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Strength evaluation of intersection between stiffeners and primary supporting members considering the effect of shear force on the primary member web

Tetsuo Okada*, Yasumi Kawamura

Faculty of Engineering, Yokohama National University, Tokiwadai 79-5, Hodogaya-ku, Yokohama 240-8501, Japan

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A B S T R A C T

The intersection between stiffeners and primary supporting members is one of the most critical details in ship hull structures. Learning from the lessons of actual damages experienced in the past, many formulae to estimate stresses around the slot cut-out structures have been developed. However, good agreement with finite element analysis or experiments has not been achieved, and the formulae have been used with empirical correction coefficient, introduced using actual damage and no-damage records or calibration based on finite element analysis results. In this study, the authors develop a consistent theoretical formula taking account of all the structural components affecting the load share of each member, in combination with the combined load effect of direct force from the longitudinal stiffener and shear force on the primary supporting member. The derived formula was verified through comparison with the results of finite element analysis and past experiments, and good accuracy was confirmed. Then, using the proposed theoretical formula, various parametric studies are carried out, and effective countermeasures to enhance the strength of slot cut-out structures are discussed. Finally, critical review on IACS CSR formulae on the slot cut-out structures is conducted. Because the rules take account of only the direct load from the longitudinal stiffeners, and do not consider the effect of the shear force on the primary supporting member, it is probable that the rules give insufficient strength when the effect of the shear force on the primary supporting member superimposes the effect of the load from the longitudinal stiffener. On the other hand, the rules may be too conservative when they cancel each other. It is shown that rational evaluation of the strength of slot cut-out structure is possible using the proposed theoretical formula.

1. Introduction

Fatigue damages are the most commonly observed failures in the ship hull structures. Among thousands of structural details in the hull structures, one of the most critical details is the slot cut-out structure, where a secondary stiffener intersects with a primary supporting member, providing load path from the stiffener to the primary supporting member. The industries have experienced many kinds of fatigue damages around the slot cut-out structures since more than half a century ago.

The first massive appearance of such damages was coincident with rapid increase in the size of crude oil tankers during 1960's. Fig. 1 shows the transition of the size of the largest crude oil tankers from 1950 to 1980 (e.g. p.4 in Ref. [1]), where we can observe rapid progress of the ship size enlargement. Typical damages experienced in these days are illustrated in Fig. 2. Most commonly

* Corresponding author.
E-mail addresses: okada-t@ynu.ac.jp (T. Okada), kawamura-yasumi-zx@ynu.ac.jp (Y. Kawamura).

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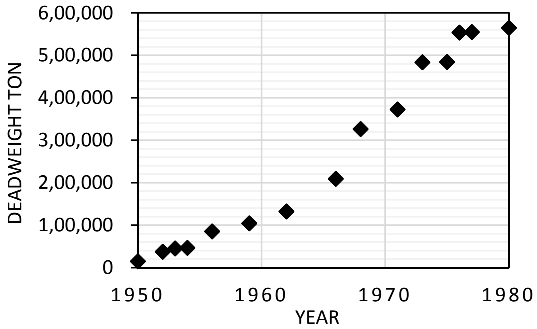

Fig. 1. Tanker size increase.

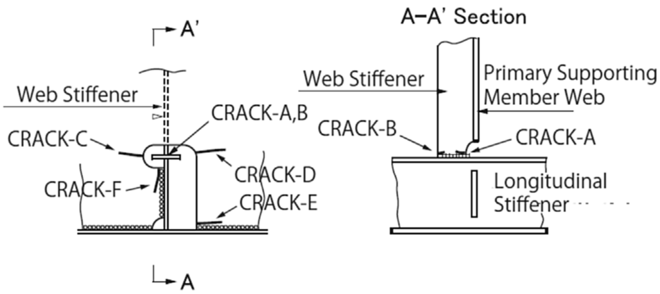

Fig. 2. Typical cracks around slot cut-out.

observed cracks initiated at the round weld toe in way of the attachment of the web stiffener to the face plate of the longitudinal stiffener, as shown as CRACK-A and CRACK-B in Fig. 2. Sometimes they were accompanied by other types of cracks CRACK-C, D, E and F in Fig. 2, mainly caused by the load redistribution due to the lost load-carrying capacity of the cracked web stiffener. Therefore, accurate assessment of the stresses at the root of the web stiffener is most important for safe design of slot cut-out structures.

Thorough investigations into the root cause of the damages were carried out then. A lot of new knowledge was obtained, and effective countermeasures were established within the design standards of each design company ([2–5], pp.202–208 in Ref. [1]). Through the investigations it was revealed that among many factors, the following points were the primary factors affecting the damages:

1. In accordance with the growth in ship size, larger spacings were employed for transverse frames and longitudinal stiffeners, resulting in the increase in the load transmitted through the slot cut-out structures.
2. To realize larger ship size efficiently, longer tanks up to about 50 m length were applied. This longer tanks caused increased vertical relative deflection between the side shell structure and the longitudinal bulkhead structure, resulting in larger shear force on the bottom transverse web frame.

The second point was important because the shear force on the primary supporting member induces tensile or compressive stresses in way of the connection between the web stiffener and the longitudinal stiffener, and superimpose or cancel the stresses caused by the loads transmitted from the longitudinal stiffener to the primary supporting member. The mechanism is explained in Fig. 3. The force W is the load transmitted from the longitudinal stiffener to the primary supporting member, and causes tensile stress at the root of the web stiffener in this case. When the slot cut-out is open in the lower side as shown in SLOT-A in Fig. 3, the shear force F in the direction as shown in SLOT-A causes compressive stress at the root of the web stiffener, and cancels the stress exerted by

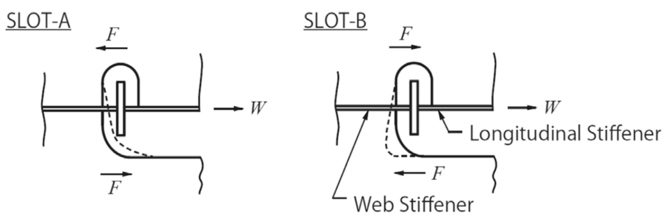

Fig. 3. Action of primary member shear force on the web stiffener stresses.