High Cycle Fatigue Analysis of a Lower Hopper Knuckle Connection of a Large Bulk Carrier under Dynamic Loading

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Abstract : The fatigue of ship structural details is of major concern in the maritime industry as it can generate fracture issues that may compromise structural integrity. In the present study, a fatigue analysis of the lower hopper knuckle connection of a bulk carrier was conducted using the Finite Element Method by means of ABAQUS/CAE software. The fatigue life was calculated using Miner’s Rule and the long-term distribution of stress range by the use of the two-parameter Weibull distribution. The cumulative damage ratio was estimated using the fatigue damage resulting from the stress range occurring at each load condition. For this purpose, a cargo hold model was first generated, which extends over the length of two holds (the mid-hold and half of each of the adjacent holds) and transversely over the full breadth of the hull girder. Following that, a submodel of the area of interest was extracted in order to calculate the hot spot stress of the connection and to estimate the fatigue life of the structural detail. Two hot spot locations were identified; one at the top layer of the inner bottom plate and one at the top layer of the hopper plate. The IACS Common Structural Rules (CSR) require that specific dynamic load cases for each loading condition are assessed. Following this, the dynamic load case that causes the highest stress range at each loading condition should be used in the fatigue analysis for the calculation of the cumulative fatigue damage ratio. Each load case has a different effect on ship hull response. Of main concern, when assessing the fatigue strength of the lower hopper knuckle connection, was the determination of the maximum, i.e. the critical value of the stress range, which acts in a direction normal to the weld toe line. This acts in the transverse direction, that is, perpendicularly to the ship's centerline axis. The load cases were explored both theoretically and numerically in order to establish the one that causes the highest damage to the location examined. The most severe one was identified to be the load case induced by beam sea condition where the encountered wave comes from the starboard. At the level of the cargo hold model, the model was assumed to be simply supported at its ends. A coarse mesh was generated in order to represent the overall stiffness of the structure. The elements employed were quadrilateral shell elements, each having four integration points. A linear elastic analysis was performed because linear elastic material behavior can be presumed, since only localized yielding is allowed by most design codes. At the submodel level, the displacements of the analysis of the cargo hold model to the outer region nodes of the submodel acted as boundary conditions and applied loading for the submodel. In order to calculate the hot spot stress at the hot spot locations, a very fine mesh zone was generated and used. The fatigue life of the detail was found to be 16.4 years which is lower than the design fatigue life of the structure (25 years), making this location vulnerable to fatigue fracture issues. Moreover, the loading conditions that induce the most damage to the location were found to be the various ballasting conditions.

Keywords : dynamic load cases, finite element method, high cycle fatigue, lower hopper knuckle
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