A Study on Development of Structural Safety Assessment System of Damaged Ships due to Marine Accidents

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ABSTRACT

Ships are likely to be subjected to accidental loads such as collision and grounding. Once she has damage on the hull, her ultimate strength will be reduced. The system addressed in this paper is to assess the safety of ship structures with damages due to marine accidents The safety assessment is based on the ultimate longitudinal strength obtained by using Smith's method.

In order to verify the system, the experimental result carried by Dow using 1/3 scaled frigate ship hull test was used. As the result, the system gives a good correlation with the experiment within 8% in difference.

KEYWORDS

Ultimate longitudinal strength; Collision; Grounding; Marine accident; Smith's method; Structural safety assessment.

INTRODUCTION

In general, the ultimate strength can be defined as the maximum load-carrying capacity of a structure. For the longitudinal hull girder strength, the ultimate strength could be defined as the maximum bending moment in the relationship between hull girder bending moment and curvature. No additional load can be carried beyond the ultimate strength.

The first attempt to evaluate the ultimate strength of ship structure was made by Caldwell (1965). He applied 'Rigid Plastic Mechanism Analysis' to evaluate the ultimate hull girder strength.

To aim more rational design, it could be quite natural to consider the ultimate strength as the strength standard instead of buckling strength. Recently, there are three big movements in the marine society, which are Goal-Based New Ship Construction Standards (GBS) by International Maritime Organisation (IMO), Common Structural Rules (CSR) by International Association of Classification Societies (IACS) and Ultimate Limit State (UL) assessment by International Organisation for Standardisation (ISO). The GBS consists of five tiers, and CSR are closely related to GBS through Tier IV. In CSR, it is required to evaluate the ultimate hull girder strength as well as the ultimate strength of plates and stiffened plates in ship structures. Also in ISO, new standards for limit state assessment of ship structures including buckling/ultimate strength are now coming up. Under such circumstances, the ultimate strength assessment is now becoming more and more important issue to ensure the safety of ship structures (ISSC, 2006).

Recently, a structural safety assessment system of damaged ships based on the ultimate strength was developed. This paper describes the calculation process of ultimate strength based on Smith's method and the configuration and features of the developed system. This system can be used in evaluating the safety of damaged ship structures due to marine accident like collision and grounding.

CALCULATION OF ULTIMATE STRENGTH

Basic Assumptions

According to Hughes (1983), the most accurate and most general method for calculating the ultimate strength is to perform incremental finite element analysis of the entire hull module, but the computational requirements are too great, or too costly, with present day computing capability. It is therefore necessary to develop a simplified approach which retains sufficient accuracy but involves an acceptable amount of computation.

From the considerations on collapse behaviours of hull module, the following two simplifications have been introduced as basic assumptions in calculating the ultimate strength in generally (Hughes, 1983).

1) Since the transverse structure is approximately orthogonal to the longitudinal structure and the shell and deck plating prevent sway in the longitudinal direction, there are only two independent modes of overall collapse: longitudinal collapse and transverse collapse.

2) By considering the relative sizes of the transverse frames and the longitudinal structure between these frames it is possible to ensure that longitudinal collapse would only occur between two adjacent transverse frames.

Calculation Process by Smith's Method

Two basic elements are a stiffened plate with a plate and a stiffener and a corner element with adjacent two plates in the corner. When the vertical bending moment is dominant, the calculation process for the ultimate strength is as follows:

[Step 1] Generate basic elements of transverse section of ship structures with only longitudinal members.

[Step 2] Define the relationship between the axial average stress and average strain of each element.

[Step 3] Calculate the ultimate strain ε_{ult} (= σ_{ult}/E) and the distance from initial neutral axis y_i for each element, where σ_{ult} is the ultimate stress and E is Young's modulus of each element.

[Step 4] Define the initial curvature ϕ_0 of the transverse section as the curvature of element with minimum value.

$$\phi_0 = MIN\left[\frac{(\varepsilon_{ult})_i}{y_i}, \frac{(\varepsilon_y)_i}{y_i}\right] \tag{1}$$

[Step 5] Calculate strain of each element $\varepsilon_i = \phi \cdot y_i$ when $\phi = \phi_0$, and then calculate stress of each element σ_i by using the relationship between average stress and average strain defined in Step 2.

[Step 6] Determine the location of new neutral axis by using the stresses of each element.

[Step 7] Recalculate the distance from the new neutral axis y_i, and then calculate the ultimate bending moment Mu as follows:

$$M_u = \sum_i \sigma_i A_i y_i \tag{2}$$

[Step 8] Increase the curvature by adding an incremental curvature ($\phi = \phi_0 + \Delta\phi$), and then repeat the process from Step 5 to 7 until when there is no increase in Mu as the increase of curvature. It is assumed the incremental curvature is 0.1 times of initial one.

Stress-Strain Relationship

In this system, the relationship developed by Rahman & Chowdhury (1996) has been applied. They had been used the approach by Hughes (1983), which was derived from buckling theory of column based on the assumption that a stiffened plate could be replaced by a beam-column. For example, Fig. 1 gives the axial average stress – strain curves under tensile or compressive loads.

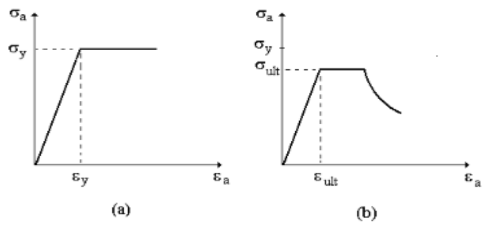


Fig. 1: Axial average stress – average strain curves. (a) under tensile load (b) under compressive load

CONFIGURATION OF DEVELOPED SYSTEM

This system has been developed by using Visual C++ 6.0 and OpenGL. Fig. 2 shows the configuration of the system. The module for defining stiffened panels has a function which generates automatically the stiffened panel elements from cross section members.

Fig. 3 is the input module of plate and stiffener. For this module, a special purposed modeller developed by the Korean Shipping Register was applied. After generating the geometric data for plates and stiffeners, thickness, material properties and location of each member are set.

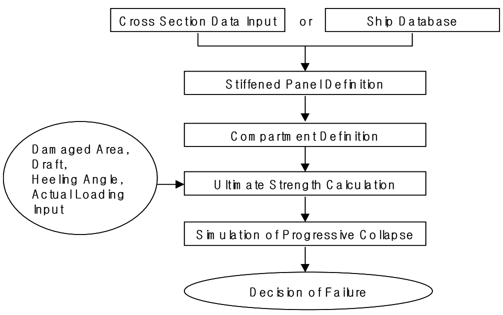


Fig. 2: System configuration and calculation flow

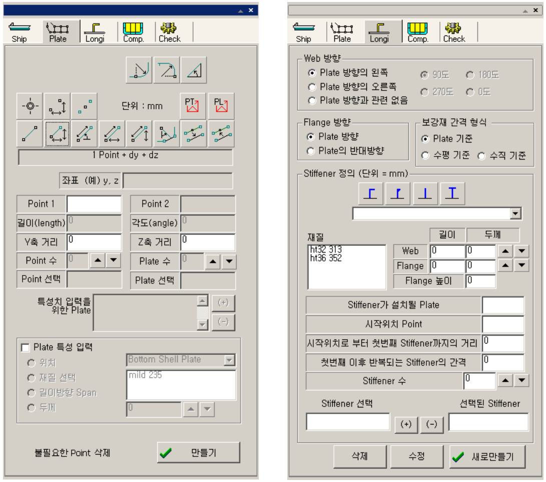
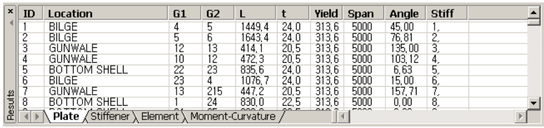


Fig. 3: Input modules of plate and stiffener



ID	Location	G1	G2	L	t	Yield	Span	Angle	Stiff
1	BILGE	4	5	1449,4	24,0	313,6	5000	45,00	1,
2	BILGE	5	6	1643,4	24,0	313,6	5000	76,81	2,
3	GUNWALE	12	13	414,1	20,5	313,6	5000	135,00	3,
4	GUNWALE	10	12	472,3	20,5	313,6	5000	103,12	4,
5	BOTTOM SHELL	22	23	835,6	24,0	313,6	5000	6,63	5,
6	BILGE	23	4	1076,7	24,0	313,6	5000	15,00	6,
7	GUNWALE	13	215	447,2	20,5	313,6	5000	157,71	7,
8	BOTTOM SHELL	1	24	830,0	22,5	313,6	5000	0,00	8,

Fig. 4: Watch bar of data for structural members

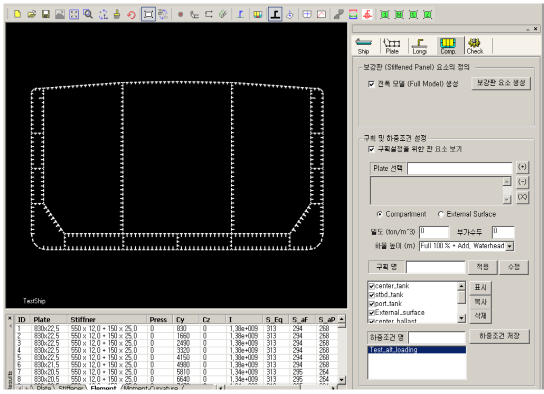


Fig. 5: Generation of stiffened panel element

In order to check the information of the generated members, the numeric data for the member appears simultaneously with the generation of the member in the watch bar below the model view as shown in Fig. 4. The watch bar consists of four components: plate, stiffener, element and moment-curvature. Among them, moment-curvature gives the calculation results for the ultimate strength. Fig. 5 shows the cross section consisted of the generated stiffened panels of double hull tanker.

In this process, mirroring function was applied to copy the members in the port side into starboard side.

Fig. 6 shows the process to define the compartment and loading conditions. Here, one of the compartments must contain the outer side shells to define hydrostatic pressures. Also, in order to consider the added mass due to flooding, all dry cargo holds should be defined as compartments.

Fig. 7 is the user interface to do the structural safety assessment of an objected ship. Age of the ship is needed to take account of the effect of corrosion due to aging. The damaged part can be selected directly by user on the graphic display. Also, the heeling angle occurred from flooding due to damage can be chosen. After setting the damaged condition including heeling angle, the pressure onto structural members by liquid cargo or ballast recalculated as in Fig. 8. The final step of this process is the calculation of ultimate strength as in the process bar in the right bottom of the check view.

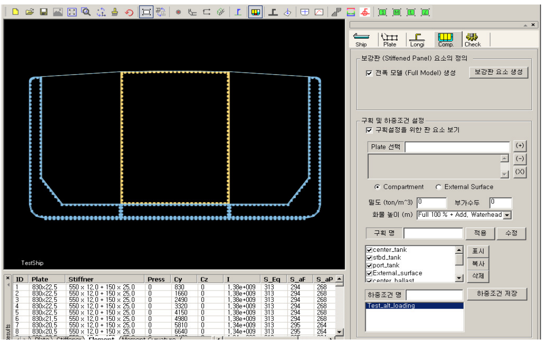


Fig. 6: Definition of compartment

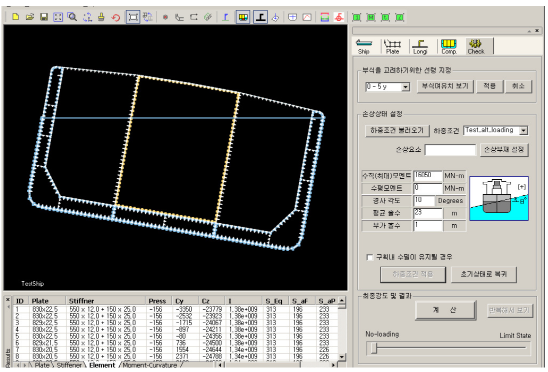


Fig. 7: Interface of structural safety check

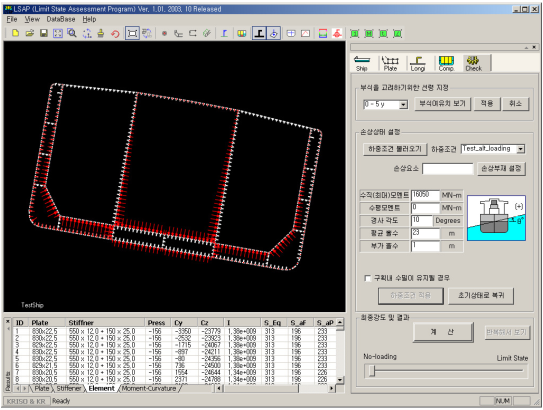


Fig. 8: Calculation of actual pressure due to damage

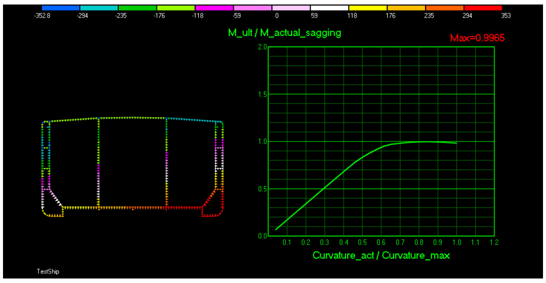


Fig. 9: Assessment for bottom damaged case of D/H tanker

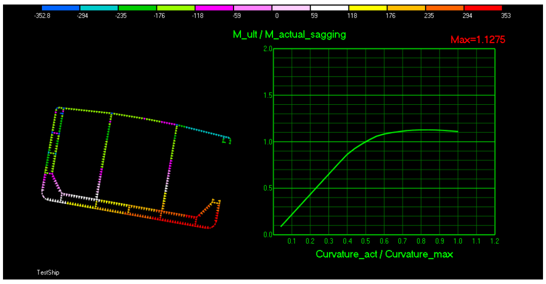


Fig. 10: Assessment for side damaged case of D/H tanker

Fig. 9 and 10 are examples for the assessment for bottom/side damaged cases of an double hull tanker. The range of damages was selected based on IGC Code 2.5, 2.7, 2.8 and IBC Code (IMO). In these figures, the actual sagging moments were the sum of still-water and wave-induced bending moments from UR S11 (IACS). The vertical and horizontal bending moment in two damaged cases was -16,050MN-m and 1,500MN-m respectively. The draft was 23m, and the added water draft was 1m. From the results, it can be assessed as very dangerous if the safety margin of vertical bending moment is below 1.0.

COMPARISON WITH TEST RESULT

A few experimental studies on the ultimate longitudinal strength by using a large scale model have been done (Lee et al., 2008). In recent, the authors carried out the experiments by using box girder models with side/bottom damage (Lee et al., 2008; Rim et al., 2008). These experimental studies have provided a very meaningful data for the verification of related assessment tools.

Among them, Dow (1991) performed the ultimate strength test using a 1/3 scaled model of frigate naval ship under sagging condition. The total length including test jig reached 18 meters. The dimension of cross-section was 4.0m (breadth)×2.8m (depth). Fig. 11 gives the cross section of test model by Dow. In this study, this test was used to verify the accuracy of the developed system.

Fig. 12 shows the model and result by the developed system. Here, No. 2 deck and center girder were modelled by plate elements because of their dimensions. As the result, the moment – curvature curve like Fig. 13 was obtained. In the graph, the solid line is the result from the present system, and dotted line is the one from ALPS/HULL (2006) with initial deformation of 10% of the thickness and residual stress of 5% of yield stress. This program was used in order to compare the ultimate strength of the same model under hogging condition which is not carry out by Dow.

The calculated ultimate vertical bending moment is bigger by 4% than the test result and smaller than that of ALPS/HULL by 1% in sagging condition. Meanwhile, in hogging condition the ultimate strength was bigger by 8% than that of ALPS/HULL. These differences might be involved the initial deformation and welding residual stress. The results by present system were not to take into account the two effects. Therefore, the present system could be thought as it gives a relatively good correlation with test result.

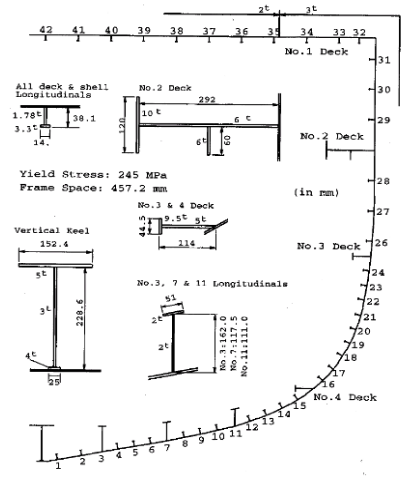


Fig. 11: Half mid-ship section of 1/3 frigate test model

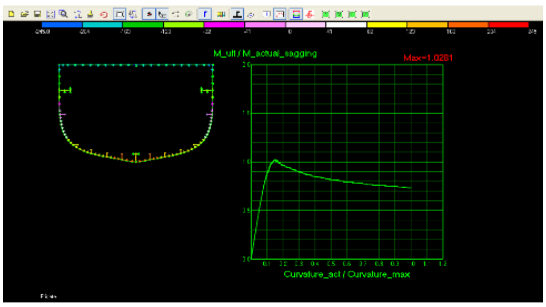


Fig. 12: Assessment result by using the developed system (M_actural_sagging = -10MNm)

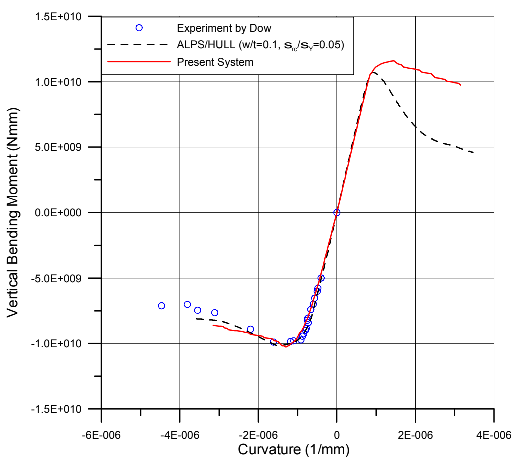


Fig. 13: Relationship between vertical bending and curvature on Dow's test model

CONCLUSIONS

In this paper, the structural safety assessment system developed to assess the integrity of damaged ship structure due to marine accidents like collision and grounding is described. The present system has a special purposed modeller for the modelling of ship structure. This modeller enables users to do easier and faster modelling of structure. The accuracy of present system was compared with the test result by using large model and special purposed commercial program. As the result, the present system gives a relatively good correlation.

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REFERENCES

ALPS/HULL, A Computer Program for Progressive Collapse Analysis of Ship Hulls (Version 2006.1), Pusan National University, Korea, 2006.

Caldwell, J.B., Ultimate Longitudinal Strength, Trans. RINA, 1965, Vol. 107, pp. 411-430.

Dow, R.S., "Testing and analysis of 1/3-scale welded steel frigate model", Proceedings of the International Conference on Advances in Marine Structure, Dunfermline, Scotland, pp. 749-773.

Hughes, O.F., Ship Structural Design, John Wiley & Sons, Inc. 1983, Chapter 17, pp. 541.

IACS (International Association of Classification Societies), UR (Unified Requirement) S.11

IMO (International Maritime Organization), International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code), 1993.

IMO, International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IBC Code), 1985.

ISSC, Proceedings of the 16th International Ship and Offshore Structures Congress, Eds. Frieze, P.A. and Shenoi, R.A., Southampton, U.K., 2006, Vol. 1, Committee III.1.

Lee, T.K., Rim, C.W., Han, D.S., Kim, B.H., Lee, J.M. and Kim, K.S., "A study of ultimate collapse strength in sagging of ship structures with side collision damage," Proc. of ISOPE'2008 (to be printed).

Rahman, M.K. and Chowdhury, M., "Estimation of ultimate longitudinal bending moment of ships and box girders," Journal of Ship Research, Vol. 40, Sept. 1996, pp. 244-257.

Rim, C.W., Lee, T.K., Han, D.S., Kim, B.H., Lee, J.M. and Kim, K.S., "The effect of bottom damage size of stranded ship on ultimate strength," Proc. of OMAE'2008 (to be printed).