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Theoretical Analysis of Truss Height-to-span Ratio Selection

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Abstract. Trusses are widely used in the field of bridge nowadays, and have the advantages of fast construction speed. However, the current researches on trusses are limited. This paper mainly studies the problem of trusses height-to-span ratio. In this paper, a single simple truss bridge with a span of 80 meters is taken as an example, and the model is established by using the structural mechanics solver. In the case of changing the height-to-span ratio, the same load is applied to the truss. The relationship between the height-to-span ratio and the maximum axial force of the truss members is analyzed, and the functional relationship is fitted. A simple cost model is established, and the performance and cost of height-to-span ratio are discussed. The final optimal height-to-span ratio was found to be 0.1268, which falls within the range of commonly used empirical values of 0.1 to 0.2, providing theoretical support for the design of truss height-to-span ratios.

Keywords: Truss; Height-to-span ratio; Theoretical analysis.

1. Introduction

The terrain of the world is rich and varied, ranging from large and high canyons to rivers of varying sizes in cities. In order to better access and develop, many places require the construction of bridges. For bridges, truss structures are widely used in the transportation industry due to their advantages of reducing the height of the main beam, providing good landscape effects, and fast construction speed [1]. Moreover, with the efforts of researchers, the efficiency and cost of truss construction technology have been reduced. For example, Wang [2] analyzed the fully prefabricated assembly of steel truss bridges in 2024, which greatly improved construction efficiency. However, in the current widely used truss, the selection of truss characteristic values is mostly based on experience, and lacks scientific verification. At this time, it is particularly important to conduct further qualitative and quantitative research on truss section number, web member angle, height-to-span ratio, and find a balance between cost and performance. Researchers have conducted some studies in the fields of internode number and abdominal angle. In terms of the angle of web members, Qiang et al. [3] published a study on the angle of truss web members in the Journal of Building Structures in 2022. Based on structural mechanics simulators and finite element simulations, static loading tests were conducted to fully explore the influence of web member angle on the stress performance of trusses. Yang's article published in 2019 on urban road bridges and flood control also studied the web member angles of double-layer steel truss bridges and obtained excellent results [4]. There have also been studies on the angle of truss web members in non civil engineering fields, such as Wang et al.'s research on optimization design of mechanical trusses web angle published in the Journal of Construction Machinery Technology and Management [5]. In terms of internode length, Wang [6] published a study on internode length in Fujian Architecture in 2021. However, there is still a limited amount of research in this area, especially in the current theoretical analysis of truss height-to-span ratios, which is greatly lacking and almost impossible to find relevant literature. And the selection of height-to-span ratios is mainly based on experience.

This paper takes a single simple truss bridge with span of 80 meters as an example to explore the height to span ratio of the truss. By studying the suitable value of height-to-span ratio, the cost and performance of the truss are balanced. This paper provides the basis for the selection of the height-to-span ratio of the truss, and provides the design suggestions for the researchers

2. Research Method

The height-to-span ratio of truss bridges is directly proportional to their performance (the ability to minimize their maximum axial force). The larger the height-to-span ratio, the greater the amount of material used, and the material cost will also increase accordingly. Simultaneously, a higher height-to-span ratio also means greater construction difficulty and construction period, which will correspondingly lead to higher construction costs. Therefore, it is necessary to find its inflection point for analysis.

This study takes a single-layer simple truss bridge with a span of 80 meters as an example for analysis. Using a structural mechanics solver to establish a model, variables are controlled by controlling the number of truss sections to 8, and the height-to-span ratio is changed. Six height-to-span ratios of 0.075, 0.10, 0.125, 0.15, 0.175, and 0.20 are used to analyze the axial force of the members, and the maximum axial force is found. A graph is drawn to find the relationship between the height-to-span ratio and the maximum axial force of the truss, and a reasonable mathematical analysis is carried out. The data is visualized through a function graph, and the linear and polynomial mathematical relationships are fitted. A simple cost estimation model is established. This article explores the relationship between maximum axial force, high span ratio, and cost through the above steps. Due to the smaller maximum axial force under the same load, the greater the load it can withstand under the same material conditions, and the stronger its bearing capacity. At the same time, if the height-to-span ratio is smaller, the corresponding cost will also decrease. Therefore, the inflection point that reduces the maximum axial force while minimizing the height-to-span ratio should be found, and this inflection point can be found by matching the slopes of two types of fitting.

3. Results and Discussion

3.1. Numerical Simulation and Fitting Results

A structural mechanics solver is used to build the truss model shown in Fig. 1. Through simulation, it can be found that the maximum axial force of the structure will appear at components (4) and (5). Accordingly, the maximum axial force and height span ratio are shown in Table 1. The corresponding images are drawn, and linear fitting and polynomial fitting are performed, respectively. The results are shown in Fig. 2 and Fig. 3, respectively.

Polynomial fitting using a third-order polynomial is sufficient to fit the image, so a third-order polynomial fitting is used. For the results of linear fitting, it shows the overall and average trend of the maximum axial force as a function of height-to-span ratio, and its slope represents the overall average change.

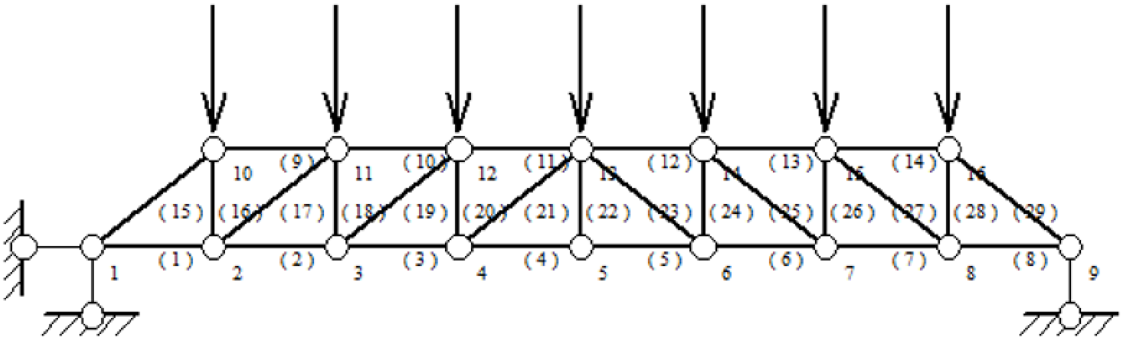

Figure 1. Schematic Diagram of Truss

Table 1. High Span Ratio and Maximum Axial Force

High Span Ratio	Maximum Axial Force
0.075	13.3333333
0.100	10.0000000
0.125	8.00000000
0.150	6.66666667
0.175	5.71428571
0.200	5.00000000

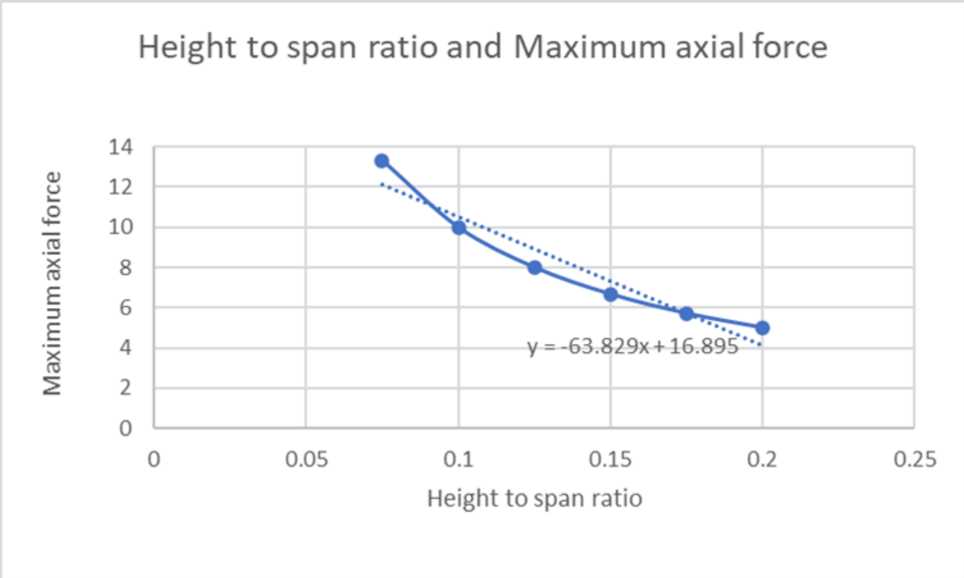

Figure 2. Height-to-span Ratio and Maximum Axial Force Function Image and its Linear Fitting

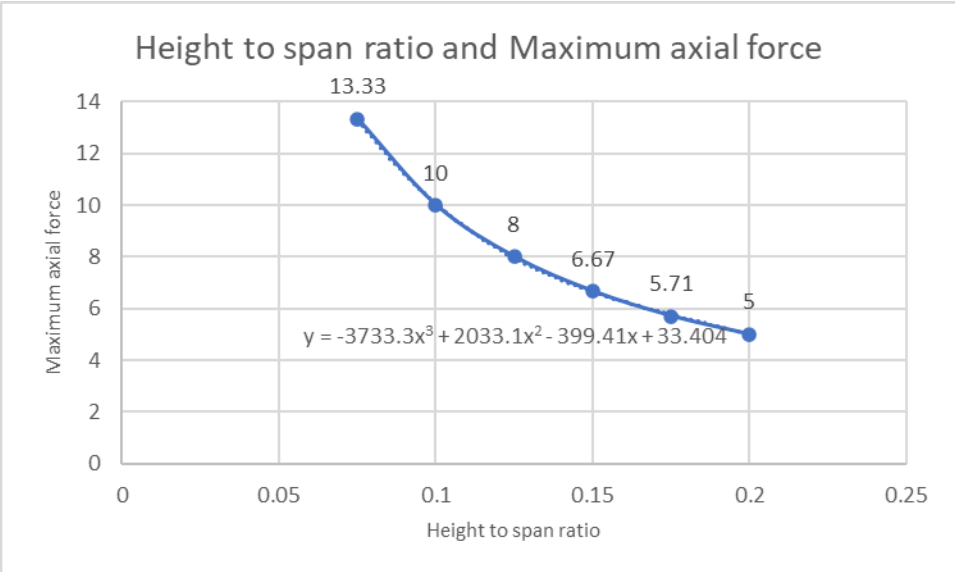

Figure 3. Height-to-span Ratio and Maximum Axial Force Function Image and its Polynomial Fitting

3.2. Establishment of Cost Models

In terms of material cost, due to a fixed span, when the height-to-span ratio changes, the same material is used for the upper and lower chords, and the material cost is roughly linearly related to the increase in height-to-span ratio. Therefore, for material costs, Eq. 1 can be listed as follows.

$$C_1=K_1x+b_1 \tag{1}$$

where C_1 represents the material cost; K_1 is the material cost constant, which is related to the material price; x represents its height-to-span ratio; B_1 represents the fixed material cost when the aspect ratio changes, such as the material cost of the constant upper and lower chords.

Regarding the construction cost, for the convenience of research, it is also regarded as linearly related to the height-to-span ratio, and the following Eq. 2 can be obtained.

$$C_2=K_2x+b_2 \tag{2}$$

where C_2 represents the construction cost; K_2 is the construction cost constant, which is related to the construction price; x represents its height-to-span ratio; B_2 represents the fixed construction cost when the height-to-span ratio changes, such as the construction cost of the constant upper and lower chords and the construction cost of the number of nodes.

3.3. Optimal Selection of Height-to-span Ratio

The corresponding point of linear fitting slope is found in cubic polynomial fitting, and it is found that when the aspect ratio is about 0.1268, the slope is equal to linear fitting.The results are also between the common experience values of 0.01 and 0.02, which further proves the optimal choice of high span ratio.

4. Conclusion

This paper studies the optimization design of truss height-to-span ratio and obtains the following main conclusions:

(1) Under the same load, the height-to-span ratio and maximum axial force of the truss were analyzed, and the functional relationship between the height span ratio and maximum axial force under this model was fitted.

(2) There is a inflection point between the performance represented by the height-to-span ratio of the truss and the required cost. And this paper explores the inflection point and conducts optimization design research on the height-to-span ratio of the truss, finding the best choice for the height-to-span ratio. The results are also consistent with the experience of the designers. This further provides a design basis for the height-to-span ratio design of trusses.

(3) Although the basic theory of the high span ratio is discussed in this study, some details are lacking. For example, the cost model is not detailed enough and only roughly shows the relationship between cost and high span ratio, which leads to incomplete model establishment. It is hoped that this paper can enlighten and help the optimization design of truss.

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