Master's Thesis

# 선박 블록의 철강 콘크리트 해상 결합 방법

# A Steel-Concrete Composite Connection Method for Ship Building Blocks at Sea and Its Feasibility


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School of Mechanical, Aerospace and Systems Engineering,

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**KAIST**


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A thesis submitted to the faculty of KAIST in partial fulfillment of the requirements for the degree of Master of Science in Engineering in the School of Mechanical, Aerospace and Systems Engineering, Division of Ocean Systems Engineering. The study was conducted in accordance with Code of Research Ethics[1]

June 11, 2014
Approved by
Associate Professor Lee, Phill-Seung

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[1]Declaration of Ethical Conduct in Research**:** I, as a graduate student of KAIST, hereby declare that I have not committed any acts that may damage the credibility of my research. These include, but are not limited to: falsification, thesis written by someone else, distortion of research findings or plagiarism. I affirm that my thesis contains honest conclusions based on my own careful research under the guidance of my thesis advisor.

# A Steel-Concrete Composite Connection Method for Ship Building Blocks at Sea and Its Feasibility

Zhang, Bi Lin

The present dissertation has been approved by the dissertation committee as a master's thesis at KAIST

June 11, 2014

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**ABSTRACT**

In this study, we introduce a steel-concrete composite connection method for ship building blocks at sea. The core concept of this method is to connect ship blocks by adopting bolting, welding and gluing method at sea outside of docks. By applying this method, the shipyard construction capacity could be increased considerably, and construction cost is supposed to be saved as well. To show the safety of this method, two ship models are employed to investigate the safety of ship hull attached with connective part. We perform the preliminary calculation of the connective part to generally determine the number of steel bars and connective part size, then the structures are analyzed in detail by applying finite element method through ADINA. To show the economic performance of this method, cost comparison is done between steel-concrete composite connection method and welding method, and the possible weight change caused by the attachment of connective part is taken into consideration. Results of these analyses show the possibility of applying this steel-concrete composite connection method into practical ship construction.




Keywords: Ship blocks connection method, Structural design, Stress assessment, Finite element method (FEM), Economic performance

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# Chapter 1. Introduction

## 1.1 Research Background

These days, for the need of bigger vessels, ships are getting a tendency of greater size and larger tonnage. In order to construct these large scale ships, most of the modern shipyards adopt the method of block fabrication method in practical construction [1]. In the manufacturing process of block fabrication method, segments of the hull are built in the shipyard, and these segments are fabricated as ship blocks. After the ship blocks are transported to the dry dock, they will be assembled there by applying the welding method to construct a whole ship. However, as we know that the maintenance and construction of dock is very expensive, if the dock usage period could be reduced or the connection procedure could be done outside the dock, the cost is supposed to be cut and construction efficiency could be increased. Not only that, when constructing ship in dock, the size of ship is strictly limited by dock size, so it is almost impossible to construct the ship which is larger than dock.

To solve the problem that dock has limitations for ship size and the high cost of construction and maintenance, a variety of methods have been applied on ship connection. For example, some shipyard has already assembled large ship sections by applying underwater welding method [1]. STX Offshore & Shipbuilding connects large ship blocks in floating dock on the sea [2], which is shown in Fig 1.1. Hanjin Heavy Industry develops a DAM module to create the dry space in the module for people to weld ship sections in the water [3], which is shown in Fig 1.2. Hyundai Heavy Industry assembles ship blocks totally on ground outside dry dock [4].

Fig. 1.1 STX connects ship sections in floating dock

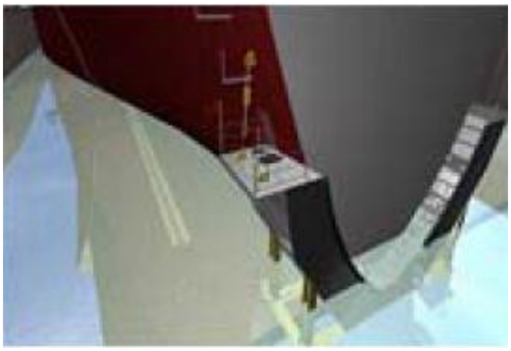
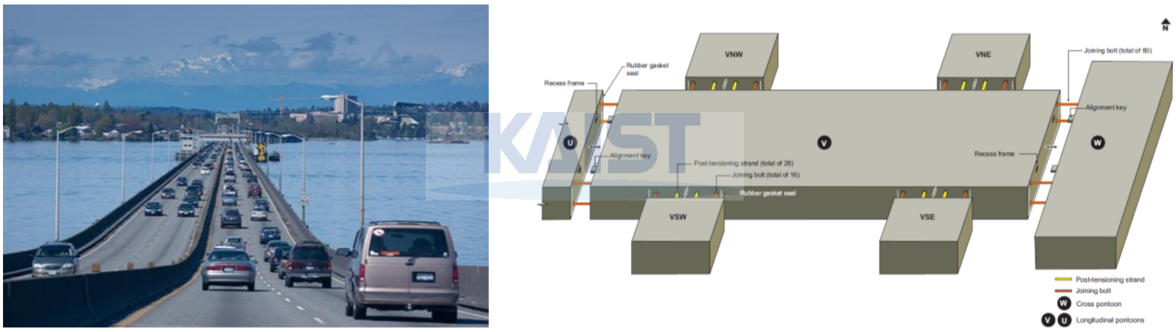


Fig. 1.2 DAM ship section connection method

Also, bolting method has been applied for connecting large structures in the water, and an example of this application is the SR520 Bridge [5], which is the longest floating bridge in the world. The floating pontoons of this bridge are connected with each other by using bolt beams on the lake Washington, which is shown in Fig. 1.3.




(a) Floating bridge (b) Floating pontoons of the bridge

Fig. 1.3 SR520 floating bridge

## 1.2 Steel-concrete composite connection method for ship building blocks at sea

Considering all these issues, a steel-concrete composite connection method for ship building blocks is made to connect ship blocks outside the dock [6]. This is a method that after large ship blocks have been fabricated, connective parts will be attached to ship blocks so that ship blocks could be connected at sea. This connection procedure adopt the method of welding, bolting and gluing together. By applying this method, ship connection procedure is independent of dock facilities, and shipyard’s production capacity could be increased considerably.

The revolutionary point of this method is the application of connective part. Connective part is consist of concrete, steel plates and steel bars. These steel plates and steel bars are used to ensure the strength of connective part. Connective part is made up of concave module and convex module, as shown in Fig. 1.4. On the left side of Fig. 1.4 is convex module, and on the right side of Fig. 1.4 is concave module. The consecutive steel plate in the middle of the connective part is for temporary use, after ship blocks connection is done, these steel plates will be removed. By applying concave module and convex module, the sea water will not come into the inner part of the ship.

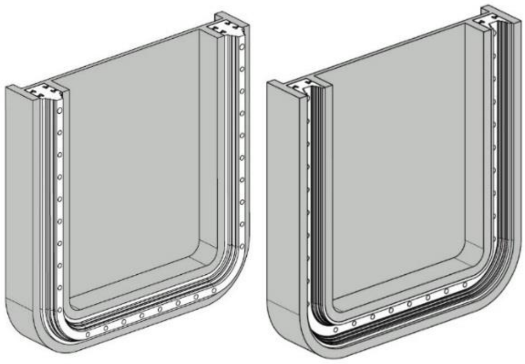


Fig. 1.4 Concave and convex module of connective part

Also we suggest the applicability of the steel-concrete composite connection method for constructing various offshore structures, especially for semi-submersible structures. By applying this connection method, problem of the variation which is larger than tolerance caused by the deformation of dry land or dock could be solved, also the procedure of launching the offshore structure becomes much easier.

## 1.3 Steel-concrete composite connection method procedure

The steel-concrete composite connection method for ship building blocks is a kind of connection method that ship blocks are connected by applying connective part and adopting bolting, welding and gluing method together. This connection procedure location is not done in the open sea environment, it is to be done along the bay or in the water surrounded by small islands, and ship blocks are connected when the sea water is relatively calm. Details of the connection procedure are shown as follows.

Step 1

After large ship blocks have been fabricated, the connective parts are fabricated on the land in advance to prepare for the block connection at sea.

Step 2

Connective parts are attached to the large ship blocks. This procedure is also done on the land, which is shown in Fig. 1.5.

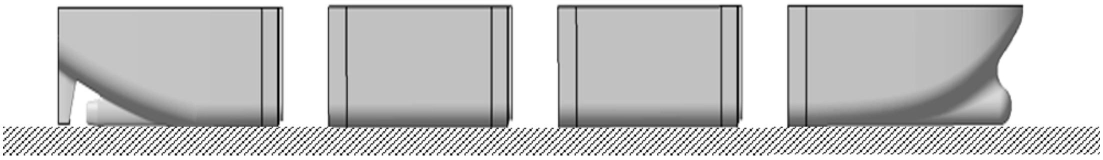


Fig. 1.5 Ship blocks attached with connective modules

Step 3

After large ship blocks are attached with connective parts, they are put into the sea to float by themselves, which is shown in Fig. 1.6.

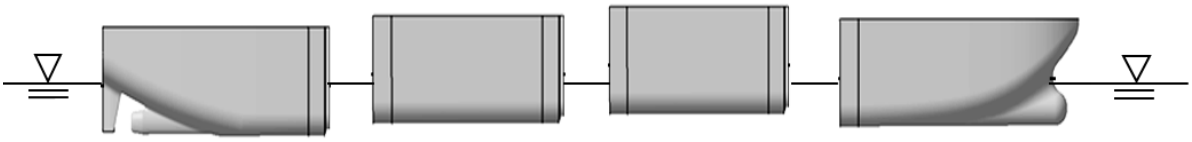


Fig. 1.6 Ship blocks float at sea

Step 4

In order to assemble ship blocks together, all these ship blocks should be in the same horizontal line. In this procedure, the water ballasts of lighter ship blocks are filled with sea water so that all the blocks could be in the same height. If the water ballasts of the ship block itself could not provide enough weight or adjust ship block to be horizontal, extra water ballasts are applied in the cargo hold to help to adjust ship blocks. This procedure is shown in Fig. 1.7.

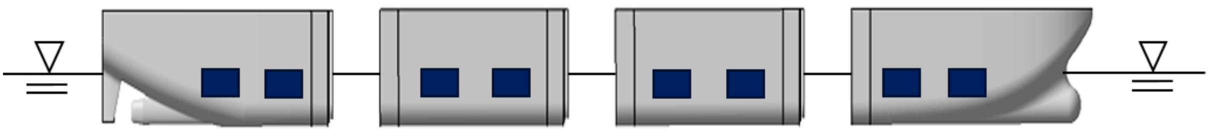


Fig. 1.7 Adjust floating ship blocks in the same horizontal line

Step 5

To drag ship blocks to be close together, tug boats are used to move ship blocks. The way to drag ship blocks is shown in Fig. 1.8.

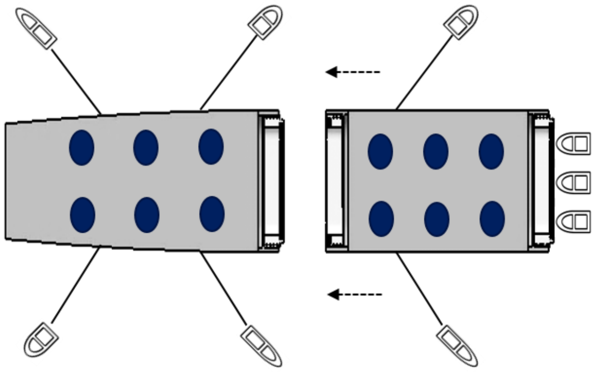


Fig. 1.8 Tug boats used to drag ship blocks

Step 6

When two ship blocks are close enough, people go into the ship blocks, put steel bars into the holes and bolt both ends of the steel bars. The ship blocks are assembled in this way one after another. Connective part's modules with both ends bolted are shown in Fig. 1.9.

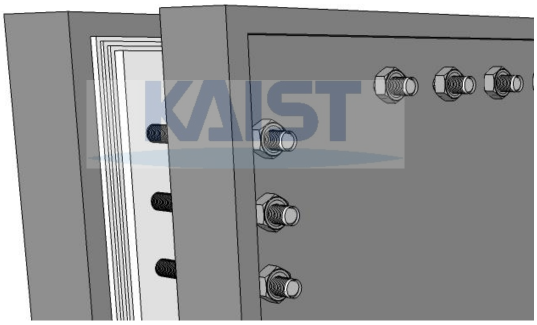


Fig. 1.9 Connective part's modules with both ends bolted

Step 7

After steel bars are bolted, there is some space between connective part's modules, which is shown in Fig. 1.10. Some water is left there during the previous steps, as a result, water is pumped out, and also big steel plates for temporary use are removed.

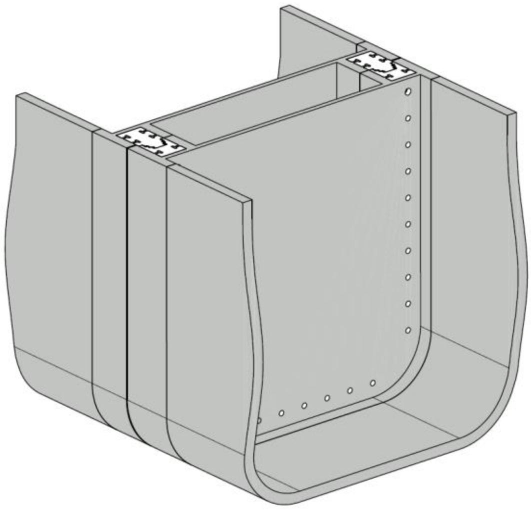


Fig. 1.10 Space between connective part's modules

Step 8

To ensure the strength of the whole ship, inner side steel plates of the connective part's modules are welded, which is shown in Fig. 1.11. Also the extra water ballasts are removed in this step.

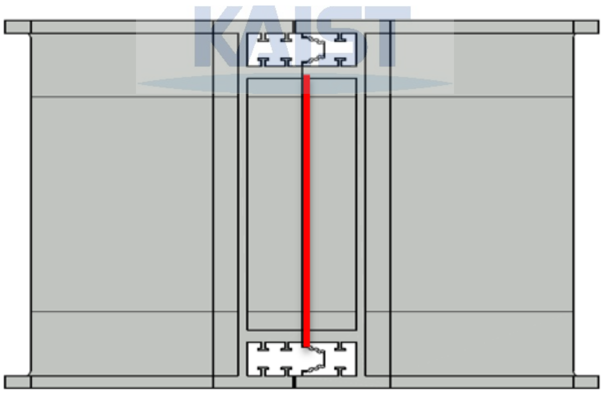


Fig. 1.11 Inner side steel plates of connective part's modules need to be welded

Step 9

Finally, there may be some space still left between convex module and concave module, paste is filled in the space to ensure the strength of the structure and guarantee the water tightness of the connective part, which is shown in Fig. 1.12.

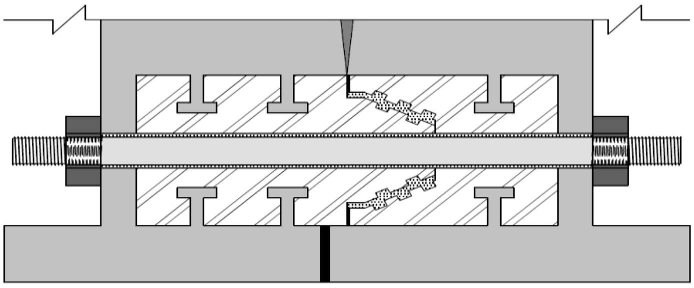


Fig. 1.12 Space between connective part's modules is filled with paste

Since this steel-concrete composite connection method has not been used before, the safety of applying this method need to be checked, and the economic feasibility should be figured out as well.

## 1.4 Summary

In this study, strength assessment of the ship blocks connected by applying this steel-concrete composite connection method is conducted. Two kinds of target ships have been chosen to do this analysis, which are bulk carrier ship and oil tanker ship. In order to assess the strength of connective part, firstly, preliminary design of the connective part is performed to determine the number of steel bars and the thickness of concrete. Next, we establish the finite element model of the 3D cargo hold model for bulk carrier target ship and 3D cargo tank model for oil tanker target ship to check the maximum effective stress of connective part. Since the attachment of the connective part probably could increase the torsional stiffness of the ship, the torsional stiffness comparison between the model attached with connective part and the model without connective part is done.

To figure out the economic feasibility of this method, construction cost and operation cost of the method are estimated, and the weight change caused by connective part is calculated as well.

For this steel-concrete composite connection method, the fatigue assessment of connective part has not been taken into consideration, and the stability of each ship block will be done in the future. Also, future calculation need to be done to minimize the size of connective part. From this research, it could be seen that this steel-concrete composite connection method is quite possible to be applied into practical construction in the future.

# Chapter 2. Structure analysis

In this chapter, we describe the stress assessment theory for structure and ship. Since the strength safety of the connective part is the very basic issue of this steel-concrete composite connection method, strength assessment of the connective part need to be done. Firstly, the theory of preliminary calculation is described, which is the composite material analysis theory, then the finite element analysis theory for ships is presented.

## 2.1 Composite material analysis theory

In order to determine the number of steel bars and connective part size generally, preliminary calculation of connective part need to be done firstly. Connective part is made up of concrete, steel plates and steel bars, which is a kind of composite material, so the preliminary calculation is done in accordance with the composite structural mechanics theory. In this section, the basic theory of composite material is introduced, also the application of this theory on the connective part is described.



### 2.1.1 Concrete and steel composite material theory

Composite materials are the materials made from two or more constituent materials with significantly different physical or chemical properties. When different materials are combined, the individual components remain separate and distinct, but the combined structure shows a characteristic that different from the individual components. Since the connective module is a steel and concrete composite material, here we show a structure made of concrete with some steel bars in the lower half of the structure [7]. This structure section is shown in Fig. 2.1.

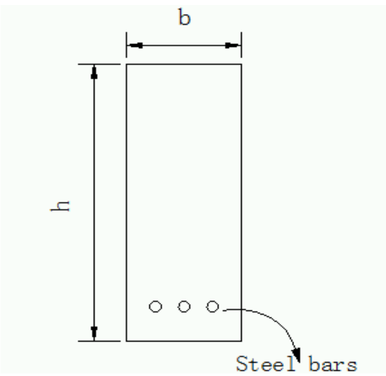



Fig. 2.1 Concrete and steel composite material structure section

When a positive bending moment is applied on this structure, upper side of the structure is bearing tensile stress, at the same time, lower side of the structure is bearing pressure stress. As we widely known that concrete could hardly bear tensile stress, so the concrete below the neutral axis, which is supposed to bearing tensile stress, is assumed not to be taken into consideration. As a result, the part below the neutral axis only has the steel bars to bear the tensile stress, which is shown in Fig. 2.2.

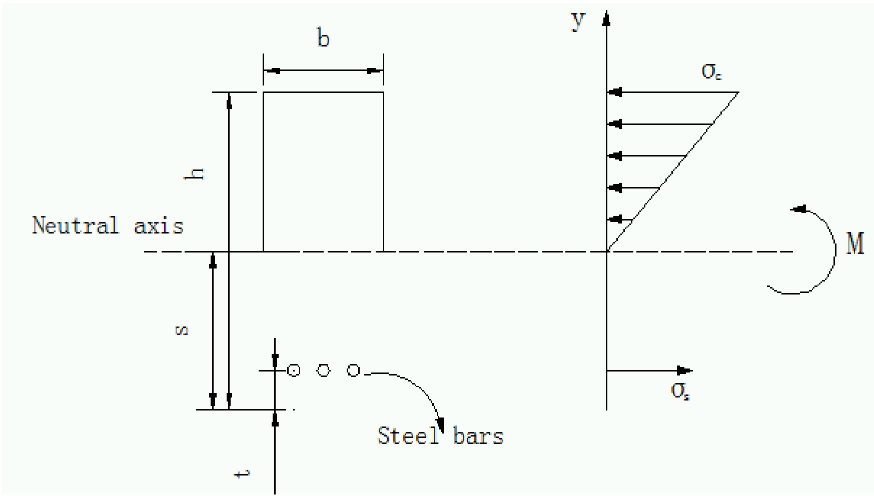



Fig. 2.2 Concrete and steel composite material structure stress image

(When apply positive bending moment)

### 2.1.2 Concrete and steel composite material calculation theory

Firstly, the neutral axis calculation theory for the concrete and steel composite material is defined as follows. According to Fig. 2.2, $y$ denotes the distance between the neutral axis and any point in the section, and it is the only variable that changes with $dA$, which is a very small area of the section. Therefore, neutral axis location of the section could be calculated by:

$$\int y dA = 0 \tag{2.1}$$

For the composite material mentioned above, the mathematical expression to calculate the neutral axis location could be represented as:

$$\frac{1}{2} b(h-s)^2 - nA_s(s-t) = 0 \tag{2.2}$$

Where $s$ is the distance between neutral axis and the bottom of section, $n$ presents the steel bar number, $A_s$ presents steel bar's diameter, and $t$ is the distance between steel bars and the bottom of section.

Secondly, the bending stiffness calculation theory for the concrete and steel composite is defined as follows. For the stress calculation for this concrete-steel composite material, bending stiffness should be calculated as average bending stiffness, which is defined as:

$$\overline{EI} = E_{bar}I_{bar} + E_{concrete}I_{concrete} \tag{2.3}$$

Where concrete young's modulus is represented as $E_{concrete}$, steel bar young's modulus is represented as $E_{bar}$, initial moment of steel bar is $I_{bar}$, and the initial moment of concrete is represented as $I_{concrete}$.

After the average bending stiffness has been calculated, the stress of each kind of material could be calculated as well. When bending moment $M_b$ is applied to the structure, the equations to calculate stress of concrete $\sigma_{concrete}$ and the stress of steel bars $\sigma_{steel}$ are shown as follows:

$$\sigma_{concrete} = \frac{M_b E_{concrete} y}{\overline{EI}} \tag{2.4}$$

$$\sigma_{steel} = \frac{M_b E_{bar} y}{\overline{EI}} \tag{2.5}$$

## 2.2 Finite element analysis theory for ships



To make sure that the steel-concrete composite connection method could be used in practical construction, only assessing the strength of connective part is not enough, the ship hull structure also need to be taken into consideration as a whole. As a result, the finite element analysis [8] for the ship attached with connective part is essential to be conducted. In this thesis, the finite element (FE) model strength assessment is conducted in accordance with the Common Structure Rules (CSR) [9,10]. For the reason that midship region of the ship is bearing the most severe stress of the whole ship, only three midship region compartments model will be constructed.

In order to do this analysis, target ships are chosen to be two different ships. One is chosen to be bulk carrier, the other one is chosen to be oil tanker. Since bulk carrier ship and oil tanker ship have different rules to follow, the analysis theories are presented separately in this section.

### 2.2.1 Bulk carrier 3D cargo hold analysis theory

#### Extent of model

The longitudinal extent of finite element model needs to include three cargo holds and four transverse bulkheads [9]. At the ends of the model, transverse bulkheads and their associated stools are to be included. The transverse extent of the model is to cover both sides of ship structures in case unsymmetrical wave-induced loads to apply on the model. In Fig. 2.3 shows the extent of a typical bulk carrier ship.

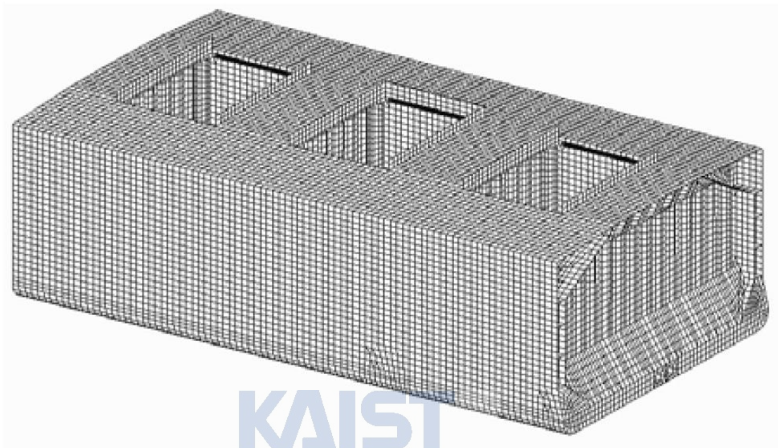


Fig. 2.3 Extent of a typical bulk carrier ship

#### Finite element types

All main structural members are to be represented in FE model, such as the inner and outer shell of the ship, floor and girder, transverse and vertical web frames and the longitudinal bulk head structures.

Stiffness of each structural member is to be represented correctly by using proper element type. For the ship hull, stiffeners are to be modeled by beam, and plates are to be modeled by shell. Shell quad and triangle elements are used as shell elements, which are shown in Fig. 2.4, and the triangle elements are to be avoided as far as possible. While for the connective part, steel bars are to be modeled by beam, plates are to be modeled by shell, and the concrete are modeled by 3-D solid.

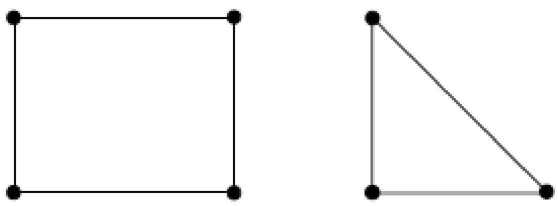


Fig. 2.4 Shell quad and triangle element

### Boundary condition

Boundary conditions for 3D cargo hold model are to be simply supported. The nodes on the longitudinal members at both end sections are to be rigidly linked to independent points according to Table 2.1. The independent points of both ends are to be fixed according to Table 2.2. Here, independent point is the point at neutral axis on centerline of the end of the model.

Table 2.1 Rigid-link of both ends of 3D cargo hold model

| Nodes on longitudinal members at both ends of the model | Translational | | | Rotational | | |
|---|---|---|---|---|---|---|
| | Dx | Dy | Dz | Rx | Ry | Rz |
| All longitudinal members | RL | RL | RL | - | - | - |
| RL means rigidly linked to the relevant degrees of freedom of the independent point | | | | | | |

Table 2.2 Support condition of the independent point of 3D cargo hold model

| Nodes on longitudinal members at both ends of the model | Translational | | | Rotational | | |
|---|---|---|---|---|---|---|
| | Dx | Dy | Dz | Rx | Ry | Rz |
| Independent point on aft end of model | - | Fix | Fix | - | - | - |
| Independent point on fore end of model | Fix | Fix | Fix | Fix | - | - |



### Loading condition

Loading conditions to be applied combining with loading patterns and load cases. Loads that need to be applied on the model are divided into three aspects, which are hull girder loads, external pressures and internal pressures. Each kind of the load is divided into static load and dynamic load, and these loads all could be calculated based on the parameters of the ship according to the CSR of bulk carrier.

Firstly, hull girder loads include the vertical wave bending moment and still water bending moment. The vertical wave bending moment is caused by the wave movement, while still water bending moment is caused by the still water buoyance.

Secondly, external pressures include the hydrostatic pressure and hydrodynamic pressure. The external static pressure is caused by the still water pressure, while the external hydrodynamic pressure is caused by the wave movement.

Thirdly, internal pressures include the static pressure and dynamic pressure. The internal static pressure is caused by the cargo static pressure. Due to the acceleration of the ship, cargo could induce dynamic pressure to the inner side of the cargo hold.

### 2.2.2 Oil tanker 3D cargo tank analysis theory

#### Extent of model

The longitudinal extent of the 3D cargo tank finite element model is to cover three cargo tank length about midships, and the transverse bulkheads at both ends of the model and the stool structure need to be included [10]. The length of the part that extending beyond the end are equal at both ends, also web frames are to be modelled. For the transverse extent of the model, it should include both port and starboard sides of the ship, also the full depth of the cargo tank is to be modelled. Typical finite element model that represents the 3D cargo tank model of Aframax oil tanker is shown in Fig. 2.5.

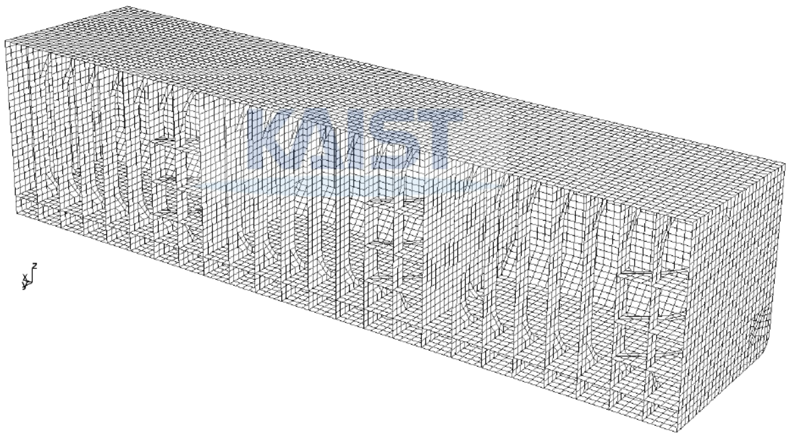


Fig. 2.5 Typical 3D cargo tank model of an Aframax oil tanker

(Only half side of the full breadth model)

#### Finite element types

All main longitudinal and transverse structural members need to be presented in the model. These members include inner and outer shell, web frames, double bottom floor, girder system and transverse and longitudinal bulkhead structures, also all stiffeners are to be modelled as well.

For the elements that are used in the 3D cargo tank model, they totally share the same rule with 3D cargo hold model, which have already been described in the previous section.

## Boundary condition

The boundary conditions of 3D cargo tank finite element model are to be applied on the both ends of the model. According to Table 2.3, all the nodes on longitudinal members at both ends of the model are to be rigidly linked to the independent points of each end section, and the independent points are to be fixed.

Table 2.3 Boundary constraints at of 3D cargo tank model ends

| Nodes on longitudinal members at both ends of the model | Translational | | | Rotational | | |
|---|---|---|---|---|---|---|
| | Dx | Dy | Dz | Rx | Ry | Rz |
| All longitudinal elements on aft end | RL | - | - | - | RL | RL |
| All longitudinal elements on fore end | RL | - | - | - | RL | RL |
| Independent point on aft end of model | - | Fix | Fix | - | - | - |
| Independent point on fore end of model | Fix | Fix | Fix | Fix | - | - |
| Deck, inner bottom and outer shell | - | Springs | - | - | - | - |
| Side, inner skin and longitudinal bulkheads | - | - | Springs | - | - | - |



The members that need to be applied spring boundary condition are shown in Fig. 2.6. The spring elements with stiffness in global y direction are applied to the grid points along inner bottom, bottom shell and deck, the other end of these spring elements are constrained in all 6 degrees of freedom. Also, the spring elements with stiffness in global z direction are applied to the grid points along inner hull longitudinal bulkheads, oil-tight longitudinal bulkheads and vertical part of the side shells, the other end of these spring elements are constrained in all 6 degrees of freedom.

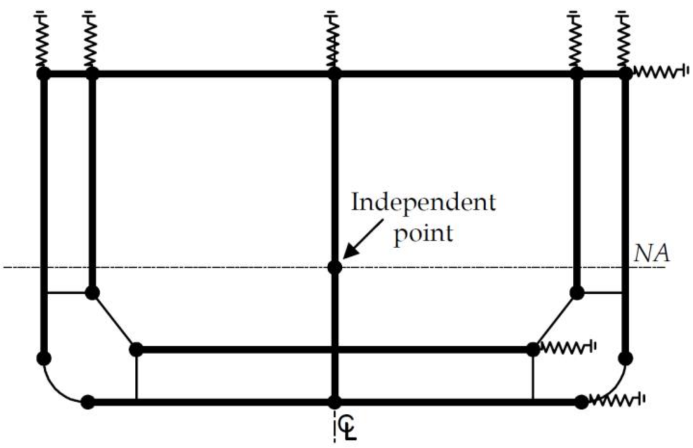



Fig. 2.6 Members to be applied spring boundary condition

The stiffness, c, of individual spring elements for each structural member which are to be applied to the three cargo tank model could be calculated by:

$$c = 0.77 \frac{A_s E}{l_t n} N / mm \tag{2.6}$$

Where $A_s$ represents the shearing area of the individual structural member under consideration, $E$ is the modulus of elasticity, $l_t$ is the length of cargo tank, and $n$ represents the number of nodal points to which the spring elements are applied to the structural member under consideration.

## Loading condition

For 3D cargo tank model, the analysis is carried out by applying loading conditions in the way of standard design load combinations. Each part of the loads need to be calculated firstly, then the calculated loads are to be multiplied by different load combination factors depending on different loading cases.

Similar to the bulk carrier loading conditions, loads which are applied on the model have been divided into three aspects, which are hull girder loads, external pressures, and internal pressures. Each kind of the load is divided into static load and dynamic load.



Firstly, hull girder loads include the vertical wave bending moment and still water bending moment. Secondly, external pressures include the static pressure and dynamic pressure. The external static pressure is caused by the still water pressure, while the external dynamic pressure is caused by wave movement. Thirdly, internal pressures include the static pressure and dynamic pressure. The internal static pressure is caused by the liquid static pressure. Also due to the acceleration of the hull, dynamic pressure caused by the liquid inside the tank is taken into consideration. All these loads could be calculated based on the parameters of the ship according to the CSR for oil tanker.

# Chapter 3. Structure analysis results

In this chapter, the results of stress assessment are presented. At first, the target ships chosen for analysis are described, then the strength analysis is conducted, which includes the preliminary calculation and finite element model stress assessment. According to the preliminary calculation results, steel bar number and the rough size of the connective part could be decided. Then the finite element models of ship hull attached with connective part are constructed. Stress assessment results of the model attached with connective part are done, also the torsional stiffness comparison between the ships attached with connective part and without connective part are presented in this section.

## 3.1 Target ship description

To conduct the strength analysis of the ship structure attached with connective part, the first thing to do is to choose the target ship. Two different ships have been chosen as the target ships. Since bulk carrier ship is a type of common ship that is quite wildly used all around world, it is chosen to be the first target ship to be analyzed. This target ship is chosen to be a double bottom ship with single-hull structure [11], and its particulars are shown in Table 3.1.

Table 3.1 Particulars of bulk carrier target ship

| Bulk carrier target ship | |
|---|---|
| Items | [m] |
| L (Length) | 223.8 |
| B (Breadth) | 32 |
| D (Depth) | 20 |
| $C_b$ | 0.896 |

The second target ship is chosen to be an Aframax oil tanker ship [12]. Oil tanker is also a kind of wildly used ship. Different from the bulk carrier ship, Aframax oil tanker has double hull bottom as well as double-hull structure, and particulars of this target ship are shown in Table 3.2.

Table 3.2 Particulars of oil tanker target ship

| Oil tanker target ship | |
|---|---|
| Items | [m] |
| L (Length) | 272.7 |
| B (Breadth) | 46.2 |
| D (Depth) | 25.3 |
| $C_b$ | 0.830 |

## 3.2 Connective part preliminary calculation

For this steel-concrete composite connection method, connective parts are to be attached to ship blocks. In order to meet the strength requirement, steel bar number of one connective part and connective part size need to be decided, as a result, the preliminary calculation is applied. Since the connective part is made up of concrete, steel plates and steel bars, which is a kind of composite material, this strength analysis is based on the composite structural mechanics theory.



### 3.2.1 Preliminary calculation procedure

In this section, the preliminary calculation procedure of bulk carrier target ship attached with connective part is presented. When the ship is in hogging condition, the deformation of hull is shown in the Fig. 3.1. The members above neutral axis are bearing tensile stress, and the members below neutral axis is bearing compressive stress.

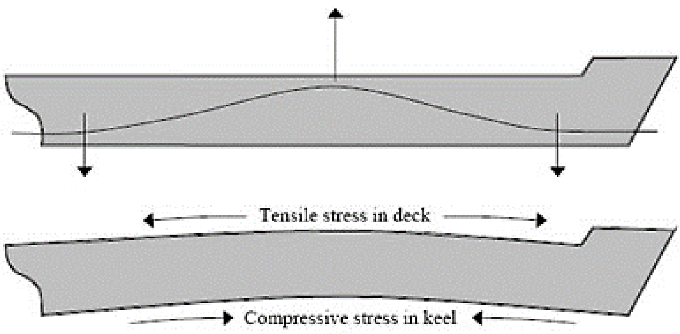



Fig. 3.1 Hull deformation when the ship in hogging condition

The cross section of connective part is plotted in Fig. 3.2. As it could be seen from the figure, connective part is made up of steel plates, steel bars and concrete. Now it is supposed that the ship is in hogging condition, as it has been mentioned above, upper side of the structure is bearing tensile stress and lower side of the structure is bearing pressure stress. As a result, the concrete above the neutral axis that is bearing tensile stress is not taken into consideration, while the concrete below the neutral axis that is bearing the pressure stress is participating the bending deflection. In order to calculate the bending capacity of connective part, neutral axis location and the inertia moment of connective part section need to be calculated.

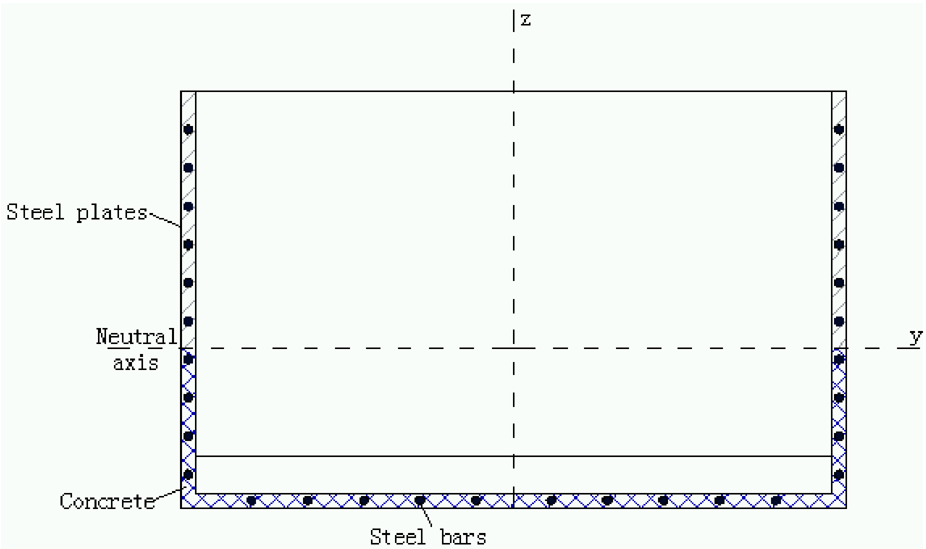



Fig. 3.2 Section of connective part

For the parameters of target ship, depth is presented as *D*, and breadth of the midship section is presented as *B*. Steel bar number of side part is represented as *a*, steel bar number of bottom part is represented as *n*, concrete thickness is presented as *m*, and *x* represents the distance between neutral axis and the bottom. Based on the Eq. 2.1, the neutral axis location of the connective part section is calculated by:

$$\begin{aligned} &B\bullet th\bullet x+2\bullet th\bullet D\bullet(x-\frac{D}{2})+2\bullet A_s a(x-\frac{D}{2})-k\bullet m(D-x)^2+(B-2m)\bullet th\bullet\left[0-(D-x)\right] \\ &+(B-2m)\bullet th\bullet\left[1.8-(D-x)\right]+k\bullet(B-2m)\bullet m\bullet\left[0-(D-x)\right]-A_s\bullet n\bullet(D-x)=0 \end{aligned} \tag{3.1}$$

Similar to the Eq. 2.3, the average bending stiffness of the connective part section is calculated by:

$$\overline{EI}=E_{steel}I_{steel}+E_{steel\_bar}I_{steel\_bar}+E_{concrete}I_{concrete} \tag{3.2}$$

While each part of initial moment is shown as follows

$$I_{steel}=th\bullet B\bullet(x^2)+2\bullet th\bullet D\bullet(x-\frac{D}{2})^2+(B-2m)\bullet th\bullet\left[0-(D-x)^2\right]+(B-2m)\bullet th\bullet\left[1.8-(D-x)\right]^2 \tag{3.3}$$

$$I_{steel\_bar}=2A_s\bullet a\bullet\left[\frac{D^2(2a+1)}{6(a+1)}-x\bullet(D-x)\right]+A_s\bullet n\bullet(D-x)^2 \tag{3.4}$$

$$I_{concrete} = \frac{2k \cdot m \cdot (D-x)^3}{4} + (B-2m) \cdot m \cdot \left[0-(D-x)\right]^2 \cdot k \quad (3.5)$$

Where $I_{steel}$ represents the initial moment of steel plates, $I_{steel\_bar}$ represents the initial moment of steel bars, $I_{concrete}$ represents the initial moment of concrete, $k = \frac{E_{concrete}}{E_{bar}}$, *th* is the thickness of steel plate, and *m* represents the thickness of concrete.

### 3.2.2 Preliminary calculation results

According to the composite material theory, the preliminary calculation of connective part has been done. In this section, we show the results of four different cases, and these cases are with different total steel bar number, concrete thickness and steel bar diameter. To meet the strength requirement of the ship section, the connective part section modules must be larger than the minimum section modules defined by Common Structural rules, which could be calculated by Eq. 3.6, and the inertia moment of the connective part must be larger than the minimum inertia moment defined by Common Structural rules, which could be calculated by Eq. 3.7 [9,10].



$$Z_{\min} = 0.9CL^2B(C_b + 0.7)k \quad (3.6)$$

$$I_{\min} = 2.7CL^3B(C_b + 0.7) \times 10^{-8} m^4 \quad (3.7)$$

Where $C = 10.75 - [(300-L)/100]^{\frac{2}{3}}$, $L$ represents the ship length, $B$ represents the ship breadth, $C_b$ represents the block coefficient.

For the two target ships, the minimum section modules and minimum inertia moment are shown in Table 3.3.

Table 3.3 Minimum inertia moment & section modules of target ships

| Items | Bulk carrier | Oil tanker |
|---|---|---|
| Minimum inertia moment | 152.7 | 410.0 |
| Minimum section modules | 22.8 | 50.1 |

The preliminary calculation results of bulk carrier target ship are shown in Table 3.4, and the preliminary calculation results of oil tanker target ship are shown in Table 3.5. It could be seen from these results that for bulk carrier ship, case 1 to 4 all meet the requirement of the inertia moment, but only case 2 could meet the section modules requirement, so the parameters of case 2 has been chosen to construct FE model. Similar to the bulk carrier target ship, the oil tanker ship also chose the case 2 to construct FE model.

Table 3.4 Preliminary calculation results of bulk carrier target ship

| Preliminary calculation results (Bulk carrier) | | | | | |
|---|---|---|---|---|---|
| Items | Unit | Case1 | **Case2** | Case3 | Case4 |
| Total steel bar number | | 24 | **30** | 30 | 30 |
| Concrete thickness | mm | 160 | **160** | 160 | 150 |
| Steel bar diameter | mm | 80 | **80** | 70 | 80 |
| Section modules (>22.8) | $m^3$ | 22.7 | **22.8** | 22.7 | 22.6 |
| Inertia moment (>152.7) | $m^4$ | 261.2 | **262.6** | 261.1 | 260.1 |

Table 3.5 Preliminary calculation results of oil tanker target ship

| Preliminary calculation results (Oil tanker) | | | | | |
|---|---|---|---|---|---|
| Items | Unit | Case1 | **Case2** | Case3 | Case4 |
| Total steel bar number | | 24 | **30** | 30 | 30 |
| Concrete thickness | mm | 160 | **160** | 160 | 150 |
| Steel bar diameter | mm | 80 | **80** | 70 | 80 |
| Section modules (>50.1) | $m^3$ | 49.9 | **50.2** | 49.9 | 49.6 |
| Inertia moment (>410.0) | $m^4$ | 664.7 | **667.3** | 664.5 | 659.9 |

## 3.3 Finite element stress assessment

To conduct the strength assessment of ship structure attached with connective part, finite element stress assessment is essential. Since the preliminary calculation has been done to decide the steel bar number of one section, finite element model of the ship hull attached with connective part should be constructed in accordance with the CSR to check the maximum stress of connective part. In this section, the finite element models are constructed by using ADINA [13], which is a widely used finite element analysis software. Also, loading conditions and strength assessment results for target ships are presented separately.

### 3.3.1 Bulk carrier analysis

Firstly, the 3D cargo hold model of bulk carrier ship is constructed [9,14]. For the bulk carrier model's connective part, parameters are chosen to be the case 2 of the preliminary analysis results, which are shown in Table 3.6. In this model, total steel bar number is chosen to be 30, concrete thickness is chosen to be 160mm, steel bar diameter is 80mm, and the length of connective part is chosen to be 450mm.

Table 3.6 Parameters of connective part of bulk barrier ship model

| Items | Unit | Case2 |
|---|---|---|
| Total steel bar number | | 30 |
| Concrete thickness | mm | 160 |
| Steel bar diameter | mm | 80 |
| Connective part length | mm | 450 |

The model construction is based on the theory presented in 2.2.1, and the plot of 3D cargo hold model is shown in Fig. 3.3.



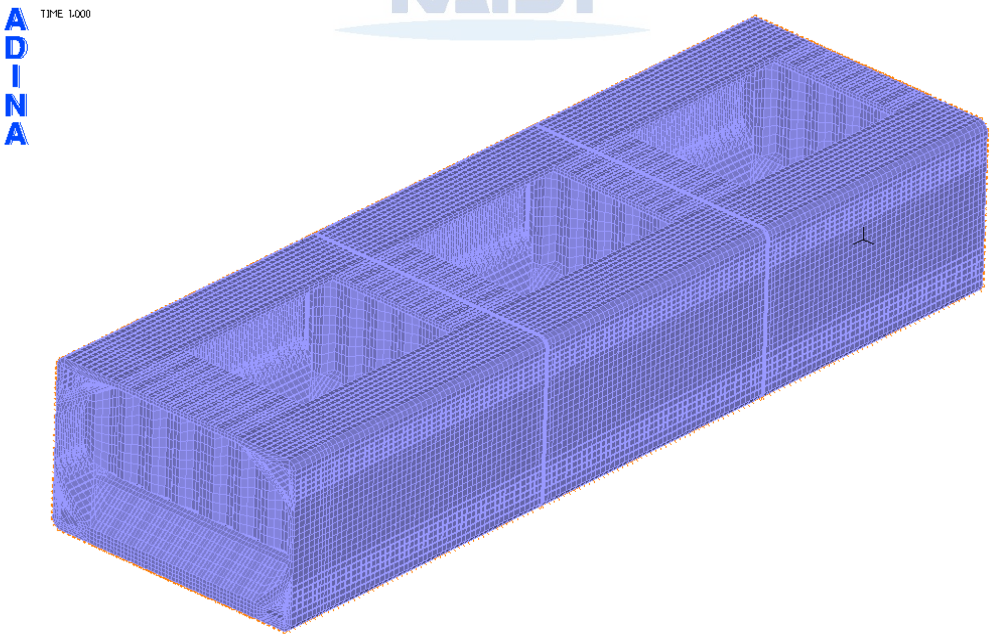



Fig. 3.3 3D cargo hold model attached with connective part

### 3.3.1.1 Bulk carrier model boundary conditions

According to the CSR, boundary conditions for 3D cargo hold model are applied in the following way. The nodes on the longitudinal members at both end sections are to be rigidly linked to independent points according to Table 2.1. The independent points of both ends are to be fixed according to Table 2.2. Plot of 3D cargo hold model boundary conditions is shown in Fig 3.4.

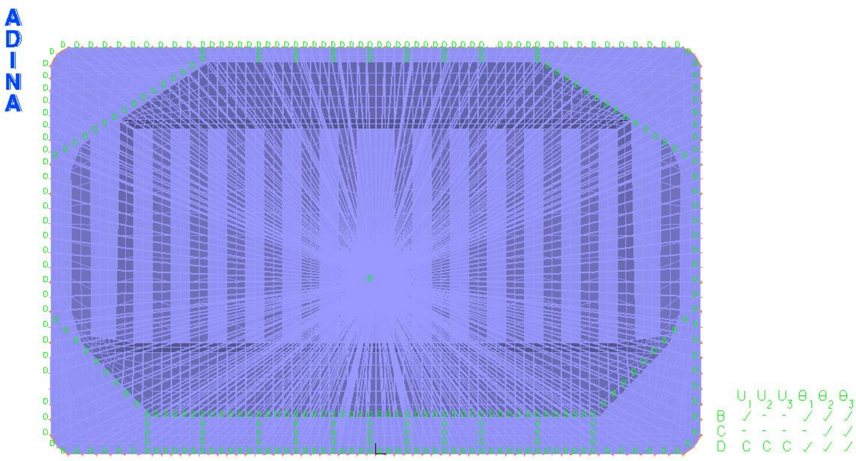



Fig. 3.4 Boundary conditions of 3D cargo hold model



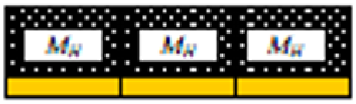
### 3.3.1.2 Loading condition

Loading conditions are to be applied combining with loading patterns and load cases. Every case of the loading conditions could be calculated based on the parameters of the ship. In this analysis, three loading cases are chosen to be applied on the model, which are the loading case A1, A2 and A3. The loading cases, external pressures of the model and analysis result plots are presented separately in this section.

**Loading case A1**

For the loading case A1, ship is in beam sea and sagging condition, draught is the scantling daft. Three cargo holds are filled with full heave cargo, which density is 3000kg/m³. Table 3.7 shows the detail of loading case A1.

Table 3.7 Loading pattern for case A1

| No. | Description | Draught | Loading Pattern | Aft | Mid | Fore | Design wave |
|---|---|---|---|---|---|---|---|
| 1 | Full Load (Heavy) | Ts |  |  |  |  | Beam sea |

The external pressure plot of loading case A1 is shown in Fig. 3.5, and internal pressure plot is shown in Fig. 3.6.

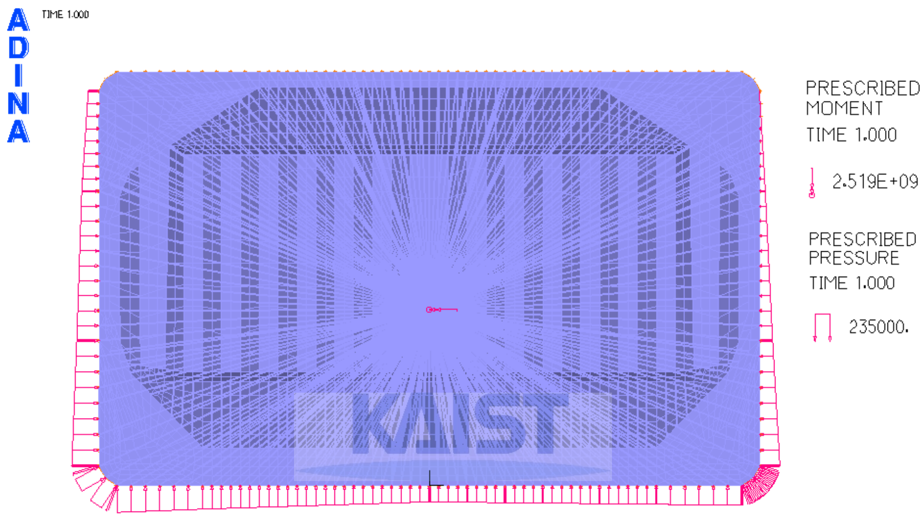



Fig. 3.5 External pressure plot of loading case A1

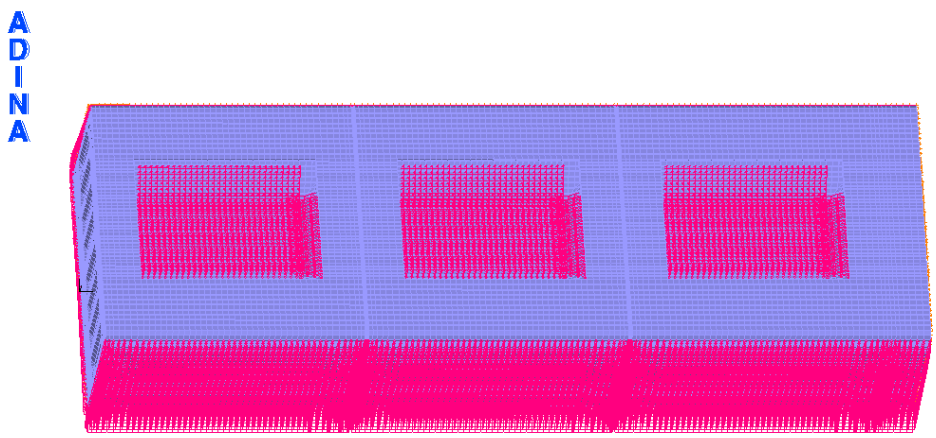



Fig. 3.6 Internal pressure plot of loading case A1

The analysis result of 3D cargo hold model attached with connective part of loading case A1 is shown in Fig. 3.7, and this is the result of effective stress.

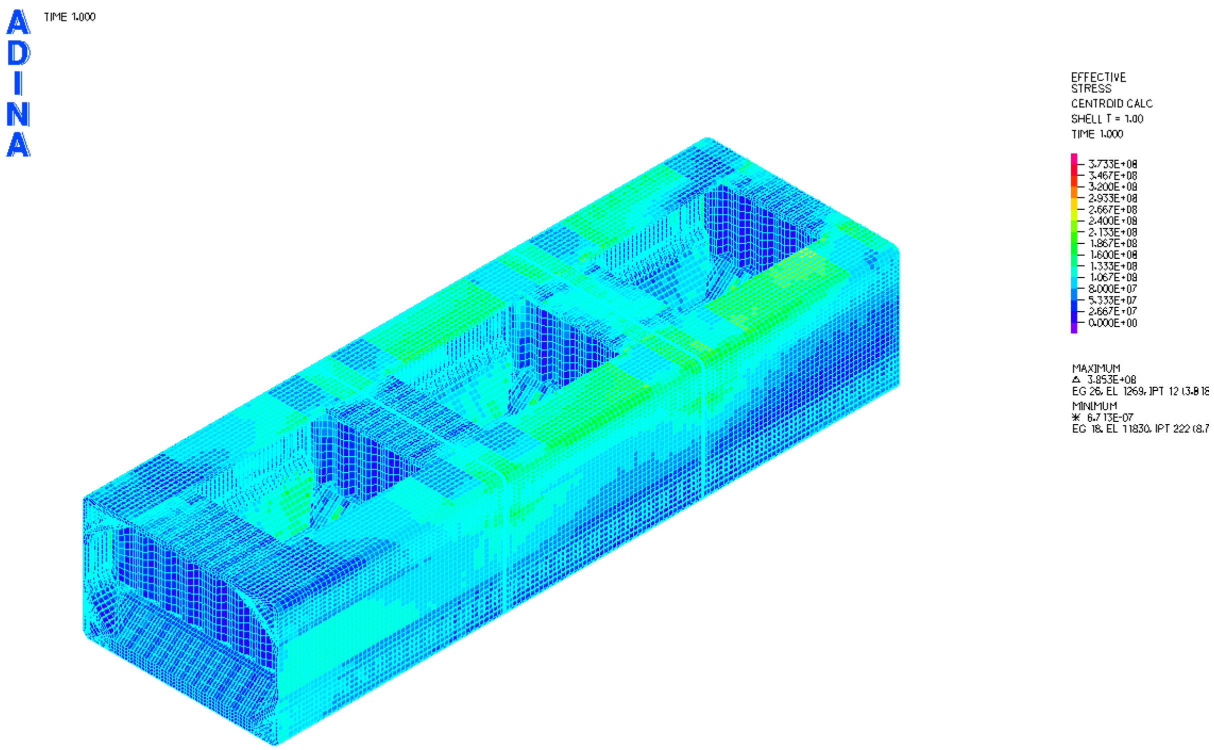


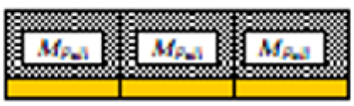

Fig. 3.7 Effective stress plot of loading case A1



### Loading case A2

For the loading case A2, which is similar to case A1, ship is in beam sea and sagging condition, draught is the scantling daft. The different part is that three cargo holds are filled with full light cargo, which density is 1000kg/m³. Table 3.8 shows the detail of loading case A2.

Table 3.8 Loading pattern for case A2

| No. | Description | Draught | Loading Pattern | Aft Mid Fore | Design wave |
|---|---|---|---|---|---|
| 2 | Full Load (Light) | Ts |  |  | Beam sea |

The external pressure plot of loading case A2 is shown in Fig. 3.8, and internal pressure plot is shown in Fig. 3.9.

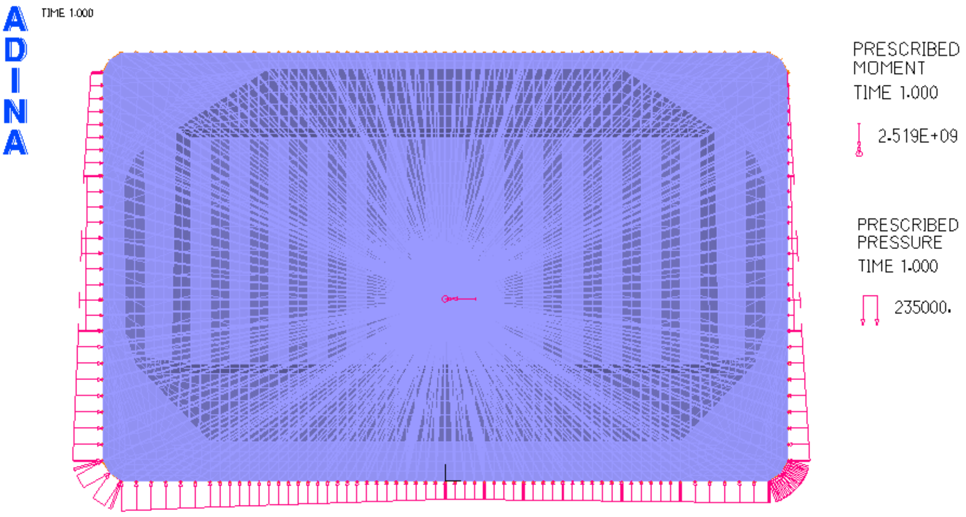



Fig. 3.8 External pressure plot of loading case A2

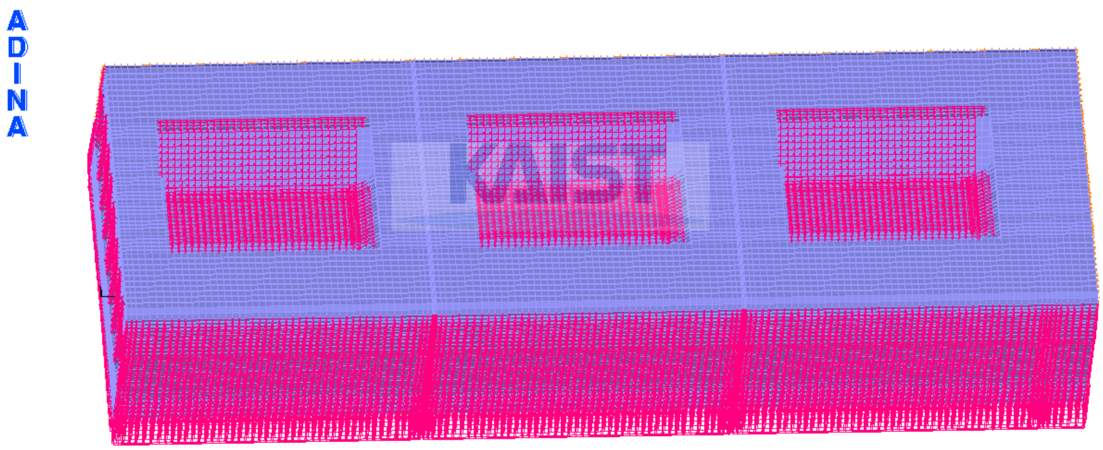



Fig. 3.9 Internal pressure plot of loading case A2

The analysis result of 3D cargo hold model attached with connective part of loading case A2 is shown in Fig. 3.10, and this is the result of effective stress.

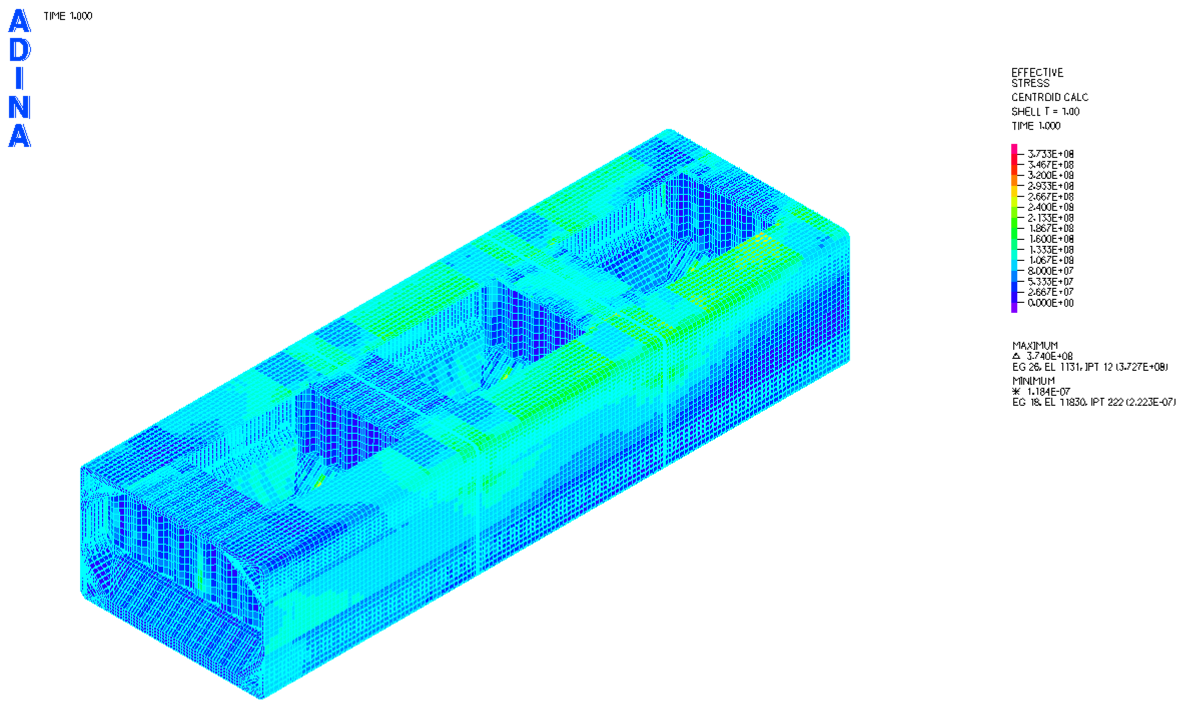



Fig. 3.10 Effective stress plot of loading case A2

### Loading case A3



For the loading case A3, it is supposed to be the most severe case. The ship is in following sea and hogging condition, draught is the scantling daft. About the internal pressure of the model, only two cargo holds on both ends of the model are filled with cargo, and the middle cargo is empty. Cargo is chosen to be heavy cargo that the density is 3000kg/m³. Table 3.9 shows the detail of loading case A3.

Table 3.9 Loading pattern for case A3

| No. | Description | Draught | Loading Pattern Aft Mid Fore | Design wave |
|---|---|---|---|---|
| 3 | Alternate Load (Heavy) | Ts |  | Follow-ing sea |

The external pressure plot of loading case A3 is shown in Fig. 3.11, and internal pressure plot is shown in Fig. 3.12.

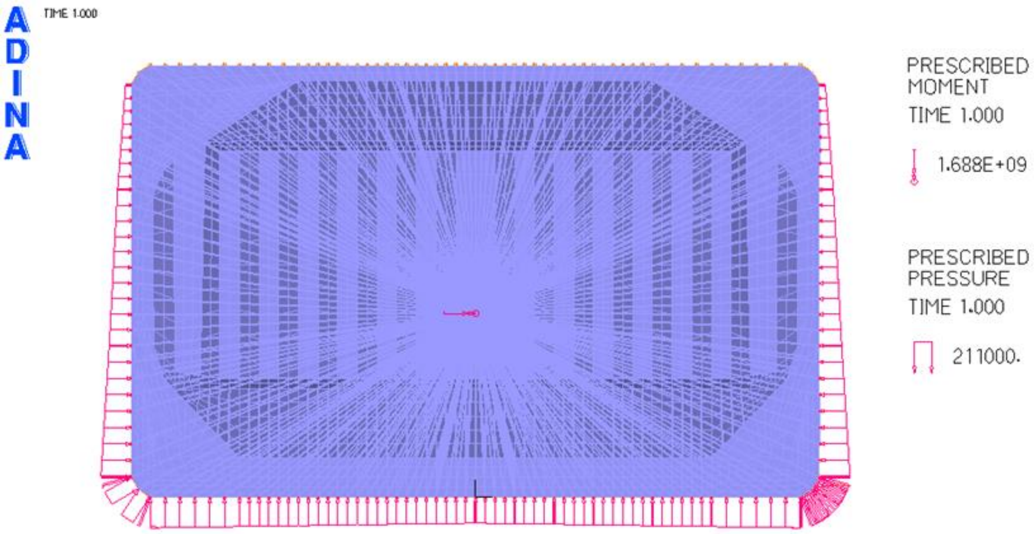



Fig. 3.11 External pressure plot of loading case A3

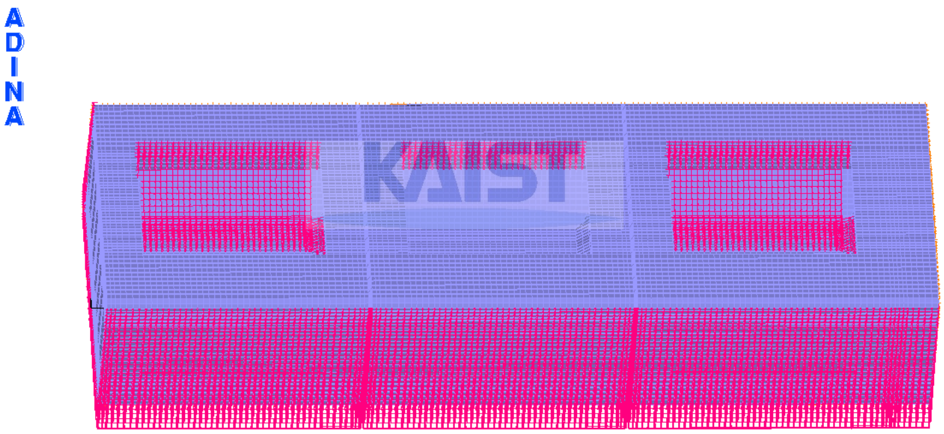



Fig. 3.12 Internal pressure plot of loading case A3

The analysis result of 3D cargo hold model attached with connective part of loading case A3 is shown in Fig. 3.13, and this is the result of effective stress.

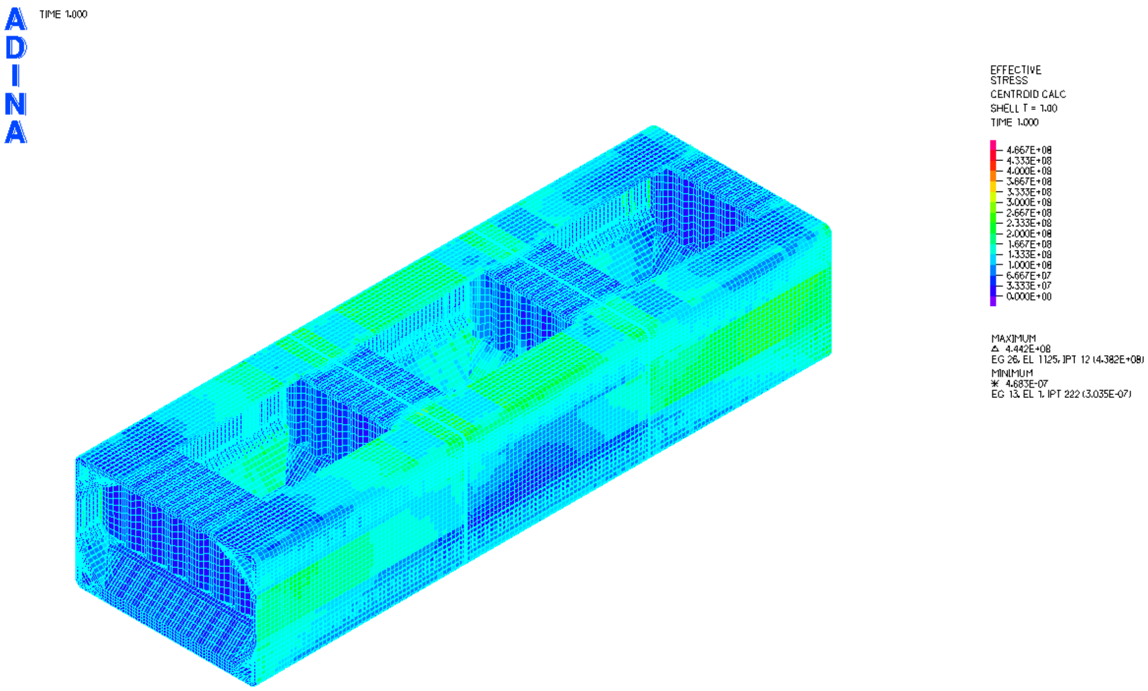



Fig. 3.13 Effective stress plot of loading case A3

### 3.3.1.3 Analysis results

In order to see the results of the connective part clearly, connective part's module is divided into six groups. Group 1 represents the concrete part, which is constructed in advance with holes in it so that steel bars could be used to fasten two ship blocks. Group 2 represents the steel bars. The steel plates on the inner side of concrete are in group 3, and the steel plates on the outer side of concrete are in group 4, also the steel plates on the back side of concrete are represented by group 5. The last group is defined as group 6, which is the deck over the connective part. All the groups except group 6 are shown in the Fig. 3.14.

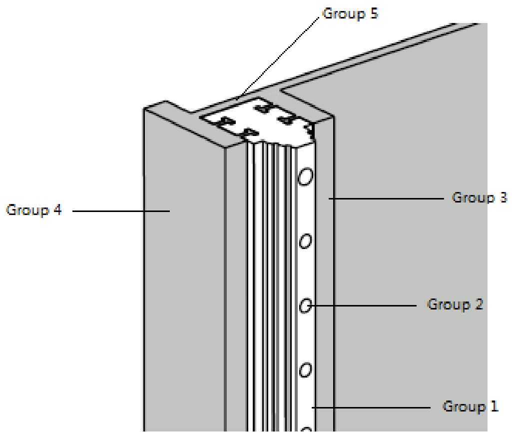



Fig. 3.14 Groups of connective part

For the connective part, appropriate thickness of each group has been chosen, which is shown in Table 3.10.

Table 3.10 Parameters of the connective part members for 3D cargo hold model

| Group | Group elements | Thickness (mm) |
| --- | --- | --- |
| 1 | Concrete | 160 |
| 2 | Steel bars | - |
| 3 | Concrete inner side steel plate | 30 |
| 4 | Concrete outer side steel plate | 30 |
| 5 | Concrete connect steel plate | 25 |
| 6 | Deck | 45 |

There are four grades of steel plates that are usually used in the ship hull construction, and the minimum yield stress and material factor of each grade of steel plate are given in Table 3.11. Since the allowable stress for FE model should not exceed 235/k N/mm² [9], for the reason that the material factor *k* has been given , the allowable stress for each grade of steel plate is calculated and shown in Table 3.11 as well.

Table 3.11 Mechanical properties of hull steels

| Steel grades for plates | Minimum yield stress (N/mm²) | Material factor (k) | Allowable stress (N/mm²) |
| --- | --- | --- | --- |
| A-B-D-E | 235 | 1.0 | 235 |
| AH32-DH32-EH32-FH32 | 315 | 0.78 | 301.3 |
| AH36-DH36-EH36-FH36 | 355 | 0.72 | 326.4 |
| AH40-DH40-EH40-FH40 | 390 | 0.68 | 345.6 |

The analysis results of three loading cases have been collected. In the Table 3.12 shows the maximum effective stress of each group of the connective part, and the allowable stress of steel is in accordance with Table 3.11.

Table 3.12 Results of stress assessment of 3D cargo hold model

| | Items | Effective stress (Mpa) | | | Allowable stress (Mpa) |
|---|---|---|---|---|---|
| Loading condition | | A1 | A2 | A3 | |
| Group | Steel bar | 324.67 | 321.35 | 311.62 | 345.6 |
| | Concrete | 22.31 | 21.52 | 28.45 | 40 |
| | Concrete inner side plate | 302.9 | 296.13 | 343.06 | 345.6 |
| | Concrete connect plate | 118.08 | 116.62 | 137.91 | 235 |
| | Concrete outer side plate | 271.42 | 270.42 | 319.15 | 326.4 |
| | Deck | 200.86 | 212.14 | 280.92 | 301.3 |

It could be seen from the results that steel bar and inner side steel plate of connective part are bearing the most effective stress comparing with other groups, so the high strength steel is chosen for these groups, and we could see that concrete part is bearing low level stress, which is in the allowable range of concrete material [15].

About the other groups of the connective part, the effective stress of the steel plates around concrete are all in the allowable range of steel material, and the stress of the deck over the connective part also meet the requirement of the strength. Overall, the maximum effective stress of concrete, steel bars and steel plates could meet the strength requirement of concrete and steel.

### 3.3.2 Oil tanker analysis

Secondly, the 3D cargo tank model attached with the connective part of oil tanker target ship is constructed [10,16]. For the oil tanker model's connective part, parameters are chosen to be the case 2 of the oil tanker preliminary analysis results that are shown in Table 3.13. All the parameters are the same as 3D cargo hold model.

Table 3.13 Parameters of connective part of oil tanker ship model

| Items | Unit | Case2 |
|---|---|---|
| Total steel bar number | | 30 |
| Concrete thickness | mm | 160 |
| Steel bar diameter | mm | 80 |
| Connective part length | mm | 450 |

The model construction is based on the theory in 2.2.2, and the plot of 3D cargo tank model is shown in Fig. 3.15.

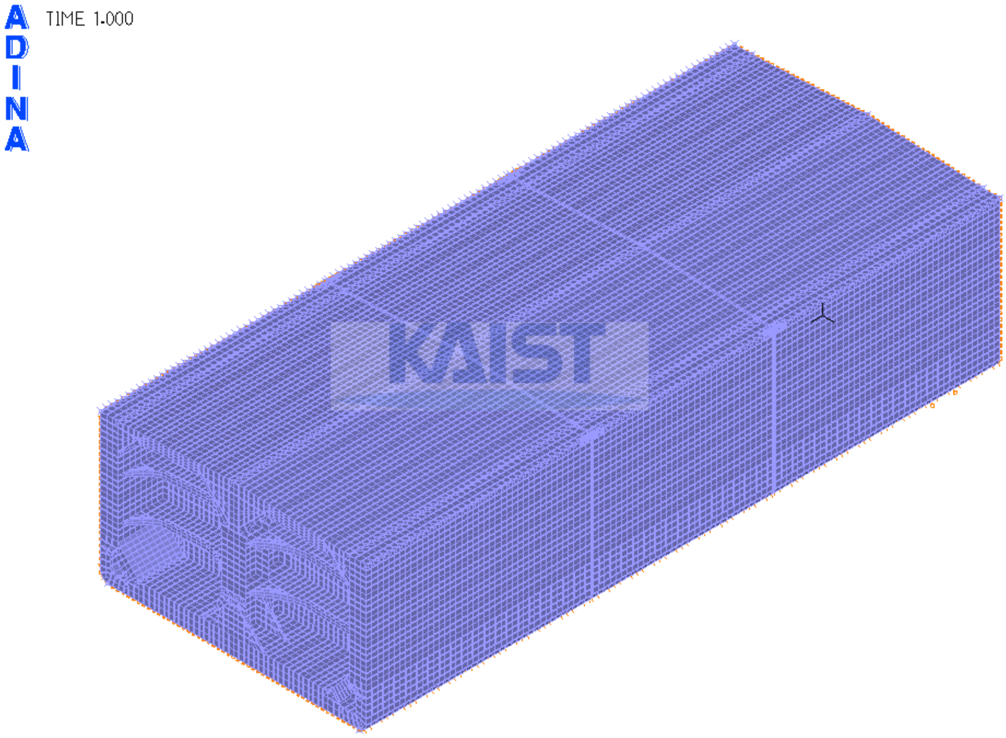



Fig. 3.15 3D cargo tank model attached with connective part

### 3.3.2.1 Oil tanker model boundary conditions

The boundary conditions of three cargo tank finite element model are to be applied on the both ends of the model. According to Table 2.3, all the nodes on longitudinal members at both ends of the model are to be rigidly linked to the independent points of each end section, and the independent points are to be fixed. Plot of 3D cargo tank model boundary conditions is shown in Fig 3.16, and the red points in the plot are the nodes applied with spring boundary conditions.

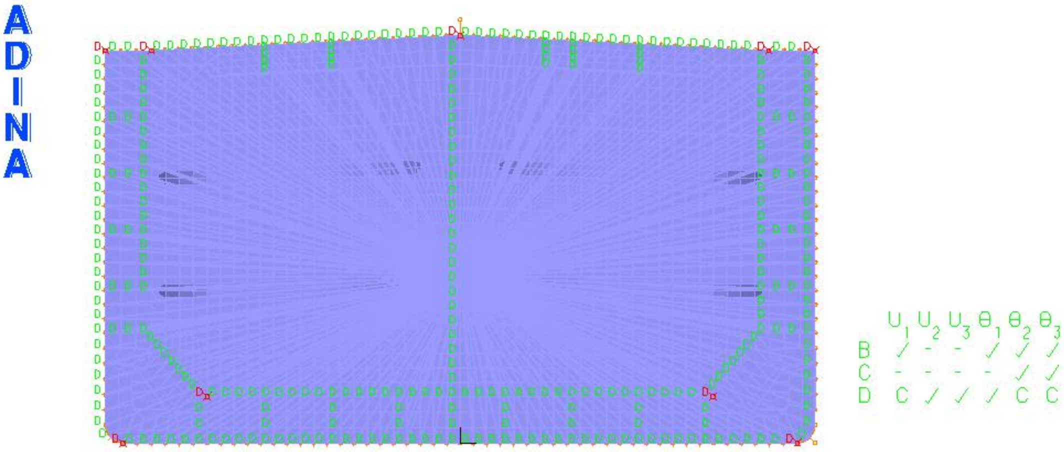



Fig. 3.16 Boundary conditions of 3D cargo tank model

According to the Equation 2.6, the stiffness of spring elements to be applied as boundary condition could be calculated, and the calculation results are shown in Table 3.14.

Table 3.14 Stiffness of spring elements for boundary condition

| Items to be applied spring boundary condition | Direction | Spring stiffness (MN/m²) |
|---|---|---|
| Side plate | Vertical spring | 1,349.3 |
| Inner hull bulkhead | | 1,471.4 |
| Longitudinal bulkhead | | 1,753.3 |
| Deck | Horizontal spring | 2,618.0 |
| Inner bottom | | 2,957.8 |
| Outer bottom plate | | 3,080.0 |

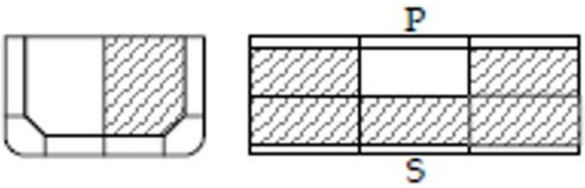
### 3.3.2.2 Loading condition

Loading conditions are to be applied combining with loading patterns and load cases. Every case of the loading conditions could be calculated based on the parameters of the ship. In this 3D cargo tank analysis, three loading cases are chosen to be applied on the model, which are the loading case B1, B2 and B3. The loading cases, external pressures of the model and analysis result plots are presented separately in this section.

## Loading case B1

For the loading case B1, ship is in head sea and sagging condition, draught is the 0.9 scantling daft. Inside the cargo tank, all the tanks except half of the middle tank are filled with liquid cargo, which density is supposed to be 1000kg/m³. Table 3.15 shows the detail of loading case B1.

Table 3.15 Loading pattern for case B1

| No. | Loading Pattern | Draught | Design sea |
|---|---|---|---|
| 1 |   | 0.9Tsc | Head sea |

The external pressure plot of loading case B1 is shown in Fig. 3.17, and internal pressure plot is shown in Fig. 3.18.

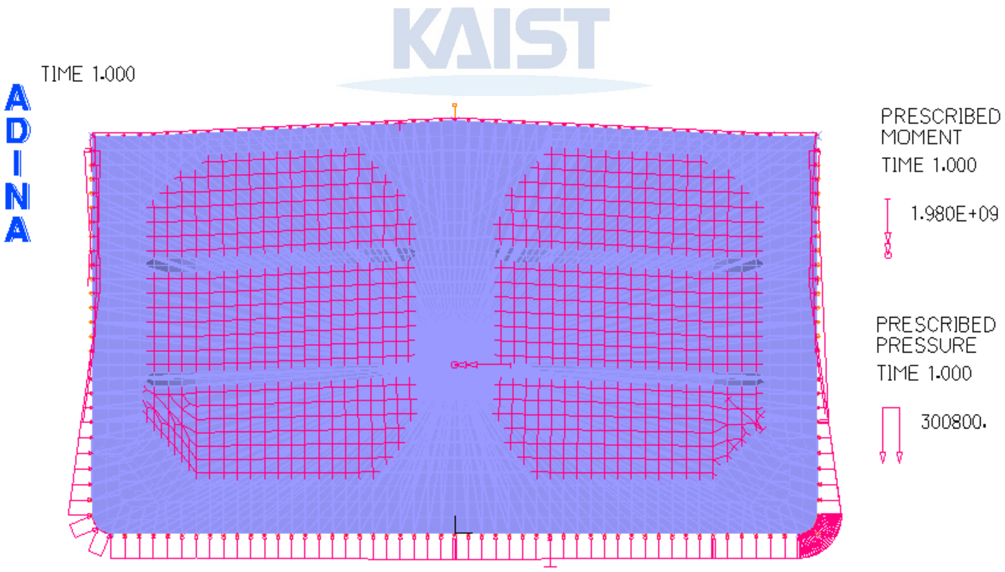



Fig. 3.17 External pressure plot of loading case B1

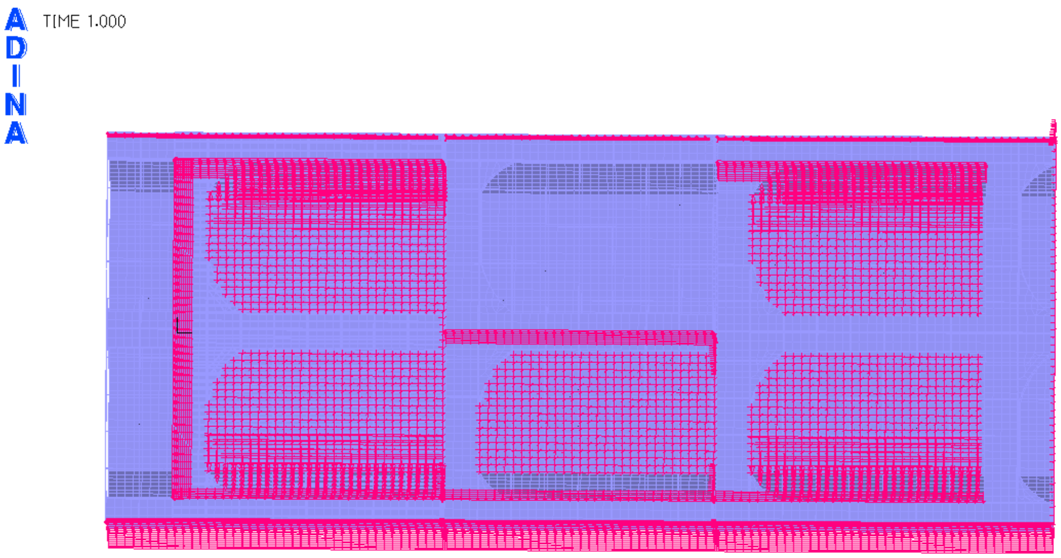



Fig. 3.18 Internal pressure plot of loading case B1

The analysis result of 3D cargo tank model attached with connective part of loading case B1 is shown in Fig. 3.19, and this is the result of effective stress.

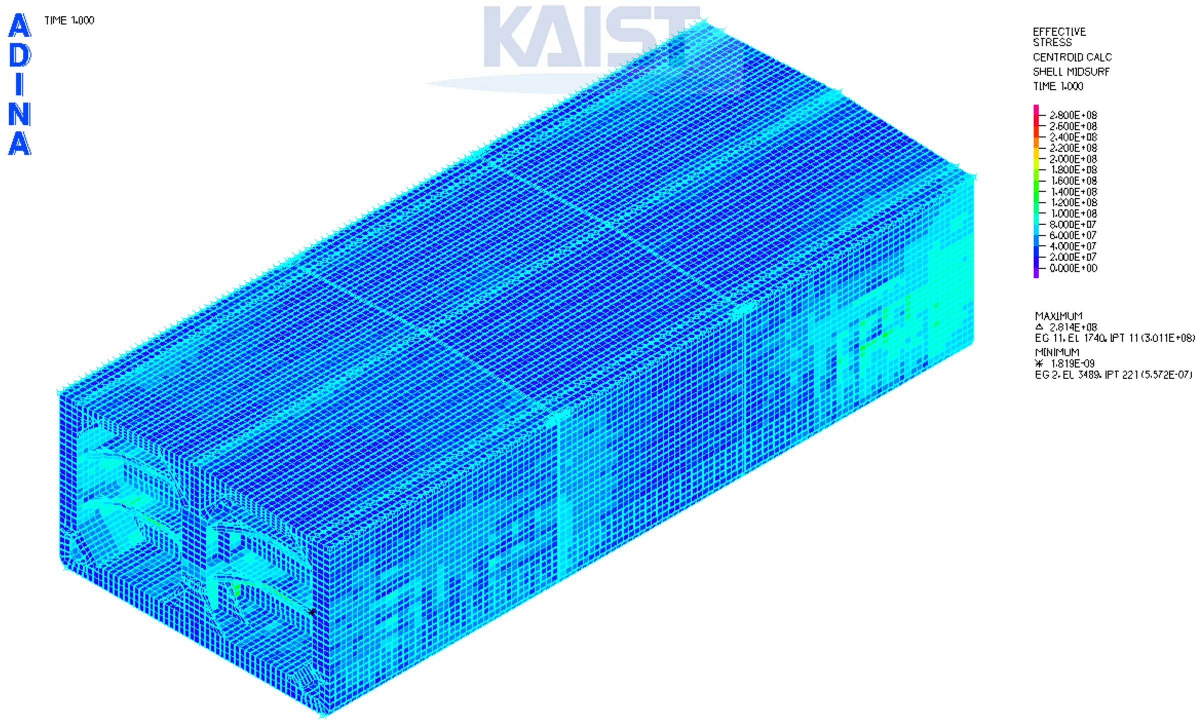
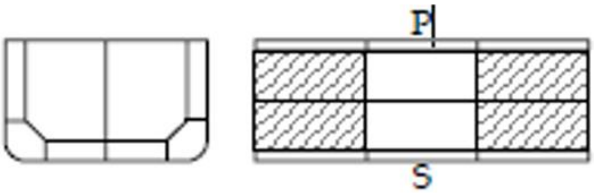



Fig. 3.19 Effective stress plot of loading case B1

## Loading case B2

For the loading case B2, which is similar to case B1, ship is in head sea and hogging condition, draught is the 0.9 scantling daft. But the different part is that inside the cargo tank of the ship, the whole middle cargo tank is empty, and the cargo tanks on both ends are filled with full liquid cargo, which density is supposed to be 1000kg/m$^3$. Table 3.16 shows the detail of loading case B2.

Table 3.16 Loading pattern for case B2

| No. | Loading Pattern | Draught | Design sea |
|---|---|---|---|
| 2 |  | 0.9Tsc | Head sea |

The external pressure plot of loading case B2 is shown in Fig. 3.20, and internal pressure plot is shown in Fig. 3.21.



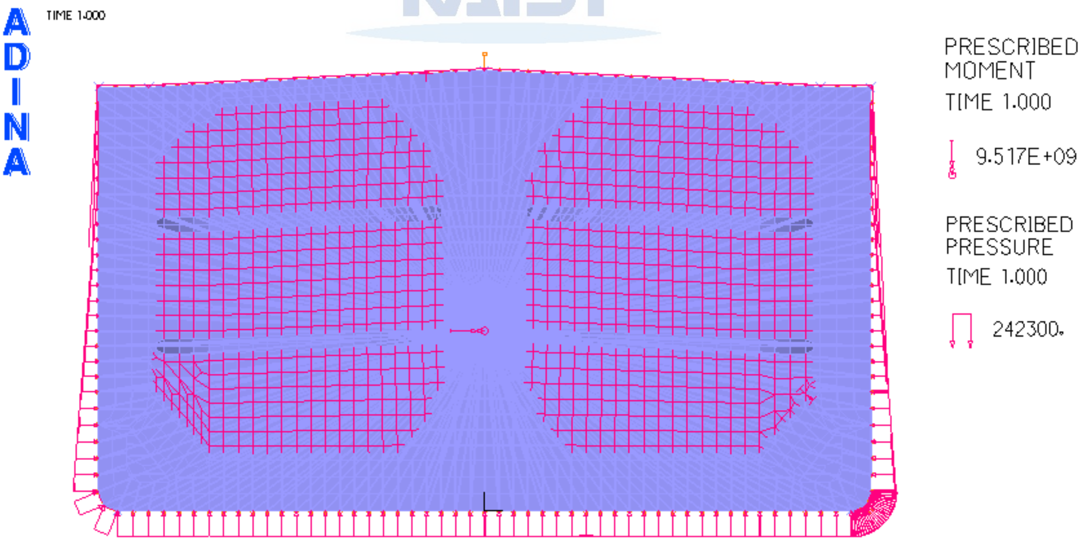



Fig. 3.20 External pressure plot of loading case B2

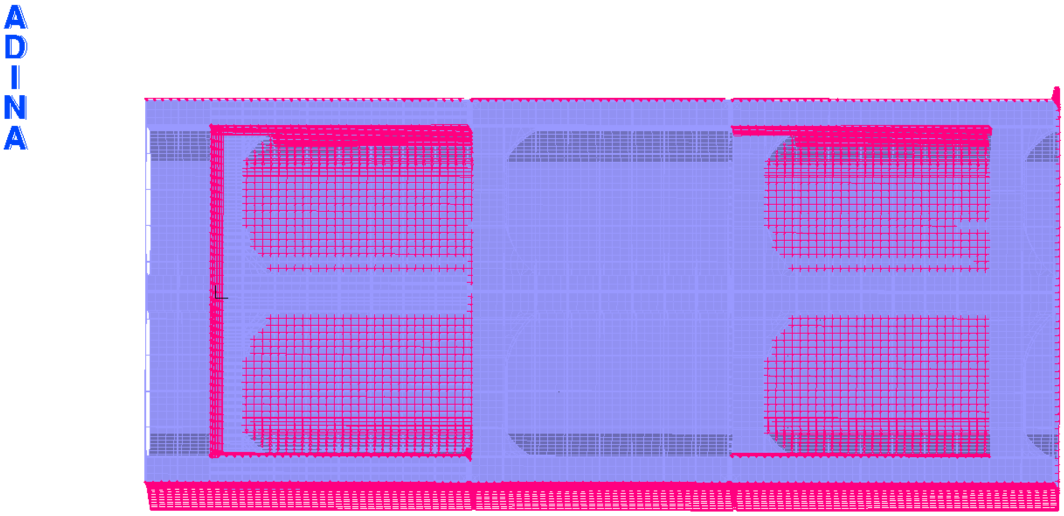



Fig. 3.21 Internal pressure plot of loading case B2

The analysis result of 3D cargo tank model attached with connective part of loading case B2 is shown in Fig. 3.22, and this is the result of effective stress.

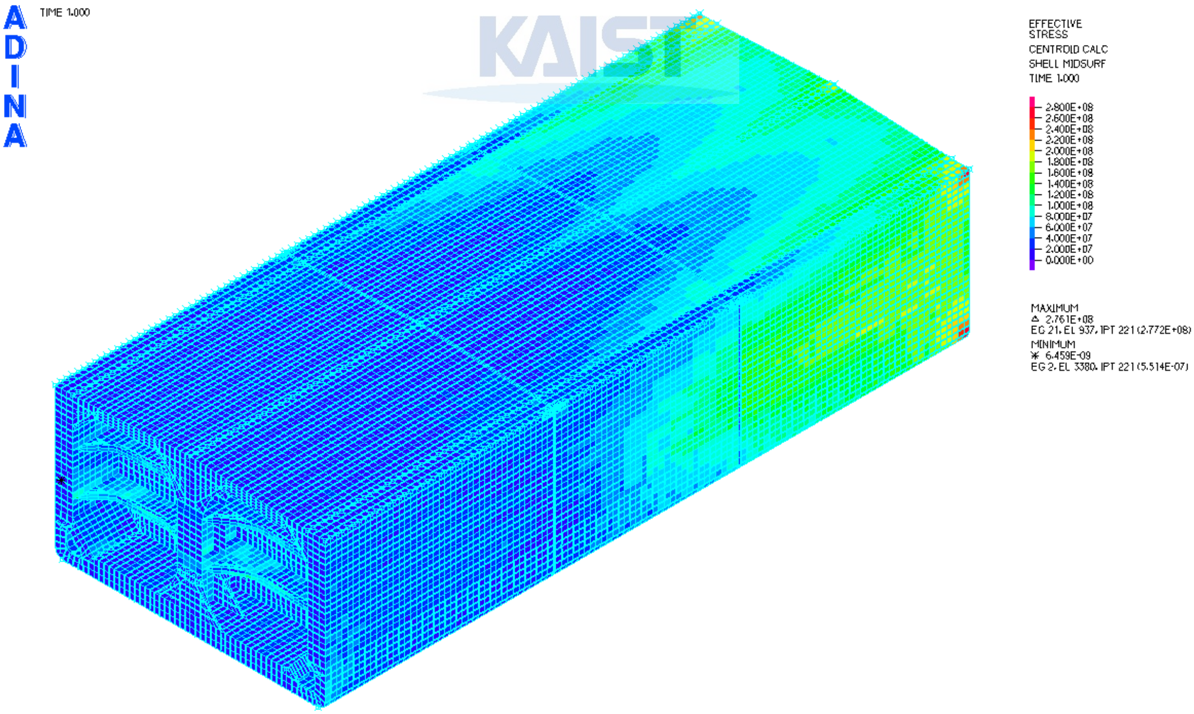
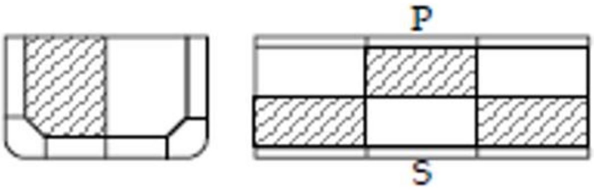



Fig. 3.22 Effective stress plot of loading case B2

## Loading case B3

For the loading case B3, ship is in head sea and sagging condition, draught is the 0.6 scantling daft. Inside the cargo tank of the ship, the cargo tanks on both sides of the model are filled with left half side of the tank, while the cargo tank in the middle is filled with right half side of the tank. The liquid cargo density is supposed to be 1000kg/m$^3$. Table 3.17 shows the detail of loading case B3.

Table 3.17 Loading pattern for case B3

| No. | Loading Pattern | Draught | Design sea |
|---|---|---|---|
| 3 |  | 0.6Tsc | Head sea |

The external pressure plot of loading case B3 is shown in Fig. 3.23, and internal pressure plot is shown in Fig. 3.24.



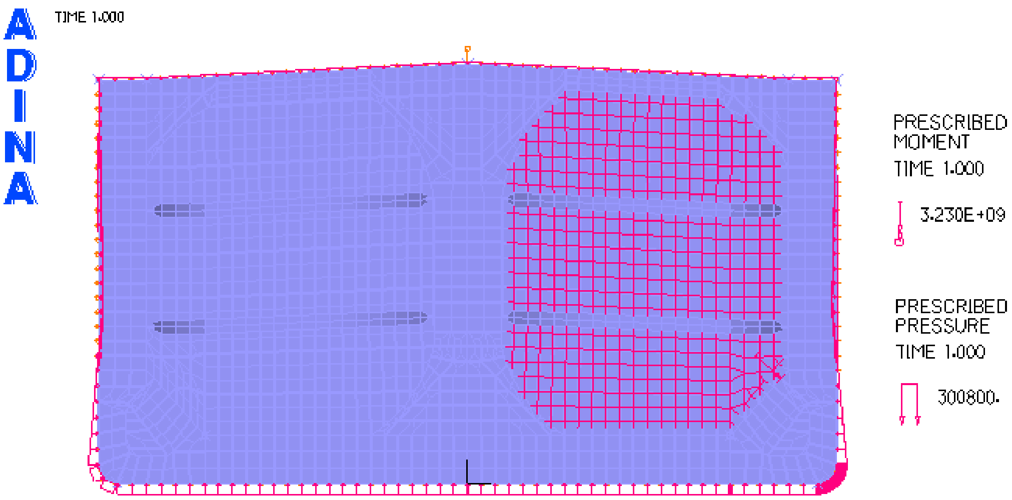



Fig. 3.23 External pressure plot of loading case B3

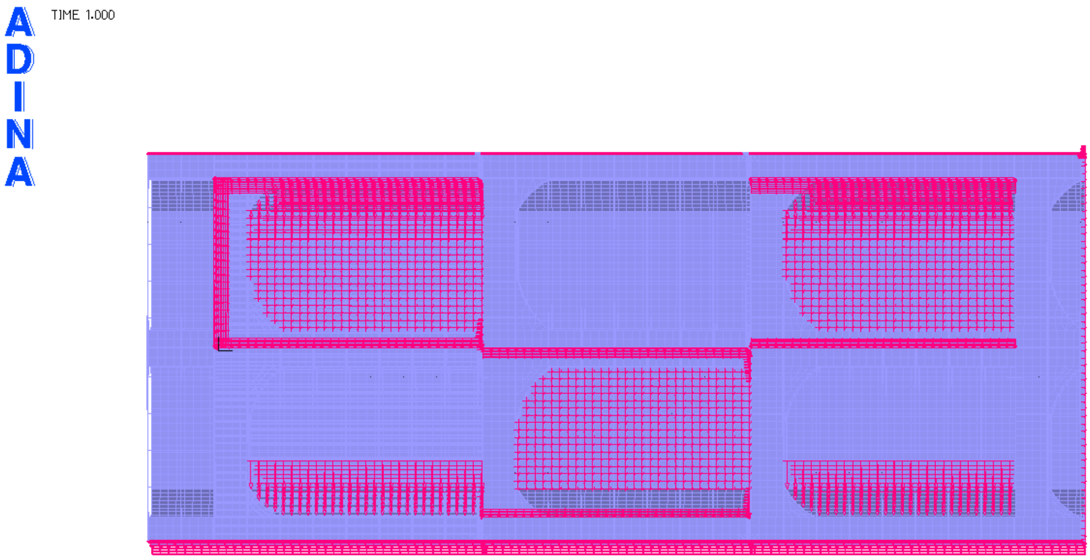



Fig. 3.24 Internal pressure plot of loading case B3

The analysis result of 3D cargo tank model attached with connective part of loading case B3 is shown in Fig. 3.25, and this is the result of effective stress.

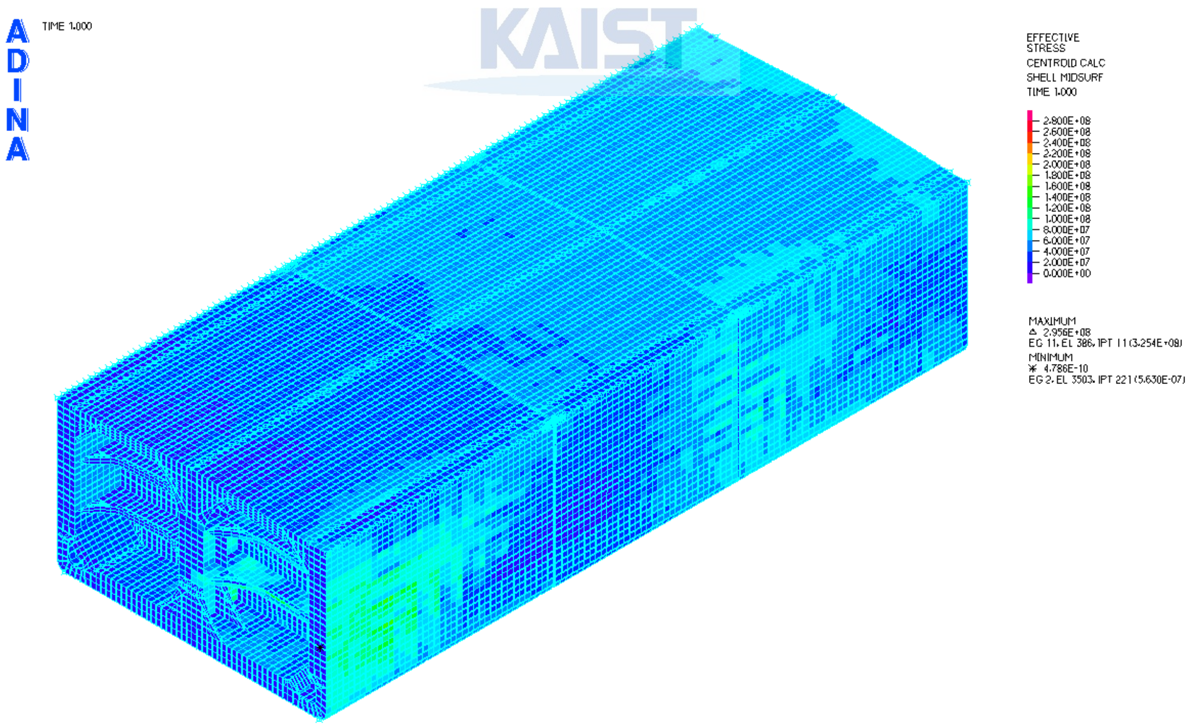



Fig. 3.25 Effective stress plot of loading case B3

### 3.3.2.3 Analysis results

Similar to the bulk carrier model, connective part of oil tanker model has been divided into 6 groups, which is totally the same with bulk carrier model. Firstly, the parameters for each group of the connective part are shown in Table 3.18. Since the structure strength of oil tanker ship is better than bulk carrier, the steel plate thickness of some group is thinner than bulk carrier model.

Table 3.18 Parameters of the connective part members for 3D cargo tank model

| Group | Group elements | Thickness (mm) |
|---|---|---|
| 1 | Concrete | 160 |
| 2 | Steel bars | - |
| 3 | Concrete inner side steel plate | 20 |
| 4 | Concrete outer side steel plate | 30 |
| 5 | Concrete connect steel plate | 25 |
| 6 | Deck | 25 |

The maximum permissible stresses for oil tanker ship are defined as $\sigma_{yd}\lambda$, where $\sigma_{yd}$ should be taken no greater than 315 N/mm², and for the structure on tank boundaries such as plating of deck and side plate, $\lambda \leq 0.9$. As a result, the maximum permissible stress for connective part's steel is 283.5 N/mm² [10].

The FE model analysis results for oil tanker ship of three loading cases have been collected. In the Table 3.19 shows the maximum effective stress of each group for connective part.

Table 3.19 Results of stress assessment of 3D cargo tank model

| | Items | Effective stress (Mpa) | | | Allowable stress (Mpa) |
|---|---|---|---|---|---|
| Loading condition | | B1 | B2 | B3 | |
| Group | Steel bar | 197.78 | 232.51 | 147.79 | 283.5 |
| | Concrete | 19.46 | 23.00 | 17.93 | 40 |
| | Concrete inner side plate | 108.40 | 109.56 | 126.53 | 283.5 |
| | Concrete connect plate | 166.70 | 189.71 | 126.64 | 283.5 |
| | Concrete outer side plate | 111.23 | 137.88 | 108.70 | 283.5 |
| | Deck | 86.57 | 268.56 | 106.82 | 283.5 |

It could be seen from the results that the effective stress level for connective part of oil tanker model is much lower than the bulk carrier ship model, for the reason that oil tanker ship has higher strength than bulk carrier ship due to the double-hull structure. For this analysis, concrete part is bearing low level stress, which is in the allowable range of concrete material.



About the other groups of the connective part, steel plates for connective part and steel bars all could meet strength requirement of steel material. Overall, the maximum effective stress of concrete, steel bars and steel plates could meet the strength requirement.

## 3.4 Torsional stiffness change by attaching connective part

For the ship hull with large deck openings such as bulk carrier ship or container ship, it is necessary to investigate the hull girder response to torsion since the large openings lead to worse torsional stiffness. By applying the steel-concrete composite connection method, it is supposed that the attachment of the connective part could help to increase the torsional stiffness of the ship structure. In order to prove this assumption, the response comparison to torsion between welding bulk carrier ship and the ship attached with connective part has been done. In this section, comparison results of effective stress and the torsional angle are shown.

### 3.4.1 Bulk carrier model for torsional stiffness analysis

To find out the torsional stiffness change caused by connective part attachment, the 3D cargo hold model with connective part and the model without connective part need to be constructed. The model with connective part has already been constructed in previous section, and the 3D cargo hold model without connective part is constructed as well, which plot is shown in Fig. 3.26.

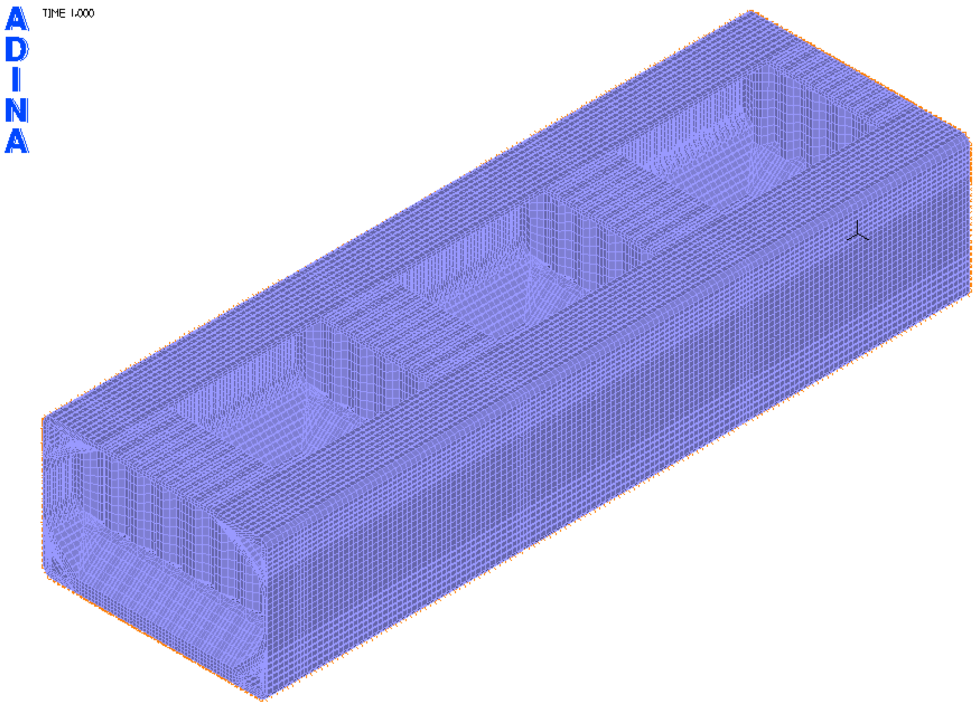



Fig. 3.26 3D cargo hold model without connective part



### 3.4.2 Loading condition and boundary condition for torsional stiffness analysis

#### Loading condition

In the torsional stiffness analysis, a single torsional moment is applied on each model. According to the CSR for bulk carriers, the torsional moment is calculated as follows. The wave torsional moment at any hull transverse section, in KN·m, is given by:

$$M_{WT} = f_p(|M_{WT1}| + |M_{WT2}|) \tag{4.1}$$

Where:

$$M_{WT1} = 0.4C\sqrt{\frac{L}{T}}B^2 DC_B F_{T1} \tag{4.2}$$

$$M_{WT2} = 0.22CLB^2 C_B F_{T2} \tag{4.3}$$

$F_{T1}$ , $F_{T2}$ are the distribution factors, which is defined as follows.

$$F_{T1} = \sin(\frac{2\pi x}{L}) \quad (4.4)$$

$$F_{T2} = \sin^2(\frac{\pi x}{L}) \quad (4.5)$$

$$C = 10.75 - (\frac{300 - L}{100})^{1.5} \quad (4.6)$$

According to the parameters of the bulk carrier ship and the above equations, the wave torsional moment to be applied on the models is calculated to be $5.21 \times 10^5 KN \cdot m$ .

### Boundary condition

The boundary condition for torsional stiffness analysis is applied on the unloaded end of the model. All degrees of freedom at the nodes of the unloaded end of the model are fixed, and the other end of the model are set to be free. This boundary condition could be more representative of real ship hull structures for torsional stiffness analysis [17].



### 3.4.3 Torsional stiffness analysis results

In order to figure out the torsional stiffness of the two models, effective stress and the torsional angle of both models are compared. Firstly, we focus on the effective stress result. The effective stress result of 3D cargo hold model attached with connective part is shown in Fig. 3.27, and result of 3D cargo hold model without connective part is shown in Fig. 3.28.

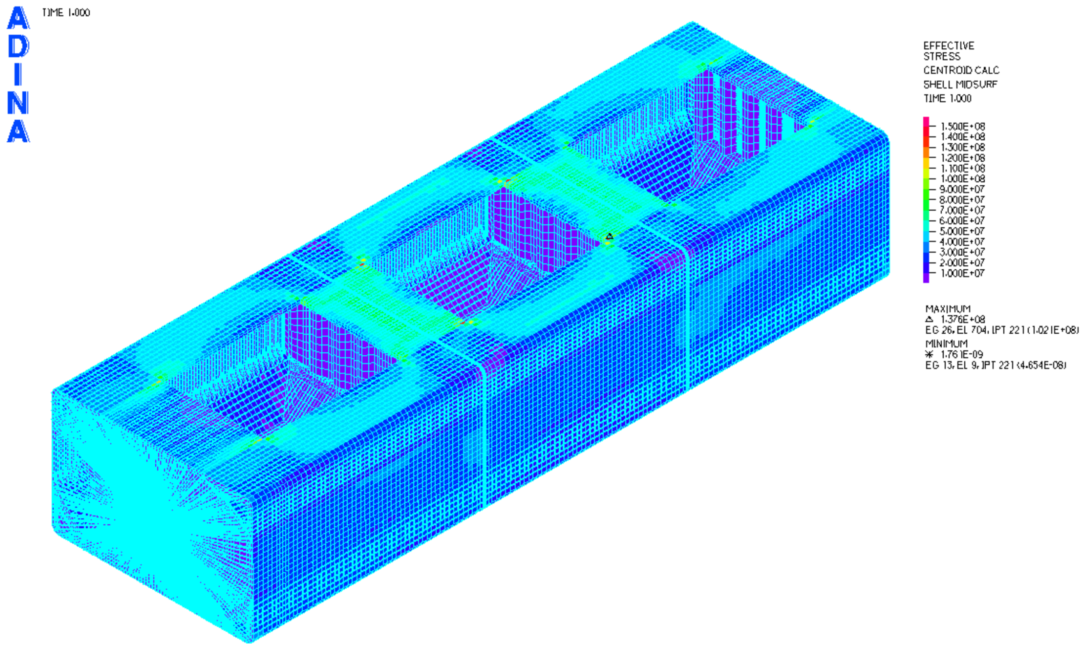



Fig. 3.27 Effective stress plot for torsional stiffness analysis of the model attached with connective part

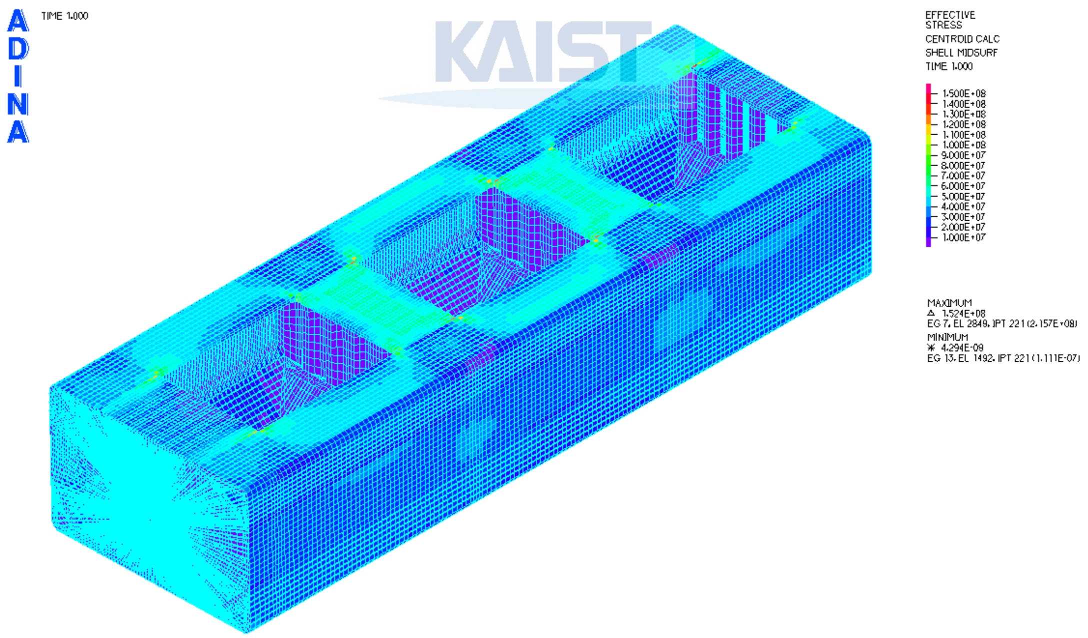



Fig. 3.28 Effective stress plot for torsional stiffness analysis of the model without connective part

From the Fig. 3.27 and Fig. 3.28, it is not easy to find out the difference of the effective stress between the two models. As a result, the maximum effective stresses of each section of the ship have been compared, which is shown in Table 3.20.

Table 3.20 Results of torsional stiffness comparison

| Section | 3D cargo hold model with connective part | 3D cargo hold model without connective part | Percentage change |
|---|---|---|---|
| | MPa | MPa | |
| Transverse bulkhead | 27.04 | 58.37 | -53.7% |
| Stool | 152.21 | 139.53 | 9.1% |
| Inner bottom | 14.58 | 15.08 | -3.3% |
| Topside tank bottom | 124.33 | 215.84 | -42.4% |
| Longitudinal girder | 94.17 | 162.18 | -41.9% |
| Cross girder | 136.81 | 129.08 | 6.0% |
| Deck knee | 94.12 | 165.73 | -43.2% |
| Side plate | 41.26 | 42.61 | -3.1% |
| Downside tank bottom | 20.62 | 140.74 | -85.3% |
| Deck | 84.65 | 184.05 | -54.0% |
| Outer bottom plating | 37.27 | 40.64 | -8.3% |



From the results shown in Table 3.20, it could be seen that when the ship model is applied torsional moment, the maximum effective stress for most of the sections of the model that attached with connective part is much lower than the effective stress of model without connective part. We can infer that the attachment of connective part could help to increase the strength of the whole ship to resist torsional moment.

Secondly, the torsional angle caused by the torsional moment of the two models has been compared. According to the finite element analysis results, the torsional angle of the model without connective part is 0.02188 radians, while the torsional angle of the model attached with connective part is 0.00216 radians. It could be seen that the torsional angle of model attached with connective part is much smaller than the torsional angle of the model without connective part, and the torsional stiffness has been increased for about 7 times because of the attachment of the connective part.

# Chapter 4. Economic feasibility

To apply the steel-concrete composite connection method into practical ship construction, economic feasibility of the steel-concrete composite connection method need to be studied. Since the steel-concrete composite connection method is independent of dock facilities, it is supposed that by applying this method, the construction cost could be saved in some degree, also the operation cost is supposed to be no difference with welding ship. Another issue is the weight change caused by applying steel-concrete composite connection method. The attachment of the connective part is supposed to influence the ship weight in some degree, as a result, the weight change percentage need to be figured out.

In this chapter, the comparison of steel-concrete composite connection method and welding method's construction cost and operation cost are described. Also the weight change caused by the attachment of connective part is figured out.

## 4.1 Cost estimation



The steel-concrete composite connection method for ship building blocks at sea is a new concept that has not been used before. After its strength safety has been checked, another big issue is the economic performance. In this section, the comparison of construction cost and operation cost are done between the ship that apply steel-concrete composite connection method and welding method.

### 4.1.1 Construction cost

To figure out the economic performance of the steel-concrete composite connection method, the construction cost is figured out first. For the reason that the exact construction cost could not be gained from shipyards, the cost shown in this section are all the estimated cost. Firstly, the target ship of this comparison is chosen to be the same bulk carrier target ship for strength assessment. This ship has 7 cargo holds that attached with 6 connective part, which is shown in Fig. 4.1. For the ship that dead weight ton is around 80,000 ton, the ship price is estimated to be $ 31,500,000 [18]. Usually the profit margin of shipyard is around 15% [19], as a result, the construction cost for this ship is estimated to be $ 26,775,000.

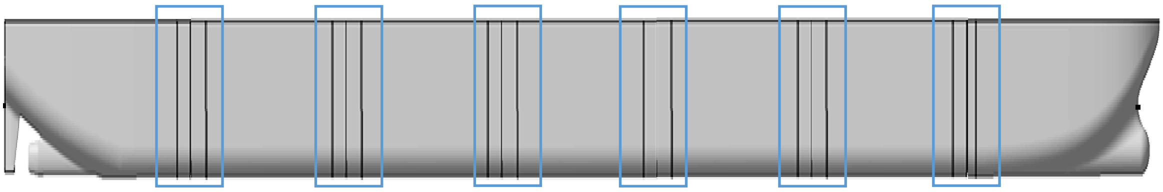


Fig. 4.1 7 Cargo holds attached with 6 connective parts

Ship construction cost is consist of four aspects, which are material cost, labor cost, overhead cost and product design cost, and the percentage of each item is shown in Table 4.1. Since the ship construction cost has been estimated, based on the data given in Table 4.1, the cost of each aspect could be estimated as well.

Table 4.1 Items of ship construction cost

| Ship construction cost | Percentage |
|---|---|
| Material | 50% |
| Labor | 15% |
| Overhead | 30% |
| Product design | 5% |

The items of construction cost that are different between steel-concrete composite connection method and welding method are estimated in Table 4.2. The amount of concrete is estimated based on the size of connective part. Since this method has never been used before, the bolting labor amount and tug boat usage time are all estimated.

Table 4.2 Cost items estimation process

| Items | Amount | Unit price | Price |
|---|---|---|---|
| Concrete | 29.7 $m^3$ | $\$130/m^3$ | 3,568 |
| Concrete labor cost | 29.7 $m^3$ | $\$80/m^3$ | 2,376 |
| Bolting labor cost | 320 hour | $20/hour | 6,400 |
| Tug boat | 48 hour | $1000+150/hour | 9,200 |
| dock fee | 40 days | $5045.2/day | 201,809 |

Dock usage time of shipyard is around 29 days to 100 days [20], and for this estimation, the dock usage period is supposed to be 40 days. Since the steel-concrete composite connection method is independent of dock facilities, the dock fee need to be excluded from the cost. Also, since the ship blocks are connected at sea, launching fee could be saved as well.

The unit price of concrete [21], concrete labor cost [22], bolting labor cost [23] and tug boat cost [24] have been collected, and the dock maintenance fee is estimated to be $5045.2/day.

The construction cost comparison between the ships that connected by applying steel-concrete composite connection method and welding method is shown in Table 4.3. It could be seen that for this bulk carrier target ship, by applying steel-concrete composite connection method, the construction cost could be saved for $240,265, which is about 0.90% of the construction cost.

Table 4.3 Ship construction cost comparison

| Ship construction cost | Steel-concrete composite connection method | Price($) | Welding method | Price($) |
|---|---|---|---|---|
| Material | Basic material | 13,387,500 | Basic material | 13,387,500 |
| | Concrete | 3,568 | | |
| Labor | Basic labor | 4,016,250 | Basic labor | 4,016,250 |
| | Concrete labor cost | 2,376 | | |
| | Bolting labor cost | 6,400 | | |
| Overhead | Basic overhead | 8,032,500 | Basic overhead | 8,032,500 |
| | Dock fee | -201,809 | | |
| | Launching fee | -60,000 | | |
| Product design | Basic product design | 1,338,750 | Basic product design | 1,338,750 |
| Extra equipment | Tug boats | 9,200 | | |
| Total cost | | 26,534,736 | | 26,775,000 |
| Cost save amount: $ 240,265 (0.90%) | | | | |

### 4.1.2 Operation cost

Cost is always considered in two aspects, construction cost and operation cost. The construction cost is in the sight of shipyard, and ship operation cost is in the sight of ship-owner. Since the steel-concrete composite connection method has never been used before, the cost could not be estimated directly. In Table 4.4 shows the ship operation cost items, and the percentage of each item is listed [25].

Table 4.4 Ship operation cost items

| Classify | Items | Percentage | Determinant |
|---|---|---|---|
| Variable cost | Fuel surcharge | 13% | Ship size<br>Ship weight<br>Load capacity<br>( 95% ) |
| | Port charge | 15% | |
| Fixed cost | Depreciation cost | 33% | |
| | Insurance expense | 8% | |
| | Lubrication fee | 4.9% | |
| | Crew cost | 12% | |
| | Management fee | 5% | |
| | Spare part fee | 3.6% | |
| | Communication fee | 0.5% | |
| | Ship survey fee | 0.5% | Ship structure<br>Ship size<br>Facilities<br>( 5% ) |
| | Voyage repair fee | 3.8% | |
| | Dock repair fee | 0.7% | |
| Sum | | 100% | |

In the above table, it could be seen that the ship operation cost is divided into variable cost and fixed cost. Of these items, the fuel surcharge, port charge, depreciation cost, insurance expense, lubrication fee, crew cost, management fee, spare part fee and communication fee are depended on the ship size, ship weight and load capacity, which percentage are 95% of ship operation cost. By applying connective part, ship size, ship weight and load capacity is supposed to be almost no difference with welding ship. As a result, the 95% of the operation cost is of no difference with welding ship’s operation cost.

About the rest 5% of the ship operation cost are ship survey fee, voyage repair fee and dock repair fee. These costs are depended on ship structure, ship size and facilities. For the attachment of connective part, the ship structure is a little bit different from the welding ship. But when focus on the ship survey fee, we suppose that the concrete part would be a little bit different with the welding ship, but ship survey fee is only 0.5% of the whole cost, we suppose the difference could be ignored. Also, about ship repair fee, the attachment of the connective part would not increase the rate of reparation. As a result, the rest 5% of the whole cost is also supposed to be almost the same with welding ship. Finally, we suppose that operation cost of the ship that apply steel-concrete composite connection method is no difference with welding ship's operation cost.

## 4.2 Connective part weight estimation

The attachment of the connective part to ship blocks may lead to weight change for the whole ship, and as we all know that the weight of the ship is very important since the cargo capacity of the ship is directly influenced by it. As a result, the weight change caused by connective part is estimated.

In this section, the ships used for weight estimation are the same target ships for strength assessment, and the weight of the ship is collected from the finite element model. The weight and cargo volume comparison between welding ship and the ship applied steel-concrete composite connection method are shown in Table 4.5.



Table 4.5 Ship hull weight and volume change

| | Items | Welding method | Steel-Concrete connection method | Difference | Change percentage | Deadweight ton (Weight change percentage) |
|---|---|---|---|---|---|---|
| Bulk carrier (Single hull) | Hull weight (ton) | 28,864.5 | 28,919.1 | +54.6 | +0.18% | 80,000 (0.07%) |
| | One cargo hold volume ($m^3$) | 14,558.7 | 14,548.3 | -10.4 | -0.07% | |
| Oil tanker (Double hull) | Hull weight (ton) | 41,990.4 | 42,071.6 | +81.2 | +0.19% | 159,000 (0.05%) |
| | One cargo tank volume ($m^3$) | 26459.4 | 26459.4 | 0 | 0 | |

Firstly, focus on the bulk carrier ship. By applying the steel-concrete composite connection method, the hull weight increased for 54.6 ton, which is 0.18% of the hull weight, and compare this weight increase to deadweight ton of the ship, it is only 0.07% of the deadweight ton. About the volume change, since the bulk carrier ship is single hull structure, the cargo volume is influenced by the connective part, and the cargo volume is cut for 10.4 $m^3$, which is about 0.07% of the whole cargo volume.

Secondly, focus on the oil tanker ship. By applying the steel-concrete composite connection method, the weight increased for 81.2 ton, which is 0.19% of the hull weight, and compare this weight increase to deadweight ton of the ship, it is only 0.05% of the deadweight ton. About the volume change, since the oil tanker ship is double hull structure, the cargo volume is not influenced by the connective part at all, so the cargo volume is not changed at all.

From the above comparison, it could be seen that the attachment of the connective apart almost bring no influence to the ship weight and cargo volume, which means that the application of steel-concrete composite connection method almost do not cut cargo capacity of the ship.

# Chapter 5. Conclusions

We have proposed a steel-concrete composite connection method for ship building blocks at sea, which is to do the ship blocks connection at sea by adopting bolting, welding and gluing method. By applying this method, shipyard construction ability could be increased considerably. Since this is a totally new concept for ship blocks connection, we conducted strength analysis for the ship hull attached with connective part to check its safety, also the economic feasibility of this method has been discussed in various aspects. From the analysis results, conclusions are drawn as follows.

Firstly, the strength analysis for steel-concrete composite connection method has been done in accordance with the CSR. From the analysis results, we could see that the number of steel bars for one section is in the acceptable range of the practical construction needs, also the connective part that attached to the ship hull could meet the strength requirement. Not only that, for the ship with large deck openings such as bulk carrier ship or container ship, the attachment of connective part could help to increase the torsional stiffness of the ship for a large degree.

Secondly, the cost comparison has been done between steel-concrete composite connection method and traditional method. It turns out that by applying steel-concrete composite connection method, construction cost could be saved in some degree, also the ship operation cost is supposed to be no difference with welding ship.

Thirdly, ship cargo capacity is a very important property. Although the ship hull is attached with connective part, according to the weight calculation results, cargo capacity of ship is almost not influenced by the connective part.

Local strength assessment such as local fatigue and buckling need to be conducted in the future, other CSR requirements must be investigated, and the stability of each ship block will be checked in the future. Also, future calculation need to be done to minimize the size of connective part to ensure that this steel-concrete composite connection method can be applied in practical construction.

Since the ship size is getting bigger and shipyard pursue better construction ability, this steel-concrete composite connection method provide a new way to connect ship blocks and large offshore structure blocks at sea. For the easy connection procedure and good economic performance, we suppose that this method could be wildly used in the future.

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**Summary**

# A Steel-Concrete Composite Connection Method for Ship Building Blocks at Sea and Its Feasibility

본 연구에서는 선박 블록의 철강 콘크리트 해상 결합 방법을 제안한다. 이 방법의 핵심 개념은 용접, bolting, gluing 방법을 이용해 선박 블록들을 해상에서 결합 하는 것이다. 이 경우 조선소 도크의 사용시간을 줄여주어 선박 생산 효율을 높일 수 있고, 생산비도 절약할 수 있다. 본 연구에서는 선박 블록 해상 결합의 실행 가능성을 입증하기 위해 표적선 두 척의 모델을 제작하여 연결블록을 (connective part) 사용시의 선박 안전성을 조사 하였다. 첫째로 연결블록의 초기 설계를 통해 steel bar 의 수량 및 콘크리트의 두께를 결정하였고, 구축된 모델을 유한 요소법을 통해 세밀하게 구조 해석 하였다. 두 번째로 위 방법의 경제성을 도출하기 위해 생산비 및 운영비를 고려하여 기존 선박 건조방법과 비교하였으며, 이때 연결블록을 사용하여 증가 할 수 있는 선체중량까지 함께 고려하여 분석 하였다. 본 연구의 해석결과에 따르면, 위에서 제시한 선박 블록의 철강 콘크리트 해상 결합 방법이 실제 조선 산업의 선박 건조방법에도 적용 가능성이 있음을 알 수 있다.

핵심어: 선박 블록 결합 방법, 구조 설계, 응력 평가, 유한 요소법, 경제성