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SIMPLIFIED APPROACH FOR FRACTURE INTEGRITY ASSESSMENT PROCEDURE OF FLAWED WELD JOINT UNDER NON-CONVENTIONAL CONDITION

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ABSTRACT

Welded pipes are widely employed in many oil and gas applications. Engineering Critical Assessment (ECA) shall be performed in order to establish acceptance levels for revealed or postulated flaws in new or existing constructions. Although methods for assessing the acceptability of flaws in all types of structures are presented in codes and standards, such as BS7910 [1], API579-1 [2], R6 [3], DNV OS-F101 [4], the approaches are typically derived by simplified geometries as plate solutions, simplified material assumption, and simplified load condition as uniaxial load condition. Dedicate numerical solution are more accurate and would improve the assessed results. But the use of appropriate conditions in the full ECA requires several specific Finite Element Analysis (FEA) which are able to identify the Crack Driving Force (CDF) for each postulated defect geometry, material assumption and load conditions. The purpose of this paper is to propose a simplified method, into a standard procedure (similar to BS7910 [1]), minimizing numerical analyses, to guaranty the safety against fracture of many kind of weld joint under non-conventional condition (such as generic weld joint geometry and/or weld joint subjected to combined axial force, bending moment and internal over pressure which are not contemplate in current code and for which dedicated FEA are recommended).

ABREVIATION

CDF : Crack Driving Force
ECA : Engineering Critical Assessment
FAD : Failure Assessment Diagram
FEA : Finite Element Analysis
FEM : Finite Element Model
JIP : Joint Industry Project
k_{tm} : Membrane stress magnification factor
k_{tb} : Bending stress magnification factor

INTRODUCTION

General

The basis of this approach arises from the guideline proposed by DNV within Joint Industry Project (JIP) phase III for welds in clad material. A rigorous guideline for design and construction of lined and clad pipelines has been proposed and validated in mentioned JIP. Regarding fracture assessment, the approach proposed by this JIP requires the identification of an equivalent material curve to be used as input in a standard analytical procedure (as the one described in BS7910 [1]).

Objective

Intention of Authors is to adopt the above mentioned approach as basis of the study presented in this paper. The objective is to establish, for weld joint under non-conventional condition, a simplified procedure able to re-conduct it into a standard scenario and capture effect of the actual condition that the weld joint is subjected to, by identifying some correction factors or adjusted input to be used in a normal integrity assessment procedure (as the one given in BS7910 [1]).

Methodology

Philosophy of the approach here presented is to adjust some relevant input parameters employed in the standard analytical ECA procedure (as the material curve or parameters like “k_{tm}”, “k_{tb}”, etc) which may allow to match the analytical CDF prediction with the CDF numerically computed by using dedicated FEM, in which all non-conventional conditions are taken into account (such as geometries, loads condition, multi-axial effect, multi materials).

For a given non-conventional scenario, it becomes possible to use an “ECA standard procedure” with adjusted inputs previously identified with few FEA. The finite element model used to compute above input should be carefully chosen, to remain conservatism while the simplified standard procedure is applied for integrity assessment.

The presented methodology has been successfully investigated on several flaw configurations, under different loads conditions (combined axial force, bending moment, internal pressure, etc..), different weld joint geometries, multi materials, and combination of above mentioned conditions.

Computational results indicate that the use of appropriate relevant input parameters (such as "equivalent material curve" or any other input parameter), obtained in order to fulfil the CDF computed by FEA, lead to conservative results when it is implemented in BS7910 or any other similar standard procedure.

GENERAL PURPOSE

The application of mentioned method should require, for each representative selected case, some finite element analyses of the weld joint considered, together with some iterations method for identification of relevant "equivalent material" and/or "equivalent parameters" to be used in the standard assessment.

Therefore the presented approach is beneficial if the numerical prediction may be reduced to only few FEMs cases which may be selected as representative of all expected scenario. For example selecting the most critical weld joint geometries, the most critical flaw geometry, and apply the most critical combined loads condition, as typically done in industry application where standardization of fabrication process takes place.

Experience is showing that the global conservatism produced by selecting few overall worst scenarios, is then largely mitigated because more appropriate solution are used in the ECA assessment since they are based on more accurate CDF extracted from FEA.

STEPS OF THE APPROACH

Basis of the method

Once identified the relevant numerical CDFs for each selected worst cases, it is proposed to perform a standard ECA analytical procedure (as the one given in BS7910) suitably adjusted by using some correction factors, extracted from few numerical analyses. To this purpose, in the present paper, it will be shown how, for a weld joint under non-conventional condition, the relevant correction factors may be easily established just following these steps:

a) Generating, for a few selected scenarios, the numerical prediction of CDFs (as per BS7910 level 3C [1]);

b) Comparison of the mismatch with the selected analytical approach (as per BS7910 level 2B [1]);

c) Identify some correction factors to be applied in the selected analytical approach in order to match the numerical CDF.

Once the equivalent inputs are identified, the use of analytical standard procedure (as the one given in BS7910 [1]), with the adjusted input, will provide fracture assessment which takes into account the actual weld joint condition (geometries, loads, multi-axial effect, materials).

Example

Here below is detailed the method in order to determine the "equivalent stress-strain curve" such that the BS7910 level 2B [1] results in the same CDF as the FE analyses.
The level 2B failure assessment curve is defined as follows:

$$K_r = f(L_r) = \left(\frac{E\varepsilon_{ref}}{L_r\sigma_y} + \frac{L_r^3\sigma_y}{2E\varepsilon_{ref}}\right)^{-0.5} \qquad \text{equation (1)}$$

The level 3C failure assessment curve is defined in terms of the elastic and total (elastic plus plastic) J-integrals (J_e and J_t respectively) as follows:

$$K_r = f(L_r) = \sqrt{\frac{J_e}{J_t}} \qquad \text{equation (2)}$$

For each load increment *i*, a point of the "equivalent" stress strain curve could be determined such that K_r from equation (1) is equal to K_r from equation (2):

$$\left[\sqrt{\frac{J_e}{J_t}}\right]_i = \left[\left(\frac{E\varepsilon_{ref}}{L_r\sigma_y} + \frac{\sigma_{ref}^3}{2\sigma_y^2E\varepsilon_{ref}}\right)^{-0.5}\right]_i \qquad \text{equation (3)}$$

The unknown in equation are σ_y and ε_{ref}. The yield stress σ_y can be first determined as follows:

At yield point, L_r=1, σ_{ref}= σ_y and ε_{ref}=0.005. In equation (3), it gives :

$$\left[\sqrt{\frac{J_e}{J_t}}\right]_{L_r=1} = \left[\left(\frac{0.005*E}{\sigma_y} + \frac{\sigma_y}{2E*0.005}\right)^{-0.5}\right]_{L_r=1} \qquad \text{equation (4)}$$

Then the "equivalent" stress-strain curve (σ_{ref} , ε_{ref}) is obtained solving for each load increment the equation 3.

CASE STUDY

In this work, a detailed finite element analysis of a flawed metallic girth weld joint was performed to determine the crack driving force in the case of a pipe subject to axial force and internal pressure. A full circumference defect has been assumed. Selected load scenario is not contemplated in current international procedure, for which some conservative recommendations are given (e.g. DNV-OS F101 [4] appendix A, such as to limit the strain to 0.4% when standard approach is employed for pressurized pipe, or neglect the mechanical proprieties of weld metal in the assessment, etc.).

Analysis details

The pipe considered was 4m long, 27.1mm thick with an outer diameter of 610mm. A full external circumference defect with a height of 2.71mm was considered. Due to the symmetry of the model, an axisymmetric model was considered. The model was meshed using 3D linear elements of type C3D8R.

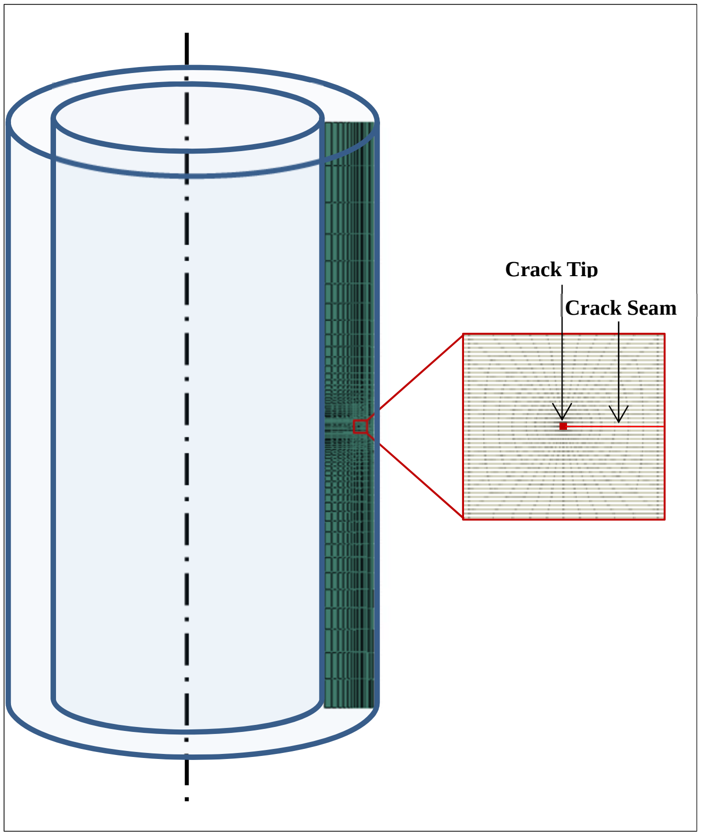

Figure 1: Finite Element Model

A Ramberg-Osgood stress-strain curve (eq 4.) of X65 carbon steel at 20°C was used in the model. The table 1 summarize material properties and parameters of Ramberg-Osgood used in equation (5).

$$\frac{\varepsilon}{\varepsilon_y} = \frac{\sigma}{\sigma_y} + A\left(\frac{\sigma}{\sigma_y}\right)^n \qquad \text{equation (5)}$$

Yield Stress (MPa)	Ultimate Strength (MPa)	Young's Modulus (MPa)	Poisson's ratio	A	n
450	600	207000	0.3	1.30	13.10

Table 1: Material and parameters data

Validation of Finite element model

Extensive finite element analyses were performed to derive the crack driving force using the domain integral method. The FEM modelling and J-integral calculation scheme were qualified comparing the results, for single edge notch bending SEN(B), with available elastic-plastic solution such as GE-EPRI [7].

The possibility to use, with appropriate meshing, the CTOD as parameters to directly derive the J-integral in the numerical simulation has been also employed for numerical validation. To summarize, the same validation steps, as described in [6] was applied.

Results

The method detailed above has been applied to compute the equivalent stress-strain curve such that the BS7910 level 2B [1] results in the same CDF as the FE analyses. Results indicate that, under appropriate assumptions, considering the joint as made of an "equivalent" material leads to conservative solution for the estimation of the crack driving force. Therefore identified "equivalent" material can be safely used for ECA in accordance with BS7910 level 2 assessment guidance as showed in below figures.

Furthermore provided results are showing the improvement on ECA allowable defect size if the proposed simplified approach is used to assess an unconventional scenario.

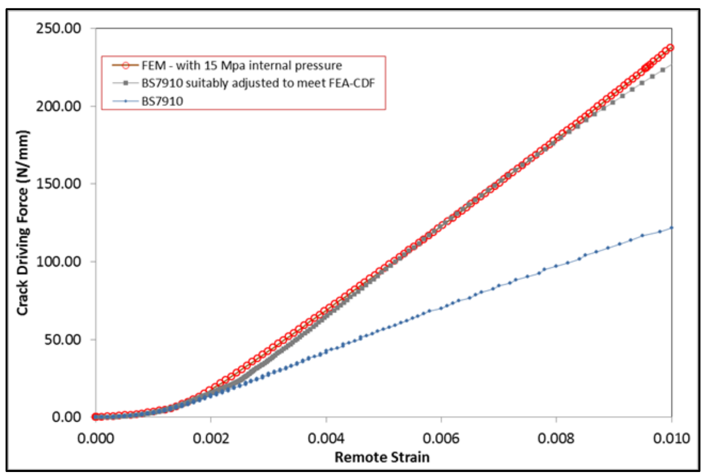

Figure 2: Crack Driving Force comparison between Proposed and standard approach with FEM prediction.

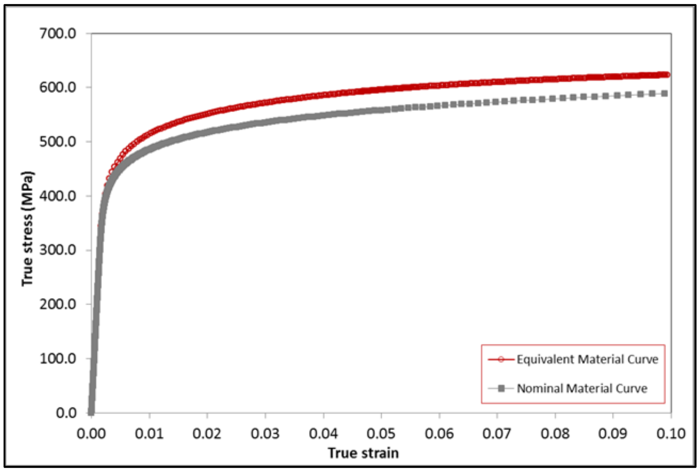

Figure 3: Stress–Strain material comparison between the nominal and equivalent ones

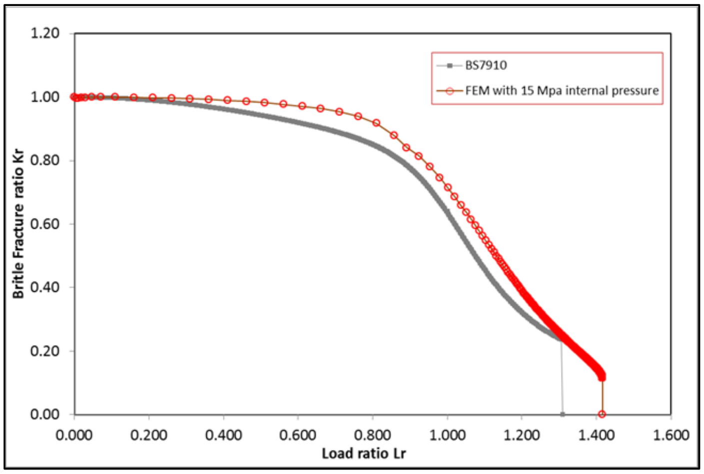

Figure 4 : FAD comparison between proposed and standard approaches with FEM prediction

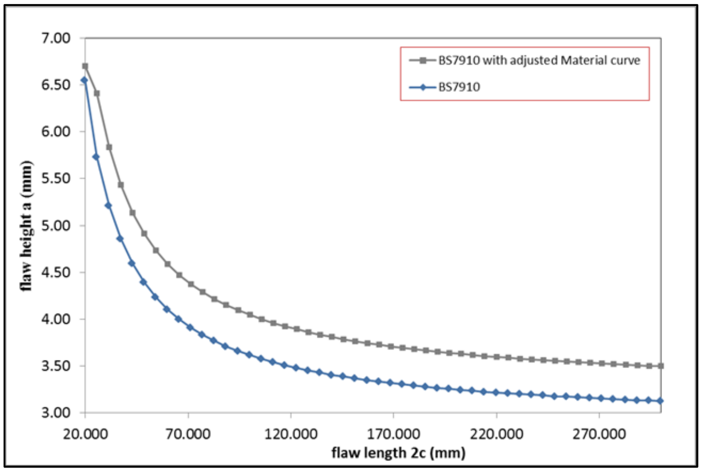

Figure 5: Comparison between ECA allowable flaws envelope obtained adopting proposed approach vs the standard ones

CONCLUSIONS

The proposed approach allows to provide a full ECA by using commercial standard tools (as Crackwise software [9]), where actual condition of a given weld joint is take into account. After identification of appropriate equivalent parameters, the approach described in this paper permits to use reference stress and stress intensity factor solutions already implemented in standard software. For example weld joint subjected to axial force, bending moment, internal over pressure, even in case of non-standard weld geometries, multi-materials weld joint, and in general any combination of above mentioned conditions.

Results indicate that, in a standard procedure and under appropriate assumptions, the assessment of non-conventional weld joint re-characterized to a conventional one using “equivalent inputs” leads to conservative solution for the estimation of the crack driving force. Therefore identified “equivalent inputs” can be safely used for ECA in accordance with BS7910 level 2 [1] to assess also many postulated non-conventional scenario.

Further work is to investigate the approach here developed with a crack driving force predicted by a damage finite element model (as per [10]). It will allows to take into account damage effect on CDF using standard commercial software.

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