Strain monitoring and analysis of thin plate structure of large cruise on Rising-Landing process

ZHANG Zuo-Yong*，LIU Zi-Ming*，SUN Jian-Zhi，SUN Yi-Qiang*，WANG Xin***

* Shanghai Shipbuilding Technology Research Institute，Shanghai 200032，China；

** Shanghai Waigaoqiao Shipbuilding Co.，Ltd.，Shanghai 200137，China

Keywords：Strain Monitoring；Thin Plate Structure；Large Cruise； Rising-Landing

ABSTRACT

As the background of the floating project in dock of the luxury cruise firstly built in china, for the purpose of obtaining the structure strain of key parts in the floating process, the local area of the two decks was selected as the monitoring object, the whole floating-pier landing process was monitored, the dynamic strain data of different states and processes were obtained. The strain data of the thin plate structure in the rising-landing process were mastered, and the release level of structural residual stress during construction is verified and analyzed, which provides a strong support for the structural optimization and construction implementation of subsequent ships.

1.Introduction

Luxury cruise is known as "the floating city on the sea", which integrates functions of sightseeing, tourism, leisure, entertainment and so on. Luxury cruise is recognized by international shipbuilding industry as high-tech, high value-added and highly reliable ships, characterized by very large hull, complex structure and sophisticated outfitting. It is known as the Pearl on the crown of the world shipbuilding industry for difficulty and cost in design and construction

The first luxury cruise built in china has the characteristics of wide width, small profile depth, long superstructure and more deck floors [1]. In order to reduce the structure weight, improve the speed and lower the center of gravity, a large number of thin plates are used, mainly 4-6mm thick. These thin plates are deformable during construction process of welding, lifting and transportation etc., deformation of thin plates will seriously affect the accuracy and quality of construction. Relevant designers of Shanghai Waigaoqiao Shipyard have done a lot of analysis on the causes of sheet deformation of the large cruise and implement control measures of sheet deformation during construction, which have been fully verified during construction and achieved good results [2-3].

During the construction of large cruise, the whole hull is located on a series of discretely distributed piers, while the whole hull floats in the water during the operation of large cruise， there is a significantly difference in response force of the whole hull under two boundary state. Considering the residual stresses of raw materials and the residual stresses produced during welding and assembling are not completely released, it is one of the focuses for shipbuilding researcher and constructor that the influence of changes in hull response forces and structure residual stresses during the conversion process of the two boundary state. Therefore, in the project of large cruise rising-landing in the dock, the typical area is selected to monitor the strain obtain the stress and strain change process during the whole process of rising-landing. The monitoring results and the relevant numerical simulation results provide data support for optimizing construction process and improving the construction quality of subsequent large cruise.

2 Preparation of test plan

This measurement mainly includes two contents: firstly，the influence of structural stress in the rising-landing process; secondly，the change of residual stress in the rising-landing process. The structural stress measurement is carried out in the way of process real-time monitoring, the stress change process of the measuring position is recorded in the whole process. For the residual stress measurement, among the frequently-used residual stress test methods at present, the radiographic method has limitations owing to site conditions, the destructive method will cause some damage to the tested structure, the indentation method needs accurate fixed points and takes a long time, and both the destructive method and the indentation method need to paste strain gauges. Considering the advantages and disadvantages of various residual stress measurement methods, combined with the requirements of the test conditions, it is decided to adopt the indentation method and a long-term monitoring method, that can not only obtain the time history diagram of the whole process, but also qualitatively evaluate the change state and stability of residual stress of the whole rising-landing process through the long-term signal change trend.

2.1 Layout of measuring points

In view of the fact that the stress and strain level in the passenger living compartment area is directly related to the cabin safety and the sensory comfort of passengers, the compartment and the surrounding area are selected as the monitoring area in this test. In order to meet the vibration and noise indicators during the use of the cabin, a damping layer with a thickness of about 10mm will be coated on the deck surface of the cabin area, as shown at the yellow areas in Figure 1. Combined with the structural form, force transmission path and simulation analysis results of the whole ship, the deck surface and corresponding enclosure of the typical areas of the sixth and ninth decks are selected as the monitoring objects.

The deck surfaces of two adjacent cabins in the middle and the surrounding walls at the sixth deck plate are selected as the monitoring areas. There are 7 monitoring points at the dressing edges of the two compartment areas on the deck, 18 monitoring points on the enclosure wall, and 25 monitoring points in total, see Figure 1 for the location diagram. The nine compartment deck surfaces and enclosure walls at the middle area of the ninth deck plate are selected as the monitoring areas, there are 19 monitoring points at the dressing edge of the nine compartment areas, 13 monitoring points on the enclosure wall, and 32 monitoring points in total, See Figure 2 for the location diagram. In the two figures, the circle number such as'①' is the deck surface measuring point, the common number such as '1' is the enclosure measuring point, which is located in the height of the 1300mm above the deck surface.

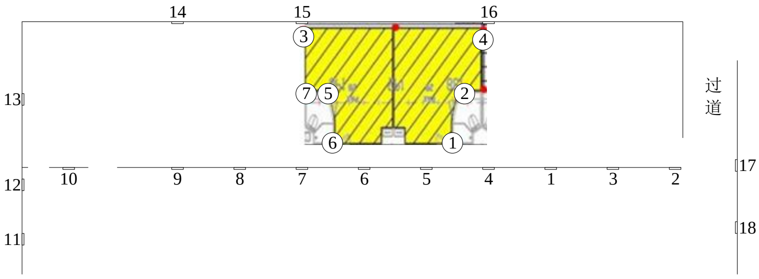

Fig.1 Schematic diagram of measuring point position of the sixth plate

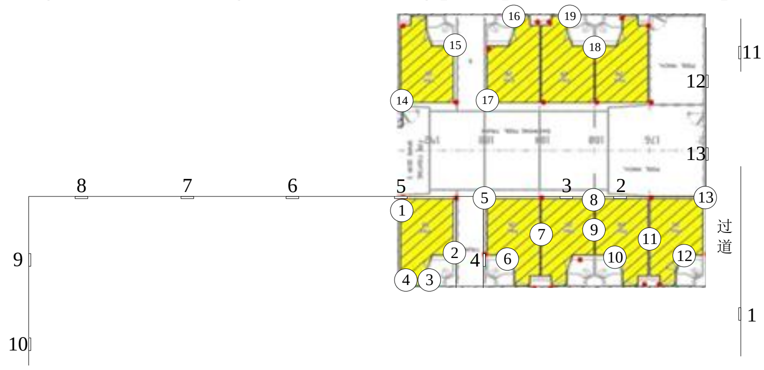

Fig.2 Schematic diagram of measuring point position of the ninth plate

2.2 Test equipment

Considering the metal structure of deck and enclosure, The resistance three-way strain rosette of BE120-3CA(11)Type is selected as the front sensor, The resistance sensitive grid of this type of strain rosette is made of constantan material and phenolic acetal material is used as the base, with a fully sealed structure; Temperature self-compensation can be realized for metal materials such as alloy steel, martensitic stainless steel and precipitation hardening stainless steel; Good flexibility, easy to paste, stable performance. See Fig. 3 for the photos of strain rosette of this model and the site photos after pasting.

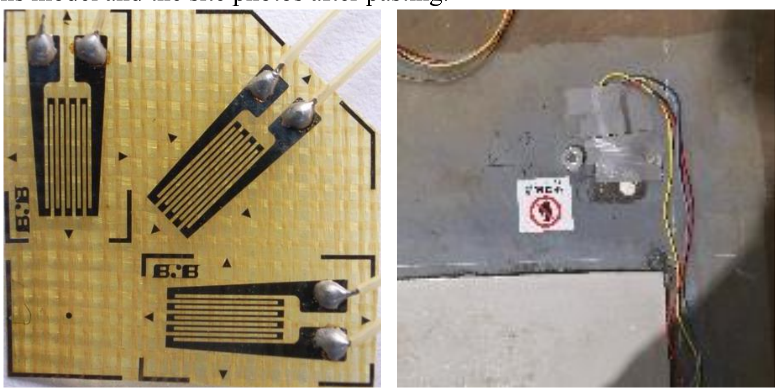

Fig.3 The resistance three-way strain rosette of BE120-3CA(11)Type

DH3823 stress-strain test and analysis system is selected as the signal acquisition instrument. This type of system adopts micro modular design, the acquisition module can be placed at the nearest measuring point to reduce the length of the signal cable and improve the test reliability. See Figure 4 for the graphics of the acquisition module and controller.

Fig.4 DH3823 stress and strain test and analysis system (Upper: acquisition module, lower: controller)

2.3 monitoring process

The whole monitoring process can be divided into preparation stage, monitoring stage and data processing stage, the monitoring stage can be divided into four process parts of rising process monitoring, floating steady-state monitoring, landing process monitoring and post-landing monitoring, as shown in Figure 5. All preparations shall be completed in the dry dock stage, and the continuous acquisition of the rising process shall be carried out on the day of rising. After the whole ship is floating state and the data remains relatively stable, the acquisition mode shall be changed to the quasi-static test mode, and the steady-state equal interval acquisition process shall be entered until the time of landing the pier; restore the dynamic acquisition mode when starting to pump water out . Start to conduct continuous acquisition for the process of pier landing until the pier falls stably, and then enter the quasi-static acquisition mode. After all the acquisition, carry out data processing.

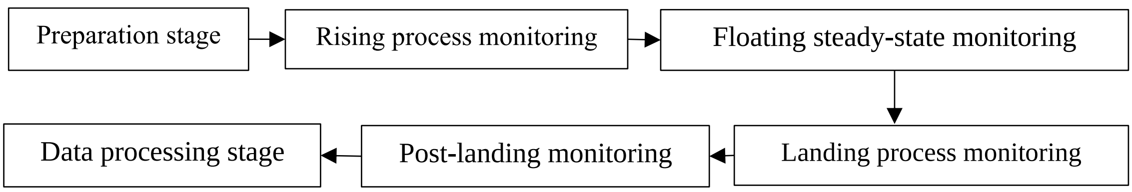

Fig.5 monitoring process

The work in the preparation stage can be divided into three parts: chip mounting, wiring management and equipment connection and commissioning, as shown in Figure 6.

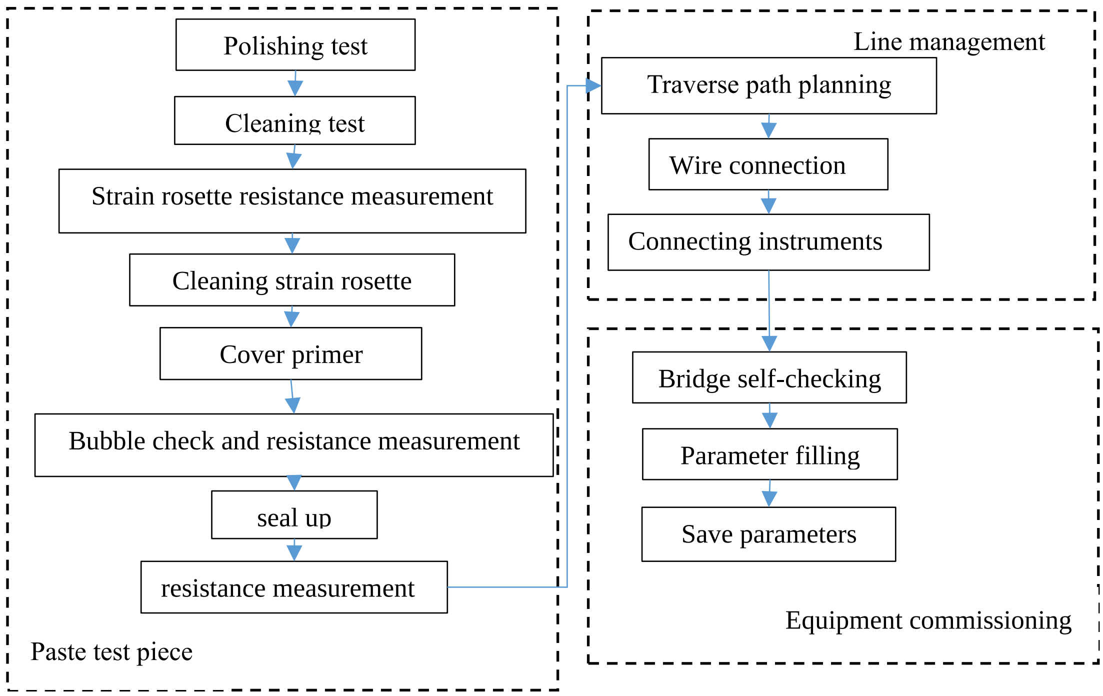

Fig. 6 The Workflow of strain monitoring preparation state

The monitoring stage is divided into four time periods, including the process of rising (from the beginning of water inflow in the dock to the stability of the ship), the process of floating state, the process of landing (from the beginning of water pumping to the stability of the ship), and the process of ship after pier landing. Continuous acquisition is adopted for the process of rising and landing with the 200Hz sampling frequency; intermittent acquisition is adopted for the steady-state process in floating with 50Hz sampling frequency, and every 60min for 20 minutes. The continuous data collection starts two hours before the water inflow of the dock, enters the intermittent data collection mode about five hours before the water discharge of the pier, and then enters the continuous data collection mode until the pier is stable. Totally 91 groups of data were collected.

3.Test results and analysis

3.1 Raw data

The acquisition is carried out according to the acquisition mode and time plan described above. The time history diagram of the rising process and landing process of the measuring points on the sixth deck is shown as Fig. 7-fig. 8, and the time history diagram of the rising process and landing process of the measuring points on the ninth deck is shown as Fig. 9-fig. 10. The data of 3 hours for rising and 5 hours for landing. The whole ship floats in the water for nearly 93 hours.

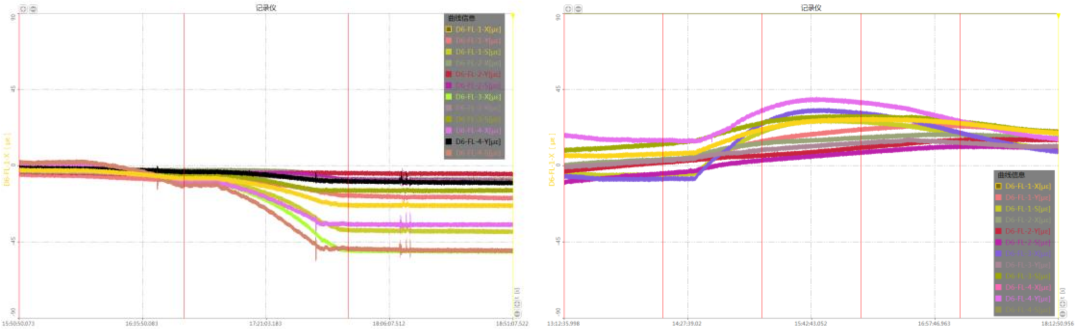

Fig. 7 Time response curve of rising and landing process of No. 1#-4# in the sixth deck

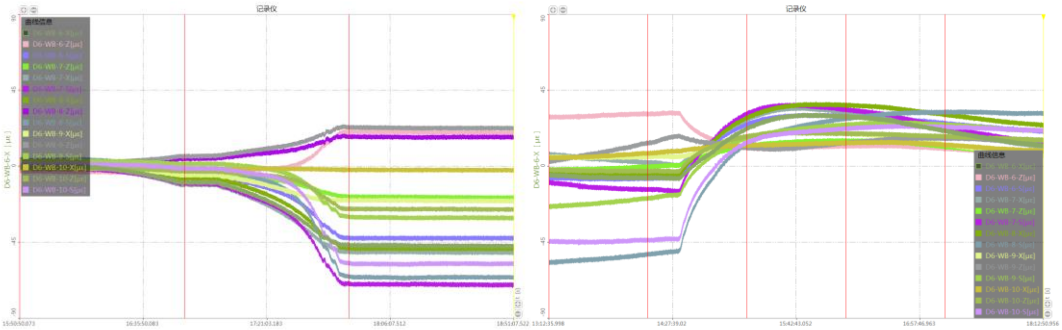

Fig. 8 Time response curve of rising and landing process of No. 6#-10# in the sixth deck's enclosure

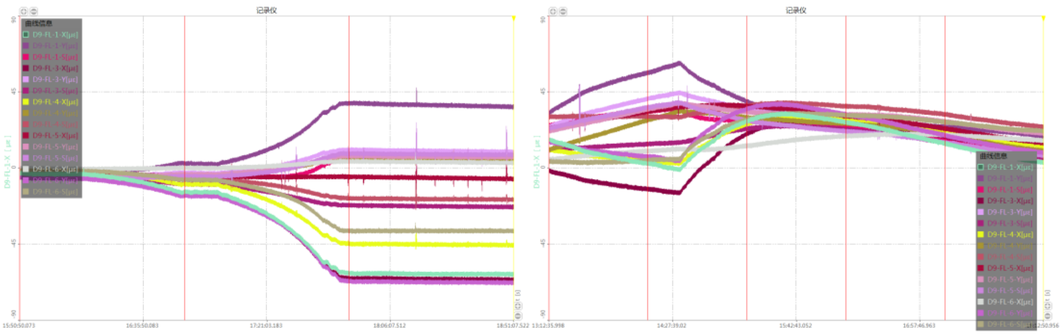

Fig. 9 Time response curve of rising and landing process of No. 1#-5# in the ninth deck

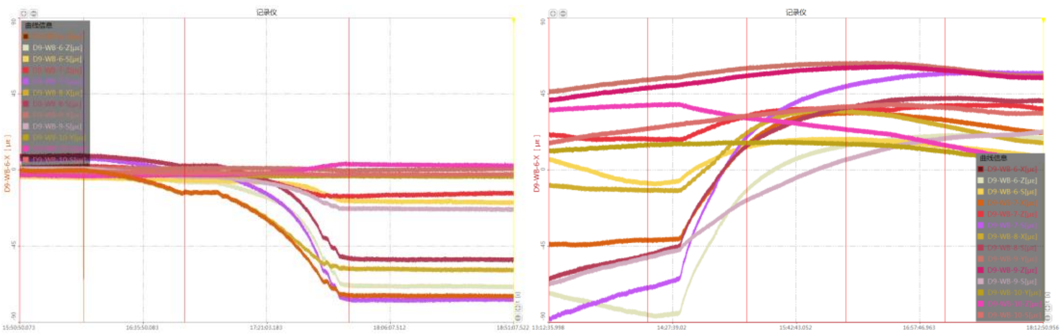

Fig. 10 Time response curve of rising and landing process of No. 6#-10# in the ninth deck's enclosure

It can be seen from the curve of the rising process that the stress of the whole ship has changed since the whole ship touches the water, the stress of the hull is stable until the whole ship is completely floating. It can be seen from the time history curve of the floating stage that the strain at the monitoring points changes when the whole ship touches the water but does not float. At the critical moment of floating, the curve at some monitoring points also jitters at a small level, and with the complete floating of the whole ship, the strain data will soon gradually stabilize. It can be concluded from the curve of the landing pier that the time of the landing piers can be clearly seen and the curve can gradually converge towards a value. In addition, the influence of the falling pier on the deformation curve is opposite to that of the floating, which shows that the structure of the hull has good consistency, and there is no distortion in the floating state, which is not conducive to the deformation of the hull structure.

During the rising process, the strain data of 26 monitoring points in the dressing area of the sixth and ninth decks are mainly negative values, indicating that the upper surface of the deck is under pressure at the floating state. The measured points of the enclosure wall are more negative and less positive values, indicating that the stress on the surface of the enclosure wall is also mainly compression.

By comparing the data at the end of the rising section and the beginning of the landing section, it can be seen during the nearly 93 hours of floating process that the strain values at each measuring point are not unchanged, and the values of all channels have changed, indicating that the whole floating process is a process of redistribution of residual stress in the structure. Taking the 26 monitoring points in the dressing area as an example, when the floating ship just presents the steady attitude, the strain value of the measure points are more negative and less positive, until before the landing pier process the strain value of the measure points gradually change to as many positive and negative values, and the dispersion of the values becomes smaller, which indicating that the residual stress has been released and redistributed, the purpose of floating has been achieved.

It can be seen from the comparison of the data of the two decks that the stress change of the measuring points of the ninth deck is obvious during the whole floating process, especially the measuring points on the enclosure wall, although the overall data has not exceeded ± 90 με， but the dispersion of the mean value of the data has increased significantly, which may be caused by the fact that the upper structure weight of the nine deck is lighter than that of the six deck, and the constraints smaller, or because the residual stress level is different.

3.2 Principal stress analysis

The monitoring mainly obtains two kinds of data, include the time history curve of the process of rising-handing process and the stability data of the three static stages of before floating, during floating and after handing piers. the dynamic time history data is used to gauge the trend of state change, the steady-state strain data is processed to obtain the stress value of the measuring points.

The monitoring work is made to obtain the surface stress of the tested structure through the strain gauge pasted on the structure surface, which belongs to the plane stress problem. The strain in three directions directly obtained by strain gauge ε_R, ε_B and ε_Y, we can get the principal strain ε_{Max}, ε_{Min} and included angle α by means of formula (1) ~ (3).

$$\varepsilon_{max} = \frac{\varepsilon_R+\varepsilon_B}{2} + \sqrt{\left(\frac{\varepsilon_R-\varepsilon_B}{2}\right)^2 + \left(\frac{\varepsilon_R+\varepsilon_B-2\varepsilon_Y}{2}\right)^2} \quad (1)$$

$$\varepsilon_{min} = \frac{\varepsilon_R+\varepsilon_B}{2} - \sqrt{\left(\frac{\varepsilon_R-\varepsilon_B}{2}\right)^2 + \left(\frac{\varepsilon_R+\varepsilon_B-2\varepsilon_Y}{2}\right)^2} \quad (2)$$

$$\alpha = \frac{1}{2}\tan^{-1}\frac{2\varepsilon_Y-\varepsilon_R-\varepsilon_B}{\varepsilon_R-\varepsilon_B} \quad (3)$$

According to the theory of material mechanics, the relationship between shear strain and strain in three directions is shown in formula (4), and the relationship between stress and strain is shown in formula (5) ~ (7).

$$\gamma_{RB} = \varepsilon_R + \varepsilon_B - 2\varepsilon_Y \quad (4)$$

$$\sigma_R = \frac{E}{1-\mu^2}(\varepsilon_R + \mu\varepsilon_B) \quad (5)$$

$$\sigma_B = \frac{E}{1-\mu^2}(\varepsilon_B + \mu\varepsilon_R) \quad (6)$$

$$\tau_{RB} = \frac{E}{2(1+\mu)}\gamma_{RB} \quad (7)$$

After obtaining the stress in three directions of the strain rosette, the magnitude and direction of the principal stress can be obtained by using formulas (8) - (10).

$$\sigma_{max} = \frac{\sigma_R+\sigma_B}{2} + \sqrt{\left(\frac{\sigma_R-\sigma_B}{2}\right)^2 + \tau_{xy}^2} \quad (8)$$

$$\sigma_{min} = \frac{\sigma_R+\sigma_B}{2} - \sqrt{\left(\frac{\sigma_R-\sigma_B}{2}\right)^2 + \tau_{xy}^2} \quad (9)$$

$$\alpha = \frac{1}{2}\tan^{-1}\frac{-2\tau_{xy}}{\sigma_R-\sigma_B} \quad (10)$$

Using the above analysis method, the main strain is analyzed by the original data with the quasi-static data, and obtain the main strain direction of every states and every measuring points. The results show that the main strain before rising process is within ± 0.4MPa, which meets the requirements of acquisition and analysis. During the initial stage of rising process, the maximum principal strain of all measuring points is 8.66MPa, which occurs at 21# measuring point located in the dressing area of the ninth deck, the minimum principal strain of 21# measuring point is -3.67MPa. The minimum principal strain of all measuring points is -21.0MPa, which occurs at the 5# measuring point located in the dressing area of the sixth deck, the maximum principal strain of 5# measuring point is -13.09mpa. At the end of monitoring work, the maximum principal stress at all measuring points is within 15MPa, and the maximum principal stress is 14.62MPa, which occurs at the 9# measuring point located in the middle of enclosure wall of the ninth deck, The minimum principal stress is -4.51mpa which occurs at the 13# measuring point located in the dressing area of the ninth deck.

4. conclusion

Through the whole process monitoring of dynamic process and the phased monitoring of steady-state process, it is realized that the stress-strain test and residual stress evaluation of the cabin position of the two decks of china's first luxury cruise in the rising-handling piers process. The test data can truthfully reflect the stress-strain characteristics of the measured area, and good results are obtained. Through this test, it can be seen that:

a. This measurement method can better present the evolution process of structural residual stress in the rising-handing process, it can be directly presented that the process of stress redistribution. At the same time, we can qualitatively evaluate the residual stress in the structure by data analysis.

b. The measuring data of the state after handing pier can be regressed to the low strain level, but it is not completely consistent with that before ship rising, which indicates that the residual stress of the hull has been redistributed during the rising-handing process， the purpose of the rising-handing process has been achieved.

References

(1) Luo Xiao-Lin, Gan Shui-Lai: Analysis of difficulties and Countermeasures in structural design of large cruise, Int, J. Ship Engineering 2017 (8): 1-4,83

(2) Sun Jian-Zhi, Feng Min-chao, Chen Xiao-Yu: Deformation control method for thin plate construction of large cruise ships Int, J. Ship Engineering 2022 (1): 1-6

(3) Chen Xiao-Yu, Zhong Hao-Dong, Zhang Hai-Yong: Lifting scheme design of large cruise ship thin plate section based on finite element method Int, J. Ship Engineering 2022 (1): 32-36

(4) Ju Li-Yang, Wu Xiao-Yuan, Liu Jian-Feng: Study on process mechanics of sheet section construction, Proceedings of Academic Conference on ship structural mechanics, 2019:271-277

Author's Biography：

ZHANG Zuo-Yong (1984-), engineer, be engaged in the research on advanced shipbuilding technology, modern shipbuilding and marine composite structure.