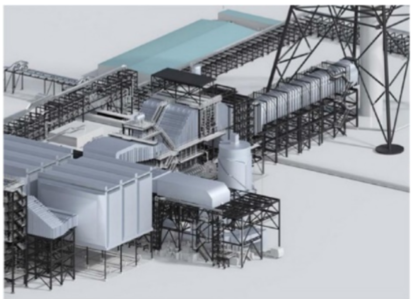
Development of Automatic Optimum Design System "M-FRAME" for Frame Steel Structure



Reference source: MHI's website
https://power.mhi.com/products/conventional

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Mitsubishi Heavy Industries, Ltd. (MHI) has developed a steel frame cross-section minimizing method for the structural design of a frame steel structure, which enables economic design through simultaneous minimization of the weights of multiple steel frame members. With this method, however, there are issues that the data input and output are not automated and the calculation takes a lot of time, only the constraint conditions for strength and deformation are considered in the calculation and the other conditions that should be considered in design are not taken into account. Therefore, the method has been applied to limited products. To solve these issues, we created a program that automatically delivered the input and output in each calculation process on the server and developed a system using a Web browser as the user interface. We also added a function of calculating the cross-section of a frame steel structure with consideration given to assimilability of members in addition to the constraint conditions for strength and deformation. This report describes the overview of the developed system and a verification example for application effects.

1. Introduction

MHI has numerous plant products and there are various sizes of frame steel structures to support them, from small ones composed of several tens of members to large ones composed of several thousands of members for main plant equipment such as large turbines and boilers. The function of these frame steel structures is to securely support plant equipment, and they must be robust enough to ensure safety and security without collapsing in natural disturbances such as earthquakes and storms. On the other hand, there is a need for weight reduction of steel frame materials from the aspect of the rise in material costs and the reduction of environmental load. In the previous report[(1)], we described the steel frame cross-section minimizing method which enabled a rational design that improved both seismic resistance and economic efficiency. In the method, however, there are issues that the data input and output in the calculation must be manually conducted, it takes a lot of time and since the design conditions with consideration for the assemblability of members, such as size adjustment at joints of members, are not taken into account, adjustment to the optimization calculation results must be made. Therefore, the method has only been applied to a limited number of products. MHI deals with various plant products, and there is a need for weight reduction of the frame steel structure of each product. In order to expand the scope of application of this method, we developed a system responding to the above issues.

2. Overview of the frame steel structure design method

In Japan, the structural design of frame steel structures is mostly conducted according to the Building Standards Act, and the structure is designed so that the responses (stress, deflection, etc.) of all steel frame members to loads such as seismic force do not exceed the allowable values. In the previous report, we developed the steel frame cross-section minimizing method, M-FRAME

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(Mitsubishi-Frame weight Reduction Algorithm for Multiple Elements), which enabled simultaneous minimization of the cross-sections of multiple members constituting a frame steel structure. By this method, a frame steel structure that minimizes the weight can be automatically derived while the above-described constraint conditions (stress, deflection, etc.) are satisfied.

As described in this report, we newly improved and expanded the functions of the M-FRAME and as a result, in addition to the above-described steel frame cross-section minimization calculation, the preparation work for calculation (such as creation of a model and setting of conditions) and the adjustment of the cross-sections of members with consideration for assemblability (Chapter 4) became automatically executed. Furthermore, the data input and output in individual work processes became automated (Chapter 3) and a series of frame steel structure design works can be automatically executed in a consistent and integrated manner.

3. Development of an automated frame steel structure design system

In order for the method to be applicable to more frame steel structure products, we created a program that allowed the data input and output in each calculation process to be automatically delivered on the server and developed a system using a Web browser as the user interface to automate the data input and output in each design process and make the system versatile. **Figure 1** shows the conventional design flow in the case the M-FRAME is not applied and the design flow in the case the developed system is applied. Each design process is automated to shorten the design time. The target scope of the development in the previous report was the "cross-section optimization" process in the figure and only the cross-section design in the conventional design flow was automated.

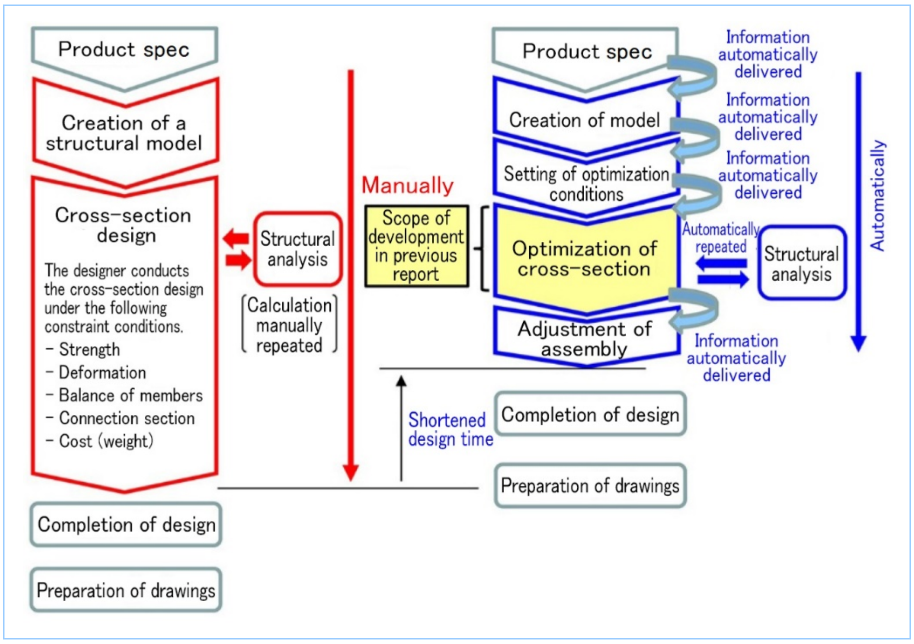

Figure 1 Comparison of design flows
When the developed system is applied, the processes from creation of a structural analysis model to calculation of an optimal cross-section can be automatically conducted in a consistent and integrated manner and the design time becomes shorter than the conventional design time.

In order to implement the frame steel structure cross-section design in a consistent and integrated manner, we made a system that enabled automatic execution of the cross-section design processes using the M-FRAME of "creation of a structural analysis model --> setting of optimization conditions --> optimization of cross-section --> adjustment of assimilability --> visualization of design result" and automatic data input and output and data delivery in each process. We selected the major design processes in the frame steel structure cross-section design using the M-FRAME and developed a system composed of a total of 10 applications.

The main function of the developed system is the "cross-section optimization" application, by which a cross-section that minimizes the weight under the constraints on strength (such as stress) is calculated. The algorithm used in the method of the previous report was improved to shorten the calculation time and adopted as the optimization algorithm. We also developed the applications such as a "model creation" application for reading the information (nodes, elements, load data, etc.) entered in the prescribed form and automatically creating a structural analysis model, an "assemblability adjustment" application for modifying the cross-section with consideration for assemblability and a "graph generation" application for outputting graphs of comparison results of frame steel structure weights, etc.

4. Design method with consideration for assemblability

From among the developed applications, the method for "assemblability adjustment" is described. In the design method of the previous report, a cross-section with consideration for constraints such as strength and deformation could be calculated, but the assemblability of members were not considered in the calculation and adjustment to the calculation result was required. Therefore, we developed a method in which a column-to-beam joint or a beam-to-beam joint as shown in **Figure 2** could be adjusted. For adjustment of a column-to-beam joint, the cross-sectional size of the column is increased according to the cross-sectional dimensions of the beam. For adjustment of a beam-to-beam joint, the cross-sectional heights of the beams are automatically changed so that "the beam to be attached ≦ the support beam" can be achieved (the cross-sectional height of the support beam is increased). As a result, the cross-sections are modified with consideration for connection so that "a girder (connecting a column and a column) ≧ a major beam (connecting a girder and a girder) ≧ a minor beam to be attached to a major beam" is achieved. In addition, adjustment of a column-to-column joint (the cross-section of the column in the upper layer ≦ the cross-section of the column in the lower layer) and adjustment of a column-to-vertical brace joint (the column width ≧ the vertical brace width) can be made.

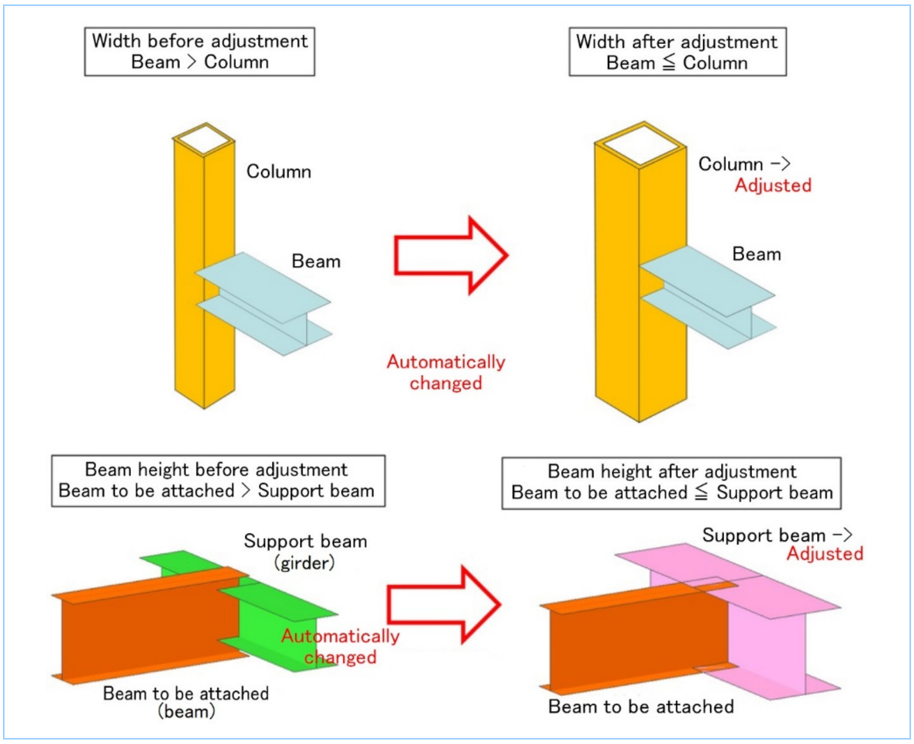

Figure 2 Example of assemblability adjustment
For a column-to-beam joint or a beam-to-beam joint, the cross-section of the column or beam is automatically changed so that the members can be assembled.

In the design method of the previous report, a change of the cross-section should be made for each element, but in the actual system, the same members were designed to have the same cross-section. Therefore, if several elements need to have the same cross-sectional shape, the cross-sections of the elements must be manually adjusted to make them uniform. In the developed method, as shown in **Figure 3**, adjustment is automatically made so that the predetermined group of elements have the same cross-section. The cross-sections are made uniform to match the cross-section of the element in the group that delivers the best cross-sectional performance (the highest bending strength, for example, in the case of beam members in which bending is critical) so that it has no problem with the constraint on strength.

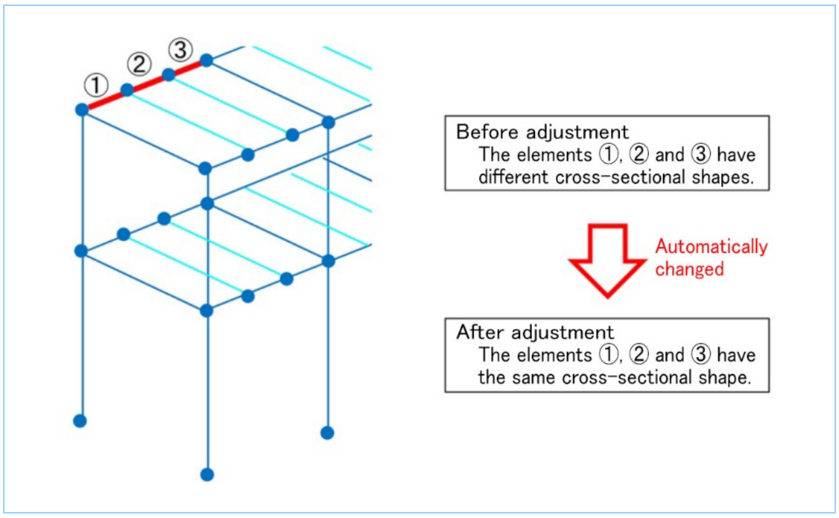

Figure 3 Adjustment of elements with the same cross-sectional shape
For the elements that should have the same cross-sectional shape, their different cross-sectional shapes are automatically changed to the same cross-sectional shape.

5. Frame steel structure design example

We performed a verification calculation to confirm the weight reduction effect and the design time shortening effect of the developed application. The target structure is shown in **Figure 4**. The target structure is a simplified model prepared for the verification.

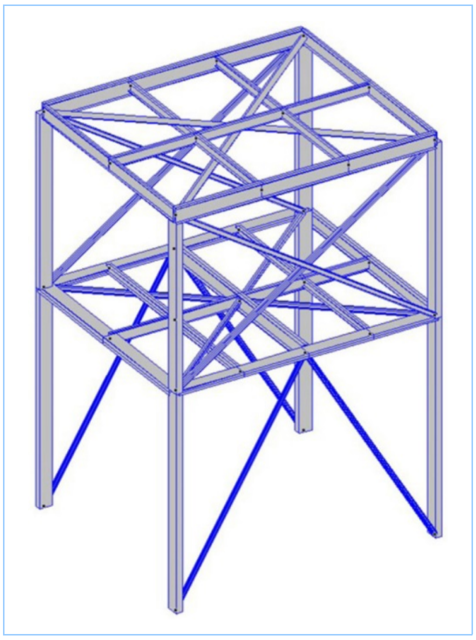

Figure 4 Target structure for verification calculation
The developed system was applied to a simplified model for the verification and a series of verification design processes from the creation of a model to the optimization of the steel frame cross-section were conducted.

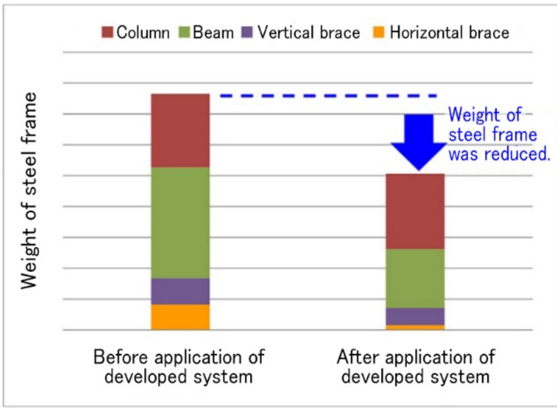

Figure 5 Weight reduction effect
The weight was reduced by the application of the developed system.

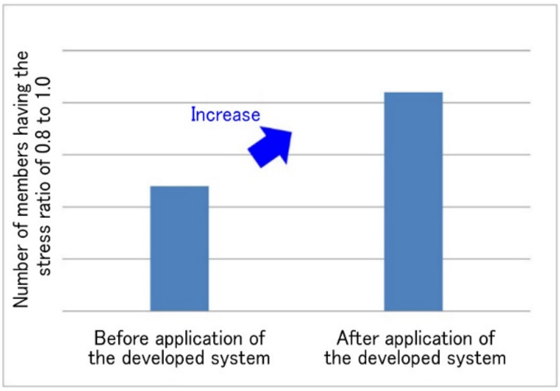

Figure 6 Change of stress ratio
Change of the number of members having the stress ratio (generated stress/allowable stress) of 0.8 to 1.0. After the application of the developed system, the number of members having the stress ratio of 0.8 to 1.0 increased.

Figure 5 shows the comparison of the initial weight and the weight after the developed system was applied. **Figure 6** shows the comparison result for the stress ratio (generated stress/allowable stress) from among the constraint conditions. As shown in Figure 6, after the developed system was applied, the number of members with the stress ratio of 0.8 to 1.0 increased. This shows that the calculated structure has no waste. As a result, as shown in Figure 5, the weight of the frame steel structure in the verification model was reduced. Thus, we confirmed that a frame steel structure cross-section for minimizing the weight could be calculated by the developed system.

Figure 7 shows the comparison of the design time using the conventional design procedure by a designer and the design time using the developed system for the simplified verification model. As shown in the figure, the design time was reduced. The effectiveness of the developed system in improving the design efficiency was also confirmed.

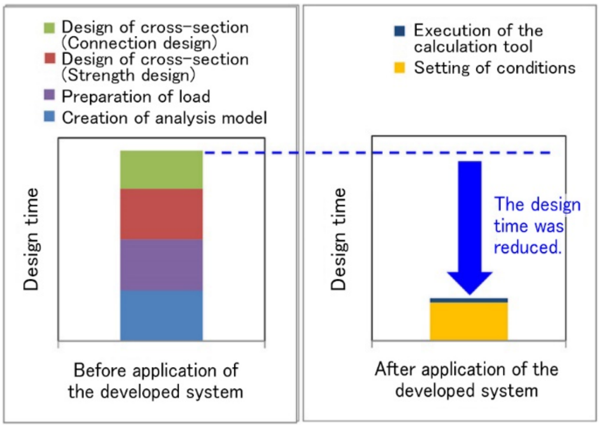

Figure 7 Design time shortening effect
With the application of the developed system, the design time was substantially reduced compared to the conventional manual design by human.

6. Conclusion

We developed a design automation system, M-FRAME, which includes the frame steel structure cross-section optimization method and an adjustment function with consideration for assemblability for steel structures such as frame steel structures. By the use of this system, the frame steel structure design processes from creation of a model to design of the cross-section can be automatically conducted in a consistent and integrated manner, and the design time is substantially shortened. As a result, it becomes easy to conduct highly economical structural design for frame steel structures and thereby becomes possible to apply them to many products. Furthermore, since the weight of a frame steel structure is reduced (the materials used are reduced), an environmentally friendly design becomes possible. In the future, we will sequentially apply the developed system to a variety of our products.

References

(1) Motoki Kato et al., Development of Rational Design Technique for Frame Steel Structure Combining Seismic Resistance and Economic Performance, Mitsubishi Heavy Industries Technical Review, Vol.52 No.1 (2015)