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ARCHED HOLLOW SECTION TRUSSES IN LONG SPAN STRUCTURES

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Abstract: *The following article's main goal is to provide insight in the utilisation of arched hollow section trusses for the creation of long span structures. It will emphasize on the importance of defining the optimal height of the truss. This is why the authors try to give an aid in the selection of the truss height by presenting several methods for it. This paper will conclude by defining the most effective methods for choosing the truss height, as well as the range of variation for this dimension of the structure.*

Key words: *arched truss, circular hollow section, optimal design, weight.*

1. Introduction

Every construction which creates a column-free place greater than 20-30 m could be defined as a long span structure.

The need to create these unobstructed places derives from the buildings functionality. Generally long span structures appear when the construction houses activities where visibility is important for large audiences (auditoriums and covered stadiums), where structural flexibility is needed (exhibition halls and certain types of manufacturing facilities), and where large movable objects are housed (aircraft hangars).

Because of the limitations of the regular reinforced concrete's (RC in the following) bearing capability for the creation of long span structures several other materials or combinations of materials could be used. Usually the long span structures are created either by using precast concrete elements, steel structures, timber structures, some special type of plastic material or by using combinations of materials (e.g. RC+ Steel).

In order to cover these great distances several structural systems could be used. These are the following:

- cable stayed structures,
- tent structures,
- pneumatic structures,
- arches,
- portal & other frame structures,
- diagrid structures,
- shell structures,
- different types of trusses,
- tensegrity structures.

This article will focus on the utilisation of arched hollow section trusses for the creation of long span buildings.

2. Objectives

The main goal of this article is to find the optimal height of an arched truss structure for different span lengths. To demonstrate the proposed objective of this paper there will be considered a building with a bay

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length of 5 m and the following span dimensions: 10 m, 20 m, 30 m, 40 m, 50 m, 60 m.

The secondary objective is to prove the higher efficiency of this structural type compared to multi-span structures, covered with multiple trusses.

2.1. The Method Used for Evaluation

For evaluating purposes as a first step there will be calculated the weights per afferent surface (kg/m^2) of the arched trusses for every span length.

The efficiency of the structure will be calculated using a simplified method. The simplification will consist of considering only the weight of the main trusses (the weights of the purlins, braces and columns will be neglected).

Basically the efficiency of the structure will be measured by dividing the weight of a structure composed of multiple trusses with the length of 10 m (multi span structure) to the weight of a single hollow section truss which covers the whole span.

3. Materials and Structural System

3.1. Materials

In order to create the arched trusses the following structural steel grades were used: S235, S275. These were preferred because of their higher ductility compared to other steel grades.

3.2. Structural System

Description of the adopted structural system

The steel trusses used to cover these long distances have curved chord members. As an independent structure each truss mimics the shape of a fish (Figure 1). Using this nature inspired form makes possible to cover these large distances.

As mentioned before the trusses will have a length between 10 and 60 m. The distances between the joints supporting the purlins will be of 1.5, respectively 2 m.

The height of each truss will be determined so that it will lead to the lowest possible steel consumption/ structural weight. The modality of determining the optimal height of the steel trusses will be discussed throughout Chapter 4.

Steel sections used for creating the arched trusses

The trusses will be made of circular hollow section (CHS) members. These sections were preferred over others because of their obvious advantages in the case of tension/compression loads, as well as in the case of bending moments.

Particularities of the arched trusses

Usually the members of straight chorded trusses are considered (and modelled) as pin ended elements. In this way these elements will only be affected by the action of the axial forces transferred through the loaded joints.

The joints of arched trusses can be designed in a similar way to those of straight chord trusses. If the arched chords are made by bending at the joint location only the chord members can also be treated in a similar way to those of straight chord trusses provided that the bending radius remains within the limitations to avoid distortion of the cross section. If the arched chords are made by continuous bending, the chord members have a curved shape between the joint locations, as shown in Figure 2.

In this case, the curvature should be taken into account in the member design by treating the chord members as beam-column [2-4]. In order to treat the chord members as beam-columns the bending moment given by the eccentricity of the chord member's axis from the straight line

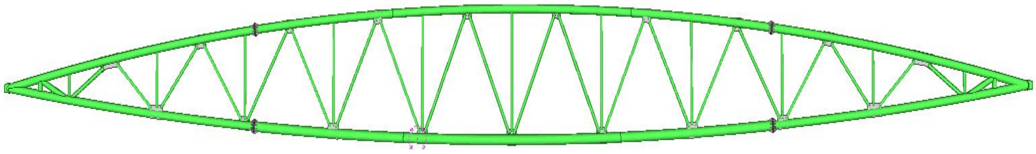

Fig. 1. *Fish-shape arched truss structure with CHS members*

joining the two end points of the frame should be considered during the design process, which could be calculated using the following formula:

$$M_{Ed} = N_{Ed} e . \tag{1}$$

4. Results and Discussions

As stated in the 2nd Chapter the main goal of this article is to find the optimal solutions, those with the lowest material consumption, for various span lengths. As it is obvious the cost of a building is in direct relation with its weight (the lower the weight the cheaper the structure). This is why the main goal of all the structural engineers is how to design a building which fulfils all of the building code requirements and has the lowest possible weight, and in consequence the smallest amount of investment during the construction process.

In order to find the optimal solutions for the proposed objectives several structural models have been analysed. Because of the large computational volume the analysis and design of each truss has been carried out using one of the industry leading finite element analysis software.

4.1. Finding the Optimal Height of the Arched Trusses

Finding the optimal height of the arched trusses isn't an easy job. It could be very much time consuming, mainly because of its iterative nature. Fortunately nowadays the most of the finite element analysis software have designing capabilities to, which reduces the time needed for the design process. In order to speed up even more the design process the starting height of the trusses should be chosen carefully by using one of the following methods.

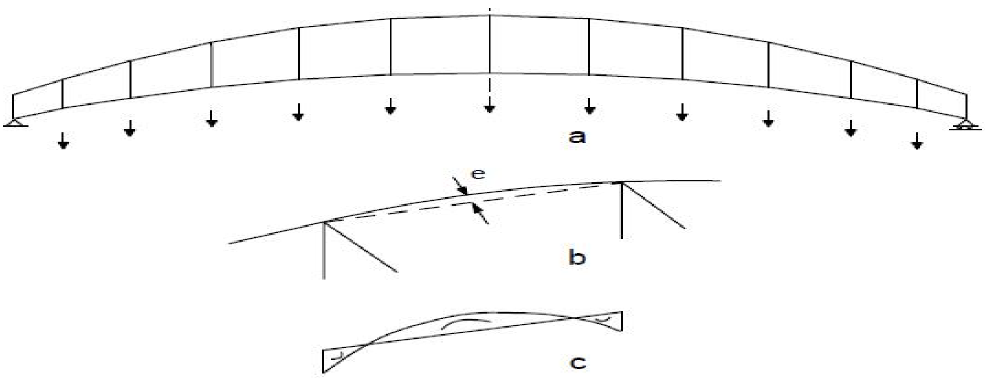

Fig. 2. *Arched trusses*

The first method is based on the cumulated experience of the engineering community. It consists of selecting the truss height as a fraction of the span length. Besides its easy to use form this method provides reasonably good results regarding the structural weight to. According to [1] the overall height of the steel trusses with curved chord members should be taken between the following intervals:

$$h = \left(\frac{1}{12} \div \frac{1}{18}\right) L . \tag{2}$$

The second method is based on using mathematical relations to determine the height of the truss. There are several empirical formulas recommended mainly for straight and parallel chord members. Those relations could also be adopted, with good results, for the design of the arched trusses.

The following relations could be used to define the optimal height of the trusses in order to obtain the necessary stiffness of the structure [1]:

$$h \geq \frac{L^2}{5190 f_a - 2L} , \tag{3}$$

$$h \geq \frac{L}{3.7 \frac{f_a}{L} \frac{E}{\sigma} - 2} . \tag{4}$$

Formulas (3) and (4) result in a truss which has the deformations in the admissible range of the building codes.

In order to yield an optimal steel consumption for the trusses [1] recommends the utilisation of the following relation for the determination of the overall height:

$$h \geq k \frac{L}{m} \sqrt{0.7m + 1} . \tag{5}$$

The recommended optimal heights of the trusses for each span length are presented in Table 1.

Starting from the results presented in Table 1 several structural models, with different overall height, have been created. These models have been analysed and designed using a finite element analysis software. At the end of each step the weight of the structure per afferent surface has been determined. Finally these calculations resulted in the optimal heights and weights of the trusses presented in Table 2.

Recommended minimal truss height for a low steel consumption Table 1

ID	Span length [m]	Optimal height [mm] according to			
		Eq. (2)	Eq. (3)	Eq. (4)	Eq. (5)
T1	10	666.67	533.05	890.83	3012.27
T2	20	1333.33	1066.1	1781.65	4016.37
T3	30	2000	1599.15	2672.48	4815.45
T4	40	2666.67	2132.2	3563.31	5499.64
T5	50	3333.33	2665.25	4454.13	6107.65
T6	60	4000	3198.29	5344.96	6660.39

Characteristics of the trusses resulted after the design process Table 2

ID	Span length [m]	Height of the truss [mm]	Weights of the single long span trusses	
			Total [kg]	Per afferent surface [kg/m^2]
T1	10	900	294.86	5.897
T2	20	3500	646.14	6.461
T3	30	4200	1718.4	11.456
T4	40	5400	3646.42	18.232
T5	50	4400	5353.91	21.416
T6	60	7600	8807.94	29.360

4.2. Determining the Efficiency of the Design Process

As mentioned in the earlier chapters the efficiency of the single long span truss structure to the multi-truss system could be measured by dividing the weight of the multi-truss structure to that of a single truss which covers the entire span.

In order to demonstrate the weights of the trusses have to be determined. These pertinent results could be found in Table 2.

The compared weight of the multi-truss structure to those of the single long span trusses could be found in Table 3.

Analysing the results of the design process lead to the conclusions presented in the following chapter.

Table 3

Comparison between the weight of the multi- and the single truss systems

ID	Span length[m]	Weight of the multi-truss structure per afferent surface [kg/m^2]	Weight of the single truss structure per afferent surface [kg/m^2]
T1	10	5.897	5.897
T2	20	11.794	6.461
T3	30	17.691	11.456
T4	40	23.588	18.232
T5	50	29.485	21.416
T6	60	35.382	29.360

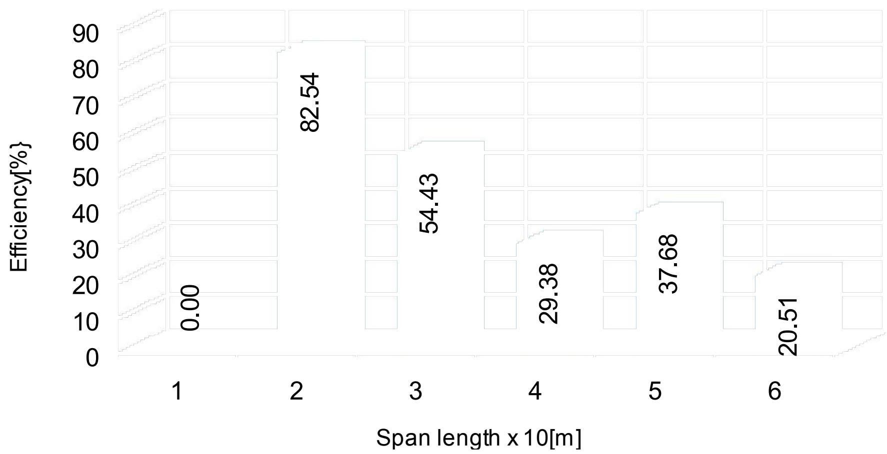

Fig. 3. *Efficiency of the single truss structure compared to the multi-truss system*

5. Conclusions

The optimal height of a curved truss composed of CHS members could be calculated in the best way using the above mentioned mathematical relations.

It is recommended especially using formulas (4) and (5), which lead to a truss height close to the optimum. As a simplification the height of the truss could be taken in a higher range from that previously mentioned in Eq. (2). The recommended truss height could be found somewhere in the interval of $(1/8 \div 1/12) \cdot L$.

As of the secondary objective of this paper it could be concluded that using a single long span truss is more efficient that a building divided in multiple spans covered by a multi-truss structure. The higher efficiency of the single long span truss compared to the multi truss system is presented in Figure 3. Analysing the results presented there it could be concluded that the single trusses are generally 37% more efficient.

It is worth to mention that although a higher truss gives a lower steel consumption it also has a couple of secondary effects on the structure.

First of all, it leads to an increase in the entire structural height.

Second, an excessive height of the truss will automatically create difficulties during the transportation and/or erection process. This is why the height of the steel trusses should be adopted in a thoughtful way, bearing in mind, even from the start of the design process, the secondary effects caused by an excessively high truss on the construction process.

6. List of Symbols Used in the Article

M_{Ed} - design bending moment of the chord member;

N_{Ed} - axial force in the chord member;

e - eccentricity of the curved chord member;

h - height of the truss;

L - span length;

f_a - admissible deformation of the truss (the recommended value of the admissible deformation is $L/250$);

E - modulus of elasticity (also known as Young's Modulus), $E = 2.1 \cdot 10^5$ MPa (given for steel);

σ - the value of the normal stress in the chord members;

k - coefficient which considers the geometry of the truss: $k = 1$ for triangular trusses, $k = 0.71$ for trusses constructed with posts and alternating brace members, $k = 0.58$ for trusses made from posts and descending brace members only;

m - number of the truss panels.

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