fine-tuning arrangement followed. These two types are Through Fastened and second one is Standing Seam. Installation of this type of roofing & cladding system can provide 30 years or more of trouble-free accommodation in most environments.

5.1.4 Bracing system

Longitudinal cross bracing, used to provide lateral stability to the structure against wind, seismic or other forces, comprises of rods, pipes, angles or cables with an eye bolt and an adjusting nut at both ends, located near the outer flange of columns or rafters and attached at the web of the rigid frame.

5.1.5 Crane systems

These pre-engineered buildings can be equipped with Overhead EOT cranes, Semi-gantry cranes, wall mounted cranes, Mono rails and under slung cranes for various material and equipment handling operations inside. These buildings are being designed for crane capacities ranging from 1MT to 250MT. The crane runway beams (Gantry Girders) are simply supported built-up sections with/without cap channels and with maintenance platforms and ladders. Catwalks for crane maintenance are usually mounted alongside the crane beams, suspended under rigid frame rafters or elevated above the top of the building roof. Cranes at various levels can also be provided. PEB vendors generally do not keep the supply of rail and Crane Bridge with crane in their scope.

5.1.6 Mezzanine systems

Standard mezzanine structure consists of built-up beam that support built-up, hot-rolled or cold-formed mezzanine joists which in-turn support a metal deck. A concrete slab is cast on the metal deck as a finished surface. Steel checkered plates may also be used as top surface. These mezzanines are used for office space, storage or equipment supports in industries. For commercial buildings and high-rise structures several types of light weight panel boards are available as horizontal surface.

5.1.7 Insulations

These buildings can be properly insulated by providing fibrous insulation slabs /rolls of non-combustible Rockwool, Aluminum foil laminated, placed over a metal mesh bed created between the purlins, and then the roofing steel sheet fixed over it. The siding walls can also be insulated by providing a double skin profile steel sheet wall cladding having Rockwool Insulation slab sandwiched in between and held in position with the help of 'Z' spacers in between the two profile steel sheets. In similar pattern a double skin insulated roofing system can also be erected.

5.1.8 Sandwich Panels

Sandwich panels are generally adopted for thermally efficient roof and wall claddings for buildings which is especially suited in high altitude areas and coldstorages. It is an alternative to the pre-fabricated insulated panels. It generally comprises of two-single skin panels with polyurethane foam insulation in between. It is extensively adopted in non-residential and residential buildings which also has good insulation properties and noise reduction properties..

5.1.9 Paints and finishes

Paints and finishes protect the surface deterioration which happens due to the interior environment and exterior environment of the structure. In general, synthetic enamel and epoxy based paints are used for painting and finishing purposes as per the recommendation of architect/client.

5.1.10 Accessories, Attachments etc.

Accessories and attachments are governed by the functional requirements and architectural aesthetics of the structure. Hence, they are supplied in ready fit condition. Also, the ventilation systems and lighting systems are to be designed and attached by consulting an expert.

5.1.11 High Strength materials

The ordinary construction utilizes the steel having nominal yield stress of approximately 250 MPa whereas the PEB construction uses steel of yield stress approximate to 340 MPa. This recent change in grade of structural steel is due to the revision of IS 2062:2006. There are reliable manufacturers for these steel manufacturers like TATA, SAIL, etc. who are manufacturing these in India. New materials like Fe 540B gives yield stress of around 410 MPa which has thickness lower than 20 mm and the galvalume or zinalume roofing and wall sheets having strengths in the range of 550MPa. Steel is popular in construction due to the flexibility it provides in design, its material strength, unorthodox geometry and volume to weight ratio. Also, economical fabrication can be done along with easy erection.

6. Loads

6.1 Dead and Collateral Loads

Dead load is the weight of all permanent construction materials, such as roofing, framing, and other structural elements. Being well defined and known in advance, dead load is assigned a relatively low factor of safety in the ultimate (load factor) design. Collateral or superimposed dead load is a specific type of dead load that includes the weight of any materials other than the permanent construction. It may account for the weight of mechanical ducts, pipes, sprinklers, electrical work, future ceilings, and re-roofing. The IS: 875 (Part 1) – 1987 Code of Practice for design loads (other than earthquake) for buildings and structures suggest the following typical values:

1. Ceilings: 0.25 to 0.74 kN/m²
2. Metal Sheeting: 0.052 to 0.131 kN/m²
3. Service pipes: 0.014 to 0.105 kN/m²
4. Thermal insulations: 1.45 to 2.95 kN/m³

The equipment load, which accounts for the weight of each specific piece of equipment supported by the roof or floor, should be specified separately. The weight of any HVAC rooftop unit heavier than 1kN, for example, is best represented by a concentrated downward force in the design of the supporting purlins. The equipment load could be —averaged outl converted to a uniform collateral load for the main framing design.

6.2 Live Load

Live load refers to the weight of building occupants, furniture, storage items, portable equipment, and partitions. Owing to the fact that live load is relatively short-term, not easily predictable or quantifiable, it carries large factors of safety (uncertainty, really) in the ultimate design methods. Other sources of live load arise during construction, repair, or maintenance of the building, and these are even more difficult to predict and quantify. To deal with this uncertainty, building codes have enacted conservative values for live loads the framing must be designed to resist the loads which might occur only once or twice in the lifetime of the structure, if at all. For example, office buildings are normally designed for the live load of 2.5 to 4 kN/m² as per IS : 875 (Part 2) – 1987 Code of Practice for design loads (other than earthquake) for buildings and structures, while the actual weight of all the people and furniture in a typical office probably does not exceed this load. It is quite probable that the design live load will occur in a relatively small area of the building at some time or another; it is much less probable that the whole floor will ever see that load. To reflect this reality, building codes set forth the rules governing the live load reduction for members supporting relatively large floor or roof areas. For single-story metal building systems, roof live load, essentially an allowance for the roof loading during its construction and maintenance, is the load being reduced. With live load reduction, larger uniform loads are assigned to secondary members supporting limited roof areas than to primary structural framing. The reduction formulas are included in the building codes.

6.3 Wind Load

To design wind-resisting structures, the engineers need to know how to quantify the wind loading and distribute it among various building elements. IS : 875 (Part 3) – 1987 Code of Practice for design loads (other than earthquake) for buildings and structures gives basic wind speed map of India, as applicable to 10 m height above mean ground level for different zones of the country. Basic wind speed is based on peak gust velocity averaged over a short time interval of about 3 seconds and corresponds to mean heights above ground level in an open terrain (Category 2). Basic wind speeds have been worked out for a 50 year return period. By using the code – provided formulas it is possible to translate the basic wind speed into a corresponding Design wind speed in m/s by applying probability, terrain and topography factor. From the design wind speed design wind pressure on the building as a whole can be determined.

- (a) Projected area method of wind load application;
- (b) Wind applied normal to all surfaces.

For a long time, engineers considered wind to be a strictly horizontal force and computed it by multiplying the design wind pressure by the projected area of the building . As wind research progressed, often pioneered by the metal building industry, a more complex picture of the wind force distribution on gable buildings gradually became acknowledged . In the current thinking, the wind is applied perpendicular to all surfaces; both pressure and suction on the roof and walls are considered, as internal and external wind pressures.

6.4 Earthquake Load

The first classic theory holds that the majority of earthquakes originate when two segments of the earth crust collide or move relative to each other. The movement generates seismic waves in the surrounding soil that are perceived by humans as ground shaking; the waves diminish with the distance from the earthquake epicenter. The wave analogy explains why earthquakes are cyclical and repetitive in nature. The second seismic axiom states that, unlike wind, earthquake forces are not externally applied. Instead, these forces are caused by inertia of the structure that tries to resist ground motions. As the earth starts to literally shift away from the building, it carries the building base with it, but inertia keeps the rest of the building in place for a short while. From Newton's first law, the movement between two parts of the building creates a force equal to the ground acceleration times the mass of the structure. The heavier the building, the larger the seismic force that acts on it.

Factors affecting the magnitude of earthquake forces on the building include the type of soil, since certain soils tend to amplify seismic waves or even turn to a liquid like consistency (the liquefaction phenomenon). The degree of the building's rigidity is also important. In general terms, the design seismic force is inversely related to the fundamental period of vibration; the force is also affected by the type of the building's lateral load-resisting system. Most building codes agree that the structures designed in accordance with their seismic code provisions should resist minor earthquakes without damage, moderate earthquakes without structural damage, but with some non structural damage, and major ones without collapse. Since the magnitude of the actual earthquake forces is highly unpredictable, the goal of collapse avoidance requires the structure to deform but not to break under repeated major overload. The structure should be able to stretch well past its elastic region in order to dissipate the earthquake-generated energy.

To achieve this goal, the codes are filled with many prescriptive requirements and design limitations particular attention is given to the design details, since any disruption of the load path destroys the system. It is important to keep in mind that real-life seismic forces are dynamic rather than static, even though their effects are commonly approximated in practice by a so-called equivalent static force method. This method is used partly for practicality, as dynamic analysis methods are quite cumbersome for routine office use, and partly for comparison of the results to those of wind-load analysis and using the controlling loading to design against overturning, sliding, and other modes of failure.

The actual formulas for determination of seismic forces are given in IS 1893: 2002 Criteria for earthquake resistant design of structures. In general, these formulas start with the weight of the structure and multiply it by several coefficients accounting for various factors.

6.5 Crane Load

Cranes are frequently needed for material handling in metal buildings. A building crane is a complex structural system that consists of the actual crane with trolley and hoist, crane rails with their fastenings, crane runway beams, structural supports, stops, and bumpers. A motorized crane would also include electrical and mechanical components. Several types of cranes are suitable for industrial metal building systems, the most common being bridge cranes (either top-running or under hung), monorail, and jib cranes. Occasionally, stacker and gantry cranes may be required for unique warehousing and manufacturing needs.

Another way to classify the cranes is by kind of movement, hand-gear or electric. Hand geared cranes are physically pulled along the rail by the operator and are less expensive, but slower, than electric cranes. Hand-gear cranes act with less impact on the structure than their faster-running electric cousins. The operator controlling an electrically powered crane can be either standing on the floor using a suspended pendant pushbutton station or sitting in a cab located on the moving bridge.

6.5 Scope of Present Work

The present work aims at comparison of conventional steel building with Pre-Engineered steel buildings for industrial warehouses equipped with Electrical Overhead Travelling (EOT) cranes. An attempt is made to compare the structure in terms of:

- 1) Steel Quantity – Amount of steel required for a structure with fixed width and supporting different capacities of EOT cranes.
- 2) Reduction in load – Reduction in the dead load of the structure due to use of tapered section and light weight secondary members.
- 3) Cost comparison of the structure.
- 4) Foundation size requirement.

In present work, the basic frame for conventional steel building is a built up column with truss as a roofing system and the basic frame for pre-engineered steel building is a pitched roof portal with tapered columns. The span to be used for the portal is 30m. Spacing of portal is 5m c/c. Inclination angle for PEB portal is 6° with respect to horizontal. The Crane of capacity of 10t is used on each frame under consideration.

6.6 Specification of Design loads

All dead loads, live loads, wind load will be confirming to IS: 875-1987. Earthquake loads will be confirming to IS: 1893-2002.

Load combinations considered:

- 1) Dead load + Impose Load

- 2) Dead load + Impose Load + Wind or Earthquake load
- 3) Dead load + Wind or Earthquake load

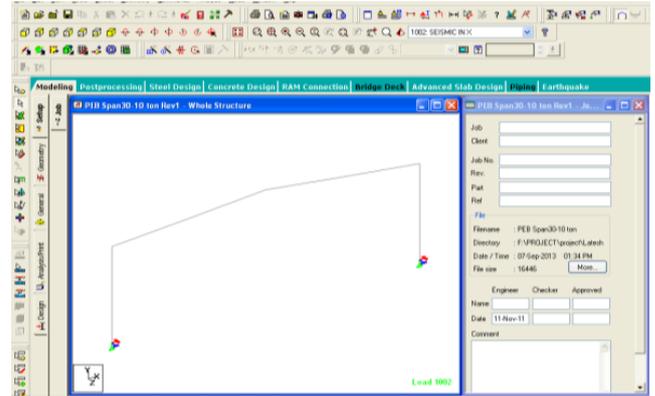


Figure 6.1: Staad-Pro Generated PEB Frame

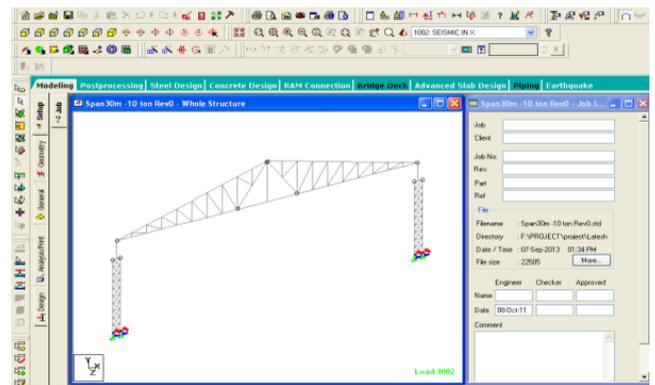


Figure 6.2: Staad-Pro Generated Frame With Truss Type

7. Result

Comparison of Conventional steel Building & Pre – Engineered Steel Building

Table 7. 1: Span 30m and crane capacity 5 ton

Parameters	Conventional Steel Building	Pre – Engineered Steel Building	Difference
Dead Load	768.96 kN	577.53 kN	191.43 kN
Steel Quantity	58.03 tons	50.01 tons	8.02 tons
Foundation Size	3.2m x 1.8m x 0.4m	2.4m x 1.6m x 0.4m	
Concrete Qty.	41.44 m ³	27.65 m ³	13.79 m ³

Table 7.2: Span 30m and crane capacity 10 ton

Parameters	Conventional Steel Building	Pre – Engineered Steel Building	Difference
Dead Load	788.58 kN	623.88 kN	164.7 kN
Steel Quantity	60.01 tons	54.71 tons	5.3 tons
Foundation Size	3.3m x 1.8m x 0.4m	2.4m x 1.6m x 0.4m	-
Concrete Qty.	42.76 m ³	27.65 m ³	15.11 m ³

Table 6.3: Span 30m and crane capacity 15 ton

Parameters	Conventional Steel Building	Pre – Engineered Steel Building	Difference
Dead Load	814.95 kN	659.25 kN	155.7 kN
Steel Quantity	62.98 tons	58.29 tons	4.69 tons
Foundation Size	3.4m x 1.8m x 0.4m	2.5m x 1.6m x 0.4m	-
Concrete Qty.	44.06 m ³	28.8 m ³	15.26 m ³

Table 6.4: Span 30m and crane capacity 20 ton

Parameters	Conventional Steel Building	Pre – Engineered Steel Building	Difference
Dead Load	849.06 kN	689.4 kN	159.66 kN
Steel Quantity	66.043 tons	61.26 tons	4.783 tons
Foundation Size	3.5m x 1.8m x 0.4m	2.6m x 1.6m x 0.4m	-
Concrete Qty.	45.36 m ³	29.95 m ³	15.41 m ³

7.1 Graphical Representation of Result

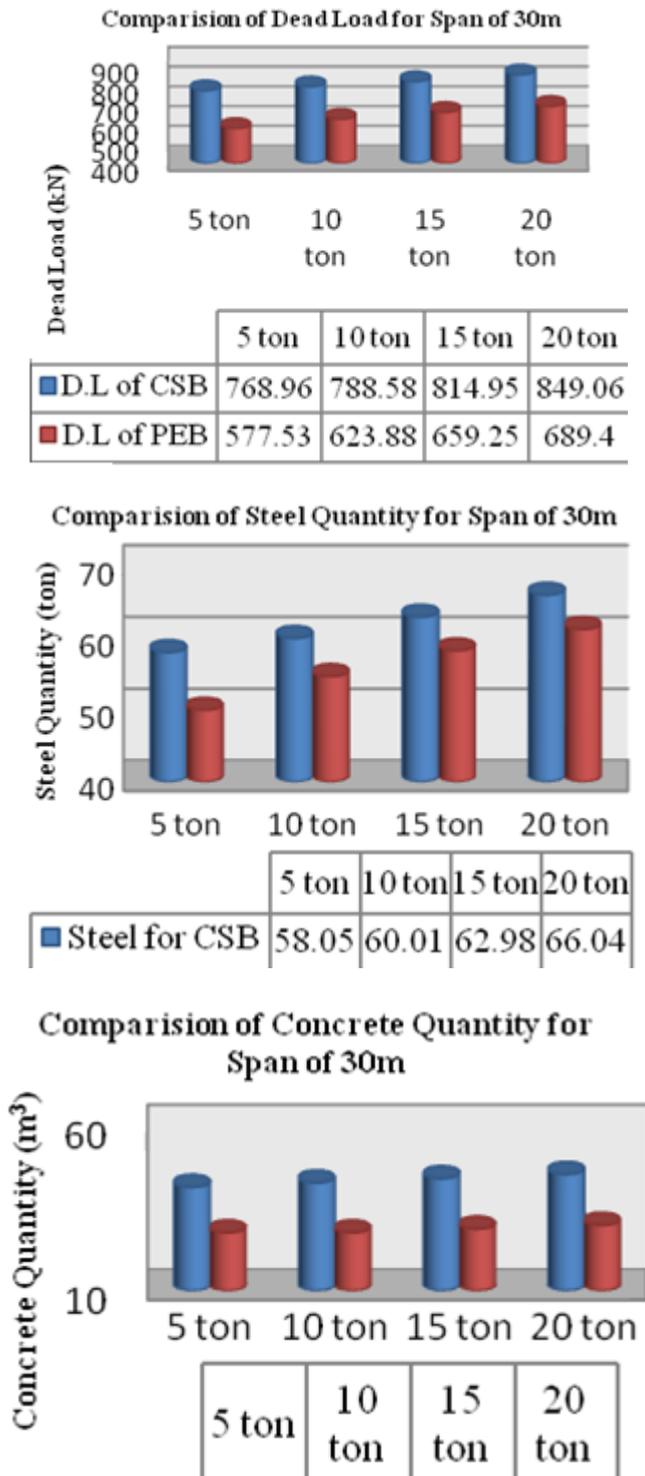


Figure 6.1: a-b-c, Graphical Representations of Results

8. Conclusion

- Using of PEB instead of CSB may be reducing the steel quantity.
- Reduction in the steel quantity definitely reducing the dead load.
- Reduction in the dead load reducing the size of Foundation.
- Using of PEB increase the Aesthetic view of structure.

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