Research on Design and Application of Steel Structure in Building Construction

Zhiyang Qu *

Houston International Institute, Dalian Maritime University, Dalian, China

* Corresponding Author Email: qzy20030716@dlmu.edu.cn

Abstract. Steel structure has been widely used in the design and construction of large venues because of its high strength, light weight and good seismic performance. However, because of the need to consider its seismic performance and instability, how to better design and construction of steel structures is particularly important. This paper starts from three aspects: steel structure stability design method, steel structure optimization design method and steel structure earthquake resistance method. The balance method, energy method and dynamic method of stability design are summarized. The case of folded string steel truss structure is summarized and analyzed, and the feasibility of the steel structure stability design method combining shape optimization and topology optimization is obtained. In addition, for the steel structure seismic, pushover analysis method and the incremental dynamic analysis (IDA) method are used. Finally, this paper summarizes the shortcomings of stability design, optimization design and seismic design in the field of steel structure design.

Keywords: Steel structure, stability design, optimization design, shock resistance design.

1. Introduction

In view of the improvement of building structure design in today's construction industry, the level of architectural design, the types of building materials and the properties of materials have also been significantly improved. In the process of designing the housing structure, the designers also need to strengthen the design and optimization of the project to ensure that it is adapted to the terrain requirements of the building, so as to develop a more sound and scientific design scheme in accordance with the requirements of engineering and construction [1].

With the rapid development of modern construction industry, steel structure construction engineering is more and more widely used in the construction field [2]. Steel structure is a structure made of steel, which is one of the main types of building structures. It has the advantages of high strength, light weight, high overall rigidity and good ductility. And because of its good safety and bearing capacity, it is widely used in engineering structure design. Its construction project is a kind of architectural form with the advantages of high efficiency and environmental protection, and is widely used in various construction fields. At present, steel structures have been widely used in various countries, and their application in the design and construction of large venues and high-rise buildings can ensure the quality of the project [3]. As an important part of building structure design, steel structure is difficult to design, and it is necessary to clarify the key points of steel structure design in combination with specific construction conditions. In the design of steel structure, it is necessary to consider the superiority of steel structure, but also to combine the characteristics of steel structure due to easy instability, and reasonably modify the structural design. At the same time, the quality of steel structure materials should be paid attention. According to the concrete situation of the project, the hidden danger of each component of the steel structure is comprehensively analyzed and studied. For example, whether there are hidden dangers in the connection nodes of the components, the safety of the building construction is analyzed and predicted. In the construction process of steel structure, in addition to paying attention to the design of its own structural materials, it should also follow the relevant design specifications of steel structure, and make adequate preparation for inspection before the installation of steel structure. Thus, the construction work can be carried out reasonably and effectively. Therefore, for the building structure based on steel structure, its structural design is particularly important.

This paper will systematically discuss the design of steel structure from the aspects of steel structure stability design, optimization design and seismic design. It will also discuss the design and application of steel structure in housing construction with cases. By recognizing the characteristics of steel structure design, summarizing the rules of steel structure design as well as its shortcomings, the paper will make use of its strengths and avoid its shortcomings, and better play its role in the design of modern architectural engineering.

2. Structural Steel Stability Design

At this stage, steel structure is used in the construction process of many building projects, and the phenomenon of insufficient structural stability often occurs when steel structure is used, which is mainly due to the lack of corresponding concepts of steel structure stability design by the relevant designers [4]. It can be seen that the stability design of steel structure is the top priority of engineering construction, once there is structural instability and other situations, both serious engineering accidents will occur, but also produce significant personnel and economic losses, so the designers are required to uphold a serious and rigorous attitude to ensure that the stability design of steel structure is foolproof. At present, the equilibrium method, dynamic method and energy method are widely used in the stability design of steel structures.

2.1. Equilibrium Method

The equilibrium method, also known as neutral equilibrium method or static equilibrium method, is a method to establish the equilibrium equations based on the force conditions of the steel structure after the occurring slight deformations and solve the stabilizing limit loads for them. In fact, the principle of static equilibrium is used, which refers to the design of the shape and dimensions of the structure to make the structure stable in the equilibrium position under loaded conditions [5]. If a small disturbance occurs in the structure, it will cause elastic deformations, but these deformations will be restored to the original equilibrium state after the disturbance disappears Through the scientific use of the equilibrium method, the elastic stabilization problem that exists in the bifurcation point can be solved to avoid deformation of the steel structure, which reduces the stability of the building [6]. The equilibrium method is utilized to calculate the minimum buckling load value and from it the limit value of the material, which improves the stability of the specific steel structure design.

2.2. Dynamic Method

Dynamics method is an effective method to solve the instability problem of steel structure based on the concept of dynamics. It applies the principle of dynamic stabilization. The dynamic stabilization principle refers to the structural stiffness and damping to consume the dynamics of the steel structure when it is subjected to the action of sustained perturbations in order to maintain the stability of the structure. When small perturbations occur, the system will determine the boundary conditions in the case of boundary conditions by the smaller displacement case and its determined value of the critical load of the system. As a result, the deformation of the steel structure decreases in the case of increased external loads, counteracting the effects of the perturbation to maintain stability. When the external load disappears, the steel structure will be displaced at a slow rate and gradually tends to the equilibrium state, which effectively maintains the stability of the steel structure and avoids the negative effects of deformation problems [5].

2.3. Energy Method

The energy method is an approximate method for solving the stability of the load carrying capacity, which is based on the principle of potential energy standing value, through the principle of conservation of energy to analyze and calculate to solve the critical load. Generally, it can only get the approximate value of buckling load, but it can get the accurate value by knowing the deformation form after buckling in advance and calculating with this method.

3. Optimized Design of Steel Structures

The optimal design of steel structure is required to meet various specifications or certain conditions, in order to give full play to the advantages of steel structure and make up for the shortcomings brought about by its limitations, to adopt a certain optimal design to make it reach certain index. In the optimal design of structure, not only the effect of external loads on the structure, but also the effect of the difference in relative stiffness between structural members on the distribution of internal forces, structural deformation, etc. should be considered [7]. Therefore, the following three structural optimization methods are generally adopted: size optimization, shape optimization, and topology optimization for optimal design.

3.1. Optimization of Design Methods

3.1.1. Dimensional optimization

Dimensional optimization belongs to parametric optimization technology and is a basic optimization method in structural optimization. Size optimization can usually be divided into two kinds, one is to optimize the structure by optimizing the cross-section parameters such as beams and plates, such as optimizing the cross-section size of beams or plate thickness. The other is to optimize the collective dimensions of the model, such as the radius of local circular holes. The difference between the two is that the former does not need to update the geometry and mesh.

3.1.2. Shape Optimization

Shape optimization is to achieve the optimum in some sense by changing the geometry of the region and requiring certain physical quantities to meet certain requirements at the boundary in order to improve the properties of the structure [8]. Shape optimization is the optimal design of a structure boundary or shape by changing the shape of the structure by moving the cell nodes or deforming the cells to another location to improve the structural performance. Unlike dimensional optimization, shape optimization not only changes the structural parameters, but also changes the shape of the original structure. Shape optimization is also divided into two categories: one is the optimization of node positions similar to size optimization, and the other is the shape of openings in the continuum.

3.1.3. Topology optimization

Topology optimization is a more innovative optimization technique. Unlike the previous two methods that do not change the topological form of the structure, topology optimization mainly takes the material distribution as the object of optimization, and compared with the previous two, it has a higher degree of freedom and space to design. The topology optimization process is generally the following process: first, the design area to be determined is divided into a number of finite units, and then based on the results of the calculation, according to certain rules, reduce or increase the density or weight of the unit. Then repeat the above process until the formation of a continuum with holes to complete the topology optimization. Take the rod structure as an example: the basic idea of the rod structure morphology topology optimization method is as follows: firstly, input the initial structural information, then carry out the finite element analysis of the structure to obtain the structural deformation, and calculate the sensitivity of the increase or decrease of the units in the structure [9].

3.2. Case Study

This paper applies the topology and shape optimization of the folded chord steel joist to create a structure. The initial structure is a folded chord truss with a span diameter of 100m, a height of 15m at the center of the span, the upper chord structure is gradually lowered from the center of the span to the ends, and the vertical bars are spaced at an interval of 10m. The bars are all made of round steel tubes with an outer diameter of 0.3m and a wall thickness of 20mm. The initial structure is shown in Fig. 1.

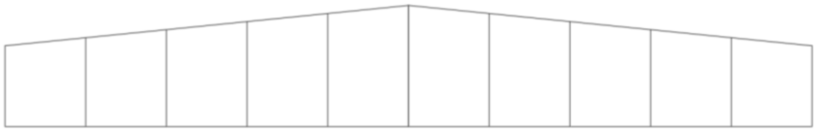

Fig 1. Initial Folded Chord Steel Joist Structure.

The structural optimization process starts with the unit increase operation, the first stage, symmetrically increasing the diagonal bar on the structure the stage is optimized, and the optimization results are shown in Fig. 2.

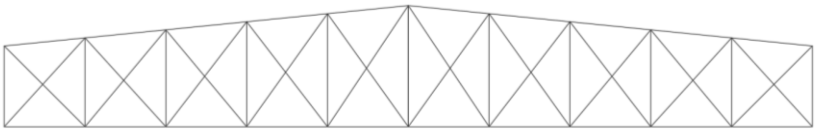

Fig 2. Addition of symmetrical diagonal bars.

In the next stage, the main operation is the unit redundant rod withdrawal, this stage for the next stage of the node movement to prepare for the withdrawal of the structure shown in Fig. 3.

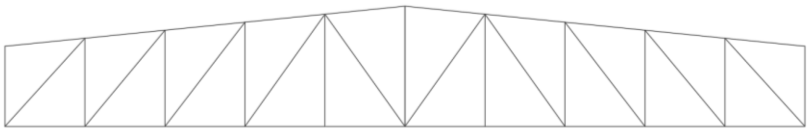

Fig 3. Withdrawal of redundant rods.

In the final stage, the nodes are moved and the vertical rods at both ends of the initial structure and the upper chord rods are withdrawn to make the overall structure more similar to a folded chord truss. The final structure after moving the nodes is shown in Fig. 4.

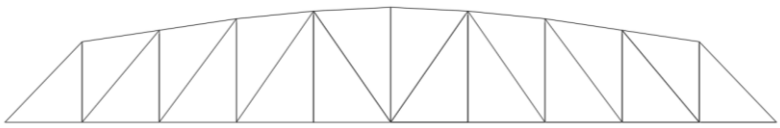

Fig 4. Folded chord steel joist after moving nodes.

With the gradual optimization, through the gradual optimization of the structure diagram, the structure of the folded string steel truss gradually tends to be complete, and the structure form is gradually stable, reaching the most stable state. It can be seen that this method can optimize the structure, meet the high stress performance and various forms, and can provide more design methods for practical engineering.

4. Seismic Design of Steel Structures

With the continuous development of national urbanization, the process is accelerating, and the population density is increasing. For some areas in the seismic zone, once an earthquake occurs, it will bring extremely serious losses. The randomness of earthquakes makes it difficult to predict the degree of damage caused by earthquakes. Therefore, it is particularly important to combine various factors to improve the seismic resistance of building structures. The use of effective seismic design methods has also been paid more and more attention. For the steel structure in the construction project, the irregular shape design of the through and symmetrical structure can better resist the distortion deformation effect in the specific application [10].

4.1. Pushover analysis method

There are four types of performance-based seismic analysis methods: linear static analysis, linear dynamic analysis, nonlinear static analysis, and nonlinear dynamic analysis. The pushover analysis method belongs to the nonlinear static analysis method, which is also known as plastic hinge analysis. The method is generally applied to structural types with higher order vibration systems and less influence of dynamic properties. The method is based on the capacity spectrum method to obtain the actual strength and deformation conditions of the structure in the elastic-plastic state. The method is aimed at establishing the load distribution under lateral loading, applying horizontal loads to the center of mass of each level of a through, symmetric form steel structure to achieve a given target displacement, and gradually superimposing horizontal internal forces in the same direction as in the previous step, just enough to cause one or a group of rods to yield or crack, so as to analyze the damage process of the structure as well as the nonlinear deformation capacity. For the yielded or cracked members, modify the stiffness and add one level of load to cause another member or group of members to yield or crack. Repeat the above steps until the structure reaches a certain target displacement or damage occurs, the state of deformation and load capacity and allowable value comparison, and judgment and optimization of steel structure design.

4.2. Incremental dynamic analysis (IDA) method

This method is to continuously adjust the seismic wave amplitude according to the elastic stage until the yield stage of the through and symmetric form steel structure, and then continuously adjust the seismic wave from the elastic stage until the destruction state of the steel structure, and then finally analyze the instability state of the steel structure accordingly. By analyzing the nonlinear dynamics of this method, the seismic capacity including the strength, deformation process, and stiffness of the steel structure is directly reflected for different levels of earthquakes. In addition, it is concluded that the application of IDA method and pushover analysis method can be combined with each other [11]. It is more conducive to the calculation of bearing capacity limit and seismic design of this type of steel structure members.

5. Conclusion

This paper mainly studies the design and application of steel structure in residential buildings, and draws the following conclusions:

(1) Steel structure stability design has three stability design methods: balance method, dynamic method and energy method. The optimization design of steel structure includes size optimization, shape optimization and topology optimization. In addition, taking folded string steel joists as an example, two methods of shape optimization and topology optimization are combined into step optimization, which proves the feasibility of the optimization method. The seismic design of steel structure can adopt pushover analysis and IDA.

(2) There are still many difficulties and shortcomings in the field of steel structure design. In the stability design of steel structures, the problems dealt with in the random impact analysis of steel structures are mostly limited to a certain range of modes. The uncertainty in practical engineering will lead to the difference of structural response. As a new optimization method, topological optimization is not mature enough for the optimization design of steel structure. For seismic design, the pushover method cannot reflect the performance under specific seismic conditions, and its analysis of common engineering models of shear wall structures is not mature at present. Therefore, the future development in this field should be more inclined to improve topological optimization, pushover method, etc., and focus on considering the instability extremum of steel structures under random parameters.

References

[1] Bin Xu. Application of building structure design optimization method in house structure design. Construction Technology Research, 2020, 3(3): 96-97.

[2] Huang Lei. Research on steel structure design and installation technology of construction engineering. Architectural Design and Research, 2021, 2(3).

[3] Zhang Chao. Discussion on construction management of steel structure construction project. Architectural Design and Research, 2023, 4(8).

[4] Wu Jianxia. Research on stability design of steel structure. Residential and real estate, 2015, (28): 93.

[5] Du Gaopeng. Discussion on the design method of stability in the design of building steel structure. Engineering Research and Practice, 2023, 4(18).

[6] Liang Dong. Stability and design points of steel structure design in construction engineering. Construction Technology Research, 2020, 3(7): 3-4.

[7] Dai Weizhi. Analysis of the basic elements of the development of welding technology for building steel structure. Modern welding. 2009, (6): 1-4.

[8] Gong Shuguang. Research and application of numerical methods for shape optimization. Hunan: Xiangtan University, 2001.

[9] Pan Chen-Liang. Research on topology and shape optimization method of rod system structure. Heilongjiang: Harbin Institute of Technology, 2023.

[10] Li Dong. Discussion and suggestions on seismic design methods for steel structures. Urban Construction Theory Research (Electronic Edition), 2023, (01): 143-145.

[11] Sun Yunjun. Discussion on seismic design method of steel structure. Encyclopedia Forum Electronic Magazine, 2021, (17): 1635.