Research on Layout of Hoisting Points and Control of Hoisting Deformation of Large Stereo Garage Block

F. Li.1,a, Z. Q. Xiang.2,b, J. Wang.3,c*, B. S. Zhang.4,d

1School of Naval Architecture, Ocean and Energy Power Engineering, Weihai Research Institute of Wuhan University of Technology, Wuhan University of Technology, Wuhan, China
2School of Naval Architecture, Ocean and Energy Power Engineering, Weihai Research Institute of Wuhan University of Technology, Wuhan University of Technology, Wuhan, China
3School of Marine Equipment Engineering, Zhenjiang International Maritime College, Zhoushan, China
4School of Naval Architecture, Ocean and Energy Power Engineering, Weihai Research Institute of Wuhan University of Technology, Wuhan University of Technology, Wuhan, China

a15663632167@163.com
bzuqan_xiang@163.com
c108016521@qq.com
d15141525385@qq.com

Abstract—This paper takes the dock hoisting technology of the large stereo garage block of 7800PCTC (Pure Car and Truck Carrier, PCTC) as research object. Due to the needs of loading vehicles, this kind of block has large structural size and weight, and the lack of vertical and horizontal bulkhead support in the middle, resulting in weak overall structural strength and structural instability and deformation during hoisting. Firstly, according to the hoisting process principle, three layouts of hoisting points are formulated, and the best hoisting points layout scheme is selected through FE (Finite Element, FE) simulation analysis. After analysing the deformation and structural strength of the section, a targeted temporary strengthening scheme is proposed according to the analysis results. The strengthened FE calculation results show that, the stress concentration and excessive structural deformation under the selected layout scheme are effectively controlled. The calculation results provide a strong guarantee for the hoisting in the dock loading stage.

1. INTRODUCTION

PCTC is the mainstream of the international automobile shipping market, and it has a good development and application prospect. The large-scale and flexible structural design of PCTC make this kind of ship have unique structural layout and structural type, which brings a series of construction technical difficulties. To shorten the construction period of dock and make full use of the dock,
construction strategy of small section production, multiple small sections forming a large stereo garage block, and then final assemble in dock is adopted in the construction process of 7800PCTC parallel midship garage area [1]. These large-scale stereo garage block have many deck layers, large transverse span and few supporting structures. After the final assembly, the structural scale is large and the weight is about 500t. It is easy to have problems such as stress concentration, instability and structural deformation when hoisting in the dock. To ensure the safety and accuracy of these large stereo garage blocks during dock hoisting, it is necessary to predict and analyze the possible structural instability and deformation in advance, and provide a solution plan to solve these defects.

Structural modeling and FE analysis are an effective and economical means of engineering structural strength evaluation. Taking the general block GS305 of 7800PCTC ship's large stereo garage as an example, this paper uses ANSYS simulation software to simulate and analyze the defects such as hoisting points layout, stress concentration and structural deformation, to provide safety guarantee for its dock loading.

2. RESEARCH BLOCK INTRODUCTION

The longitudinal direction of the GS30 block is from FR73 to FR100 ribs, and the transverse direction is the whole ship width. The block size (Length × Width × Height) is 20.8 × 22.6 × 13 meters.

![Figure 1. GS305 block model.](image)

The structural model of the block is shown in Figure 1. The block is mainly composed of bridge Deck (8mm thickness), 2ND deck (12mm thickness), upper deck (14 mm thickness) and broadside (10mm thickness). The block is combined framing system. The bridge deck and broadside are transverse framing system, and the 2ND deck and upper deck are longitudinal framing system. The spacing is 0.7m during ribs. T-shaped strong transverse beams are set every 3 ribs under the bridge deck, and the spacing of strong longitudinal beam is 3m. The pillar between the bridge deck and the 2ND deck are arranged at the intersection of the strong transverse beam and the strong longitudinal beam at the ribs of FR73, FR82, FR91 and FR100.

The dock is equipped with two 300t gantry cranes, which can cover the assemble site at the same time. The maximum lifting weight of the two cranes including the lifting row is 510t in total. The total weight of the structure, outfitting, coating and lifting tools of GS305 block is 492.362t, so two cranes are used for joint lifting.

3. RELAYOUT OF HOISTING POINTS

3.1 Selection of Hoisting Points Layout

The block has thin plate, large span and weak support. To avoid serious deformation and stress concentration, this paper mainly considers the follows:

1) Position of hoisting points. During the hoisting of the block, the points shall be symmetrical to the center of gravity as far as possible [2]. To reduce the deformation, the stress on the hoisting points is more uniform. The structure of the study block basically conforms to the characteristics of left-right
symmetry, so the hoisting points are symmetrically distributed on both sides. What’s more, the decks’ thickness is very thin, and the location of the hoisting points requires a large support force. If there are no pillars under the hoisting points, the structure will have great stress and deformation. Therefore, it is considered to arrange the hoisting points above the pillars.

(2) Number of hoisting points. Ordinary block generally set four hoisting points when hoist. The arrangement is easy to analyze. However, the garage studied block has large weight, thin plate, weak support and large left and right spans. The scheme is prone to severe stress concentration and large deformation. Therefore, the hoisting points scheme of six or eight points is considered [3].

(3) Direction of lifting rafts. In addition, during hoisting, the direction is arranged transversely and longitudinally along ship-length direction. Longitudinal arrangement is relatively common in shipyard. But the research block has large span. If the longitudinal arrangement is adopted, it is easy to cause large deformation and stress concentration in the midship due to insufficient stiffness. However, the direction is arranged transversely can effectively avoid the problems [3].

Based on the above considerations, three different schemes are proposed, as shown in Figure 2. Figure 2 is the top view of the block GS305. Since the main block structure is symmetrical left and right, only the port side (starboard hoisting points and port side are symmetrical) is shown in the figure. The hoisting points are located at the intersection of the strong longitudinal and transverse beam. In the figure, "▋" means that hoisting rings are installed here, "○" means that pillars are set below the deck, "●" means that hoisting rings are set on the deck surface and pillars are set under the deck.

### 3.2 Strength Calculation under Different Arrangements

ANSYS is used to carry out FE simulation for above three layout schemes. The hull structure is simulated by shell element and beam element. The model refers to *The guide for direct calculation of hull structure strength* issued by CCS (China Classification Society, CCS). The grid is divided into QUAD4 quadrilateral shell element with a minimum angle of 45 °, and the change gradient of adjacent grid size is less than 1.25 [4,5]. MPC (Multi-Point Constraints, MPC) are used to simulate the lifting
process of the block. The MPC is established with the hook as the independent points and the hoisting points of the main section as the associated points, and the displacement of the independent point (hook) in the longitudinal, transverse and vertical directions is limited. The full restraint is applied to the side bottom, the dead weight of the hull structure is applied as the load, the gravity acceleration \( g = 9.81 \text{m/s}^2 \), the elastic modulus of the material is 210GPa and the Poisson's ratio is 0.3.

In scheme I (Figure 3), 492.96mm downward deformation occurs on both sides of bridge deck. The maximum stress is 328.53MPa, and it’s between 2ND deck and upper deck. What’s more, the deformation of 2ND deck, upper deck and broadside is greater than 500mm. In scheme II (Figure 4), bridge deck has 136.08mm downward deformation. Affected by pillars, 2ND deck and upper deck have downward bending deformation, and the stress concentration occurs in the area where the hoisting points are located, with the maximum stress of 191.43MPa; In scheme III (Figure 5), the maximum deformation of deck is 84.154mm, the stress concentration occurs at the ribs of FR82 and FR91, the maximum stress is 380.21MPa. The torsional deformation occurs at broadsides, with the maximum deformation of 90.113mm. The maximum stress of each deck and broadsides is shown in Table 1, and the maximum deformation is shown in Table 2.
Table 1. Maximum stress during hoisting.

| Scheme | Bridge Deck/MPa | 2ND Deck/MPa | Upper Deck/MPa | Broadside /MPa |
|--------|-----------------|--------------|----------------|---------------|
| I      | 328.53          | 43.939       | 55.801         | 124.616       |
| II     | 191.43          | 38.242       | 43.452         | 75.502        |
| III    | 380.21          | 56.941       | 21.974         | 145.908       |

Table 2. Maximum deformation during hoisting.

| Scheme | Bridge Deck/mm | 2ND Deck/mm | Upper Deck/mm | Broadside /mm |
|--------|----------------|-------------|---------------|---------------|
| I      | 493.74         | 515.394     | 515.32        | 528           |
| II     | 136.08         | 132.394     | 125.32        | 30.24         |
| III    | 84.154         | 85.017      | 85.94         | 90.113        |

The above three schemes can be strengthened. In terms of stress, the maximum stress of scheme I and III exceeds 300MPa, exceeding the required stress of materials; In scheme II, stress concentration occurs in the hoisting points area, with the maximum stress of 136.08MPa. In schemes I and II, pillars between bridge deck and 2ND deck can be strengthened, or temporary pillars can be added below the hoisting points to enhance the stress transmission channel, to reduce the stress concentration; In scheme III, there are two places with stress concentration, and the position is about 1m away from the broadsides, so the structural reinforcement is easy to realize. In terms of deformation, in scheme I and II, downward bending deformation occurs in the midship. The maximum deformation of the deck in scheme I and II are 515.394mm and 136.08mm. In addition, the 528mm deformation of broadsides in scheme I is much greater than 30.24mm in scheme II; The deformation of plate in scheme III is smaller than scheme II, and the stress concentration part is less than that in scheme II. The deformation of broadsides is 90.113mm, which is 30.24mm larger than scheme II, but the deformation control measures are simple. Therefore, considered to adopt the hoisting points arrangement of scheme III for structural reinforcement and strength analysis.

4. STRUCTURAL STRENGTHENING SCHEME

4.1 Structural strength calculation and analysis

The calculation results show, the broadsides deformation is large, according to scheme of scheme III. It is mainly due to the large vertical deformation of the deck, resulting in large vertical deformation of broadsides. The deformation of the broadsides cannot be accurately judged, only according to Figure 5, the transverse and longitudinal deformation diagrams under scheme of scheme III shall be made by ANSYS.

Figure 6. Deformation diagram of X-Axis and Y-Axis in scheme III.

Figure 5 shows that, in terms of stress, stress concentration occurs during hoisting, with the maximum stress of 380.21MPa, which occurs in the hoisting points area of FR82 and FR91 ribs. In
terms of deformation, both ends of three decks are bent downward. What’s more, it can be seen from Figure 6 that the free edges have inward bending deformation, with the maximum deformation of 20.214mm. And there is also wavy deformation on the broadsides, with a maximum deformation of 16.439mm.

According to the requirements of ABS (American Bureau of Shipping, ABS) MODU (Mobile Offshore Drilling Units, MODU), the allowable stress of the material used in the block is $156 \text{MPa} \leq 0.7 \times 235 \text{MPa}/1.5 \approx 156 \text{MPa}$ [6]. Combined with the hoisting experience of shipyards, the structure is allowed 1~3mm deformation within 1000mm. Therefore, under the arrangement scheme, structural reinforcement shall also be carried out for stress concentration and free edges deformation on the broadsides.

4.2 Scheme of Reinforced Structural

In view of the problems of large deformation in broadsides, and the stress concentration with excessive stress of the bridge deck during hoisting, the structure is strengthened as follows:

![Figure 7-a](image1)

Set 18#/a channel sized as temporary reinforcement.

![Figure 7-b](image2)

Free edge connection with 18#/a channel steel

![Figure 7-c](image3)

Temporary reinforcement of skeleton

Figure 7. Schematic diagram of block strengthening scheme.
(1) In Figures 7-a, longitudinal stiffeners are set at the bottom of the broadsides. They rigidly connect the frames. The stiffeners are 18#/a channel steel, which are arranged at FR73 ~ FR82, FR82 ~ FR91 and FR91 ~ FR100 ribs. The scheme strengthens the stiffness of broadside, and reduce the wavy deformation of the free sides.

(2) In Figures 7-b, two 18#/a channel steels are added at FR73 and FR100, which are rigidly connected with ends of the stiffener and the ribs. It increases the transverse support, and reduce the inward free edges deformation of the free edges.

(3) In Figures 7-c (hidden bridge deck), stress concentration occurs in FR80 ~ FR84. Diagonal supports are added between longitudinal and corresponding frame, which is 10.5m away from the middle. To enhance the internal force transmission channel, and reduce the stress concentration on the deck, they are connected to the longitudinal and transverse beams.

After the block is strengthened, the stress and deformation are calculated by ANSYS, and shown in Figures 8-9. The before and after strengthening comparison is shown in Table 3.

Figure 8. Deformation and stress diagram of reinforced structure.

Figure 9. Transverse and longitudinal deformation diagram after reinforced.
Table 3. Comparison of calculation results before and after reinforced.

| Direction  | Scheme               | Max Stress (MPa) | Max Deformation (mm) |
|------------|----------------------|------------------|----------------------|
| whole      | Before strengthening | 380.21           | 90.113               |
|            | After strengthening  | 35.384           | 12.595               |
| Transverse | Before strengthening | -20.214          |                      |
|            | After strengthening  | 0.58             |                      |
| Longitudinal| Before strengthening | 16.439           |                      |
|            | After strengthening  | -1.23            |                      |

From Figures 8-9, the maximum deformation is 92.402mm, and its position appears on the channel steel as temporary reinforcement. This is because there is still 0.58mm bending deformation at the bottom of broadsides, and the total length of the channel steel is 22.6m. Both ends of the channel steel are under the inward pressure of the broadsides, so bending deformation occurs in the middle. About decks, the maximum deformation is 31.452mm, and the maximum stress is 35.384MPa, which is far less than the yield strength. Therefore, the deformation can be recovered after hoisting. According to the transverse and longitudinal deformation diagram, the inward deformation of broadsides is reduced to 0.58mm, and the maximum deformation of torsional deformation is 1.2296mm. In conclusion, the structure by this strengthened hoisting scheme will not be damage during hoisting.

5. CONCLUSION
Aiming at the deformation control problem of the large stereo garage block of 7800 PCTC hoisting in dock, this paper puts forward a hoisting points layout and its deformation control scheme, and draws the following conclusions:

(1) This paper analyzes the influence of three kinds of hoisting points layout on the deformation of the block during hoisting. According to the experience and principle of hoisting points layout and the structural characteristics of the block, a hoisting points layout scheme with small deformation of the block is proposed.

(2) In this paper, the deformation of the free edges is controlled. To improve the overall strength of the structure, the structure is strengthened in the stress concentration area. Through the FE analysis, it is verified that the structural strength meets the specification requirements.

(3) In this paper, the hoisting points layout scheme and the deformation control of the free edge proposed, solve the deformation control problem of the block of the stereo garage with large volume, heavy weight and weak support to a certain extent.

After strengthening, the FE calculation and analysis are carried out again, and the deformation meets the requirements.

REFERENCES
[1] X. Y. Liu. (2017) Huang Weijiang. Feasibility Study on Hoisting of Stereo General Block of Large Garage of Automobile Transport Ship. China Water Transport, (06): 42-43.
[2] H. Huang. (2013) Hull Craft Manual. National Defense Industry Press, Beijing.
[3] Y. Cao. (2015) Design of Superstructure Hoisting Scheme. In: Overall Hoisting Strength Analysis of LNG Ship Superstructure. Jiangsu University of Science and Technology, Zhenjiang. 6.
[4] G. J. Zhai, R. Z. Lu, K. Zhang. (2019) Optimization Design of Integral Hoisting of Tail Section of 38000t Bulk Carrier Based on BLS. Marine Technology, (04): 44-47+60.
[5] CCS. (2001) Guide for Direct Calculation of Hull Structural Strength. China Communication Press.

[6] ABS. (2005) Rules for Building and Classing Mobile Offshore Drilling Units 2006. American Bureau of Shipping.