Research On Optimal Design and Application of Truss Structures

Xin Wen *

International Institute of Engineering, Changsha University of Science & Technology, Changsha, China

* Corresponding Author Email: 1808010424@stu.hrbust.edu.cn

Abstract. The truss structure has a history spanning thousands of years. Over time, it has evolved from a simple planar geometric structure to today's intricate spatial configuration. Furthermore, its utilization, construction techniques, and material selection have undergone significant advancements. Optimizing the truss structure is particularly crucial in accordance with specific working conditions. Targeted optimization can enhance structural strength, augment aesthetic appeal, reduce project costs, and minimize environmental pollution. Truss structure optimization primarily encompasses size and shape optimization, topology optimization, and material optimization. Size and shape optimization involves determining the optimal dimensions and form of the truss under operational conditions using programs and algorithms. Topology optimization focuses on complex truss structures by employing various algorithms to identify the most efficient components while eliminating inefficient ones. Material optimization entails utilizing new materials that align with engineering requirements as well as environmental sustainability and economic benefits; traditional materials may not necessarily be used entirely or partially for constructing the truss. In the future, with the development of the application of trusses and construction technology, optimizing their structure will become more and more important.

Keywords: Truss structure; structural optimization; optimal design.

1. Introduction

The earliest truss structures date back to ancient Rome. Historians note in reliefs that this structure was designed as the upper end of the Trey River Bridge [1]. The modern truss structure can be divided into triangle truss, plane truss and space truss according to the spatial distribution. Triangular trusses are the simplest type of truss, consisting of separate beams or other structures connected by triangles. The plane truss is a truss structure composed of several triangular trusses connected on a plane, and these trusses are connected in parallel. The space truss is a three-dimensional truss structure connected by connecting points, usually made of tetrahedral phase splicing [2].

Compared with more traditional structures such as beams and arches, truss structures have higher mechanical efficiency, and do not generate force on the support, and construction is convenient, high strength, and in the case of achieving the same load capacity, the weight is smaller. The initial truss is faced with the defects of large internal force difference, unreasonable material and not enough economy. In order to solve these problems, various structural optimization designs for trusses came into being, such as single-column trusses, double-column trusses, Fink trusses, beam trusses and so on. The structural optimization of these trusses is mainly divided into size optimization and shape optimization. At the same time of achieving the same bearing capacity, through these two structural optimizations, the total weight of the truss is lighter, the volume is smaller, and the aesthetic is higher. Material optimization is using new materials, such as aluminum alloy, as well as green new materials, so that the truss has better properties, while more environmentally friendly. In addition, topology optimization is to optimize the cross-section structure of the truss by obtaining the optimal topology layout and other methods. At the same time, with the development of modern computer technology, various algorithms have been applied to the optimization of truss structures, such as particle swarm optimization. Therefore, this paper mainly analyzes the optimization design methods of truss structure, including size optimization, shape optimization, material optimization and topology optimization.

Then a concrete-filled steel tube truss bridge is taken as an example to explain the optimization process and effect of the truss structure in detail.

2. Truss Structure Optimization Design Method

2.1. Size and Shape Optimization

In the design of the truss, the economic cost and strength index should be considered comprehensively. Through the optimization of the size and shape of the truss, the economic cost can be reduced when the strength meets the standard. At the same time, the non-standard truss length will also bring the consequences of insufficient strength, for example, for trussed Bridges, too long span will lead to the increase of the bending moment and shear force in the middle section of the structure, resulting in its actual load greater than the strength index. The unreasonable shape will often make the efficiency of the structure force is low, and it is more likely to appear uneven force, and then lead to the local damage of the structure. Therefore, the size of the truss structure must be controlled within a reasonable range, and it is necessary to design the optimal size, but also to design the optimal structure shape, in order to achieve the best mechanical effect and the best cost. For the truss member, its shape is generally a circular cross-section member, and its size optimization is usually optimized for its length and section diameter. For its shape optimization, it is usually optimized for its arrangement, Angle and so on. For size optimization, mathematical model can be established to calculate, first through the establishment of structural model to analyze the internal force of the structure, can be analyzed according to linear analysis method, linear finite element analysis method. Then, considering materials, working conditions and other factors, the load combination is calculated, and then compared with the strength index, the feasibility is obtained, and the optimal solution is obtained by repeating steps [1]. The schematic diagram of the process is shown in Fig. 1. This idea can also be adopted for truss shape optimization.

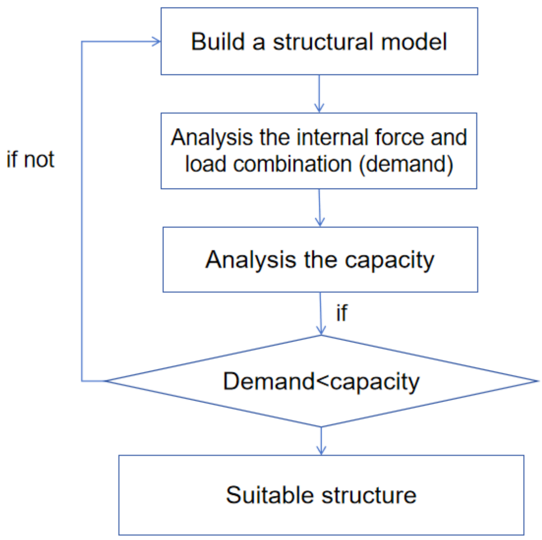

Fig. 1 Size optimization flow chart [1]

This idea can also be used for collaborative optimization of shape and size, as shown in Fig. 2, by establishing mathematical models of size and shape at the same time to optimize both. First, the structural model is established, then the objective function is set as the lightest weight, and the node coordinates and dimensions are set as variables. By comparing the constraints, the feasibility is obtained, and the optimal solution is obtained by repeating steps [2].

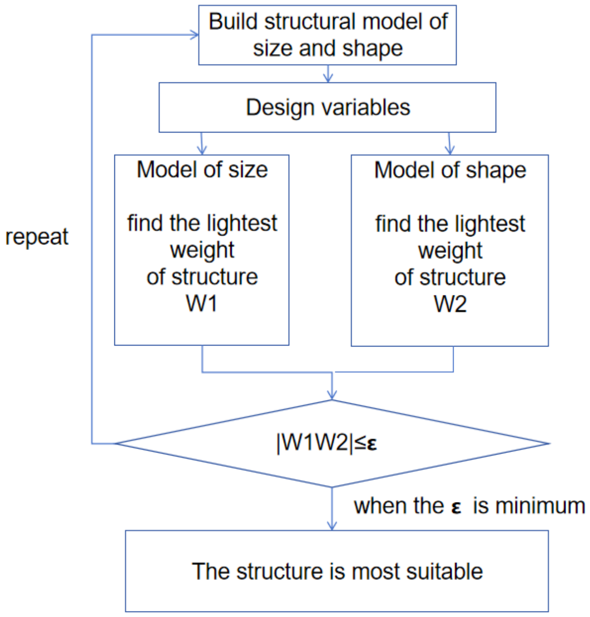

Fig. 2 Flow chart of shape and size collaborative optimization [2]

2.2. Topology Optimization

For some complex structures, the continuum topology optimization method can be used. Its main logic is to use Matlab, Python and other programs to write algorithms. First, the model is established, then the internal force is analyzed, and the parameters are set. After operation, the structural part with low force efficiency is deleted, and the structural part with high force efficiency is retained, as shown in Fig. 3 [3].

Topology optimization analysis can establish constraints according to the design objectives, and then obtain the required region. Topology optimization is widely used to help in size, shape and material optimization. Topology optimization can select the best layout and selection [4].

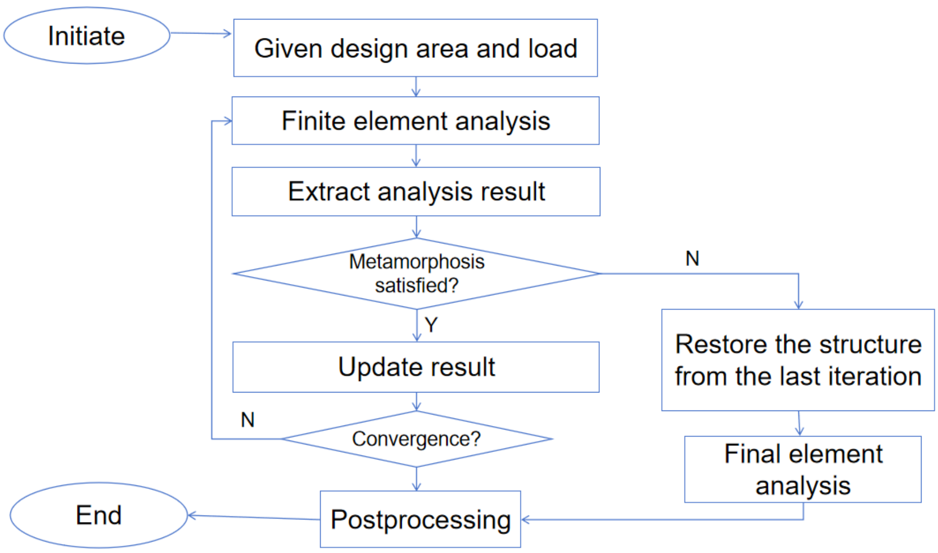

Fig. 3 Continuum topology optimization flow chart [2]

The results of topology optimization are often uneven, so it needs to be supplemented, so topology optimization usually needs to be combined with other analysis methods, such as finite element analysis, unit modeling, skeleton extraction algorithm, etc. The mechanical properties were analyzed by unit modeling method and the constraints were compared. Topological calculation is carried out by finite element analysis to remove the inefficient part of the structure with less force. However, the topology result contains redundant information, so the skeleton extraction method is used to remove the redundant information, and the topology result is transformed into a truss structure to complete the topology optimization.

2.3. Material Optimization and Selection

Material limitations are a significant factor in engineering and structural design limitations, and material optimization has led to more complex and robust structures. Traditional truss structure, the material is usually Q235 and Q345 steel, its high strength, corrosion resistance, relatively economical price, suitable for large truss structures, such as bridges, large stadiums and so on. Based on steel structure trusses, the concrete-filled steel tube structure, as shown in Fig. 4, can further improve the strength of the truss structure. It is composed of concrete chord and hollow steel pipe group, which carries forward the characteristics of steel structure with economy and light weight, and further improves the mechanical properties [5]. Due to the tight action of the concrete inside the steel pipe and the external steel, the concrete exerts stress on the steel pipe and enhances the mechanical properties of the external steel pipe.

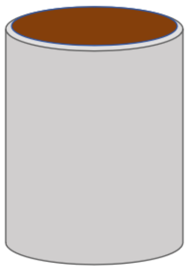

Fig. 4 Structure diagram of concrete-filled steel tube

When designing the concrete-filled steel tube truss structure, static and dynamic load experiments and finite element analysis can be used to verify the feasibility of the structure [6]. By comparing the mechanical index and economic benefit of steel structure, the feasibility of optimization is obtained.

Aluminum alloys are also widely used in truss structures. For some light truss structures, aluminum alloy can be described as the most ideal building material. Aluminum alloy on the basis of high strength, its light weight, good corrosion resistance, easy processing, up to 100% utilization, but also make it become environmentally friendly materials. Aluminum alloy is mainly used as a bridge building material, as early as 1949, the United States will be aluminum alloy as the main bridge material. Then in 1956, Germany built the famous Warren aluminum alloy bridge [7]. For aluminum alloy truss structure, it can be combined with topology optimization, using MIDAS and ANSYS to carry out finite element analysis to seek the optimal solution and get the optimal shape of the truss. Studies have shown that for Bridges with aluminum alloy truss structure, the span is from 12 m to 45 m, and the usage of aluminum alloy increases almost linearly, so it is of great significance to optimize the size [7].

3. Case Analysis of Truss Structure Optimization Design

Taking a concrete-filled steel tube truss bridge (Fig. 5) as an example, the optimization design of the truss structure is analyzed. The main span of the bridge is 71m, and the form is half through. The bridge is optimized in terms of structure shape and material. Topology optimization, finite element analysis and program calculation are adopted. For the traditional truss bridge, the main material of the truss rod is hollow lever, and the shape of the truss rod is mostly round. This project uses round steel pipe concrete with upper chord, the size is φ1000mm×54mm. The lower chord adopts the truss section shape of square tube concrete-filled steel tube, the size is 900mm×900mm×30mm. C50 concrete and Q390E steel were used [4].

Fig. 5 Elevation of optimized truss [4]

By using ABAQUS software, the finite element model of a single concrete-filled steel tube truss plate shell and solid body is established, as shown in Fig. 6. The mechanical parameters are input, the calculation is carried out, and the possibility of this structure is obtained after topology optimization. After building a force transmission model, by analyzing the mechanical conditions of all surfaces of the truss members, it is concluded that such structural optimization and material optimization meet the strength requirements, and compared with the traditional structure, such optimization has obviously higher strength [4].

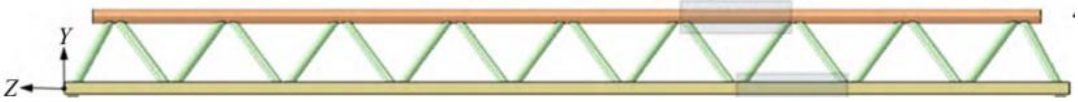

Fig. 6 Finite Element model [4]

4. Conclusion

Truss structure has a long history. With the development of truss structure, the optimization of truss structure is becoming more and more important to engineering. This paper mainly studies the optimization of the size and shape of the truss structure, the topology optimization of the truss structure, and the material optimization of the truss structure, and draws the following conclusions:

(1) The size and shape optimization of the truss can save economic costs, improve the strength of the structure, and also improve the coordination and aesthetics of the overall structure. For the optimization of the size, the structural model can be established first to analyze the internal forces of the structure. Then consider the material, working conditions and other factors, calculate the load combination, and then compare with the strength index to get the feasibility, repeat the steps to get the optimal solution. This method can also optimize the size and shape of the truss structure at the same time, establish the model of both, set the objective function as the lightest weight, and then set the node coordinates and size as variables. By comparing the constraints, the feasibility can be obtained, and the optimal solution can be obtained by repeating steps.

(2) Topology optimization of truss structure is a method to remove inefficient parts for complex structures. Often combined with algorithms and software use. For size, shape, material optimization can play a role, topology optimization can choose the best layout, type selection. However, the results of topology optimization are often irregular, so it is necessary to transform them into truss structures with skeleton extraction method.

(3) The material optimization of truss structure is to select the appropriate material according to different working conditions, purpose and cost. For lightweight structures, aluminum alloy can be used as a material, which has light weight and considerable strength. Concrete-filled steel tube is also a good choice, the strength is higher than traditional steel pipe.

(4) With the development of science and technology, truss structure optimization will be used in a wider range of building forms in the future, such as aerospace instruments, and increasingly high requirements for technology and materials, the future truss structure optimization will be combined with more intelligent technology, 5G technology and other advanced technologies, the use of higher strength, lower cost, smaller quality, more green materials, while various optimization methods will be more organically combined and more fully developed.

References

[1] Liu Shutang. On Sizing Optimization Design of Long Span Trussed Beam String structures. Journal of Henan University (Natural Science Edition), 2014, 44(02): 244-247.

[2] Zhang Zhenwei, Yao Weixing. Study On Size and Shape Collaborative Optimization Method of Truss Structure. Aviation Engineering Progress, 2012, 3(02): 138-143.

[3] Wang Renhua, Zhao XIanzhong. Methodology Investigation on Topology Optimization of Planar Truss Structure. Mechanical Quarterly, 2010, 31(02): 310-317.

[4] Cui Jian. Optimal design and finite element analysis of steel truss bridge joints. Journal of Xi 'an Jiaotong University, 2016, 50(09): 1-9.

[5] Zhao baojun, Zhang Zhiheng. Analysis on internal force transfer characteristics of concrete-filled steel tubular truss chord. Aviation Engineering Progress, 2012, 3(02): 138-143.

[6] Zhang Lei. Load test and overall structural evaluation of concrete-filled steel tube truss arch bridge. Sichuan Architecture, 2023, 43(03): 273-275.

[7] Yan Zhitao. A new topology optimization structure of aluminum alloy truss. Journal of Sichuan Building Science, 2020, 46(05): 43-49.