April 11, 2018

e-mail: zubair.m@eng.unhas.ac.id, bair_offshore@yahoo.co.id
Dr. Muhammad Zubair MUIS ALIE +624118981032, mobile: +6281382815767
Naval B, Second Floor, Department of Ocean Engineering
Hasanuddin University Passport No.: B9365479
Jl. Poros Malino km.6 Bontomarannu
Gowa, So. Sulawesi 92172 INDONESIA

Ref: ISOPE-2018 Sapporo Conference
Paper No: 2018-TPC-0201

Dear Dr. MUIS ALIE,

As Co-Chairs of the ISOPE-2018 Sapporo Conference, we are pleased to invite you to present your paper and participate, at your expense, in the *28th International Offshore and Polar Engineering Conference (ISOPE-2018)* to be held in Sapporo, Japan, June 10-15, 2018. This conference will hold the world's largest technical program of its kind with peer-reviewed papers in this field. Technical Program Committee (TPC) members from 29 countries have assisted in organizing the Conference. The Conference is sponsored by the International Society of Offshore and Polar Engineers (ISOPE) in cooperation with 28 other major international societies and organizations. Following a peer review process, more than 700 peer-reviewed papers out of more than 1,400+ abstracts from 50+ countries have been accepted for presentation as well as for inclusion in the Conference Proceedings. Please visit www.isope.org for further information.

You are one of the well-known experts in this field, and your organization has been very active in this line of research or business. We believe that your participation in the conference will be essential and beneficial to the international technical and research communities.

On behalf of the ISOPE-2018 TPC, we would appreciate if your organization and the Embassy or Consular Office of Japan would expedite travel approval and entry visa issuance so that you can participate in time, allowing time preceding the conference for travel, and about a week beyond the conference dates for additional scientific visits.

Please note that the *29th International Offshore and Polar Engineering Conference (ISOPE-2019)* will be held in Honolulu, HI, USA, June 16-21, 2019.

Truly yours,

Dr. Hiromitsu Kitagawa
Co-Chair, ISOPE-2018 Sapporo Conference
Ocean Policy Research Institute
The Sasakawa Peace Foundation
1-15-16, Toranomon
Minato-ku, Tokyo 105-8524 JAPAN
Phone: +81-3-5157-5206
E-mail: kitasanh@jasmine.ocn.ne.jp

Truly yours,

Prof. Jin S. Chung
Co-Chair, ISOPE-2018 Sapporo Conference
ISOPE
495 North Whisman Road, Suite 300
Mountain View, California 94043-5711, USA
Phone: +1-650-254-1871
E-mail: *jschung@isope.org*

INTERNATIONAL SOCIETY OF OFFSHORE AND POLAR ENGINEERS
STATE OF CALIFORNIA

Y:\INVITATION LETTERS\2018 Invitation Letter

Universitas Hasanuddin

Muhammad Zubair Muis Alie, Ph.D <zubair.m@eng.unhas.ac.id>

ISOPE-2018 Sapporo, Japan - TPC has Accepted your Abstract - 2018-TPC-0201

Starr Koga <isope-5@sbcglobal.net> Thu, Oct 19, 2017 at 5:47 AM
Reply-To: isope-5@sbcglobal.net
To: "Dr. Muhammad Zubair Muis Alie" <zubair.m@eng.unhas.ac.id>
Cc: "Prof. Tetsuya Yao" <yao@naoe.eng.osaka-u.ac.jp>

Dr. Muhammad Zubair Muis Alie (*zubair.m@eng.unhas.ac.id*) October 18, 2017

Hasanuddin University

Gowa, INDONESIA

Paper No. **2018-TPC-0201**

Paper Title: ***The Ultimate Hull Girder Strength Analysis Considering Section Modulus under Longitudinal Bending***

Dear Dr. Muis Alie:

Welcome to the ISOPE-2018 Conference, Sapporo, Japan. On behalf of the ISOPE-2018 Technical Program Committee (TPC), I am happy to inform you that your paper is tentatively scheduled, on the basis of the abstract review, for ISOPE-2018, Sapporo, Japan, June 10–15, 2018. To request an extension of the **January 15** manuscript deadline, ask your TPC member.

Please: (1) E-mail the abstract NOW to your session organizer (S.O. = TPC member), given below.

(2) Always include your paper number in e-mail Subject line; and use your "Sender" name in English to prevent spam-filtering.

(3) E-mail copyright form to isope-2@isope.org, or Fax to 650-254-2038, when you submit a manuscript (MS) for review

Send the manuscript (MS) to S.O. for review by: January 15, 2017 or earlier

(cc: to isope-5@sbcglobal.net OR isope-5@isope.org)

Final revised MS deadline for acceptance by: **March 24, 2017** or earlier

Your session organizer (S.O. or TPC member) is:

Name:	*Prof. Tetsuya Yao*
Org:	*(Osaka University), Higashi-Hiroshima, Japan*

E-mail: *yao@naoe.eng.osaka-u.ac.jp*

One advance registration per paper is required by **March 24, 2018** (and for some by **January 10**) for inclusion in the program and proceedings. Download the Advance Registration Form and Hotel Reservation Form in January 2018 from **http://www.isope.org/conferences/conferences.htm**. The advance registration fee starts from **$690** for members and **lower** for students.

From this moment, we rely on E-mails for MS submission, review, and final revised MS. **Please include your paper number** in the **E-mail *Subject* line** in **every** communication, and communicate directly with and submit your MS to your S.O. above. For any questions, please contact me or your TPC member.

* **Special ISOPE room rates** at various hotels from US$**80+** per night.

Sincerely yours,

Prof. Jin S. Chung

ISOPE-2018 TPC Member

Email: meetings@isope.org; www.isope.org; www.deepoceanmining.org

____

Attached: Copyright form and ISOPE conference paper template

cc: Yao, T

****

- Final acceptance for presentation and for inclusion in the conference proceedings is contingent upon favorable peer-review results and registration of each paper. Manuscript (MS) preparation must follow the style and format of the enclosed ISOPE conference template. The manuscript for review should be typed on the template, not exceeding 8 template pages, also downloadable from www.isope.org.
- Conference papers may be reviewed further for possible ISOPE Journal publication if recommended initially by conference reviewers.
- You will receive later the reviewer comments and a request to revise and prepare the final MS as a PDF file, and you shall follow the high-quality PDF-making instructions that will be provided and that can also be downloaded later from www.isope.org.

2 attachments

Template-Word-MS-2018.docx
32K

Copyright-ISOPE-2018-EZfill.pdf
81K

Reviewer 1:

Category(2) Changes which in your judgment should be made before publication.

Equation (8) in page 2

You use the equation given by the local classification, but you do not show the reference. Please show it.

The material factor k is used in equation (8). Why is material property needed to calculate the moment of inertia of the cross section? You should explain physical meanings of k and show the value for your target ship.

Equation (11) in page 3

Please show the value of the degree of deck opening f_r which you use for your target ship.

Fig. 4 and 5 in page 4 and 5

The figures are not clear. Please improve their quality.

Fig. 9 and 10 in page 6

I think you estimate ultimate strength by using section modulus, but your procedure is not clear. You must clearly show how is the ultimate strength obtained from the section modulus.

Fig. 11 and 12 in page 6

You analyze progressive collapse behaviors of Ro-Ro ships shown in Fig. 6 and 7 by using Smith's method. It seems that the Ro-Ro ship's double bottoms are composed by unstiffened panels. How do you treat these panels in Smith's method? You must mention a way of the element division and show average stress-average strain curves which you use in the calculation.

Reviewer 2:

(1) P. 1; Left column; L. 19.

one of the ship type → one of the ship types

(2) P. 1; Right column; L. 31-32.

the side shell and bottom part → the side shell and bottom parts

(3) P. 2; Right column; L. 8.

The neutral axis, *g*, of the full cross section as shown in Fig. 2 … → This reviewer cannot find *g* in Fig. 2.

(4) P. 3; Left column; L. 9-10.

in hogging and sagging condition → in hogging and sagging conditions

(5) P. 3; Left column; L. 10.

Eq. (12) and (13) → Eqs. (12) and (13)

(6) P. 3; Fig. 4.

Are notations of y_i and z_i correct in this figure?

→ This reviewer thinks the followings are correct; $z_i \rightarrow y_i$ and $y_i \rightarrow z_i$.

(7) P. 4; Left column; L. 11.

in Fig. 4 and Fig. 5 → in Figs. 4 and 5

(8) P. 4; Right column; L. 6.

The Ro-Ro ships consists of →The Ro-Ro ships consist of

(9) P. 4; Right column; L. 14-17.

This paper is beneficial from the point of view of practical use. Since this paper did not treat any kinds of initial imperfections, e.g., initial deflection and welding residual stress, the authors should add comments for the effect of initial imperfections on the ultimate hull girder strength.

(10) P. 4-5; Figs. 4-5.

Figs. 4 and 5 are not clear. They should be modified if possible.

(11) P. 5; Left column; L. 5-6.

to obtained → to obtain

(12) P. 5; Left column; L. 12.

in Fig. 6 and 7 → in Figs. 6 and 7

(13) P. 5; Right column; L. 5-6.

two ships consists of → two ships consist of

(14) P. 5; Figs. 6-7.

Do not Ro-Ro ships have longitudinal stiffeners in double bottom structures? If so, how did you divide into elements for the double bottom structures of target Ro-Ro ships in the Smith's method. The authors should describe in this regard because this is one of the characteristics of Ro-Ro ships.

(15) P. 6; Right column; L. 10.
in Fig. 9 and 10 → in Figs. 9 and 10

(16) P. 6; Right column; L. 12.
in table 2 and 3 → in tables 2 and 3

(17) P. 6; Figs. 9 and 10 & Tables 2 and 3.
Figs. 9-10 and tables 2-3 show almost same meanings. Are these two figures and two tables are necessary? Leastwise, the authors should express in the main sentence that left and right bar charts in Figs. 9 and 10 show the results in hogging and sagging conditions, respectively.

(18) P. 7; Left column; L. 2.
in Fig. 11 and 12 → in Figs. 11 and 12

(19) § RESULTS AND DISCUSSION
This reviewer thinks it is important to discuss the relationship between the ultimate hull girder strength and the section modulus quantitatively, viz., how can the ultimate hull girder strength of Ro-Ro ships be estimated from the section modulus obtained from Eq. (15)? Some descriptions should be added.

The question or comments from two reviewers are not completely replied. It is still not clear how the section modulus is used to evaluate the ultimate strength. This should be clearly indicated. The followings are comments from the editor which my improve the quality of this paper.

(1) ABSTRACT; 3rd line: "the object of the ship" → "object ship"
(2) ABSTRACT; 10th line: "is applied" → "is imposed on plate and stiffened plate elements in the cross-section"
(3) Page 1; left column; 12th – 10th lines from the bottom: "In this regards, the ship … section modulus." Is difficult to understand. It could be changed as: "In this regards, the section modulus could be one of the important parameters from the viewpoint of assessing the ultimate strength of all the decks on which cars, passengers and so on are put." ???
(4) Page 1; left column; 7th line from the bottom: "merchant including" → "merchant ships including"
(5) Page 1; left column; 5th line from the bottom: "experimental of" → "experimental results of"
(6) Page 1; left column; 3rd line from the bottom: "theretical" → "theoretical"
(7) Page 1; right column; 9th line: "structural loading response of" → "loading conditions on"
(8) Page 2; left column; 12th line: "characteristic gives" → "characteristics affect"
(9) Page 2; left column; 2nd line from the bottom: "as shown" → "are shown"
(10) Page 2; right column; 1st line below Eq.(5): "The neutral axis, g, of" → The location of the neutral axis, g, of"
(11) Page 2; right column; 1st line below Eq.(6): "Where" → "where"
(12) Page 2; right column; 3rd – 4th lines below Eq.(6): "the deck when z=0 is taken at the base line" → "the i-th element. z=0 is taken as the base line.
(13) Page 2; right column; 1st – 2nd lines below Eq.(7): "iy_i is the local of moment of inertia for each element such as stiffener, plate between stiffeners corresponding to neutral axis."
(14) → "iy_i is the moment of inertia of each element such as stiffener, plate between stiffeners with respect to the neutral axis of each element."
(15) Page 2; right column; 2nd line above Eq.(8): "local classification" → "local Classification Society rules"
(16) Page 2; right column; 1st line below Eq.(8): "Where" → "where"
(17) Page 2; right column; 2nd line above Eq.(9): "modulus" → "moduli"
(18) Page 2; right column; 1st line below Eq.(10): "Where" → "where"
(19) Page 2; right column; 1st line below Eq.(10): "For the local classification" → "According to the local Classification Society rule"
(20) Page 3; left column; 1st line below Eq.(11): "Where" → "where"

(21) Page 3; left column; 1st line below Eq.(11): What is the "permissible stress"? How is it defined?

(22) Page 3; left column; Eq.(11): What is the meaning of 10^3? If you include this in Eq.(11), you have to specify the units for three parameters in this equation.

(23) Page 3; lift column; 1st line above Eq.(16): "relationship by considering of buckling and yielding" → "relationship is derived considering the influences of buckling and yielding"

(24) Page 3; left column; 1st line below Fig. 3: "f_i(0)=0.The" → "f_i(0)=0. The" Blank is necessary between "0." and "The".

(25) Page 3; right column; Eq.(18): "y_i" has to be "$(y_i - g)$"

(26) Page 4; left column; METHODOLOGY; 3rd line: "the object of the ships" → "the object ships"

(27) Page 4; left column; METHODOLOGY; 4th line: "local classification" → "local Classification Society rules"

(28) Page 4; right column; 1st line below Table 1: "those are" → "which are"

(29) Page 4; right column; 2nd line below Table 1: "top decks, the" → "top decks. The"

(30) Page 4; right column; 2nd line below Table 1: "Ro-Ro for type-1 and type-2" → "type-1 and type-2 Ro-Ros"

(31) Page 4; right column; 4th line below Table 1: "on the bottom" → "in the bottom"

(32) Page 4; right column; 5th - 6th lines below Table 1: "Also, the dimensions .... For ship breadth." → "Type-2 Ro-Ro is deeper than type-1 Ro-Ro, while type 1 Ro-Ro is wider than type-2 Ro-Ro."

(33) Page 4; right column; 6th - 7th lines below Table 1: "The longitudinal … one-frame space." → "One-frame space is considered in the longitudinal direction."

(34) Page 4; right column; 11th line below Table 1: "is done" → "is calculated"

(35) Figures 4, 5, 6 and 7: It looks that no longitudinal stiffeners are placed in the bottom structure. This means that bottom structure shall have many floors, and the span length in the bottom is shorter than that of deck parts. Such explanation may be necessary,

(36) It is also necessary how the average stress-average strain relationships is derived for the plate element in bottom structure.

(37) Page 5; left column; 1st line: "DISCUSSION" → "DISCUSSIONS"

(38) Page 5; left column; 1st line in "RESULTS AND DISCUSSION": "strength" → "strengths"

(39) Page 5; left column; 2nd line in RESULTS AND DISCUSSION: "with the Smith's method developed by Yao and Nikolov (1992)." → "applying the method developed by Yao and Nikolov (1992) according to the Smith's method."

(40) Page 5; left column; 4th line in RESULTS AND DISCUSSION: "both hogging" → "both under hogging"

(41) Figures 8, 9 and 10: It is necessary to indicate how the section modulus is calculated. Which equation is used? Eqs.(9), (10), (11) or (15)? What bending moment is indicated? At the ultimate strength in hogging and sagging?

(42) Page 7; left column; left column; 8^{th} – 9^{th} lines: "local classification" → "local Classification Society rules"

(43) Page 7; left column; 3^{rd} line in CONCLUSIONS: "local classification" → "local Classification Society rules"

ISOPE - 2018
Ocean Arctic Energy
www.isope.org
MUH. ZUBAIR MUIS ALIE
TEKNIK KELAUTAN
AUTHOR


28th Anniversary
ISOPE - 2018
Sapporo, Japan, June 10-15
Ocean Arctic Energy
www.isope.org
Hokkaido Government
City of Sapporo

No	Comments	Response
1	ABSTRACT; 3rd line: "the object of the ship" → "object ship"	Has been corrected
2	ABSTRACT; 10th line: "is applied" → "is imposed on plate and stiffened plate elements in the cross-section"	Has been corrected
3	Page 1; left column; 12th – 10th lines from the bottom: "In this regards, the ship … section modulus." Is difficult to understand. It could be changed as: "In this regards, the section modulus could be one of the important parameters from the viewpoint of assessing the ultimate strength of all the decks on which cars, passengers and so on are put." ???	Has been modified
4	Page 1; left column; 7th line from the bottom: "merchant including" → "merchant ships including"	Has been corrected
5	Page 1; left column; 5th line from the bottom: "experimental of" → "experimental results of"	Has been corrected
6	Page 1; left column; 3rd line from the bottom: "theretical" → "theoretical"	Has been corrected
7	Page 1; right column; 9th line: "structural loading response of" → "loading conditions on"	Has been corrected
8	Page 2; left column; 12th line: "characteristic gives" → "characteristics affect"	Has been corrected
9	Page 2; left column; 2nd line from the bottom: "as shown" → "are shown"	Has been corrected
10	Page 2; right column; 1st line below Eq.(5): "The neutral axis, g, of" → The location of the neutral axis, g, of"	Has been corrected
11	Page 2; right column; 1st line below Eq.(6): "Where" → "where"	Has been corrected
12	Page 2; right column; 3rd – 4th lines below Eq.(6): "the deck when z=0 is taken at the base line" → "the i-th element. z=0 is taken as the base line.	Has been corrected
13	Page 2; right column; 1st – 2nd lines below Eq.(7): "iy_i is the local of moment of inertia for each element such as stiffener, plate between stiffeners corresponding to neutral axis."	Has been corrected
14	→ "iy_i is the moment of inertia of each element such as stiffener, plate between stiffeners with respect to the neutral axis of each element."	Has been corrected
15	Page 2; right column; 2nd line above Eq.(8): "local classification" → "local Classification Society rules"	Has been corrected
16	Page 2; right column; 1st line below Eq.(8): "Where" → "where"	Has been corrected
17	Page 2; right column; 2nd line above Eq.(9): "modulus" → "moduli"	Has been corrected

18	Page 2; right column; 1st line below Eq.(10): "Where" → "where"	Has been corrected
19	Page 2; right column; 1st line below Eq.(10): "For the local classification" → "According to the local Classification Society rule"	Has been corrected
20	Page 3; left column; 1st line below Eq.(11): "Where" → "where"	Has been corrected
21	Page 3; left column; 1st line below Eq.(11): What is the "permissible stress"? How is it defined?	Permissible stress is allowable stress. It is defined based on the local classification.
22	Page 3; left column; Eq.(11): What is the meaning of 10^3? If you include this in Eq.(11), you have to specify the units for three parameters in this equation.	Has been explained
23	Page 3; lift column; 1st line above Eq.(16): "relationship by considering of buckling and yielding" → "relationship is derived considering the influences of buckling and yielding"	Has been corrected
24	Page 3; left column; 1st line below Fig. 3: "f_i(0)=0.The" → "f_i(0)=0. The" Blank is necessary between "0." and "The".	Has been corrected
25	Page 3; right column; Eq.(18): "y_i" has to be "$(y_i - g)$"	Has been corrected
26	Page 4; left column; METHODOLOGY; 3rd line: "the object of the ships" → "the object ships"	Has been corrected
27	Page 4; left column; METHODOLOGY; 4th line: "local classification" → "local Classification Society rules"	Has been corrected
28	Page 4; right column; 1st line below Table 1: "those are" → "which are"	Has been corrected
29	Page 4; right column; 2nd line below Table 1: "top decks, the" → "top decks. The"	Has been corrected
30	Page 4; right column; 2nd line below Table 1: "Ro-Ro for type-1 and type-2" → "type-1 and type-2 Ro-Ros"	Has been corrected
31	Page 4; right column; 4th line below Table 1: "on the bottom" → "in the bottom"	Has been corrected
32	Page 4; right column; 5th - 6th lines below Table 1: "Also, the dimensions .... For ship breadth." → "Type-2 Ro-Ro is deeper than type-1 Ro-Ro, while type 1 Ro-Ro is wider than type-2 Ro-Ro."	Has been corrected
33	Page 4; right column; 6th - 7th lines below Table 1: "The longitudinal ... one-frame space." → "One-frame space is considered in the longitudinal direction."	Has been corrected
34	Page 4; right column; 11th line below Table 1: "is done" → "is calculated"	Has been corrected
35	Figures 4, 5, 6 and 7: It looks that no longitudinal stiffeners are placed in the bottom structure. This means that bottom structure shall have many floors,	Has been explained

	and the span length in the bottom is shorter than that of deck parts. Such explanation may be necessary,	
36	It is also necessary how the average stress-average strain relationships is derived for the plate element in bottom structure.	Has been explained
37	Page 5; left column; 1st line: "DISCUSSION" → "DISCUSSIONS"	Has been corrected
38	Page 5; left column; 1st line in "RESULTS AND DISCUSSION": "strength" → "strengths"	Has been corrected
39	Page 5; left column; 2nd line in RESULTS AND DISCUSSION: "with the Smith's method developed by Yao and Nikolov (1992)." → "applying the method developed by Yao and Nikolov (1992) according to the Smith's method."	Has been corrected
40	Page 5; left column; 4th line in RESULTS AND DISCUSSION: "both hogging" → "both under hogging"	Has been corrected
41	Figures 8, 9 and 10: It is necessary to indicate how the section modulus is calculated. Which equation is used? Eqs.(9), (10), (11) or (15)? What bending moment is indicated? At the ultimate strength in hogging and sagging?	The section modulus can be obtained by calculating the moment of inertia of cross-section. In conjunction with this, the moment of inertia of each element of the cross section is calculated in advance. Here, Eqs. (9) and (10) represent section modulus for deck and bottom, respectively, so that the ultimate strength can be obtained.
42	Page 7; left column; left column; 8th – 9th lines: "local classification" → "local Classification Society rules"	Has been corrected
43	Page 7; left column; 3rd line in CONCLUSIONS: "local classification" → "local Classification Society rules"	Has been corrected

The Ultimate Hull Girder Strength Analysis Considering Section Modulus under Longitudinal Bending

Muhammad Zubair Muis Alie, Department of Naval Architect and Ocean Engineering, Hasanuddin University, Indonesia*
Samuel Izaak Latumahina, Department of Naval Architect and Ocean Engineering, Hasanuddin University, Indonesia

* Corresponding author:
Department of Naval Architect and Ocean Engineering
Engineering Faculty, Hasanuddin University.
Jl. Poros Malino km. 6 Bontomarannu postal code: 92172
Gowa, South Sulawesi, Indonesia.
Email zubair.m@eng.unhas.ac.id
Tel: +62-411-586015, FAX: +62-411-586015

ABSTRACT

The ship hull girder is very esential to againts the internal loads, particularly the external loads such as pressure and wave loads. The hull girder play an important role in the investigation for the ultimate strength calculation. The objective of the present study is to assess the ultimate hull girder strength taking the section modulus into account under longitudinal bending. A Ro-Ro Ship is taken as the object of the ship. A Ro-Ro Ship has a unique character because most of the longitudinal elements locate above neutral axis. While there are not the longitudinal elements under the neutral axis particularly at the bottom part so that the bottom part consists plate only. The Ro-Ro ship consists of some decks such as car, passenger and top. According to these, it is absolutely different the section modulus on the car, passenger and top deck. The distance between car, passenger and top deck are also different. Therefore, the section modulus for above and under the neutral axis must be investigated toward the ultimate strength and their progressive collapse behavior for car, passenger and top deck. In this regard, the elements attached on those decks must be assessed in more detail for deformation under longitudinal bending. The simple expression implemented into in-house program to calculate the section modulus of ship cross section is performed. The cross section is assumed to be remained plane and the simply supported of boundary condition is applied. The ultimate strength of ship's hull is calculated under hogging and sagging conditions. The hull girder of Ro-Ro ship is devided into elements compose plate and stiffened plates to calculate the section modulus. The vertical bending moments are imposed to both sides of the cross section. The ultimate hull girder strength is calculated by considering the section modulus including their progressive collapse behavior for Ro-Ro ship hull.

Keywords: Ship hull, cross section, section modulus, ultimate strength

Comments from reviewers	Respons
Reviewer 1:	
Equation (8) in page 2 You use the equation given by the local classification, but you do not show the reference. Please show it. The material factor *k* is used in equation (8). Why is material property needed to calculate the moment of inertia of the cross section? You should explain physical meanings of *k* and show the value for your target ship.	Has been added in the reference. The material is very important to calculate moment of inertia based on the equation (8).
Equation (11) in page 3 Please show the value of the degree of deck opening f_r which you use for your target ship.	Has been explained
Fig. 4 and 5 in page 4 and 5 The figures are not clear. Please improve their quality.	Has been modified, it is maximum.
Fig. 9 and 10 in page 6 I think you estimate ultimate strength by using section modulus, but your procedure is not clear. You must clearly show how is the ultimate strength obtained from the section modulus.	Has been explained
Fig. 11 and 12 in page 6 You analyze progressive collapse behaviors of Ro-Ro ships shown in Fig. 6 and 7 by using Smith's method. It seems that the Ro-Ro ship's double bottoms are composed by unstiffened panels. How do you treat these panels in Smith's method? You must mention a way of the element division and show average stress-average strain curves which you use in the calculation.	In this study, Ro-Ro ships have not longitudinal stiffeners in the bottom part, however, the bottom part must be devided into element. The procedure is same even the bottom part consists of stiffeners.

Reviewer 2:	Response:
(1) P. 1; Left column; L. 19. one of the ship type → one of the ship types	Has been corrected
(2) P. 1; Right column; L. 31-32. the side shell and bottom part → the side shell and bottom parts	Has been corrected
(3) P. 2; Right column; L. 8. The neutral axis, *g*, of the full cross section as shown in Fig. 2 ... → This reviewer cannot find *g* in Fig. 2.	Has been corrected
(4) P. 3; Left column; L. 9-10. in hogging and sagging condition → in hogging and sagging conditions	Has been corrected
(5) P. 3; Left column; L. 10. Eq. (12) and (13) → Eqs. (12) and (13)	Has been corrected
(6) P. 3; Fig. 4. Are notations of y_i and z_i correct in this figure? → This reviewer thinks the followings are correct; z_i → y_i and y_i → z_i.	Has been corrected
(7) P. 4; Left column; L. 11. in Fig. 4 and Fig. 5 → in Figs. 4 and 5	Has been corrected
(8) P. 4; Right column; L. 6. The Ro-Ro ships consists of →The Ro-Ro ships consist of	Has been corrected
(9) P. 4; Right column; L. 14-17. This paper is beneficial from the point of view of practical use. Since this paper did not treat any kinds of initial imperfections, e.g., initial deflection and	Thank you for the comment, at this time, the initial imperfection and so on are not considered in the analysis. Those influences will be taken at the next paper.

welding residual stress, the authors should add comments for the effect of initial imperfections on the ultimate hull girder strength.	
(10) P. 4-5; Figs. 4-5. Figs. 4 and 5 are not clear. They should be modified if possible.	Has been modified, it is maximum.
(11) P. 5; Left column; L. 5-6. to obtained → to obtain	Has been corrected
(12) P. 5; Left column; L. 12. in Fig. 6 and 7 → in Figs. 6 and 7	Has been corrected
(13) P. 5; Right column; L. 5-6. two ships consists of → two ships consist of	Has been corrected
(14) P. 5; Figs. 6-7. Do not Ro-Ro ships have longitudinal stiffeners in double bottom structures? If so, how did you divide into elements for the double bottom structures of target Ro-Ro ships in the Smith's method. The authors should describe in this regard because this is one of the characteristics of Ro-Ro ships.	In this study, Ro-Ro ships have not longitudinal stiffeners in the bottom part, however, the bottom part must be devided into element. The procedure is same even the bottom part consists of stiffeners.
(15) P. 6; Right column; L. 10. in Fig. 9 and 10 → in Figs. 9 and 10	Has been corrected
(16) P. 6; Right column; L. 12. in table 2 and 3 → in tables 2 and 3	Has been corrected
(17) P. 6; Figs. 9 and 10 & Tables 2 and 3. Figs. 9-10 and tables 2-3 show almost same meanings. Are these two figures and two tables are necessary? Leastwise,	Has been explained

the authors should express in the main sentence that left and right bar charts in Figs. 9 and 10 show the results in hogging and sagging conditions, respectively.	
(18) P. 7; Left column; L. 2. in Fig. 11 and 12 → in Figs. 11 and 12	Has been corrected
(19) RESULTS AND DISCUSSION This reviewer thinks it is important to discuss the relationship between the ultimate hull girder strength and the section modulus quantitatively, viz., how can the ultimate hull girder strength of Ro-Ro ships be estimated from the section modulus obtained from Eq. (15)? Some descriptions should be added.	Has been explained

No	Comments	Response
1	ABSTRACT; 3rd line: "the object of the ship" → "object ship"	Has been corrected
2	ABSTRACT; 10th line: "is applied" → "is imposed on plate and stiffened plate elements in the cross-section"	Has been corrected
3	Page 1; left column; 12th – 10th lines from the bottom: "In this regards, the ship … section modulus." Is difficult to understand. It could be changed as: "In this regards, the section modulus could be one of the important parameters from the viewpoint of assessing the ultimate strength of all the decks on which cars, passengers and so on are put." ???	Has been modified
4	Page 1; left column; 7th line from the bottom: "merchant including" → "merchant ships including"	Has been corrected
5	Page 1; left column; 5th line from the bottom: "experimental of" → "experimental results of"	Has been corrected
6	Page 1; left column; 3rd line from the bottom: "theretical" → "theoretical"	Has been corrected
7	Page 1; right column; 9th line: "structural loading response of" → "loading conditions on"	Has been corrected
8	Page 2; left column; 12th line: "characteristic gives" → "characteristics affect"	Has been corrected
9	Page 2; left column; 2nd line from the bottom: "as shown" → "are shown"	Has been corrected
10	Page 2; right column; 1st line below Eq.(5): "The neutral axis, g, of" → The location of the neutral axis, g, of"	Has been corrected
11	Page 2; right column; 1st line below Eq.(6): "Where" → "where"	Has been corrected
12	Page 2; right column; 3rd – 4th lines below Eq.(6): "the deck when z=0 is taken at the base line" → "the i-th element. z=0 is taken as the base line.	Has been corrected
13	Page 2; right column; 1st – 2nd lines below Eq.(7): "iy_i is the local of moment of inertia for each element such as stiffener, plate between stiffeners corresponding to neutral axis."	Has been corrected
14	→ "iy_i is the moment of inertia of each element such as stiffener, plate between stiffeners with respect to the neutral axis of each element."	Has been corrected
15	Page 2; right column; 2nd line above Eq.(8): "local classification" → "local Classification Society rules"	Has been corrected
16	Page 2; right column; 1st line below Eq.(8): "Where" → "where"	Has been corrected
17	Page 2; right column; 2nd line above Eq.(9): "modulus" → "moduli"	Has been corrected

18	Page 2; right column; 1st line below Eq.(10): “Where” → “where”	Has been corrected
19	Page 2; right column; 1st line below Eq.(10): “For the local classification” → “According to the local Classification Society rule”	Has been corrected
20	Page 3; left column; 1st line below Eq.(11): “Where” → “where”	Has been corrected
21	Page 3; left column; 1st line below Eq.(11): What is the “permissible stress”? How is it defined?	Permissible stress is allowable stress. It is defined based on the local classification.
22	Page 3; left column; Eq.(11): What is the meaning of 10^3? If you include this in Eq.(11), you have to specify the units for three parameters in this equation.	Has been explained
23	Page 3; lift column; 1st line above Eq.(16): “relationship by considering of buckling and yielding” → “relationship is derived considering the influences of buckling and yielding”	Has been corrected
24	Page 3; left column; 1st line below Fig. 3: “$f_i(0)$=0.The” → “$f_i(0)$=0. The” Blank is necessary between “0.” and “The”.	Has been corrected
25	Page 3; right column; Eq.(18): “y_i” has to be “$(y_i - g)$”	Has been corrected
26	Page 4; left column; METHODOLOGY; 3rd line: “the object of the ships” → “the object ships”	Has been corrected
27	Page 4; left column; METHODOLOGY; 4th line: “local classification” → “local Classification Society rules”	Has been corrected
28	Page 4; right column; 1st line below Table 1: “those are” → “which are”	Has been corrected
29	Page 4; right column; 2nd line below Table 1: “top decks, the” → “top decks. The”	Has been corrected
30	Page 4; right column; 2nd line below Table 1: “Ro-Ro for type-1 and type-2” → “type-1 and type-2 Ro-Ros”	Has been corrected
31	Page 4; right column; 4th line below Table 1: “on the bottom” → “in the bottom”	Has been corrected
32	Page 4; right column; 5th - 6th lines below Table 1: “Also, the dimensions .... For ship breadth.” → “Type-2 Ro-Ro is deeper than type-1 Ro-Ro, while type 1 Ro-Ro is wider than type-2 Ro-Ro.”	Has been corrected
33	Page 4; right column; 6th - 7th lines below Table 1: “The longitudinal ... one-frame space.” → “One-frame space is considered in the longitudinal direction.”	Has been corrected
34	Page 4; right column; 11th line below Table 1: “is done” → “is calculated”	Has been corrected
35	Figures 4, 5, 6 and 7: It looks that no longitudinal stiffeners are placed in the bottom structure. This means that bottom structure shall have many floors,	Has been explained

	and the span length in the bottom is shorter than that of deck parts. Such explanation may be necessary,	
36	It is also necessary how the average stress-average strain relationships is derived for the plate element in bottom structure.	Has been explained
37	Page 5; left column; 1st line: "DISCUSSION" → "DISCUSSIONS"	Has been corrected
38	Page 5; left column; 1st line in "RESULTS AND DISCUSSION": "strength" → "strengths"	Has been corrected
39	Page 5; left column; 2nd line in RESULTS AND DISCUSSION: "with the Smith's method developed by Yao and Nikolov (1992)." → "applying the method developed by Yao and Nikolov (1992) according to the Smith's method."	Has been corrected
40	Page 5; left column; 4th line in RESULTS AND DISCUSSION: "both hogging" → "both under hogging"	Has been corrected
41	Figures 8, 9 and 10: It is necessary to indicate how the section modulus is calculated. Which equation is used? Eqs.(9), (10), (11) or (15)? What bending moment is indicated? At the ultimate strength in hogging and sagging?	The section modulus can be obtained by calculating the moment of inertia of cross-section. In conjunction with this, the moment of inertia of each element of the cross section is calculated in advance. Here, Eqs. (9) and (10) represent section modulus for deck and bottom, respectively, so that the ultimate strength can be obtained.
42	Page 7; left column; left column; 8th – 9th lines: "local classification" → "local Classification Society rules"	Has been corrected
43	Page 7; left column; 3rd line in CONCLUSIONS: "local classification" → "local Classification Society rules"	Has been corrected

Comments from reviewers	Respons
Reviewer 1:	
Equation (8) in page 2 You use the equation given by the local classification, but you do not show the reference. Please show it. The material factor *k* is used in equation (8). Why is material property needed to calculate the moment of inertia of the cross section? You should explain physical meanings of *k* and show the value for your target ship.	Has been added in the reference. The material is very important to calculate moment of inertia based on the equation (8).
Equation (11) in page 3 Please show the value of the degree of deck opening f_r which you use for your target ship.	Has been explained
Fig. 4 and 5 in page 4 and 5 The figures are not clear. Please improve their quality.	Has been modified, it is maximum.
Fig. 9 and 10 in page 6 I think you estimate ultimate strength by using section modulus, but your procedure is not clear. You must clearly show how is the ultimate strength obtained from the section modulus.	Has been explained
Fig. 11 and 12 in page 6 You analyze progressive collapse behaviors of Ro-Ro ships shown in Fig. 6 and 7 by using Smith's method. It seems that the Ro-Ro ship's double bottoms are composed by unstiffened panels. How do you treat these panels in Smith's method? You must mention a way of the element division and show average stress-average strain curves which you use in the calculation.	In this study, Ro-Ro ships have not longitudinal stiffeners in the bottom part, however, the bottom part must be devided into element. The procedure is same even the bottom part consists of stiffeners.

Reviewer 2:	Response:
(1) P. 1; Left column; L. 19. one of the ship type → one of the ship types	Has been corrected
(2) P. 1; Right column; L. 31-32. the side shell and bottom part → the side shell and bottom parts	Has been corrected
(3) P. 2; Right column; L. 8. The neutral axis, *g*, of the full cross section as shown in Fig. 2 … → This reviewer cannot find *g* in Fig. 2.	Has been corrected
(4) P. 3; Left column; L. 9-10. in hogging and sagging condition → in hogging and sagging conditions	Has been corrected
(5) P. 3; Left column; L. 10. Eq. (12) and (13) → Eqs. (12) and (13)	Has been corrected
(6) P. 3; Fig. 4. Are notations of y_i and z_i correct in this figure? → This reviewer thinks the followings are correct; z_i → y_i and y_i → z_i.	Has been corrected
(7) P. 4; Left column; L. 11. in Fig. 4 and Fig. 5 → in Figs. 4 and 5	Has been corrected
(8) P. 4; Right column; L. 6. The Ro-Ro ships consists of →The Ro-Ro ships consist of	Has been corrected
(9) P. 4; Right column; L. 14-17. This paper is beneficial from the point of view of practical use. Since this paper did not treat any kinds of initial imperfections, e.g., initial deflection and	Thank you for the comment, at this time, the initial imperfection and so on are not considered in the analysis. Those influences will be taken at the next paper.

welding residual stress, the authors should add comments for the effect of initial imperfections on the ultimate hull girder strength.	
(10) P. 4-5; Figs. 4-5. Figs. 4 and 5 are not clear. They should be modified if possible.	Has been modified, it is maximum.
(11) P. 5; Left column; L. 5-6. to obtained → to obtain	Has been corrected
(12) P. 5; Left column; L. 12. in Fig. 6 and 7 → in Figs. 6 and 7	Has been corrected
(13) P. 5; Right column; L. 5-6. two ships consists of → two ships consist of	Has been corrected
(14) P. 5; Figs. 6-7. Do not Ro-Ro ships have longitudinal stiffeners in double bottom structures? If so, how did you divide into elements for the double bottom structures of target Ro-Ro ships in the Smith's method. The authors should describe in this regard because this is one of the characteristics of Ro-Ro ships.	In this study, Ro-Ro ships have not longitudinal stiffeners in the bottom part, however, the bottom part must be devided into element. The procedure is same even the bottom part consists of stiffeners.
(15) P. 6; Right column; L. 10. in Fig. 9 and 10 → in Figs. 9 and 10	Has been corrected
(16) P. 6; Right column; L. 12. in table 2 and 3 → in tables 2 and 3	Has been corrected
(17) P. 6; Figs. 9 and 10 & Tables 2 and 3. Figs. 9-10 and tables 2-3 show almost same meanings. Are these two figures and two tables are necessary? Leastwise,	Has been explained

the authors should express in the main sentence that left and right bar charts in Figs. 9 and 10 show the results in hogging and sagging conditions, respectively.	
(18) P. 7; Left column; L. 2. in Fig. 11 and 12 → in Figs. 11 and 12	Has been corrected
(19) RESULTS AND DISCUSSION This reviewer thinks it is important to discuss the relationship between the ultimate hull girder strength and the section modulus quantitatively, viz., how can the ultimate hull girder strength of Ro-Ro ships be estimated from the section modulus obtained from Eq. (15)? Some descriptions should be added.	Has been explained

The Ultimate Hull Girder Strength Analysis Considering Section Modulus Under Longitudinal Bending

Muhammad Zubair Muis Alie and Samuel Izaak Latumahina
Department of Naval Architect and Ocean Engineering, Engineering Faculty, Hasanuddin University
Gowa, South Sulawesi, Indonesia

ABSTRACT

The objective of the present study is to assess the ultimate hull girder strength taking the section modulus into account under longitudinal bending. A Ro-Ro Ship is taken as object ship. A Ro-Ro Ship has a unique character because most of the longitudinal elements locate above neutral axis. While there are not the longitudinal elements under the neutral axis particularly at the bottom part so that the bottom part consists plate only. The simple expression implemented into in-house program to calculate the section modulus of ship cross section is performed. The cross section is assumed to be remained plane and the simply supported of boundary condition is imposed on plate and stiffened plate elements in the cross section. The vertical bending moments are imposed to both sides of the cross section. It is found that the effect of the section modulus on the ultimate hull girder strength is significant not only in hogging but also sagging condition. The ultimate hull girder strength is calculated by considering the section modulus including their progressive collapse behavior for Ro-Ro ship hull.

KEY WORDS: Ship hull; cross section; section modulus; ultimate strength.

INTRODUCTION

The Ro-Ro ship is one of the ship types which transport the cargo in horizontal direction and eliminate the need for onboard or deckside lift-on and/or lift off instrument. The Ro-Ro ship has been innovated to carry processed forest product, lumber, playwood, cars and many things. Ro-Ros are an imprortant connection for the intermodal transportation network. In this regard, the section modulus could be one of the important parameters from the viewpoint of assessing the ultimate strength of all the decks on which cars, passengers and so on are put. In spite of human error, the structural degradation during loading and unloading gives impact to the ultimate strength of ship's hull.

The ultimate hull girder strength of merchant ships including Ro-Ro ship has been assessed by some researchers. Kukkanen, T and Matusiak, J (2014) presented the numerical and experimental results of nonlinear wave loads. A nonlinear time domain method had been developed and the theoretical background of the method were provided. The method was based on the source formulation expressed by means of the transient three-dimensional Green function. The time derivative of the velocity potential in Bernoulli's equation was solved with similar source formulation to that of the perturbation velocity potential. Korkut, E et al (2005) carried out measurements of global loads acting on a Ro-Ro model in regular waves for intact and damaged conditions. The stationary model was tested in different wave heights and wave frequencies for the head, beam and stern quartering seas in order to explore the effect of damages and wave heights on the global loads acting on the model. The analysis of the result indicated that the damages had an adverse effect on the loading conditions on the model depending upon the directionality of the waves and frequency range applied. This effect might cause structural damage on the ship and danger the safety of the ship and passenger on board. Kim, D.H and Paik, J.K (2017) developed a fully automated methodology for the optimum design of hull structural scantlings for merchant cargo ships that were modelled by plate-shell finite elements. A full optimization technique with multi-objectives was applied for minimizing structural weight and maximizing structural safety, as per design constraints associated with the ultimate limit states of the plate panels, support members and hull girders. The developed procedure was applied to the hull structural scantlings of a very large crude oil carrier (VLCC), and the test demonstrated the procedure's capacity to meet the strength requirements of common structural rules. Muis Alie, M.Z et al (2016) investigate the influence of superstructure on the longitudinal ultimate strength of a Ro-Ro ship. To investigate the ultimate strength, the Smith's method was adopted and implemented into the thin-walled beam. The cross section of Ro-Ro ship was taken to be analyzed. Muis Alie, M.Z et al (2017) assessed the ultimate hull girder strength of Ro-Ro ship after damaged. The cross section of Ro-Ro was taken to be analyzed. The collision and grounding damages were assumed to be placed on the side and bottom area. The damages were created by removing the element from the side shell and bottom parts. Finally, the result obtained was compared with one another. Also, the progressive collapse analysis of ship hull girder based on Smith's method was developed by Yao and Nikolov (1992). Naar, H et al (2004) described a couple beam method, which estimate elastic response in the longitudinal bending of a passenger ship with a large multi-deck superstructure. The method could be applied during an early project stage, when detailed three-dimensional finite element modelling was not yet possible. The theory was based on assumption that each deck in the superstructure and also the main hull could be considered as thin-walled beam.

In the present study, the ultimate hull girder strength analysis is assessed considering the section modulus. The cross section of a Ro-Ro ship is considered to be analyzed. Bottom part, car and passenger decks are calculated for the section modulus where those located above and/or under the neutral axis. Their result is investigated toward the ultimate strength for the global structure.

ANALYTICAL SOLUTION

The section modulus of ship indicates the ship strength not only in longitudinal but also transversal direction. The classification societies have been stated requirements so that the section modulus should be greater than a prescribed value. It is well known that ship structural characteristics affect significantly on the ultimate strength depending on the cargo types, configuration of structural scantling and so on. The fundamental theory of strength of material may be used for calculating the section modulus of the ship hull cross section. In structural modelling, the ship hull cross section is idealized by stiffened and unstiffened plate combination. Fig. 1 shows the cross section of Ro-Ro ship and Fig. 2 the typical type of stiffened plate with attached plating.

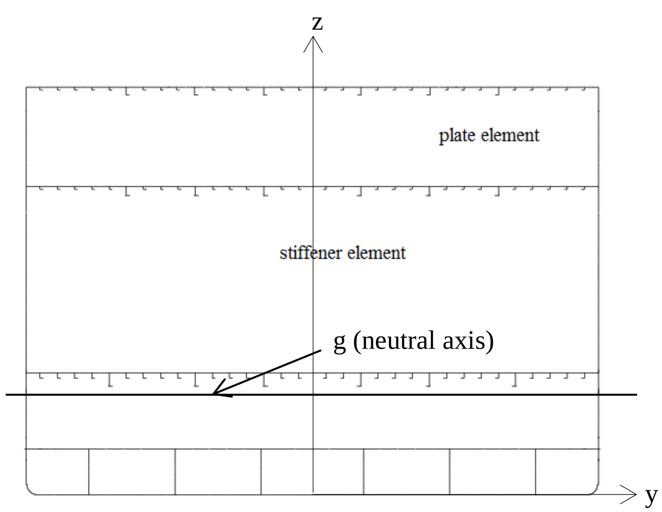

Fig. 1 Cross section of Ro-Ro ship

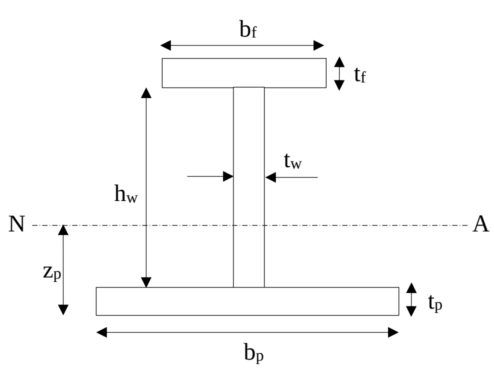

Fig. 2 Typical type of stiffened plate with attached plating

The profile and consists of web, flange and attached plating including the neutral axis (N-A) are shown in Fig. 2. The moment of inertia of the profile may be expressed as

$$I = \frac{b_p (t_p)^3}{12} + A_p \left(z_p - \frac{t_p}{2} \right)^2 + \frac{h_w^3 t_w}{12} + A_w \left(z_p - t_p - \frac{h_w}{2} \right)^2 + \frac{b_f t_f^3}{12} + A_f \left(t_p + h_w + \frac{t_f}{2} - z_p \right)^2 \quad (1)$$

Where

$$A_p = b_p t_p \quad (2)$$

$$A_w = h_w t_w \quad (3)$$

$$A_f = b_f t_f \quad (4)$$

$$z_p = \frac{0.5 b_p t_p^2 + A_w (t_p + 0.5 h_w) + A_f (t_p + h_w + 0.5 t_f)}{(A_p + A_w + A_f)} \quad (5)$$

The location of the neutral axis, g, of the full cross section as shown in Fig. 1 above the base line can be obtained by assuming that all longitudinal strength elements are fully effective, those are

$$g = \frac{\sum A_i z_i}{\sum A_i} \quad (6)$$

where A_i is the cross-sectional area of the *i* th plate stiffener element with fully attached plating and z_i is the coordinate of the *i*-th element, $z = 0$ is taken at the base line. The moment of inertia of the hull cross section is calculated by the following formula

$$I_y = \sum A_i (z_i - g)^2 + \sum i y_i \quad (7)$$

Where iy_i is the moment of inertia of each element such as stiffener, plate between stiffeners with respect to the neutral axis of each element. The local classification society rules determines the moment of inertia by the following approach

$$I_y = 3 x 10^{-2} W \frac{L}{k} \quad (8)$$

where W, L and k are the section modulus, lenght of ship and material factor (BKI, 2017). According to the formula, the material factor is very important to obtain moment of inertia. The section moduli at the deck and bottom part denoted by W_D and W_B are given by

$$W_D = \frac{I_y}{D - g} \quad (9)$$

$$W_B = \frac{I_y}{g} \quad (10)$$

where D represents as the ship's depth. According to local Classification Society rules, the section modulus related to deck W_D

and bottom W_B, respectively can be obtained by the following formula

$$W = f_r \frac{|M_T|}{\sigma_p 10^3} \tag{11}$$

where f_r, M_T and σ_p are the factor depending on the degree of deck opening, total bending moment (Nmm) and permissible longitudinal bending stress (N/mm^2), respectively.

The stress components on deck and bottom part can be obtained by using simple expression as follow,

$$\sigma = \frac{Mg}{I} \tag{12}$$

$$\sigma = \frac{M}{W} \tag{13}$$

where M is the moment on the deck and/or bottom part in hogging and sagging conditions. Here, Eqs. (12) and (13) can be simply expressed as

$$\frac{Mg}{I} = \frac{M}{W} \tag{14}$$

Here, the section modulus can be obtained as

$$W = \frac{I}{g} \tag{15}$$

In the Smith's method, which is applied in the program code developed by Yao and Nikolov (1992) is used. The explanation is briefly described such as the axial stress σ_i corresponding to the axial strain ε_i is given by the average stress-average strain relationship for the individual elements as illustrated in Fig. 3. The average stress-average strain relationship is derived considering of buckling and yielding

$$\sigma = f_i(\varepsilon) \tag{16}$$

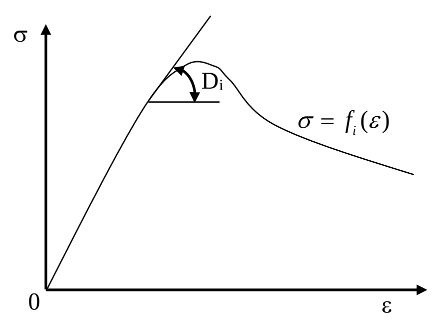

Fig.3 Average stress-average strain relationship for structural element

where $f_i(0) = 0$. The axial force P, the vertical bending moment M_V, and the horizontal bending moment M_H can be obtained by integrating axial stresses over the intact part of cross section as

$$P = \sum_{i=1}^{N} \sigma_i A_i \equiv 0 \tag{17}$$

$$M_H = \sum_{i=1}^{N} \sigma_i \left(y_i - g \right) A_i \tag{18}$$

$$M_V = \sum_{i=1}^{N} \sigma_i z_i A_i \tag{19}$$

The y and z are the coordinates of the cross section measured from the origin at the bottom keel as shown in Fig. 4.

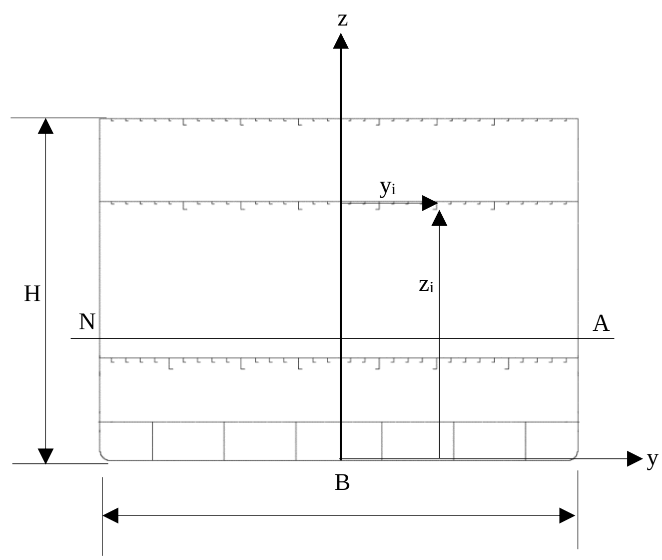

Fig.4 The coordinate systems of the cross section

When the axial load is added to bi-axial bending, the stiffness equation is expressed in term of general formula,

$$\begin{Bmatrix} \Delta P \\ \Delta M_H \\ \Delta M_V \end{Bmatrix} = \begin{bmatrix} D_{AA} & D_{AH} & D_{AV} \\ D_{HA} & D_{HH} & D_{HV} \\ D_{VA} & D_{VH} & D_{VV} \end{bmatrix} \begin{Bmatrix} \Delta \varepsilon \\ \Delta \phi_H \\ \Delta \phi_V \end{Bmatrix} \tag{20}$$

Where

ΔP : increment of axial force
ΔM_H : increment of horizontal bending moment
ΔM_V : increment of vertical bending moment
$\Delta \varepsilon$: increment of axial displacement
$\Delta \phi_H$: increment of horizontal curvature
$\Delta \phi_V$: increment of vertical curvature

and the tangential stiffness of the cross section are written as

$$D_{AA} = \sum_{i=1}^{n} D_i A_i \tag{21}$$

$$D_{AH} = D_{HA} = \sum_{i=1}^{n} D_i y_i A_i \tag{22}$$

$$D_{HH} = \sum_{i=1}^{n} D_i y_i^2 A_i \tag{23}$$

$$D_{AV} = D_{VA} = \sum_{i=1}^{n} D_i z_i A_i \tag{24}$$

$$D_{VV} = \sum_{i=1}^{n} D_i z_i^2 A_i \tag{25}$$

$$D_{HV} = D_{VH} = \sum_{i=1}^{n} D_i y_i z_i A_i \tag{26}$$

METHODOLOGY

The ultimate strength analysis considering the cross-section modulus of Ro-Ro ship hull girder is performed using analytical formulation. The cross section of Ro-Ro ship is taken to be analyzed. Two Ro-Ro ships, Type-1 and Type-2 are considered as the object ships as shown in Table 1. Both of them are designed based on the local Classification Society rules as shown in Figs. 5 and 6.

Table 1 Ship dimensions

Ro-Ro Ship	Type-1	Type-2
L (mm)	65000	50500
B (mm)	15000	14000
D (mm)	10693	10950

The Ro-Ro ships consist of three decks, which are car, pessanger and top decks. The differences between of type-1 and type-2 Ro-Ros are number and dimension of the stiffeners, number of cars and pessangers and the configuration of the structural shape particularly in the bottom part. Type-2 Ro-Ro is deeper than type-1 Ro-Ro, while type-1 Ro-Ro is wider than type-2 Ro-Ro. One-frame space is considered in the longitudinal direction. The material properties such as young's modulus and yield strength are related to the ship's characteristics, while poisson's ratio is set to be constant. The initial imperfection, welding residual stress, damage, and crack are not considered in the analysis. The ultimate strength is calculated for the intact only in hogging and sagging conditions. It should be noted that there are no longitudinal stiffeners in the bottom of Ro-Ros. Only floors in transversal direction are placed on it. The average stress-strain relationship of each element is derived considering buckling and yielding and integrated to the cross-section.

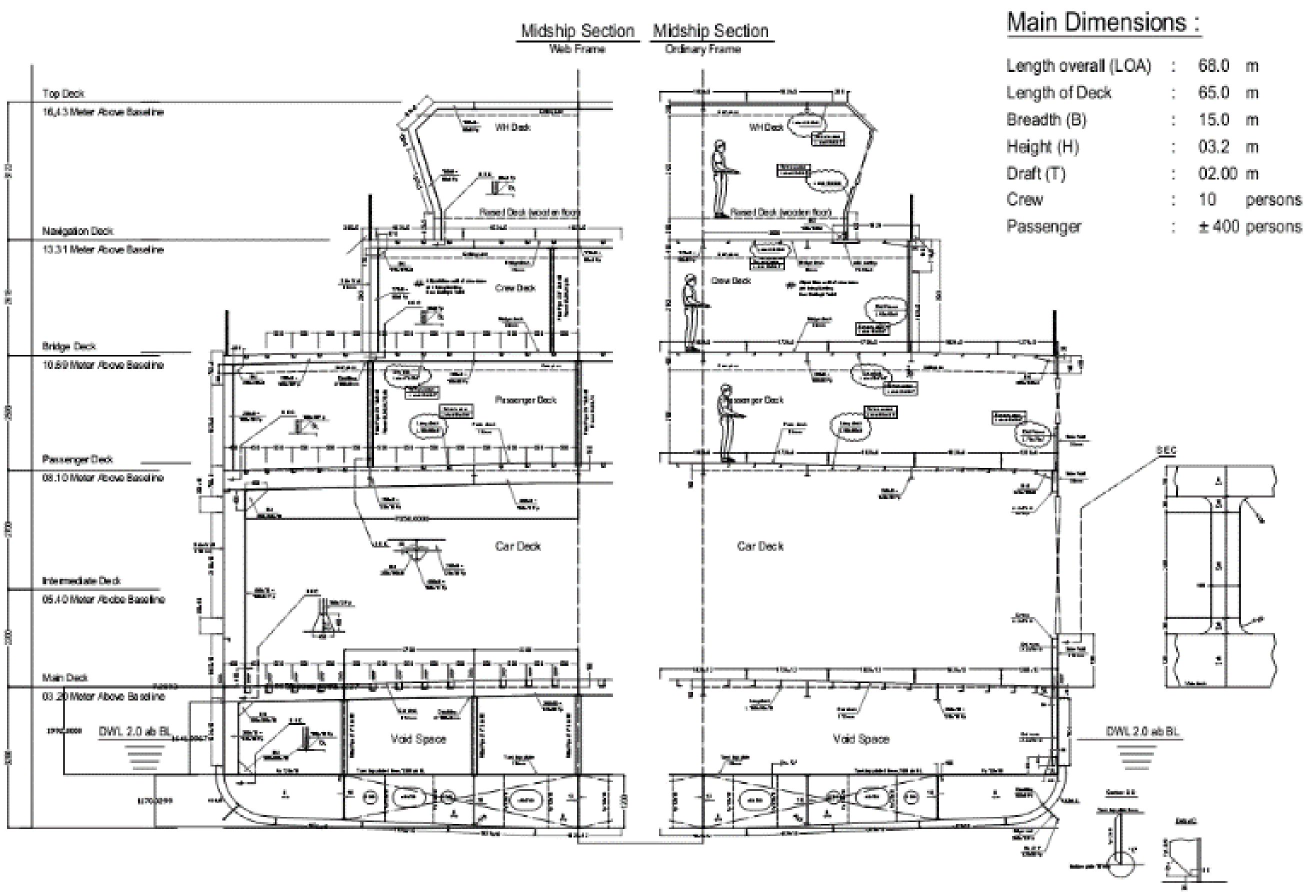

Fig. 5 Ro-Ro type-1

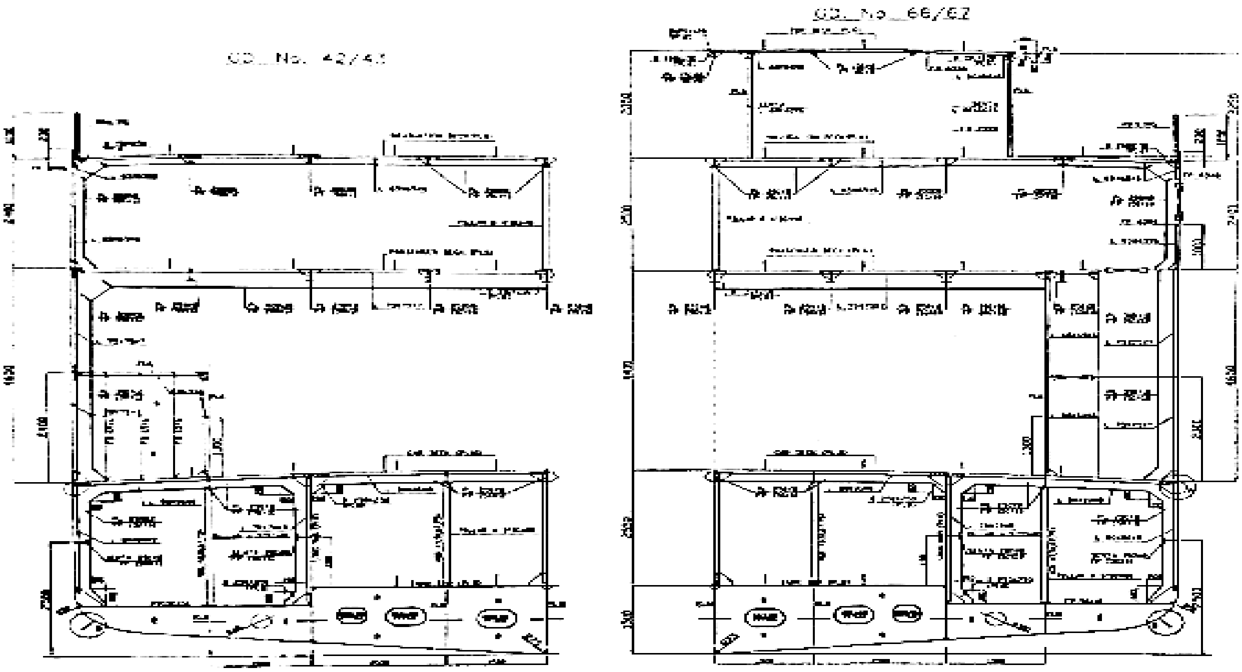

Fig. 6 Ro-Ro type-2

RESULTS AND DISCUSSIONS

The ultimate strengths of Ro-Ro ships considering their section modulus are confirmed applying the method developed by Yao and Nikolov (1992) according to Smith's method. In this case, the incremental iterative approcah is adopted to obtain the ultimate strength both under hogging and sagging condition. In the Smith's method, the cross section is devided into the elements composed of the stiffened and unstiffened plates. The cross section is assumed to be remained plane during progressive collapse and there is no interaction between adjacent elements in the cross section. The vertical bending moment is applied at both sides of the cross section. The cross section of the ships are illustrated in Figs. 7 and 8, respectively. The navigation and upper deck of Ro-Ro ships are assumed to be eliminated.

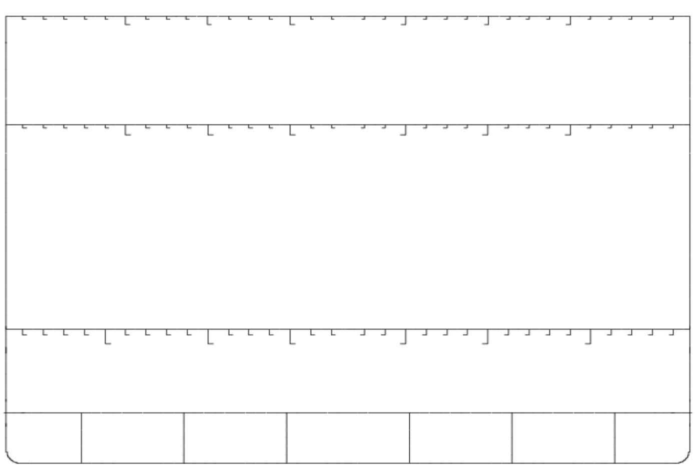

Fig. 7 Cross section of Ro-Ro type-1

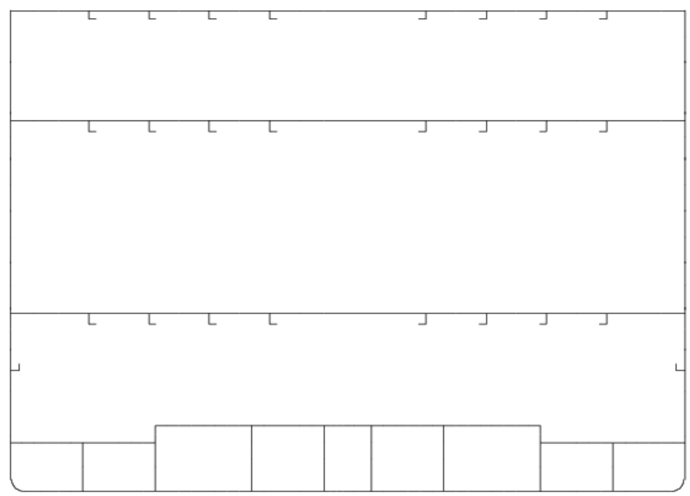

Fig. 8 Cross section of Ro-Ro type-2

The hull girder cross section is very sensitive leading to their ultimate strength and behaviour. It is well known that there is relationship between stress, moment, moment of inertia, neutral axis and section modulus. These relationships are expressed in Eqs. 12, 13, 14 and 15. This is why section modulus depends on bending moment and the section modulus can be obtained by calculating the elements. The coresponding section modulus to the Ro-Ro ship types is shown in Fig. 9. It is observed that the section modulus for type-2 is smaller than type-1. The characteristics of the both ship are completely different starting from the bottom part to the deck. However, two ships consist of three decks, but the shape configuration including number and dimension of stiffeners and double bottom structure also give significant influence to the section modulus and their ultimate strength.

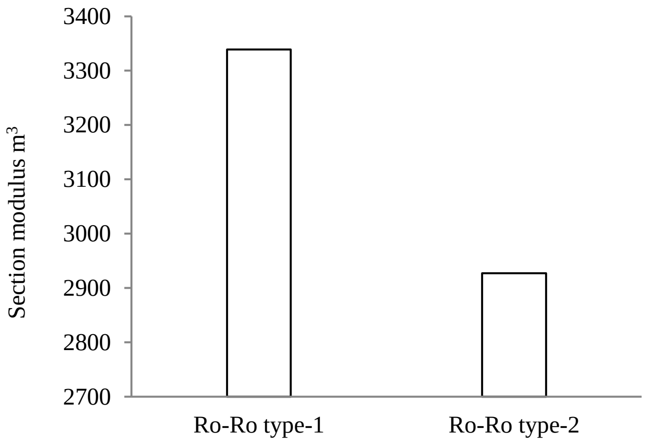

Fig. 9 Section modulus of Ro-Ro ships

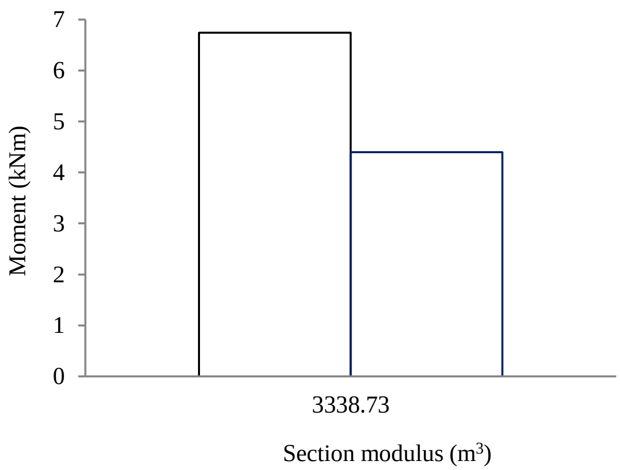

Fig. 10 Moment-section modulus for Ro-Ro type-1

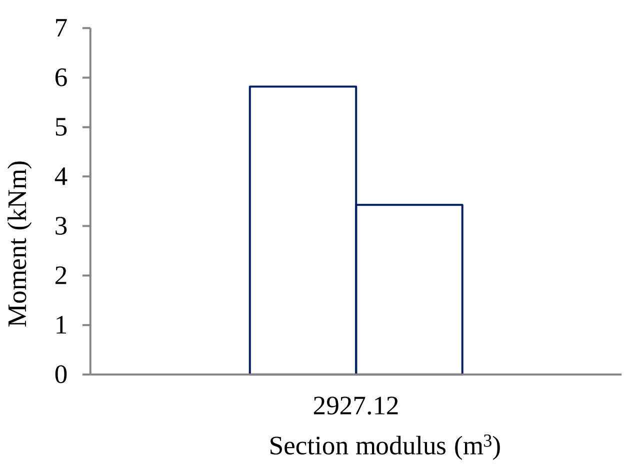

Fig. 11 Moment-section modulus for Ro-Ro type-2

Table 2 Moment-section modulus relationship for hogging

Ship types	M hogging (kNm)	Section modulus (m^3)
Roro type-1	6.74	3338.73
Roro type-2	5.82	2927.12

Table 3 Moment-section modulus relationship for sagging

Ship types	M sagging (kNm)	Section modulus (m^3)
Roro type-1	4.40	3338.73
Roro type-2	3.43	2927.12

The relationship between moment and section modulus of two Ro-Ro ships are described in Figs. 10 and 11 in hogging and sagging conditions, respectively. The moment-section modulus relationship for type-1 is also larger than for type-2 in hogging and sagging condition as shown in tables 2 and 3. The shapes of the cross section for two ships are quite different especially for type-2, because type-2 has double bottom which is not straight line where those area consists of some pillars. The pillars attached on the vertical plate to overcome the structural deformation at the car deck.

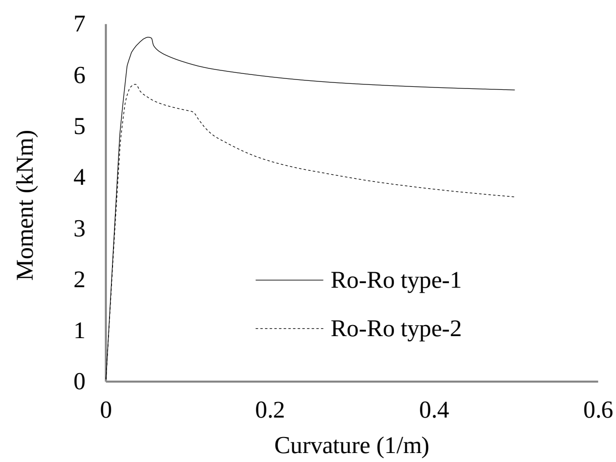

Fig. 12 Moment-curvature relationship for hogging

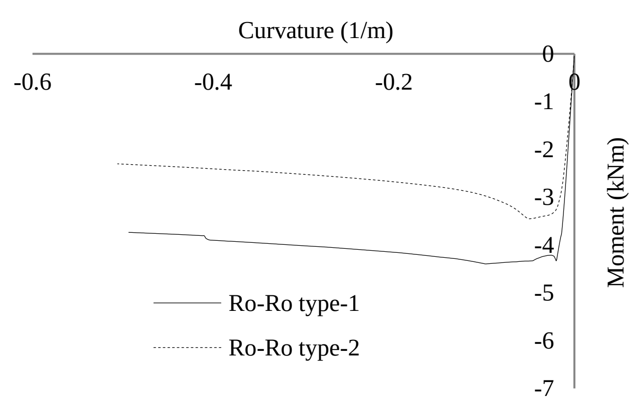

Fig. 13 Moment-curvature relationship for sagging

The moment-curvature relationship in hogging and sagging conditions for Ro-Ro type-1 and type-2 are described in Figs. 12 and 13. The solid lines express the moment-curvature relationship for Ro-Ro type-1, while the dashed one illustrates for Ro-Ro type-2. The moment-curvature relationship for hogging condition between type-1 and type-2 gives significant differences for the ultimate strength and beyond the ultimate strength. This phenomenon also occurs for sagging condition. The value of the ultimate strength is almost identic with the local Classification Society rules.

CONCLUSIONS

The ultimate hull girder strength analysis considering section modulus of Ro-Ro ship under longitudinal bending have been performed based on simple formula of the local Classification Society rules and the Smith's method. The following conclusions are; the effect of the section modulus on the ultimate hull girder strength is significant not only in hogging but also sagging condition. The effect may be caused by the structural configuration of the Ro-Ro ships such as dimensions and number of plate and unstiffened plate, especially on the bottom part to support car deck by some pillars.

REFERENCES

Biro Klasifikasi Indonesia (BKI). (2017). "Rules for the Classification and Construction," Volume II.

Kim, D.H and Paik, J.K. (2017). "Ultimate Limit State-Based Multi-Objective Optimum Design Technology for Hull Structural Scantlings of Merchant Cargo Ships," *Ocean Engineering*, 129, 318-334.

Korkut, E, Atlar, M and Incecik, A (2005). "An Experimental Study of Global Loads Acting on an Intact and Damaged Ro-Ro Ship Model," *Ocean Engineering*, 32, 1370-1403.

Kukkanen, T and Matusiak, J (2014). "Nonlinear Hull Girder Loads of a RoPax Ship," *Ocean Engineering*, 75, 1-14.

Naar, H, Varsta, P and Kujala, P (2004). "A Theory of Cupled Beams for Strength Assessment of Passenger Ships," *Marine Structures*, 17, 590-611.

Muis Alie, M.Z, Sitepu, G, Juswan, Wahyuddin, Nugraha, A.M and Alamsyah (2016). "The Influence of Superstructure on the Longitudinal Ultimate Strength of a RO-RO Ship," *Proc 26th Int Offshore and Polar Eng Conf*, Greece, ISOPE, 4, 1022–1029.

Muis Alie, M.Z, Sitepu, G and Latumahina, S.I (2017). "The Assessement of the Ultimate Hull Girder Strength of Ro-Ro Ship after Damages," *Proc 27th Int Offshore and Polar Eng Conf*, USA, ISOPE, 4, 913–919.

Yao, T. and Nikolov, P.I. (1992). "Progressive Collapse Analysis of a Ship's Hull Girder under Longitudinal Bending (2nd Report)," *J Soc. Naval Arch. of Japan*, Vol 172, 437-446.

Universitas Hasanuddin

Muhammad Zubair Muis Alie, Ph.D <zubair.m@eng.unhas.ac.id>

Confirmation of Your ISOPE-2018 Abstract Submission

ISOPE-2018 TPC <meetings@isope.org> Sun, Oct 8, 2017 at 5:17 PM
Reply-To: meetings@isope.org
To: "Dr.Muis Alie"@mail.unhas.ac.id, Muhammad Zubair <zubair.m@eng.unhas.ac.id>, ISOPE-2018 TPC <meetings@isope.org>

Welcome to ISOPE-2018 Sapporo Conference.Your abstract was sent to ISOPE-2018 TPC. The TPC will notify you in time of further information,including the conference template with instructions and the information on the TPC member who will handle peer-review of your manuscript (MS).Look for updates on www.isope.org .The latest information including the manuscript (MS) template with instructions will be posted on www.isope.org > Program, Venue, Hotel.

Following is a summary of your ISOPE-2018 Abstract Online Submission:

Title: The Ultimate Hull Girder Strength Analysis Considering Section Modulus under Longitudinal Bending

General Topic: Mechanics, Structures & Analysis
Specific Topics, primary: 77 Mechanics & experiment - general
secondary: 78 Reliability, risk & safety, emergency

Author 1 :
Dr. Muis Alie*, Muhammad Zubair
Naval Architect and Ocean Engineering
Hasanuddin University
Jalan Poros Malino Km. 6 Bontomarannu
Gowa, South Sulawesi
92172
Indonesia
Tel: +62-411-586015 Ext: Fax: +62-411-586015
E-mail: zubair.m@eng.unhas.ac.id

Author 2 :
Mr. Latumahina, Samuel Izaak
Naval Architect and Ocean Engineering
Hasanuddin University
Jalan Poros Malino km. 6 Bontomarannu
Gowa, South Sulawesi
92172
Indonesia
Tel: +62-411-586015 Ext: Fax: +62-411-586015
E-mail: samuellatumahina@student.unhas.ac.id

I was invited to submit this abstract by: ISOPE

Abstract:
The ship hull girder is very esential to againts the internal loads, particularly the external loads such as pressure and wave loads. The hull girder play an important role in the investigation for the ultimate strength calculation. The objective of the present study is to assess the ultimate hull girder strength taking the section modulus into account under longitudinal bending. A Ro-Ro Ship is taken as the object of the ship. A Ro-Ro Ship has a unique character because most of the longitudinal elements locate above neutral axis. While there are not the longitudinal elements under the neutral axis particularly at the bottom part so that the bottom part consists plate only. The Ro-Ro ship consists of some decks such as car, passenger and top. According to these, it is absolutely different the section modulus on the car, passenger and top deck. The distance between car, passenger and top deck are also different. Therefore, the section modulus for above and under the neutral axis must
be investigated toward the ultimate strength and their progressive collapse behavior for car, passenger and top deck. In this regard, the elements attached on those decks must be assessed in more detail for deformation under longitudinal bending. The simple expression implemented into in-house program to calculate the section modulus of ship cross section is performed. The cross section is assumed to be remained plane and the simply supported of boundary condition is applied. The ultimate strength of ship's hull is calculated under hogging and sagging conditions. The hull girder of Ro-Ro ship is devided into elements compose plate and stiffened plates to calculate

the section modulus. The vertical bending moments are imposed to both sides of the cross section. The ultimate hull girder strength is calculated by considering the section modulus including their progressive collapse behavior for Ro-Ro ship hull.

Universitas Hasanuddin

Muhammad Zubair Muis Alie, Ph.D <zubair.m@eng.unhas.ac.id>

Paper No. 2018-TPC-0201 - Extension to 1/26

Starr Koga <isope-5@sbcglobal.net> Wed, Jan 17, 2018 at 2:58 AM
Reply-To: isope-5@sbcglobal.net
To: Tetsuya YAO <yao@naoe.eng.osaka-u.ac.jp>, Zubair <zubair.m@eng.unhas.ac.id>

Dear Dr. Muis Alie :

ISOPE-2018 Secretariat Office grants an extension for submission of draft manuscript to January 26, 2018.
If you require more time beyond January 26, 2018, session organizer will need to approve.

If you have not already done so, please fax or e-mail copyright form now so that there will be no delay to begin the review process when you submit draft manuscript. Thank you.

Please cc: isope-5@sbcglobal.net or isope-5@isope.org when you send draft MS to Session Organizer.

You must allow S.O. enough time to send the paper out to reviewers, return comments to the author, and have the author complete required revisions in time to meet the ISOPE Printer's deadline for FINAL paper by March 24. This year in particular, due to the fact that the conference is taking place 2 weeks earlier in June than usual, ISOPE must be quite strict on enforcing receipt of FINAL (reviewed, revised, accepted) PDFs by March 24.
Thank you for your understanding and cooperation in meeting the deadlines.

Best regards,

Mrs. Starr Koga, Admin. Asst.
ISOPE-2018 Secretariat Office
International Society of Offshore & Polar Engineers (ISOPE)
495 North Whisman Road, Suite 300
Mountain View, California 94043-5711, USA
www.isope.org
Tel: 1-650-254-1871; Fax: 1-650-254-2038
isope-5@sbcglobal.net

If your mail to us at "@sbcglobal.net" is blocked by our ISP, please send to:
isope-5@isope.org OR isope@isopemail.org. Thank you for your patience.

-----Original Message-----
From: Tetsuya YAO [mailto:yao@naoe.eng.osaka-u.ac.jp]
Sent: Sunday, January 14, 2018 5:02 PM
To: Zubair <zubair.m@eng.unhas.ac.id>
Cc: Starr Koga <isope-5@sbcglobal.net>
Subject: Re: need extension for manuscript ISOPE 2018-TPC 0201

Dear Zubair,

It is OK. Please let me know when is the new deadline for your manuscript. I recommend you to set the new deadline.

Best Wishes.....Tetsuya
--
Tetsuya YAO <yao@naoe.eng.osaka-u.ac.jp>

Universitas Hasanuddin

Muhammad Zubair Muis Alie, Ph.D <zubair.m@eng.unhas.ac.id>

Re: ISOPE 2018 TPC-0201

Tetsuya YAO <yao@naoe.eng.osaka-u.ac.jp> Sun, Jan 21, 2018 at 3:00 PM
To: Zubair <zubair.m@eng.unhas.ac.id>
Cc: Starr Koga <isope-5@sbcglobal.net>

Dear Muhammad Zubair Muis Alie,

Thank you for submitting your manuscript (MS) "ISOPE 2018-TPC-0201: The Ultimate Hull Girder Strength Analysi Considering Section Modulus Under Longitudinal Bending" for presentation at and for publication in the Proceedings of The 28th (2018) International Ocean and Polar Engineering Conference, Sapporo, Japan, June 10-15, 2018.

E-mail the copyright form only to isope-2@isope.org or fax to +1-650-254-2038 as soon as possible if you have not yet sent it.

As soon as the manuscript has been reviewed and evaluated, I will advise you as to its acceptability. Any changes in length, content, or style that seem desirable will be indicated. We will try to complete the review in 4 weeks, or by February 19, 2018. When you are notified of any revision request, you will also receive review comments. If you are not notified of the review results by these dates, please contact me immediately.

Only after receiving the revision request, you should type your final revised MS using the ISOPE conference template in WORD. The template specifies ISOPE conference paper format, style and font. It can also be downloaded from <http://www.isope.org/> www.isope.org if not already e-mail-attached by your session organizer. Later, we will be asking for your final revised manuscript as a PDF file (as well as WORD file in case you used a local version of WORD from China, Hong Kong, Taiwan, Korea or Japan).

Visit www.isope.org <http://www.isope.org/> for updated instructions.

. Deadline for the final revised MS as PDF (on the ISOPE-2018 Final WORD-to-PDF template) to ISOPE TPC is March 24, 2018 (very important date!). We will provide a specific email address for you to send your final revised MS as a PDF file smaller than 8 MB.

. Use your paper number 2018-xxx-yyyy in every communication and in email Subject line. In case you misplaced the 2018 Final (WORD-to-PDF) template, request a file from <mailto:isope-2@isope.org> isope-2@isope.org.

. Like many other major engineering societies, the ISOPE conference requires at least one author (or co-author) per paper to pay the advance registration fee no later than March 24, 2018 or earlier (if notified from ISOPE office) for inclusion in the proceedings. The fee starts from approximately US$690 [and lower for the students.]

. Tourist season starts in June. Book rooms at the hotel of your choice as early as from January as a limited number of rooms are allocated at special ISOPE room rates, ranging $80-$240 per night at a range of hotels in Sapporo.

Thank you for your patience and cooperation. If you have any questions, please contact me by e-mail or fax.

Sincerely yours,

Tetsuya YAO; a TPC member; email address: yao@naoe.eng.osaka-u.ac.jp

cc: ISOPE-2018 TPC

--
Tetsuya YAO <yao@naoe.eng.osaka-u.ac.jp>

---

2 attachments

Regadv-2018 Sapporo-EZ-Fill-due0110.pdf
101K

Template-Word-MS-2018.docx
31K

Universitas Hasanuddin

Muhammad Zubair Muis Alie, Ph.D <zubair.m@eng.unhas.ac.id>

RE: ISOPE 2018 TPC-0201 (copyright)

Starr Koga <isope-5@isope.org> Tue, Jan 30, 2018 at 4:20 AM
Reply-To: isope-5@isope.org
To: Zubair <zubair.m@eng.unhas.ac.id>

Thank you!

Best regards,

Mrs. Starr Koga, Admin. Asst.
ISOPE-2018 Secretariat Office
International Society of Offshore & Polar Engineers (ISOPE)
495 North Whisman Road, Suite 300
Mountain View, California 94043-5711, USA
www.isope.org
Tel: 1-650-254-1871; Fax: 1-650-254-2038
isope-5@sbcglobal.net

If your mail to us at "@sbcglobal.net" is blocked by our ISP, please send
to:
isope-5@isope.org OR isope@isopemail.org. Thank you for your patience.

-----Original Message-----
From: Zubair [mailto:zubair.m@eng.unhas.ac.id]
Sent: Saturday, January 27, 2018 11:22 PM
To: isope-5@isope.org
Subject: RE: ISOPE 2018 TPC-0201 (copyright)

Dear Mrs. Starr Koga

Attachment, please find the copyright of ISOPE 2018-TPC-0201

Sincerely yours,
Muhammad Zubair Muis Alie

On 2018-01-27 02:17, Starr Koga wrote:
> Dear Dr. Muis Alie:
> A copy of your draft paper has been received at ISOPE Secretariat
> Office.
> Thank you!
> If you have not already, please e-mail completed copyright form to
> isope-2@isope.org.
>
> Best regards,
>
> Mrs. Starr Koga, Admin. Asst.
> ISOPE-2018 Secretariat Office
> International Society of Offshore & Polar Engineers (ISOPE)
> 495 North Whisman Road, Suite 300
> Mountain View, California 94043-5711, USA
> www.isope.org
> Tel: 1-650-254-1871; Fax: 1-650-254-2038
> isope-5@sbcglobal.net
>
> If your mail to us at "@sbcglobal.net" is blocked by our ISP, please
> send

> to:
> isope-5@isope.org OR isope@isopemail.org. Thank you for your
> patience.
>
> -----Original Message-----
> From: Zubair [mailto:zubair.m@eng.unhas.ac.id]
> Sent: Saturday, January 20, 2018 9:33 PM
> To: yao@naoe.eng.osaka-u.ac.jp; isope-5@sbcglobal.net
> Cc: isope-5@sbcglobal.net; isope-5@isope.org
> Subject: ISOPE 2018 TPC-0201
>
> Dear Professor Tetsuya Yao
> cc : Mrs. Starr Koga
>
>
> Attacment, please find the manuscript for ISOPE 2018 TPC-0201.
>
>
> Sincerely yours,
>
> Muhammad Zubair Muis Alie

Universitas Hasanuddin

Muhammad Zubair Muis Alie, Ph.D <zubair.m@eng.unhas.ac.id>

Review has been dinished on ISOPE Paper 2018-TPC-0201

Tetsuya YAO <yao@naoe.eng.osaka-u.ac.jp> Tue, Feb 13, 2018 at 10:31 PM
To: zubair.m@eng.unhas.ac.id

Dear Dr. Muis Alie,

Review has been completed on your paper. ISOPE Paper 2018-TPC-0201. Review results are attached here.

* Please read the comments and revise accordingly. If you don't agree with certain comments, say so in your email with the revised final manuscript (MS).

* Final (PDF) manuscript deadline is March 24. Copy your paper to the ISOPE template, which already has correct margins and font type and size.

* The advance registration fee payment for the presenting author of each paper is due by March 24 to ensure inclusion of your paper in the proceedings.

* Make your room reservation in February or early March to get a room at ISOPE's special rates range from \10,000 to \26,000 per night at many hotels for single. These rates include tax and breakfast.

To secure a room, book real early online. http://www.jtb.co.jp/ripple/isope2018/ .

Your final MS template must reach ISOPE by March 24.

u Original PDF files of the final MS: Authors must E-mail the PDF file of the paper as an attachment to <mailto:isope@ttia.com:> : <mailto:isope-5@sbcglobal.net> isope-5@sbcglobal.net and cc: <mailto:isope-2@isope.org> isope-2@isope.org and

u E-mail (cc) a copy of the final MS to your session organizer (S.O.) for quick re-review and approval.

The PDF files in the conference proceedings USB 3.0 made in the USA may not display any local fonts used in PDF files, such as Asian fonts and some Russian fonts. The printer will not be able to include any PDF files with local or missing fonts.

You are required to use Times New Roman font as specified in the attachment for text, symbols, equations and figures. For this purpose, ISOPE's WORD-to-PDF conversion procedure is on the Template page 3.

The full version of the ISOPE-2018 conference program with some 151 sessions, plenary and keynote presentations will be posted on <http://www.isope.org/conferences/conferences.htm> http://www.isope.org/conferences/conferences.htm.

Best regards,

Tetsuya YAO, ISOPE-2018 Sapporo TPC member

Osaka University,

Email address: yao@naoe.eng.osaka-u.ac.jp

cc: ISOPE (isope-5@sbcglobal.net)

495 North Whisman Rd, Suite 300

Mountain View, CA 94043-5711, USA

T 1-650-254-1871; F 1-650-254-2038; <http://www.isope.org/> www.isope.org

--
Tetsuya YAO <yao@naoe.eng.osaka-u.ac.jp>

--
Tetsuya YAO <yao@naoe.eng.osaka-u.ac.jp>

4 attachments

Comments from reviewers.doc
98K

Copyright-ISOPE-2018-EZfill.pdf
81K

Regadv-2018 Sapporo-EZ-Fill-due0110.pdf
101K

Template-Word-MS-2018.docx
31K

Universitas Hasanuddin

Muhammad Zubair Muis Alie, Ph.D <zubair.m@eng.unhas.ac.id>

Re: ISOPE 2018-TPC-0201

Starr Koga <isope-5@isope.org> Tue, Feb 27, 2018 at 5:57 AM
Reply-To: isope-5@isope.org
To: Zubair <zubair.m@eng.unhas.ac.id>
Cc: Tetsuya YAO <yao@naoe.eng.osaka-u.ac.jp>

Dear Author:

This e-mail confirms your FINAL MANUSCRIPT has been received by ISOPE Secretariat Office.
Registration form also received.

Session Organizer will soon reply if the paper requires further technical changes or issue Formal Acceptance notice.

Additional information will be sent after the file has been checked by our Printer.
Thank you.

Best regards,

Mrs. Starr Koga, Admin. Asst.
ISOPE-2018 Secretariat Office
International Society of Offshore & Polar Engineers (ISOPE)
495 North Whisman Road, Suite 300
Mountain View, California 94043-5711, USA
www.isope.org
Tel: 1-650-254-1871; Fax: 1-650-254-2038
isope-5@sbcglobal.net

If your mail to us at "@sbcglobal.net" is blocked by our ISP, please send to:
isope-5@isope.org OR isope@isopemail.org. Thank you for your patience.

-----Original Message-----
From: Zubair [mailto:zubair.m@eng.unhas.ac.id]
Sent: Sunday, February 25, 2018 2:02 PM
To: Tetsuya YAO <yao@naoe.eng.osaka-u.ac.jp>
Cc: Starr Koga <isope-5@isope.org>
Subject: ISOPE 2018-TPC-0201

Dear Professor Tetsuya YAO
cc : Mrs. Starr Koga

Attachment, please find Full Paper of ISOPE 2018-TPC-0201, answer from the author and Registration Form.

Faithfully yours,
Muhammad Zubair Muis Alie

Universitas Hasanuddin

Muhammad Zubair Muis Alie, Ph.D <zubair.m@eng.unhas.ac.id>

ISOPE-2018 Sapporo - 2018-TPC-0201 PDF format - OK and Author Info

Starr Koga <isope-5@sbcglobal.net> Thu, Mar 1, 2018 at 6:00 AM
Reply-To: isope-5@sbcglobal.net
To: Zubair <zubair.m@eng.unhas.ac.id>
Cc: "Prof. Tetsuya Yao" <yao@naoe.eng.osaka-u.ac.jp>

Dear Corresponding Author,

Thank you for your manuscript (MS) PDF file for the ISOPE-2018 Sapporo Conference. The display of your PDF file on our monitor indicates our printer can use it for the conference proceedings.

* If you haven't already done so, immediately e-mail the PDF file to your S.O. for approval.
* Your session organizer (S.O.) will promptly check your compliance with the reviewer comments, then issue an acceptance or rejection letter.

For Your Action: Always check for conference updates at: **http://www.isope.org/conferences/conferences.htm** > ISOPE-2018 Sapporo.
* The presenting author of each paper must advance register by **March 24** (if not yet done) to ensure inclusion of your peer-reviewed paper in the ISOPE-2018 Proceedings. The printer uses the registration list to include the individual papers.
* Make hotel reservation (online only)**: http://www.jtb.co.jp/ripple/isope2018** by early March to secure a room at the special ISOPE rates. The venue is Royton Sapporo Hotel. You may also find other hotels on internet.

* E-mail any special equipment request (e.g., video) to rent at your expense to ISOPE (isope-2@isope.org) **by May 12**. Projector/Laptop are available in each session room.

* The **conference session and paper list**: Near the end of February, go to **http://www.isope.org/conferences/conferences.htm** > ISOPE-2018 > paper and session list.

Apply now for an entry visa to Japan. Citizens of some countries are required to have an entry visa -- See the general information from the **Visa application form.**

* **Visa application form.** The form is available from the Consulate Office of Japan in your country, or in Google, search for Visa Application for Japan > VISAS. If the Consulate requires you to submit an **official letter of invitation**, it will be provided *upon request*, after your advance registration is complete.

* Sightseeing tour: General information will be available later at **http://www.isope.org/conferences/conferences.htm** > ISOPE-2018.

* **Tips for Paper Writing and Presentation** at ISOPE Conference – We have already sent to you. Also available at **http://www.isope.org/conferences/conferences.htm** > ISOPE-2018.
Use font size 24 point or bigger for your **Power point presentation**. **Do not** just copy and read the text of your paper.

* Laptops with MS Office and LCD Projectors are available in every session room for presentation and practice. In case you can't plug in your computer to the projector in 5 minutes, the chair can ask the next speaker to take over to avoid delay.

After checking the PDF file of your final MS and your S.O.'s letter, the TPC expects to include some **650+ peer-reviewed** papers in the ISOPE-2018 Conference Proceedings out of more than **1,300+ abstracts**.

* We invite you to join ISOPE (Form on ISOPE website), which includes subscription to ISOPE Transactions Journal.

Sincerely yours,

ISOPE TPC (meetings@isope.org; Fax 1-650-254-2038; Tel 1-650-254-1871)
495 North Whisman Road, Suite 300
Mountain View, CA 94043-5711, USA

Attachments: PPT presentation + self- introduction template, PPT presentation tips, Conference Registration

---

3 attachments

ISOPE PowerPointPresent-Guide-2014jc.pdf
15K

Regadv-2018 Sapporo-EZ-Fill-due0324-Seal.pdf
251K

ISOPE PPT Template-2018-bio(2)-use-.ppt
277K

Universitas Hasanuddin

Muhammad Zubair Muis Alie, Ph.D <zubair.m@eng.unhas.ac.id>

ISOPE-2018 Conference Registration Complete for 2018-TPC-0201 - Entry Visa/Invitation Letter info.

Starr Koga <isope-5@sbcglobal.net> Fri, Mar 2, 2018 at 8:10 AM
Reply-To: isope-5@sbcglobal.net
To: Zubair <zubair.m@eng.unhas.ac.id>

Dear Dr. Muis Alie:

Your conference registration is complete and we look forward to seeing you in Sapporo in June!

(note, this does not include your wife's banquet ticket. That charge has not been processed yet.)

PDF-RECEIPT for your registration is attached.

All attendees will need to present photo ID at the conference registration desk to pick up name badge and conference materials.

See below for ***important information regarding Entry Visa*** for travel to Japan.

===

To all ISOPE-2018 Conference Attendees:

Some persons may need an Entry Visa to travel to Japan for the Conference.

As of July 2017, Japan has Visa Exemption Arrangements with 68 countries and regions. To see if the passport you hold will exempt you from requiring an entry visa, visit: http://www.mofa.go.jp/j_info/visit/visa/short/novisa.html .

If you hold a passport from a country not listed on that page, please visit: http://www.mofa.go.jp/j_info/visit/visa/index.html for more detail on what is required for your individual case.

For those who must apply for an entry visa, you may need a **Letter of Invitation** from ISOPE.

Complete the attached "2018-Invitation Letter Request Form" and return to ISOPE-5.

ISOPE is allowed to issue an official letter of invitation on behalf of the conference co-chairs for your application of entry visa to the USA *only* ***after*** you have:

1. **Advance Registered** and
2. **Submitted Paper for Review**

(e-mail to Session Organizer and cc: to isope-5@sbcglobal.net OR isope-5@isope.org)

In addition, on the Ministry of Foreign Affairs of Japan, official "**Visa Application Form to Enter Japan,**" you will need the following information entered in these fields:

For "Purpose of visit to Japan" – enter "Participate in ISOPE-2018 Sapporo Conference"

For "Guarantor or reference in Japan" – enter:

Name: Dr. Hiromitsu Kitagawa

Tel.: 81-3-5157-5206

Address: 1-15-16 Sasakawa Peace Foundation Bldg. 6F, Minato-Ku, Tokyo

Date of birth: 30/11/1935

Sex: Male

Relationship to applicant: Co-chair of International Conference, ISOPE-2018 Sapporo

Profession or occupation and position: Visiting Research Fellow, OPRI, Sasakawa Peace Foundation

Nationality and immigration status: Japanese

For "Inviter in Japan" – enter: "SAME AS ABOVE"

Entry Visa application process can take many weeks, and even sometimes more than one month to complete. PLEASE start the process as early as possible to ensure that you can attend the conference to present your paper!

* Make your room reservation in February or early March to get a room at ISOPE's special rates ranging from ¥10,000 to ¥26,000 per night at many hotels for single. These rates include tax and breakfast.

To secure a room, book real early online. http://www.jtb.co.jp/ripple/isope2018/

ISOPE office does not handle reservations, reserve directly through this link.

We look forward to meeting you at the Conference and to your presentation.

Best regards,

ISOPE-2018 Secretariat Office

International Society of Offshore & Polar Engineers (ISOPE)

495 North Whisman Road, Suite 300

Mountain View, California 94043-5711, USA

www.isope.org

Tel: 1-650-254-1871; Fax: 1-650-254-2038

isope-5@sbcglobal.net

-

If your mail to us at "@sbcglobal.net" is blocked by our ISP, please send to:

isope-5@isope.org **OR** isope@isopemail.org*. Thank you for your patience.*

3 attachments

2018-Invitation Letter Request EZ-fill.pdf
541K

Invitation Letter Form-ISOPE.PDF
228K

2018 Reg Recpt MuisAlie,MZ-TPC-0201.pdf
129K

Universitas Hasanuddin

Muhammad Zubair Muis Alie, Ph.D <zubair.m@eng.unhas.ac.id>

Re: Review results on ISOPE Paper 2018-TPC-0201

Tetsuya YAO <yao@naoe.eng.osaka-u.ac.jp> Fri, Mar 16, 2018 at 8:56 AM
To: Zubair <zubair.m@eng.unhas.ac.id>
Cc: Starr Koga <isope-5@sbcglobal.net>

Dear Dr. Muhammad Zubair Muis Alie,

Thank you for sending me your revised manuscript.

Congratulations! It is my pleasure to inform you that your paper has been accepted for the annual ISOPE 2018 Conference, Sapporo, June 10-15, 2018. The Technical Program Committee (TPC) will follow up with additional details.

The printer will include your final revised paper in the conference proceedings only after ISOPE receives the copyright form (isope-2@isope.org) and the advance conference registration from one author by March 24.

The revised final paper in PDF should have correctly followed the instructions on the template. Follow instructions carefully regarding margin, format, font (must use Times New Roman, not local font), "High Quality Print" or "Press Quality" PDF-conversion procedure, etc. You should have emailed the final PDF (with companion Word file) to isope-5@sbcglobal.net and cc: isope-2@isope.org.

Normally, each author is given 15 minutes for presentation and 5 minutes for discussion, with more time for plenary, keynote and review papers. A laptop and an LCD projector are available in each session room. The author biography is one of your PowerPoint presentation slides (PPT Template is attached-view Slide Master to edit). You should have received or will receive the full conference program by email and session table by mail ? in early March.

You can download registration form, and Program from <http://www.isope.org/conferences/conferences.htm> http://www.isope.org/conferences/conferences.htm

Give a copy of this letter to your co-author(s). You are invited to the Reception and the annual Conference Banquet. A link to information on travel to Sapporo is available in the ISOPE-2018 Conference General Information at <http://www.isope.org/conferences/conferences.htm> http://www.isope.org/conferences/conferences.htm

Make hotel reservation (online only): <http://www.jtb.co.jp/ripple/isope2018> http://www.jtb.co.jp/ripple/isope2018 by early March to secure a room at the special ISOPE rates. The venue is Royton Sapporo Hotel. You may also find other hotels on internet.

On behalf of the TPC, I would like to express our appreciation for your contribution to ISOPE?2018, again featuring the world's largest technical program of its kind with peer-reviewed papers in 151 opening and technical sessions and 9 plenary and keynote presentations on state-of-the-art technologies.

We look forward to seeing you in Sapporo. I would also like to take this opportunity to invite you to ISOPE?2019 Honolulu, Hawaii, June 16-21, 2019.

Best regards,

Tetsuya YAO,

TPC member

E-mail address: yao@naoe.eng.osaka-u.ac.jp

ISOPE

495 North Whisman Road, Suite 300

Mountain View, CA 94043-5711, USA

Tel 1-650-254-1871; Fax 1-650-254-2038; www.isope.org

Attachment: PowerPoint Template etc.

--
Tetsuya YAO <yao@naoe.eng.osaka-u.ac.jp>

4 attachments

Copyright-ISOPE-2018-EZfill.pdf
81K

ISOPE PowerPointPresent-Guide-2014jc.pdf
15K

ISOPE PPT Template-2018-bio(2)-use-.ppt
275K

Regadv-2018 Sapporo-EZ-Fill-due0324-Seal.pdf
251K

Universitas Hasanuddin

Muhammad Zubair Muis Alie, Ph.D <zubair.m@eng.unhas.ac.id>

RE: Full Paper of ISOPE 2018-TPC-0201

Starr Koga <isope-5@isope.org> Wed, Mar 21, 2018 at 1:07 AM
Reply-To: isope-5@isope.org
To: Zubair <zubair.m@eng.unhas.ac.id>, Tetsuya YAO <yao@naoe.eng.osaka-u.ac.jp>

Dear Author:

This e-mail confirms your FINAL MANUSCRIPT has been received by ISOPE Secretariat Office.
Additional information will be sent after the file has been checked by our Printer.

Best regards,

Mrs. Starr Koga, Admin. Asst.
ISOPE-2018 Secretariat Office
International Society of Offshore & Polar Engineers (ISOPE)
495 North Whisman Road, Suite 300
Mountain View, California 94043-5711, USA
www.isope.org
Tel: 1-650-254-1871; Fax: 1-650-254-2038
isope-5@sbcglobal.net

If your mail to us at "@sbcglobal.net" is blocked by our ISP, please send to:
isope-5@isope.org OR isope@isopemail.org. Thank you for your patience.

-----Original Message-----
From: Zubair <zubair.m@eng.unhas.ac.id>
Sent: Thursday, March 15, 2018 5:14 PM
To: Tetsuya YAO <yao@naoe.eng.osaka-u.ac.jp>
Cc: Starr Koga <isope-5@isope.org>
Subject: Full Paper of ISOPE 2018-TPC-0201

Dear Professor Tetsuya YAO
cc : Mrs. Starr Koga

Attachment, please find the revision of Full Paper ISOPE 2018-TPC-0201.

Sincerely yours,
Muhammad Zubair Muis Alie

The Ultimate Hull Girder Strength Analysis Considering Section Modulus under Longitudinal Bending

Muhammad Zubair Muis Alie, Department of Naval Architect and Ocean Engineering, Hasanuddin University, Indonesia*
Samuel Izaak Latumahina, Department of Naval Architect and Ocean Engineering, Hasanuddin University, Indonesia

* Corresponding author:
Department of Naval Architect and Ocean Engineering
Engineering Faculty, Hasanuddin University.
Jl. Poros Malino km. 6 Bontomarannu postal code: 92172
Gowa, South Sulawesi, Indonesia.
Email zubair.m@eng.unhas.ac.id
Tel: +62-411-586015, FAX: +62-411-586015

ABSTRACT

The ship hull girder is very esential to againts the internal loads, particularly the external loads such as pressure and wave loads. The hull girder play an important role in the investigation for the ultimate strength calculation. The objective of the present study is to assess the ultimate hull girder strength taking the section modulus into account under longitudinal bending. A Ro-Ro Ship is taken as the object of the ship. A Ro-Ro Ship has a unique character because most of the longitudinal elements locate above neutral axis. While there are not the longitudinal elements under the neutral axis particularly at the bottom part so that the bottom part consists plate only. The Ro-Ro ship consists of some decks such as car, passenger and top. According to these, it is absolutely different the section modulus on the car, passenger and top deck. The distance between car, passenger and top deck are also different. Therefore, the section modulus for above and under the neutral axis must be investigated toward the ultimate strength and their progressive collapse behavior for car, passenger and top deck. In this regard, the elements attached on those decks must be assessed in more detail for deformation under longitudinal bending. The simple expression implemented into in-house program to calculate the section modulus of ship cross section is performed. The cross section is assumed to be remained plane and the simply supported of boundary condition is applied. The ultimate strength of ship's hull is calculated under hogging and sagging conditions. The hull girder of Ro-Ro ship is devided into elements compose plate and stiffened plates to calculate the section modulus. The vertical bending moments are imposed to both sides of the cross section. The ultimate hull girder strength is calculated by considering the section modulus including their progressive collapse behavior for Ro-Ro ship hull.

Keywords: Ship hull, cross section, section modulus, ultimate strength

The Ultimate Hull Girder Strength Analysis Considering Section Modulus Under Longitudinal Bending

Muhammad Zubair Muis Alie and Samuel Izaak Latumahina
Department of Naval Architect and Ocean Engineering, Engineering Faculty, Hasanuddin University
Gowa, South Sulawesi, Indonesia

ABSTRACT

The objective of the present study is to assess the ultimate hull girder strength taking the section modulus into account under longitudinal bending. A Ro-Ro Ship is taken as object ship. A Ro-Ro Ship has a unique character because most of the longitudinal elements locate above neutral axis. While there are not the longitudinal elements under the neutral axis particularly at the bottom part so that the bottom part consists plate only. The simple expression implemented into in-house program to calculate the section modulus of ship cross section is performed. The cross section is assumed to be remained plane and the simply supported of boundary condition is imposed on plate and stiffened plate elements in the cross section. The vertical bending moments are imposed to both sides of the cross section. The ultimate hull girder strength is calculated by considering the section modulus including their progressive collapse behavior for Ro-Ro ship hull.

KEY WORDS: Ship hull; cross section; section modulus; ultimate strength.

INTRODUCTION

The Ro-Ro ship is one of the ship types which transport the cargo in horizontal direction and eliminate the need for onboard or deckside lift-on and/or lift off instrument. The Ro-Ro ship has been innovated to carry processed forest product, lumber, playwood, cars and many things. Ro-Ros are an improtrant connection for the intermodal transportation network. In this regard, the section modulus could be one of the important parameters from the viewpoint of assessing the ultimate strength of all the decks on which cars, passengers and so on are put. In spite of human error, the structural degradation during loading and unloading gives impact to the ultimate strength of ship's hull.

The ultimate hull girder strength of merchant ships including Ro-Ro ship has been assessed by some researchers. Kukkanen, T and Matusiak, J (2014) presented the numerical and experimental results of nonlinear wave loads. A nonlinear time domain method had been developed and the theoretical background of the method were provided. The method was based on the source formulation expressed by means of the transient three-dimensional Green function. The time derivative of the velocity potential in Bernoulli's equation was solved with similar source formulation to that of the perturbation velocity potential. Korkut, E et al (2005) carried out measurements of global loads acting on a Ro-Ro model in regular waves for intact and damaged conditions. The stationary model was tested in different wave heights and wave frequencies for the head, beam and stern quartering seas in order to explore the effect of damages and wave heights on the global loads acting on the model. The analysis of the result indicated that the damages had an adverse effect on the loading conditions on the model depending upon the directionality of the waves and frequency range applied. This effect might cause structural damage on the ship and danger the safety of the ship and passenger on board. Kim, D.H and Paik, J.K (2017) developed a fully automated methodology for the optimum design of hull structural scantlings for merchant cargo ships that were modelled by plate-shell finite elements. A full optimization technique with multi-objectives was applied for minimizing structural weight and maximizing structural safety, as per design constraints associated with the ultimate limit states of the plate panels, support members and hull girders. The developed procedure was applied to the hull structural scantlings of a very large crude oil carrier (VLCC), and the test demonstrated the procedure's capacity to meet the strength requirements of common structural rules. Muis Alie, M.Z et al (2016) investigate the influence of superstructure on the longitudinal ultimate strength of a Ro-Ro ship. To investigate the ultimate strength, the Smith's method was adopted and implemented into the thin-walled beam. The cross section of Ro-Ro ship was taken to be analyzed. Muis Alie, M.Z et al (2017) assessed the ultimate hull girder strength of Ro-Ro ship after damaged. The cross section of Ro-Ro was taken to be analyzed. The collision and grounding damages were assumed to be placed on the side and bottom area. The damages were created by removing the element from the side shell and bottom parts. Finally, the result obtained was compared with one another. Also, the progressive collapse analysis of ship hull girder based on Smith's method was developed by Yao and Nikolov (1992). Naar, H et al (2004) described a couple beam method, which estimate elastic response in the longitudinal bending of a passenger ship with a large multi-deck superstructure. The method could be applied during an early project stage, when detailed three-dimensional finite element modelling was not yet possible. The theory was based on assumption that each deck in the superstructure and also the main hull could be considered as thin-walled beam.

In the present study, the ultimate hull girder strength analysis is assessed considering the section modulus. The cross section of a Ro-Ro ship is considered to be analyzed. Bottom part, car and passenger decks are calculated for the section modulus where those located above and/or under the neutral axis. Their result is investigated toward the ultimate strength for the global structure.

ANALYTICAL SOLUTION

The section modulus of ship indicates the ship strength not only in longitudinal but also transversal direction. The classification societies have been stated requirements so that the section modulus should be greater than a prescribed value. It is well known that ship structural characteristics affect significantly on the ultimate strength depending on the cargo types, configuration of structural scantling and so on. The fundamental theory of strength of material may be used for calculating the section modulus of the ship hull cross section. In structural modelling, the ship hull cross section is idealized by stiffened and unstiffened plate combination. Fig. 1 shows the cross section of Ro-Ro ship and Fig. 2 the typical type of stiffened plate with attached plating.

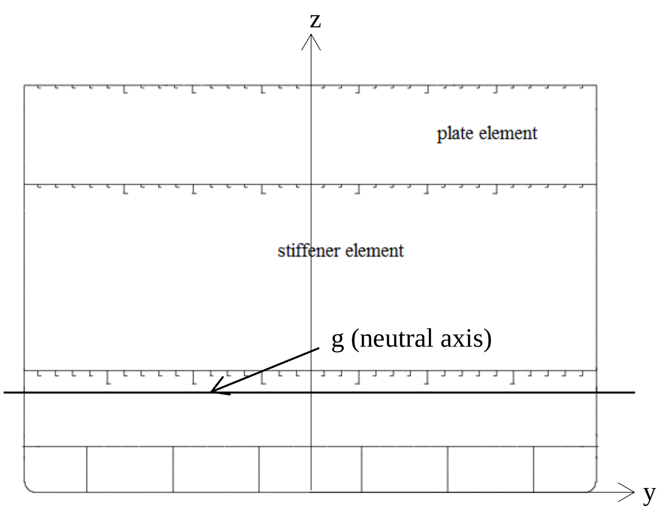

Fig. 1 Cross section of Ro-Ro ship

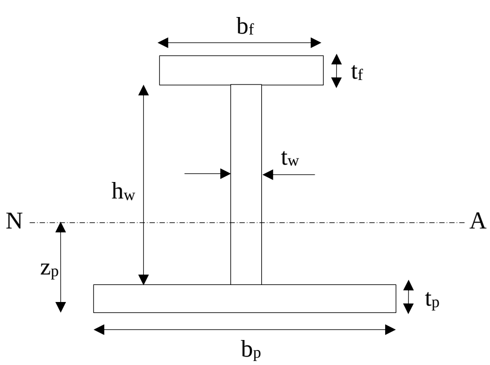

Fig. 2 Typical type of stiffened plate with attached plating

The profile and consists of web, flange and attached plating including the neutral axis (N-A) are shown in Fig. 2. The moment of inertia of the profile may be expressed as

$$I = \frac{b_p (t_p)^3}{12} + A_p \left(z_p - \frac{t_p}{2} \right)^2 + \frac{h_w^3 t_w}{12} + A_w \left(z_p - t_p - \frac{h_w}{2} \right)^2 + \frac{b_f t_f^3}{12} + A_f \left(t_p + h_w + \frac{t_f}{2} - z_p \right)^2 \tag{1}$$

Where

$$A_p = b_p t_p \tag{2}$$

$$A_w = h_w t_w \tag{3}$$

$$A_f = b_f t_f \tag{4}$$

$$z_p = \frac{0.5 b_p t_p^2 + A_w (t_p + 0.5 h_w) + A_f (t_p + h_w + 0.5 t_f)}{(A_p + A_w + A_f)} \tag{5}$$

The location of the neutral axis, g, of the full cross section as shown in Fig. 1 above the base line can be obtained by assuming that all longitudinal strength elements are fully effective, those are

$$g = \frac{\sum A_i z_i}{\sum A_i} \tag{6}$$

where A_i is the cross-sectional area of the *i* th plate stiffener element with fully attached plating and z_i is the coordinate of the *i*-th element, $z = 0$ is taken at the base line. The moment of inertia of the hull cross section is calculated by the following formula

$$I_y = \sum A_i (z_i - g)^2 + \sum i y_i \tag{7}$$

Where iy_i is the moment of inertia of each element such as stiffener, plate between stiffeners with respect to the neutral axis of each element. The local classification society rules determines the moment of inertia by the following approach

$$I_y = 3 x 10^{-2} W \frac{L}{k} \tag{8}$$

where W, L and k are the section modulus, lenght of ship and material factor (BKI, 2017). According to the formula, the material factor is very important to obtain moment of inertia. The section moduli at the deck and bottom part denoted by W_D and W_B are given by

$$W_D = \frac{I_y}{D - g} \tag{9}$$

$$W_B = \frac{I_y}{g} \tag{10}$$

where D represents as the ship's depth. According to local Classification Society rules, the section modulus related to deck W_D and bottom W_B, respectively can be obtained by the following formula

$$W = f_r \frac{|M_T|}{\sigma_p 10^3} \tag{11}$$

where f_r, M_T and σ_p are the factor depending on the degree of deck opening, total bending moment (Nmm) and permissible longitudinal bending stress (N/mm^2), respectively.

The stress components on deck and bottom part can be obtained by using simple expression as follow,

$$\sigma = \frac{Mg}{I} \tag{12}$$

$$\sigma = \frac{M}{W} \tag{13}$$

where M is the moment on the deck and/or bottom part in hogging and sagging conditions. Here, Eqs. (12) and (13) can be simply expressed as

$$\frac{Mg}{I} = \frac{M}{W} \tag{14}$$

Here, the section modulus can be obtained as

$$W = \frac{I}{g} \tag{15}$$

In the Smith's method, which is applied in the program code developed by Yao and Nikolov (1992) is used. The explanation is briefly described such as the axial stress σ_i corresponding to the axial strain ε_i is given by the average stress-average strain relationship for the individual elements as illustrated in Fig. 3. The average stress-average strain relationship is derived considering of buckling and yielding

$$\sigma = f_i(\varepsilon) \tag{16}$$

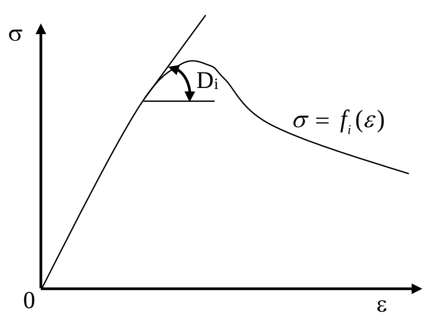

Fig.3 Average stress-average strain relationship for structural element

where $f_i(0) = 0$. The axial force P, the vertical bending moment M_V, and the horizontal bending moment M_H can be obtained by integrating axial stresses over the intact part of cross section as

$$P = \sum_{i=1}^{N} \sigma_i A_i \equiv 0 \tag{17}$$

$$M_H = \sum_{i=1}^{N} \sigma_i \left(y_i - g \right) A_i \tag{18}$$

$$M_V = \sum_{i=1}^{N} \sigma_i z_i A_i \tag{19}$$

The y and z are the coordinates of the cross section measured from the origin at the bottom keel as shown in Fig. 4.

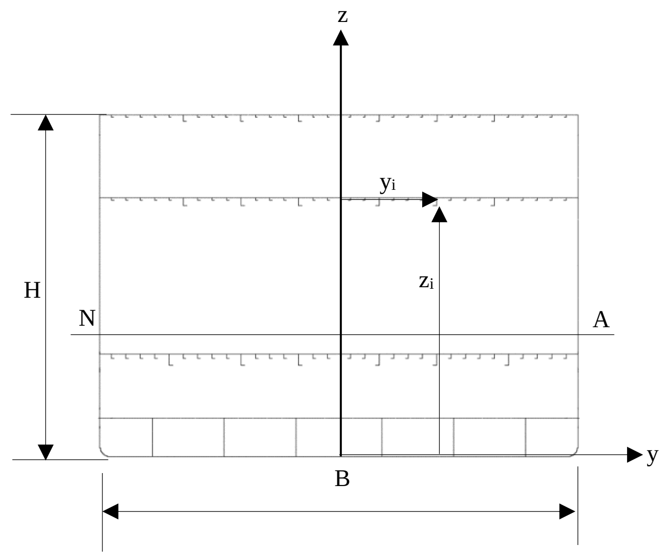

Fig.4 The coordinate systems of the cross section

When the axial load is added to bi-axial bending, the stiffness equation is expressed in term of general formula,

$$\begin{Bmatrix} \Delta P \\ \Delta M_H \\ \Delta M_V \end{Bmatrix} = \begin{bmatrix} D_{AA} & D_{AH} & D_{AV} \\ D_{HA} & D_{HH} & D_{HV} \\ D_{VA} & D_{VH} & D_{VV} \end{bmatrix} \begin{Bmatrix} \Delta \varepsilon \\ \Delta \phi_H \\ \Delta \phi_V \end{Bmatrix} \tag{20}$$

Where

ΔP	: increment of axial force
ΔM_H	: increment of horizontal bending moment
ΔM_V	: increment of vertical bending moment
$\Delta \varepsilon$	: increment of axial displacement
$\Delta \phi_H$	: increment of horizontal curvature
$\Delta \phi_V$	: increment of vertical curvature

and the tangential stiffness of the cross section are written as

$$D_{AA} = \sum_{i=1}^{n} D_i A_i \tag{21}$$

$$D_{AH} = D_{HA} = \sum_{i=1}^{n} D_i y_i A_i \tag{22}$$

$$D_{HH} = \sum_{i=1}^{n} D_i y_i^2 A_i \tag{23}$$

$$D_{AV} = D_{VA} = \sum_{i=1}^{n} D_i z_i A_i \tag{24}$$

$$D_{VV} = \sum_{i=1}^{n} D_i z_i^2 A_i \tag{25}$$

$$D_{HV} = D_{VH} = \sum_{i=1}^{n} D_i y_i z_i A_i \tag{26}$$

METHODOLOGY

The ultimate strength analysis considering the cross-section modulus of Ro-Ro ship hull girder is performed using analytical formulation. The cross section of Ro-Ro ship is taken to be analyzed. Two Ro-Ro ships, Type-1 and Type-2 are considered as the object ships as shown in Table 1. Both of them are designed based on the local Classification Society rules as shown in Figs. 5 and 6.

Table 1 Ship dimensions

Ro-Ro Ship	Type-1	Type-2
L (mm)	65000	50500
B (mm)	15000	14000
D (mm)	10693	10950

The Ro-Ro ships consist of three decks, which are car, pessanger and top decks. The differences between of type-1 and type-2 Ro-Ros are number and dimension of the stiffeners, number of cars and pessangers and the configuration of the structural shape particularly in the bottom part. Type-2 Ro-Ro is deeper than type-1 Ro-Ro, while type-1 Ro-Ro is wider than type-2 Ro-Ro. One-frame space is considered in the longitudinal direction. The material properties such as young's modulus and yield strength are related to the ship's characteristics, while poisson's ratio is set to be constant. The initial imperfection, welding residual stress, damage, and crack are not considered in the analysis. The ultimate strength is calculated for the intact only in hogging and sagging conditions. It should be noted that there are no longitudinal stiffeners in the bottom of Ro-Ros. Only floors in transversal direction are placed on it. The average stress-strain relationship of each element is derived considering buckling and yielding and integrated to the cross-section.

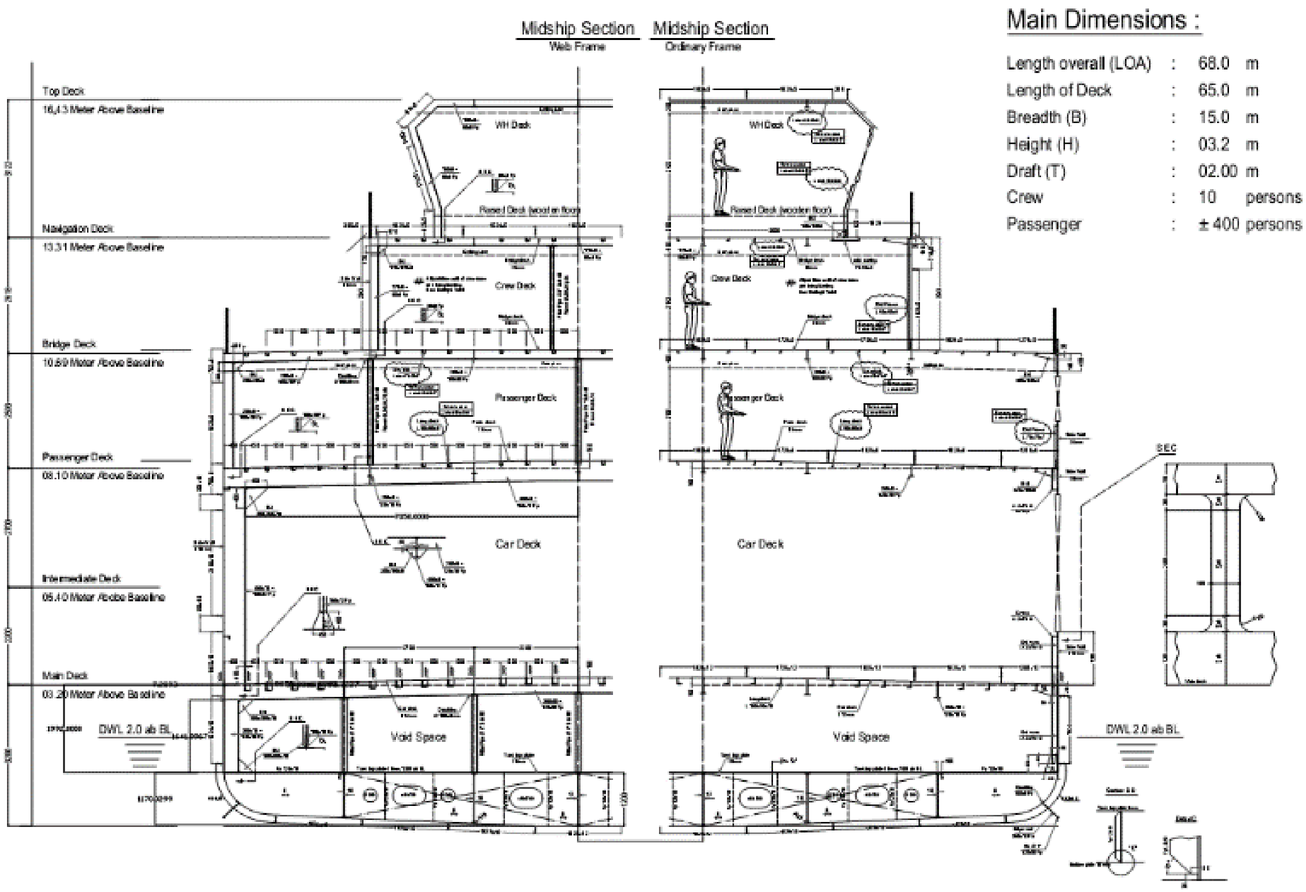

Fig. 5 Ro-Ro type-1

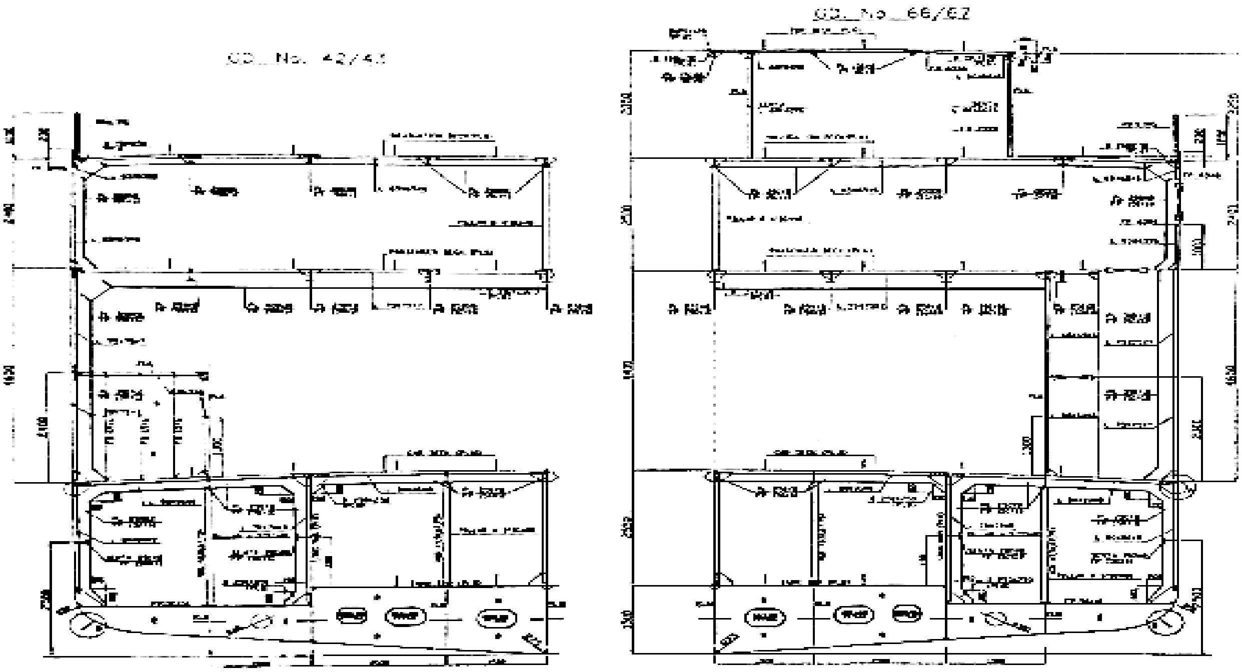

Fig. 6 Ro-Ro type-2

RESULTS AND DISCUSSIONS

The ultimate strengths of Ro-Ro ships considering their section modulus are confirmed applying the method developed by Yao and Nikolov (1992) according to Smith's method. In this case, the incremental iterative approcah is adopted to obtain the ultimate strength both under hogging and sagging condition. In the Smith's method, the cross section is devided into the elements composed of the stiffened and unstiffened plates. The cross section is assumed to be remained plane during progressive collapse and there is no interaction between adjacent elements in the cross section. The vertical bending moment is applied at both sides of the cross section. The cross section of the ships are illustrated in Figs. 7 and 8, respectively. The navigation and upper deck of Ro-Ro ships are assumed to be eliminated.

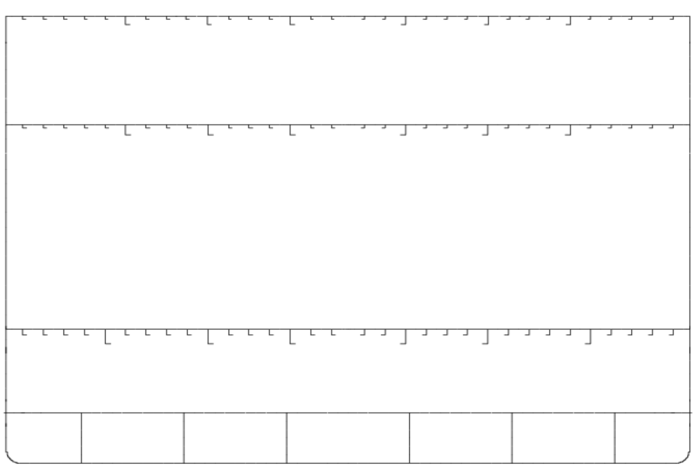

Fig. 7 Cross section of Ro-Ro type-1

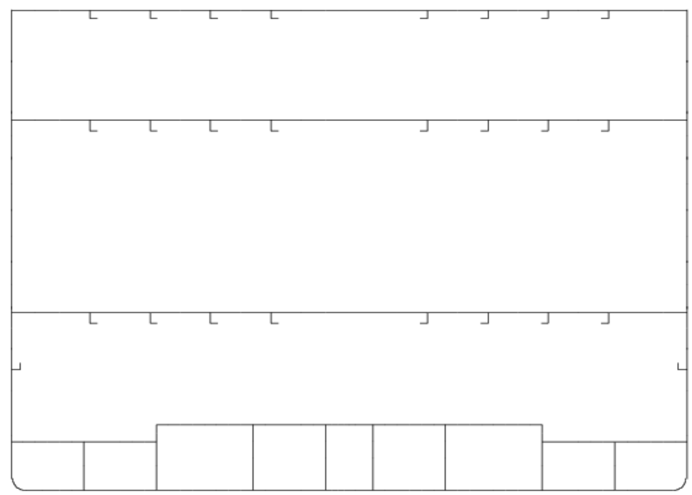

Fig. 8 Cross section of Ro-Ro type-2

The hull girder cross section is very sensitive leading to their ultimate strength and behaviour. It is well known that there is relationship between stress, moment, moment of inertia, neutral axis and section modulus. These relationships are expressed in Eqs. 12, 13, 14 and 15. This is why section modulus depends on bending moment and the section modulus can be obtained by calculating the elements. The coresponding section modulus to the Ro-Ro ship types is shown in Fig. 9. It is observed that the section modulus for type-2 is smaller than type-1. The characteristics of the both ship are completely different starting from the bottom part to the deck. However, two ships consist of three decks, but the shape configuration including number and dimension of stiffeners and double bottom structure also give significant influence to the section modulus and their ultimate strength.

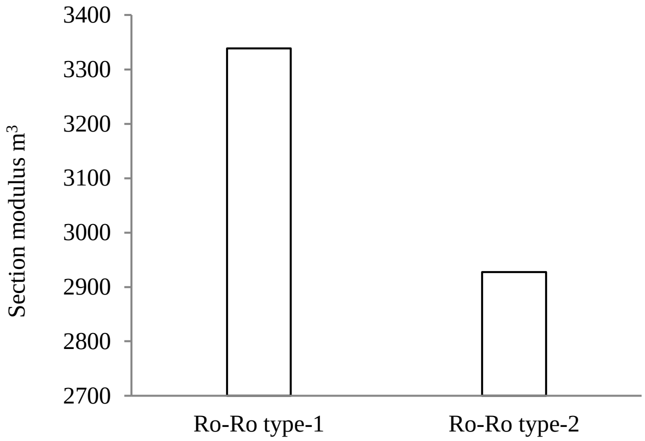

Fig. 9 Section modulus of Ro-Ro ships

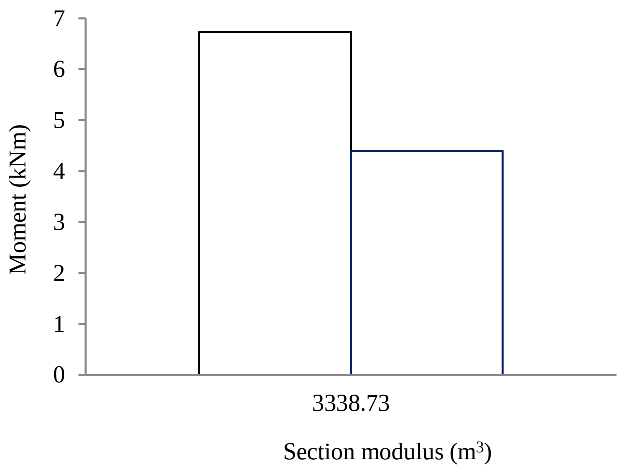

Fig. 10 Moment-section modulus for Ro-Ro type-1

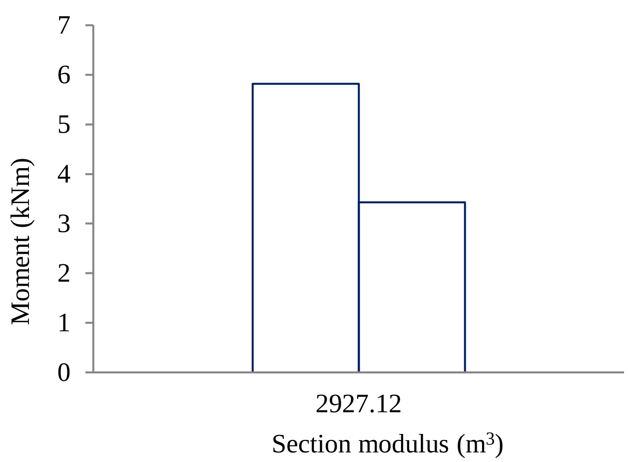

Fig. 11 Moment-section modulus for Ro-Ro type-2

Table 2 Moment-section modulus relationship for hogging

Ship types	M hogging (kNm)	Section modulus (m^3)
Roro type-1	6.74	3338.73
Roro type-2	5.82	2927.12

Table 3 Moment-section modulus relationship for sagging

Ship types	M sagging (kNm)	Section modulus (m^3)
Roro type-1	4.40	3338.73
Roro type-2	3.43	2927.12

The relationship between moment and section modulus of two Ro-Ro ships are described in Figs. 10 and 11 in hogging and sagging conditions, respectively. The moment-section modulus relationship for type-1 is also larger than for type-2 in hogging and sagging condition as shown in tables 2 and 3. The shapes of the cross section for two ships are quite different especially for type-2, because type-2 has double bottom which is not straight line where those area consists of some pillars. The pillars attached on the vertical plate to overcome the structural deformation at the car deck.

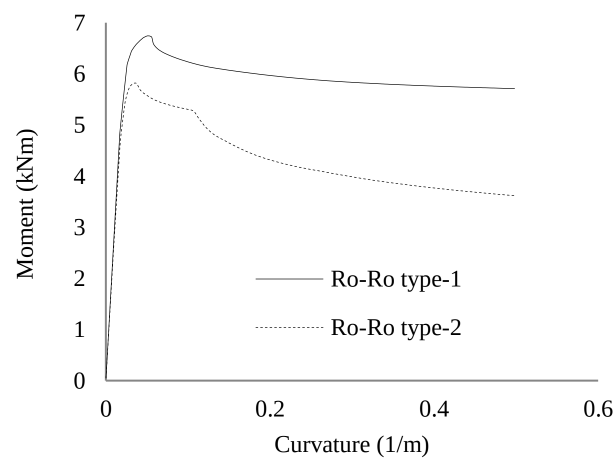

Fig. 12 Moment-curvature relationship for hogging

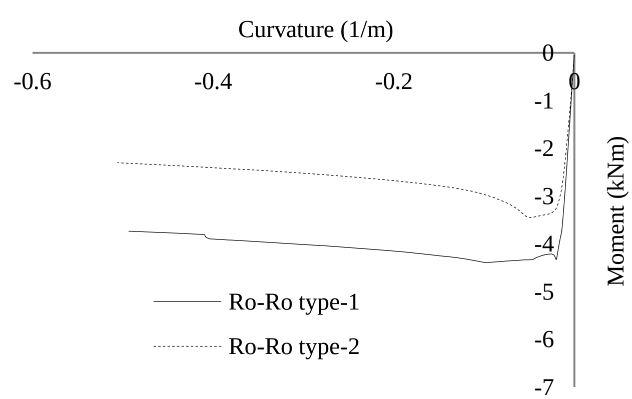

Fig. 13 Moment-curvature relationship for sagging

The moment-curvature relationship in hogging and sagging conditions for Ro-Ro type-1 and type-2 are described in Figs. 12 and 13. The solid lines express the moment-curvature relationship for Ro-Ro type-1, while the dashed one illustrates for Ro-Ro type-2. The moment-curvature relationship for hogging condition between type-1 and type-2 gives significant differences for the ultimate strength and beyond the ultimate strength. This phenomenon also occurs for sagging condition. The value of the ultimate strength is almost identic with the local Classification Society rules.

CONCLUSIONS

The ultimate hull girder strength analysis considering section modulus of Ro-Ro ship under longitudinal bending have been performed based on simple formula of the local Classification Society rules and the Smith's method. The following conclusions are; the effect of the section modulus on the ultimate hull girder strength is significant not only in hogging but also sagging condition. The effect may be caused by the structural configuration of the Ro-Ro ships such as dimensions and number of plate and unstiffened plate, especially on the bottom part to support car deck by some pillars.

REFERENCES

Biro Klasifikasi Indonesia (BKI). (2017). "Rules for the Classification and Construction," Volume II.

Kim, D.H and Paik, J.K. (2017). "Ultimate Limit State-Based Multi-Objective Optimum Design Technology for Hull Structural Scantlings of Merchant Cargo Ships," *Ocean Engineering*, 129, 318-334.

Korkut, E, Atlar, M and Incecik, A (2005). "An Experimental Study of Global Loads Acting on an Intact and Damaged Ro-Ro Ship Model," *Ocean Engineering*, 32, 1370-1403.

Kukkanen, T and Matusiak, J (2014). "Nonlinear Hull Girder Loads of a RoPax Ship," *Ocean Engineering*, 75, 1-14.

Naar, H, Varsta, P and Kujala, P (2004). "A Theory of Cupled Beams for Strength Assessment of Passenger Ships," *Marine Structures*, 17, 590-611.

Muis Alie, M.Z, Sitepu, G, Juswan, Wahyuddin, Nugraha, A.M and Alamsyah (2016). "The Influence of Superstructure on the Longitudinal Ultimate Strength of a RO-RO Ship," *Proc 26th Int Offshore and Polar Eng Conf*, Greece, ISOPE, 4, 1022–1029.

Muis Alie, M.Z, Sitepu, G and Latumahina, S.I (2017). "The Assessement of the Ultimate Hull Girder Strength of Ro-Ro Ship after Damages," *Proc 27th Int Offshore and Polar Eng Conf*, USA, ISOPE, 4, 913–919.

Yao, T. and Nikolov, P.I. (1992). "Progressive Collapse Analysis of a Ship's Hull Girder under Longitudinal Bending (2nd Report)," *J Soc. Naval Arch. of Japan*, Vol 172, 437-446.

The Ultimate Hull Girder Strength Analysis Considering Section Modulus Under Longitudinal Bending

Muhammad Zubair Muis Alie and Samuel Izaak Latumahina
Department of Naval Architect and Ocean Engineering, Engineering Faculty, Hasanuddin University
Gowa, South Sulawesi, Indonesia

ABSTRACT

The objective of the present study is to assess the ultimate hull girder strength taking the section modulus into account under longitudinal bending. A Ro-Ro Ship is taken as object ship. A Ro-Ro Ship has a unique character because most of the longitudinal elements locate above neutral axis. While there are not the longitudinal elements under the neutral axis particularly at the bottom part so that the bottom part consists plate only. The simple expression implemented into in-house program to calculate the section modulus of ship cross section is performed. The cross section is assumed to be remained plane and the simply supported of boundary condition is imposed on plate and stiffened plate elements in the cross section. The vertical bending moments are imposed to both sides of the cross section. It is found that the effect of the section modulus on the ultimate hull girder strength is significant not only in hogging but also sagging condition. The ultimate hull girder strength is calculated by considering the section modulus including their progressive collapse behavior for Ro-Ro ship hull.

KEY WORDS: Ship hull; cross section; section modulus; ultimate strength.

INTRODUCTION

The Ro-Ro ship is one of the ship types which transport the cargo in horizontal direction and eliminate the need for onboard or deckside lift-on and/or lift off instrument. The Ro-Ro ship has been innovated to carry processed forest product, lumber, playwood, cars and many things. Ro-Ros are an imprortant connection for the intermodal transportation network. In this regard, the section modulus could be one of the important parameters from the viewpoint of assessing the ultimate strength of all the decks on which cars, passengers and so on are put. In spite of human error, the structural degradation during loading and unloading gives impact to the ultimate strength of ship's hull.

The ultimate hull girder strength of merchant ships including Ro-Ro ship has been assessed by some researchers. Kukkanen, T and Matusiak, J (2014) presented the numerical and experimental results of nonlinear wave loads. A nonlinear time domain method had been developed and the theoretical background of the method were provided. The method was based on the source formulation expressed by means of the transient three-dimensional Green function. The time derivative of the velocity potential in Bernoulli's equation was solved with similar source formulation to that of the perturbation velocity potential. Korkut, E et al (2005) carried out measurements of global loads acting on a Ro-Ro model in regular waves for intact and damaged conditions. The stationary model was tested in different wave heights and wave frequencies for the head, beam and stern quartering seas in order to explore the effect of damages and wave heights on the global loads acting on the model. The analysis of the result indicated that the damages had an adverse effect on the loading conditions on the model depending upon the directionality of the waves and frequency range applied. This effect might cause structural damage on the ship and danger the safety of the ship and passenger on board. Kim, D.H and Paik, J.K (2017) developed a fully automated methodology for the optimum design of hull structural scantlings for merchant cargo ships that were modelled by plate-shell finite elements. A full optimization technique with multi-objectives was applied for minimizing structural weight and maximizing structural safety, as per design constraints associated with the ultimate limit states of the plate panels, support members and hull girders. The developed procedure was applied to the hull structural scantlings of a very large crude oil carrier (VLCC), and the test demonstrated the procedure's capacity to meet the strength requirements of common structural rules. Muis Alie, M.Z et al (2016) investigate the influence of superstructure on the longitudinal ultimate strength of a Ro-Ro ship. To investigate the ultimate strength, the Smith's method was adopted and implemented into the thin-walled beam. The cross section of Ro-Ro ship was taken to be analyzed. Muis Alie, M.Z et al (2017) assessed the ultimate hull girder strength of Ro-Ro ship after damaged. The cross section of Ro-Ro was taken to be analyzed. The collision and grounding damages were assumed to be placed on the side and bottom area. The damages were created by removing the element from the side shell and bottom parts. Finally, the result obtained was compared with one another. Also, the progressive collapse analysis of ship hull girder based on Smith's method was developed by Yao and Nikolov (1992). Naar, H et al (2004) described a couple beam method, which estimate elastic response in the longitudinal bending of a passenger ship with a large multi-deck superstructure. The method could be applied during an early project stage, when detailed three-dimensional finite element modelling was not yet possible. The theory was based on assumption that each deck in the superstructure and also the main hull could be considered as thin-walled beam.

In the present study, the ultimate hull girder strength analysis is assessed considering the section modulus. The cross section of a Ro-Ro ship is considered to be analyzed. Bottom part, car and passenger decks are calculated for the section modulus where those located above and/or under the neutral axis. Their result is investigated toward the ultimate strength for the global structure.

ANALYTICAL SOLUTION

The section modulus of ship indicates the ship strength not only in longitudinal but also transversal direction. The classification societies have been stated requirements so that the section modulus should be greater than a prescribed value. It is well known that ship structural characteristics affect significantly on the ultimate strength depending on the cargo types, configuration of structural scantling and so on. The fundamental theory of strength of material may be used for calculating the section modulus of the ship hull cross section. In structural modelling, the ship hull cross section is idealized by stiffened and unstiffened plate combination. Fig. 1 shows the cross section of Ro-Ro ship and Fig. 2 the typical type of stiffened plate with attached plating.

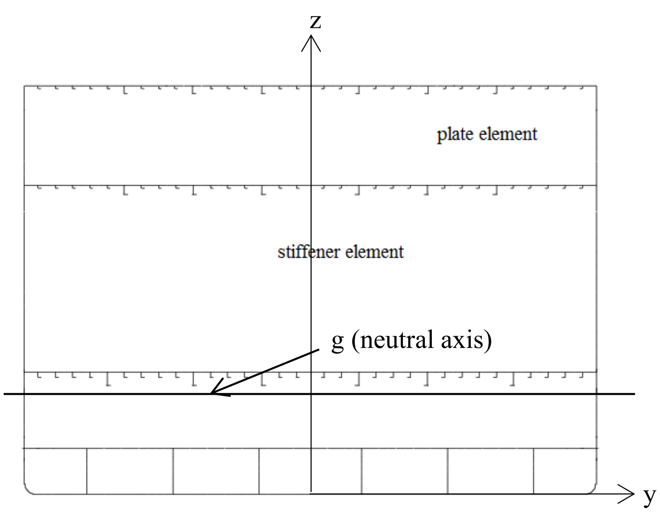

Fig. 1 Cross section of Ro-Ro ship

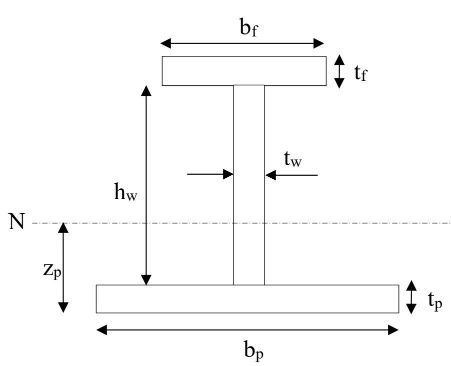

Fig. 2 Typical type of stiffened plate with attached plating

The profile and consists of web, flange and attached plating including the neutral axis (N-A) are shown in Fig. 2. The moment of inertia of the profile may be expressed as

$$I = \frac{b_p (t_p)^3}{12} + A_p \left(z_p - \frac{t_p}{2} \right)^2 + \frac{h_w^3 t_w}{12} + A_w \left(z_p - t_p - \frac{h_w}{2} \right)^2 + \frac{b_f t_f^3}{12} + A_f \left(t_p + h_w + \frac{t_f}{2} - z_p \right)^2 \quad (1)$$

Where

$$A_p = b_p t_p \quad (2)$$

$$A_w = h_w t_w \quad (3)$$

$$A_f = b_f t_f \quad (4)$$

$$z_p = \frac{0.5 b_p t_p^2 + A_w (t_p + 0.5 h_w) + A_f (t_p + h_w + 0.5 t_f)}{(A_p + A_w + A_f)} \quad (5)$$

The location of the neutral axis, g, of the full cross section as shown in Fig. 1 above the base line can be obtained by assuming that all longitudinal strength elements are fully effective, those are

$$g = \frac{\sum A_i z_i}{\sum A_i} \quad (6)$$

where A_i is the cross-sectional area of the i th plate stiffener element with fully attached plating and z_i is the coordinate of the i-th element, $z = 0$ is taken at the base line. The moment of inertia of the hull cross section is calculated by the following formula

$$I_y = \sum A_i (z_i - g)^2 + \sum i y_i \quad (7)$$

Where iy_i is the moment of inertia of each element such as stiffener, plate between stiffeners with respect to the neutral axis of each element. The local classification society rules determines the moment of inertia by the following approach

$$I_y = 3 x 10^{-2} \, W \frac{L}{k} \quad (8)$$

where W, L and k are the section modulus, lenght of ship and material factor (BKI, 2017). According to the formula, the material factor is very important to obtain moment of inertia. The section moduli at the deck and bottom part denoted by W_D and W_B are given by

$$W_D = \frac{I_y}{D - g} \quad (9)$$

$$W_B = \frac{I_y}{g} \quad (10)$$

where D represents as the ship's depth. According to local Classification Society rules, the section modulus related to deck W_D

and bottom W_B, respectively can be obtained by the following formula

$$W = f_r \frac{|M_T|}{\sigma_p 10^3} \tag{11}$$

where f_r, M_T and σ_p are the factor depending on the degree of deck opening, total bending moment (Nmm) and permissible longitudinal bending stress (N/mm^2), respectively.

The stress components on deck and bottom part can be obtained by using simple expression as follow,

$$\sigma = \frac{Mg}{I} \tag{12}$$

$$\sigma = \frac{M}{W} \tag{13}$$

where M is the moment on the deck and/or bottom part in hogging and sagging conditions. Here, Eqs. (12) and (13) can be simply expressed as

$$\frac{Mg}{I} = \frac{M}{W} \tag{14}$$

Here, the section modulus can be obtained as

$$W = \frac{I}{g} \tag{15}$$

In the Smith's method, which is applied in the program code developed by Yao and Nikolov (1992) is used. The explanation is briefly described such as the axial stress σ_i corresponding to the axial strain ε_i is given by the average stress-average strain relationship for the individual elements as illustrated in Fig. 3. The average stress-average strain relationship is derived considering of buckling and yielding

$$\sigma = f_i(\varepsilon) \tag{16}$$

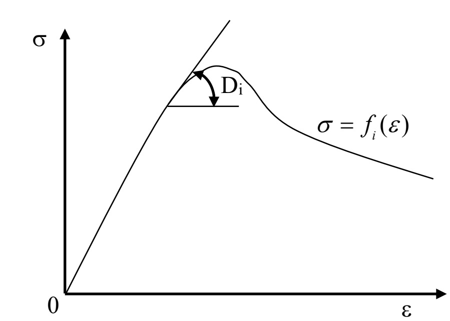

Fig.3 Average stress-average strain relationship for structural element

where $f_i(0) = 0$. The axial force P, the vertical bending moment M_V, and the horizontal bending moment M_H can be obtained by integrating axial stresses over the intact part of cross section as

$$P = \sum_{i=1}^{N} \sigma_i A_i \equiv 0 \tag{17}$$

$$M_H = \sum_{i=1}^{N} \sigma_i (y_i - g) A_i \tag{18}$$

$$M_V = \sum_{i=1}^{N} \sigma_i z_i A_i \tag{19}$$

The y and z are the coordinates of the cross section measured from the origin at the bottom keel as shown in Fig. 4.

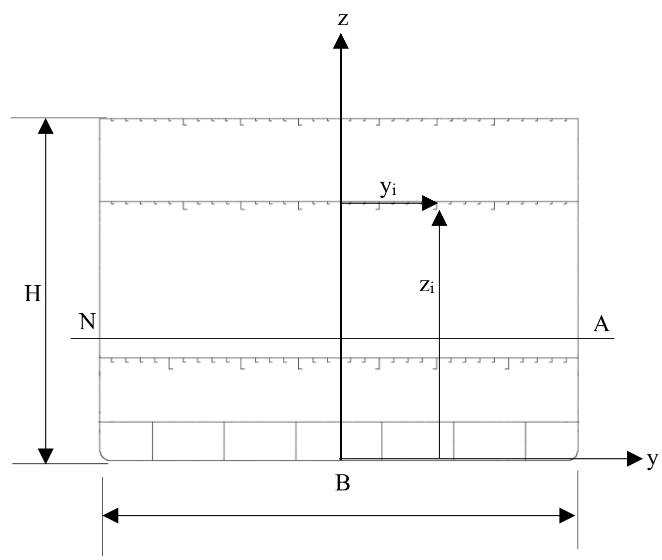

Fig.4 The coordinate systems of the cross section

When the axial load is added to bi-axial bending, the stiffness equation is expressed in term of general formula,

$$\begin{Bmatrix} \Delta P \\ \Delta M_H \\ \Delta M_V \end{Bmatrix} = \begin{bmatrix} D_{AA} & D_{AH} & D_{AV} \\ D_{HA} & D_{HH} & D_{HV} \\ D_{VA} & D_{VH} & D_{VV} \end{bmatrix} \begin{Bmatrix} \Delta \varepsilon \\ \Delta \phi_H \\ \Delta \phi_V \end{Bmatrix} \tag{20}$$

Where

ΔP : increment of axial force
ΔM_H : increment of horizontal bending moment
ΔM_V : increment of vertical bending moment
$\Delta \varepsilon$: increment of axial displacement
$\Delta \phi_H$: increment of horizontal curvature
$\Delta \phi_V$: increment of vertical curvature

and the tangential stiffness of the cross section are written as

$$D_{AA} = \sum_{i=1}^{n} D_i A_i \tag{21}$$

$$D_{AH} = D_{HA} = \sum_{i=1}^{n} D_i y_i A_i \quad (22)$$

$$D_{HH} = \sum_{i=1}^{n} D_i y_i^2 A_i \quad (23)$$

$$D_{AV} = D_{VA} = \sum_{i=1}^{n} D_i z_i A_i \quad (24)$$

$$D_{VV} = \sum_{i=1}^{n} D_i z_i^2 A_i \quad (25)$$

$$D_{HV} = D_{VH} = \sum_{i=1}^{n} D_i y_i z_i A_i \quad (26)$$

METHODOLOGY

The ultimate strength analysis considering the cross-section modulus of Ro-Ro ship hull girder is performed using analytical formulation. The cross section of Ro-Ro ship is taken to be analyzed. Two Ro-Ro ships, Type-1 and Type-2 are considered as the object ships as shown in Table 1. Both of them are designed based on the local Classification Society rules as shown in Figs. 5 and 6.

Table 1 Ship dimensions

Ro-Ro Ship	Type-1	Type-2
L (mm)	65000	50500
B (mm)	15000	14000
D (mm)	10693	10950

The Ro-Ro ships consist of three decks, which are car, pessanger and top decks. The differences between of type-1 and type-2 Ro-Ros are number and dimension of the stiffeners, number of cars and pessangers and the configuration of the structural shape particularly in the bottom part. Type-2 Ro-Ro is deeper than type-1 Ro-Ro, while type-1 Ro-Ro is wider than type-2 Ro-Ro. One-frame space is considered in the longitudinal direction. The material properties such as young's modulus and yield strength are related to the ship's characteristics, while poisson's ratio is set to be constant. The initial imperfection, welding residual stress, damage, and crack are not considered in the analysis. The ultimate strength is calculated for the intact only in hogging and sagging conditions. It should be noted that there are no longitudinal stiffeners in the bottom of Ro-Ros. Only floors in transversal direction are placed on it. The average stress-strain relationship of each element is derived considering buckling and yielding and integrated to the cross-section.

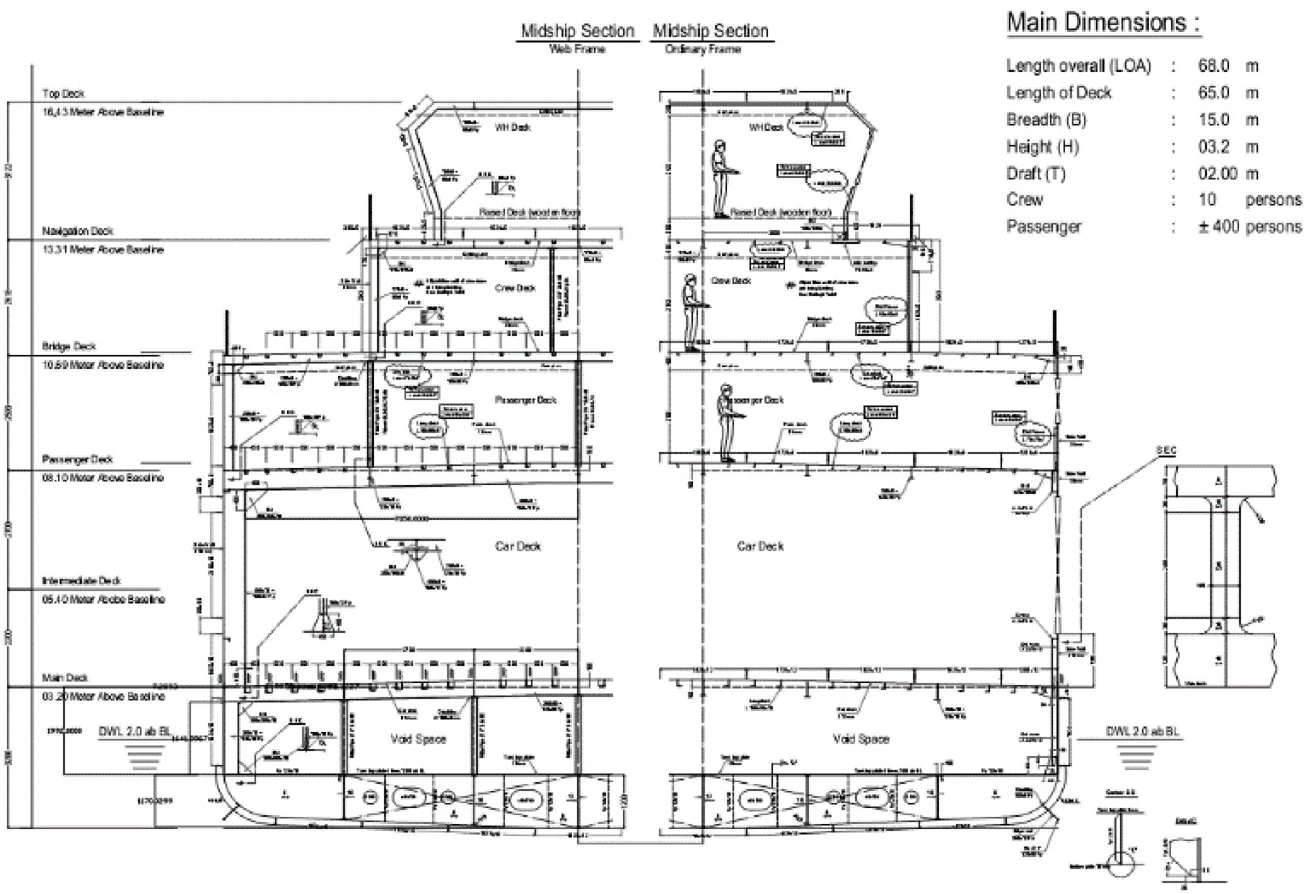

Fig. 5 Ro-Ro type-1

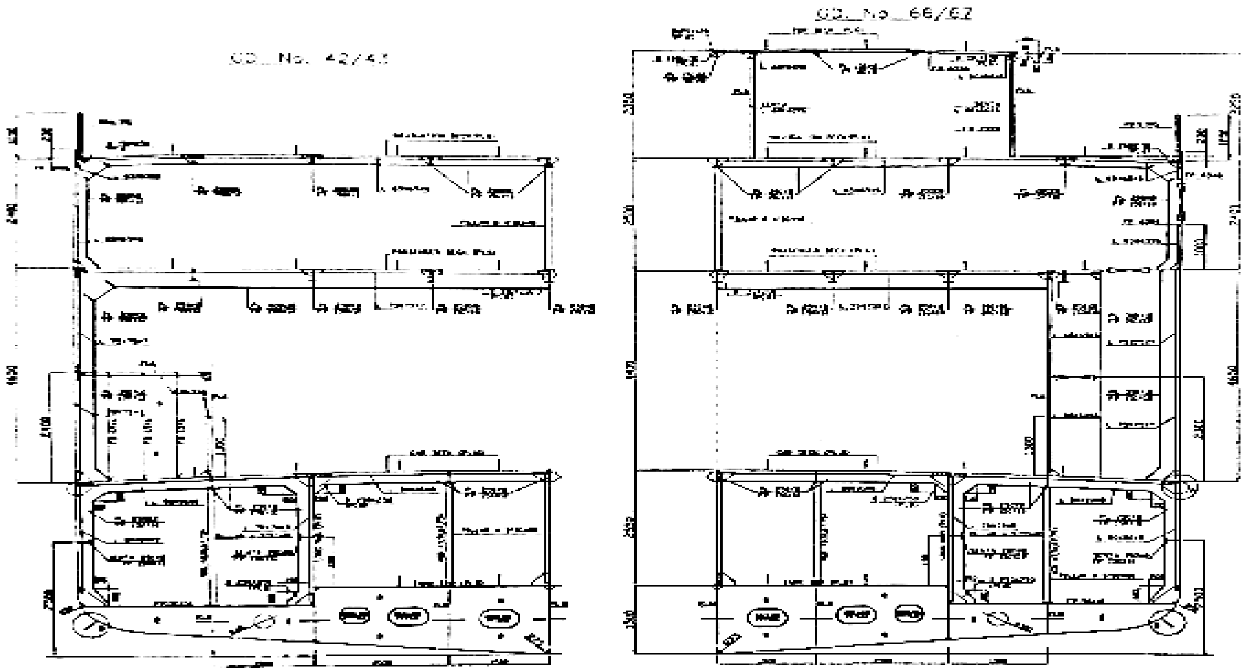

Fig. 6 Ro-Ro type-2

RESULTS AND DISCUSSIONS

The ultimate strengths of Ro-Ro ships considering their section modulus are confirmed applying the method developed by Yao and Nikolov (1992) according to Smith's method. In this case, the incremental iterative approcah is adopted to obtain the ultimate strength both under hogging and sagging condition. In the Smith's method, the cross section is devided into the elements composed of the stiffened and unstiffened plates. The cross section is assumed to be remained plane during progressive collapse and there is no interaction between adjacent elements in the cross section. The vertical bending moment is applied at both sides of the cross section. The cross section of the ships are illustrated in Figs. 7 and 8, respectively. The navigation and upper deck of Ro-Ro ships are assumed to be eliminated.

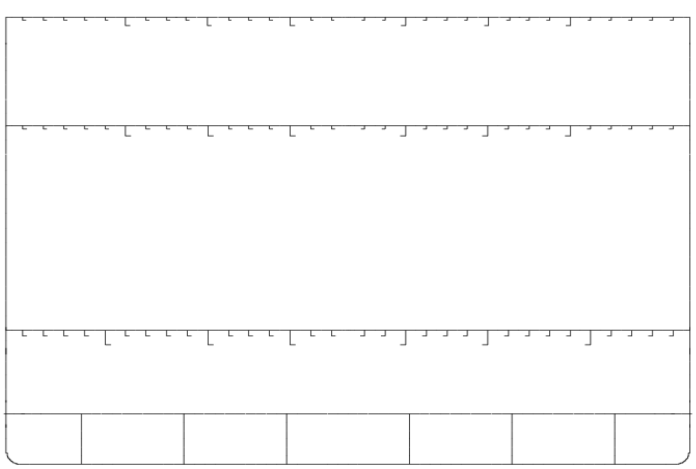

Fig. 7 Cross section of Ro-Ro type-1

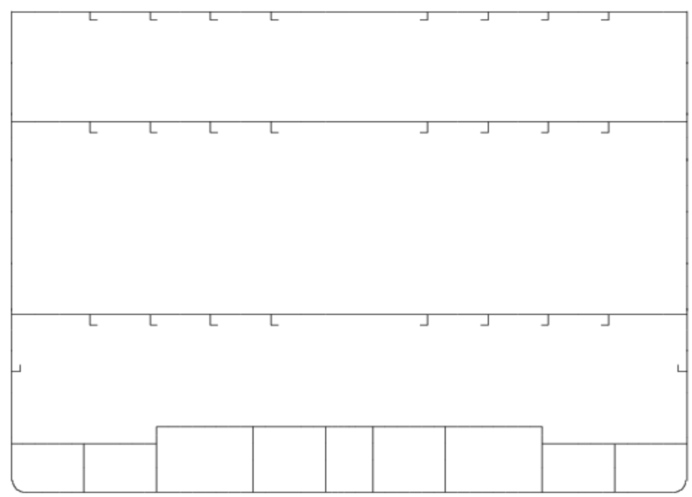

Fig. 8 Cross section of Ro-Ro type-2

The hull girder cross section is very sensitive leading to their ultimate strength and behaviour. It is well known that there is relationship between stress, moment, moment of inertia, neutral axis and section modulus. These relationships are expressed in Eqs. 12, 13, 14 and 15. This is why section modulus depends on bending moment and the section modulus can be obtained by calculating the elements. The coresponding section modulus to the Ro-Ro ship types is shown in Fig. 9. It is observed that the section modulus for type-2 is smaller than type-1. The characteristics of the both ship are completely different starting from the bottom part to the deck. However, two ships consist of three decks, but the shape configuration including number and dimension of stiffeners and double bottom structure also give significant influence to the section modulus and their ultimate strength.

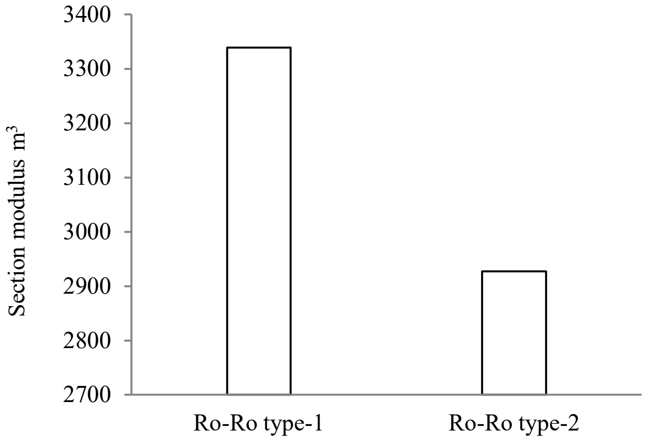

Fig. 9 Section modulus of Ro-Ro ships

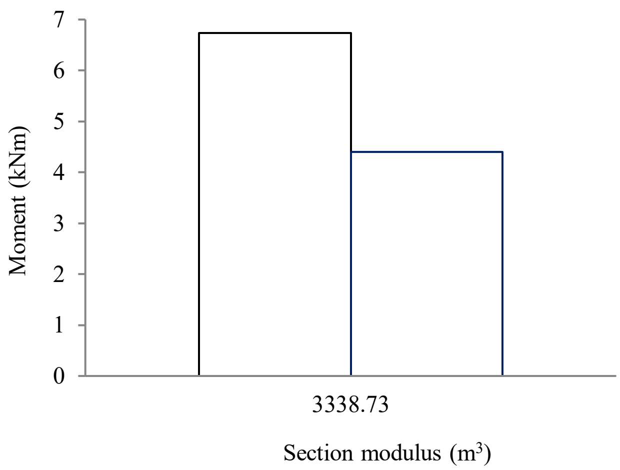

Fig. 10 Moment-section modulus for Ro-Ro type-1

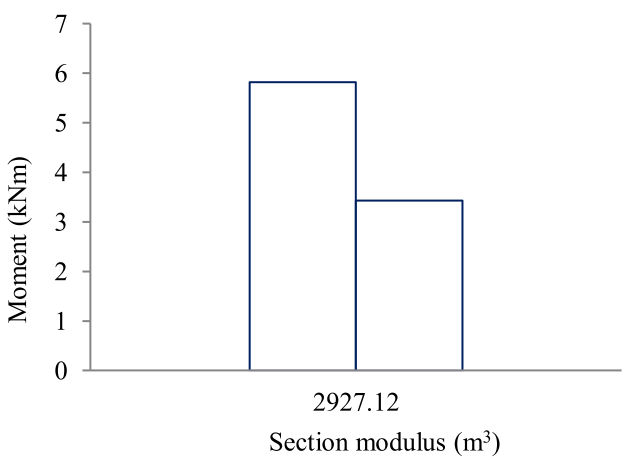

Fig. 11 Moment-section modulus for Ro-Ro type-2

Table 2 Moment-section modulus relationship for hogging

Ship types	M hogging (kNm)	Section modulus (m^3)
Roro type-1	6.74	3338.73
Roro type-2	5.82	2927.12

Table 3 Moment-section modulus relationship for sagging

Ship types	M sagging (kNm)	Section modulus (m^3)
Roro type-1	4.40	3338.73
Roro type-2	3.43	2927.12

The relationship between moment and section modulus of two Ro-Ro ships are described in Figs. 10 and 11 in hogging and sagging conditions, respectively. The moment-section modulus relationship for type-1 is also larger than for type-2 in hogging and sagging condition as shown in tables 2 and 3. The shapes of the cross section for two ships are quite different especially for type-2, because type-2 has double bottom which is not straight line where those area consists of some pillars. The pillars attached on the vertical plate to overcome the structural deformation at the car deck.

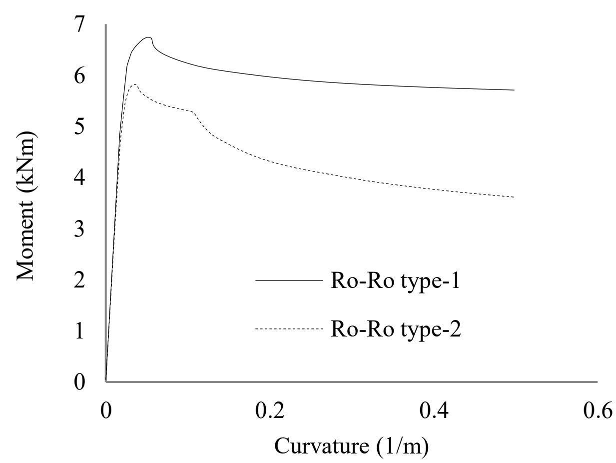

Fig. 12 Moment-curvature relationship for hogging

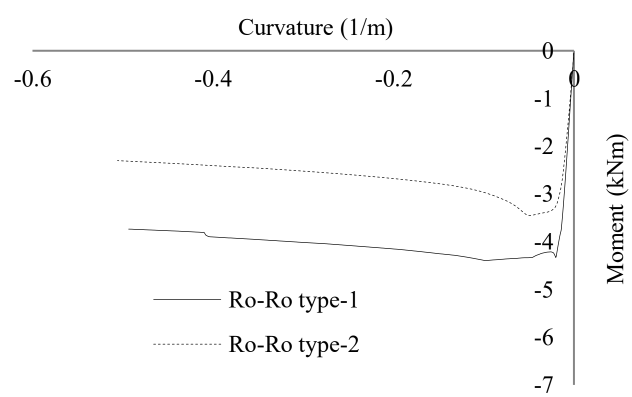

Fig. 13 Moment-curvature relationship for sagging

The moment-curvature relationship in hogging and sagging conditions for Ro-Ro type-1 and type-2 are described in Figs. 12 and 13. The solid lines express the moment-curvature relationship for Ro-Ro type-1, while the dashed one illustrates for Ro-Ro type-2. The moment-curvature relationship for hogging condition between type-1 and type-2 gives significant differences for the ultimate strength and beyond the ultimate strength. This phenomenon also occurs for sagging condition. The value of the ultimate strength is almost identic with the local Classification Society rules.

CONCLUSIONS

The ultimate hull girder strength analysis considering section modulus of Ro-Ro ship under longitudinal bending have been performed based on simple formula of the local Classification Society rules and the Smith's method. The following conclusions are; the effect of the section modulus on the ultimate hull girder strength is significant not only in hogging but also sagging condition. The effect may be caused by the structural configuration of the Ro-Ro ships such as dimensions and number of plate and unstiffened plate, especially on the bottom part to support car deck by some pillars.

REFERENCES

Biro Klasifikasi Indonesia (BKI). (2017). "Rules for the Classification and Construction," Volume II.

Kim, D.H and Paik, J.K. (2017). "Ultimate Limit State-Based Multi-Objective Optimum Design Technology for Hull Structural Scantlings of Merchant Cargo Ships," *Ocean Engineering*, 129, 318-334.

Korkut, E, Atlar, M and Incecik, A (2005). "An Experimental Study of Global Loads Acting on an Intact and Damaged Ro-Ro Ship Model," *Ocean Engineering*, 32, 1370-1403.

Kukkanen, T and Matusiak, J (2014). "Nonlinear Hull Girder Loads of a RoPax Ship," *Ocean Engineering*, 75, 1-14.

Naar, H, Varsta, P and Kujala, P (2004). "A Theory of Cupled Beams for Strength Assessment of Passenger Ships," *Marine Structures*, 17, 590-611.

Muis Alie, M.Z, Sitepu, G, Juswan, Wahyuddin, Nugraha, A.M and Alamsyah (2016). "The Influence of Superstructure on the Longitudinal Ultimate Strength of a RO-RO Ship," *Proc 26th Int Offshore and Polar Eng Conf*, Greece, ISOPE, 4, 1022–1029.

Muis Alie, M.Z, Sitepu, G and Latumahina, S.I (2017). "The Assessement of the Ultimate Hull Girder Strength of Ro-Ro Ship after Damages," *Proc 27th Int Offshore and Polar Eng Conf*, USA, ISOPE, 4, 913–919.

Yao, T. and Nikolov, P.I. (1992). "Progressive Collapse Analysis of a Ship's Hull Girder under Longitudinal Bending (2nd Report)," *J Soc. Naval Arch. of Japan*, Vol 172, 437-446.

The Ultimate Hull Girder Strength Analysis Considering Section Modulus Under Longitudinal Bending

Muhammad Zubair Muis Alie and Samuel Izaak Latumahina
Department of Naval Architect and Ocean Engineering, Engineering Faculty, Hasanuddin University
Gowa, South Sulawesi, Indonesia

ABSTRACT

The objective of the present study is to assess the ultimate hull girder strength taking the section modulus into account under longitudinal bending. A Ro-Ro Ship is taken as object ship. A Ro-Ro Ship has a unique character because most of the longitudinal elements locate above neutral axis. While there are not the longitudinal elements under the neutral axis particularly at the bottom part so that the bottom part consists plate only. The simple expression implemented into in-house program to calculate the section modulus of ship cross section is performed. The cross section is assumed to be remained plane and the simply supported of boundary condition is imposed on plate and stiffened plate elements in the cross section. The vertical bending moments are imposed to both sides of the cross section. The ultimate hull girder strength is calculated by considering the section modulus including their progressive collapse behavior for Ro-Ro ship hull.

KEY WORDS: Ship hull; cross section; section modulus; ultimate strength.

INTRODUCTION

The Ro-Ro ship is one of the ship types which transport the cargo in horizontal direction and eliminate the need for onboard or deckside lift-on and/or lift off instrument. The Ro-Ro ship has been innovated to carry processed forest product, lumber, playwood, cars and many things. Ro-Ros are an imprortant connection for the intermodal transportation network. In this regard, the section modulus could be one of the important parameters from the viewpoint of assessing the ultimate strength of all the decks on which cars, passengers and so on are put. In spite of human error, the structural degradation during loading and unloading gives impact to the ultimate strength of ship's hull.

The ultimate hull girder strength of merchant ships including Ro-Ro ship has been assessed by some researchers. Kukkanen, T and Matusiak, J (2014) presented the numerical and experimental results of nonlinear wave loads. A nonlinear time domain method had been developed and the theoretical background of the method were provided. The method was based on the source formulation expressed by means of the transient three-dimensional Green function. The time derivative of the velocity potential in Bernoulli's equation was solved with similar source formulation to that of the perturbation velocity potential. Korkut, E et al (2005) carried out measurements of global loads acting on a Ro-Ro model in regular waves for intact and damaged conditions. The stationary model was tested in different wave heights and wave frequencies for the head, beam and stern quartering seas in order to explore the effect of damages and wave heights on the global loads acting on the model. The analysis of the result indicated that the damages had an adverse effect on the loading conditions on the model depending upon the directionality of the waves and frequency range applied. This effect might cause structural damage on the ship and danger the safety of the ship and passenger on board. Kim, D.H and Paik, J.K (2017) developed a fully automated methodology for the optimum design of hull structural scantlings for merchant cargo ships that were modelled by plate-shell finite elements. A full optimization technique with multi-objectives was applied for minimizing structural weight and maximizing structural safety, as per design constraints associated with the ultimate limit states of the plate panels, support members and hull girders. The developed procedure was applied to the hull structural scantlings of a very large crude oil carrier (VLCC), and the test demonstrated the procedure's capacity to meet the strength requirements of common structural rules. Muis Alie, M.Z et al (2016) investigate the influence of superstructure on the longitudinal ultimate strength of a Ro-Ro ship. To investigate the ultimate strength, the Smith's method was adopted and implemented into the thin-walled beam. The cross section of Ro-Ro ship was taken to be analyzed. Muis Alie, M.Z et al (2017) assessed the ultimate hull girder strength of Ro-Ro ship after damaged. The cross section of Ro-Ro was taken to be analyzed. The collision and grounding damages were assumed to be placed on the side and bottom area. The damages were created by removing the element from the side shell and bottom parts. Finally, the result obtained was compared with one another. Also, the progressive collapse analysis of ship hull girder based on Smith's method was developed by Yao and Nikolov (1992). Naar, H et al (2004) described a couple beam method, which estimate elastic response in the longitudinal bending of a passenger ship with a large multi-deck superstructure. The method could be applied during an early project stage, when detailed three-dimensional finite element modelling was not yet possible. The theory was based on assumption that each deck in the superstructure and also the main hull could be considered as thin-walled beam.

In the present study, the ultimate hull girder strength analysis is assessed considering the section modulus. The cross section of a Ro-Ro ship is considered to be analyzed. Bottom part, car and passenger decks are calculated for the section modulus where those located above and/or under the neutral axis. Their result is investigated toward the ultimate strength for the global structure.

ANALYTICAL SOLUTION

The section modulus of ship indicates the ship strength not only in longitudinal but also transversal direction. The classification societies have been stated requirements so that the section modulus should be greater than a prescribed value. It is well known that ship structural characteristics affect significantly on the ultimate strength depending on the cargo types, configuration of structural scantling and so on. The fundamental theory of strength of material may be used for calculating the section modulus of the ship hull cross section. In structural modelling, the ship hull cross section is idealized by stiffened and unstiffened plate combination. Fig. 1 shows the cross section of Ro-Ro ship and Fig. 2 the typical type of stiffened plate with attached plating.

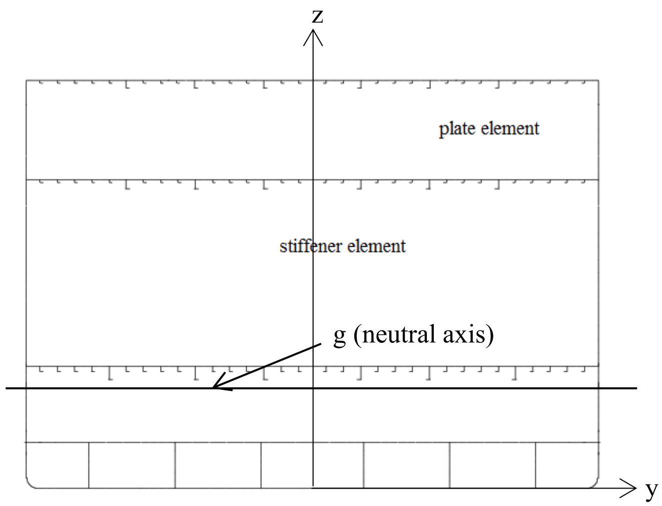

Fig. 1 Cross section of Ro-Ro ship

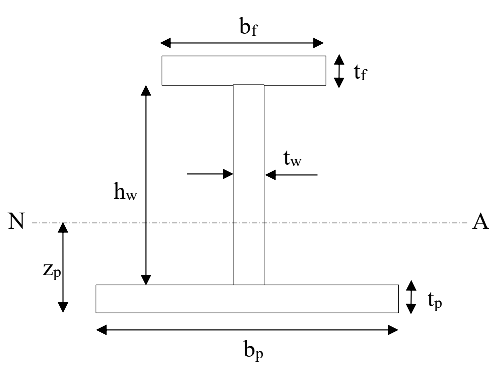

Fig. 2 Typical type of stiffened plate with attached plating

The profile and consists of web, flange and attached plating including the neutral axis (N-A) are shown in Fig. 2. The moment of inertia of the profile may be expressed as

$$I = \frac{b_p (t_p)^3}{12} + A_p\left(z_p - \frac{t_p}{2}\right)^2 + \frac{h_w^3 t_w}{12} + A_w\left(z_p - t_p - \frac{h_w}{2}\right)^2 + \frac{b_f t_f^3}{12} + A_f\left(t_p + h_w + \frac{t_f}{2} - z_p\right)^2 \quad (1)$$

Where

$$A_p = b_p t_p \quad (2)$$

$$A_w = h_w t_w \quad (3)$$

$$A_f = b_f t_f \quad (4)$$

$$z_p = \frac{0.5 b_p t_p^2 + A_w(t_p + 0.5 h_w) + A_f(t_p + h_w + 0.5 t_f)}{(A_p + A_w + A_f)} \quad (5)$$

The location of the neutral axis, g, of the full cross section as shown in Fig. 1 above the base line can be obtained by assuming that all longitudinal strength elements are fully effective, those are

$$g = \frac{\sum A_i z_i}{\sum A_i} \quad (6)$$

where A_i is the cross-sectional area of the *i* th plate stiffener element with fully attached plating and z_i is the coordinate of the *i*-th element, $z = 0$ is taken at the base line. The moment of inertia of the hull cross section is calculated by the following formula

$$I_y = \sum A_i (z_i - g)^2 + \sum i y_i \quad (7)$$

Where iy_i is the moment of inertia of each element such as stiffener, plate between stiffeners with respect to the neutral axis of each element. The local classification society rules determines the moment of inertia by the following approach

$$I_y = 3 x 10^{-2}\, W \frac{L}{k} \quad (8)$$

where W, L and k are the section modulus, lenght of ship and material factor (BKI, 2017). According to the formula, the material factor is very important to obtain moment of inertia. The section moduli at the deck and bottom part denoted by W_D and W_B are given by

$$W_D = \frac{I_y}{D - g} \quad (9)$$

$$W_B = \frac{I_y}{g} \quad (10)$$

where D represents as the ship's depth. According to local Classification Society rules, the section modulus related to deck W_D and bottom W_B, respectively can be obtained by the following formula

$$W = f_r \frac{|M_T|}{\sigma_p 10^3} \quad (11)$$

where f_r, M_T and σ_p are the factor depending on the degree of deck opening, total bending moment (Nmm) and permissible longitudinal bending stress (N/mm^2), respectively.

The stress components on deck and bottom part can be obtained by using simple expression as follow,

$$\sigma = \frac{Mg}{I} \quad (12)$$

$$\sigma = \frac{M}{W} \quad (13)$$

where M is the moment on the deck and/or bottom part in hogging and sagging conditions. Here, Eqs. (12) and (13) can be simply expressed as

$$\frac{Mg}{I} = \frac{M}{W} \quad (14)$$

Here, the section modulus can be obtained as

$$W = \frac{I}{g} \quad (15)$$

In the Smith's method, which is applied in the program code developed by Yao and Nikolov (1992) is used. The explanation is briefly described such as the axial stress σ_i corresponding to the axial strain ε_i is given by the average stress-average strain relationship for the individual elements as illustrated in Fig. 3. The average stress-average strain relationship is derived considering of buckling and yielding

$$\sigma = f_i(\varepsilon) \quad (16)$$

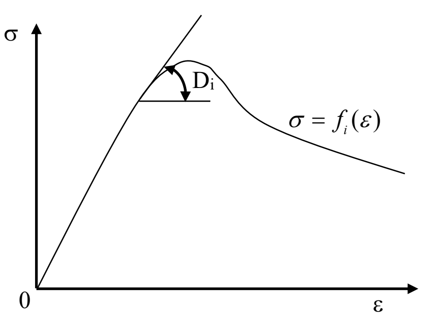

Fig.3 Average stress-average strain relationship for structural element

where $f_i(0) = 0$. The axial force P, the vertical bending moment M_V, and the horizontal bending moment M_H can be obtained by integrating axial stresses over the intact part of cross section as

$$P = \sum_{i=1}^{N} \sigma_i A_i \equiv 0 \quad (17)$$

$$M_H = \sum_{i=1}^{N} \sigma_i \left(y_i - g \right) A_i \quad (18)$$

$$M_V = \sum_{i=1}^{N} \sigma_i z_i A_i \quad (19)$$

The y and z are the coordinates of the cross section measured from the origin at the bottom keel as shown in Fig. 4.

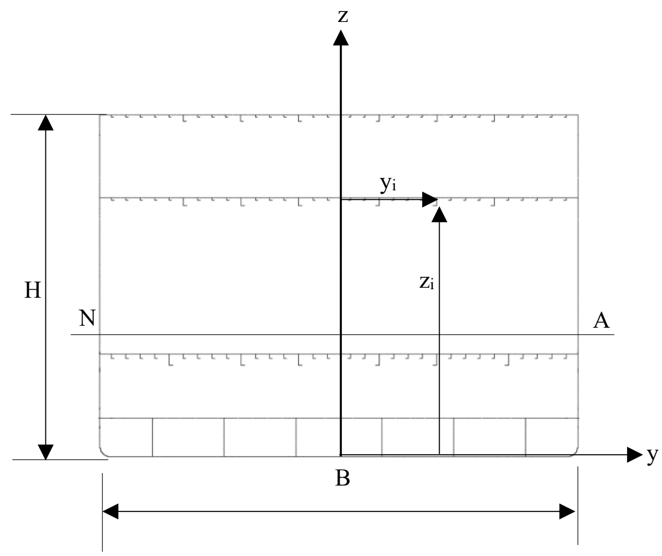

Fig.4 The coordinate systems of the cross section

When the axial load is added to bi-axial bending, the stiffness equation is expressed in term of general formula,

$$\begin{Bmatrix} \Delta P \\ \Delta M_H \\ \Delta M_V \end{Bmatrix} = \begin{bmatrix} D_{AA} & D_{AH} & D_{AV} \\ D_{HA} & D_{HH} & D_{HV} \\ D_{VA} & D_{VH} & D_{VV} \end{bmatrix} \begin{Bmatrix} \Delta\varepsilon \\ \Delta\phi_H \\ \Delta\phi_V \end{Bmatrix} \quad (20)$$

Where

ΔP : increment of axial force
ΔM_H : increment of horizontal bending moment
ΔM_V : increment of vertical bending moment
$\Delta\varepsilon$: increment of axial displacement
$\Delta\phi_H$: increment of horizontal curvature
$\Delta\phi_V$: increment of vertical curvature

and the tangential stiffness of the cross section are written as

$$D_{AA} = \sum_{i=1}^{n} D_i A_i \quad (21)$$

$$D_{AH} = D_{HA} = \sum_{i=1}^{n} D_i y_i A_i \quad (22)$$

$$D_{HH} = \sum_{i=1}^{n} D_i y_i^2 A_i \qquad (23)$$

$$D_{AV} = D_{VA} = \sum_{i=1}^{n} D_i z_i A_i \qquad (24)$$

$$D_{VV} = \sum_{i=1}^{n} D_i z_i^2 A_i \qquad (25)$$

$$D_{HV} = D_{VH} = \sum_{i=1}^{n} D_i y_i z_i A_i \qquad (26)$$

METHODOLOGY

The ultimate strength analysis considering the cross-section modulus of Ro-Ro ship hull girder is performed using analytical formulation. The cross section of Ro-Ro ship is taken to be analyzed. Two Ro-Ro ships, Type-1 and Type-2 are considered as the object ships as shown in Table 1. Both of them are designed based on the local Classification Society rules as shown in Figs. 5 and 6.

Table 1 Ship dimensions

Ro-Ro Ship	Type-1	Type-2
L (mm)	65000	50500
B (mm)	15000	14000
D (mm)	10693	10950

The Ro-Ro ships consist of three decks, which are car, pessanger and top decks. The differences between of type-1 and type-2 Ro-Ros are number and dimension of the stiffeners, number of cars and pessangers and the configuration of the structural shape particularly in the bottom part. Type-2 Ro-Ro is deeper than type-1 Ro-Ro, while type-1 Ro-Ro is wider than type-2 Ro-Ro. One-frame space is considered in the longitudinal direction. The material properties such as young's modulus and yield strength are related to the ship's characteristics, while poisson's ratio is set to be constant. The initial imperfection, welding residual stress, damage, and crack are not considered in the analysis. The ultimate strength is calculated for the intact only in hogging and sagging conditions. It should be noted that there are no longitudinal stiffeners in the bottom of Ro-Ros. Only floors in transversal direction are placed on it. The average stress-strain relationship of each element is derived considering buckling and yielding and integrated to the cross-section.

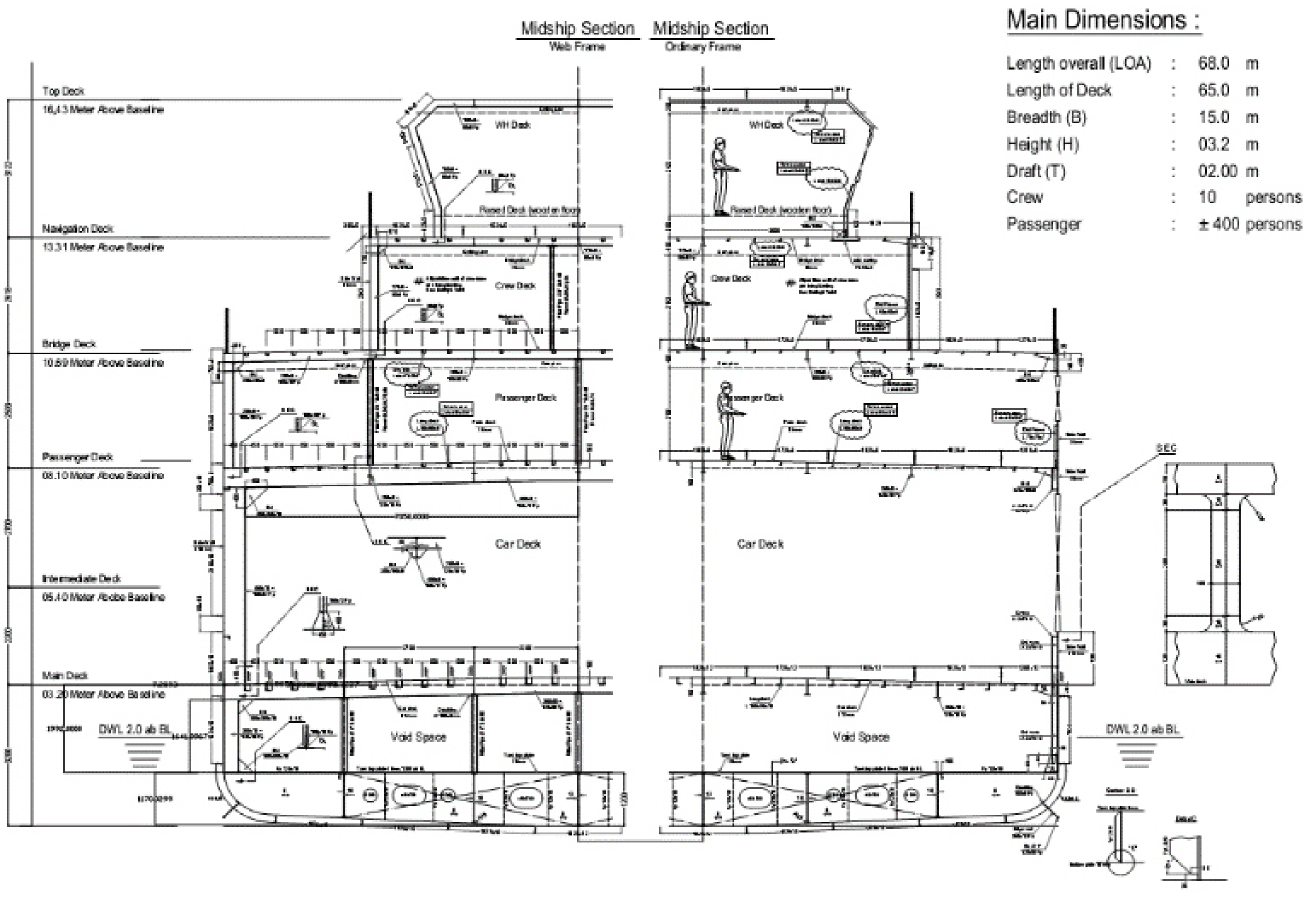

Fig. 5 Ro-Ro type-1

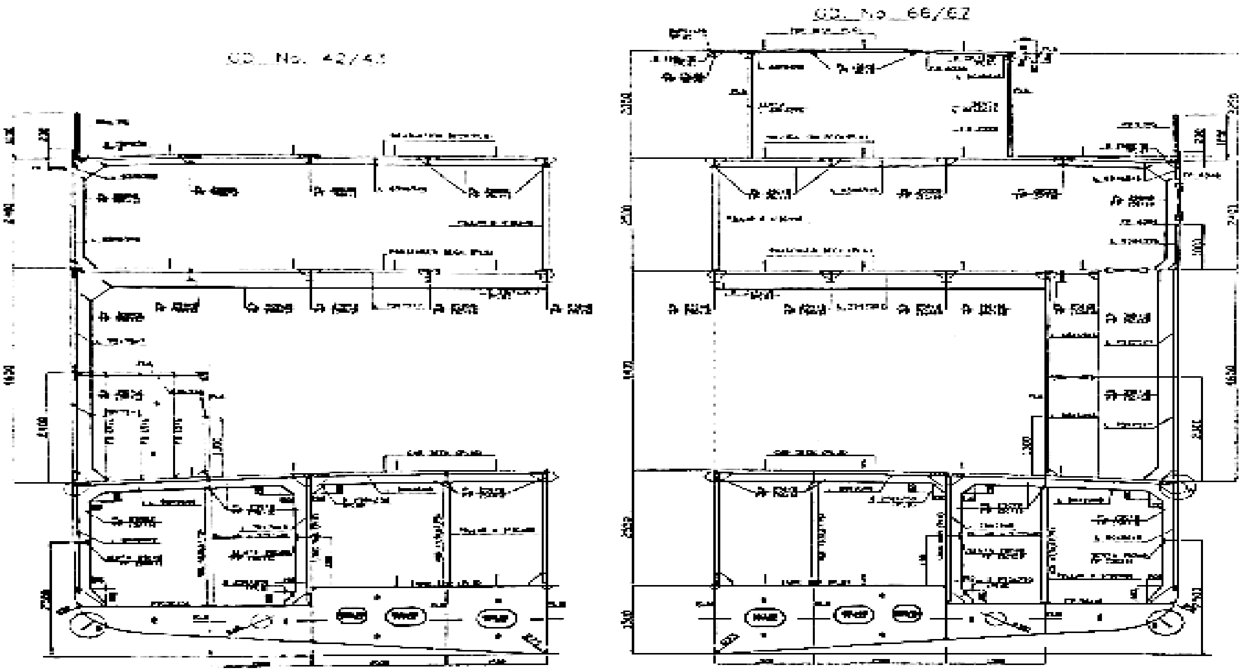

Fig. 6 Ro-Ro type-2

RESULTS AND DISCUSSIONS

The ultimate strengths of Ro-Ro ships considering their section modulus are confirmed applying the method developed by Yao and Nikolov (1992) according to Smith's method. In this case, the incremental iterative approcah is adopted to obtain the ultimate strength both under hogging and sagging condition. In the Smith's method, the cross section is devided into the elements composed of the stiffened and unstiffened plates. The cross section is assumed to be remained plane during progressive collapse and there is no interaction between adjacent elements in the cross section. The vertical bending moment is applied at both sides of the cross section. The cross section of the ships are illustrated in Figs. 7 and 8, respectively. The navigation and upper deck of Ro-Ro ships are assumed to be eliminated.

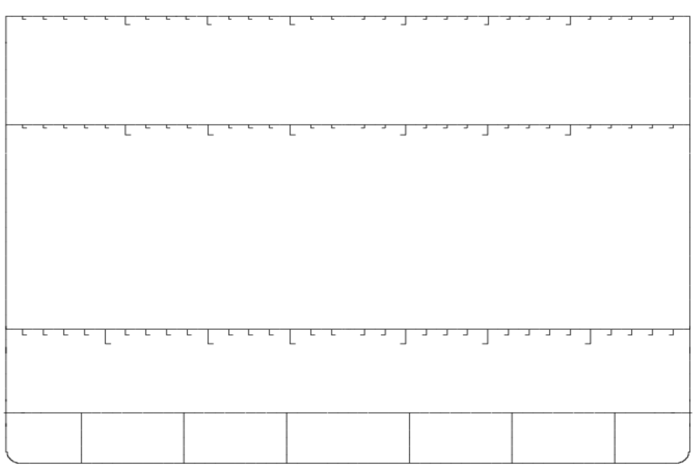

Fig. 7 Cross section of Ro-Ro type-1

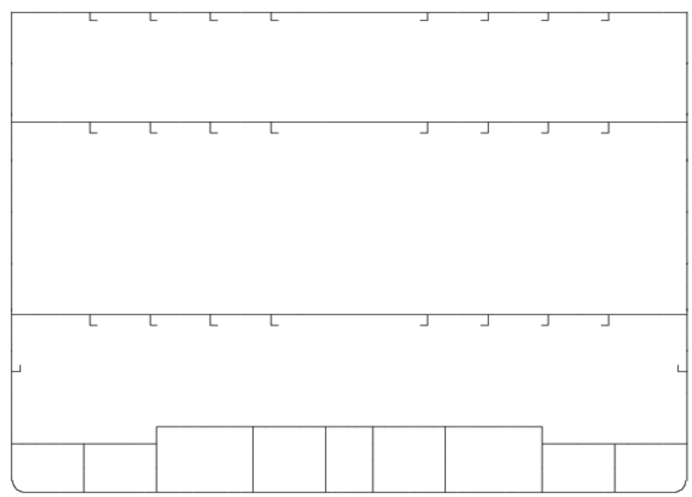

Fig. 8 Cross section of Ro-Ro type-2

The hull girder cross section is very sensitive leading to their ultimate strength and behaviour. It is well known that there is relationship between stress, moment, moment of inertia, neutral axis and section modulus. These relationships are expressed in Eqs. 12, 13, 14 and 15. This is why section modulus depends on bending moment and the section modulus can be obtained by calculating the elements. The coresponding section modulus to the Ro-Ro ship types is shown in Fig. 9. It is observed that the section modulus for type-2 is smaller than type-1. The characteristics of the both ship are completely different starting from the bottom part to the deck. However, two ships consist of three decks, but the shape configuration including number and dimension of stiffeners and double bottom structure also give significant influence to the section modulus and their ultimate strength.

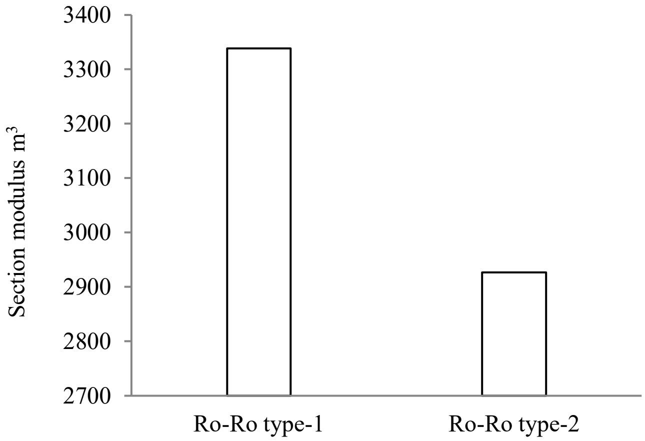

Fig. 9 Section modulus of Ro-Ro ships

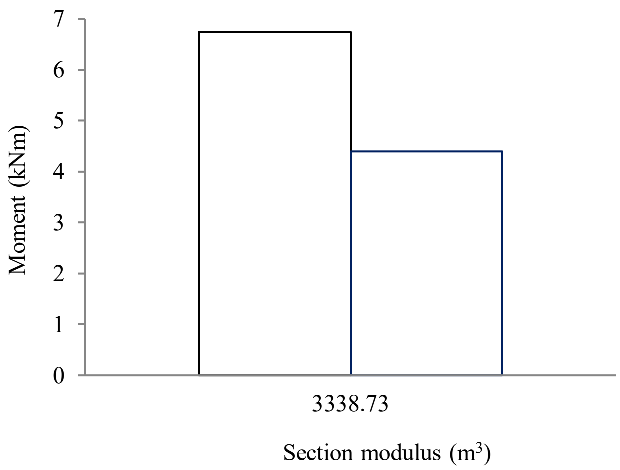

Fig. 10 Moment-section modulus for Ro-Ro type-1

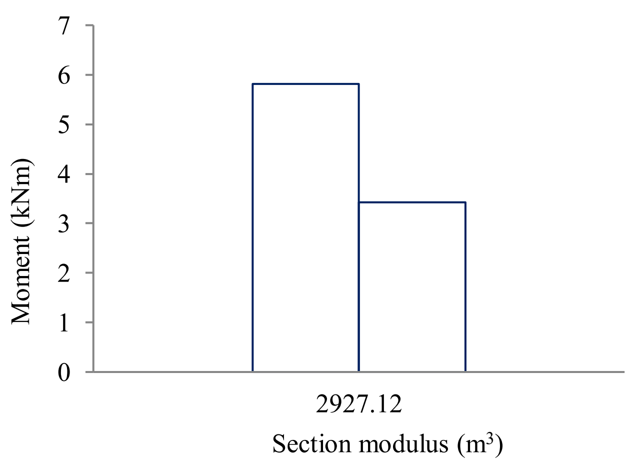

Fig. 11 Moment-section modulus for Ro-Ro type-2

Table 2 Moment-section modulus relationship for hogging

Ship types	M hogging (kNm)	Section modulus (m^3)
Roro type-1	6.74	3338.73
Roro type-2	5.82	2927.12

Table 3 Moment-section modulus relationship for sagging

Ship types	M sagging (kNm)	Section modulus (m^3)
Roro type-1	4.40	3338.73
Roro type-2	3.43	2927.12

The relationship between moment and section modulus of two Ro-Ro ships are described in Figs. 10 and 11 in hogging and sagging conditions, respectively. The moment-section modulus relationship for type-1 is also larger than for type-2 in hogging and sagging condition as shown in tables 2 and 3. The shapes of the cross section for two ships are quite different especially for type-2, because type-2 has double bottom which is not straight line where those area consists of some pillars. The pillars attached on the vertical plate to overcome the structural deformation at the car deck.

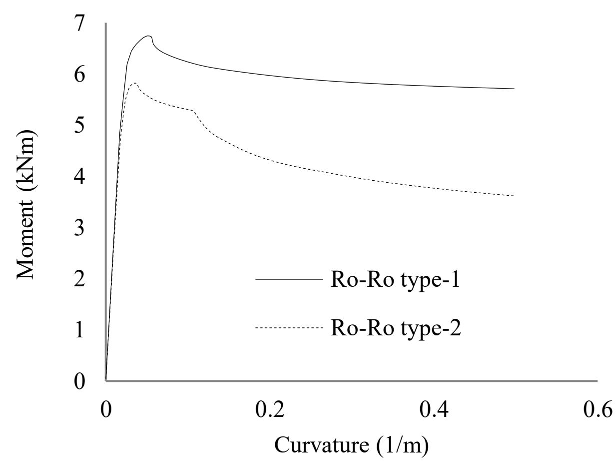

Fig. 12 Moment-curvature relationship for hogging

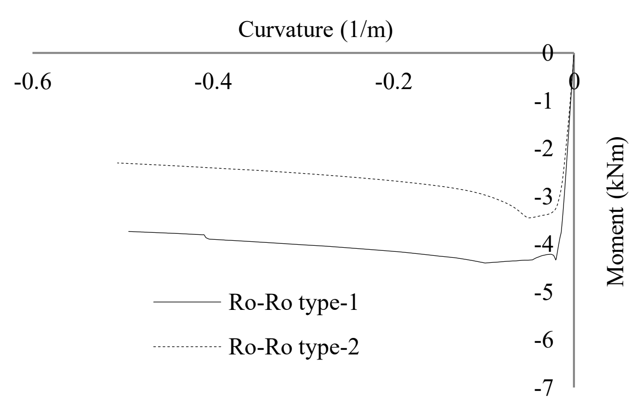

Fig. 13 Moment-curvature relationship for sagging

The moment-curvature relationship in hogging and sagging conditions for Ro-Ro type-1 and type-2 are described in Figs. 12 and 13. The solid lines express the moment-curvature relationship for Ro-Ro type-1, while the dashed one illustrates for Ro-Ro type-2. The moment-curvature relationship for hogging condition between type-1 and type-2 gives significant differences for the ultimate strength and beyond the ultimate strength. This phenomenon also occurs for sagging condition. The value of the ultimate strength is almost identic with the local Classification Society rules.

CONCLUSIONS

The ultimate hull girder strength analysis considering section modulus of Ro-Ro ship under longitudinal bending have been performed based on simple formula of the local Classification Society rules and the Smith's method. The following conclusions are; the effect of the section modulus on the ultimate hull girder strength is significant not only in hogging but also sagging condition. The effect may be caused by the structural configuration of the Ro-Ro ships such as dimensions and number of plate and unstiffened plate, especially on the bottom part to support car deck by some pillars.

REFERENCES

Biro Klasifikasi Indonesia (BKI). (2017). "Rules for the Classification and Construction," Volume II.

Kim, D.H and Paik, J.K. (2017). "Ultimate Limit State-Based Multi-Objective Optimum Design Technology for Hull Structural Scantlings of Merchant Cargo Ships," *Ocean Engineering*, 129, 318-334.

Korkut, E, Atlar, M and Incecik, A (2005). "An Experimental Study of Global Loads Acting on an Intact and Damaged Ro-Ro Ship Model," *Ocean Engineering*, 32, 1370-1403.

Kukkanen, T and Matusiak, J (2014). "Nonlinear Hull Girder Loads of a RoPax Ship," *Ocean Engineering*, 75, 1-14.

Naar, H, Varsta, P and Kujala, P (2004). "A Theory of Cupled Beams for Strength Assessment of Passenger Ships," *Marine Structures*, 17, 590-611.

Muis Alie, M.Z, Sitepu, G, Juswan, Wahyuddin, Nugraha, A.M and Alamsyah (2016). "The Influence of Superstructure on the Longitudinal Ultimate Strength of a RO-RO Ship," *Proc 26th Int Offshore and Polar Eng Conf*, Greece, ISOPE, 4, 1022–1029.

Muis Alie, M.Z, Sitepu, G and Latumahina, S.I (2017). "The Assessement of the Ultimate Hull Girder Strength of Ro-Ro Ship after Damages," *Proc 27th Int Offshore and Polar Eng Conf*, USA, ISOPE, 4, 913–919.

Yao, T. and Nikolov, P.I. (1992). "Progressive Collapse Analysis of a Ship's Hull Girder under Longitudinal Bending (2nd Report)," *J Soc. Naval Arch. of Japan*, Vol 172, 437-446.

ISOPE International Society of Offshore and Polar Engineers

Paper Review Form (Page 1/2)

For ***Conference*** *and* ***Symposium***

Paper No: **ISOPE-2017**-TPC-0617 Date of Review Request: 24/01/17

Paper Title: The Assessment of the Ultimate Hull Girder Strength of RO-RO Ship after Damages

Authored by: Muhammad Zubair Muis Alie, Ganding Sitepu and Samuel Izaak Latumahina

Please complete review by: 20 February 2017

Please return this manuscript **immediately if** you can not complete the review by the indicated date.

PAPER PROFILE

Please check in the boxes, which best describe the following features of the manuscript.

	YES	NO	REMARKS (e.g., Not Sure if you are not sure)
Are data presented to support the technical claims?	X	❑	
Are the references based on theories or results of refereed papers?	X	❑	Some are ❑ Didn't check ☒
Are you aware of prior publication or presentation of this work?	❑	X	
Is this manuscript free of commercialism (e.g., software sales)?	X	❑	
Is this manuscript too lengthy for the materials covered?	❑	X	
Are you associated with the project or program for this paper?	❑	X	

Category	Poor*	Marginal*	Acceptable	Good	Outstanding
1. Originality of the Work			X		
2. Significance of the Work or Results			X		
3. Acknowledgment of the Work of Others in References			X		
4. Completeness of the Reported Work			X		
5. Clarity in Writing, Tables, Graphs or Illustrations			X		

*** "Poor" and "Marginal" are not of acceptable quality.** Justify and provide guidance for improvement in the ***Reviewer's Remarks*** on the back side.

A. Type of Paper	YES	NO	REMARKS
Is this paper an original contribution to the technical literature?	X	❑	
Is this paper a review or progress report?	❑	X	
Does this paper have current interest value?	X	❑	
Does this paper provide permanent value to the technical literature?	❑	X	

B. Quality (**Degree of Excellence**) [**Guideline for Reviewers:** Provide **written comments** on backside.] The quality of the paper is:

❑ **Acceptable**: *Check "Good" or "Outstanding" on* ***all 5 categories*** *and provide* ***specific comments on back side*** [The paper should include some new technical information of significance.

❑ **Acceptable with editorial changes** [The paper requires only editorial changes and/or possible minor additions or deletions.]

X **Acceptable with revision: List specific comments on back side**. [The paper requires changes or revisions of a moderate nature that would aid the authors in presenting the information more clearly. The paper may not require re-review.]

❑ **Acceptable only if revised: List specific comments on back side**. ***Require re-review***. [The paper requires changes in content that would clarify or incorporate the information or data that are essential for clear presentation.]

❑ **Not acceptable for reasons stated on back side**. [This includes those papers having an obvious sales approach (e.g., patent or software sales) to a technical problem, those that have been previously published, those that have been submitted elsewhere, or those based on fallacious or dubious engineering analysis or those that present an approach superficially descriptive of widely accepted engineering practice.]

Return review to:

Name: Constantine Michailides

Affiliation: Liverpool John Moores University

Country: UK

E-mail: C.Michailides@ljmu.ac.uk

Reviewer Name _____ Date ____

Co./Univ: ______________________________

Address: __

City: _____________ Zip/Postal Code _ Country ______

E-mail: ________ Fax: _____________________________

PLEASE COMPLETE THE REVIEW FORM AND KEEP A COPY FOR YOUR RECORDS.

Paper No. **ISOPE-2017**-TPC-0617

The reviews only with written comments are sent to the authors .

Lead Author : Muhammad Zubair

C. Publication Classification Recommendation.

If acceptable (with revisions if necessary), I recommend that the paper be published:

x In **Conference or Symposium Proceedings only** (**not sufficient** as Transactions Journal paper)

❑ In Conference or Symposium Proceedings and as Transactions Journal paper (the paper must have **permanent value**.): *International Journal of Offshore and Polar Engineering*

❑ In Conference or Symposium Proceedings and as Brief Transactions Journal paper (this shorter version must also have **permanent value**.)

D. Reviewer's Remarks. To assist the author in revising his manuscript, please separate your remarks into two clearly identified categories. Remarks that are not clearly identified will be assumed to fall into **category** (1) below. For additional comments, please attach a sheet.

Type or legible handwriting please! Comments: ❑ attached on separate sheet ❑ not attached.

Category (1) Those suggestions which, in your opinion, would improve the quality of the manuscript but are not essential for publication.

Te definition of "post-ultimate behavior" should be included in the manuscript

Category (2) Changes which in your judgment should be made before publication.

1- Please proofread the paper for editorial and grammatical errors (eg in Abstract, the size of some letters is larger compared to the size that the text should be in the paper)
2- In Introduction, please emphasize the originality of the paper as well as clearly state what is new with this paper.
3- Please explain if the breadth of ship that is 15000 mm and the depth is 10693 mm affects the method that you used. Can you use your method with different dimensions? If yesm, please provide some thresholds about the max and min dimensions that the used analytical method can be used.
4- Same question as comment n.5 as far as the longitudinal direction that is represented as one-frame space which has 550 mm in length.
5- Please provide the uncertainties when someone is using your method.
6- If possible provide more results for more loading conditions.

MAILING ADDRESS OF SUGGESTED DISCUSSERS

List names and postal and E-mail addresses of potential discussers. The reviewer may include his or her own name.

PLEASE ANSWER THE FOLLOWING QUESTION

What, in your opinion, is the significant contribution of this paper to the permanent literature?


ISOPE-2018 Sapporo, Hokkaido
The 28th International Ocean and Polar Engineering Conference
Sapporo, Hokkaido, Japan, June 10–15, 2018
INDIVIDUAL ELEMENT CALCULATION OF CROSS SECTION
plate with attached plating
ISOPE