University of Strathclyde
Department of Naval Architecture, Ocean and Marine Engineering and Advanced Forming Research Centre

Research Proposal: Assessment of Strain Effects in Pipeline Dents

Requirement for the Research

Dent damage in pipelines may result from impact damage caused by third parties or by rock damage during pipeline construction. Third party damage is recognised worldwide as contributing to the highest number of pipeline failures. Code guidance exists for the assessment of dents under both static and dynamic loading and, in most cases, these methods are extremely conservative, resulting in excavation and repair of benign dents. However, in recent years there have been a number of in-service failures at dents that were within code limits, that were reported through standard ILI technologies, but were not considered to be significant. Such occurences have raised technical concerns from regulators regarding the perceived conservatism of current dent assessment methods. Operators are also concerned regarding the best practice for the safe and economic operation of dented pipelines[1,2]

Historically, the defect assessment methods, industry codes and guidance for dent assessment have relied on a measurement of dent depth to determine acceptability. Subsequently it was considered that the level of strain induced in the pipe as a result of the dent would give a better indication of dent acceptability rather than the depth. A methodology for determining total dent strain from geometrical dent measurements was encoded into ASME B31.8 in 2004 and a total strain limit was set at 6% for plain dents in the body of the pipe and 4% for plain dents on ductile welds. Since the implementation of the strain criteria into defect assessment codes, the pipeline industry has developed procedures for calculating the strain in the dent using measurements of the dent profile, either taken by high resolution In-Line Inspection (ILI) calliper tools or in-field measurements. ***The challenge is to translate these geometrical measurements into a representative value of the total strain in the dent.*** The current method presented in ASME B31.8 is open to interpretation and it is considered that further research is required to understand whether the current strain limit of 6% is realistic or could be increased or decreased.

This proposal aims to address these research gaps and to i) provide a validated, pragmatic and useable model for determining the strain in pipeline dents from geometric measurements and ii) challenge the 6% strain limit through a series of full scale tests and finite element modelling on manufactured pipeline dents.

Limitations of the Current Approaches

When a pipeline is dented, strain is induced into the pipe material in both the circumferential and longitudinal directions. Within each of these directions, the total strain can be separated into membrane and bending components. In the methodology in ASME B31.8, the bending strain in the longitudinal and circumferential directions is calculated from the dent shape and specifically the radius of curvature described by the dent in both directions. The longitudinal membrane strain is calculated using an empirical approximation based on the dent depth and deformed length and the circumferential membrane strain is assumed to be negligible. Consequently, the use of the ASME B31.8 methodology to determine the strain in the dent reduces to a problem of calculating the radius of curvature of the dent in both the longitudinal and circumferential directions. The ASME code does not provide any guidance on how to calculate the radius of curvature and no standard method has been adopted by the industry[3-6]. Indeed, in some dent management programmes only the longitudinal bending strain is used to compare to the dent strain criterion, as this is the easiest to measure both in the field and using ILI data, an approach that is considered to be under conservative[7]. ***This could mean that critical dents remain in the pipeline following an integrity assessment.*** As a result, there is concern in the literature that the methodology for determining dent strain is not yet robust enough to accurately predict dent strains based in dent profile[1,3,6].

Key requirement 1: What is required is a methodology for calculating total dent strain that: i) is easy to use with measurements that can be readily made in the field or obtained from ILI data; ii) does not require intensive and expensive FEA to be conducted on every dent and iii) recognises the key parameters that contribute to strain concentration in the dent. These essential requirements will be addressed by the model proposed in this research.

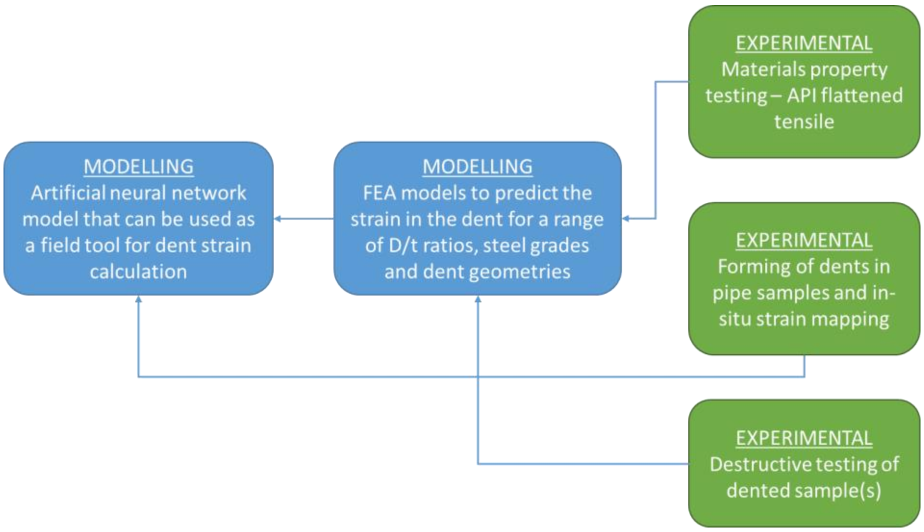
Once the strains are calculated they need to be compared to a strain criterion. The derivation of the 6% strain limit in ASME B31.8 is based on the hypothesis that the strain limit should lie between the cold strain limit of 3% for pipeline field bends and the observation that the likelihood of puncture of dents increases where the material strain exceeds 12% (56). Consequently a limit of 6% was adopted in the standard. However, there has been no validation of this limit in the published literature and therefore it is not fully understood whether this limit is realistic or under or over conservative. One of the issues is that it is difficult to measure the strain in a dent non-destructively and then to perform a burst test on the same dent.

Key requirement 2: What is required is an experimental technique that can measure the strain in the dent prior to performing a burst test on the same dent to determine a critical strain limit that could result in failure at pipeline operating pressures.

This proposal aims to address these two key requirements through a combined programme of modelling and experimental testing.

Research Proposed

The proposed methodology for this PhD programme is detailed in the flow diagram below:



The core of the programme is the development of a Finite Element (FE) model to simulate the formation of dents of varying geometric shapes in pipelines of different dimensions and material properties. The output from the FE model will be a dataset of total dent strain values for a range of dent and pipe geometries. This dataset will be used to develop an Artificial Neural Network (ANN) model that can be used to determine dent strain using either field measurements or ILI data. ANNs are a form of statistical learning methodology that perform multifactorial analysis on a series of inputs to predict an output. They find particular application in the analysis of problems that have a large number of inputs with a complex relationship to each other and the output. As with other artificial learning methodologies, ANNs 'learn' to weight the connections between inputs and output by being presented with a training dataset. Once the ANN has been trained and tested, it can be used to predict an output given input data within the range of the training data set. The ANN that will be developed in this research will take input data that can be readily measured in the field or from ILI data *e.g.* dent depth, length and width, and known pipeline parameters *e.g.* diameter, wall thickness, pipe grade, and will determine the strain in the dent. The training dataset for the ANN will come from the output of the FE model. Thus the ANN becomes a tool that can be used in the field to calculate dent strain without the requirement for FE on every dent or to make assumptions in relation to membrane and bending strains.

The second component of the research programme is a series of experimental tests to provide input data for and validation of the FEA model. One of the essential inputs for the FEA models is material data, therefore the first phase in the experimental programme will generate materials property data for the pipe material to be used in the experimental programme. In order to validate the output of the FEA model, it is proposed to manufacture dents in pipeline spools using controlled cold forging techniques that will produce dents under known loading conditions with known indented shapes that can be simulated with FEA.

The strain in the produced dent will be measured using destructive and non-destructive procedures that can be used to validate the FEA models and develop prediction models. Proposed techniques for assessing the level of strain present within each test piece/dent generated are:

- Electronic speckle pattern interferometry (ESPI),
- Residual Stress MTS 3000 hole drilling system and
- X-Ray Diffraction (XRD), adopting in-situ 2D Displacement and strain mapping using digital image correlation.

For selected dent(s), for which the strain has been measured non-destructively, full-scale burst tests will be conducted to determine the failure pressure and failure mode of the dented pipe in order to assess the applicability of the 6% strain limit.

Deliverables

The primary deliverables from this research will be:

- A robust, easy-to-use and experimentally verified dent strain model that can be used by pipeline operators assessing the fitness for purpose of dented pipelines from ILI or field data.
- Guidance on the use of 6% strain limit for the assessment of plain dents in pipelines.
- An experimental methodology and procedure for determining strain in dents non-destructively.
- Publications in international journals and conferences to provide extensive peer-review of the approaches.

Impact and Benefit of the Research

In reality, a large number of pipelines contain a large number of dents, the majority of which do not impair integrity or affect operation. The industrial benefit of this research lies in the application of a validated dent strain assessment procedure that will give pipeline operators confidence that their dent maintenance strategies are ***identifying safety critical dents whilst avoiding high cost excavation, inspection and repair of insignificant dents.***

Contact

If you are interested in this proposal and would like to discuss potential participation in this work then please contact:

Dr Julia Race
Senior Lecturer Pipeline and Subsea Engineering | Director of Postgraduate Taught Studies

UK Entrepreneurial University of the Year 2013/14
UK University of the Year 2012/13

Department of Naval Architecture, Ocean and Marine Engineering | University of Strathclyde
HD3.19, Henry Dyer Building, 100 Montrose Street, Glasgow G4 0LZ, United Kingdom
t: +44 (0)141 548 5709 | e: julia.race@strath.ac.uk | w: www.strath.ac.uk/naome

References

[1] J. M. Race, J. V. Haswell, R. Owen, and B. Dalus, "UKOPA dent assessment algorithms: A strategy for prioritising pipeline dents," in *2010 8th International Pipeline Conference, IPC2010*, Calgary, AB, 2010, pp. 923-933.

[2] J. M. Race, "Integrity assessment of plain dents subject to fatigue loading," UKOPA UKOPA-08-0087, 2008.

[3] S. A. Lukasiewicz, J. A. Czyz, S. Chao, and S. Adeeb, "Calculation of strains in dents based on high resolution in-line caliper survey," in *2006 6th International Pipeline Conference, IPC 2006*, Calgary, AB, 2007, pp. 129-134.

[4] S. J. Dawson, A. Patterson, and A. Russell, "Emerging techniques for enhanced assessment and analysis of dents," in *2006 6th International Pipeline Conference, IPC 2006*, Calgary, AB, 2007, pp. 397-415.

[5] M. J. Rosenfeld, P. C. Porter, and J. A. Cox, "Strain estimation using Vetco deformation tool data," in *Proceedings of the 1998 International Pipeline Conference, IPC. Part 1 (of 2)*, Fairfield, NJ, United States Calgary, Can, 1998, pp. 389-397.

[6] D. B. Noronha, R. R. Martins, B. P. Jacob, and E. Souza, "The use of B-splines in the assessment of strain levels associated with plain dents," presented at the Rio Pipeline Conference and Exposition, Rio de Janeiro, Brazil, 2005.

[7] M. Baker, "Dent Study," November 2004 2004. TTO Number 10: Integrity Management Program: Delivery Order DTRS56-02-D-70036,DOT Research and Special Programs Administration, Office of Pipeline Safety