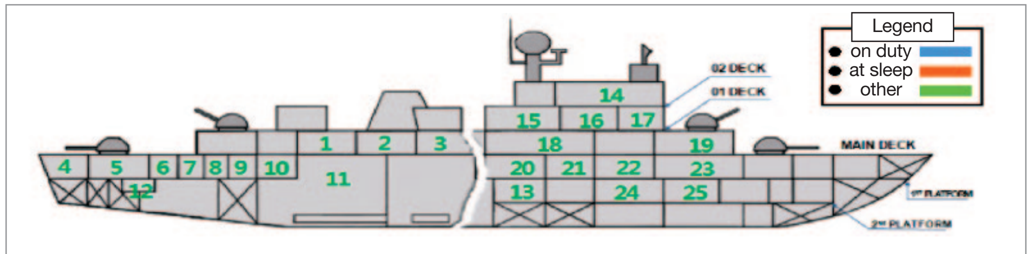
lieved that a torpedo caused the incident; furthermore, sentries testified they heard the noise and witnessed the flash of light. Considering all the observations above, these are consistent with the UNDEX bubble effect phenomenon.

4. Results of Postmortem and Surviving Patient Examinations



■ Casualty(40)
1. Crews' mess hall: 1 PO1 and 1 PO2
2. Machinery control room: 1 SCPO and 1 PO1
3. CPOs' mess hall: 1 SCPO
4. Rear gearing room: 1 CPO, 1 PO1, 1 PO2, and 1 PO3
5. 72 gun R/S: 1 CPO and 1 PO1
6. Machinery storage/Internal combustion admin. room: 2 PO1s
7. Decontamination room : 1 PO1
8. Rear head: 3 CPOs, 2 PO1s, and 1 seaman
9. CPO lounge(portside): 1 CPO
10. Machinery crew berthing: 4 CPOs, 2 PO1s, 4 PO2s, 3 PO3s, 1 seaman, and 1 seaman apprentice
11. Diesel engine room: 2 PO1s
12. Electricity storage: 1 PO3s
13. Gyro room: 1 PO1

■ Missing(6)
1 MCPO, 1 SCPO, 1 CPO, 1 PO1, 1 seaman, and 1 seaman apprentice

■ Survivor(58)
14. Bridge: 1 LT, 1 CPO, 3 PO1s, 1 PO2, and 1 seaman
15. Combat information Center: 1 LTJG, 1 CPO, 4 PO1s, and 1 PO3
16. Commanding officer room: 1 CDR
17. Communication center: 1 SCPO and 1 PO2
18. Officers berthing: 1 LCDR, 1 LT, and 1 LTJG
19. 41 gun R/S: 1 LT(s), 1 CPO, and 1 PO2
20. SCPOs' berthing: 5 SCPOs, 1 MCPO(s) and 1 CPO
21. Operation crew berthing: 1 CPO, 6 PO1s, and 1 PO1
22. Sail/Gunnery crew: 2 SCPOs, 1 PO1(P), 1 PO1, 1 seaman, 1 CPO, 3 PO1s, 3 PO2s, and 1 PO3
23. Deck admin room: 1 PO1
Front head(portside): 1 seaman, and 3 seaman apprentice
24. Elec. maintenance room: 1 PO1
25. Ordnance office: 1 SCPO

〈Figure III-4-1〉 Location of crew members in ROKS Cheonan at the time of the incident

All of the 58 survivors were hospitalized for any possible stress from the psychological shock by the incident as well as for physical injuries. Patients with light injuries such as hypothermia, bruises, and sprain got out of the hospital after 10~12 days of treatment. 6

CAT	TOT	Hypothermia	Laceration and bruise	Concussion	Sprain	Cord rupture/ teeth fracture
Light injuries	50	4	11	2	29	4

CAT	TOT	Neck bone, lumber vertebra fractures	Rib fractures	Thigh fracture	Clavicle fracture	Ankle fracture
Severe injuries	8	3	2	1	1	1

〈Table III-4-1〉 Patients status

patients among the 8 severely injured with rib fractures left the hospital after 1~2 months of treatment. But one patient with acute stress and two patients with fractures of the lumber vertebra, and thigh received treatment for over 2 months before leaving the hospital.

According to Dr. Shin from KAIST(who had studied the conditions of survivors of a torpedo attack), and the UK Investigation Team(which had previous experience with under water explosion), bubble effects may result in fractures, laceration, and bruises to the crew members because of the shock and the pressure wave. This observation could be utilized in proving that the phenomena were caused by bubble effects.

The postmortem analysis was conducted on the 40 bodies recovered during the search and rescue and the bow/stern salvaging process, in order to verify the existence of fragments, scorch marks, and direct causes of death. The JIG carried out medical examinations, visual analysis, X-ray filming, and other precise analyses.

1) Bodies Discovered during the Search and Rescue Activities(2)

Regarding the SCPO's body discovered during the search and rescue process on April 3rd, a postmortem examination was conducted on April 4 from 1000 to 1040. It was found that the SCPO's face and upper/lower jawbones, as well as the right arm's upper part, were fractured and that the right upper arm and its muscles were torn. There were several stab and torn wounds in the left facial region and the neck.

During the stern search and salvage process, the body of the SCPO was found near the machine control room's breakplane. A postmortem examination was conducted from 1953 to 2130 hours on April 7. SCPO's elbow was fractured, with several lacerations or scratch marks on the skin, but the body had not been hit by fragments or been punctured.

1) Bodies Found at the Stern(36)

For the 36 bodies collected during the internal search of the stern after salvaging operations had been complete, a postmortem analysis and X-ray assessments were performed from 1800 hours on April 15 to 0300 hours on April 16. Comparatively slight external wounds such as laceration, subcutaneous bleeding, bruises, and fractures were identified, and 5 bodies including 1 PO2, 3 PO1s and 1 seaman were discovered without any external wound.

Lacerations were found on the facial and occiput region. Subcutaneous bleeding, excoriation, and bruises were found on the overall body including the face, arms, legs, abdominal, ankles, and waist. The lumbar vertebra, temporal, and metatarsal bones were fractured. It must be noted that major damages on a body went from the right shoulder region, to the right upper arm, then to the right waist, and then to the right knee. Another body's major damages started from the left cephalic region, then moved down to the left shoulder, and then to the left arm. The single direction of wounds indicates that the hull was tilted to one side by an external force, and that the wounds occurred as the crew members fell to one side and hit the interior structures of the hull.

Overall, laceration, fractures, and bruises were found on the bodies, but no fragments or scorch marks were found. These external wounds did not seem to be the main cause of death. While the exact cause of death can be determined through autopsy, it was not conducted considering the opinions of the families of the deceased. The JIG assessed that the crew members were drowned rather than killed by external wounds. Based on the degree of decomposition, it was assessed that all of them had died around a similar time frame. The damage status is as follows.

CAT	Laceration	Excoriation	Subcutaneous bleeding	Bruise	Fracture	Cutting wound	Other
PAX	15	15	14	10	7	3	1 teeth loss, 1 skin rupture, and 1 dislocation

〈Table III-4-2〉 Results of postmortem examination and X-ray on 36 bodies

3) One Body Collected from the Stack

An SSU[8] member, while conducting underwater operations in order to hoist the stack which was fallen off from the stern, discovered a PO1 wearing BDUs in the stack at 2120 hours on April 22. The postmortem analysis of the PO1 was conducted on April 23, between 0930~1013 hours. As a result, lacerations on the PO1's left forehead and contusions on the right knee were discovered.

4) One Body Found at the Bow Gyro Room

During the initial drainage process, a PO1's body was found in the gyro room underneath the operation crews' berthing and in front of the gas turbine room during the initial drainage process. His body went through a postmortem analysis between 1703 and 1747 hours on April 24, and the JIG discovered fractures on the shinbones, crushed hyoid bone, and lacerations on the skin, soft tissue and left scalp area.

5) Sub-conclusion

Combined analysis of postmortem and surviving patients examination results indicates that burns, fragment injuries, or punctures did not occur, and that most bodies had light injuries such as fractures or lacerations. The conditions of injured crews included fractures, lacerations, and bruises. When it comes to the deceased members, it was assessed that injury unlikely caused the death, and the circumstances pointed to drowning as the most probable cause. When these bodies were found, they were wearing exercise clothing, workwear, or underwear, and they were located in berthing, lounges or heads. This indicates that they had died during off duty hours.

The observations on the bodies of the surviving patients identified injuries of fracture, laceration, and bruises, that are assessed to have resulted from falling to either right or left side and bumping against the hull structure. These are consistent with the phenomena of bubble effect.

8) SSU(Ship Salvage Unit): A special unit that carries out various tasks such as rescue missions on the sea, and removal of natural/artificial obstacles on harbors and watercourses.

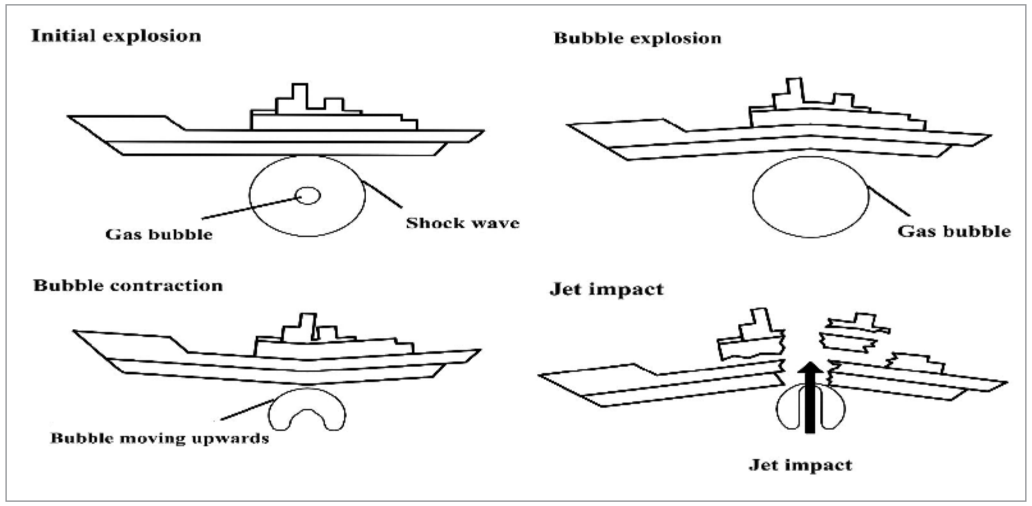
5. Explosion Type Analysis

The investigation on the cause of the sinking revealed that the hull of ROKS Cheonan was split by a strong non-contact underwater explosion. The propulsion device(the conclusive evidence) recovered from the seabed indicated that the underwater explosion was caused by a torpedo. Based on these results, this section focuses on estimating the performance of the torpedo(charge size) and the point(depth and location) of the explosion. The US and UK team estimated the charge weight and location with their own expert methods in support of the objective, and in basis of the US and the UK estimation, the ROK team carried out a simulation analysis.

1) Physical Aspects of Underwater Explosion

To facilitate the understanding on the cause of the sinking of ROKS Cheonan, the devastating effects of a bubble formed by an underwater explosion(below the hull) are shown in 〈Figure III-5-1〉.

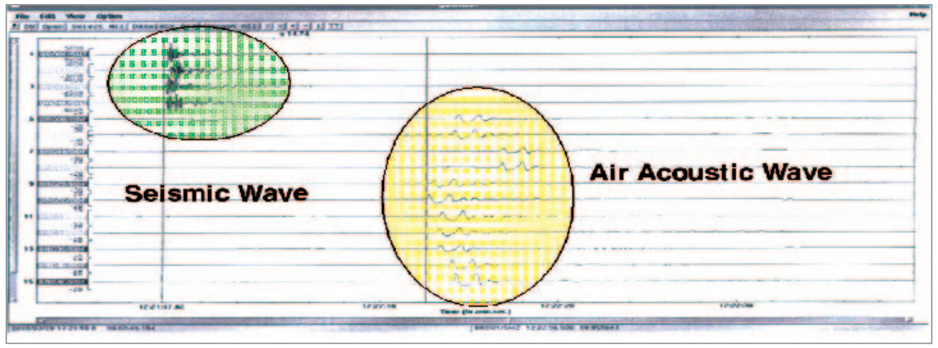
As an explosive charge is detonated below the hull, a shockwave is generated and impacts the hull after propagating in water at a very high speed. Although the peak pressure of the shockwave is very high initially, it gets attenuated very rapidly as the shockwave propagates in water. Moreover, since the shockwave travels outward in a spherical form, the actual impact on the hull is not severe. For these reasons, the damage inflicted by the shockwave is known to be not significant, causing only mild damages and malfunctions to on-board power supply and communication systems. After the shockwave release, the bubble is formed slowly, with lower pressure inside compared to the shockwave. As the bubble expands, the hull is deformed into a reverse V-shape under the force acting upward. After reaching the maximum expansion, the bubble begins to contract, pulling the hull downward to produce a V-shape deformation. As the contraction continues, the bubble collapses and a high speed water jet is formed at the lower part of the bubble. As the water jet becomes larger, it inflicts a heavy impact on the hull, and eventually severs the ship. Since the water jet impact is much more destructive than the other shockwave, most countries employ a non-contact underwater explosion weapon system that maximizes the bubble effect. More details on the underwater explosion is included in Appendix II.



〈Figure III-5-1〉 The progress of physical effects by bubble formed below the hull

2) Explosion Type Analysis(Charge Size and Explosion Location) by the US Team

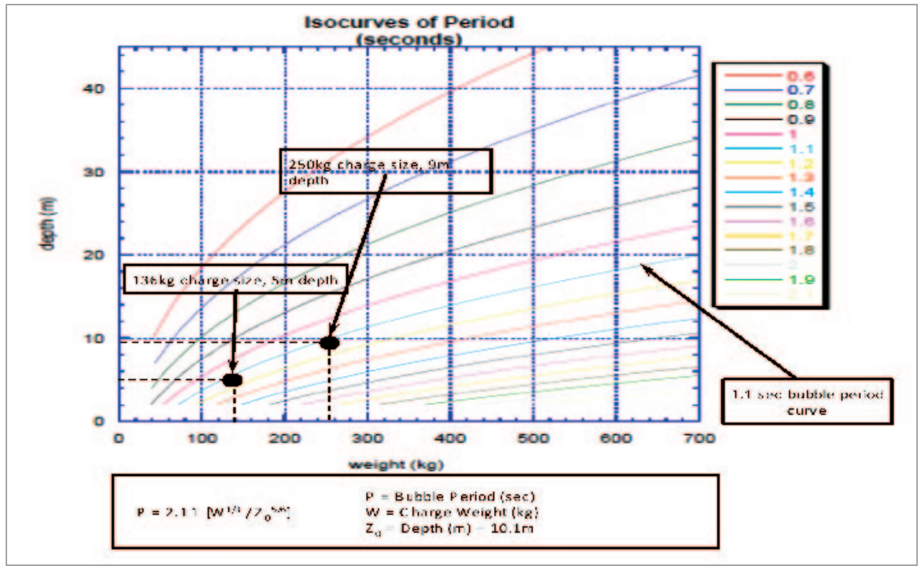
In order to verify the charge size and explosion location of the torpedo that severed ROKS Cheonan, the US team analyzed the seismic and acoustic waves detected from the seismic research center at the time of explosion as illustrated in 〈Figure III-5-2〉. 1.5 magnitude of seismic wave was identified at 4 seismic detecting stations located on Baekryong Island, and acoustic wave containing 2 acoustic pulses with 1.1 second interval was detected at 11 acoustic detecting stations. When an explosive detonates un-



〈Figure III-5-2〉 Detection results of seismic and air acoustic wave on the incident day

Detailed Analysis Results by Team

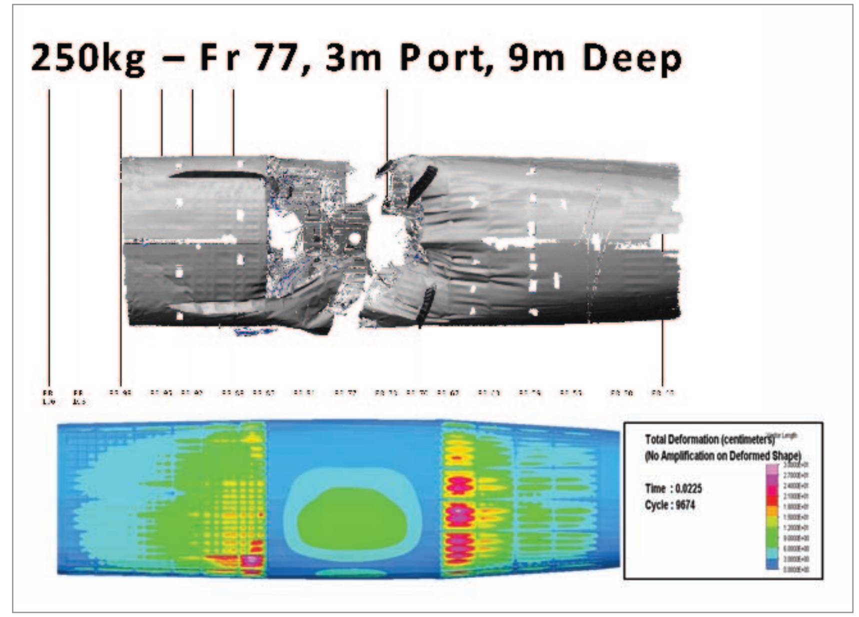
derwater, 2 acoustic pulse are generated; 1 initiated at the time of explosion, and the other produced upon the expansion of the bubble; the 1.1 second of interval represents the bubble period created by an underwater explosion. Based on the measured data, the charge weight and explosion depth are analyzed applying Willis formula, and the result is shown in 〈Figure III-5-3〉.



〈Figure III-5-3〉 Charge size and depth of explosion according to bubble periods

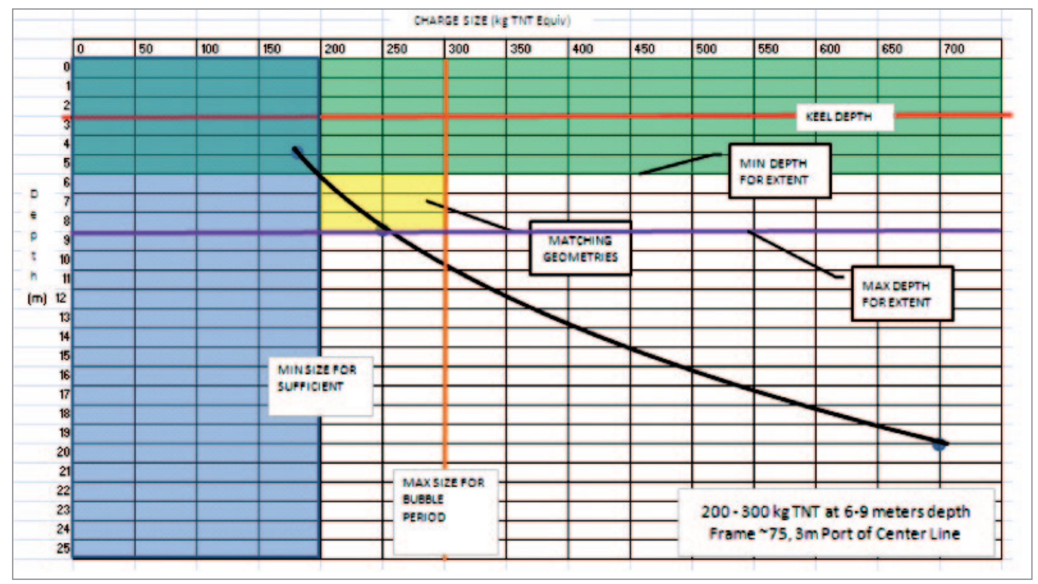
As a result of visual inspection carried out on the breakplane and hull bottom after the recovery of the hull, dishing was identified along with the damages and bending of the hull due to bubble effect. In order to analyze this phenomenon, an assessment on a possible charge size and depth sufficient to sever the hull was made by constructing a hull whipping computation model[9] for the shock resistance of the hull against the whipping effect. After comparing the actual measurements of the dishing on the hull bottom and the estimated numbers according to the deformation finite element analysis[10], it was concluded that TNT 250kg detonated below the gas turbine room in depth of 6~9m, 3m port from the centerline(See 〈Figure III-5-4〉).

9) Hull whipping computation model: A simulation model used to calculate the hull strength that can endure external shock.
10) Finite element analysis: A method of analyzing an object through a mathematial model made by dividing the object into a finite number of elements.



〈Figure III-5-4〉 Explosion type similar to dishing of ROKS Cheonan hull bottom

〈Figure III-5-5〉 depicts an analysis result considering depth, charge size, and internal shock model to produce bubble period 1.1 second, combined with the finite element analysis result on hull deformation.



〈Figure III-5-5〉 Result of examination on explosion type of ROKS Cheonan

The depth shown in 〈Figure III-5-5〉 is estimated to be 6~9m considering the longitudinal distribution of dishing depicted in 〈Figure III-5-4〉, and through the internal shock and bubble period analysis results, the charge size is assessed as TNT 200~300kg.

3) Explosion Type Analysis(Charge Size and Explosion Location) by ROK

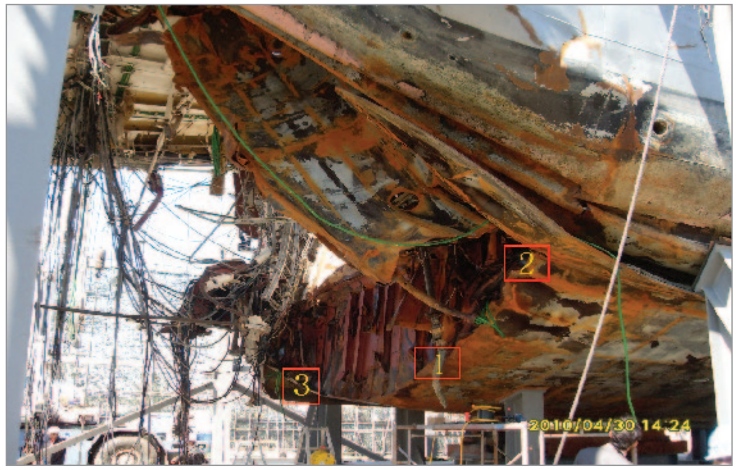
Taking the analysis results of the US and the UK team as a reference, the ROK team analyzed the actual damage pattern of hull, utilizing a simulation technique on the hull. During the process, the torpedo propulsion motor(conclusive evidence) was recovered and used as an additional evidence, and the explosion location of the US team analysis was reconfirmed through an analysis on the fractured surface of the hull.

(1) Analysis on the Direction and Location of the Explosion(Analysis on Breakplane)

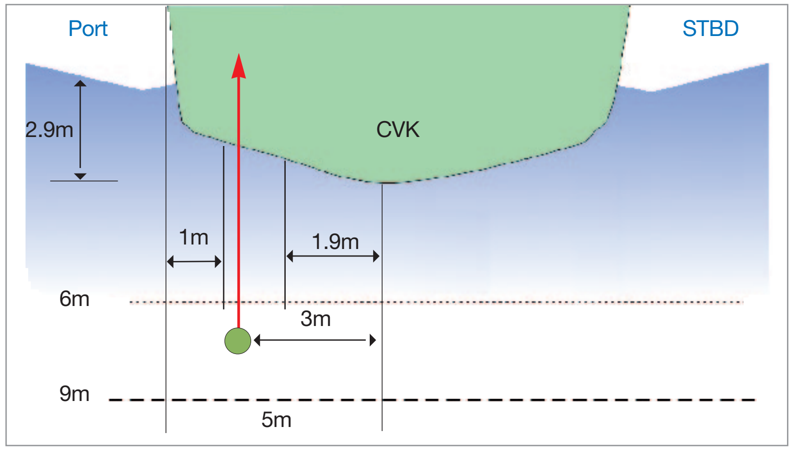
In order to confirm the direction and location of the explosion, the breakplane of the hull was observed, and based on those observations, the point of action and direction were analyzed.

As shown in 〈Figure III-5-6〉, samples of approximately 15cm x 15cm size were collected from three locations at the breakplane of the stern. All the collected samples were identified to be shear and brittle fractures, and revealed no signs of ductile[11] or fatigue fracture. Sample #2 shows shear fracture patterns, sample #3 displays a typical brittle fracture, and sample #1 presents a mixture of the two fractures. Also it was confirmed that the patterns showed only shear fracture between sample locations #1 and #2 and only brittle fracture between sample locations #1 and #3.

The detailed analysis on the breakplane of ROKS Cheonan(See Appendix III) revealed that an upward plastic deformation occurred in large curvature shape due to a strong explosion originating from the portside bottom, then a strong external force caused shear fracture. The origin of the fracture is estimated at 1.9m to the port from CVK. Thus, given that the hull is 5m in width on the port side, it could be estimated that an explosion took place between 1.9~5m to the port from CVK. The possible location of the explosion on the hull bottom was estimated to be 3m, which is the center of 1.9~4m from CVK(See 〈Figure III-5-7〉).



〈Figure III-5-6〉 Sample collection locations at fractured surface



〈Figure III-5-7〉 Possible range of explosion

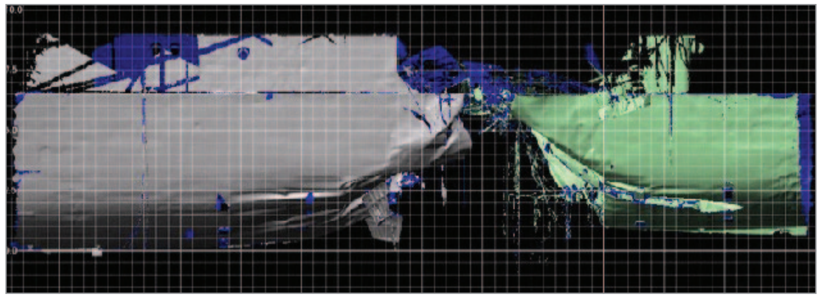
(2) Simulation Analysis on Explosion Type

Based on the location and direction of explosion derived from the aforementioned analysis on the breakplane, a simulation analysis was conducted in order to estimate the explosion type(charge size and depth) similar to the explosion that occurred in ROKS Cheonan incident.

Regarding the scope of the simulation analysis, a simplified model(partial modeling

11) Ductile fracture: As strength exceeding elasticity is exerted, an object gets over-stretched and fractured.

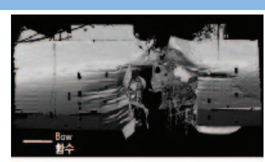
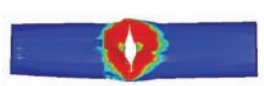
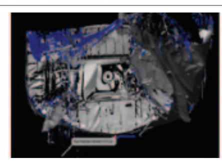
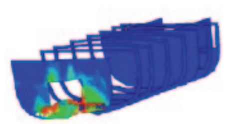
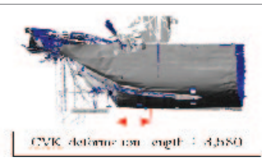
of the ship on the region of main damage, including hull, CVK, rib and bulkheads) was used to derive a result within a limited period of time. The simulation conditions with different charge size and location were set to recreate the damage similar to which is seen on ROKS Cheonan.



〈Figure III-5-8〉 Damage from the explosion seen on ROKS Cheonan

Three criteria were selected for a comparison of numerical analysis results with the actual damage presented in ROKS Cheonan, and the explosion types that satisfied all three as probable explosion types were nominated. 〈Figure III-5-9〉 shows the result of the comparison.

The simulation analysis on the charge weight of TNT 250kg resulted in depth of 6m as a possible explosion type. For TNT 300kg, the possible explosion type was at the depth

Criteria	Actual deformation	Simulation
Extent of hull bottom damage		
Deformation/ fracture at the stern breakplane bulkhead		
CVK deformation length from stern breakplane bulkhead		

〈Figure III-5-9〉 Three comparison criteria

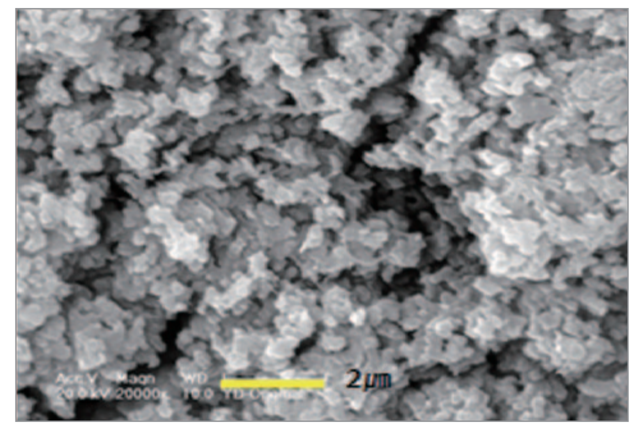
of 7m, and for TNT 360kg, the depth of 7m ~ 9m was selected as the possible explosion types to cause similar split pattern as ROKS Cheonan. More details regarding the simulation analysis are included in Appendix IV.

4) Analysis of Adhered Materials

Significant amount of the adhered white powder was found on the fractured surface. Also, white adhered material similar to the ones discovered at the fractured surfaces was collected on the propulsion motor. These adhered materials were on the surface of aluminum materials as well as on that of non-aluminum materials.

As a result of analyzing through SEM images, EDS, and XRD, the adhered materials found in ROKS Cheonan and propulsion section of torpedo were found to contain the same elements and they were porous agglomerates of fine particles of sub-micrometer size, and mainly consisted of amorphous oxides of aluminum(Al_xO_y) and moisture with a small portion of carbon, sulfur or sulfur compound, sand, and salt.

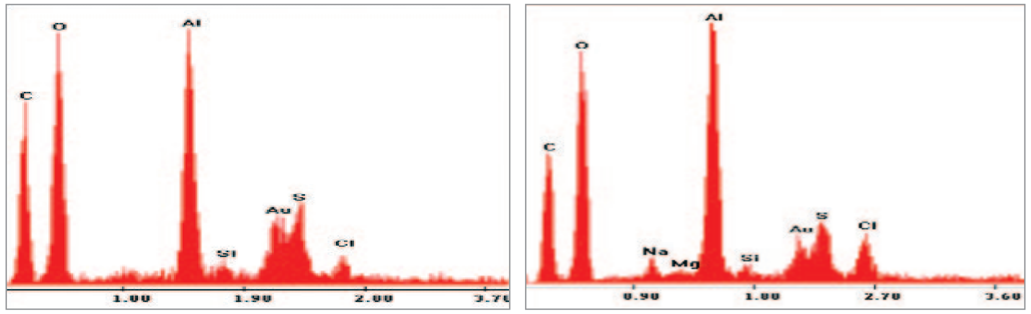
The substances adhered on the ROKS Cheonan hull and torpedo propulsion motor



〈Figure III-5-10〉 SEM image of adhered materials

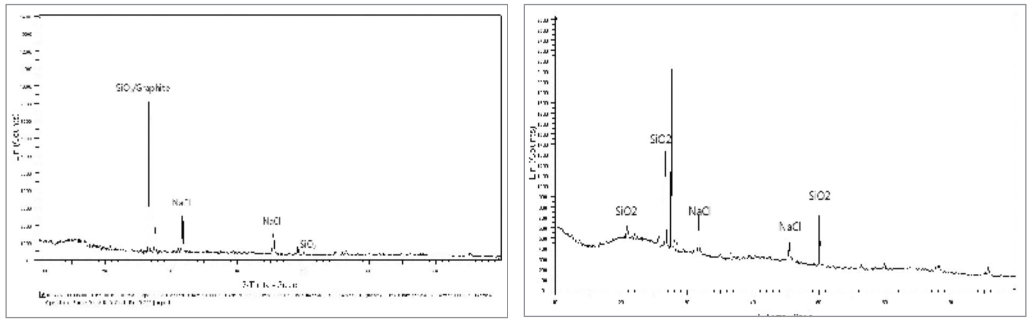
have been confirmed as the identical materials, consisted mainly of amorphous aluminum oxide. This led to the assessment that the adhered materials are the explosive residue from the underwater explosive charge containing aluminum.

The experiment result of the underwater explosion testing with small water tank, and the detailed analysis result on the adhered materials are included in Appendix II and V.



ROKS Cheonan   Propulsion part of torpedo

〈Figure III-5-11〉 EDS analysis result of adhered materials



ROKS Cheonan   Propulsion part of torpedo

〈Figure III-5-12〉 XRD analysis result of adhered materials

5) Sub-conclusion

The performance of the weapon system used in the ROKS Cheonan incident was analyzed through the results of US team analysis including detailed examinations on the acoustic and seismic signals, hull dishing, and internal shock by whipping, combined with the results of the ROK analysis such as inspections on the fractured surface(breakplane), and simulation analysis.

The result of the US team analysis showed that the possible explosion type (which can incur a similar damage as seen in ROKS Cheonan), is an explosion of TNT 200~300kg at a point of 3m to the port from the central bottom of gas turbine room, and at a depth of 6~9m.

Analysis result of ROK assessed that the explosion occurred at 3m port from the central bottom of the gas turbine room. As a result of simulations, the explosion type led ROKS Cheonan to sink was estimated to range in 250~360kg of TNT equivalent charge at a depth of 6~9m, and the explosive was defined as an aluminized underwater explosive according to the analysis on the adhered material.

In conclusion, when the analysis on explosion type was taken into consideration along with the examination on the recovered conclusive evidence, it can be analyzed that ROKS Cheonan was sunk due to bubble effect caused by a torpedo, loaded with 250kg explosive, detonating in a non-contact manner, at a depth of 6~9m, and at a point of 3m to the port from the center of the gas turbine room.

6. Analysis on Shock Response to Underwater Explosion

At the initial stage of investigation, the whipping response of the hull girder of ROKS Cheonan from an underwater explosion gas bubble pulse was conducted for identifying possible cause of the incident with no explosion type(charge sizes, standoffs, etc.) defined. This analysis was based on the 1-dimensional beam analogy method to swiftly analyze forms of explosion that can cause the type of destruction inflicted on the ROKS Cheonan. Later on, damage patterns of the hull structure were analyzed in detail on the probable explosion condition provided by the Explosive Analysis Team. Comparative analysis, between the estimated damage patterns and the actual damage patterns observed in the ROKS Cheonan, was performed to evaluate the validity of the given explosion condition. A 3D analysis on close-in proximity underwater explosion was established by the detailed modeling on the structure.

1) Underwater Explosion and Shock Response Method

(1) General Shock Response Analysis Method

As for design of a naval ship, an underwater explosion is considered the most serious threat in combat survivability. However, in order to withstand a close-in underwater explosion severe enough to cause the separation such as the one inflicted on ROKS Cheonan, the design would become unrealistic for a ship to carry its structure and equipments. Therefore, a non-contact underwater explosion from a relatively long distance is assumed in design standard for underwater explosion condition.

For a long distance non-contact underwater explosion, the shockwave and the bubble can be considered as separate entities. When considering shockwave from a long distance, the designs of the internal equipments are primarily taken into account, and not overall structure, because the overall structure of the ship is strong enough to withstand it. Generally, the specific analysis code, developed by doubly asymptotic approximation[12], is employed for the analysis of the shock response effect on the ship(including the ship structure and its equipments).

The effects of the bubble expansion and contraction are related with the main strength of the hull(longitudinal strength), and since the lengthwise profile overwhelms the widthwise profile in the ship structure, the hull can be considered as the 'beam'. The abrupt hogging[13] and sagging[14] of the hull girder under the effect of bubble expansion and contraction is defined as whipping, and the calculation for the whipping is referred as whipping analysis in ship design. The software employed to analyze the effect of the bubble pulse on the hull without the effects from the shock wave is called a whipping analysis code.

It is worth a note that the long distance non-contact underwater explosion is not reflected in the ship design as the phenomenon such as water jet, generated by the bubble collapse upon bubble's contact with the hull, cannot occur in that condition.

(2) Shock Analysis Method For ROKS Cheonan

Normally, for a standoff underwater explosion, the shockwave and bubble effect are explained separately in designing a ship. For a close-in underwater explosion, the hogging and sagging caused by the bubble and the subsequent bubble effect(generated by the asymmetric contraction of the bubble through contact with the hull during the expansion) all occur almost simultaneously and interrelatedly, so they cannot be considered separately. The explosion that led to the sinking of ROKS Cheonan was assessed as a close-in underwater explosion, and the JIG had to consider all of these factors listed above; therefore, the JIG conducted a two-step analysis. First, since the ship's loss of longitudinal strength contributed greatly to the fracture of the ship, a 1-dimensional whipping analysis based on the beam analogy method[15] was conducted. This was done in the early stage of the investigation to swiftly analyze what kind of explosion could have caused a destruction found in ROKS Cheonan.

A 3D analysis using hydrocode considered the hull, water, air, explosive charge, and explosive effects to include the majority of impacts produced by a close-in underwater explosion. The hydrocode refers to an appropriate analysis code category for fluid-structure coupling, rapid deformation and destruction analysis. For the 3D analysis, the detailed finite element modeling of the ship was prepared from the early phase of the investigation; the actual analysis began after the probable explosion types were selected. It was assessed that the major process causing the separation of the hull could be derived from the analysis since it would allow the consideration in combined effects of the shockwave, and the expansion and the contraction of the bubble. The water jet causes the damage to the ship through the complex effects of the high speed water ejection and the dispersion of water; even though it is limited by current numerical analysis technology to encompass all the effects, it was believed that indirect effects such as the event sequence of the incident could be evaluated through the 3D analysis.

2) Whipping Response Analysis of Hull Girder

Through the whipping response analysis, the longitudinal strength of the hull girder of ROKS Cheonan against the repeated bubble expansion and contraction caused by an underwater explosion was investigated from the perspective of ultimate strength. 〈Table III-6-1〉 summarizes main specifications of ROKS Cheonan.

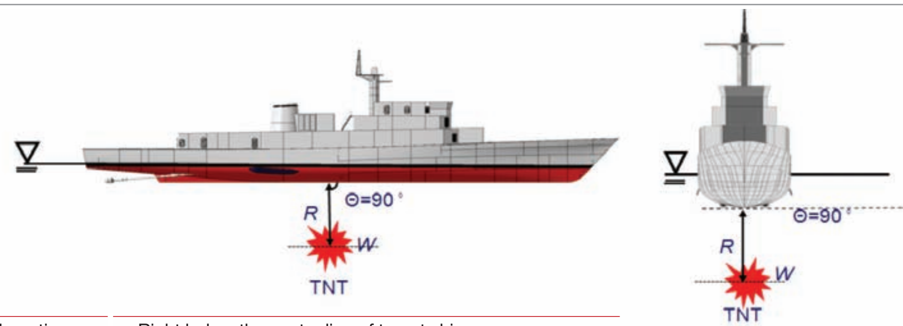
Items	Specs
Length overall	88.32m
Length between perpendiculars	83.47m
Width	10.0m
Depth	6.2m
Mean draft at full load	2.88m
Displacement at full load	1,223tons

〈Table III-6-1〉 Main specifications of ROKS Cheonan

12) Doubly asymptotic approximation: A kinetics technique that analyzes the interaction and phenomenon of water and ship structure in case of an underwater explosion.
13) Hogging: The bending phenomenon of a hull in which the center of the ship is lifted compared to the stern and bow.
14) Sagging: The bending phenomenon of a hull in which the center of the ship sags compared to the stern and bow.
15) Beam analogy method: A method used to calculate the sudden bending of the hull(caused by an underwater explosion) by considering the hull as a beam.

(1) Underwater Explosion Conditions for Whipping Response Analysis

〈Figure III-6-1〉 shows underwater explosion conditions for the whipping response analysis. As shown in the figure, hypothetical situations under which charge weights of 45kg, 100kg, 150kg, 200kg, 250kg, 300kg, 350kg, and 400kg of TNT-equivalent explode right below the center line of target ship at standoff distance of 10m, 20m, 30m, and 40m were applied.

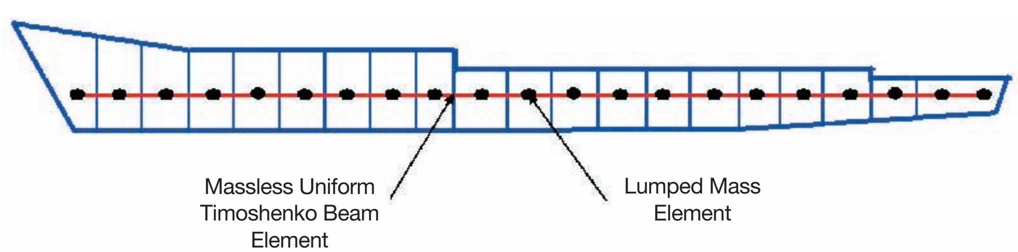


Location	Right below the center line of target ship
Explosive	TNT
Charge Size	45kg, 100kg , 150kg, 200kg, 250kg, 300kg, 350kg, 400kg
Distance(R)	10m, 20m, 30m, 40ma

〈Figure III-6-1〉 Underwater explosion conditions for whipping analysis

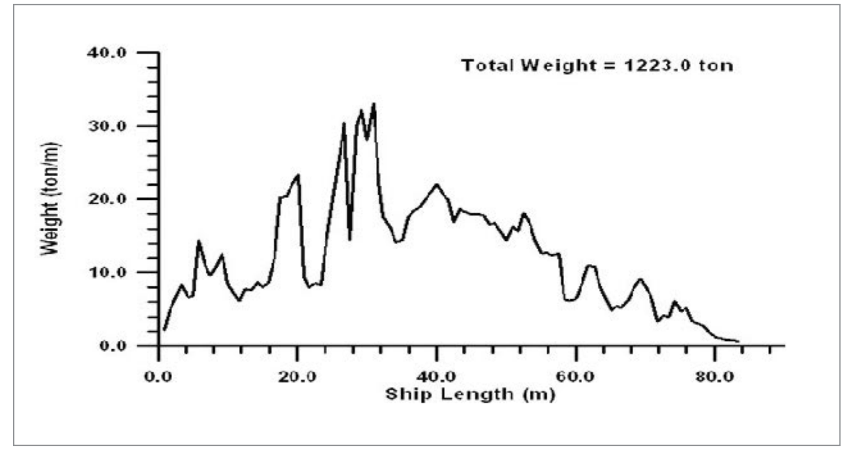
(2) Analysis Methods & Assumptions

For the analysis, the JIG considered the hull as a Timoshenko beam(a simple beam theory incorporated with shear deformation and rotational inertia effect) and rendered it as a finite element model with 25 nodes[16] and 24 equilateral uniform beam elements as shown in 〈Figure III-6-2〉. The JIG treated the weight of ROKS Cheonan(including added water weight) as concentrated at the nodes and assumed that the beams connecting these nodes had zero mass. The full load condition was assumed for ship loading, and 〈Figure III-6-3〉 depicts the weight distribution in the longitudinal direction.



〈Figure III-6-2〉 Beam whipping analysis model

16) Node: The point that connects between elements of the structure in analysis model.



〈Figure III-6-3〉 Weight distribution along the ship in fully-loaded condition

The 2nd section moment, effective shear coefficient, modified bending rigidity coefficient for each modes of oscillation, 2D added water weight, and modified 3D added water weight coefficient of the Timoshenko beam element were calculated using the vibration analysis program VIBHUL[17] developed by the Korea Institute of Machinery and Materials(KIMM).

For the whipping response analysis, the program UNDEX_WHIP, developed by the KIMM based on the Hicks' bubble behavior analysis theory and the mode superposition method, was used. To calculate the whipping response by the mode superposition method, the JIG only considered the first 5 wetted vertical vibratory modes. The reasons are that the vibration analysis based on the beam analogy method illustrates relatively accurate results only for the first 5~6 modes and that the whipping response of the hull girder is governed by these lower vertical vibratory modes. The damping[18] effects were neglected.

Also, the JIG only considered the impact of 1st bubble pulse for calculation of hy-

17) VIBHUL: The program developed by KISTI for analyzing the vibration of the hull when designing, constructing, and commissioning a ship.
18) Damping: The material returning to the original(normal) state from phenomenon of the bending, vibration, etc.

drodynamic impact on hull, because the Hicks' bubble behavior analysis theory only shows a relatively accurate result on the 1st cycle of the bubble. For calculation of the hydrodynamic impacts due to the bubble behavior, the JIG considered the free surface effect and the vertical migration of the bubble.

Before the whipping, ROKS Cheonan is assumed to have been afloat in calm with draft of 2.88m, the average when in full load. After the start of the whipping motion, the change in draft was neglected.

Considering the 1st bubble pulsation period calculated on each underwater explosion condition, the whipping response of the hull girder was calculated in two seconds, because it was assessed that two seconds worth of analysis is enough to reveal the property of the whipping response of ROKS Cheonan hull.

In order to investigate the longitudinal strength stability of the hull girder against the underwater explosion bubble pulse from the perspective of the ultimate strength, the calculated whipping bending moment and the ultimate bending moment were compared. The ultimate bending moment was calculated with the program ULSAN, which was developed by Ulsan University based on the Smith theory.

(3) Analysis Result

① Wetted Vertical Vibration Analysis Result

The analysis results of the wetted vertical vibrations on the load conditions of ROKS Cheonan are listed in 〈Table III-6-2〉. As shown in the table, the minimum difference in natural vibration of the hull girder is 2.32Hz, and its mode shape is 2 node.

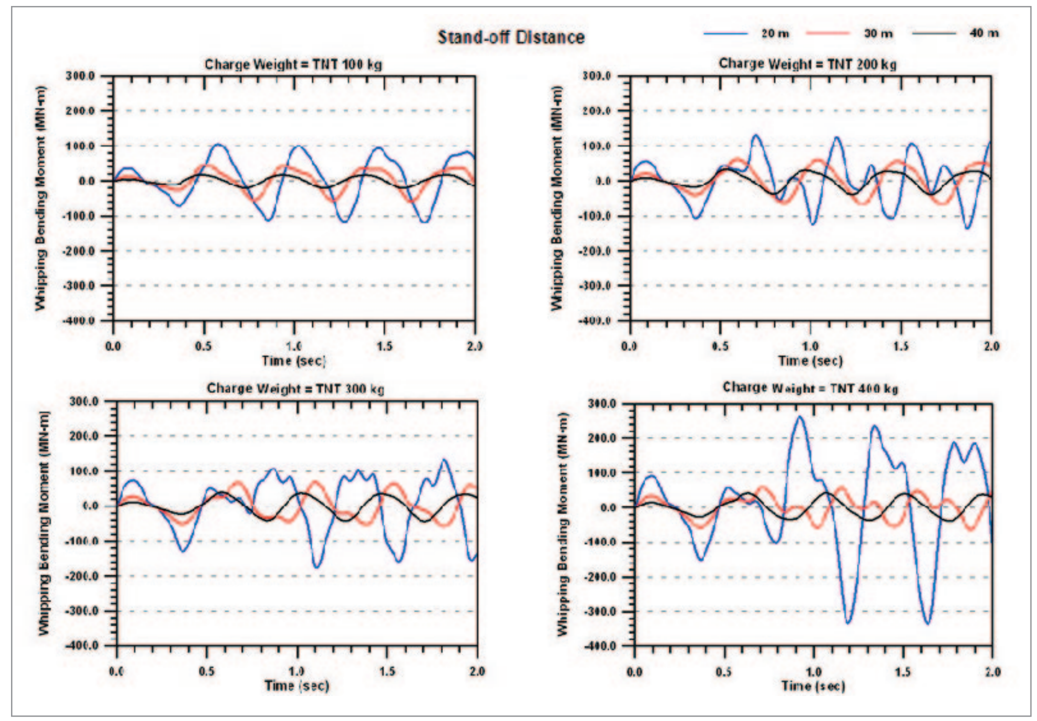
#	Vibration mode	Calculated(Hz)
		Full load condition
1	2-node vibration form	2.32
2	3-node vibration form	4.74
3	4-node vibration form	7.71
4	5-node vibration form	10.41
5	6-node vibration form	13.40

〈Table III-6-2〉 Natural frequency analysis in a fully-loaded condition

② Calculation Result on Whipping Bending Moment

Of the considered underwater explosion conditions, the JIG excluded that of standoff distance at 10m from the whipping analysis. The reason for that is, in order for the Hicks' bubble theory to hold true, the explosion depth has to be at least 2.5 times deeper than the maximum width at the waterline. Since ROKS Cheonan's max width at the waterline is 10m, in order to get a valid whipping analysis, the explosion depth must be at least 25m(standoff distance of 22.12m); therefore, in principle, it needs to exclude standoff distance of 20m also, but since it is close enough to the limit line and the conditions were assessed to be valuable for us to conduct the analysis, the analysis was conducted in that condition.

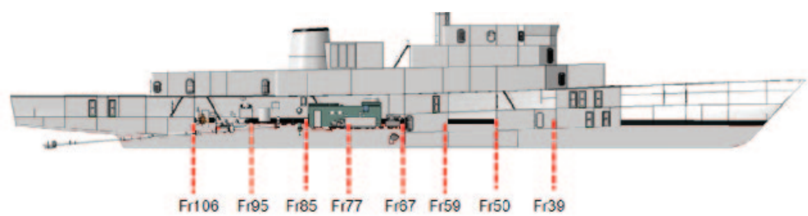
In 〈Figure III-6-4〉, the calculated whipping bending moments from the center of ROKS Cheonan over time was plotted for charge weight of 100kg, 200kg, 300kg and 400kg. As shown in the figure, the whipping response of the hull girder is mostly governed by the first vertical vibratory mode, and if the charge weight is the same, one can see that the shorter the standoff distance, the larger the whipping bending moment. Especially, if



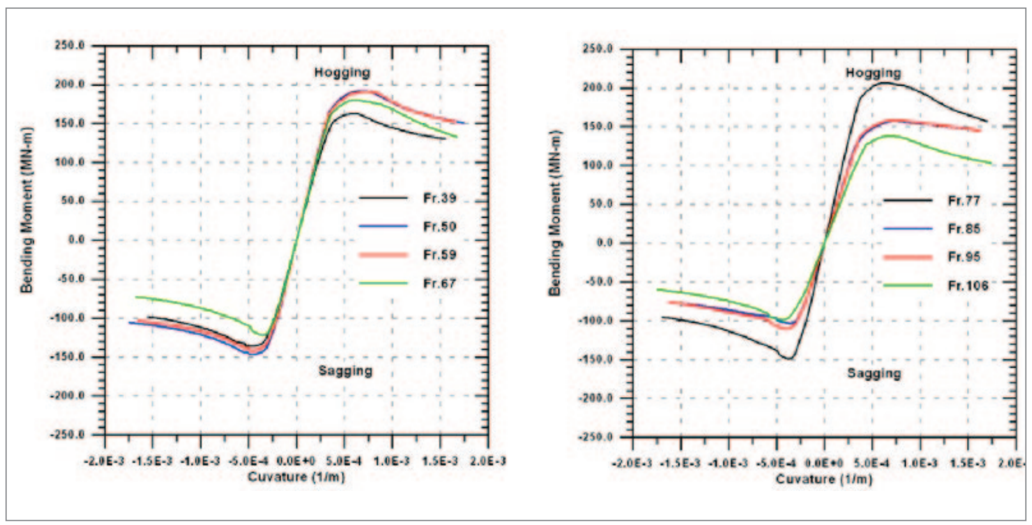
〈Figure III-6-4〉 Calculated whipping bending moments for different charge weights and standoff distances the charge weight is 400kg and 20m away, the whipping bending moment is a lot bigger than when the standoff distance is 30m or 40m away.

③ Ultimate Bending Moment Calculation Result

As shown in 〈Figure III-6-5〉, ULSAN was used to calculate the ultimate bending moments on the 8 frames[19]. In 〈Figure III-6-6〉, the JIG calculated curvature-bending moment for each section, and the resulting ultimate bending moments are summarized in 〈Table III-6-3〉. As shown in the figures and the table, ROKS Cheonan was more vulnerable to the sagging than the hogging.



〈Figure III-6-5〉 Frame locations calculated in ultimate bending moment



〈Figure III-6-6〉 Curvature-bending moments for each frame

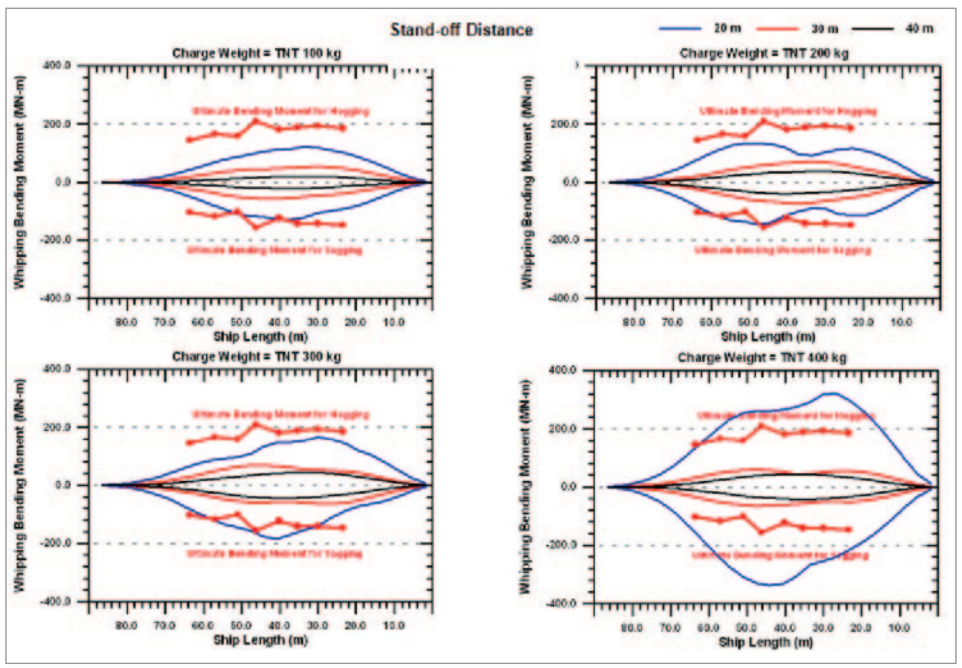
19) The concentrated area for this analysis was between Frame 67 and Frame 85 because of the lost gas turbine room and other adjacent compartments.

Frame location	Ultimate bending moment(: 10^6 N-m)	
	Hogging	Sagging
Frame 39	185.7	147.4
Frame 50	194.4	141.3
Frame 59	188.5	141.0
Frame 67	182.0	122.7
Frame 77	210.7	156.0
Frame 85	159.3	100.4
Frame 95	165.8	116.2
Frame 106	144.9	103.2

〈Table III-6-3〉 Ultimate bending moments for each frame

④ Results for Longitudinal Strength Stability Review

In order to examine the longitudinal strength stability of the hull girder, the JIG compared the maximum whipping bending moment with the ultimate bending moment for charge weights of 100kg, 200kg, 300kg, and 400kg, and the result is shown in 〈Figure III-6-7〉. As shown in the figure, for TNT charges of 100kg, 200kg, and 300kg, hogging, for



〈Figure III-6-7〉 Comparison of whipping bending moments and ultimate bending moments for various charges up to 20m, is sufficiently stable in perspective of the ultimate strength, but for sagging, TNT charge of 100kg at standoff distance of 20m can cause damage to the longitudinal members which contribute to the longitudinal strength of ROKS Cheonan hull girder.

(4) Sub-conclusion

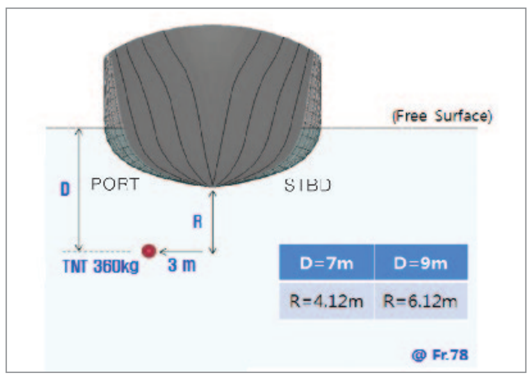
Through the whipping response analysis on ROKS Cheonan hull experiencing the bubble pulsation from the repetitive expansion and contraction due to underwater explosion based on the 1-dimensional beam analogy method, a TNT charge of above 100kg, if exploded under the center of ROKS Cheonan and at a standoff distance of 20m, is assessed to be able to cause a massive whipping bending moment bigger than the ultimate bending moment in some frames of ROKS Cheonan. This can cause a severe damage to longitudinal members which contribute to the longitudinal strength of the hull girder.

3) Close-in Underwater Explosion Shock Analysis

With 2 close-in underwater explosion conditions provided by the Explosive Analysis Team, the JIG conducted a 3D simulation of the fluid-structure interaction of the hull. After comparing the calculated damage and the actual damage of ROKS Cheonan, the JIG tried to deduce how ROKS Cheonan was sunk.

(1) Conditions of Underwater Explosion

Conditions of a close-in underwater explosion are shown in 〈Figure III-6-8〉. As shown in the figure, the conditions included TNT charge of 360kg at a depth of 7~9m[20] near frame 78(2 frames(1.2m) away from frame 76 that is located at the longitudinal center of detached gas turbine room), and the explosion point was 3m on the portside from the centerline.



〈Figure III-6-8〉 Conditions for a close-in underwater explosion analysis

20) The simulation for close-in underwater explosion analysis was conducted under the condition of TNT 360kg charge size detonating at depth of 7 and 9m,(these were the conditions for generating the most similar deformation pattern) and TNT 360kg is included in the explosion range for high performance explosive of 250kg.

(2) Analysis Method & Assumptions

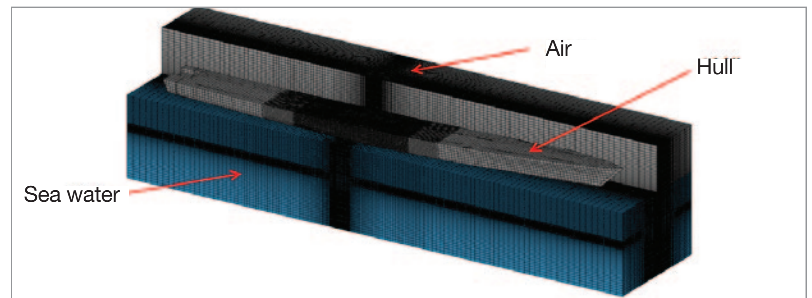
Before the underwater explosion, the assumption was that ROKS Cheonan was at full load and floating over calm water with mean draft. Since structural response was considered, which happens at a very short time period, damping effect was ignored.

For the analysis, the JIG used LS-DYNA Version 971[21], a commercial program.

In order to consider the fluid-structure interaction, the JIG included explosives, sea water, ship interior, and the air above the free surface as factors in modeling, and utilizing the Multi-Material Arbitrary Lagrangian Eulerian fluid-structure coupling analysis technique. The JIG assumed the form of the explosion to be a sphere.

(3) Analysis Model

All finite element and other relevant information are shown in 〈Figure III-6-9〉. Since comprehensive finite element model includes over 3 million nodes and elements as listed in the table of 〈Figure III-6-9〉, 16 Xeon E5430 2.66GHz CPUs were used to conduct the calculation. The following describes models for the ship structure, charge, and fluids(seawater and air).



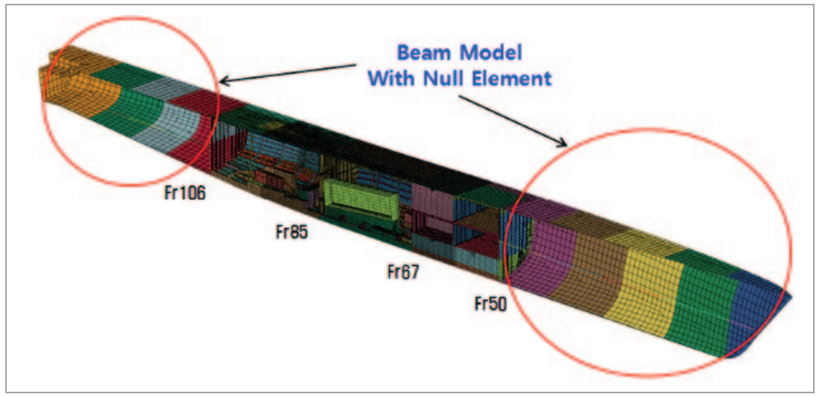
Item		360kg, Depth 7m	360kg, Depth 9m
Node No.		3,250,718	3,340,126
Element No.	Shell (for Ship)	158,826	158,826
	Beam (for Ship)	84	84
	Rigid Link (for Ship)	1,616	1,616
	Solid (for Fluid)	3,029,820	3,118,524
	Total	3,190,346	3,279,050

〈Figure III-6-9〉 Comprehensive finite element analysis model

21) The program used to describe and analyze the phenomenon that occurs in a short period of time. It is usually used for testing ground vehicle mobilization.

① Analysis Model for Hull

The analysis model on the hull is shown in 〈Figure III-6-10〉. The main objective of this analysis is to simulate the damage to the gas turbine room and to identify the cause of gas turbine detachment. Therefore, the JIG made a detailed model for the gas turbine room and the adjacent compartments(Frame 50 ~ Frame 106), and the remaining parts were modeled in equivalent Timoshenko beam elements. The JIG used a Rigid Link element[22] between null elements[23] without mass, rigidity, and other beam elements in order to maintain the original form. Also, for the ship structure modeling, the JIG only considered up until the main deck which contributes to the longitudinal strength. The openings such as soft patch at the upper main deck of gas turbine room have been excluded and replaced with the plate of equivalent rigidity.

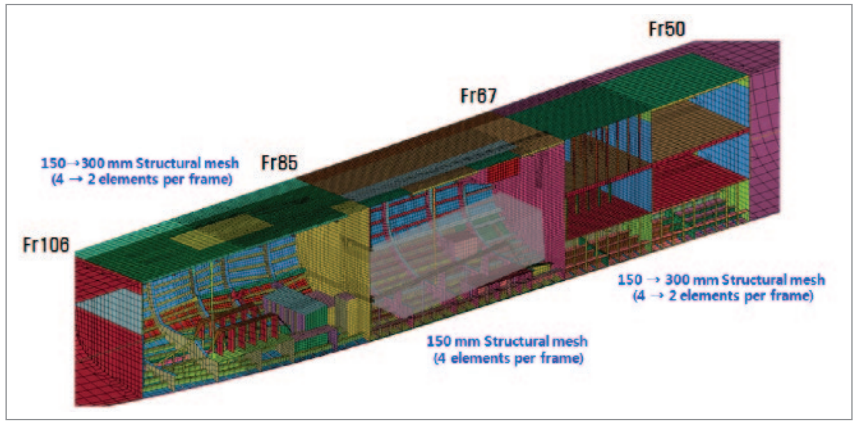


〈Figure III-6-10〉 Finite element analysis on the hull

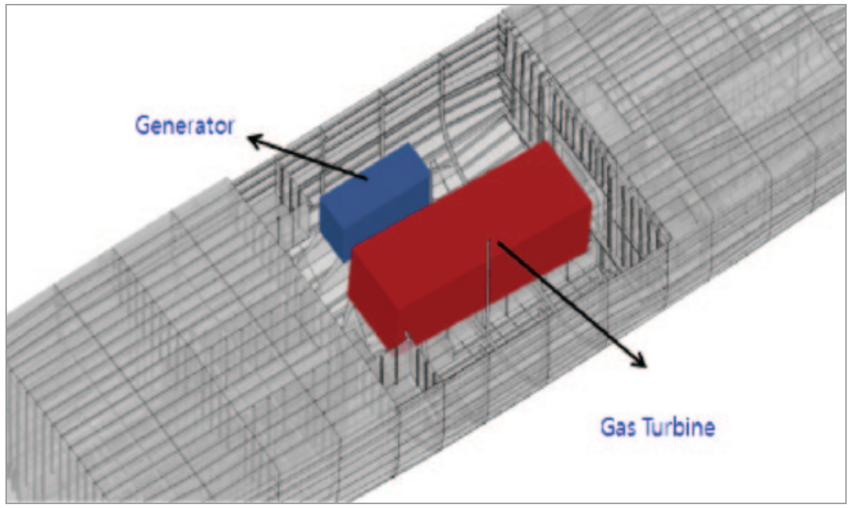
〈Figure III-6-11〉 shows the detailed modeling in the center of the ship structure between Frame 50 and Frame 106, the main area of interest for the analysis. As shown in the figure, for the gas turbine room, four elements were modelled for each frame(=600mm), and 2 elements between frames for the adjacent compartments that are further away from the gas turbine room. In order to include damages to the stiffeners along with other shell members, the JIG modelled all the stiffeners as a shell element. Also, the gas turbine, the generator, the diesel engine, and the reduction gear struts were modelled. As shown in

22) Rigid link element: An element that links the null element and the load element for deformation analysis in case of an impact.

23) Null element: An element in a ship design that does not have mass or rigidity, which is used to maintain the shape of the hull.



〈Figure III-6-11〉 Detailed modeling through Frame 50 to Frame 106



〈Figure III-6-12〉 Modeling for gas turbine and generator

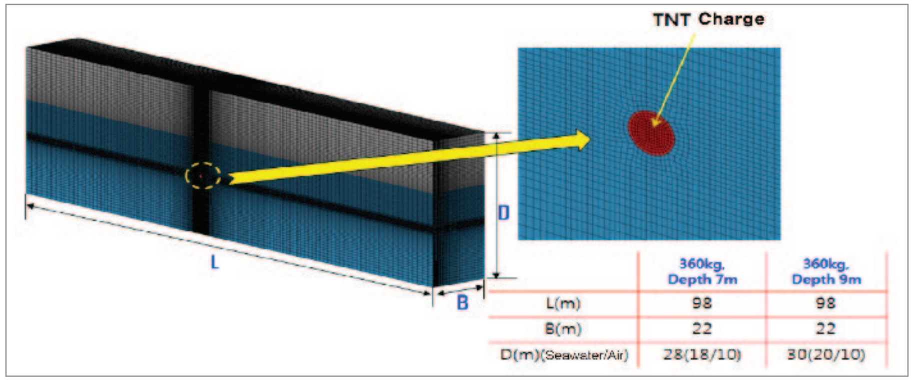
〈Figure III-6-12〉, the gas turbine and the generator were modelled almost to the exact specification with 3D rigid blocks.

For the analysis of the damage, the materials of the shell were modelled to be carbon material, in order to consider the strain rate effect(possible to be included in Cowper-Symonds model) that corresponds to 'Piecewise Linear Plasticity Material Model, LS-DYNA Material No. 24.

② Analysis Model for Charge, Seawater, and Air

The model for charge, seawater and air is shown in 〈Figure III-6-13〉. The explosive charge was modeled as Euler[24] element that has Jones-Wilkins-Lee(JWL)'s equation of state(EOS), while seawater and air were modeled as Euler element subject to polynomial and Gruneisen EOS. The height and width of box-shaped fluid model were set to encompass maximum size bubble in the model(that is, considering the maximum radius of the bubble in given underwater explosion conditions).

As seen in 〈Figure III-6-13〉, the height of fluid area would be 28m(seawater 18m, air 10m) at explosion depth of 7m, and 30m(seawater 20m, air 10m) at depth of 9m. The width of fluid area was set as 22m in both explosion depths. The length of the fluid area was modeled 98m, sufficient to cover the longitudinal length of ROKS Cheonan.



	360kg. Depth 7m	360kg. Depth 9m
L(m)	98	98
B(m)	22	22
D(m)(Seawater/Air)	28(18/10)	30(20/10)

〈Figure III-6-13〉 Modeling for charge, seawater, and air

(4) Analysis Result and Discussion

Regarding the 1st bubble pulse period of the considered two close underwater explosion conditions, that each explosive of 360kg TNT equivalent explodes at depths of 7m and 9m, an analysis was going to be executed for 2 seconds on both of the conditions.

However, as shown in 〈Figure III-6-14〉, an analysis on the condition that an explosive of 360kg TNT equivalent explodes at a depth of 9m revealed that the projected damage level is minimal compared to that of ROKS Cheonan, and hence, an analysis carried out until 0.9 second for this condition.

The side view observation of the hull response and bubble behavior according to the explosion of an explosive of 360kg TNT equivalent at a depth of 9m is depicted in 〈Figure III-6-15〉 along with representative time periods. As shown in 〈Figure III-6-15〉, since it is a close underwater explosion, the weight generated by the shockwave and bubble behavior is condensed and acts specifically upon the gas turbine room and the compartments in adjacent. Also, the occurrence of hogging and sagging of the hull as a result of the expansion and contraction of the bubble can be clearly observed.

Based on the analysis result of an explosion of 360kg TNT equivalent at a depth of 7m, separation and loss of gas turbine room and the sequence of events leading to the sinking can be explained in detail.

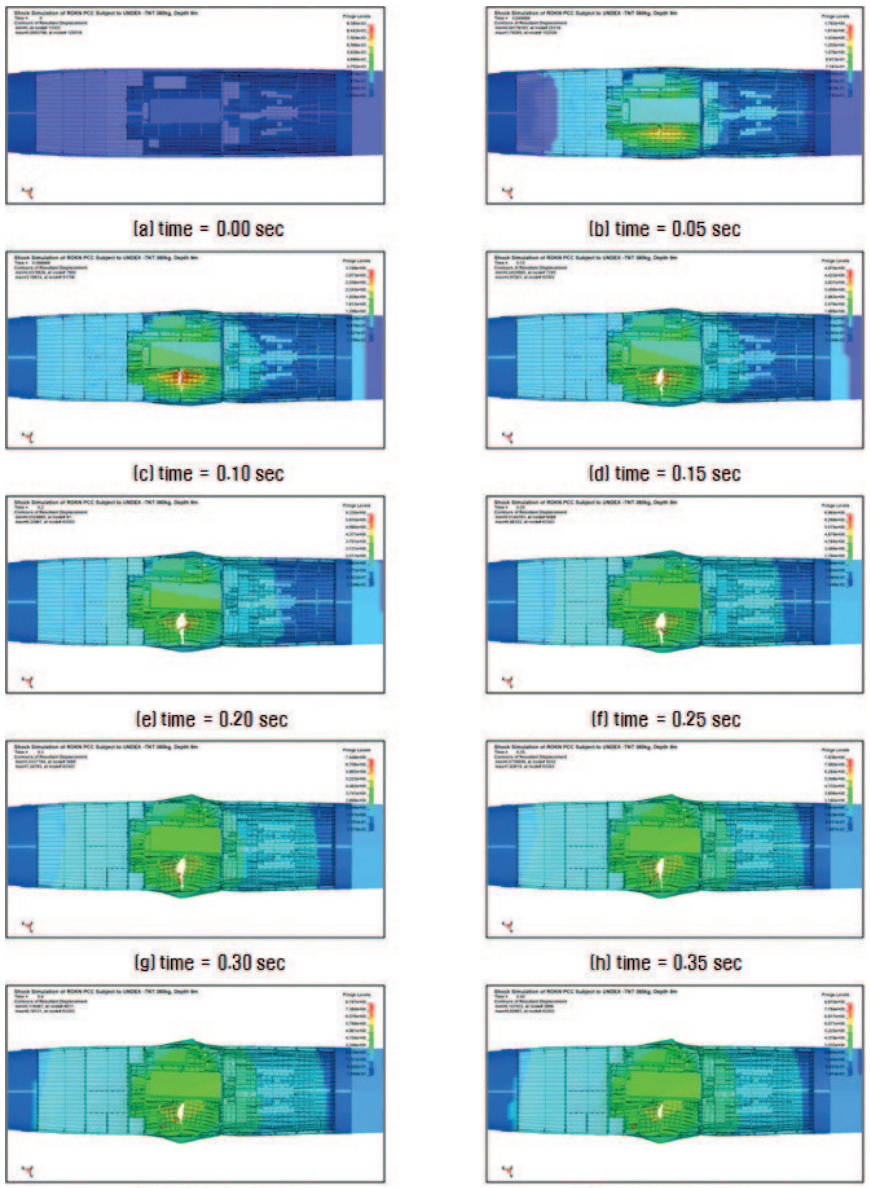
In 〈Figure III-6-16〉 and 〈Figure III-6-22〉, the analysis results of an explosion of 360kg TNT equivalent at a depth of 7m seen from different angles and divided according to critical time periods are illustrated.

As shown in 〈Figure III-6-16〉 and 〈Figure III-6-17〉, an energy created by shockwave and bubble pulsation is concentrated toward the gas turbine room and its adjacent compartment, as well as sagging and hogging, especially on hull, through repetition of bubble expansion and contraction.

Through 〈Figure III-6-18〉 ~ 〈Figure III-6-22〉, the JIG was able to infer clear damage sequence of how ROKS Cheonan's gas turbine room was detached. First, as the shockwave contacted the ship, a "Punching Shear" effect was created(diagonal fracture in the direction of thickness due to sudden pressure acting perpendicular to the plates) tearing the weakest member on the portside bottom shell plates of the gas turbine room, after a series of bubble expansion, contraction, and re-expansion(bubble process) deforming the hull severely upward, downward, and then again, upward; this causes the tearing fracture of the hull to grow. The gas turbine at the center of the gas turbine room and the generator at the starboard side, along with their foundations, are sharply inclined to the starboard direction due to the shockwave and series of bubble process. The members and bottom shells near the foundations towards stern are severely deformed and torn apart as a result. However, members on the foundation towards the respective bottom plates have undergone less severe deformation with sufficient level of strength maintained.

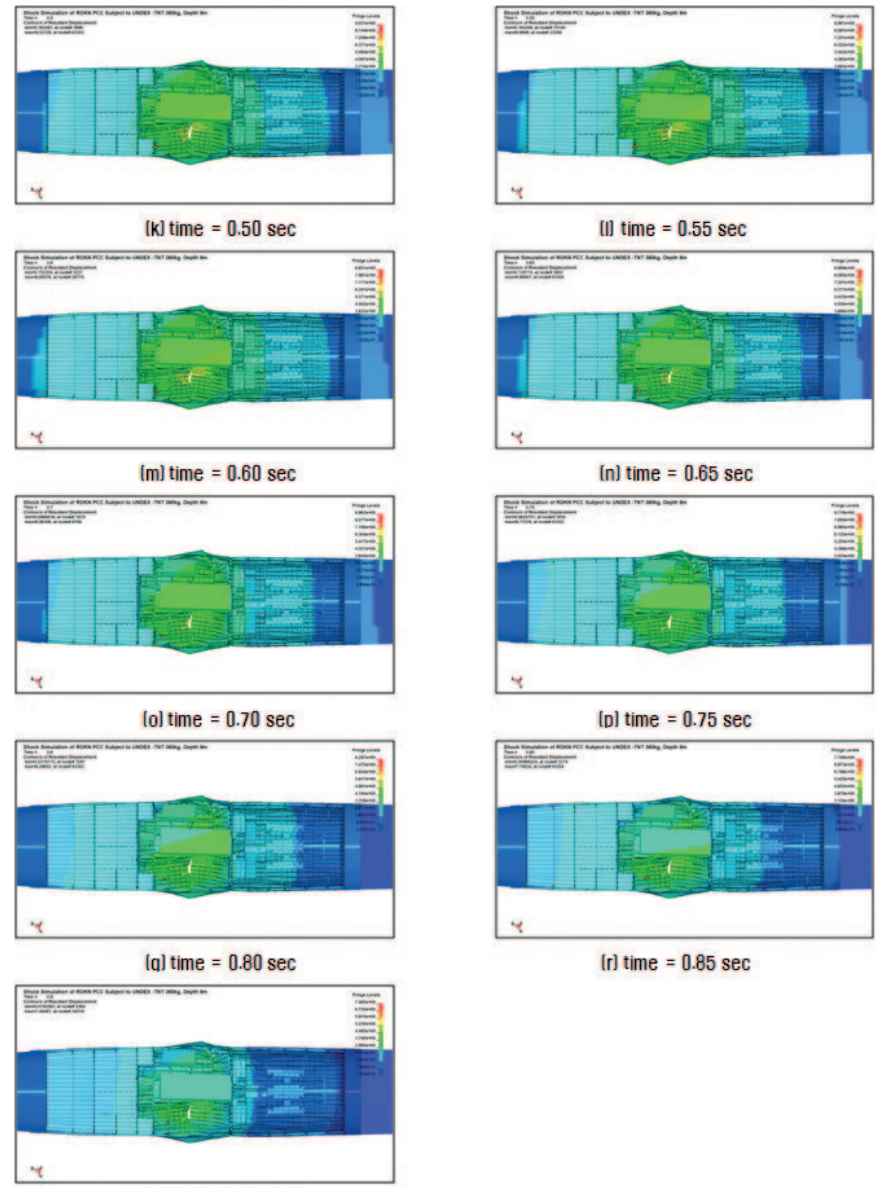
Additionally, although a mass deformation is observed on the starboard shell plates, no destructive damages are found. This enabled us to infer the possibility of gas turbine and generator foundation, shell plates supporting them, as well as starboard shell plates being detached without separation.

24) A formula made by a mathematician, Leonhard Euler, that is used to find out the movement of a fluid that does not have any viscosity.



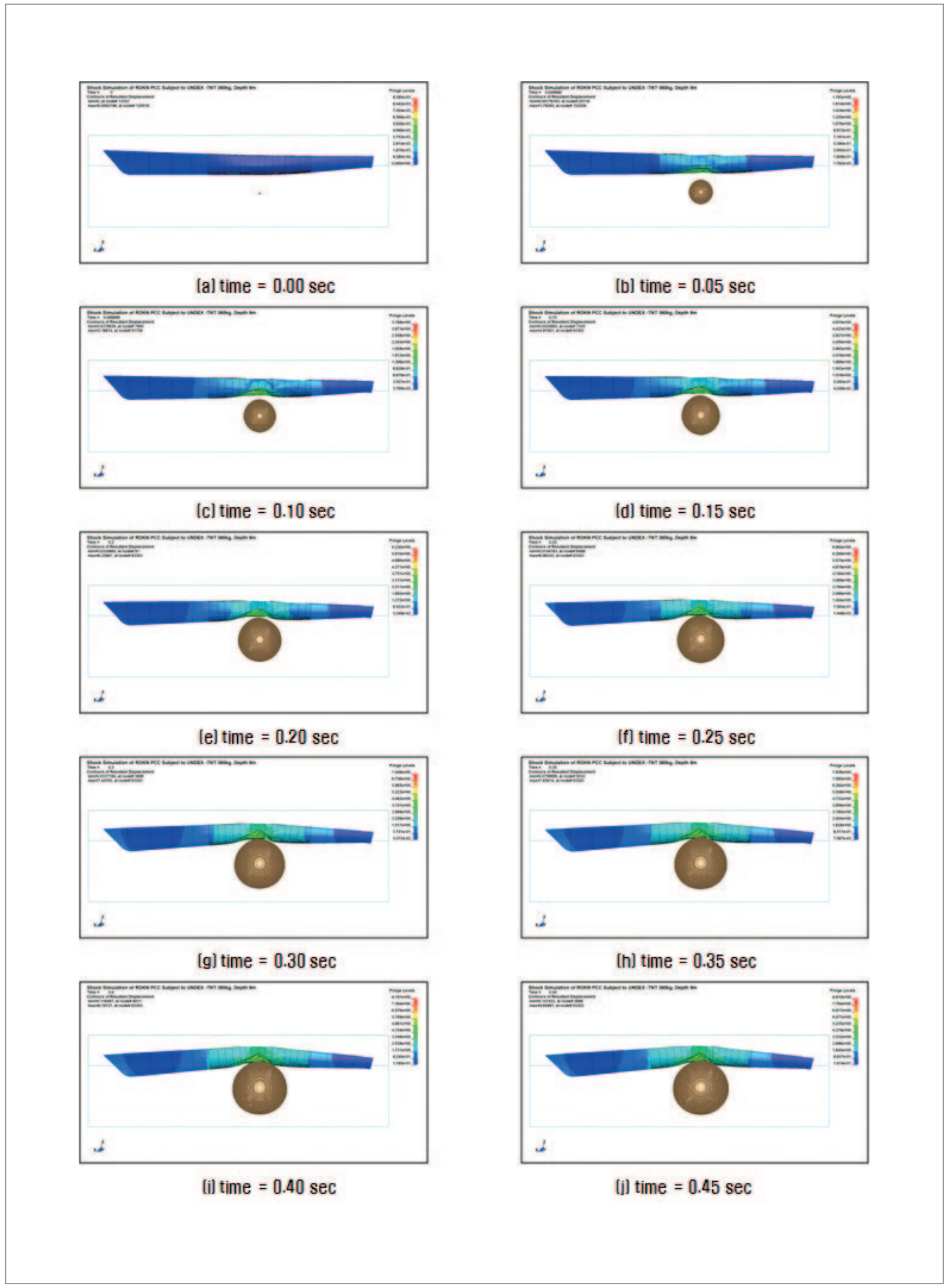
(a) time = 0.00 sec
(b) time = 0.05 sec
(c) time = 0.10 sec
(d) time = 0.15 sec
(e) time = 0.20 sec
(f) time = 0.25 sec
(g) time = 0.30 sec
(h) time = 0.35 sec
(i) time = 0.40 sec
(j) time = 0.45 sec

〈Figure III-6-14〉 Analysis result(TNT 360kg at 9m depth): damage in gas turbine room

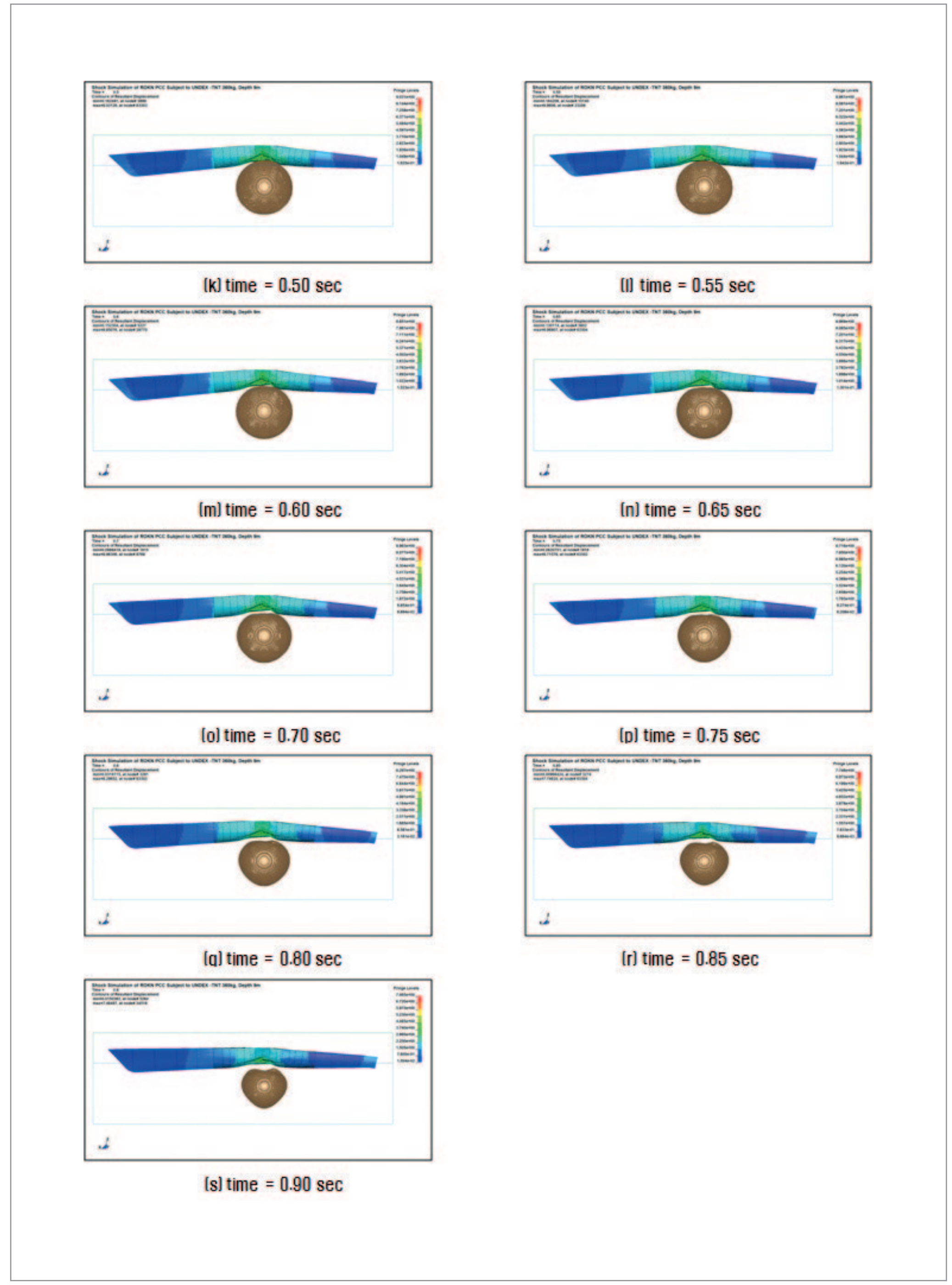


(k) time = 0.50 sec
(l) time = 0.55 sec
(m) time = 0.60 sec
(n) time = 0.65 sec
(o) time = 0.70 sec
(p) time = 0.75 sec
(q) time = 0.80 sec
(r) time = 0.85 sec
(s) time = 0.90 sec

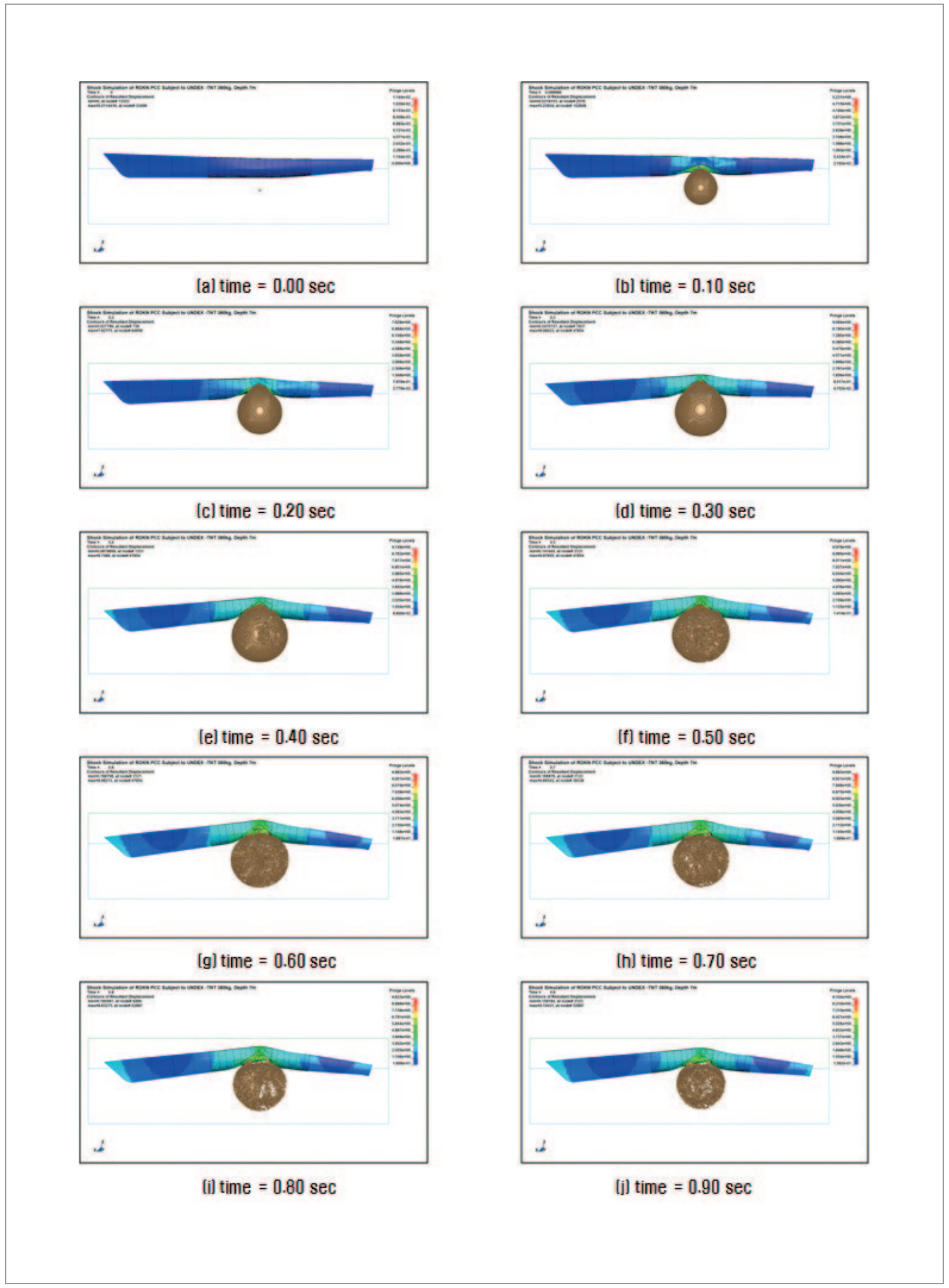
〈Figure III-6-14〉 Analysis result(TNT 360kg at 9m depth): damage in gas turbine room (continued)



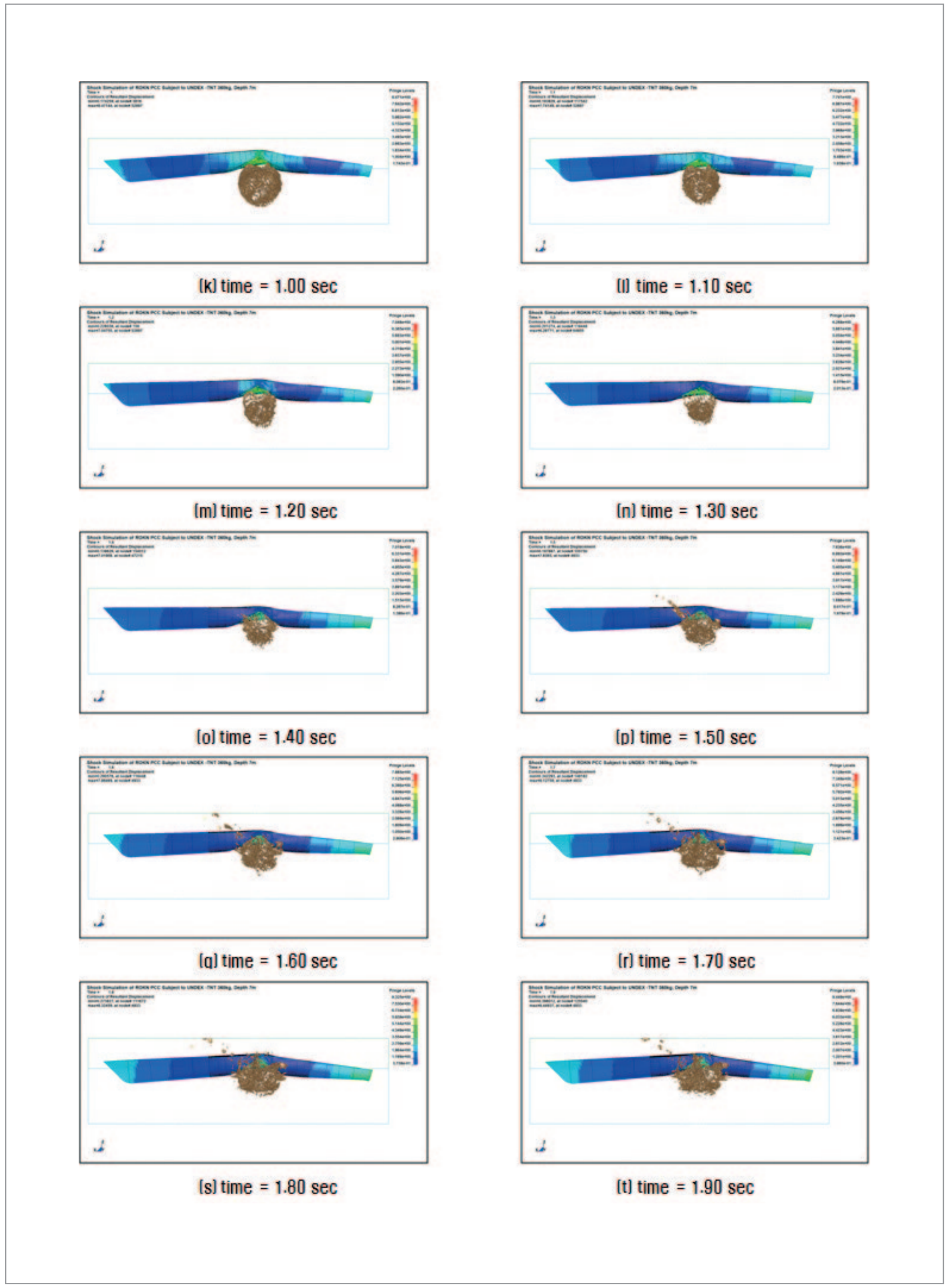
〈Figure III-6-15〉 Side view of analysis result(TNT 360kg at 9m depth) on bubble migration and shock response



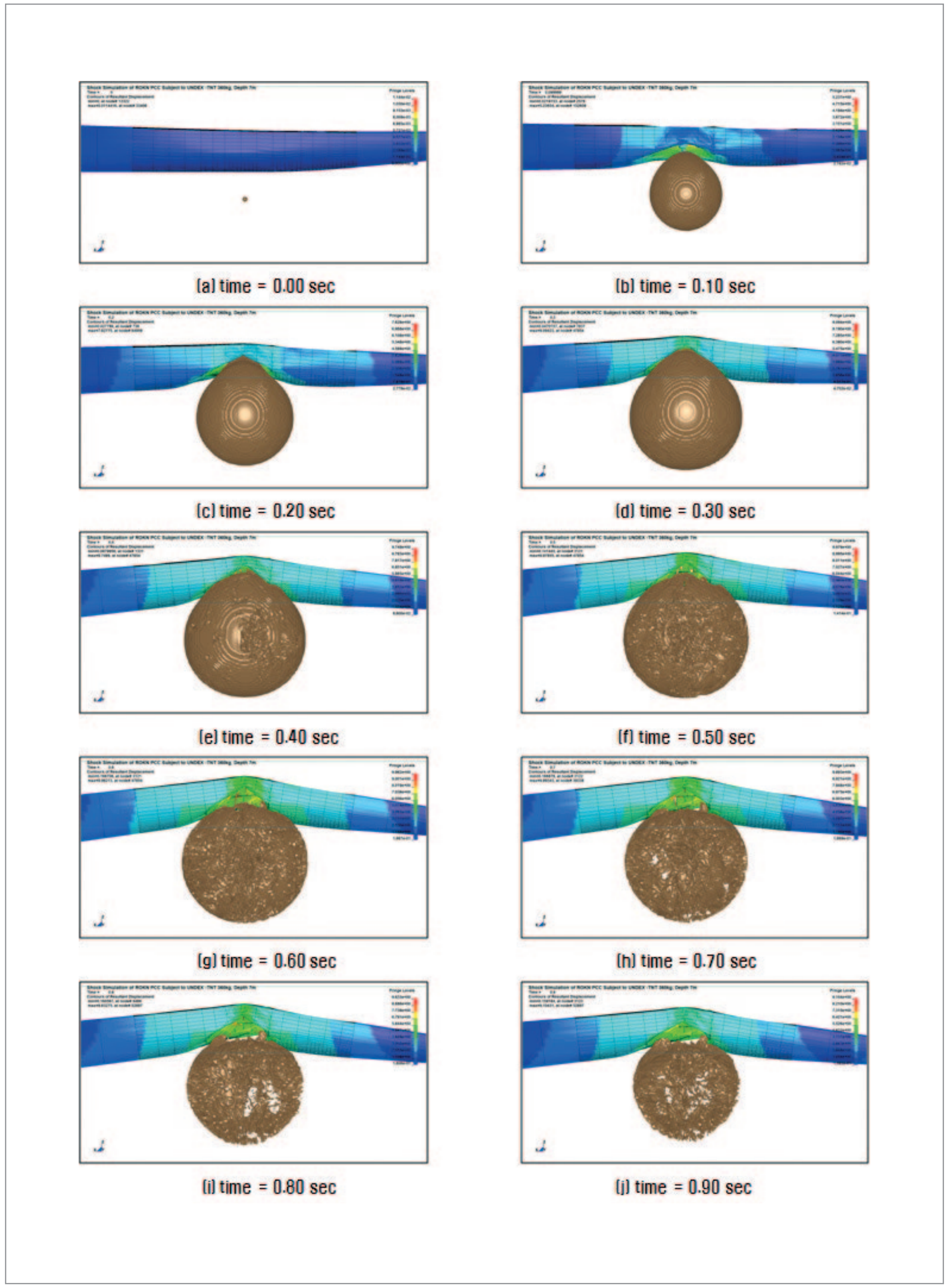
〈Figure III-6-15〉 Side view of analysis result(TNT 360kg at 9m depth) on bubble migration and shock response (continued)



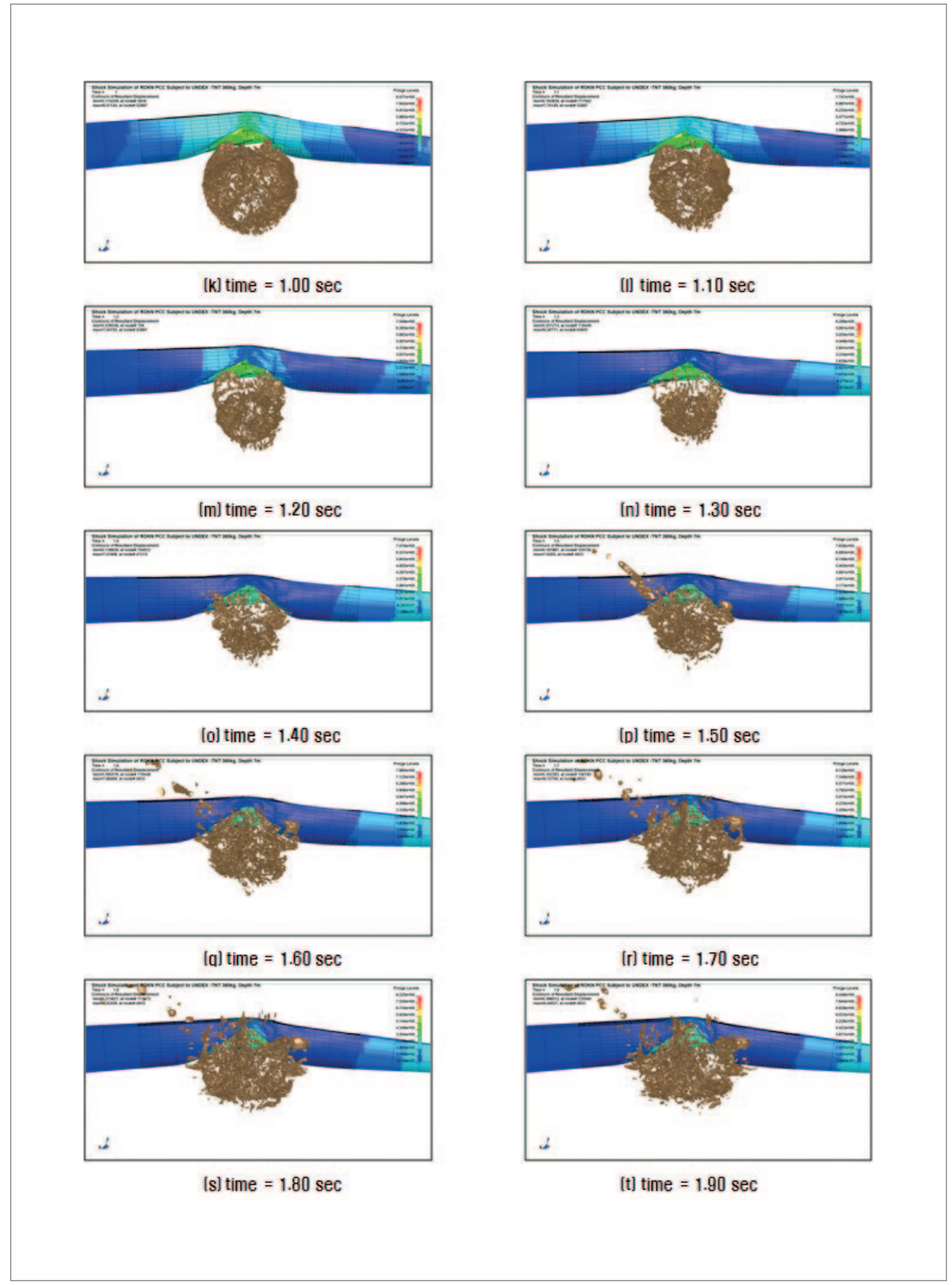
〈Figure III-6-16〉 Side view of analysis result(TNT 360kg at 7m depth)



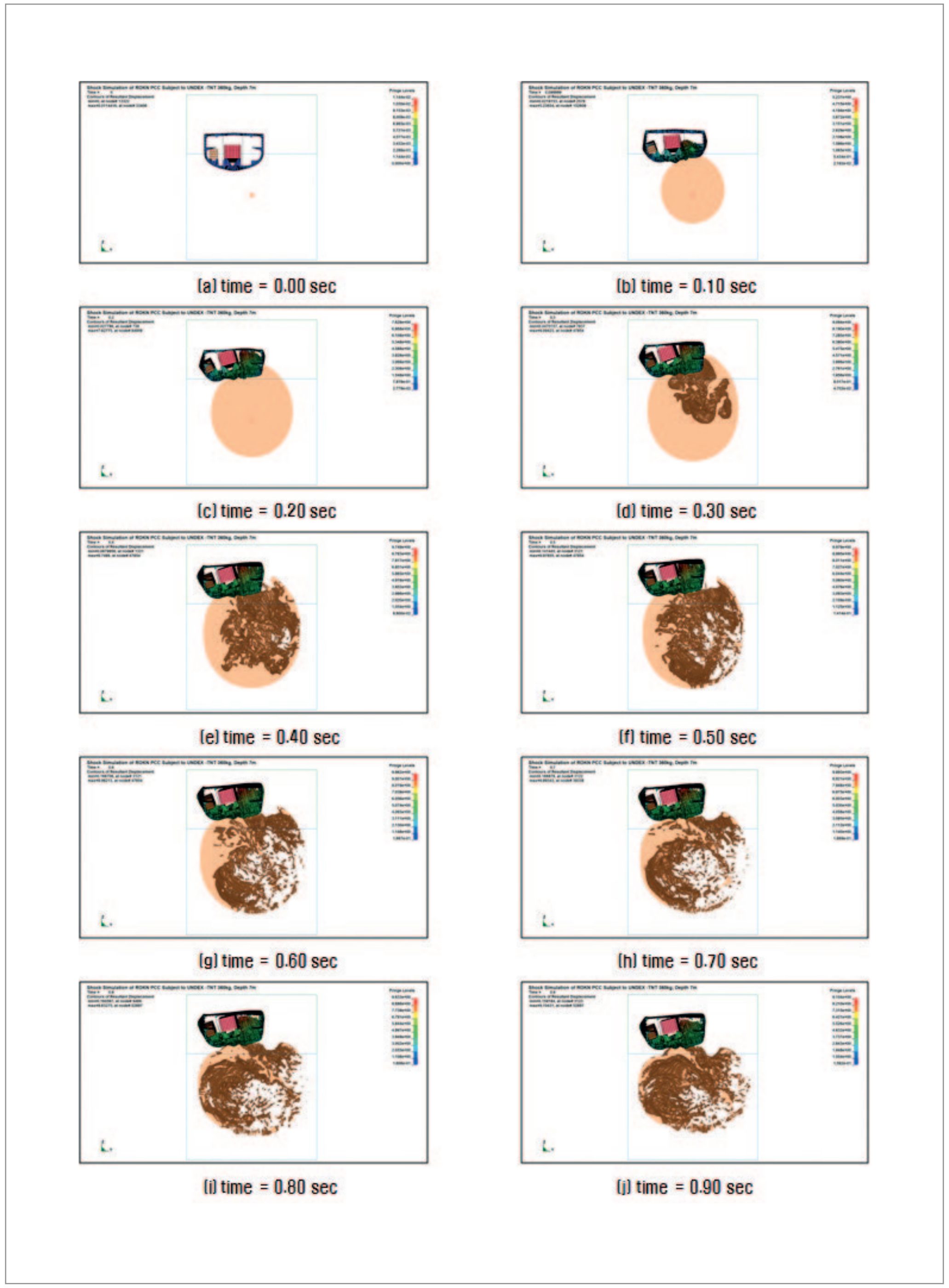
〈Figure III-6-16〉 Side view of analysis result(TNT 360kg at 7m depth) (continued)



〈Figure III-6-17〉 Side view(closed-in) of analysis result(TNT 360kg at 7m depth)

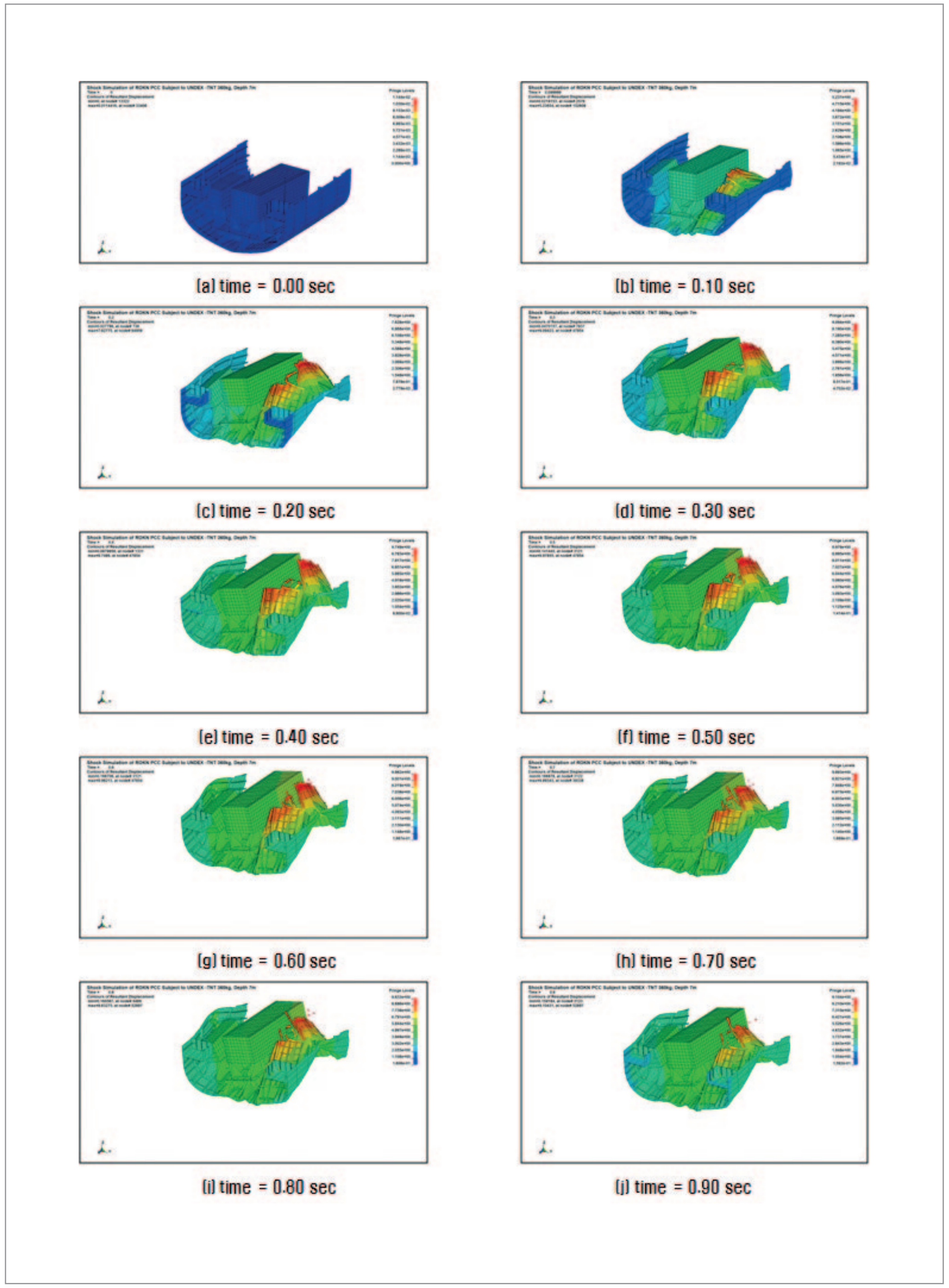


〈Figure III-6-17〉 Side view(closed-in) of analysis result(TNT 360kg at 7m depth) (continued)

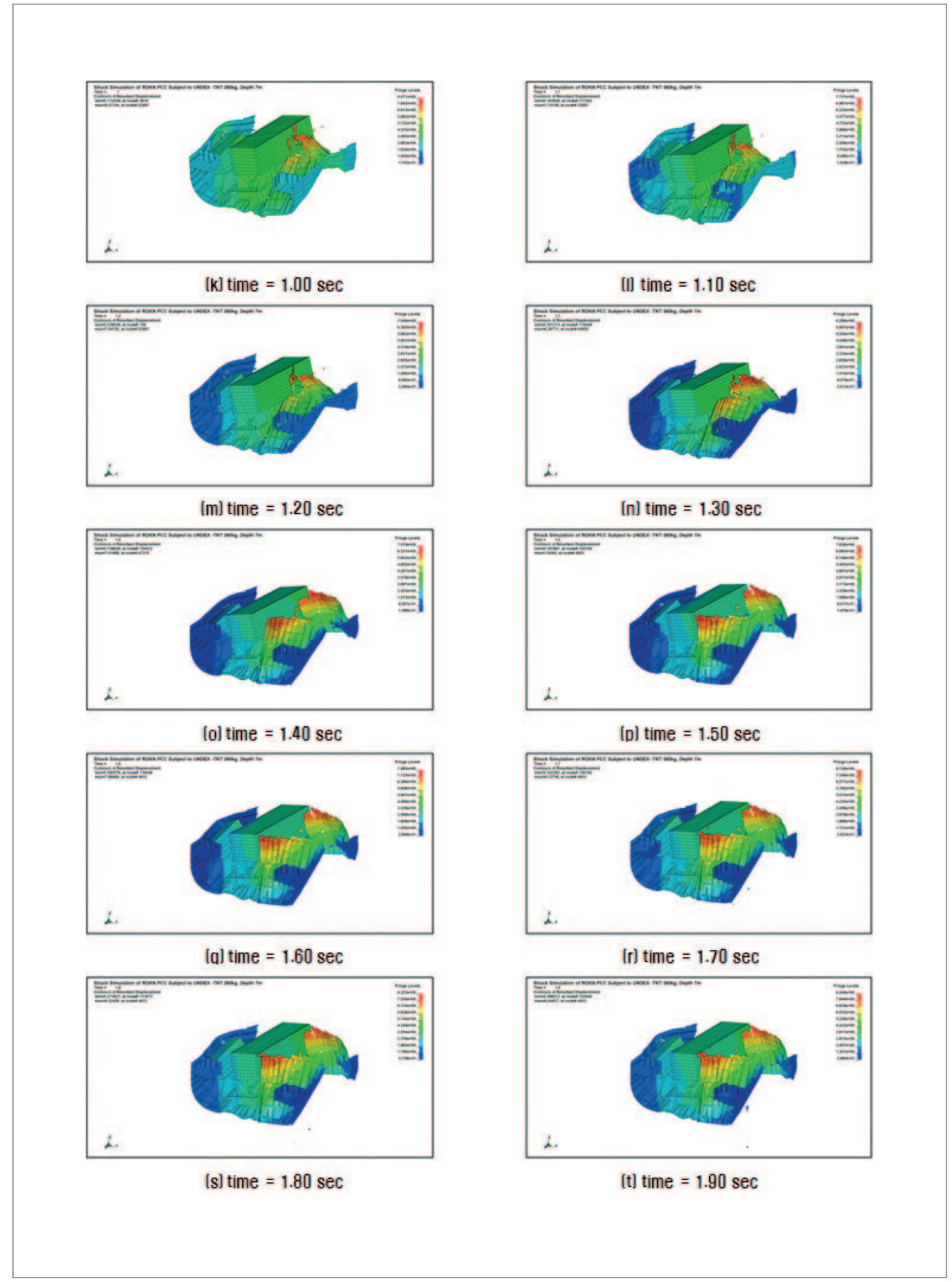


〈Figure III-6-18〉 Section view of analysis result(TNT 360kg at 7m depth)

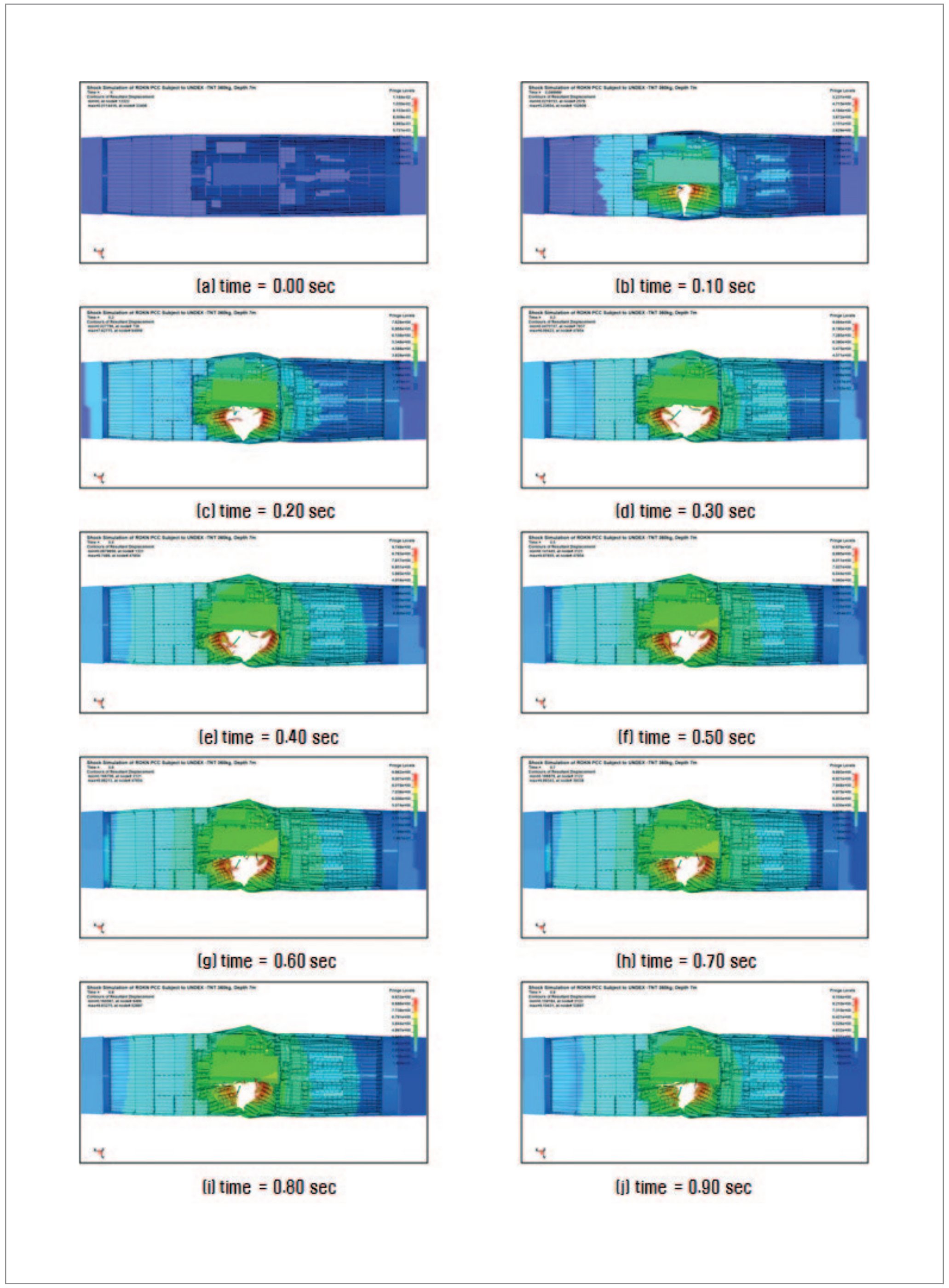
〈Figure III-6-18〉 Section view of analysis result(TNT 360kg at 7m depth) (continued)



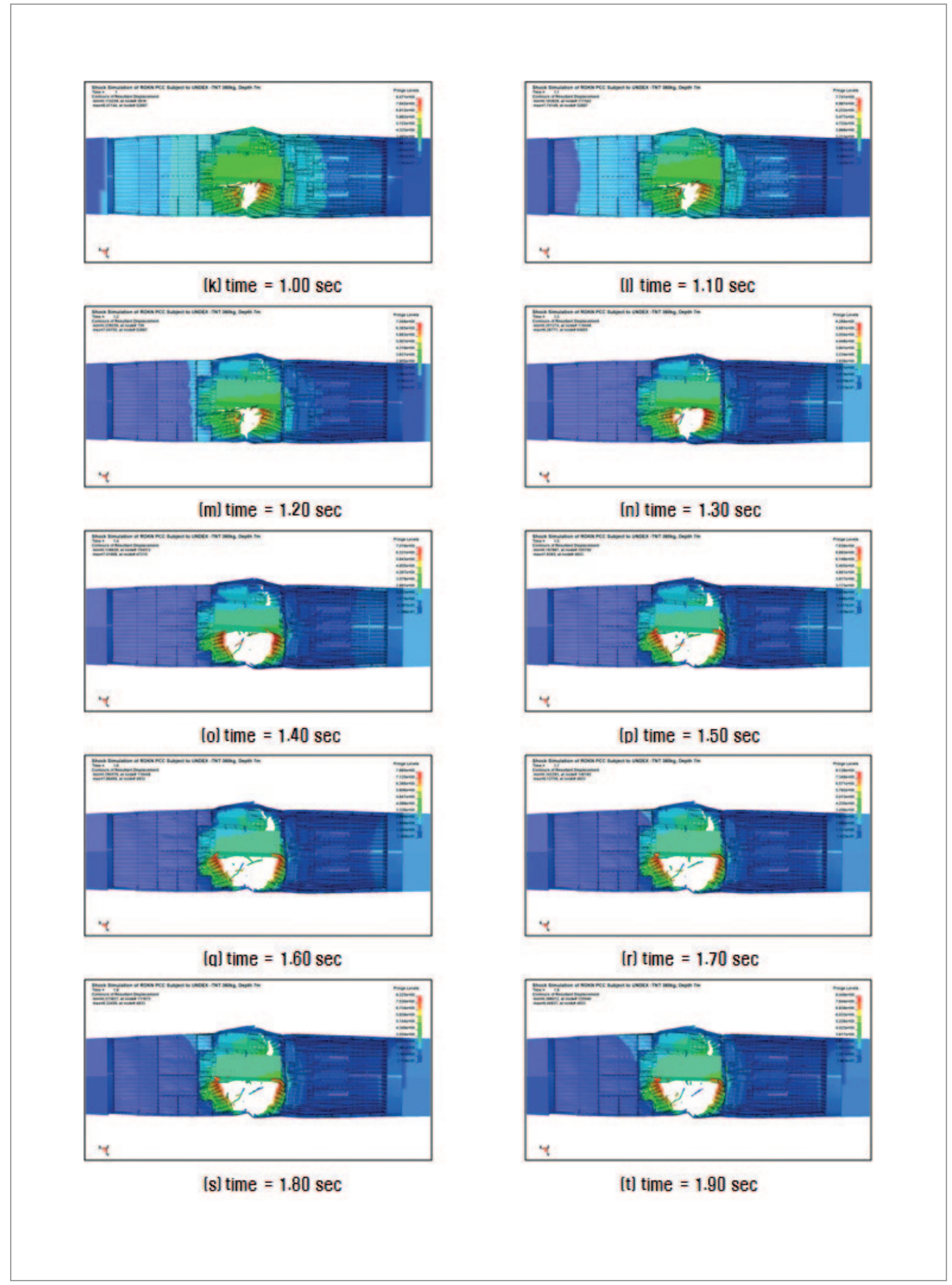
〈Figure III-6-19〉 Internal view of analysis result(TNT 360kg at 7m depth)



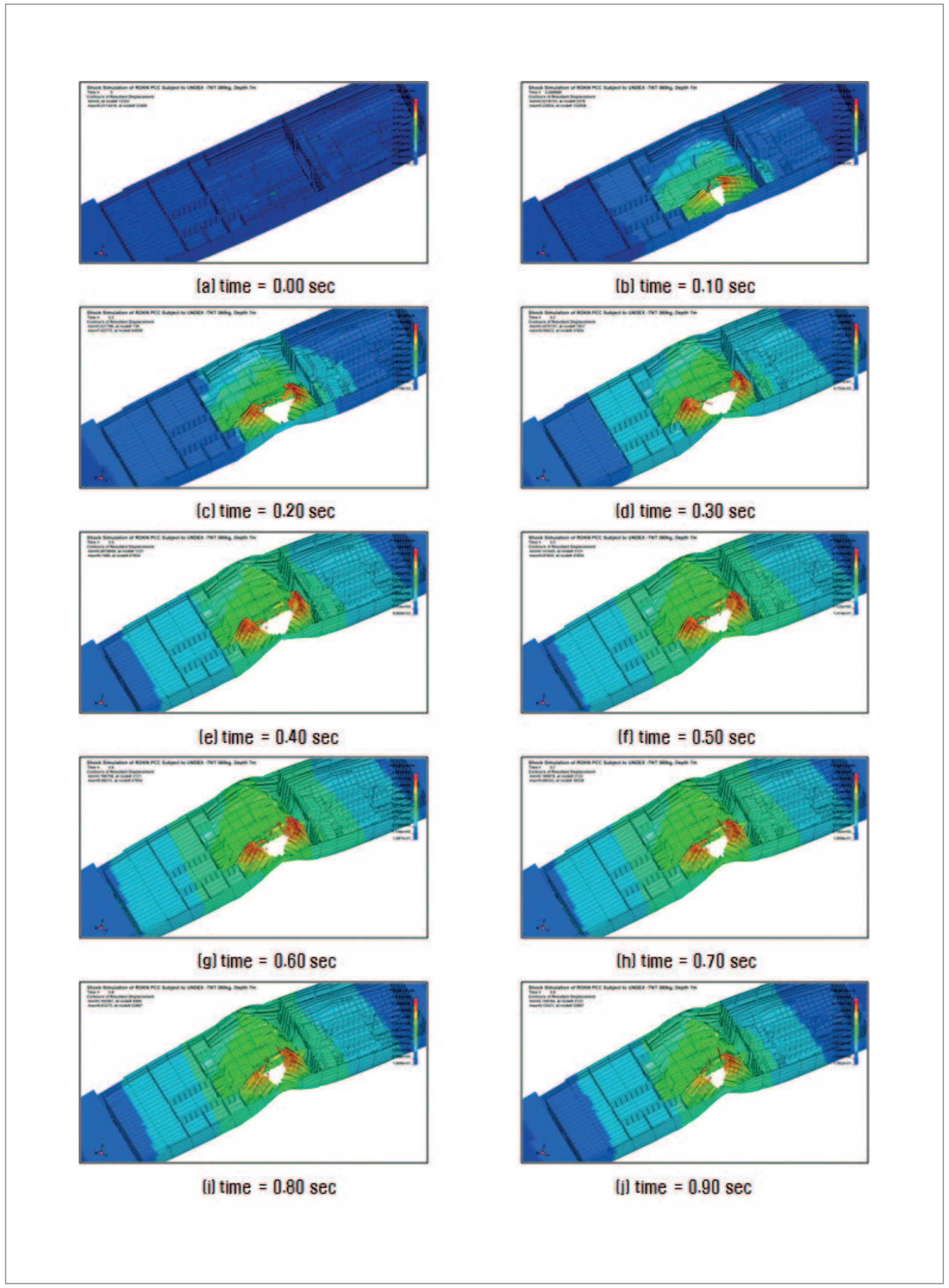
〈Figure III-6-19〉 Internal view of analysis result(TNT 360kg at 7m depth) (continued)



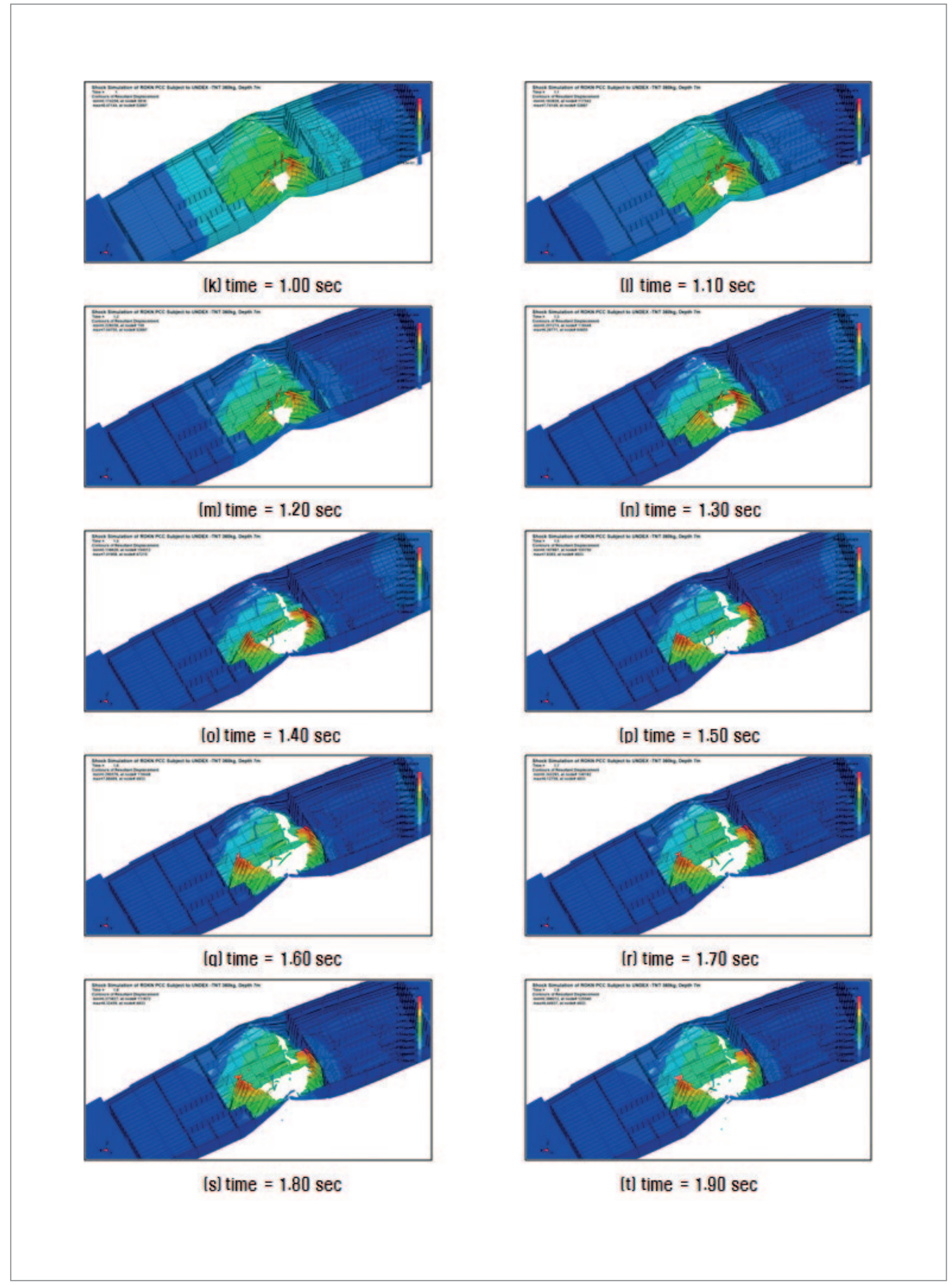
〈Figure III-6-20〉 Internal top view of analysis result(TNT 360kg at 7m depth)



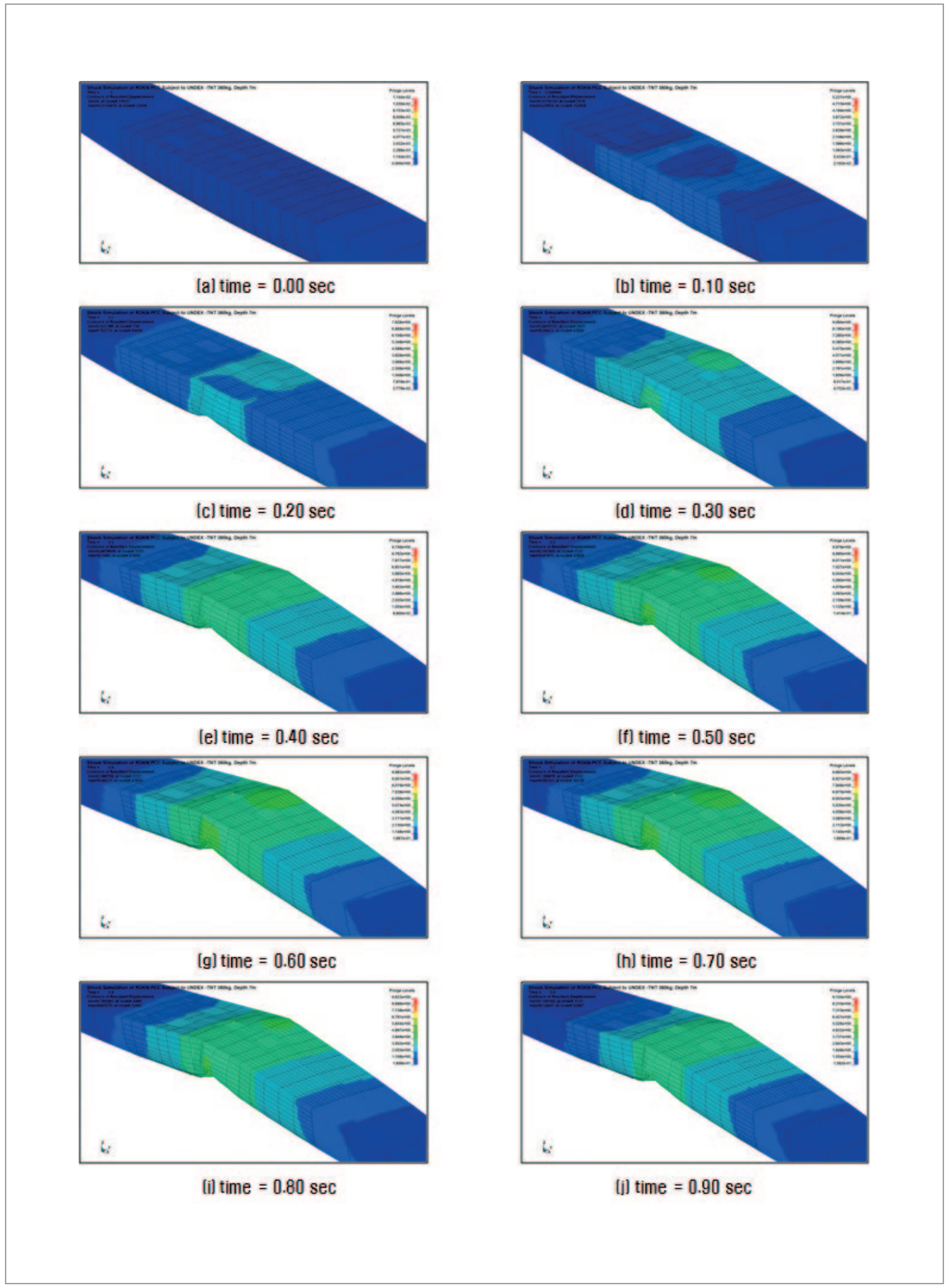
〈Figure III-6-20〉 Internal top view of analysis result(TNT 360kg at 7m depth) (continued)



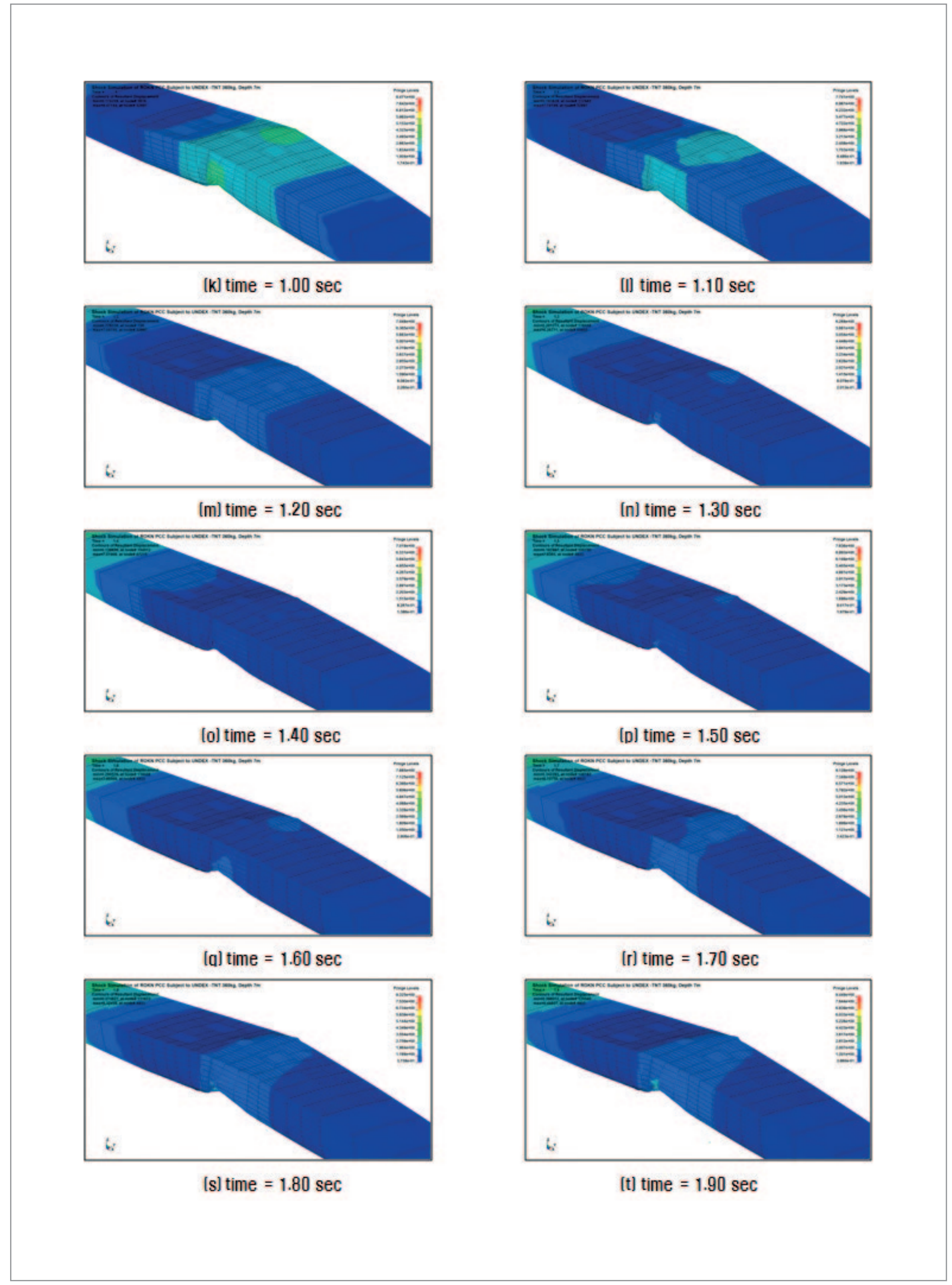
〈Figure III-6-21〉 Internal-side view of analysis result(TNT 360kg at 7m depth)



〈Figure III-6-21〉 Internal-side view of analysis result(TNT 360kg at 7m depth) (continued)

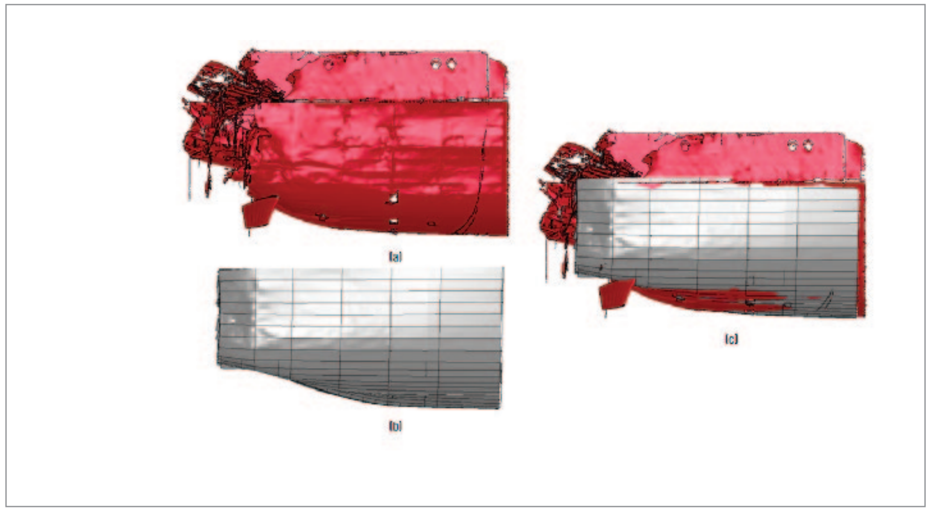


〈Figure III-6-22〉 Deck view of analysis result(TNT 360kg at 7m depth)

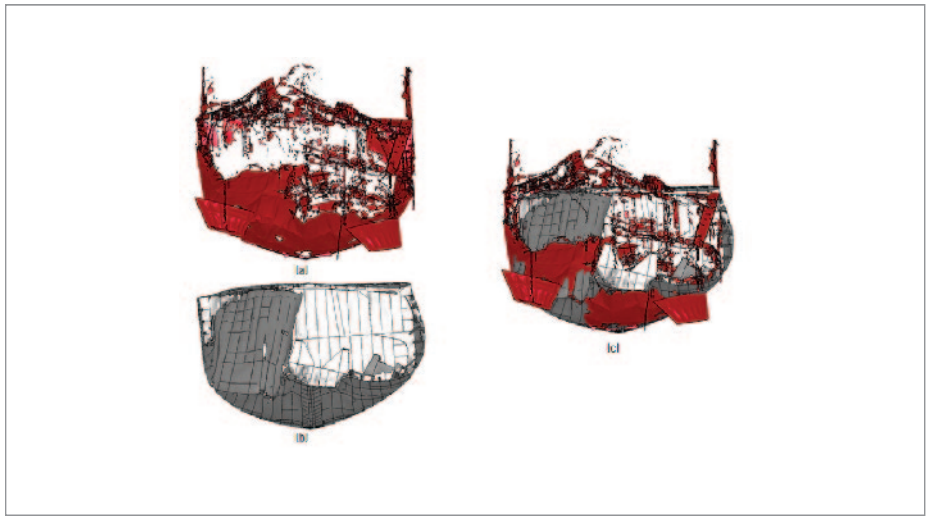


〈Figure III-6-22〉 Deck view of analysis result(TNT 360kg at 7m depth) (continued)

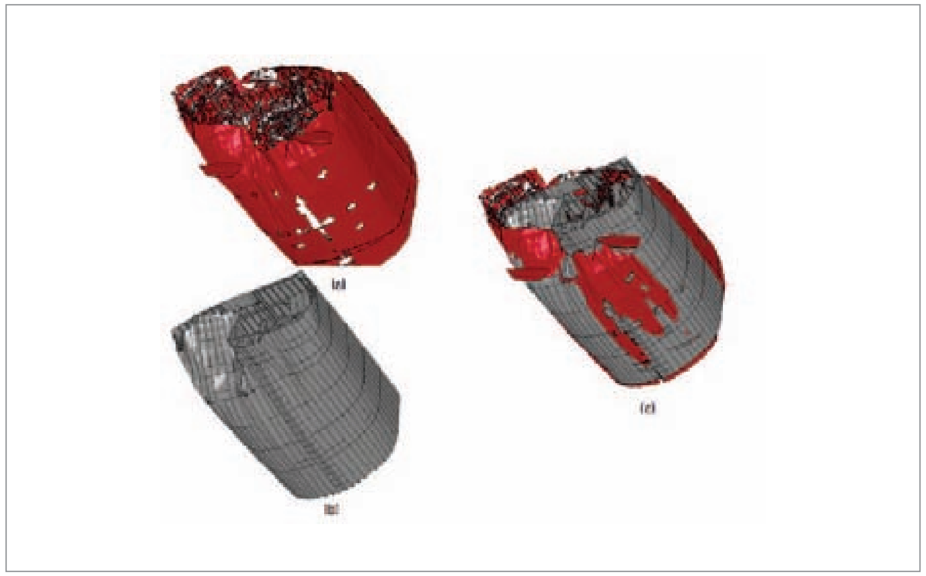
〈Figure III-6-23〉 ~ 〈Figure III-6-28〉 illustrate the comparison between modelled damage result and the damages actually measured from 3D laser scanning image of ROKS Cheonan. Sub-caption (a) indicates the actual damage, (b) indicates the estimated damage results by the model, and (c) is the overlap of (a) and (b). As seen in these sub-captions, the modelled damage and the actual damages appear fairly similar.



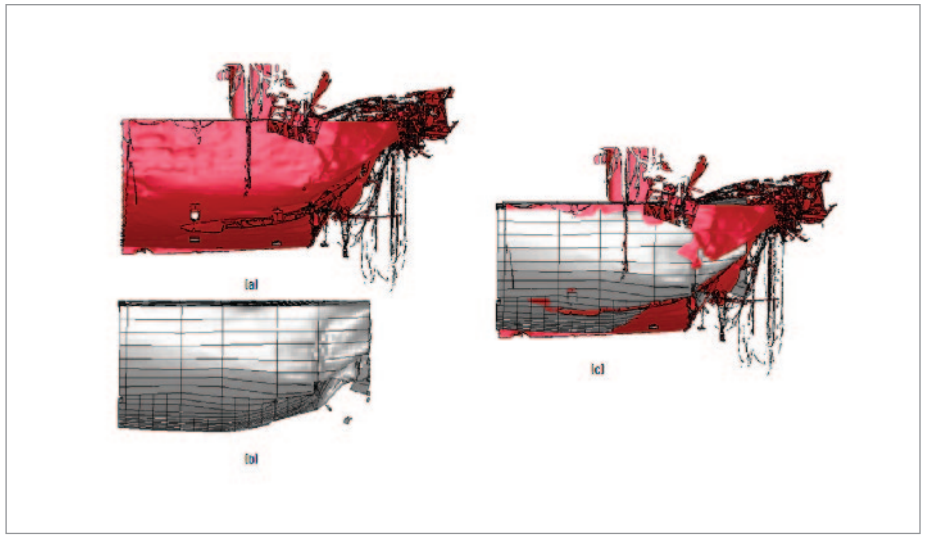
〈**Figure** III-**6-23**〉 Comparison between modelled damage and actual damage of ROKS Cheonan (side view of bow)



〈**Figure** III-**6-24**〉 Comparison between modelled damage and actual damage of ROKS Cheonan (front view of bow)

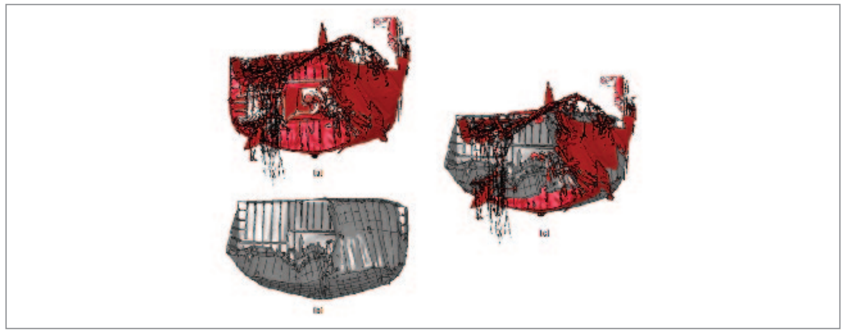


〈**Figure** III-**6-25**〉 Comparison between modelled damage and actual damage of ROKS Cheonan (bottom view of bow)



〈**Figure** III-**6-26**〉 Comparison between modelled damage and actual damage of ROKS Cheonan (side view of stern)

Detailed Analysis Results by Team



〈Figure III-6-27〉 Comparison between modelled damage and actual damage of ROKS Cheonan (front view of stern)

〈Figure III-6-28〉 Comparison between modelled damage and actual damage of ROKS Cheonan (bottom view of stern)

(5) Sub-conclusion

The JIG received 2 explosion conditions from the Explosive Type Analysis Team, of TNT 360kg charge size in 7m and 9m depths. The JIG confirmed fairly similar damage results between modelled damage and actual damage of ROKS Cheonan from TNT 360kg charge size and 7m depth by conducting 3D finite element analysis incorporating the interrelation between the structure and the fluid.

Also, the JIG was able to obtain scientifically credible inference on the process of the gas turbine room split and detachments of the structures leading to ROKS Cheonan's sinking through the analysis result of TNT 360kg explosion at 7m depth. That is, the initial shock wave reached the hull and created the fracture called "punching shear", tearing out the most vulnerable areas of portside bottom shell plates in the gas turbine room. This became more severe due to the series of bubble process(expansion, contraction, and re-expansion of the bubble); the estimated damage results on the portside were very similar to the actual damages from a 3D laser scanning. Additionally, the detachments of gas turbine foundation, generator foundation, bottom shell plates, and starboard shell plates as a whole(without separation) were consistent with the damage patterns from the analysis.

7. Analysis on Sea Area of the Incident

1) Overview

A precise investigation on the underwater terrain and the tidal current at the site of the sinking in the vicinity of Baekryong Island was conducted in order to find how they can possibly affect the cause of the incident and North Korean infiltration assets such as submarine or midget submarine.

2) Situation at the Time of the Incident

The ROKS Cheonan sank at 2122, March 26, in 2.5km Southwest of Baekryong Island(37°55'45"N – 124°36'02"E), at 47m in water depth. At the time, sea weather[25] was: southwest 2wind 20kts, wave height 2.5m, tidal current[26] 161°– 2.89kts, visibility 2.5NM, flood tide[27] at 0225(2.3m) / 1515(2.7m), and ebb tide at 0843(0.7m)/2147(0.8m).

3) Investigation Focus

(1) Underwater Terrain in vicinity of Baekryong Island

The investigation was conducted to identify existence of underwater obstacles, focusing on the maneuvering route(patrol area at the time of the incident) of ROKS Cheonan. Conducted in a joint manner with advisory committee members[28] from National Oceanographic Research Institute(Ministry of Land, Transportation and Maritime Affairs) and

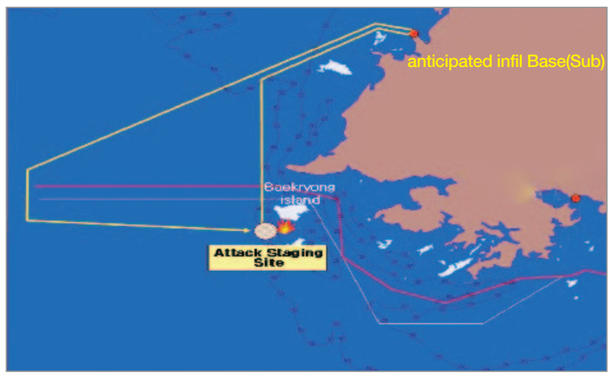
25) At 1625 on March 26, 2010, Hwangcheon class 5(wave height of 2.6~3.0m and wind speed of 26~30kts) was declared in the waters near Baekryong Island.
26) Tidal current is a horizontal movement of seawater generated by ebb and flood tide.
27) Tide is a gradual movement of seawater in vertical direction.
28) NORI Maritime Branch chief and a researcher from KORDI participated as advisory members.

Korea Ocean Research and Development Institute(Ministry of Education, Science and Technology), the investigations and verifications were systematic and scientific.

〈Figure III-7-1〉 The sinking site of ROKS Cheonan

(2) Tidal Current in the vicinity of Baekryong Island

The investigations and analyses were carried out in order to find out how the tidal movement and currents in the vicinity of Baekryong Island affected maneuvering of ROKS Cheonan during the time of incident and how tidal currents between Baekryong Island and anticipated North Korea infiltration bases affect maneuvers of North Korean infiltration assets such as submarine or midget submarine. The investigations and analyses also attempted to reveal how tidal currents affect employments of arms such as torpedo launch and mine installation by North Korean submarine or midget submarine.



〈Figure III-7-2〉 Anticipated infiltration routes of North Korean submarine or midget submarine

4) Analysis on Underwater Terrain in the vicinity of Baekryong Island

(1) Investigation Method

First, the JIG obtained every available chart to confirm any underwater obstacle. Then, the JIG committed Navy Search and Rescue Group ships(March 28 ~ April 17) and Korea Ocean Research and Development Institute's research vessels(April 4 ~ May 8) to conduct search operations. Furthermore, the JIG checked with Baekryong Island local members of fishery group, government ships and fishers whether there was any underwater obstacle missing on the charts.

(2) Investigation Result

① Verification of all Available Charts for Waters around Baekryong Island

Through coordination with National Oceanographic Research Institute(NORI)[29], the JIG acquired 6 relevant charts including the underwater terrain chart shown in 〈Table III-7-1〉. Comparison on the water depth and underwater obstacles(reef, unknown sunken vessel, and fishery) was made using the charts. The result was that there were no underwater obstacles in the actual maneuvering route of ROKS Cheonan.

CAT	Chart no.	Scale	Published by	Purpose
Chart	① No.360	1:30,000	NORI('05)	Military(maritime police)/merchant/fishery
	② No.360	1:30,000	NORI('08)	NORI research project
	③ No.315	1:75,000	NORI('04)	Military(maritime police)/merchant/fishery
	④ No.323	1:250,000	NORI('06)	Military(maritime police)/merchant/fishery
Underwater terrain chart	⑤ No.4534	1:200,000	NORI('90)	Military
Marine zone chart	⑥ No.101	1:2,000,000	NFFC(NORI)	Fishery

〈Table III-7-1〉 All available charts for waters near Baekryong Island[30), 31)]

Maritime branch chief at the NORI, while serving also as an advisor to the Joint Investigation Group, stated that all obstacles such as fishing ground that could affect the safety of ships on maneuvering have been depicted on charts upon identification, although no pre-planned research on the waters such as measuring water depth has been conducted since 1992 due to the sensitive nature of the area in the vicinity of Baekryong Island. He confirmed that there were no underwater obstacles on any chart that could have affected the maneuvering of ROKS Cheonan(maneuvering course of ROKS Cheonan in the patrol area)[32].

29) NORI is responsible for the publication of domestic marine charts.
30) The charts ①, ③ and ④ published by the NORI are used commonly by the civilian & military. The chart ② is the latest chart kept within the NORI only.
31) The chart ⑤ also published by the NORI is used only in military and the Marine zone chart ⑥ published by National Federation of Fisheries Cooperatives does not include information about water depth and reef.
32) On March 30, 2010, the NORI officially announced that there was no reef in the vicinity of the sinking site of ROKS Cheonan.

② Search Operation by Navy Search and Rescue Group in the Sinking Site

From March 28 until April 17, 4 minesweeping ships(ROKS Yangyang, Ongjin, Gimpo, and Goryong) conducted search with Side Scan Sonar[33], focusing on ROKS Cheonan's patrol area. Except for the unknown sunken vessel(75×15×10m), 18 contacts found were minor objects consisting mostly of crab fishing net, iron object, and bedrock as shown in 〈Table III-7-2〉, confirming that there were no underwater obstacles in ROKS Cheonan's maneuvering route.

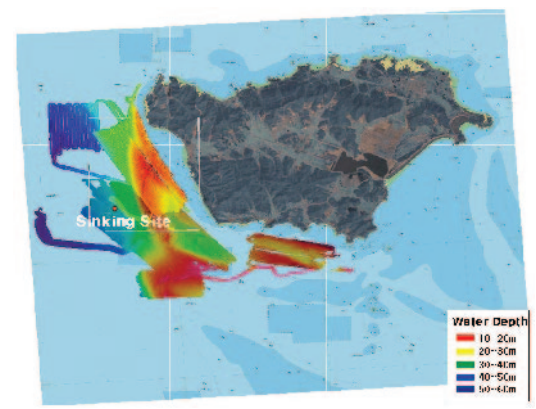
CAT	ID time	Location of object	Size(m)	Depth(m)	Found
1	2231 Mar 28	37° 55' 40"N, 124° 36' 06"E	33×10	47	Stern
2	1427 Mar 29	37° 55' 48"N, 124° 36' 00"E	75×15×10	42	Unknown sunken vessel
3	1550 Mar 30	37° 55' 22"N, 124° 34' 03"E	-	50	Bedrock
4	0924 Mar 31	37° 55' 41"N, 124° 36' 06"E	3.7×10.1	44	Bedrock
5	0933 Mar 31	37° 55' 42"N, 124° 36' 06"E	3.4×1.3	44	Metal object
6	1315 Apr 2	37° 54' 12"N, 124° 37' 57"E	2×3	18	Concrete structure
7	1345 Apr 2	37° 54' 52"N, 124° 37' 07"E	2×2	25	Concrete structure
8	1435 Apr 2	37° 54' 45"N, 124° 37' 12"E	2×2	27	Concrete structure
9	1515 Apr 2	37° 54' 46"N, 124° 37' 52"E	-	34	Bedrock
10	1858 Apr 2	37° 55' 42"N, 124° 36' 22"E	-	17	Bedrock
11	1350 Apr 14	37° 55' 41"N, 124° 36' 05"E	6.6×3.8	42	Stack
12	1405 Apr 14	37° 55' 42"N, 124° 36' 04"E	1.5×2	44	Copper pipe
13	1413 Apr 14	37° 55' 42"N, 124° 36' 03"E	1.2×0.6	43	Boat engine cover
14	1415 Apr 14	37° 55' 43"N, 124° 36' 03"E	2.4×2.3	44	Crab fishing net
15	1420 Apr 14	37° 55' 44"N, 124° 36' 03"E	2.1×0.7	43	ROKS Cheonan generator
16	1430 Apr 14	37° 55' 41"N, 124° 36' 03"E	2.2×0.8	42	ROKS Cheonan harpoon
17	1700 Apr 14	37° 55' 43"N, 124° 36' 02"E	5×0.1	43	External pipe
18	1703 Apr 14	37° 55' 43"N, 124° 36' 03"E	1.8×0.5	43	Triangular Aluminum particle
19	2030 Apr 17	37° 55' 10"N, 124° 37' 37"E	2×2×1.1	31	Bedrock

〈Table III-7-2〉 Objects found in the sinking site by Navy Search and Rescue Group

33) Side Scan Sonar: It obtains sea bottom terrain informations by detecting the irregularity using sonar with supersonic transmitter.

③ Search Operation by KORDI Vessels in the Sinking Site

From April 4 to May 8, 2 research vessels(Yiuhdo and Jangmok) were committed for search operation with Multi-Beam Echo Sounder[34] and Side Scan Sonar, focusing on the sinking location of the stern of ROKS Cheonan and following the maneuvering route of ROKS Cheonan. The operation found 1 unknown sunken vessel(75×15×10m) and only 11 small objects ranging from 0.4 to 4m in size(See 〈Table III-7-3〉). The operation con-

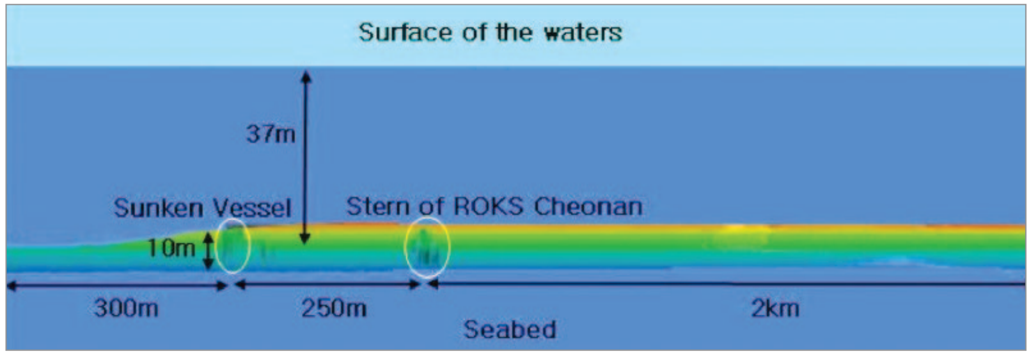


〈Figure III-7-3〉 Area of underwater terrain search operation at the sinking site by the KORDI

CAT	ID time	Location of object	Size(m)	Depth(m)
1	0214 Apr 18	37° 55' 40"N, 124° 36' 03"E	1.7×0.6	47
2	0214 Apr 18	37° 55' 41"N, 124° 36' 04"E	0.8×0.6	46
3	0214 Apr 18	37° 55' 40"N, 124° 36' 04"E	0.7×1.1	46
4	0214 Apr 18	37° 55' 40"N, 124° 36' 04"E	4.0×0.7	47
5	0214 Apr 18	37° 55' 38"N, 124° 36' 03"E	0.6×1.6	47
6	0218 Apr 18	37° 55' 32"N, 124° 36' 13"E	0.7×1.2	46
7	0239 Apr 18	37° 55' 36"N, 124° 36' 08"E	0.5×0.4	47
8	0240 Apr 18	37° 55' 39"N, 124° 36' 05"E	0.4×0.7	46
9	0240 Apr 18	37° 55' 40"N, 124° 36' 05"E	2.5×0.5	46
10	0241 Apr 18	37° 55' 40"N, 124° 36' 03"E	2.5×0.5	47
11	0243 Apr 18	37° 55' 44"N, 124° 36' 02"E	1.3×0.5	48

〈Table III-7-3〉 Objects found in the sinking site by the KORDI

34) Multi-Beam Echo Sounder: a depth finder that emits multi-beam echo sound and receives returning sound to measure the depth and the underwater terrain simultaneously. It can measure transverse cross section of the seabed and depict contour lines and terrain in color graphic.



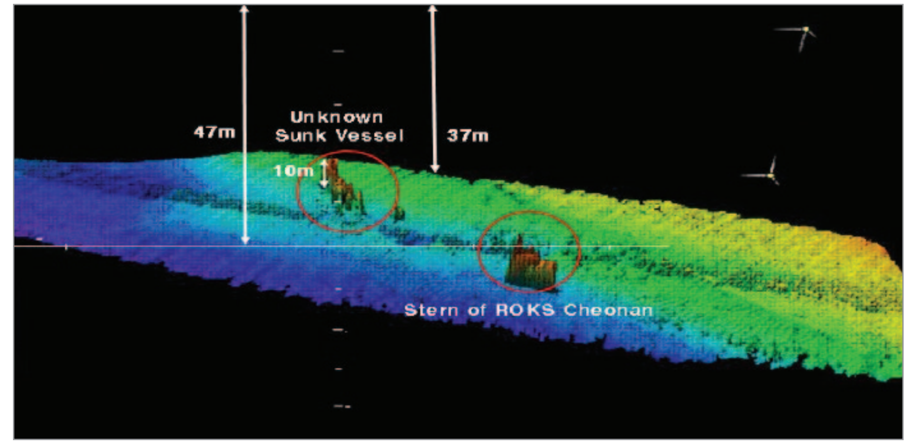
〈Figure III-7-4〉 Result of underwater terrain search in the sinking site

cluded that there were no underwater obstacles in ROKS Cheonan's maneuvering route.

The unknown sunken vessel found in the sinking site is not depicted on the charts. The type of the vessel and the time of its sinking were unknown, and Navy Search and Rescue Group divers conducted investigation on the vessel several times. Acoustic image from Side Scan Sonar found that the vessel had the shape of a merchant vessel(steering gear room in the stern and multiple columns in the middle deck), and many rivettings of the metal structure recovered from near the unknown sunken vessel support the high likelihood that it was a merchant vessel which sunk scores of years ago.

〈Figure III-7-5〉 Metal structure found near unknown sunken vessel

Given the water depth of the location of the unknown sunken vessel(47m), the height of the unknown sunken vessel(10m), and the draft of ROKS Cheonan(2.88m), it was confirmed that the unknown sunken vessel would not have impacted the safety of ROKS Cheo-

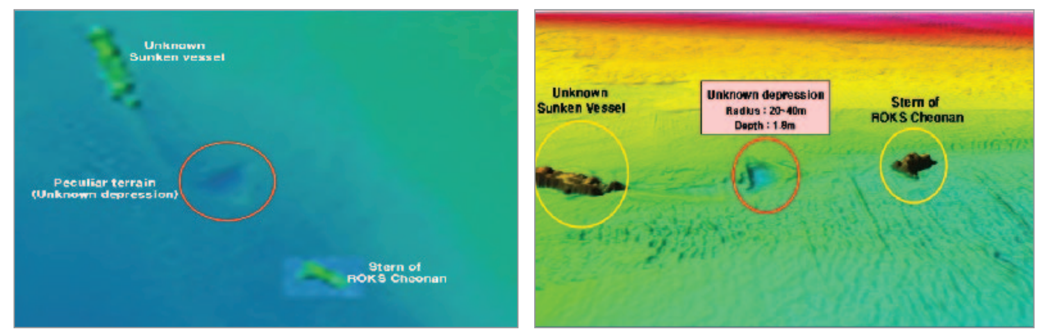


〈Figure III-7-6〉 Underwater terrain around the unknown sunken vessel

nan's maneuvering.

KORDI Research vessels found an unknown depression(20~40m in radius and 1.8m in depth) at the seabed between the unknown sunken vessel and the stern of ROKS Cheonan. In order to verify the cause on the formation of this depression, a month long accumulation and erosion process on the seabed was observed through 3D Multi-Beam Echo Sounder. This combined with the further on-site search conducted by the divers resulted in a confirmation that the seabed geography consisted of hard mud and gravels.

After having a discussion with these results of investigation, experts[35] concluded that the depression was created not artificially but by alteration of current flow due to the unknown sunken vessel and that it had no relevance to ROKS Cheonan incident.



〈Figure III-7-7〉 Depression at the seabed near the incident site

35) The civilian chairman of the JIG, a professor from KAIST, researchers from ADD, a researcher from KORDI, and an advisor from National Assembly Recommended Investigation Committee participated in the discussion among the experts on the unknown depression.

④ Consulting Local Personnel on the possible Underwater Obstacles in vicinity of the sinking site

The JIG visited relevant members of fishery group, government vessels, and fishers in Baekryong Island and checked whether there exist underwater obstacles in the vicinity of the sinking site but are not depicted on charts. Regarding the unknown sunken vessel, a fisher in Baekryong Island stated that he heard from his father that the vessel sunk sometime during Japanese colonial rule. Regarding the reef, Honghapyeo, reported by the Korean Broadcasting System(KBS) on March 30, 2010, is 10km southeast of the sinking site as shown in 〈Figure III-7-8〉, and no unknown obstacles were found.

〈Figure III-7-8〉 Reef(Honghapyeo) near Baekryong Island shown on a chart

(3) Sub-conclusion

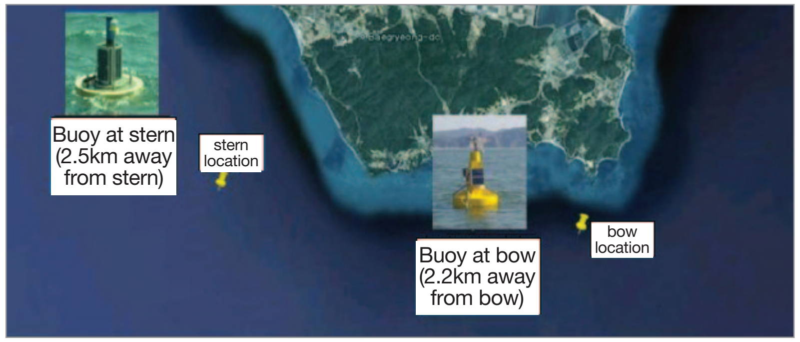
Ships of Navy Search and Rescue Group and of KORDI identified 30 objects underwater in total in the vicinity of ROKS Cheonan's sinking site. Most of the objects were confirmed to be debris of ROKS Cheonan, bedrock, and abandoned fishing net which could not have affected the sinking of ROKS Cheonan. All findings relevant to the maneuvering route of ROKS Cheonan such as the KORDI's research on underwater terrain, investigation on obstacles including the unknown sunken vessel and artificial reef, and NORI's confirmation on chart measurement data ultimately verified that there were no factors that could have affected the sinking of ROKS Cheonan.

5) Analysis on the Tidal Currents Near Baekryong Island

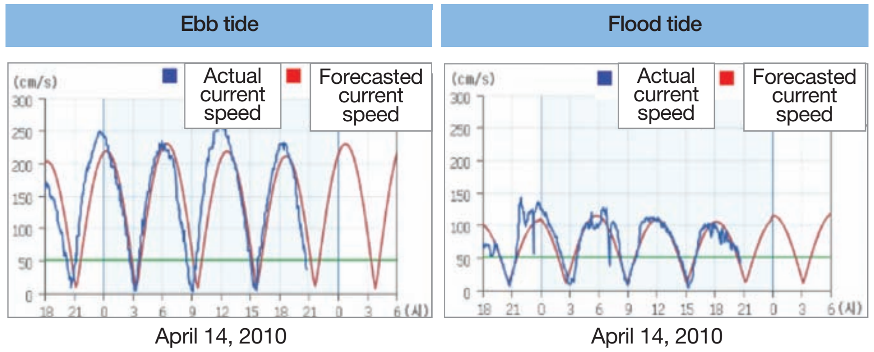
(1) Investigation Method

Analysis on the tidal currents near Baekryong Island utilized「Military Operational Tidal Movement and Tidal Currents Forecasting System」[36] jointly developed by ROKN Maritime Tactical Intelligence Group and NORI. NORI verified the forecasting system with actual measurement data from 2 meteorological observation buoys installed in the sinking site to support the search and rescue operation since the sinking of ROKS Cheonan.

The comparison between「Military operational tidal movement and tidal current forecasting system」and the actual current speed measurement of data of buoys confirmed that the first one serves as a credible numeric model.



〈Figure III-7-9〉 Locations of observation buoys of the NORI near Baekryong Island



〈Figure III-7-10〉 Comparison between「Military Operational tidal movement and tidal current forecasting system」 and the actual current speed measurement data of buoys

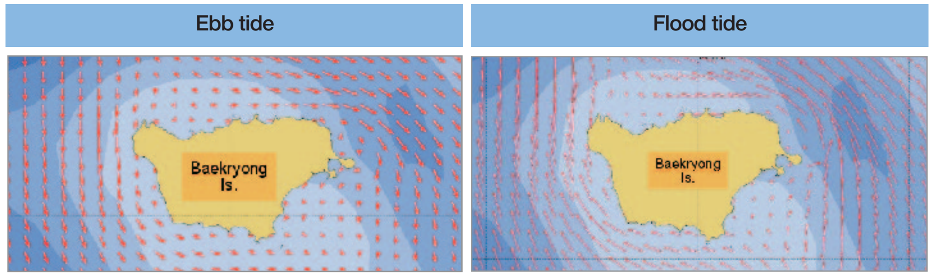
36)「Military Operational tidal movement and tidal currents forecasting system」is digital forecasting program that exactly forecasts flood and ebb tide and current. It was developed in and has been operating since 2008. It forecasts speed of the current, time of flood and ebb tide by date.

(2) Investigation Result

① Analysis on the Tidal Movement and Currents Near Baekryong Island

ⓐ Characteristics

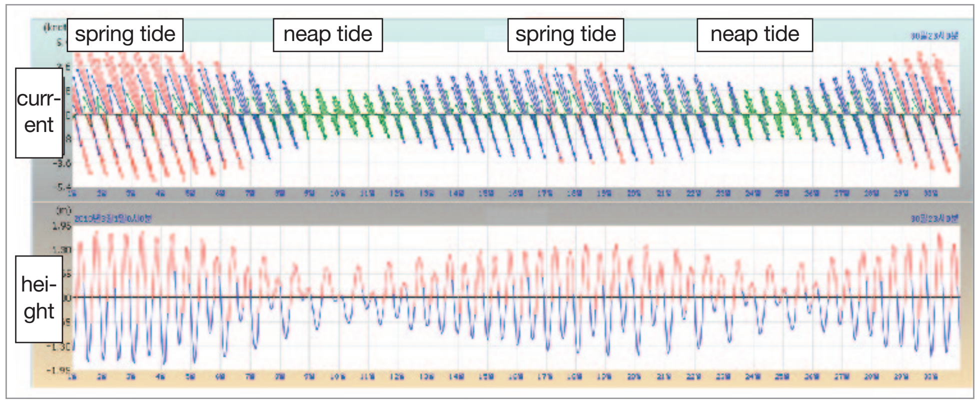
Tidal movement occurs twice a day(ebb and flood tide)[37]. Generally the tidal current is parallel to the coastline. The flood tide moves to the north, whereas the ebb tide moves to the south. The highest current speed is 5.3kts(the lowest current speed is 0.3kts). The time difference between the ebb and flood tide is 6 hours.



〈Figure III-7-11〉 Tidal current at ebb and flood tide near Baekryong Island

ⓑ Tidal Movement and Current in March

Normally, the speed of current in March is between 0.3 ~ 5.3kts and is low at neap tide[38] and is fast at spring tide[39]. Tidal difference[40] at neap tide is 0.3m and spring tide is 3.6m.

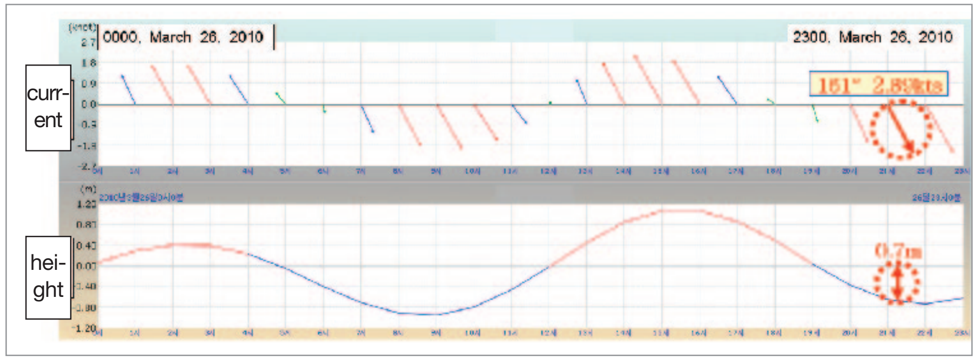


〈Figure III-7-12〉 Tidal current and height in March
(↖: direction and speed of tidal current, : height of flood and ebb tide)

37) Flood tide is when sea water rises to its highest, and ebb tide is when sea water falls to its lowest level.
38) Neap tide is when the tidal difference is at its minimum.
39) Spring tide is when the tidal difference is at its maximum.
40) Tidal difference is the difference of height between flood tide and ebb tide.

ⓒ Tidal Current(Direction and Speed) and Movement on the Incident Day(March 26)

Simulation result for the incident day calculated that the direction and speed of the tidal current were 161°-2.89kts and that the height of current was 0.7m(the lowest current is 0.8m) at the time of the incident(2122).



〈Figure III-7-13〉 Tidal current and height on the incident date(March 26)

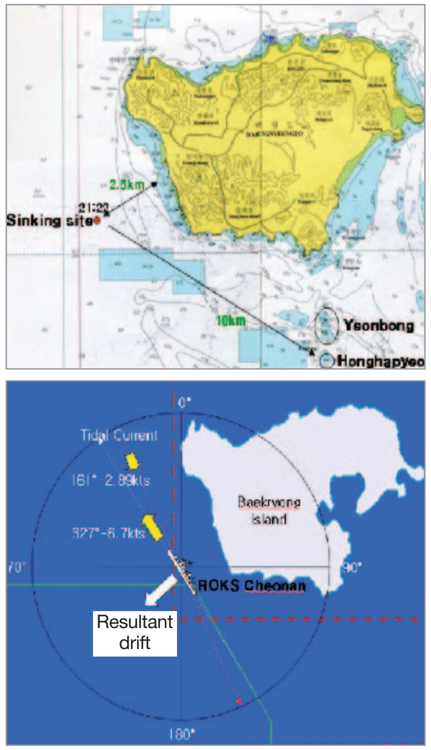
② Effects of the Tidal Current on Maneuvering in ROKS Cheonan's Patrol Area

ⓐ Conditions

At the time of the incident(2122 March 26), the wind was blowing from southwest at 20kts, the wave height was 2.5m, the visibility was 2.5NM, and the course and speed of ROKS Cheonan was 327°- 6.7 kts.

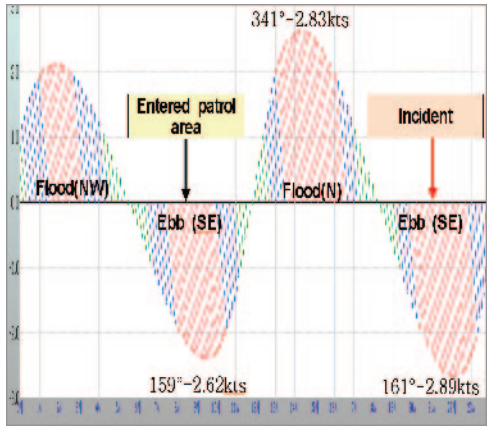
ⓑ Simulation Result

At ebb tide(161°- 2.89kts), strong current can push maneuvering ship towards the open sea by some extent. But it was assessed that the maneuvering of ROKS Cheonan experienced no limitation because the speed of ROKS Cheonan(6.7kts) was greater than the speed of the tidal current.



〈Figure III-7-14〉 Maneuvering course of ROKS Cheonan on the incident day(March 26)

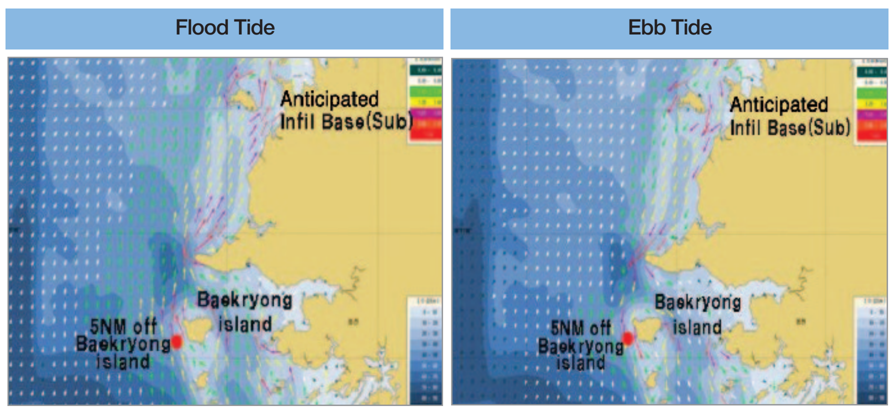
Max flood / ebb tide			Course of ROKS Cheonan
Time	Bearing	Speed	
0840	159° (Ebb)	2.62 kts	345° (effect from maneuvering against current)
1500	341° (Flood)	2.83 kts	135° (effect from maneuvering against current)
2122	161° (Ebb)	2.89 kts	327° (effect from maneuvering against current)



〈Figure III-7-15〉 Direction and speed of current on the incident day(March 26)

③ Analysis on the Tidal Current between Anticipated North Korea Infiltration Base of North Korean submarine or midget submarine and Baekryong Island

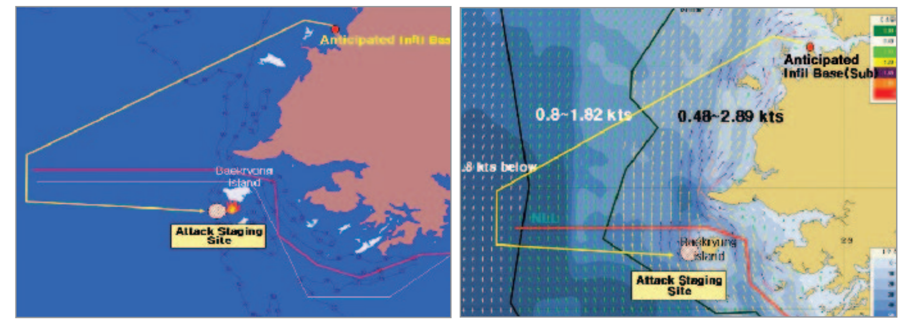
In the region, the tidal current near the coast is fast(0.48~2.89kts) but becomes gradually slower(below 0.83kts) towards the open sea. Attack position, assessed to be 5NM west of Baekryong Island, has currents at 0.22~4.66kts. Therefore, it is assessed that infiltrating and escaping of submarine or midget submarine through the open sea that has less effects of the tidal current rather than along the coastline is advantageous.



〈Figure III-7-16〉 Result of simulation on the tidal current from March 23 until 2120 March 26 between the anticipated infiltration base and Baekryong Island

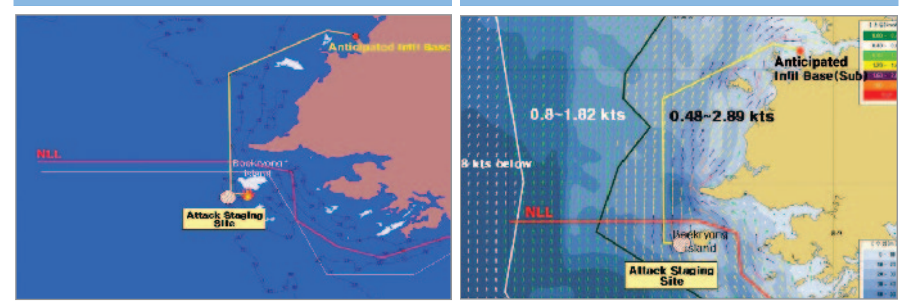
④ Effects of the Tidal Current on Maneuvering of North Korean submarine or midget submarine

ⓐ Infiltration through the open sea(anticipated North Korea infiltration base → turning point in the open sea → attack staging site near Baekryong Island) would receive relatively less effect from the tidal current because the speed of current near the coastline is 0.48~2.89kts whereas the speed in the open sea is 0.23~1.82kts with average speed of 1.2kts. Given the total infiltration distance(○ ○ ○ NM) and infiltration duration(○ ○ hours), modifying the speed of infiltration according to necessary mode of maneuver(snorkel[41], submerged) will allow the vessel to overcome the effect of the current.



〈Figure III-7-17〉 Anticipated infiltration route and current speed when submarine or midget submarine from the anticipated North Korea infiltration base infiltrates through the open sea

ⓑ Infiltration using the shortest route(anticipated North Korea infiltration base →



〈Figure III-7-18〉 Anticipated infiltration route and current speed when submarine or midget submarine from the anticipated North Korea infiltration base infiltrates through the shortest route

41) Snorkel is a mode of submarine or midget submarine maneuvering only exposing snorkel induction mast above the surface in order to charge electric battery.

NLL → attack staging site near Baekryong Island) would receive more effects of current(speed of current 0.48~2.89kts/average speed of current 2.4kts) than when infiltrating through the open sea. Given the total infiltration distance(○ ○NM) and infiltration duration(○hours), covert underwater infiltration would be limited due to strong current occurring in opposite direction every 6 hour.

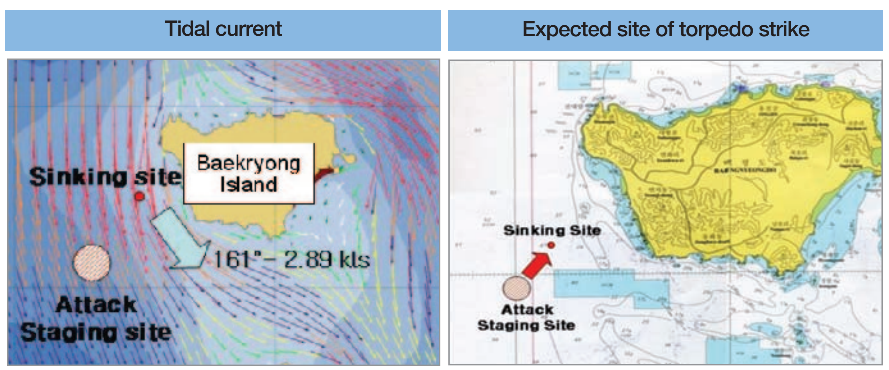
⑤ Effects of tidal current on the employment of North Korean submarine or midget submarine armaments

ⓐ Assumptions

North Korean infiltration submarine or midge submarine has weapons to strike ROKS Cheonan at the sinking site, 2.5 km southwest of Baekryong Island.

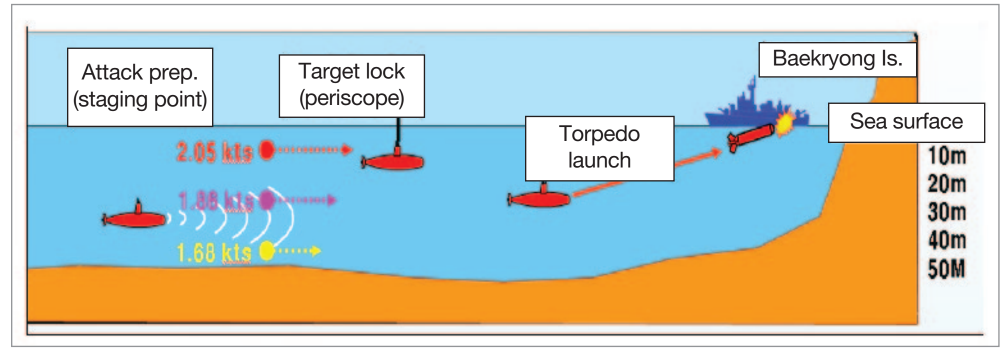
ⓑ Effects of Tidal Current on Torpedo Launch

If a North Korean submarine or midget submarine is going to fire a torpedo, in order to conduct a TMA[42], it needs a speed of at least 6kts, and at least 5kts for the torpedo to stay on course. In order to minimize the effect of current, the torpedo would need to be fired from deeper than the surface of the sea. However, considering the speed of torpedoes(at least 30kts) and guiding method(acoustic), the current would not have a significant effect on the torpedo.



〈Figure III-7-19〉 Current at time of incident & expected attack staging site

42) TMA(Target Motion Analysis): An analysis of a target's movement(distance, speed) by a submarine for a torpedo launch.

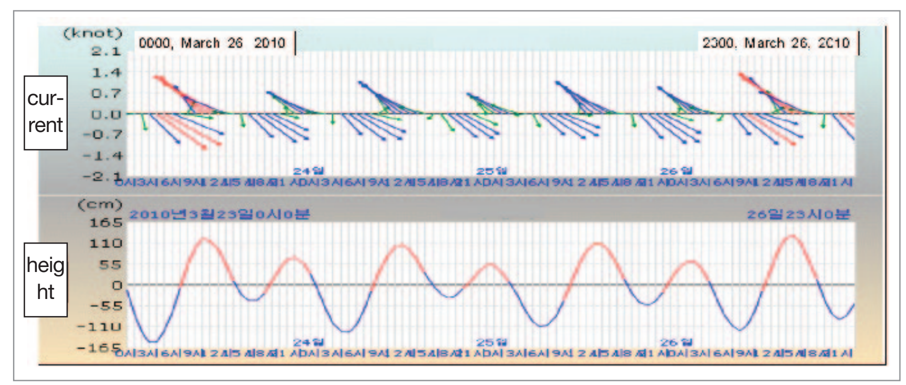


〈Figure III-7-20〉 Current speed at various depths near Baekryong Island and tactics for torpedo employment by North Korean submarine

ⓒ Effects of Tidal Current on Mine Laying

In order to lay a mine precisely, a North Korean submarine or midget submarine has to choose the time when the current has the least effect in mine laying, so it is most likely to select slack tide time or favorable tide to lay the mine. Considering the expected arrival date of the submarine or midget submarine(before March 26) in the vicinity of Baekryong Island and the current direction and speed at the time of the incident(approx. 2122)[43], the expected course of

	March 23	March 24	March 25	March 26
Current direction & speed (Time)	220°-0.10kts (0100) 225°-0.11kts (1400)	222°-0.10kts (0220) 231°-0.17kts (1530)	217°-0.12kts (0400) 219°-0.18kts (1700)	260°-0.14kts (0520) 253°-0.19kts (1800)



〈Figure III-7-21〉 Current direction & speed at slack tide during March 23~26

43) The current at the time of the incident on March 26 was 161°-2.89kts.

mine laying would be 161°~ 253°. However, in case of mine laying, it would have to maneuver at low speed of about 3kts, so the current would have severely affected the laying.

(3) Sub-conclusion

The current near Baekryong Island is considerably strong(max 5.3kts); however at the time of the sinking incident(2122 March 26), the current through detailed simulation was 161°- 2.89kts(charter current 142°- 2kts). Although how much the current affects the maneuver of ROKS Cheonan and North Korean submarine or midget submarine may vary depending on different waters, it is believed that North Korean submarine or midget submarine would have overcome the effect the current might have had by altering its speed or mode of maneuvering(snorkel/submerged). Also, if the North Korean submarine or midget submarine used a torpedo, considering the speed(at least 30kts) and guiding method(acoustic), current would not have a significant effect on the torpedo. Employment of sea mines must have been executed operating in a low speed for its precise emplacement, and therefore it would have been heavily affected by currents.

8. Propulsion Motor System of Torpedo

The scientific investigation team actively looked for a critical evidence in the early stages of the incident. The Navy search/rescue group played a central role in collecting underwater evidences. Also, 8 ships including a mine searching vessel and rescue boats were committed from the ROK side, the US used USS Salvor, and the KORDI committed Ship Jangmok and Ship Yiuhdo in support of collecting underwater evidences. Also, 106 divers(73 from SSU and 33 from EOD) and the robot Haemirae participated in the searching operations. However, Baekryong Island, the incident site, is surrounded by frequent fogs causing limited visibility of 100y~1NM(91m ~ 1.828m), high current of 3~5kts on average, and water 40~50 meters deep. These environmental conditions made the operation more difficult.

Accordingly, not only civilian and military personnel, but also foreign experts were involved in numerous discussions for identifying the effective method for collecting evidences. As a result, the employments of special magnets for collecting magnetic fragments and remains, and dredging ship that conducts indraft and separates muds and sands on the seabed with water pump were suggested along with the application of fishing boats with nets.

However, special magnet was unable to collect non-magnetic fragments and remains, and employment of dredging ship was restricted due to the shallow water depth in the incident area as well as its preparatory period of more than 30 days. The fishing boat with nets could only be utilized in regions with only mud and sand of smooth surface. Therefore, all three options were not expected to make any significant finding.

While searching for other effective and practical collecting methods, the team became aware of a previous case where the ROK Air Force used a special net to collect the remains of a wrecked plane, and hosted a meeting for discussing the method of collecting the remains on April 17 with 3 personnel including the ROKAF Safety Office inspector, CEO of Daepyong Corp., and primary contractor at that time.

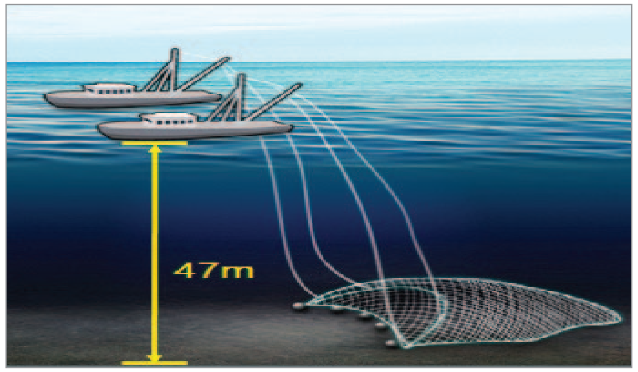
At this meeting, the ROKAF inspector notified that the ROKAF utilized the special net made by Daepyong Corp., and successfully collected in three weeks most of the remains of a F-15 fighter jet that had sunk on June 7, 2006 in East Sea, 372 meters deep, and those of a F-16 sunk on July 20, 2007 in West Sea, 45 meters deep. Therefore, the JIG saw that the special net can be a viable option in collecting the evidence and conducted a thorough review on the subject. As the co-chairmen of the JIG received the approval of the Minister of National Defense on April 18, the JIG began the underwater evidence collection operation using the special net.

1) Time sequence

On April 19, representatives from JIG and ROK Navy HQ met with CEO of Daepyong Corp. at ROKN HQ, and signed a contract(Navy construction contract-1327). The operation period was decided to be from April 27 until May 24. The initial operation was to be carried out with 500 × 500yds net with additional contract as required, and all operating personnel were to go under appropriate security measures.

Daepyong Corp. initiated the manufacturing of the special net on April 21 and finished on April 26, one day ahead of schedule. After loading the special net on the ship, the ship departed Busan Port on April 27. Upon arrival in Daechung Island on the dawn of April 30, preparations were made by understanding the underwater terrain and currents near the operation site.

With evidence collection team(13) from JIG deployed on May 1 by a CH-47, the



〈Figure III-8-1〉 Conceptual diagram of the special net and bull trawler

stones weighing over 300kg, 70kg of gravel, 30kg of shellfish, 4 sandbags were collected as results of two test runs of the special net twice outside the core area on May 3. However the geography of seabed consisted of more gravels and bedrocks than anticipated, causing severe damaging to the special net. Therefore, on May 4, the JIG entered Pyeongtaek port where the net was rewoven and strengthened with 14mm wires, and two reserve sets of the net were picked up. The team departed Pyeongtaek port on the 6th and arrived at Baekryong Island site on the 7th.

The ROK Joint Chiefs of Staff directed to "utilize the special net after salvaging massive objects such as the gas turbine in the operational area" thus putting off the usage of the net; however, on May 9, the 5-inch rope of the sea crane used by ROKS Gwangyang broke while salvaging the object later identified as the gas turbine. The ROK Navy proposed to the ROK JCS to contract a civilian company[44] for another sea crane. These circumstances(including preparation and transportation period) delayed the process as the company was planned to arrive at the site on May 17; thus, SAR Group proposed to JCS to start special net operations earlier than planned. After approval of this proposal, the collection operation using the special net began at 1800 on May 10.

The multinational investigation personnel(USA 4, Sweden 1, England 2) visited the seabed evidence collection site, where a special net was applied on the operation, during 1300~1800 on May 14. After conducting an inspection on the site boarding a helicopter, they moved to segregated collection area of Battalion(ROKMC), the place where all the collected materials from the seabed were categorized and evidences were selected. Later, they embarked RIB at Jangchon pier and transferred to the bull trawlers to observe the evidence collection site. Through those above, the multinational investigation personnel could verify the procedure and method of seabed evidence collection which utilized a special net.

44) Yusung Underwater Development, which salvaged the stern side and whose ship Yusung can salvage up to 150t

2) Procedures for Collection and Gathering

Concerning the specifications of the special net, the dimensions were 60m × 25m × 15m, the size of the mesh was 5mm by 5mm[45], and the weight was 5 tons. Objects, sand, and mud larger than 1mm could be collected with the net. The net was operated by two 135-ton ships(Daepyong 11 and 12) and 500 × 500yds operational area was set up centering on the point of explosion and was divided into 25 blocks(20 × 20yds). Daily areas of operation were set up accordingly to make sure no area was missed. In particular, it was assessed that it would be difficult to locate the special net under strong current using the fish detectors on the ships, and thus a minesweeper was used to support the operation.

Concerning the procedures for the collection of the objects and gathering the evidences, two ships cast the net under the sea while moving in the speed of 2~4kts, then after collecting the objects on the seabed the net was pulled, after which JIG Collection Team, UDT control personnel, and the crew of Daepyong 11 and 12 conducted a preliminary classification

Date	# of Operations (AM/PM)	Collected Objects	Gathered Evidences
May 10(Mon)	0 / 3	Rocks, etc.	2, including soil under seat cover
May 11(Tue)	3 / 2	7, including guidance deception device	7, including aluminum pieces
May 12(Wed)	3 / 4	1 x iron structure	4, including asbestos pieces
May 13(Thu)	3 / 5	24, including cook stove	1 x metal piece from stokehold floor
May 14(Fri)	3 / 3	17, including laminated blueprint	2, including metal piece from stokehold dashboard
May 15(Sat)	1 / 4	35, including PC	7, including torpedo propulsion device
May 16(Sun)	5 / 0	14, including pipe switch	
May 19(Wed)	4 / 0	3, including military binoculars	

〈Table III-8-1〉 Recovery and collection status applying special net

45) The special net was manufactured in a sack shape. Not the overall net mesh was composed with 5mm density but only the end part; in underwater, the density is reduced to 1mm due to tensile force created after casting.

on the deck. Then the objects were transported to a port(Jangchonri Port) via RIB and in turn to the collection site set up at Battalion, Marine Corps 6th Brigade via vehicle(military vehicle 5/4t) stationed in Baekryong Island. At the collection site, the objects were classified in further detail using hands and metal(mine) detector, after which JIG Collection Team gathered objects that were considered as evidence[46].

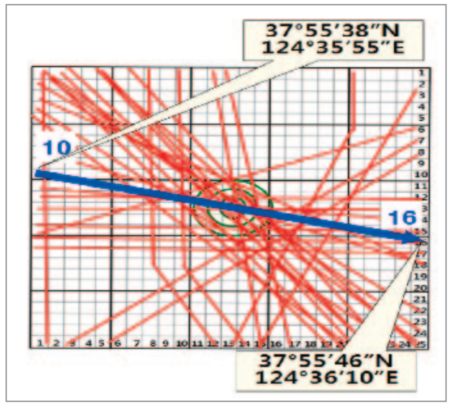
3) Collection of Torpedo Propulsion Device

Despite the risks involved due to weather conditions such as wave height above 2m, wind speed above 20kts, and limitations on visibility, the operation was conducted at X-axis 8, 10, and 11 from incident site in range of 3 to 8 times a day from May 10, in order to secure successful outcome.

Date	Weather condition	Operation	Operation
4.30(Fri)	Wave height 1.5m, visibility 3NM	Arrival	Coord. discussion(1400)
5. 1(Sat)	Wave height 1.5m, visibility 3NM	X	On-site visit, preparation
5. 2(Sun)	Wave height 2m, visibility 3NM	O	Experimental employment(2)
5. 3(Mon)	Wave height 2m, wind 25kts, visibility 3NM	O	Experimental employment(net damage)
5. 4(Tue)	Wave height 1.5m, visibility 100y	X	Return to Pyeongtaek for net repair
5. 5(Wed)	Wave height 2m, wind 30kts,visibility 50y	X	Net repair
5. 6(Thu)	Wave height 3m,wind 30kts,visibility 1NM	X	Additional net loading, depart(1800)
5. 7(Fri)	Wave height 2m,wind 30kts,visibility 3NM	X	Returned to Baekryong Island(0800)
5. 8(Sat)	Wave height 1.5m, visibility 5NM	X	Standby for gas turbine recovery
5. 9(Sun)	Wave height 1m, visibility 7NM	X	Failed to recover gas turbine
5.10(Mon)	Wave height 1.5m, visibility 3NM	O(3)	Ops. began(JCS instruction)
5.11(Tue)	Wave height 1.5m, visibility 5NM	O(5)	
5.12(Wed)	Wave height 1.5m, visibility 3NM	O(7)	
5.13(Thu)	Wave height 1.5m, visibility 4NM	O(8)	
5.14(Fri)	Wave height 1.5m, visibility 5NM	O(6)	
5.15(Sat)	Wave height 1m, visibility 5NM	O(5)	Propulsion device recovered
5.16(Sun)	Wave height 1m, visibility 5NM	O(5)	
5.17(Mon)	Wave height 1m, visibility 5NM	X	Standby for gas turbine recovery
5.18(Tue)	Wave height 1.5m, visibility 1NM	X	Adverse weathe
5.19(Wed)	Wave height 1.5m, visibility 100y	O(4)	
5.20(Thu)	Wave height 1~1.5m, visibility 3NM	Departure	
Total	3 test runs in 2 days, 43 operations in 8 days		

〈Table III-8-2〉 Recovery Operation status applying special net

The seabed evidence collection team aboarded the bull trawler which was embarked near the Jangchon pier in Baekryong Island around 0750 hours on May 15[47], left the pier and started the operation from the Y-axis block 10 as seen in 〈Figure III-8-2〉. From that, the ship maneuvered to the block 16 and started the 30th round of the operation, which ended around 0923 hours, and started salvaging the collected objects using the Daepyong No. 11.



〈Figure III-8-2〉 Propulsion device location

Around 0925 hours, a crew member of Daepyong No.11 told a JIG investigator (MSG[48]) that "there is a strange object in the net", and investigators and crew members confirmed that the object was a material with two propellers. The Navy search and salvage leader who came aboard at 0930, and the UDT Squadron Commander, CDR, were there to double check. With the measurements during on-site examination of the overall length of the propulsion device that included the propeller width, blade length, and other parts sizes, and after photographs of each part were taken by an investigator of the JIG at 0931, the recovery of the propulsion device was reported to the JIG HQ at 0936. Afterwards, a bulk of copper considered to be the motor was addi-

46) For large objects that cannot be transported via RIB, a Navy ship was used to transport directly to 2nd Fleet Command.

47) Daepyong 11, 17 crew: The Navy search and salvage leader, UDT Squadron Commander, Chief Steering Officer, 2 JIG investigators , captain and 11 crews
Daepyong 12, 15 crew: UDT(LCDR), steering(SCPO), JIG investigator(SCPO, CPO), Captain, and crew

48) MSG had previously witnessed a torpedo while visiting a military acquisition company(LIG Nexone) who, based on that memory, assessed the evidence to be a torpedo.

tionally recovered at 0938 which was assessed to be associated with the torpedo, and the JIG took photographs and conducted size measurements of the object. Search and Rescue Group Commander, and 5 personnel arrived at the scene at 0940 and verified the evidence.

The JIG Evidence Collection Team leader and 2 other members arrived at 0950, verified the evidences, and conducted a precise evidence collection on the site at 0955[49]. At 1005, the JIG requested some blankets for packaging the evidence at ROKS Sunginbong, and used the blankets to do the initial packaging at 1015, the secondary packaging using vinyl tents, tying it up with rope, and at 1023 the JIG collection team leader and 2 others, and 4 people who packaged the evidence used RIBs to transport the evidence to Port Jangchon at Baekryong Island.

An Air Force helicopter at the 6th Brigade(ROKMC) helipad was used to transport them to Pyeongtaek; the helicopter arrived at the 2nd Fleet helipad at 1320. The evidences were moved to the JIG office at the 2nd Fleet, where security measures such as entrance/exit restrictions were taken into effect, after which the JIG Military chairman and the Scientific Investigation Team leader verified the evidence at 1400, and conducted precision analyses from 1500~1630.

During 0900~1000 May 17, four foreign investigation representatives(US Naval Captain Mark Thomas, Australia Naval Commander Powell, Sweden Agne Widholm, UK David Manley), torpedo experts from the Multinational Combined Intelligence TF, and ADD(Alexander Kathy and Dr. Lee respectively), Chief of the scientific investigation division, and Chief of general management team convened and had a joint discussion regarding the recovered torpedo propulsion device.

The recovery and evidence selection procedure of the torpedo propulsion device is shown in 〈Figure III-8-3〉.

① Cast the special net ② Salvage collected objects

49) CPO filmed the videos and photographs of the torpedo propulsion section, and the site vicinity, and re-did the measurements.

③ Identify the evidence ④ On-site examination

⑤ Package the evidence ⑥ Ground transportation

⑦ Helicopter transportation ⑧ Precise examination

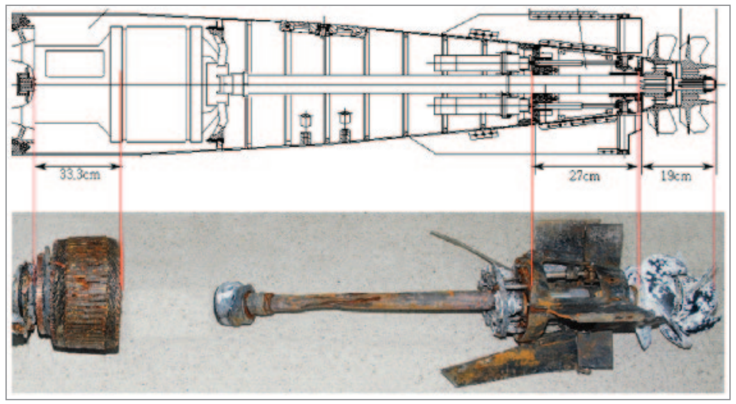
〈Figure III-8-3〉 Recovery and collection of the evidence

4) Analysis Results

The conclusive evidence is a propulsion device of a torpedo and consists of steering device(71.1kg) and propulsion motor(81.85kg). The steering device is composed of the shaft, propeller, and aft section that contains 4 fins, each of which had stabilizer in the anterior and rudder in the posterior. To determine what model of torpedo this evidence belongs to, many models of torpedoes from different countries were analyzed. As a result it was confirmed that it resembles North Korean CHT-02D torpedo manufactured for exportation, and the JIG obtained the blueprint and conducted the analysis.

〈Figure III-8-4〉 Blueprint of CHT-02D

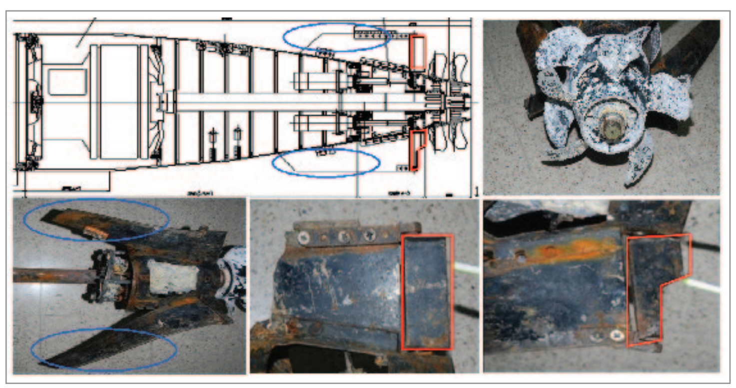
The JIG received the image of CHT-02D torpedo from Intelligence Analysis Team and obtained the length of each part after magnifying the image over 10 times in order to confirm the consistency with the evidence. Also, upon investigation of the inscriptions resembling Japanese character on the blueprint, the JIG concluded that it did not make any sense in Japanese and appeared in the process of reading and printing the North Korean computer font with ROK computers and printers. It was confirmed that the blueprint preprinted by North Korea has Korean on it.



〈Figure III-8-5〉 Size comparison between the blueprint of CHT-02D and the evidence

As shown in 〈Figure III-8-5〉, the length from the propeller to the shaft is: 112cm, propeller: 19cm, the rear: 27cm, propulsion motor: 33.3cm, upper stabilizer: 33cm, and the lower stabilizer was 45cm. All of these coincided with the data from the blueprint.

For the shape of the evidence, the contra-rotating propeller has 5 blades, the slanted stabilizer, the rectangular upper rudder, and the P-shaped lower rudder, all of which were the same as the blueprint. The lower stabilizer contained 9 supporting holes while the lower



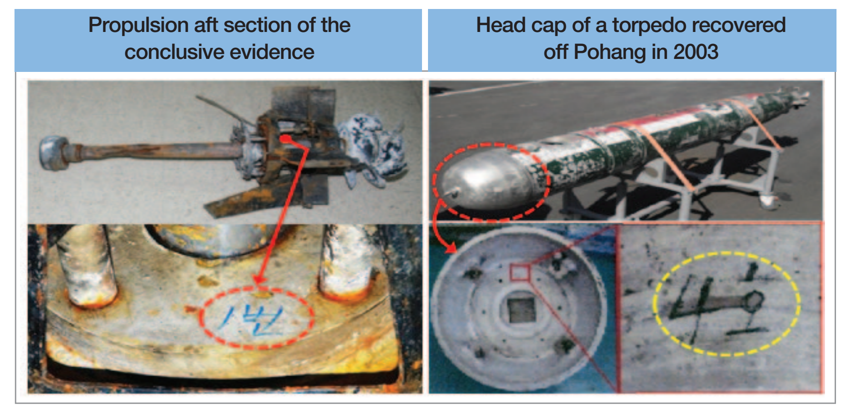
〈Figure III-8-6〉 Shape comparison between the blueprint of CHT-02D and the evidence

rudder had 2, which also coincided with the blueprint.

Also, as a result of conducting an analysis on the white adhered material from the propeller part, aluminum oxide, carbon(partially graphite), and aluminum powder were detected, which later turned out to be identical with the adhered material on ROKS Cheonan hull and stack.

Additionally, at 0925 on May 15, the scientific investigation team found the Korean marking(1번 or No. 1 in English) inside the end of the propulsion part. This was not initially found when examined aboard the recovery ship due to the lack of a precise examination. However, it was found when being observed after having been transported by a helicopter to 2nd ROK Fleet(Pyeongtaek), where the civilian-military JIG is located.

Also, it was acknowledged that the Korean marking '1번(No. 1 in English)' found on the end of propulsion part is similar to that found on the inside of the head cap of a light weight torpedo collected off Pohang in 2003, which says '4호(Unit 4 in English)'[50] and the JIG considered conducting handwriting analysis. Even though it was limited by the difference in the markings themselves(they were made of different vowels and consonants), as the composition analysis of the ink of the marking was conducted, it was confirmed that the marking '1번' was written before the corrosion since salt was precipitated on the marking and corroded interior steel was found to be risen above the ink.



〈Figure III-8-7〉 The Korean inscriptions on torpedo propulsion motor and North Korean light torpedo

50) According to the "North Korean Dictionary of Korean", North Korea uses both '호(unit)' and '번(no.)'. According to statements made by North Korean defectors, North Korea uses '번(no.)' to indicate order, and '호(unit)' to distinguish different types of objects. In locations where order is necessary such as a distribution office or a bus stop, the '번' is used. For other objects, depending on their user, or type of object, such as 'Resort Unit 1' and 'Unit 15 Concentration Camp', and 'Unit 10', the '호(unit)' is used, and when two different types of missiles are being produced in a factory, the missiles are distinguished by using the letters 'Unit 1' or 'Unit 2'. Among the same type of missiles, the missiles are differentiated by using 'No.', for instance in 'No.1' or 'No.2'

No explosive was detected on the torpedo parts, and the propeller was made of an aluminum alloy(Aluminum 86%, Silicon 14%) while the fixed wings were made of iron(Fe).

In addition, samples were collected from the bow and stern breakplanes in order to analyze the degree of corrosion that had occurred both on the torpedo propulsion section and the hull of ROKS Cheonan. Seoul National University(Prof. Kwon Dong-il), Kangneung Wonju University(Prof. Choi Byung-hak), and the National Institute of Scientific Investigation(Dr. Kim Ui-su), conducted joint visual analysis of the evidence. They found that the torpedo propulsion section iron portions(rudder) and ROKS Cheonan hull metal fragments' degrees of corrosion were similar.

The '1번' markings had not evaporated or discolored despite exposure to high temperatures of over 150℃, but were left clear blue. To determine the reason for this, the JIG used a spectrometer to conduct precision analysis of the rear propulsion section where the marking was located, as a result of which it was found that a type of anti-corrosive paint was used upon the stainless steel(polyvinyl butyral)[51]. This incident was a non-contact underwater explosion at 3℃ water temperature, and the torpedo consisted of the target detection section(70cm), the warhead section(72cm), the battery section(4.125m), and the propulsion section(1.805m). Therefore, even if the explosion had occurred at the warhead section(72cm), the battery section which is 4.125m long would have provided a shock absorber. Also, The portion with the '1번' markings in the propulsion aft section was protected by a maintenance cover; it was filled up with seawater at the time of launch; and a gas bubble of 6m in diameter was created during the explosion of 250kg charge weight, pushing the propulsion section backwards 30~40m. Given these facts, the high heat would not have damaged the surface of the propulsion aft section and the ink(where the anti-corrosive paint had been applied), leaving the markings in its original state and clear condition.

Related to this matter, an expert in the field of thermodynamics from KAIST, professor Tae-ho Song, conducted a study on the changes of the temperature in case of an underwater explosion caused by a torpedo. His findings were that the flame of 3,000℃ caused by the explosion cools down to normal temperature(28℃) within 0.1 second due to adiabatic expansion, and that although the flame may raise the disk temperature 2~3℃ above the water temperature(3℃) in the process, heat transfer would not occur all the way to the rear, and thus no significant change in temperature would have resulted in the area where the marking '1번'(No. 1 in English) is written. Also, professor Song suggested that even under harsher conditions, no part of the propulsion motor is heated above 20℃ and thus the marking on the rear cannot receive heat damage. Through such results, professor Song explicated the scientific reason for the marking '1번'(No. 1 in English) to remain intact.

Comparison analysis between five marker ink samples made in China was conducted to determine the source of the '1번' ink. The ingredients for the paint was analyzed at the KIST Characteristic Analysis Center, where precise analysis of the ingredients was conducted; however, since many countries use the same type of ingredients to produce paint, the JIG was unable to identify the country in which it was produced.

51) Polyvinyl butyral is a high-polymer substance, which is applied to prevent rusting on metals, glass, and ceramics, and is comprised of Al, Mg, Si, Ti, P, and Zn.

5) Sub-conclusion

The facts that the evidence, the propulsion device of torpedo, matches in size and shape with the blueprint of North Korean CHT-02D torpedo with Korean alphabet('1번' : No.1) marked on it, and that the inventory inspection on ROKN underwater weapons resulted with no missing assets, indicate that the propulsion device of torpedo collected near the origin of explosion is the remains of CHT-02D torpedo manufactured in North Korea. This confirms the assessment that ROKS Cheonan was sunk by the explosion of a North Korean CHT-02D torpedo.

Diameter	21 inches(53.4cm)	Length	7.35m
Explosive	250kg	Weight	1,700kg±10kg
Cruising distance	10~15km	Homing method	Sonic track · manual

〈Figure III-8-8〉 CHT-02D Torpedo

Part IV
Conclusion

ROKS Cheonan was sunk by a North Korean torpedo attack while conducting its normal mission in vicinity of Baekryong Island at 2122 hours on March 26, 2010. Immediately following the sinking of the ship, the ROK military conducted a surface, coastal and underwater search until April 3, and transitioned from a personnel recovery operation to a salvaging operation on April 4.

The salvage and transportation of the separated bow and stern section were completed on April 25. During the salvage of the ship, 40 bodies were recovered as well. Following the salvage of the ship, emphasis was placed on search operations and a detailed search was conducted focusing on the areas where the likelihood of collecting debris was assessed to be the highest. A detailed search of the seabed using special nets commenced on May 10 and parts of a torpedo propulsion section, including a propulsion motor and propellers, were recovered on May 15.

The analysis on the cause of the sinking initially left open every possibility and explored the possibilities of a non-explosion, internal explosion or external explosion for causing the sinking. However, a detailed investigation following the salvage of the ship eliminated the possibilities of a non-explosion and internal explosion, leading the JIG to assess that an external explosion, and more specifically an underwater explosion, was the most likely cause behind the sinking. The possibility of a non-contact torpedo generating an underwater explosion was assessed to have the highest likelihood and the possibility of a moored mine was not ruled out despite its low likelihood.

The basis of our assessment that a torpedo attack caused the sinking is as follows:

First, precise measurement and analysis of the damaged hull showed that a shockwave and bubble effect caused significant upward bending of the Center Vertical Keel compared to its original state. The shell plating was steeply bent with parts of the ship fragmented. On the main deck, fractures occurred along the large openings used for the maintenance of equipment in the gas turbine room and the portside was deformed significantly in an upward direction. The bulkhead of the gas turbine room was significantly damaged and deformed. The upward bending of the bottom of the stern and bow proves that an underwater explosion occurred.

Second, a thorough investigation of the interior and exterior of the ship found evidence of extreme pressure on the fin stabilizer(which prevents significant rolling of the ship); traces of high water pressure and bubble effect on the bottom of the hull; and wires cut with no traces of heat; and traces of spherical pressure on the gas turbine room. The above indicate that a strong shockwave and bubble effect caused the splitting and sinking of the ship.

Third, the JIG analyzed statements made by survivors that they heard a near simultaneous explosion once or twice and water was splashed on the face of the port lookout who fell from the impact. Furthermore, the statements were made by coastal sentries on Baekryong Island that they saw a 100-meter high pillar of white flash for 2~3 seconds. The analysis of these testimonies indicated that the aforementioned phenomena are consistent with the occurrence of a water plume resulting from a shockwave and bubble effect. Also, no traces of fragmentation or burn injury were found from our examination of the wounded survivors and the deceased service members, while fractures and lacerations were observed. These observations are consistent with phenomena resulting from a shockwave and bubble effect.

Fourth, the seismic and air acoustic wave analysis conducted by the Korea Institute of Geoscience and Mineral Resources(KIGAM) showed the following. A seismic wave of magnitude 1.5 was detected at 4 stations. Two air acoustic waves with a 1.1 second interval were detected at 11 stations. The seismic and air acoustic waves originated from an identical site of explosion. All these are consistent with the phenomena that arise from a shockwave and bubble effect produced by an underwater explosion.

Fifth, the 1st analysis result by US team, from the hull deformation showed that the possible explosion type is an explosion of TNT equivalent of 200~300kg charge size at a point of 3m to the port from the central bottom of the gas turbine room, and at a depth of 6~9m. 2nd analysis result on simulation, by the ROK, resulted in the identical location, with TNT equivalent 250~360kg charge size. The efforts on this was also supported by the UK Investigation Team.

Sixth, based on the analysis of tidal currents in the vicinity of Baekryong Island, the

Conclusion

JIG determined that although the currents would have had a minimal influence on the launch of a torpedo, they were strong enough to limit the emplacement of mines.

Seventh, analysis of the explosive residue found HMX from 28 locations including the stack and fractured surface; RDX from 6 locations including the stack and seabed; and traces of TNT from 2 locations including the fin stabilizer. Based on this analysis, the use of an explosive compound containing HMX, RDX, and TNT was confirmed.

Lastly, on May 15, 2010, the JIG recovered conclusive evidence that confirmed the use of a torpedo while conducting a detailed search in the vicinity of the incident location using special nets. The conclusive evidence was a torpedo propulsion motor system including propellers, a propulsion motor and steering section. The evidence is consistent in its size and design to the torpedo schematics included in an introductory brochure produced by North Korea for export purposes.

A composition analysis of the adhered materials from ROKS Cheonan showed that the materials are identical to that found on the rear section of the torpedo. The Korean marking '1번(No. 1 in English)' inside the rear section of the propulsion system is also consistent with the marking of a North Korea test torpedo obtained in 2003. The above evidence confirm that the recovered torpedo parts were manufactured by North Korea.

In conclusion, taking the entirety of the analysis results of the CIV-MIL Joint Investigation Group and Multinational Combined Intelligence TF on the following factors into consideration – the torpedo propulsion system recovered from the incident location, deformation of the hull, statements by related personnel, medical examination of the deceased and wounded service members, seismic and infrasound waves, simulations of underwater explosions, tidal currents in vicinity of Baekryong Island, analysis of explosive components, recovered torpedo parts, and the identification of the perpetrator – the JIG and MCITF concluded the following:

ROKS Cheonan was split and sunk due to shockwave and bubble effect generated by the underwater explosion of a torpedo. The detonation location was 3m to port from the center of the gas turbine room and at a depth of 6~9m. The weapon system used was a CHT-02D torpedo with approximately 250kg of explosives manufactured and used by North Korea.

Conclusion