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Comparative Analysis of the Geometry of the Pre-Engineered Building (Warehouse)

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Abstract: The rapid development in the industry of global supply chains has resulted from traditional construction methods to high-efficiency Pre-Engineered Building (PEB) systems. This provides a comprehensive comparative analysis of PEB warehouse structures, specifically focusing on the interplay between frame geometry and span configurations. As warehouse requirements evolve from standard storage units to complex logistics hubs, the demand for varied span lengths ranging from economical short-spans to expansive, column-free long-spans—has introduced significant engineering challenges regarding material optimization and structural stability.

The study looked at clear-span warehouses with a maximum long clear span of 50m. We compared them by adding a column at the middle to make a short span frame. We see how well these Pre-Engineered Building structures work when they must handle kinds of loads. We pay attention to how strong they are compared to how much their weight is and how much their cost is. We also look at the things about having short or long spans in Pre-Engineered Buildings.

Key findings highlight that while long-span structures (50 meters) significantly enhance logistical throughput and accommodate automated storage systems, they require specialized geometric adjustments to manage exponential increases in bending moments and lateral deflection. Conversely, short-span systems offer superior material efficiency but limit internal adaptability. By consolidating recent advancements in structural modelling and optimization algorithms, this review serves as a strategic roadmap for engineers and architects in selecting the most viable PEB geometry to balance structural performance with functional warehouse requirements.

Keywords: Pre-Engineered Building, Warehouse Geometry, Short and Long Span Structure, Steel Structure.

I. INTRODUCTION

A. The Rise of Pre-Engineered Buildings (PEB) in India

Since it came to the Indian market in the late 1990s, Pre-Engineered Building (PEB) technology has moved from being a special idea to a common standard in construction. Today, it is widely used in major national projects and large developments. The reason for its growing popularity is that it offers modern, high-tech, and faster ways to build. When compared to traditional methods, PEB gives a better mix of cost savings and quicker project completion. The PEB method uses a specific set of materials that are both standardized and adaptable, allowing it to meet various design and structural needs. Structural Components typical pre-engineered steel structure is composed of three primary integrated systems:

1) Primary Framing: Heavy-duty, built-up "I" beams used for the main columns and rafters.
2) Secondary Members: Cold-formed steel shapes, specifically "Z" and "C” & hollow section sections, which serve as roof purlins, eave struts, and wall girts.
3) Building Envelope: Roll-formed profiled sheeting used for durable roof and wall cladding.

Figure 1: Built-Up “I” Shaped Primary Structural Framing Members

Figure 2: Cold-Formed “Z” And “C” Structural Members.

Figure 3: Roll Formed Profiled Shaped Secondary Structural Members. Sheeting.

B. Architectural Composition of PEBs

Pre-engineered steel buildings use a mix of different steel parts, like hot-rolled sections, built-up parts, and cold-formed steel. The outside layer is usually made from either single-layer metal sheets with insulation or high-performance insulated panels. The main aim of this design is to create a building shell that reduces heat loss, cuts down on material waste and weight, and is specially designed to fit the client's specific needs Versatility and Customization.

One of the system's greatest strengths is its adaptability. Structures can be enhanced with various functional and aesthetic additions, such as:

1) Internal Features: Mezzanine flooring, interior partitions, and specialized accessories.
2) External Enhancements: Canopies and decorative trimmings.
3) Weatherproofing: The use of specialized filler strips, mastic beads, and precision flashings ensures the structure remains entirely watertight.

Because the interior can be configured for any use and the exterior can be styled for high visual appeal, PEBs offer a sophisticated alternative to traditional masonry or concrete construction

C. Strategic Advantages of Pre-Engineered Buildings

1) Accelerated Project Delivery

Among the most notable advantages is the massive savings in construction time. Since the process of laying the foundation and casting anchor bolts takes place concurrently with the manufacturing process at the plant, the building becomes ready for erection almost immediately after getting its plans approved. In India, this could reduce construction time by half.

2) Economic Efficiency

Integration of the "systems approach" ensures low costs during design, production, and assembly. Low costs are achieved by making logistics efficient since secondary parts and claddings can fit together, reducing transportation costs.

3) Scalability and Expansion

PEBs provide unlimited flexibility due to their modularity. The owner is able to add extra bays to increase the overall length of the building. If enough foresight is used when designing the original building, expansion can also take place laterally or vertically.

4) Impressive Clear Spans

These structures support vast open internal spaces, with the capability to reach clear spans of approximately 80 meters. This eliminates the need for restrictive interior columns, maximizing usable floor area.

5) Superior Thermal Performance

Efficiency in energy consumption is inherent in the design. Buildings can be equipped with improved insulation materials, including fiberglass batting and PUF sheets, to fulfill specified standards for heat transfer and minimize heating and cooling expenses.

6) Architectural and Aesthetic Freedom

Functionality is not compromised by design elements. A variety of architectural features may be included in PEBs, such as:

a) Decorative fascias and curved eaves.
b) Functional canopies.
c) Integration with traditional materials like masonry, pre-cast concrete panels, or glass curtain walls.

7) Streamlined Procurement (Single-Source Responsibility)

PEB projects are easy to manage, since everything is supplied by one manufacturer. That way, you don't have any problems with compatibility, since all elements, from the largest beam to the tiniest accessory, are compatible with each other.

II. LITERATURE REVIEW

1) The paper, "Comparative Analysis of PEB Structure with Varying Bay Spacing." A systematic evaluation was performed for nine different designs using STAAD-PRO software. The experiment used a standardized building floor plan having a span of 30 meters and overall dimensions of 96 meters long while altering two main geometric parameters, namely bay spacing (set at 5m, 6m, and 7m) and ridge angles (slopes of 1 in 10, 1 in 15, and 1 in 20). Loading factors on environmental forces were specified for Bangalore based on the Indian code IS: 875 (Part-3): 2015 with a base velocity of 33 m/s. As for the boundary condition, all columns used pin joints for assessing their structural behavior within this scenario. The authors' conclusions suggest that pre-engineered buildings are a cheaper and faster solution than traditional steel buildings since they save on steel by reducing sections depending on bending moments. Structural efficiency is highly dependent on the selected bay spacing and ridge angle, where the best outcomes are observed at bay spacing of 5m and 6m with a ridge slope of 1 in 10.

2) "Seismic analysis of industrial structures using Bracings and Dampers" is another research paper where an attempt was made by researchers to examine the efficiency of Lateral Load Resisting Systems (LLRS) in stabilizing Pre-Engineered Buildings (PEB) which are present in high seismic zones in India. With the use of computer software like SAP2000 and ETABS, seven different models were analyzed using these systems and the results suggest that even though all systems provide improvement in lateral stability, X-bracing system appears to be more efficient and economical as compared to others as it offers maximum reduction in base shear force and maximum lateral displacement. It was also noticed that with the use of these systems for improving stiffness of structures, the natural period of the structure reduces drastically; however, it was further noticed by the authors that bracing systems have been more convenient than dampers since they require less maintenance and better control lateral displacement of storey.

3) The research paper "Structural Performance of Pre-Engineered Building: A Comparative Study" aims at the efficiency of Pre-Engineered Buildings (PEB) through their structural performances a various environmental condition. In the study, using the STAAD.Pro program, the researchers conducted their analysis on an industrial warehouse of a multi-bay building located in two parts of India viz., Vijayawada and Hyderabad having different wind zones and seismic activities. Structural performance was determined from the bending moments and shear force values. Thus, it was established that materials were dependent on environmental conditions, which resulted in the use of 11.04% additional weight in steel for Vijayawada building in comparison to the building in Hyderabad owing to high basic wind speed and intensity. From the findings, it is concluded that even though PEBs have efficient designs and fast installation compared to other steel buildings, structural weight is very much dependent on environmental conditions.

4) The Research paper, "Study, Design and Analysis of Pre-Engineered Building with Different Parameters Using Staad.Pro Software." Conventional Steel Buildings (CSB) make use of normal hot-rolled sections. These have been known to be very wasteful in terms of material use and cost. In contrast, the method used in constructing PEB is such that tapered sections are used which precisely fit the bending moment demand, minimizing wastage. There are numerous references in literature that point out the benefits of this transition. According to Hemant Sharma, a maximum of 37% material savings is achieved in PEB relative to CSB. Further, it has been demonstrated that prefabricated PEB buildings are flexible, adaptable and better in terms of quality due to their customized nature and fabrication in plants. Moreover, the use of advanced software such as STAAD Pro has enabled a completely new way of designing by making finite element analysis and verification against lateral loads possible.

5) The research paper, "Structural Analysis of (PEB) Pre-Engineered Building Using Different Types of Bracing on Lateral Load." In this research work, a comparative analysis is performed to study the performance characteristics of Pre-Engineered Buildings (PEB) versus Conventional Steel Buildings (CSB), emphasizing the influence of various types of bracing systems subjected to both wind and seismic loads. This is done by analyzing the response of twenty-four models in four zones and with variations in wind velocity in India using the software program STAAD-Pro. These include six types of bracing systems such as

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V-bracing system, Inverted V-bracing system, diagonal bracing system, K-bracing system, X-bracing system, and tie-runners bracing system. The authors concluded that PEB building constructions are more sustainable and economical in comparison with CSB constructions, where the reduction in the steel consumption was up to 50%, and the cost was reduced by about 35%. The Inverted V-bracing system was found to be the most economical and efficient out of all bracing types considered.

III. OBJECTIVES

1) Structural Understanding of the PEB structure.
2) Develop a complete 3D structural model in STAAD.Pro
3) Determine and apply all relevant loads (Dead, Live, Collateral load (solar) load, Wind, and Seismic load).
4) Analyze the structure under three different geometries with 3 different sections in each geometry.
5) Compilation of structural performance, material consumption (steel weight), and cost for each geometry.

IV. METHODOLOGY

1) Pre-Design Data Collection and Study

Establishes the basis for modelling and loading:

Making an industrial warehouse with a height of 10m and a size of 50m wide and 100m long.

Structure Configuration Specification

Location	: Nagpur, India.
Length	: 96 m
Width	: 50 m
Eave height	: 8.75m (clear)
Apex level	: 10m
Seismic zone	: II
Wind speed	: 44 m/sec
Wind terrain category: 2	
Slope of roof	: 1:20

2) Model Details

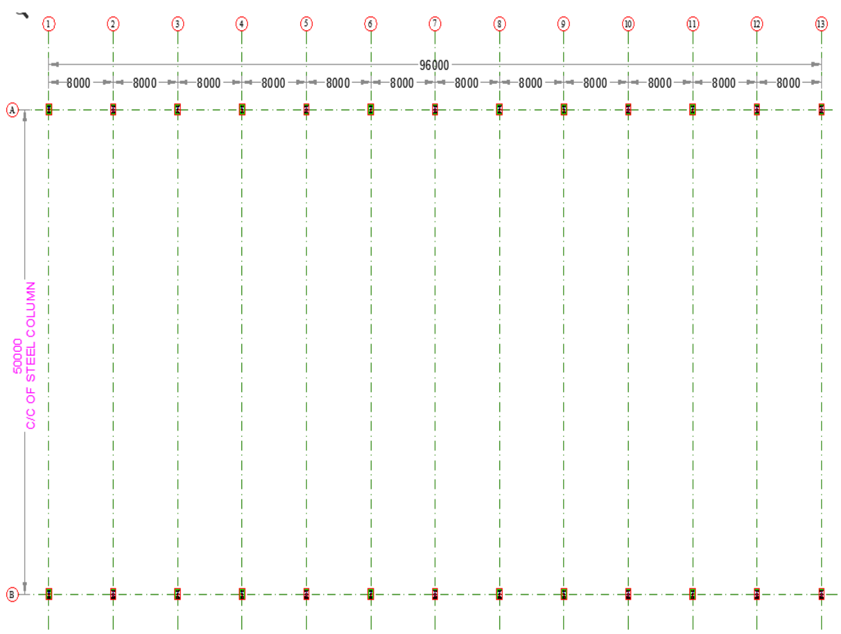

Figure 4: Geometry "A"

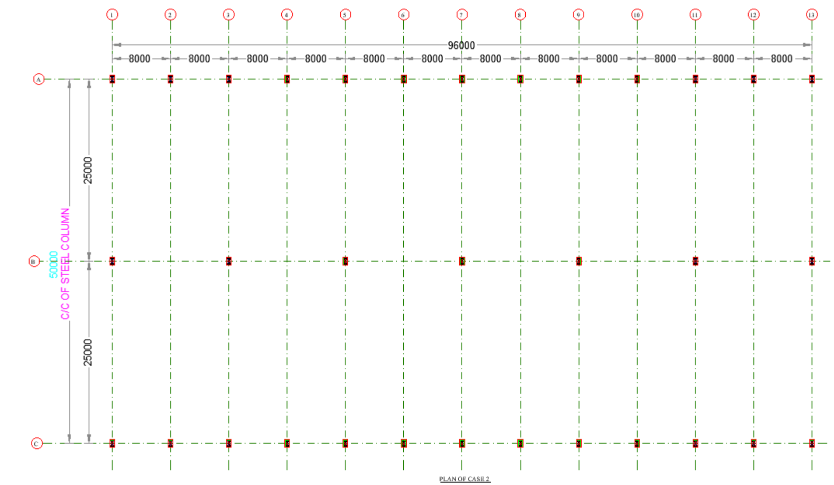

Figure 4: Geometry “B”

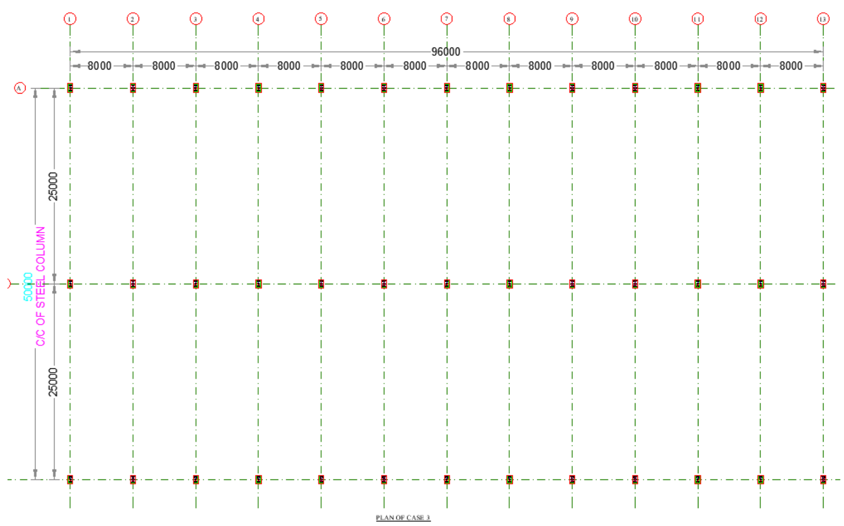

Figure 5: Geometry C

Project Models			
Sr. No.	Geometry Code	Model No.	Section Used
1	A	A1	I Section
		A2	Tapered I Section
		A3	Hollow Section
2	B	B1	I Section
		B2	Tapered I Section
		B3	Hollow Section
3	C	C1	I Section
		C2	Tapered I Section
		C3	Hollow Section

Table I: Model Chart

3) STAAD Pro Modelling and Sectioning:

The PEB structure will be created as a 3D space frame model in STAAD Pro the steps are as follows:

a) Geometry Creation: Model the primary members (columns and rafters) and secondary members (purlins, girts, and bracing).

b) Support Conditions: Assign appropriate support conditions, typically pinned or fixed at the column bases, based on the design requirement.

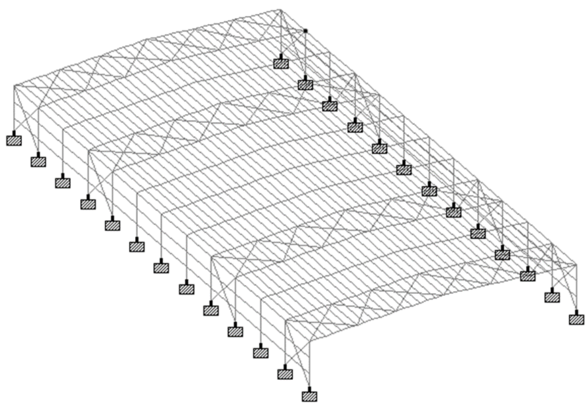

Figure 6: STAAD.Pro model Geometry "A"

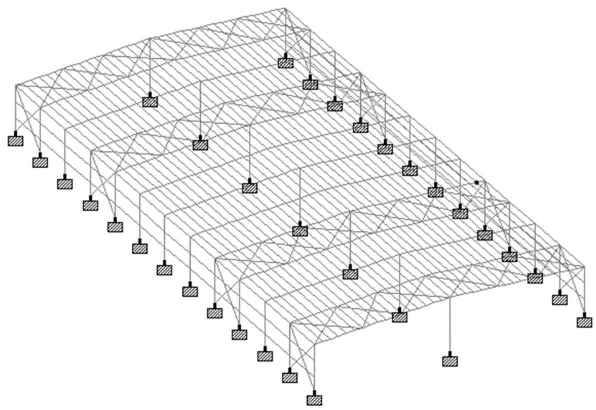

Figure 7: STAAD.Pro model Geometry "B"

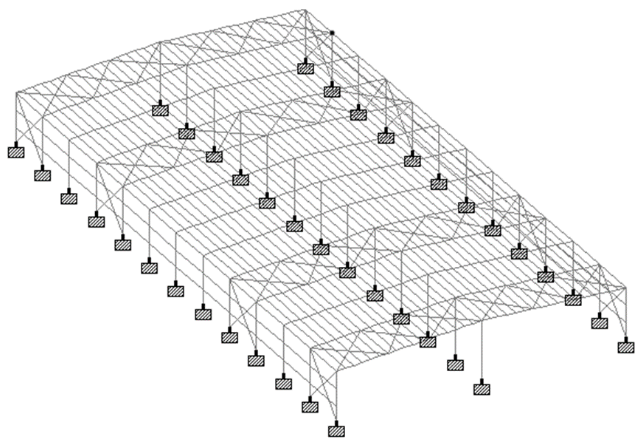

Figure 8: STAAD.Pro model Geometry C

c) Custom Section Generation: Since PEBs use tapered sections, define the geometry for built-up I-sections, and use Hollow Section for another model.

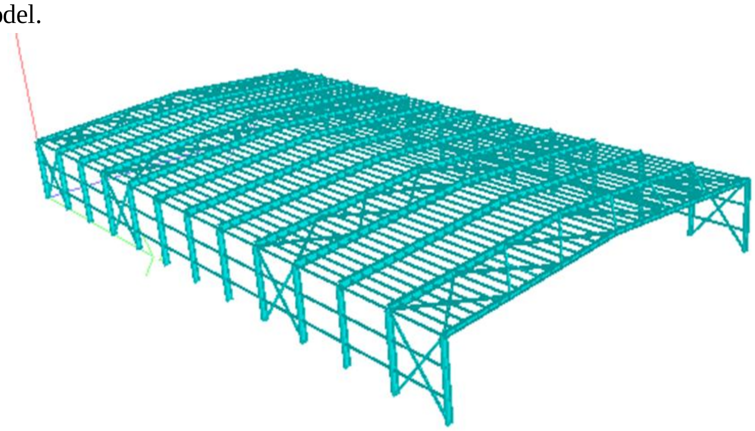

Figure 9: Rendered View of Warehouse Model

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4) Load Calculation and Application

Loads will be calculated based on the building's location and geometry, and then applied to the model.

a) Seismic Load: Employ the Response Spectrum Analysis Technique (dynamic analysis) using IS 1893 (Part 1) to calculate the seismic base shear and forces, considering this for both major directions (X). The seismic load needs to be determined first before any additional loads can be considered.

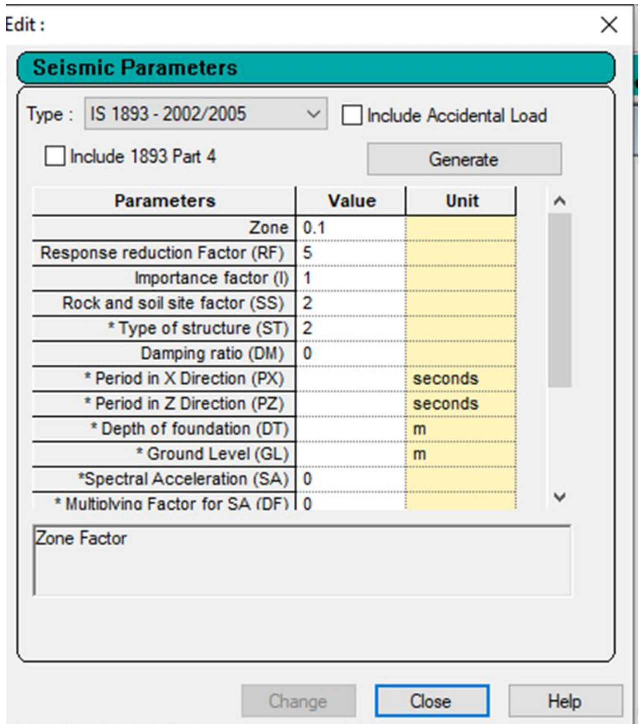

Figure 10: Seismic Parameter

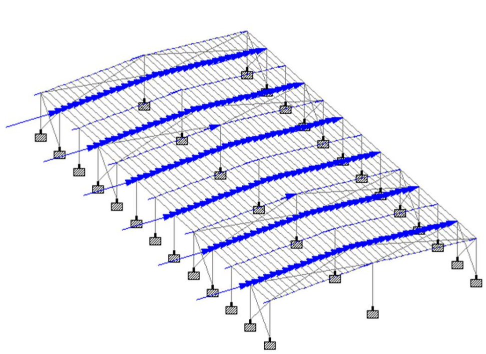

Figure 11: Seismic load from +X Direction

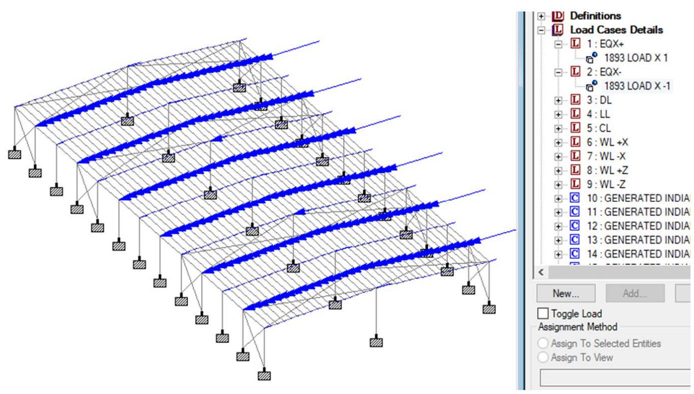

Figure12: Seismic load from -X Direction

b) Dead Load

The Dead Load consists of the weight of all the structural and artificial material weight. Weight of structural member can be applied by adding self-weight. And weight of sheet and other accessories to be applied uniform distributed load on purlins.

Dead Load = 0.105 KN/m^2

(Wt. of sheet 4.78 Kg/m2, other accessories 5.75kg/m2)

Dead Load on Purlin = 0.105 X 1.5

= 0.158 KN/m

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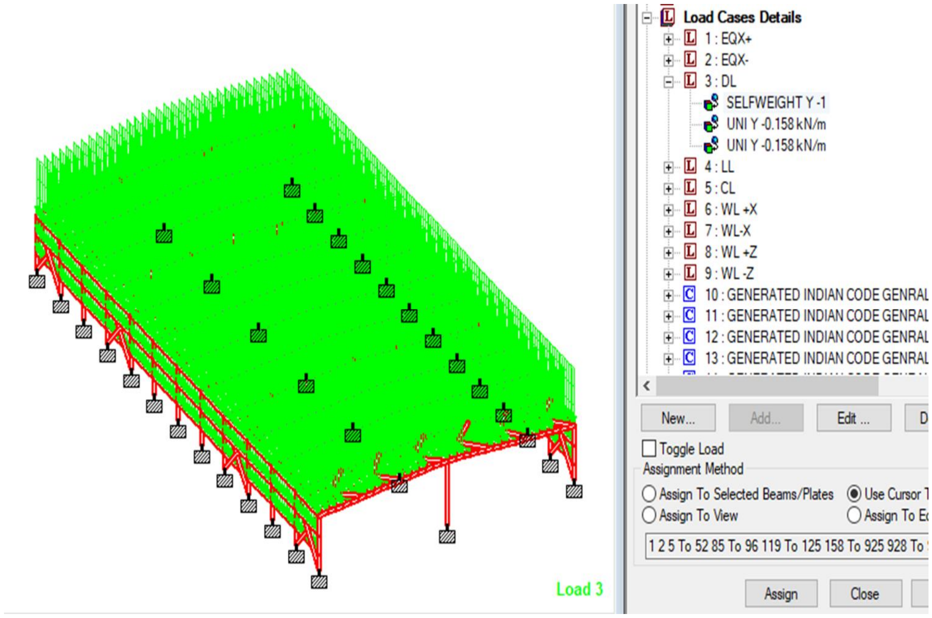

Figure 13: Dead Load

c) Live Loads

As this is a warehouse that means the roof is comes in non-accessible area and so that apply the specified occupancy loads (Live Load) as per IS 875 (Parts 1 & 2).

Live Load = 0.75 KN/m^2 (for Non accessible area/roof)

Live Load on Purlin = 0.75 X 1.5

= 1.125 KN/m

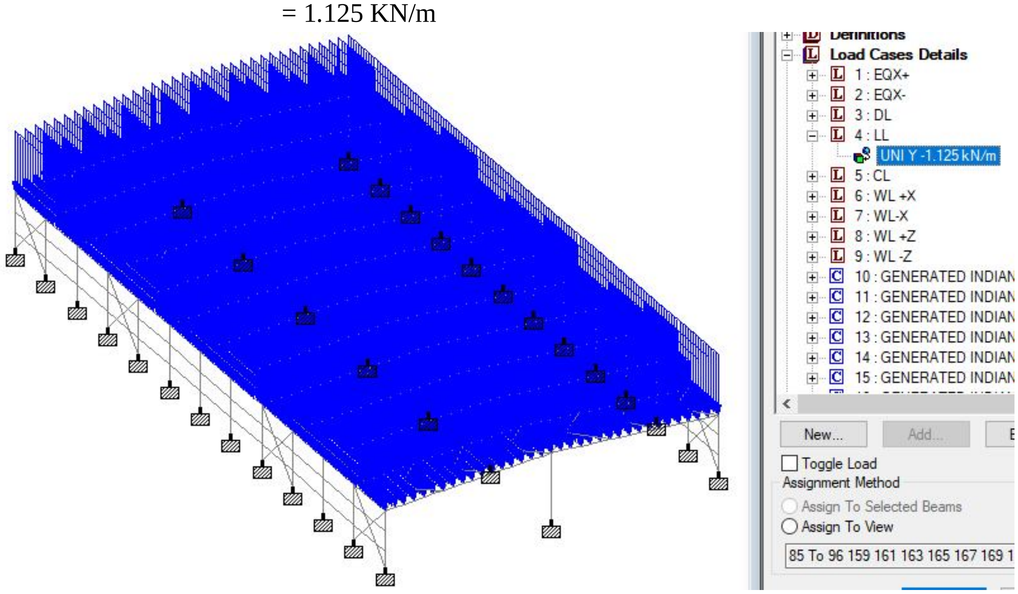

Figure14: Live Load

5) Collateral Load

Collateral Load is the load of extra optional item like solar Panels.

Collateral Load = 0.25 KN/m^2 (Solar)

Collateral Load on Purlin = 0.25 X 1.5 X1

= 0.375 KN/m

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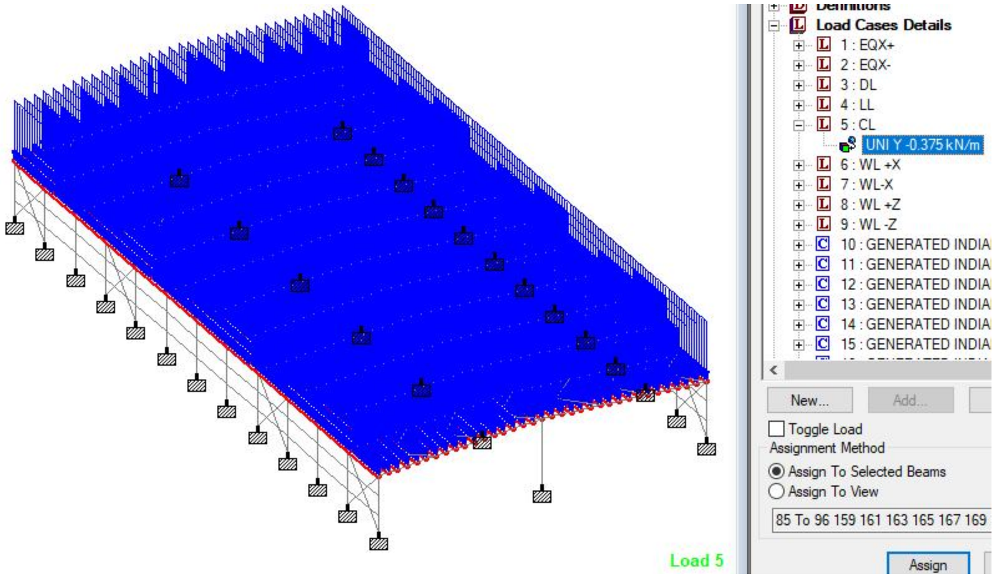

Figure 15: Collateral Load

6) Wind Load

It is very important to add the wind load from all the direction. We need only location and some basic data of the locality through which we can add it through staad.pro software.

According to the IS 875 (Part 3) - 2015 code, the basic wind speed for Nagpur City at a height of 10 meters above ground level is 44 m/s.

Vz= Vb*K1*K2*K3*K4

Where: Vb= Basic wind speed (44 m/s)

K1= Risk coefficient (probability factor) - depends on the desired design life and importance of the structure (IS 875, Table 1)

K2= Terrain roughness and height factor - depends on the ground roughness category (IS 875, Table 2).

K3= Topography factor (IS 875, Clause 6.3.3)

K4= Importance factor for cyclonic regions (IS 875, Clause 6.3.4).

Vz=Vb*K1*K2*K3*K4   =44 x 1.0 x 1.0 x 1.0 x 1.0

Vz=44 m/s

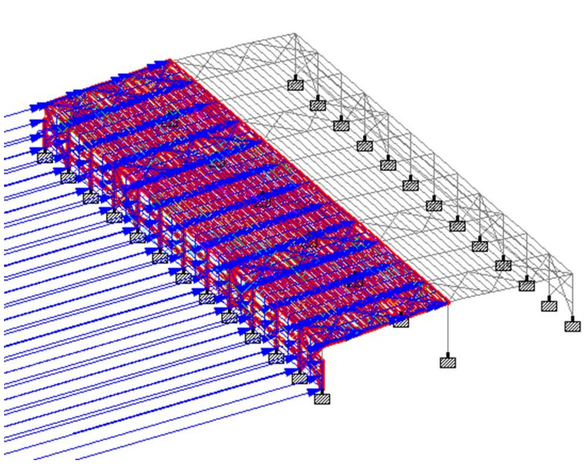

Figure 16: Wind Load (+X Direction)

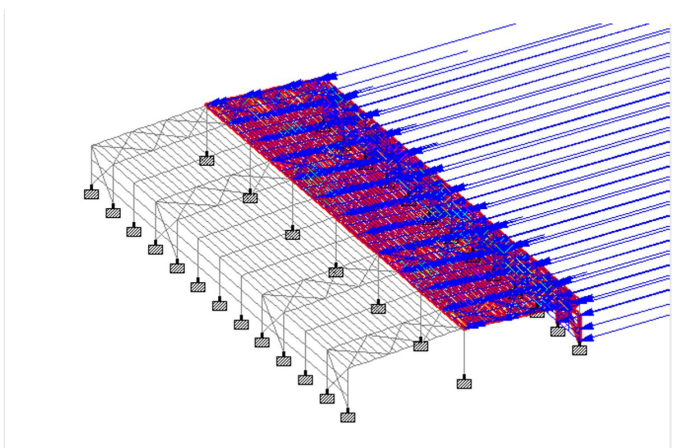

Figure 17: Wind Load (-X Direction)

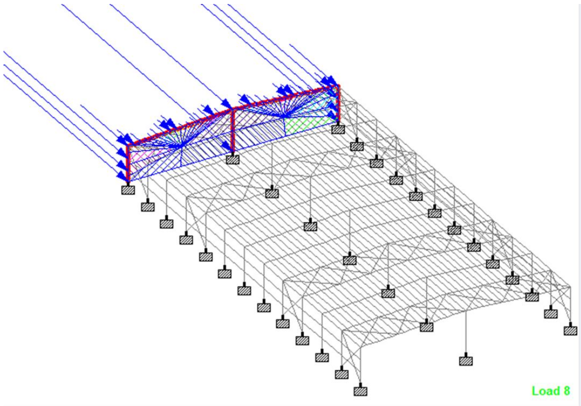

Figure 18: Wind Load (+Z Direction)

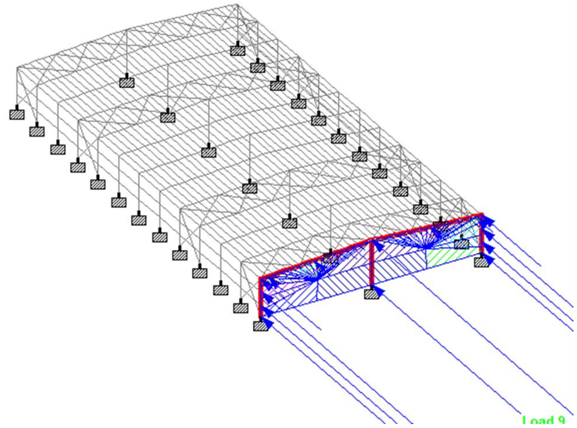

Figure 19: Wind Load (-Z Direction)

7) Load Combination

Create mandatory and critical load combinations for design checks as per IS codes.

SR.NO.	LOAD COMBINATION	SR.NO.	LOAD COMBINATION
1	1.5DL+1.5LL	16	1.5DL+1.5WLZ
2	1.2DL+1.2LL+1.2WLX	17	1.5DL+1.5WL-Z
3	1.2DL+1.2LL+1.2WL-X	18	1.5DL-1.5WLX
4	1.2DL+1.2LL+1.2WLZ	19	1.5DL-1.5WL-X
5	1.2DL+1.2LL+1.2WL-Z	20	1.5DL-1.5WLZ
6	1.2DL+1.2LL-1.2WLX	21	1.5DL-1.5WL-Z
7	1.2DL+1.2LL-1.2WL-X	22	1.5DL+1.5EQX
8	1.2DL+1.2LL-1.2WLZ	23	1.5DL+1.5EQ-X
9	1.2DL+1.2LL-1.2WL-Z	24	1.5DL-1.5EQX
10	1.2DL+1.2LL+1.2EQX	25	1.5DL-1.5EQ-X
11	1.2DL+1.2LL+1.2EQ-X	26	0.9DL+1.5EQX
12	1.2DL+1.2LL-1.2EQX	27	0.9DL+1.5EQ-X
13	1.2DL+1.2LL-1.2EQ-X	28	0.9DL+1.5EQX
14	1.5DL+1.5WLX	29	0.9DL+1.5EQ-X
15	1.5DL+1.5WL-X		

Table III: Load Combination

8) Structural Analysis and Design Checks

Run the analysis using STAAD Pro software for obtaining results for all the load combinations considered. Examine the lateral and vertical displacement (sway and drift) in the members with respect to the allowable values in IS 800 and IS 875. Ensure that the axial loads, shear loads, and bending moments in all the main and minor members are suitably resisted by the provided sections. Especially examine the column and rafter sections for resisting buckling.

V. ASSIGNED PROPERTIES

The Properties shown in table no. IV – XII are applied on the model. The properties are assigned as per the bending moment as in all frame it is different as per that properties are assigned to make the structure economical. The properties are shown below:

MODEL A1 (No Column at Middle)						
SR. NO.	MEMBER	MEMBER LOCATION	I- SECTION PROPERTIES			
			Depth of Web (mm)	Thk. of Web (mm)	Flange Width (mm)	Flange Thk. (mm)
1	Column	Corner	1000	12	300	12
2		side Inner	1000	12	350	16
3	Rafter	Inner & corner	1000	16	350	12
4		2nd Rafter From Both Side	1000	16	350	16
5		5th grid	1000	16	400	16

Table IV: A1 Model Properties

MODEL A2 (No Column at Middle)						
SR. NO.	MEMBER	MEMBER LOCATION	TAPERED I- SECTION PROPERTIES			
			Depth of Web (mm)	Thk. of Web (mm)	Flange Width (mm)	Flange Thk. (mm)
1	Column	All	750-1000	16	350	16
2	Rafter	All	620-1000	12	350	12

Table V: A2 Model Properties

MODEL A3 (No Column at Middle)					
SR. NO.	MEMBER	MEMBER LOCATION	Square / Rectangle Hollow SECTION PROPERTIES		
			Depth (mm)	width (mm)	thickness (mm)
1	Column	ALL	800	800	16
2	Rafter	Edge	1100	350	12
3		Inner	900	350	12

Table VI: A3 Model Properties

MODEL B1 (Alternate Column at Middle)						
SR. NO.	MEMBER	MEMBER LOCATON	I- SECTION PROPERTIES			
			Depth of Web (mm)	Thk. of Web (mm)	Flange Width (mm)	Flange Thk. (mm)
1	Column	side column where 25m span & middle column & Corner	450	12	300	12
2		side column where 50m span	800	12	300	12
3		Side Column	500	10	300	12
4	Rafter	Edge Rafter	600	12	300	12
5		25m Rafter	550	12	350	12
6		50m Rafter	800	12	350	12

Table VII: B1 Model Properties

MODEL B2 (Alternate Column at Middle)						
SR. NO.	MEMBER	MEMBER LOCATON	TAPERED I- SECTION PROPERTIES			
			Depth of Web (mm)	Thk. of Web (mm)	Flange Width (mm)	Flange Thk. (mm)
1	Column	Middle Column	250-300	10	300	10
2		25m Clear span Col.	250-350	10	300	10
3		50m Clear span Col.	400-550	10	300	10
4	Rafter	25m Clear span Col.	550-450	10	250	12
5		50m Clear span Col.	900-500	10	250	12

Table VIII: B2 Model Properties

MODEL B3 (Alternate Column at Middle)					
SR. NO.	MEMBER	MEMBER LOCATION	Square / Rectangle Hollow SECTION PROPERTIES		
			Depth (mm)	width (mm)	thickness (mm)
1	Column	Corner and column Where 25m span and middle	300	300	12
2		Side column Where 50m span	450	450	12
3	Rafter	Edge	400	300	9
4		Inner rafter where 50m Span	600	300	12
5		Inner rafter where 25m Span	400	300	16

Table IX: B3 Model Properties

MODEL C1 (Column at Middle)						
SR. NO.	MEMBER	MEMBER LOCATION	I- SECTION PROPERTIES			
			Depth of Web (mm)	Thk. of Web (mm)	Flange Width (mm)	Flange Thk. (mm)
1	Column	Corner	300	10	250	10
2		Inner & Outer Column	450	12	300	12
3		Side Column	350	10	300	10
4	Rafter	all	500	12	350	12

Table X: C1 Model Properties

MODEL C2 (Column at Middle)						
SR. NO.	MEMBER	MEMBER LOCATION	TAPERED I- SECTION PROPERTIES			
			Depth of Web (mm)	Thk. of Web (mm)	Flange Width (mm)	Flange Thk. (mm)
1	Column	Inner	250-400	10	300	10
2		Outer	250-500	12	300	12
3	Rafter	All	370-500	12	300	12

Table XI: C2 Model Properties

MODEL C3(Column at Middle)					
SR. NO.	MEMBER	MEMBER LOCATION	Square / Rectangle Hollow SECTION PROPERTIES		
			Depth (mm)	width (mm)	thickness (mm)
1	Column	All	400	400	9
2	Rafter	Edge	450	300	9
3		Inner rafter	450	350	12

Table XII: C3 Model Properties

VI. RESULT

A. *Bending Moment Diagram*

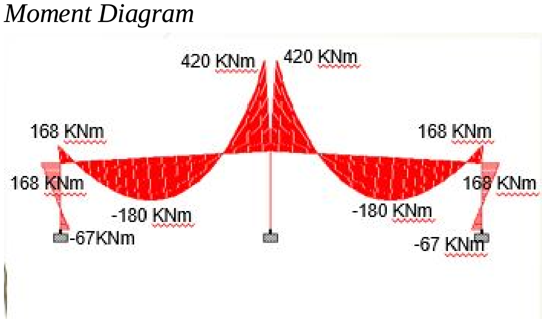

Figure 20: BMD in 25m Span

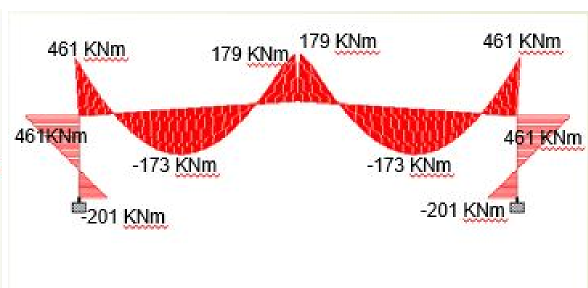

Figure 21: BMD in 50m Span

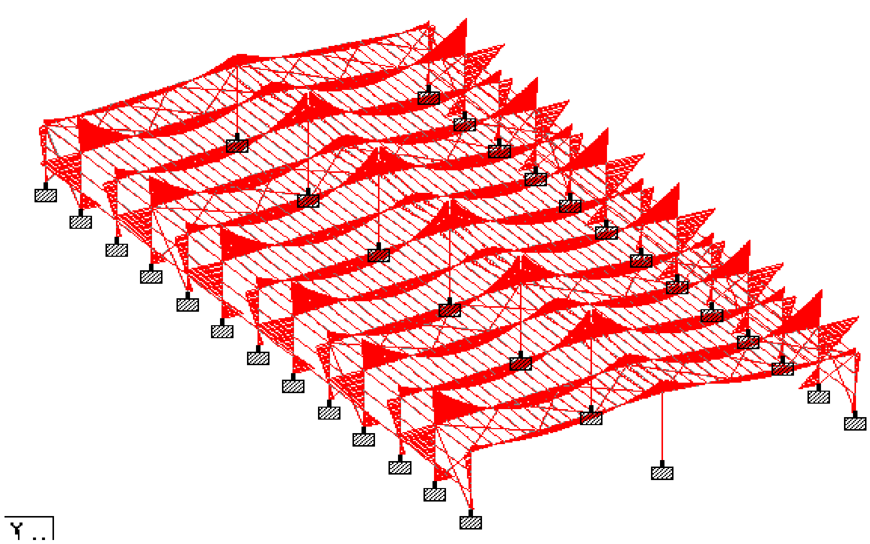

Figure 22: Bending Moment Diagram of whole section

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B. Shear Forces

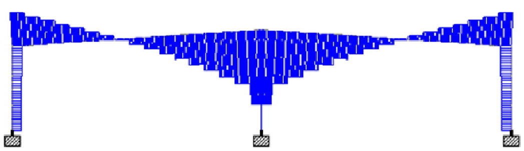

Figure 23: SFD in 25m Span

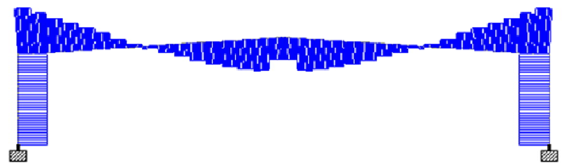

Figure 24: SFD in 25m Span

C. Deflection

As per the IS: 800-2007, Clause 5.6.1, Table No. 6 (deflection Limit), this clause provide the permissible deflection for the building/ structure. Our model is below the permissible value. Below is the some typical diagram of deflection Shown in fig. 25- 27.

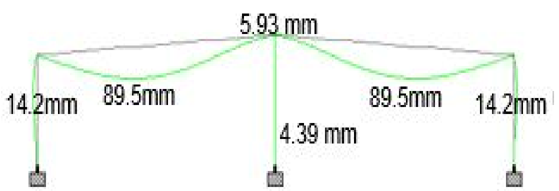

Figure 25: Deflection in 25m Span

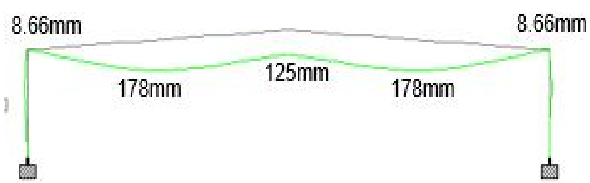

Figure 26: Deflection in 50m Span

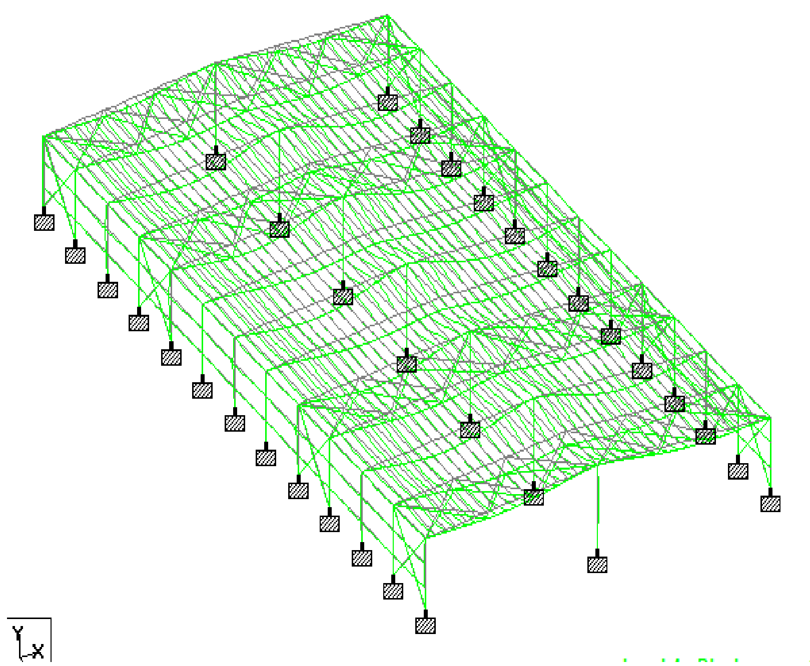

Figure 27: Deflection Diagram

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D. Steel Quantity

Model	Steel Take off (KN)
A1	2650
A2	2341
A3	3167
B1	2207
B2	2102
B3	2473
C1	2047
C2	2010
C3	2272

Table XIII: Steel Quantities

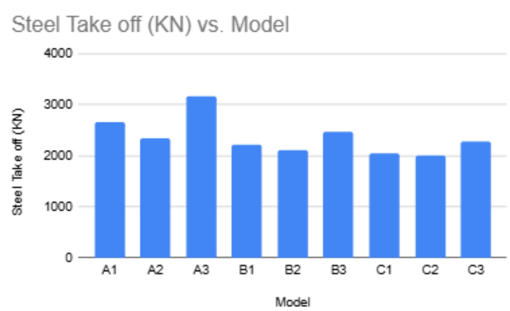

Figure 28: graph of Steel Quantities

E. Base Shear

Model	base shear (KN)
A1	66.25
A2	58.525
A3	79.175
B1	55.175
B2	52.55
B3	61.825
C1	51.175
C2	50.25
C3	56.8

Table IX: Base Shear

F. Costing

We had consider the average cost of the steel is 67 Rs/Kg for the costing. Steel rate is dynamic it varies day to day.

Model	Steel Take off (KN)	Steel Used in Kg	Cost
A1	2650	270220.5	₹18,104,774
A2	2341	238711.77	₹15,993,689
A3	3167	322938.99	₹21,636,912
B1	2207	225047.79	₹15,078,202
B2	2102	214340.94	₹14,360,843
B3	2473	252171.81	₹16,895,511
C1	2047	208732.59	₹13,985,084
C2	2010	204959.7	₹13,732,300
C3	2272	231675.84	₹15,522,281

Table XV: Steel Costing

VII. CONCLUSION

1) While Comparing I Section and Tapered I Section, it is clear that Tapered (A2 Model – Long span) section is 11.66% lighter than Continuous I section (A1 Model-Long span). Tapered (B2 Model – Alternate column) is 4.76% lighter than Continuous I section (B1). Tapered (C2) is 1.81% lighter than Continuous I section (C1).
2) While Comparing I section and Hollow Section for each Geometry type separately, it is clear that Hollow section (A3) needs 19.51% more steel compared to Standard (A1). Hollow (B3) needs 12.05% more steel than Standard (B1). Hollow (C3) needs 10.99% more steel than Standard (C1).
3) The Tapered I-Section (Model C2) is the best optimized model in this dataset with a total value of 2010 KN. Also, the Hollow Section (Model A3) is the most inefficient section in terms of weight with a value of 3167 KN.
4) In I section, C1 all columns at mid-model is the most rigid section for controlling the vertical and resultant deflections.
5) Although B2 offers a good solution for controlling the vertical deflection, A2 is the most resistive section to horizontal displacements.
6) Tapered I-section models (A2, B2, and C2) were always more economical with materials than regular I-section models and hollow models across all geometries (A, B, and C). Model C2 is the most economical design, and its cost is estimated to be ₹13,732,300.
7) Transitioning from the least economical model (A3) to the most economical model (C2) leads to savings of approximately 36.5% on the overall cost of the project.
8) The 50m geometry frame span has greater bending loads at the knee and apex nodes than that of the 25m geometry frame span. Consequently, the section needs to be very deep, and high-strength steel must be used.
9) Shearing loads at the support reactions and joint connections between the rafters and columns of the 50m span are double the loads of the 25m span frame structure.

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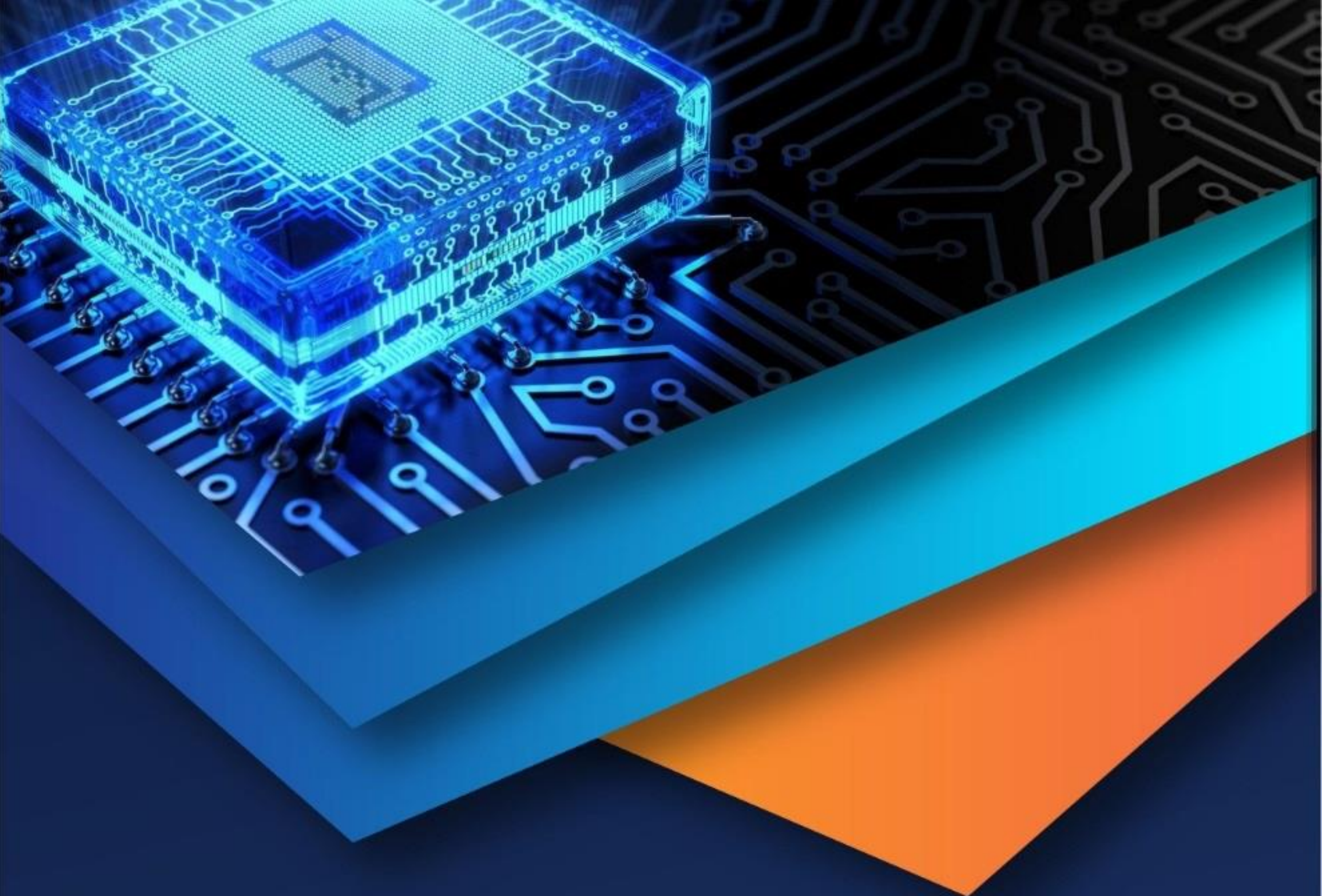

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