STRAIN ANALYSIS OF DENTED PIPELINES BASED ON DENT PROFILE

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ABSTRACT

Dents are plastic deformations on a pipeline’s cross-section caused by contact with external forces. They are known to have the potential to adversely affect the structural integrity of the pipeline as they induce localized strains and stresses on the pipeline. In this study, the finite element analysis of a dented plate and an analytical approach to the determination of strains based on a dent profile are compared in a bid to develop a procedure for evaluating the strains on a dented pipeline based solely on the dent profile.

Keywords: Strains, Dents, Pipelines

1. INTRODUCTION

Oil and gas pipelines are often subjected to external mechanical forces which can result in the distortion of their geometric cross section. Most international pipeline codes including CSA Z662-15 code consider plain dents injurious if they exceed a depth of 6% of the nominal pipe diameter. This criterion however does not consider the effects of other parameters such as the localised strains which may also govern the failure of the pipeline. A major drawback in the use of localised strains as criterion for the assessment of dent severity is the lack of efficient and accurate measures of determining the strains (Stanislaw et al. 2006). Currently, finite element analysis is used for the strain analysis of pipelines as the evaluation of such strains requires the solution of a series of nonlinear differential equations. However, finite element analysis is also complex and computationally demanding especially for three dimensional models involving a large number of unknowns.

In this paper, we present an analytical approach by which the strains in the pipeline can be evaluated based on the dent profile. Our analytical technique assumes "large displacement" and allows for evaluating the bending and membrane strains in the pipeline without resorting to the finite element analysis. Appendix R of the ASME B31.8 code provides non mandatory equations for strain evaluation in pipelines from the radii of curvature of the dent; however, the equations are based on the Euler Bernoulli hypothesis of small deformations. The mathematical expression of the small strain tensor used to generate the equations is shown in Equation 1

\[
\varepsilon_{\text{Small}} = \frac{1}{2} (F + F^T) - I;
\]
Where, F is the deformation gradient, \( F^T \) the transpose of the deformation gradient and I, the identity matrix. This strain measure is limited to small rotation as such it pollutes the results when used to evaluate the strains associated with large nonlinear rotations. The proposed strain measure in this study is the green strain tensor which is also derived from the relationship between the deformation gradient and the identity matrix and expressed mathematically as shown in equation 2.

\[
\varepsilon_{\text{Green}} = \frac{1}{2} (F^T F - I)
\]

The green strain measure takes into consideration the nonlinear nature of the elasto-plastic deformation as it computes strains that are independent of rotation thus allowing for large displacements and rotations.

2. METHODOLOGY

The strain analysis of a dented pipeline cross section was performed on the mid–plane of a two dimensional plate element, the justification being the Kirchhoff Love plate theory from which it follows that the displacement of the plate can be determined from the mid surface displacement vector (Yoshibash and Kirby, 2005). The indenting process was simulated with the FEA software (ABAQUS 6.14). The plate model was 1000mm in length and 30mm thick. The boundary conditions imposed on the model restricted translation and rotation at both ends of the plate. Quadrilateral solid elements were used to mesh the plate and a frictionless contact was modelled as the surface interaction between the plate and the indenter through the master-slave algorithm. The indenter used was a rigid body 600mm in length which plastically deformed the plate to a depth of 100mm.

Third order B splines were used to describe the position vector of any point on the interpolated geometry of the dent with a function. The strain tensors used for this study were developed on the assumption that plane sections remained plane and perpendicular to the neutral axis throughout the deformation process.

3. RESULTS

The small and the green strain tensors predicted longitudinal strains which were functions of the coordinates of the dent. The green strain contours shown in figure 1 had a good correlation with the logarithmic strains from the finite element analysis, as both strain measures predicted higher tensile than compressive strains in the plate. The small strain tensor predicted pure bending as shown by the contours in figure 2. This is an oversimplification of analysis and would likely lead to impractical results. The green strain measure thus presents a more realistic deformation mode and can be computed in a three dimensional pipeline model thus providing a more analytical criterion for dent analysis.

4. RECOMMENDATIONS

The study carried out so far is limited to the evaluation of longitudinal strains hence further work should be done on implementing the green strain measure in computing the strains in a three dimensional pipeline model.
5. REFERENCES

ASME B31.8 2012-Gas and Transmission Distribution Piping Systems.

CSA Z662-15- Oil and Gas Pipeline Systems.
