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Research on Roll-on and Roll-off transportation of large-scale equipment in Dalian

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RESEARCH ON ROLL-ON AND ROLL-OFF TRANSPORTATION OF LARGE-SCALE EQUIPMENT IN DALIAN

By

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The People's Republic of China

A research paper submitted to the World Maritime University in partial Fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

In

MSEM

DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

Signature: Lianbo Li

Date: June 28, 2020

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Professor
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ABSTRACT

Title of Dissertation: Research on Roll-on and Roll-off Transportation of Large-scale Equipment in Dalian

In recent years, the number of roll-on and roll-off transportation of large-scale equipment above 1000 tons is growing rapidly in Dalian area and the growth rate will be accelerated in the next few years. In view of the complexity, high risk and particularity of safety supervision of large-scale equipment in transportation, it is necessary to carry out research on roll-on and roll-off transportation of large-scale equipment in Dalian.

This research first combed the current situation of roll-on and roll-off transportation of large-scale equipment and try to identify the risk of roll-on roll-off transportation of large-scale equipment in Dalian area at present. Through on-site field research and analysis of relevant data, the research mainly lie in the following four aspects. Firstly, the data of deck barges of different tonnage will be collected and analyzed to basically determine the ship type for transportation, scale of deck barges, and the tonnage of bulk cargo berths that can be berthed. Secondly, research are made on the ship dimension and tonnage of berth available of deck barges. Thirdly, the influence of deck barges' "T-shaped" berthing mode on surrounding waters will be discussed, and corresponding regulatory requirements are put forward. Fourthly, the loading and unloading operation standard of "T-shaped" berthing mode will be studied to give reference to the safety supervision of Ro-Ro transportation of large-scale equipment

At last, the methods and suggestions to solve the problems are put forward so that the maritime safety supervision of roll-on roll-off transportation of large-scale equipment in Dalian area can change from extensive management to refined management.

KEY WORDS: Roll-on and Roll-off; Large-scale equipment; Dalian Area; "T-shapped" berthing; Ship dimension; Loading and unloading standard

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LIST OF ABBREVIATIONS

B	moulded breadth
COSCO	China Ocean Shipping Company
DWT	deadweight tonnage
H	moulded depth
kn	knot(s)
L	total length
MSA	Maritime Safety Administration
PIANC	Permanent International Association of Navigation Congresses
Ro-Ro	Roll on and Roll off
SPMT	Self-propelled modular transporter
SPT	Self-propelled transporter
T	designed draft
VTS	Vessel Traffic Service

Chapter 1: Introduction

1.1 Research Background and Significance

With the rapid development of China's economy and the acceleration of modernization, the increasing number of large-scale construction and expansion projects in energy, chemical industry, etc. has lead to ever increasing demands of engineering logistics. The equipment used in these large-scale construction and expansion projects are characterized by complex shapes, high precision, extra heavy in weight and super large in size. Moreover, they need to be transported from the production site or wharf to the installation site within the specified time, which requires high transportation quality and technique.

Petrochemical industry and large-scale equipment manufacturing is one of the important pillar industries of Dalian's economic development. In recent years, the number of roll-on and roll-off transportation (hereinafter referred to as Ro-Ro transportation) of large-scale equipment above 1000 tons is growing rapidly in Dalian area and the growth rate will be accelerated in the next few years.

In view of the complexity, high risk and particularity of large-scale equipment transportation and in order to better ensure the safety of navigation and berthing of ships in and out of the ports, and the operation process of loading and unloading, it is necessary to carry out research on the roll-on and roll-off transportation of large-scale equipment in Dalian. Therefore, this study is not only of great significance to control the risks of Ro-Ro transportation of large-scale equipment, prevent major berthing and wharf operation accidents, and ensure safety in Dalian waters; but also works as an important driving role and a valuable reference for the Ro-Ro transportation in other areas.

1.2 Research Methodology and Purpose

Through on-site field research and analysis of relevant data, this research aims to find out the risks existing in the current Ro-Ro transportation of large-scale equipment and put forward rational suggestions to solve some problems existing. This research plans to first collect data from field study about the current status of Ro-Ro transportation of large-scale equipment in Dalian area. Then from theoretical analysis and quantative data calculation, key techniques in Ro-Ro transportation field will be discussed and suggestions on the controlling of the risk of roll-on and roll-off transportation of large-scale equipment will be given by the reference of the current port situation in Dalian and discussions with experts in the field.

Specifically, the focus of the research mainly lie in the following four aspects. Firstly, the data of deck barges of different tonnage will be collected and analyzed to basically determine the ship type for transportation, scale of deck barges, and the tonnage of bulk cargo berths that can be berthed. Secondly, research are made on the ship dimension and tonnage of berth available of deck barges. Thirdly, the influence of deck barges' "T-shaped" berthing mode on surrounding waters will be discussed, and corresponding regulatory requirements are put forward. Fourthly, the loading and unloading operation standard of "T-shaped" berthing mode will be studied to give reference to the safety supervision of Ro-Ro transportation of large-scale equipment.

1.3 Outline of the Thesis

In pursuit of the research purpose, this thesis is organized as follows. Chapter 1 introduces the research background, purpose, methodology, and significance of the research and outlines the thesis in terms of how the idea is developed. Current situation and previous studies on Ro-Ro transportation of large-scale equipment are introduced in Chapter 2. By consulting and collecting relevant books and literature, Chapter 3 explores scheme of ro-ro transportation of large-scale equipment and gives risk analysis of maritime supervision. Chapter 4 researches on the ship dimension and tonnage of berth available of deck barges. Chapter 5 gives the impact analysis of "T-shaped" berthing on surrounding waters. Chapter 6 shows two methods of determination of loading and unloading standards during "T-shaped" berthing. Chapter 7 summarizes the findings in this study, and gives constructive suggestions.

Chapter 2: Literature Review

2.1 Current Situation of Ro-Ro Transportation of Large-scale Equipment

Roll-on and roll-off transportation of large-scale equipment is a kind of shipping mode in response to the development of "door-to-door" direct transportation. This mode of transportation originated from the Baltic Sea in the 1960s, developed in Europe and expanded rapidly to all parts of the world. Since the 1990s, more and more attention has been paid to the research on the Ro-Ro transportation process and scheme of large-scale equipment such as petroleum platform, chemical equipment, port machinery, etc. The Ro-Ro transportation of large-scale equipment is quite common in countries such as Europe, America, Japan, etc., and their research on the subject has achieved great achievements. Hou (2015) and Lei et al. (2010) believed that the Ro-Ro transportation of large-scale equipment in the countries mentioned above is in a leading position in many aspects.

Firstly, the transportation technology is relatively mature. In order to smoothly implement the Ro-Ro transportation of large-scale equipment, the Ro-Ro technology has been studied for a long time. A variety of apparatus such as Ro-Ro approach bridge and platform vehicle have been developed according to the requirements of transportation of different types of equipment. Moreover, on the basis of rich practical experience and relatively mature management and operation procedures, a batch of shipping companies who are equipped with strong transportation capacity and advanced technical means, such as the famous German RICKMERS, Dutch DOCKWISE, FAIRSTAR, BIGLIFE, and Norwegian OCEAN HEAVEY LIFT (OHT), SEIAMETRIC, etc., has regarded the transportation of large-scale equipment as one of the core shipping businesses in the company (Ge, 2008). Secondly, the transport equipment is relatively developed. In recent years, in order to transport more special equipment and goods, a kind of ship designed specifically for large-scale equipment has emerged. It is characterized by stronger transportation capacity, higher degree of automation, and more specialization of deck, cabin and its auxiliary equipment. Thirdly, the transportation management level is relatively advanced. The international shipping companies with rapid development and extensive business have already integrated engineering logistics theory into their management. They have adopted the management system integrating quality management, environmental management and occupational safety management, and formulate the operation plan with the help of information technology such as computer-aided design, electronic map, positioning communication and real-time monitoring to ensure the safety of transportation task.

China has a vast territory, long coastline and good port water conditions. It also owns inland river networks crisscrossed with large rivers like the Yangtze River, the Yellow River and the Huai River, etc., which are abundant in water resources (Lei et al., 2010). Compared with land transportation, water transportation is convenient and labor-saving, and the transportation objects are almost unlimited, especially suitable for overweight and extra long goods transportation (Lin, 2007). Since the 1990s, China's water transportation industry has developed rapidly, with the growth of a number of shipping companies with considerable large scale, strong transportation capacity and rich practical experience. For example, COSCO Shipping Special Carriers Co., Ltd., a subsidiary of China COSCO Shipping Group, has established a special transportation fleet of considerable scale, equipped with world's most advanced transportation barges and special cargo handling equipment. The ships has reasonable ship structure, strong carrying capacity and cargo adaptability, and are good at energy conservation and environmental protection. They can carry ultra long, overweight, and super large pieces including drilling platform, locomotive and train carriage, wind power equipment, bridge crane, etc., with the carrying capacity ranging from 1 ton to 100,000 tons.

The safety in the transportation process of large-scale equipment is considered quite important. Although at this stage, the transportation of large-scale equipment shows a good momentum of development and rapid progress in China, there is still a certain gap between Chinese shipping companies and world-class companies, especially in the aspects of management implementation and transportation process. Some domestic transportation enterprises are lack of high-level management and technical personnel, so it is hard to reach perfection in every link of the process of embarking and disembarking of large-scale equipment and sea transportation (Lin, 2007). From the on-site field observation of Ro-Ro transportation of large-scale equipment, the organization and command of transportation are somewhat arbitrary, with problems such as insufficient scheme preparation, inadequate guarantee of rented equipment, unsynchronized organization and coordination of all parties involved, and deviation in understanding, etc., resulting in the damage in parts of and even all of the large-scale equipment.

2.2 Previous Studies on Ro-Ro Transportation of Large-scale Equipment

As mentioned above, the research on Ro-Ro transportation of large-scale equipment abroad is more in-depth, with rich practical experience. They apply the means and methods of management to the implementation process, adopt advanced decision support system, and mature risk assessment, decision-making and control methodology, so as to ensure the safety of transportation in the transportation process. For the design of ballast water allocation in roll on and roll off scheme, Ferguson et al. (1983) developed the calculation program of barge load adjustment and real-time tide level compensation for the ballast water allocation in jacket launching process. Hofferber (1991) studied the establishment of main ballast system and tide level compensation system in barge ballast system. Kurniawan and Ma (2009) studied how to minimize the jacket burning degree and curvature and maximize the water transfer efficiency by establishing the jacket platform burning curve equation and adopting the multi-objective optimization method,. Yang, Park and Ha (2005) used two semi submersibles to realize the sliding launching of the structure and designed the main control calculation software for calculating the load adjustment scheme of the barge. In terms of technical means, advanced computer-aided design, specialized software package, and information technology such as electronic map and GPS real-time positioning communication are widely used to bring each link into the vision of management and monitoring, so as to ensure the safety and timeliness of the transportation process (Tierney, 2018; Xin et al., 2017).

Compared with foreign countries, the research on Ro-Ro transportation of large-scale equipment started late in China, but it has already attracted many scholars and enterprises' attention. In 2003, Xu and Jiang (2003) made an in-depth study on the calculation of ship stability in the process of loading and unloading of heavy cargoes, proposed the method of adjusting ship heeling, and provided theoretical guidance for the loading and unloading procedure. Lu (2004) and Wei (2017) carried on the stress analysis and the binding design of heavy cargoes, and introduced the reinforcement and binding method of the heavy cargo in details. Ge (2009) and Wu (2016) conducted in-depth research on Ro-Ro transportation process of large-scale equipment and discussed the construction method and technological requirements of loading and unloading of large-scale equipment. Xiao (2009) designed a software package of floating Ro-Ro calculation method according to the stress balance equation, which can carry out real-time and full-course calculation on the barges; through the analysis of tide change, he put forward the feasibility criteria for combining Ro-Ro with tides condition, so as to solve the safety and reliability problems such as the determination of Ro-Ro time and reasonable barge attitude. Wu (2015) tried to adopt the roll-on roll-off construction scheme from small barge to large barge, and carried out stress analysis and design optimization for Ro-Ro process, realizing safe and reliable Ro-Ro transfer of large equipment with low cost and short period. Based on the principle of ship statics, Zhou (2015) analyzed the Ro-Ro plan of generator stator adopted by Dayawan Nuclear Power Station in recent years. Wang, Ye and Tian (2008) analyzed the methods of loading and unloading by barge, gave the calculation formula, designed the Ro-Ro scheme by referring to the requirements of relevant specifications and transportation practice, and verified the validity of the scheme in practice .

To sum up, great progress has been made in the research on the sea transportation of large-scale equipment and goods, but there is still a disconnection between theoretical research and engineering practice. The theoretical research is relatively in-depth and detailed, but fails to integrate the advanced management and risk control methods into the engineering practice. In the implementation process of the engineering project, the practical application of machine technology in the decision-making scheme of heavy equipment transportation is relatively backward.

Chapter 3: Scheme of Ro-Ro Transportation of Large-scale Equipment and Risk Analysis in Maritime Supervision

3.1 Scheme of Ro-Ro Transportation of Large-scale Equipment

3.1.1 Conditions of the Wharf to be Berthed

Currently, most outbound terminals of large-scale equipment in Dalian are bulk cargo terminals; however, bulk cargo terminals cannot fulfill the requirements of roll-on and roll-off loading-unloading methods and "T-shaped" berthing method. Therefore, the key issue for maritime safety supervision authorities and companies that deal with transportation for large-scale equipment is whether the design of the wharf to be berthed can meet the requirements for the shipment of such goods.

The conditions of the design of the wharf mainly include ship type for transportation, berth operating standards and loads. The normative analysis of the scale of berths for the "T-shaped" berthing method of deck barges is an important part of the plan for the Ro-Ro transportation of large-scale equipment. It mainly includes the following parts: the length of the berth, the mooring width of the wharf apron, the width of the wharf apron, the design water depth of the wharf apron and the bottom or top elevation of the wharf apron.

Moreover, the ship load capacity of the wharf to be berthed is also an important consideration for the "T-shaped" berthing method. Ship load capacity acting on fixed mooring and berthing structures should include the mooring force generated by wind and current, the squeezing force generated by wind and current, the impact force generated when the ship wharfs, and the impact force generated under the influence of waves of the mooring ship. The calculation of these factors to be considered are listed below.

(1) Wind pressure. Ship load is calculated according to *Load Code of Harbor Engineering* (2010). The calculated wind pressure acting on the ship (the transverse wind force perpendicular to the front line of the wharf and the longitudinal wind force parallel to the front line of the wharf) can be calculated according to the following formula:

$$F_{xw} = 73.6 \times 10^{-5} A_{xw} V_X^2 \zeta_1 \zeta_2$$

$$F_{yw} = 49.0 \times 10^{-5} A_{yw} {V_y}^2 \zeta_1 \zeta_2$$

where, F_{xw}, F_{yw}——the transverse and longitudinal wind forces (kN) of the calculated wind pressure acting on the ship;

A_{xw}, A_{yw}——the transverse and longitudinal wind areas (m^2) above the current surface of the hull, the wind area under the loading conditions is adopted;

V_x, V_y——the transverse and longitudinal components of the design wind speed (m/s), V=20.8m/s is adopted;

ζ_1——reduction coefficient of the uneven wind pressure;

ζ_2——correction coefficient of the height change of the wind pressure.

(2) Mooring force. The standard value of the mooring force N and its transverse component N_x perpendicular to the front line of the wharf, the longitudinal component N_y parallel to the front line of the wharf, and the vertical component N_Z perpendicular to the surface of the wharf can be calculated according to the following formula:

$$N = \frac{K}{n}\left[\frac{\sum F_x}{\sin\alpha\cos\beta} + \frac{\sum F_y}{\cos\alpha\cos\beta}\right]$$

$$N_x = N\sin\alpha\cos\beta$$

$$N_y = N\cos\alpha\cos\beta$$

$$N_z = N\sin\beta$$

where, N ——the standard value of mooring force;

K ——the coefficient of uneven force distribution of the bollard, the number of bollards which are actually under the strain is n, n=2, K=1.2; n>2, K=1.3;

n ——the number of bollards when the ship is under the strain at the same time;

$\sum F_X$, $\sum F_Y$—the transverse and longitudinal components generated by the wind and current which may act on the ship simultaneously;

α——the angle between the horizontal projection of the mooring rope and the front line of the wharf (°);

β——the angle between the mooring rope and the horizontal plane (°).

(3) Ship squeezing force. When the rubber fenders are arranged intermittently, the standard value of squeezing force can be calculated according to the following formula:

$$F'_j = \frac{K'_j}{n} \sum F_x$$

where, F'j——the standard value of squeezing force (KN) acting on a group or a rubber fender when the rubber fenders are arranged intermittently;

K'j——the coefficient of uneven squeezing force, and K'j is 1.3;

$\sum F_x$——the sum of transverse component (KN) generated by the wind and current which may act on the ship simultaneously;

n——the number of groups of rubber fenders or the number of rubber fenders that contact with the ship.

(4) Impact force. The impact force when the ship wharfs is calculated according to the following formula in *Load Code of Harbor Engineering* (2010):

$$E_0 = \frac{\rho}{2} M V_n^2$$

where, E_0—— effective impact energy (kJ) when the ship wharfs;

ρ ——effective kinetic energy coefficient, and the range from 0.7 to 0.8 is adopted;

M —— The mass of the ship (t);

V_n —— Normal velocity when the ship wharfs (m/s).

The impact force of the moored ships under the influence of transverse waves is calculated according to the following formula in *Load Code of Harbor Engineering* (2010):

$$E_{w0} = \frac{1}{2} k C_m m V_B^2$$

$$C_m = \alpha_m + \beta_m \frac{D^2}{Bd}$$

$$V_B = \alpha \frac{H}{T} \left(\frac{L}{B}\right)^{\beta} \left(\frac{D_0}{D}\right)^{\gamma}$$

$$E_W = K_2 E_{w0}$$

where, Ew_0 ——effective impact energy (kJ) of the moored ships under the influence of transverse waves;

E_w—— effective impact energy (kJ) of the single fender;

α, β, γ——coefficient;

k——reduction coefficient of the eccentric impact energy;

C_m——added water influence coefficient;

m—— mass of the ship (t);

V_B——normal impact velocity of moored ship under the influence of transverse waves;

αm, βm——structural influence coefficient of the wharf, for shore-wall wharf, αm=1.00, βm=1.69; for dolphin wharf, αm=1.04, βm=0.9

H ——calculated wave height (m);

L ——wavelength (m);

d ——the frontal depth of the mooring and berthing structure (m);

B——the moulded breadth of the ship;

D_0——the loaded draft of the ship (m);

D——the average draft (m) corresponding to the calculated loading degree of the ship;

K_2 ——the uneven coefficient of impact.

3.1.2 The Berthing and Unberthing Methods

The Ro-Ro method adopted by the ship include along with fore or aft slope springboard method, fore or aft straight springboard method, crotch springboard method, and the "T-shaped” fore or aft springboard method. In Dalian, the “T-shaped” berthing method is the main berthing method of the deck barges for filling transportation of large-scale equipment.

3.1.2.1 Berthing

When berthing, first toss the double anchors in the stem (the double anchors are put into character “eight”), and then reverse the engine at a slow speed, so that the stern is close to the wharf. When the distance between the ship and the wharf is about 20 meters, moor the heaving line to the wharf and bring the stern line on both sides of the stern to the bitt, then slowly tighten the micro cable, so that the stern slowly berths at the wharf. Finally, bring the cable that like the character eight to the bitt at the wharf, gradually tighten it, and adjust the length of the anchor chain and the force of each cable at the same time, so that the ship can berth at the wharf safely (see Figure 1).

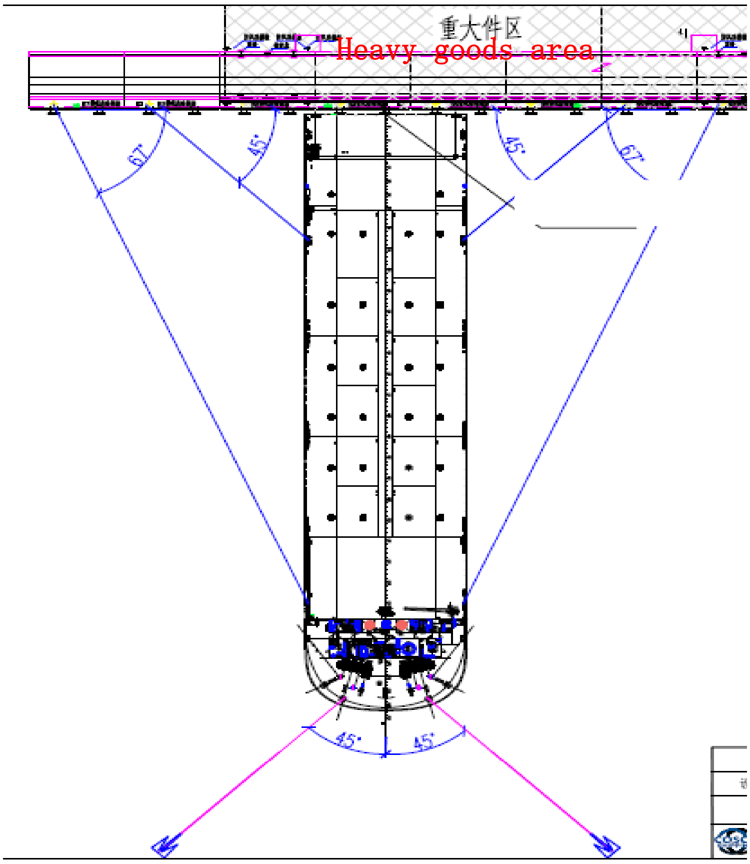

Figure 1. Schematic diagram of barge berthing

For different ships, the maneuverability is different, so before carrying out the stern berthing operation, it is necessary to formulate a berthing plan based on the ship's own maneuverability and the influence of external wind flow. The relevant factors that should be considered especially in the process of reversing engine, anchoring, steering and mooring include the reverse performance of the ship, the deflection effect caused by the single-vehicle reversing, the performance of the thruster; the number of tugs, the power and maneuverability of the tugs, and the working conditions of the anchor equipment and mooring equipment. Good coordination of vehicles, rudders, thrusters, anchors, cables and tugs is another key point to ensure the success of berthing operations.

When formulating the berthing plan, risk assessments should be made for various possible emergencies, and corresponding plans and risk control measures should also be formulated. If the maneuverability of the ship is not fully understood, the residual speed during reversing should not be too fast, and the speed of entering and reversing when berthing should not be too fast either, but the number of tugs and the power of them should be increased. Since the freeboard of the heavy-duty cargo carriers on decks is generally low, it is necessary to fully consider whether the tugs can normally carry out the pushing operation when applying for tugs.

The length of the anchoring chain should not be too long and the angle should not be too large, otherwise it will affect the navigation or anchoring of other ships. In addition, the length of the anchoring chain should not be too short and its angle should not be too small. If the length of the anchoring chain is too short, the undercover chain may be too short and the gripping force may not be enough. If the angel is too small, the swing amplitude of the stem may be comparatively large and the difference of the distance from the stem to the stern may also be too large, so that one side may crack on the wharf.

3.1.2.2 Mooring

After the barge berths in the way of “T-shaped” method, the mooring method adopted is using four cables and open mooring jointly to guarantee the safety of mooring, as shown in Figure 1.

(1) One after line on each side of the stern;;

(2) One fore line is provided on each side of the bow to form a splay cable mode;

(3) Open mooring at the bow.

3.1.2.3 Unberthing

First, take off the cables brought to the wharf one by one, and weigh anchor at the same time. Use twin-screw to control the speed and course of the ship during weighing anchor. When the anchor is off the bottom, gradually increase the speed of the engine and navigate according to the planned route. Since the barge adopts the stern "T-shaped" berthing method, it is easy to maneuver the ship during unberthing.

3.1.3 Ship Type for Ro-Ro Transportation for Large-Scale Equipment

At present, the main ship type for Ro-Ro transportation for large-scale equipment in Dalian is deck barge, and the outbound terminals are mostly the bulk cargo terminals. Deck barges are not included in the design ship types of the wharf, and the design ship types of the deck barges are also not mentioned in the *Design Code of General Layout for Sea Ports* (2013). In the analysis of the conditions of the intended berth, the design ship type of the ship needs to be calculated and analyzed. Therefore, it is particularly important to determine the ship type scale of deck barges which are of different tonnage for the development of Ro-Ro transportation plans for large-scale equipment. Some obvious characteristics of the deck barges can be concluded from the data obtained, which includes the following aspects: the length is smaller than the breadth, the square coefficient is comparatively large, and its draft is shallow.

3.1.4 Safety Operation of Ro-Ro Ships

3.1.4.1 Design Principles of Transportation Scheme

The main work of Ro-Ro Transportation for Large-Scale Equipment includes the formulation and implementation of transportation schemes, loading, bundling and reinforcement, reverse transportation, shipment, sea transport, coordination and other full-process services. This thesis focuses on the loading and unloading ships at Ro-Ro terminals for large-scale equipment. The main principles of the transportation scheme are as follows.

First, Security principle. The transportation of awkward and length cargo is very different from the transportation of ordinary cargo. The transportation of awkward and length cargo is difficult to complete, and more attention is paid to the safety and integrity of the cargo; while for ordinary cargo, more attention is paid to the economical requirements. Therefore, in the design of the transportation scheme, it must be determined after analyzing the safety of all aspects concerning the road and transportation means involved in the entire transportation. Secondly, maximizing customer satisfaction principle. Design the scheme according to customer needs, and adjust it in time according to the changes in customer needs. Thirdly, practical design principle. In order to make the scheme more practical-oriented, at the beginning of the design, we will determine the depth and breadth of the design based on the conditions, information and decision-making analysis, making it more practical and instructive. Fourthly, absorption and simplicity principle. In the process of scheme design, domestic and foreign advanced methods and tools should be fully absorbed, existing resources should be used, and starting from scratch should be avoided, so that the process of scheme design and the quality of the scheme can be improved. Fifthly, coordination principle. The multimodal transport scheme is a complex operation scheme, so the entire scheme must be decomposed and coordinated, and scientific decomposition and effective coordination must be carried out to achieve overall satisfactory results. Therefore, for the overall optimization, various designed transport modes should be coordinated and compromised.

3.1.4.2 The Procedure of Roll-on and Roll-off

Ro-Ro shipment depends on the change of tide and the adjustment of barge ballast water. Generally speaking, roll-on shipment is carried out at high tide, and roll-off shipment is carried out at low tide. The Ro-Ro shipment procedure include the following seven aspects.

(1) Cargo vehicles stop after reaching 20 meters in front of the Ro-Ro terminal, and

check the data on by one, such as air pressure, hydraulic pressure, distance between each module, direction of vehicle board, vehicle board height. If all the indicators meet the technical requirements, the vehicles can be rolled on board;

(2) Place the barge and wharf in a “T” shape and fix them, adjust the height and posture of the barge, lay the roll-on springboard, align the vehicles and the springboard, and prepare for the roll-on shipment;

(3) If the height of the barge is appropriate and the steel road substrate connecting the wharf and the barge is placed securely, wait for the tide to rise;

(4) Drive the vehicle to the barge when the tide rises, and the average operating speed should be less than 0.5 km/h (The actual speed must be determined according to the speed of discharging the ballast water of the barge);

(5) As the cargo is gradually gotten on board, the stern will drop. If the descending speed of the stern is greater than the sum of the speed of tide rising and the discharging speed of ballast water, slow down the speed of vehicle and maintain close communication with the shipper during the roll-on shipment;

(6) Repeat the above operations until the cargo vehicles are fully aboard;

(7) The schematic diagram of the Ro-Ro shipment procedure is shown from Figure 2 to Figure 6.

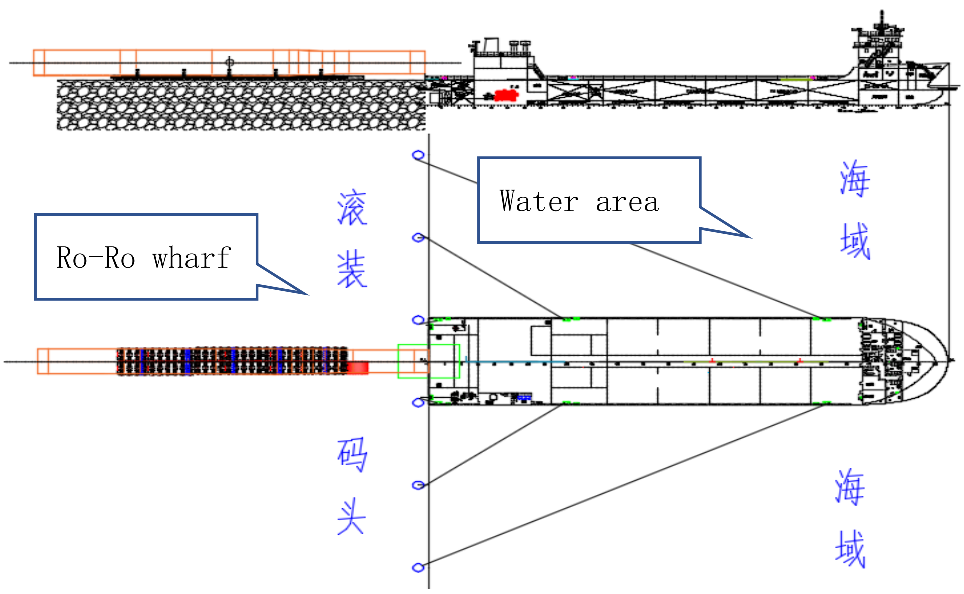

Figure 2 Preparation before roll on

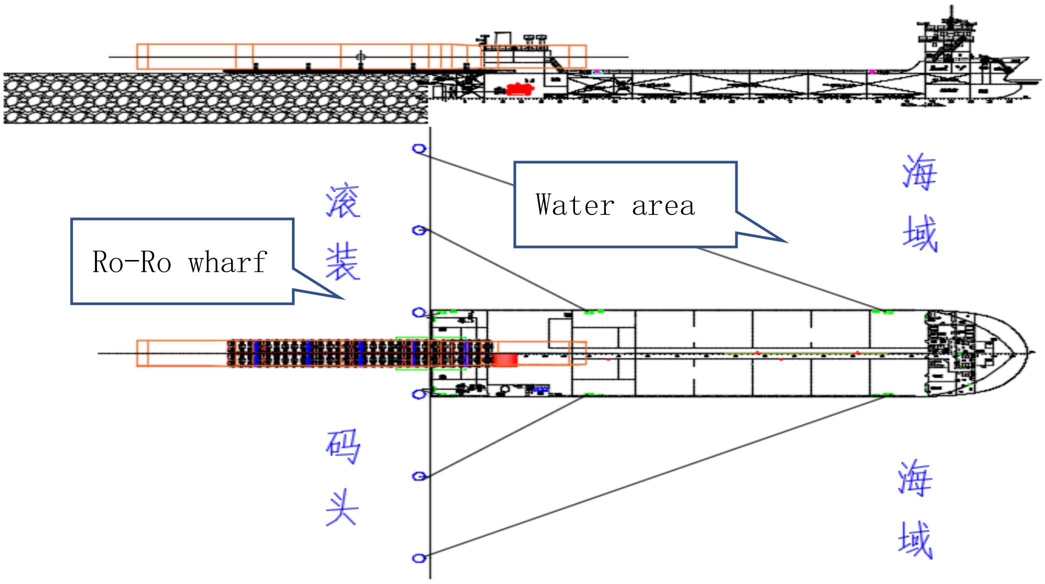

Figure 3 Roll on 25%

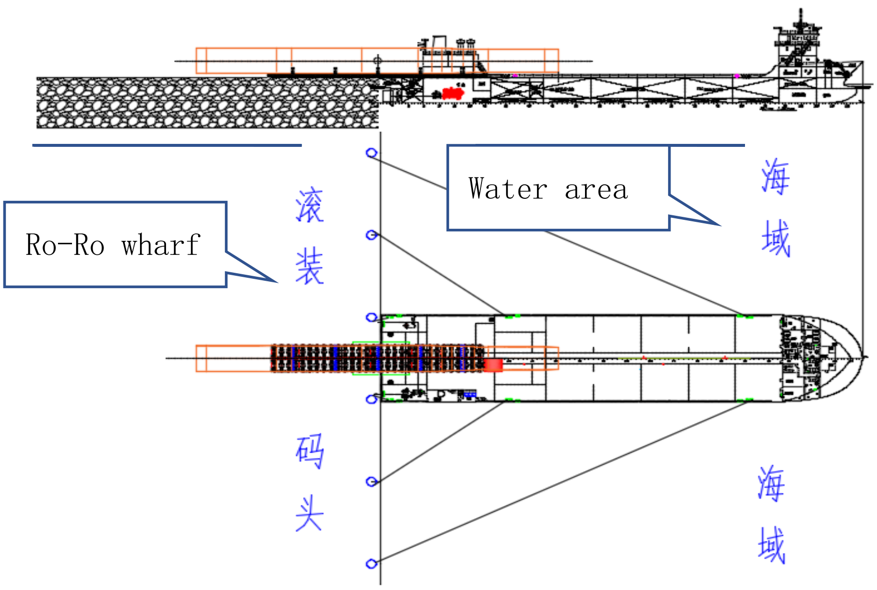

Figure 4 Roll on 50%

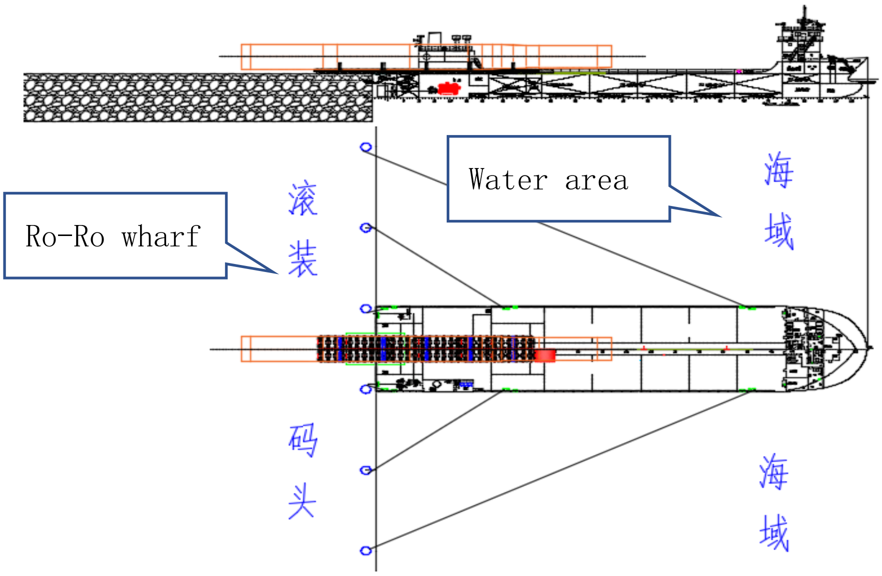

Figure 5 Roll on 75%

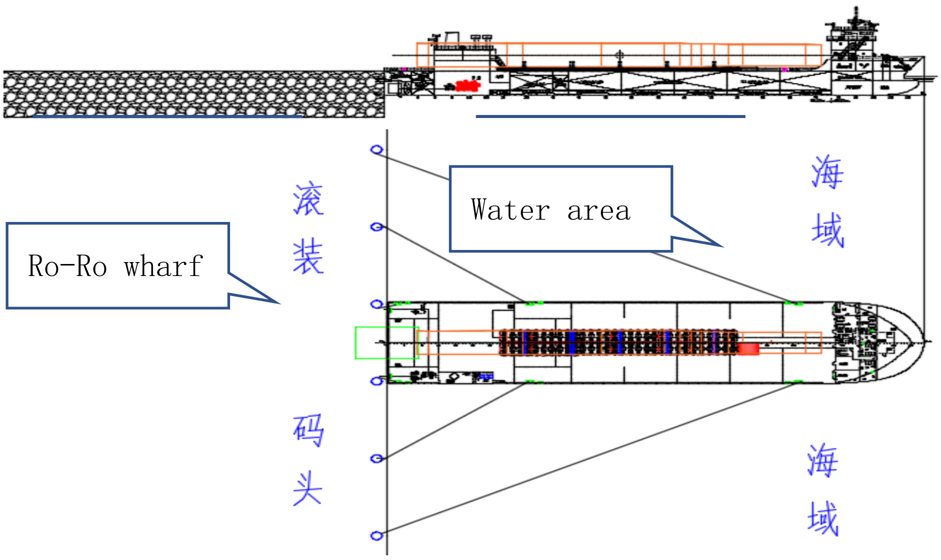

Figure 6 Roll on finished

After the roll-on shipment is completed, the post-shipment inspection is carried out. After confirming that it meets the technical conditions of the transportation scheme, the vehicle should be slowly lowered so that the saddle and the buttress are in full contact, and then the vehicle should be withdrawn from the ship across the sweep to complete the shipment. There are six attention points for Ro-Ro shipment.

(1) Maintain communication with the technicians on the barge during boarding to prevent the following problems: large changes in the height between the barge and the ground due to the difference among the speed of tide rising, the discharging speed of ballast water and the load speed of the barge; the transverse angle of the barge is excessively large;

(2) During the period, the operational and monitoring personnel at each position must be highly concentrated. According to the operation manual, if any hidden dangers are found, they should notify the person who is in charge of the overall situation on the spot in time. Then unified arrangements should be made to ensure the safety of the operation of vehicle board, and the risk of the overload of vehicle board caused by local suspension should be particularly avoided;

(3) When all the self-propelled hydraulic boards are boarded, navigate slowly in accordance with the route signs, and maintain the stability of the ship by adjusting the ballast water until the equipment is safely placed above the pre-arranged buttress;

(4) Drop the equipment on the buttress slowly in accordance with the technical requirements, that is forming a stable triangular when the height of the self-propelled hydraulic flatbed vehicle is lowered;

(5) Drive away from the self-propelled hydraulic flatbed vehicle as required;

(6) In order to ensure the safety of the Ro-Ro shipment, the shipment should be implemented in coordination with the tide, and the time for shipment should be completed within two hours.

3.1.4.3 Technical Requirements for Ro-Ro Shipment

During the process of roll-on shipment, using the tide of seawater and the adjustment of the ballast water to ensure the distance between the height of the deck and the wharf that is within an allowable and reasonable range. And the key point is the adjusting ballast water capacity of the barge.

When the deck surface of the barge is about 10 centimeters below the wharf surface, the roll-on shipment of the vehicles should be stopped. The vehicles should then wait for high tide and the adjustment of ballast water. Pump the ballast water of the aft tanks to the fore tanks and wait for the high tide. When the deck surface is from 20 to 30 centimeters above the wharf surface, continue the operation and repeat the above operation process until the entire equipment is loaded.

During the roll-on shipment, the barge deflects with the change of the vehicles' position on the barge. When the center of gravity of the vehicle and the cargo coincides with the load center of the barge, the barge can maintain its normal posture. Therefore, during the process of roll-on shipment, the ballast water must be used to adjust the barge posture at any time to ensure that the posture is within an allowable range.

If the loading of the equipment cannot be completed within a tide, the equipment should be rolled off when the tide is low to ensure the safety of the equipment.

3.1.4.4 Bundling of the Large-scale Equipment

The determination and calculation of shipping securing schemes are mainly based on the relevant provisions in the *Guidelines for the Preparation of the Cargo Securing Manual* (1998) of China Classification Society, and the balance between slippage and overturning is also calculated.

The securing scheme should be selected and determined according to the main parameters of the transport barge and the cargo. In general, it should be calculated according to the maximum heeling angle (30 degrees) and the maximum trim angle (10 degrees) of the ship. In the real situation, the loading and securing devices must be used to prevent the equipment from moving and turning over. The longitudinal force, lateral force and vertical force should be calculated according to the relevant regulations in the *Guidelines for the Preparation of Cargo Securing Manual* (1998) of China Classification Society to ensure the safety during the process of binding the large-scale equipment. There are eight attention points for binding large-scale equipment.

(1) When binding the rigging, appropriate pre-stress should be given to it. The connection between the rigging and the tensioner should be properly handled, the wire rope clips should be operated in accordance with the standard, and the tightening force of each bolt should be the same;

(2) Notice that the contact part of the steel wire rope and the equipment should be fully protected to prevent the wire rope from damaging the equipment;

(3) The contact part between the wire rope and the equipment should be inserted with protective materials to prevent the wire rope from polluting the equipment, and also prevent the wire rope from being damaged by the sharp edges of the equipment;

(4) To ensure that the equipment is bundled and reinforced well, the integrity of the rigging should be checked before binding. If the rigging is seriously worn, it is forbidden to use them;

(5) Protect the equipment during welding to avoid damaging the cargo. Carry a fire extinguisher at any time during the process to prevent the fire;

(6) The equipment should be bound firmly and reliably but not be damaged at the same time. The equipment must be protected when it is bound--the wire rope should be covered with rubber hoses to ensure that the surface or packaging of the equipment is not damaged. The binding place must be cushioned with rubber sheets or partitions to prevent polluting the equipment itself;

(7) The site of the binding and reinforcing operation should be supervised and confirmed by the technical director and safety quality assurance personnel;

(8) When using electric welding to remove auxiliary settings, a protective plate must be used above the equipment to prevent sparks and slag from splashing onto the packaging materials of the equipment and causing fire or damage to it.

3.1.4.5 Roll-off Procedure

The roll-off procedure is similar to the roll-on shipment. First, determine the date and time of roll-off shipment according to the hydrology and tide of the port. Then, roll off the delivery equipment vehicles and unload them on the wharf in accordance with the reverse steps of roll-on procedure. When the height of the tide is parallel to the barge deck and the plane of the wharf, the large-sized delivery vehicles begin to disembark. When the barge lifts so high that the vehicles cannot travel, they should stop disembarking and wait for the tide to recede. When the barge deck is again parallel to the wharf, the large-sized delivery vehicles moves forward again. The process is repeated until the vehicles are all disembarked. The process of roll-off shipment is shown in the following steps in diagram from Figure 7 to Figure 12.

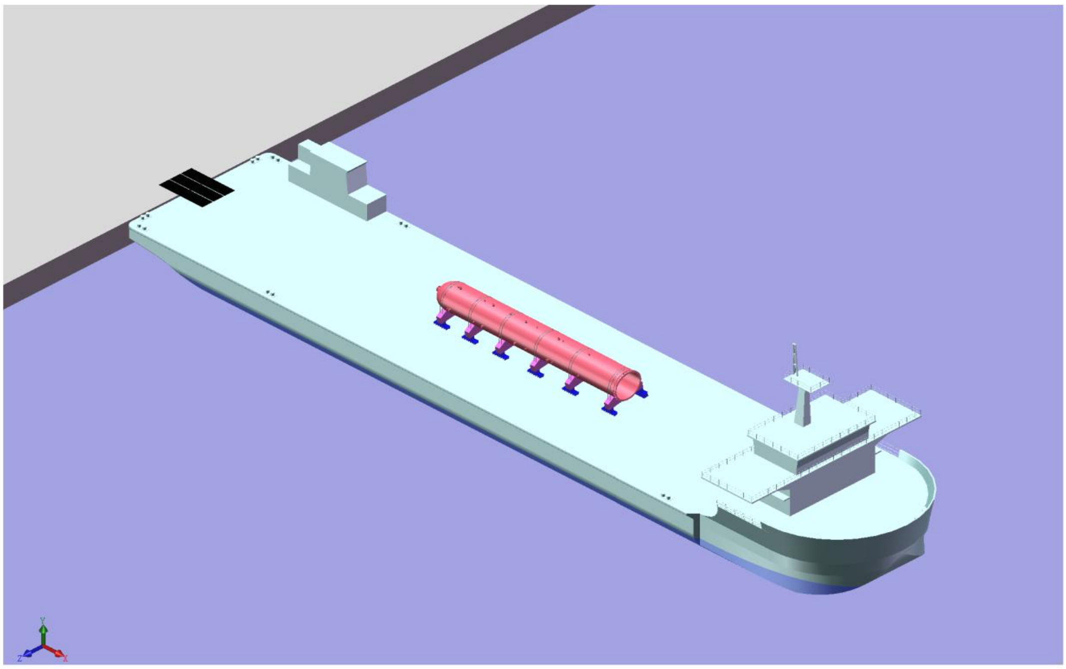

Figure 7 "T-typed" berthing of deck barge

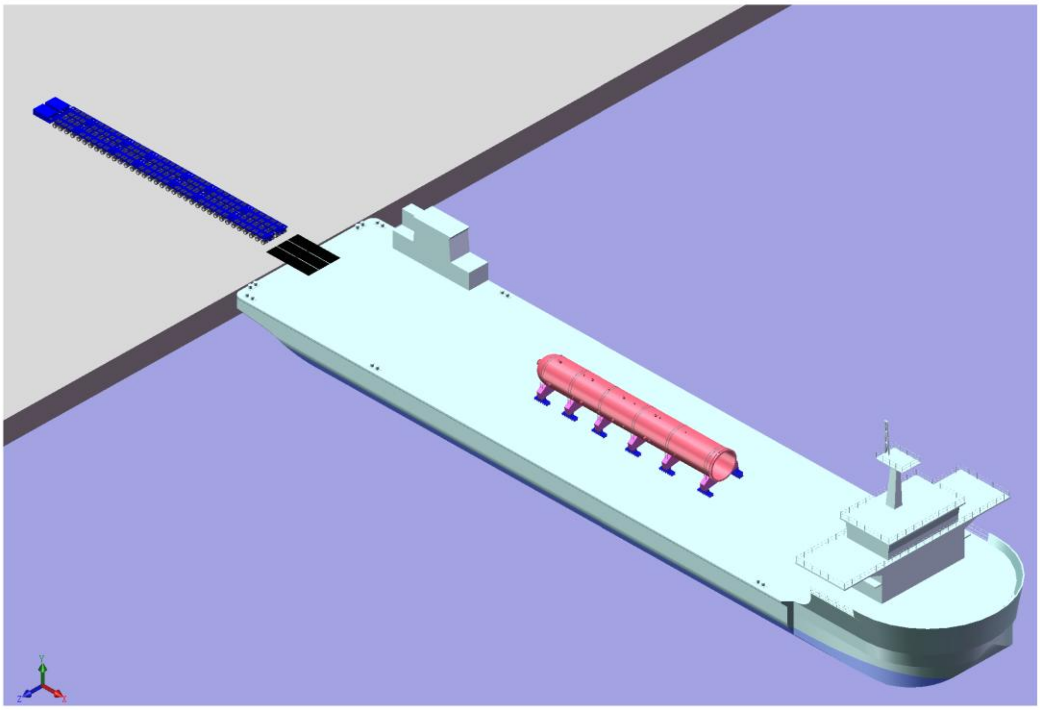

Figure 8 The carrier vehicle is ready on board

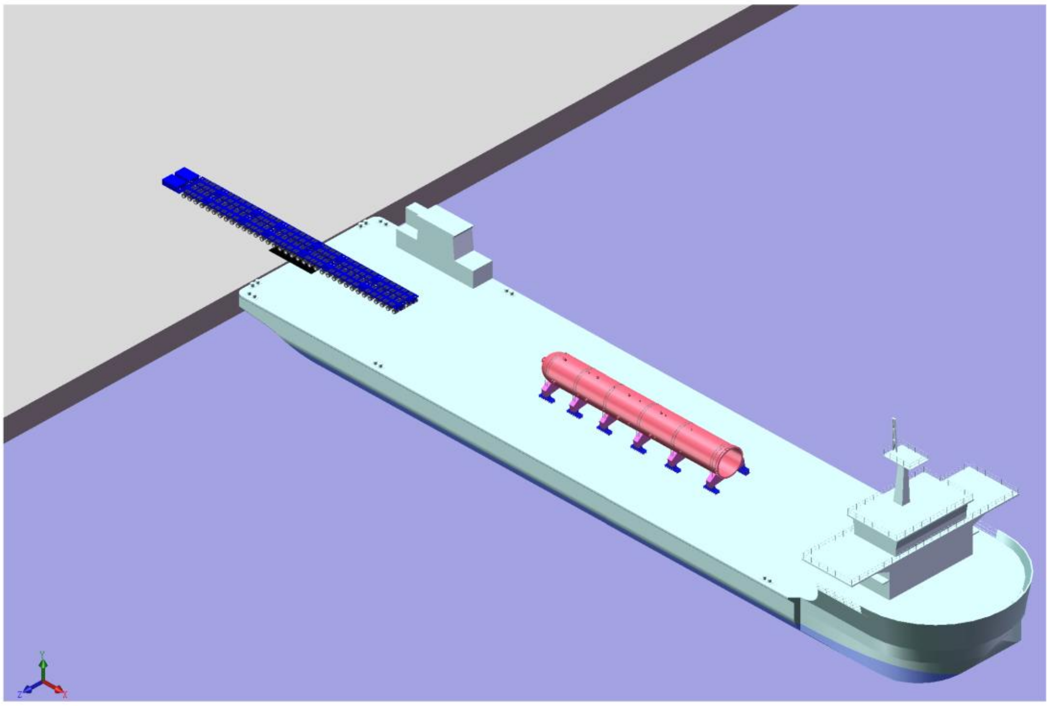

Figure 9 The carrier vehicle is on board

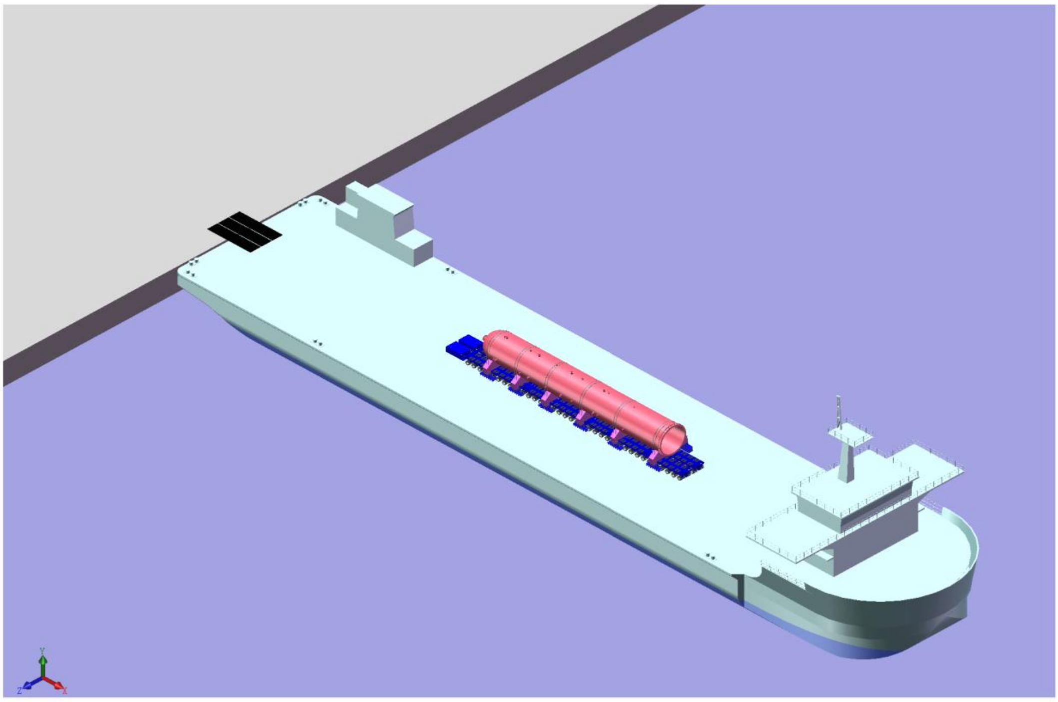

Figure 10 Large equipment loading on vehicle

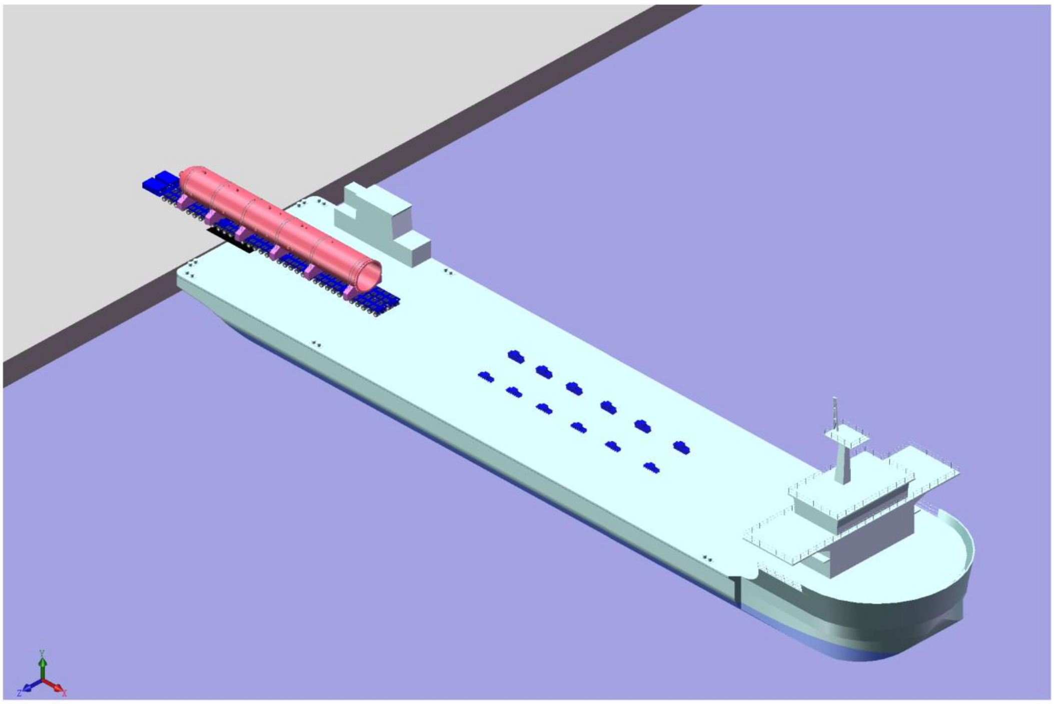

Figure 11 Roll off from board

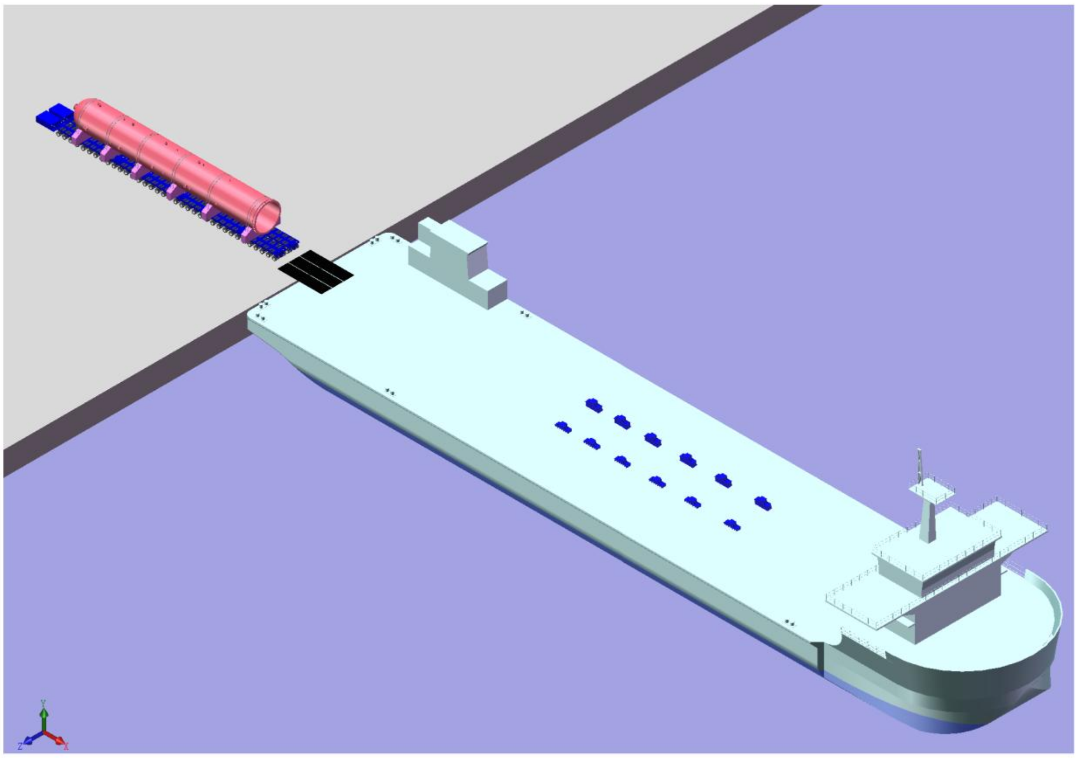

Figure 12 Roll off finished

3.1.4.6 Calculation Software

Scholars at home and abroad have developed mature software and auxiliary decision-making systems for roll-on and roll-off shipment of awkward and lengthy cargo. Large-scale equipment is of high value so it is recommended to use certified calculation software or auxiliary decision-making development system combined with the practical experience of the staff to ensure the safety of the operation during the Ro-Ro shipment.

3.2 Risk Analysis of Maritime Supervision

3.2.1 Estimation of Risks and Countermeasures

Table 1 below details the estimation of risks and countermeasures of each step of Ro-Ro shipment.

Table 1 Estimation of risks and countermeasures for each step of Ro-Ro shipment

No.	Operation Procedure	Risks	Countermeasures
1	T-shaped berthing	Unclear Parameter	Before operating, conduct JSA disclosure record, check whether the PPE is fully worn, and whether there are lifejackets and other anti-dropping facilities. Operate according to the requirements of the scheme. Send someone to the ship to understand the actual situation of the ship. JSA disclosure record should be signed by the personnel.
		Cannot berth	Find a tug with sufficient traction in advance
			Investigate the situation of the wharf and invite experts to conduct feasibility analysis on the wharf in due course. And written confirmation is needed.
		Cannot be fixed or deviated	Learn about the weather changes through mobile phones and other advanced instruments, arranging the time for barge to berth in advance
		Cable-broken	Prepare spare cables and maintain the cables regularly. The personnel prepare for protection add wear the PPE completely. The safety officer prompts supervision and makes inspection records for the supplier
2	Lay steel plate	No sleeper or insufficient quantity	Learn about the surrounding timber market, buy the sleeper in advance or borrow from the terminal

3		Insufficient auxiliary dunnage	Pass the JSA disclosure before leaving, clear the division of labor and check the implementation. Prepare according to the requirements of the implementation plan
		Steel plate to fall	Purchase according to the *Equipment Purchase Management Measures*
		The plate fall in wrong direction or position	Safety officer prompts supervision and checks record form
3	Ro-Ro shipment	Broken wharf	Pave wooden square roll-on springboards in the Ro-Ro area of the wharf in advance for load sharing
		Broken and worn vehicle plates	Observe the tide changes two days before to grasp the timing of Ro-Ro shipment
			Adjust the height of the vehicle plate to compensate for the tire lifting stroke due to the drop between the wharf and the barge
			Observe the distance between the vehicle plate and the ship, the distance between the vehicle plate and wharf at any time during the process. When the distance is insufficient, stop the operation and wait for the tide and barge to be adjusted
		Barge undulates and swings seriously	Learn about weather changes through mobile phones and other advanced instruments, and arrange the time for roll-on shipment in advance
		At a low tide or tide falls quickly	Obtain the tide table in advance, make a roll-on shipment plan according to the tide table, and operate as required. Increase the number of

			observers to observe at the spot
		Continue to board the ship when the height difference between the wharf and the deck is greater than 200mm	Add observers for measurement. Safety officer prompts supervision and make inspection records
		The barge is tilted longitudinally and transversely, and is tending to leave the wharf	Adjust the ballast water in advance and make inspection records for the supplier. Test before using and prepare tugs, land tractors, etc. The safety officer supervise the process, make inspection records for the supplier and make sure that the communication facilities are in good conditions
		The barge or vehicle capsizes	Operate according to the stowage plan. Arrange technicians and safety officers to track and supervise the stowage of barge
			When the swell causes the barge to swing significantly, the operation should be stopped (the swing amplitude does not exceed 500mm)
			Roll on or roll off along the center line of the barge. During the Ro-Ro shipment, the drop between the barge and the wharf should be measured constantly on both sides of the vehicle plate to ensure that the drop on both sides does not exceed 100mm
			Operation is forbidden if the wind force is greater than or equal to 6 level

			Make sure the lighting is adequate. In principle, work at night is prohibited. If necessary, work at night requires adequate lighting
		Someone falls into the ocean	If there is a warning line in the operation area of the wharf, people who are not related to the operation should be prohibited from entering the operation area
			All operators on board should wear lifejackets
4	Place the buttress	The forklifts fall into the ocean	Space on board is limited, so when the forklift is placed on the wharf, a person must be arranged to accompany
5	Use electric welding or gas welding	Fire and explosion	Welding and cutting personnel should have a special operation certificate and obtain a fire clearance permit
			Keep the operation place away from combustibles and prepare fire-fighting measures for fire extinguishers in advance
			The distance between the gas cylinder and the fire source should be maintained in a safe range. The anti-dumping measures should be reliable and bottle cap rubber ring should be kept complete
6	Use hand-held motor-operated electric tools	Mechanical injury	The hand-held motor-operated electric tools are in good condition and their shields are complete
			Reasonable operating direction, strength and angle
			Personal protective equipment such as face masks, earplugs and masks must be worn during grinding and cutting operations.

7	Use lights, hand-held motor-operated electric tools, electrical equipment, etc.	Electric shock	Check whether the electrical equipment is intact before operation. Repair the faults before use. The power connection and electrical maintenance should be performed by a professional technician.
			Protect the power cord and prevent it from being cut, pulled, dug, burn, crushed or immersed in water.
			Use qualified on-site power box, and make sure that grounding and leakage protection are intact

3.2.2 Risk Analysis in Maritime Supervision

Through the analysis of the characteristics of Ro-Ro transportation for large-scale equipment, the "T-shaped" berthing method is different from the traditional berthing method—berthing along the wharf. There is no clear regulatory standard for this shipping method in Dalian. The following risks mainly exist in maritime supervision.

Firstly, the problem of matching ships with wharfs. The ships that carry large-scale equipment are mostly deck barges. There is no standard of design ship type for this kind of ship in *Design Code of General Layout for Seaports*, so the design ship type of the relevant shipping terminal cannot include such ships. Therefore, there is a difference in the navigational scale between the ship and the intended berth, and they cannot be accurately matched.

Secondly, the problem of matching berthing methods with wharfs. "T-shaped" berthing method is often adopted of deck barges for carrying large-scale equipment. The anchor is dropped from the stem to fix the stern, and the cargo is rolled on and off from the stern. If the water area occupied by the ship during loading and unloading has far exceeded the berthing water area determined when designing the wharf (in most cases, the turning basin has been occupied), it will also be a problem whether this special berthing method can accurately match the berthing conditions and the supervision method of the intended wharf.

Thirdly, standards of loading and unloading operation As mentioned above, the transportation of large-scale equipment is different from traditional loading and unloading process. The original loading and unloading operation standards of wharfs are no longer applicable. How to control the loading and unloading standards for such operations is also one of the focuses of maritime safety supervision.

In view of the above risks, this report will elaborate on the following aspects: how will the scale of the deck barge, its berth tonnage, the strength of the wharf surface, the layout of sites and the "T-shaped" berthing method influence the surrounding waters; how to determine the loading and unloading operation standards during berthing. This report provides a reference for companies engaged in Ro-Ro Transportation for Large-Scale Equipment, loading and unloading personnel, crew on the barge and maritime safety supervision.

Chapter 4: Research on the Ship Dimension and Tonnage of Berth Available of Deck Barges

4.1 Research on Ship Dimension of Deck Barges

In Dalian, the types of Ro-Ro transportation ships for large-scale equipment are mainly self-propelled deck barges. There is no design ship scale for deck barges but scale for Ro-Ro cargo ships in *Design Code of General Layout for Sea Ports* (2013). Ro-Ro cargo ship refers to the general term for Ro-Ro container ship, Ro-Ro general cargo ship and Ro-Ro cargo ship with spreaders, and it does not include deck barges. The design ship types of the relevant outbound terminals in Dalian also do not include such ships. Whether the navigation scale of the intended berth can accurately match the scale of this kind of ship has become a problem in maritime supervision. Therefore, studying the type scale of deck barges is important for the berth safety of the Ro-Ro Transportation for Large-Scale Equipment and maritime supervision.

4.1.1 Design Ship Type

The design ship type scale is the basis for determining the relevant dimensions of the wharfs at port, turning basin, waterway and anchorage, and the selection of the equipment for loading and unloading ships. It has an important role for ports to operate safely and economically. Different design ship types often control different design parameters respectively. For example, the design ship type with deep draft generally controls the water depth of the wharf and channel, while the design ship type with shallow draft and large wind area generally determines the wharf mooring and berthing facilities and the width of the channel. At present, the design ship type scale in China is generally selected from the data provided in Appendix A *Design Code of General Layout for Sea Ports* (2013).

The following principles should be considered when determining the design ship type.

(1) The determination of the wharf, port and channel facilities that are expected to be used by the ship should be considered in design ship type;

(2) The design ship type should be analyzed and determined comprehensively according to the following aspects: the nature and function of the berth, the economics of transportation, the current status and natural conditions of the port, the existing ship type and the future development trend of the ship type;

(3) The specific scale of the design ship type should be determined through analysis and demonstration, and it can also be determined according to the design ship type scale of the corresponding ton class in Appendix A;

(4) When there is a new ship type not covered by the code or the scale of ship type involved changes significantly, the statistical analysis method can be used for the analysis and demonstration of the scale of design ship type.

According to the practice of the Permanent International Association of Navigation Congresses (PIANC) , our country and other countries in the world, as well as the actual needs of planning, designing, operating and managing the port, deadweight tonnage (DWT) is used as statistical standard for ships that mainly carry cargo. Deck barges belong to this kind of ship, so DWT is adopted as the statistical standard in this research.

The statistical analysis method is usually adopted when analyzing and demonstrating the scale of design ship type. It determines the statistical parameters based on different types of ship, and classify the ships according to their tonnage, and then counting the total length (L), moulded breadth (B), moulded depth (H), and designed draft (T) according to the guarantee rate required by the terminal operation.

Regarding the standard value of the guaranteed rate of the design ship type, it is inappropriate to adopt a too high or too low guarantee rate. Since there are adjustable factors in the length and water depth of the berth, after a comprehensive analysis and demonstration, it is shown that it is economical and reasonable to select the design ship type scale with a guarantee rate of 85%.

4.1.2 Determination of Moulded Dimension

The statistical database related to deck barges is insufficient, so the project team has collected 158 articles of the deck barges with a deadweight from 700 to 30,000 tons through communication and research with related companies engaged in Ro-Ro Transportation for Large-Scale Equipment, wharfs, maritime bureaus and relevant leasing companies. According to two principles in 4.3 of *Design Code of General Layout for Sea Ports* (2013), when there is a new ship type not covered by the code or the scale of ship type involved changes significantly, the statistical analysis method can be used for the analysis and demonstration of the scale of design ship type; and the specific scale of the design ship type should be determined through analysis and demonstration, and it can also be determined according to the design ship type scale of the corresponding ton class in Appendix A. The research on the scale of deck barges can refer to the principles of tonnage classification of general cargo ships and Ro-Ro cargo ships, so the tonnage of ships can be divided into 1000 (700～1500), 2000 (1501～2500), 3000 (2501～4500), 5000 (4501～7500), 10000 (7501～12500), 15000 (12501～18000) and 30,000, corresponding to the number of ships 14, 22, 41, 44, 24, 11 and 2 respectively. Then count the total length (L), moulded breadth (B), moulded depth (H), and designed draft (T) of 7 deck barges of different tonnages according to the guarantee rate of 85%, and finally obtain the recommended type scale of deck barges. Compare it with the design ship type scale of general cargo ships, bulk carriers and Ro-Ro cargo ships, and analyze the characteristics of deck barges in order to provide reference for port, wharf, maritime supervision and regulation formulation. The characteristic values of the scales of deck barges are shown in Table 2.

Table 2 Dimension characteristic value of deck barge

Ship tonnage DWT(t)	Length overall (m)			Moulded breadth(m)			Moulded depth (m)			Load draught (m)			Statistical quantity of ships
	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.	Min.	Average	
1000 （700-1500）	82	50	63	18	12	14.8	3.8	2.9	3.2	3	2	2.3	14
2000 （1501-2500）	90	67	76	18	13.2	16.3	4.9	3.2	4	3.3	2.2	2.7	22
3000 （2501-4500）	106	63	88	28.5	15	18.7	6	3.5	4.7	4.2	2.3	3.5	41
5000 （4501-7500）	130	89	102	27.3	16.6	22.7	6.8	4.6	6	4.8	3	4.4	44
10000 （7501-12500）	143	100	118	35.8	25	28	8	6	7.1	5.7	4	5.1	24
15000 （12501-18000)	153	125	145	40	26	33.5	9	7.2	8.3	6.8	5	5.8	11
30000	153.8/150			38.6/40			10.8/10.5			7.35/7.5			2

Note：The ship dimensions of 30000 tonnage deck barge are the actual ship data only for reference.

According to the guarantee rate of 85%, the total length (L), moulded breadth (B), depth (H) and load draft (T) of the 6 deck barges with different tonnage from 1000 to 15,000 tons are shown in Table 3 to Table 8. There are only 2 deck barges with 30,000 tons, so the data is for reference only.

Table 3 Dimension comparison of 1000 tonnage

Dimension comparison of 1000 tonnage (m)					
Ship type	DWT (T)	LOA (m)	Moulded breadth (m)	Moulded depth (m)	Designed draft (m)
Deck barge	1000（700-1500）	77	16	3.4	2.3
General cargo ship	1000（1000-1500）	85	12.3	7	4.3
Ro-Ro cargo ship	1000（851-1500）	115	20	9	5

Table 4 Dimension comparison of 2000 tonnage

Dimension comparison of 2000 tonnage (m)					
Ship type	DWT (T)	LOA (m)	Moulded breadth (m)	Moulded depth (m)	Designed draft (m)
Deck barge	2000（1501-2500）	85	18	4.6	3.2
General cargo ship	2000（1501-2500）	86	13.5	7	4.9

Bulk ship	2000 （1501-2500）	78	14.3	6.2	5.0
Ro-Ro cargo ship	2000 （1501-2500）	120	21	10	5.5

Table 5 Dimension comparison of 3000 tonnage

Dimension comparison of 3000 tonnage (m)					
Ship type	DWT (T)	LOA (m)	Moulded breadth (m)	Moulded depth (m)	Designed draft (m)
Deck barge	3000 （2501-4500）	95	20	5.2	4
General cargo ship	3000 （2501-4500）	108	16	7.8	5.9
Bulk ship	3000 （2501-4500）	96	16.6	7.8	5.8
Ro-Ro cargo ship	3000 （2501-4500）	140	22	12.8	6.3

Table 6 Dimension comparison of 5000 tonnage

Dimension comparison of 5000 tonnage (m)					
Ship type	DWT (T)	LOA (m)	Moulded breadth (m)	Moulded depth (m)	Designed draft (m)
Deck barge	5000 （4501-7500）	108	25	6.6	4.6

General cargo ship	5000（4501-7500）	124	18.4	10.3	7.4
Bulk ship	5000（4501-7500）	115	18.8	9.0	7.0
Ro-Ro cargo ship	5000（4501-7500）	164	24	15	7

Table 7 Dimension comparison of 10000 tonnage

Dimension comparison of 10000 tonnage (m)					
Ship type	DWT (T)	LOA (m)	Moulded breadth (m)	Moulded depth (m)	Designed draft (m)
Deck barge	10000（7501-12500）	132	30	7.5	5.4
General cargo ship	10000（7501-11500）	146	22	13.1	8.7
Bulk ship	10000（7501-12500）	135	20.5	11.4	8.5
Ro-Ro cargo ship	10000（7501-12500）	193	26	17	8

Table 8 Dimension comparison of 15000 tonnage

Dimension comparison of 15000 tonnage (m)					
Ship type	DWT (T)	LOA (m)	Moulded breadth (m)	Moulded depth (m)	Designed draft (m)

Deck barge	15000 （12501-18000）	152	38	8.6	6
General cargo ship	15000 （11501-16500）	157	23.3	13.6	9.6
Bulk ship	15000 （12501-17500）	150	23	12.5	9.1
Ro-Ro cargo ship	15000 （12501-17500）	195	31	18	9.4

According to the above comparison table, it can be concluded that compared with the design ship type scale of general cargo ships, bulk carriers and Ro-Ro cargo ships，the recommended type scale of deck barges given in this report has the following features: the length is smaller than width; the square coefficient is large; the draft is shallow; the equipment on it is simple; most type is large; the shape is usually simple; the structure is relatively fixed; it is easy to load and unload; it is suitable for transporting large-scale equipment; its center of gravity is high, its stability is poor. With reference to the format in Appendix A *Design Code of General Layout for Sea Ports* (2013), this thesis gives recommended ship type scales for deck barges of 7 grades, as shown in Table 9. This table can provide reference for ports, wharfs, maritime supervision, construction and specifications of ships.

Table 9 Recommended dimension of deck barge

DWT (t)	Recommended dimension (m)			
	LOA (m)	Moulded breadth (m)	Moulded depth (m)	Designed draft (m)
1000 (700-1500)	77	16	3.4	2.3
2000 (1501-2500)	85	18	4.6	3.2
3000 (2501-4500)	95	20	5.2	4
5000 (4501-7500)	108	25	6.6	4.6
10000 (7501-12500)	132	30	7.5	5.4
15000 (12501-18000)	152	38	8.6	6
30000	153.8/150	38.6/40	10.8/10.5	7.35/7.5

Note：The ship dimensions of 30000 tonnage deck barge are the actual ship data only for reference.

4.2 Research on the Tonnage of Berth Available of Deck Barges

At present, most outbound terminals of Ro-Ro transportation for large-scale equipment in Dalian are bulk cargo terminals. Deck barges are not included in the design ship types of wharf. Whether the ship that tends to berth can accurately match the navigation standards of the bulk cargo terminals has brought inconvenience to maritime supervision. On the basis of the relevant navigation standards for wharfs in the code, and combing the code with the recommended ship scale for deck barges, this study analyzes the tonnage of berths that can be berthed by deck barges of different tonnages.

4.2.1 Design Water Depth in the Wharf Apron

The design water depth in the wharf apron shall be determined according to the requirements for ensuring that the designed ships wharf safely under load draft when the water level is low.

According to the Articles 5, 4 and 12 of *Design Code of General Layout for Sea Ports* (2013), the design water depth in the wharf apron:

$$D = T + Z1 + Z2 + Z3 + Z4$$

$$Z2=KH4\%-Z1$$

$$Z2=KH4\%$$

where, D—Design water depth in the wharf apron (m);

T—Load draught (m) of design ship type. For general cargo ships, it should be demonstrated according to the specific circumstances—the impact of the actual load rate on the draft should be considered; for the estuary port, it should be considered the impact of the difference in the proportion of saline and fresh water on the draft of design ship type;

Z1—Minimum under-keel clearance. The values in Table 10 are adopted;

Z2—Wave depth of wave richness (m). It should be determined according to the actual measurement or simulation results; it can also be determined based estimation. For the situation of shielding well, the formula Z2=KH4%-Z1 can be used for calculation, and when the calculation result is negative, take Z2=0; for the open situation, the formula Z2=KH4% can be used for estimation; for the situation of partial shielding, the result of the formula Z2=KH4% can be appropriately reduced based on experience and then be adopted, but its result should not be less than the value of formula Z2=KH4%-Z1;

K—Coefficient. Smooth waves take 0.3 and transverse waves take 0.5~0.7;

$H_{4\%}$—The wave height whose cumulative frequency of the wave train allowed in the wharf apron is 4%. It is determined based on the waves and the conditions of the wharf in local areas;

Z_3—The increased stern draft (m) of the ship due to uneven loading. Dry bulk carriers and liquid bulk carriers take 0.15m, Ro-Ro ships take the values in Table 11, and other ship types do not take any value;

Z_4—The superdepth of the sedimentation (m). It is determined according to the sedimentation intensity and the siltation volume during the interval of dredging maintenance.

Design bottom elevation of the wharf apron = design low water level-D

Table 10 Minimum under-keel clearance Z_1

Seabed sediment	Z_1 (m)	Seabed sediment	Z_1 (m)
muddy soil	0.2	Massive soil with sand or clay	0.4
Sand with silt, sand with clay or loose sand	0.3	Rock soil	0.6

Table 11 The increased stern draft (m) of the ship due to uneven loading Z_3

Ship tonnage		Z_3(M)
DWT（t）	GT(t)	
≤1000	≤3000	0.3
＞1000	＞3000	0.2

According to the comparison between the recommended type scale of deck barges and the design vessel scale of general cargo ships, bulk carriers and Ro-Ro cargo ships of the same tonnage, the draft of the deck barge is shallower than that of the above three types of ships, with a difference of about 1.7m～3m. Therefore, when the deck barges of the same tonnage navigate into the berth of the bulk cargo carriers and Ro-Ro cargo carriers of the same tonnage, the design water depth of the wharf apron and the design bottom elevation of the wharf apron meet the requirements of navigation.

4.2.2 Length of "T-shaped" Ro-Ro Berth

According to Article 5.5.7 of *Design Code of General Layout for Sea Ports* (2013), for straight type ramp-way of 3000GT and below, when wind, wave and current are in good conditions, “T-shaped” berthing method can be adopted in the arrangement. The calculation of the berth length should conform with the following regulations.

(1) For the arrangement of a single berth, its length should be calculated as follows:

$$L_b = 3B$$

where, L_b — Length of the wharf berth (m);

B—The moulded breadth of the Ro-Ro ship (m).

(2) When there are more than one berth arranged, the length can be calculated according to the following formula:

$$\text{End berth } L_b = 2B + 0.5d_B$$

$$\text{Intermediate berth } L_b = B + d_B$$

where, L_b — Length of the wharf berth (m);

B — Moulded breadth of the Ro-Ro ship (m);

d_B ——The super width among ships (m). It should not be 1 times less than the moulded breadth of design ship type.

In Dalian, most deck barges of Ro-Ro transportation for large-scale equipment usually anchor in bulk cargo berths, and the "T-shaped" berthing method is usually adopted. Therefore, the scale of the bulk cargo terminal of the same tonnage conforms with the berth length required by the "T-shaped" berthing method.

4.2.3 Water Width of the Berthing Area in the Wharf Apron

According to Article 5.5.11 of *Design Code of General Layout for Sea Ports* (2013), the water width of the berthing area in the wharf apron whose arrangement is "T-shaped" berthing method can be determined as follows:

$$B_t = L_t + L + B$$

where, B_t——Water width of the berthing area in the wharf apron (m);

L——Length of the design ship (m);

B——Moulded breadth of Ro-Ro ships (m);

Lt——The length from the outer end of the stem or stern to the outer end of the wharfing facility.

Regarding the actual survey of the outbound terminals of Ro-Ro shipment for large-scale equipment in Dalian, the berthing method adopted in bulk cargo terminal is berthing along the wharf. The water width of the berthing area in the wharf apron required by the "T-shaped" berthing method is much larger than that required when bulk cargo carriers berth alongside the wharf. The water width of the berthing area in the wharf apron is one of the important considerations for the selection of berth of Ro-Ro operation. It is recommended to calculate the water width of the berthing area in the wharf apron, and then judge whether there is enough water area at the front edge of the selected berth to meet the requirements of navigation standards. It is necessary to further verify whether the design water depth and design bottom elevation of some waters that exceed the frontal water width of the original wharf meet the requirements.

4.2.4 Top Elevation in the Wharf Apron

According to Article 5.4.8 of *Design Code of General Layout for Sea Ports* (2013), the determination of the top elevation in the wharf apron should conform with the top water control standards and top superstructure stress control standards of the wharf. The top elevation in the solid-structure wharf apron can be determined according to the water control standard, and if necessary, it can be checked according to the force control standard.

If a bulk cargo berth wharf is chosen as a wharf of Ro-Ro transportation for large-scale equipment, it is important to consider the overlapping between the stern springboard of the bulky transport ship and the wharf surface. When the awkward and length cargo is rolled on board, the deck of the ship should be at the level of the wharf surface, that is: the top elevation of the front edge of the wharf = the water level of operation + the height of freeboard. During the Ro-Ro shipment, if the draft of the ship increases greatly, the ballast water of the ship should be discharged to adjust the draft of the ship, so as to keep the deck and wharf surface in a horizontal level. Therefore, there are three important factors to be considered whether the barge that tends to berth can accurately match the navigation scale of the intended berth—the top elevation of the front edge of the wharf, the data of tide level at local areas and the loading rate of the ship.

In summary, the following conclusions can be drawn:

(1) When a deck barge anchors at the berth for bulk cargo and Ro-Ro cargo of the

same tonnage, the design water depth in the wharf apron and the design bottom or top elevation of the front edge of the wharf meet the requirements of navigation;

(2) The length of bulk cargo berths and Ro-Ro cargo berths of the same tonnage conforms with the length of berths required by the "T-shaped" berthing method;

(3) The water width of the berthing area in the wharf apron required by the "T-shaped" berthing method is much larger than that required when bulk cargo carriers berth alongside the wharf. Select the berth based on the calculated water width of the berthing area at the front, observe if there is enough water areas. At the same time, calculate the design water depth and design bottom or top elevation of some waters that exceed the frontal water width of the original wharf;

(4) The top elevation of the front edge of the wharf, the data of tide level at local areas and the loading rate of the ship are important considerations for the selection of the intended berth of Ro-Ro transportation for large-scale equipment.

Chapter 5: Impact Analysis of "T-Shaped" Berthing on Surrounding Waters

When carrying large-scale equipment on deck barges in Jurisdiction of Dalian Maritime Safety Administration (MSA), "T-shaped" berthing method is often adopted, with weather moor at the bow, the stern fixed by stern lines, and the cargo rolled up and down by the stern through hydraulic conveyance vehicle, Self-propelled transporter (SPT) and Self-propelled modular transporter (SPMT) . Most of the large-scale equipment berthing facilities in jurisdiction of Dalian MSA are bulk and general cargo terminals, and "T-shaped" berthing method has not been considered in the design of most terminals and their harbor waters. The waters occupied during the period of "T-shaped" berthing are far more than the berthing waters in the original design of the terminals. In most cases, it has occupied the turning water areas, which has a great impact on the navigation of the surrounding waters. Therefore, the research on the rationality of "T-shaped" berthing and the corresponding regulatory requirements in the existing bulk and general cargo terminals in jurisdiction of Dalian MSA is the focus of the Ro-Ro transportation of large-scale equipment in maritime supervision at present.

5.1 Normative Analysis of Berth Scale

5.1.1 Berth Length

According to Article 5.5.7 of *Design Code of General Layout for Sea Ports* (2013), for straight type ramp-way Roll-on Roll-off terminal of 3000GT and below, when wind, wave and current are in good conditions, “T-shaped” berthing method can be adopted in the arrangement. The calculation of the berth length should conform with the following regulations.

(1) For the arrangement of a single berth, its length should be calculated as follows:

$$L_b = 3B$$

where, L_b — Length of the dock berth (m);

B— Molded breadth of the Ro-Ro ship (m).

(2) When there are more than one berth arranged, the length can be calculated according to the following formula:

End berth $L_b = 2B + 0.5d_B$

Intermediate berth $L_b = B + d_B$

where, L_b — Length of the wharf berth (m);

B — Molded breadth of the Ro-Ro ship (m);

d_B ——The superwidth among ships (m). It should not be 1 times less than the molded breadth of design ship type.

According to the analysis in 4.2.2 in the thesis, the scale of the same tonnage bulk and general cargo terminals in jurisdiction of Dalian MSA can meet the berth length of the "T-shaped" berthing mode of the same tonnage deck barge.

5.1.2 Wharf Apron Water Area

5.1.2.1 Water Width of the Berthing Area in the Wharf Apron

According to Article 5.5.11 of *Design Code of General Layout for Sea Ports* (2013), the water width of the berthing area in the wharf apron whose arrangement is "T-shaped" berthing method can be determined as follows:

$$B_t = L_t + L + B$$

where, B_t——Water width of the berthing area in the wharf apron (m);

L——Length of the design ship (m);

B——Molded breadth of the Ro-Ro ship (m);

Lt——The length from the outer end of the stem or stern to the outer end of the docking facility.

5.1.2.2 Width of Water Area in the Wharf Apron

According to Article 5.3.8 of *Design Code of General Layout for Sea Ports* (2013), the width of the water area in front of the wharf shall be determined by considering whether the turning function of the ship and the angle between the wharf axis and the channel. For the water area in front of multi-berth wharf, the width should not be less than 1.5 times of the design ship length Plus 1.0 times of the design ship width when considering the requirements of ship turning. The width of the water area in the wharf apron shall not be less than 0.8 times of the designed length without considering the requirement of ship turning. The width of berthing waters at the wharf apron required for "T-shaped" berthing shall be selected as the berth considering the requirements of ship turning.

5.1.2.3 Design Water Depth And Bottom Elevation Of Wharf Apron

Referring to Section 4.2.1 in the thesis, the design water depth of the wharf apron can be calculated, and the design bottom elevation of the wharf apron can be calculated according to the following formula:

the design bottom elevation of the wharf apron

＝design lowest stage－the design water depth of wharf apron

Due to the fact that the full load draft of deck barge is much smaller than that of the same tonnage bulk and general cargo ship , and the actual load draft of large-scale equipment roll on and roll off transportation is often smaller than full load draft, when the same tonnage deck barges berth the same tonnage bulk and general cargo or cargo roll on / roll off berths, the design water depth and the design bottom elevation of wharf apron meet the navigation requirements.

When a deck barge berths in "T-shape", the width of berthing waters at the wharf apron is much larger than that at "alongside". In most cases, part of turning water area is occupied. When carrying out normative analysis on the water depth at the berth apron, it is necessary to consider not only the designed bottom elevation of the existing wharf apron, but also the designed bottom elevation of the harbor basin and the turning water area.

5.2 Normative Analysis of Harbor Basin and Turning Water Area

5.2.1 Diameter of Turning Water Area

According to Article 5.5.11 of *Design Code of General Layout for Sea Ports* (2013), the turning water area of ships shall be set in waters that are convenient for ships to enter and leave the port and to berthing maneuver. When berths are arranged continuously in a straight line, the turning water area should be set up in a continuous way, and its scale should take into account the local wind, wave, current and other conditions, the ship's own performance, port tug configuration and other factors. The scale of the turning water area of the ship can be determined according to Table 12.

Table 12 Scale of ship turning waters

Scope of application	Diameter of turning water area (m)
Good cover conditions, smaller current, and tugboat assistance in port	(1. 5～2.0) L
Wharf with poor covering conditions	2.5L
Water area that is allowed to borrow wharf or turning pier to assist turning	1. 5L

The length of turning head water area along the current direction should be lengthened properly for the port greatly affected by the current, and the lengthen should be determined through the ship maneuvering test; in the absence of test basis, the length along the current direction can be taken as (2.5-3.0) L.

NOTE：

①The turning water area can occupy the navigation water area, and it can be set separately after demonstration when the ships enter and leave frequently.

②In case of no thruster or tugboat assistance, the turning circle diameter of the ship can be taken as (2.0-3.0)L, which can be increased appropriately in case of poor covering conditions；

③ L is the design length (m).

The required turning water area diameter is calculated according to the covering conditions, current conditions, whether there are tugboats or not in ports and the ship type dimensions of deck barge, and compared with the turning water area dimensions in the harbor of the berth. Based on the comparison between the recommended ship dimensions of deck barge and the design ship dimensions of general cargo ship, bulk cargo ship and Ro-Ro ship of the same tonnage, it can be concluded that the ship length of deck barge is smaller than that of bulk and general cargo ship and Ro-Ro ship of the same tonnage. Therefore, when the deck barges berth to the same tonnage bulk and general cargo ship and Ro-Ro ship , the turning water area in the original wharf shall meet the navigation requirements of deck barge.

5.2.2 Design Bottom Elevation of Harbor Basin and Turning Water Area

According to Article 5.3.9 of *Design Code of General Layout for Sea Ports* (2013), the design water depth of the basin outside the berth area of the wharf apron is consistent with the design water depth of the channel.

According to Article 6.4.6 of *Design Code of General Layout for Sea Ports* (2013), the navigable depth and design depth of the channel are calculated according to the following formula:

$$D_0 = T + Z_0 + Z_1 + Z_2 + Z_3$$

$$D = D_0 + Z_4$$

Design bottom elevation of channel = Tide-bound Water Level-D

where, D_0— Navigable depth（m）;

D— Design depth of the channel （m）;

T— Designed draft （m）;

Z_0—Squat caused by vessel sailing（m）;

Z_1—Minimum under-keel clearance by vessel sailing(m) ;

Z_2—Wave depth of wave richness (m);

Z_3—Loading trim depth of wave richness (m);

Z_4—Design water depth for silt preparation(m).

The roll on and roll off time of large-scale equipment in jurisdiction of Dalian MSA is generally controlled within 2-3 hours. According to the specific situation of each project, check the tide time and the tide level at 90% cumulative frequency of high tide level, so as to calculate the design bottom elevation of the channel. Therefore, the design bottom elevation of the harbor basin and turning water area other than the berthing area of the wharf apron can be obtained.

5.2.3 Impact Analysis of "T-Shaped" Berthing on Surrounding Waters

Based on the analysis of 5.1.1 and 5.1.2 in this thesis, the tonnage of deck barge that can be matched by berth can be calculated according to berth length, Water width of the berthing area in the wharf apron, width of water area in the wharf apron, design water depth and bottom elevation of wharf apron, diameter of turning water area and designed bottom elevation of harbor basin and turning water area, and recommended type scale of deck barge, so that the tonnage of deck barges and berths in jurisdiction of Dalian MSA can be matched more accurate matching and more reasonable resource allocation.

According to normative analysis of berth scale and normative analysis of the basin and turning water area, the navigable scale conditions of the wharf and the water area in the harbor can meet the requirements of "T-shaped" berthing scale of barges to be berthed on deck, so "T-shaped" berthing mode is feasible. If the "T-shaped" berthing mode occupies the common turning water area, the use of the common turning water area will be affected during the "T-shaped" berthing of deck barges.

Generally, four cables and weather moor at the bow are used to ensure the mooring safety after the deck barge berths in a "T-shaped" mode.

(1) One after line on each side of the stern;

(2) One fore line is provided on each side of the bow to form a splay cable mode;

(3) open mooring at the bow.

Weather moor at the bow can prevent the barge from deflection under the action of wind and current, especially under the action of cross wind or cross current, and avoid accidents such as cable break and collision with the wharf. Generally speaking, when the included angle of open mooring is 60°, the effect of sway suppression is better, but the water area occupied is larger. According to the pilot's experience and practice, when the included angle of anchor chain is 90°, it can not only meet the requirements of reducing sway, but also reduce the scope of occupied water area. According to the tonnage of the deck barge, the scope of the water area in the wharf apron, the navigation requirements of the ships in the surrounding berths and the hydrological and meteorological conditions during the ships berthing , under the condition of ensuring the safety of the berthing of the ships with "T-shaped", the chain length of the open mooring should be shortened as much as possible, and in general, the chain length should not exceed 3-4 knots.

According to the use of the harbor basin waters near the wharf, if the harbor waters near the berth is a common water area, the water area occupied by the ship berthing and departing operations, especially the "T-shaped" berthing operations, is relatively large. It is suggested that the owner should establish a contact and coordination mechanism with the adjacent terminal owners and VTS, master the port entry plan of other berths, and try to choose the berthing operations when there are no other ships entering or leaving the harbor. If the barge is berthing in in "T-shape", the vessels in other berths around shall be suspended from navigation.

During the berthing of deck barges, due to the large occupied water area, there is a great impact on the passing ships. The main type of accidents that may occur is fouling hawse between the passing ships and the bow anchor. During berthing of barge, the anchor marks shall be set for identification of other ships, and lookout shall be strengthened to avoid other ships passing through the water above the anchor chain.

At the same time, in order to reduce the impact of the berthing operation on the entering and leaving of ships in other berths in the port, the operation time of the berthing operation should be shortened as much as possible. After the cargoes are loaded and reinforced as necessary, it is recommended that the ship return to the normal port or starboard berthing state, and then fully reinforce cargo lashing according to the relevant requirements.

5.2.4 Maritime Supervision Requirements for "T-Shaped" Berthing

Most of the large equipment Ro-Ro ships in jurisdiction of Dalian MSA are berthed in "T-shape", and most of the planned berthing wharves are bulk and general cargo wharves. This berthing mode is not considered in the design of the wharves. The rationality of this berthing mode and corresponding regulatory requirements are important concerns of the competent maritime authorities at present. According to the above analysis, this research report gives the following suggestions on maritime supervision.

(1) The operation unit shall submit to the competent maritime authority a plan for roll on / roll off operation of large equipment prepared according to the design parameters of the berths, the ship type and scale of the operation ship and the requirements of relevant specifications, in which the rationality of berthing the existing bulk and general cargo berths with "T-shaped" , as well as the navigation impact analysis of surrounding waters shall be discussed in detail.

(2) The owner of the operation unit shall establish contact and coordination mechanism with the owner of adjacent berths and VTS, make the optimal berthing plan and berthing operation time period, and report to the maritime authority within the jurisdiction.

(3) During berthing operation, anchor marks shall be set up according to the length of anchor chain for identification of other ships, and lookout shall be strengthened to avoid other ships passing through the water area above the anchor chain.

(4) Install a tide gauge near the berth, measure the tide, and adjust the loading and unloading plan in real time according to the actual tide level.

(5) If it has a great impact on the navigation of surrounding waters, it is suggested to shorten the berthing time of "T-shaped" as far as possible. After the cargoes are loaded and necessary reinforcement is carried out, the barge is changed from "T-shaped" berthing to "alongside", and the cargoes are fully consolidated and bound.

Chapter 6: Determination of Loading and Unloading Standards During "T-Shaped" Berthing

Rolling-on/rolling-off operation mode of large equipment is different from traditional loading and unloading, and adopts "T-shaped" berthing mode. Because the shipping wharves are mostly bulk and general cargo wharves, the loading and unloading operation standard of the original wharves corresponding to this special operation mode and berthing mode may not be applicable. The supervision on the loading and unloading operation of barges berthed at the bulk and general cargo wharf with "T-shaped" has become the focus of supervision by the maritime authorities in Dalian area.

The status of ships in port can be divided into two types, one is the operation state of loading and unloading ships, and the other is the non operation state. The most important thing of berthing system is to ensure berthing safety, mooring safety and operation safety. Mooring safety and operation safety conditions are collectively referred to as tranquility condition. The loading and unloading operation standard of the ships shall be determined according to the berthing ship type, natural conditions and tugboat configuration of the wharf.

According to Article 5.4.26 of *Design Code of General Layout for Sea Ports* (2013), the following main factors should be considered when determining the tranquility condition and operation conditions of the wharf:

(1) The natural conditions of the port, including the size and distribution characteristics of wind, wave and current;

(2) Requirements for wharf Handling technology, cargo type and ship safe loading and unloading operation;

(3) The relationship between the coverage degree and the axial direction of the wharf and the wind, wave and current;

(4) Wharf structure type, anti-collision and mooring facilities.

6.1 Loading and Unloading Standards Based on Wind, Wave and Current

At present, the norms of many countries give the limited values of allowable wind, wave, current and other influencing factors for ships with different deadweight tons and different cargo types, which are used as the standard for judging the allowable operation of ships.

According to Article 5.4.27 of *Design Code of General Layout for Sea Ports* (2013), it is given that the allowable wave height of ship loading and unloading operation should not exceed the value of table 5.4.27 in the specification for ships with different DWT and wharfs with average period less than 9s. This standard has good operability in most cases. Although the wave height standard is convenient for engineering application, it can only indirectly and roughly reflect the tranquility condition of the ships in the wharf apron, and has little influence on the wave period, wave propagation direction, current and frequency response characteristics of the moored ships.

According to the investigation of the relevant companies engaged in the Ro-Ro transportation of large-scale equipment, the wharf and the maritime authorities operating in the competent jurisdiction, the loading capacity of the deck barge engaged in the Ro-Ro transportation of large-scale equipment in Dalian jurisdiction is mostly 10000 tons and 5000 tons; when engaged in the transportation of large-scale equipment, especially when the "T-shaped" berthing roll on and roll off, the loading and unloading operation standard of the deck barge is higher than those of bulk carriers, general cargo ships and cargo Ro-Ro ships of the same tonnage, and also higher than the original loading and unloading standards of bulk cargo berths . According to the schemes and practical operation experience of several companies engaged in Ro-Ro transportation of large-scale equipment, relevant national industry standards and relevant research, this paper gives the recommended loading and unloading standards of deck barges berthed by "T-shaped" roll on roll off of large-scale equipment in Dalian jurisdiction as shown in Table 13.

Table 13 Comparison table of loading and unloading standards

Ship types	DWT	Allowable operation wave height and period			Force level	Visibility
		Following waves	Beam waves	period		
Deck barges	10000	≤0.6m	≤0.4m	≤6s	≤6	≥0.2km
Bulk carriers		≤1.0m	≤0.8m	≤6s	≤6	≥0.5km
General cargo		≤1.0m	≤0.8m	≤6s	≤6	≥0.5km

ships						
Cargo Ro-Ro ships		≤0.8	≤0.6m	≤6s	≤6	≥0.5km
Deck barges	5000	≤0.6m	≤0.4m	≤6s	≤5	≥0.2km
Bulk carriers		—	—	—	≤6	≥0.5km
General cargo ships		≤0.8	≤0.6m	≤6s	≤6	≥0.5km
Cargo Ro-Ro ships		≤0.8	≤0.6m	≤6s	≤6	≥0.5km

6.2 Loading and Unloading Standards Based on Allowable Ship Movement

At present, the limitation of the main motion components (six motions) of ships is adopted as the control condition for judging the tranquility condition of ships in the current international codes. According to Article 5.4.29 of *Design Code of General Layout for Sea Ports* (2013), when conditions permit, the ship loading and unloading operation standard should be expressed by the limit value of the main moving components of the ship, and each limit value should be determined according to the ship type and loading and unloading process. Using the ship motion as the control standard to determine the operation conditions, the expression is intuitive and more targeted. The allowable ship motion components of different types of ships and loading and unloading processes can be determined and go through tests if necessary. The allowable motion quantities of "bow" and "stern" springboards in Ro-Ro ships are of great reference value.

According to the investigation results, at present, the companies and wharves engaged in roll-roll transportation of large-scale equipment seldom use the wave element standard corresponding to the allowable movement of ships for statistics. Through literature analysis, the current international standards for ship loading and unloading operations are mainly expressed by the allowable movement of ships. According to Article 5.4.29 of *Design Code of General Layout for Sea Ports* (2013), the allowable ship motion for loading and unloading operations of Ro-Ro ship "bow" and "bow" springboard, general cargo ship and bulk carrier are screened and compared, and the recommended allowable ship motion for loading and unloading operations of deck barge berthed by Ro-Ro "T" for large equipment is given, as shown in Table 14.

Table 14 Table of allowable ship movement for loading and unloading operations

Ship types	Handing facilities	Allowable ship movement					
		Surge (m)	Sway (m)	Heave (m)	Yaw (°)	Pitch (°)	Roll (°)
Deck barges	"Stern" springboard	0.8	0.6	0.3	1	1	2
Cargo Ro-Ro ships	"Bow""Stern" springboard	0.8	0.6	0.8	1	1	4
General cargo ships	—	2	1.5	1	3	2	5

Bulk carriers	grab ship-unloader	2	1	1	2	2	6
	continuous type ship unloader	1	0.5	1	2	2	2
	ship loader	5	2.5	—	3	—	—

In the process of roll on and roll off of large equipment, it is very important to adjust the height of ship deck and dock within the reasonable range. Using the tide and the ballast water regulation of barge, when the deck surface is 20~30cm higher than the wharf surface, the operation is started. When the deck surface of the barge is about 10cm lower than the wharf surface, stop rolling, wait for the tide to rise and adjust the ballast water. When the deck a surface is about 20 ~30cm higher than the wharf surface again, continue the operation and repeat the above operation process until the whole equipment is on board. At the same time, in order to meet the safety of cargo transportation, the cargo is placed along the center of the ship, so that the center of gravity of the cargo coincides with the load center of the barge, and the barge can maintain a normal posture, which indicates that rolling has an impact on the roll on of the barge. According to the above analysis, referring to the allowable movement of "bow" and "stern" springboard in Ro-Ro ship, the recommended movement of heave ship is 0.3m and that of rolling ship is 2 °.

Chapter 7: Conclusions and Suggestions

7.1 Conclusions

Four conclusions are generalized based on the discussion in the thesis.

(1) Recommended dimension of deck barge

With reference to the format in Appendix A *Design Code of General Layout for Sea Ports* (2013), this thesis gives recommended ship type dimension for deck barges of different tonnage, as shown in Table 15.

Table 15 Recommended dimension for deck barge of different tonnage

DWT (t)	Recommended dimension (m)			
	LOA (m)	Moulded breadth (m)	Moulded depth (m)	Designed draft (m)
1000 (700-1500)	77	16	3.4	2.3
2000 (1501-2500)	85	18	4.6	3.2
3000 (2501-4500)	95	20	5.2	4
5000 (4501-7500)	108	25	6.6	4.6
10000 (7501-12500)	132	30	7.5	5.4
15000 (12501-18000)	152	38	8.6	6
30000	153.8/150	38.6/40	10.8/10.5	7.35/7.5

Note：The ship dimensions of 30000 tonnage deck barge are the actual ship data only for reference.

(2) Research on the Tonnage of Berth Available of Deck Barges

① When a deck barge berths at the berth for bulk cargo and Ro-Ro cargo of the same tonnage, the design water depth in the wharf apron and the design bottom or top elevation of the front edge of the wharf meet the requirements of navigation.

② The length of bulk cargo berths and Ro-Ro cargo berths of the same tonnage conforms with the length of berths required by the "T-shaped" berthing method;

③ The water width of the berthing area in the wharf apron required by the "T-shaped" berthing method is much larger than that required when bulk cargo carriers berth alongside the wharf. The width of the berthing area in the wharf apron shall be calculated according to the specifications

④ The top elevation in the wharf apron, the data of tide level at local areas and the loading rate of the ship are important considerations for the selection of the intended berth of Ro-Ro transportation for large-scale equipment.

(3) Impact Analysis of "T-Shaped" Berthing on Surrounding Waters

Through normative analysis of intended berths and normative analysis of harbor basin and turning water area, if the navigation scale conditions of wharf and harbor waters can meet the requirements of "T-shaped" berthing scale of deck barges to be berthed, so "T-shaped" berthing mode is feasible. If the "T-shaped" berthing occupies the common turning water area, the use of the common turning water area will be affected during the "T-shaped" berthing of deck barges.

(4) Loading and Unloading Standards During "T-Shaped" Berthing

In this thesis, the recommended loading and unloading standards of deck barges berthed by "T-shaped" in Dalian area are given in two ways, as shown in Table 16and Table 17 respectively.

Table 16 The recommended loading and unloading standards of deck barges

Ship types	DWT	Allowable operation wave height and period			Force level	Visibility
		Following waves	Beam waves	period		
Deck barges	10000	≤0.6m	≤0.4m	≤6s	≤6	≥0.2km
Deck barges	5000	≤0.6m	≤0.4m	≤6s	≤5	≥0.2km

Table 17 The recommended allowable ship motion for loading and unloading operations of deck barge

Ship types	Handing facilities	Allowable ship movement					
		Surge (m)	Sway (m)	Heave (m)	Yaw (°)	Pitch (°)	Roll (°)
Deck barges	"Stern" springboard	0.8	0.6	0.3	1	1	2

6.2 Suggestions

(1) Based on the statistical analysis of the data of 158 deck barges with deadweight of 700 ~ 30000 tons, the recommended ship dimension of deck barges is obtained,

and there are few data samples. In order to further improve the accuracy of the recommended ship dimension of deck barges, more data of deck barges with different tonnage should be collected.

(2) When a deck barge berths in "T-shape", the width of berthing waters at the wharf apron is much larger than that at "alongside". In most cases, part of turning water area is occupied. When conducting normative analysis on the water depth at the berth apron, it is necessary to consider not only the designed bottom elevation of the existing wharf apron, but also the designed bottom elevation of the harbor basin and the roundabout waters.

(3) The operation unit shall submit to the competent maritime authority a plan for roll on / roll off operation of large equipment prepared according to the design parameters of the berths, the ship type and scale of the operation dimension and the requirements of relevant specifications, in which the rationality of berthing the existing bulk and general cargo berths with "T-shaped" , as well as the navigation impact analysis of surrounding waters shall be discussed in detail.

(4) The owner of the operation unit shall establish contact and coordination mechanism with the owner of adjacent berths and VTS, make the optimal berthing plan and berthing operation time period, and report to the maritime authority within the jurisdiction.

(5) During berthing operation, anchor marks shall be set up according to the length of anchor chain for identification of other ships, and lookout shall be strengthened to avoid other ships passing through the water area above the anchor chain.

(6) Install a tide gauge near the berth, measure the tide, and adjust the loading and unloading plan in real time according to the actual tide level.

(7)If it has a great impact on the navigation of surrounding waters, it is suggested to shorten the berthing time of "T-shaped" as far as possible. After the cargoes are loaded and necessary reinforcement is carried out, the barge is changed from "T-shaped" berthing to "alongside", and the cargoes are fully consolidated and bound.

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