Optimal Design of Steel Frame using Rolled, Fabricated & PEB Sections for Comparison of Cost and Time

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Abstract: **In recent years, the introduction of Pre-Engineered Building (PEB) design of structures has been as an optimised alternative for the design of sheds. The adoption of PEB design concept instead of use of conventional rolled section resulted in many advantages as the members are designed as per bending moment diagram thereby reducing the material requirement. This methodology is versatile not only due to its quality of predesigning and prefabrication, but also due to its light weight and economical construction. This concept has many advantages over the conventional method involving buildings with roof trusses.**

In this study, an industrial structure is analysed and designed according to the Indian standards. One model each for PEB and Conventional sections is considered for analysis using rolled, fabricated, cold formed sections and parametric study is carried out to assess the cost effectiveness. Comparison is made in terms of weight, cost and time of material procurement, fabrication, transportation & construction.

***Keywords*— Side Girts, steel portal, weight comparison, method of fabrication, transportation, erection.**

I. Introduction

Industrial sheds are very common structures required in all kinds of plants, industries and commercial sectors. At the start of design, engineers require the comparative data for selection of best optimal scheme regarding the type & selection of structural steel sections. The project is aimed at the analysis & design of shed structure of defined geometry and loading using FEA. This project will provide the comparison of cost and erection time for various structural sections.

For comparison, the shed structure of 30m effective cross section, 36m length with steel portals spaced at 6m c/c each and 15m eaves height is considered. The shed has 11m clear height up to the crest level. The shed is provided with rafter bracings and longitudinal bracings at design interval for longitudinal stability. The shed does not have any ties across the cross section. It is closed at the Gable ends and the total opening area considered for ventilation is approx... 20% of total floor area through louvers.

1.1 Steel

Steel is a general nomenclature for iron containing small amounts of carbon, manganese and other elements. Nowadays, steel is broadly used as the main material in the construction of many buildings around the world. Its high strength to weight ratio and durability has made steel a suitable material for structures which are required to have large space without intermediate columns. The steel members of the frames are manufactured in different forms and cross-section shapes depending on their functions and characteristics.

1.2 Characteristics of steel portal frames

Steel Portal Frames (SPFs) are generally used in single storey buildings. It is estimated that 50% of the all steelwork constructed in the UK is in the primary framework of single-storey buildings. Because of its economy and versatility for large spans construction, such as shopping centres, warehouses, barns, retail shops, pools, factories, etc., the SPF has become the structure most often used within this sector. The SPF can be the option for single storey buildings in countries which are at a reconstruction stage. After the war, Iraq and specifically the Kurdistan region has stepped into a new stage of reconstruction which required more buildings with SPFs; essentially a demand for factories, warehouses and modern retail parks.

Although SPFs appear to be simple structures, there are more limitations imposed by the codes of practice than for complex structures. The non-prismatic shape of the members used in SPFs requires checking of more limitations than are considered in multi-storey buildings. The major applied loads to a SPF are the combination of dead load, imposed load and wind load. Due to the large area of cladding in a SPF, the wind load has a great impact on the behaviour of the entire structure.

The majority of portal frames use conventional hot-rolled steel sections for the primary load carrying members (i.e., columns and rafters) and cold-formed steel for the secondary members (i.e., purlins, side rails and cladding). Using hot-rolled steel, spans of up to 60 m can be achieved. For frames of more modest spans, the use of cold-formed steel for the primary load carrying members (i.e., columns and rafters) should be an alternative to conventional hot-rolled steel.

However, because fabrication and erection costs for cold-formed steel are much lower than for hot-rolled steel, there is scope to vary the frame spacing and pitch. Other advantages of cold formed steel frames compared to hot-rolled steel are as follows.

Pre-galvanized cold-formed steel sections that do not require painting to prevent rusting and hence they are maintenance free. The transportation costs are lower owing to efficient stacking of cold-formed steel sections. Also, the acquisition costs are lower as the cold-formed steel used for the secondary members can be purchased from the same manufacturer/supplier.

Cold-formed steel portal frames are a popular form of construction in Australia and the UK. They are commonly used for low-rise commercial, light industrial and agricultural buildings with spans of up to 20 m. For such frames, moment-resisting joints at the eaves and apex can be formed through mechanical interlock. With longer span frames, to reduce the section sizes of both the column and rafter members, a knee brace is often included at the eaves. The effect of including a knee brace is that the bending moment that needs to be resisted by both the column and rafter around the joint is reduced, with the axial load carried through the knee brace.

Optimization plays an important role in the current practice of structural design. Typically, the optimum design of a structural system is an attempt to find the best set of structural members that yields the most economical final design. Meanwhile, for practical applications the optimum design should satisfy a set of predefined constraints imposed according to a selected code of design practice. In general, the optimum design of truss structures can be categorized as sizing, shape, and topology optimization. In sizing optimization the cross-sectional areas of members are treated as design variables. This can further be divided into two subcategories as continuous and discrete sizing optimization in terms of the nature of the design variables employed. In continuous sizing optimization any positive value can be assigned to cross-sectional areas of the members. However, this is usually not the case in practical applications, where structural members are to be selected from a set of available profiles. The latter is referred to as discrete sizing optimization. In shape optimization the best shape of a structure is sought by varying the nodal coordinates (positions) for a selected group of joints. The third category, namely topology optimization interrogates the presence or absence of structural components, such as members and nodes for optimum layout design of a structure. This study covers discrete sizing optimization of steel trusses, which is the most common case in real world applications.

1.3 Optimisation method proposed:

The optimization method proposed addresses all the relevant combinations of the permanent and imposed loads, incorporating the range of design constraints and considers all feasible wind load combinations. It is assumed here that lateral restraint is applied to columns through vertical bracings and to rafters through the rafter bracings and tie bracings. It is also assumed that the cost of the purlins, side runners and sheeting is independent of frame spacing.

The present research differs from previous work on hot-rolled steel portal frames in the cross sectional sizes of the columns, rafters and the topology of the building, including the pitch and frame spacing, are all jointly optimized. The decision variables used in the design optimization are the spacing of the frames; the pitch of the roof and the cross-sectional sizes of the main structural elements. Self-evidently, the solution space has both discrete variable for roof purlin, side runner and continuous variables for column and rafter.

II. LITERATURE REVIEW

More recently, Issa and Mohammad varied the length and depth of haunched part of rafter in a specified range with the use of fixed intervals to determine the optimum size of haunched member.

Hernández et al. (2005) proposed the optimum design software called PADO, based on mathematical programming, for optimizing the design of hot-rolled steel portal frame in accordance with Spanish code of practice (EA-95). Chen and Hu (2008) used genetic algorithms to optimize a hot-rolled steel portal frames having tapered members, based on the Chinese specification for portal frames (CECS-102).

In order to have the deep check in the subject under research various technical papers were scanned for the data availability and the research done. Few research papers are highlighted below specifically which touch the technicalities of the subject. A very brief preview of the papers is listed below for the topics covered and the future scope of research work.

1.0 Comparison Between Design And Analysis Of Various Configuration Of Industrial Sheds - Vrushali Bahadure, Prof. R. V. R. K. Prasad / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622

Paper includes the comparison between different configurations of industrial shed. There are various types of industrial sheds. But here comparison of different configurations of industrial sheds, such as hot rolled steel shed using Howe truss, A-type, portal truss etc. This paper gives the suitable configuration of industrial shed by making and comparing design and analysis of various configurations of industrial sheds. STAAD-Pro 2007 is used to design of industrial shed, which gives results very quickly and accurately. This paper compares the design of different configuration of industrial shed and can be concluded that which is suitable
& economical in all views.

The configuration of three type of geometries are considered and the design is carried out for 60m cross section of shed with intermediate column. The conclusion drawn is that the SAW type roof truss is economical than the conventional roof truss whereas Portal frame analysis using PEB is not carried out for the comparison.

2.0 Design & Comparison of Various Types of Industrial Buildings - Sagar D. Wankhade, Prof. P. S. Pajgade / International Refereed Journal of Engineering and Science (IRJES)

In this paper Industrial Steel truss Building of 14m x 31.50m, 20m x 50m, 28m x 70m and bay spacing of 5.25m, 6.25m and 7m respectively having column height of 6m is compared with Pre-engineered Building of same dimension. Design is done using on IS 800-2007 (LSM) Load considered in modelling are Dead load, Live Load, Wind load along with combinations as specified in IS. Analysis results are observed for column base as hinge base. Results of Industrial steel truss buildings are compared with the same dimensions of Pre-Engineering Building.

The design of roof purlin of Steel Truss building and Pre-Engineering Building (PEB) is carried out. Various configurations of roof purlins using rolled channel sections, angle truss section and cold formed Z section purlin are considered. The most economical section for weight is Cold formed section but considering the cost effect, angle truss section is economical. Again the same shed with dimensions is analysed for the truss frame. With the usage of Pipe section in truss and purlin, Truss Building is found economical compared with PEB. Also the design using angle section for Truss and channel section for purlins, Steel Truss Building using pipe section and PEB is found to be economical compared to Steel Truss Building using angle section.

Concluding all above the configuration of Steel truss purlin using angles, roof truss using pipe sections is economical as compared to PEB portal and cold formed or channel purlins.

3.0 *Analysis and Design of Conventional Industrial Roof Truss and Compare it with Tubular Industrial Roof Truss* - Yash Patel, Yashveersinh Chhasatia, Shreepalsinh Gohil, Het Parmar / IJSTE - International Journal of Science Technology & Engineering.

Almost all of the steel building sheds are made up with orthodox sections of steels which are designed and built by traditional approaches. This results in weighty or too expensive structures. Tubular steel is the best possible alternatives to the traditional with their comparatively better specifications. Dead weight is tending to be decreased for many structural members so it is clear that because of the tube section, it helps in reducing overall economy. This is regarding the economy, load carrying capacity of all members and their relative safety measures. Economy is main aim of the present work including comparing conventional structures and tubular structures. Results imply that up to 15 to 25% saving in cost is accomplished by usage of tubular sections. Analysis of shed's elements was carried out by Staad Pro V8i computer software, with manually applying Indian Standards. Several spread sheets for different structural elements like Purlin, compression member, Roof Truss, Tension member etc. were carried out using Microsoft office excel. Lastly estimation sheet is prepared for each Conventional Roof Truss section as well as Tubular roof truss section.

Total weight of one roof truss components in Kg was calculated for Top chord members, Bottom chord members and other members of conventional steel section as well as Tubular steel section. Comparison is made between both type of sections and from the results of weight of roof truss members cost estimation sheet is carried out.

Tubular section has proved to be more economical.

4.0 *Design of industrial storage shed and analysis of stresses produced on failure of a joint* - Subhrakant Mohakul, Dr. Shaik.Yajdani, Abhay Dhurde / International Journal Of Civil Engineering And Technology (IJCIET)

In this project work submitted, it is proposed to carry out the design of an industrial steel shed and consideration of forces coming through the other members when one of the member fails, due to failure of end connecting joint. In this Project Case study for an accident in nearby area was done and root cause for failure is found out.

The main aim of the study to provide the analysis of practical industrial building by limit state method and also which method is a most economical method and, high bending strength, more load carrying capacity and high flexural strength by analysis of both working stresses and limit state method.

The sections designed using Limit State Method are more economical than the sections that are designed by Working Stress Method. In this study, the total roofing load configuration is same in both the working stress and limit state method. In IS 800 (1984) the local buckling is avoided by specifying b/t limits. However, In IS 800 (2007), the local buckling is the first aspect as far as the beam design is concerned (by using section classification). The section designed as per LSD is having more reserve capacity for BM and SF as compared to WSM. In this study with the help of the results obtained, we can conclude that limit state method is more reliable and economical than the working stress method for designing structure. The results of the limit state method of bending moment and load carrying capacity are higher than working stress method. The limit states provide a checklist of the basic structural requirements for which design calculations may be required. Limit states to design, provide consistent safety and serviceability.

III. THE NEED FOR OPTIMISATION

The design process makes sure that a given structure fulfils the architectural requirement, on one hand, and is safe, serviceable and durable for a cost-effective design, on the other hand. For a simple structure which is meant to be designed, it is common practice to use the experience and intuition of the structural engineer. Due to the complexity of large structures, it is somewhat difficult to achieve an economical design solution just by using the designer's experience, particularly when the structure experiences various load case scenarios. This is because there are so many criteria which should be considered during the design and all of them have influences on the response of the structure if the member properties are slightly changed. On the other hand, there is an obvious gap between the progress of optimisation techniques and their practical applications in structural engineering. This is because the complexity of available optimisation techniques represents major obstacles for the design even though the designer is keen to use optimisation techniques. There is a reluctance to use optimisation techniques in practice because of the difficulty of formulating a comprehensive set of equations for the design problem so that it could be easily used by anyone. This is very true when the technique which is supposed to be used is a mathematical programming method, as they are based on gradient and a derivative has to be taken.

In recent years, the world has witnessed a number of novel and innovative techniques for optimisation of structural schemes which have had various degree of success. Most of them involve a stochastic search. They are structurally and functionally simple to use in practice. However, they are slow-process techniques and some changes need to be addressed to speed up their performance. In addition, rapid development of the domestic personal computer over the past years has increased the motivation to formulate design problems using one of the stochastic optimisation techniques and implement them in the practical field of structural engineering. Nevertheless, efforts should be made to reduce the computation time and make the optimisation technique robust to obtain global optimum and cost effective solutions for design problems. To achieve this, consequently, it is necessary to investigate more studies to modify the available optimisation techniques so that they will be capable of handling real life design problems in the offices of structural engineers.

IV. PROBLEM STATEMENT

Findings of the research studies listed above:

1.0 *Comparison of the use of rolled sections with truss and cold formed sections are compared for the weight but the comparison for fabrication ease and transportation is not done.*

Vast studies are done for the analysis of the economical sections by comparison of various configurations using conventional or PEB structures. Cost comparison of very few cases according to the weight of steel is carried out but the comparison is not done for time taken for the procurement, transportation and erection of structures.

Hence to provide the optimal design solution for sheds of medium spans during engineering the above project is formulated.

V. Objectives

Selection of Geometry, arrangement & loading of shed structure.

1.0 Analysis and design using Rolled sections & cold formed sections for roof purlins & Side runner.
2.0 Analysis and design using Rolled sections, fabricated sections & PEB sections for Portal frame.
3.0 Comparison of each type (Sr. no. 2 & 3) for the cost required for material, fabrication & erection & time required for fabrication & erection.

VI. SCOPE

The Project study is limited to the medium span (36m x 30m x 15m height) shed and does not provide the comparison for sheds of smaller sizes and non-regular shapes such as Dome, spherical or circular. Use of hollow sections for bracings is also excluded from the scope of study since the procurement cost is much higher.

The Project study excludes space frame design for sheds.

VII. METHODOLOGY

1.0 Analysis is done for the Shed of size 36m x 30m x 15m height. The spacing between the portals will be 6m c/c apart.
2.0 Firstly side runner and roof purlin will be analysed for section optimization.
3.0 Steel portal will be analysed for rolled, fabricated and PE design based on the forces transferred from side runner and roof purlins.
4.0 The material take off, prices for steel procurement, fabrication & erection, time required for material procurement, steel fabrication, transportation & erection will be compared.

VIII. DESIGN AND ANALYSIS

Steel Girts are designed for the wind speed of 150 km/hr. and the corresponding members were designed. Steel Girts are designed as cold formed sections versus hot rolled sections. The result are tabulated as below:

Sr. No.	Sections Size	Weight	Procurement Cost	Fabrication Cost
1	ISMC200	50,041 Kg	39x50041=Rs. 19,51,600	Rs. 13/kg, 50041x13=6,50,533
2	Z200x2.4	15,708 Kg	59x15708=Rs. 9,26,800	Rs. 13/Kg 15708x13=2,04,204

Similarly comparing for the shed portal by using hot rolled and PEB design of sections the comparison is as below:

For rolled section

Sr. No.	Sections Size	Weight	Procurement Cost	Fabrication Cost
1	ISMB600	52180	52180x39=2035020	52180x13=678340
2	ISA75X75X6	3430	3430x39=133770	3430x13=44590
3	ISA90X90X6	5070	5070x39=197730	5070x13=65910
4	Plate 8 &10thk	15820	15820x39=616980	15820x15=237300

Total steel tonnage = 76500 kg. Total cost of structure including erection = 2983500+1026140+1147500 = Rs. 51,57,140/-

Sr. No.	Sections Size	Weight	Procurement Cost	Fabrication Cost
1	Plate 25 Thk	10560	10560x39=411840	10560x15=158400
2	Plate 20 Thk	9140	9140x39=356460	9140x15=137100
3	Plate 12 Thk	20610	20610x39=803790	20610x15=309150
4	Plate 10 Thk	18500	18500x39=721500	18500x15=277500
5	ISA75X75X6	3430	3430x39=133770	3430x13=44590
6	ISA90X90X6	5070	5070x39=197730	5070x13=65910

Total steel tonnage = 67310 kg. Total cost of structure including erection = 2625090+992650+1009650 = Rs. 4627390/-

IX. CONCLUSION

The overall savings in the structures with the configuration by the use of Cold formed section Purlin & Girts with the Pre-fabricated building structures (PEB) is 11%. The aspect of transportation of structures is not covered in the research since the transportation price will be the same for both type of structures. Hence with precise engineering of prefabricated structures, we can conclude that approx.. 11% overall savings is possible.

X. REFERENCES

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