Picture will go here

Peyman Amirafshari
I am a third year Ph.D. student at the National Structural Integrity Research Centre (NSIRC) at Cambridge, UK. I am registered with the Naval Architecture, Ocean and Marine Engineering department at the University of Strathclyde, and work with Lloyd's Register Foundation, TWI Ltd and the university in pursuance of my Ph.D degree. Prior to starting my Ph.D, I worked as a research assistant at the University of Strathclyde particularly on the EC funded project INCASS looking at risk based inspection planning in ships. Before this, I read for an MSc in Structural Engineering at the University of Manchester. My first degree is BSc in Civil Engineering from Tehran Azad University.

# APPLICATION OF PROBABILISTIC FRACTURE MECHANICS IN RISK BASED NON DESTRUCTIVE EXAMINATION OF NEW BUILDING SHIPS

Ujjwal Bharadwaj[2], Nigel Barltrop[1],Martyn Wright[3], Selda Oterkus[1]

University of Strathclyde[1]

Asset and Fracture Integrity Management TWI[2], Lloyds Register EMEA[3]

3rd Year of PhD

***Keywords: Risk Based Inspection, Ship Building, Engineering Critical Assessment, Probabilistic Assessment. Weld defect.***

## I. INTRODUCTION

Risk-based methods can be used to optimise Non Destructive Examination (NDE) planning of new building ship hull structures [1]. A key step in this method is the estimation of failure probability of fabrication weld defects under fatigue loading. This is achieved through probabilistic fatigue and fracture mechanics assessment. As example, a probabilistic fatigue and fracture mechanics analysis of a butt weld for a ship deck plate is presented here.

## II. METHODOLOGY/APPROACH

### *A. Introduction*

Risk-based methods are particularly useful in the assessment of systems where prioritisation of inspection or maintenance action is required [2]. Once the risk that is associated with components or system is estimated, one can take action to mitigate the risk of failure. Failure criteria caused by the effect of fabrication weld defect in fatigue and failure mode is potentially brittle or ductile fracture. Assessment of weld defect under this condition is also known as Engineering Critical Assessment (ECA). Figure 1 illustrates three main variables required for ECA analysis: 1. Stress, 2. Material mechanical properties, and 3. Defect size. Fatigue life of a structure containing a defect, depends on these three variables. Because of the uncertainty in the determination of these variables, they are often estimated in terms of probability distributions.

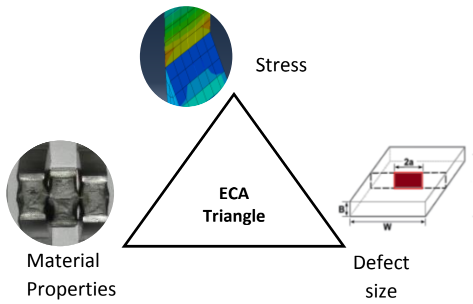


*Figure 1 Engineering Critical Assessment Triangle*

## III. FINDINGS

### A. Stress

Since fatigue is a process of cycle-by-cycle accumulation of damage, assessment of fatigue stress of a ship structural component requires determination of long-term load history of the structure and finite element analysis of the structure. This is done by evaluation of stress long-term Weibull distribution. Finite Element Analysis (FEA) results for extreme load conditions on hogging and sagging states are used to estimate scale parameter of Weibull distribution (Figure 2 and Figure 3).

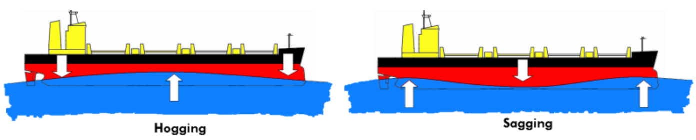


*Figure 2 Schematic view of ship in Hogging and Sagging condition [3]*

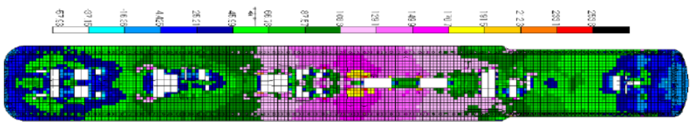

*Figure 3 Normal stress (MPa) contour plot of the study ship under extreme loading condition*

Shape parameter was estimated using ship's basic geometry properties. Scale and shape parameters were evaluated [4]. Then stress distribution of the structures was defined; this estimates the number cycles the component undergoes for each stress level over the life of the vessel (Figure 4).

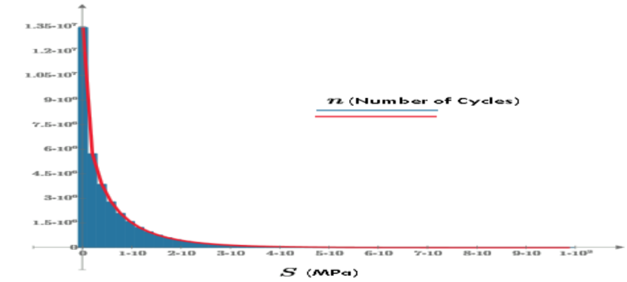


*Figure 4 Long-term Weibull distribution of cyclic stress*

B. Defect size

ECA assessment requires measurement of initial defect size and the frequency of finding the corresponding defect size. Such data need to be fitted to a probability distribution to account for undetected defects. Lognormal and Weibull distribution generally show good fits for fabrication defects, where a higher number of small defects and lower number of bigger defects are expected to be present. Recorded data was fit to appropriate distributions using Maximum likelihood estimate. Figure 5 shows probability density function of Longitudinal cracks (parallel to weld line direction) size created by fitting to Lognormal distribution.

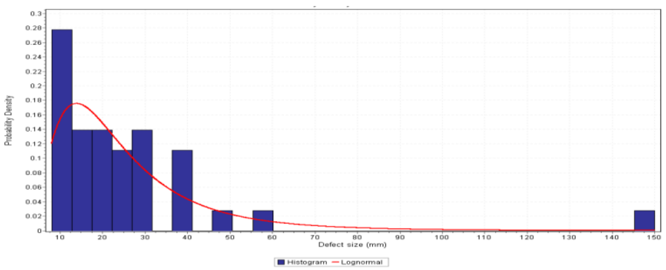


*Figure 5 Longitudinal Crack size data fitted to Lognormal distribution*

C. Material Properties

As there is a significant variation among fracture toughness values of ship plates, it needs to be studied in probabilistic terms. Ferritic material exhibit lower fracture toughness as the temperature drops which increases the chance of brittle failure. Charpy impact test data of ship still grades has been analysed. Figure 6 shows Charpy impact energy values for a ship steel grade. Test data are fitted to a polynomial curve using regression analysis.

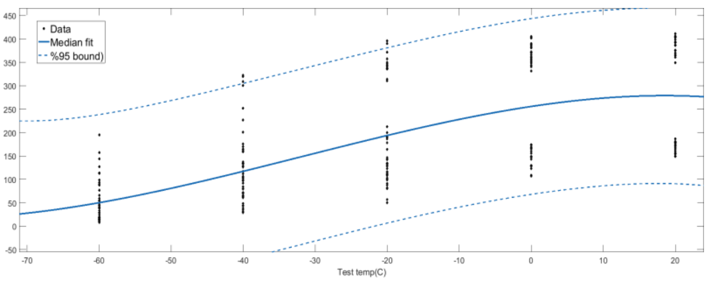


*Figure 6 Charpy impact energy of a manufacturer for AH36 grade steel*

D. Crack growth Analysis:

ECA analysis based on [5] was used to conduct a crack growth calculation. The values used were long-term Weibull stress distribution, 95th percentile values of fracture toughness for three operational temperature and various detected through thickness defect sizes. Figure 7 shows the remaining life of a critical butt weld joint versus of initial crack size for three operational temperatures.

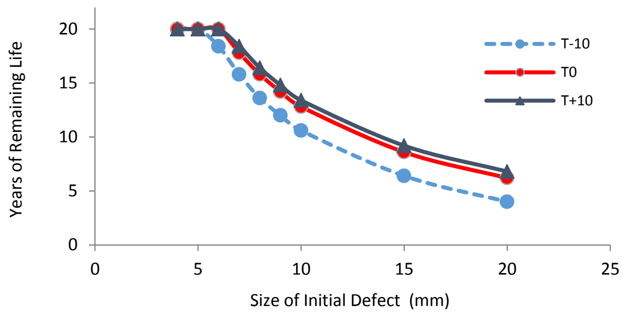


*Figure 7 Remaining life of a critical weld joint versus initial crack size*

## CONCLUSION

In this work, probabilistic analysis of input variables of ECA for a ship deck butt weld connection is presented and subsequent fatigue and fracture analysis is performed.

It was found that for defects below 6 mm no failure occurs throughout the life of the vessel. Defects above 20 mm are likely to fail before the first special survey at year five of service and risk-based inspection should target these defect sizes. Defects between 6 mm and 20 mm can be managed by adopting an appropriate Risk-based in-service inspection plan so that damage tolerant design philosophy of the structure is fulfilled.

## FUTURE PLAN

Future plan includes the evaluation of failure probabilities and associated risk. Once the risk associated with all critical components is evaluated, the extent and prioritisation of inspection within such a system of structural components can be assessed incorporating other variables such as inspection capabilities, probabilities of non-detection, human errors etc.

## REFERENCES


[1] P. Amirafshari, N. Barltrop, U. Bharadwaj, M. Wright, and S. Oterkus, "A Review of Nondestructive Examination Methods for New-building Ships Undergoing Classification Society Survey," *Journal of Ship Production and Design*, 2017.

[2] ASME, "Risk Based Methods for Equipment Life Management," 2003, vol. 41, p. 115.

[3] [Online]. Available: https://commons.wikimedia.org/wiki/File:Arrufoqueb ranto.PNG. [Accessed: 24–05-2017].

[4] I. A. of C. Societies, *No.56 FATIGUE ASSESSMENT OF SHIP STRUCTURES*. International Assosiation of Classification Societies, 1999.

[5] B. S. BS7910, "BS 7910:2013+A1:2015," *British Standards Institutions, London*, vol. 2015, 1999.