Economizing Steel Building using Pre-engineered Steel Sections

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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. 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, STAAD-pro etc

1. INTRODUCTION

Origin
The first building with an iron frame was the Dithering ton Flax Mill constructed in Shrewsbury, England, in 1796. Cast-iron columns were substituted for the usual timber in a calico mill constructed in nearby Derby 3 years earlier. These experiments with iron were prompted by frequent devastating fires in British cotton mills of the time. Once the fire-resistant properties of metal in buildings had been demonstrated, wrought-iron and cast-iron structural components gradually became commonplace. In the middle of the nineteenth century, experimentation with rolling of iron beams finally culminated in construction of the Cooper Union Building in New York City, the first building to utilize hot-rolled steel beams. In 1889, Rand McNally Building in Chicago became the first skyscraper with all-steel framing. Prefabricated metal buildings first appeared at about the same time. As early as the mid-nineteenth century, “portable iron houses” were marketed by Peter Naylor, a New York metal-roofing contractor, to satisfy housing needs of the 1848 California Gold Rush fortune seekers; at least several hundred of those structures were sold. A typical iron house measured 15 by 20 ft and, according to the advertisements, could be put together in less than a day by a single man. Naylor’s ads claimed that his structures were cheaper than wood houses, fireproof, and more comfortable than tents. Eventually, of course, California’s timber industry got established and Naylor’s invention lost its market. In the first two decades of the twentieth century, prefabricated metal components were mostly used for garages. Founded in 1901, Butler Manufacturing Company developed its first prefabricated building in 1909 to provide garage space for the ubiquitous Model T. That curved-top building used wood framing covered with corrugated metal sheets. To improve fire resistance of its buildings, the company eventually switched to all-metal structures framed with corrugated curved steel sheets. The arch like design, inspired by cylindrical grain bins, influenced many other prefabricated metal buildings.

Pre-Engineered Buildings
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 40 ft. In a few years, 50, 60, and 70-ft buildings became possible. By the late 1950s, rigid frames with 100-ft spans were made.

Figure 1. Dithering on Flax Mill constructed in Shrewsbury, England, in 1796.

Second, in the late 1950s, ribbed metal panels became available, allowing the buildings to look different from the old tired corrugated appearance.

Third, colored panels were introduced by Stran-Steel Corp. in the early 1960s, permitting some design individuality. At about the same time, continuous span cold-formed Z purlins were invented (also by Stran-Steel), the first factory-insulated panels were developed by Butler, and the first UL-approved metal roof appeared on the market. And last, but not least, the first computer-designed metal buildings also made their debut in the early 1960s. With the advent of computerization, the design possibilities became almost limitless. All these factors combined to produce a new metal-building boom in the late 1950s and early 1960s. As long as the purchaser could be restricted to standard designs, the buildings could be properly called pre-engineered.

2. REVIEW OF LITERATURE

Article published in The Magazine for Decision Makers “Building Profit spring 2001 A century of excellence” Vol 21 No:1. This article gives idea about the

First Mass – Produced Rigid Frame Building
1939 marked a major breakthrough for the buildings business. At the request of the U.S. Navy, Wilbur Larkin, then chief engineer of Butler’s farm equipment, and his brother Kenneth, a consulting engineer, successfully applied the principles of rigid frame design to create structurally stable pre-engineered metal buildings.

Father of Pre-Engineered Building
The Larkin brothers’ made the revolutionary metal rigid-frame design and was subjected to strenuous laboratory testing. Lacking today’s technology, they whitewashed the frames to pinpoint areas of stress.

Major Turning Point
In 1969, Butler manufacturing company unveiled two interrelated products. The MR-24 standing seam roof system, coupled with the Landmark structural framing system. It was a major turning point for pre-engineered construction. As with the help of these system roof with extremely low pitch as low as 1/4:12 could be erected And it turned out to be the first pre-engineered roof system able to accommodate more than minimal insulation without accelerating damage from thermal stress—a major advantage when the energy crisis hit in the early 70s. With the introduction of the Landmark “structural system and MR-24 roof system”, the appearance of pre-engineered buildings changed dramatically.

Paper drafted on “Pre-Engineered metal Buildings the latest trend in building construction” by K.K.Mitra – Gen. Manager (marketing) Lloyd Insulations (India) Limited. This paper covers in detail about the concept of Pre-Engineered Building, its construction system, benefits, applications and various categories of buildings.
Concept
Pre-Engineered Steel Buildings use a combination of built-up sections, hot rolled sections and cold formed elements which provide the basic steel frame work with a choice of single skin sheeting with added insulation or insulated sandwich panels for roofing and wall cladding. The concept is designed to provide a complete building envelope system which is air tight, energy efficient, optimum in weight and cost and, above all, designed to fit user requirement like a well fitted glove.

Construction System
In the assembling of PEB the varied components of the PEB are joined to each other based on the nut and bolt methodology as against the welding and riveting methodology used for structural steel buildings.

Benefits
Quality design, manufacturing and erection.
Pre-painted and has low maintenance requirement.
The building can be dismantled and relocated easily.
Future extensions can be easily accommodated without much hassle.

Paper on “How Fabricators can Combat Metal Buildings” by Jeffrey S. Nawrocki, P.E at NSCC Chicago in 1997. This paper highlights the cons of PEB by stating Pre – Engineered Buildings are not generating adequate work to skilled forces and automation is also causing low employment and hence the Fabricators should capitalize on the flexibility and strength of structural steel buildings to increase market share in warehouse and industrial applications.

A Better System
One way that steel-framed buildings can compete with pre-engineered metal buildings is through a team approach, where a fabricator and engineer work together to market, design and fabricate a structure. For this type of arrangement to be successful, it is essential that the engineer has a good working relationship with the fabricator and that the fabricator is willing to be creative and is able to supply some up-front research and marketing time to gain projects. The third member of the team is a general contractor who knows the engineer and/or fabricator and is willing to work with them on negotiated or design/build projects and compare structural buildings to pre-engineered structures.

Pro – Active Marketing
Pre-engineered buildings are gaining market share because fabricators are not taking a proactive stance to promote the many benefits steel-framed structures and the relative disadvantages of pre-engineered metal buildings. Obviously, if bottom line is first cost, the only factor for an owner, it is a waste of time to try and compete in that market against pre-engineered structures. However, many owners are willing to take a longer range view, especially if the premium for a steel-framed building is minimal. Also, certain types of buildings clearly lend themselves to being sold as a steel framed structure rather than a pre-engineered metal building. Likely candidates include industrial and warehouse structures subject to some level of abuse and this includes any building with fork lift trucks, loaders, crane ways or industrial processes. In addition, complex and multistory buildings are, and have always been a natural for structural steel. It’s essential that fabricators begin to think in terms of a team approach and to pro-actively market their product. Pre-engineered metal building salesmen are master sellers. But structural steel fabricators have the advantage of selling a better product, they just need to be willing to educate the owner and sell their product.
3. FRAMING SYSTEM

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, and are in excess of design requirements.

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.

Advantages & Application of Pre-Engineered Steel Buildings

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.

**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.

**4. LOADS**

**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 1 kN, for example, is best represented by a concentrated downward force in the design of the supporting purlins. The equipment load could be “averaged out” converted to a uniform collateral load for the main framing design.

**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.

**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.

![Figure 4.Wind load on Cable Buildings](image-url)

(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 (Fig. 4a). 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 (Fig. 4b). 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.

**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.

**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-geared or electric. Hand geared cranes are physically pulled along the rail by the operator and are less expensive, but slower, than electric cranes. Hand-geared 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.

**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.

Specifiation 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**

Fig.5 Staad-Pro Generated PEB Frame

Fig.6 Staad-Pro Generated Frame With Truss Type
5. RESULT

Comparison of Conventional steel Building & Pre – Engineered Steel Building

Table 1. Span 30m and crane capacity 5 ton

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Conventional Steel Building</th>
<th>Pre – Engineered Steel Building</th>
<th>Difference</th>
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</thead>
<tbody>
<tr>
<td>Dead Load</td>
<td>768.96 kN</td>
<td>577.53 kN</td>
<td>191.43 kN</td>
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<tr>
<td>Steel Quantity</td>
<td>58.03 tons</td>
<td>50.01 tons</td>
<td>8.02 tons</td>
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<tr>
<td>Foundation Size</td>
<td>3.2m x 1.8m x 0.4m</td>
<td>2.4m x 1.6m x 0.4m</td>
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<tr>
<td>Concrete Qty.</td>
<td>41.44 m³</td>
<td>27.65 m³</td>
<td>13.79 m³</td>
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Table 2. Span 30m and crane capacity 10 ton

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<th>Pre – Engineered Steel Building</th>
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<td>Dead Load</td>
<td>788.58 kN</td>
<td>623.88 kN</td>
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<td>Steel Quantity</td>
<td>60.01 tons</td>
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<tr>
<td>Foundation Size</td>
<td>3.3m x 1.8m x 0.4m</td>
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<tr>
<td>Concrete Qty.</td>
<td>42.76 m³</td>
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Table 3. Span 30m and crane capacity 15 ton

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<td>Dead Load</td>
<td>814.95 kN</td>
<td>659.25 kN</td>
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<td>Steel Quantity</td>
<td>62.98 tons</td>
<td>58.29 tons</td>
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<tr>
<td>Foundation Size</td>
<td>3.4m x 1.8m x 0.4m</td>
<td>2.5m x 1.6m x 0.4m</td>
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<tr>
<td>Concrete Qty.</td>
<td>44.06 m³</td>
<td>28.8 m³</td>
<td>15.26 m³</td>
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Table 4. Span 30m and crane capacity 20 ton

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<td>Dead Load</td>
<td>849.06 kN</td>
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<td>Steel Quantity</td>
<td>66.043 tons</td>
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<tr>
<td>Concrete Qty.</td>
<td>45.36 m³</td>
<td>29.95 m³</td>
<td>15.41 m³</td>
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6. GRAPHICAL REPRESENTATION OF RESULT
7. 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.

REFERENCES

[1] IS: 875 (Part 1) – 1987 Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures (Dead Load)