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Reliability based inspection planning using fracture mechanics based fatigue evaluations for ship structural details

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ABSTRACT

Survey and inspection of ship structures is essential in order to monitor the integrity of the hull. With increasing ship size, the number of details susceptible to fatigue damage may be significant. Also as the ship nears the end of its design life, more effective inspections are required to ascertain the structural health of the ship. Reliability based inspection techniques are a possible way for ensuring the effectiveness of the surveys. In the present work, the applications of fracture mechanics based fatigue crack evaluations have been demonstrated to prepare reliability based inspection plans for a Very Large Crude Carrier (VLCC). Probabilistic considerations have been applied taking into account the uncertainty in various parameters related to the loads, materials as well as the parameters of fatigue crack growth. Scheme for updating of reliability of a given ship structural detail has been presented which employs Bayesian approach. Effect of utilization of various inspection techniques has been demonstrated. Various cases such as no-detection of crack, detection of crack with & without repair have been considered. Finally, the results have been also compared with the reliabilities in the current practice of fixed periodical inspections. The paper demonstrates that reliability based inspections are a feasible technique for integrity management of ship structural details while maintaining a practicable work schedule.

1. Introduction

Ship structures are designed to withstand all possible loads expected during their life. The design is checked considering the ultimate loads as well as the service loads in form of fatigue assessment. The major contribution to fatigue damage comes from the fluctuating stresses due to the wave environment. Ship structures are an assembly of welded plates. The stress concentrations at different welded joint details (e.g. longitudinal stiffener and transverse web-frame connection, hopper knuckle connections etc.) could potentially lead to cracking and subsequent failure. Hence, ships are regularly inspected in order to ascertain the condition of the hull and thereby the integrity of the ship structure. Such inspections are periodical in nature within fixed intervals.

The computation of fatigue damage for a given detail within a ship is subject to several uncertainties. One of the sources of the uncertainties is the loads encountered by the ship during its lifetime. Ships are generally designed for world-wide service

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Nomenclature & abbreviations

a	Crack depth
a_c	Critical crack depth
a_d	Detectable crack size
a_i	Initial crack depth
a_f	Final crack depth
b	Width of the plate
BTM	Bottom
C	Paris Law constant
COV	Coefficient of Variation
CSR	IACS Common Structural rules for oil tankers
c	Crack length
c_c	Critical crack length
c_i	Initial crack length
D	Fatigue Damage
DFF	Design Fatigue Factor
K	Stress intensity factor
K_2	S-N Curve Constant
L	Length of welded attachment
LBHD	Longitudinal Bulkhead
m	Paris Law exponent
m_{SN}	S-N curve exponent
N	Number of Cycles
N_L	Number of waves encountered
N_R	Life Cycles at characteristic stress range in IACS Common Structural rules ($=10^4$)
S	Stress Range
$S_{\exp}$	Expected value of stress range
S_q	Stress range at the intersection of the two segments of the bilinear SN curve
S_R	Stress Range corresponding to probability of exceedance once in N_R cycles
SPi	i^{th} Special Survey
SSHL	Side Shell
t	Thickness of the plate
$\underline{t_L}$	Fatigue life (random variable) in years
T_{FM}	Fatigue Life in years using Fracture Mechanics Approach
T_{SN}	Fatigue Life in years using SN curve Approach
VLCC	Very Large Crude Carrier
α	Fraction of Service life representing Ship in service ($=0.85$)
β	Reliability Index
β_i	Coefficients of crack growth evaluation
Δm	Change in slope of bilinear SN curve
$\gamma()$	Incomplete gamma function, Legendre form
$\Gamma()$	Gamma function
ξ	Weibull Shape Parameter for long term stress ranges
λ	Weibull Scale parameter for long term stress ranges
η	Calibration factor for fatigue life obtained from fracture mechanics

and may also be subject to change of ownership and hence trading patterns. The waves encountered along a sailing route are stochastic in nature presenting a source of uncertainty. The uncertainty in calculated fatigue damage is also governed by uncertainties in fatigue strength (i.e. S-N curve and Palmgren-Miner summation).

Large ships such as VLCCs, post panamax bulk carriers and containerships represent an enormous challenge for survey and inspection because of the sheer magnitude of potential weld hotspots to be inspected. Traditional method of fixed periodical surveys may not be a very efficient choice in terms of efforts required for verifying the structural health during the ship's life.

Reliability based inspection planning offers a broader and rational scope for ship surveys as they are able to address the aspects as aforementioned. This technique has been popularly used for offshore structures inspections. The technique also enables updating of the reliability index for a given ship detail based upon the information received from the inspection. The consideration of fracture mechanics based fatigue evaluation helps utilize the results of the survey more effectively.