Optimization of Object-oriented 3D CAD Pre-processing System for Steel Structure of High-rise Buildings

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Abstract. In this paper, the object-oriented method is used to study the pre-processing system of 3D high-rise building steel structure CAD. For the high-rise building steel structure design optimization system, users mainly contact with the functions of modeling, analysis, design checking and drawing. In fact, all these functions are carried out around the data stored behind. Three-dimensional high-rise building steel structure CAD pre-processing subsystem mainly integrates three-dimensional entity construction module, node design and editing module, construction drawing, processing drawing and CNC data output module. In this paper, the wall element is used to simulate the shear wall element, and the wall element can be automatically refined into a shell element composed of quadrilateral membrane element with rotational degree of freedom and generalized conforming bending plate element for thick and thin plate, which improves the speed and accuracy of analysis and calculation of shear wall. Various loads of high-rise building are calculated, especially the wind load of space action. It provides a new idea for wind load calculation of high-rise buildings. It is better to put forward a practical system optimization model, which can deal with the objective function, variables and constraints in a large number of engineering processing, and consider the actual constraints as fully as possible, which has strong practicability.

Keywords: Object oriented, high-rise building, steel structure, computer aided design (CAD), processing system.
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1 INTRODUCTION

With the rapid development of economy, high-rise buildings are developing rapidly, and the design ideas are constantly updated. The structural system is becoming more and more diversified, and the layout and vertical shape of buildings are becoming more and more complex. Since the 1990s, CAD technology of structural engineering has developed to a higher level on the basis of making full use of modern computer technology. Structural engineering CAD software is in the contradictory development. On the one hand, structural engineering CAD software becomes more and more complex due to the higher and higher requirements of structural designers for structural engineering CAD software; on the other hand, structural engineering CAD software is updated faster and faster, and the development cycle is shorter and shorter [1-2]. Object oriented programming is a new method of software system design and implementation. Kaplan et al improved the productivity of software developers by increasing the scalability and reusability of software, and can control the complexity of maintenance software and the cost of software maintenance [3]. Park et al realized the development of structural engineering CAD software with object-oriented method, which provides an effective way to solve this contradiction [4].

Jung et al analysis software of building structure design can be divided into three parts: pre-processing, structural calculation and post-processing [5]. The preprocessing part is the input part of graphics and calculation information by Nemova et al [6]. The main function of this part is to input the basic information of the structure model, such as structure geometry, material information, section size, etc.; and the basic information of structural load, such as dead load, live load, wind load, earthquake load, etc. [7-8]. The pre-processing part will generate the unit node information of the structural model to prepare for the structural analysis, so its function must match the function of the analysis module [9]. If the core of its calculation is a powerful general structural analysis software, then its preprocessing should also be a module with flexible input and strong adaptability. Its fast modeling function can also generate a basic structural skeleton. Then, the generated 2D or 3D model can be quickly and accurately edited and modified by its powerful editor. In addition, the pre-processing part is directly related to whether the software is accepted by most engineers. The basic requirement of friendly input interface is convenient, fast, accurate and easy to master. Most engineers cannot spend a lot of time learning an application software, especially the data input part.

Compared with the foreign CAD software of steel structure, the domestic software has a simple user interface, data input and operation, which is more in line with the habits of engineers. The design and analysis results of simple structure have basically reached the level of foreign software. However, there are still many shortcomings, such as the limited theoretical level of result analysis, which affects the ability and accuracy of complex structure analysis, the function of automatic optimization is not perfect, the systematic structure design is insufficient, and the standard node library is small. Moreover, in the aspect of post-processing, the domestic software is still at a low level, the function of automatically generating drawings is still very weak, and the ability of generating processing details is poor. From the technical analysis, the joint design has great flexibility and variation characteristics. The specific design result of a node depends on the geometry and engineering constraint properties of the members connected with the node, and also depends on the style and habits of the designer and the Institute, so the requirements for the whole system model and node model are very high. From the research and application of steel structure at home and abroad, there is no software that can fundamentally solve the problem of steel structure CAD node design and drawing node diagram. Therefore, the design of steel structure joints and the research and development of engineering detail software are of great significance for the development of 3D high-rise building steel structure CAD.

2 DESIGN AND IMPLEMENTATION OF SYSTEM ARCHITECTURE

2.1 Object Oriented System Analysis Method

The idea of object-oriented was first put forward as a programming technology, and then gradually used in the field of software engineering. Object oriented software engineering methods include object-oriented analysis, object-oriented design, object-oriented programming, object-oriented testing and maintenance, etc. [10]. Object oriented method is a kind of software development method which uses the concepts of object, class, inheritance, encapsulation, aggregation, message transmission and polymorphism to construct the system. "Object" is the most basic concept used in object-oriented methodology. An object is a unity composed of data describing the properties of the object and all operations that can be applied to the data. Objects are independent of each other. They communicate by sending information. A description of objects with the same structure and operation is called "class". An object is an instance of a class. One of the main characteristics of class is inheritance, which enables similar objects to share program code and data structure. In the standard part design system of steel structure, inheritance enables designers to reuse the previous standard parts more. Object oriented system analysis (OOA) refers to the use of object-oriented methods for requirements analysis. Its basic task is to use object-oriented method to analyze and understand the problem domain and system responsibility, to have a correct understanding of the things in it and the relationship between them, and to find out the classes and objects needed to describe the problem domain and system responsibility. Define the attributes and services of these classes and objects, as well as the structure, static relationship and dynamic relationship between them. Finally, an OOA model and its detailed description that can meet the user's requirements and directly reflect the problem domain and system responsibility are generated. There are many methods, such as Shaler & Mellor method, Coad & Yourdon method, Booch method, OMT method and so on. The system model established by OOA method is shown in Figure 1, which mainly includes three parts: basic model, supplementary model and detailed description. The basic model is the core of OOA model, which expresses the most important system information in an intuitive way; the supplementary model provides a topic diagram to help understand the basic model and an interaction diagram that reflects how the system meets the needs of users. The topic diagram is an additional granularity control mechanism on the basic model, and the interaction diagram establishes the contrast between usecase and object service. The detailed description of the system is mainly composed of "class description template" corresponding to each class in the model, which is the detailed definition and interpretation of model semantics.

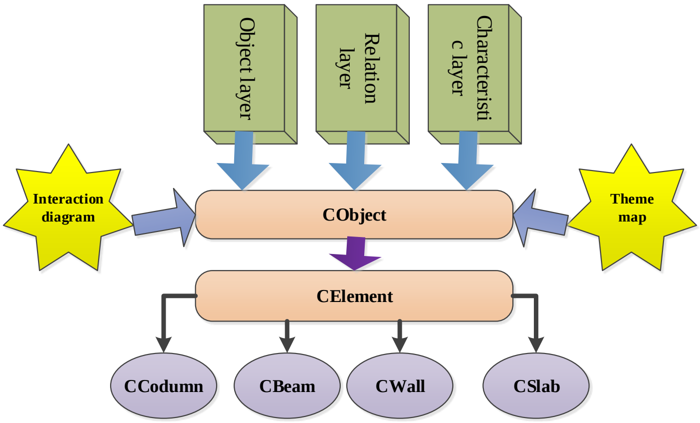

Figure 1: Structural unit system model.

2.2 Design of Overall System Framework

In terms of high-rise building steel structure design optimization system, users are mainly exposed to the functions of modeling, analysis, design checking and drawing. In fact, all these functions are carried out around the data stored behind, and the organization mode of all these functions is determined by the frame design. In addition, compared with the function, the framework design and data structure are relatively stable and basic. Once there is a defect in the design, the cost of adjustment and improvement is very high. In some cases, the whole module or even the whole system will be overturned again. Therefore, without a reasonable framework and data structure organization, the expansibility, maintainability and functionality of the system are bound to be greatly limited. Therefore, it requires us to attach great importance to the system framework and data structure design when developing large-scale building structure CAD system.

In order to do a good job in the design of framework and data structure, on the one hand, it is necessary to have a deep understanding of the functional requirements of the optimization system for the design of steel structure of buildings; on the other hand, it is also necessary to analyze and plan the system in combination with the new technology and experience of software development; it can be said that it is the most comprehensive, complex and critical work in the whole system. This chapter first determines the overall frame design according to the characteristics of the high-rise building steel structure design optimization system; then analyzes the system problem domain in-depth, and obtains the design of the core framework object; finally, proposes the structured storage scheme of the database.

A-E-C is an integrated collaborative work and information sharing technology of architecture, structure and construction, that is, from the perspective of architecture, structure and construction, the requirements and interfaces are considered as a whole, and finally the information interaction and collaboration of various systems are realized through unified planning and design. This technology is also one of the main development directions of CAD technology at home and abroad. The steel structure design optimization system of high-rise building adopts the basic framework idea of AEC. the five different models in the design process are related to each other and have their own different information. Therefore, this paper abstracts the whole design process into a five-stage design model.

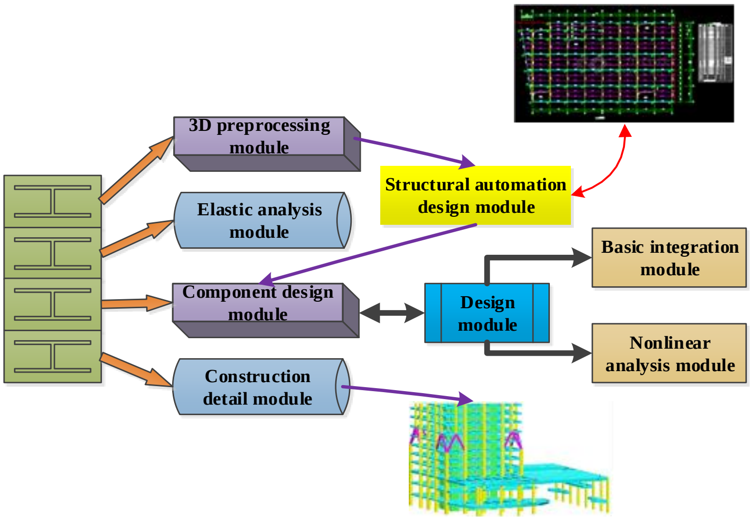

Figure 2: System function module composition diagram.

The relationship of each model is shown in Figure 2. The characteristics and relationships of each model are as follows:

(1) Building model is the basis of structural design. This model mainly deals with the building information related to structural problems, which requires it to meet the requirements of architects accurately and conveniently. The information corresponding to each stage of structural design is different. The information corresponding to the elastic analysis stage is mainly related to the analysis, such as nodes and elements; corresponding to the design stage, it is mainly related to the component design, such as the design of local openings and stiffeners.

(2) Based on the building model, the finite element concept is abstracted, and the element attribute information is added, and the load is arranged to obtain the elastic analysis model. According to the elastic model, the finite element analysis is carried out to obtain the internal force of the element, the displacement of the node and the dynamic characteristics of the structure, which are all the result information of the elastic model. Based on these results, the whole checking calculation can be carried out according to the standard. .

(3) Based on the elastic analysis model information, according to the complexity of the structure, the secondary modeling processing based on intervention is carried out. Through the element merging and other processing, the design components and design nodes are formed, and the attribute, internal force and displacement of the design component and design node object are formed.

(4) According to the design model, it can be transformed into the structural installation model, and form the initial properties of the installation components and installation nodes, and reasonably supplement the information of the building structure and the structure structure. At this stage, the focus is that the engineering implementation method of the components and nodes is basically irrelevant to the mechanical analysis results, and can form the component processing and accurate engineering civil engineering budget.

(5) According to the design model, it can be transformed into the unit information of the nonlinear analysis model (more design attribute information than the elastic analysis model, and the nonlinear analysis parameters are added to set, the nonlinear analysis can be carried out, and the structural response under various nonlinear conditions can be obtained; the main concern is the nonlinear response of the structure. The system adopts the database and functional component program framework in the object-oriented set, and its implementation diagram is shown in Figure 3.

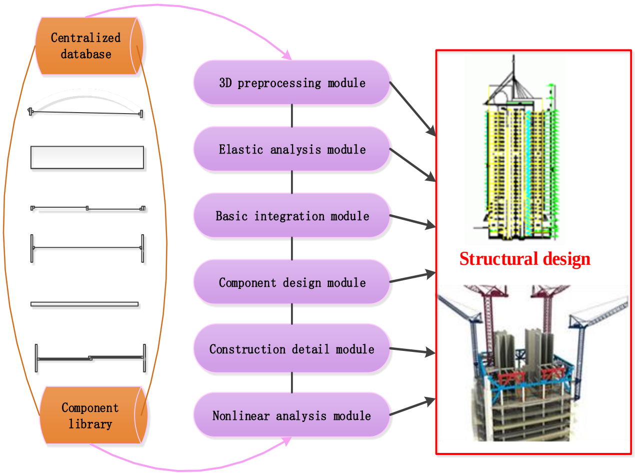

Figure 3: System implementation diagram.

3 LOAD AND ELASTIC STATIC ANALYSIS OF TALL BUILDINGS

3.1 Load of Steel Structure of High-rise Building

Steel structure of high-rise building, like all structures, must be able to resist various external loads and meet the requirements of ultimate bearing capacity and normal use. The external effects on the structure include: the self-weight of the building and the service load, wind load, earthquake action and other factors such as temperature change, uneven settlement of foundation, etc. Among them, the dead weight and service load of the building are vertical load, and wind load is horizontal load; the seismic action is mainly horizontal earthquake action. In high intensity area, vertical seismic action must be considered for high-rise buildings, high-rise structures and long-span structures. According to the current load code, the fswas system automatically completes the calculation of various loads and actions by inputting some basic parameters by the user. According to the requirements of the finite element calculation, various loads and actions are equivalent to the nodes to form the column vector of the load and action. Finally, the most unfavorable load combination is carried out. The load column vector at the right end of the structure core finite element calculation is formed. The flow chart of load calculation of fswas system is shown in Figure 4.

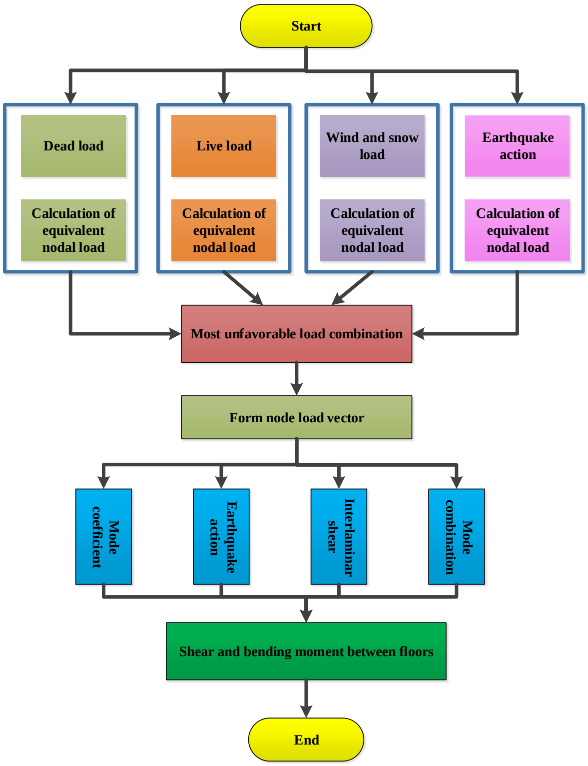

Figure 4: Load calculation process of high-rise building.

There are two kinds of loads acting on the structure, one is concentrated load, the other is distributed load. For concentrated load, the action point of concentrated load should be a node when meshing. If the concentrated load is not acting on the node, the equivalent node load should be calculated. As for the distributed load, the equivalent node load should be replaced to facilitate the calculation. This kind of load replacement must be carried out according to the principle of static equivalence. Only in this way can the stress error caused by the replacement be local and not affect the overall stress.

(1) Equivalent node load of beam element

When there are no node loads acting on the beam element, according to the method of structural mechanics, the corresponding bar end force can be obtained by using the load constant of statically indeterminate beam.

(2) Equivalent nodal load of plane problems in elasticity

The idea of virtual work equivalent principle is: for an element, after the load acting on the element is moved to the node, it should be equivalent to the virtual work of the original actual load. The calculation method is: for any allowable small virtual displacement, the virtual work done by the original load is equal to the virtual work done by the equivalent node load after the displacement.

Vertical load includes dead weight of structure and service load of building. The self-weight of the structure includes the self-weight of beam, column, wall, plate and other structural components as well as decoration and maintenance materials. The self-weight of structure is a typical distributed force, which must be equivalent to the node to form the equivalent load column vector. The calculation of the dead weight of real element is completed by the heavy load function of each element class. In addition, it should be noted that the equivalent nodal load is the value in the element coordinate system, and the total gravity load column vector can be formed only by converting the coordinate into the overall coordinate. The live load mainly acts on the slab. According to the load code, the value is equivalent to the node of the plate element to obtain the equivalent node load. Similarly, the live load column vector can be formed only after coordinate transformation.

3.2 Establishment of Structural Mechanics Model

The basic method of internal force calculation of high-rise building structure is finite element method. No matter how complex the structure is, it is composed of several basic components, such as slab, beam, column, support or shear wall. In the calculation, the spatial mechanical model is established by using the element corresponding to the type of member, and the displacement and internal force of the structure under the action of vertical load, wind load and earthquake force are analyzed. The basic stress components of high-rise structure are column, beam, brace, shear wall and floor. The following is the finite element simulation of these components.

(1) Columns, beams and supports

The column, beam and support are all one-dimensional members, and the stress state can be simulated by space bar element with rigid arms at both ends. According to the different constraint conditions, the space bar element can be divided into three cases: one end fixed, one end hinged and two ends hinged. In general, the influence of shear deformation is negligible when the bar is subjected to transverse load. However, when the height of the cross-section is greater than 1 / 5 of the length, the influence of shear deformation on the deflection cannot be ignored. In high-rise structure, the section size of column and beam is larger. Therefore, the influence of shear deformation is considered in the single stiffness matrix of spatial bar element.

The bar element considering shear deformation can be divided into the following two types:

- Tmoshekno beam element is characterized by independent interpolation of deflection and rotation angle, which is easy to produce shear self-locking, so it is necessary to reduce integral or other methods to eliminate this phenomenon.
- When the height h is very small relative to the length L, the influence of shear deformation can be ignored, and it will automatically degenerate to the beam element without considering shear deformation, and there is no shear self-locking.

(2) Shear wall

Shear wall is the main lateral force resisting member of high-rise structure, which bears both horizontal load and vertical load. In view of the current development level of finite element theory, it is more practical to use shell element to simulate the stress state of shear wall, because shell element has both in-plane stiffness and out of plane stiffness as shear wall. In order to reduce the difficulties of geometric description and shell element division of shear wall and improve the efficiency of analysis, considering the randomness of geometric size, opening size and spatial position of shear wall in engineering. In this paper, the concept of wall element proposed by SAP84 is used for reference. On the basis of four nodes, a super element called wall element is constructed by using substructure method and static condensation principle.

(3) Floor

In theory, the shell element can be used to simulate the stress state of the floor, which may increase a lot of calculation work. In order to reduce the degree of freedom, the assumption of "infinite rigidity in floor plane" was adopted in the past high-rise analysis model. However, as mentioned above, this assumption leads to large errors in many projects. In this paper, three assumptions are made for the floor slab, and one or several of them are adopted in the calculation of the actual project. These three assumptions are as follows:

- It is assumed that the floor is infinite rigid in the whole plane;
- It is assumed that the slab is infinite rigid in the plane;
- The floor is assumed to be elastic.

3.3 Optimization Model of High-rise Building Steel Structure

Although the research of structural optimization theory has a long history and a lot of optimization practices, it is generally established for small-scale structural optimization. Relatively speaking, the optimization algorithms and programs for large-scale structures are still relatively scarce. On the one hand, it is restricted by the previous calculation speed conditions; on the other hand, large-scale structure has complex constraints, many load combinations, and rich cross-section and component forms. Therefore, it is very wide to establish a comprehensive and practical algorithm. In addition, in such a structural optimization program system, in addition to a lot of work to achieve and improve the general optimization algorithm itself, it also involves the organization of data structure, the finite element analysis kernel and the embedding of standard checking calculation. Without a large number of analysis and checking program codes and their pre-processing and post-processing of a powerful structural design software, it is difficult to implement a practical structural optimization program system. The optimization model of high-rise building steel structure includes processing steps, data model and processing method.

In the cross-section optimization design of high-rise steel structures, there are two stages of optimization problems: Section conceptual optimization design and algorithm-based group section optimization. In the conceptual optimization design stage, the main work is to determine the reasonable grouping of components and the reasonable setting of section orientation; the work of conceptual optimization design stage is the premise of algorithm optimization stage, because the algorithm optimization stage is obtained under the premise of conceptual optimization design. On the one hand, only the reasonable processing of conceptual optimization can ensure the rationality of algorithm optimization results; on the other hand, compared with algorithm optimization, conceptual optimization design is a higher-level optimization, and the rationalization of its processing can maximize the structural potential. In the stage of section conceptual optimization design, the stress ratio distribution and the work distribution under the overall constraint can be used. According to the mechanical characteristics of components, the reasonable initial definition domain of component group can be established, and the orientation of component can be set up. This part of work needs software to provide processing tools and combine with artificial concept intervention to complete. Section algorithm optimization generally considers two kinds of constraints: the global displacement and the local force of the component. The two kinds of constraints jointly form the structural constraints. In the process of optimization, one kind of constraint may play a controlling role all the time, or the two constraints may be controlled separately at different stages, which needs to be analyzed and judged according to the structural characteristics.

The model established in this paper has generality. Besides steel members, it can also deal with concrete members and various composite members, including concrete shear wall members based on wall element treatment. Because of the diversity of component types and materials, the weight of concrete and material is taken as the objective function, which can no longer reflect the direct relationship between the cost and the upper process, so it is no longer applicable. Therefore, this paper takes the material cost as the objective function, which is expressed as follows:

$$D=\sum_{i=1}^{k}\left(w_i B_i\left(\psi_i, C_i\right)\right)+\sum_{i=1}^{t}\left(W_i s_i\right) \tag{1}$$

The first item is the sum of the cost of all member objects, K is the number of member groups (distinguished by section), and its W_i is the cost coefficient corresponding to unit area of group i section:

$$W_i = w_i \sum_{t=1}^{S_i} d_{it} \tag{2}$$

s_i is the total number of i-section; d_{it} is the geometric length of the s-th member of the i-section. After summation, the total length of the members of the same type of section is counted according to the component group. The longer the total length of the component, the greater the sensitivity to the cost; w_i is the cost per cubic meter of the class s_i section, all costs are comprehensive unit price, including materials, processing, installation, profit, etc.

$$E_{wi} = D_{wi} \sum_{s=1}^{M_k} B_{sk} \tag{3}$$

D_{wi} is the cost per cubic meter of type i wall, which is divided into concrete part and reinforcement part; M_k is the total number of class i walls; B_{sk} is the area of the K block of type i wall.

4 EXPERIMENT AND ANALYSIS

Generally, steel frame scheme is adopted for multi-story steel structure. In example 1, a typical two-story steel structure project is selected, and the cross-sections are all H-shaped steel sections. In this case, the optimization performance of multi-story steel structure is evaluated, and the structural optimization characteristics under various conditions are analyzed. Figure 5 shows the overall optimization results based on continuous variables, and Figure 6 shows the overall optimization results based on discrete variables. In the case of continuous solution, the optimal solution is 361860 yuan (decreased by 2,8.6%), and the corresponding overall constraint ratio is 1. O: in the case of discrete solution, the optimal solution is 26298 yuan (decreased by 38.4%), and the corresponding overall constraint ratio is 0.996.

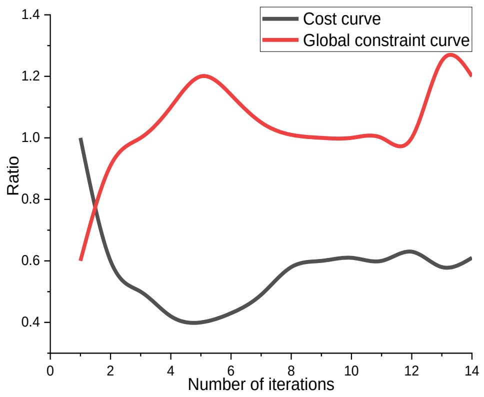

Figure 5: Continuous optimization process curve with global constraints.

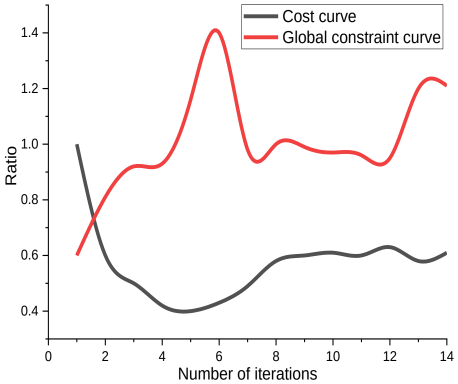

Figure 6: Discrete optimization process curve with global constraints.

It can be seen that Figure 5 has better optimization results for global constraints when the variables are continuous; Figure 6 discretizes the continuous results, basically maintaining the characteristics of continuous results. In addition, because discretization is the search result of feasible region solution based on continuous solution, the trend of discretization is the same as that of continuous solution, but it does not correspond to each other. Generally, the overall stress is slightly lower than the optimization process curve, and the cost is slightly higher than the curve. Through Figure 5 and Figure 6, we can see that the algorithm in this paper has good convergence for this example. At the same time, it is proved that the discretization method proposed in this paper is also very suitable, and basically keeps the characteristics of continuous solution.

Figure 7 shows the local optimization results based on discrete variables. It can be seen that the local stress ratio is basically the same as that of the whole, and the local stress ratio is always higher than the overall stress ratio. It can be seen that the project is controlled by the local stress ratio. The cost is 421300 (decreased by 28.5%), the overall constraint ratio is 0.715, and the local constraint ratio is 0.997. Therefore, no comprehensive optimization is needed, and local optimization can be carried out directly. In addition, it can be found that the local constraint search method established in this paper has better local detailed search characteristics without large jump. In addition, it can be seen from Figure 7 that the stress ratio of the optimization process has a certain local jump around 1.0, so it is a better optimization strategy to retain all process results for users to choose the better solution.

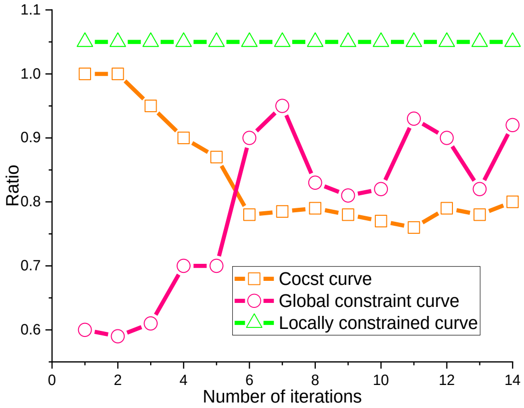

Figure 7: Local optimization process curve with global constraints.

It can be seen from the structural layout plan that the main stressed beams are arranged in the weak axis plane of the column, so the stress of the structural column members is controlled in the weak axis plane. According to the treatment principle proposed in the paper, the azimuth angle of structural column members should be rotated by 90 degrees, so as to make the component layout more reasonable. Figure 8 is the optimization curve obtained based on the adjusted scheme. According to the adjusted local optimization curve, the optimal solution is 371300, which is reduced by 37% (the overall constraint ratio is 0.931, and the local constraint ratio is 0.985). It can be seen that the potential of structural optimization can be further tapped through conceptual optimization, which proves the value of orientation adjustment and optimization.

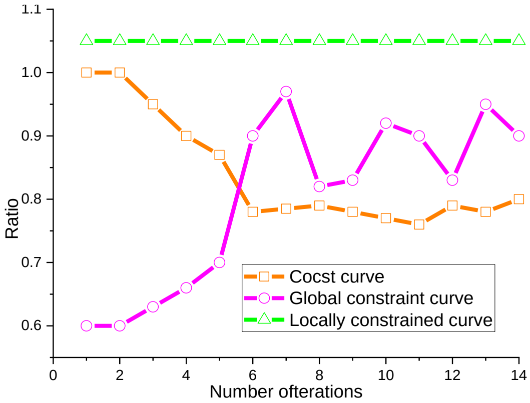

Figure 8: Local optimization process curve after concept orientation adjustment.

5 CONCLUSION

In the CAD software of steel structure architecture, the design of standard parts plays an important role, and the standard parts of steel structure are used very frequently. There are many kinds of steel structure standard parts and their structures are complex. In addition, designers can also carry out creative design of nodes under the condition of meeting the stress of nodes, which makes the design of nodes more complex. Due to the limitations of data collection and technical level, the system can not achieve absolutely flexible node design, and the development of steel structure standard parts design system needs to be further in-depth. Automatic dimensioning in construction drawings plays an important role in steel structure design software, which is almost an important index to measure the design level of a steel structure design software. At the beginning of the system design, we hope to solve the problem of automatic dimensioning by ourselves, but because of the time and technical problems, it didn't succeed in the end. In this system, the automatic marking of nodes adopts the dimension marking function of 501idworks software, which has a lot of shortcomings, and the final labeling effect often has the problem of collision and the layout of the drawing is not beautiful and unreasonable.

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