The Significance Study of Mechanical Damage in Gas Transmission Pipelines

Avanish Kumar Mishra¹, Dr. Om Prakash Netula², Swati Shankar³

¹Associate Professor, Civil Engineering Department, Suresh Gyan Vihar University, Jaipur, INDIA
²Head of Department, Civil Engineering Department, Suresh Gyan Vihar University, Jaipur, INDIA
³M.Tech, Scholar, Suresh Gyan Vihar University, Jaipur, INDIA

ABSTRACT

Oil and gas transmission pipelines have a good safety record. This is due to a combination of good design, materials and operating practices. However, like any engineering structure, pipelines do occasionally fail. The major causes of pipeline failures around the world are external interference and corrosion; therefore, 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. These workmanship limits are somewhat arbitrary, but they have been proven over time. However, a pipeline will invariably contain larger defects at some stage 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 a large number of full scale tests of defects in pipelines, and 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 draws together all of the assessment techniques, or assesses each method against the published test data, or recommends best practice in their application.

Keywords--- Nonlinear, Seismic, Offshore, Piles, BNWF

I. INTRODUCTION

The most common causes of damage and failures in onshore and offshore, oil and gas transmission pipelines in Western Europe and North America are external interference (mechanical damage) and corrosion. Accordingly, the behaviour of defects in pipelines has been the subject of considerable study over the past 40 years, with a large number of full scale tests, analyses and other work having been undertaken. Many different fitness-for-purpose methods have been developed. Fitness-for-Purpose

Fitness-for-purpose, as discussed here, means that a particular structure is considered to be adequate for its purpose, provided the conditions to reach failure are not reached[1]. Note that fitness-for-purpose may also have a legal and contractual meaning in different countries. Fitness-for-purpose is based on a detailed technical assessment of the significance of the defect. Local and national legislation and regulations may not permit certain types of defects to be assessed by fitness-for-purpose methods or may mandate specific limits. Such issues should always be considered prior to an assessment. Safety must always be the prime consideration in any fitness-for-purpose assessment. It is always necessary to appreciate the consequences of a failure. These will influence the necessary safety margin to be applied to the calculations.

Pipeline Integrity Management

Pipeline failures are usually related to a breakdown in a ‘system’, e.g. the corrosion protection ‘system’ has become faulty, and a combination of ageing coating, aggressive environment, and rapid corrosion growth may lead to a corrosion failure. This type of failure is not simply a ‘corrosion’ failure, but a ‘corrosion control system’ failure. Similar observations can be drawn for failures due to external interference, stress corrosion cracking, etc.. These considerations lead to the conclusion that a ‘holistic’ approach to pipeline defect assessment and integrity is necessary; understanding the equation that quantifies the failure load is only one aspect. Pipeline integrity management is the general term given to all efforts (design, construction, operation, maintenance, etc.) directed towards ensuring continuing pipeline integrity. The American Petroleum Institute (API) has developed an
industry consensus standard that gives guidance on developing integrity management programmes (API 1160)[2]. The American Society of Mechanical Engineers (ASME) is also developing an integrity management appendix for ASME B31.8[3].

The Pipeline Defect Assessment Manual

The Pipeline Defect Assessment Manual (PDAM) presents a considered view of the ‘best’ currently available methods for assessing the fitness-for-purpose of defects in pipelines. It is based on a critical review of the published fitness-for-purpose methods and test data. PDAM intended to be a document that will assist in maintaining pipeline integrity. The PDAM project is due for completion in August 2002. PDAM will be made available to the pipeline industry. This paper summarises the methodology and gives an outline of the contents of PDAM. The best methods for assessing a variety of different types of defect are summarised (see Table 3). Empirical toughness limits derived from published test data are given and the assessment of external interference (dents and gouges) is described in more detail. The PDAM recommendations for the assessment of other types of defect will be described in future papers.

II. FITNESS FOR PURPOSE, ENGINEERING CRITICAL ASSESSMENTS (ECAs) AND PIPELINES

The fitness-for-purpose of a defect in a pipeline may be determined by a variety of methods ranging from previous relevant experience (including workmanship acceptance levels), to model testing, to ‘engineering critical assessments’ (ECAs), where a defect is appraised analytically.

2.1 GENERIC

Various technical procedures are available for assessing the significance of defects in a range of structures. These methods use a combination of fracture mechanics and limit state (plastic collapse) methods. Both BS 7910 : 1999[1] and API RP 579[4] contain detailed engineering critical assessment methods which can be applied to defects in pipelines (although the latter document is biased towards defects in process plant).

2.2 PIPELINE-SPECIFIC

Documents such as the above are generic; they can be conservative when applied to specific structures such as pipelines. Therefore, the pipeline industry has developed its own fitness-for-purpose methods over the past 40 years (and, indeed, documents such as BS 7910 recommend that such methods be used). These pipeline specific methods are usually based on experiments, sometimes with limited theoretical validation; they are semi-empirical methods. Consequently, the methods may become invalid if they are applied outside their empirical limits. Accordingly, PDAM has considered the limits of the experimental validation of commonly used pipeline specific methods.

Methods and guidelines developed by the pipeline industry range from the NG-18 equations[5] (which formed the basis of methods such as ASME B31G[6] and RSTRENG[7]) and the Ductile Flaw Growth Model (DFGM) (implemented as PAFFC (Pipe Axial Flaw Failure Criteria))[8,9] developed by the Battelle Memorial Institute in the USA on behalf of the Pipeline Research Council International (PRCI), to the guidelines for the assessment of girth weld defects[10], mechanical damage[11] and ductile fracture propagation[12] produced by the European Pipeline Research Group (EPRG).

The conservatism of generic methods compared to pipeline specific methods can largely be attributed to issues of constraint and ductile tearing. Constraint is the restriction of plastic flow in the vicinity of the crack tip due to stress triaxiality. Stress triaxiality is induced by load and geometry. The standard test methods used to measure fracture toughness are designed to give conditions of high constraint at the crack tip to ensure conservative results. Pipelines have low constraint because they are thin walled (geometry) and are predominantly subject to membrane tensile loading (loading mode). Conventional (single parameter) fracture mechanics does not consider the elevation in fracture toughness due to a reduction in the level of constraint, and hence an inherent margin of safety is included when applied to low constraint structures. The semi-empirical pipeline specific methods consider constraint implicitly because they have been developed from full scale tests in which these effects manifest themselves directly. Similarly, the increase in toughness with ductile crack growth (a rising resistance curve) is also considered implicitly. The difference between pipeline specific and generic methods diminishes when sophisticated fracture mechanics (two-parameter fracture mechanics, tearing analysis, etc.) and limit state methods are applied.

III. PIPE-SOIL INTERACTION CHARACTERISTICS

Once in contact, the interaction between the pipeline and the soil can be described in terms of 3 degrees-of-freedom; penetration into the seabed (normal to the seabed), axial movements along the axis of the pipeline and lateral movement perpendicular to the pipeline. For each degree-of-freedom a model needs to capture certain characteristics.

Lateral resistance of partially embedded pipelines

The main purpose for developing the present model for pipe-soil interaction is to be able to account for the lateral resistance of unburied or partially embedded pipelines in case there is risk of e.g. lateral buckling. As emphasized e.g. by the SAFEBUCK project, Bruton et al. (2006), the lateral resistance is highly dependent on the
magnitude of the lateral movement as well as by the load history. Considering Fig. 1 the resistance can be divided into various phenomena:
(1) At monotonic loading the lateral resistance curve exhibits at first a rather stiff, almost linear elastic response until it reaches the peak resistance. As the lateral movement increases further, the resistance level will gradually decrease to a residual resistance level. This might cause instability leading to e.g. lateral buckling of a pipeline.

(2) If the pipeline is unloaded the response is almost linear elastic until the lateral resistance is reached in the opposite direction.
(3) During cyclic loading it is observed that the overall behavior resembles that of the monotonic condition. There exists a peak, which is traditionally attributed to suction. Once this suction is released the lateral resistance reduces to a residual resistance.

(4) During sliding, it is also experimentally observed that there is a slight increase in resistance, which is assumed to be due to the gradual built up of an active berm in front of the pipeline.
(5) At reversed loading this berm remains in the extreme position, hence will act as a so-called dormant berm which may be reactivated in case the loading direction changes again. While the dormant berm certainly gives a significant resistance reserve, it is apparently only activated at very large movements, say 10D, hence it may not be important for practical design.

All these characteristics can be captured by an elasto-plastic model that is able to include a combination of isotropic and kinematic softening and hardening effects. The present model accounts for the first four items listed above, but can be expanded to include reactions from the dormant berm if required.

IV. DEVELOPMENT AND APPLICATION OF MODELS FOR THE STABILITY ANALYSIS OF AUSTRALIA’S OFFSHORE PIPELINES

There are many other geotechnical problems related to the design of offshore pipelines. These include, amongst others, soil characterisation, self-burial, trenching, pipe-laying, ploughing, pipeline buckling and walking, and the impact of geohazards such as submarine landslides. These are not covered in this paper. For a thorough introduction to these issues reference can be made to relevant chapters in the offshore geotechnical engineering books of Dean (2010) and Randolph and Gourvenec (2010), as well as to state-of-the-art review papers of Cathie et al. (2005), White and Cathie (2010) and Randolph et al. (2011).
V. 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 all of the 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 published test data, based on the prediction interval of the classical linear regression model.

PDAM provides the written text, the methods, recipes for application, acceptance charts and simple examples, and is supported by literature reviews. Simple electronic workbooks have been developed to permit easy implementation of the ‘best’ methods. The role of PDAM in the fitness-for-purpose assessment of a defect in a pipeline is summarised in Fig. 9. PDAM has been closely scrutinised throughout its development by the sponsors, and all literature reviews and chapters of the manual have been independently reviewed by international experts in the field of pipeline defect assessment.

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

VI. 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
- environmental cracking

In addition, guidance is given on the treatment of the interaction between defects, and the assessment of defects in pipe fittings (pipe work, fittings, elbows, etc.). Guidance is also given on predicting the behaviour of defects upon penetrating the pipe wall (i.e. leak or rupture, and fracture propagation). The following types of loading have been considered in the development of the guidance: internal pressure, external pressure, axial force and bending moment.

Methods are given in PDAM for assessing the burst strength of a defect subject to static loading and for assessing the fatigue strength of a defect subject to cyclic loading. There are some combinations of defect type, orientation and loading for which there are no clearly defined assessment methods. In summary, the assessment of defects subject to static or cyclic internal pressure loading is well understood, but, in general, other loads and combined loading are not.

Hodder and Cassidy (2010) use a hyperbolic factor $\phi$ to provide a transition between the value of $h_0$ at zero embedment ($h_0, \text{surface}$) and that for a deeply embedment ($h_0, \text{deep}$).
embedded pipe (h0,deep), which was defined to be constant at embedments greater than 3.5 diameters.

Loads can be redistributed along the pipe to sections of higher constraint. Often a segment of pipe starts to slide (with loading conditions on the parallel point of the plasticity model). In a two-dimensional analysis of a pipe segment, no more load could be added to this pipe. However, in a three-dimensional model any additional loads can be redistributed to the neighbouring sections of pipe where the pipe-soil model may still predict restraint.

Embedment of the pipe model due to the laying process and also through additional penetration due to the cyclic horizontal loads provides for additional restraint within the pipe-soil models (though not shown here this effect is enhanced by use of the cyclically embedding “bubble” model of Zhang et al., 2002b and Tian and Cassidy 2011b).

By calculating the pipe movement and embedment at each segment of pipe, appropriate hydrodynamic reductions can be applied. This reduced the maximum lateral displacement from 6.89 to 3.81 m in this example.

VII. CONCLUSIONS

A robust and versatile spring element for pipe-soil interaction analysis has been presented. The model is formulated in a three dimensional elasto-plastic framework allowing for coupling of penetration and combined axial and lateral movement. A robust numerical implementation is developed in order to facilitate the integration of the spring element into a finite element code for pipeline analysis. The capability of the model is tested by several examples demonstrating that the model is able to capture essential features of partially embedded pipelines, such as transition from peak to residual resistance under monotonic loading and cyclic performance accounting for both suction release and active berm development. The elasto-plastic framework with a multiplicative hardening/degradation formulation allows for easy extension of the model. Furthermore, embedment of a contact algorithm into the penetration part and a possible coupling between mobilized sliding and penetration resistance adds to the capabilities of the model without any significant computational costs.

REFERENCES


