공학석사 학위논문

Design Criteria of Collision & Grounding in Small FRP LNG Fueled Ship using FSI Analysis Technique

유체-구조 연성 해석기법을 이용한 소형 FRP LNG
연료추진선의 충돌 및 좌초에 대한 설계기준 정립

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초 록

최근 국제해사기구 (IMO)가 황산화물, 질소산화물, 이산화탄소 및 선박제조 연비지수 (EEDI) 등의 확산을 규제하고 강화함에 따라 LNG 연료추진선의 관심이 증가하고 있다. IGF 코드에 기준을 둔 소형 LNG 연료추진선의 규정은 500톤 이상의 선박에 적용할 수 있으므로 소형 LNG 연료추진선의 충돌 및 좌초에 규정을 확립할 필요가 있다.

본 연구에서는 소형 FRP LNG 연료추진선의 충돌 및 좌초에 대한 LNG 탱크 위치의 적합한 설계기준을 정립하기 위하여 FRP 판의 파단 시뮬레이션 결과를 중량물 낙하실험 결과와의 비교를 통하여 FRP 판의 파단기준을 정립하고, 해수에서의 여러 가지 간섭효과 등을 고려하여 유체-구조 연성 (Fluid- Structure Interaction, FSI) 해석기법을 적용한 고도 정밀 Modeling & Simulation (M&S) 시스템을 적용하여 현실적이고 정확한 실선 충돌 및 좌초 시뮬레이션을 수행하였다.

FRP 판의 파손 응답해석 기법과 파단기준은 실선 시뮬레이션 수행 시 입체 요소의 사용으로 인한 막대한 계산 시간의 문제로 인하여 LS-DYNA 코드의 적층 판 이론과 MAT_ENHANCED_COMPOSITE_DAMAGE 복합재 물성치 모델을 사용하여 검증하였으며, 중량물 낙하실험 결과와의 검증을 통하여 파단 응답 거동을 대체로 잘 구현할 수 있었다.

소형 FRP LNG 연료추진선과 방제선은 선도, 일반배치도 및 복원성 계산서를 통하여 전반적인 선형과 구조배치를 파악하였고, FRP 구조 기준에 따라 구조부재를 계산하고, 부양 시뮬레이션과 유체정역학적 특성치 프로그램 계산을 수행하여 유체정역학적 특성치를 복원성 계산서의 결과와 비교를 통하여 전선 모델링을 정확히 구현하였다. 그 이외에 합리적인 실선 충돌 및 좌초 시뮬레이션을 수행하기 위하여 실선 모델들을 정확히 부양시켰고 정상적인 추진력을 적용시켰으며, 해수에서의 두 선박의 충돌 및 암초와의 좌초로 인한 거동이 공기 중에서와는 달리 부력에 의해 실제와 같이 잘 구현되었을 확인할 수 있었다.

충돌각도 70°로 충돌하는 경우에는 연료탱크실의 선측의 선각과 보강재에, 암초가 선체의 중심선과 중심선에서 1.0m 벗어난 위치에서 좌초하는 경우 모두에서 선측-바닥의 선각과 보강재에 다소 큰 파단손상이 발생하였지만 연료탱크에는 직접적인 충격손상은 발생하지 않았다. 충돌 시 충돌선 선수부와 좌초 시 암초와 연료탱크와의 간격이 각각 0.29m와 0.27m로 발생한 실선 충돌 및 좌초 시뮬레이션 결과를 바탕으로 500톤 이상의 선박에 적용되는 IGF 코드에 기초한 가스 연료추진선의 충돌 및 좌초에 대한 규정을 소형 FRP LNG 연료추진선에 대하여 제안하였다. 본 연구에서 제안한 규정은 전세계의 모든 소형 가스추진선에 적용하기에는 다소 부족하지만 하나의 초석이 될 것으로 사료된다. 앞으로 다양한 크기와 형상의 가스추진선과 연료탱크에 대한 실선 시뮬레이션을 통하여 보다 객관적인 규정을 제안하는 것이 필요할 것이다.

KEY WORDS : 소형 FRP LNG 연료추진선; 고도 정밀 M&S 시스템; 유체-구조 연성 해석기법; 가스 확산 및 폭발 응답 해석; 설계 기준.

Design Criteria of Collision & Grounding in Small FRP LNG Fueled Ship using FSI Analysis Technique

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Abstract

As IMO has been in place to regulate and strengthen the emission of SOx, NOx, CO2 and EEDI in recent years, interest in LNG fueled ship is on the rise. Since the standards for small LNG fueled ship based on IGF Code can be applied to the ships weighing more than 500 tons, its regulations of small LNG fueled ship are necessary to be established for the design criteria of the collision and ground accidents.

In this study, realistic and exact full-scale small FRP LNG fueled ship collision and grounding simulations were carried out to make sure of reasonable design criteria of collision and grounding for the LNG tank location in small FRP LNG fueled ship, verifying fracture criterion of FRP plate compared with weight drop impact test results and its fracture simulations, and using highly advanced Modeling & Simulation (M&S) system with Fluid-Structure Interaction (FSI) analysis technique considering several interface effects of ship in the sea water.

Fracture failure response analysis technique and fracture criterion of FRP plate was verified using laminated shell theory and MAT_ENHANCED_COMPOSITE_DAMAGE composite material of LS-DYNA code with composite

single plate, not by composite solid one due to huge computational time in full-scale ship simulations. It could be confirmed that fracture failure response behaviors were relatively well realized to the weight drop impact test ones.

Full-scale small FRP LNG fueled ship and water surface cleaner were modeled exactly by investigating its hull form, general arrangement and stability calculation, by calculating its structural members according to FRP structural criterion, and by comparing its hydrostatic characteristics using floating simulation and hydrostatic characteristic program calculation with stability calculation. Full-scale ship models were accurately floated and steady sailing ship propulsion force was also adopted for the reasonable full-scale ship collision and grounding simulations. It could be confirmed that the collision behaviors between two ships and the grounding ones against a rock were well realized in the sea water by buoyancy, unlike those in the air.

There occurred a large amount of fracture damage on the hull and stiffeners in the side of fuel tank room in the case of attack angle 70°, and in the side-bottom of fuel tank room in both cases of a rock position along the centerline and 1.0m off the centerline of the hull. However, there was no direct impact damage to the fuel tank in both collision and grounding accidents. A gap between the colliding ship bow and fuel tank in the case of collision and that between the rock and fuel tank in the case of grounding were 0.29m and 0.27m, respectively. From the full-scale ship collision and grounding simulations, Standards of Gas Fueled Ship for Collision and Grounding based on the IGF code applicable to ships weighing more than 500 tons was suggested for small FRP LNG Gas Fueled Ship for Collision and Grounding. Even though this suggestion of standards is not suitable to every small Gas Fueled Ship in the world, it could be thought to be the cornerstone, and more diverse full-scale ship simulations will be necessary for the more generalized standards with diverse size and type of small gas fueled ship and fuel tank.

KEY WORDS : Small FRP LNG Fueled Ship; Highly Advanced M&S (Modeling & Simulation) System; Fluid-Structure Interaction Analysis Technique; Gas Diffusion and Explosion Response Analyses; Design Criteria.

1. Introduction

In recent years, International Maritime Organization (IMO) has been in place to regulate the emission of SOx (sulfur oxides) and NOx (nitrogen oxides), where SOx content will be strengthened with less than 0.5% from 3.5% in the whole seas, and Tier III regulation for the NOx emission came into force in the ECA (Emission Control Area) from 2016 additionally to Tier II regulation in 2011. EEDI (Energy Efficiency Design Index) was also regulated to apply the new ship form January in 2013 and will be strengthened step by step with relation to the CO2 (carbon dioxide) regulation by IMO. Further extended ECA regulation seas will be expected and SOx regulation criterion (0.5%) is applied to the more strengthened criterion 0.1% in this ECA. Interest in LNG fueled ship is on the rise, since LNG fuel is cheaper than low sulfur oil, and its noxious emissions are noticeably small and can be satisfied with IMO environmental regulations, such as EEDI, etc., where it can reduce CO2 by about 20%, NOx by 85～95%, and SOx until 100%.

Even though small LNG fueled ship should be applied to the standards of Ships Carrying Liquefied Gases in Bulk and Gas Fueled Propulsion Ship (Ministry of Oceans and Fisheries) (MOF, 2015), Chapter 5 of Part 7 Ships of Special Service of Korean Register for gas explosion (KR, 2019a), as shown in Table 1, it is difficult to apply the standards for small LNG fueled ship based on IGF Code (International Code of Safety for ships using gases or other low-flashpoint fuels) since the standards are applicable to ships weighing more than 500 tons. Therefore, the regulations of small LNG fueled ship are necessary to establish for the design criteria of the collision and ground accidents.

Table 1 Standards of Gas Fueled Propulsion Ship for collision and grounding (MOF, 2015; KR, 2019a; IMO, 2009)

classification	collision / grounding
article number	Article 12 (Storage of gas fuel) Sec. 4 Clause 2
article description	2. The gas storage tank(s) should be placed as close as possible to the centreline, and away from each of the following requirements. 1) minimum, the lesser of B/5 and 11.5m from the ship side; 2) minimum, the lesser of B/15 and 2.0m from the bottom plating; 3) not less than 760mm from the shell plating.

In general, small size ship structure is usually made of FRP (Fiber Reinforced Plastic) materials, as shown in Fig. 1, which is efficient for toughness and strength due to economical and functional aspects instead of steel plates or other compositions. To ensure reasonable design criteria of collision and grounding in small FRP LNG fueled ship, full-scale simulations would be the best approach using highly advanced Modeling & Simulation (M&S) system with Fluid-Structure Interaction (FSI) analysis technique of LS-DYNA code (LSTC, 2013) for the collision and grounding (Lee, 2019). All scenarios of collision and grounding are set up based on the risk analysis.

Fig. 1 Photos of small size FRP ship and FRP materials

The objective of this study is reasonably to establish the design criteria of collision and grounding in small FRP LNG fueled ship with realistic and exact FRP fracture criterion and full-scale ship collision and grounding simulations. For the reasonable prediction of design criteria of collision and grounding in small FRP LNG fueled ship, the following two phases of research were largely carried out.

The correct fracture criterion and response behavior prediction of FRP plate is needed for the full-scale ship collision and grounding simulations, and FRP plate should be treated as single plate, not by composite solid one (Lee at al., 2011a; Lee at al., 2011b) due to the computational time. In Chapters 2 and 3 of this study, fracture failure response analysis technique and its criterion were established by verifying the fracture failure simulation results using laminated shell theory and MAT_ENHANCED_COMPOSITE_DAMAGE composite material in LS-DYNA code in highly advanced M&S (Modeling & Simulation) system with weight drop impact test ones. 12 and 16 layer FRP plates were tested according to the impact amount.

Through the realization of several interface effects of ship in the sea water, such as its floating, motion, making wave, squeezing pressure, and bank effect, more realistic and exact full-scale ship collision and grounding simulations could be realized using FSI analysis technique, and full-scale ship modeling should be also performed exactly in the collision and grounding accidents by investigating its hull form, general arrangement and stability calculation, by calculating its structural members according to FRP structural criterion, and by comparing its hydrostatic characteristics using floating simulation and hydrostatic characteristic program calculation with stability calculation. In Chapters 3 and 4 of this study, exact full-scale ship modeling, and realistic collision and grounding simulations were performed for the design criteria of collision and grounding in small FRP LNG fueled ship, using highly advanced M&S system with FSI analysis technique.

2. Weight Drop Impact Test of FRP Plate

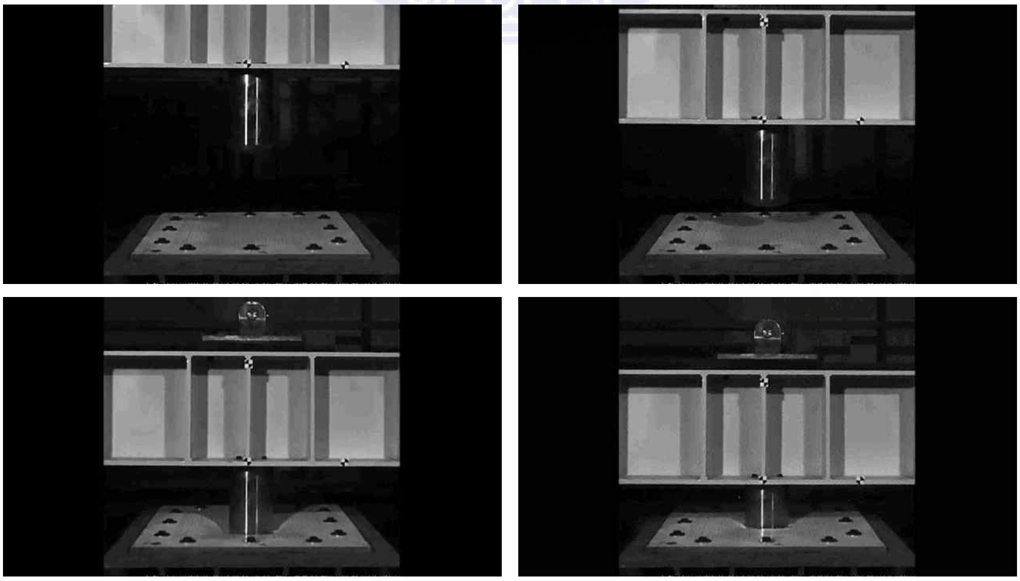
The tensile and flexural strengths for the full-scale ship collision and grounding simulations were measured by conducting specimen tests, as shown in Fig. 2, and their test results are shown in Table 2. Figure 3 shows the weight drop impact test for 12 and 16 layer FRP plates with weight drop impact test facility in The Korea Ship and Offshore Research Institute of Pusan National University. A total of 8 FRP impact test plates were tested, Tables 3∼4 illustrate their dimensions and measured thicknesses, and its laminate schedule, respectively. Figure 4 shows its setting on the steel jig with its dimension.

Fig. 2 Photos of FRP test specimens

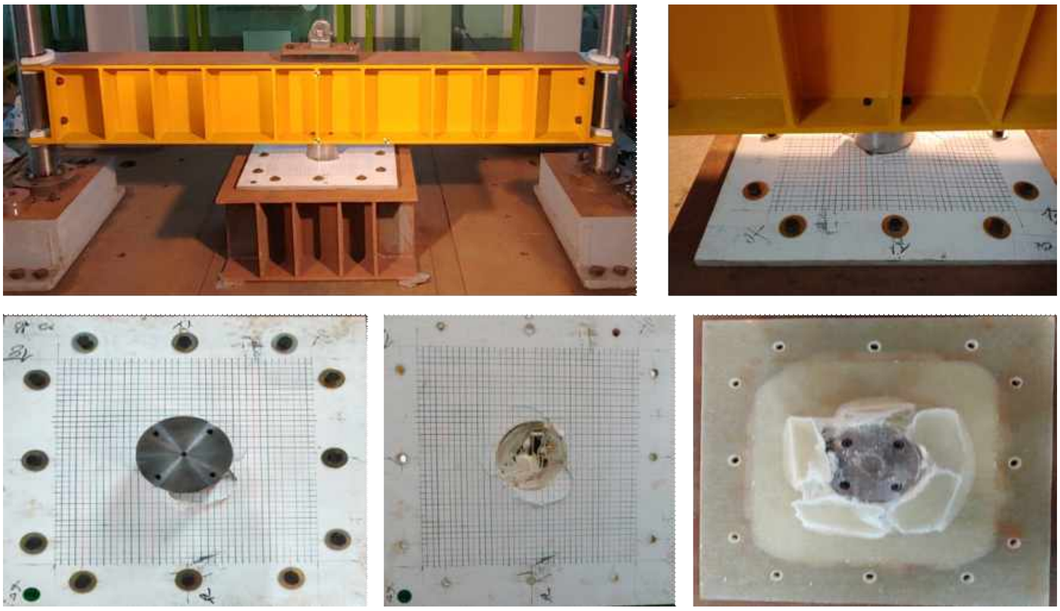
Table 2 Results of FRP test specimens

test item	results	testing method
tensile strength	177 MPa	KS M ISO 527-4 : 2002
flexural strength	238 MPa	KS M ISO 178 : 2012

(a) weight drop impact test facility



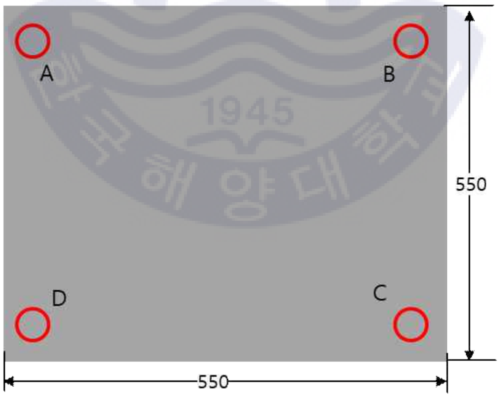
(b) weight drop impact test



(c) weight drop impact test results

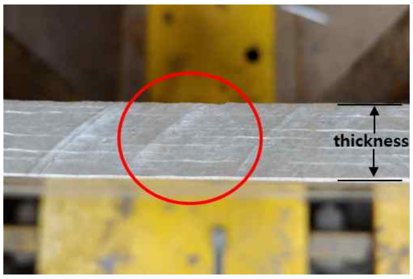
Fig. 3 Weight drop impact test of FRP plates

Table 3 Dimensions and measured thicknesses of FRP plate specimens according to specimen



specimen		measured thickness (mm)				
No.	ply	A	B	C	D	average
1	12	16.1	15.8	15.0	14.0	15.2
2	16	16.6	16.9	17.2	18.2	17.2
3	12	15.9	15.7	14.3	13.3	14.8
4	12	15.0	14.6	14.6	13.9	14.5
5	16	16.0	16.4	17.0	15.7	16.3
6	12	13.1	13.5	15.0	14.0	13.9
7	16	16.7	17.1	16.0	16.6	16.6
8	16	17.1	16.0	17.2	17.6	17.0

Table 4 Laminate schedule of FRP plate specimen

	FRP's laminate schedule	
	12 ply	GC+M+(M+R)x5+M
	16 ply	GC+M+(M+R)x7+M
	Note - M: Mat (0.45 g/m^2) - R: Roving (0.57 g/m^2) - GC: Gel coat (0.3~0.5mm)	

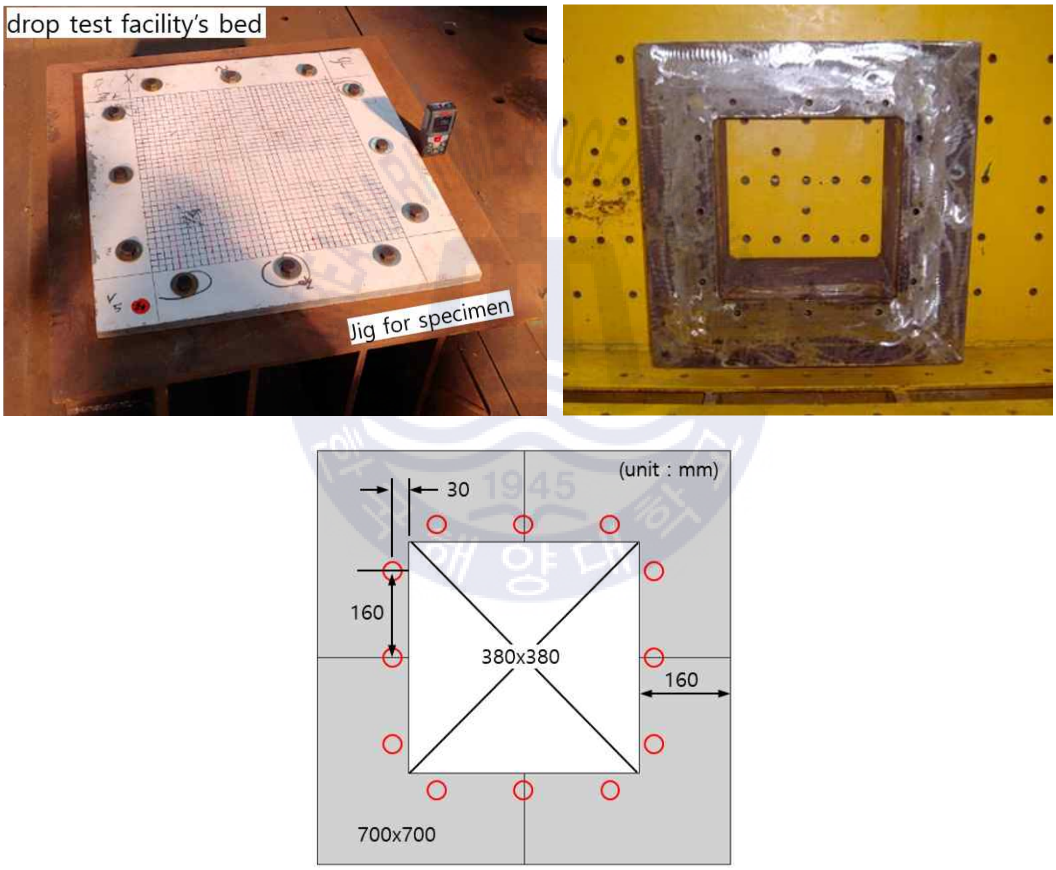


Fig. 4 Setting of FRP plate specimen on steel jig

Figure 5 and Table 5 illustrate the details and capacity of weight drop impact test facility, and Fig. 6, the weight and height of weight drop. Weight drop impact test was carried out according to the scenario of weight drop impact test, as shown in Table 6, and its damage response behaviors are shown in Fig. 7.

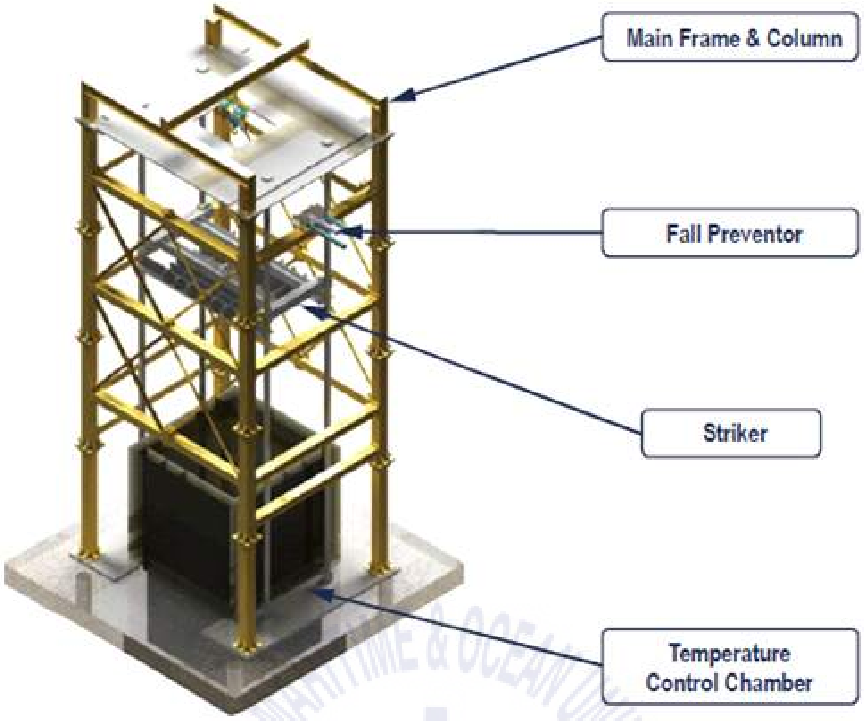


Fig. 5 Details of weight drop impact test facility

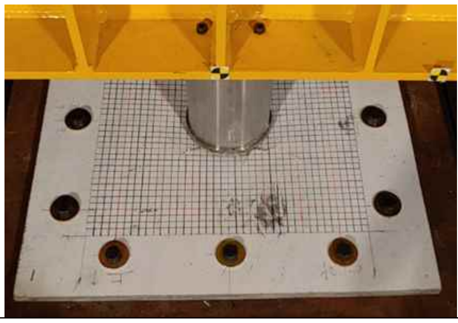
Table 5 Capacity of weight drop impact test facility

item	capacity
test bed	L3m x W3m (H9.7m)
drop object holder capacity	50kN, 100kN
load cell capacity	1MN, 2MN, 24MN
high speed camera	108,000 fps

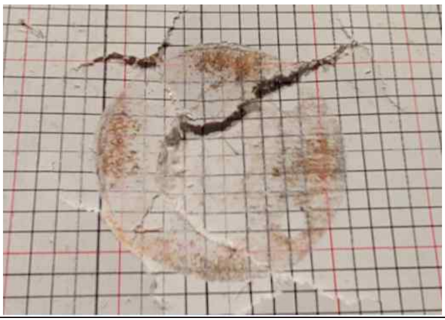
Fig. 6 Weight and height of weight drop impact test

Table 6 Scenario of weight and height of weight drop impact test according to FRP plate specimen

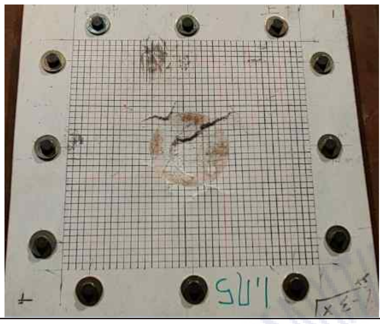
specimen No.	ply	average thickness(mm)	drop weight(kN)	drop height(m)	velocity before contact(m/s)
1	12	15.2	2.298	1.75	5.86
2	16	17.2	2.298	2.50	7.00
3	12	14.8	2.298	2.00	6.26
4	12	14.5	2.298	2.50	7.00
5	16	16.3	2.298	2.00	6.26
6	12	13.9	2.298	2.25	6.64
7	16	16.6	2.298	3.00	7.67
8	16	17.0	2.298	1.50	5.42



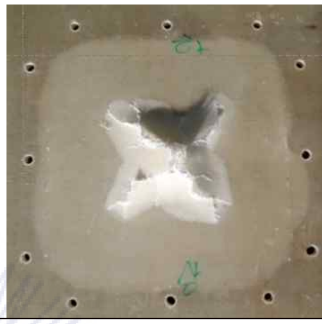
after drop test



close view of impact region

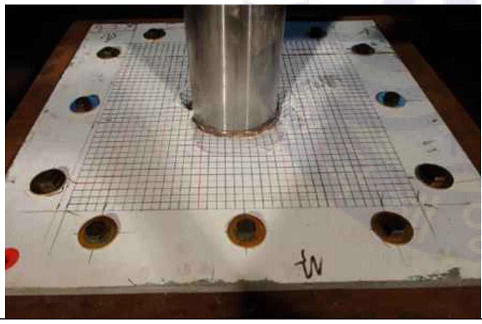


top view of specimen

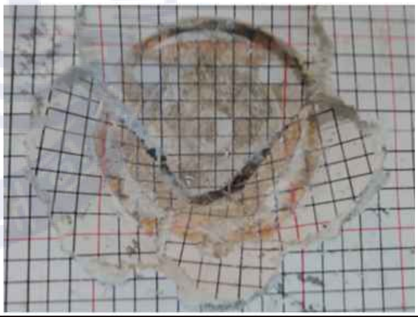


back view of specimen

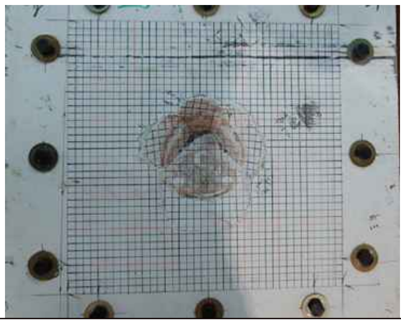
(a) No. 1 specimen



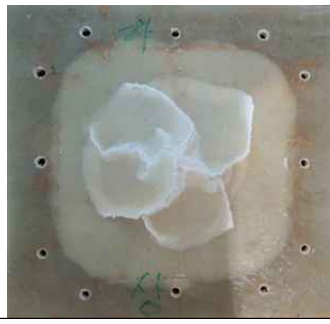
after drop test



close view of impact region

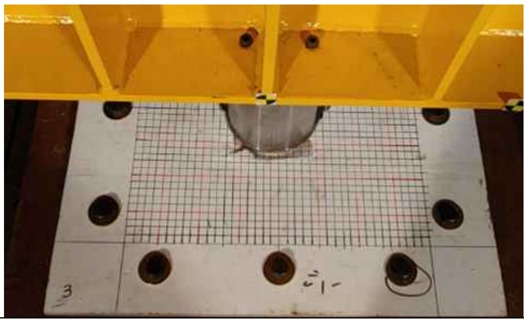
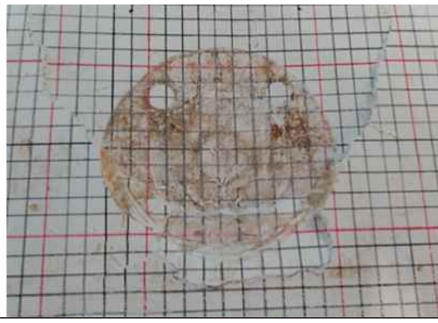
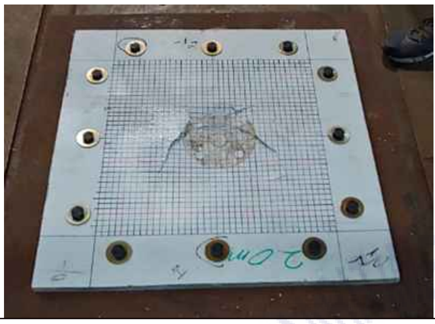
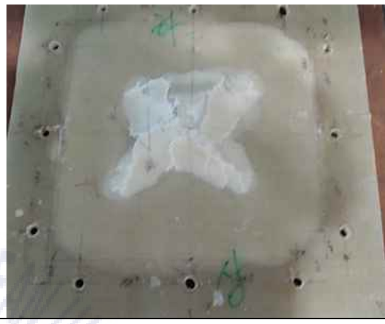


top view of specimen

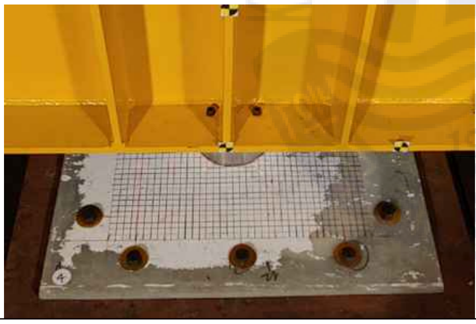
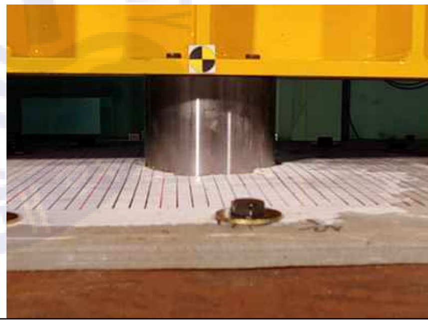
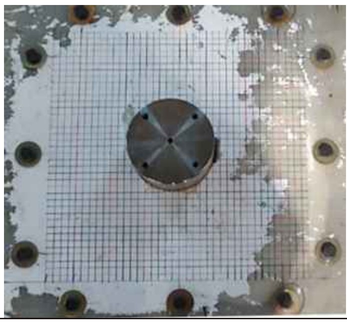
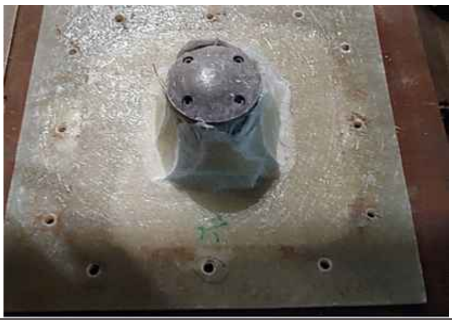


back view of specimen

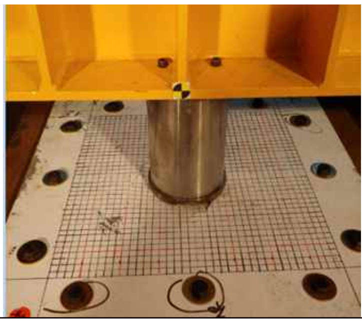
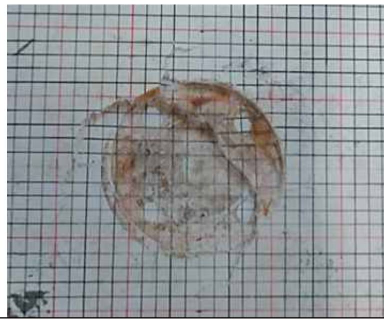
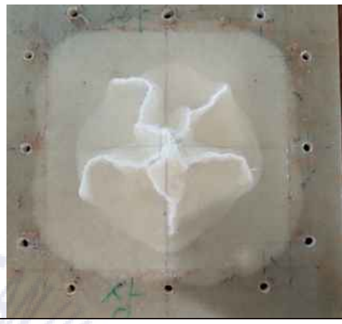
(b) No. 2 specimen

	
after drop test	close view of impact region
	
top view of specimen	back view of specimen

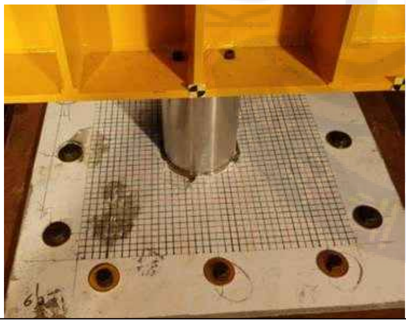
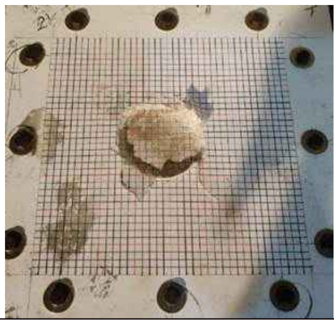
(c) No. 3 specimen

	
after drop test	close view of impact region
	
top view of specimen	back view of specimen

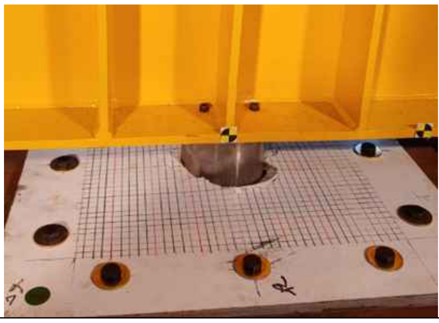
(d) No. 4 specimen

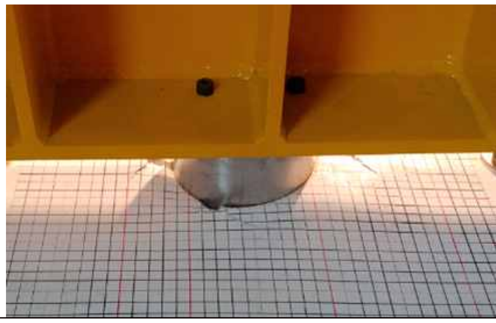
	
after drop test	close view of impact region
	
top view of specimen	back view of specimen

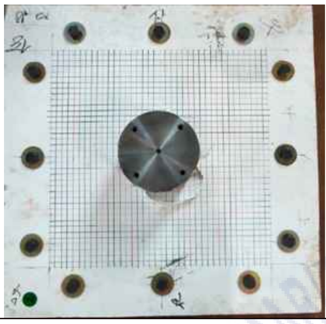
(e) No. 5 specimen

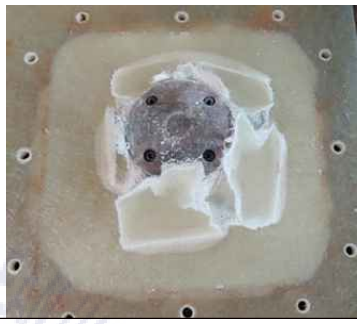
	
after drop test	close view of impact region
	
top view of specimen	back view of specimen

(f) No. 6 specimen

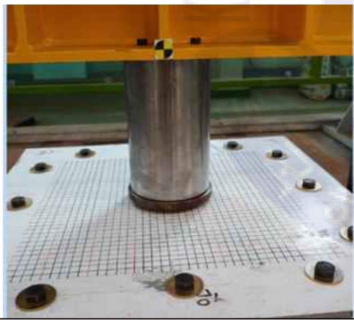

after drop test

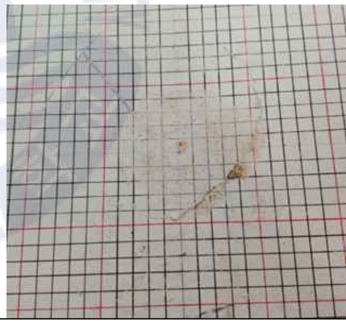

close view of impact region

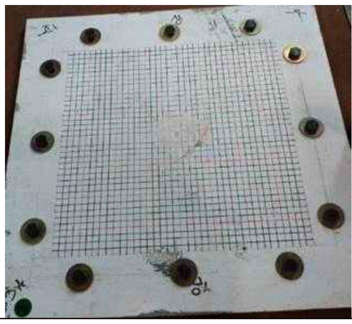

top view of specimen


back view of specimen

(g) No. 7 specimen


after drop test


close view of impact region


top view of specimen


back view of specimen

(h) No. 8 specimen

Fig. 7 Damage response behaviors of weight drop impact tests

3. Fracture Failure Response Analysis of FRP Plate

Fracture failure response analysis was carried out for verification of its technique and criterion by comparing the fracture failure simulation results using laminated shell theory and MAT_ENHANCED_COMPOSITE_DAMAGE composite material in LS-DYNA code in highly advanced M&S system with weight drop impact test ones, such as No. 7 specimen with penetration fracture damage and No. 8 one without penetration fracture one. Fracture criteria of FRP plate was predicted by the examination of diverse parameters of MAT_ENHANCED_COMPOSITE_DAMAGE composite material.

Fracture criteria of MAT_ENHANCED_COMPOSITE_DAMAGE (MAT_054) of LS-DYNA code is as follows:

- tensile fiber mode

$$\sigma_{aa} > 0 \; then \; e_f^2 = \left(\frac{\sigma_{aa}}{X_t}\right)^2 + \beta\left(\frac{\sigma_{ab}}{S_c}\right) - 1 \begin{cases} \geq 0 \; failed \\ < 0 \; elastic \end{cases} \tag{1}$$

$$E_a = E_b = G_{ab} = v_{ba} = v_{ab} = 0$$

- compressive fiber mode

$$\sigma_{aa} < 0 \; then \; e_c^2 = \left(\frac{\sigma_{aa}}{X_t}\right)^2 - 1 \begin{cases} \geq 0 \; failed \\ < 0 \; elastic \end{cases} \tag{2}$$

$$E_a = v_{ba} = v_{ab} = 0$$

- tensile matrix mode

$$\sigma_{bb} > 0 \; then \; e_m^2 = \left(\frac{\sigma_{bb}}{Y_t}\right)^2 + \left(\frac{\sigma_{ab}}{S_c}\right)^2 - 1 \begin{cases} \geq 0 \; failed \\ < 0 \; elastic \end{cases} \tag{3}$$

$$E_a = v_{ba} = 0, \; \rightarrow G_{ab} = 0$$

- compressive matrix mode

$$\sigma_{bb} > 0 \; then \; e_d^2 = \left(\frac{\sigma_{bb}}{2S_c}\right)^2 + \left[\left(\frac{Y_c}{2S_c}\right) - 1\right]\frac{\sigma_{bb}}{Y_b} + \left(\frac{\sigma_{ab}}{S_c}\right)^2 - 1 \begin{cases} \geq 0 \; failed \\ < 0 \; elastic \end{cases} \tag{4}$$

$$E_b = v_{ba} = 0, \; \rightarrow G_{ab} = 0$$

$$X_c = 2X_e \, for \; 50\% \; fiber \; vloume$$

Fracture criteria of MAT_ENHANCED_COMPOSITE_DAMAGE (MAT_055) is as follows:

- tensile and compressive matrix mode

$$e_{md}^2 = \frac{\sigma_{bb}^2}{Y_c Y_t} + \left(\frac{\sigma_{ab}}{S_c}\right)^2 + \frac{(Y_c - Y_t)\,\sigma_{bb}}{Y_c Y_t} - 1 \begin{cases} \geq 0 \; failed \\ < 0 \; elastic \end{cases} \tag{5}$$

As mentioned before, FRP plate should be treated as composite single plate in the full-scale ship simulation due to the computational time, using PART_ COMPOSITE option. This option is a simplified method of defining a composite material model for shell elements and thick shell ones that eliminates the need for the user defined integration rules and part ID's for each composite layer with its own laminate thickness and direction, as shown in Fig. 8.

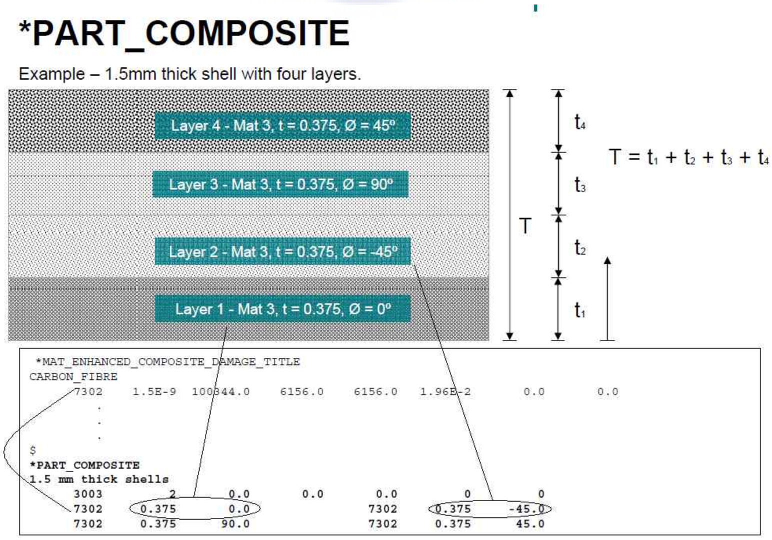
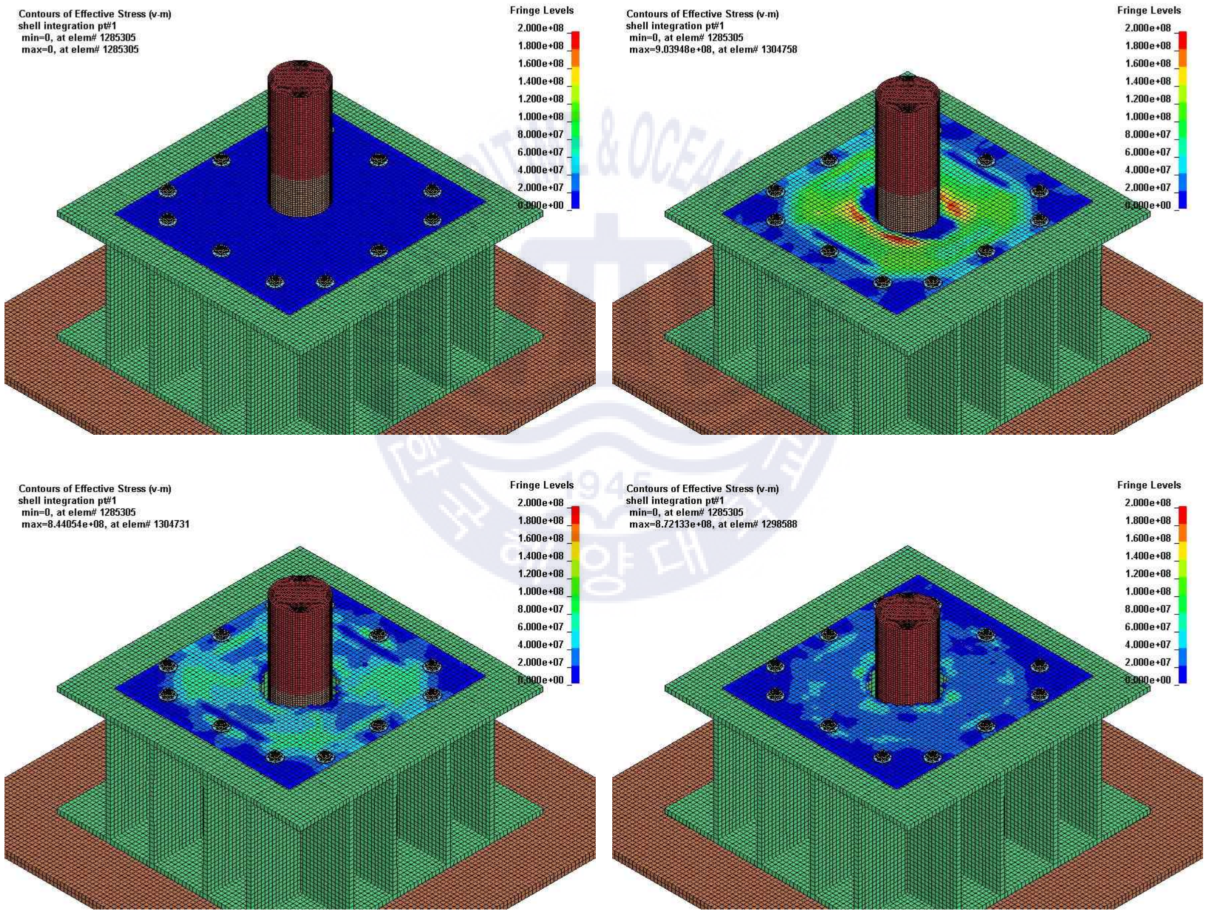
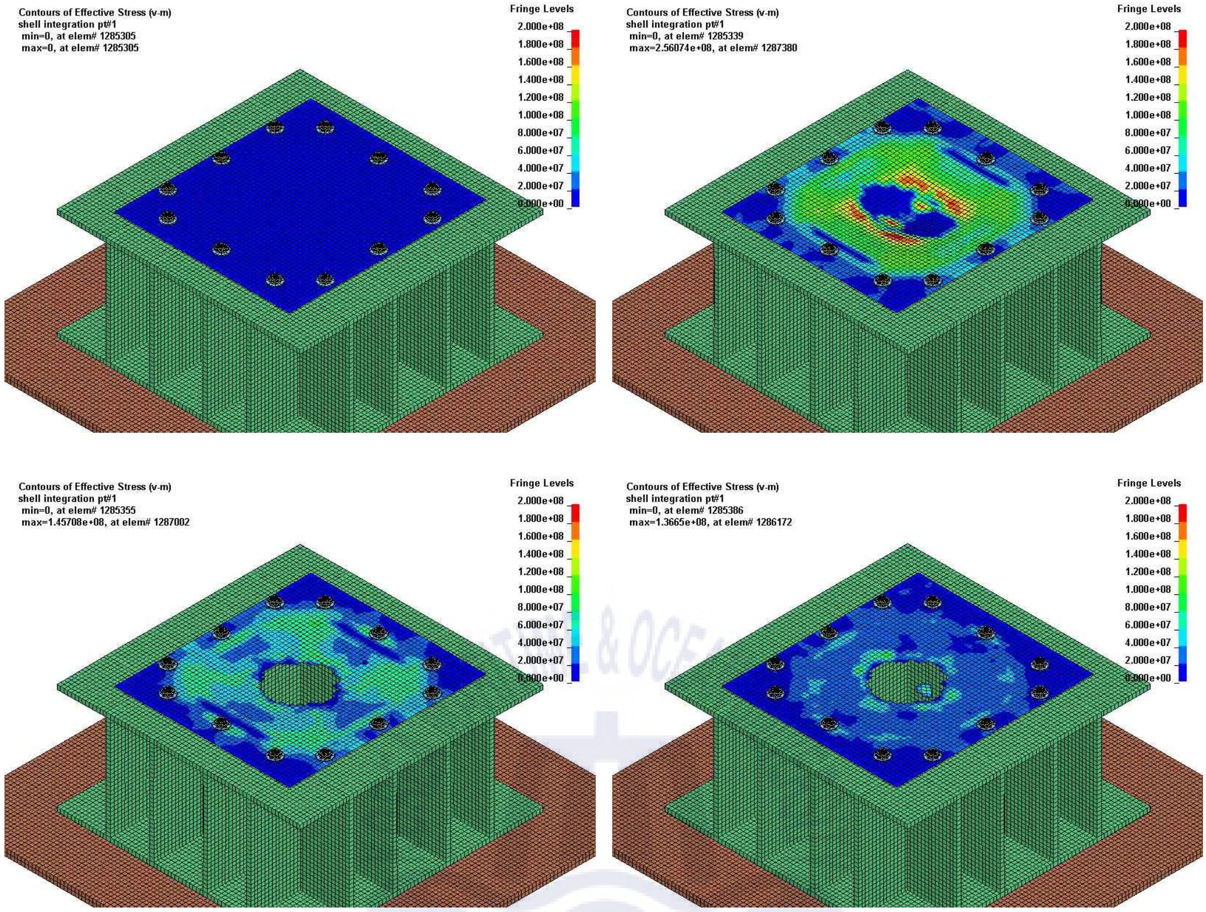


Fig. 8 Example of 1.5mm thick shell with 4 layers using PART_COMPOSITE option

Figures 9～10 shows the facture failure response behaviors of typical No. 8 and 7 FRP plate specimens, respectively. Comparing the fracture failure response behaviors in Figs. 9～10 with those of weight drop impact tests in Fig. 7(h)～(g) by adjusting a lot of parameters of Eqs. 1～5, fracture criteria of MAT_ ENHANCED_COMPOSITE_DAMAGE composite material using highly advanced M&S system of LS-DYNA code, it could be confirmed that fracture failure response behaviors were relatively very well matched.

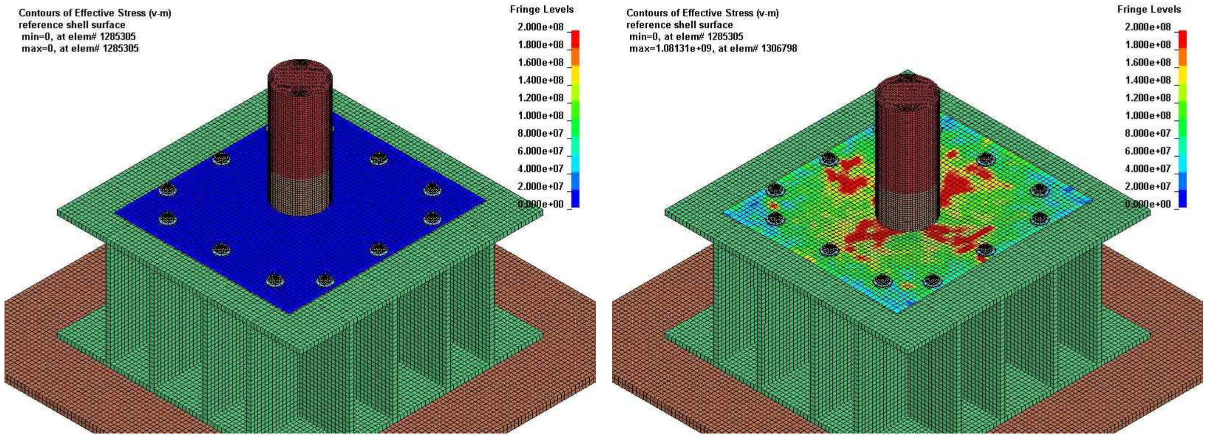


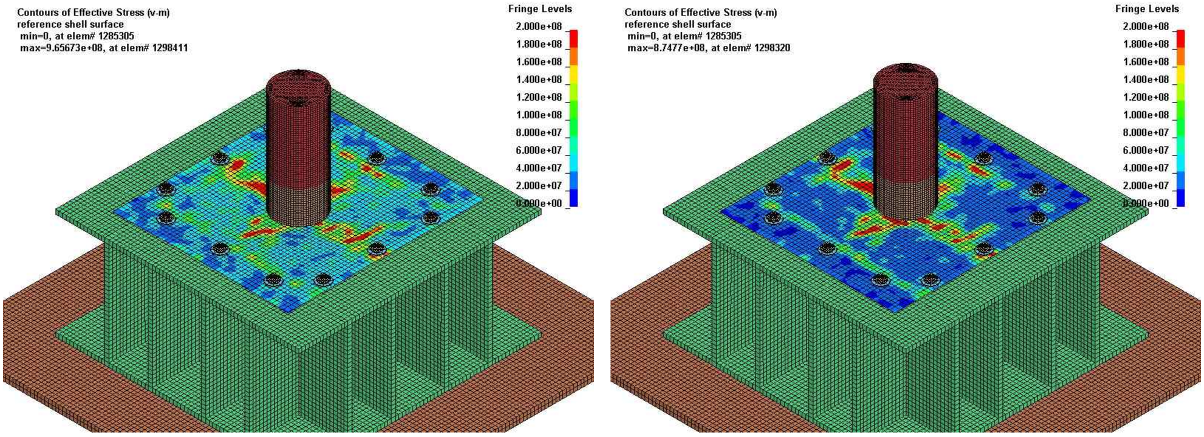
(a) Fracture response behavior with indentor



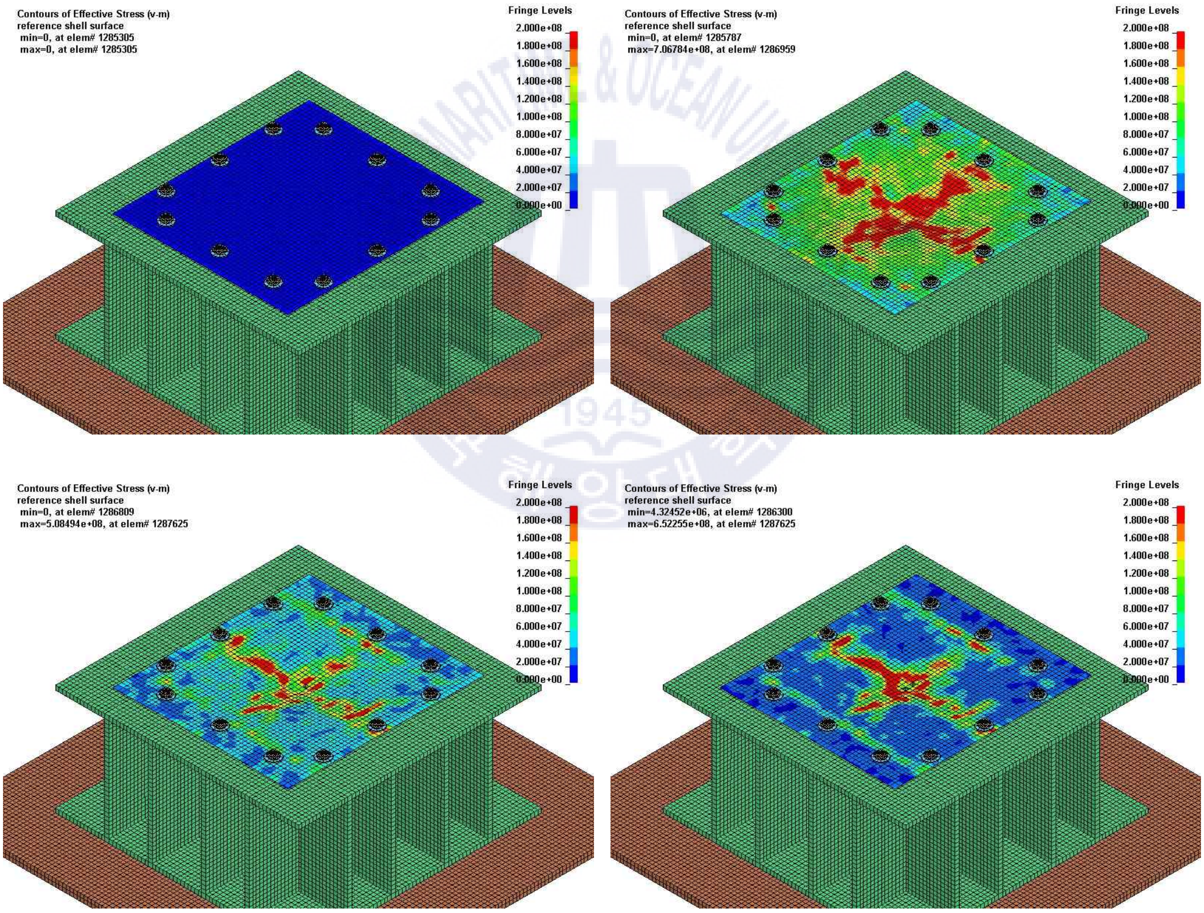
(b) Fracture response behavior without indentor

Fig. 9 Fracture response behavior of No. 8 FRP plate specimen under weight drop impact test simulation





(a) Fracture response behavior with indentor

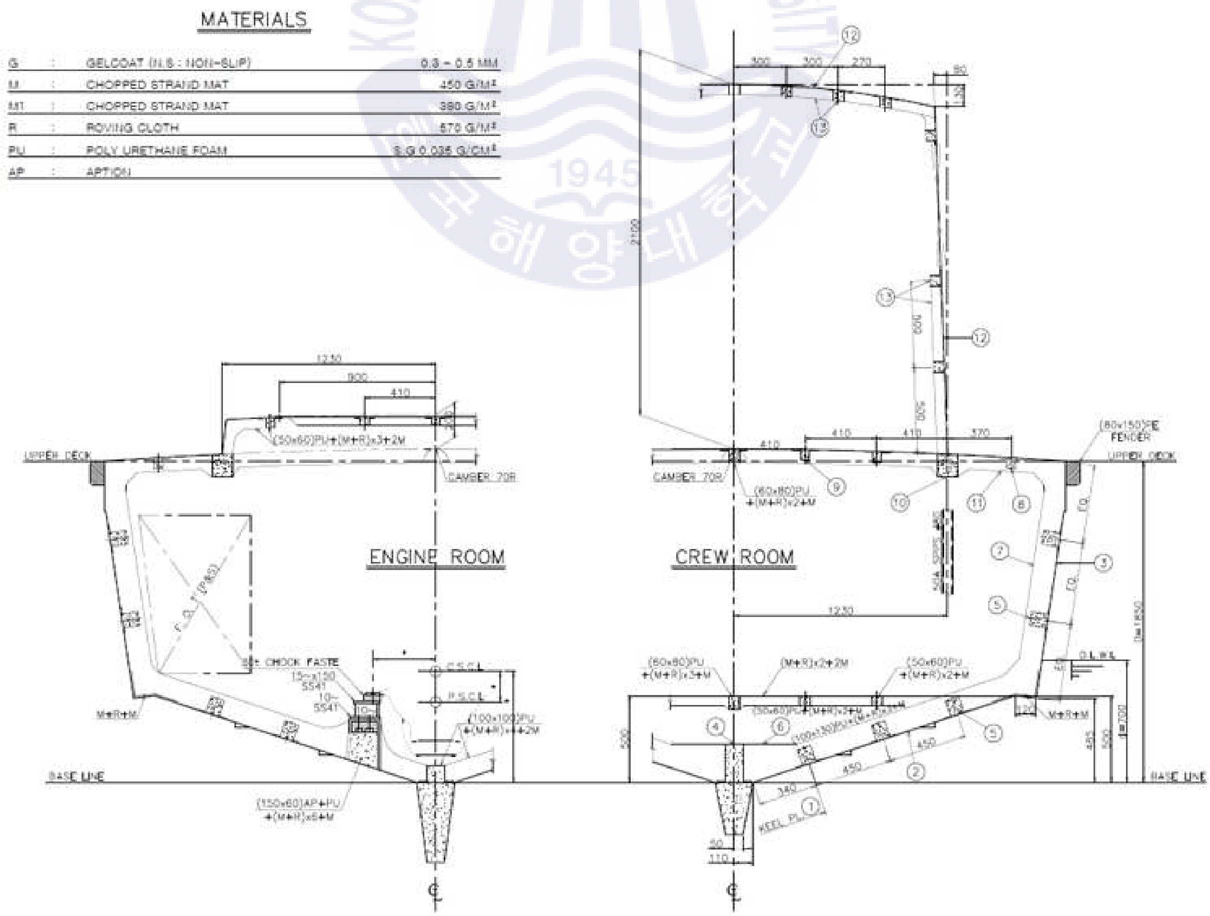


(b) Fracture response behavior without indentor

Fig. 10 Fracture response behavior of No. 7 FRP plate specimen under weight drop impact test simulation

4. 3D Full-Scale Ship Modeling

Full-scale small FRP LNG fueled ship was modeled by investigating its hull form and general arrangement, as shown in Fig. 11, and stability calculation, by calculating its structural members according to FRP structural criterion (KR, 2019b), as shown in Fig. 12, and by comparing its hydrostatic characteristics using floating simulation and hydrostatic characteristic program calculation with stability calculation. Small FRP LNG fueled ship is operating off the coast and its main dimension is as follows: L.O.A. 17.20m, L.B.P. 15.10m, Breadth 3.82m, Depth 1.85m and Gross Tonnage 19.00ton.



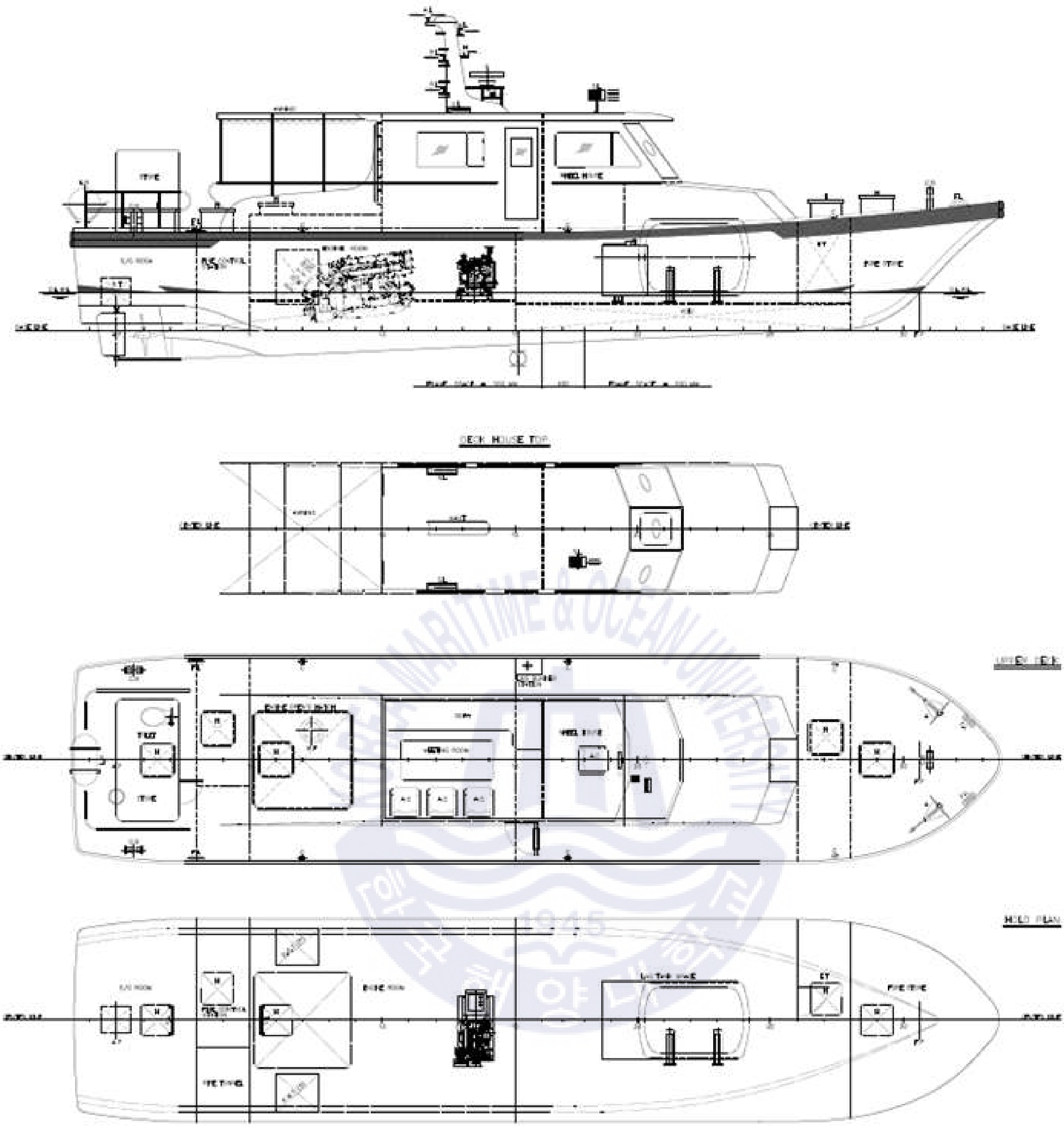


Fig. 11 Design drawing of small FRP LNG fueled ship

A. 일반사항

		선명(공사번호) :		19TON
Length	(O. A)	17.20	m	
Length	(B. P)	15.10	m	
Length	(W. L)	15.82	m	
Length	(Scantling)	15.34	m	
Length	(Freeboard)	16.08	m	
Breadth		3.82	m	
Depth		1.85	m	
Draft	(D.L.W.L)	0.70	m	
Draft	(Scantling)	0.80	m	

항행구역	연해	총톤수(톤)	19	C_b	0.68

B. 수정계수

1) 판 두께	σ_B =	15	수정계수	αt =	1
2) 단면계수	σ_T =	12	수정계수	α_z =	0.833

항 목	규 정 치		실 선	
1. 선체횡단면계수(㎤)	$Z = C \cdot L^2 \cdot B_w \cdot (C_b+0.7) \cdot \alpha z$ =	41658		
	(단, B_w = 3.50 m)			
2. 선체횡단면의 단면2차모멘트(cm^4)	I = 4.2 Z · L =	2683941.6		
3. 용골				
1) 너비(㎜)	b = 530 + 14.6 L =	754	900	O.K
2) 두께(㎜)	t = (9.0 + 0.4 L) · αt =	15.14	18.28	O.K
4. 중심선거더(중앙부)				
1) Web 두께(㎜)	t = (0.4 L + 4.7) · αt 또는 최소값	7.59	10.9	O.K
	※ HAT형 한쪽 두께(기관실)	9	10.9	O.K
	※ HAT형 한쪽 두께(선수미)	6.45	10.9	O.K
2) 면재				
①너비(㎜)	b = 4 L + 30 =	91	100	O.K
②두께(㎜)	t = (0.4 L + 4.7) · αt =	7.59	10.9	O.K
	※ HAT형 한쪽 두께(기관실)	9.49	10.9	O.K
	※ HAT형 한쪽 두께(선수미)	5.53	10.9	O.K
3) 깊이(㎜)	※ 늑판 상단까지의 깊이	213	220	O.K

적층판 및 HAT-TYPE 부재

KEEL PLATE & CENTER KEELSON

재료선택								
MAT	450	600	300		ROVING	570	860	580
THICK	1.055	1.407	0.703		THICK	0.703	1.061	0.715
NO.	①	②	③		NO.	④	⑤	⑥

LAMINATE	①	②	③	④	⑤	⑥	THICKNESS	
DECK	12			8			18.284	(mm)
LAMINATE	①	②	③	④	⑤	⑥	THICKNESS	
W.F.A	7			6			11.603	(mm)

	BREADTH	HEIGHT	
P.U	10	22	(cm)

	BREADTH	HEIGHT	
O.P			(cm)

명칭	b	h	A	L	AL	K	K^2A	I
SHELL	42.32	1.83	77.38	0.91	70.74	6.23	3003.19	21.56
WEB	2.32	22.00	51.05	12.83	654.93	5.68	1649.58	2059.15
FACE	12.32	1.16	14.30	24.41	348.93	17.26	4260.95	1.60
ATTACH	10.00	1.16	11.60	2.41	27.95	4.74	260.21	1.30
O.P								
SUM			154.33		1102.55		9173.92	2083.61
							I_T =	11257.53

L_G	7.14	
Y_T	24.99	
Z	630.87	(cm^3)

100x220PU + (M+R)x6+M

<DIMENSION>

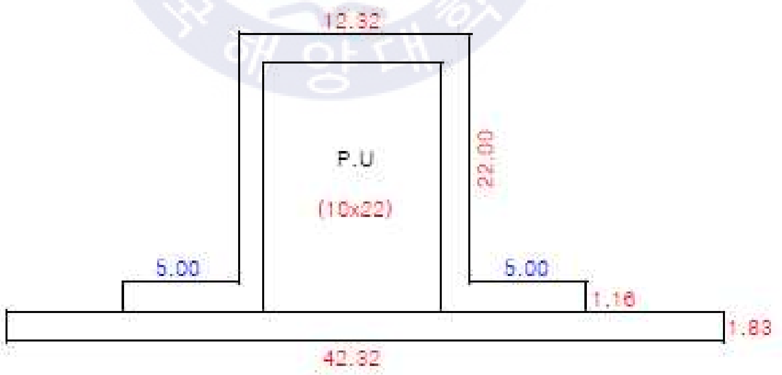


Fig. 12 Scantling review of small FRP LNG fueled ship drawing

Internal and external of full-scale small FRP LNG fueled ship was exactly modeled using lines, as shown in Figs. 13~14, for the accurate behavior in the sea and precise realization of damage state by the collision and grounding. Precise full-scale ship modeling can be carried out through the validation of hydrostatic characteristics (centers of gravity, buoyance & floatation), and fore & aft drafts with stability calculation using floating simulation and hydrostatic characteristics program calculation, as shown in Fig. 15 and Table 7.

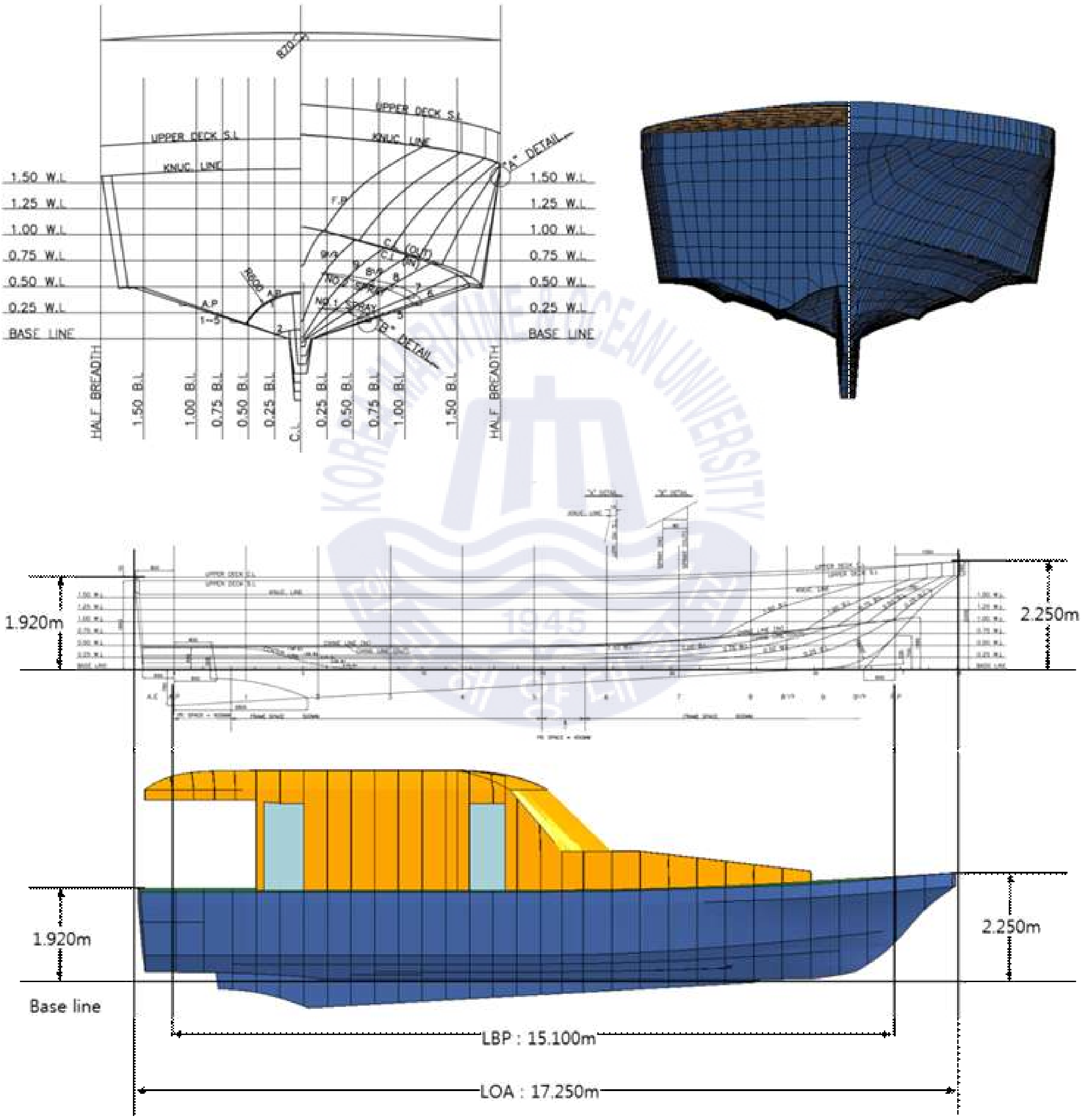


Fig. 13 Full-scale small LNG fueled ship modeling using lines

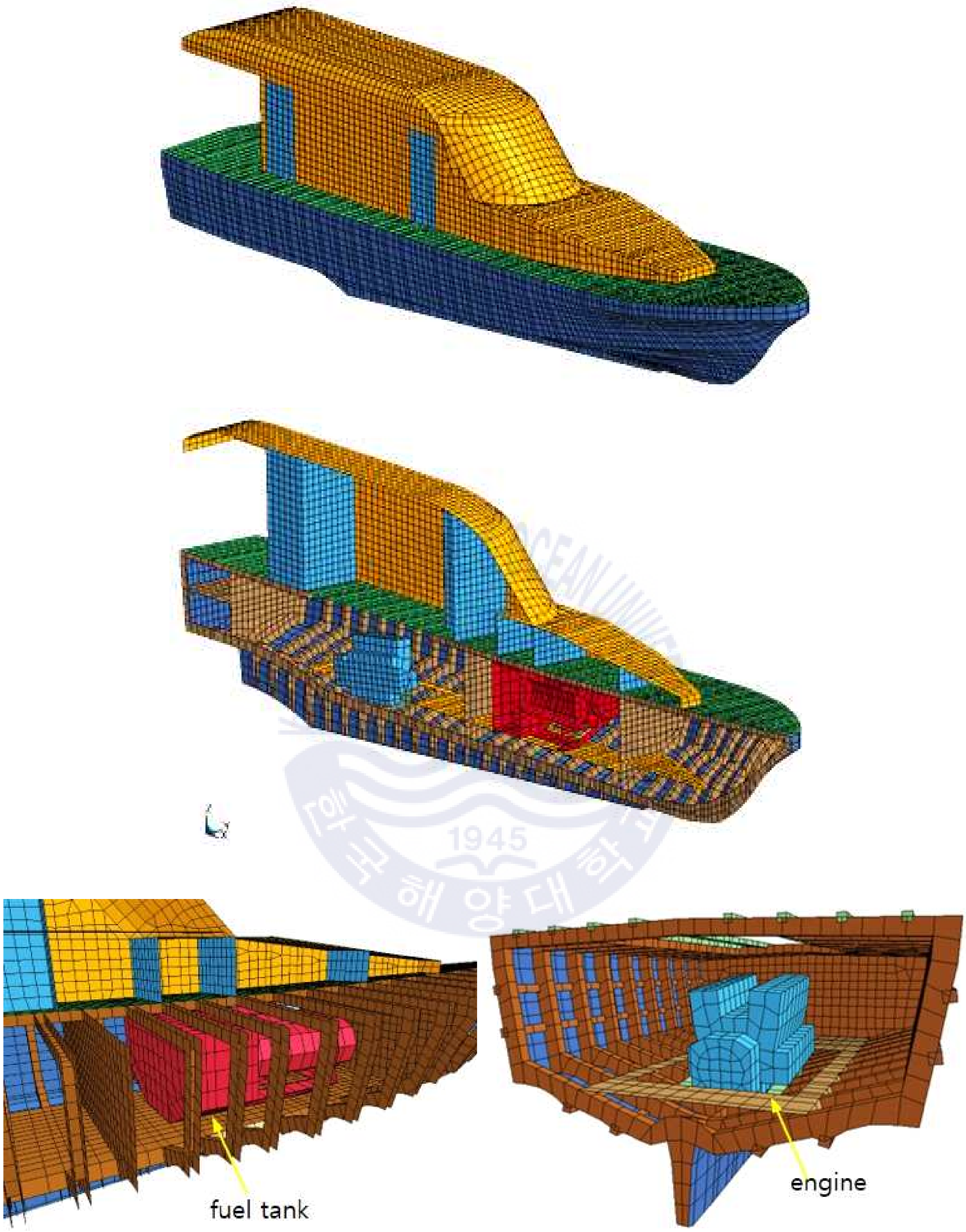
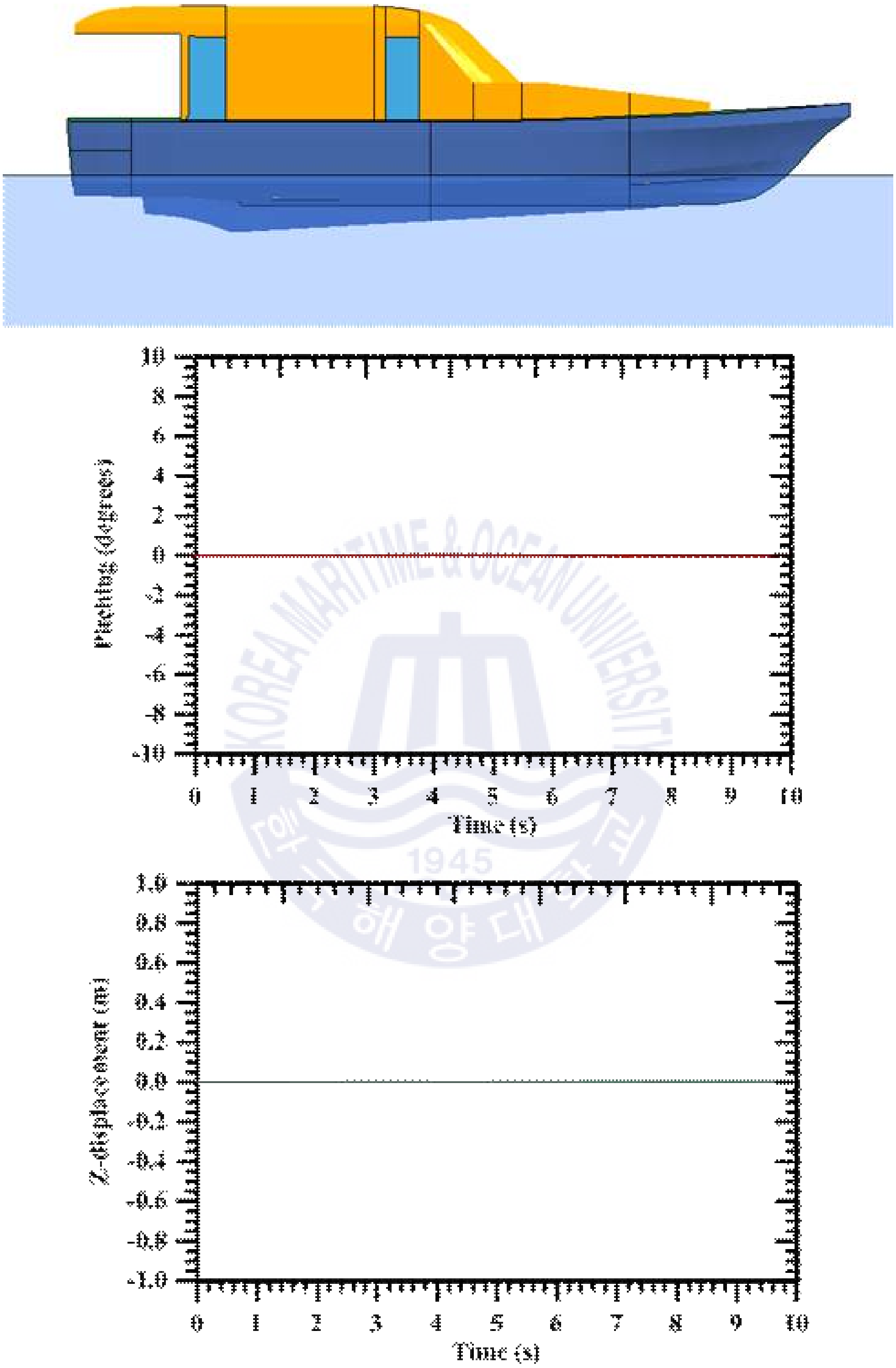
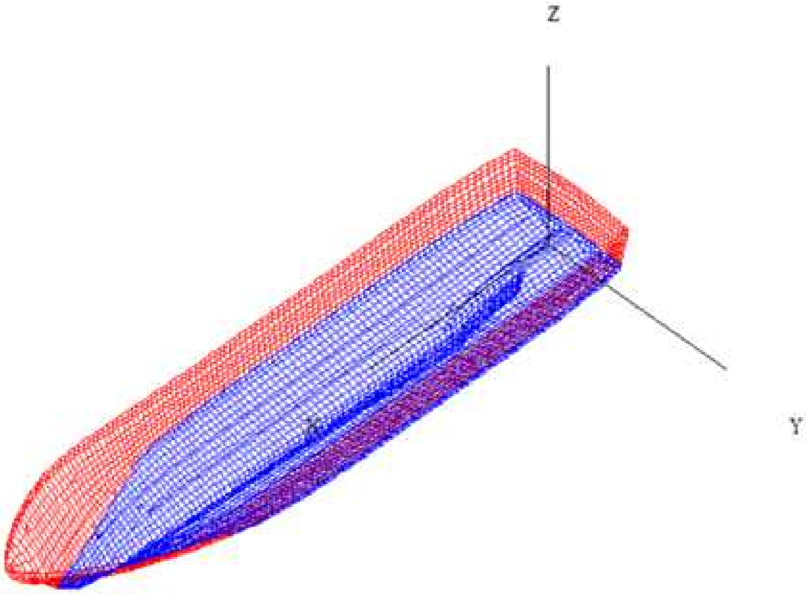


Fig. 14 Internal and external modeling of full-scale small LNG fueled ship



(a) floating simulation, vertical displacement and pitching responses




```
!                                                                              !
! WATER-LINE AREA                        :          46.7                       !
! UNDERWATER VOLUME                      :         17.096                      !
! CENTER OF HULL                         :     6.165      0.000       0.457   !
!  IN THE FRAME                          :                                     !
! CENTER OF HULL                         :     0.000      0.000       0.000   !
! CENTER OF GRAVITY                      :     0.000      0.000       0.000   !
!  IN THE FRAME                          :                                     !
! CENTER OF GRAVITY                      :     0.000      0.000       0.000   !
! MAXIMUM DRAUGHT OF THE STRUCTURE       :       1.264                         !
! UNDERWATER LENGTH                      :       15.77                         !
! UNDERWATER BREADTH                     :        3.53                         !
! TRANSVERSAL METACENTRIC RADIUS         :     2.632                           !
! GMt                                    :       2.175                         !
! TRANSVERSAL TANKS STABILITY LOST       :       0.000                         !
! GMt (WITH TANKS)                       :       2.175                         !
! LONGITUDINAL METACENTRIC RADIUS        :    40.278                           !
! GML                                    :       40.03                         !
! LONGITUDINAL TANKS STABILITY LOST      :        0.00                         !
! GML (WITH TANKS)                       :       40.03                         !
! CENTER OF GRAVITY OF THE WATER-LINE    :     6.093      0.000                !
! CENTER OF LATERAL RESISTANCE           :     6.170      0.000       0.198   !
! LATERAL WETTED AREA                    :        14.9                         !
! INERTIES AND GYRATION RADIUS           :                                     !
! IXX                                    :  1.176E+04   7.958E-01             !
! IXY                                    : -1.546E-03  -2.884E-04             !
! IXZ                                    :  4.520E+02  -1.560E-01             !
! IYY                                    :  2.577E+05   3.724E+00             !
! IYZ                                    : -9.406E-04  -2.250E-04             !
! IZZ                                    :  2.681E+05   3.799E+00             !
!                                                                              !
```

```
WATER-LINE AREA                      :        49.6
UNDERWATER VOLUME                    :        27.224
CENTER OF HULL                       :    6.198      0.000      0.581
IN THE FRAME
CENTER OF HULL                       :    0.000      0.000      0.000
CENTER OF GRAVITY                    :    0.000      0.000      0.000
IN THE FRAME                         :
CENTER OF GRAVITY                    :    0.000      0.000      0.000
MAXIMUM DRAUGHT OF THE STRUCTURE     :     1.471
UNDERWATER LENGTH                    :     15.99
UNDERWATER BREADTH                   :      3.59
TRANSVERSAL METACENTRIC RADIUS       :    1.798
GMt                                  :     1.469
TRANSVERSAL TANKS STABILITY LOST     :     0.000
GMt (WITH TANKS)                     :     1.469
LONGITUDINAL METACENTRIC RADIUS      :   29.896
GML                                  :     29.57
LONGITUDINAL TANKS STABILITY LOST    :      0.00
GML (WITH TANKS)                     :     29.57
CENTER OF GRAVITY OF THE WATER-LINE  :    6.366      0.000
CENTER OF LATERAL RESISTANCE         :    6.360      0.000      0.300
LATERAL WETTED AREA                  :     18.2
INERTIES AND GYRATION RADIUS         :
IXX                                  : 2.229E+04  8.795E-01
IXY                                  :-1.880E-01 -2.555E-03
IXZ                                  :-6.390E+00 -1.489E-02
IYY                                  : 4.259E+05  3.845E+00
IYZ                                  :-6.467E-04 -1.498E-04
IZZ                                  : 4.451E+05  3.931E+00
```

```
WATER-LINE AREA                      :        48.0
UNDERWATER VOLUME                    :        21.071
CENTER OF HULL                       :    6.163      0.000      0.519
IN THE FRAME
CENTER OF HULL                       :    0.000      0.000      0.000
CENTER OF GRAVITY                    :    0.000      0.000      0.000
IN THE FRAME                         :
CENTER OF GRAVITY                    :    0.000      0.000      0.000
MAXIMUM DRAUGHT OF THE STRUCTURE     :     1.350
UNDERWATER LENGTH                    :     15.87
UNDERWATER BREADTH                   :      3.56
TRANSVERSAL METACENTRIC RADIUS       :    2.190
GMt                                  :     1.670
TRANSVERSAL TANKS STABILITY LOST     :     0.000
GMt (WITH TANKS)                     :     1.670
LONGITUDINAL METACENTRIC RADIUS      :   35.096
GML                                  :     34.82
LONGITUDINAL TANKS STABILITY LOST    :      0.00
GML (WITH TANKS)                     :     34.82
CENTER OF GRAVITY OF THE WATER-LINE  :    6.223      0.000
CENTER OF LATERAL RESISTANCE         :    6.255      0.000      0.240
LATERAL WETTED AREA                  :     16.3
INERTIES AND GYRATION RADIUS         :
IXX                                  : 1.595E+04  8.374E-01
IXY                                  : 4.679E-01 -4.535E-03
IXZ                                  : 3.545E+02 -1.248E-01
IYY                                  : 3.246E+05  3.777E+00
IYZ                                  :-3.873E-03 -4.126E-04
IZZ                                  : 3.386E+05  3.857E+00
```

(b) hydrostatic characteristics program calculation (light ship, full load and ballast departure conditions)

ITEM	CONDITION	Light Ship Cond.	Full Load Dep. Cond.	Full Load Arr. Cond.	Ballast Dep. Cond.	Ballast Arr. Cond.
DISPLACEMENT	(TON)	17.428	27.830	24.783	21.670	18.623
DRAFT(deq.)	(M)	0.993	1.200	1.141	1.079	1.018
(B.L상 흘수)		0.663	0.870	0.811	0.749	0.688
DRAFT	(dF) (M)	1.007	1.231	1.235	1.033	1.032
	(#) (M)	0.577	0.801	0.805	0.603	0.602
	(dA) (M)	0.984	1.177	1.073	1.112	1.008
	(#) (M)	1.414	1.607	1.503	1.542	1.438
	(dM) (M)	0.995	1.204	1.154	1.072	1.020
	(#) (M)					
TRIM (- : 선미트림)	(M)	0.023	0.053	0.161	-0.079	0.024
K.M.T	(M)	3.080	2.381	2.522	2.712	2.961
K.G	(M)	1.551	1.675	1.744	1.474	1.534
G.M	(M)	1.529	0.707	0.778	1.238	1.427
GG'	(M)	0.000	0.005	0.006	0.007	0.008
Go.M	**(M)**	**1.529**	**0.701**	**0.772**	**1.231**	**1.419**

DRAFT B.O.K	DISPT	MOLDED VOLUME	T.P.C	M.T.C	L.C.B	L.C.F	K.B	K.M.T
M	TON	M**3	TON/CM	M*TON	M	M	M	M
0.99	17.26	17.30	0.488	0.51	-1.378	-1.453	0.461	3.098

ITEM	CONDITION	Light Ship Cond.	Full Load Dep. Cond.	Full Load Arr. Cond.	Ballast Dep. Cond.	Ballast Arr. Cond.
DISPLACEMENT	(TON)	17.428	27.830	24.783	21.670	18.623
DRAFT(deq.)	(M)	0.993	1.200	1.141	1.079	1.018
(B.L상 흘수)		0.663	0.870	0.811	0.749	0.688
DRAFT	(dF) (M)	1.007	1.231	1.235	1.033	1.032
	(#) (M)	0.577	0.801	0.805	0.603	0.602
	(dA) (M)	0.984	1.177	1.073	1.112	1.008
	(#) (M)	1.414	1.607	1.503	1.542	1.438
	(dM) (M)	0.995	1.204	1.154	1.072	1.020
	(#) (M)					
TRIM (- : 선미트림)	(M)	0.023	0.053	0.161	-0.079	0.024
K.M.T	(M)	3.080	2.381	2.522	2.712	2.961
K.G	(M)	1.551	1.675	1.744	1.474	1.534
G.M	(M)	1.529	0.707	0.778	1.238	1.427
GG'	(M)	0.000	0.005	0.006	0.007	0.008
Go.M	**(M)**	**1.529**	**0.701**	**0.772**	**1.231**	**1.419**

DRAFT B.O.K	DISPT	MOLDED VOLUME	T.P.C	M.T.C	L.C.B	L.C.F	K.B	K.M.T
M	TON	M**3	TON/CM	M*TON	M	M	M	M
1.20	27.83	27.50	0.517	0.58	-1.349	-1.174	0.577	2.381

ITEM	CONDITION	Light Ship Cond.	Full Load Dep. Cond.	Full Load Arr. Cond.	Ballast Dep. Cond.	Ballast Arr. Cond.
DISPLACEMENT	(TON)	17.428	27.830	24.783	21.670	18.623
DRAFT(deq.) (B.L상 흘수)	(M)	0.993 0.663	1.200 0.870	1.141 0.811	1.079 0.749	1.018 0.688
DRAFT	(dF) (M)	1.007	1.231	1.235	1.033	1.032
	(#) (M)	0.577	0.801	0.805	0.603	0.602
	(dA) (M)	0.984	1.177	1.073	1.112	1.008
	(#) (M)	1.414	1.607	1.503	1.542	1.438
	(dM) (M)	0.995	1.204	1.154	1.072	1.020
	(#) (M)					
TRIM (- : 선미트림)	(M)	0.023	0.053	0.161	-0.079	0.024
K.M.T	(M)	3.080	2.381	2.522	2.712	2.961
K.G	(M)	1.551	1.675	1.744	1.474	1.534
G.M	(M)	1.529	0.707	0.778	1.238	1.427
GG'	(M)	0.000	0.005	0.006	0.007	0.008
Go.M	**(M)**	**1.529**	**0.701**	**0.772**	**1.231**	**1.419**

DRAFT B.O.K	DISPT	MOLDED VOLUME	T.P.C	M.T.C	L.C.B	L.C.F	K.B	K.M.T
M	TON	M**3	TON/CM	M*TON	M	M	M	M
1.08	21.72	21.60	0.502	0.54	-1.379	-1.316	0.511	2.709

(c) stability calculation (light ship, full load and ballast departure conditions)

Fig. 15 Floating simulation and hydrostatic characteristics program calculations of small LNG fueled ship according to loading condition

Table 7 Comparison between stability and hydrostatic characteristics program calculation of small LNG fueled ship according to loading condition

light ship condition	displacement (ton)	KB (m)	LCB (m)	LCF (m)	KMT (m)
stability calculation	17.428	0.461	-1.378	-1.453	3.080
modeling	17.525	0.457	-1.385	-1.457	3.089
error(%)	0.56%	0.87%	0.51%	0.28%	0.29%
full load departure condition	displacement (ton)	KB (m)	LCB (m)	LCF (m)	KMT (m)
stability calculation	27.830	0.577	-1.349	-1.174	2.381
modeling	27.905	0.581	-1.352	-1.184	2.379
error(%)	0.27%	0.69%	0.22%	0.85%	0.08%
ballast departure condition	displacement (ton)	KB (m)	LCB (m)	LCF (m)	KMT (m)
stability calculation	21.670	0.511	-13.87	-1.316	2.712
modeling	21.598	0.519	-13.52	-1.327	2.709
error(%)	0.33%	1.57%	2.52%	0.84%	0.11%

Water surface cleaner of gross tonnage 24.0ton, operating off the coast, similar size with small LNG fueled ship was selected as the colliding ship, as shown in Fig. 16, with main dimension as follows: L.O.A. 20.41m, L.B.P. 19.00m, Breadth 4.60m, Depth 2.30m and Displacement abt. 89.13ton. Internal and external of full scale water surface cleaner was also exactly modeled using lines, as shown in Figs. 17～18, for the accurate behavior in the sea and precise realization of damage state by the collision. Precise full-scale ship modeling can be modified through the validation of hydrostatic characteristics, and fore & aft drafts with stability calculation using floating simulation and hydrostatic characteristics program calculation, as shown in Fig. 19 and Table 8.

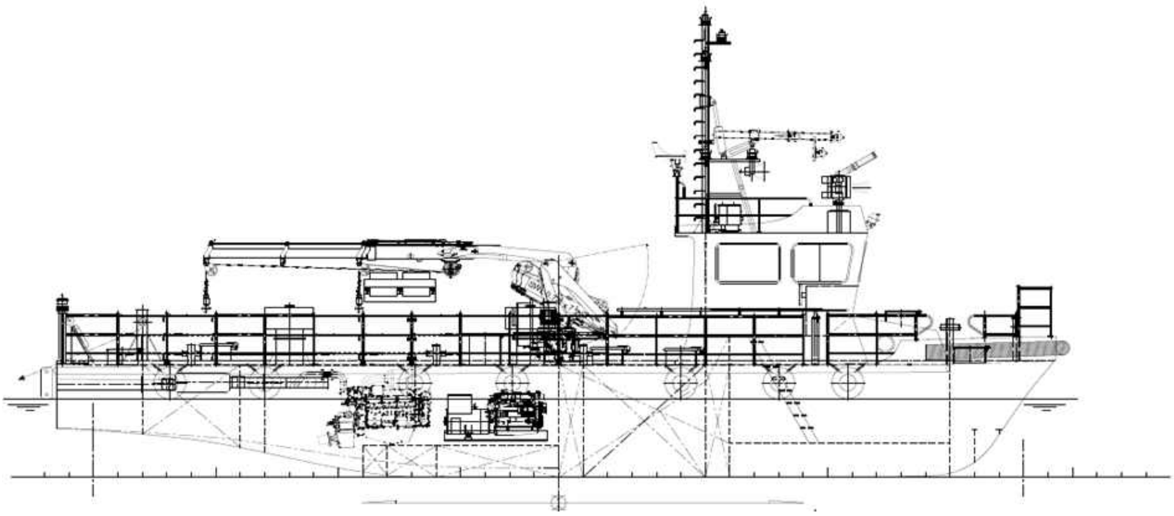


Fig. 16 General arrangement of water surface cleaner

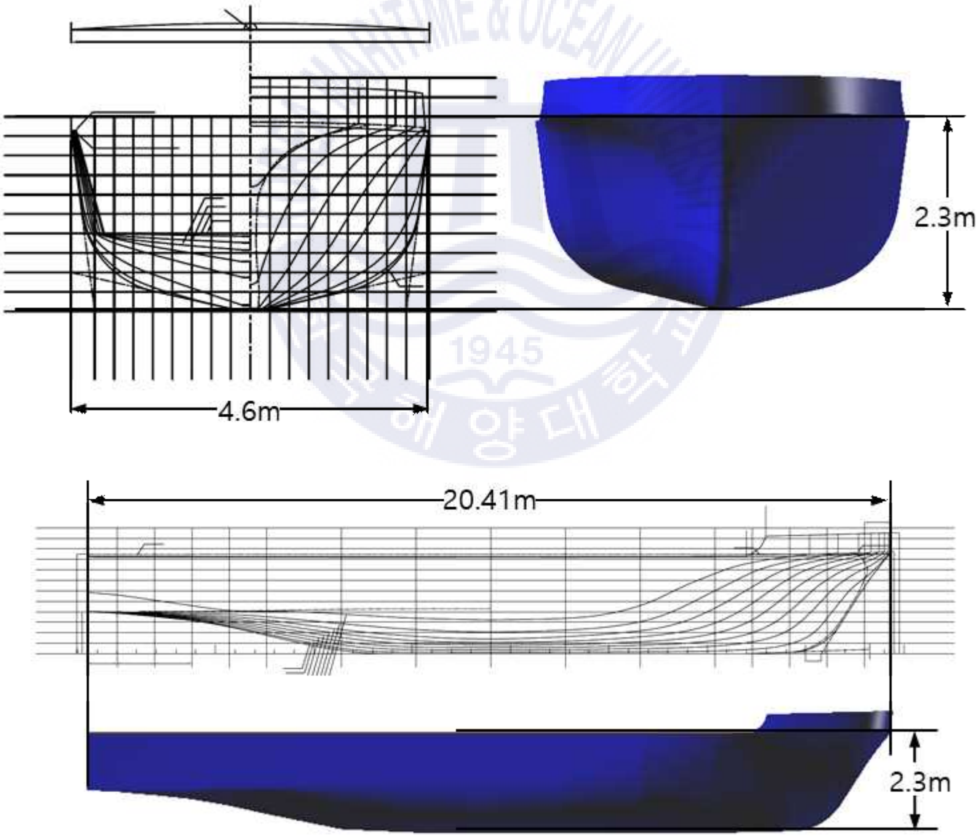


Fig. 17 Full-scale water surface cleaner modeling using lines

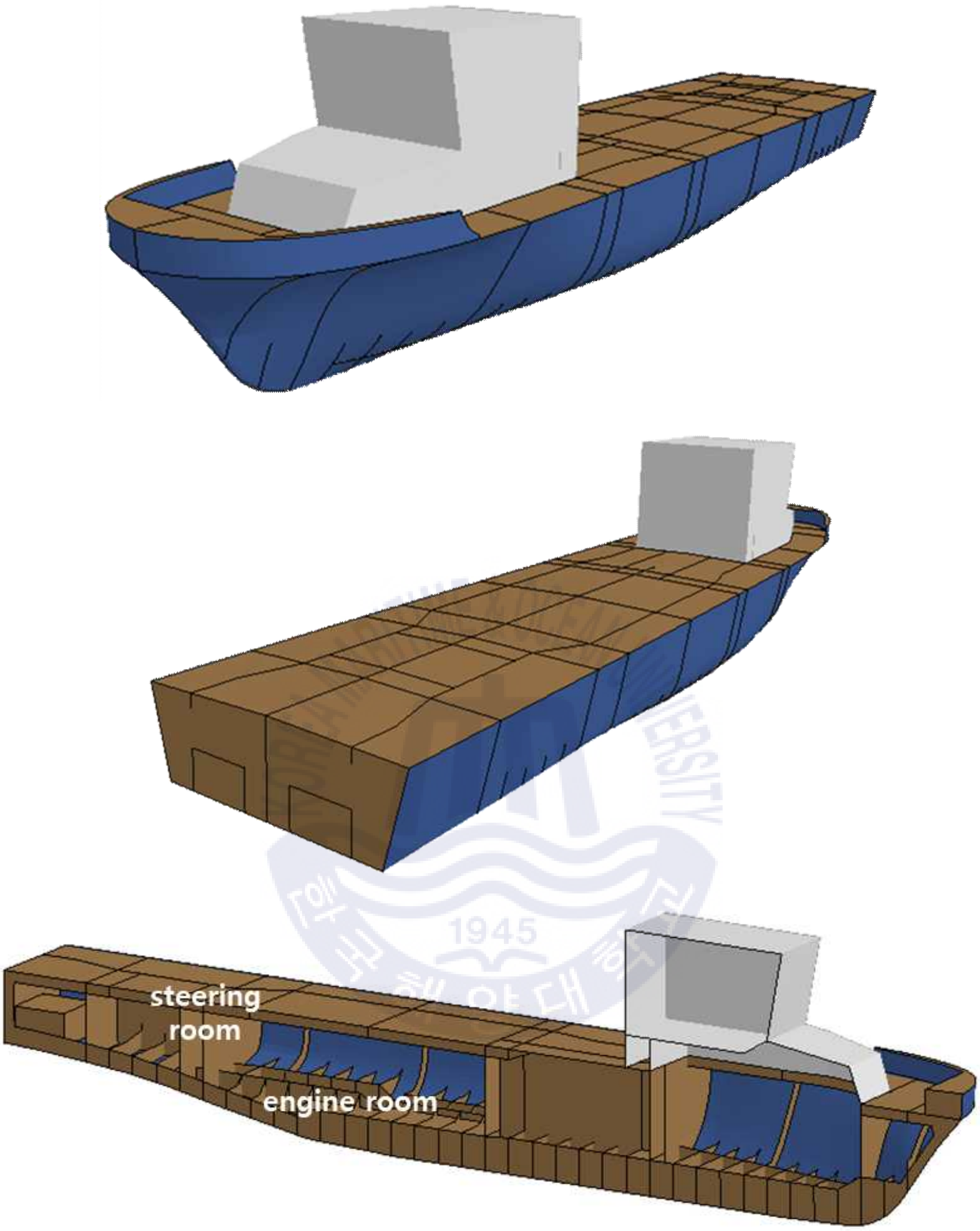
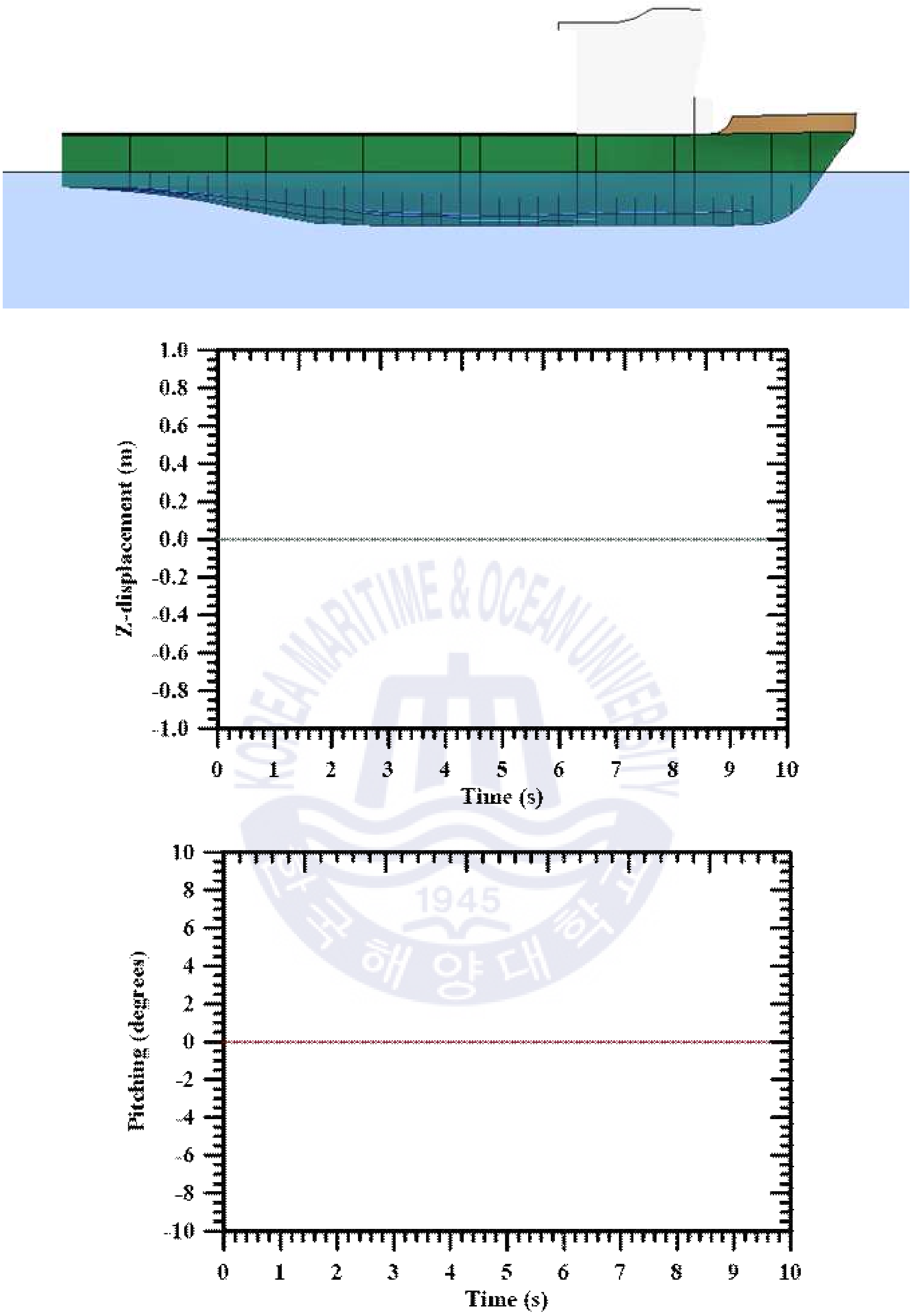
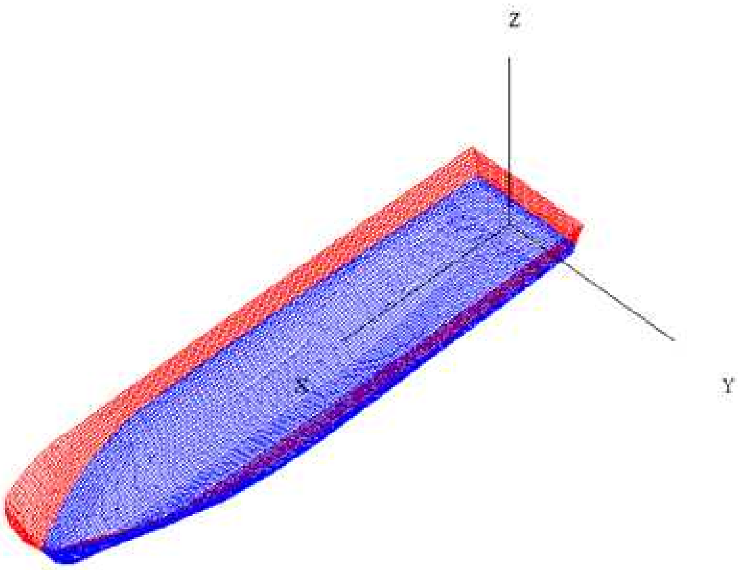


Fig. 18 Internal and external modeling of full-scale water surface cleaner



(a) floating simulation, vertical displacement and pitching responses



WATER-LINE AREA	:	73.4		
UNDERWATER VOLUME	:	60.259		
CENTER OF HULL	:	9.039	0.000	-0.489
IN THE FRAME	:			
CENTER OF HULL	:	0.000	0.000	0.000
CENTER OF GRAVITY	:	0.000	0.000	0.000
IN THE FRAME	:			
CENTER OF GRAVITY	:	0.000	0.000	0.000
MAXIMUM DRAUGHT OF THE STRUCTURE	:	1.363		
UNDERWATER LENGTH	:	19.58		
UNDERWATER BREADTH	:	4.36		
TRANSVERSAL METACENTRIC RADIUS	:	1.673		
GMt	:	1.184		
TRANSVERSAL TANKS STABILITY LOST	:	0.000		
GMt (WITH TANKS)	:	1.184		
LONGITUDINAL METACENTRIC RADIUS	:	31.494		
GML	:	31.00		
LONGITUDINAL TANKS STABILITY LOST	:	0.00		
GML (WITH TANKS)	:	31.00		
CENTER OF GRAVITY OF THE WATER-LINE	:	8.086	0.000	
CENTER OF LATERAL RESISTANCE	:	10.109	0.000	-0.612
LATERAL WETTED AREA	:	21.7		

WATER-LINE AREA	:	75.1		
UNDERWATER VOLUME	:	71.029		
CENTER OF HULL	:	8.901	0.000	-0.549
IN THE FRAME	:			
CENTER OF HULL	:	0.000	0.000	0.000
CENTER OF GRAVITY	:	0.000	0.000	0.000
IN THE FRAME	:			
CENTER OF GRAVITY	:	0.000	0.000	0.000
MAXIMUM DRAUGHT OF THE STRUCTURE	:	1.508		
UNDERWATER LENGTH	:	19.68		
UNDERWATER BREADTH	:	4.39		
TRANSVERSAL METACENTRIC RADIUS	:	1.492		
GMt	:	0.943		
TRANSVERSAL TANKS STABILITY LOST	:	0.000		
GMt (WITH TANKS)	:	0.943		
LONGITUDINAL METACENTRIC RADIUS	:	27.929		
GML	:	27.38		
LONGITUDINAL TANKS STABILITY LOST	:	0.00		
GML (WITH TANKS)	:	27.38		
CENTER OF GRAVITY OF THE WATER-LINE	:	8.168	0.000	
CENTER OF LATERAL RESISTANCE	:	9.989	0.000	-0.678
LATERAL WETTED AREA	:	24.6		

WATER-LINE AREA	:	77.6		
UNDERWATER VOLUME	:	86.454		
CENTER OF HULL	:	8.781	0.000	-0.635
IN THE FRAME	:			
CENTER OF HULL	:	0.000	0.000	0.000
CENTER OF GRAVITY	:	0.000	0.000	0.000
IN THE FRAME	:			
CENTER OF GRAVITY	:	0.000	0.000	0.000
MAXIMUM DRAUGHT OF THE STRUCTURE	:	1.710		
UNDERWATER LENGTH	:	19.82		
UNDERWATER BREADTH	:	4.45		
TRANSVERSAL METACENTRIC RADIUS	:	1.311		
GMt	:	0.676		
TRANSVERSAL TANKS STABILITY LOST	:	0.000		
GMt (WITH TANKS)	:	0.676		
LONGITUDINAL METACENTRIC RADIUS	:	24.492		
GML	:	23.86		
LONGITUDINAL TANKS STABILITY LOST	:	0.00		
GML (WITH TANKS)	:	23.86		
CENTER OF GRAVITY OF THE WATER-LINE	:	8.295	0.000	
CENTER OF LATERAL RESISTANCE	:	9.870	0.000	-0.771
LATERAL WETTED AREA	:	28.6		

(b) hydrostatic characteristics program calculation (light ship, full load and homogeneous conditions)

Condition / Item	No. / Unit	No. 1 Light Ship Condition	No. 2 Full Load Departure Condition	No. 3 Full Load Arrival Condition	No. 4 (S.G. = 0.7) Homogeneous Condition
D/W Constant	ton		1.351	1.603	1.351
Fuel Oil	ton		5.252	0.526	5.252
Recoevery Oil	ton		0.000	0.000	15.812
O.D.L. Oil	ton		4.502	0.450	4.502
Dead Weight	ton	0.000	11.105	2.579	26.917
Light Weight	ton	62.213	62.213	62.213	62.213
Displacement	ton	62.213	73.318	64.792	89.130
Deq. (equiv.)	m	1.363	1.508	1.397	1.710
L.C.G. (AFT ; -)	m	-1.131	-0.722	-1.001	-0.754
L.C.B. (AFT ; -)	m	-0.449	-0.589	-0.486	-0.711
L.C.F. (AFT ; -)	m	-1.412	-1.336	-1.394	-1.221
M.T.C	t*m	1.023	1.070	1.037	1.140
T.P.C	ton	0.750	0.770	0.760	0.800
B.G.L	m	-0.682	-0.133	-0.515	-0.043
Trim (B.L 기준)	m	-0.415	-0.091	-0.322	-0.034
(I.T 기준)	m	0.000	0.000	0.000	0.000
dF (fore)	m	1.125	1.456	1.212	1.691
Draft dA (aft)	m	1.540	1.547	1.534	1.725
dM (mean)	m	1.333	1.502	1.373	1.708
K.M.T	m	2.537	2.450	2.512	2.386
K.G	m	1.709	1.627	1.687	1.580
GGo	m	0.000	0.082	0.021	0.106
KGo	m	1.709	1.709	1.708	1.686
G.M	m	0.828	0.823	0.825	0.806
GoM	m	0.828	0.741	0.804	0.700
Stability Criteria		GoM > 0.350 or Required Cal.	GoM > 0.350 or Required Cal.	GoM > 0.350 or Required Cal.	GoM > 0.350 or Required Cal.
Required Cal.		0.134	0.060	0.110	0.085
Judgement		**Satisfied**	**Satisfied**	**Satisfied**	**Satisfied**

Item \ Condition	No. / Unit	No. 1 Light Ship Condition	No. 2 Full Load Departure Condition	No. 3 Full Load Arrival Condition	No. 4 (S.G. = 0.7) Homogeneous Condition
D/W Constant	ton		1.351	1.603	1.351
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(I.T 기준)	m	0.000	0.000	0.000	0.000
dF (fore)	m	1.125	1.456	1.212	1.691
Draft dA (aft)	m	1.540	1.547	1.534	1.725
dM (mean)	m	1.333	1.502	1.373	1.708
K.M.T	m	2.537	2.450	2.512	2.386
K.G	m	1.709	1.627	1.687	1.580
GGo	m	0.000	0.082	0.021	0.106
KGo	m	1.709	1.709	1.708	1.686
G.M	m	0.828	0.823	0.825	0.806
GoM	m	0.828	0.741	0.804	0.700
Stability Criteria		GoM > 0.350 or Required Cal.	GoM > 0.350 or Required Cal.	GoM > 0.350 or Required Cal.	GoM > 0.350 or Required Cal.
Required Cal.		0.134	0.060	0.110	0.085
Judgement		**Satisfied**	**Satisfied**	**Satisfied**	**Satisfied**

Item \ Condition	No. / Unit	No. 1 Light Ship Condition	No. 2 Full Load Departure Condition	No. 3 Full Load Arrival Condition	No. 4 (S.G. = 0.7) Homogeneous Condition
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Fuel Oil	ton		5.252	0.526	5.252
Recoevery Oil	ton		0.000	0.000	15.812
O.D.L. Oil	ton		4.502	0.450	4.502
Dead Weight	ton	0.000	11.105	2.579	26.917
Light Weight	ton	62.213	62.213	62.213	62.213
Displacement	ton	62.213	73.318	64.792	89.130
Deq. (equiv.)	m	1.363	1.508	1.397	1.710
L.C.G. (AFT ; -)	m	-1.131	-0.722	-1.001	-0.754
L.C.B. (AFT ; -)	m	-0.449	-0.589	-0.486	-0.711
L.C.F. (AFT ; -)	m	-1.412	-1.336	-1.394	-1.221
M.T.C	t*m	1.023	1.070	1.037	1.140
T.P.C	ton	0.750	0.770	0.760	0.800
B.G.L	m	-0.682	-0.133	-0.515	-0.043
Trim (B.L 기준)	m	-0.415	-0.091	-0.322	-0.034
(I.T 기준)	m	0.000	0.000	0.000	0.000
dF (fore)	m	1.125	1.456	1.212	1.691
Draft dA (aft)	m	1.540	1.547	1.534	1.725
dM (mean)	m	1.333	1.502	1.373	1.708
K.M.T	m	2.537	2.450	2.512	2.386
K.G	m	1.709	1.627	1.687	1.580
GGo	m	0.000	0.082	0.021	0.106
KGo	m	1.709	1.709	1.708	1.686
G.M	m	0.828	0.823	0.825	0.806
GoM	m	0.828	0.741	0.804	0.700
Stability Criteria		GoM > 0.350 or Required Cal.	GoM > 0.350 or Required Cal.	GoM > 0.350 or Required Cal.	GoM > 0.350 or Required Cal.
Required Cal.		0.134	0.060	0.110	0.085
Judgement		Satisfied	Satisfied	Satisfied	Satisfied

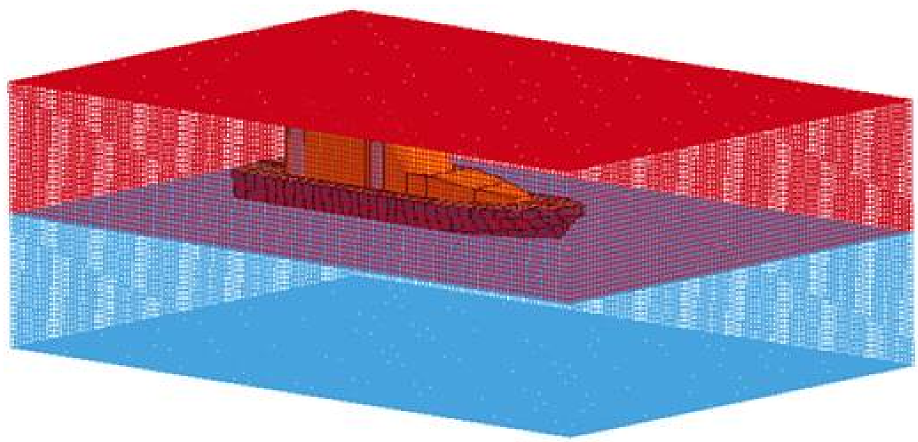
(c) stability calculation (light ship, full load and homogeneous conditions)

Fig. 19 Floating simulation and hydrostatic characteristics program calculation of water surface cleaner according to loading condition

Table 8 Comparison between stability and hydrostatic characteristics program calculations of water surface cleaner according to loading condition

full load departure condition	displacement (ton)	KB (m)	LCB (m)	LCF (m)	KMT (m)
stability calculation	73.318	0.950	-0.589	-1.338	2.450
modeling	72.805	0.959	-0.599	-1.332	2.451
error(%)	0.70%	0.95%	1.70%	0.45%	0.04%
homogeneous condition	displacement (ton)	KB (m)	LCB (m)	LCF (m)	KMT (m)
stability calculation	89.130	1.066	-0.711	-1.221	2.388
modeling	88.615	1.075	-0.719	-1.205	2.386
error(%)	0.58%	0.84%	1.13%	1.31%	0.08%

It is important to float a ship accurately in the still sea water for the full-scale ship collision and grounding simulations, and to give a sailing ship propulsion for the maintenance of ship speed. Hydrostatic pressure has to be kept according to depth in the sea for the accurate floating of ship in the still sea water. Figures 20～21 illustrate the full-scale ship and air-sea water modeling for the floating and propulsion simulations, respectively, and Fig. 22(a)～(b), hydrostatic pressure response according to the depth and floating responses of the ship in the sea water, respectively. Figure 23 shows the propulsion behavior of the ship in the sea water.



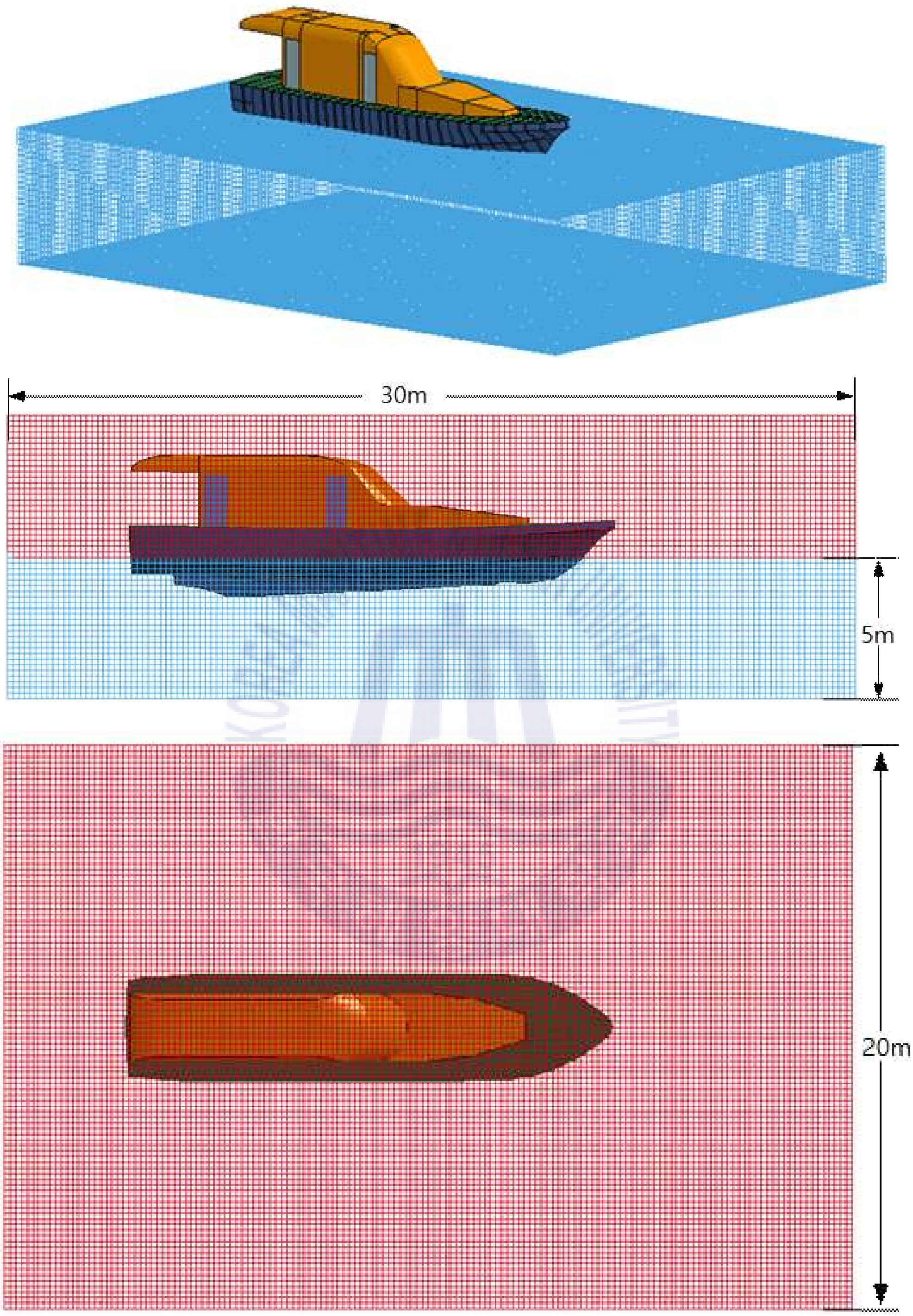


Fig. 20 Full-scale ship and air-water modeling for floating simulation

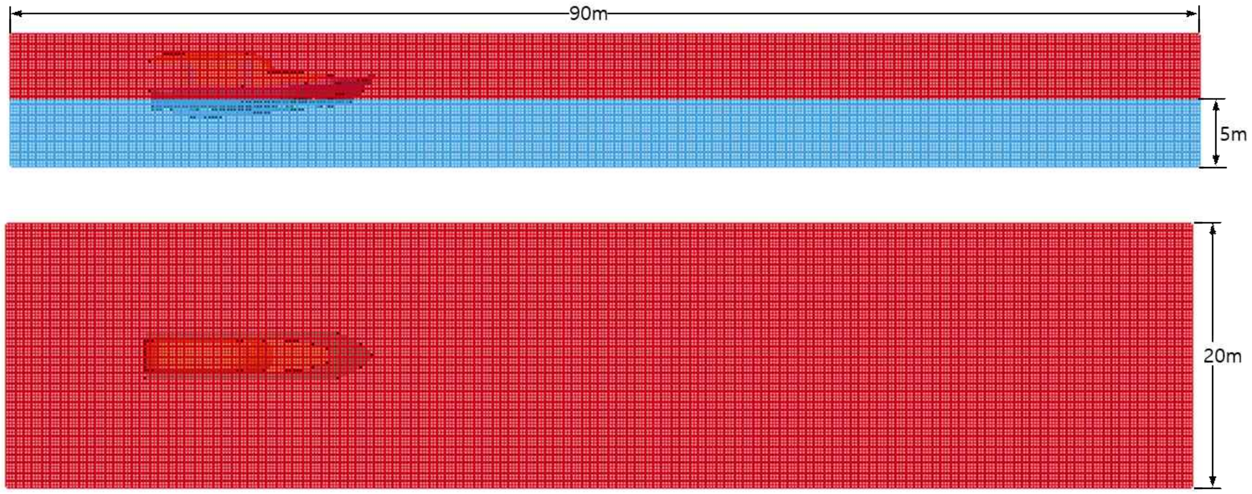
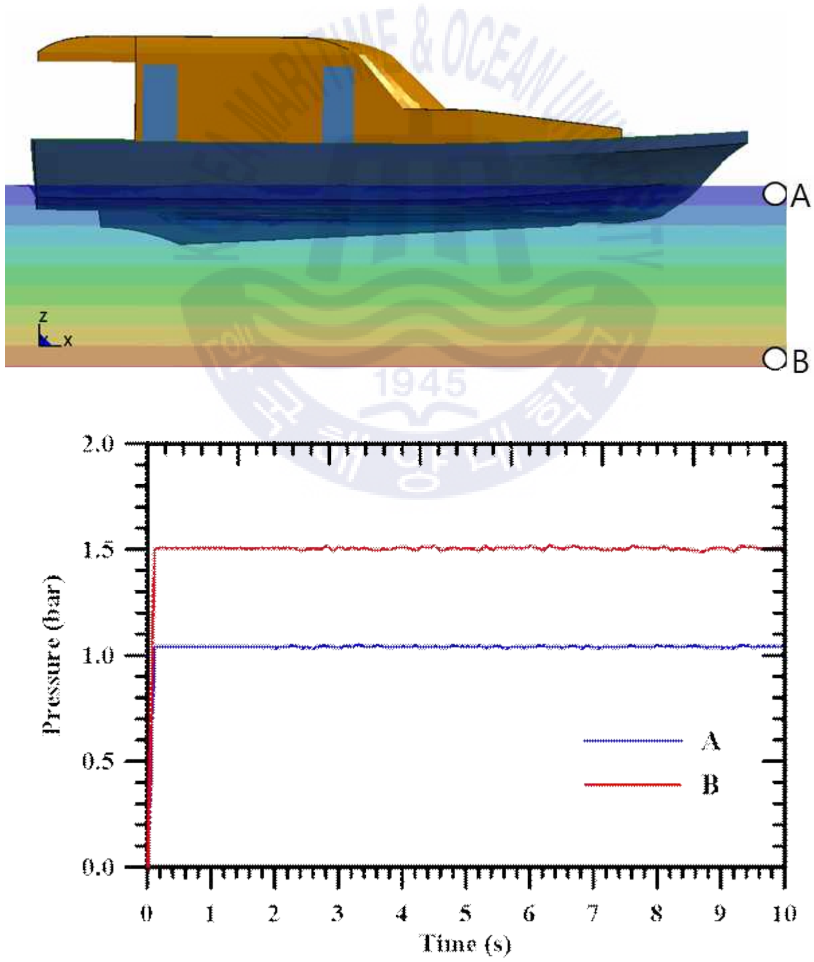
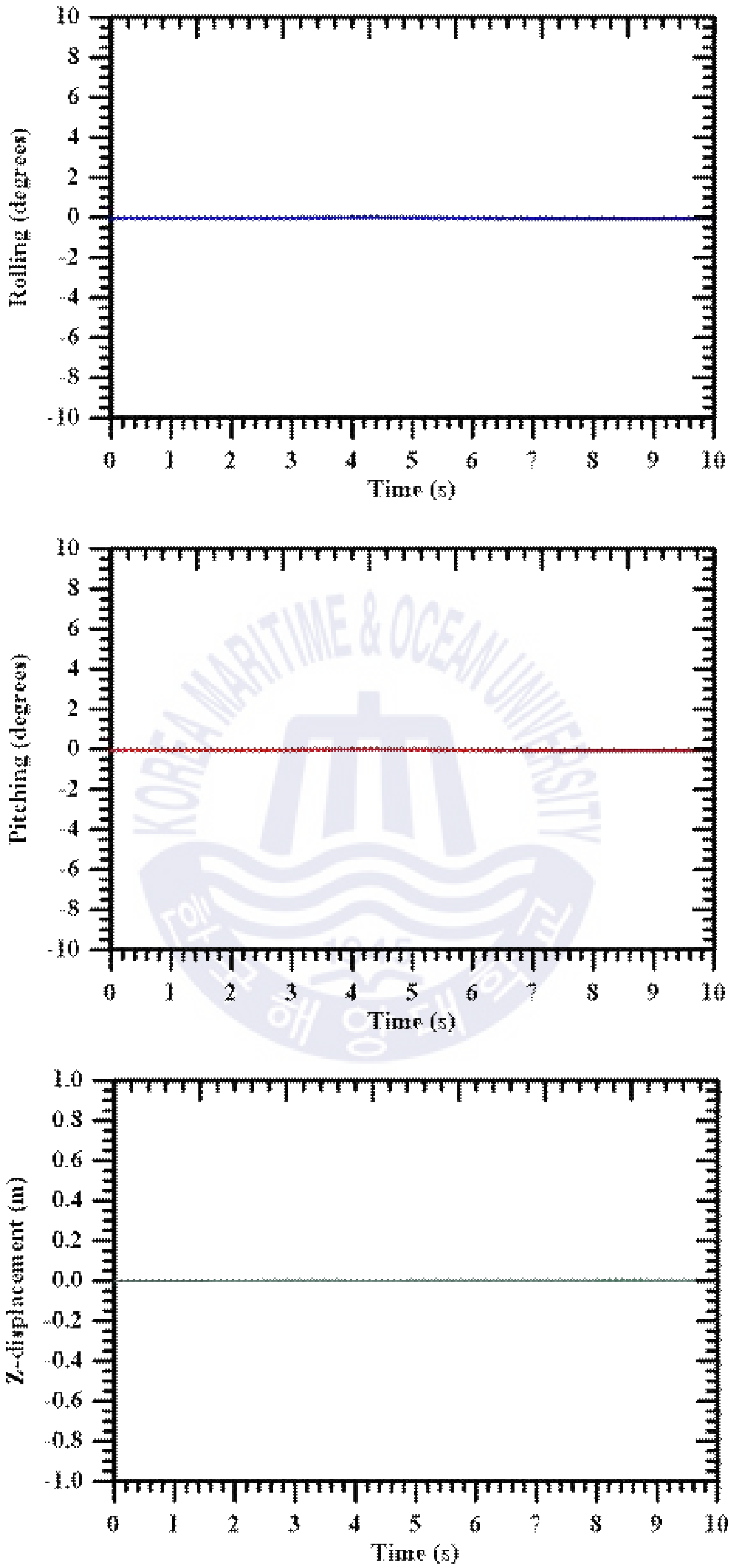


Fig. 21 Full-scale ship and air-water modeling for propulsion simulation

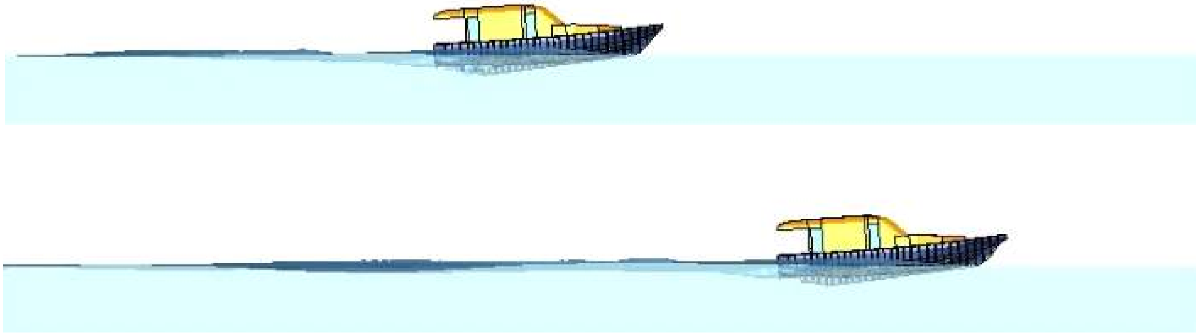


(a) hydrostatic pressure response

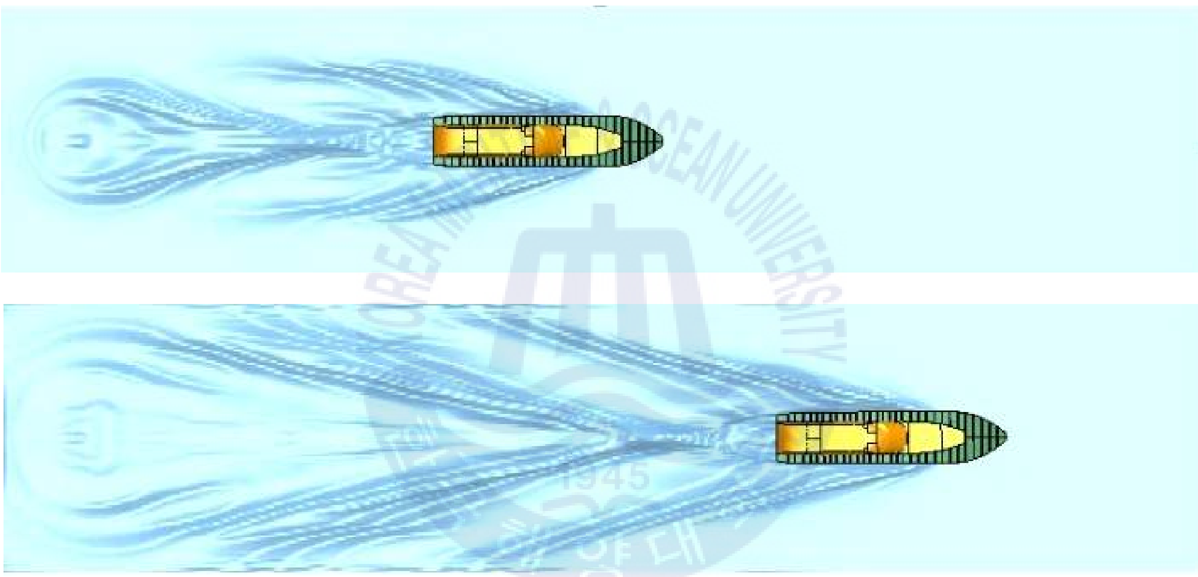


(b) floating response (rolling, pitching, heaving)

Fig. 22 Hydrostatic pressure and floating responses



(a) side view

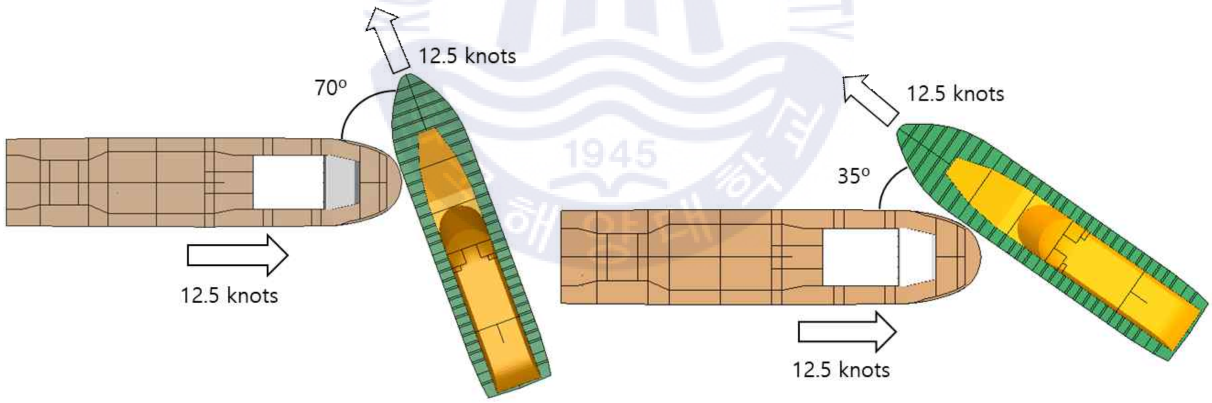


(b) plan view

Fig. 23 Propulsion behavior of ship in the sea water

5. Full-Scale Ship Collision and Grounding Simulation

Ship speed of striking and struck ships was set to operate at the maximum one 12.5 knots based on the their operation conditions on the coast. Full-scale ship collision simulation was carried out according to collision scenarios of attack angle 70° and 35° to fuel tank of small FRP LNG fueled ship by water surface cleaner of gross tonnage 24.0ton, as shown in Fig. 24, and full-scale ship grounding simulation, according to the grounding scenarios of small FRP LNG fueled ship against a rock rising 0.3m above the free surface along the centerline and 1.0m off the centerline of the hull with the maximum ship speed 12.5 knots, as shown in Fig. 25.

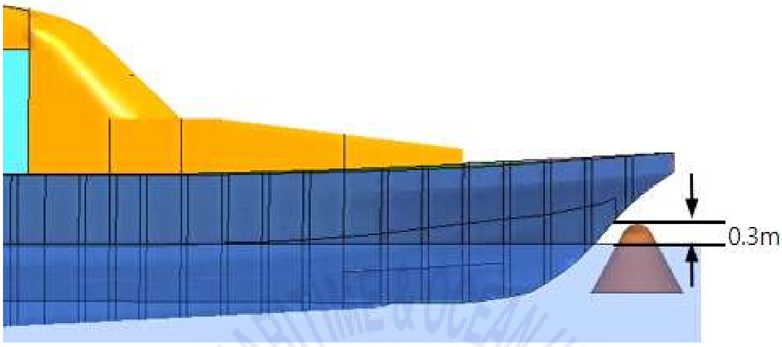


(a) attack angle : 70° (b) attack angle : 35°

Fig. 24 Collision scenario of small LNG fueled ship

(a) rock position: center

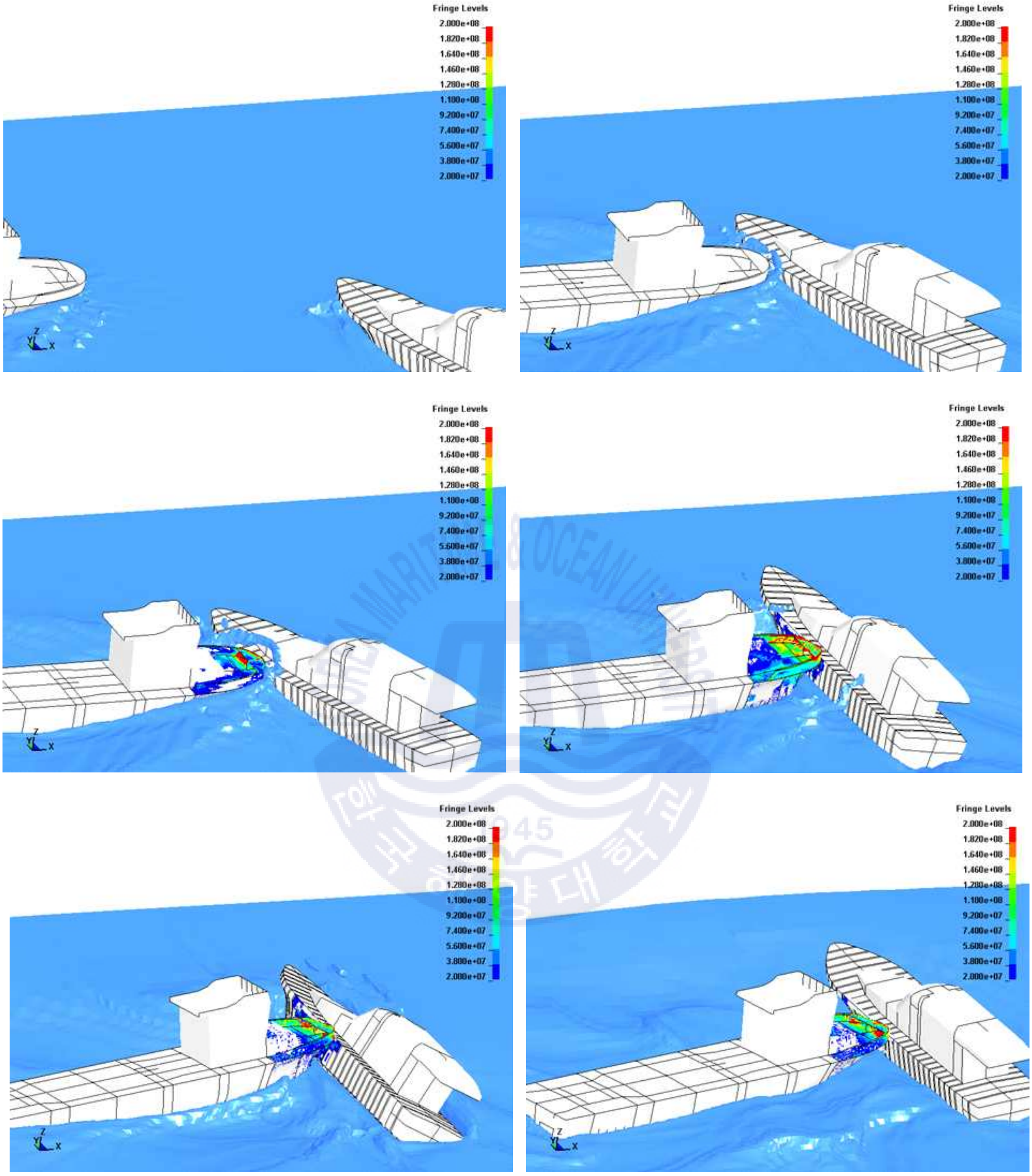
(b) rock position : 1.0m off



(c) rock height: 0.3m

Fig. 25 Grounding scenario of small LNG fueled ship

Figures 26～27 show the full-scale ship collision response behaviors under attack angle 70° and 35°, respectively, using FSI analysis technique. It could be confirmed that the collision behaviors between two ships were well realized in the sea water by buoyancy, unlike those in the air. In the case of attack angle 70°, there occurred a large amount of damage than the case of attack angle 35°, but even though there was some fracture on the stiffeners in the side of fuel tank room, there was no direct impact damage to the fuel tank.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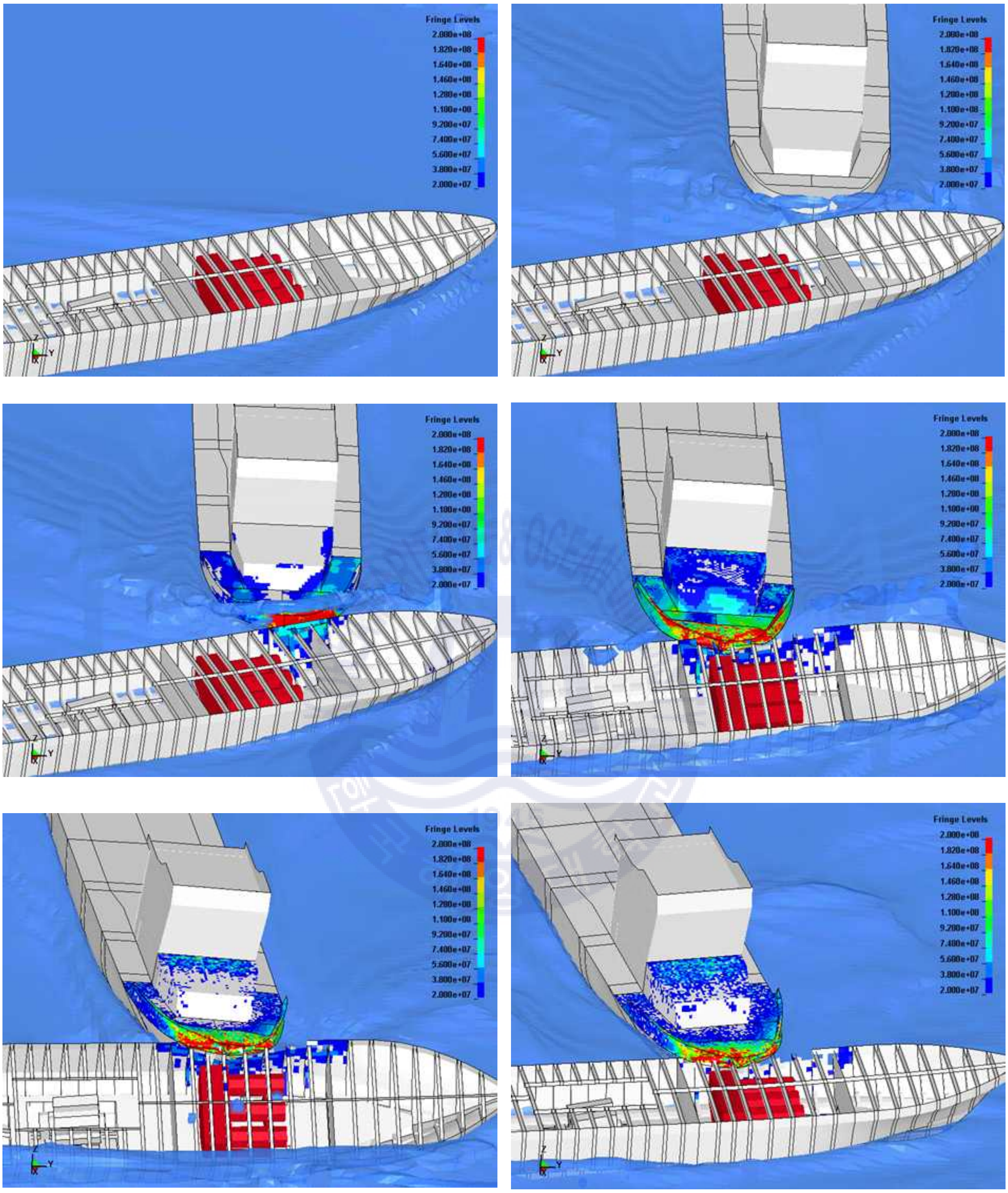
1.280e+08
1.100e+08
9.200e+07
7.400e+07
5.600e+07
3.800e+07
2.000e+07

(a) over view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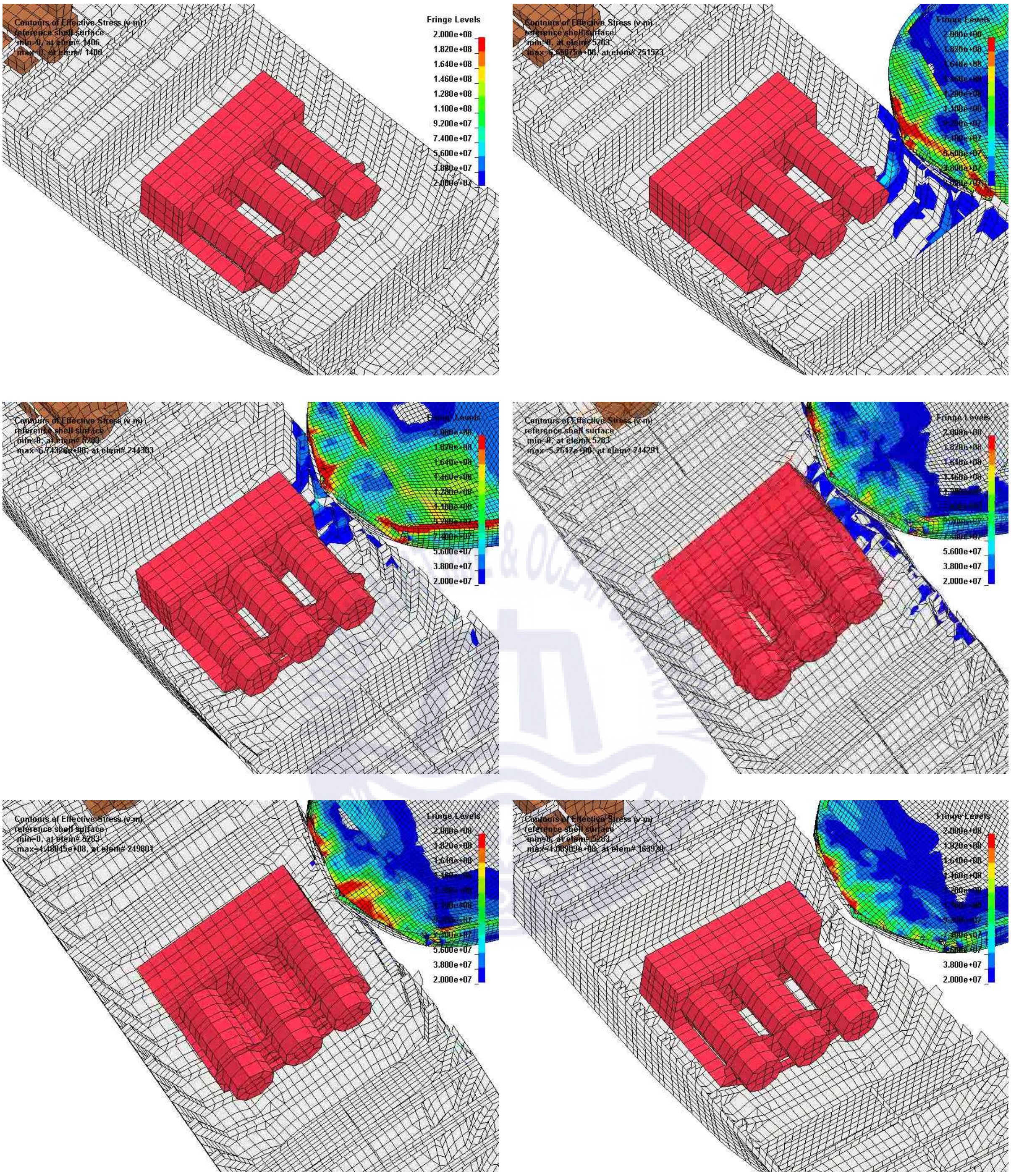
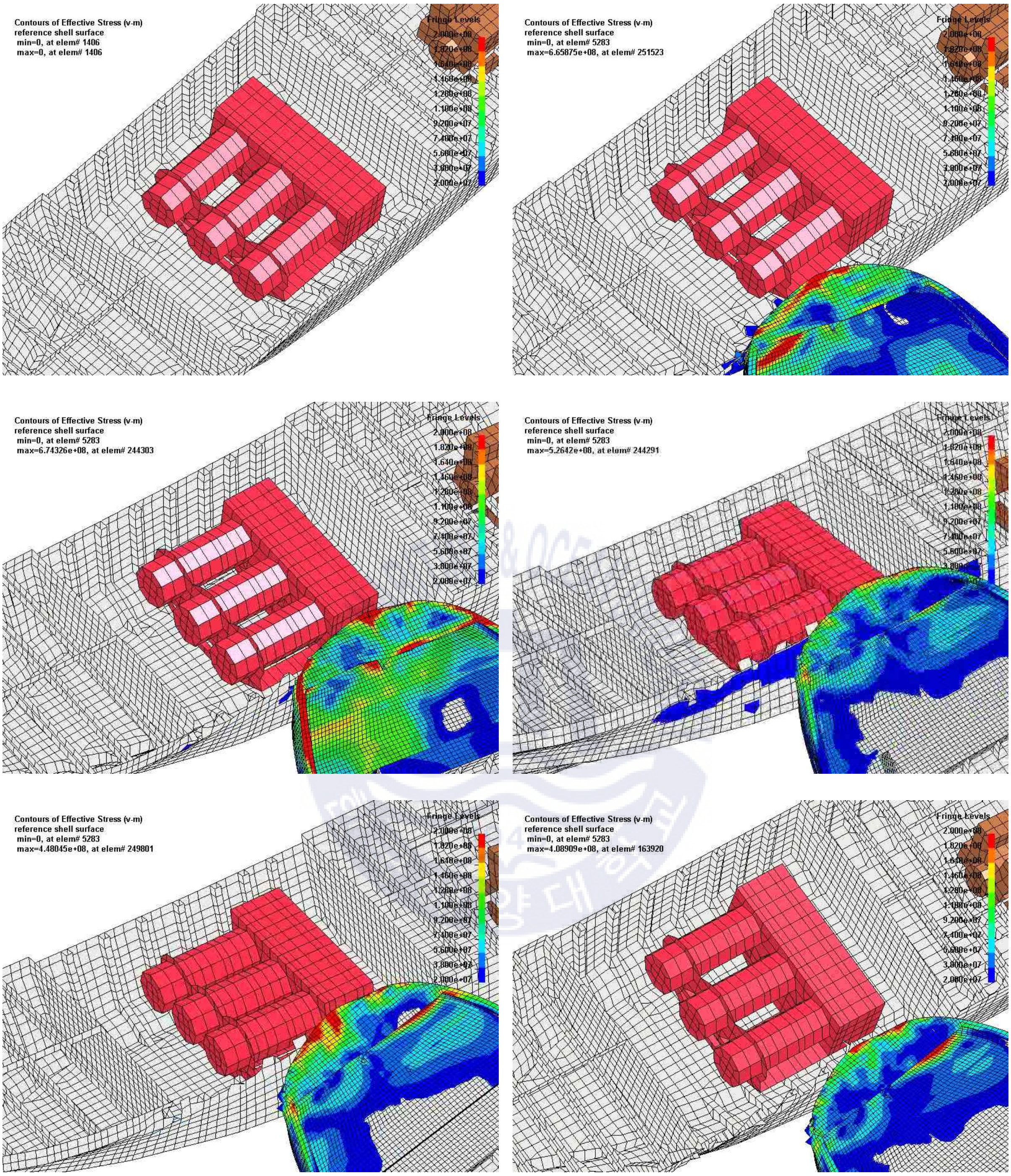
5.600e+07
3.800e+07
2.000e+07
(b) close view

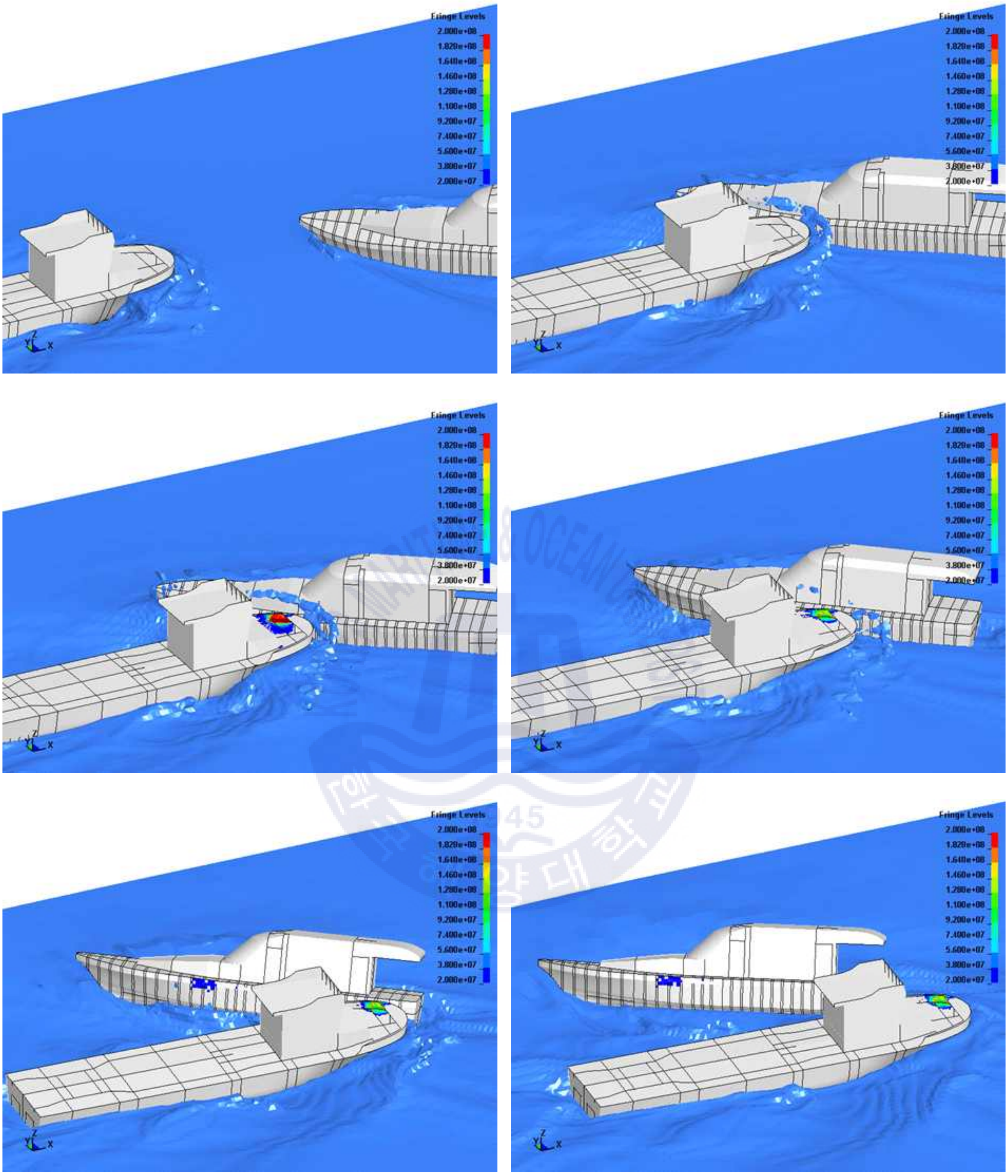


(c) zoom view of LNG tank room (inside)



(d) zoom view of LNG tank room (outside)

Fig. 26 Collision response behavior under attack angle 70°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3.800e+07
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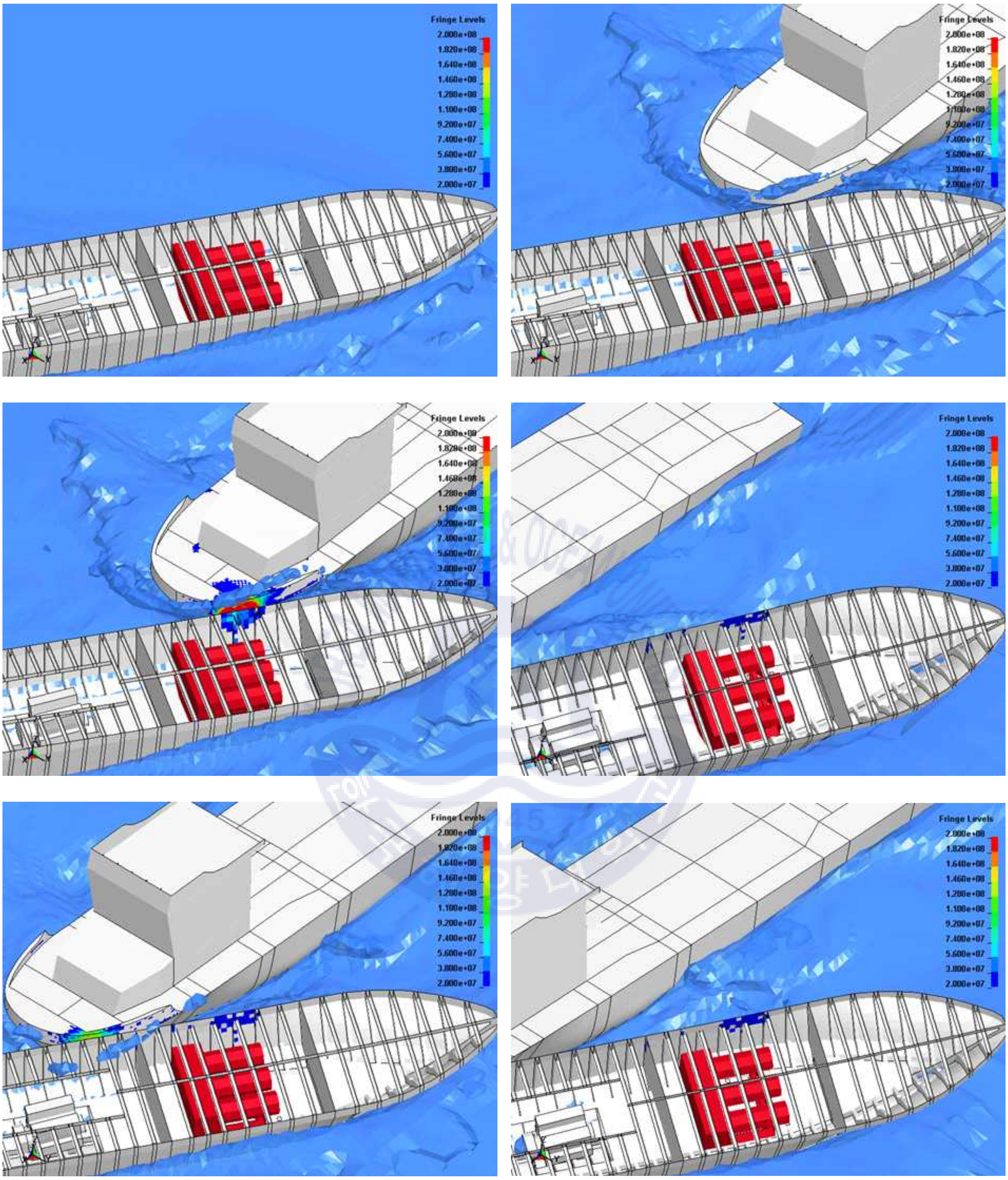
(a) over view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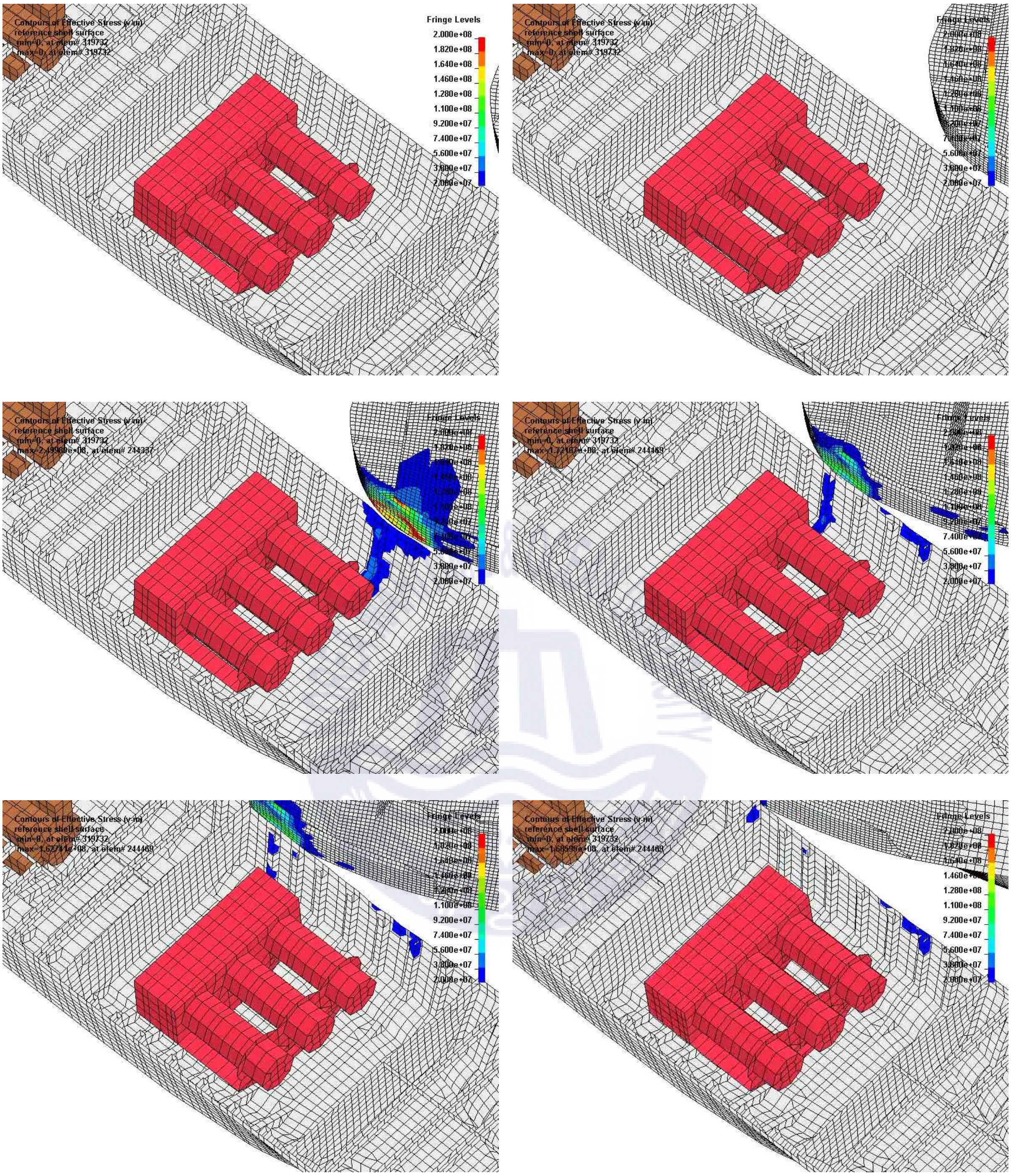
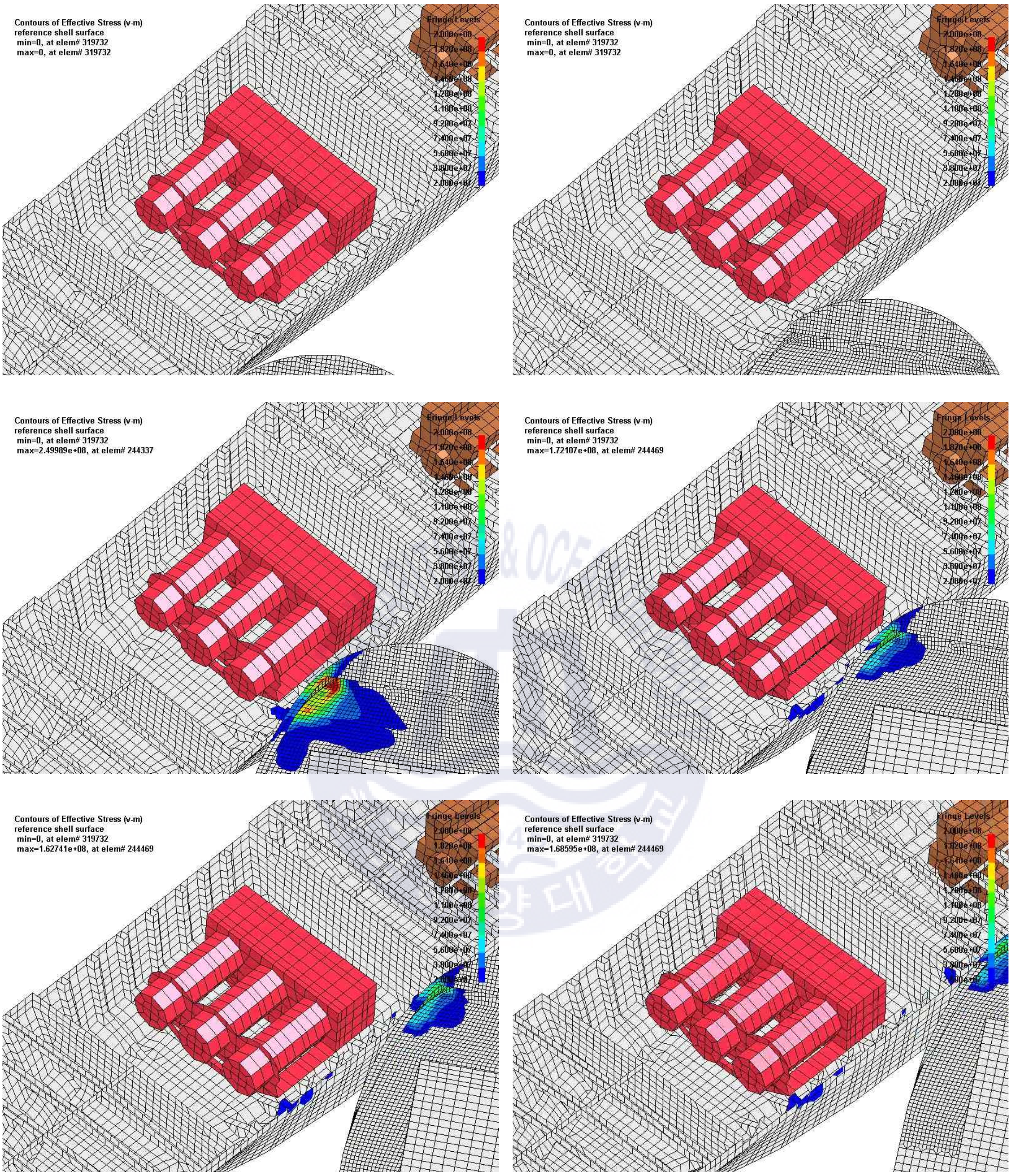
(b) close view



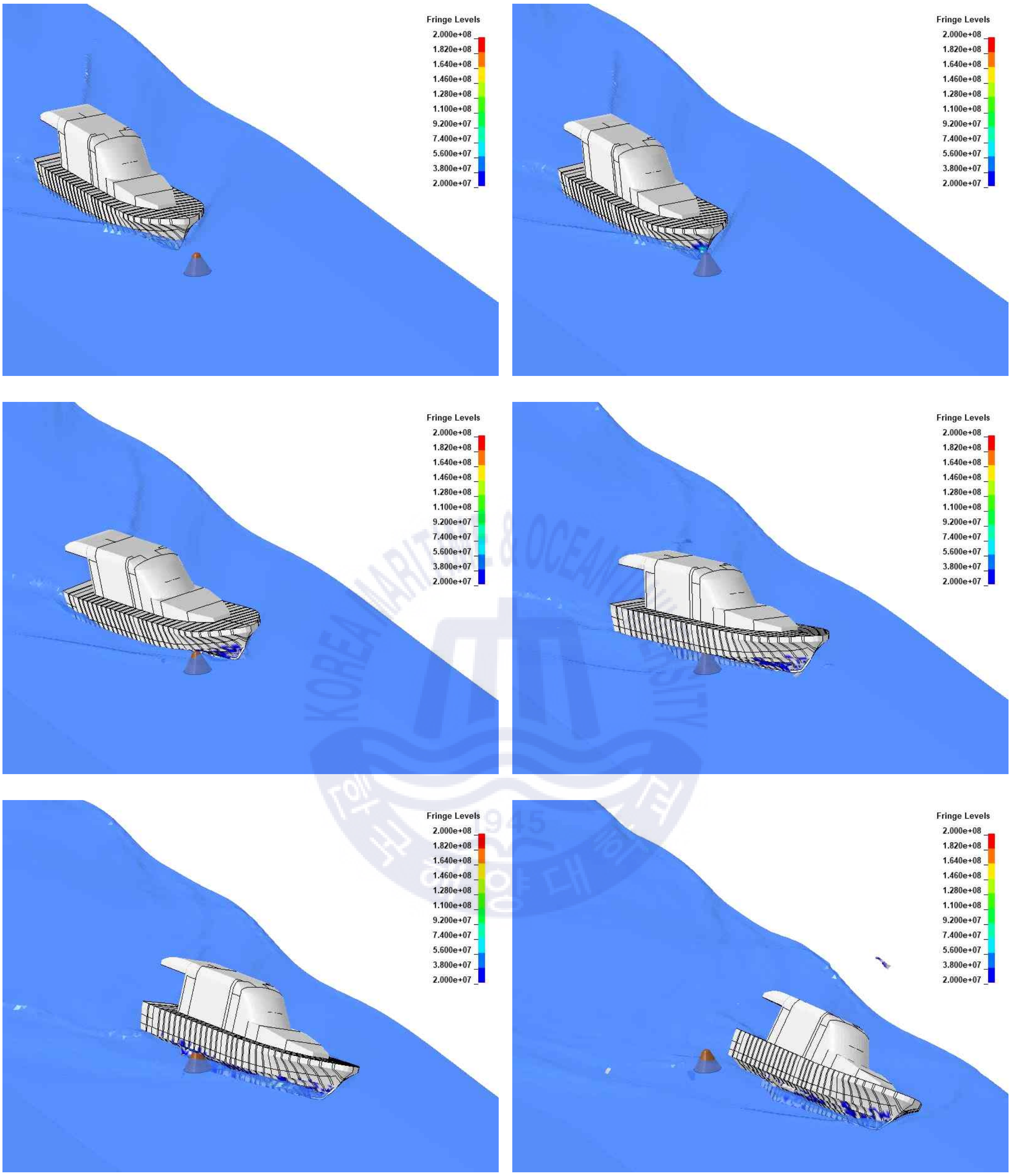
(c) zoom view of LNG tank room (inside)



(d) zoom view of LNG tank room (outside)

Fig. 27 Collision response behavior under attack angle 35°

Figures 28～29 show the full-scale ship grounding response behaviors against a rock along the centerline and 1.0m off the centerline of the hull with ship speed 12.5 knots. It could be also recognized that the grounding behaviors against a rock were well realized in the sea water under its own weight by buoyancy, unlike those in the air. There occurred a large amount of fracture damage on the stiffeners in the side-bottom of fuel tank room in both cases of a rock position along the centerline and 1.0m off the centerline of the hull, and there was a little bit larger damage in the former case than in the latter one. There was also no direct impact damage to the fuel tank.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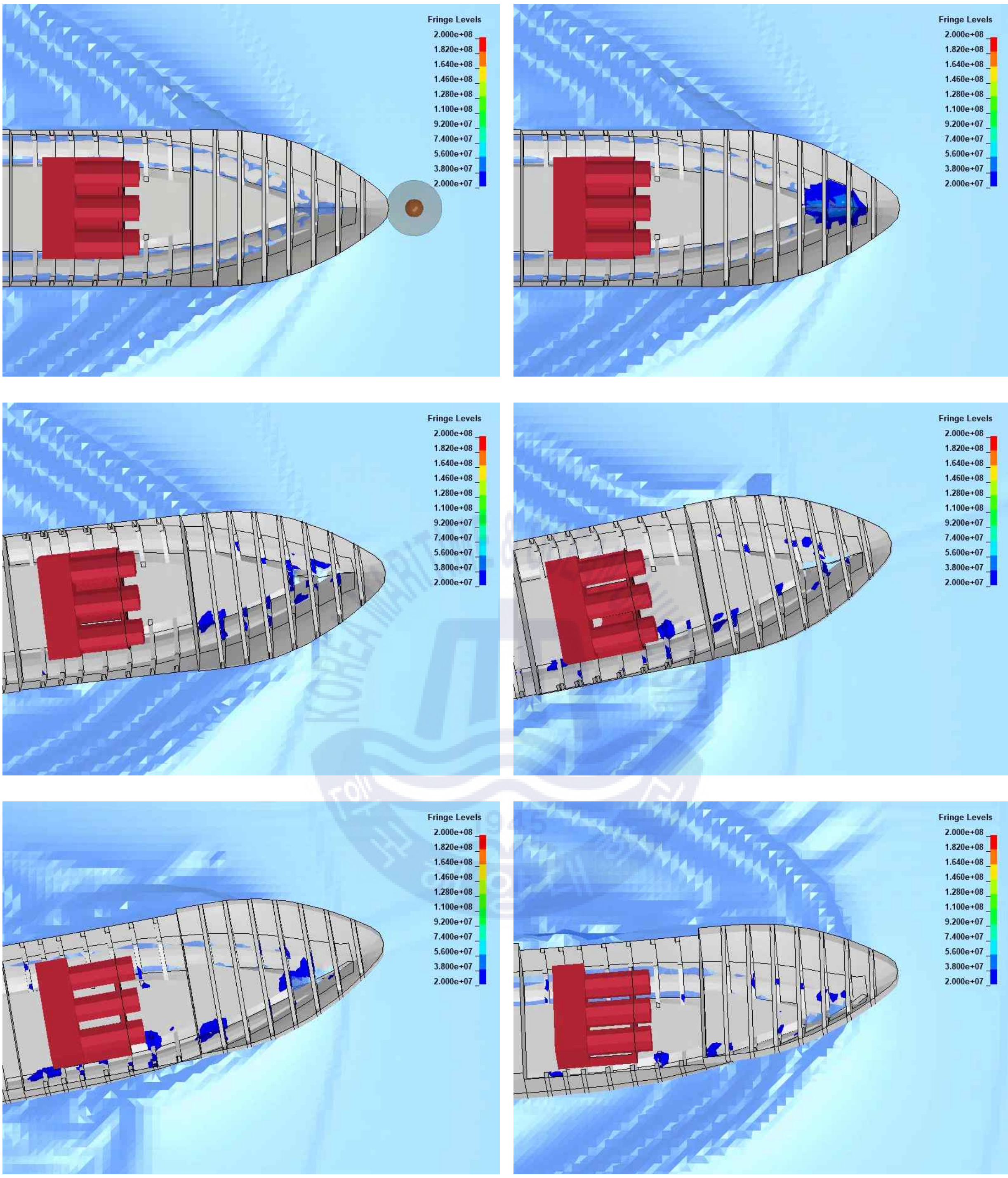
3.800e+07
2.000e+07

(a) over view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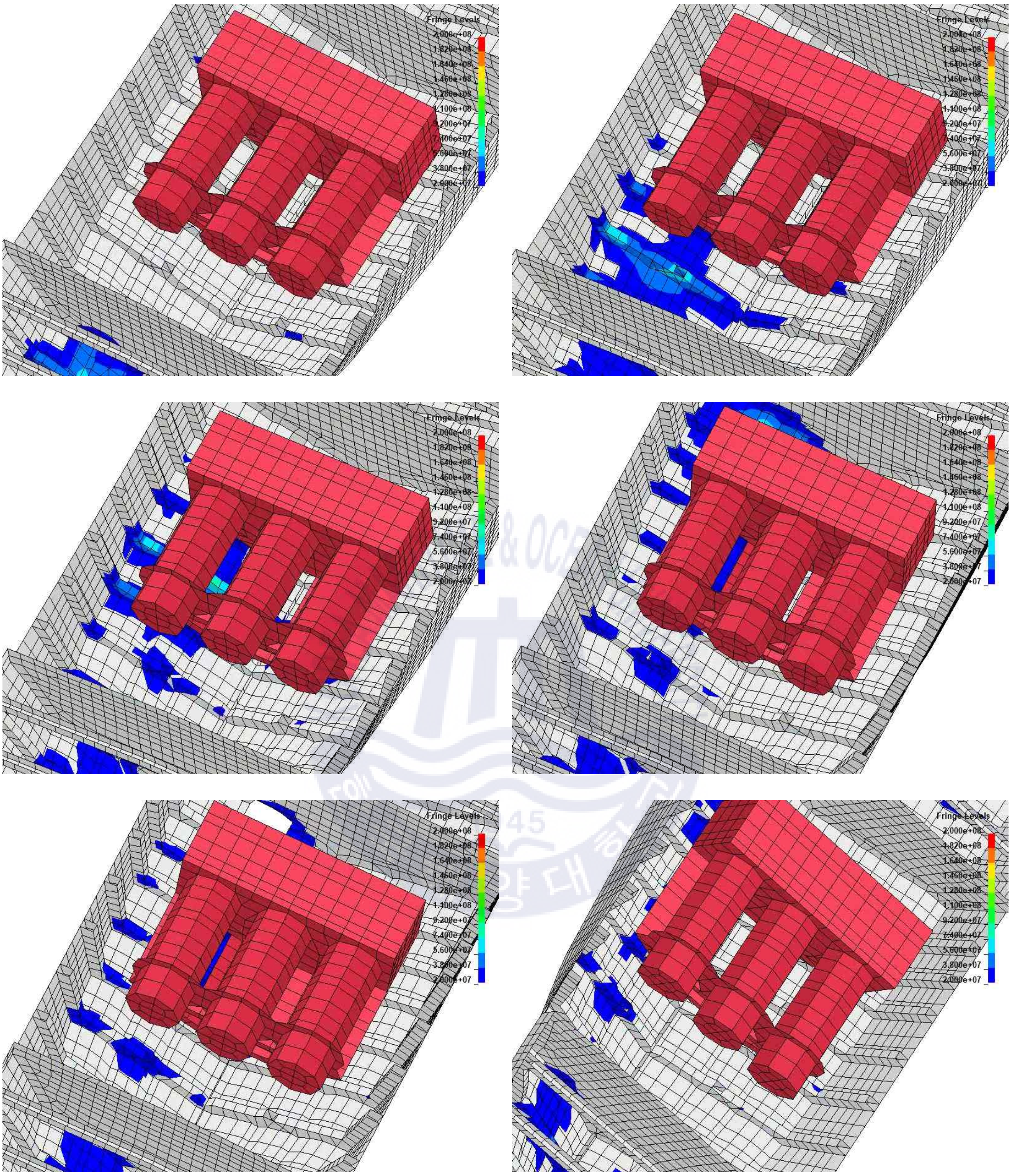
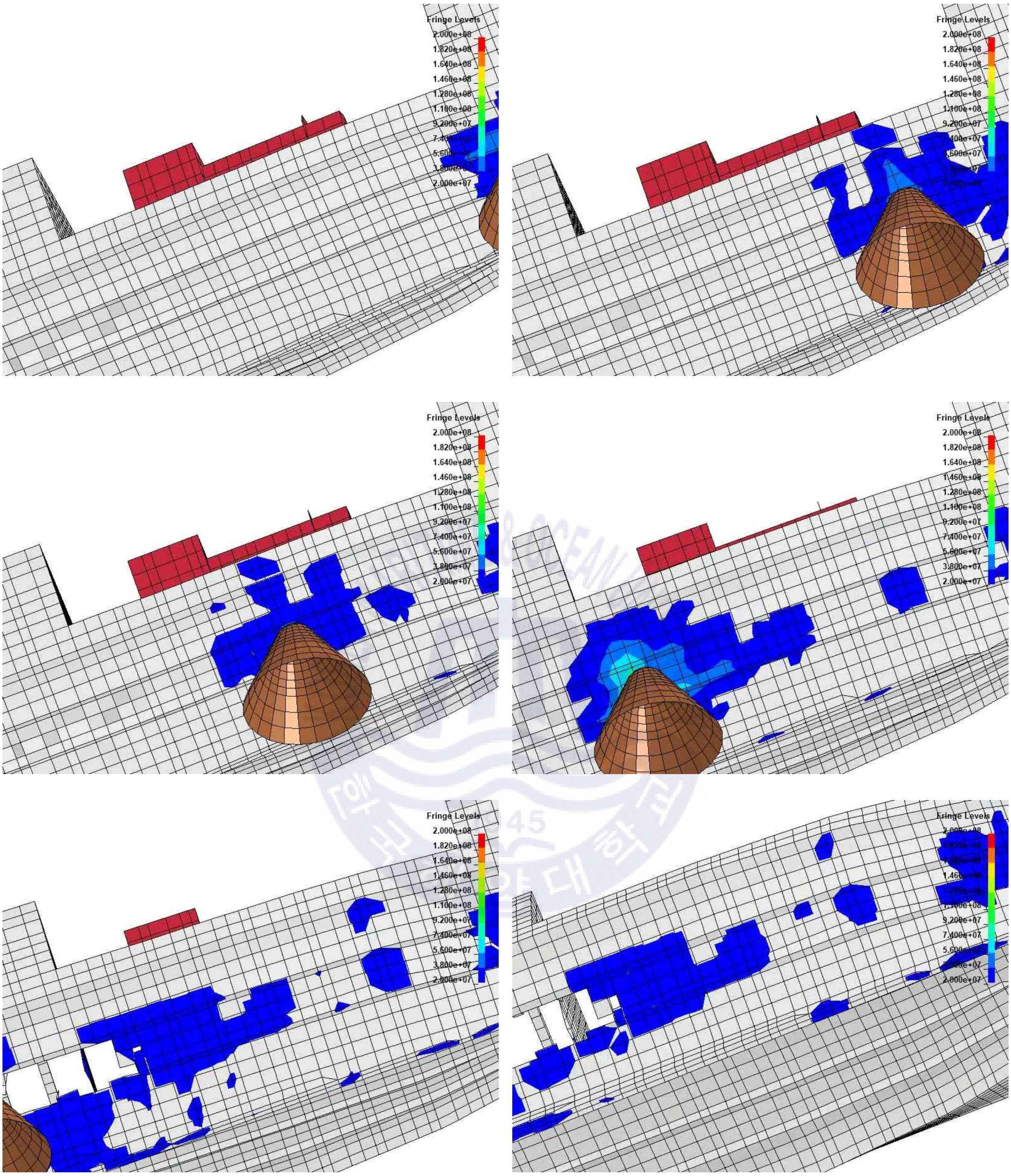
(b) close view

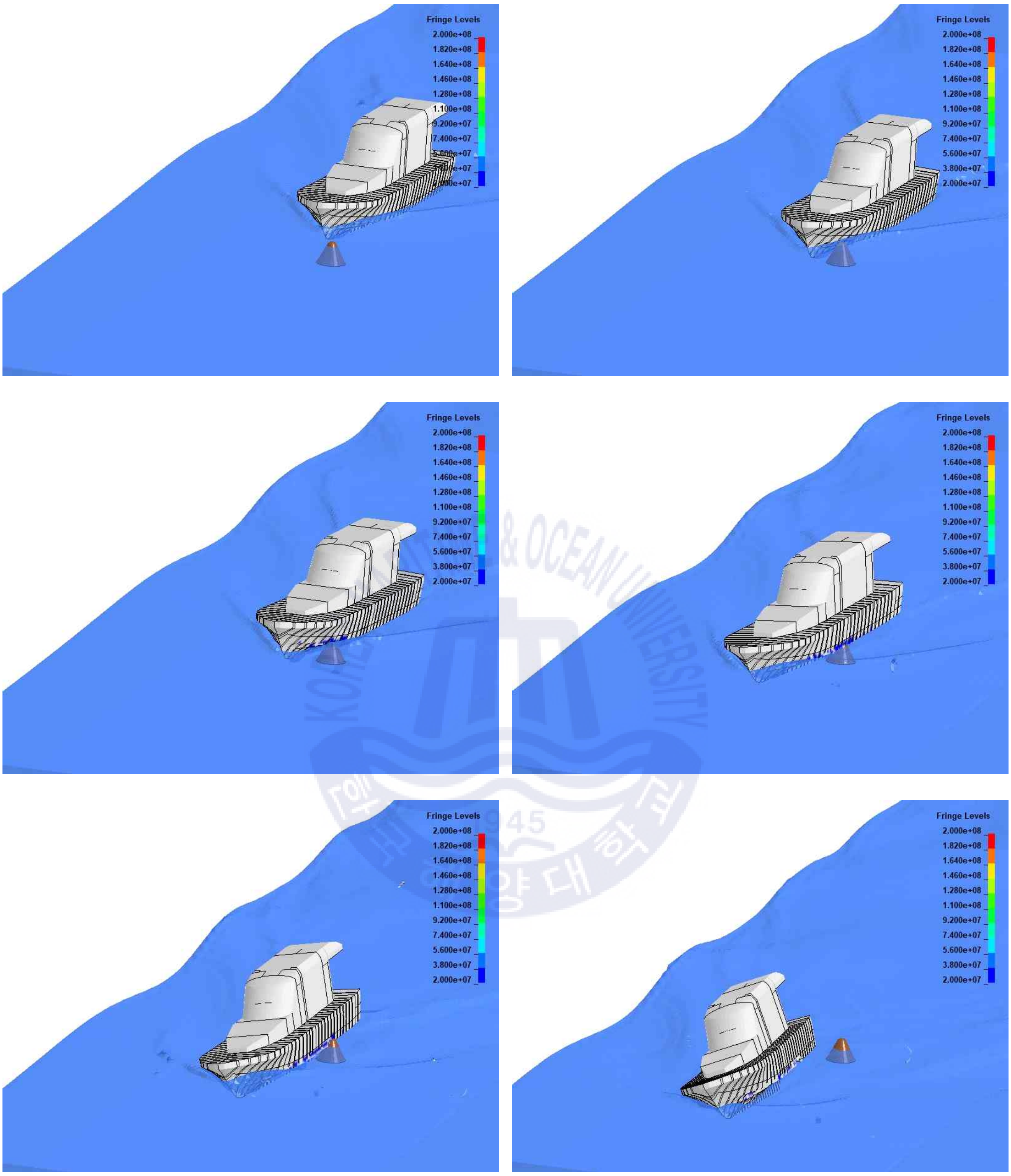


(c) zoom view of LNG tank room (inside)



(d) zoom view of LNG tank room (outside)

Fig. 28 Grounding response behavior under rock position in the longitudinal centerline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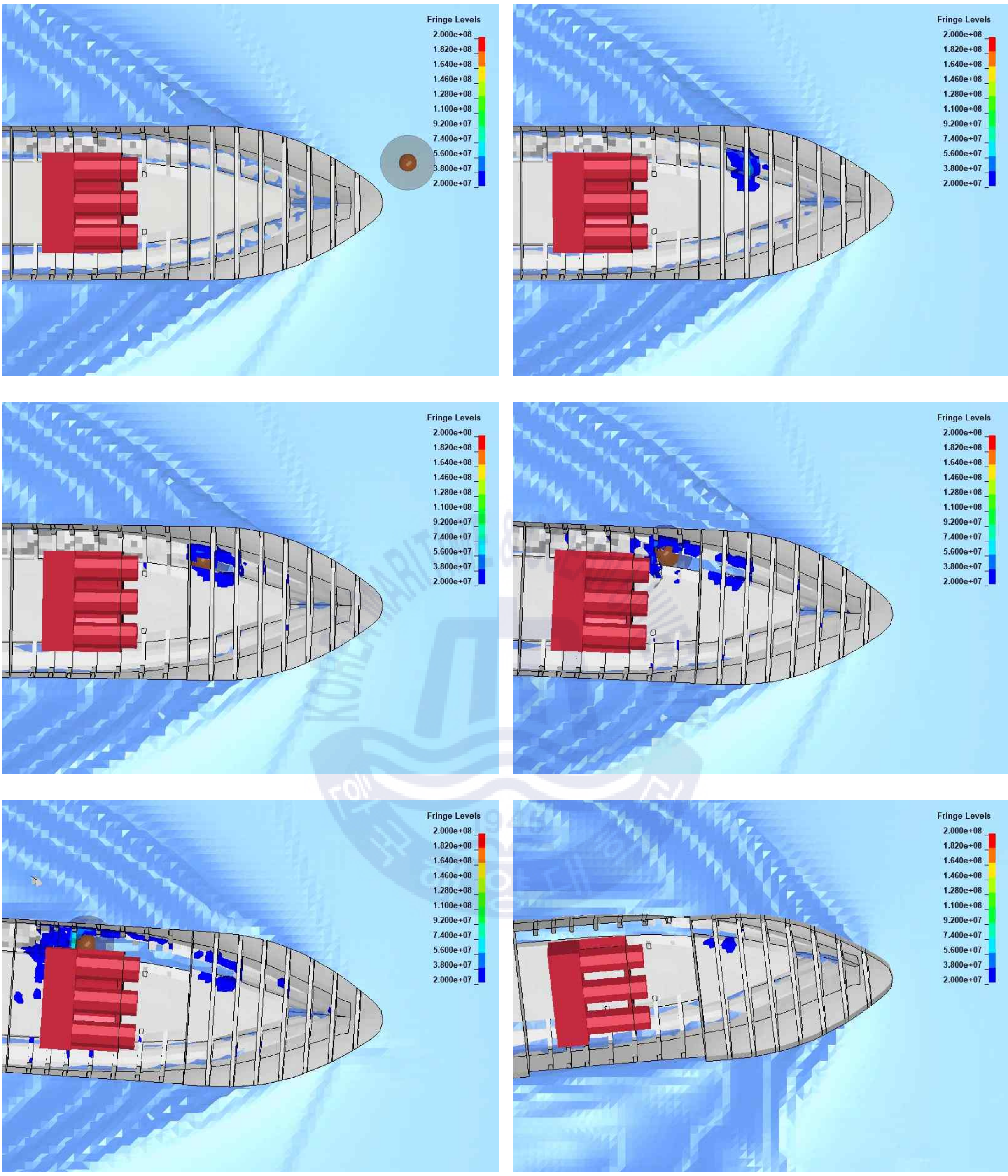
5.600e+07
3.800e+07
2.000e+07

(a) over view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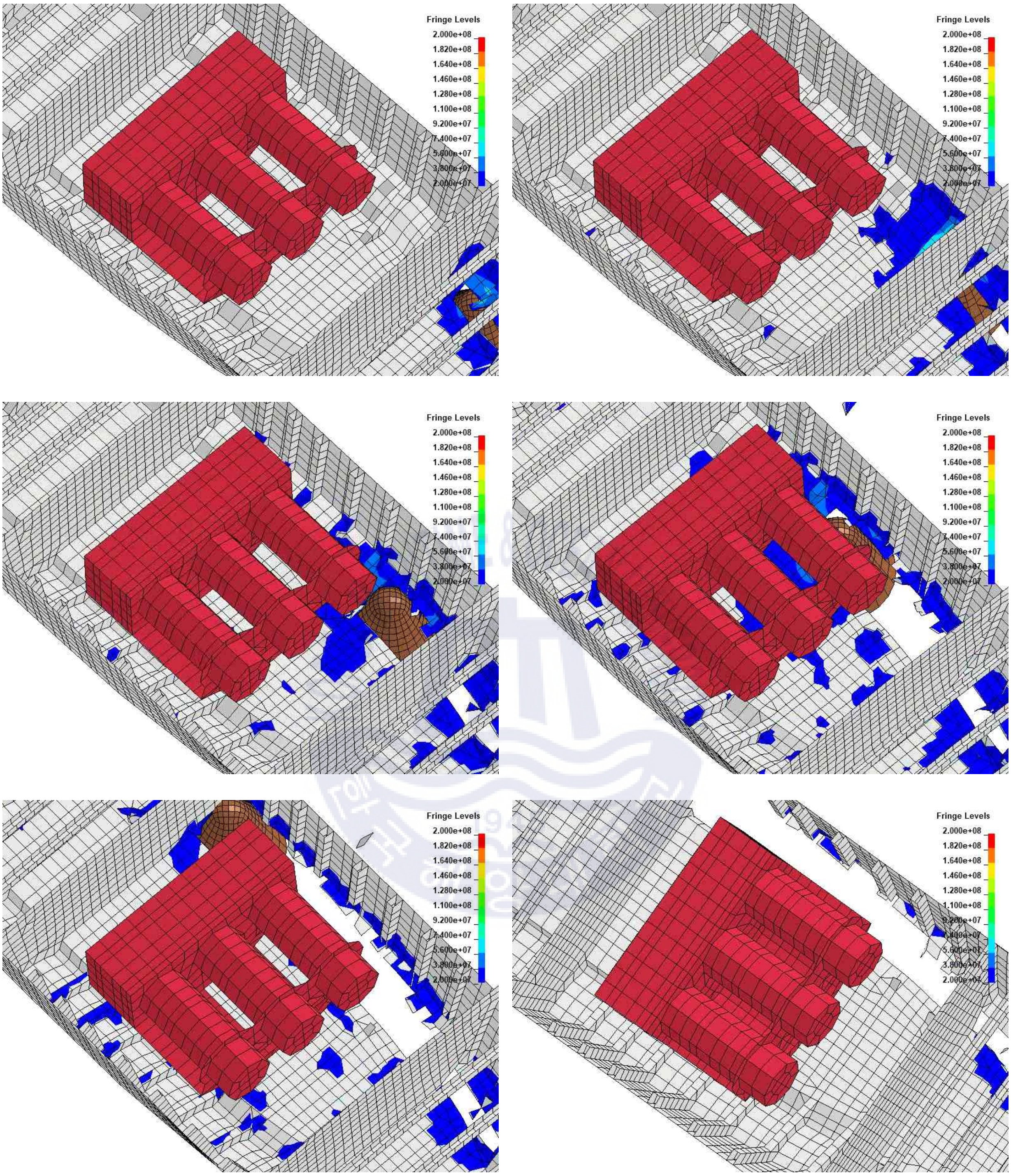
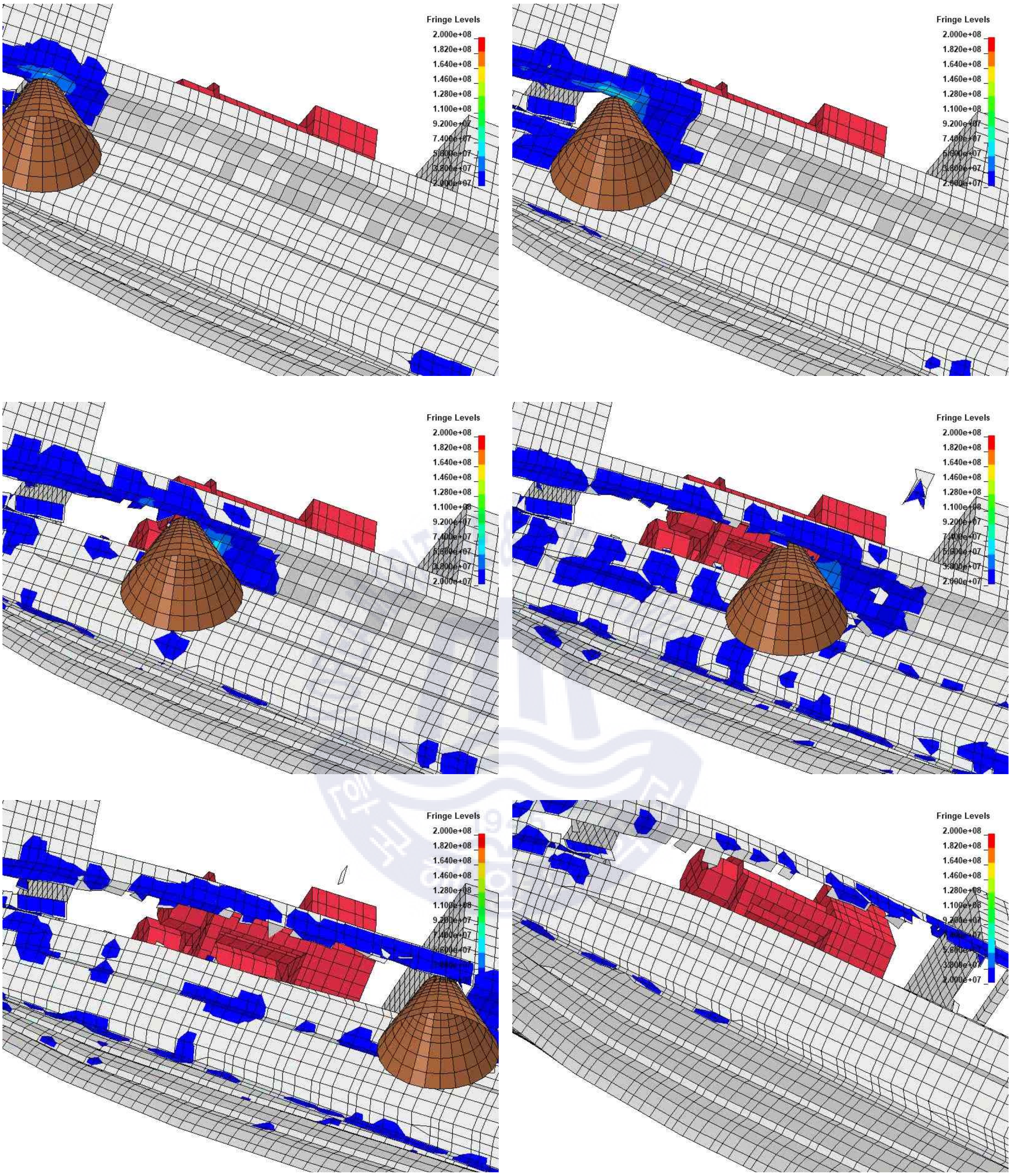
7.400e+07
5.600e+07
3.800e+07
2.000e+07

(b) close view



(c) zoom view of LNG tank room (inside)



(d) zoom view of LNG tank room (outside)

Fig. 29 Grounding response behavior under rock position 1.0m off the longitudinal centerline

Figures 30～31 show the penetration distance responses of colliding ship bow structure from the side hull of fuel tank room in the case of collision accidents and the penetration distance responses of a rock from the side-bottom hull of fuel tank room in the grounding accidents, respectively. Whereas the maximum penetration distance of the colliding ship bow structure from the side hull of fuel tank room was 0.30m based on the distance from the side hull to the fuel tank, 0.59m, in the collision accident with attack angle 70°, the maximum penetration distance of a rock from the side-bottom hull of the fuel tank room was 0.26m based on the distance of side-bottom hull to the fuel tank, 0.53m, in the grounding accident with a rock along 1.0m off the centerline.

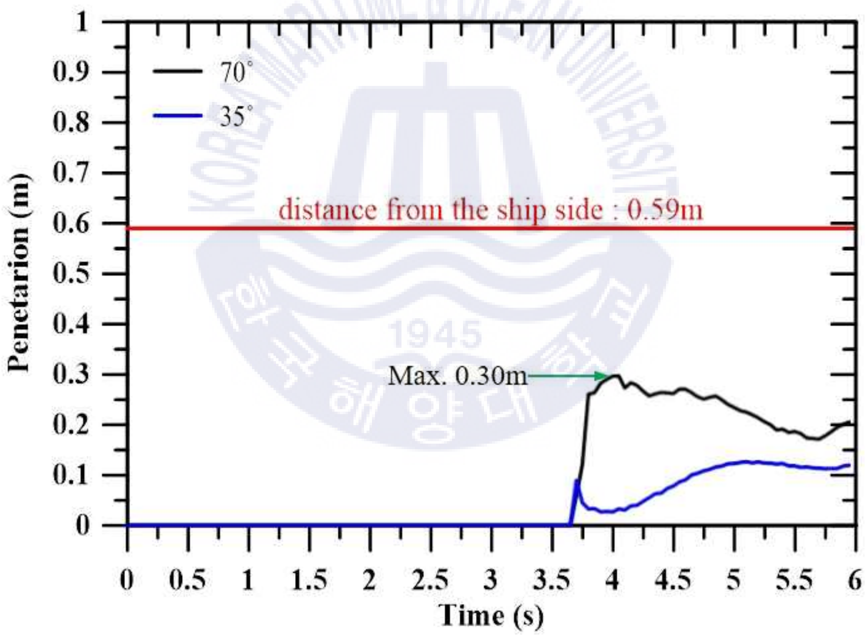


Fig. 30 Penetration distance response in full-scale ship collision simulation

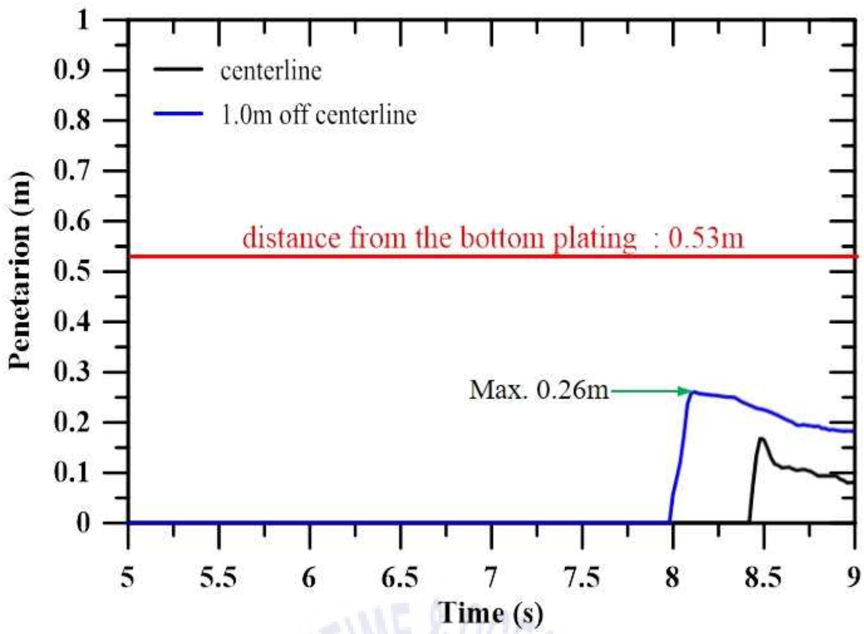


Fig. 31 Penetration distance response in full-scale ship grounding simulation

It could be found that a gap between the colliding ship bow and fuel tank was 0.29m in the case of collision, and that a gap between the rock and fuel tank was 0.27m in the case of grounding. From the full-scale ship collision and grounding simulations, Standards of Gas Fueled Ship for Collision and Grounding based on the IGF code applicable to ships weighing more than 500 tons in Table 1 could be modified to Suggestion of Standards of small FRP LNG Gas Fueled Ship for Collision and Grounding in Table 9. Even though this suggestion of standards is not suitable to every small Gas Fueled Ship in the world, it could be thought to be the cornerstone, and more diverse full-scale ship simulations will be necessary for the more generalized standards with diverse size and type of small gas fueled ship and fuel tank.

Table 9 Suggestion of Standards of small FRP LNG Gas Fueled Ship for Collision and Grounding

2. The gas storage tank(s) should be placed as close as possible to the centreline, and away from each of the following requirements. 1) minimum, the lesser of B/6.5 and 0.59m from the ship side; 2) minimum, the lesser of B/7.2 and 0.53m from the bottom plating; 3) not less than 530mm from the shell plating.	
gas storage tank position	1) distance from the ship side : 0.59m 2) distance from the bottom plating : 0.53m
penetration distance of collision and grounding	1) attack angle 70° : 0.30m, 35° : 0.13m 2) centerline : 0.17m, 1.0m off centerline : 0.26m

6. Conclusion

As IMO has been in place to regulate and strengthen the emission of SOx, NOx, CO2 and EEDI in recent years, interest in LNG fueled ship is on the rise since LNG fuel is cheaper than low sulfur oil, and its noxious emissions are noticeably small and can be satisfied with IMO environmental regulations. It is difficult to apply the standards for small LNG fueled ship based on IGF Code since the standards are applicable to ships weighing more than 500 tons. Therefore, the regulations of small LNG fueled ship are necessary to establish for the design criteria of the collision and ground accidents.

In this study, full-scale small FRP LNG fueled ship collision and grounding simulations were carried out according to the collision and grounding scenarios based on the risk analysis to make sure of reasonable design criteria of collision and grounding in small FRP LNG fueled ship with realistic and exact FRP fracture criterion and full-scale ship collision and grounding simulations, using highly advanced M&S system with FSI analysis technique considering several interface effects of ship in the sea water, and verifying fracture criterion of FRP plate compared with weight drop impact test results and its fracture simulations.

Fracture failure response analysis technique and fracture criterion of FRP plate was verified by comparing the fracture failure simulation results using laminated shell theory and MAT_ENHANCED_COMPOSITE_DAMAGE composite material in LS-DYNA code in highly advanced M&S system with weight drop impact test ones with total 8 FRP plates. It could be confirmed that fracture failure response behaviors were relatively very well realized to the weight drop impact test ones.

Full-scale small FRP LNG fueled ship was modeled by investigating its hull form, general arrangement and stability calculation, by calculating its structural members according to FRP structural criterion, and by comparing its hydrostatic characteristics using floating simulation and hydrostatic characteristic program calculation with stability calculation. Ship model was accurately floated and steady sailing ship propulsion force was also adopted for the reasonable full-scale ship collision and grounding simulations.

It could be confirmed that the collision behaviors between two ships and the grounding ones against a rock were well realized in the sea water by buoyancy, unlike those in the air. There occurred a large amount of damage some fracture on the stiffeners in the side of fuel tank room in the case of attack angle 70° than that of attack angle 35°, and in the side-bottom of fuel tank room in both cases of a rock position along the centerline and 1.0m off the centerline of the hull with a little bit larger damage in the former case than in the latter one. However, there was no direct impact damage to the fuel tank in both collision and grounding accidents. Whereas the maximum penetration distance of the colliding ship bow structure from the side hull of fuel tank room was 0.30m based on the distance from the side hull to the fuel tank, 0.59m, in the collision accident with attack angle 70°, the maximum penetration distance of a rock from the side-bottom hull of the fuel tank room was 0.26m based on the distance of side-bottom hull to the fuel tank, 0.53m, in the grounding accident with a rock along 1.0m off the centerline.

It could be found that a gap between the colliding ship bow and fuel tank in the case of collision and that between the rock and fuel tank in the case of grounding were 0.29m and 0.27m, respectively. From the full-scale ship collision and grounding simulations, Standards of Gas Fueled Ship for Collision and Grounding based on the IGF code applicable to ships weighing more than 500 tons was suggested for small FRP Gas Fueled Ship for Collision and Grounding. Even though this suggestion of standards is not suitable to every small Gas Fueled Ship in the world, it could be thought to be the cornerstone, and more diverse full-scale ship simulations will be necessary for the more generalized standards with diverse size and type of small gas fueled ship and fuel tank.

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