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Quantitative Study of Howe Truss (A- Type) and Parallel Chord Scissor Truss (B- Type) by Applying External Pre-Stressing

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***Abstract*— The cost effectiveness of steel roof systems is becoming increasingly apparent with the decrease in manufacturing cost of steel components, reliability and efficiency in construction practices for economic and environmental concerns. The purpose of this project is to study the external pre-stressing on two different configuratation of truss shapes for spans 8m,20m,30m,50m,50,100m and find out the most economical section. The need of this study arises where sometimes it is difficult or taking much time to choose an effective and economical truss shape during the design period. The design loads are distributed to the joints so that there is no moment to be resisted by the members. A total of two types of trusses i,e. Howe truss (A-type) and parallel chord scissor truss (B-type), containing six spans, with two different loadings analyzed and designed. Optimal truss from each set of trusses is to be compared to determine which type of truss is more economical for different spans. The load carrying capacity of the truss may vary with different types of truss shapes for the same quantity of steel. The self weights obtained from the STAAD PRO are in the unit of Kn and can then be converted into masses in Kg which are used in calculating the cost of the materials since the rates are in running meter per unit Kg. However, close results might be obtained where it does help to provide a good guideline in choosing a truss that does not waste much material. This study shows that by introducing external pre-stressing in trusses there is a huge certainty in determining the most effective truss between these two shapes with different spans.**

Keywords*— Howe truss, parallel chord scissor truss, applying, pre-stressing

INTRODUCTION

A truss is an assemblage of long, slender structural elements that are connected at their ends. Trusses are used in roofs of single storey industrial buildings, long span floors and roofs of multi-storey buildings, to resist gravity loads. Trusses are also used in multi-storey buildings and walls and horizontal planes of industrial buildings to resist lateral loads and give lateral stability. Trusses are used in long span bridges to carry gravity loads and lateral loads. Trusses often serve the action of the girder in transferring the gravity load over larger span, and are referred to also as lattice girders. Such lattice girders are usually deeper and much lighter than regular girders and hence are economical. In addition to their practical importance as useful structures, truss elements have a dimensional simplicity that they will help us to extend further the concepts of mechanics introduced in the modules dealing with uniaxial response. The truss system offers considerable flexibility in deciding on the configure ration and detaisl of the structure. For instance, it is logical to deduce that further advantage is available if the distance between flanges varies with the applied moment, and this leads to the adoption of curved booms. Strictly speaking this meant that the members were no longer under simple axial loads but also had a bending component. This was usually small enough to be ignored but nowadays curved truss girders are less popular.

Economy of trusses

Trusses consume a lot less material compared to beams to span the same length and transfer moderate to heavy loads. However, the labor requirement for fabrication and erection of trusses is higher and hence the relative economy is dictated by different factors. In India these considerations are likely to favour the trusses even more because of the lower labor cost. In order to fully utilize the economy of the trusses the designers should ascertain the following:

Method of fabrication and erection to be followed, facility for shop fabrication available, transportation restrictions, field assembly facilities.

- Preferred practices and past experience.
- Availability of materials and sections to be used in fabrication.
- Erection technique to be followed and erection stresses.
- Method of connection preferred by the contractor and client (bolting, welding or riveting).
- Choice of rolled or fabricated sections.

Applications and Technique of Pre-Stressing Steel

Depending on the type of structure and its future working conditions, pre-stress may be applied during the erection or at the manufacturing plant. Pre-stressing can be applied in single or multiple stages. In utilizing the material, the greater effect may be obtained in multistep pre-stressing. This pre-stressing is possible only if the load is constant. The Sequence of steps used to create pre-stressing depends on the type of structure or loading and is subject to its effect on the economies being sought from pre-stressing. Pre-stressing is used in the design of new structures as well as for the existing ones. Reinforcing of an existing Structure by pre-stressing results in an increase in its load carrying capacity and stiffness with Minimal consumption of additional material. Considering its structural use, pre-stressing has been successfully applied in the design of new structures such as girders, frames, arches, trusses, buildings, towers, masts and bridges as well as to strengthen old bridges.

Some of the typical applications of technique of pre-stressed steel where external tendons are feasible, practical and economical are as follows.

1. Trusses: Pre-stressed trusses are used in industrial buildings and in the roofs of the boilers.
2. Bridges: Many large metal bridges have been built recently with the application of Pre- Stressing (bridge girders pre-stressed by tendons)
3. Sheet Structures and Wall Structures: These are pre-stressed so that they can take the Compressive load effectively.
4. Masts and Towers: Pre-stressed steel is used in Masts and Towers to increase the rigidity of the structure.

REVIEW OF LITERATURE

There are limited research studies available on analysis and design of steel truss. Literature Review consists of research work from the articles of various journals. Trusses starts from the study of types of trusses and the components involved in it. The research on trusses optimization has been carried out since decades ago. There were a lot of researches involved in the trusses optimization field for the purpose of getting minimum truss weights. Among the well-Known were M.P.Saka, H.Randolph Thomas, William Prager, S.Rajasekaran, Andrew B.Templemen, Ming Zhou, Zhang Qulin, GUAN Xian-Jun, Zhang Zhao-Bin, Wang Xintang and Renwei Xia, etc. A lot of research papers were produced. Besides, there were also graduates from UTA doing their thesis on this study. There are various optimizing approaches used by the researchers, generally can be classified into two: specific methods and general methods. Some of the methods make use of the concept of ground structure and member removals, while some take the position of joints as design variables.

General methods normally used by the previous researches are optimality criteria approach and mathematical programming methods. Optimality criteria approach is considered as an indirect method which first of all tries to establish conditions of uniqueness which characterize the optimum of a problem and distinguish it from all the other points. They then attempt to device a scheme which interactively satisfies optimality conditions or criteria. Whereas mathematical programming methods include linear programming, on linear programming, unconstraint and constraint optimization, and so on. However, they were attempts of using dual approach which combines the optimality criteria approach and the mathematical programming methods and it was found to be very efficient.

Krishna M. Agrawal et al. (1974) investigated a general method of weight optimization using the complex method. In the paper Weight Optimization of Plane Trusses has been presented. Geometric and some topological variables are included in the optimization. The method is adaptable to solve discrete member spectrum where it includes the effect of member interaction. Besides, the program can be extended to include three –dimensional space trusses by modifying the analysis algorithm.

Andrew et al. (1976) introduced the theories of dual approach by in “A Dual Approach to Optimum Truss Design”. A discussion of the implications and the usefulness of the dual approach was also given. This study considered the problem of determining the optimal member sizes which minimizes the weight of a pin-jointed truss of a fixed geometry which satisfies certain constraints.

William Prager (1976) produced the geometrical procedures developed such as being discussed in the paper “Geometric Discussion of the Optimal Design of a Simple Truss”. This paper discussed about the optimal design of a truss which consists of bars connecting the loading joint to fixed joints on a horizontal ceiling where only a single load and two alternative loads were considered. The discussion is on plastic and elastic design.

Randolph Thomas et al (1977) produced Optimum Least-Cost Design of a Roof Truss System. In this paper an algorithm is presented encompassing the application of optimization methods to the least-cost elastic design of roof systems composed of rigid steel trusses, web joists and steel roof deck where the systems are normally used in gymnasiums, field houses, warehouses and other public and industrial facilities. The study showed that the design can be formulated as an nonlinear programming problem. The flexibility and the generality of the design approach are also demonstrated.

Saka et al. is a researcher who has carried out a lot of studies about the optimization on the structure of trusses. Paper produced by him such as “Shape Optimization of Trusses (1980), Minimum Cost Topological Design of Trusses (1981), Optimal Design of Roof Trusses, etc. In the paper entitled Geometry Design of Roof of Trusses by optimality criteria method (1991), an effective optimum design method for a fixed geometry is employed to decide the most suitable shape for roof trusses among a few commonly used shapes using double angle sections. The design logarithm which was from the optimality criteria approach is then extended to take the slope as design variables to determine the optimum slope. The design procedure was programmed in Basic. The example for the optimization of upper chord slope is also shown in the paper.

Rajasekaran.S (1983) produced Computer Aided Optimal Design of Industrial Roof, who has carried out a research on the optimal design of industrial roof where a computer aided search technique is used to find the optimal spacing of industrial roof trusses. The objective of this investigation is to find out the optimal spacing of a roof of a given type, given span and length of a factory building to get the optimum weight of a roofing system; and to arrive at the optimal spacing for various types which gives the minimum weight is chosen among the trials. The computer program can be used to find out optimal spacing.

Zhang Qulin produced Optimum design of pre-stressed truss, who has carried out a research on optimization design of pre-stressed steel trusses not only includes the optimization of sectional dimensions of the bar also the optimization of the different schemes of steel cables and the different pretensions of steel cables. In this paper, the target function is cost of pre-stresses steel trusses. The analysis of an example proves that te economical benefit of the optimization design is evident and the optimization design is significant in engineering design.

GUAN Xian-Jun produced Optimization design of plane pre-stressed steel truss and optimal height study, By using sequence unconstrained minimization technique and having costs of steel trusses as objective functions, optimized the computational models of plane steel trusses and plane pre-stressed steel trusses with parallel cords. By study of large amount of computational results, the optimal heights of plane steel trusses and plane pre-stressed steel trusses with parallel cords of several spans are got. For the relatively smaller loads, the economical height-to-span ratio scopes of plane steel trusses and plane pre-stressed steel trusses with parallel cords can be found.

Zhang Zhao-Bin produced a paper in Journal of Anhui Institute of Architecture published paper on “Design and analysis on the pre-stressed steel truss”, in this paper gives a quick review of the conception of pre-stressed steel truss. The principle and basic steps of design and analysis are described. The prospect of its application in future is also discussed.

Wang Xintang produced optimal analysis of spatial pre-stressed steel trusses and plan comparison. In this paper the computational method for optimization of the spatial cable. A pre-stressed steel truss is further put forward. Using the optimum method, different pre-stressed steel trusses are analyzed and the relations between total steel products, the maximum ratio of deflection to span and the pretension of the cables, external loads of the corresponding structures studied are obtained upon a large amount of computations. The effects of arrangement of cables and the ratio of height to span on the optimum results are also studied, which provides a basis for plan choosing and design of spatial cable pre-stressed steel trusses.

ANALYSIS AND DESIGN OF DIFFERENT TRUSSE

In this chapter the load calculations and quantity of steel before and after pre-stressing of two different types of trusses obtained from the computer aided program STAAD.pro. Howe truss (A- type) and parallel chord scissor truss (B- type) are considered for truss analysis. The typical sketches of the trusses are shown below.

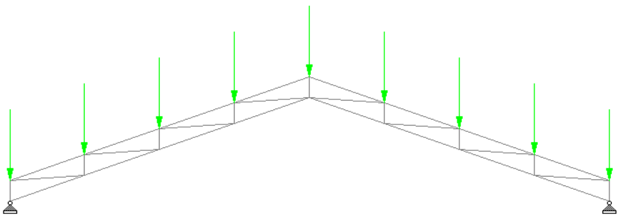


Fig: 1 Howe truss (A- type)

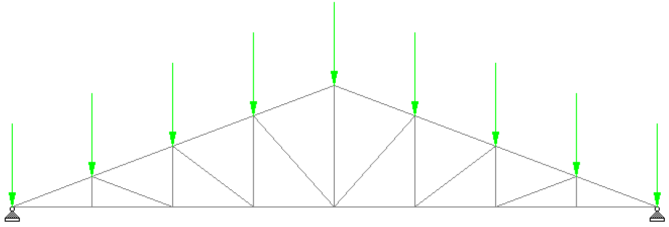


Fig: 2 parallel chord scissor truss (B- type)

LOAD CALCULATIONS FOR TRUSS A-TYPE OF SPAN 8m:

Dead Load :- (IS: 875 parts-I)
Assuming a roof covering material as galvanized Iron sheets for A-type truss of 8m span with a weight of 0.13KN/m^2
Live Load :- (IS: 87-5 part-II)
For A-type truss 8m span, the live load assumed as 0.73KN/m^2.

CALUCULATIONS

Assuming truss as intermediate truss and purling distance is taken as 4m
Dead Load = 0.13 x 1.07 x 4 = 0.5564KN.m
Live Load = 0.73 x 1.07 x 4 = 3.1244KN.m
The Quantity of Steel for each Pipe section has been obtained from STAAD output the respective values are presented in table: 1

Table: 1

S.No	Profile	Length (m)	Weight (KN)
1	ST PIP213.0L	12	0.112
2	ST PIP213.0M	4.14	0.049
3	ST PIP424.0M	2.14	0.066
4	ST PIP424.0L	4.27	0.109
5	ST PIP337.0L	2.14	0.42
6	ST PIP269.0L	2.5	0.035
7	ST PIP269.0H	3.01	0.056
TOTAL = 0.468KN = 47.7Kg			

Application of pre-stressing force in compression members of A-Type truss for 8m span:

The amount of pre-stressing force is introduced in the tension members of a A-type with pre-stressing is same as their compressive force of A-type truss without pre-stressing

The Quantity of Steel for each Pipe section has been obtained after pre-stressing from STAAD output and the respective values are presented in table: 2

Table: 2

S.No	Profile	Length(m)	Weight(KN)
1	ST PIP213.0L	25.92	0.241
2	ST PIP269.0H	2.14	0.04
3	ST PIP269.0L	2.14	0.3
Total = 0.310KN= 31.6Kg			

LOAD CALCULATIONS FOR TRUSS B-TYPE OF SPAN 8m:

Dead Load :- (IS: 875 part-I)

Assuming a roof covering material as galvanized Iron sheets for B-type truss of 8m span with a weight of 0.13KN/m^2

Live Load :- (IS: 875 part –II)

For B-type truss 8m span, the live load assumed as 0.73KN/m^2.

CALUCULATION

Assuming truss as intermediate truss and purling distance is taken as 4m

Dead Load = 0.13 x 1.07 x 4 = 0.5564KN.m

Live Load = 0.73 x 1.07 x 4 = 3.1244KN.m

The Quantity of Steel for each Pipe section has been obtained from STAAD output and the respective values are presented in table 3

Table: 3

S.No	Profile	Length(m)	Weight(KN)
1	ST PIP337.0M	4.27	0.102
2	ST PIP269.0L	4.14	0.058
3	ST PIP213.0L	13.12	0.122
4	ST PIP337.0L	6.28	0.124
TOTAL = 0.406KN = 41.38Kg			

Application of pre-stressing force in compression members of B-Type truss for 8m span*:*

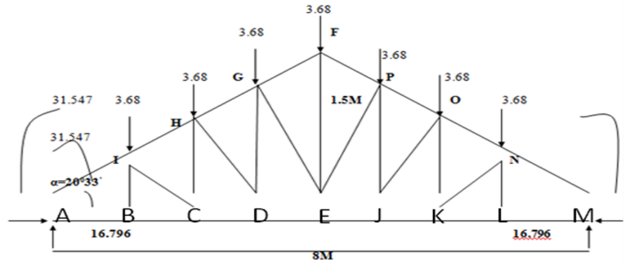
The amount of pre-stressing force is introduced in the tension members of a A-type with pre-stressing is same as their compressive force of A-type truss without pre-stressing

The Quantity of Steel for each Pipe section has been obtained after pre-stressing from STAAD output and the respective values are presented in table: 4.

Table: 4

S.No	Profile	Length (m)	Weight (KN)
1	ST PIP337.0M	4.27	0.102
2	ST PIP269.0L	4.14	0.058
3	ST PIP213.0L	13.12	0.122
4	ST PIP337.0L	6.28	0.124
TOTAL = 0.406KN = 41.38Kg			

In this connection take 8m long truss and calculated the forces in each member by manually.



MEMBER	FORCE	CRITICAL CONDOTION
F_{AB}	3.24	TENSION
F_{BC}	3.24	TENSION
F_{CD}	1.58	COMPRESSION
F_{DE}	6.48	COMPRESSION
F_{EJ}	6.48	COMPRESSION
F_{JK}	1.58	COMPRESSION
F_{KL}	3.32	TENSION
F_{LM}	3.32	TENSION
F_{AI}	36.68	COMPRESSION
F_{IH}	31.44	COMPRESSION
F_{HG}	26.20	COMPRESSION
F_{GF}	20.96	COMPRESSION
F_{FP}	20.96	COMPRESSION
F_{PO}	26.20	COMPRESSION
F_{ON}	31.44	COMPRESSION
F_{NM}	36.68	COMPRESSION
F_{IB}	0	TENSION
F_{HC}	1.84	TENSION
F_{GD}	3.68	TENSION
F_{FE}	11.04	TENSION
F_{PJ}	3.68	TENSION
F_{OK}	1.84	TENSION
F_{NL}	0	TENSION
F_{IC}	5.24	COMPRESSION
F_{HD}	6.13	COMPRESSION
F_{GE}	7.38	COMPRESSION
F_{PE}	7.38	COMPRESSION
F_{OJ}	6.13	COMPRESSION
F_{NK}	5.24	COMPRESSION

In the same way the quantities of steel weights are calculated for all the spans.

RESULTS AND DISSCUSION

Different spans (8m, 20m, 30m, 50m, 75m, and 100m) and different types of trusses (Howe truss (A-type) and Parallel chord truss(B-type) are considered for truss analysis. The analysis is carried in STAAD.Pro software. The quantity of steel for each truss was observed and compared with each other and tabulated below.

Table: 5 weight of trusses with and without pre-stressing

Span (m)	Weight(Kg) of truss without pre-stressing			Weight(Kg) of truss with pre-stressing		
	A	B	% diff	A	B	% diff
8	47.7	41.3	13.2	31.6	41.38	23.63
20	275.02	182.5	33.6	202.7	168.6	16.84
30	637.2	416.9	34.5	612.9	313.8	48.71
50	3259.1	1316	59.6	3128	1186.6	62.06
75	8481.9	3013	64.4	8139	2756.3	66.13
100	23095.	5769	75.0	11436	5514.0	51.78

1. Effect of quantity of steel between A and B trusses without pre-stressing

The graph is plotted for different span in the X-axis and weight of the truss in the Y-axis. It is observer that the graph is not regular. The weight of the truss is increased with increase of the span of the truss.

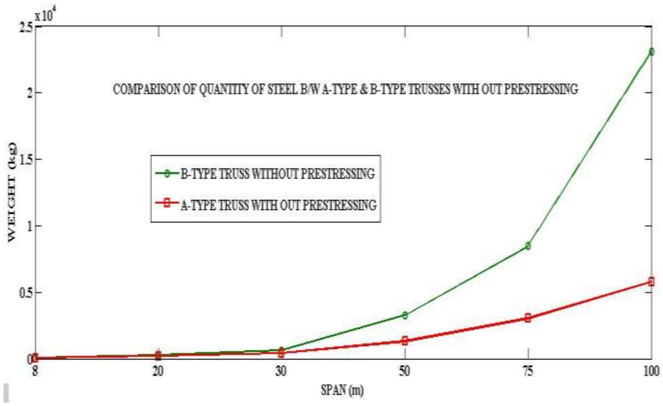


Fig: 3. Effect of quantity of steel between A and B trusses without pre-stressing

2.Effect of quantity of steel between A and B trusses with pre-stressing

The graph is plotted for different span in the X-axis and weight of the truss in the Y-axis. It is observer that the graph is not regular. The weight of the truss is increased with increase of the span of the truss.

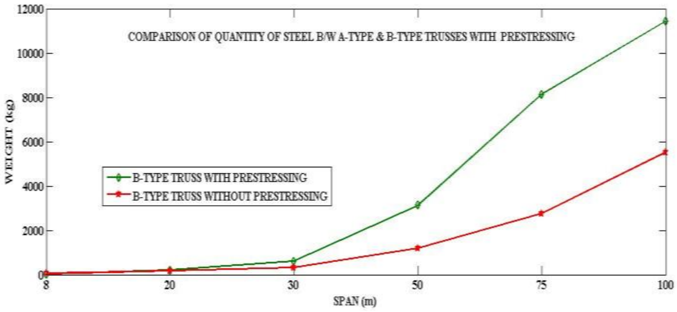


Fig: 4. Effect of quantity of steel between A and B trusses with pre-stressing

3.Effect of comparison of quantity of steel between A and B type trusses with and without prestressing:

The graph is plotted for different span in the X-axis and weight of the truss in the Y-axis. It is observer that the graph is not regular. The weight of the truss is increased with increase of the span of the truss.

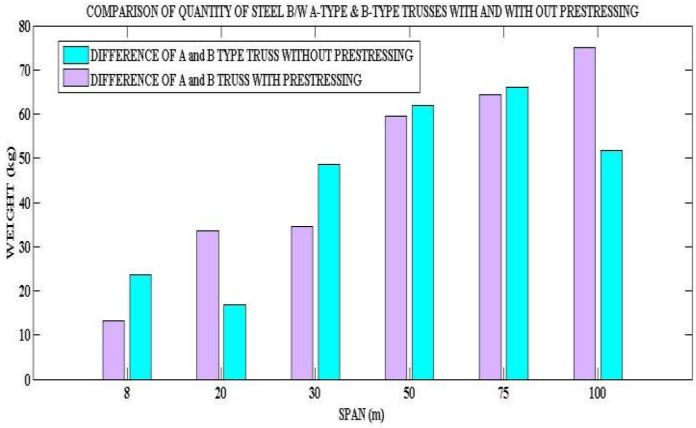


FIG: 5 EFFECT OF COMPARISON OF QUANTITY OF STEEL BETWEEN A AND B TYPE TRUSSES WITH AND WITHOUT PRESTRSSING

CONCLUSIONS

1. For span 8M, A-Type truss with pre-stressing seems to be economical the percentage saving in the material is 13.24 and 23.63 when compared with B-type with and without pre-stressing but from the practical considerations, applying pre-stressing force to the truss is costly process, therefore whatever the percentage of saving in material may be utilized for process of applying pre-stressing force.

   Therefore it can be considered that B-Type truss without pre-stressing as economical truss for 8M span.
2. For span 20M, 30M, 50M, 75M, 100M, after observing the percentage of steel before and after pre-stressing both for A-type and B-type trusses, B-Type truss with pre-stressing seems to be economical but from the practical considerations, applying pre-stressing force to the truss is costly process, therefore whatever the percentage of saving in material may be utilized for process of applying pre-stressing force.

   Therefore it can be considered that B-Type truss without pre-stressing as economical truss for spans 20M, 30M, 50M, 75M, and 100M.

3. In a whole for all spans of trusses B-Type truss is advisable when compare with A-Type except for 8M span.
4. Applying of external pre-stressing to the A-Type trusses has influenced more in quantity of steel for 100M span.

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