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Ultimate strength assessment of corroded box girders

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ABSTRACT

This work deals with the evaluation of the ultimate bending moment of two box girders subjected to different levels of corrosion degradation and experimentally tested under pure vertical bending moment. A series of nonlinear finite element analysis have been conducted. Two models of corrosion degradation have been used representing an average general corrosion thickness reduction, and the real corrosion thickness as it is measured. Based on the real corrosion measurements, experimental ultimate strength and finite element calculations, a relationship has been developed to predict the expected difference in the ultimate strength calculations based on the FE models representing the corrosion degradation as an average thickness reduction or as the real measured corrosion reduction.

1. Introduction

Corrosion is one of the dominant life-limiting factors of ship structures because the hull structural members are exposed to corrosive environment resulting in weakness of the structure strength. Therefore, it is an important issue to evaluate the ultimate strength of the ship hull considering the corrosion degradation effect. The ultimate longitudinal strength assessment is a nonlinear problem in which both the nonlinearity related to material behaviour and geometry is involved (Hu et al., 2001).

There are a few applications of the finite element method to analyse the ship hull collapse. One early attempt was done by Chen et al. (1983) who took into account elasto-plastic properties of the material, nonlinear geometric behaviour of the elements, and their buckling and post-buckling strength, after him the FE method was used by Kutt et al. (1985) and Valsgård et al. (1991).

A series of finite element analyses were conducted to simulate the behaviour of tested box girders and midship sections of bulk carries by many authors. Hansen (1996) performed four finite element analyses with different considerations for the cross-section selected from the models tested by Nishihara (1984). The model was loaded incrementally with force vector at the end of the load section in order to ensure the overall bending.

Qi et al. (2005) performed a series of nonlinear finite element analyses for the ultimate strength of tested box girders simulating a large surface ship, frigate and double hull tanker. Harada and Shigemi (2007) carried out a series of nonlinear finite element analyses for a double hull VLCC and a cape size bulk carrier to obtain the ultimate longitudinal strength in hogging and sagging conditions.

Amlashi and Moan (2008) investigated the ultimate strength of a Capsize bulk carrier by carrying out extensive nonlinear FE strength analyses under alternate hold loading, by modelling of 1/2+1+1/2 hold tanks. An extension of this work has been performed by Shu and Moan (2009) where an extended model, which covers 3 cargo holds and four transverse bulkhead in the midship region was set up to investigate the ultimate strength of the same bulk carrier. The ultimate strengths in hogging condition were evaluated and compared with the results from simplified approaches, and it was concluded the finite element analysis can provide more information about the ultimate strength and collapse mode beyond the ultimate strength. The difference between the ultimate strength of the hull girder in hogging was very small with or without consideration of the geometric imperfections.

Several different approaches have also been adopted for the evaluation of the ultimate strength of hull girders as for example in Ozguc et al. (2006), Paik et al. (2006) and Vhanmane and Bhattacharya (2008).

Nikolov (2009) performed a comparison between the experimental results and different simplified methods of five different box girders used for ultimate strength test. The stress–strain and moment-curvature relationships were obtained, and the comparison showed that there is a significant difference between the numerical and some experimental results.

Shi and Wang (2012) compared the experimental results of ultimate hogging strength of a container ship test model with a linear analysis, nonlinear finite element analysis and idealised structural unit method. The collapse modes and stress distributions for plating and longitudinals were discussed. Welding

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residual stresses and initial distortions are simulated and was concluded that the ultimate strength results obtained by the arc-length method are consistent with the experimental results.

Recently, Saad-Eldeen et al. (2012c) conducted a series of nonlinear finite element analyses of an intact box girder. The principal objective was to define the most appropriate parameter description for the developed finite element model by varying both the initial imperfection (shape and amplitude) and mesh size, which turns out to be one of the most important governing parameters affecting the ultimate strength and post-collapse behaviour. The results achieved by the developed finite element model demonstrated a good agreement with the experimentally defined two-linear trend of the moment-curvature relationship of the intact box girder.

All of the mentioned studies were dealing with intact structures. The step forward is the study of ultimate strength of aged box girders performed by Saad-Eldeen et al. (2012e), where the ultimate strength of a slightly corroded box girder subjected to four-point loading using nonlinear finite element method was analysed. Series nonlinear analyses have been performed and the ultimate strength has been analysed using different stress–strain relationships and also different weld toe shapes. An elasto-plastic modified stress–strain model has been developed accounting for residual stress effect. The post-buckling behaviour demonstrated a very good agreement with the experimental results. Comparisons between numerical and experimental results have been performed for the slightly corroded box showing a very good agreement.

Saad-Eldeen et al. (2012d) evaluated the ultimate bending moment of a severe corroded box girder subjected to pure vertical bending moment through a series of nonlinear finite element analysis. Two models of corrosion degradation have been adopted, one defining an average general corrosion thickness reduction, and the other is a model based on the real corrosion thickness measurements. New stress–strain relations have been developed to account for the effect of corrosion on the low carbon steel mechanical properties. To validate the new developed stress–strain relationships, a comparison between the finite element analysis results using the existing stress–strain models, the newly developed ones and the experimental test results of a severely corroded box girder have been conducted. The comparison showed a good agreement and supported the choice of the newly developed stress–strain relationships of corroded structures.

Saad-Eldeen et al. (2012b) investigated the effect of corrosion degradation on the ultimate strength of the steel box girders, dissipated energy, resilience, ductility, and elastic limit. A significant reduction in the stiffness, stress–strain relationship and the elastic modulus was observed. It was concluded that in addition to the thickness reduction, corrosion has an additional influence on changing the mechanical properties of steel.

The present work deals with the evaluation of the ultimate bending moment of two box girders subjected to different corrosion degradation levels and tested under pure vertical bending moment, through a series of finite element analyses, taking into consideration the effect of the shape of the corrosion plate thickness reduction due to corrosion degradation. Two models of corrosion degradation have been used representing an average general corrosion thickness reduction, and the real corrosion thickness as it is measured. Based on the real corrosion measurements, experimental ultimate strength and finite element calculations, a relationship has been developed to predict the expected difference in the ultimate strength calculations based on the FE models representing the corrosion degradation as an average thickness reduction or as the real measured corrosion reduction.

2. Hull girder strength assessment

The hull girder ultimate strength is defined as the maximum bending capacity of the hull girder beyond which the hull will collapse. Hull girder failure is controlled by the ultimate strength of structural elements accounting for buckling and yielding. The principal parameters governing the structural design of ship's hull subjected to compressive loading and influencing the compressive strength are the plate and column slenderness, in addition to the material yield stress (σ_y) and the Young modulus (E).

The plate slenderness is defined as the ratio of the plate breadth to the thickness:

$$\text{Plateslenderness,}\quad \beta = \frac{b}{t_p}\sqrt{\frac{\sigma_y}{E}} \tag{1}$$

where t_p is the plate thickness, $b$is the plate width between stiffeners.

The column slenderness is defined as the ratio of the effective length of a column to the least radius of gyration of its cross section and

Column slenderness,

$$\text{Columnslenderness,}\quad \lambda = \frac{a}{r}\sqrt{\frac{\sigma_y}{E}} \tag{2}$$

where a is the stiffener span between frames, and k is the radius of gyration of the cross-section area of the stiffener with the

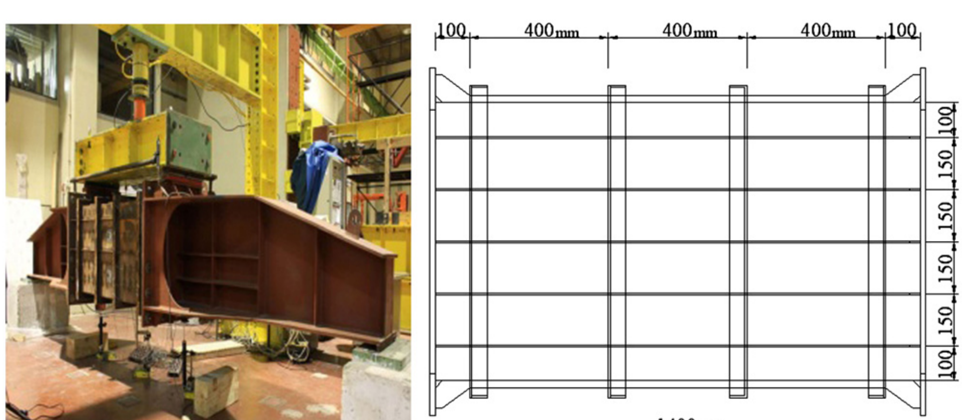

Fig. 1. Experimental set up (left) and top view (right).