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

Vol. 19, No. 3, September 2009, pp. 224–231

Finite Element Analysis for Telescopic Deformation and Tearing Rupture of Wrinkled Pipe

Navid Nazemi, Sreekanta Das and Sara Kenno
Department of Civil and Environmental Engineering, University of Windsor Windsor, Ontario, Canada

Buried pipeline may be subjected to various complex combinations of loads and deformations. This may result in localized curvature, strains and associated deformations in the pipe wall. As a result, wrinkle (local buckling in the pipe wall) may form. The wrinkled pipeline may then develop a fracture and even rupture in the pipe wall and lose its structural integrity if it is subjected to further sustained deformation and/or load. When an NPS10 field line pipe ruptured due to tearing in the pipe wall in the wrinkle region, it was felt that a wrinkle formed in the line pipe, and then or simultaneously the wrinkle region of the line pipe was subjected to transverse load, causing the tearing-type rupture at the foot of the wrinkle, although actual load-deformation history wan not known. Thus, a research program consisting of full-scale tests and parametric study using the finite element method was designed and undertaken to understand the load-deformation combination that may produce a deformed shape and a tearing rupture that looks similar to the one observed in the field NPS10 line pipe. This paper discusses results obtained from the tests and parametric study.

INTRODUCTION

Field observations of buried pipelines indicate it is not uncommon for geotechnical movements to impose large displacements on buried pipelines resulting in large localized deformations, strain and curvature in the pipe wall. Such displacements may be associated with river crossings, unstable slopes, fault movement, or regions of discontinuous permafrost. Often the deformation of the pipe wall results in local buckling and in its post-buckling range of response, wrinkles develop rapidly and can be of significant magnitude (for example, Gresnigt, 1986; Mohareb et al., 1993; Murray, 1997; Bai et al., 2000; Keng et al.,. 2007; Ahn et al., 2007; Dama et al., 2007). This can occur under loading conditions that may be idealized as combinations of variable internal pressure, compressive axial load, transverse load and moment.

This investigation into post-wrinkling behavior and failure mode in the wrinkle of line pipe under transverse loading was motivated by the diagnosis and exposure of a rupture that occurred at the wrinkle location of a field NPS10 (line pipe with a nominal diameter of 10 in or 254 mm) energy steel pipeline, as shown in Fig. 1. Das et al. (2000, 2007) in their other studies found that line pipes are highly ductile and do not normally fail in rupture if subjected to monotonically increasing axisymmetric compressive axial deformation and internal pressure. However, if the same line pipe is subjected to strain reversal because of variations in primary loads, rupture can occur in the wrinkled region.

From the field inspection and the description of the load history, it was understood that no strain reversals occurred in this NPS10 field line pipe (Fig. 1). From physical inspection of the ruptured line pipe, it was felt that the pipe wall in the wrinkle region experienced a tearing-type rupture (rupture due to sliding and rubbing of one surface of the pipe against another) due to application of transverse load. It was felt that a wrinkle formed under an axial deformation and with or without presence of internal pressure. Subsequently or simultaneously, a transverse load above the wrinkle might have caused the telescopic-shaped deformation of the wrinkled line pipe and a tearing rupture at the top foot of the wrinkle (Fig. 1). However, the actual load and deformation combination that caused the telescopic-deformation shape and tearing rupture was not known. A load not aligned with the longitudinal axis of the line pipe is termed a transverse load in this paper.

A few studies on pipe behavior under combined transverse load and internal or external pressures are available in the open literature (for example, Watson et al., 1976; Karamanos and Eleftheriadis, 2004; Karamanos and Eleftheriadis, 2005; Houliara and Karamanos, 2006; and Karamanos and Andreadakis, 2006). However, in these studies, the transverse load was applied on the virgin (not wrinkled) pipes, and no axial load was applied. The primary objective of these studies was to understand the behavior of pressurized virgin pipes when subjected to accidental and other transverse loads, and thus no considerations were made for axial load and wrinkle formation in the pipe wall. Current design codes, standards and guidelines (for example, ALA and ASCE, 2001; ASME, 2003; CSA, 2003; BSI, 2004; and DNV, 2005) do not mention telescopic deformation and tearing rupture in the wrinkle due to transverse load.

Therefore, a research program with 3 full-scale laboratory tests and detailed parametric study using the finite element (FE) method was designed and undertaken to study the possible load

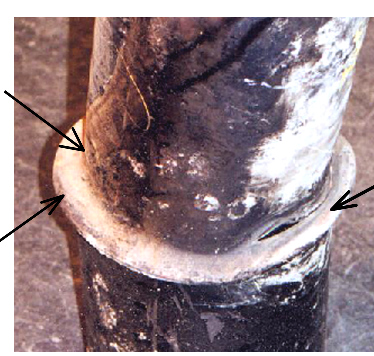

Fig. 1 Tearing rupture in wrinkle of field NPS10 line pipe

Received February 26, 2008; revised manuscript received by the editors June 22, 2009. The original version was submitted directly to the Journal.
KEY WORDS: Line pipe, wrinkle, transverse load, telescopic deformation, tearing-type rupture, laboratory tests, finite element analysis, parametric study.