International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 18, No. 1, March 2008, pp. 50–55

Failure of X52 Wrinkled Pipeline Subjected to Monotonic Bending Deformation and Internal Pressure

Yonghong Zhang and Sreekanta Das
Department of Civil and Environmental Engineering, University of Windsor
Windsor, Ontario, Canada

This study was undertaken to investigate and understand the complete post-wrinkling behavior and failure modes of pressured X52-grade wrinkled buried energy pipeline when subjected to monotonically increasing bending deformation. This study involved both experimental and numerical investigations. Detailed parametric study was undertaken using a numerical approach, and it was found that the X52-grade steel linepipe generally exhibits a ductile behavior. The parametric study shows that X52 linepipe with a diameter-to-thickness ratio of 35 or higher does not fail in rupture. However, these linepipes eventually fail in a deformation mode due to excessive cross-sectional deformation. It was also found that the rupture failure occurs only at the wrinkle face of the bent linepipe.

INTRODUCTION

The 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 energy pipelines are in operation. Many additional pipeline projects of various scales are under way, especially in West Canada and Alaska, such as the Mackenzie Gas Project and Alaska Highway Pipeline. Most of these pipelines run below ground (Yukon Government, 2006).

Field observations of buried energy 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; Jayadevan et al., 2004). Often the local deformations of the pipe wall result in its local buckling (the so-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; Bai et al., 2000).

Extensive research has been carried out during the last decades to study the initiation and formation of wrinkles under the various load and deformation conditions that buried pipelines experience in the field (Bouwkamp and Stephen, 1973; Gresnigt, 1986; Murray, 1997; Dorey et al., 2006). As a result, most of the current pipeline design standards and practices recommend various limit state design methods for energy pipelines based on noticeable cross-sectional deformation and formation of local buckling/wrinkling that corresponds to material strain of 0.5% to 2.0% (CSA, 2003; DNV, 2005; BSI, 2004). An experimental study by Dorey et al. (2000) shows that the energy pipeline exhibits significant ductility in its early post-wrinkling stage if the pipeline is subjected to internal pressure and monotonically increasing bending deformation. This study, however, was limited to smaller bending deformation since its objective was to determine critical wrinkling strains. It is however suspected that a wrinkled pipeline may lose its integrity due to formation of rupture either in the compression face (wrinkle face) or in the tension face (no-wrinkle face) if it is subjected to continuously increasing, monotonically bending deformations imposed by settlement of surrounding soil layers.

Thus, the current study was undertaken to understand the complete post-wrinkling behavior, failure conditions and failure modes of wrinkled X52-grade steel linepipe with realistic operating internal pressure when subjected to monotonically increasing bending deformation. A failure in this study refers to the rupture in the pipe wall and/or excessive cross-sectional deformation that jeopardizes the safe operation and/or maintenance of a field linepipe.

EXPERIMENTAL PROCEDURE

Two full-scale tests (Table 1) were undertaken to study the post-wrinkling behavior, fracture limit strains and failure modes of wrinkled NPS12 (pipeline with 305-mm or 12-in nominal diameter) linepipe subjected to monotonically increasing bending deformation and internal pressure. The wall thickness of both specimens was 6.84 mm (0.27 in), hence the diameter-to-thickness ratio (D/t) was 45. Steel grade was X52 with specified minimum yield strength (SMYS) of 358 MPa (52 ksi). The actual yield strength of pipe material was found to be 357 MPa. The linepipe had one longitudinal seam weld. This pipeline is used in the Norman Wells Pipeline operated by Enbridge Pipelines (NW) Inc. Table 1 shows the test setup, instrumentation and loading procedures used to obtain the information.

Test Setup

Fig. 1 gives the schematic of test specimen and test setup. The outside surface of the specimens was sandblasted to remove paint and other surface debris so as to facilitate the installation of gauges and instruments, and to provide a clean surface for

Test	Pressure (% of p_y)	Max. long strain (%)		Max. circum. strain (%)
Instrument type →		SG	Exten	SG
1	40	−9.8	−21.0	+8.60
2	80	−9.0	−14.0	+12.0

Table 1 Test parameters and strains

Received July 14, 2007; revised manuscript received by the editors October 23, 2007. The original version was submitted directly to the Journal.
KEY WORDS: Wrinkled linepipe, monotonic bending deformation, test, finite element analysis, failure.