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Original Article

Alternate Design forms for an Industrial Structure

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Abstract *- The development of fresh options for industrial structures is improved structural design. Based on their span, height, spacing, and potential alternate roofing systems, the structure has been reduced in cost in this research. This work offers various structural plans for long-span light-roof industrial structures. The traditional Pratt truss, pre-engineered building truss and lattice truss are the alternatives that are being investigated. They have been evaluated, and created following IS 800-2007. An industrial building with a plan dimension of 24 m x 50 m, an eave height of 12 m, and practically viable roof slopes is considered for analysis and design in this study. An industrial building with the best alternative roofing system is proposed for its tonnage by retaining the same height and breadth of the frame for all alternative designs.*

Keywords *- Alternate design form, Industrial building, Lattice truss, Pratt truss, Pre-engineered building.*

1. Introduction

Industrial buildings are made to serve a specific purpose in the production of raw materials and raw equipment. A truss is a structural unit comprised of straight bars that can be bent into triangles or other stable and stiff shapes. It is composed of structural members, joints, angles and polygons. It serves as a means of transferring pressure or weight to the weight-bearing structures on each side of the opening. There are numerous different forms of steel trusses, which are frequently used for big roofs and bridges. Trusses are classified into two types: planar truss and space truss. Members and nodes in planar trusses are in the 2D plane. They are also known as simple trusses. Members and nodes in the 3D plane are known as space trusses. There are a few different types of steel trusses that are more prevalent than others, while any truss may be built of steel to increase its load-carrying capacity, and many do so frequently.

Trusses are utilised in many structures, primarily when long spans are necessary, such as in airport terminals, aircraft hangars, the roofs of sports stadiums, auditoriums, and other leisure facilities. Trusses can also be utilised as transfer structures to support enormous loads. It enables engineers to construct expansive open areas with less material. Using fewer materials also enables builders to develop projects at a lower cost. Pipes and wires can readily run through the ceiling because of spaces in trusses. Although they have a specific design, engineers can use various trusses. Typically, the end sections are fastened with bolts or welded to a common plate known as a gusset plate to provide the joint connections. Since it is considered that all external loads acting on a truss only act at the joints, all of the truss members are two-force members. The individual members are solely susceptible to axial forces, which can be either compression or tension, rather than bending moments and shear forces. It enables them to maintain creativity and incorporate architectural features like vaulted ceilings. The secret to a truss's effectiveness for large spans is that the forces on each member are axial. No material is lost when a member is axially loaded since the force is distributed evenly over the entire member. Truss members can be lighter as a result while still having larger load capacities and more effectively utilised cross-sections.

Trusses are used in structures because they enable architects and engineers to design huge, open areas out of less material. Using fewer materials also enables builders to develop projects at a lower cost. It enables them to maintain creativity and incorporate architectural features like vaulted ceilings.

The fundamental benefit of trusses is that they may be used successfully without the need for expensive heavy machinery or extensive setup. They are also simple and quick to install. Typically, trusses are constructed at a factory before being shipped as a complete set to a construction site, where the structure is then constructed. Trusses are frequently leant against the top of the wall, slid into position, turned upright, and then fastened into place.

There are different types of trusses used in the industry.

1.1. Conventional truss system

The truss consists of a post, rafter, and struts along a column. Each element is linked to a node. It is common to assume that these connections are nominally pinned. The diagonal members are tensed, whereas the vertical members are compressed. Because less steel can be used in the diagonal members (in tension), the design becomes more effective and simpler. In the late nineteenth and early twentieth century, numerous modifications and adaptations of the Pratt truss were developed. It is a straightforward and effective design that is inexpensive to build and simple to manufacture. The type of truss used for these structures is the pitched Pratt truss, as shown in fig1.1.Various roofing systems are used depending on the angle or pitch of the truss. The state of conventional steel structure is unique, working with a specific cross-section depending on the requirements, and modifications are always possible to a certain extent.

1.2. Lattice truss system

These are openwork frameworks consisting of a criss-cross pattern of strips. These are fabricated truss systems with parallel top and bottom chord members mainly resisting axial forces, either compression or tension. The web members are resisting mainly the shear forces. These types are generally suitable for slightly loaded large span structural members.

1.3. PEB truss system

It is a new concept replacing traditional manufacturing. It is constructed with all of the design completed in a factory, and the building materials are delivered to the construction site already assembled.

The construction of these structures involves tapered sections for primary framing of the structure and cold framed sections, such as the Z shape, that are used according to the inner requirements of the stresses to secondary framing members, resulting in less steel waste and a lighter foundation. These are the most rigidly joined structure frames made from hot rolled and cold formed areas, with purlins and sheeting rails supporting the rooftops and side cladding. In the case of PEB, the rooftop slope is chosen between 5 and 12 degrees concerning the practical application.

2. Objectives and methodology

2.1. Objectives

The study's objective is to improve and enhance the design of an industrial steel structure. And to propose and justify the most feasible structure using conventional, lattice, and pre-engineered building truss. The study's main objectives are listed below.

1. To study and understand conventional pitched pratt truss, Pre-engineered building truss and Lattice truss
2. To manually calculate dead, live, and wind load under Indian standards.
3. In STAAD Pro, create a 3D model of an industrial structure with the same dimensions for a conventional pratt frame, a pre-engineered building frame, and a lattice girder frame.
4. To assign the manually calculated loads on the models prepared.
5. To compare conventional PEB and lattice frames based on the steel quantity obtained from steel take-off.
6. To propose a feasible Industrial structure from the comparison.

2.2. Methodology

Analysis of all the investigation procedures and methods is methodology**.** The methodology depends on the objective of the project. Based on the objective, the methodology is decided. In the present case, the model preparation, analysis, and design are based on objective manual calculation. Finally, the results are plotted on the graph to get a clear idea, and a comparison is carried out.

1. Detail study of conventional steel pratt frame, PEB frame and lattice frame are carried out.
2. The necessary data such as height, span, length, and type of section are decided based on most construction practices in India.
3. The dead load on the structure is manually calculated using IS 875 (Part1)
4. The imposed load on the structure is manually calculated using IS 875(Part2)
5. The wind load on the structure is manually calculated using IS 875(Part3)
6. Using STAADPro. Software models of conventional truss, Lattice truss and PEB is carried out by keeping the same plan dimension and eave height.
7. Manually calculated loads are applied to the models prepared.
8. Different types of frames are designed using Indian standard code 800-2007(limit state design).
9. Using STAAD Pro, the steel structure is analyzed and designed by subjecting the frame to various load combinations and sections.
10. A comparison of these structures is carried out based on their cost, stability, and weight.
11. The present study mainly concentrates on the steel take-off of the conventional pratt truss, lattice truss and PEB and compares the most feasible structure.

3. Analysis and design of steel structure

3.1. Data

1. Plan size - 24m x 50m
2. Eave Height - 12 m
3. The type of sheeting used is galvanized iron sheet
4. The place where the structure is to be constructed is Benguluru
5. Load cases

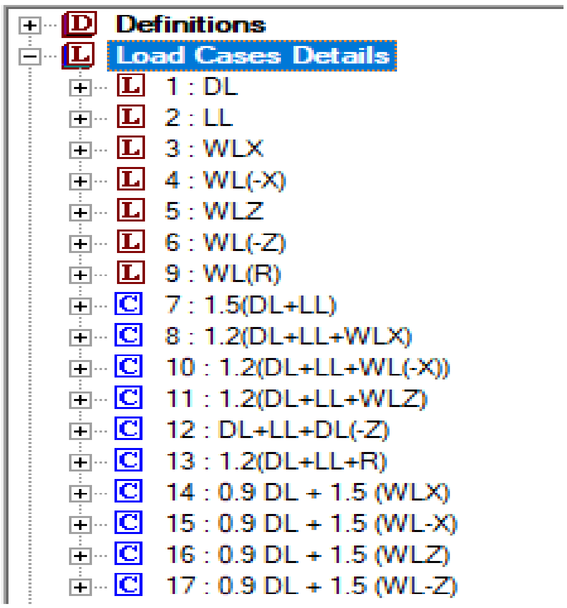


Fig. 1 Load combination as per code

6. Design parameters in software

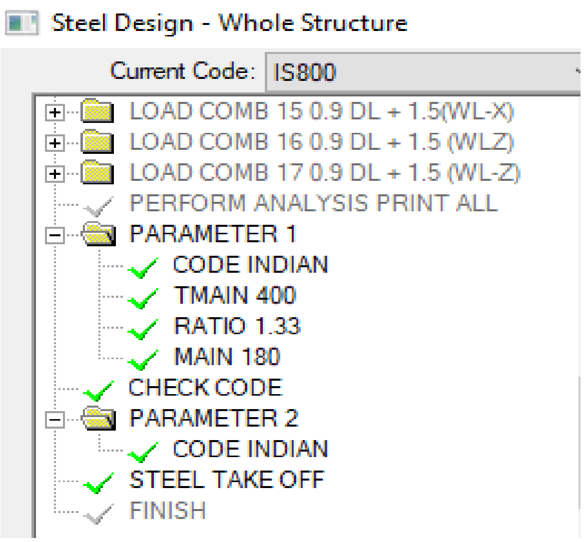


Fig. 2 Design Parameters used as per design

3.2. Conventional steel truss with pitched Pratt roof

3.2.1. Dimension

1. Plan size : 24x50m
2. Width : 24m
3. Length: 50m
4. Eave height: 12m
5. Bay spacing: 5m
6. Roof angle : 18.43◦
7. Percentage of opening in the building: 5% to 20%
8. Roof type: Pitched

3.2.2. Dead load calculation

1. Galvanized iron sheeting : 0.085kN/m^2
2. Fixings : 0.025kN/m^2
3. Service load : 0.100kN/m^2
4. Total dead load : 0.210kN/m^2
5. Dead load of roof : 0.210*24*5=25.2kN/m^2
6. Weight of purlin(assuming 70N/m^2) : 0.07*24*5=8.4kN
7. Welded sheet roof truss weight: 0.125kN/m^2
8. One truss frame self weight : 0.125*5*24 = 15.024kN
9. Total dead load: 48.624kN
10. Number of internal nodes at top chord: 10
11. Intermediate nodal point dead load : 48.624/10 = 4.8624kN
12. End nodal point dead load : 4.8624/2 =2.4312kN

3.2.3. Live load calculation

1. Since the roof angle is more than 10◦ following reduction is to be considered
2. Live load : 0.75-0.02(18.43^o - 10^o) = 0.5814kN/m^2
3. Total live load : 0.5814*5*24 = 69.768kN
4. Intermediate nodal live load : 69.768/10 =6.97kN
5. End Nodal point live load : 6.97/2 = 3.485kN

3.2.4. Wind load calculation

Indian standard 875 part 3 is used for the following wind load analysis

Design wind pressure:

1. Design wind speed Vz: Vb * k1 * k2 * k3 * k4
   = 33*0.94*0.934*1*1 = 28.97 m/s
2. Design wind pressure(pz) : 0.6Vz^2 = 0.6 * 28.97^2 : 0.504 kN/m^2

3.2.5. Analysis and design of Pratt truss with ISHB column and built-up column in STAAD. Pro

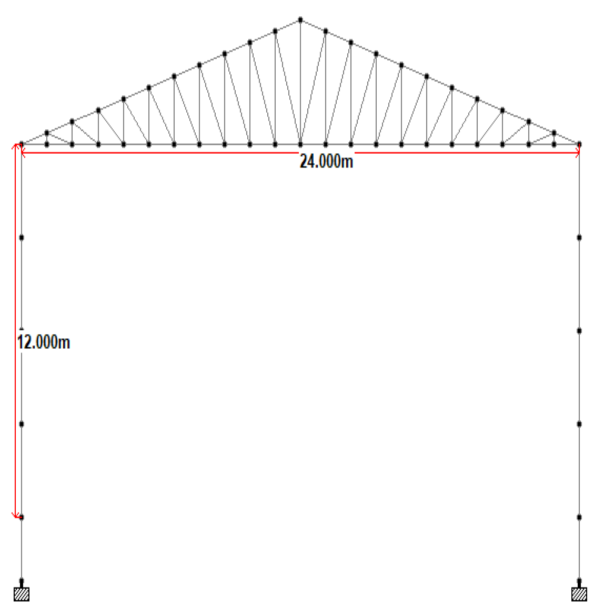


Fig. 3 Elevation of Pratt truss with ISHB column

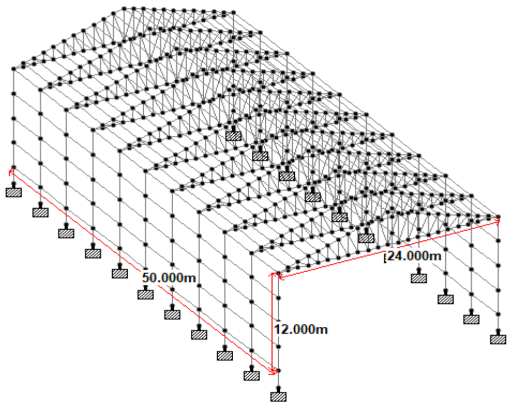


Fig. 4 3D view of Pratt truss with ISHB column

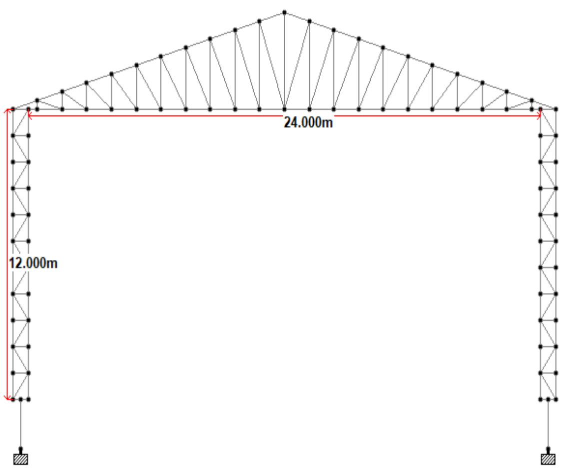


Fig. 5 Elevation of Pratt truss with built-up column

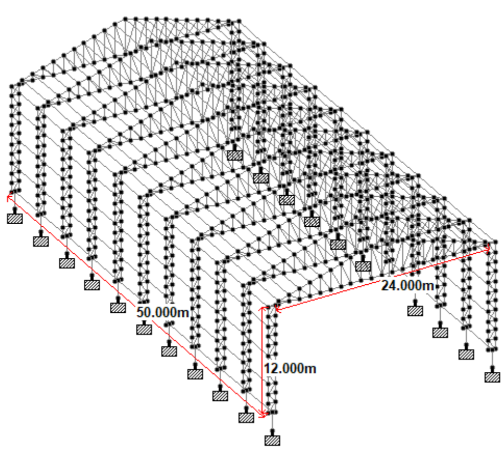


Fig. 6 3D view of Pratt truss with built-up column

Sections used

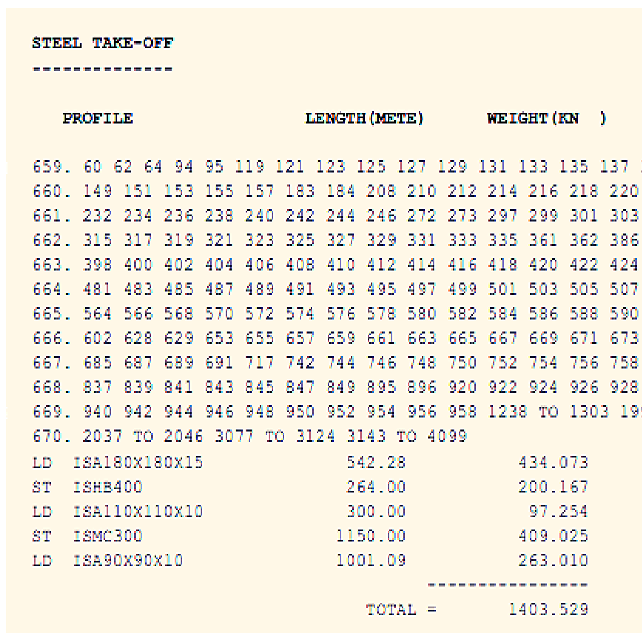
Table 1. Pratt Truss with ISHB column

Top and bottom chord	ISA180X180X15LD
Column	ISHB 400
Inner members	ISA 90X90X10
Purlin	ISMC300
Bracing	ISA110X110X10LD

Table 2. Pratt Truss with built-up column

Top and bottom chord	ISA150X150X20LD
Column (built-up)	ISMC125
Inner members	ISA 90X90X10
Purlin	ISMC300
Bracing	ISA110X110X10LD

Steel tonnage calculation for 3-D Pratt truss with ISHB column and built-up column



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STEEL TAKE-OFF
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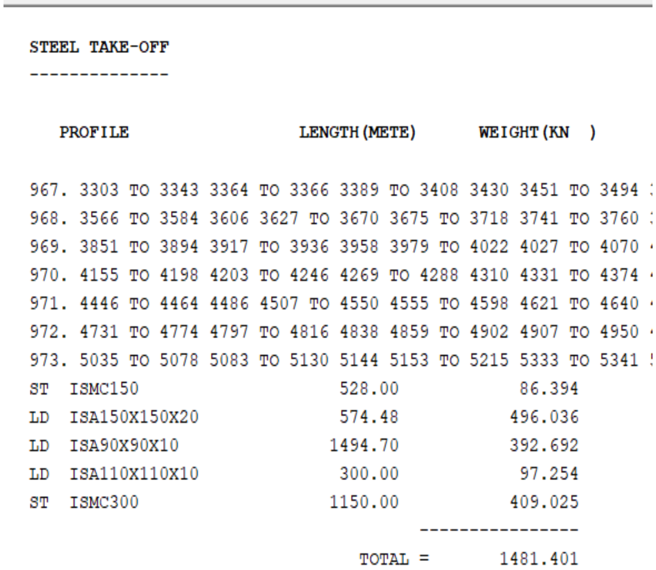
  PROFILE                   LENGTH(METE)      WEIGHT(KN   )

659. 60 62 64 94 95 119 121 123 125 127 129 131 133 135 137 1
660. 149 151 153 155 157 183 184 208 210 212 214 216 218 220
661. 232 234 236 238 240 242 244 246 272 273 297 299 301 303
662. 315 317 319 321 323 325 327 329 331 333 335 361 362 386
663. 398 400 402 404 406 408 410 412 414 416 418 420 422 424
664. 481 483 485 487 489 491 493 495 497 499 501 503 505 507
665. 564 566 568 570 572 574 576 578 580 582 584 586 588 590
666. 602 628 629 653 655 657 659 661 663 665 667 669 671 673
667. 685 687 689 691 717 742 744 746 748 750 752 754 756 758
668. 837 839 841 843 845 847 849 895 896 920 922 924 926 928
669. 940 942 944 946 948 950 952 954 956 958 1238 TO 1303 19
670. 2037 TO 2046 3077 TO 3124 3143 TO 4099
LD  ISA180X180X15               542.28            434.073
ST  ISHB400                     264.00            200.167
LD  ISA110X110X10               300.00             97.254
ST  ISMC300                    1150.00            409.025
LD  ISA90X90X10                1001.09            263.010
                                            ----------------
                               TOTAL =           1403.529
```

Fig. 7 Steel consumption for Pratt truss with ISHB column

Calculation:
Take off = 1403.529 kN
= 1403.529/9.96 = 140.916 ton
Per rack = 140.916 /11 = 12.81/rack
Area of building = 24 X 50 = 1200 m^2 =12916.8 sq.ft
Tonnage = 12.81 X 1000 / 12916.8 = 0.99 kg/ft



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STEEL TAKE-OFF
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  PROFILE                      LENGTH(METE)       WEIGHT(KN   )

967. 3303 TO 3343 3364 TO 3366 3389 TO 3408 3430 3451 TO 3494
968. 3566 TO 3584 3606 3627 TO 3670 3675 TO 3718 3741 TO 3760
969. 3851 TO 3894 3917 TO 3936 3958 3979 TO 4022 4027 TO 4070
970. 4155 TO 4198 4203 TO 4246 4269 TO 4288 4310 4331 TO 4374
971. 4446 TO 4464 4486 4507 TO 4550 4555 TO 4598 4621 TO 4640
972. 4731 TO 4774 4797 TO 4816 4838 4859 TO 4902 4907 TO 4950
973. 5035 TO 5078 5083 TO 5130 5144 5153 TO 5215 5333 TO 5341
ST   ISMC150                     528.00             86.394
LD   ISA150X150X20               574.48            496.036
LD   ISA90X90X10                1494.70            392.692
LD   ISA110X110X10               300.00             97.254
ST   ISMC300                    1150.00            409.025
                                           ----------------
                                TOTAL =          1481.401
```

Fig. 8 Steel consumption for Pratt truss with built-up column

Calculation:
Take off = 1481.401 kN
= 1481.401/9.96 = 148.73 ton
Per rack = 148.73/11 = 13.52/rack
Area of building = 24 X 50 = 1200 m^2 =12916.8 sqft
Tonnage = 13.52 X 1000 / 12916.8 = 1.0468 kg/ft

3.3. Lattice truss

3.3.1. Dimension

1. Plan size : 24X50m
2. Width : 24m
3. Length: 50m
4. Eave height: 12m
5. Bay spacing: 5m
6. Percentage of opening in the building: 5% to 20%

3.3.2. Dead load calculation

1. Galvanized iron sheeting : 0.085kN/m^2
2. Fixings : 0.025kN/m^2
3. Service load : 0.100kN/m^2
4. Total dead load : 0.210kN/m^2
5. Spacing of purlin = 1.099 m
6. Dead load of roof : 0.210X1.099 = 0.23079kN/m
7. Weight of purlin = 70N/m^2 = 0.07kN/m

3.3.3. Live load calculation

1. Live load: 0.75kN/m^2 (for access not provided except maintenance)
2. Total live load : 0.75x5X24 = 90 kN

3.3.4. Wind load calculation

Indian standard 875 part 3 is used for the following wind load analysis
Design wind pressure:

1. Design wind speed Vz : Vb * k1 * k2 * k3 * k4 = 33*0.94*0.934*1.0*1.0 = 28.97 m/s
2. Design wind pressure(pz) : $0.6Vz^2 = 0.6 * 28.97^2$: 0.504 kN/m^2

3.3.5. Analysis and design of Lattice truss in STAAD.Pro

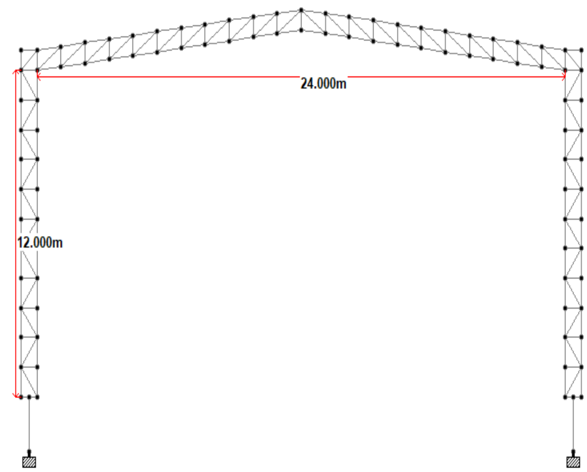

Fig. 9 Elevation of Lattice truss

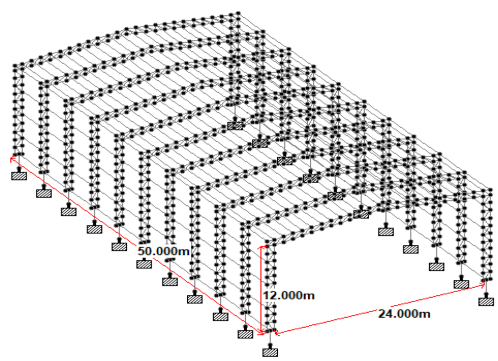

Fig. 10 3D view of Lattice truss

Sections used

Table 4. Lattice Truss sections

Top and bottom chord	ISA180X180X15LD
Column	ISMC300
Inner members	ISA90X90X10LD
Purlin	ISMC300
Bracing	ISA110X110X10LD

Steel tonnage calculation for 3-D Lattice truss

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STEEL TAKE-OFF
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   PROFILE                    LENGTH(METE)       WEIGHT(KN   )

1005. 64 TO 67 74 TO 77 81 TO 84 87 TO 90 97 TO 100 104 TO 107 110 TO 1
1006. 120 TO 123 127 TO 130 133 TO 136 143 TO 146 150 TO 153 156 TO 159
1007. 166 TO 169 173 TO 176 179 TO 182 189 TO 192 196 TO 199 202 TO 205
1008. 212 TO 215 219 TO 222 225 TO 228 235 TO 238 242 TO 245 248 TO 251
1009. 258 TO 261 265 TO 268 289 TO 308 329 TO 348 369 TO 388 409 TO 428
1010. 449 TO 468 489 TO 508 529 TO 548 569 TO 588 609 TO 628 649 TO 668
1011. 689 TO 708 729 730 752 TO 777 959 TO 1030 1059 TO 1078 1099 TO 11
1012. 1140 TO 1158 1179 TO 1198 1219 TO 1238 1259 TO 1278 1299 TO 1318
1013. 1379 TO 1398 1419 TO 1438 1459 TO 1478 1499 TO 1518 1539 TO 1558
1014. 1579 TO 1598 1619 TO 1638 1659 TO 1678 1699 TO 1718 1739 TO 1758
1015. 1779 TO 1798 1819 TO 1838 1859 TO 1878 1899 TO 1918 1941 TO 1964
1016. 1987 TO 2010 2033 TO 2056 2079 TO 2102 2125 TO 2148 2171 TO 2194
1017. 2217 TO 2240 2263 TO 2286 2309 TO 2332 2355 TO 2378 2401 TO 2424
1018. 2427 TO 3391 3393 TO 3594
 ST  ISMC300                     1811.01            644.126
 LD  ISA180X180X15                565.11            452.347
 LD  ISA110X110X10                300.00             97.254
 LD  ISA90X90X10                 1022.11            268.532
                                            ----------------
                                   TOTAL =         1462.259
```

Fig. 11 Steel consumption for Lattice truss

Calculation:
Take off = 1462.259 kN
= 1462.259/9.96 = 146.81315 ton
Per rack = 146.81315/11 = 13.346/rack
Area of building = 24 X 50 = 1200 m^2 =12916.8 sq.ft
Tonnage = 13.346 X 1000 / 12916.8 = 1.033 kg/ft

3.4. Pre-engineered building truss

3.4.1. Dimension

1. Plan dimension : 24X50m
2. Width : 24m
3. Length: 50m
4. Eave height: 12m
5. Bay spacing: 5m
6. Roof angle : 5.946◦
7. Percentage of opening in the building: 5% to 20%
8. Roof angle : Pitched

3.4.2. Dead load calculation

1. Length of principle rafter = $\sqrt{(12^2 + 1.249^2)}$ =12.093m
2. Number of purlins =12.093/1.008 =11.99 =12no
3. Total no of purlins = 12 +12 +1 =25 no
4. Galvanized iron sheeting : 0.085kN/m^2
5. Fixings : 0.025kN/m^2
6. Service load : 0.100kN/m^2
7. Total dead load : 0.210kN/m^2 =0.210X1.008 = 0.21168kN/m
8. Weight of purlin(assuming 70N/m^2) : 0.07kN/m

3.4.3. Live load calculation

1. Live load : 0.75kN/m^2
2. Live load on purlins: 0.75x1.209= 0.90675kN/m

3.4.4. Wind load calculation

Indian standard 875 part 3 is used for the following wind load analysis
Design wind pressure:

1. Design wind speed Vz : Vb X k1 X k2 X k3 X k4 = 33X0.94X0.934X1.0 X 1.0 = 28.97 m/s
2. Design wind pressure(pz) : $0.6Vz^2 = 0.6 \times 28.97^2$: 0.504 kN/m^2

3.4.5. Analysis and design of PEB truss in STAAD.Pro

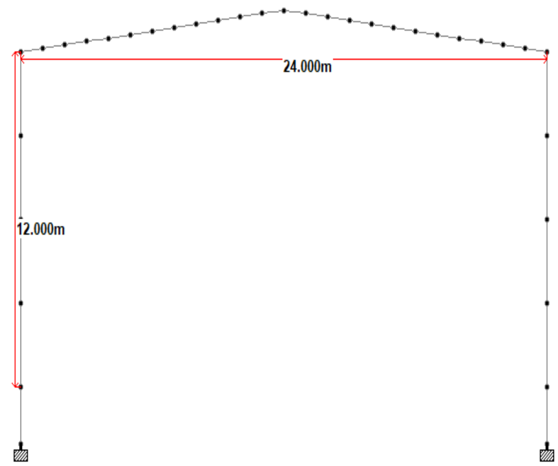

Fig. 12 Elevation of PEB truss

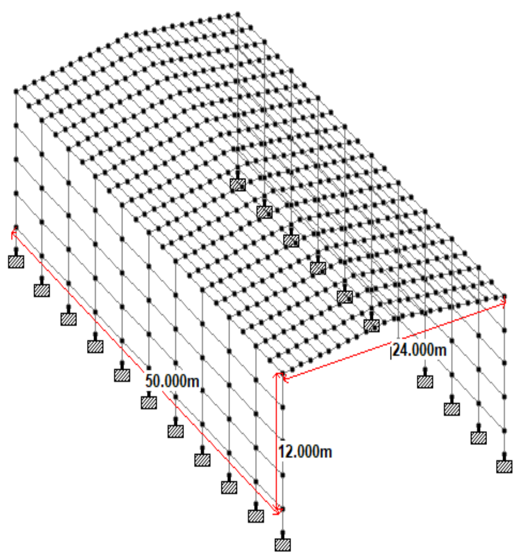

Fig. 13 3D view of PEB truss

Sections used
Purlin -12ZS3.25X135
Bracing -ISA110X110X10LD
Sag rod – 30mm
Column – Taperred sections

Steel tonnage calculation for 3-D PEB truss

PROFILE	LENGTH (METE)	WEIGHT (KN)
825. 72 TO 75 82 TO 85 92 TO 95 102 TO 105 112 TO 115 356 TO 400 4		
826. 609 TO 1164 1187 TO 1676		
Tapered MembNo: 12	66.00	84.975
Tapered MembNo: 13	66.00	62.970
Tapered MembNo: 356	66.00	74.834
Tapered MembNo: 357	66.00	57.900
ST 12ZS3.25X135	1250.00	161.870
LD ISA110X110X12	300.00	115.690
Tapered MembNo: 671	22.17	14.449
Tapered MembNo: 673	22.17	16.861
Tapered MembNo: 715	22.17	18.565
Tapered MembNo: 716	22.17	20.268
Tapered MembNo: 717	22.17	21.971
Tapered MembNo: 718	22.17	23.674
Tapered MembNo: 719	22.17	25.377
Tapered MembNo: 770	22.17	14.733
Tapered MembNo: 771	22.17	15.016
Tapered MembNo: 772	22.17	15.300
Tapered MembNo: 773	22.17	15.584
Tapered MembNo: 774	22.17	15.868
PRISMATIC STEEL	241.87	16.722
	TOTAL =	792.629

Fig. 14 Steel consumption for different sections used in PEB truss

Calculation:
Take off = 792.629 kN
= 792.629/9.96 = 79.5812 ton
Per rack = 79.5812/11 = 7.234/rack
Area of building = 24 X 50 = 1200 m^2 =12916.8 sq.ft
Tonnage = 7.234 X 1000 / 12916.8 = 0.5600 kg/ft

4. Results and Discussion

The analysis and design results of conventional Pratt truss, lattice truss, and pre-engineered buildings are compared, and the amount of steel consumed is given.

4.1. Graphical representation of steel consumptions for pratt trusses with different column sections.

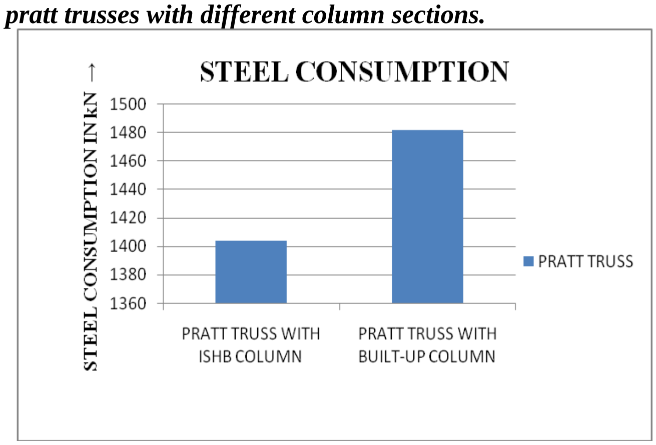

Fig. 10 Steel consumption comparison for different column sections in Pratt truss

Pratt truss with column section ISHB consumes less steel when compared to Pratt truss with the built-up column. We can observe that there is very less variation. ISHB section is heavy compared to the channel section, but built-up columns are provided, including lacing. The steel quantity will be more. Hence the steel quantity for Pratt truss with the built-up column is more.

A Pratt truss with an ISHB column is used for further investigation as the steel quantity is less.

4.2. Graphical representation of maximum support reaction for different types of industrial trusses

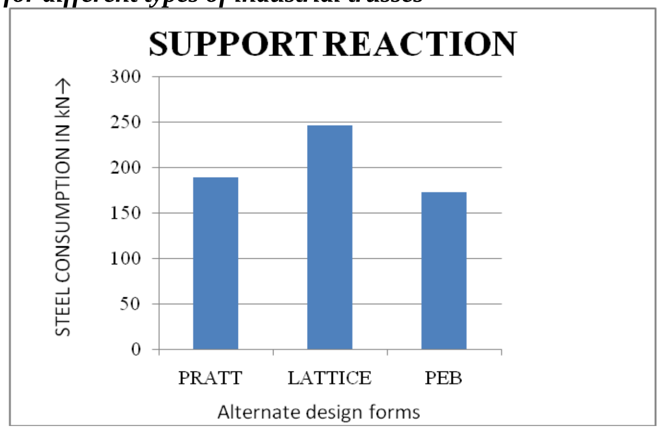

Fig. 11 Maximum support reaction comparison for different types of industrial trusses

The above figure gives the graphical representation of the maximum support reaction between different alternate design steel forms. We notice that the maximum support reaction for PEB is less than Pratt and Lattice truss. It is because of the use of tapered sections and cold-formed steel sections as secondary members. As the weight is less, the dead load will be less, and hence the support reaction will also be less. And as the support reaction is less foundation cost is less. Hence pre-engineered building has less support reaction comparatively.

4.3 Graphical representation of steel consumption for different types of industrial trusses.

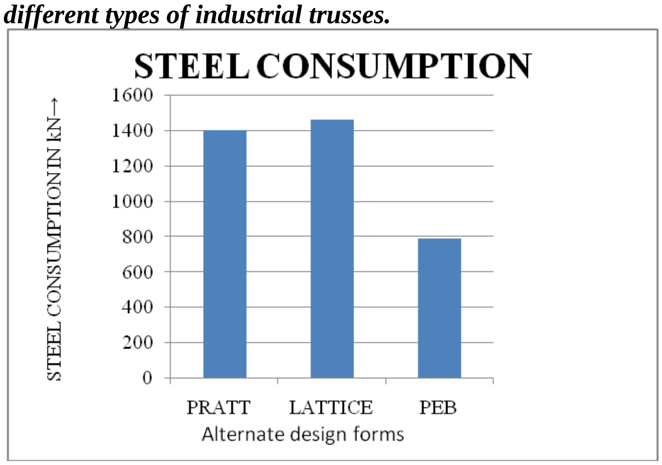

Fig. 12 Steel consumption comparison for different types of industrial trusses

The figure gives the graphical representation of steel consumption between different alternate design steel forms. We can see that pre-engineered buildings are significantly less expensive than the other two options. The reason for this is the use of tapered and cold-formed steel sections as secondary members. This helps to reduce steel consumption to a greater extent, demonstrating that lattice girders and conventional frames are not as economical for fewer span structures and are unsuitable when cost comparison is based primarily on steel consumption**.** Hence pre-engineered building is more economical.

5. Conclusion and Future Scope

5.1. Conclusion

Following conclusions can be made from the analysis

1. Pratt truss with column section ISHB consumes less steel when compared to Pratt truss with the built-up column. Hence Pratt truss with the ISHB column is economical when compared to the Pratt truss with the built-up column.
2. Maximum support reaction for PEB is less than Pratt truss and Lattice truss
3. Steel consumption in the case of a lattice truss is 4.05% more than a conventional truss.
4. Steel consumption in the case of conventional is 43.5% more than PEB truss.
5. It can be concluded that Pre-engineered building is more economical when compared with conventional and lattice based on steel consumption.

5.2. Future scope

1. Alternate design forms like vierendeel and castellated truss forms can be compared for the same dimensions.
2. Earthquake analysis of the structures can be carried out.
3. Design and analysis of gantry girder for different trusse

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