

THE ROLE OF ECA IN THE DEVELOPMENT OF DYNAMIC RISER SYSTEMS

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ABSTRACT

An Engineering Critical Assessment (ECA) is a procedure that may be used to define and characterise critical flaw sizes from which acceptance criteria for non-destructive examination (NDE) can be developed or confirmed.

Dynamic riser systems are fatigue sensitive structures that are commonly regarded as one of the most challenging aspects of a deepwater development. An ECA provides the facility to increase confidence as it develops an understanding of the margin of safety afforded by the derived acceptance criteria based upon variations in extreme and long-term loads, material properties such as fracture toughness, quality standards for welding, control of stress concentration factors and the nature of potential failure.

The paper will demonstrate the objectives, adopted methodology and explore the conclusions of an ECA with the aid of examples.

INTRODUCTION

An ECA plays an important role in the development of dynamic riser systems. It draws on information from all aspects of the riser design including: extreme and long-term load data, material testing and resulting properties, fatigue testing of full scale or strip specimens, quality standards for welding, control of stress concentration factors and weld acceptance criteria. As such, it provides a powerful tool for understanding the reliability of the riser system, increasing confidence and removing unnecessary conservatism.

ECA utilizes both fracture mechanics and fatigue crack/flaw growth analyses to determine maximum tolerable weld flaw sizes from which an acceptance criteria may be derived, or the standard specified in a selected welding code such as API 1104 [3] be confirmed as 'fit for purpose'. The maximum tolerable flaw sizes determined are the maximum flaw sizes in the weld that avoid both unstable fracture during extreme events such as the 100 year hurricane and fatigue failure within the specified life of the system. In addition, ECA develops an understanding of the margin of safety afforded by the derived acceptance criteria based upon variations in:

- Riser system loading at various locations along the riser;
- Material properties such as tensile strength and fracture toughness;
- Quality standard of welding such as weld cap transition and height, presence of undercut and make-up geometry;
- Residual stresses;
- Control of stress concentration factors;
- The nature of potential failure as a consequence of either fracture, plastic collapse or damage by fatigue.

In addition, if sufficient parametric analysis is carried out, ECA can be used to effectively identify a suitable course of action if design changes occur, or material properties and/or fabrication details do not turn out as expected after conducting the relevant qualification testing.

OBJECTIVES

The ultimate objective of an ECA may vary depending on the party involved. Some may want to use it to demonstrate a high margin of safety in the prescribed weld acceptance criteria whilst others may want to use it to relax the weld acceptance criteria and thus minimise cut outs and subsequent costs. However, these differences aside, the key objectives of an ECA are as follows:

- Demonstrate that the riser has adequate fracture strength;
- Determine the nature of unstable fracture, i.e. whether fracture would occur prior to leakage;
- Define acceptable material properties;
- Define acceptable initial flaw sizes and hence requirements for post-fabrication inspection methods;
- Define variability in limiting flaw sizes along the riser due to variations in extreme and fatigue load conditions;
- Define benefits of weld or fabrication improvements;

- Characterise fatigue crack growth such that in-service inspection techniques (if required) can be evaluated.

The ECA may be used to derive or confirm a weld acceptance criterion. A weld acceptance criterion for the West Seno export SCR, developed from the results of an ECA is presented in Table 1. It should be noted that an ECA is an additional activity that is complimentary to good workmanship, not a replacement.

Diameter		Wall Thickness		Acceptance Criteria (Ref. ECA in Accordance with BS 7910)	
inch	mm	inch	mm	Surface flaws / Buried flaws	
				Height (mm)	Length (mm)
12.75	323.9	0.689	17.5	<= 1.5	20
				>1.5 - 2.0	17
				>2.0 - 2.5	14
				>2.5 - 3.0	12

Table 1 – Acceptance Criteria for SCR ‘Pipe to Pipe’ Welds

APPROACH

A number of codes provide guidance for carrying out ECAs including BS 7910 – “Guide on methods for assessing the acceptability of flaws in metallic structures” [1] and API-RP-579 - “Recommended Practice for Fitness for Service” [2].

The results presented in this paper are determined in accordance with BS 7910. The procedure used is summarised as follows:

- Determine extreme and long-term riser loads;
- Conduct fracture analysis to determine maximum allowable flaw sizes for a range of flaw height/length aspect ratios from 1 to 100;
- Select small initial flaw dimensions, conduct fatigue crack growth to determine life based on long-term load data;
- Iteratively vary initial flaw dimensions and repeat flaw growth analysis until target design life is achieved;
- Repeat for a range of flaw aspect ratios to determine distribution of maximum acceptable flaw dimensions;
- Repeat for internal and external surface flaws and embedded flaws;
- Develop or confirm acceptance criteria.

To demonstrate how allowable flaw sizes may be derived, the above approach is demonstrated, working backwards. This is carried out using the allowable flaw sizes derived for a 12inch oil export steel catenary riser (SCR) in approximately 1000m water depth for Unocal’s West Seno Development. The results are condensed to provide a simple example. The rationale for using key parameters such as material properties and stress

concentration factor and the effect of variations in the parameters is discussed in further detail on subsequent pages. A plot of allowable flaw size as a function of height and length is illustrated graphically in Figure 1 and is also given in Table 1. This may be used when defining or confirming the weld acceptance criteria.

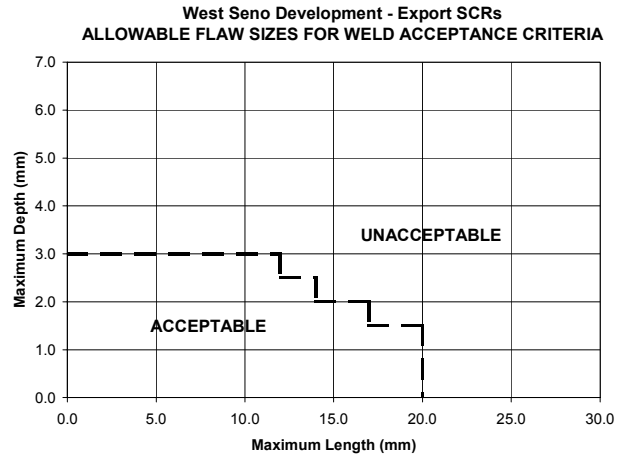


Figure 1 – Allowable Flaw Dimensions from which Weld Acceptance Criteria may be Defined

The allowable flaw dimensions shown in Figure 1 are in terms of four length and depth combinations and are derived using the results of an ECA and the sensitivity of the NDE equipment that is to be used for determining flaw dimensions. Four blocks were used for West Seno but more or less can be used as required. The maximum allowable flaw sizes from the ECA are superimposed onto the allowable defect size plot in Figure 2. Flaws are unacceptable if their dimensions exceed either of the two lines. The allowable flaw dimensions are derived assuming +/-0.5mm tolerance on flaw depth detection for the NDE.

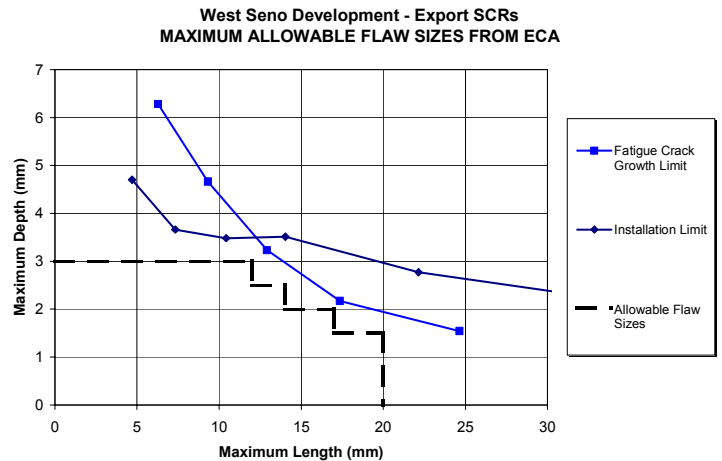


Figure 2 – Allowable Flaw Dimensions and Maximum Allowable Flaws from ECA

The maximum allowable flaw dimensions are based on the following criteria:

- Maximum initial flaw size that will not lead to fatigue failure within the design life;
- Maximum tolerable flaw size that does not lead to unstable fracture during installation and extreme events.

The installation limit is driven by unstable fracture whilst the fatigue limit is driven by a combination of fatigue crack growth and unstable fracture. Fatigue failure is considered to have occurred when either the flaw becomes through wall or the flaw grows to a size equal to the end of life flaw sizes. The end of life flaw sizes are the flaw sizes that result in unstable fracture based on an assumed end of life load condition. The 100 year storm was used as the end of life condition for this example.

The growth of flaw depth with time for a range of initial flaw aspect ratios is presented in Figure 3. The initial flaw size is determined by iteratively varying the initial flaw size until fatigue failure occurs at the target design life which is 200 years in this case. The fatigue limit shown in Figure 2 is determined from the fatigue crack growth results in Figure 3 and is actually a plot of the flaw sizes at zero years. The curves are seen to converge and this is due to the fact that the length/depth aspect ratio reduces as flaws grow. Typically, the flaw depth grows more rapidly than the flaw length.

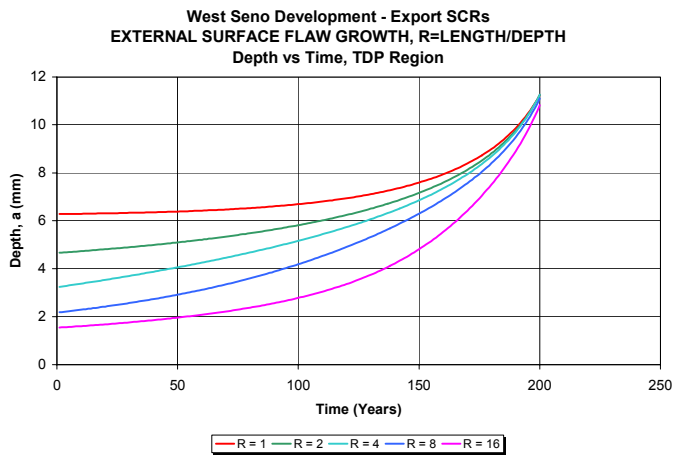


Figure 3 – External Surface Flaw Growth, 200 Year Design Life

The above results provide an example of the procedure that may be used as part of an ECA to determine allowable defect sizes to be used in determining the acceptance criteria of weld flaws. The allowable defect size is sensitive to variations in input parameters such as fatigue life factor of safety, material properties, stress concentration factors and quality standards such as weld cap and root geometry and presence of undercut. Each of these parameters needs to be understood and considered so that a reasonable but not overly conservative result can be achieved and to help define a suitable course of action should material properties be below the specified requirement.

DESIGN ITERATION

The key inputs and outputs of an ECA are presented in Figure 4. The implication of variation in each of the key input parameters is discussed in more detail below. The objective of fatigue testing is to qualify the production welds as supplied by the selected installation contractor, demonstrating that the weld fatigue performance is in excess of the fatigue design (S-N) curve used in the riser design analysis. In addition, the fatigue testing provides a number of additional benefits such as: help to determine the likely nature of fatigue failure, highlight critical flaw types and their respective locations, confirm the presence of stress concentration factors and the achievement of fit-up tolerances specified in the weld procedures.

Material testing and qualification of weld procedures are typically the last activities to be carried out prior to installation and the results of an ECA may be required before completion of these activities. In addition, carrying out an ECA at a relatively early stage of the project is recommended as it provides an understanding of the significance that each of the parameters has on the acceptance criteria and can highlight any potential problems early enough to resolve them. As a result, a number of design iterations may be required as an understanding of the project specific requirements develops as follows:

- Conduct ECA using assumed material properties and stress concentration factor;
- Carry out parametric analysis to understand sensitivity to critical parameters;
- Define preliminary inspection requirements;
- Define requirements for material testing and welding procedures;
- As project progresses conduct fatigue testing, material testing and qualification of welding procedures to confirm design and determine project specific material data;
- Repeat ECA as required;
- Confirm acceptance criteria based on proven properties.

Using this approach, the results of the parametric analysis can be used to help define a suitable course of action if material properties do not turn out as expected on completion of the qualification testing. For example, if CTOD values are lower than initially specified, revised inspection requirements may be adopted or attempts to improve Hi-Lo mis-match at critical locations may be considered. Providing adequate parametric analysis is carried out in the initial ECA a suitable course of action can be quickly identified.

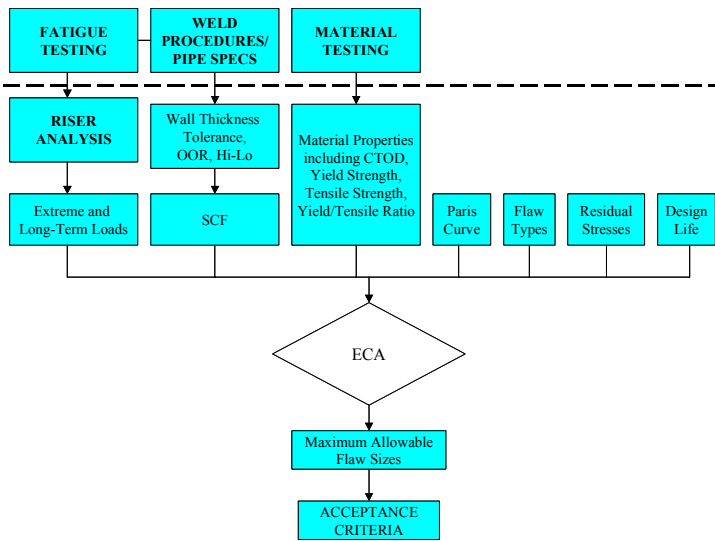


Figure 4 – Flow Chart Showing ECA Inputs and Outputs

FLAW TYPES

The flaw types that may be considered in an ECA are categorized as surface, embedded and through thickness flaws [1]. Surface flaws may occur on either the inner surface or outer surface of a welded riser joint and are defined as internal surface or external surface flaws respectively. The representations of flaw dimensions in accordance with BS 7910 are shown in Figure 5.

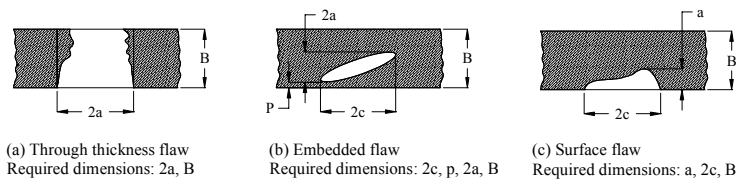


Figure 5 – Flaw Configurations [1]

Typically, surface flaws result in more stringent maximum allowable flaw sizes compared with that of embedded flaws, where a more stringent flaw size is defined as the maximum allowable flaw size with smaller dimensions. In addition, external surface flaws typically result in more stringent maximum allowable flaw sizes than internal surface flaws as presented in Figure 6. This is predominantly due to the occurrence of higher stresses at the outer surface compared to the inner surface under bending loads.

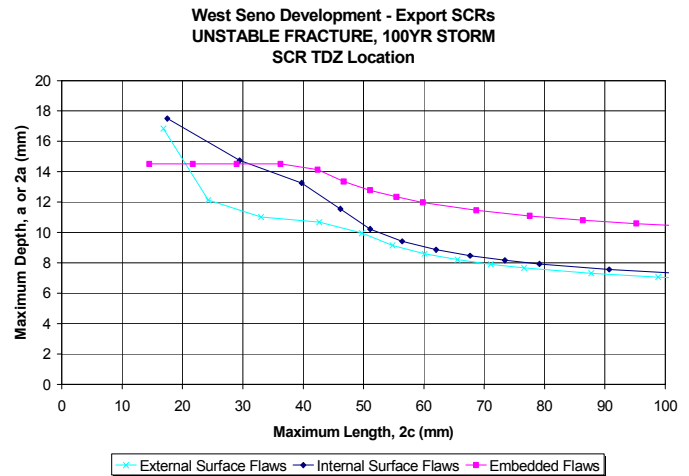


Figure 6 – Variation in Tolerable Flaw Size due to Unstable Fracture for Various Flaw Types

KEY INPUTS

The outcome of an ECA is affected by variations in input parameters. As discussed above, the design iteration should carefully consider variations in inputs such that the result is not overly conservative. Each input is a subject on its own. Key inputs that can have the greatest impact on the results of an ECA are summarised as follows:

- Extreme and long-term loads – should consider regions where the riser experiences high stress concentrations, extreme loads and fatigue damage rates. Long-term loads should include accurate estimates of all effects that contribute to total fatigue of the riser system including fatigue loads from installation, first and second order effects and vortex induced vibrations (VIV);
- Factors of safety (FOS) - the fatigue design requirement is that the largest plausible flaw size remaining after manufacture and subsequent inspection shall not propagate to a size resulting in unstable fracture within a specified factor of the service life. The factor may vary depending on project specific requirements but in general the factor is typically smaller than the safety factor adopted for fatigue using the S-N approach. FOS of 5 and 10 were considered for the West Seno ECA and an FOS of 10 was used for selection of the allowable defect sizes. Whilst there is a rationale for using a lower FOS than that of the S-N curve, it was felt that there were still sufficient uncertainties to warrant the higher FOS;
- Crack growth data – can be expressed in the form of a two stage Paris Law. Paris curve data that represents welded joints in a range of operating conditions are given in BS7910. This data may be used if project specific data is not available. Testing can be carried out to derive material and operational specific fatigue crack growth curves and may be required if the riser is fatigue sensitive, is subjected to sour service

conditions or there is uncertainty regarding the long term effectiveness of the cathodic protection (CP) system;

- Material properties - the material data used for the West Seno export riser pipe to pipe welds is presented in Table 2. The minimum fracture toughness value for the weld metal and associated heat-affected zones (HAZ) is based on the criteria specified in API 1104 [3], which is based on a minimum crack tip opening displacement (CTOD) value of 0.010 inch (0.254mm);
- Stress concentration factors (SCFs) - occur at girth welds from geometrical differences between the pipe walls. Geometrical differences can result from a number of variables including wall thickness variation, out of roundness (OOR) and alignment. Careful control of these variables can help to minimise stress concentrations. Calculation of SCFs may be carried out using finite element analysis (FEA) or published formulas. A large number of sources exist that provide formulae for determining SCFs. Examples are BS 7910 [1], DNV [5] and Zettlemoyer et Al. [9-10]. For the West Seno export riser tight control of internal Hi-Lo through the use of an internal line-up clamp and low ovality resulted in a small maximum centreline eccentricity and a calculated maximum SCF of less than 1.5. However, the sensitivity of the ECA to variations in SCF was also determined.

The automated ultrasonic testing (AUT) system used to detect flaws for the West Seno project is shown in Figure 7. The selected NDE technique must possess the ability to quantify the dimensions of the detectable flaws in order to establish whether they are greater than the critical flaw size determined by the ECA. Flaws greater than the critical flaw size would be an indication that the welded joint is not of the desired standard (i.e. 'fit for purpose') and therefore needs to be repaired or cut-out.

In addition, in order to facilitate the complete assessment of its 'fitness for purpose' the welding and/or NDE specification needs to detail the following allowable specifics of the welded joint:

- Hi-Lo misalignment;
- Presence and extent of undercut;
- Cap profile and height limit;
- Specifics of weld cap sanding;
- Joint description;
- Surface flaw height vs tolerated length dimension;
- Embedded flaw height vs tolerated length dimension.

Welding of the West Seno export risers utilising an automated gas metal arc welding (GMAW) system is presented in Figure 8. The weld acceptance criteria for the West Seno export SCRs, which was developed from the results of an ECA is given in Table 1.

Parameter	Input Value
Material Grade	API 5L X65
Yield / Tensile Strength Ratio	0.9
Ultimate Tensile Strength (MPa)	576 MPa
Elastic Modulus at Room Temperature (GPa)	207 GPa
Poissons Ratio	0.3
Minimum Fracture Toughness as a CTOD value- (mm)	0.3

Table 2 – 12inch Oil Export Riser Material Properties

ACCEPTANCE CRITERIA

The purpose of the ECA is to determine the critical nature of surface breaking and embedded flaws relating to the specific service loading histories. It establishes the critical flaw sizes beyond which the SCR will fail prematurely due to crack propagation and/or fracture.

The critical flaw sizes derived from ECA are to be incorporated into the project NDE acceptance criteria as a standard in which the NDE contractor can calibrate the specified NDE technique and maintain continuity of the system throughout the project. For each of the flaw types considered, different size limits are derived and the sensitivities associated with detection of each flaw type must then be considered in order to define the limiting size of flaw that is acceptable.



Figure 7 – Calibrating Automated Ultrasonic Testing (AUT) System



Figure 8 – Automatic GMAW Welding of the West Seno Export SCR

CONCLUSIONS

An Engineering Critical Assessment (ECA) is a procedure that may be used to define and characterise critical flaw sizes from which acceptance criteria for non-destructive examination (NDE) can be developed or confirmed. The role of ECA in the development of dynamic riser systems is an important one. It pulls together the information relating to riser analysis, material testing, fatigue testing, quality standards of the deposited weld metal, control of stress concentration factors and weld acceptance criteria.

The methodology is described with the aid of examples from the West Seno Development export riser ECA. The use of an iterative design process and parametric analysis provides an understanding of the significance of each of the design parameters and can be used to further define a suitable course of action if material properties or manufacturing tolerances are out of specification.

The main objective of an ECA may change depending on the party involved. However, some of the objectives and benefits are summarised as follows:

- Can be used to define or confirm weld acceptance criteria;
- Provides an understanding of the effect of variation in input parameters;
- Increases confidence in the riser design and analysis;
- If conducted at a sufficiently early stage in the project it may be used to help define the required properties of the base material and the deposited weld metal;
- The use of ECA can minimise conservatism when defining weld acceptance criteria resulting in less cut-outs and cost. Alternatively it may be used to

demonstrate a high margin of safety in the prescribed weld acceptance criteria.

It should be noted that whilst there are significant benefits to carrying out an ECA it is not an alternative to good workmanship. For example, if numerous flaws are found the weld is unlikely to be acceptable even if each of the flaws comply with the ECA defined criteria. In addition, for cases that are not fatigue sensitive or are unlikely to see high loads there may not be a requirement for ECA and simplified methods such as those defined in API-1104 may be used instead.

REFERENCES

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