Application of Probabilistic Fracture Mechanics (PFM) to Engineering Critical Assessment (ECA)

JOINT INDUSTRY PROJECT OUTLINE

PROP303979

Summary

The use of Engineering Critical Assessment (ECA) procedures such as BS 7910 ("Guide to methods for assessing the acceptability of flaws in metallic structures") has allowed designers and operators of safety-critical welded structures to assess flaws, and set flaw acceptance criteria, on the basis of fracture mechanics concepts, not merely on the basis of historical precedent. This can mean that the flaw acceptance criteria are more generous than those given in application codes, allowing more economical, but safe, manufacture and operation of infrastructure. Conversely, especially when dealing with unprecedented service conditions (eg strain-based assessment of pipelines) or situations in which the inputs are poorly understood, ECA procedures can imply very poor defect-tolerance, sometimes in contradiction with service experience.

Probabilistic Fracture Mechanics (PFM) based on BS 7910 has been used for many years; it was, for example, employed in developing Annex K ('Probabilistic assessment') of BS 7910. This includes a method for using Partial Safety Factors (PSFs) to derive Probability of Failure (POF), but the method has many disadvantages, is rarely used, and is sometimes used incorrectly [1].

There is now an increased drive in various industries, including nuclear power, hydropower and oil & gas, for quantification of the probability of failure associated with an ECA. In response to this, TWI has recently developed a probabilistic version of CW5 (ProCW5) which allows the user to input the distributions of stress, flaw size, tensile properties, fracture toughness and other variables directly into an ECA and thereby calculate probability of failure without recourse to the PSF method. A Joint Industry Project (JIP) is proposed, to allow further exploration of the potential of the method across a range of industries.

TWI Ltd, Granta Park, Great Abington, Cambridge CB21 6AL, United Kingdom. Tel: +44 (0)1223 899000

Objectives

- To provide a probabilistic fracture mechanics solution to consider uncertainties in Engineering Critical Assessment (ECA).
- To evaluate engineering cases selected by the participants using a probabilistic fracture mechanics approach.

Benefits

- Provision of a Beta version of ProCW5 to participants during the project.
- Calibration of deterministic against probabilistic fracture mechanics techniques in ECA cases relevant to participants.
- Support to users wishing to use PFM in safety cases.

Approach

BS 7910 is usually used 'deterministically' (see Figure 1). A single (conservative) value of each of the inputs (such as flaw size, applied and residual stress, fracture toughness and tensile properties) is used, and a decision is made as to whether the flaw is safe or potentially unsafe based on whether it lies inside or outside the Failure Assessment Line (FAL). In order to ensure that the assessment is always conservative, it is common practice to assume worst-case conditions, eg to consider a flaw sited in an area subjected to maximum stress, in a microstructure with worst-case fracture toughness, operating at the minimum design temperature. Yet in practice these three worst-case conditions will not necessarily coincide, a concept long used in so-called Limit State Design or Load and Resistance Factor Design (LRFD) in structural steelwork. Attempts have been made to extend this approach to the prevention of brittle fracture by defining the FAL as a failure surface and assuming all of the inputs to be statistically distributed instead of being defined in terms of a single deterministic value. This approach, known as Probabilistic Fracture Mechanics (PFM), requires extensive computation, not least because millions of calculations are required in order to demonstrate a suitably low Probability of Failure (POF) for high-integrity structures.

There is now an increased drive in various industries, including nuclear power, hydropower and oil & gas, for quantification of the POF associated with an ECA. In response to this, TWI has recently developed a probabilistic version of CW5 (ProCW5) which allows the user to input the distributions of stress, flaw size, tensile properties, fracture toughness and other variables directly into an ECA and thereby calculate POF without recourse to the PSF method (see Figure 2). The proposed JIP includes three stages.

Stage 1: State of the art and definition of sponsors' requirements

This stage will comprise a review of the open literature and TWI's earlier research work (not all of which is in the public domain), citing cases in which PFM has been successfully employed in a quantitative or semi-quantitative context. Sponsors will be invited to share their experience and priorities; for some, the relationship between inspection technique and POF may be critical – for others, it might be the influence of materials properties on POF.

Stage 2: Calibration

PFM is quite unlike a deterministic assessment, in which the inputs are uniquely defined and can be traced directly to the outputs. Repeated probabilistic calculations will produce slightly different results and it is important to 'calibrate' the results of the analysis against earlier calculations, both deterministic and probabilistic.

The second stage of the project will therefore comprise a series of calculations comparing the results of previous analyses with those carried out using ProCW5. For example, ProCW5 results may be compared with those of earlier work carried out at TWI, eg [2]. Sponsors will also be invited to propose their own pre-existing probabilistic studies for re-assessment using ProCW5, subject to the inputs being sufficiently well-defined and transparent, and open to sharing with other sponsors.

Application of Probabilistic Fracture Mechanics (PFM) to Engineering Critical Assessment (ECA)

Stage 3: Application of PFM to new problems

A series of new example problems will be solved, using both deterministic and probabilistic methods. These problems will be based on the issues raised by sponsors in Stage 1.

Deliverables

The main deliverable, at the end of Stage 3, will be a detailed report on the capabilities and challenges of PFM, along with the results of all analyses.

Sponsors who have an interest in developing experience with the method within their own company outside of the project will also be issued with a temporary licence to use ProCW5 for the duration of the project. In the event of the subsequent commercialisation of the software, sponsors will be offered preferential rates.

Price and Duration

The overall estimated price for the work is £100,000 (excluding VAT), which requires £20,000 per company. The expected timescale is one year. It is anticipated that the project will commence with an agreed scope of work with a minimum of four Sponsors.

Further Information

For further information on how a Joint Industry Project (JIP) runs please visit:

http://www.twi-global.com/services/research-and-consultancy/joint-industry-projects/

JIP Co-ordinator: Tracey Stocks

Email: jip@twi.co.uk

Project Leader: Guiyi Wu

Email: guiyi.wu@twi.co.uk

References

1. Isabel Hadley: 'Treatment of reliability in fracture assessments to BS 7910', to be submitted to International Journal of Pressure Vessels and Piping
2. Henryk Pisarski: 'Comparison of deterministic and probabilistic flaw assessment methods for a welded joint', TWI Industrial Members' Report 618/1997

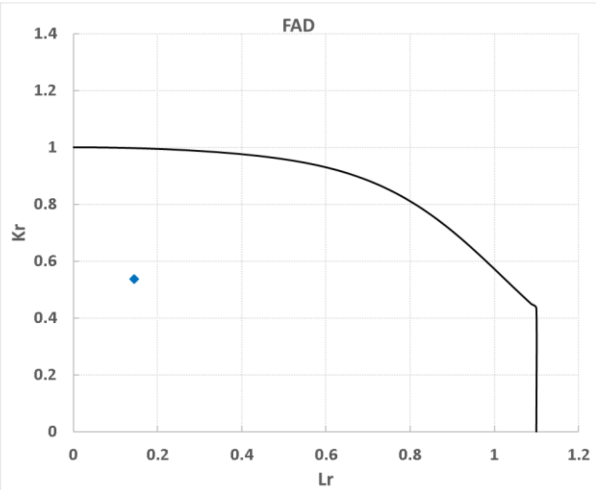

Figure 1 Example of a deterministic ECA

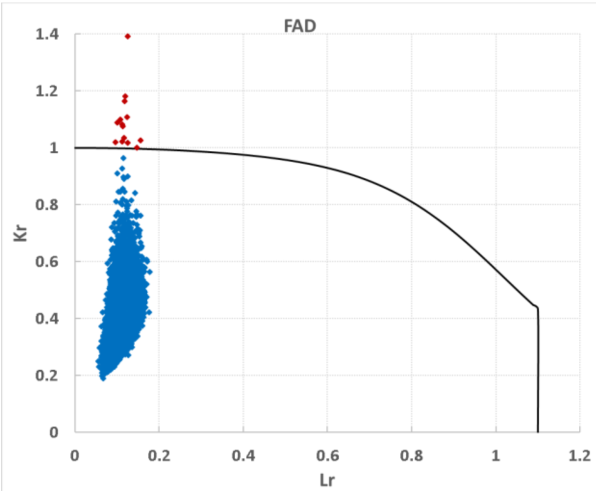

Figure 2 Example of a probabilistic ECA, with POF=8×10^{-5}