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Numerical Study on Failure of X52 Wrinkled Pipelines Subjected to Bending Deformation

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ABSTRACT

Two full-scale tests on X52 grade NPS12 oil/gas pipeline show that this pipeline is able to maintain its integrity and does not rupture when subjected to monotonic bending deformation and moderate to high internal pressure. However, this kind of test is expensive and time consuming and thus, an alternative tool using finite element method was developed to study the behavior of wrinkled pipeline under similar load-deformation condition. This finite element model uses true non-linear material and non-linear geometry. A special contact and sliding algorithm was used to model the folding and sliding behavior of the inside surfaces of the wrinkle. The finite element model was validated with the data obtained from the full-scale tests. A good agreement was obtained between the post-wrinkling behaviors obtained from the test and from the numerical analysis. This paper discusses the numerical modeling technique that was used in this study and the results obtained from the study.

KEY WORDS: Wrinkled pipelines; monotonic bending deformation; test; finite element analysis; failure.

INTRODUCTION

North American oil and gas industry 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 oil/gas pipelines are in operation. Many additional pipelines projects especially in West Canada and Alaska of various scales such as Mackenzie Gas Project and Alaska Highway Pipeline are underway. The majority of these pipelines run below ground (Yukon Government, 2006).

Field observations of buried oil/gas pipelines indicate that the subsurface geotechnical movements with or without thermal loads can introduce large forces and displacements on buried pipelines resulting in localized curvature, strains, and associated deformations in the pipe wall (Yoosef-Ghodsi et al. 1995; and Jayadevan et al. 2004). Often the local deformations of the pipe wall results 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. 2000; and Bai et al. 2000).

Extensive research was carried out during the last decades to study the initiation and formation of wrinkles under various load and deformation conditions that buried pipelines experience in the field (Bouwkamp and Stephen 1973; Gresnigt 1986; Murray 1997; Dorey et al. 2005; and Dama et al. 2007). As a result, most of the current pipeline design standards and practices recommend various limit state design methods for oil/gas pipelines based on noticeable cross-sectional deformation and formation of local buckling (wrinkling) that corresponds to material strain in the range of 0.5% to 2.0% (ISO 2000; CSA 2003; BSI 2004; and DNV 2005).

Several experimental studies (Gresnigt 1986; Mohareb et al. 1993; Yoosef-Ghodsi et al. 1995; Dorey et al. 2005; Dama et al. 2007; and Das et al. 2007) were undertaken to understand the wrinkling and post-wrinkling behavior of the pipeline subjected monotonic bending deformation. These studies were limited to early-wrinkling stage because of limitations in the test set-up and safety concerns with the test setup and instruments used in the tests. Thus, the current study was undertaken to determine the complete post-wrinkling behavior of X52 grade line pipe of D/t equals to 45 using finite element (FE) method. The FE model was validated using available test data.

EXPERIMENTAL PROCEDURE AND TEST RESULTS

Two full-scale tests were undertaken to study the post-wrinkling behavior, fracture limit strains, and failure modes of wrinkled NPS12 (pipeline with 305 mm or 12 inch nominal diameter) line pipe subjected to monotonically increasing bending deformation, and constant axial load and internal pressure. The wall thickness of both the specimens was 6.84 mm (0.27 inch) and thus, the diameter-to-thickness ratio (D/t) was 45. Grade of steel was API X52 (API 2004) with specified minimum yield strength (SMYS) of 358 MPa (52 ksi). Both specimens were 1270 mm long. The specimen 1 had a girth (circumferential) weld at its mid length whereas the specimen 2 did not have any girth weld. The test procedure and test results obtained are discussed next.

Test Procedure

The schematic of test specimen and test setup is shown in Fig. 1. Two