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Comparative Study of Tubular Steel Truss Profiles for Roofing Varying Span

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***Abstract* - The main objective of this study is to determine the optimized truss profile and its effect to the design of plane truss by using tubular sections with the aid of STAAD Pro v8i 2007. Minimum mass is chosen as the objective function. The study is focused to achieve the following objectives:**

(a) To determine the most effective truss profiles in term of its mass among the 23 candidate fixed geometry of profiles, in the design of trusses using steel tubular section for certain spans and rise to save the time of design by avoiding the efforts of trial and error.

(b) To determine whether under which conditions the same optimum profile of truss can be applied considering the different spans, rise and span over rise ratios of trusses.

(c) To determine the best possible truss profile to be applied in normal practice.

Keywords – IS:800-2007, IS:875-1987 for tubular section, STADD Pro V8.

1. INTRODUCTION

1.1 General

Roof truss is a framed structure in which number of line members (straight members) are so arranged and connected at the ends that the members form a triangle. The loads and reactions occur only at the joints of a truss. The centroidal axis of each member is straight and coincides with the line passing through the centre of the joints at each end of members. The members of a truss are subjected to direct stress only. In roof trusses, the entire section of each member is subjected to uniform stress and so the strength of the member is fully utilized. The force in the members are either compressive or tensile. Due to their efficiency, trusses are desirable in long span structures with high demands in stiffness and strength. The members used in steel truss system are normally angles, double angles, C-channels, double C-channels, square hollow section (SHS), rectangular hollow section (RHS), circular hollow section (CHS), cold-formed steel and so on.

Currently the sustained efforts of designers, manufacturers of materials and builders to innovate and incorporate unmatched excellence in the construction of roof trusses of large areas have resulted in highly functional, economical and pleasing structures. Function halls, theaters, huge gathering areas and warehouses are housing unit with roof and enclosing walls, but with no further floors above. The characteristics of such units are long span storage area, column free space for uninterrupted view and movement of vehicular traffic for loading and unloading of materials and goods. The most suited roof for such structures is steel trusses.

The truss structures are required to be designed in such a way that they have enough strength and rigidity to satisfy the strength and serviceability limitation. The subject of optimization is a lively topic in almost every discipline. Structural optimization has become a valuable tool for engineers and designers in last two decades. Although it has been applied for over forty years, optimization in engineering has not been a commonly used design tool until high performance computing systems were made widely available. The increasing interest in this area the last few decades is due to the availability of cheap and powerful computers, along with rapid developments in methods of structural analysis and optimization. Structures are becoming lighter, stronger and cheaper as industry adopts higher forms of optimization. This type of problem solving and product improvement is now a crucial part of the design process in today's engineering industry.

The basic principle of optimization is to find the best possible solution under given circumstances. The term optimal structure is very uncertain. This is because a structure can be optimal in different aspects. These different aspects are called objectives, and may for instance be the weight, cost or stiffness of the structure. The solution of problem depends on various factors like objective function formulation, constraint formulation, method adopted, starting point, step size etc. Truss optimization is not a new idea; a large body of previous research attempts to provide solutions to the questions of optimal member sizing, geometry, or topology. Optimal design of truss-structures has always been an active area of research in the field of research and optimization. Various techniques based on classical optimization methods have been developed to find optimal truss-structures. Sizing optimization is the simplest form of structural optimization. The profile of the structure is known and the objective is to optimize the structure by adjusting sizes of the components. In the sizing optimization of trusses, cross sectional areas of members are considered as design variables and the coordinates of the nodes and connectivity among various members are considered to be fixed

It is not difficult to conceive that there are quite a number of structures with different profiles which meet the requirement. But among them it is the most economical one that interests the structural engineer the most. Until the advent of structural optimization, the usual path to follow in the solution of this problem was to make use of the experience and intuition of the design engineering, so as in structural engineering. There has been quite a large number of research works which the profile of the structure was treated as a design variable.

1.2 Problem statement

An optimal truss is one that has been engineered to be structurally stable, as light as possible, and in compliance with relevant codes. The mass of that optimal structure is called the optimum mass. In normal practice it is difficult to adopt non-uniform sections, as it causes difficulty in fabrication and also cost of fabrication work. In order to avoid this difficulty, designer has to adopt a uniform section throughout the chord length in top and bottom and for web members. That possible truss in normal practice is called the practical truss and the overall mass of such structure is called practical mass. The design of trusses has to be carried out according to two important requirements. Firstly, the best geometrically layout of bars and nodes has to be determined, and secondly, the most adequate cross sections need to be calculated. In general, the structural profile depends on the engineer's criteria and its design depends partly on economical, aesthetical, construction techniques and environmental aspects.

Moreover, the dimensions of the bars depend on failure and functional criteria. The design requires determining member forces and comparing stresses and deflections with allowable values. Whereas the stability of a truss structure depends on its overall profile, number of members, arrangement of members and the support condition. In spite of an engineer can design following his own criteria, there must exist an optimum profile and a cross section distribution that bears the external loads.

In present study, 23 candidate truss profiles has been selected which are categorized in 5 groups based on slope and layout of top chord. The different geometries are analyzed and designed for varying span from 12m to 27m with increment of 5m and rise of truss varying from 1.5m to 3.5m with a constant spacing of 5m, height of column 10m, normal permeability with 5% openings in relation to wall area, wind zone with basic wind speed of 47m/s, purlin spacing of truss in each group is also fixed accordingly. The design of truss is carried out with the aid of STAAD Pro 2007 using steel tubular section to find out the most efficient truss profile from each group.

Trusses

A truss is a structure of assembled bars, often arranged in a triangular profile. Theoretically, the bars in a truss are assumed to be connected to each other by friction-free joints. In practice, the joints are more or less stiff due to welding or screwing the bars together. All the joints are considered to be pinned although some or all the joints may be fixed rather than pinned. We can assume a joint behaves as if it was pinned as long as all the bars passing through a joint intersect at a single point. Typical scopes of uses are bridges, long-span roof structures and transmission towers. Some well-known examples of truss structures are the Howrah Bridge in West Bengal, the Eiffel tower in Paris and the Harbor Bridge in Sydney.

Methods of Analysis

There are several methods normally used for the analysis of trusses. Among the general one are method of joints, method of sections, graphic statics, flexibility method, stiffness method and finite element method.

Assumptions for Design

a) All members are connected at both ends by smooth frictionless pins.
b) All loads are applied at joints (member weight is negligible). Centroids of all joint members coincide at the joint.
c) All members are straight.
d) All load conditions satisfy Hooke's law.

Truss types

There are two basic types of truss:

1. The pitched truss, or common truss, is characterized by its triangular profile. It is most often used for roof construction. Some common trusses are named according to their web configuration. The chord size and web configuration are determined by span, load and spacing.
2. The parallel chord truss, or flat truss, gets its name from its parallel top and bottom chords. It is often used for floor construction.

Structural Optimization

In the current tubular truss optimization problem topology, profile of truss members is fixed during optimization. Optimum structural design is typically concerned with the problem of finding in some sense best structure for given purposes. The topology of the truss should be chosen from the group of selected topologies and the sizes of profiles from the given selection of standard hot rolled hollow sections.

Optimization can be done with respect to two or more different objective functions. This is referred to as multi-objective optimization (also called multi-criterion or vector optimization. One example of this is Galante's (1996) attempt to find a minimal weight of a truss using as few different profiles as possible. In multi-objective optimization, one general objective function can be put together by weighted parts of the involved objective functions. Hence, by changing the weights, different optima are obtained. Other methods for dealing with multi-objective optimization are also possible.

Limit State Design

For a structural design to be satisfactory designer have generally four major objectives- (i) utility (ii) safety (iii) economy and (iv) elegance must be fulfilled. Thus safety is one of the paramount responsibilities of the designer. However, it is difficult to assess at the design stage how safe a proposed design will actually be. There is, in fact, a great deal of uncertainty about the many factors, which influence both safety and economy. The uncertainties affecting the safety of a structure are due to

· Uncertainty about loading

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· Uncertainty about material strength and
· Uncertainty about structural dimensions and behavior.

These uncertainties together make it impossible for a designer to guarantee that a structure will be absolutely safe. All that the designer can ensure is that the risk of failure is extremely small, despite the uncertainties. The uncertainty here is both due to variability of the loads applied to the structure, and also due to the variability of the load distribution through the structure. Thus, if a particularly weak structural component is subjected to a heavy load which exceeds the strength of the structural component, clearly failure could occur. Unfortunately it is not practicable to define the probability distributions of loads and strengths, as it will involve hundreds of tests on samples of components.

$$\text{Allowable Stress } = \frac{\text{Yield Stress}}{\text{Partial safety factor}}$$

Partial safety factor for materials, γ_m
Resistance, governed by yielding, γ_{m0} = 1.10
Resistance of member to buckling, γ_{m0} = 1.10
Resistance, governed by ultimate stress, γ_{m1} = 1.25

Background of STAAD Pro

STAAD Pro was developed by a group of practicing engineers for practicing engineers around the globe. It has evolved over 20 years and is constantly guided by a premier industry-based steering committee. It has building codes for most countries including US, Britain, Canada, Australia, France, Germany, Spain, Norway, Finland, Sweden, India, China, Euro Zone, Japan, Denmark and Holland. More are constantly being added. Besides, it supports multi-material design codes such as timber, steel, cold-formed steel, concrete and aluminum. Over the past 20 years, the users have designed everything from residential buildings to skyscrapers to tank to tunnel etc. Complex models can be quickly and easily generated through powerful graphics, text and spreadsheet interfaces that provide interactive model generation, editing and analysis.

In STAAD Pro, a structure can be defined as an assemblage of elements.

STAAD can be used to analyze and design structures consisting frame, plate/shell and solid elements. Almost all types of structure can be analyzed by STAAD. Among them are:

a) A space structure, the most general structure which is a three dimensional framed structure with loads applied in any plane.
b) A plane structure within the global X-Y coordinate system with loads in the same plane.
c) A truss structure consists of truss members who can have only axial member forces and no bending in the members.
d) A floor structure where it is in two or three dimension and does not have horizontal movement of the structure. Columns can also be modeled with the floor in a floor structure as long as the structure has no horizontal loading, else it must be considered as a space structure.

STAAD Pro does implement stiffness analysis method where the structure is first idealized into an assembly of discrete structural components (frame members or finite elements). Each component has an assumed form of displacement which satisfies the force equilibrium and displacement compatibility at the joints. The number of equations to be solved can be reduced by determining the correct types of structures for the analysis. This results in faster and more economic solutions for the user.

2. MATERIALS AND METHODS

Loads

The forces that act on a structure are called loads. For the safe design of structure, it is essential to have knowledge of various types of loads and their worst combinations to which it may be subjected during its life span. The loads on trusses would depend upon the application for which the trusses are used. In the present application we would discuss about loading on roof truss and the loads under consideration are dead load, live load and wind load.

3. TUBULAR SECTION

Tubular section forms the most efficient sections for some of the structural elements. The economy of steel tube construction is incomparable. The large span roof trusses with tube sections have smaller self-weight and many a times the supporting R.C.C. columns may even be replaced by masonry columns deriving considerable economy. The use of tubes as compression member was limited over decades due to the difficulty in making connections with rivets/bolts. But with development of welding techniques its use has become frequent for reasons. Structural hollow sections are especially suitable for compression and torsion members. Lateral buckling and torsional buckling are not usually limiting phenomenon.

Truss Profiles

Basically the 23 candidate profiles of trusses can be categorized into 5 groups as in
figures below:
(a) Trusses with constant slope [Truss 1 to Truss 8]
(b) Trusses with various slopes [Truss 9 to Truss 12]
(c) Trusses with slope and horizontal top chords [Truss 13 to Truss 16]
(d) Trusses with horizontal top chords [Truss 17 to Truss 20]
(e) Nonsymmetrical trusses [Truss 21 to Truss 23]

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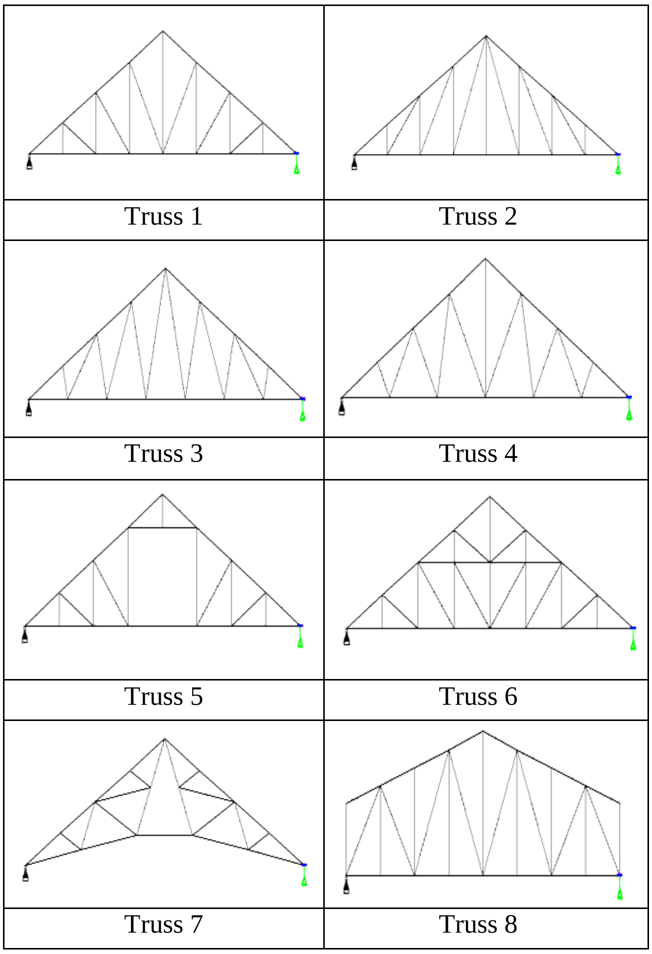

Figure 3.1Trusses with constant slopes [Truss 1 to Truss 8]

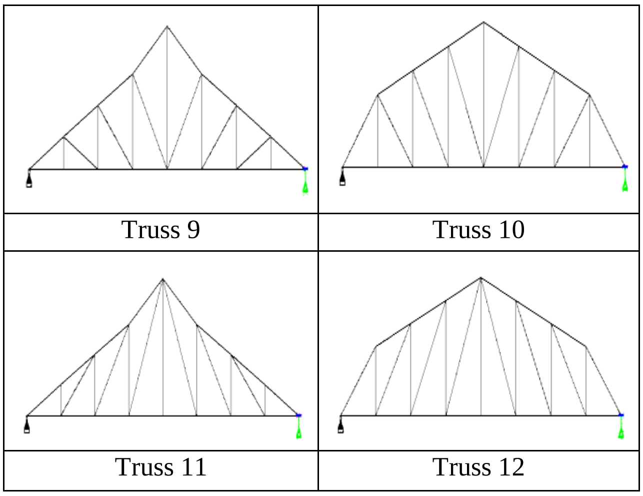

Figure 3.2Trusses with various slopes [Truss 9 to Truss12]

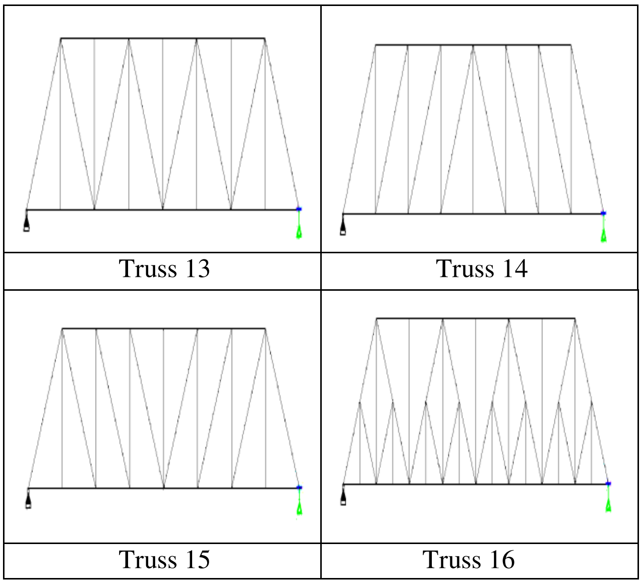

Figure 3.3Trusses with slope and horizontal top chords [Truss 13 to Truss 16]

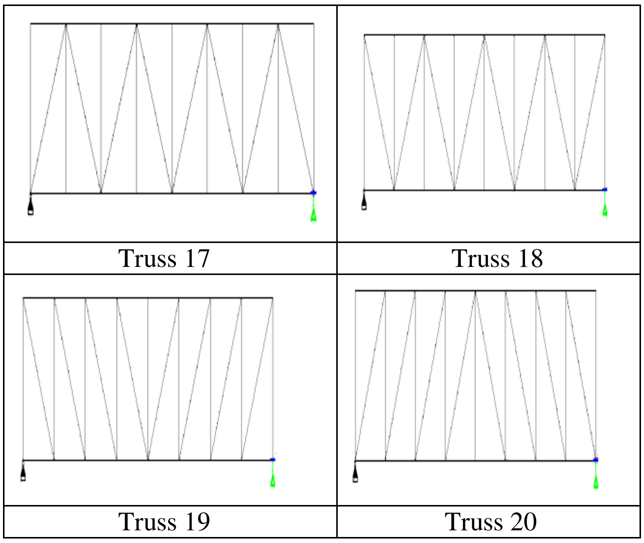

Figure 3.4 Trusses with horizontal top chords [Truss 17 to Truss 20]

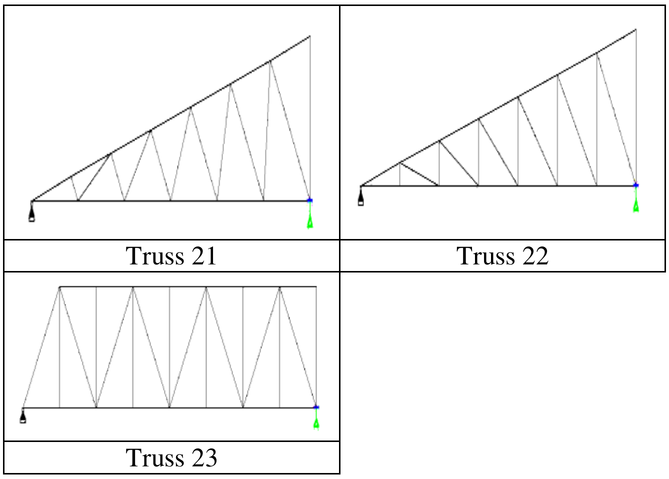

Figure 3.5 Nonsymmetrical trusses [Truss 21 to Truss 23]

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4. SUMMARY OF LIGHTEST TRUSS FOR EACH GROUP

From the analysis results, summary in which truss of lightest mass from each group is obtained. Truss profile with least optimal mass and corresponding practical mass for different span and rise is shown in Table 4.1-4.4. Percentage difference of mass for so obtained optimal and practical truss is also shown.

Table 4.1 Truss profile with lightest mass for each group of span 12m

Group	Rise	Optimal truss (mass in kg)	Practical truss (mass in kg)	Difference (%)
Group I	1.5m	Truss 08 (143.63)	Truss 03 (162.79)	13.34
Group II		Truss 12 (135.68)	Truss 12 (146.48)	7.96
Group III		Truss 13 (120.08)	Truss 13 (164.83)	37.27
Group IV		Truss 17 (133.13)	Truss 19 (170.34)	27.95
Group V		Truss 23 (128.03)	Truss 23 (176.86)	38.14
Group I	2.5m	Truss 05 (109.17)	Truss 03 (133.64)	22.41
Group II		Truss 10(113.56)	Truss 10 (125.69)	10.68
Group III		Truss 15 (151.38)	Truss 16 (187.46)	23.83
Group IV		Truss 17 (158.82)	Truss 19 (212.23)	33.63
Group V		Truss 23 (155.05)	Truss 23 (229.26)	47.86
Group I	3.5m	Truss 05 (102.75)	Truss 05 (117.64)	14.49
Group II		Truss 09 (118.45)	Truss 09 (158.61)	33.90
Group III		Truss 13 (208.77)	Truss 14 (310.91)	48.92
Group IV		Truss 17 (231.80)	Truss 18 (299.29)	29.11
Group V		Truss 21 (160.14)	Truss 21 (249.13)	55.57

Table 4.2 Truss profile with lightest mass for each group of span 17m

Group	Rise	Optimal truss (mass in kg)	Practical truss (mass in kg)	Difference (%)
Group I	1.5m	Truss 08 (367.38)	Truss 03 (530.58)	44.42
Group II		Truss 10 (341.39)	Truss 10 (380.63)	11.49
Group III		Truss 13 (274.31)	Truss 16 (417.94)	52.36
Group IV		Truss 17 (284.40)	Truss19 (399.60)	40.51
Group V		Truss 23 (280.63)	Truss 23 (449.95)	60.33
Group I	2.5m	Truss 08 (277.98)	Truss 03 (348.01)	38.14
Group II		Truss 10 (243.43)	Truss 10 (282.67)	16.11
Group III		Truss 13 (280.83)	Truss 16 (400.31)	42.54
Group IV		Truss 18 (296.94)	Truss 19 (415.70)	39.99
Group V		Truss 23 (289.40)	Truss 23 (514.78)	77.88
Group I	3.5m	Truss 05 (234.86)	Truss 06 (305.91)	30.25
Group II		Truss 10 (249.95)	Truss 10 (295.51)	18.23
Group III		Truss 16 (377.78)	Truss 16 (482.67)	27.76
Group IV		Truss 17 (384.19)	Truss 17 (639.04)	66.33
Group V		Truss 21 (378.39)	Truss 23 (618.76)	63.52

Table 4.3 Truss profile with lightest mass for each group of span 22m

Group	Rise	timal truss (mass in kg)	Practical truss (mass in kg)	Difference (%)
Group I	1.5m	Truss 08 (758.31)	Truss 03 (1161.57)	53.18
Group II		Truss 10 (582.57)	Truss 10 (777.67)	33.49
Group III		Truss 13 (529.76)	Truss 16 (852.80)	60.98
Group IV		Truss 18 (541.79)	Truss 19 (808.66)	49.26
Group V		Truss 23 (540.26)	Truss 23 (885.12)	63.83
Group I	2.5m	Truss 08 (542.71)	Truss 03 (771.25)	42.11
Group II		Truss 12 (470.23)	Truss 10 (567.79)	20.75
Group III		Truss 13 (472.17)	Truss 16 (769.62)	62.99
Group IV		Truss 17 (487.36)	Truss 19 (839.35)	72.22
Group V		Truss 23 (483.68)	Truss 23 (838.12)	73.28
Group I	3.5m	Truss 05 (469.32)	Truss 03 (621.81)	32.49
Group II		Truss 10 (438.84)	Truss 10 (542.61)	23.65
Group III		Truss 13 (565.85)	Truss 16 (875.94)	54.80
Group IV		Truss 17 (583.28)	Truss 18 (930.27)	59.49
Group V		Truss 23 (579.31)	Truss 23 (991.95)	71.23

Table 4.4 Truss profile with lightest mass for each group of span 27m

GROUP	Rise	Optimal truss (mass in kg)	Practical truss (mass in kg)	Difference (%)
Group I	1.5m	Truss 08 (1404.28)	Truss 03 (1528.24)	8.83
Group II		Truss 10 (1047.60)	Truss 10 (1432.01)	36.69
Group III		Truss 13 (882.06)	Truss 14,15 (1391.74)	55.78
Group IV		Truss 19 (836.69)	Truss 19 (1305.40)	56.02
Group V		Truss 23 (885.12)	Truss 23 (1447.29)	63.51
Group I	2.5m	Truss 08 (906.32)	Truss 03 (1299.89)	43.42
Group II		Truss 10 (769.42)	Truss 10 (1024.06)	33.10
Group III		Truss 13 (738.94)	Truss 13 (1235.78)	67.24
Group IV		Truss 17 (754.43)	Truss 18,19 (1225.58)	62.45
Group V		Truss 23 (715.59)	Truss 23 (1231.80)	72.14
Group I	3.5m	Truss 08 (757.45)	Truss 03 (1086.03)	43.38
Group II		Truss 10 (713.45)	Truss 10 (905.61)	26.93
Group III		Truss 13 (820.18)	Truss 16 (1362.18)	66.08
Group IV		Truss 17 (842.81)	Truss 18 (1434.96)	70.26
Group V		Truss 23 (833.94)	Truss 23 (1455.45)	74.53

The table of results summary shows that by using tubular section, truss 10 and truss 23 in group II, group V, respectively is mostly effective truss profile in term of material by having least difference in its practical mass and optimal mass compared to others regardless the span and rise of the truss. However trusses in group IV and V are least effective in term of material mass compared to other groups. The variation between optimal lightest mass and practical lightest mass is large and can reach up to

80%. The percentage difference of optimal lightest mass and practical lightest mass is also increased with the increase in span of truss. Besides, the optimal lightest mass and practical lightest mass vary from 4.13% to 80% which shows that truss with optimal light mass might not always be practical to use in term of member arrangement.

Proposed Effective Truss profiles to be Used Practically

Based on the above results and discussions, there are some effective trusses in term of material to be proposed in the practical usage for certain spans, rises and span over depth ratios. They are shown in Table 4.6 according to the different spans and rise.

Table 4.6 Proposed Trusses

Span and rise	Group I	Group II	Group III	Group IV	Group V
Span = 12m Rise = 1.5m	03	12	13	19	23
Span = 12m Rise = 2.5m	03	10	16	19	23
Span = 12m Rise = 3.5m	05	09	14	18	21
Span = 17m Rise = 1.5m	03	10	16	19	23
Span = 17m Rise = 2.5m	03	10	16	19	23
Span = 17m Rise = 3.5m	06	10	16	17	23
Span = 22m Rise = 1.5m	03	10	16	19	23
Span = 22m Rise = 2.5m	03	10	16	19	23
Span = 22m Rise = 3.5m	03	10	16	18	23
Span = 27m Rise = 1.5m	03	10	14,15	19	23
Span = 27m Rise = 2.5m	03	10	16	18,19	23
Span = 27m Rise = 3.5m	03	10	16	18	23
12m<span<27m Rise = 1.5m	03	10	16	19	23
12m<span<27m Rise = 2.5m	03	10	16	19	23
12m<span<27m Rise = 3.5m	3,5,6	10	16	17,18	23

The selection of proposed trusses above is based on the least practical masses of trusses which are suitable to use practically and found economical without wastage of much material. In this selection, trusses which are considered efficient to use are those with least practical mass and less percentage difference of masses in each relevant group.

5. SUMMARY AND CONCLUSIONS

Summary

In the present study, thirty candidate truss profiles has been selected which are categorized in five groups based on slope and layout of top chord. The different geometries are analyzed and designed for varying span from 12m to 27m with increment of 5m and rise of truss varying from 1.5m to 3.5m with constant spacing of 5m, height of column 10m, normal permeability with 5% openings in relation to wall area, wind zone with basic wind speed of 47m/s, purlin spacing of truss in each group is also fixed accordingly. The design of truss is carried out with the aid of STAAD.Pro V8i using steel tubular section. The optimal and practical mass of each truss is computed.

CONCLUSIONS

Based on the investigation undertaken, the following conclusions can be drawn for steel roof trusses. The items investigated relate to total mass of truss, effective truss profile, optimal truss profile that can be used practically and the resulting economy. The following conclusions are drawn on the basis of the study.

1. This study can be used to determine the most effective truss profiles in term of mass among the thirty candidate fixed geometry of profiles, in the design of trusses using steel tubular section for certain spans and rises. It will later help to save the time of design by avoiding the efforts of trial and error.
2. This study will be able to help, to compare the cost of material of the different truss profiles normally used in the construction industry by considering the price rate per unit mass of truss.
3. The same optimum profile of truss cannot be applied to other different spans, rises and span over depth ratios. However it can be used as a guideline where there are a few truss profiles that often give lighter mass than others. For instance, among the thirty candidate trusses, Truss 3 and 8 are considered most effective in Group 1; Truss 9 and 10 for Group II; Truss 13 and 16 for Group III; Truss 17 and 18 for Group IV and; Truss 23 for Group V.
4. Out of all twenty three candidate trusses, Truss 08 is found most effective not only in terms of least optimal and practical mass but also least difference in5 the masses 4.13%-41.28%), regardless the span and rise of the truss. This makes that truss most suitable for practical purpose without wastage of much material.
5. As the rise of truss increases both its optimal and practical mass decreases, except for the case of trusses in Group III and IV (i.e. trusses having horizontal top chord). This concludes that for truss having horizontal top chord, rise must be chosen as minimum recommended.
6. Among all the groups, trusses of Group V (Non-symmetrical trusses) prove uneconomical. As the trusses in this group are having most optimal and practical mass and their percentage mass differences varies as much as 165.57%, which makes them least effective compare to trusses from rest of groups.
7. This study is a simple and primitive method (trial-and-error method) that helps to choose the optimal truss profiles among the candidate profiles and is suitable to be applied to other similar studies.

Apart from the conclusions that can be made based on the objectives of the study, a few observations can also be obtained as parts of conclusions:

a. Each truss type has its own effective rise or its own effective span over depth ratio which differs from others.

b. The trusses which are effective in distributing load to their members might not be practical to use in the construction of real structures.

c. Standardization of member sizes will increase the mass of material but the sections are not utilized and thus cause a lot of wastes.

6. SCOPE OF FURTHER STUDY

This study can be continued for particular truss profiles by using different spans and rise to determine the optimal rise or optimal span over depth ratio for a single particular truss type. The spans and rises of trusses can be grouped to be more specific. For example we can use spans 15m, 20m, 30m, and 35m and rise 1.2m, 2.8m, 3m and 3.5m which are not much different to determine the limit where the optimal trusses can be applied. The study can also be carried out for other types of sections such as double angle section and circular hollow section in order to compare the effective trusses among different sections under various spans and rises.

REFERENCES

[1] Duggal S.K., "Limit State Design of Steel Structures" edition No. 5. 7 west patel Nagar, New Delhi, Tata McGraw hill. 2009
[2] India. IS 800-2007, "Code for practice for general construction in Steel third revision". Bahadur shah Zafarmarg New Delhi. Bureau of Indian standard.
[3] India. IS: 875 (Part 1-3) "Code of practice for Design loads (other than earthquake) for building and structures". Bahadur shah Zafarmarg New Delhi. Bureau of Indian standard.
[4] India. SP: 38 (S&T) "Handbook for typified designs for structures for steel roof trusses", bahadur shah Zafarmarg, New Delhi. Bureau of Indian standard. 1987
[5] India. SP: 64 (S&T) "Explanatory Handbook on Indian standard code of practice for design load (other than earthquake) for buildings and structures", bahadur shah Zafarmarg, New Delhi. Bureau of Indian standard.
[6] Templemen Andrew B. "A Dual Approach to Optimum Truss Design". 1976
[7] Prager William, "Geometric Discussion of the Optimal Design of a Simple Truss". 1976
[8] Lipson Samuel L. and Agarwal Krishna M. "Weight of optimization of plane truss", 1974
[9] Thomas H. Randolph, Jr and Brown Daniel M. "Optimum Least-Cost Design of a Truss Roof System".1977
[10] Saka M.P. "Profile optimization of trusses", 1980
[11] Saka M.P., "Minimum cost topological Design of trusses" 1981

[12] Saka M.P, "Optimum geometry design of roof trusses by optimality criteria method". 1991
[13] Rajasekaran S. "Computer Aided Optimal Design of Industrial Roof", 1983
[14] Ohsaki M. "Genetic Algorithm for Topology Optimization of Trusses". 1994
[15] Gil Lluis and Andreu Antoni, "Profile and cross-section optimization of a truss structure" 2001
[16] Yunus Weniyarti Bt. "To Investigate the Effects of Different Truss Shapes on Design. 2005
[17] Punmia B.C. Jain A. K "Design of Steel Structures" edition No. 2.113, Golden house, Darya Ganj, New Delhi Laxmi Publications 1998
[18] Reddy C.S. "Basic structural analysis" edition No. 3.7 west patel Nagar, New Delhi, Tata McGraw hill.(P46-P72), 2011
[19] Duggal S.K. "Design of Steel Structures" edition No. 3. 7 west patel Nagar, New Delhi, Tata McGraw hill.(P69-P70, P808-P819), 2009