Journal of the Korean Society of Marine Environment & Safety
Vol. 19, No. 3, pp. 290-301, June 30, 2013 (pISSN 1229-3431 / eISSN 2287-3341)

Research Paper
http://dx.doi.org/10.7837/kosomes.2013.19.3.290

# Parametric Study for Assessment of Reaction Forces on Ship Docking Supports

Cheol-Ho Ryu*† · Sung-Chan Kim** · Jang-Hyun Lee***

*, ** Dept. of Naval Architecture and Ocean Engineering, Inha Technical College, Incheon, 402-752, Republic of Korea
*** Dept. of Naval Architecture and Ocean Engineering, Inha University, Incheon, 402-752, Republic of Korea

Abstract : *The docking analysis of a global ship structure is requested to evaluate its structural safety against the reaction forces at supports during docking works inside a dry dock. That problem becomes more important recently as the size of ships is getting larger and larger. The docking supports are appropriately arranged in a dock to avoid their excessive reaction forces which primarily cause the structural damages in docking a ship and, up to now, the structural safety has been assessed against the support arrangement by the finite element analysis (FEA) of a global ship structure. However, it is complicated to establish the finite element model of the ship in the current structural design environment of a shipyard and it takes over a month to finish the work. This paper investigates a simple and fast approach to carry out a ship docking analysis by a simplified grillage model and to assign the docking supports position on the model. The grillage analysis was considered from the motivation that only the reaction forces at supports are sufficient to assess their arrangement. Since the simplified grillage model of the ship cannot guarantee its accuracy quantitatively, modeling strategies are proposed to improve the accuracy. In this paper, comparisons between the proposed approach and three-dimensional FEA for typical types of ships show that the results from the present grillage model have reasonably good agreement with the FEA model. Finally, an integrated program developed for docking supports planning and its evaluation by the proposed approach is briefly described.*

Key Words : *Ship docking, Docking analysis, Docking supports planning, Grillage analysis, Reaction force*

## 1. Introduction

A ship docking analysis is a kind of static analysis to evaluate the structural safety of a ship in the condition to be supported by many pillar structures (Fig. 1) inside a dry or floating dock, not in the sea-going condition. This docking analysis is not a regulation of a classification society since a docking load is not in the sea-going condition, but is strongly required by ship owners. As a shipbuilding industry has been radically expanded, a new production technique has been attempted to improve its productivity and thereby unpredicted structural failures have been encountered. The docking problem is one of them which result from the enlargement of a ship and its block size. The load concentration at supports causes a damage of a bottom structure. A tanker, a bulk carrier, and a FPSO are liable to be exposed to excessive concentrated load owing to their heavy weight. And a containership and a LNG/LPG carrier are apt to experience excessive concentrated load at their slender bow and stern. A good production planning or a good arrangement of supports inside a dock can provide a solution to avoid a heavy load which may be beyond an allowable value at the supports. But a shipyard wants to determine a docking plan at design phases, not production phases, in order to improve the productivity. Also docking analysis has attracted attention by increasing requirement of industrial safety for the docking work.

For the robust docking work, Hedger(2005) published training manual for a dock master in the united states. He pointed that dockmasters are not structural or marine engineers and are not expected to design dry docks but a basic understanding of how a dock is designed and built provides insight into how and why the dock’s operational limitations have been derived can assist the dockmaster when he is assessing situations that do not meet standard operating procedures. Cheng et al.(2004) proposed how to design optimal and robust docking supports in the uncertain conditions for loading from the ship and material properties of the supports. Bryant et al.(1991) investigated strength characteristics of the docking timbers and their built-up blocks. Such strength properties of docking supports for docking analysis to calculate the reaction forces must be obtained, but most shipyards uses their own properties established through many structural experiments.

A three-dimensional finite element method (FEM) is a primary tool to evaluate a ship structural safety through design phases. Owing to the remarkable improvement of numerical analysis technology and computers, the 3D FEM has been successfully

---

† Corresponding Author : cheolho_ryu@inhatc.ac.kr, 032-870-2173

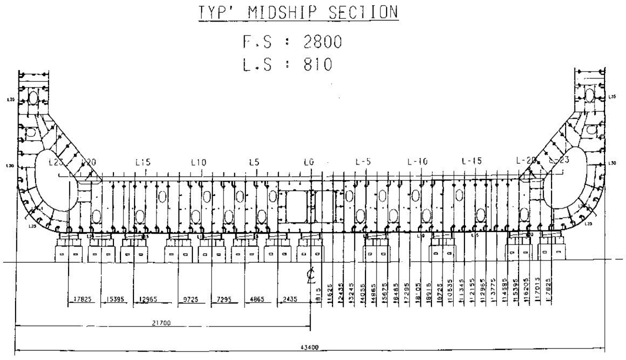


Fig. 1. Sectional illustrations for a docking supports.

applied to ship design process in spite of the computational load of a large and complex numerical ship model. Such efforts have been made without an exception in the docking analysis. Choi et al.(2002) developed an application to carry out the docking analysis in MSC.ACUMEN, a kind of 3D FEA tool. It is not regular to make the big FE model of a whole ship only for a 3D docking analysis as that is not a mandatory demand of ship classification societies. Therefore, any FE models available from other analyses have been reused in the docking analysis. The application developed by Choi et al.(2002) supports a 3D docking analysis that is conducted with the existing FE models. Chun et al.(2006) proposed how to evaluate structural safety in docking a ship. They examined the causes of damages which may occur in a docking process and the characteristics of reaction forces for materials of docking supports. Also, they suggested a method to estimate allowable reaction force for the damage protection of hull structures. They used 3D FEM of a whole ship in their work.

This 3D FEM is apparently a good tool to assess impacts of a given docking plan on a ship structural safety since ship structures are exactly represented, its light weight and the ballast condition can be practically and smoothly absorbed into the FE model as static external loads and consequently those ensure the accuracy of the analysis results. However, it is told that it takes over a month to make a complete 3D FE model of a whole ship, a big and complex steel structure. Even though any FE models of the ship are available, it takes a lot of time and effort to fix them for the docking analysis. And there may be many cases that it is not possible to obtain any FE model of the ship due to the design time frame in a shipbuilding industry. The time when a ship owner requests a docking analysis or when a docking planning is reported can be prior to the release of its complete structural drawings. That means the lack of data which are expected in order to make a 3D FE model for a docking analysis.

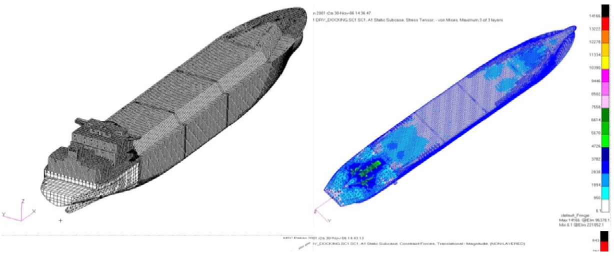


Fig. 2. A sample (LNG Carrier) of 3D docking analysis.

The authors have employed a two dimensional grillage method for the docking analysis whereby the docking supports are easily arranged and the docking plan could be quickly evaluated despite the lack of ship design data at an initial design phase(Kim et al., 2008). In order to improve the accuracy of the simplified grillage analysis for a docking support planning, the further studies for variables subject to stakeholders' practices of the docking analysis are required. For example, the section properties of beam elements and compensation of loads which lose when simplified from 3D structure to 2D grillage are dominant factors. In this paper, we will in detail explain the simplified docking analysis with a mathematical formulation of a load estimation, propose strategies to improve its results or reaction forces at docking supports through further parametric studies of the sample grillage models. Also, a ship docking analysis and planning system is integrated so that end users can easily make a 2D grillage model of a ship and define support positions in a shipyard.

## 2. Three Dimensional Ship Docking Analysis

As previously mentioned in the introduction, a ship docking analysis is performed to evaluate structural safety of a ship against a concentrated force at docking supports inside a dry or floating dock, not in a sea-operational condition. That is usually pushed by request of a ship owner and also a special production event concerned with docking.

Few studies about the ship docking analysis have been found in the literatures to our knowledge. A ship classification society or Lloyd's Register (LR) reported a simple two-dimensional (2D) Grillage analysis of an oil tanker in which ship structure parts were modeled by beam elements and the grillage model was used to assess structural strength and safety against a static docking condition according to Choi et al.(2002). Also the LR proposed how to put a load distribution to bottom grillage model. Since this simplified grillage analysis really gives not the stress inside the

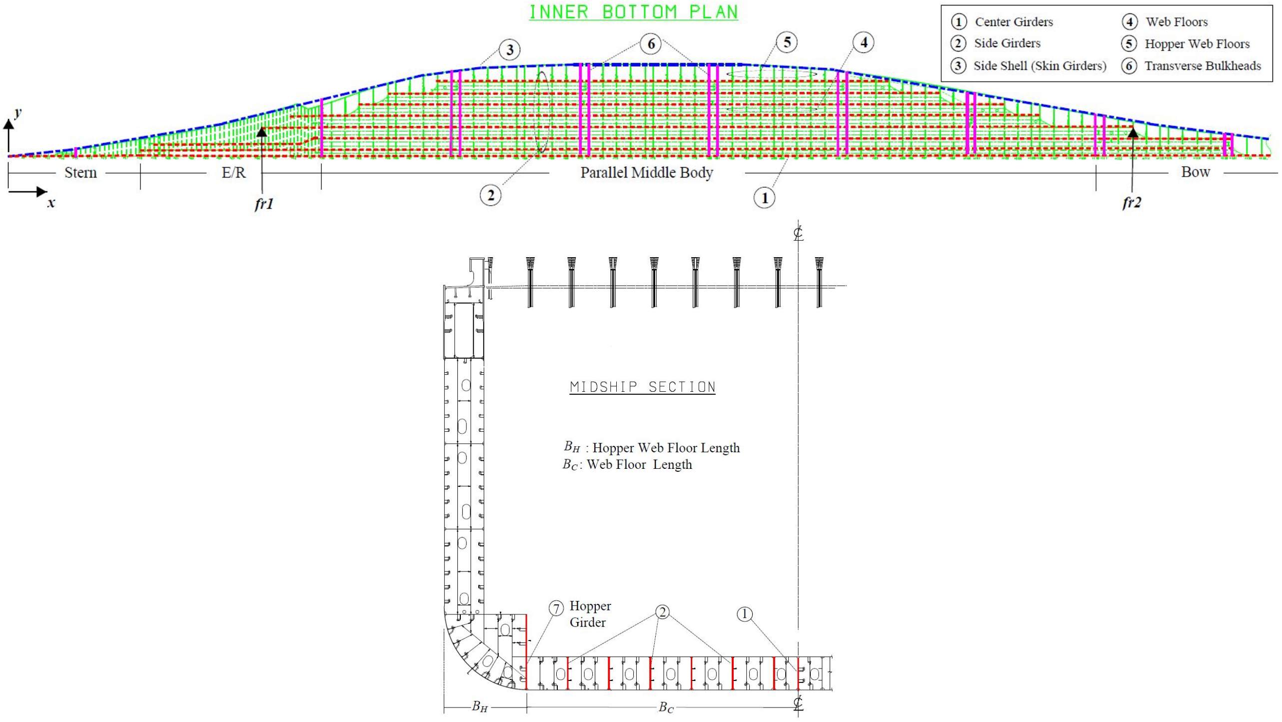


Fig. 3. Definition of a grillage model for 2D docking analysis
(a) Inner bottom plan and selected structural members and (b) Midship section drawings

elements but reaction forces at the boundary constraints, the strength of bottom structures or the buckling problem was separately investigated against reaction forces at the docking supports(Chun et al., 2006; Fujikubo, 2005).

For a couple of decades, the outstanding development of computers and numerical methods has made a three dimensional finite element analysis of a big and complex marine structure possible. Such FEA for sea-operational conditions became mandatory to all the ship by ship owners and ship classifications. Even though the docking analysis is not mandatory from their regulations, that has been carried out with the help of 3D FEA for a whole ship as depicted in Fig. 2. The figure shows a 3D docking analysis of a containership with its 3D FE model, position of docking supports, and stress distribution over the bottom. The shipyard followed an static elastic analysis procedure suggested by the LR in which each docking support is modeled by a spring element and a docking load condition is considered as an external load case. The docking load condition includes light weight of a ship and ballast load cases. As the ballast water tanks are filled with sea or fresh water to keep the trim of the ship while launching, the ballast load cases should be investigated. Finally, the strength and safety of the docking supports and the bottom structures is evaluated from analysis results, the reaction forces at the supports and the stress distribution over the bottom.

## 3. Two Dimensional Ship Docking Analysis Model

The shipyards have tried to reduce FE modeling man-hours spent with the 3D docking analysis and to overcome the possible lack of structural design data, understanding the drawbacks in 3D FEM. They came to be interested in a two dimensional grillage analysis again even though the 3D FEM outperforms in assessing structural strength and safety and have made a research in how to improve its accuracy. The grillage docking analysis presented in this paper will also employ overall practices of the LR as we could not find what other classification societies recommend. From now on, the efforts to obtain reliable results from a simplified docking analysis will be explained in detail.

A grillage model in the conventional 2D grillage analysis is made from main structural parts, that is, transverse parts of web floors and transverse bulkheads and longitudinal parts of girders, longitudinal bulkheads, and side shell as illustrated in Fig. 3 and

Fig. 4 (Rigo and Rizzuto, 2003). They can be identified from a tank top plan drawing and construction profile drawings at the centerline.

The completeness of this grillage model has difficulties in (1) calculating load distribution from static docking condition, (2) calculating transverse load distribution, and (3) calculating section properties of beam elements. It is explained in this section how the 2D ship docking analysis is improved and automated in these three aspects after describing how to simplify a ship structure to its grillage model. The improvements will enable results of this simplified 2D docking analysis to have a good agreement with those of a 3D docking analysis within an allowable range.

### 3.1 Simplified Grillage Model of a Whole Ship Structure

As previously mentioned, a grillage model of a global ship structure in the conventional 2D grillage analysis is made from main structural members, which can be identified from a tank top plan drawing and midship section drawings, e.g. Fig. 3. The main structural members include transverse parts of web floors and transverse bulkheads and longitudinal parts of girders, longitudinal bulkheads, and side shell which are colored and numbered in the figures. In our grillage model, the secondary members in the bottom structure such as longitudinal stiffeners and small parts are not taken into consideration.

The longitudinal members are grouped to two classes, a girder group and a skin girder group, in our grillage model. The side shell is assigned to the skin girder group linearly approximating the outer contour of the tank top. The girder group primarily includes center and side girders. Also the longitudinal bulkheads can belong to the girder group such as VLCC. In the case of a double hull ship, its inner hull structures are usually identified to skin members but, in this study, involved in the girder group. Position information of the longitudinal members are identified in terms of the starting frame number $fr_1$, the starting $y$ coordinate value $y_1$, the finishing frame number $fr_2$, and the finishing $y$ coordinate value $y_2$ from the tank top plan or inner bottom plan. Their $x$ coordinate values with each frame $fr_1$ and $fr_2$ can be easily obtained from the frame system which is a prerequisite for establishing the grillage model.

The transverse members are divided by a floor group and a hopper web floor group in our model. The floors in the bottom structure and the transverse bulkheads are included in the floor group. The extended hopper web floors, which will be explained in detail later, are assigned in the hopper web floor group. The transverse members can be sufficiently identified in terms of each frame number $fr_1$ as they are positioned on the frame intentionally for design convenience. Their $x$ coordinate values can be calculated easily from the frame system. But the $y$ coordinate values of floors and hopper web floors are differently computed. A floor starts on the center line ($y$=0) and ends at intersection with any skin girder. A hopper web floor starts from the end of its connected floor and ends outside the skin girder by its extension length.

It is recommended that the structural members are selected, longitudinally separating a ship into four domains: stern, engine room (E/R), parallel middle body and bow. In the parallel middle body, girders which pass from aft body to fore body, partial girders which cross beneath the transverse bulkheads and hull structures are selected as the longitudinal members. Also the floors on the frames are considered as the transverse members. Since the transverse bulkheads are usually located on the floors, they are not regarded as separate members but specially taken into account in determining section properties. In other areas of stern, E/R and bow, special caution is necessary since their structures are more complex than that of the parallel middle body. The members in the complex areas should be chosen so that the docking loads can be transferred to adjacent members like behavior of 3D real structures. The partial girders and the side shell belong to their longitudinal groups, respectively girders and skin girders, and the floors on the frames are assigned to the transverse members. Like in the parallel middle body, the transverse bulkheads are not separate grillage members. Fig. 4 shows the complete grillage model.

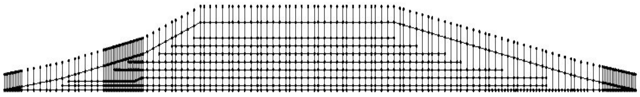


Fig. 4. A finished grillage model from Fig. 3.

### 3.2 Calculation of Load Distribution

The ship docking is governed by two load conditions: the light weight distribution of a ship and the distribution of ballast waters. These can be easily applied in the 3D docking analysis by defining material density of finite elements, gravity acceleration, and external distributed loads. But the load distribution should be separately computed in order to assign the docking load conditions to the grillage model in the 2D docking

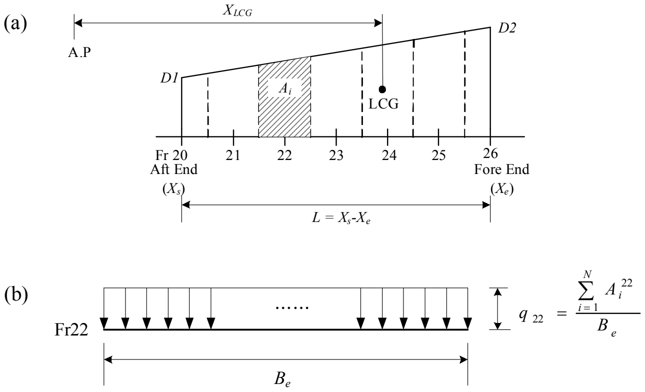


Fig. 5. A schematic diagram for definition of load distribution. (a) The *i*-th weight or load distribution and its discretization at affected frames, and (b) Transverse uniform distribution from a lumped load at a sample frame(modified from Kim et al, 2008).

analysis. A two-step calculation of a docking load distribution is presented in this paper as depicted in Fig. 5: firstly computing lumped longitudinal loads along frames and then computing a transverse uniform distribution along breadth of each frame from its lumped longitudinal load.

Two data sets are requested while computing the load distribution: a light weight distribution from a ship design system and a docking condition from trim & stability tests. Both of them are available at the initial design phase. The light weight distribution data includes weight ($W$), longitudinal positions ($X_s$ and $X_e$), and longitudinal center of gravity ($X_{LCG}$) of all the hull structures and additional equipments. The trim & stability (T&S) test case gives those of the fuel oil and the ballast water. The longitudinal load (weight) distribution can be estimated from them. As the load is primarily transferred through main structural parts, we assume that the load is longitudinally lumped at each frame on which web floors and transverse bulkheads are located. Thereby, the lumped longitudinal load is defined in terms of a frame position. The transverse load is obtained by uniformly distributing the lumped longitudinal load at a frame along the breadth of the frame. Since there is no way to get the transverse load data of a ship such as the longitudinal case, the uniform distribution is assumed.

Fig. 5(a) depicts how a weight $W$ of any hull structure or equipment is longitudinally lumped at a frame. As mentioned previously, all the load items are given in terms of weight ($W$), longitudinal positions ($X_s$ and $X_e$), and longitudinal center of gravity ($X_{LCG}$). Therefore, it is necessary to approximate their distributions over their own effective areas in order to compute the load between $X_s$ and $X_e$, and those are assumed to a linear function with $D1$ and $D2$ at both ends where the centers of gravity (LCGs) of the approximated distributions are coincident with their given $X_{LCG}$. In the case of Fig. 5(a), $D1$ and $D2$ are yielded as follows.

$$D1 = \frac{4W}{X_e - X_s} - \frac{6W(X_{LCG} - X_s)}{(X_e - X_s)^2}$$
$$D2 = \frac{6W(X_{LCG} - X_s)}{(X_e - X_s)^2} - \frac{2W}{X_e - X_s} \tag{1}$$

Finally, the load distribution is discretized onto the frames between its ends like the hatched area in Fig. 5(a). After performing the discretization process for all the docking load items, the lumped longitudinal load $P_T^n$ at a frame $n$ is expressed by equation (2).

$$P_T^n = \sum_{i=1}^{N} P_i^n \tag{2}$$

where $N$ is the number of docking load items which are involved in a light weight distribution from a ship design system and a docking condition from trim & stability tests, and $P_i^n$ is a lumped longitudinal load of an $i$-th docking load item at the frame $n$ which is the same area as the hatched trapezoid in Fig. 5(a).

Assuming that the transverse load at a frame has uniform distribution along the breadth of the frame, the lumped longitudinal load at a frame expressed by equation (2) is divided by an effective breadth $B_e$ at the frame as shown in Fig. 5(b).

$$q^n = \frac{P_T^n}{B_e} = \frac{\sum_{i=1}^{N} P_i^n}{B_e} \tag{3}$$

Here, it is noted that the effective breadth $B_e$ includes a length of the floor at the frame and an extension length of the hopper web floor which will be explained later.

This approach provides a rough load distribution. The longitudinal load distribution can be empirically evaluated to be significant. However, the uniform load distribution along the transverse direction of a frame does not match with an intuitive fact that the hopper web area close to side shell of a ship takes much greater load than other positions. The computation of the transverse load distribution has room for improvement.

## 3.3 Improvement of Transverse Load Distribution

The transverse load data cannot be obtained easily through the design phases and also many efforts must be made in order to collect them from many structural drawings. It is practically impossible to obtain the complete transverse load and hence that cannot help being modeled by proper assumption. It was already mentioned in the previous section that the transverse load is approximated to uniform distribution from the lumped longitudinal load at a frame. By taking two possibilities of modeling the transverse load distribution into consideration, it will be discussed what led to the assumption and how that could be improved.

(1) Weighted load distribution

The transverse load distribution at a frame is determined by weighting factors for the transverse position in the frame, varying uniform distribution $q^n$ for the length $B_n$ of the frame from equation (3). They can be adjusted so that the load at the side of a ship or any excessive weights is larger than at other position and the sum of the weighted load distribution at a frame equals the lumped longitudinal load at the frame. This places emphasis on approximating overall distribution along transverse direction at the frame. The weight $w^i$ should be determined so that they can be satisfied with

$$P_T^n = \int_0^{B_n} w(s) q^n ds \approx \sum_{i=0}^{m} w^i q^n L_i \tag{4}$$

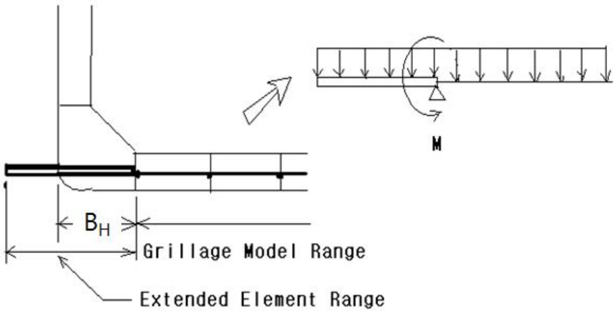


Fig. 6. Extension of hopper web floor for improving the transverse load distribution(Slightly modified from Kim et al., 2008).

where $q^n$ is obtained by equation (3) for $B_e$=$B_n$ (without the extension), $m$ is the number of discrete segments of the frame and $L_i$ is a length of the $i$-th segment. The weight factor $w^i$ of the $i$-th segment comes to be determined empirically for all the frames referring to design drawings. The weight factor is constant in one segment.

(2) Extension of hopper web floors

This is a method to extend the length of the hopper web floors outside the hopper girder while the transverse load is still uniformly distributed as illustrated in Fig. 6. The sum of the uniformly distributed load $P_T^n$ at a frame equals the lumped longitudinal load at the frame like equation (3). This focuses on the reaction forces around the side shell rather than other positions of the center and mid-span of web floors. It is empirically observed that the light weight distribution at the hopper girder is larger than that of the center and mid-span of the web floors and hence the distributed load along additional hopper web floors yields the expected load condition. In equation (3), the effective breadth $B_e$ includes a length of the floor at the frame and an extension length of the hopper web floor.

$$B_e = B_C + (\alpha + 1) B_H \tag{5}$$

where $Bc$ is a length from the centerline to the hopper girder and $B_H$ is a length of the hopper web floor. The extension ratio $\alpha$ should be determined depending on a ship type and size.

Both of them have controllable parameters for a ship type and size. In the first method, the number of weighting factors and their values must be determined at all the frames or for specified longitudinal subdivisions of the ship such as stern, engine room, parallel middle body and bow. Also in the second method, the extension length of the hopper web floors must be determined similarly with the first method. In this paper, we intend to employ the second approach to extend the hopper web floors since its control parameters to be determined are fewer than those of the weighted load distribution approach. Through parametric studies, the extension ratio of hopper web floors for longitudinal subdivisions will be discussed. Consequently, the extension length of the hopper web floors becomes different for a shipyard design rule, and a kind and size of a ship.

## 3.4 Section Properties of Beam Elements in Grillage Model

In order to compute the stiffness of beam elements in the grillage analysis, their section properties of a section area ($A$), a torsional moment of inertia ($J$), and a bending moment of inertia ($I$) are required. They are usually calculated with main structural parts and their adjacent parts. In our grillage model, a ship is longitudinally subdivided into stern, engine room (E/R), parallel middle body and bow as described in the previous section. Also the structural members are categorized to six groups of (1) centerline girders, (2) side girders, (3) side shell (skin girders), (4) web floors and hopper web floors, (5) transverse bulkheads and (6) longitudinal bulkheads. A ship structure includes all the groups or not. For the simplicity in this paper, the section properties are defined for the subdivisions. That is, beams included in the same longitudinal subdivision and structural group are supposed to have the same section properties. Let each longitudinal subdivision be denoted with subscription $m$ (for the parallel middle body), $s$ (for stern and E/R) and $b$ (for bow) and then section properties of beams in each subdivision are expressed by

$$\begin{array}{ll} \text{For parallel middle body} & A_{mi}\ \ J_{mi}\ \ I_{mi} \\ \text{For stern and E/R} & A_{si}\ \ J_{si}\ \ I_{si} \\ \text{For Bow} & A_{bi}\ \ J_{bi}\ \ I_{bi} \end{array} \tag{6}$$

where $i$ ($i$ =1~6) is a subscription for six structural groups described above.

Linearly dependent relationships between the section properties of beams in parallel middle body and those in other longitudinal subdivisions are experimentally derived depending on a ship type. That initiates from the fact that the same type of ships usually have common and typical design. Since the section properties of beams in the parallel middle body are comparatively easily calculated from the design drawings, the sufficient experiments for such relationships help calculating section properties of other subdivision in spite of lack of structural design data. The linear dependent relationships are expressed by

$$\begin{array}{lll} A_{si}=\alpha_{si}A_{mi} & J_{si}=\beta_{si}J_{mi} & I_{si}=\gamma_{si}I_{mi} \\ A_{bi}=\alpha_{bi}A_{mi} & J_{bi}=\beta_{bi}J_{mi} & I_{bi}=\gamma_{bi}I_{mi} \end{array} \tag{7}$$

where $\alpha$, $\beta$ and $\gamma$ are linear coefficients for each section property, $m$, $s$ and $b$ which stand for parallel middle body, stern and E/R, and bow respectively denote longitudinal subdivisions, and $i$ ($i$ =1~6) is a subscription for six structural groups. Since the coefficients are different depending on the ship type, their real values for any ship are not provided in this paper.

The LR showed a typical example for a crude oil tanker in their old report(Rigo and Rizzuto, 2003),. Even though the kind of ships, their structure and size have changed for a couple of decades, the old concept was evaluated to be satisfactory enough to apply to this docking analysis. Therefore the section properties of the beam elements are initially calculated by the LR method and they are adjusted specifically at stern, engine room and bow with the help of only a few drawings, for example, midship section drawings and construction profile drawings at the centerline. Many case studies are necessary to determine the adjusting level since it is various depending on a ship type. The adjustment level at stern, E/R and bow is very close to linear coefficients in equation (7).

Finally, further experimental studies have been performed in order to define the section properties of all the beam elements in terms of an area and a moment of inertia at a midship section of a ship. It will provide a very simple solution to compute section properties of beams in any longitudinal subdivisions and eventually help overcoming lack of the necessary information at the initial design phase. Because the relationships between the section properties of beams in parallel middle body and those in other longitudinal subdivisions have been already defined in equation (7), what is required now is a relationship between the properties of beams in parallel middle body and those of the midship section. Let the midsection properties of area, torsional moment of inertia and bending moment of inertia be respectively denoted with $A_c$, $J_c$ and $I_c$, and then the following linear dependency with those of beams in parallel middle body is proposed.

$$A_{mi}=\alpha_{mi}A_c \ \ J_{mi}=\beta_{mi}J_c \ \ I_{mi}=\gamma_{mi}I_c \tag{8}$$

where $\alpha_{mi}$, $\beta_{mi}$ and $\gamma_{mi}$ are linear coefficients for each section property for six structural groups ($i$=1~6). Since the coefficients are different depending on the ship type, their real values for any ship are not provided in this paper.

## 4. Case studies and discussions

To validate the proposed 2D docking analysis and determine reliable parameters related with extension length of hopper web floors and section properties, 2D and 3D docking analyses for total seven ships of three LNGCs (Liquefied Natural Gas carriers), two containerships, one PCTC (Pure Car Truck Carrier), and one crude oil tanker were carried out and compared with each other in this study. The comparisons showed that the result of this simplified docking analysis method which was complemented with the proposed improvement strategies can have a good agreement with that of 3D FE docking analysis which has been actually used in shipyards. The extension length of hopper web floors for the transverse load distribution and the linear coefficients for the section parameters have been investigated depending on a ship type through these comparisons even if more comparisons and actual records for real ships are necessary in order to secure robust 2D docking analysis.

If the results of all case studies are not included in this paper, two studies on an 8400 TEU containership and an LNG carrier are discussed. The principal dimensions and midship section data of the ships are listed in Table 1. Fig. 7 and Fig. 8 contain variations of their grillage models according to the extension length of hopper web floors. The models of the containership are depicted in Fig. 7, where Model (1) in which designed positions (solid circles) of docking supports are assigned is without extension of hopper web floors, Model (2) is with 300% extension of hopper web floor length at all frames, Model (3) is with 300% extension of hopper web floor length at parallel middle body and 100% extension at stern, E/R and bow and Model (4) is with 100% extension of hopper web floor length at parallel middle body and 300% extension at stern, E/R and bow. And those of the LNG carrier are shown in Fig. 8

Table 1. Principal dimensions of the containership and the LNG carrier

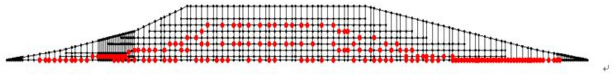
| | | Containership | | LNG Carrier | |
|---|---|---|---|---|---|
| L.O.A. | | 330 | (m) | 287 | (m) |
| L.B.P | | 317.2 | (m) | 270.4 | (m) |
| Breadth | | 43.2 | (m) | 43.4 | (m) |
| Depth (Molded) | | 24.5 | (m) | 26 | (m) |
| Draft (Molded) | | 13 | (m) | 11.5 | (m) |
| At midship section | $A_c$ | 4.12 | ($m^2$) | 6.72 | ($m^2$) |
| | $J_c$ | 1117 | ($m^4$) | 2575 | ($m^4$) |
| | $I_c$ | 772 | ($m^4$) | 1501 | ($m^4$) |

Table 2. Section properties of grillage model of a containership

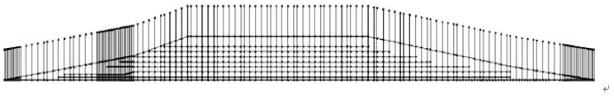
| | Parallel Middle Body | | | Stern and E/R | | | Bow | | |
|---|---|---|---|---|---|---|---|---|---|
| | $A_m$ | $J_m$ | $I_m$ | $A_s$ | $J_s$ | $I_s$ | $A_b$ | $J_b$ | $I_b$ |
| 1. Centerline girder | 0.016 | 0.047 | 0.053 | 0.355 | 144 | 144 | 0.355 | 144 | 144 |
| 2. Side girder | 0.0216 | 0.0714 | 0.0776 | 0.0216 | 0.0714 | 0.0776 | 0.0216 | 0.0714 | 0.0776 |
| 3. Side shell | 0.711 | 144 | 144 | 0.355 | 144 | 144 | 0.355 | 144 | 144 |
| 4. Web floors and hopper web floors | 0.026 | 0.115 | 0.124 | 0.001 | 0.001 | 0.001 | 0.0216 | 0.0879 | 0.0941 |
| 5. Transverse Bulkhead | 0.355 | 144 | 144 | 0.355 | 144 | 144 | 0.355 | 144 | 144 |
| 6. Longitudinal Bulkhead | 0.711 | 144 | 144 | | | | | | |

Table 3. Section properties of grillage model of a LNG carrier

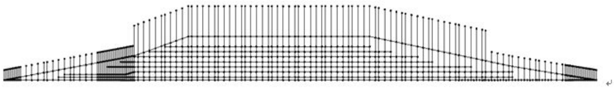
| | Parallel Middle Body | | | Stern and E/R | | | Bow | | |
|---|---|---|---|---|---|---|---|---|---|
| | $A_m$ | $J_m$ | $I_m$ | $A_s$ | $J_s$ | $I_s$ | $A_b$ | $J_b$ | $I_b$ |
| 1. Centerline girder | 0.024 | 0.112 | 0.132 | 0.416 | 375 | 375 | 0.416 | 375 | 375 |
| 2. Side girder | 0.048 | 0.224 | 0.265 | 0.048 | 0.224 | 0.265 | 0.048 | 0.224 | 0.265 |
| 3. Side shell | 0.835 | 375 | 375 | 0.416 | 375 | 375 | 0.416 | 375 | 375 |
| 4. Web floors and hopper web floors | 0.0416 | 0.258 | 0.294 | 0.0416 | 0.258 | 0.294 | 0.0416 | 0.258 | 0.294 |
| 5. Transverse Bulkhead | 0.835 | 375 | 375 | 0.835 | 375 | 375 | 0.835 | 375 | 375 |
| 6. Longitudinal Bulkhead | 0.835 | 375 | 375 | | | | | | |



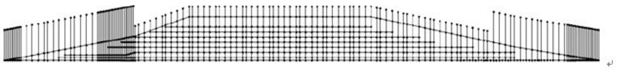
(1) Without extension length of hopper web floors



(2) With 300% extension length of hopper web floors

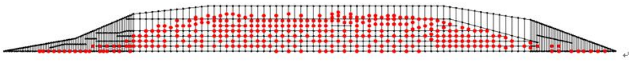


(3) With 300% extension in parallel middle body and 100% extension in stern and bow

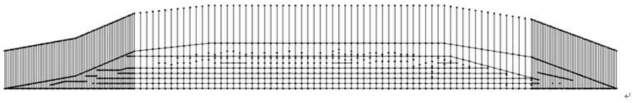


(4) With 100% extension in parallel middle body and 200% extension in stern and bow

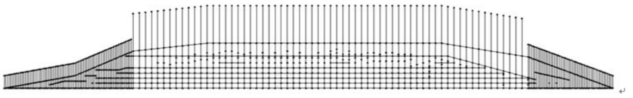
Fig. 7. Grillage models of a containership and designed docking supports.



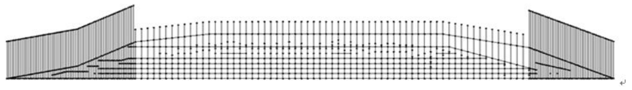
(1) Without extension length of hopper web floors



(2) With 300% extension length of hopper web floors

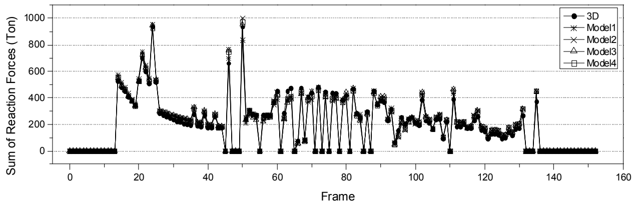


(3) With 300% extension in parallel middle body and 100% extension in stern and bow

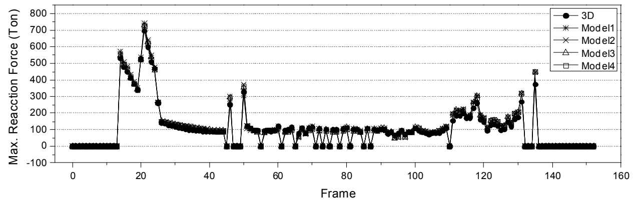


(4) With 100% extension in parallel middle body and 200% extension in stern and bow

Fig. 8. Grillage models of a LNG carrier and designed docking supports.

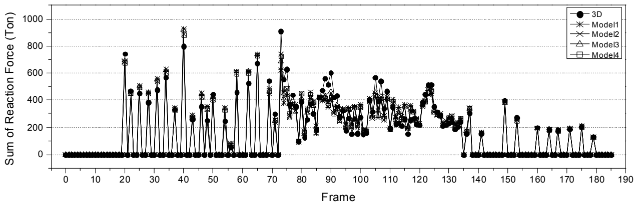


(a) Sum of reaction forces at docking supports in a frame

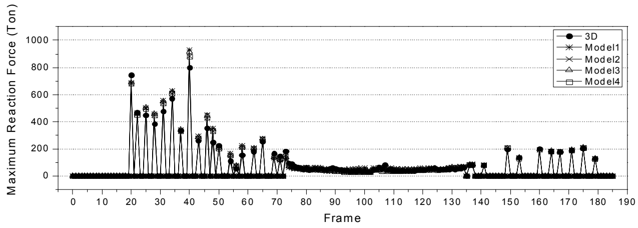


(b) Maximum reaction forces at docking supports in a frame

Fig. 9. Reaction forces in docking analysis of a containership.



(a) Sum of reaction forces at docking supports in a frame

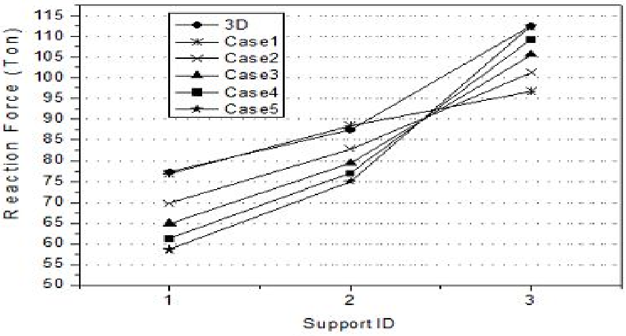


(b) Maximum reaction forces at docking supports in a frame

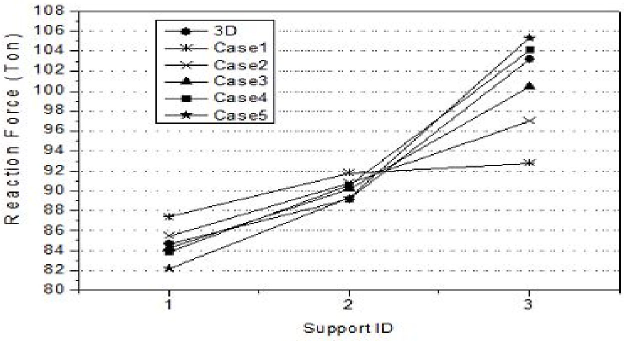
Fig. 10. Reaction forces in docking analysis of a LNG carrier.

where they have the same variations of the models as the containership. The section properties, sectional area, and vertical and torsional moment of inertia of beam elements in the grillage models are determined from the midship section data with linear coefficients as proposed in the previously section. The values in Table 2 and 3 are section property factors for elements in stern, E/R, bow and parallel middle body.

First, the 2D docking analyses for three grillage models are compared with the corresponding 3D docking analysis in aspect of the reaction forces at the docking supports. In this paper, a sum of reaction forces is compared to verify the longitudinal distribution, and a maximum reaction force in a frame is compared because the docking supports are required and arranged in order to take their reaction forces below force limit given for supports used in a shipyard. Fig. 9 and Fig. 10 depict the comparison results of docking analyses for the containership and the LNG carrier, respectively. In the figures, a sum of reaction forces at all the docking supports located on the same frame is drawn in Graph (1) and a maximum reaction force at each frame



(a) In Fr67



(b) In Fr82

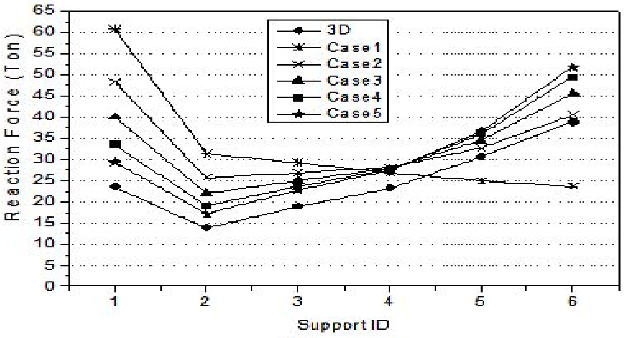
Fig. 11. Transverse distribution of reaction forces of a containership.

Table 4. Difference between 3D and grillage docking according to grillage variations (Unit: Ton)

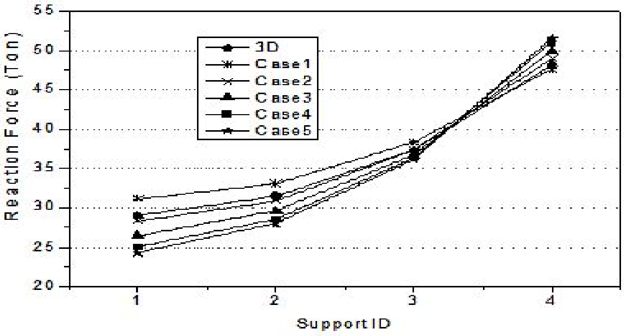
| Model No. | Containership (Support No: 175) | | | |
|---|---|---|---|---|
| | Max | Min | Mean | Std. Deviation |
| 1 | 76.1 | 0.09 | 12.16 | 11.83 |
| 2 | 74.12 | 0.01 | 11.70 | 11.18 |
| 3 | 73.26 | 0 | 12.62 | 10.87 |
| 4 | 76.52 | 0.01 | 10.26 | 10.78 |
| Model No. | LNG Carrier (Support No: 336) | | | |
| | Max | Min | Mean | Std. Deviation |
| 1 | 127.94 | 0.12 | 12.32 | 15.41 |
| 2 | 84.04 | 0.01 | 8.81 | 11.40 |
| 3 | 117.02 | 0.05 | 9.52 | 13.97 |
| 4 | 82.06 | 0.08 | 9.43 | 11.47 |

Table 5. Test cases for extension length of hopper web floor

| Case No. | Extension Length |
|---|---|
| 1 | No Extension |
| 2 | 100% of $B_H$ |
| 3 | 200% of $B_H$ |
| 4 | 300% of $B_H$ |
| 5 | 400% of $B_H$ |



(a) In Fr100



(b) In Fr 127

Fig. 12. Transverse distribution of reaction forces of a LNG carrier.

in Graph (2). The figures show that the result of 2D docking analysis for Model (2) is much closer to that of 3D analysis than other grillage model, which is verified from Table 4. The table contains statistics of reaction force differences between 3D and four grillage models (Model 1~4) at all docking supports, including maximum, minimum, mean difference and their standard deviation. Here, a problem is how to determine an extension ratio of hopper web floors, for example, 300% or 100% of their length.

The extension problem of hopper web floors are treated by experimentally changing the extension ratio in next investigations. All the frames are uniformly extended in these experiments such as Model (2) in Fig. 7 and Fig. 8. The five test cases are listed in Table 5. Fig. 11 and Fig. 12 depict the reaction forces at docking supports on a couple of frames of each test ship with comparison of those of the 3D docking analysis. Since the extension of hopper web floors decreases the size of the transverse load and increases the concentration of the load around the side shell, the reaction forces corresponding to the extension rate are increasing around the side shell but decreasing around the center line. We cannot conclude which case provides the solution close to 3D docking analysis from the figures of a couple of frames. Table 6 shows statistics of reaction force

Table 6. Difference according to the extension length of the hopper web floor (Unit: Ton)

| Case No. | Containership (Support No: 175) | | | |
|---|---|---|---|---|
| | Max | Min | Mean | Std. Deviation |
| 1 | 76.1 | 0.09 | 12.16 | 11.83 |
| 2 | 75.6 | 0.08 | 11.08 | 10.68 |
| 3 | 74.92 | 0.06 | 11.29 | 10.79 |
| 4 | 74.12 | 0.01 | 11.70 | 11.18 |
| 5 | 73.3 | 0.05 | 12.27 | 11.48 |
| Case No. | LNG Carrier (Support No: 336) | | | |
| | Max | Min | Mean | Std. Deviation |
| 1 | 127.94 | 0.12 | 12.32 | 15.41 |
| 2 | 112.80 | 0.00 | 10.12 | 13.83 |
| 3 | 97.72 | 0.00 | 9.16 | 12.47 |
| 4 | 84.04 | 0.01 | 8.81 | 11.40 |
| 5 | 72.03 | 0.02 | 8.44 | 10.41 |

differences between 3D and grillage docking analysis at all docking supports, including maximum, minimum, mean difference and their standard deviation. Apparently, the extension length of the hopper web floors gives a better agreement between 3D and grillage docking analysis. As shown in Table 6, the optimum extension rate is dependent on a ship type. In the test cases, the 100% extension of a hopper breadth results in a better reaction forces for the containership and the 300% extension for the LNG carrier.

As previously mentioned, a few case studies for LNG carriers, containerships, tankers, and PCTCs were conducted even though one case study is described in this paper, and, consequently, good contribution of the proposed approaches in the 2D docking analysis has been convincing.

## 5. Development of Integrated Docking Analysis System

We also developed an integrated docking analysis system using the proposed 2D docking analysis method. The appearance of the docking analysis system is shown in Fig. 13. This system provides the following functions: (1) Manual input of principal dimensions and main structural parts (Frames, Girders, Web floors, and Side Shells), (2) Automatic generation of the grillage model of the docking analysis from the simple ship design data, (3) Convenient definition of docking supports, (4) Load distribution generation from light weight data and docking T&S data of the ship, (5) Execution of the docking analysis, and (6) Discussion and evaluation of analysis results. Currently, this system has no function to automatically calculate section properties of beam elements in the grillage model since an easy scheme to calculate them for various kinds of ships has been being continuously developed and it needs further studies. Instead, the LR method was implemented in MS Excel™ and its modification rule was recommended to the shipyard. In the future, that will be included in the updated program for the user convenience as proposed in this paper.

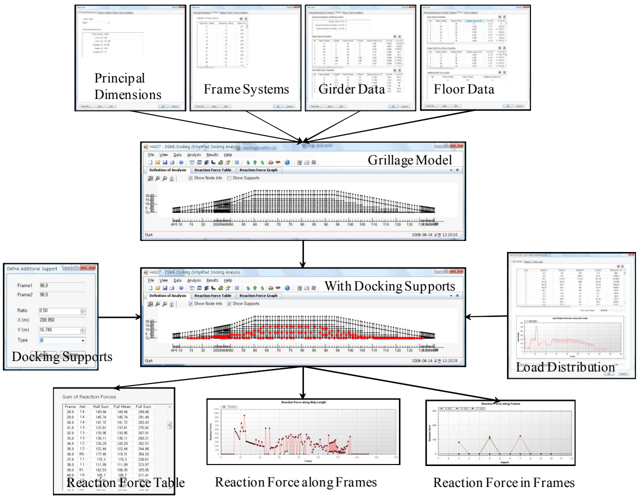


Fig. 13. Integrated docking analysis system using a grillage analysis.

## 6. Conclusions

While a ship docking analysis has been carried out for a whole ship model with a three dimensional finite element method, problems with the FE model of the ship have been addressed. Though the FE models could be sometimes obtained from other whole ship analyses such as vibration and structural strength, it took much time to change them to those which were suitable for a docking analysis and docking supports could not be placed at their designed position due to element size in the 3D FE models. If any docking plan is requested before the structural design is not completed, no helpful FE models can be obtained from any other phases. The analysis model should be generated with basic design data and the docking supports should be conveniently defined at any position of the model in order to overcome such problems.

In this paper, a simplified docking analysis method using the grillage method was proposed with development of an integrated docking analysis system. Easy and accurate computation of load distribution from available light weight and T&S data, improvement of transverse load distribution and detail investigation for section properties of beam elements resulted in great improvement of the proposed 2D docking analysis. It was verified by comparing the reaction forces at the docking supports with those of 3D docking analyses of several ships. And the integrated docking analysis system provides the following user convenience: automatic generation of a grillage model from basic design data, automatic computation of load distribution with light weight and T&S (Trim & Stability) data, convenient and interactive placement of docking supports at any positions, and representation of analysis results or reaction forces at the supports.

To increase stability and performance of this proposed docking analysis system, section properties of a grillage model should be computed much more sophisticatedly through possible comparison between 2D and 3D docking analysis results of more kind of ships. Such efforts will provide a solid background on the suggestion that they can be defined in terms of only midship section properties of a ship against the insufficiency of design data which may happen at the initial ship design phase.

## Acknowledgements

This work was financially supported by Inha Technical College. Also The Daewoo Shipbuilding and Marine Engineering, Co. (DSME) greatly supported real case studies for verification. The authors would like to express great gratitude for their great supports.

## Nomenclature

| | |
|---|---|
| $B_H$ | Length of the hopper web floor |
| $B_C$ | Length from the centerline to the hopper girder |
| $B_e$ | Effective breadth of web floor |
| $\alpha$ | Extension ratio of hopper web floor |
| $W$ | Weight of each load item in T&S (Trim & Stability) data |
| $X_s$ | Longitudinal start positions of each load item |
| $X_e$ | Longitudinal End positions of each load item |
| $X_{LCG}$ | Longitudinal center of gravity of each load item |
| $D1$, $D2$ | End loads by approximating linear distribution of each longitudinal load item |
| $P_T^n$ | Total Lumped longitudinal load at a frame $n$ |
| $P_i^n$ | Lumped longitudinal load of $i$-th load item at a frame $n$ |
| $A$ | Sectional area of a beam element |
| $J$ | Torsional moment of inertia of a beam element |
| $I$ | Bending moment of inertia of a beam element |

## References

[1] Bryant, B. S., R. F. England, J. G. Gates, R. L. Haith, and J. M. Ross(1991), Strength Properties of Drydocking Timbers and Blocks, Proceeding of the 1991 Ship Production Symposium, SNAME, San Diego, CA, (Sep. 3-6, 1991), pp. VIIIB2-1~12.

[2] Cheng, Y. S., F. T. K. Au, L. G. Tham, and G. W. Zeng(2004), Optimal and Robust Design of Docking Blocks with Uncertainty, Engineering Structures, Vol. 26, pp. 499-510.

[3] Choi, J. H., S. H. Oh, C. H. Hang, and M. J. Jun(2002), Development of Docking Analysis System, Proceeding of the Annual Autumn Meeting, SNAK, Busan, (Nov. 2002), (in Korean), pp. 437-442.

[4] Chun, M. S., Y. S. Seo, K. S. Heo, S. W. Chung, S. M. Park, and H. G. Cho(2006), A Study on Structural Safety Assessment for Docking Condition," Special issue of the Society of Naval Architects of Korea, (Sep. 2006), (in Korean), pp. 89-96.

[5] Fujikubo, M.(2005), Structural analysis for the design of VLFS, Marine Structures, Vol. 18, pp. 201-226.

[6] Hedger, R.(2005), Dockmaster Training Manual, pp. 1.2-14.5, http://www.hegerdrydock.com/dockmaster_training_manual.pdf, Accessed in April 10, 2007.

[7] Kim, S. C., C. Ryu, J. H. Lee, K. S. Lee, K. D. Baek, S. Y. Sohn, and J. H. Choi(2008), On the Docking Analysis of Global Ship Structure Using Simplified Grillage Model, Journal of the Society of Naval Architects of Korea, Vol. 45, No. 6, pp. 710-718.

[8] Rigo, P. and E. Rizzuto(2003), Analysis and Design of Ship Structure, In T. Lamb (ed), Ship Design and Construction, Vol.1, The Society of Naval Architects and Marine Engineers, Jersey City, NJ, (2003), pp. 18-1~76.

---

Received : 2013. 05. 03.
Revised : 2013. 05. 24.
Accepted : 2013. 06. 25.