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Development of Design and Validation Technology for Blast Hardened Bulkheads

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ABSTRACT

Water tight bulkheads could lose their effectiveness and integrity resulting in total ship loss in the case of internal explosions caused by threats such as semi-armor piercing missile. To contain explosions to the one compartment directly affected by explosion and maintain water tight integrity in other compartments, blast-hardened bulkheads can be designed to maintain integrity against certain level of internal explosions by absorbing huge mechanical energy with plastic deformations. Since bulkheads with such a design can result in expensive weight increments of the ship, a systematic design technology to reduce the weight has been developed based on high strain rate large deformation study, structural behavior predictions by idealizations, and numerical methods for fluid-structure interaction and was verified through real explosive tests in partial full-scale.

INTRODUCTION

Warships are exposed to various threats during their operation. As the threat weapons evolve, the types of threats are more varied and the survivability of warships are kept threatened. To countermeasure these threats, the effort to increase the survivability of warships to ensure mission completion and survival of crew members should start from the early conceptual design stage and be considered throughout the detail design and construction (Shin 2012).

The survivability of a warship is a measure on active and passive defense capability and can be evaluated in three categories: susceptibility, recoverability, and vulnerability. The susceptibility is defined by the probability of hit when exposed to various sensors and threat weapons. The recoverability is defined by the effectiveness of damage control to quickly recover from damage and maintain mission capability after hit by a weapon. The vulnerability is a measure on effectiveness of hit on completing the mission (Trouwborst 2012). The modern warship survivability is enhanced considering the three categories. Among the three categories, one of the measures that can be considered from the structural design stage to enable a warship to fight through damage and enable mission completion is blast hardened bulkhead (Cowardin 2013).

Among the threat weapons against warship, Semi-Armor Piercing (SAP) missile that can pierce through the outer hull of a ship and explode inside using delayed fuse can damage adjacent compartments as well as the compart directly hit by opening up water tight bulkheads which are only designed to withstand water pressure could possibly cause total ship loss. The blast hardened bulkhead is an improvement on water tight bulkhead to withstand internal explosion shock and gas pressure from the explosion of warhead and burning of missile fuel. The Blast Hardened Bulkhead (BHB) can limit the damage to the one compartment directly hit to increase the probability of the mission completion and improve the survivability of the ship.

This work tried to enable the design of the BHB from the early conceptual design stage by offering the proper dimensions of BHB for given level of attack and for given dimension of the compartment and provide validity of the design. To enable these capabilities the following works were completed. Computational methods to correctly simulate the effect of internal explosion and the behavior of the bulkheads was developed. Design formulae based on idealization of the internal pressure variation from the internal explosion and the behavior of bulkheads have been derived. Graphical user interfaces were developed to enable ship designer to easily go through the design of bulkhead along with the verification of the design. Moreover, the computational methods and design formulae were validated through partial full-scale test that employed TNT.

OVERVIEW OF BLAST HARDENED BULKHEAD

The major role of BHB is to maintain water tight integrity and minimize deformation to prevent damage to adjacent major equipment. Water tight bulkheads are commonly used in ships to contain water from damaged compartments and maintain buoyancy and stability in case of emergency but they could lose their effectiveness and integrity resulting in total ship loss in the case of internal explosion.

Unlike external explosion, internal implosion cause damage through two types of load. The damage to bulkhead is caused firstly by shock wave and secondly by internal gas pressure from expansion of high temperature and pressure from explosion as well as burning of rocket fuel. Figure 1 shows real measurement of simplified shock pressure and gas pressure. The bulkheads are damaged by the combined effect of the two types of pressure profile. Compared to shock pressure, the gas pressure can be assumed to be quasi-static due to its time wise profile.

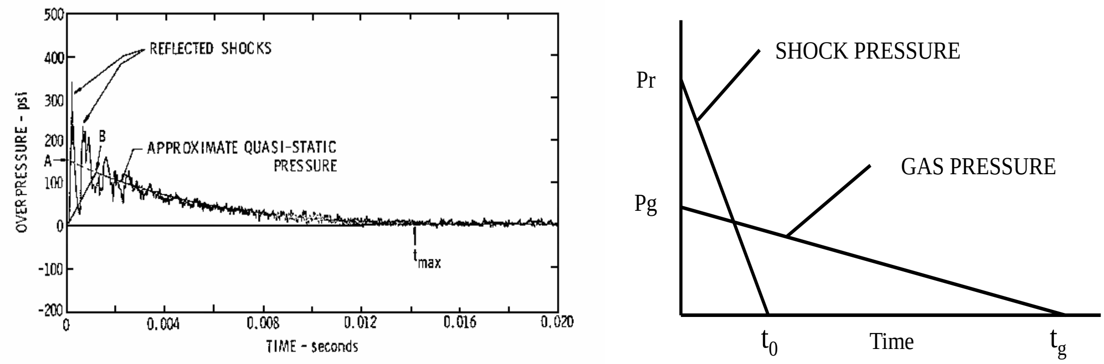

Fig. 1 Typical internal pressure profile and simplified pressure profile (USDOD, 2008)

The structural failures of water tight bulkheads typically occurs at the connecting part that joins bulkheads to decks due to excessive deformations caused by the shock pressure and gas overpressure as shown in Fig. 2. A better way to mitigate these shock and gas pressure damage is making the bulkhead to carry the load in plane and absorb the energy through plastic deformations in major parts of the structure. To achieve this, the connecting part should withstand shear and bending load and transfer loads to major parts of the bulkhead in planar direction. The most typical type of blast hardened bulkhead, called curtain type BHB, achieves this aim through having curtain like thicker parts near the connecting part as shown in Fig. 3. The curtain type BHB has thicker plate near the connecting part and thinner plate in the middle. In this way, the bulkhead can withstand shear and bending loads transferring the load in the middle.

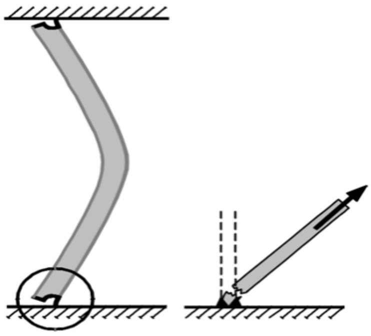

Fig. 2 Failure of connecting part from excessive deformation

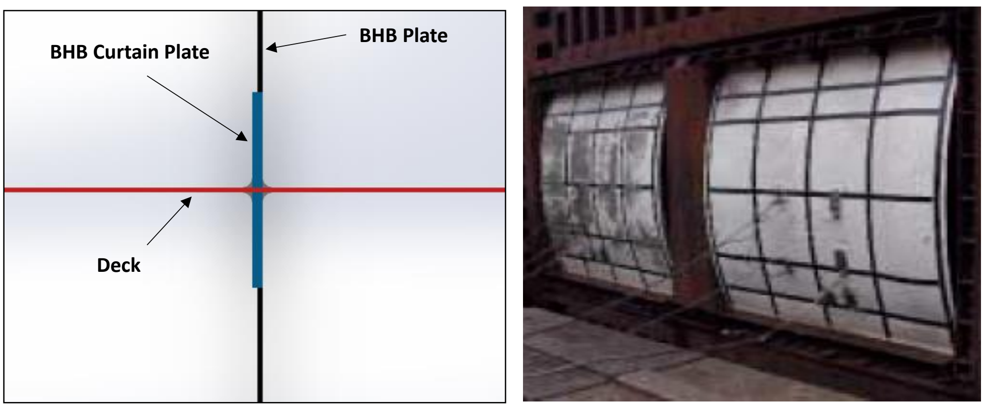

Fig. 3 The curtain type BHB and deformation shape of BHB (TNO, 2012)

DEVELOPMENT OF BLAST HARDENED BULKHEAD DESIGN SYSTEM

BHB have been applied to recent warships but they have been on a case by case basis. There has not been a systematic approach to apply BHB into ship design process. Due to this reason, BHB has not been considered in conceptual design stage and could result in significant design changes resulting in weight gains and affecting survivability measure at the later stage. A systematic approach to apply BHB is quite essential to enhance survivability in the early design stage.

To establish a systematic approach, a design process for BHB application based on given level of threat and dimension of the compartment was constructed as shown in Fig. 4. One assumption is that threat level and explosion load is provided

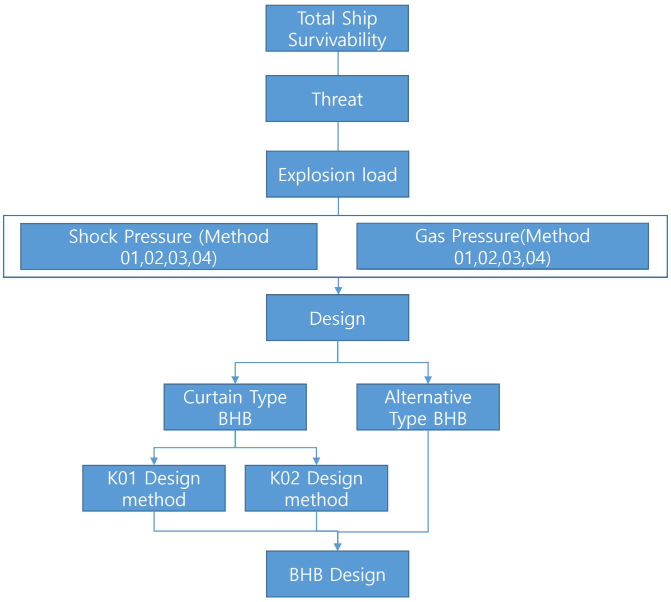

Fig. 4 BHB design process

To apply BHB in a systematic matter, the first consideration was predicting the behavior of structural materials in the environment of internal explosion based on analysis of high strain rate velocity rate and large strain rate based on tensile tests and dynamic tensile tests and derivation strain hardening equation. This research was performed by Sang-Rai Cho of Ulsan University.

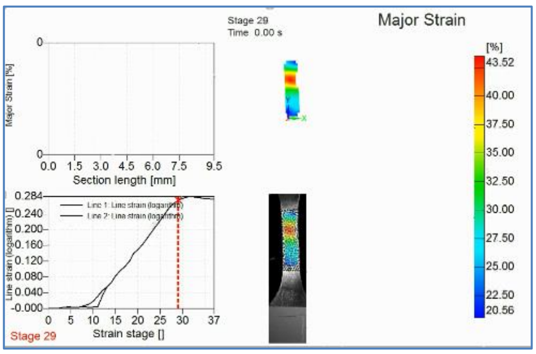

Fig. 5 Dynamic tensile test

To be able to provide ship designer with initial design specifications, design formulae for BHB were constructed based on idealization of internal explosion impact pressure and behavior of BHB and connecting part structure assuming beam like behavior as shown in Fig. 6 along with effectiveness analysis. The idealizations were also based on real explosive tests and previous applications of BHB. The idealization research was performed by In Sik Nho of Chungnam national university.

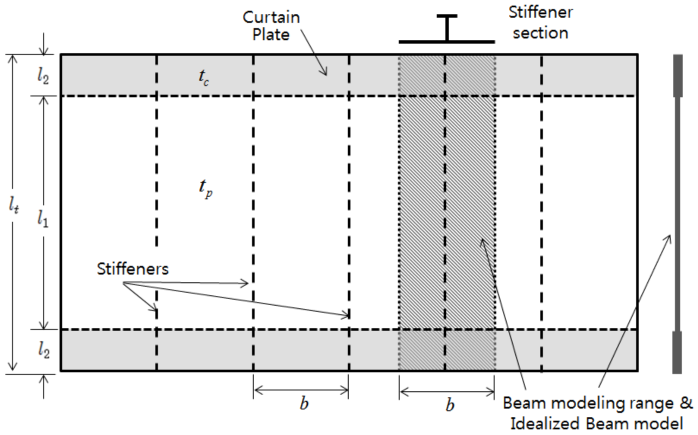

Fig. 6 Assumption of beam model

To evaluate the design and study the whole process in detail numerical methods for fluid-structure interaction were employed. The numerical analysis were based on LS-Dyna and was developed by Sangab Lee of Korea Maritime University.

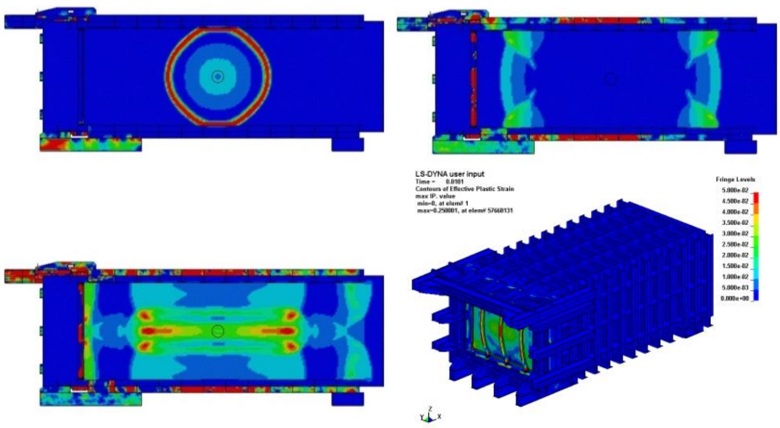

Fig. 7 Numerical analysis on internal explosion and BHB behavior

To verify the numerical methods and design of BHB along with predictions on structural behavior, partial full-scale that employed real explosive tests were performed with help of Hanwha cooperation.

Fig. 8 Partial full-scale real explosive TNT test

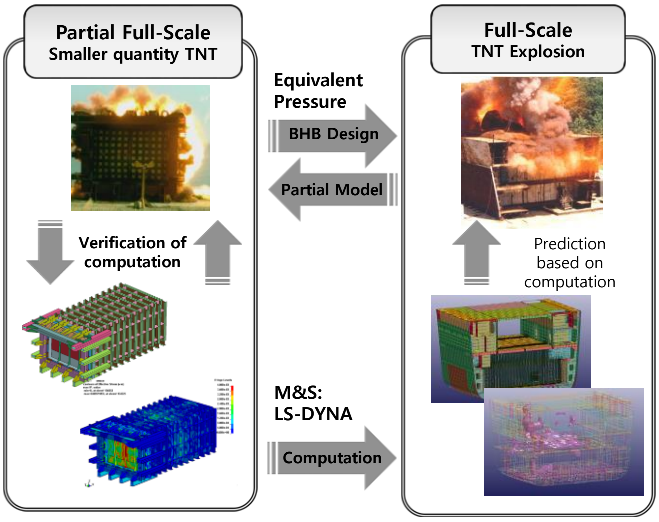

Fig. 9 Relation between partial full-scale test and full-scale analysis

The relation between partial full-scale test and full-scale test is shown in Fig. 9. As can be seen in the figure, partial full-scale test and numerical analysis could provide reliability in numerical analysis in full-scale.

ACKNOWLEDGMENTS

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REFERENCES

Cowardin, B., Waltham-Sajdak, J., Miller, R., Kwon, J. I (2013), “Early Considerations of Survivability in the Design of Naval Combatants–Blast Hardened Bulkhead and Integrated Box Girder Structural Vulnerability Reduction Measures – Part I (Blast

Hardened Bulkheads).” *Proceeding of SNAME Annual Meeting & Expo*, Bellevue.
Shin, Y.H., Chung, J.H., Kwon, J.I., Park, J.H.(2012), “A review on structural integrity analysis methods of water tight bulkhead by internal blast.” *Proceeding of the Society of Naval Architects of Korea*, Daegu.
Van Erkel, A. (2012), “Blast resistance design.” *Survivability Design against Above Water Threats and/or Design against Underwater Shock, TNO Two+Two day course*, Rotterdam
USDOD (2009) *UFC-3-340-02: Structures to Resist the Effects of Accidental Explosions.* Dept. of Army, Navy, and Air Force, Washington, DC.