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An Analytical Study on Pre-Engineered Buildings Using Staad Pro

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Abstract:
The idea of Pre-Engineered Buildings (PEB) involves using pre designed and factory-made steel structures that are assembled on-site. Today's construction needs demand attractive design, good quality, fast completion, cost savings, and innovative methods. To meet these requirements, alternative building methods like PEB are becoming more popular. PEB uses steel structures that are designed for strength and efficiency, helping to reduce both time and cost during construction.

The paper mainly focuses on explain the idea of PEB are and how it helps save money and time. Compared to traditional construction methods, PEB is more sustainable and efficient. It offers quicker installation and is often more affordable than standard steel construction. In conventional steel structures, the construction process takes longer and costs more, while PEB provides a faster and more economical solution. Overall, PEB stands out as a smart choice for modern construction needs due to its speed, strength, and cost-effectiveness.

Literature Review:

Shrunkhal V. Bhagatkar et al. (2015) A research was conducted on PEB, reviewing the work of various researchers in this field. The purpose of the paper was to understand how PEBs have developed over time and how their use has grown in the construction industry. Although the use of PEBs is increasing, it is still not fully adopted across the entire industry. The review showed that PEBs can be designed using simple procedures that follow national building codes. These structures are energy-efficient, faster to construct, cost-effective, and more sustainable than traditional building methods. Most importantly, they are reliable and perform well under various conditions. Because of these benefits, PEB systems offer great potential for future construction. The study suggests that more research and development should be done to fully explore the advantages of PEBs and encourage wider use of this modern construction technique.

Sagar Wankhede et al. (2014) A research was presented comparing traditional Steel Buildings (CSB) and Pre Engineered Buildings (PEB). The research begins by discussing the main parts of an industrial building, including purlins, sag rods, main rafters, roof trusses, gantry girders, brackets, columns, column bases, girt rods, and bracing systems. It then examines how loads and load combinations are considered, following the guidelines of IS 875-1987. The author provides a basic explanation of the PEB concept, highlighting its benefits, efficient use, and structural frame

system. A detailed comparison between PEB and CSB is included, showing the differences in performance and application.
The study concludes that PEBs are more beneficial than CSBs when it comes to cost savings, better quality control, faster construction, and easier installation.

C.M. Meera (2013), A comparative study was conducted to evaluate PEB and Traditional Steel Buildings. This study looks at a common frame used in industrial warehouses was designed using these two concepts. The structural elements designed include roof trusses or main rafters, columns, column bases, purlins, sag rods, tie rods, gantry girders, and bracing systems. The analysis was performed using STAAD Pro, a structural design and analysis software. The paper begins by explaining the methods used in the study and details the load calculations and combinations based on standard codes. It also includes a section highlighting the role and procedure of the software in analyzing the structural behavior of the warehouse frames.
The final section presents the results obtained from the software analysis and insights gained from related literature. This paper focuses on to offer a clear understanding of PEB design principles and demonstrate its benefits over CSB, such as cost, speed, and construction efficiency.

Syed Firoz, et al. (2012) PEBs are a smart and practical solution, especially for single-story structures. These systems offer a cost-effective and efficient alternative to conventional construction methods. With the help of design tools like STAAD Pro, engineers can create real-time, coordinated models that integrate multiple disciplines. Steel is the primary material used in PEBs because it is strong, durable, cost-efficient, and recyclable. It can be sourced from many locations and is available in various shapes, sizes, and colors. Choosing steel also supports sustainability, as it uses less energy during construction and can be recycled many times without losing its properties.
Most steel buildings constructed today are low-rise and serve industrial functions like manufacturing plants, power stations, warehouses, storage units, workshops, and garages. These buildings often require large open spaces without internal columns, making steel an ideal material. Many also need high ceilings to support equipment like overhead cranes. In PEBs, secondary structural members are crucial. These include purlins for roofs and girts for walls. They connect the main structural frames and also help resist external forces.
Another important component is the eave strut, which functions as both a purlin and girt at the building's edge. These secondary members are typically made from cold-formed steel, known for its strength and lightweight properties. Understanding how to design with cold-formed steel is key to building strong and efficient PEBs. Overall, pre-engineered steel buildings offer speed, strength, flexibility, and sustainability—making them a leading choice in modern industrial construction.

1. Introduction:

Technological progress over the years has significantly boosted living standards by introducing new and improved products and services. One such advancement in construction is the use of Pre-Engineered Buildings (PEBs). This modern building method involves using a standardized set of materials that have been carefully tested and proven reliable. These materials are designed to meet various structural and architectural needs, making PEBs a flexible and efficient choice for many types of construction projects.

1.1 Importance of Pre-Engineered Buildings (PEBs)

The steel industries are expanding quickly all over the world. Using metal framework is not only cost-effective but more environmentally friendly too, especially at a time when concerns about global warming are rising. Traditional steel construction methods often take more time and cost more money, making the process less affordable overall. In contrast, pre-engineered building systems offer a better solution. Most of the construction work is done in a factory, where structural parts are manufactured based on the design. These prefabricated components are then delivered to the construction site and assembled, usually within 6 to 8 weeks, saving both time and money.

1.2. History of PEB

PEBs were mostly used in Northern part of America and the Arabian countries until around 1990. Since then, their popularity has expanded to many parts of Asia and Africa, where the idea has become well-known and liked. PEBs are now recognized for being one of the most adaptable and cost-effective construction methods available.

In today’s building industry, these steel structures are valued for their affordability, fast delivery, and quick installation. Their ability to meet various functional and design needs while reducing construction time makes them a preferred choice in many regions around the world.

2. Element of a PEB:

Here is the short explanation below:

- **Sag Rod:** These are round rod sections attached to the web or purlin. In industrial buildings, the roof coverings are flexible and don’t offer enough support. A sag rod is made to work in tension and helps resist the sideways forces caused by the roof load and the weight of the purlin.

- **Rafter:** The uppermost part of a roof truss is called the principal rafter. It mostly carries compressive force, but it can also bend if purlins are not placed at the joints of the truss.

- **Roof Trusses:** They are structural parts of a building. The different parts of a truss face straight forces—some are stretched (tension), and others are pressed (compression).

- **Gantry Girder:** They are built as beams without side support. In industrial buildings, overhead cranes move heavy equipment, machines, and materials from one spot to another.

- **Brackets:** Brackets are connection pieces used when two parts need to be joined but don’t meet directly.

- **Column:** The column is vertical part of structure that carries equal compressive forces from both ends.

- **Girt:** Girts are beams that experience uneven bending. They support vertical loads from the wall and horizontal forces like wind.

3. Hardware:

Anchor bolts:

Primary connection bolts are used to join main structural parts or combined members. Usually, these bolts are designed to handle pressure by bearing.

Secondary connection mobiles:

These are used to connect secondary structural parts to main parts or to other secondary parts.

4. Accessories:

Skylight

Translucent panels are used to allow sunlight into the building. They are attached with self-drilling screws. When placed on the roof, they are known as skylights, and when installed in the wall, they are known as wall lights. Generally, two types of skylight panels are used which are given below:

- Polycarbonate sheets
- Fiber Reinforced Plastic sheets

Turbo vent

These are fans that use natural airflow to help remove hot and dirty air from a building without using electricity. They spin easily because of special ball bearings that allow the fan to turn even with small air movement. The spinning fan creates a vacuum using centrifugal force, which pulls warm air out from inside the building and releases it outside.

Louvers

Standard fixed louvers and industrial louvers are often used when good airflow is needed. Industrial louvers usually have a bird mesh at the bottom to stop birds from entering. Fixed louvers are made of strong, natural anodized steel and are designed to match wall panels properly.

5.Technical parameters:

Design coded and standards

In general, PEBs are designed based on American or Indian codes of practice based on customer requirements

- AISC-89 & AISC-2005 are used for primary members
- MBMA-96 is used for load combinations
- IS 1984 & IS 2007 are used for serviceability conditions

6. Types of load

Dead load

It comprises the weight of primary members like frames, as well as secondary structural parts like purlins, girts, flange braces, roof and wall braces, and wall panels.

Live load

Live load is the temporary weight on a building, like people, furniture, vehicles, or movable equipment. It can change depending on how the space is used.

- Maintainance done by workers using tools and materials.
- Movable items inside the building during its use, excluding water, snow, earthquake forces, or permanent loads.

Seismic load

Earthquake forces create seismic loads that act horizontally at the building’s center of gravity. The structure is planned and built to handle these lateral forces within a set range, following this formula:

$$V_b = A_h W$$

$$Ah = Z/2 * I/R * S_a/g$$

Wind load

Wind load depends on factors like speed of wind, roof angle, eave height & how enclosed the building is. The internal pressure coefficient is chosen according to the building’s enclosure type.

Mechanical/Equipment load

Besides the building structure, external dead loads include the weight of items like sprinklers, mechanical & electric equipment, partitions & ceiling.

Crane load

Wind pressure is calculated based on the following formula

Pz ¼ 0.6Vz2

7.Load combination

Load combinations are considered based on building codes. There are various types of load combinations used according to different codes used for PEB layout.

- Load Combinations as per MBMA (Metal Building Manufacturers Association) and AISC (American Institute of Steel Construction)

- Load Combinations as per IS875/IS800-2019

- Load Combinations as per IS800-2007

8. Design software
All technical data and results are produced, reviewed, and shared in digital form, including model calculations, construction plans, general arrangement and anchor bolt drawings, shop drawings, and bills of materials (BOM).

To produce quality design and diagrams for a PEB, the following code is used:

- STAAD Pro V8i
- Tekla Structures
- AutoCAD

9.Material specification
To keep enough raw materials in stock and prevent shortages, the design team will send a detailed list of materials needed for each job to the purchasing department ahead of time for buying.

Main structural members
Built-up members are constructed using high-strength steel plates with at least 345 MPa yield strength. These plates usually range from 4–50 mm in thickness, 1250–1500 mm in width, and 2100–6000 mm in length.

Supporting members (Cold formed section)
Built-up members are made from high strength steel plates which have a minimum strength of 345 MPa. Cold-formed members use steel sheets 1.5 mm to 3.15 mm thick. Steel coils with the same strength and thicknesses like 1.50 mm, 1.60 mm, 1.75 mm, 2.00 mm, 2.50 mm, and 3.15 mm are commonly used to shape these members.

a. Supporting members (hot-formed section)

Pipe shaped members sizes ranging from 25 to 350 mm in diameter, along with angle sections, channel sections, and beam sections, are commonly used.

Exterior covering
The materials listed below are commonly used to make sheets for roofing and wall coverings:

0.47 mm thick bare galvalume
0.50 mm thick color coated galvalume
0.8–1.0 mm thick GI decking sheet

10.Add-ons in a building

Crane

It is a machine usually equipped using a hoist along with ropes, chains & pulleys, which helps lift and lower materials as well as move them horizontally.

Mezzanine

Mezzanine floor systems are semi-permanent floors often added inside buildings for industrial use. They can either stand on their own or be supported by the main building's columns.

Framed openings

They are specially designed gaps in walls and roofs. These openings use carefully shaped cold-formed steel members to make it easy to install accessories during construction. Typically, the framing is made from C or Z-shaped sections, which are connected using bent plate clips and machine bolts.

Fascia

The flat surface at the edge of a roof overhang or the end of a cantilever, often used as a decorative trim on the front wall, is called a fascia. Adding a this system to buildings improves their look, turning a plain structure into a more attractive one.

Methodology

PEB and Traditional steel metal framework are both designed to withstand forces like wind and earthquakes. Wind analysis was done manually following IS 875 Part III — 1987, while seismic analysis was carried out according to IS 1893–2002. For comparison, a building frame with a width of 20 meters, a height of 5 meters, and a roof slope of 1 in 10 was considered. In PEB, tapered sections are used.

Results

The design ratio is the comparison between actual load a beam carries and the load it is designed to handle. Ideally, this ratio should be equal to or less than one to ensure the structure is safe and efficient. In this study, the total weight of the structural components in the Pre-Engineered Building (PEB) is 1301 kg, while for the conventional steel structure, it is 2013 kg. This clearly shows that the PEB system uses significantly less steel—almost 50% less—when compared to the traditional method. This reduction in steel not only lowers material costs but also makes the structure lighter, easier to transport, and quicker to assemble. It highlights the efficiency of PEBs in terms of material usage and overall economy, especially for structures that require large spans or are part of industrial applications where cost and time savings are essential.

11.Applications

(i)**Parking shelters**

Benefits of using metal buildings for vehicle parking shelters include:

- Fewer columns: Larger Bay sizes mean fewer columns, which improves security and makes better use of space.

- Fast delivery
- Easy and quick to assemble
- Strong and dependable structural design

(ii)Poultry buildings
Metal buildings are often the top choice for poultry farms because they are easy and quick to build, deliver fast, and require little maintenance. Poultry buildings are used for different purposes like raising chickens, broiler houses, and laying houses. One important factor in these buildings is having a good ventilation system to keep the environment clean and healthy for the birds. When designing a poultry building, it's also important to carefully manage heat balance to ensure the animals stay comfortable and healthy.

(iii)Storage sheds
When metal buildings are used as storage sheds for granular materials like wheat, sugar, or cement, special design factors need to be considered. The shape and size of the storage building depend on the angle at which the material naturally settles (called the angle of rest) and how much material needs to be stored. The pressure that the stored material puts on the walls of the building relies upon the material's heigh, its weight per unit, and internal friction angle between the particles.

(iv)Aircraft hangar
Metal buildings are increasingly being used to house and service aircraft for commercial, civilian, and military purposes. Metal buildings are a popular choice for aircraft hangars because they are affordable and offer high quality. Quick installation can reduce construction time by several months, which helps reduce costs and allows quicker use of the hangar. Key features of aircraft hangars include large clear span widths, usually between 45 to 85 meters & very tall eave heights, ranging from 20 to 35 meters.

Advantages

- Easy to customize
- Flexible for different uses
- Strong and long-lasting
- Affordable upfront cost
- High-quality materials and work
- Quick to build
- Low costs for maintenance and operation

12. Analysis using STAAD Pro V8i
In this project, Staad Pro V8i SS5 software was used to analyze and design both PEB and conventional steel structures. The 1st example involved creating a 3D model of warehouse using PEB, which was then compared to a similar building made with traditional steel. In the second case, a 2D frame with a width of 88 meters was designed using tapered sections typical for PEB.

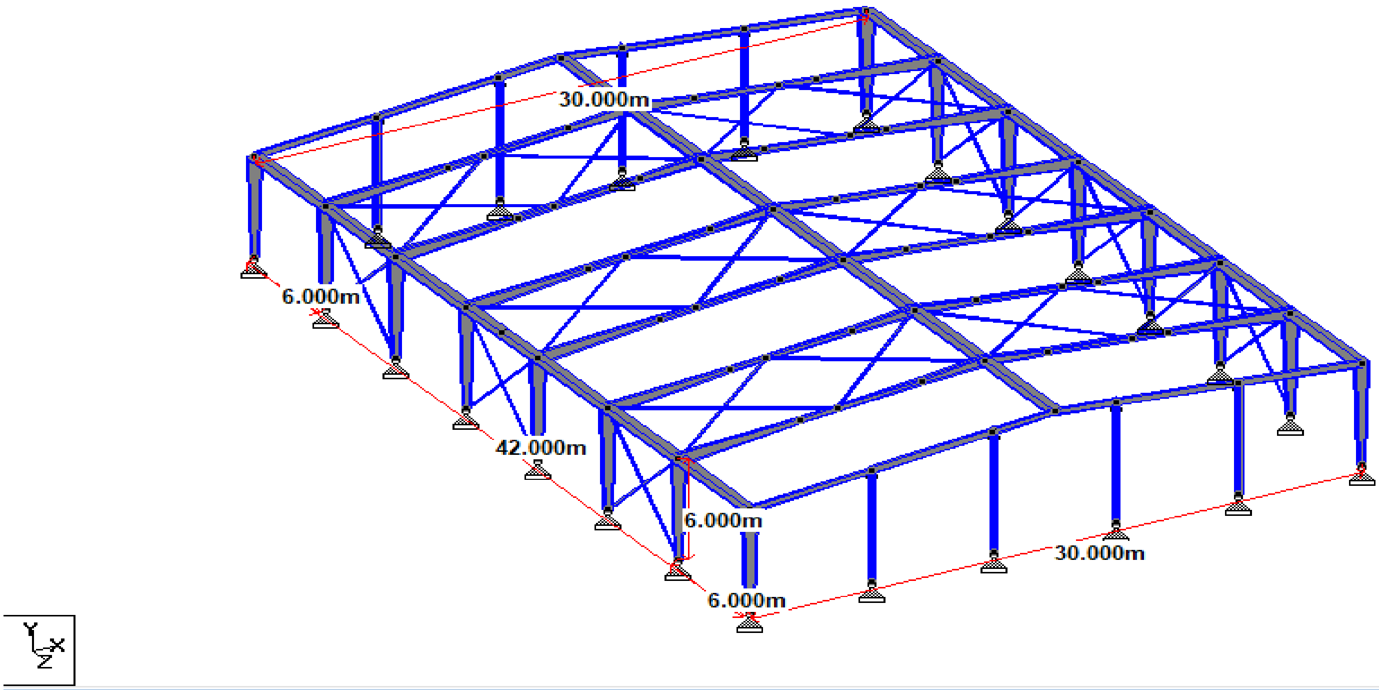
This design would be difficult and costly to build with conventional methods. Different spacing between the bays was tested to find the most efficient layout. Overall, the project shows how PEB offers practical and economic advantages for certain types of building designs compared to traditional steel construction.

PEB by STAAD Pro

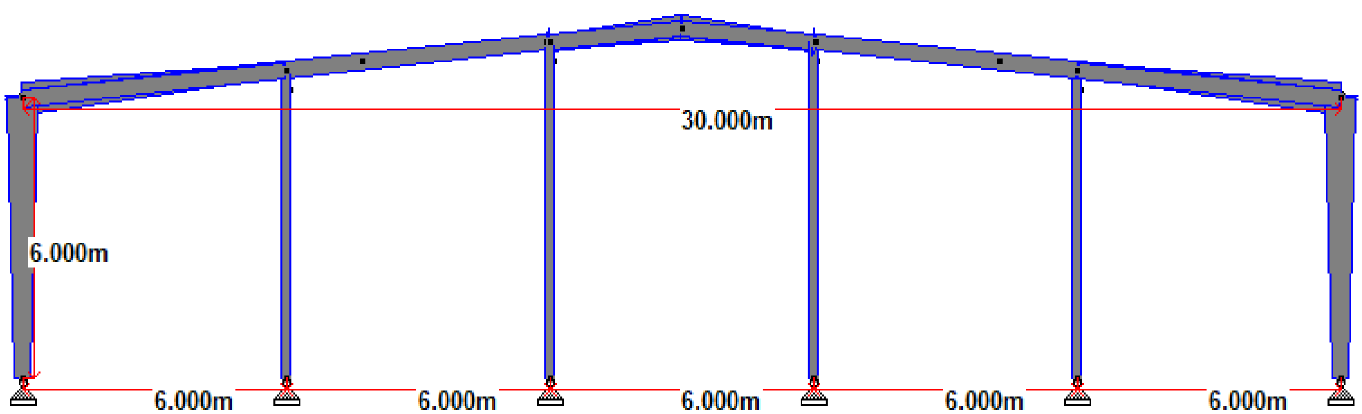
STAAD Pro V8i SS5 is a user-friendly software widely used for analyzing and designing steel structures, including PEBs and traditional steel buildings. It allows engineers to perform both design and analysis at the same time, making it easier to spot and fix any errors quickly. The software supports testing different sizes and shapes of structural members, like tapered I-sections for PEBs, and offers access to standard rolled steel sections for conventional designs. STAAD Pro can calculate important forces such as bending moments, axial forces, shear forces, torsion, and stresses on beams, helping to ensure the structure is safe and reliable. In this project, the analysis was done using the stiffness matrix method, with tapered sections modeled using the software's tools. Fixed supports were assigned to represent real conditions accurately. Loads on the structure were manually calculated first and then carefully input into the software to simulate real situations. This helps the software analyze how the building will behave under those loads. Overall, STAAD Pro V8i SS5 simplifies the design process, allowing engineers to create safe, strong, and cost-effective steel buildings with quick feedback on their designs.

Numerical Data

BUILDING DETAILS	
Length	42m
Width	30m
Height	6 m
Basic wind speed	47m/s
Roof slope	1:10
Bay spacing	6m
Weight of sheets	5kg/sq. Metre
Weight of purlins	4.12 kg/sq. Metre



WHOLE SECTION OF THE WAREHOUSE WITH DIMENSIONS



Side View Of The Structure

13. Calculation Of Live Load

As per IS 875, FOR NON ASSESSIBLE ROOFS, THE VALUE OF LIVE LOADS IS 75 KG/ SQ. METRE, which is 0.75 KN/ m2

UDL load = 0.75 * 6

= 4.23 kn. M

Calculation Of Wind Load

As per IS 875 Part II (1987), using a basic wind speed of 47 m/s. Building is assumed to be in open terrain under 10 m high and spaced over 50 m. Based on this, factors K1, K2, and K3 are determined as per the code.

Terrain Category- 2,

K1- Probability factor- 1.0

K2- Terrain, height and size factor- 1

K3- Topography factor- 1.0 (SLOPE LESS THAN 3 DEGREE)

K4- NON-CYCLONIC REGION- 1

Design wind speed, Vz= Vb (K1 x K2 x K3 X K4)
Vz= 47m/s

Design pressure, P= 0.06 Vz^2
= 1.384 kN/m^2

Ratio- H/W=0.2, L/W=2.1

Wind Pressure Coefficients

Wind pressure and suction values are calculated for all external and internal surfaces of the building. Since the openings in the building are less than 5%, the internal pressure coefficients are taken as +0.2 and -0.2.

Both internal and external wind pressure coefficients are determined based on the guidelines given in IS 875 Part II (1987).Wind load for individual members

F= (Cpe- Cpi) x A x P (5)

Load Combination

	Node	L/C	Horizontal X mm	Vertical Y mm	Horizontal Z mm	Resultant mm	Rotational rX rad	Rotational rY rad	Rotational rZ rad
Max X	87	3 WLTR	71.509	0.194	-0.000	71.509	-0.000	0.000	-0.004
Min X	87	9 DL+LL+WR	-73.250	-121.145	-0.572	141.569	-0.009	0.000	0.003
Max Y	29	3 WLTR	53.588	174.207	-4.412	182.317	0.006	0.000	-0.003
Min Y	23	5 DL+LL	-0.001	-242.481	-0.422	242.481	0.002	0.000	-0.000
Max Z	83	3 WLTR	38.240	-0.013	346.670	348.773	0.050	-0.037	0.001
Min Z	94	4 WRTL	-36.247	-0.006	-347.626	349.510	-0.050	-0.040	-0.001
Max rX	5	9 DL+LL+WR	-36.287	-0.753	-57.045	67.612	0.273	-0.002	-0.000
Min rX	68	8 DL+LL+WL	38.192	-0.562	-0.477	38.199	-0.357	-0.002	0.000
Max rY	76	3 WLTR	0.000	0.000	0.000	0.000	0.031	0.077	-0.005
Min rY	77	3 WLTR	0.000	0.000	0.000	0.000	0.032	-0.077	-0.005
Max rZ	99	5 DL+LL	9.820	-140.283	-1.923	140.640	0.001	-0.000	0.028
Min rZ	98	5 DL+LL	-9.823	-140.281	-1.922	140.638	0.001	0.000	-0.028
Max Rs	94	4 WRTL	-36.247	-0.006	-347.626	349.510	-0.050	-0.040	-0.001

The table below shows a summary of node displacements for each member used in the design.

14. Comparison between pre-engineered buildings and conventional steel buildings

Below is the comparison between pre-engineered steel buildings and conventional steel buildings:

Design

- **Design criteria:** Pre-engineered steel building requires AISC, MBMA, and AWS while conventional steel building requires AISC, AWS, JIS, DIN, and BS.

- **The applicability of design:** Pre-engineered buildings are made for quick and precise construction, saving time and money. In contrast, conventional buildings may not offer the same level of precision, which can lead to longer construction times and higher material use. PEBs provide better design control and efficiency overall.

- **Design of accessories:** Items like windows, doors, ventilation, etc. in pre-engineered steel buildings are standardized and sometimes interchangeable to fit the standard system worldwide. On the contrary, those accessories are designed specifically to fit different conventional steel building structures.

Construction

- **Sourcing:** In pre-engineered buildings, one supplier handles everything-from design and fabrication to construction making the process smooth and simple. In contrast, conventional buildings involve multiple parties for design, material supply, and construction, which can lead to coordination issues and slower progress.

- **Foundation:** Pre-engineered steel buildings need only a simple, lightweight foundation due to their lower overall weight. On the other hand, conventional steel buildings are heavier and require deeper, more complex foundations, which increases construction time, material use, and cost. This makes PEBs more efficient and faster to build.

- **Structural base material:** The steel used in pre-engineered buildings is stronger, with a minimum strength of 50 ksi (345 N/mm^2), compared to 36 ksi (250 N/mm^2) in traditional buildings. This makes PEB steel more durable and reliable.

- **Erection:** Pre-engineered steel building is considered easier, faster, and cheaper to erect while construction of a conventional steel building requires more labor, time, and costs. It is estimated that the cost of conventional steel building erection is around 20% higher than that of pre-engineered steel building construction.

Structure weight: The structure weight of PEB is about 30% lighter since the primary framing parts are shaped as colonial and the highest stress is put on the bottom of the colonial; the secondary framing parts are Z or C-shaped. In contrast, in conventional steel buildings, primary parts are selected from T sections, and secondary parts are selected from I and C sections.

- **Delivery:** It commonly takes 6 to 8 weeks to deliver components from the factory to the construction site in building pre-engineered steel structures, whereas it takes 5 to 6 months to do that in building conventional steel structures.

After construction

- **Changes:** Pre-engineered steel building structure is very flexible, allowing it to be expanded or narrowed down easily. Meanwhile, making changes in conventional steel building structures is difficult due to the extensive design.

- **In use:** All parts of pre-engineered steel buildings are standardized as a system all over the world, so it is simple to predict their conditions and make improvements if required. Meanwhile, components of conventional steel buildings are designed and erected specifically, which means estimating their conditions is uncertain.

- **Seismic resistance:** Pre-engineered steel buildings are highly resistant to seismic force thanks to their flexible and light frames. Meanwhile, the heavy structure of conventional steel buildings makes them less effective in seismic areas.

15. Conclusion

Pre-engineered buildings (PEBs) are a cost-effective and eco-friendly alternative to conventional steel structures. One major advantage is that the steel used in PEBs can be recycled if the structure is dismantled, making them a sustainable construction option. In this study, it was observed that using tapered I-sections for a warehouse reduced the overall steel usage by about 30%, which highlights the material efficiency of PEB systems.

Conventional steel buildings are not ideal for long-span structures due to limitations with clear spans. In contrast, PEBs are well-suited for such applications as they allow for larger spans without the need for interior columns. For instance, this project successfully designed an industrial structure with an 88-meter span using tapered sections. Thanks to modern design software, engineers can now optimize the structure with greater accuracy, making it easier to create customized, lightweight designs for buildings up to 90 meters wide.

While PEBs offer many benefits for large-span, low-rise structures, they may not always be the best choice for smaller buildings due to higher initial costs. The study also shows that the weight of a PEB structure varies with bay spacing. Initially, increasing the spacing reduces the weight, but after a certain point, the weight begins to rise again. In summary, PEBs are a practical solution for large-span structures where open space is a priority, offering flexibility, material savings, and sustainable benefits.

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