Study on the Correlation Between Geometric and Mechanical Properties of Parallel Truss Bridges

Wu Jiangchen
Central South University, Changsha, Hunan, China

Abstract: Truss bridge is a widely used structural form in bridge engineering, whose main feature is to realize the support and stability of the bridge by truss structure. The structure of truss bridge consists of a series of truss units, which are connected by rods of steel or other materials with triangles as the basic members. In terms of geometric performance, the geometric design of parallel truss bridges involves the arrangement of truss units, length of rods, and node connection methods. Parallel truss structures are usually characterized by symmetry and uniform distribution, which makes their geometric performance show better stability and consistency in large-span bridges. This paper reveals the key role of structural geometry on bridge performance by comparatively analyzing the effects of different geometric parameters on the overall stability and deformation characteristics of bridges. As for mechanical properties, the mechanical properties of parallel truss bridges include load distribution, stress distribution, stiffness and strength. Studies have shown that parallel truss bridges can effectively distribute and transfer stresses when subjected to static and dynamic loads, thus improving the load carrying capacity and deformation resistance of bridges. In this paper, the mechanical response of parallel truss bridges under actual loading is discussed in depth, which reveals the mechanical behavior of truss units and their influence on the overall performance of bridges.

Keywords: Truss Bridge; Geometric Properties; Mechanical Properties; Load Distribution; Load Carrying Capacity

1. Background of the Study

A truss bridge is a form of bridge that utilizes a truss structure as the primary load-bearing system. The truss structure disperses and transfers the external force to the abutments through a series of triangular units, thus realizing the stability and strength of the bridge. Truss bridge is widely used in modern bridge engineering due to its advantages of high material utilization efficiency, structural stability, light weight and so on.[1] The truss bridge is widely used in modern bridge engineering.

The background of truss bridge research can be traced back to the Industrial Revolution in the 19th century. With the rapid development of railroad and road transportation, the need for strong and lightweight bridges increased. Truss bridges were widely used during this period, especially in crossing rivers, canyons and other obstacles. Unlike traditional arch or girder bridges, truss bridges achieve the goal of spanning larger spans and carrying heavier loads through simple geometry and efficient use of materials[2] .

In the 20th century, with the development of material science and structural mechanics, the design and construction technology of truss bridge has been further improved. Especially, the introduction of high strength steel and prestressed concrete made truss bridges show great potential in the field of large span bridges. In addition, the development of computer technology also makes it possible to design and analyze complex truss structures, thus improving the economy and safety of truss bridges.[3] The development of computer technology has also made it possible to design and analyze complex truss structures, thus improving the economy and safety of truss bridge.

In recent years, with the continuous innovation of bridge engineering, the application of truss bridge is also expanding. Not only in traditional highway and railroad bridges, truss bridges are also widely used in pedestrian bridges, landscape bridges and other special-purpose bridges. Meanwhile, with the emphasis on sustainable development, the design of lightweight and high-efficiency truss bridges has become an important direction in bridge engineering research.

In general, truss bridges have a deep research background. From early material and structural research to modern computer-aided design and analysis, truss bridges have always occupied an important position in bridge engineering. In the future, with the continuous introduction of new materials and technologies, the design and application of truss bridges will continue to maintain its importance and play a role in a wider range of fields.

Truss bridges have a good development prospect, however, there are problems in the design of trusses: which geometric form to take under different conditions is often based on experience and lack of scientific proof.

Therefore, this study compares the truss geometrical forms and mechanical properties through the Suggestions for truss selection are provided for establishment personnel

2.Subjects and Methodology of the Study

2.1Research Object: Parallel Truss Bridge

Parallel Truss Bridge is a common form of bridge structure, which is mainly characterized by the use of parallel trusses as the main load-bearing structure of the bridge. This kind of bridge is widely used in highways, railroads and pedestrian bridges, and is favored because of its simple structure, high material utilization and high load carrying capacity.

2.1.1 Basic structure of a truss bridge

The main load-bearing structure of a truss bridge is the truss, which consists of a series of rectilinear members connected by nodes. The geometry of a truss is usually triangular, because triangles are the most stable geometric shapes and are effective in distributing and resisting external forces. A parallel truss bridge usually consists of upper and lower chords (i.e., top and bottom chords), as well as diagonal and straight rods connecting the top and bottom chords[4] The parallel truss bridge usually consists of a top and bottom chord (i.e., top chord and bottom chord), and diagonal and straight rods connecting the top and bottom chords.

2.1.2 Types of parallel truss bridges

Parallel truss bridges can be categorized into different types according to the specific structural design, and the following types are common:

Pratt Truss Bridge: In this type of bridge, the top chord and vertical rods are mainly under compression while the diagonal rods are mainly under tension. The advantage of the Pratt Truss is that it is simple in design and suitable for medium span bridges.

Howe Truss Bridge: A Howe truss is the opposite of a Pratt truss in that the top chord and diagonal rods are primarily compressed while the vertical rods are primarily tensioned. Howe trusses are usually used in timber bridges and are suitable for shorter spans.

Warren Truss Bridge: Warren truss consists of equilateral triangles with equal lengths of rods and more uniform force distribution. Warren truss is widely used in modern bridges because of its compact structure and high material utilization.

2.1.3 Advantages of parallel truss bridges

High Material Utilization: Parallel truss bridges can withstand large loads with minimal material usage through rational geometric design, thus reducing material costs.

Ease of construction: The components of a truss bridge are simple and easy to prefabricate and assemble on site, shortening the construction period and improving construction efficiency.

Strong structural stability: The triangular structure of the truss bridge has good stability and can effectively resist various external forces, such as wind loads, vehicle loads and seismic forces.

2.1.4 Parallel truss bridge applications

Parallel truss bridges are widely used in highway bridges and railroad bridges, especially suitable for short and medium span bridges. Due to its simple structure, parallel truss bridge is also often used as temporary bridge or emergency rescue bridge. In addition, some large-span bridges, such as bridges across rivers and canyons, also adopt the structural form of parallel truss bridge to provide sufficient load carrying capacity and stability.

2.1.5 Design and maintenance

The design of parallel truss bridges requires consideration of several factors, such as span, loads, materials, and environmental conditions. When designing, engineers are often required to use computer-aided design (CAD) and finite element analysis tools to ensure the safety and reliability of the bridge. In addition, regular maintenance and inspections are essential to extend the life of a truss bridge, including monitoring of corrosion, fatigue and damage to members.

2.2 Impact of Environmental Factors

Environmental factors, such as wind load and earthquakes, are critically important in bridge design because they directly affect the structural safety and longevity of the bridge. Wind loads can cause vibrations and, in extreme cases, structural instability. It is essential to account for these forces through wind tunnel tests or computational models to assess their impact on the bridge. Earthquakes are another key factor, especially in seismic regions, where seismic analysis must be conducted to ensure the structure's load-bearing capacity and deformation control during seismic events.

CAD (Computer-Aided Design) is used in bridge design to create precise geometric models of the structure, aiding designers in visualizing the bridge's components.It allows accurate representation of each part of the bridge, enabling quick modifications and adjustments to different design proposals.CAD also provides detailed engineering drawings, including structural and construction details, ensuring that the bridge can be built exactly according to the design.

Finite Element Analysis (FEA) is used to evaluate the mechanical behavior of a bridge under various load conditions, such as stress, deformation, and vibration.FEA helps engineers analyze the structural response of complex bridge structures, playing a crucial role in both static and dynamic load analysis.FEA also can simulate the nonlinear properties of bridge materials and the staged changes during construction, helping ensure the structure's safety and stability.

Discussions and analysis of these external conditions can be based on historical data, regional environmental characteristics, and scientific calculations to ensure the bridge's safety and stability.

2.3 Reach a Verdict

Parallel truss bridges have become a form of bridge widely used all over the world due to its advantages of simple structure, low cost and high load carrying capacity. With the advancement of technology, the design and construction of truss bridges will be more optimized and continue to play an important role in modern bridge construction.

2.4 Research Content

Determination of the Geometric Parameters of Trusses: span, number of panels, height, load level, etc.

To determine the optimal structure of the truss under different parameters, calculations are required [5]. First, the span of the truss is determined, for example, 40 meters, 60 meters, 80 meters, and so on.

Next, under the same span, different numbers of panels are set. For instance, if the total span is 40 meters, the number of panels can be 5, 6, 7, or 8. When the number of panels is set to 5, each segment length is the total span (40 meters) divided by 5, which equals 8 meters.

Following this, the height-to-span ratio is discussed. For example, when the total span is 40 meters and the number of panels is 5, the height-to-span ratio can be 1/7, 1/8, or 1/9, and so on. The specific height can then be calculated based on the total span and the chosen height-to-span ratio.

Afterward, the amount of material consumed under these different parameters is calculated. In this study, the total material consumption is represented by the sum of the product of axial force and the length of the bars [6]. The truss form with the least material consumption is tentatively regarded as the optimal form. Subsequently, the difference in structure with and without vertical rods under the same form is analyzed. Finally, a comprehensive analysis of the material consumption and stiffness variation is conducted to determine the final optimal truss form [7].The step-by-step flowchart is shown Figure 1.

3. Research

Taking the parallel truss bridge with a total span length of 40m as an example, it is firstly divided into 5 sections, 6 sections, and 7 sections, and then the high span ratios of 1/7, 1/8, 1/9, and 1/10 are selected for the calculations under different sections, and the load is taken to be 100kN, and the tensile strength and the flexural strength are both taken to be 200MPa.

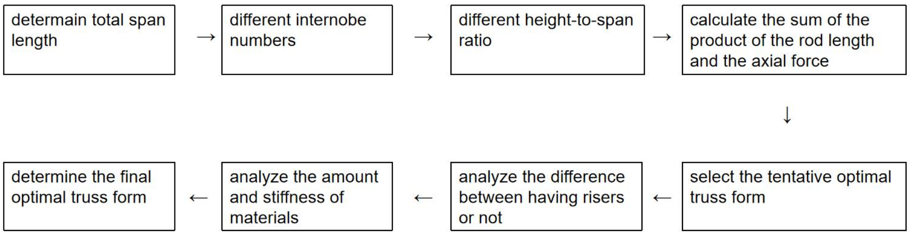
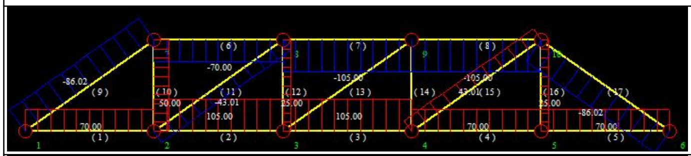
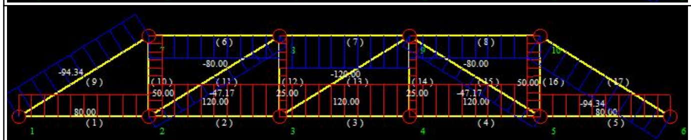
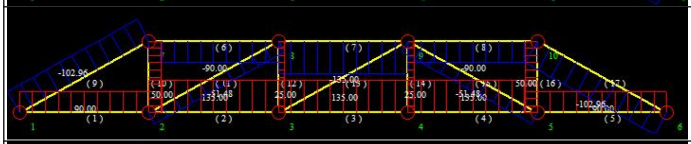
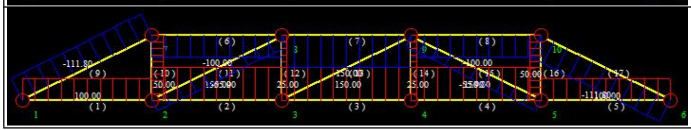


Figure 1. Flowchart of Truss Optimization Process

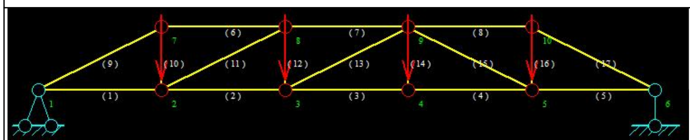
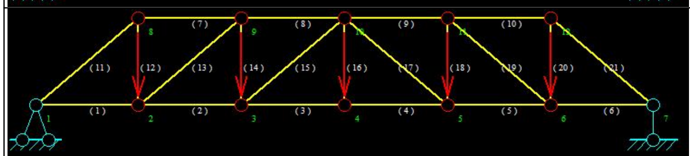
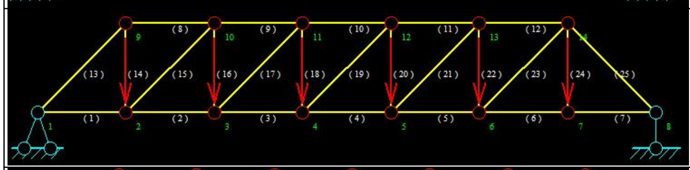
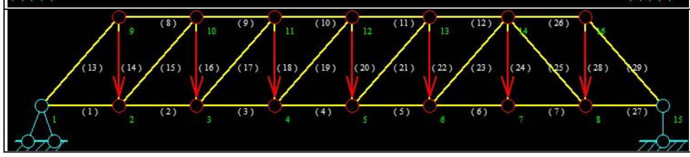
Table 1. Material Usage and Center Point Displacement for Different Height-to-Span Ratios with 5 Sections

Number of sessions: 5	high aspect ratio	Amount of material used	Center point displacement (stiffness)
	1/7	8708.512	43.344
	1/8	9819.990	55.429
	1/9	10692.499	68.057
	1/10	11599.388	82.270

From the above table, it can be seen that when the number of internodes is 5, the optimum form with minimum material usage as well as minimum displacement at the center point is obtained when the height-to-span ratio is 1/7.

Next, the optimal form is calculated when the number of intervals is not used in the case of high span ratio of 1/7. The number of intervals is calculated from 5 to 8:

Table 2. Material Usage and Center Point Displacement for Different Number of Sections with Height-to-Span Ratio of 1/7

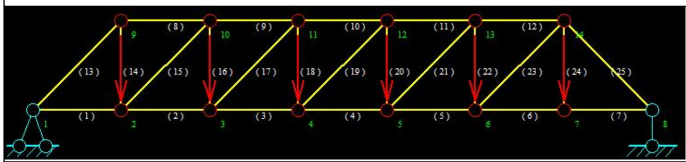
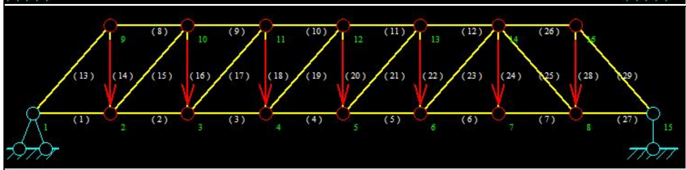
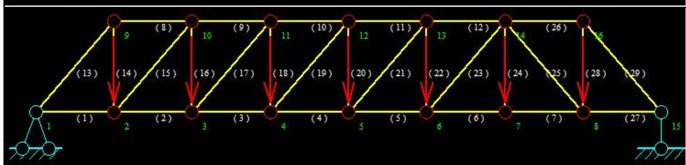
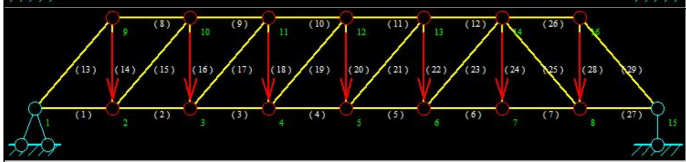
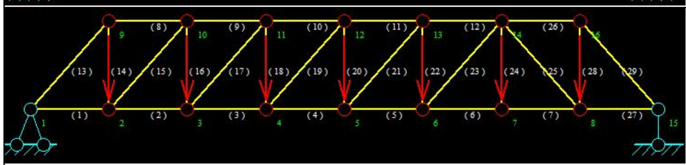
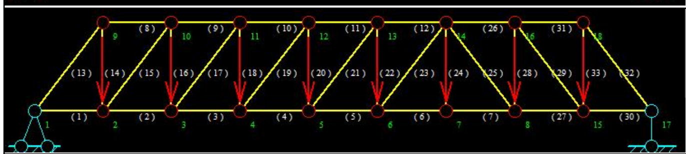
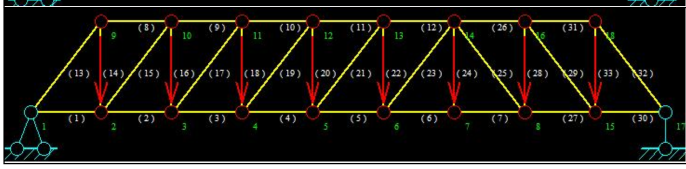
High span ratio: 1/7	internode	Amount of material used	Center point displacement (stiffness)
	5	8708.512	43.344
	6	8901.388	40.464
	7	8380.564	39.271
	8	8616.990	38.307

The analysis of the data can be scored: the minimum amount of material is 8380.564 when the number of knots is 7, and the minimum displacement of the center point is 38.307 when the number of knots is 8.
1-38.307/39.271 = 2.455 per cent
1-8380.564/8616.990 = 2.743 per cent
Calculations show that the 7-intersection form is comparatively superior by sacrificing 2.455% of stiffness and saving 2.743% of material usage as compared to the 8-intersection.

It can be obtained that: the parallel truss bridge with a total span of 40m is tentatively recognized as the optimal truss form under the parameter of 7 sections and 1/7 height-to-span ratio.

By analogy, for parallel truss bridges from 40m to 100m, the following tentative optimal truss forms were calculated by the similar process described above:

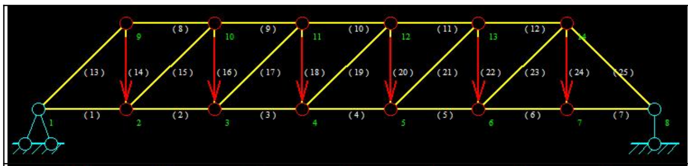
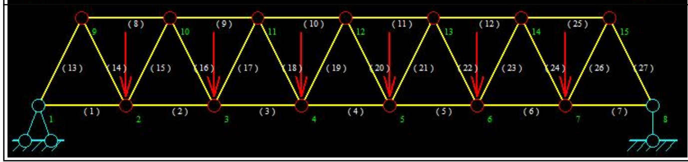
Table 3. Optimal Truss Forms for Different Span Lengths

	horizontal distance between vertical supports	internode	Amount of material used	center displacement
	40m	7	8380.564	39.271
	50m	8	10771.535	47.884
	60m	8	12610.867	57.155
	70m	8	15080.127	66.681
	80m	8	17234.016	76.615
	90m	9	19718.392	87.443
	100m	9	19628.754	97.159

Next, analyze the difference between the presence and absence of risers:
The data obtained for the different cases with and without risers at 40m, 7 intervals, and a height-to-span ratio of 1/7 are as follows:

Table 4. Comparison of Material Usage and Center Point Displacement with and without Risers for 40m Span

40m, 7 sections, height to span ratio 1/7	With or without poles	Amount of material used	Center point displacement (stiffness)

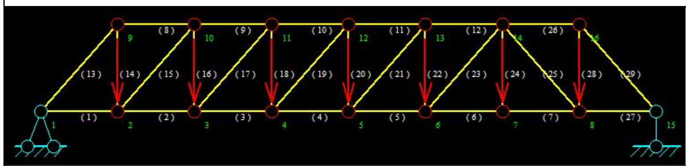
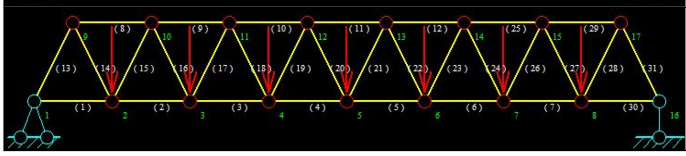
	there are	8708.512	43.344
	not have	7140.605	36.795

Analyzing the data, we can see that all the indicators are better when there are no poles.

To summarize: the optimal form for a parallel truss bridge with a total span of about 40m is a 7-section intersection with a height-to-span ratio of 1/7 and no risers.

The data obtained for the different cases with and without risers for 50m, 8 section intervals and 1/7 height to span ratio are as follows:

Table 5. Comparison of Material Usage and Center Point Displacement with and without Risers for 50m Span

50m, 8 sections, height to span ratio 1/7	With or without poles	Amount of material used	Center point displacement (stiffness)
	there are	10771.535	47.884
	not have	10835.075	55.234

Analyzing the data, we can see that all the indicators are better in the presence of a standing bar

To summarize: the optimal form for a parallel truss bridge with a total span of about 50m is an 8-section intersection with a height-to-span ratio of 1/7, with risers.

By analogy, the optimal trusses with different spans obtained earlier are calculated with or without risers to obtain the final optimal truss forms for different spans:

The optimum form of the parallel truss bridge with a total span of about 40m is a 7-section intersection with a height-to-span ratio of 1/7 and no risers.

The optimum form of parallel truss bridges with a total span of about 50m is an 8-section intersection with a height-to-span ratio of 1/7 with risers.

The optimum form of the parallel truss bridge with a total span of about 60m is an 8-section intersection with a height-to-span ratio of 1/7 with risers.

The optimum form for parallel truss bridges with a total span of about 70m is an 8-section intersection with a height-to-span ratio of 1/7 and no risers.

The optimum form of the parallel truss bridge with a total span of about 80m is an 8-section intersection with a height-to-span ratio of 1/7 with risers.

The optimum form for parallel truss bridges with a total span of about 90m is 9 intersections with a height-to-span ratio of 1/7 and no risers.

The optimum form of parallel truss bridges with a total span of about 100m is a 9-section intersection with a height-to-span ratio of 1/7 with risers.

4. Conclusions and Outlook

4.1 Conclusion

Parallel truss bridges have become a form of bridge widely used all over the world due to its advantages of simple structure, low cost and high load carrying capacity. With the advancement of technology, the design and construction of truss bridges will be more optimized and continue to play an important role in modern bridge construction. In this study, the optimal form of truss bridge for different spans can be calculated by mechanical related properties, so that the designers can no longer judge which form to use only by experience as in the past, and the designers are given suggestions on truss selection. For parallel truss bridges of any length, it is possible to compare the advantages and disadvantages by calculating the specific data such as material consumption and center displacement and settlement as proposed in this study.

4.2 Outlook

With the progress of material science, the application of new materials in bridge construction will bring new development opportunities for truss bridges. For example, the application of high strength steel and alloy materials. Traditional truss bridges are mostly made of common steel. In the future, the application of high-strength steel and new alloy materials can reduce the cross-section size of members, lower the deadweight, and improve the fatigue resistance and corrosion resistance of the structure.

There are also applications of composites composites such as carbon fiber reinforced composites (CFRP) have the advantages of high strength, light weight and corrosion resistance. Introducing composites into the design of truss bridges can significantly improve the durability of bridges, reduce maintenance costs, and is especially suitable for bridges in harsh environmental conditions.

Smart Materials: Smart materials that include self-healing features are expected to be introduced into the construction of truss bridges in the future, which can automatically repair damage and extend the life of the bridge.

Computer Aided Design (CAD) and Simulation Technology: Future truss bridge design will rely more on advanced CAD tools and finite element simulation technology to optimize structural design, reduce material usage and improve structural performance. These technologies can help engineers to quickly evaluate design options, simulate multiple working conditions, and improve design efficiency and accuracy.[8] . There is also Building Information Modeling (BIM): BIM technology will be widely used in the design, construction and management of bridges to provide full life cycle management and optimization. Through BIM modeling, digital modeling, construction process monitoring, and operation and maintenance management of truss bridges can be realized, effectively improving project quality and management efficiency.

Sustainability and Environmentally Friendly Design: With the use of green materials, the future development of truss bridges will focus more on environmental protection and sustainability. The use of environmentally friendly and recyclable materials, as well as materials that reduce carbon footprints in the manufacture of truss bridges will become an important direction of development.

Energy Management and Utilization: The design of the truss bridge will incorporate renewable energy technologies such as solar panels integrated into the bridge structure to provide power for the bridge's lighting and monitoring systems. At the same time, the energy absorption and storage capabilities of the bridge structure can be investigated to convert kinetic traffic energy into electrical energy.

Intelligent Monitoring and Maintenance, Structural Health Monitoring System (SHM): Future truss bridges will widely adopt sensor technology and Internet of Things (IoT) technology to realize real-time monitoring of bridge structural condition. Sensors can monitor parameters such as stress, temperature, vibration, etc. to detect structural abnormalities in time and provide early warning to improve the safety and reliability of the bridge.

Drone and Robotic Maintenance: Drone and robotic technology will be used for regular inspection and maintenance work on bridges. Drones can perform high-precision visual inspections of bridges to detect cracks, rust and corrosion, while robots can perform delicate repairs and maintenance, reducing labor costs and improving maintenance efficiency.

Finally, there is the modular and movable design. MODULAR CONSTRUCTION: The modular design of the truss bridge will allow the bridge to be constructed more quickly and efficiently. Modular components can be prefabricated in the factory and assembled on site, which not only shortens the construction period, but also reduces the environmental impact of the construction site.

References

[1] Zhang Yi. Technical condition and bearing capacity evaluation of triangular truss arch bridge[J]. Transportation Technology and Management,2024,5(10):108-110.
[2] Kong Pu. Research on design and construction program of large-span simply supported steel truss structure[J]. Urban Road and Bridge and Flood Control,2022,(11):77-79+92+15. DOI: 10.16799/j.cnki.csdqyfh.2022.11.022.
[3] Chen S.P. Mechanical performance analysis and experimental study of GFRP truss bridge [D]. Southeast University,2017.
[4] Li Xinkui. Optimization Design Method of Simply Supported Steel Truss Bridge Based on Reliability [D]. Dalian Maritime University, 2008.
[5] SHEN Sheng, YANG Ming, WANG Xinru, et al. A review of design analysis and optimization of steel truss bridge[J]. Shanxi Architecture,2015,41(15):166-169. DOI: 10.13719/j.cnki.cn14-1279/tu.2015.15.090
[6] Jiang Rui. Secondary stresses in semi-rigid connection of parallel chord steel truss bridge and its numerical analysis[D]. Northeastern University, 2009.
[7] WU Jin. Simple calculation method for controlling deflection of parallel chord steel joist[J]. Petrochemical Technology and Application,2000, (03):171-174.
[8] QIAO Kai, HAN Lei, GUO Yipeng, et al. Digital simulation and safety prediction technology for jacking construction of steel truss bridge[J]. Construction Technology (in Chinese and English),2023,52(20):56-60.