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Research on Type Selection of Truss Bridge Structure Based on Optimization Design

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Abstract. Truss selection design is an important link in both theoretical research and practical engineering problems. The topic of this study is truss selection based on optimization design. Firstly, this paper analyzes the mechanical properties. Then, the material ratios of the three different truss structures are studied by changing the axial force data of the three members using the structural mechanics solver. Finally, through comprehensive analysis and system optimization consideration, the conclusion is drawn that the parallel truss has better performance than the triangular truss and the parabolic-like truss. Through the comparison of three common truss structures and the comprehensive consideration of force analysis, the different advantages and disadvantages of the three trusses are obtained, which provides reference for the selection design of trusses. This paper aims to provide an effective reference for the optimization design of trusses, and also provides inspiration for other professionals to study more types of trusses in the future.

Keywords: Truss, selection, design, optimization.

1. Introduction

At present, trusses have been widely used in various fields of engineering and are the most widely used in steel structures [1]. For example, the main parts of the construction of the huge inclined arch and the long-span truss roof of Xiamen new Stadium are truss structures [2]. In addition, the awning cable structure of the Barracuda Bay professional football stadium in Dalian also adopts a large number of truss structure design [3]. In addition, the main bridge of Qingshuitang Bridge adopts the design of long-span steel truss arch bridge [4].

Trusses are stressed by nodes, that is, the force on the chain rod will eventually converge to the node, and the members only bear the axial tension and pressure. Therefore, the truss is stable and not easy to deform. Moreover, the designer of the truss can appropriately reduce the self-weight on the premise of ensuring the rigidity, so it has certain economic benefits [1]. The design and selection of trusses plays an important role in practical engineering construction and plays an important role in solving practical engineering problems.

The truss system can be classified from many aspects, such as the arrangement of the belly bar, whether the support has thrust or not. In terms of appearance, trusses can be divided into five categories: triangle, trapezoid, parabola, broken line and parallel string shape [5]. However, at present, in the field of truss design, the selection of truss structure and geometric form is more based on personal experience and lacks systematic and scientific scientific demonstration and theoretical support [6]. This paper mainly discusses the selection of truss bridge structure based on optimal design. According to the design requirements of a certain project, the materials and economic analysis of triangular, parabolic and parallel trusses are carried out. By changing the different geometric forms of the trusses and using the control variable method, the different properties of three different trusses under the same load are explored by controlling several factors unchanged. By establishing a geometric model and comparing the mechanical properties of different geometric forms, the designer provides suggestions for the selection of the truss geometric structure.

2. Research Methods

2.1. Research Object

A bridge is built on the 80m wide river surface with a truss structure, where the water surface of the river is 15m from the horizon and the riverbed is 25m from the horizon. A complete space of 5m high and 50m wide should be reserved under the bridge for ships to pass. In order not to affect the appearance of the truss, the distance above the ground plane should not exceed 8m. The load is 150KN/m. The minimum size of the solid square cross-sectional chain rod is 0.01m, and the allowable strength of the material is 400MPa, considering the stability of the compression rod. The elastic modulus of the material is 200GPa.

2.2. Truss Design

The optimization method adopted in this paper is to control the same area surrounded by the three types of truss bridge, the same span, apply the same load at the joints on the chord, and compare the material size of the three types of trusses. The optimization goal is to use the least number of materials. The constraint, material and load Settings in the structural mechanics solver are as follows:

(1) Constraints are set to make the bridge a statically indeterminate structure, which is verified by the structural mechanics solver.

(2) Material properties are set, because the three bridges are statically determinate structures, and the purpose of the experiment is to compare the amount of materials used in the three truss bridges. Therefore, the setting of material properties as long as it is consistent.

(3) According to the engineering background, the load is set at 150KN/m. According to the calculation, when the load is applied to the outer and peripheral nodes of the truss, nodes 11 and 1 require 637.5N load, while nodes 12 to 20 require 1275N load.

2.2.1. Parallel truss design

According to the design requirements of the engineering background, a parallel truss with span of 80m, internode number of 10 and height of 5m is drawn by using the structural mechanics solver, as shown in Fig. 1. The parallel truss is formed by the connection of binary bodies, and the area surrounded by the truss can be calculated to be 360 square meters. The area enclosed by the triangular and parabolic trusses is the same as that of the parallel trusses.

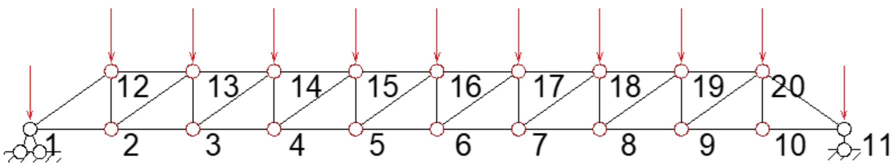

Figure 1. Parallel trusses

2.2.2. Parabolic-like truss

With Node 1 as the origin, the horizontal direction as the X-axis, and the vertical direction as the Y-axis, a plane rectangular coordinate system is established to construct a parabola with an area of 360 square meters through the origin and the point (80,0). Through calculation, the equation of the parabola is calculated, and the coordinates of nodes located on the parabola on the truss bridge are calculated. The coordinates from Node 12 to Node 20 are (8, 2.6) (16, 4.6) (24, 6) (32, 6.9) (40, 7.2) (48, 6.9) (56, 6) (64, 4.6) (72, 2.6). According to the calculated coordinates, the parabola-like truss diagram is drawn by the structural mechanics solver, as shown in Fig. 2.

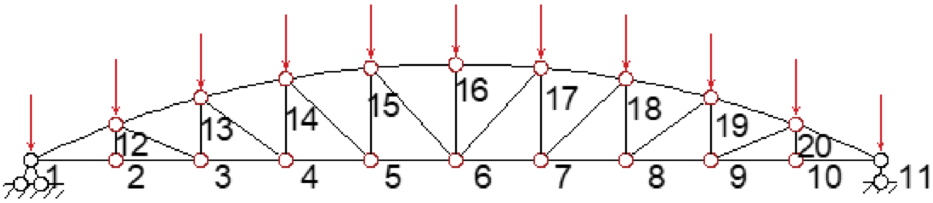

Figure 2. Parabolic truss

2.2.3. Triangular truss

Through the triangular area formula, the height of the truss should be 9m. Since the number of internodes of the truss is 10, the coordinates of each point on the chord can be easily obtained. From Node 12 to Node 20, they are successively (8, 1) (16, 2) (24, 3) (32, 4) (40, 5) (48, 4) (56, 3) (64, 2) (72, 1). According to the calculated coordinates, the triangular truss diagram is drawn by the structural mechanics solver, as shown in Fig. 3.

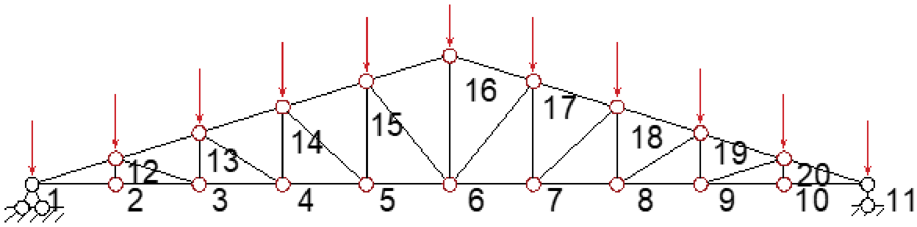

Figure 3. Triangular truss

3. Results and Discussion

3.1. Results

Using the structural mechanics solver to output the axial force data of each member of three different truss types, the amount of materials used in the three trusses can be calculated according to Eq. 1 and Eq. 2. According to the Eq. 1, the cross-sectional area of the member is proportional to the axial force.

$$Ai = \frac{N\mathrm{i}}{f_y}. \tag{1}$$

$$v_i = A_i L_i. \tag{2}$$

where: A_i is the cross-sectional area of the member bar, and the unit is square meter;

N_i is the axial force of the member bar, and the unit is Newton;

f_y is a constant number;

v_i is the size of the member bar, and the unit is cubic meter;

L_i is the cross-sectional area of the member, and the unit is meter.

Among them, the axial force output results of parallel trusses are shown in Table 1. The axial force output results of parabolic trusses are shown in Table 2. The axial force output results of the triangular truss are shown in Table 3.

Table 1. Axial force calculation results of parallel truss

Unitary code	Axial force	Unitary code	Axial force
1	-8568.0000	11	-10825.4933
2	-1428.0000	12	-9180.0000
3	3672.0000	13	-16320.0000
4	6732.0000	14	-21420.0000
5	7752.0000	15	-24479.9999
6	6732.0000	16	-25500.0000
7	3672.0000	17	-24480.0000
8	-1428.0000	18	-21420.0000
9	-8568.0000	19	-16320.0000
10	-8568.0000	20	-10825.4933

Table 2. Axial force calculation results of parabolic truss

Unitary code	Axial force	Unitary code	Axial force
1	17635.8461	11	-18562.7904
2	17635.8461	12	-18285.0771
3	17739.1304	13	-18121.2669
4	17850.0000	14	-17851.0329
5	17739.1304	15	-17720.7801
6	17739.1304	16	-17720.7801
7	17850.0000	17	-17851.0329
8	17739.1304	18	-18121.2669
9	17635.8461	19	-18285.0771
10	17635.8461	20	-18562.7904

Table 3. Axial force calculation results of triangular truss

Unitary code	Axial force	Unitary code	Axial force
1	25520.0000	11	-26137.5000
2	25520.0000	12	-23233.3333
3	22666.6666	13	-20329.1666
4	19833.3333	14	-17425.0000
5	17000.0000	15	-14520.8333
6	17000.0000	16	-14520.8333
7	19833.3333	17	-17425.0000
8	22666.6666	18	-20329.1666
9	25520.0000	19	-23233.3333
10	25520.0000	20	-26137.5000

3.2. Discussion

Based on the data calculated by the structure solver, the material sizes of the three trusses can be obtained according to Eq. 1. Because the three kinds of truss Bridges bear the same load and have the same span, the one with the least material has more economic advantages. It is calculated that the material volume ratio of parallel truss, triangular truss and parabolic truss is about: 1934080.74:1902725.052:1483847.1956. Therefore, from the perspective of saving materials and saving construction investment funds, the selection of parabolic trusses has a higher cost performance among the three types of trusses.

From the point of view of mechanical performance, triangular truss is superior to parabolic truss with same span and load. Because the structure of the triangular truss is more stable, it can better distribute the load and reduce the impact of the load on a single member, thereby improving the bearing capacity and stability of the entire structure. However, the structure of parabolic truss is relatively complicated, the load distribution is not uniform, and the local stress is easy to appear too large, which affects the stability and bearing capacity of the whole structure. Therefore, from the point of view of mechanical performance, the triangular truss is the better choice.

Compared with the parallel string truss and the triangular truss, the triangular truss uses slightly less material than the parallel string truss. However, considering that the two surround the same area, the height of the triangular truss bridge is as high as nine meters, which has a little impact on the beauty, and the construction difficulty of the parallel string truss is much lower than that of the triangular truss. Therefore, according to the comprehensive analysis, the parallel string truss is more dominant than the triangular truss in the selection design of such construction background.

4. Conclusion

In this paper, for the purpose of truss bridge selection design, the mechanics and material usage of three different truss types are analyzed by structural mechanics solver, and the main conclusions are as follows:

(1) Parabolic truss is the most economical in terms of material consumption, and its material volume ratio is the lowest, which is 1483847.1956, showing that under the same load and span conditions, this type of truss has obvious advantages in the use of materials. This shows that parabolic trusses are

the most cost-effective choice of the three from the point of view of saving materials and reducing construction costs.

(2) The triangular truss has the best performance in terms of mechanical performance. Its structural design allows it to distribute loads more effectively and reduce the pressure on individual members, thereby improving the bearing capacity and stability of the overall structure. This makes triangular trusses a more suitable choice in applications where high structural stability is required.

(3) Although the material consumption of the triangular truss is only slightly lower than that of the parallel truss, its structural height is higher, which may have a certain impact on the aesthetics of the bridge. In addition, the construction difficulty of triangular trusses is also higher than that of parallel trusses, which is an important consideration when choosing the type of truss.

(4) Considering the factors such as material consumption, mechanical performance, construction difficulty and aesthetics, parallel truss may be the better choice in most cases. Although it is slightly higher than the parabolic truss in terms of material consumption, it has obvious advantages in terms of construction simplicity and overall aesthetics.

(5) There are some limitations of this paper. The construction difficulty of variable section is not considered. Although the material consumption and mechanical performance of different truss types are discussed in this paper, the construction difficulty and cost of variable section truss are not considered in detail. The design and construction process of variable section truss may involve more complex technical requirements and higher costs, which has guiding significance for future research and practical application. In the analysis, all truss types were calculated using the same material characteristics, without considering the possible effects of different materials on the performance of the truss. The use of different materials can have a significant impact on the weight, durability and cost of the truss.

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