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Prediction of Fracture in Wrinkled Energy Pipelines Subjected to Cyclic Deformations

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An experimental study based on limited full-scale tests on a 305-mm-diameter wrinkled gas/oil pipeline indicates that the integrity of this pipeline is severely threatened and fracture may occur quickly if it is subjected to cyclic load-deformations. However, this kind of test is extremely time-consuming and expensive, so that an experimental study is not a realistic solution for understanding the behavior and assessing the risk associated with every scenario of wrinkled pipelines in the field. This work was then undertaken to develop an accurate numerical model for better understanding the post-wrinkling behavior and predicting the remaining fracture life of field wrinkled steel pipelines subjected to cyclic deformations.

INTRODUCTION

The oil and gas industry in North America uses steel pipelines as the primary mode for transporting natural gas, crude oil and various petroleum products. In Canada alone, about 700,000 km of energy pipelines are in operation (Yukon Government, 2006). Many additional pipeline projects are underway, especially in West Canada and Alaska, such as the Mackenzie Gas Project and the Alaska Highway Pipeline.

Field observations of buried energy pipelines indicate that the subsurface geotechnical movements with or without thermal loads can introduce large forces and displacements on these pipelines, resulting in localized curvature, strains and associated deformations in the pipe wall (Yoosef-Ghodsi et al., 1995; Jayadevan et al., 2004). Often the local deformations of the pipe wall result in local buckling of the pipe wall (called wrinkling) and, in its post-buckling range of response, local buckles (wrinkles) in the pipe wall grow under sustained deformations. The wrinkling usually occurs under the combinations of internal pressure, axial load, and with or without bending moment (Yoosef-Ghodsi et al., 1995; Dorey et al., 1999; Bai et al., 2000). The shape of the wrinkle is nearly axisymmetric (referred to as axisymmetric wrinkle) if the wrinkle forms under internal pressure and axisymmetric axial load or deformation only as shown in Fig. 1a. However, the shape of the wrinkle becomes non-axisymmetric (referred to as non-axisymmetric wrinkle) if it forms due to application of internal pressure, axial load, and bending moment or deformation as shown in Fig. 1b (Zhou and Murray, 1993; Yoosef-Ghodsi et al., 1995; Dorey et al., 2006).

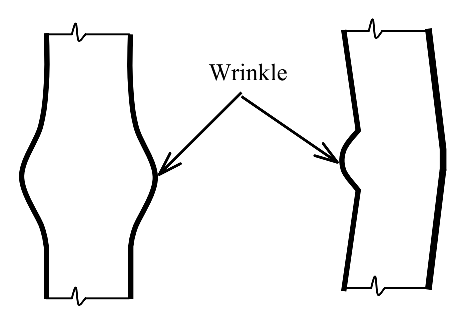
A wrinkled pipeline may then be subjected to various load/deformation combinations and load/deformation hysteresis such as:

- monotonically increasing axisymmetric or non-axisymmetric deformations
- monotonically increasing shear deformations
- cyclic axisymmetric or non-axisymmetric deformations.

A buried pipeline may experience cyclic deformation hysteresis due to temperature variation, cyclic freeze-thaw of ground, fluctuations of operating pressure, seismic loads, etc. (Bai et al., 2000; Palmer and William, 2005; Oswell et al., 2005).

An extensive and long-term research program at the University of Alberta was launched in 1999 to study the complete post-wrinkling behavior of buried pipelines under various field load and deformation conditions. As part of this program, an earlier study on a plain pipe specimen with diameter-to-thickness ratio (D/t) of 45 and material yield strength of 357 MPa shows that an accordion-type (formation of multiple wrinkles that looks like an accordion) deformation failure occurs, but that no fracture occurs in the buried pipeline if it experiences internal pressure and monotonically increasing axisymmetric deformations (Das et al., 2000). However, subsequent experimental study shows that this particular wrinkled pipeline will introduce fracture at the wrinkled location if it is subjected to cyclic deformations and internal pressure (Das et al., 2001).

Because experimental study of this nature is extremely expensive and time-consuming, it is not a realistic solution for understanding the post-wrinkling behavior and assessing the risk associated with every wrinkled pipeline in the field. This study was then undertaken to develop an easy and quick alternative, using the finite element (FE) modeling and analysis technique, which the pipeline industry can use to assess the risk associated with



(a) Axisymmetric wrinkle   (b) Non-axisymmetric wrinkle

Fig. 1 Typical bulge wrinkle shapes

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