Study on Modular Design and Construction of Steel Cage Skeleton in Nuclear Engineering

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Abstract. This article aims at realizing the steel cage skeleton module in nuclear engineering. The article conducts research and analysis of the steel cage skeleton module of the HPR1000, and propose standardized design methods for the division of steel cage skeleton module, node designing, module lifting, etc. Testing at some nuclear island factories in the HPR1000, and comparing the efficiency of traditional construction methods, the application of steel cage skeleton technology can effectively improve construction efficiency and shorten the construction period of civil construction. At the same time, the nuclear power plant operates production electricity in advance, which has high social economic value.

Keywords: steel cage skeleton module; division; node design; module lifting; construction efficiency.

1 Introduction

At present China's nuclear power is in a stage of rapid development, but with the aging of the population is becoming increasingly prominent, highly skilled and experienced workers have become increasingly scarce, and it is no longer realistic to organize large-scale workers to engage in heavy physical labor for a long time. Therefore, the field of nuclear engineering and civil construction must be industrialized transformation and upgrading to alleviate labor intensity and improve the working environment.

Reinforcement engineering accounts for a considerable proportion in the civil engineering of nuclear power plants. If the industrial production and modular construction of steel skeleton can be realized, the construction efficiency will be greatly improved. In the field of civil construction, the modular construction technology of steel cage skeleton has been studied and practiced [1-3]. In nuclear power projects, due to

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the large wall items, large diameter, complex form and dense arrangement of steel bars, the traditional construction method of binding steel bars at the construction site is generally adopted. Therefore, further research and analysis is needed to popularize the modular technology of steel cage framework in nuclear power projects.

2 Division of Steel Cage Skeleton

The nuclear island plant is of thick wall and thick plate structure, and the steel bars in the walls are large in diameter, complex in form and dense in arrangement. The division of steel cage skeleton modules is directly related to the division of construction sections, construction sequence and hoisting of equipment at the construction site [4-7]. In order to improve construction efficiency and construction economy, the division of steel skeleton modules should meet the following principles.

1) The division of the steel skeleton module cannot change the force of the original structure, nor can it change the type and arrangement of the original steel bars.

2) The division of the steel cage skeleton module should be combined with the transportation and hoisting capacity of the construction site, It should be based on the principle of less specifications and more combinations, which is conducive to the realization of the standardized production of the steel skeleton module.

3) In order to reduce the connection of steel bars and improve work efficiency and economy, we should make use of the modulus of steel bars and use large size steel bars as much as possible. For example, the length direction can be 6m, 9m, 12m and other lengths according to the steel modulus, and the height direction can be determined by the height of the structure.

4) The division of the steel skeleton module should be determined by the construction drawing of the structure, combined with the corresponding relationship between the upper and lower floors of the structure, considered complex holes and joints and other factors. The steel bars at the location of the complex hole and the junction of the wall can be combined with the construction situation by manual binding at the construction site.

5) In the division of the steel skeleton module, it is necessary to set a reasonable reference position point to accurately express the position of the steel skeleton module in the structure. It can express the position of the sleeve, embedded parts, holes and other items on the steel skeleton module. Fig. 1 below is a steel cage skeleton module division diagram of HPR1000 nuclear island at the electrical plant. The division principle is that along the length of the structure, longer steel skeleton modules are arranged in turn, and most of them are divided into sections according to 12m. Along the width direction of the structure, most of them are divided into sections according to 9m.

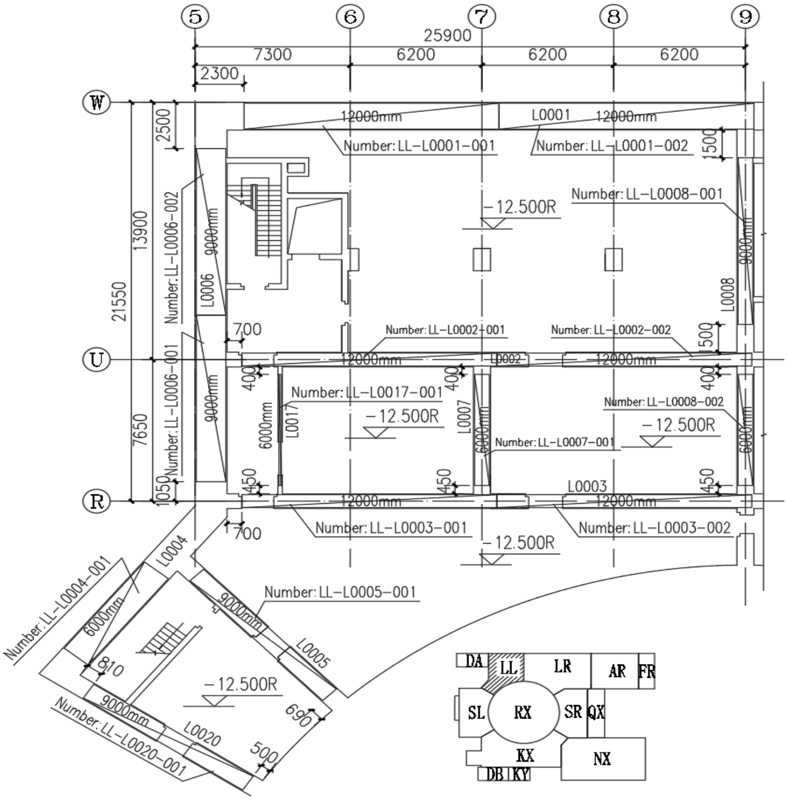

Fig. 1. Division of the steel skeleton modules on the wall of nuclear island

3 The Node Design

The wall layout of the nuclear island structure is complicated and there are many heterosexual walls. In order to ensure that the bearing capacity of the structural can meet the requirements after concrete poured. The design of the nodes between each module is very critical. The connections between adjacent steel skeleton modules shall be connected by mechanical sleeves. When the wall thickness is large and the steel bars in the steel skeleton module are four layers, in order to facilitate the connection of the mechanical sleeve, the inner and outer layers of steel bars can be staggered a certain distance according to the construction process and the characteristics of the mechanical sleeve, so as to meet the requirements of the operation space of the mechanical sleeve [8-10], as shown in Fig. 2 ~ 4. The steel skeleton module should be produced by factory in order to ensure the precise connection between adjacent steel modules. In order to improve the construction efficiency, the common --shaped, +-shaped, T-shaped and L-shaped connection nodes are analyzed to form the standardized construction logic of the steel skeleton module.

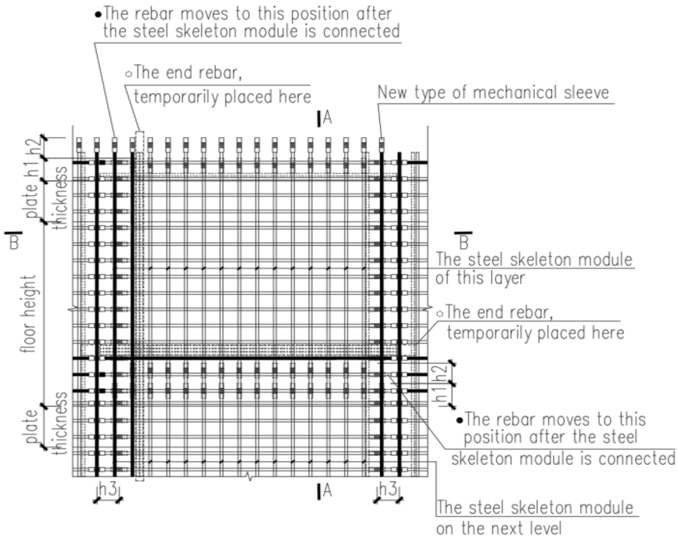

Fig. 2. Schematic diagram of steel skeleton module

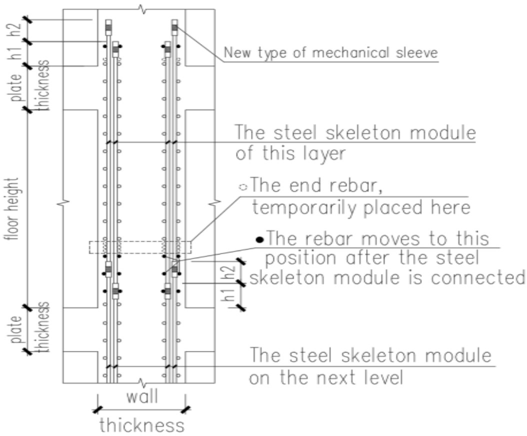

Fig. 3. Profile A-A

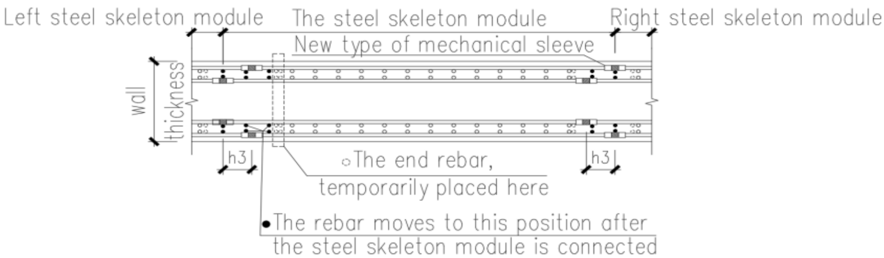

Fig. 4. Profile B-B

3.1 The Design of -Shape

The design of -shape is shown in Fig. 5. When installed on the construction site, the first step is to lift the wall-1 steel skeleton module and connect it with the vertical mechanical sleeve; At this time, the end steel bar temporarily placed is not connected to the mechanical sleeve. The second step is to lift the wall-2 steel skeleton module and connect it with the vertical mechanical sleeve. At this time, the end steel bar temporarily placed is not connected to the mechanical sleeve. The third step is to install the horizontal mechanical sleeve. The fourth step is to install the temporary steel and connect it to the vertical mechanical sleeve.

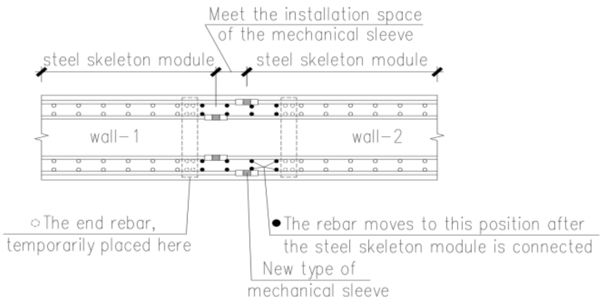

Fig. 5. The design of —-shape

3.2 The Design of +-Shape

The design of +-shape is shown in Fig. 6. When installed on the construction site, the first step is to lift the wall-1 steel skeleton module and connect it to the vertical mechanical sleeve. The second step is to lift the wall-2 steel skeleton module and connect it with the vertical mechanical sleeve. The third step is to lift the wall-3 steel skeleton module and connect it with the vertical mechanical sleeve. In the fourth step, the horizontally connected steel bars are placed and connected to the wall-2 steel skeleton by ordinary mechanical sleeves. In the fifth step, mechanical sleeve are used to connect the horizontal steel bars to the steel skeleton of wall-3. The sixth step is to install the vertical steel bar inside the node and connect it with the vertical mechanical sleeve.

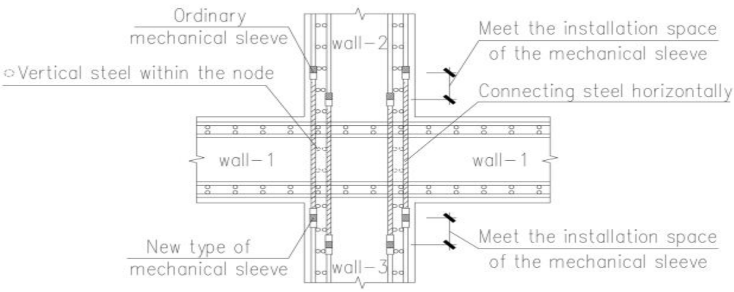

Fig. 6. The design of +-shape

3.3 The Design of T-shape

The design of T-shape is shown in Fig. 7. When installed on the construction site, the wall-1 steel skeleton module is hoisted and connected to the vertical mechanical sleeve. The second step is to lift the wall-2 steel skeleton module and connect it with the vertical mechanical sleeve. The third step is to place horizontal anchorage steel and connect them through mechanical sleeves. The fourth step is to install the vertical steel bar at the joint and connect it with the vertical mechanical sleeve.

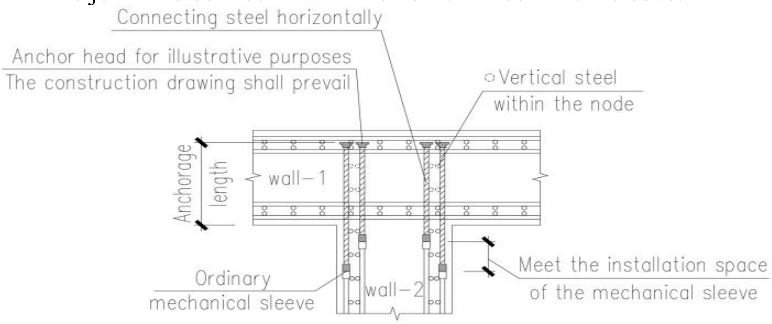

Fig. 7. The design of T-shape

3.4 The Design of L-shape

The design of L-shape is shown in Fig. 8. When installed on the construction site, the first step is to lift the wall-1 steel skeleton module and connect it to the vertical mechanical sleeve. The second step is to lift the wall-2 steel skeleton module and connect it with the vertical mechanical sleeve. The third step is to install the vertical steel bar at the joint and connect it to the vertical mechanical sleeve. The fourth step is to place the horizontal straight anchorage bar and connect it through the mechanical sleeve. The fifth step is to bend the anchorage bar horizontally and connect it through a mechanical sleeve.

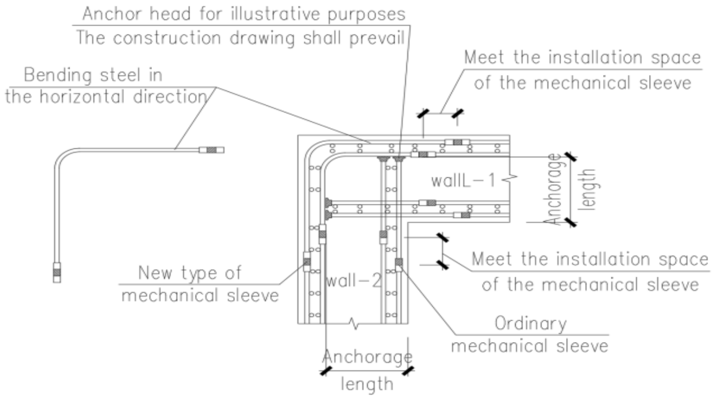

Fig. 8. The design of L-shape

4 Lifting and Installation of Steel Skeleton Modules

In the process of lifting the steel skeleton module, whether the steel bar has a large deformation is very important for installation. In order to ensure the fast and accurate installation of each steel skeleton module, it is necessary to standardize various measures during the production, storage, transportation and lifting of the steel cage skeleton module.

4.1 The Production of Steel Skeleton Module

In the production of steel skeleton module, it is necessary to install the casing and embedded parts on the module. In the production of steel skeleton module, the device used should be able to limit the position and spacing of steel bars, so as to minimize the error between steel bars. After the device is in position, reliable fixing measures should be taken to ensure that the steel bars do not move during the production of the steel skeleton. Fixed position device can be used in a variety of forms. Fig. 9 is the typical fixed-position device made of angle steel and steel plate grooving, The other forms of device can also be used.

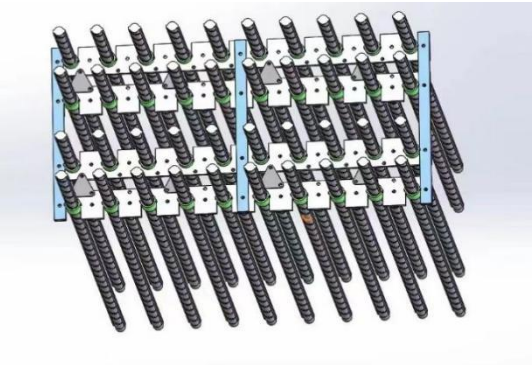

Fig. 9. The typical fixed-position device

4.2 The Storage of Reinforced Skeleton Modules

After the production of the steel skeleton module, it is necessary to select a suitable storage location, and arrange it neatly according to the structural parts, the sequence of construction flow sections and the specifications. To ensure that it is not damp, rust, pollution, and deformation. When the steel skeleton module is stored, the storage area should be kept neat to ensure that the material, specifications and quantity of the steel skeleton module are consistent with the record file. When the steel skeleton module is stored in the open air, measures must be taken to prevent it from being rusted, crushed and contaminated. At the same time, in order to quickly confirm the position of the steel skeleton module and ensure the accuracy of the transportation and lifting of the steel skeleton module, the identification plate with fixed firmness and certain durability must be set up after the production of the steel skeleton module. The identification plate must contain the number of the steel skeleton module, and the position information inside and outside the steel skeleton module. At the same time, it is also necessary to indicate the factory building and level of the steel skeleton module. For the steel skeleton module with embedded parts, casing, clamp rails and other items on the wall, the coordinates of the reference point should be specified in detail, and the position of the reference point should be marked on the steel skeleton module with a prominent identification plate.

4.3 The Lift of Steel Skeleton Modules

During the lifting process of the steel skeleton module, reliable fixed tools should be set up to increase the overall stiffness of the steel skeleton module and reduce the deformation of the steel bars during storage, transportation and lifting. It is advisable to use detachable tooling. After lifting and installing the steel skeleton module, the tooling can be removed. A typical tooling is shown in Fig. 10.

Fig. 10. The typical lifting tooling

5 Construction Efficiency

The traditional construction method of steel bar engineering in nuclear power plants is to use manual binding of steel bars, as shown in Fig. 11 below. This method is inefficient, and with the acceleration of China's aging population, there is a shortage of skilled workers in nuclear power projects [11]. Adopting the steel skeleton module technology, and the steel skeleton module is produced automatically by the factory, as shown in Fig. 12 ~ 14 below, which can greatly reduce the number of labor in the construction process. By testing the wall of HPR1000 nuclear island, the traditional on-site binding of steel bars is compared with the method of steel skeleton module, as shown in Table 1 and 2 below. It is concluded that the construction efficiency can be increased by 100% when steel skeleton module technology is adopted.

Fig. 11. Manual binding of steel bars

Fig. 12. Production equipment of steel skeleton module

Fig. 13. Steel fixing equipment

Fig. 14. Steel skeleton module products

Table 1. Efficiency of traditional manual binding of steel bars

<table>
<tr><th colspan="5">Efficiency of traditional manual binding of steel bars</th></tr>
<tr><th>Process</th><th>Construction period (day)</th><th>Number of workers</th><th>Weight (tons)</th><th>Construction efficiency (ton/ day)</th></tr>
<tr><td>Transverse rebar arrangement</td><td>3</td><td rowspan="3">8</td><td rowspan="3">19.8</td><td rowspan="3">0.3</td></tr>
<tr><td>Longitudinal rebar arrangement</td><td>3</td></tr>
<tr><td>Reinforcement and tension arrangement</td><td>2.3</td></tr>
</table>

Table 2. Construction efficiency of reinforced skeleton module

<table>
<tr><th colspan="5">Construction efficiency of reinforced skeleton module</th></tr>
<tr><th>Process</th><th>Construction period (day)</th><th>Number of workers</th><th>Weight (tons)</th><th>Construction efficiency (ton/ day)</th></tr>
<tr><td>Assembly of equipment</td><td>0.5</td><td>8</td><td rowspan="6">19.8</td><td rowspan="6">0.6</td></tr>
<tr><td>Transverse rebar arrangement</td><td rowspan="2">1.5</td><td rowspan="2">8</td></tr>
<tr><td>Longitudinal rebar arrangement</td></tr>
<tr><td>Reinforcement and tension arrangement</td><td>1</td><td rowspan="3">8</td></tr>
<tr><td>Dismantling of fixed tooling</td><td>0.5</td></tr>
<tr><td>Hoisting for connection</td><td>0.64</td></tr>
</table>

6 Economic Benefits

Reinforcement engineering is the most manpower and construction period in the civil engineering of nuclear power plant. The application of steel skeleton module will greatly improve the working environment of steel bar construction, improve the efficiency of steel bar construction in nuclear power project, and reduce the influence of steel bar engineering on the construction period.

After testing on HPR1000 nuclear island plant, it is concluded that the construction period of the steel bar sub-project can be shortened by 40%~50% after adopting the steel bar framework module. The construction cycle of a nuclear power plant is about 60 months. The popularization and application of steel skeleton modules can effectively shorten the civil construction period, save a lot of labor costs. On the other hand, the nuclear power plant can be completed in advance and commercial power generation, there are high social and economic benefits.

7 Conclusion

This paper studies and analyzes the steel skeleton module technology of nuclear engineering, and puts forward the following normative standards based on the HPR1000 nuclear island plant. After the test of some nuclear island plant, it is concluded that the construction efficiency can be increased by 100% after the steel skeleton module is used in the wall steel bar sub-project, which can effectively shorten the civil construction period and save a lot of labor costs. At the same time, nuclear power plants can be completed in advance and commercial operation of electricity generation, with higher social and economic benefits.

1) In order to ensure the accuracy of the position of each item of the wall, the division principle of the steel skeleton module is determined.

2) According to the layout of steel bars in the wall of nuclear island plant and the intersection of various walls, a standardized design method is proposed to ensure that the joint bearing capacity meets the force requirements.

3) Various measures in the process of manufacturing, storage, transportation and lifting of the steel skeleton module are standardized, so that the mechanical sleeves at the end of the steel bar can be accurately docked to ensure the rapid installation of the steel skeleton module.

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