A Developing of Arctic Shuttle Tanker with RS Arc7 ICE Class

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Abstract

Samsung Heavy Industries has the delivery record of three(3) Arctic shuttle tankers with RMRS Arc 6 ICE Class in 2008 for the first-time over the world. Now the same client ordered to build new Arctic shuttle tanker with RMRS Arc 7 ICE Class.

Therefore new arctic shuttle tankers with improved design such as upgraded the ice class with lower design temperature, special hull lines for high performance in open-water sea state, additional compartment-Deck Trunk and Pipe Duct in cargo hold zone for easy and safe operation and maintenance was developed based on previous Arc 6 ICE Class vessels. Four(4) cases non-linear analyses were performed in order to verify the fore body's special hull lines and the after structure's ice breaking strength under the cooperation with Russian research center.

This study introduces the design of Samsung Heavy Industries' new Arctic shuttle tanker with Arc 7 ICE Class in view of these improvements and strengths in detail.

1 Introduction

Samsung Heavy Industries(SHI) has the delivery record of three(3) Arc 6 ICE Class-Arctic shuttle tankers with Russian Maritime Register of Shipping(RMRS) in 2008 for the first-time. And the same client requested to produce again more fortified(Arc 7) Arctic shuttle tanker in order to operate between Murmansk and NOVIY Port as shown in Fig. 1. New sailing route requests a vessel to have shallow draft, lower design temperature and higher ice class. According to these conditions SHI has developed new Arctic shuttle tanker.

Table 1 shows how many design variables have been updated on this new Arctic shuttle tanker project.

Table 1. Comparison of 2008's and 2015's Arctic Shuttle Tanker

	Previous Project	New Project
LOA x B x D	257m x 34.0m x 21.0m	249m x 34.0m x 15.0m
DWT	*70,000MT*	*42,000MT*
Propulsion	Azi-POD 10MW x 2	Azi-POD 11MW x 2
Ice Class	RS Arc 6	RS Arc 7
Ice Speed (astern)	3.0kts at 1.4m ice	3.5kts at 1.4m ice
Open water design Speed	15.7kts	14.0kts
Design Temperature	-40 °C	-45°C
Bottom Duct &	No	Yes
Access Trunk	No	Yes
Bow shape	Extreme bow	Moderated bow

This study would introduce the design of SHI's new Arctic shuttle tanker in view of the improvements and structural strengths in detail.

Fig.1 Trading Route & Cruising concept

2. Characteristic of Arc 7 notation

This chapter introduces the characteristic of Russian Maritime & Resister shipping(RMRS) Arc 7 notation[1] and modification of structures.

2.1 Characteristic of "Arc" notation

Requirements specified in Arc 7 notation for ice ships and icebreakers are as below.

First, RMRS defines the requirement of the hull configuration as shown in Fig 2. It makes fore hull configuration very sharp.
Second, flat transom is not allowed in ice belt. This is the critical limitation for development of after hull configuration.
Third, stem structure shall be made of solid steel section. This means that cast steel should be used for stem.
Finally, design temperature of the compartment *such as Deck Trunk, Ballast Tank, Cargo tank, etc* shall not be not exceed -30°C with the member thickness exceeding 25mm otherwise RMRS may requires improved weld ability and steel compliance. This means that steels shall be marked with an additional super script "Arc". However no mill maker can supply this material.

Since the Buyer requested for this project to have both of "Double Acting Ice Breaking" and high forward-direction *resistance* performance in open-water sea state, SHI developed original aft hull configuration for "Double Acting Ice Breaking" and fore hull configuration in order to have both functions – ice breaking at iced sea state and high *resistance* performance at open water sea state *in order to make propulsion optimization*. After then, SHI verified these special hull shapes and strength using an ice breaking model test[2] and unique hull strength verification procedure developed by SHI and Kroylov Shipbuilding Research Institute(KSRI)[3].

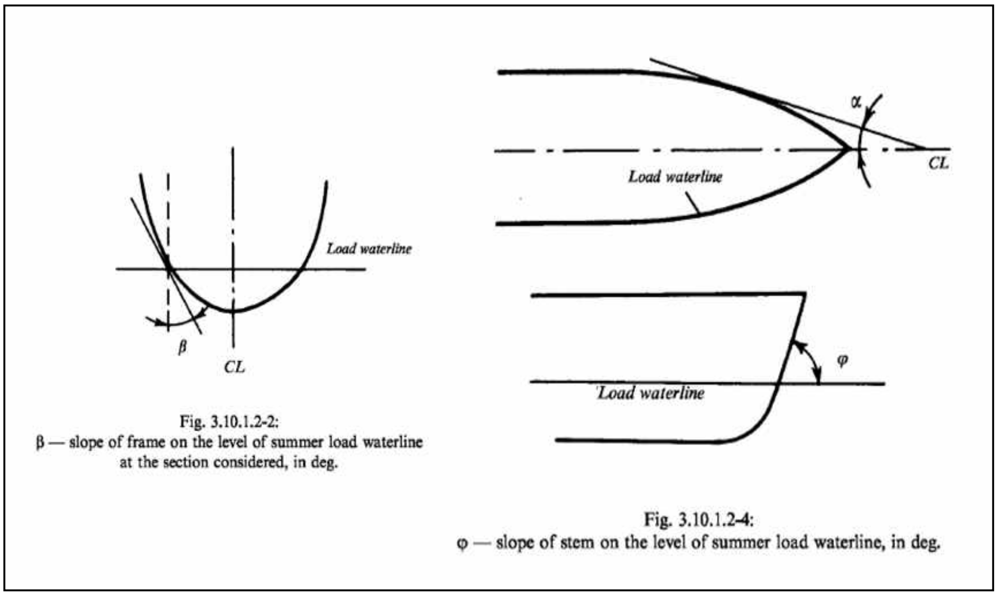

Fig. 3.10.1.2-2:
β — slope of frame on the level of summer load waterline at the section considered, in deg.

Fig. 3.10.1.2-4:
φ — slope of stem on the level of summer load waterline, in deg.

Fig.2 Requirement of the hull configuration

2.2 Comparison of Arc 6 and 7 Notation

According to RMRS' rule, ice pressure acting on the stem under Arc 7 is increased 147% comparing to Arc 6. The ice thickness of the fore end body for Arc 7 is 6mm thicker than that of Arc 6. In Arc 7 notation the transverse stiffening system is more reasonable than the longitudinal systems because dramatic increment of steel weight is required when longitudinal stiffening system is applied.
Table 2 and 3 shows the variation of ice pressure and scantling between RMRS Arc 6 and Arc 7.

Table 2 Ice Pressure Comparison of Arc notation 6 and 7

Hull Ice Region	Arc 6(kPa)	Arc 7(kPa)	Deviation
A-I	5749	8435	147%
A1-I	4975	6760	136%
A1-II	3234	4394	136%
A1-IV	2488	3380	136%
B-I	3824	4406	115%
B-II	1912	2203	115%
B-III	1721	1983	115%

Table 3 Shell plate Comparison of Arc notation 6 and 7

Hull Ice Region	Arc 6(mm)	Arc 7(mm)	
A-I	35”DH36”	41”EH47”	
A1-I	38”DH36”*	39”EH47”	44”EH47”*
A1-III	32.5”DH36”*	32”EH47”	35”EH47”*
A1-IV	29”DH36”*	37.5”AH40”*	
B-I	32.5”DH36”*	33”EH40”	35.5.”EH40”*
B-II	24.5”DH36”*	25”DH40”	26.5”DH40”*
B-III	24.5”DH36”*	25”DH40”*	
*Longitudinal stiffening system is considered			

3 Improvements of SHI’s Arctic Shuttle Tanker

3.1 Fore body configuration

Fig.3 shows the hull configurations of previous and new projects. The fore body’s configuration of new project has been improved in order to enhance the *resistance* performance in open-water sea state compared with the previous project, which is called as “moderated bow shape”. However this hull configuration is unsatisfied with RMRS’s rule. So this new hull configuration was verified with following four(4) steps.

① Ice breaking performance is verified using ice model test.
② Local Scantling is defined according to RMRS requirement with proper ice load calculation.
③ Nonlinear analysis is carried out. The procedure is developed by SHI and KSRI.
④ RMRS rechecked this structure using their internal checking system.

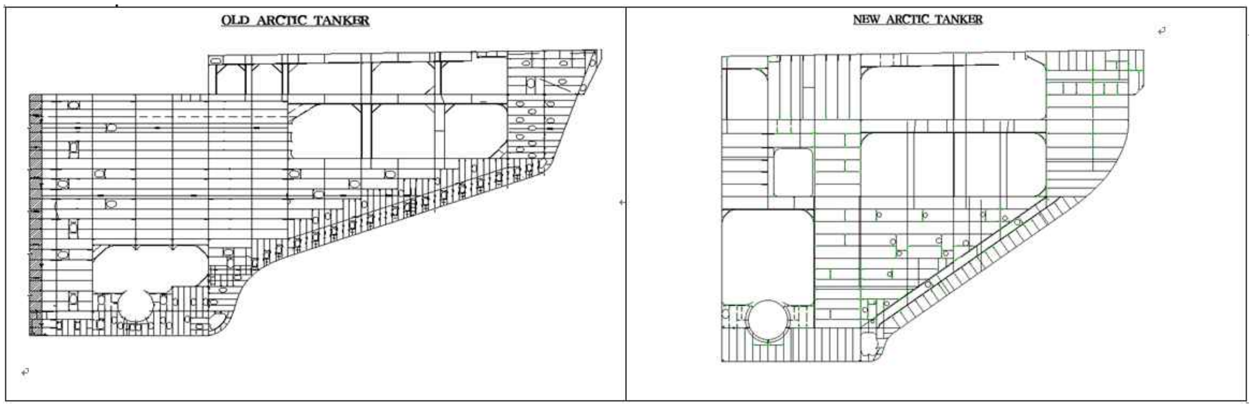

Fig. 3 Bow shape of old Arctic shuttle tanker and new Arctic shuttle tanker

3.2 Material and New compartment

In previous project, HT36 steel was used for ice strength zone. As the ice class is upgraded from Arc 6 to Arc 7 the shell plate thickness shall be increased about 30%. So SHI decided to use the extra high tensile steel, HT40 and HT47 in order to reduce the steel weight and plate thickness because key factors for this project are the shallow draft and the design temperature of -45°C. So, “EH40” steel and “EH47” Steel were very suitable material to satisfy these key factors. However “EH47” steel thinner than 50mm is not produced by Mill-makers except over 50mm and “EH47” steel thinner than 50mm is needed for this project. So, Japanese and Korean Mill makers had developed “EH47” steel not exceed thickness of 50mm with new chemical components. Accordingly Welding Procedure Specification(WPS) for FCAW method of “EH47” steel was developed by SHI successfully. Furthermore WPS for “SAW” method of “EH40” steel was also developed first for this project.

In this project, new compartments are added for easy operating in Arctic environment - Trunk on the upper deck and Pipe duct at bottom region in cargo hold zone. Two compartments enable easier & safer operation and maintenance anytime. But complex compartment arrangements make difficult to define design temperature for each compartments. So SHI divided these compartments into three(3) sub-categories - heating, insulation and non-heating area as shown in Fig. 4 and decided the design temperature for each compartment. The report “STEEL GRADE APPLICATION” was made based on this study and provided to RMRS and LR for their approval[4]. The compartment with the lowest design temperature is the Trunk on the upper deck since insulations are installed inside of the outer wall. As mentioned in Paragraph 2.1 it is very important to control the thickness of plate and profile equal to or thinner than thickness of 25mm on the initial design stage in order not to use the special steel with “Arc” notation. The trunk height was moved upside 800mm in order to meet required section modulus with the trunk deck plate and profile designed with thickness of 25mm in this project.

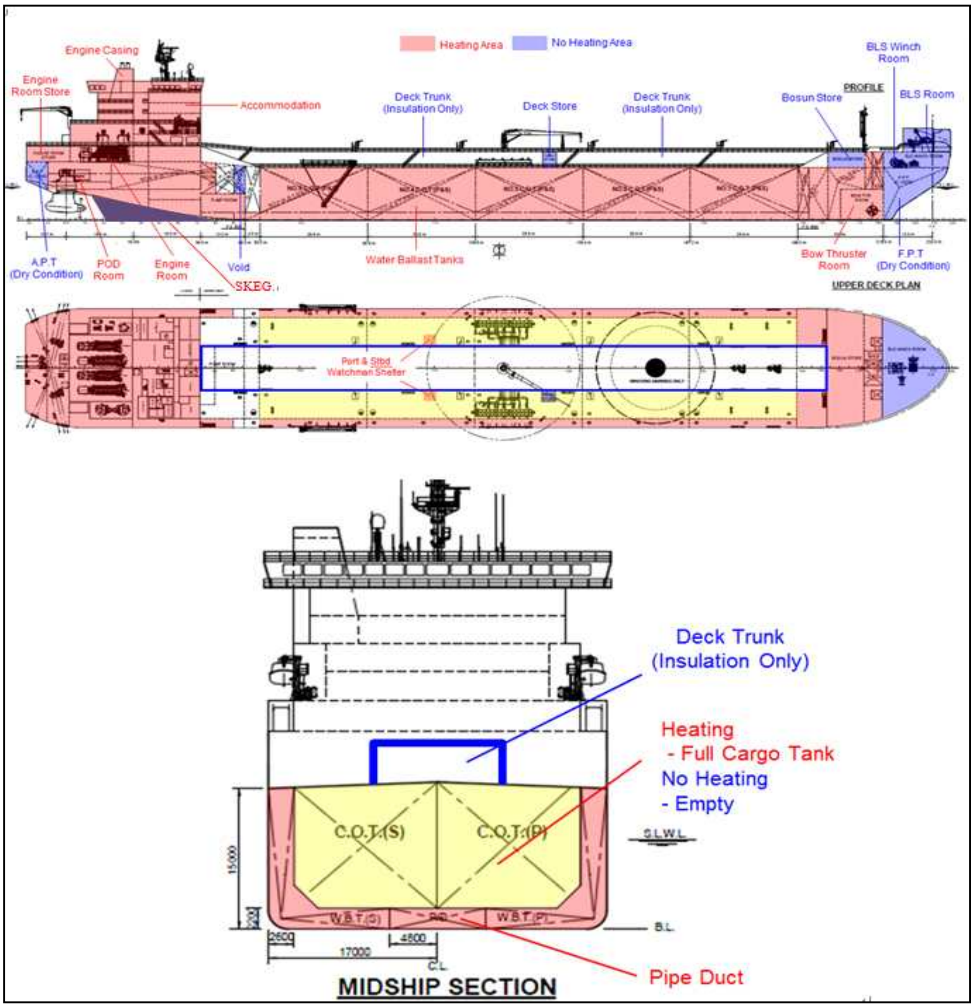

Fig. 4 Definition of Design Temperature

3.3 Fore body structure

Two subjects-configuration and stem structure are focused in the design stage.

First, since the configuration of fore body was developed in order to have high resistance performance it is difficult to satisfy RMRS's rule. Therefore we imposed the special considerations with RMRS's cooperation. Firstly we assumed reasonable ice pressure using RMRS rule and calculated ice load using hydrodynamic model verification procedure developed by SHI and KSRI. And both values were compared. Normally the assumed ice pressures using RMRS rule were higher than those from hydrodynamic model. Next, the scantling was decided with higher ice pressure using RMRS rule. Finally, we conducted the non-linear analysis using FE method and verified that *the scantling determined from the RMRS rules* and arrangement has sufficient strength against the ice pressure.

Second, according to the RMRS' rule, the solid stem using the casting steel is recommended for the vessel corresponding to Arc 7 notation. However SHI knew that the casting steel has diverse weakness as follows;

-low brittle characteristic
-low reliability of welding for the connection of casting steel to casting steel
-difficulty of the maintenance is expected since this material cannot be provided easily.

Then, SHI developed innovative stem design with high grade extra high tensile steel as below.

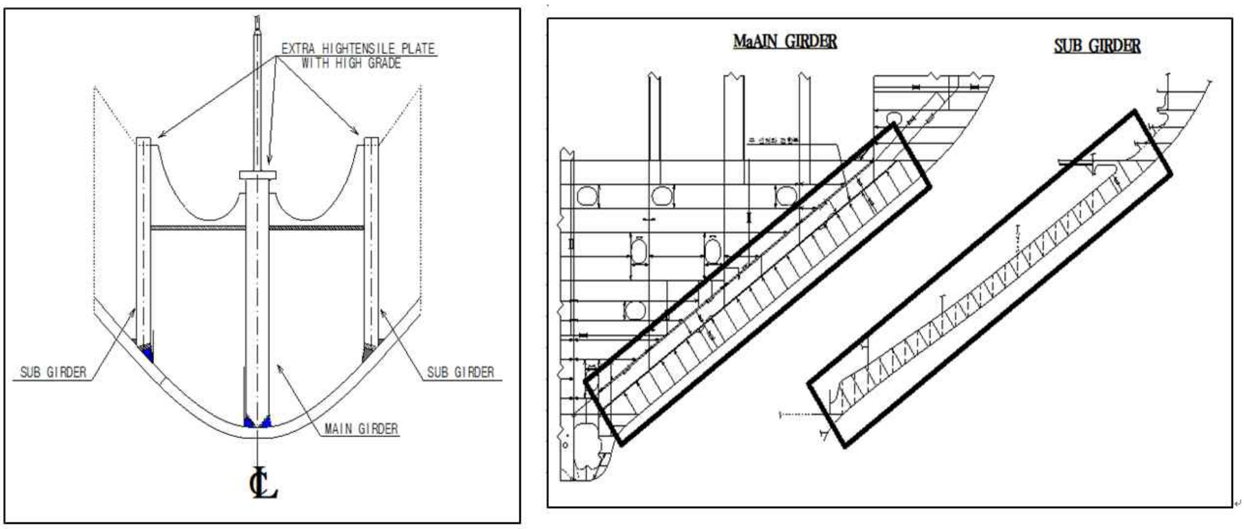

Fig. 5 Stem Design

Three large girders are arranged possible-closely and tripping brackets are installed in tightly spaced along the large girders. So it can be behaved as one solid structure against ice pressure as a solid stem structure. The strong points of this structure are as follows;

-The extra high tensile plate with high grade such as “EH” and “FH” has outstanding brittle characteristic.
-The welding method is well developed because SHI had many experiences and recodes for the welding of those special steel plates. Then the strong reliability can be achieved for stem structure.
-Since this material can be supplied world-widely easy maintenance is possible all the time.
-Production schedule can be shortened dramatically.

3.4 After body structure

According to RMRS, there is no definition of after direction ice breaking. Then, after body configuration was decided according to ice breaking model test for after direction. And the length of “Region C” and ice strength area of “A-I”, “A1-I”, “A1-III” and “A1-IV” in “Region C” was decided using the same concept for the fore body according to the experience and record on previous project. And the scantling for after body was also decided using the same ice breaking pressure for the fore body. But additional considerations are required for after direction ice breaking as follows;

1) The transit area from after bottom to middle bottom was reinforced as “A1-IV” grade as shown in Fig. 6. in order to protect hull against some broken pack ice flowed inside SKEGS after ice is broken.

2)The transit area from after side shell to middle side shell was reinforced additionally from “B-region” grade to “A-region” grade in order to increase the ice breaking redundancy in the turning situation for changing the ice breaking direction.

3) The plate thickness of SKEG structure were increased 5mm and 2mm respectively according to the recommendation from RMRS’s rechecked result using their internal checking system.

4) Additional girders were installed along to the ice knife line in order to reinforce the after-end body connected to the ice at ice breaking situation according to RMRS’s recommendation.

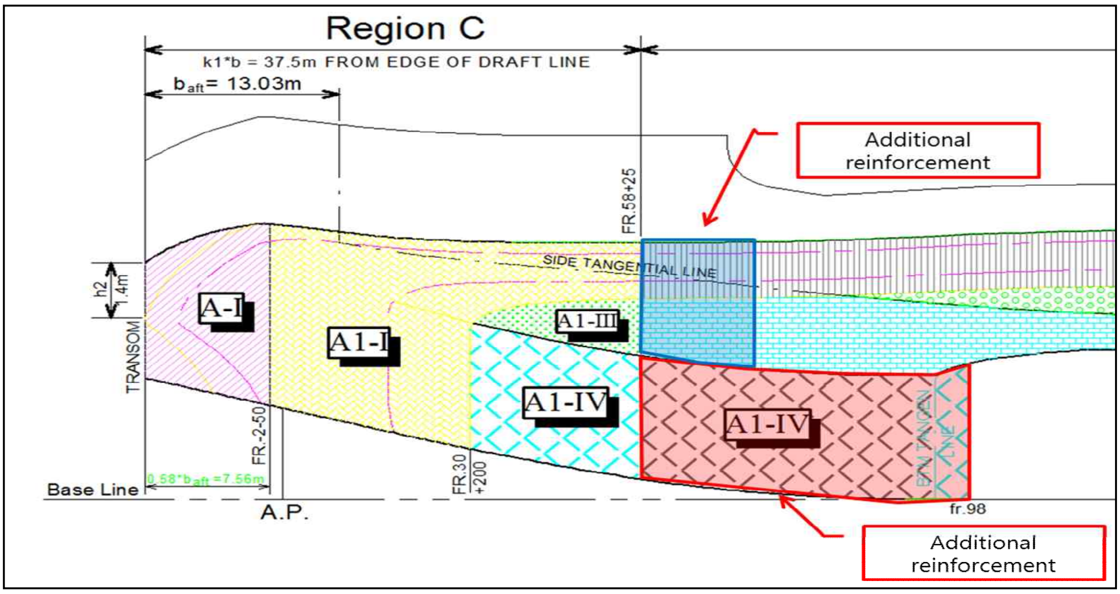

Fig. 6 Ice Strength concept for AFT Ice Breaking

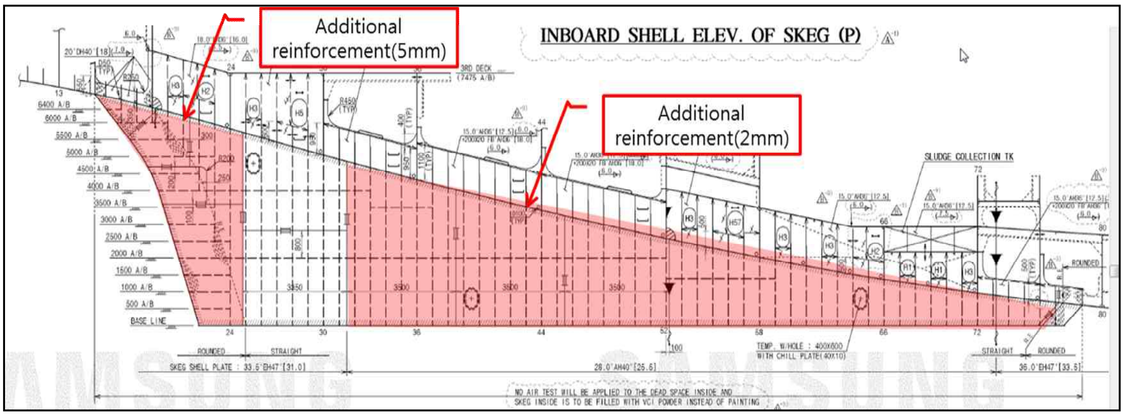

Fig. 7 Additional reinforcement for SKEG structure

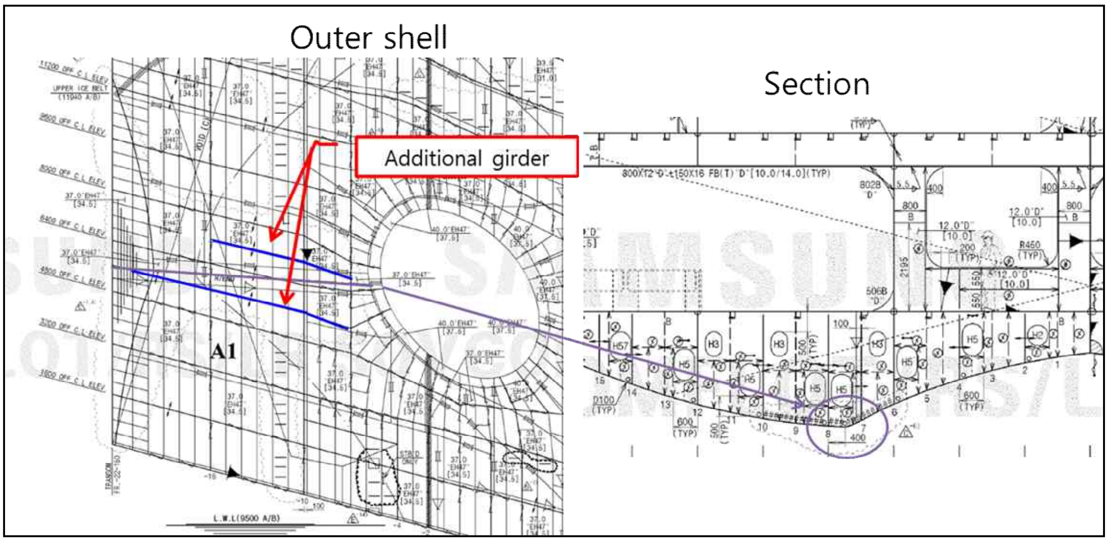

Fig. 8 Additional reinforcement for after-end body

4 Verification of hull strength for local ice loads

4.1 Procedure

This procedure was developed with KSRI after finishing first Arctic shuttle tanker in order to set up an ice strength verification procedure independently and this procedure was confirmed by RMRS.
The ice load calculation conditions and pattern for direct strength calculation are shown in Fig. 9.

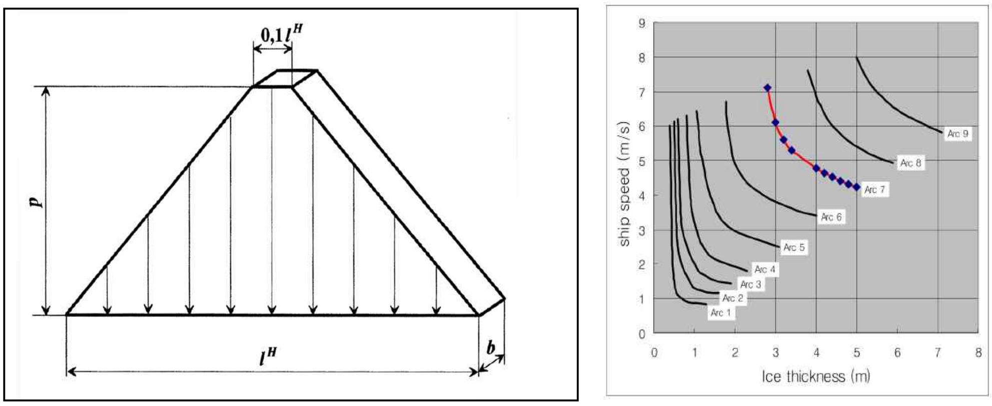

Fig. 9 Ice load pattern form and ice load

The requirements of RMRS's rules for ice strengthening structure scantlings are based on the ultimate strength criterion. So, ultimate strength capacity is used to allowable criteria in the verification procedure. If ultimate strength capacity of ice strengthening structure is greater than design ice load current structure can be considered to have sufficient ice breaking strength. In order to obtain the ultimate strength capacity of the structure elasto-plastic finite element analysis has to be performed. From the elasto-plastic finite element analysis, pressure-deflection curve could be plotted. The ultimate strength capacity could be determined by the scheme presented in Fig. 10[5]~[6].

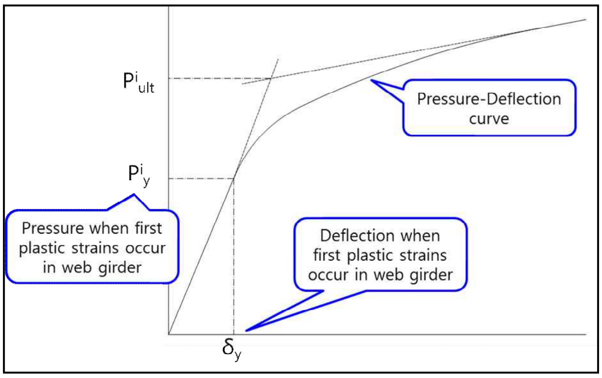

Fig. 10 Scheme for P^i_{ult} definition by finite element analysis

For the elasto-plastic finite element analysis, a detailed finite element model was developed. All structural elements including web members (longitudinal and transverse diaphragms of the double side) with stiffeners, primary framing beams, plating plates, brackets were modeled by shell element. The web stiffeners and face plates of primary supporting members near load applied locations were modeled by shell element. Triangular elements were avoided as far as possible. The element size is approximately 100mm X 100mm on load applied area. The web height of longitudinal is divided into at least into 3 elements. The web height of the intermediate web frames is divided into 6 elements.

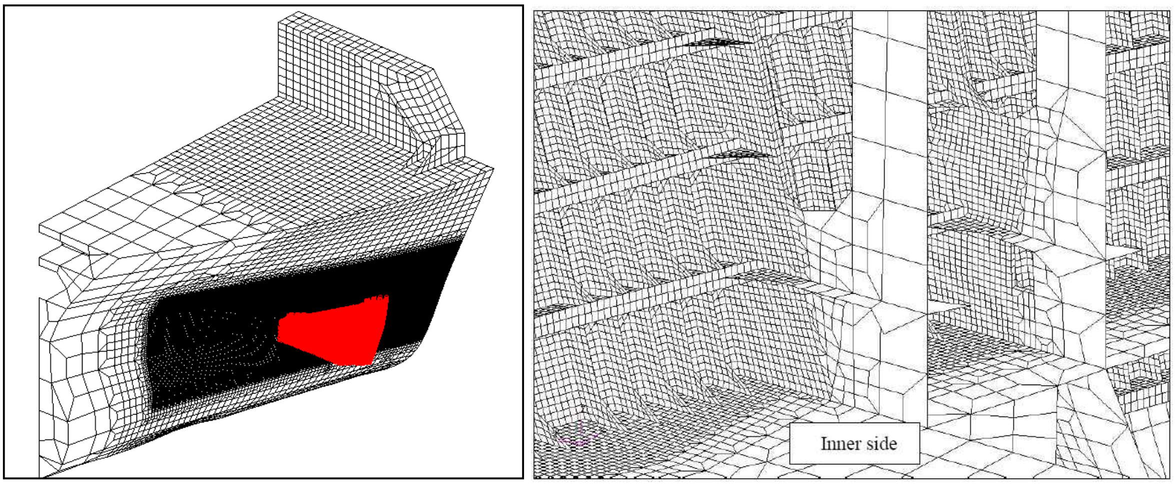

Fig. 11 Example of FE model for the direct analysis

Geometric nonlinearity and material's nonlinearity are considered in the analysis. For the material's nonlinearity, the nonlinearity is assumed as shown in Fig.12. Generally, E = 206000MPa and E_T = 1000MPa are used.

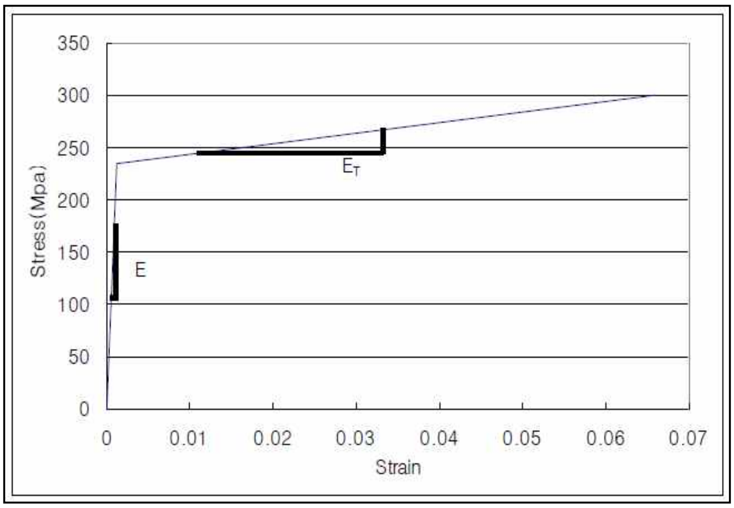

Fig. 12 Example of nonlinear stress-strain relation

FE analysis was carried out with commercial nonlinear FE analysis software, MSC.Marc. This program can handle material's nonlinearity and large deformation (geometric nonlinearity).

4.2 Comparison of Ice Pressure between RMRS rule and direct analysis

As explained in Paragraph 3.1 & 3.3, since current fore body configuration does not satisfy RMRS rule SHI assumed proper ice load using RMRS rule and compared these values with calculated ice load using hydrodynamic model checking program developed by SHI and KSRI.

According to Table 4 we found that the assumed values *of the ice pressures* for local scantling are much higher than those calculated values from the direct analysis and are reasonable ice pressures for local scantling of ice strengthen.

Table 4. Comparison of Ice Pressure between RMRS's rule and direct analysis

Ice region	Ice Pressure using RMRS's rule (A)	Ice Pressure using hydrodynamic model(B)	A/B
A-I	8.44 MPa	6.52 MPa	1.29
A1-I	6.76 MPa	4.98 MPa	1.36

4.3 Non-linear Analysis for fore body

As explained in Paragraph 2.1 SHI conducted Non-linear analysis in order to prove fore body's adequacy in the ice breaking situation. Two(2) FE models were developed for A-I region(bow region) and A1-I region(intermediate region) respectively as shown in Fig. 13. *Some examples of* the load cases are shown in Fig. 14 and the ice pressure-deflection curves are shown in Fig. 15 *respectively*.

And comparison between the ultimate strength capacity of designed structure and the design ice pressure calculated with hydrodynamic model is summarized in Table 5. We can find that the ultimate strength capacity of designed structure is higher than the design ice pressure calculated with hydrodynamic model

Therefore we could conclude that the current scantlings and structural arrangement of the fore body have sufficient strength against the design ice load.

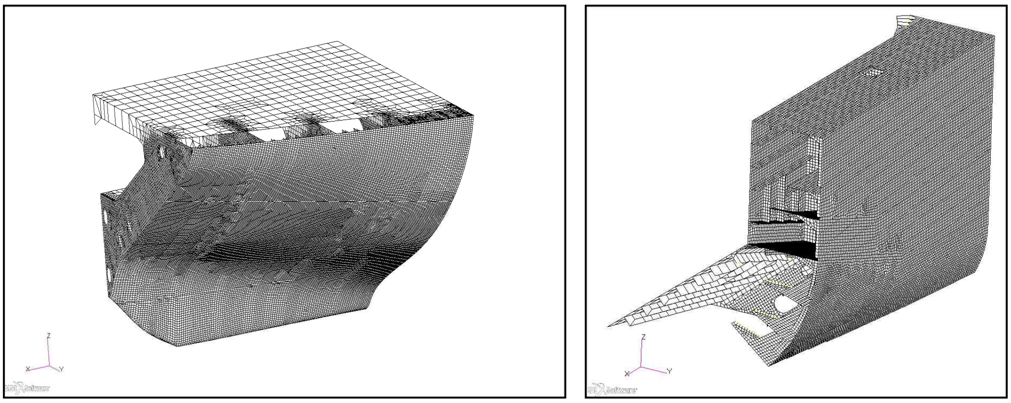

Fig. 13 FE model for the fore body

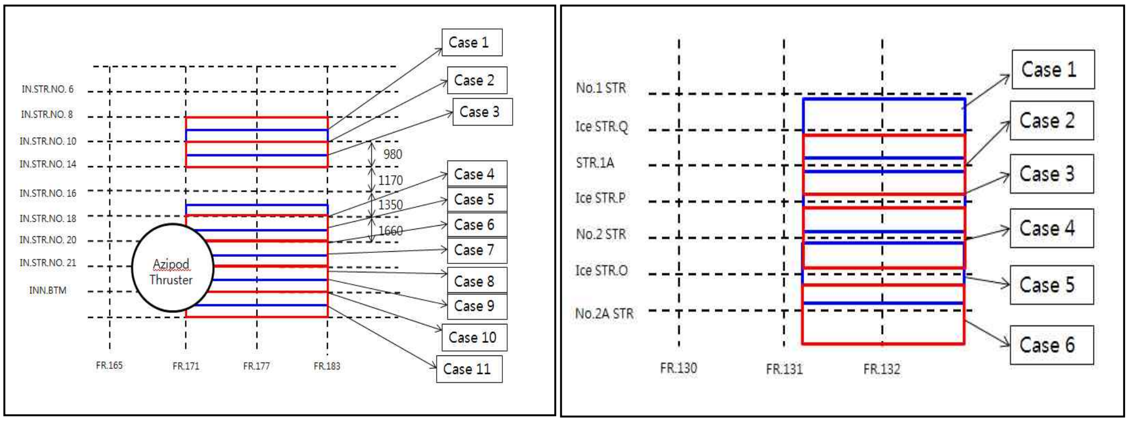

Fig. 14 Load case for the fore body's FE analysis

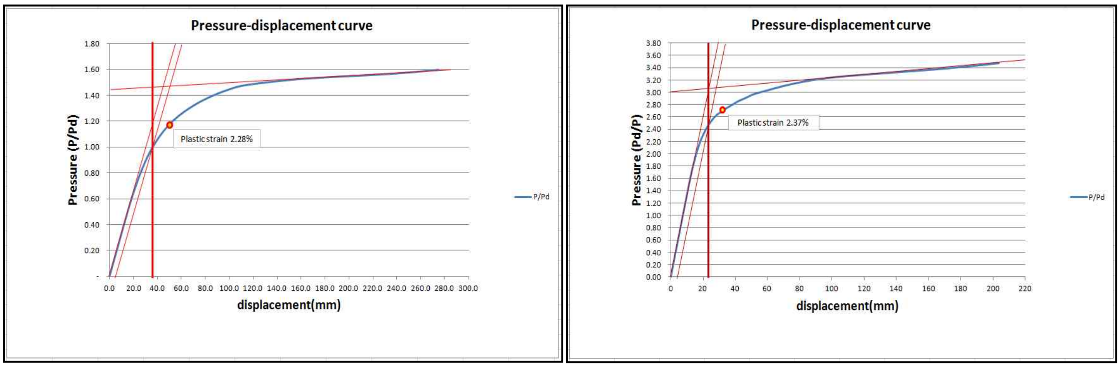

Fig. 15 pressure-maximum structural deformation Curve

Table 5 Summary of strength assessment for fore body

Load case	Area A-I		Area A1-I	
	P_{ult} / P_{design}	Permanent Deformation (mm)	P_{ult} / P_{design}	Permanent Deformation (mm)
Case1	1.46	5.0	3.08	4.0
Case2	1.47	5.0	3.17	4.0
Case3	1.55	4.7	3.40	5.0
Case4	1.76	7.8	3.65	4.1
Case5	1.64	6.8	3.72	4.2
Case6	1.52	6.5	4.40	4.0

4.3 Non-linear Analysis for aft body

SHI conducted Non-linear analysis in order to investigate for the aft body's adequacy against ice load. Two(2) FE models were developed for A-I region and A1-I region as shown in Fig. 16. *Some examples of* the load cases are shown in Fig. 17 and the ice pressure-deflection curves are shown in Fig. 18 respectively.

And comparison between the ultimate strength capacity of designed structure and the design ice pressure calculated with hydrodynamic model is summarized in Table 6. We can find that the ultimate strength capacity of designed structure is higher than the design ice pressure calculated with hydrodynamic model Therefore we could conclude that the current scantlings and structural arrangement of the fore body have sufficient strength against the design ice load.

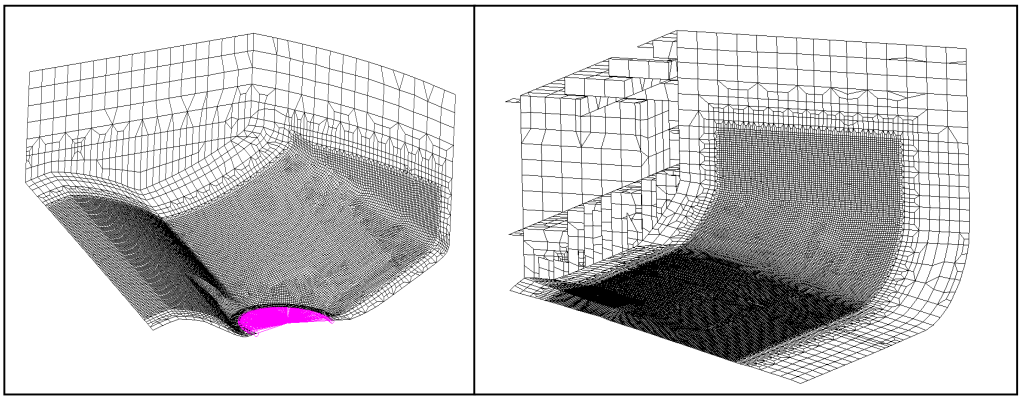

Fig. 16 FE model for the aft body

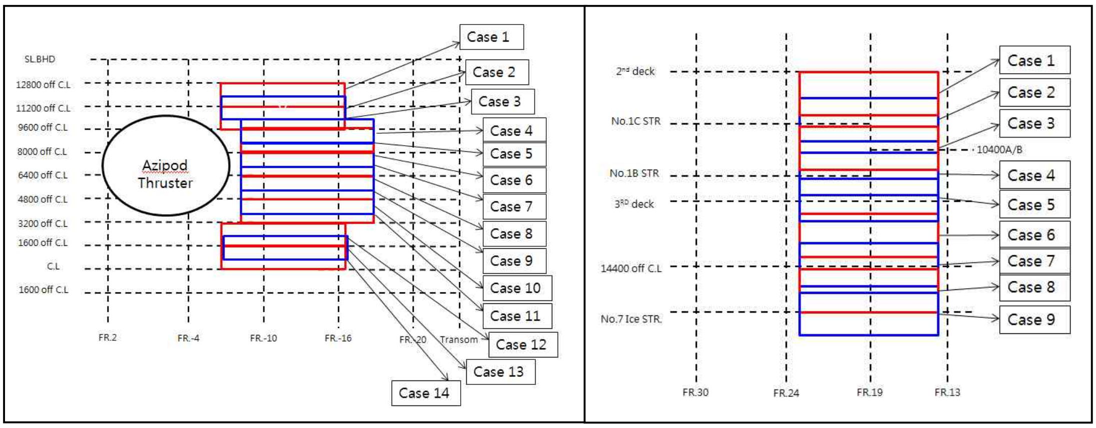

Fig. 17 Load case for the aft body's FE analysis

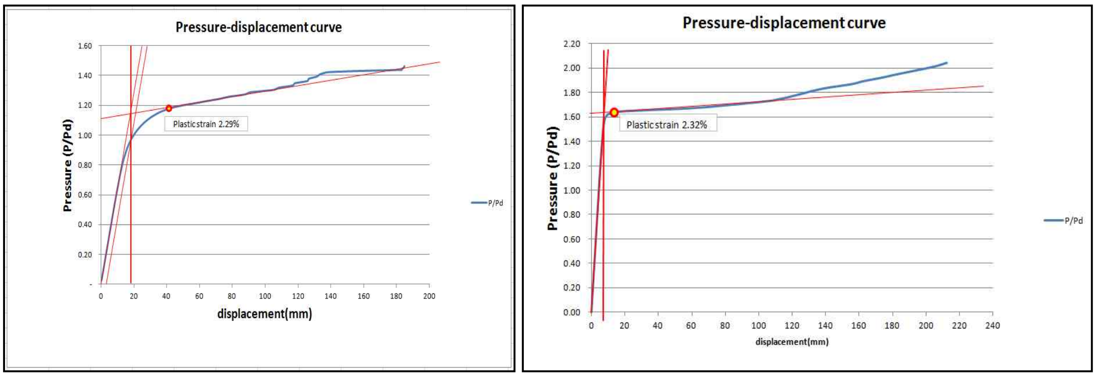

Fig. 18 pressure-maximum structural deformation Curve

Table 6 Summary of strength assessment for after body

Load case	Area A-I		Area A1-I	
	P_{ult} / P_{design}	Permanent Deformation (mm)	P_{ult} / P_{design}	Permanent Deformation (mm)
Case1	1.15	4.0	1.62	0.98
Case2	1.46	3.9	1.82	3.85
Case3	1.19	2.0	1.84	1.85
Case4	2.18	3.5	2.42	1.75
Case5	1.95	4.0	1.63	1.85
Case6	2.18	2.5	1.79	3.8

4.4 RMRS's verification

RMRS did check the ice scantling independently using their internal checking software since this vessel is the largest Arctic shuttle tanker with Arc 7 notation and double acting ice breaking function. They confirmed that all structural scantlings and arrangements are acceptable except SKEG structures. As shown in Fig. 7 the plate thickness of the SKEG structures is increased 2~5mm.

5 Conclusions

SHI has developed Arctic shuttle tanker with ARC 7 notation successfully and there are many improvements in the new vessel based on the experience from Arctic shuttle tanker with ARC 6 notation.

We could summarize the improvements for new Arctic shuttle tanker.

① New compartments-Deck Trunk and Pipe duct are installed in cargo hold zone for easy and safe operation and maintenance.
② Original fore body configuration is developed to have both characters of ice breaking in the iced sea state and high *resistance* performance in the open water sea state *in order to make propulsion optimization*.
③ New EH47 steel thinner than 50mm and relative WPS is developed.
④ New stem concept composited by steel plate only is developed.
⑤ After body configuration is developed for the ice breaking and it is verified by the ice breaking model test. Furthermore additional reinforcements are considered for safer structure.
⑥ Non-linear analysis using the verification procedure developed by SHI and KSRI is conducted for fore and aft ice breaking zone. And it is verified to have sufficient ice breaking strength.

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[3] KSRI, 2008, Development of programs for evaluation of ice loads under tangent impact against the ice, ice entrapment loads, global ice loads and motion parameters in ramming, JDP report

[4] SHI, Steel Grade Application, Rev.A

[5]SHI, Procedure of local ice load calculation based on hydrodynamic model, Rev.0

[6]SHI, Procedure of strength assessment under local ice load, Rev.0