A review of Pipeline Defect Assessment Manual (PDAM) project

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Abstract: The Pipeline Defect Assessment Manual (PDAM) project is a joint industry project sponsored by fifteen international oil and gas companies, to produce a document specifying the best methods for assessing defects in pipelines. PDAM document is the best available techniques currently available for the assessment of pipeline defects (such as corrosion, dents, gouges, weld defects, etc.) in a simple and easy-to-use manual, and gives guidance in their use. In this paper the best practices for the assessment of corrosion in pipelines are presented.

1. INTRODUCTION

Due to a combination of good design, materials and operating practices, oil and gas transmission pipelines have a good safety record; however, like any engineering structure, pipelines do occasionally fail. The most common causes of damage and failures in onshore and offshore, oil and gas transmission pipelines in Western Europe and North America are formats for your particular conference. External interference (mechanical damage) and corrosion [1-3]. Assessment methods are needed to determine the severity of such defects when they are detected in pipelines. Defects occurring during the fabrication of a pipeline are usually assessed against recognised and proven quality control (workmanship) limits. However, a pipeline will invariably contain larger defects during its life, and these will require a ‘fitness-for-purpose’ assessment to determine whether or not to repair the pipeline. Consequently, the past 40 years has seen the development of a number of methods for assessing the significance of defects. Some of these methods have been incorporated into industry guidance, others are to be found in the published literature. However, there is no definitive guidance that contains Safety must always be the prime consideration in any fitness-for-purpose assessment and it is always necessary to appreciate the consequences of a failure. These will influence the necessary safety margin to be applied to the calculations

2 THE PIPELINE DEFECT ASSESSMENT MANUAL

PDAM is based upon a comprehensive, critical and authoritative review of available pipeline defect assessment methods. This critical review includes a compilation of published full scale test data used in the development and validation of existing defect assessment methods. The full-scale test data is used to assess the inherent accuracy of the defect assessment methods, and to identify the ‘best’ methods (considering relevance, accuracy and ease of use) and their range of applicability. PDAM describes the ‘best’ method for assessing a particular type of defect, defines the necessary input data, gives the limitations of the method, and defines an appropriate factor to account for the model uncertainty. The model uncertainty for each assessment method has been derived from a statistical comparison of the predictions of the method with the inches in width.

PDAM does not present new defect assessment methods; it presents the current state of the art in the fitness-for-purpose assessment of defective pipelines. Limitations of the methods recommended in PDAM represent limitations of the available methods and of knowledge.

Fig 1: Corrosion in Pipelines
3. TYPES OF DEFECT CONSIDERED IN THE PIPELINE DEFECT ASSESSMENT MANUAL

PDAM contains guidance for the assessment of the following types of defect:

- Defect-Free Pipe
- Corrosion
- Gouges
- Plain Dents
- Kinked Dents
- Smooth Dents on Welds
- Smooth Dents Containing Gouges
- Smooth Dents Containing Other Types of Defects
- Manufacturing Defects in the Pipe Body
- Girth Weld Defects
- Seam Weld Defects
- Cracking

4. THE FORMAT OF THE PIPELINE DEFECT ASSESSMENT MANUAL

The Pipeline Defect Assessment Manual broadly follows the following format for each defect type and assessment method:

1. A brief definition of the type of defect.
2. A figure illustrating the dimensions and orientation of the defect relative to the axis of the pipe, and a nomenclature.
3. Brief notes that highlight particular problems associated with the defect.
5. The minimum required information to assess the defect.
6. The assessment method.
7. The range of applicability of the method, its background, and any specific limitations.
8. An appropriate model uncertainty factor to be applied to the assessment.

5. ASSESSMENT METHODS IN THE PIPELINE DEFECT ASSESSMENT MANUAL

A summary of all of the methods recommended in the Pipeline Defect Assessment Manual Longitudinally and circumferentially-orientated defects are considered. The ‘primary’ methods (indicated in normal font) are plastic collapse (flow stress dependent or limit state) failure criteria, and are only appropriate if a minimum toughness is attained. The secondary methods (indicated in italic font) are the alternative methods recommended when a minimum toughness is not attained. Upper shelf behaviour is assumed throughout. The general procedures for assessing flaws in structures, based on fracture mechanics, given in BS 7910[4] (and API 579[17]) can be applied in general (irrespective of upper or lower shelf behaviour), but will generally be conservative compared to the pipeline specific methods.

6. CORROSION IN PIPELINES

Corrosion is an electrochemical process. It is a time dependent mechanism and depends on the local environment within or adjacent to the pipeline. Corrosion usual appears as either general corrosion or localised (pitting) corrosion. There are many different types of corrosion, including galvanic corrosion, microbiologically induced corrosion, AC corrosion, differential soils, differential aeration and cracking. Corrosion causes metal loss. It can occur on the internal or external surfaces of the pipe, in the base material, the seam weld, the girth weld, and/or the associated heat affected zone (HAZ).

Internal and external corrosion are together one of the major causes of pipeline failures. Data on onshore gas transmission pipelines in Western Europe for the period from 1970 to 1997 indicates that 17 percent of all incidents resulting in a loss of gas were due to corrosion. Incident data from the Office of Pipeline Safety in the USA for the year 200 Corrosion in a pipeline may be difficult to characterise. Typically, it will have an irregular depth profile and extend in irregular pattern in both longitudinal and circumferential directions. It may occur as a single defect or as a cluster of adjacent defects separated by full thickness (uncorroded) material. There are no clear definitions of different types of corrosion defects. The simplest and perhaps most widely recognised definitions are as follows: pitting corrosion, defined as corrosion with a length and width less than or equal
to three times the uncorroded wall thickness, and general corrosion, defined as corrosion with a length and width greater than three times the uncorroded wall thickness.

The Pipeline Operators Forum (POF) has developed a set of specifications and requirements for the inspection of pipelines by intelligent pigs, including definitions of types of metal loss features (pinhole, pitting, slotting, grooving and general) ‘Blunt’ has been defined in the literature as defects whose minimum radius equals or exceeds half of the pipe wall thickness and defects with a width greater than their local depth [Footnote]. Place the actual footnote at the bottom of the column in which it is cited; do not put footnotes in the reference list (endnotes).

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7. THE ROLE OF GEOMETRY AND FLOW STRESS

7.1 Ductile Failure

Two possible scenarios for the ductile failure of a blunt part-wall defect in a tough line pipe steel (i.e. excluding the possibility of cleavage fracture) have been identified, as described by Leis and Stephens (1997) and Fearnehough et al.,

1. As the load (pressure) increases, local wall thinning will occur in the remaining net section. This local wall thinning could continue, leading to necking of the wall and failure due to void nucleation, growth and coalescence in a manner comparable to that of a tensile test specimen.

2. Alternatively, a crack could initiate at the base of the defect due to the presence of microstress raisers (e.g. local surface irregularities caused by a corrosion mechanism) through a process of void nucleation and growth. The behaviour after the initiation of a crack would depend on the toughness of the material. In a high toughness material, initiation would be delayed to a higher load and further stable ductile tearing would be slower, or a growing crack could blunt; wall thinning would continue and the failure load would tend to that of plastic collapse. However, in a lower toughness material, once initiated, the crack would extend by stable ductile tearing, reducing the remaining wall thickness and hence reducing (1), we calculated the potential.” the degree of wall thinning that occurs before failure. The load at failure would be less than that predicted by the plastic collapse limit state because of the stable ductile tearing.

7.2 The Role of Geometry

The failure of a part-wall defect in a pipeline subject to internal pressure has two limits:

1. a defect with a length and depth tending towards zero (i.e. defect-free pipe), and
2. an infinitely long defect of finite depth (see Figure 5).

It is assumed that the line pipe material is tough and that failure occurs due to plastic collapse (i.e. unstable plastic flow). In the first case, the failure stress tends towards the failure stress of defect-free pipe, based on the full wall thickness (t), and in the second case it tends towards the failure stress of defect-free pipe, but based on the reduced wall thickness (t-d). The failure stress of a part-wall flaw of finite length lies between the above two extremes; it is a function of (1) the geometry of the pipe and the geometry of the defect, and (2) the material.

7.3 The Role of Flow Stress

The failure stress of defect free pipe tends towards the ultimate tensile strength of the material, as measured in a uniaxial tensile test, although account must be taken of large scale geometry effects (a cylinder under internal pressure exhibits geometric softening: as the pressure increases, the diameter increases; the hoop stress increases because of both the increase in pressure and the increase in diameter). Theoretically, the failure stress depends upon the strain hardening characteristics of the material and the assumed yield criterion (Tresca or von Mises) experimental results indicate that the failure stress lies between the Tresca and von Mises bounds, and is reasonably approximated by the ultimate tensile strength. The failure stress of defect free
pipe can be interpreted as a flow stress, although the term from the term flow stress as used in fracture mechanics6. The flow or reference stress describes the role of the material.

7.4 The Failure of a Blunt, Part-Wall Defect

Therefore, the failure stress of a blunt, part-wall defect subject to internal pressure can be predicted by a failure criteria that comprises a flow stress term and a geometry term. The geometry term includes the effects of bulging, the global stiffness, the stiffness of the defect, defect acuity, etc., The flow, or reference, stress represents the material behaviour. Note that the complete separation of material and geometry terms is an approximation, introducing some scatter into predictions of test data or numerical data.

8. THE EFFECT OF TOUGHNESS

The effect of toughness on the failure stress of blunt, part-wall defects can be observed through comparisons with the published burst tests of real and artificial corrosion. The influence of toughness is clear in tests of part-wall V-shaped notch tests, as conducted by Battelle during the development of the NG-18 as the toughness decreases, a flow stress dependent failure criterion becomes inappropriate (the predictions become increasingly non-conservatively). The influence of toughness on the failure of corrosion defects is less clear because: (1) corrosion defects are blunt, and (2) the irregular profile of a real corrosion defect introduces experimental scatter.

9. COMPARISON OF METHODS FOR ASSESSING CORROSION DEFECTS

9.1 Problems with Scatter in the Data

Large scatter is apparent in the predictions of the burst strength of real corrosion when using a method based on a simple geometric idealisation (rectangular, parabolic, etc.), because maximum depth and maximum length are insufficient to describe the irregular shape of a real corrosion defect

9.2 Problems with Comparing the Methods

There is insufficient data in the published literature to do a thorough comparison of the methods for assessing corrosion. If there were enough detailed data, then the first step in a comparison would be burst tests of artificial, flat-bottomed corrosion defects, to avoid scatter associated with approximations to an irregular profile. The approach would be to (1) consider those tests which are known to have failed by plastic collapse (i.e. the flow stress or reference stress (defect-free failure stress) is equal to the ultimate tensile strength) and define an appropriate failure criterion. 2) identify those tests which do not follow the predictions of the criterion, and then (3) determine what is different about these outliers and thence define the limitations of the failure criterion. Only then would the methods be compared against burst tests of real corrosion defects.

Fig. 2 Key Element of Pipeline Integrity Management
10. RECOMMENDATIONS IN PDAM

The recommendations in PDAM for assessing the burst strength of a corrosion defect (considering depth and longitudinal length) are:

1. DNV-RP-F101 for moderate to high toughness line pipe, and
2. modified B31G and RSTRENG in older, lower grade line pipe, and when there is no confidence that the requirements for the application of the more recent methods are satisfied.

Moderate to high toughness line pipe is defined as:

i. modern (clean) line pipe with a 2/3 thickness specimen size upper shelf Charpy V-notch impact energy equal to at least 18 J (the full size equivalent is 27 J)
ii. meeting the minimum elongation requirements in API 5L [58], and
iii. excluding line pipe steels suspected of containing a significant number of inclusions, second phase particles or other contaminants; typically, this means lower grade line pipe (such as grades A and B) and other older line pipe.

Note that none of the methods have been proven in line pipe with a wall thickness greater than 25.4 mm

11. ASSESSING A CORRODED AREA

11.1 The Assessment Method

The best methods for assessing a corrosion defect (considering depth and longitudinal length) in a pipeline subject to internal pressure have been identified.

11.2 The Assessment Procedure

The flowchart provides a general overview of the issues that need to be considered when assessing an area of corrosion in a pipeline, and identifies the appropriate method to be used. The flowchart does not give practical guidance of how to conduct the assessment.

Screening

1. Identify the critical defects (i.e. depth greater than 80 percent of the wall thickness, failure pressure less than the maximum operating pressure). This assessment assumes that all defects are single defects, it does not take account of defect interaction. This is non-conservative; therefore the assessment cannot stop at this stage.

Interaction

2. Determine whether the defect(s) can be considered as a single feature or as part of a group of interacting features. A number of different interaction rules have been described in the literature. One commonly used rule is that adjacent defects are considered to interact if the spacing (in the longitudinal or circumferential direction) between the defects is less than the respective dimension (i.e. length or width) The depth of the composite defect is defined by the maximum depth and the length and width by the dimensions of an enveloping rectangle
It is always conservative to assume that all of a cluster of adjacent defects interact. The dimensions of the composite defect are defined as above.

Assessment

3. Assess the single defect(s).
4. Assess the interacting defect(s), using the dimensions of the composite defect(s).

Review

5. Consider more accurate assessment methods (less conservative) interaction rules, a river-bottom profile, etc.) for those defect(s) which are not acceptable. Alternatively, repair the defect or downrate the pipeline.
REFERENCES