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Incorporating mesh-insensitive structural stress into the fatigue assessment procedure of common structural rules for bulk carriers

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ABSTRACT: *This study introduces a fatigue assessment procedure using mesh-insensitive structural stress method based on the Common Structural Rules for Bulk Carriers by considering important factors, such as mean stress and thickness effects. The fatigue assessment result of mesh-insensitive structural stress method have been compared with CSR procedure based on equivalent notch stress at major hot spot points in the area near the ballast hold for a 180 K bulk carrier. The possibility of implementing mesh-insensitive structural stress method in the fatigue assessment procedure for ship structures is discussed.*

KEY WORD: Mesh-insensitive structural stress; Common structural rules; Fatigue strength evaluation; Bulk carriers; Hot spot stress.

INTRODUCTION

It is well known that most fatigue damages in bulk carriers occur mostly in the area near ballast holds because its structural members are subjected to high internal pressure due to ballast water.

According to the International Association of Classification Societies (IACS) damage record, fatigue damages to members in the ballast hold of bulk carriers is 99.8% of the total damage cases for primary members. Therefore, the damages to cargo holds in bulk carriers other than ballast holds are less than 0.2%. Approximately 72% of fatigue damages occurred at the connections between the inner bottom platings and the plates of lower stools or hopper tanks (IACS, 2010a). It is evident that fatigue problem in bulk carriers is an on-going issue and a highly accurate fatigue assessment method is needed to ensure safety of ship structures and prevent pollution as well as lifesaver.

Hot spot stress approach is commonly used for fatigue life assessment of ship structures (Lee et al., 2010; Park et al., 2011). Fatigue assessment procedure in Common Structural Rules (CSR) for Bulk Carriers also incorporates the equivalent notch stress range obtained by multiplying the equivalent hot spot stress range by a fatigue notch factor. Finite element analysis using very fine mesh with a typical element size of the plate thickness is commonly employed for fatigue assessment of the ballast hold, such as at the lower stool and the bilge hopper connections. The calculation of hot spot stress in the vicinity of the weld toe involves many difficulties and uncertainties. In addition, the design rule procedures sometimes provide inconsistent results

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depending on the calculation method for the hot spot stress with respect to stress extrapolation and element selection. Recently, a mesh-size insensitive structural stress definition that provides a stress state at the weld toe using a relatively large mesh size was proposed (Dong, 2001). The structural stress definition is based on elementary structural mechanics theory and provides an effective measure for the stress state in front of the weld toe. The structural stress is expressed in the form of membrane and bending stress components that satisfy equilibrium conditions based on finite element analysis. In this method, balanced nodal forces are used to estimate the local stresses in the vicinity of the considered weld toe. The results, therefore, have less deviation than the stress obtained from shape functions inside the elements (Dong and Hong, 2003).

The structural stress approach for fatigue assessments has been widely investigated in various industrial fields. In the field of shipbuilding, a comparative study has been performed employing hot spot stress and structural stress approach to evaluate the fatigue strength at the shell on the longitudinal side of a container vessel (Kim et al., 2009). While many studies on the application of structural stress approach for fatigue assessment of structural details have been carried out (Dong, 2004; Healy, 2004; Hong and Dong, 2004; Dong, 2005), there is no attempt to employ the approach for fatigue assessment of bulk carriers.

In this study, a fatigue assessment procedure that incorporates mesh-insensitive structural stress method based on CSR for Bulk Carriers is suggested and compared with the fatigue evaluation result based on hot spot stress method commonly used in CSR.

SUMMARY OF FATIGUE ASSESSMENT PROCEDURE IN CSR

Fatigue assessment procedure in CSR for Bulk Carriers (IACS, 2010b) is adopted based on the equivalent notch stress range obtained by multiplying the equivalent hot spot stress range by a fatigue notch factor.

Extrapolation-based hot spot stress is employed to obtain stresses at geometric discontinuities using the mesh size that corresponds to the plate thickness as shown in Fig. 1.

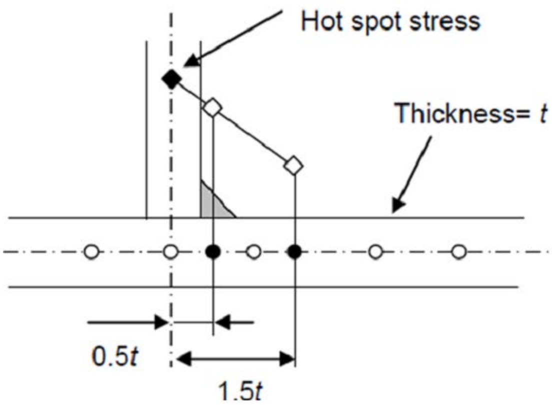

Fig. 1 Definition of hot spot stress at an intersection of two plates.

From the calculated hot spot stress range, $\Delta\sigma_W$, the equivalent notch stress range $(\Delta\sigma_{equiv})$ can be calculated using Eq. (1).

$$\Delta\sigma_{equiv} = f_{mean} \cdot \Delta\sigma_W \tag{1}$$

where f_{mean} is the correction factor for mean stress.

The equivalent notch stress range is calculated with Eq. (2).

$$\Delta\sigma_{eq,j} = K_f \cdot \Delta\sigma_{equiv} \tag{2}$$

where K_f indicates the fatigue notch factor as defined in Table 1.