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Review

Ultimate strength of cracked ship structural elements and systems: A review

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ABSTRACT

Many ships around the world are getting older. As the ships grow older, more defects such as cracks will come up exposing the ship hull structure to structural failures. Although many investigations have been carried out on the ultimate strength of cracked ship structural elements, there is a gap in design phase of a ship hull structure accurately considering such defects. In particular, available manuscripts by the regulatory bodies simply deal with the repair methods rather than practical design codes and guidelines. Many researchers have employed different methods to investigate ultimate strength of cracked ship structural elements to understand effects of various parameters. But as there is not a benchmark study to be referenced as a standard, sometimes contrasts are observed in the investigations. This paper presents a detailed review on the effects of different crack parameters such as crack length, crack location, crack orientation and gap size, plate thickness, aspect ratio, boundary conditions on the ultimate strength of ship hull elements in a comparative manner to be used as a reference for future investigations.

1. Introduction

Many ships can be named that have been broken into two parts due to incorrect loading, severe corrosion, improper design, cracking or crack-like discontinuities. MOL Comfort suffered a crack amidships in bad weather and was broken into two in 2013 [1]. In plated marine structures such as ships, cracks often can be found along the weld lines and at the intersection of stiffening elements. Cracks initiated from the weld lines may propagate through the depth of the parent materials namely plates or stiffeners. Propagation of the cracks leads to the reduction of the load carrying capacity of the plates and stiffened plates, where it eventually reduces the hull girder strength.

Reduction of the ultimate strength as a result of the crack damages can be considered in two aspects including diminish of the moment of inertia of the element's cross-section and increase of the distance from the location of crack damage to the neutral axis [2]. Cargo loads, environmental loads and corrosion can worsen condition of the cracks and crack-like discontinuities in the ship hull structure. Cracks may grow under certain conditions resulting in either environmental or economic catastrophes.

For the ships having cracks, the casualty may be so sudden that cannot be prevented readily, since it is impossible to find and repair the crack during the ship's operation. Thus, assessment of the effects of the cracks on the strength of plates, stiffened plates and ship hull girders is as important as study of the outcomes of the corrosion and other defects. Fig. 1 shows the MOL Comfort at the early minutes of the casualty.

Increase of the marine casualties has caused the classification societies to involve strongly the safety issues in design, operation and maintenance of the ships. According to a study performed by American Bureau of Shipping (ABS) on 2717 commercial vessels

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Nomenclature

α_0	A parameter to account for variability of the maximum initial deflection
β	Plate slenderness parameter
υ	Poisson's ratio
λ	Column slenderness parameter
σ_T	Ultimate tensile stress
σ_{XU0}	Ultimate axial strength of un-cracked plating
σ_{XU}	Ultimate axial strength of cracked plating
σ_Y	Yield stress
σ_{Yeq}	Equivalent yield stress over the cross section of plating and stiffeners
a	Plate length
A_0	Total cross sectional area of un-cracked plating
A_c	Remaining cross-sectional area of cracked plating
b	Plate breadth
E	Elastic modulus
E_t	Tangent modulus
K_I	Stress intensity factor
m	Buckling-mode half wave number
r	Polar coordinate
t	Plate thickness
W_0	Plating initial distortion function
W_{0c} [18], W_{0s} [34]	Column-type initial distortion function
W_{0pl}	Maximum plate initial deflection
W_{0s} [18], W_{0t} [34]	Sideways initial distortion function

Fig. 1. MOL Comfort before breaking into two. Image credit: IANS NEWS [1].

surveyed between the years 2002 and 2008, it was found that the majority of reported fractures (more than 90%) were structural failures such as weld defect, buckling, fracture and cracking [3]. Unlike corrosion that its effects on ship scantlings is accounted for in the design stages in terms of the so-called "corrosion addition or allowance", cracking damages are not considered adequately within the classification rules or guidance notes. The International Association of Classification Societies (IACS) has produced a series of manuals regarding the survey, assessment and repair of hull structures for certain ship types [4]. Det Norske Veritas-Germanischer Lloyd (DNVGL) has published some procedures for evaluation of fatigue strength of steel ship structures taking into account of the wave-induced cyclic stresses [5].

Survey and inspection of the ship structures are carried out during design stage, at the time of construction and also in service state. In the design stage the focus is only on inspectabillty, redundancy and critically-stressed areas rather than the crack effects on the strength of the plates, stiffened plates and ship hull girders. In ship inspection always there is a doubt whether a found crack of a certain size and location will become a threat to the safety of the vessel during its operation. However, there is no appropriate failure criteria with sufficient safety margin for determining the fracture failure of the cracked structures that can be used to make decisions about the follow-up actions and consideration of repair options depending upon the size and location of the found cracks [6]. C. M. Rizzo et al. in [7] have summarized the report of the ISSC 2006 Committee V.6 presenting current practices, recent advances and future trends on condition assessment of aged ships. Their work is a summary of existing mathematical models of age-related deteriorations, corrective/protective measures that can be taken and current inspection, maintenance and repair methods.

Limit state design has gradually taken the place of allowable stress design in design of ships and other marine structures. A limit state can be defined as a condition beyond which the structure, or part of a structure, no longer satisfies the requirements. The structural performance of a ship hull girder or its components should generally be described with reference to a specified set of limit states that separate desired states of the structure from the undesired states [8].

Many researches have been carried out about the effects of cracks and crack-like discontinuities on the ultimate strength of plated