International Journal of Offshore and Polar Engineering
Vol. 8, No. 2, June 1998 (ISSN 1053-5381)

Fatigue of Cracked Ship Critical Structural Details: Cracked S-N Curves and Load Shedding

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ABSTRACT

This paper presents a cracked SN curve approach for the fatigue assessment of cracked ship CSD. Based on FM analyses, S-N curves are developed that reflect the effects of various through-thickness crack lengths. This approach takes advantage of the insights provided by FM yet preserves the traditional SN procedures used by naval architects to evaluate fatigue durability. As cracks propagate, stresses are redistributed to adjacent boundaries and elements that comprise CSD. This load shedding acts to retard the crack growth. A phenomenological load shedding model is developed and integrated into the cracked S-N curve approach. A numerical example is presented to illustrate these developments.

INTRODUCTION

Fatigue-related cracks in the Critical Structural Details (CSD) of Very Large Crude Carriers (VLCC) and Ultra Large Crude Carriers (ULCC) constitute one of the largest single maintenance problems associated with these ships. The fundamental reason for these cracks is excessively high cyclic stresses in the CSD. Generally, there are two ways to reduce these stresses: (1) reduce the numbers of high cyclic loads, and (2) reduce the magnitude of high cyclic stresses. There are not too many practical ways to reduce the sources of high cyclic loads, although slowing the ship down and choosing headings in severe seas can help minimize the cyclic loads. The most effective way to reduce fatigue cracking is to reduce the stress levels. This can be accomplished by a variety of structural strategies, such as increasing the scantlings of the steel sections, providing gradual changes in stiffness of intersections, providing balanced stiffness and strength in connections to eliminate secondary stresses, improving weld profiles, reducing fabrication misalignments, and developing more effective and efficient detail design.

A general fatigue analysis based on stress range-number of cycles to failure (SN) approach was developed and updated to provide the naval architects with the necessary information to reduce the chances of experiencing unexpected fatigue cracking and with an acceptable degree of durability in the CSD (Bea, 1992; Xu, 1995). However, experience has amply demonstrated that fatigue analysis should not be expected to result in a perfectly crack-free ship. The uncertainties and variabilities associated with the fatigue analysis, design, construction and operations will not allow a perfectly crack-free ship to be practically realized. In addition, it is not always possible nor perhaps reasonable to immediately repair cracks that have been found. Thus, there is a practical need to develop a simple fatigue assessment procedure for cracked ship CSD.

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Received March 6, 1996: revised manuscript received by the editors September 18, 1997. The original version (prior to the final revised manuscript) was presented at the Sixth International Offshore and Polar Engineering Conference (ISOPE-96), Los Angeles, USA, May 26-31, 1996.
KEY WORDS: Fatigue, ship critical structural details, cracked SN curves, load shedding.

Traditionally, the fatigue assessment of cracked ship CSD is conducted by the fracture mechanics analysis. However, this paper presents an alternative cracked SN curve approach developed by the hybrid SN-FM methodology. The hybrid SN-FM methodology developed in the early ’70s is a method of reconciling the fatigue test data (S-N) and crack growth test data (a-N). This methodology was mainly used to calibrate or verify the SN curves established by small test specimens (Fisher et al., 1972; Gurny, 1975). Due to the differences between the small test specimens where the fatigue model is established, and the large ship CSD where the model is applied, and other difficult issues such as critical crack size in fatigue problems, this methodology has not been widely applied in the fatigue assessment of cracked ship CSD. Recent researches developed some guidelines to deal with the differences between small specimens and large ship CSD in the fatigue assessment (Xu, 1995; Xu and Bea, 1997). Hence, the hybrid SN-FM methodology is practically realized to be applied in the large ship CSD.

The objective of this paper is to extend the hybrid SN-FM methodology to develop a cracked SN approach to perform the fatigue assessment of cracked ship CSD. This approach takes advantage of the insights provided by FM yet preserves the traditional SN procedures used by naval architects to evaluate fatigue durability.

As cracks develop and propagate in ship CSD, the stresses causing the crack growth can be redistributed to adjacent elements and boundaries (one of the differences between small test specimens and large ship CSD). This phenomenon is identified as load shedding. As a part of the development of the cracked S-N approach, load shedding mechanisms were investigated and their effects are characterized and integrated to the cracked SN approach.

At the end of the paper, we present a numerical example to illustrate the technical developments.

HYBRID SN-FM METHODOLOGY AND CRACKED S-N APPROACH

Hybrid SN-FM Methodology

The hybrid SN-FM methodology developed here is based on the following primary assumptions: