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Response of Pipelines under Fault Crossing

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ABSTRACT

Seismic events pose one of the greatest dangers to pipeline systems. Pipelines may fail from the large displacements imposed at fault crossing and from liquefaction. Seismic wave could pose great threats to above ground facilities and perhaps lesser threats to buried pipelines. For buried pipelines safe and effective design against large displacements is one of the greatest challenges to pipeline designers. The tensile and compressive strains of buried pipelines resulted from large ground displacements are analyzed with finite element analysis. Seismic data of major active faults encountered in a planned pipeline project were used. The pipe was modeled with shell elements near the fault crossing and beam elements elsewhere. The fault was modeled with relative ground movement on either side of the fault. The pipe-soil interaction was modeled with soil-spring elements. The relationship of the maximum strain and the pipe-fault angle was investigated. The effects of material properties and pipe wall thickness on the integrity of the pipeline were examined.

KEY WORDS:

Strain-based design, strain demands, fault crossing, seismic design, finite element

INTRODUCTION

Pipelines may experience large strains well beyond their elastic regime. The strain caused by severe seismic events is one such example. The step-like permanent ground deformation caused by fault movement can create large tensile and compressive strains in the buried pipelines. Pipeline may fail by tensile rupture and/or compressive buckling.

Successful pipeline design against seismic events relies on the accurate prediction of strain demands on the pipelines. There have been a number of efforts in developing a simplified procedure for estimating the strain caused by fault crossing. The ASCE guidelines (1984) for buried pipelines adopted the original work developed by Kennedy et al (1977). In Kennedy's work, tension is assumed to be the prevailing deformation mode and the bending stiffness is neglected. Wang and Yeh (1985) and more recently, Karamitros et al (2007), improved Kennedy's solution by considering the bending stiffness of the pipelines. However, the simplified solutions were usually developed for two dimensional (2D) fault deformations and for most cases with simplified material properties (e.g. bi-linear stress-strain relationship). In reality, the fault movement can be three dimensional (3D). Furthermore the bi-linear stress-strain relationship may not represent the materials response under large strains, especially for some modern linepipe steels with round-house stress strain curves and reduced strain-hardening capacities.

Given the limitations of the simplified solutions, finite element method (FEM) is often used to address the shortcomings of the analytical method since the FEM can simulate the full 3D deformation with true material properties. In this paper, a 3D finite element model was constructed to investigate the strain demands of a pipeline under the impact of a 3D fault crossing. The focus is given to the features of the strain induced by the fault movement and the factors affecting the strain demand.

FINITE ELEMENT MODELS

The schematic drawing of the finite element model is shown in Figure 1. A total of 100-m pipe segment at the fault trace was modeled with bi-linear shell elements with 24 elements in the circumference. In addition, a 2000-m pipe segment on either side of the shell section was modeled with linear beam elements. The shell and beam segments were connected with rigid bars. The commercial FEM package ABAQUS® was used to conduct the analyses. The length of the model was chosen so that the relative movements between the pipe and the soil at the far ends of the model were very slight. The pipe-soil interaction in axial, horizontal, and vertical directions was modeled with spring