Buried Steel Pipelines Crossing Strike-Slip Faults

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ABSTRACT

The paper examines the behaviour of buried steel pipelines crossing active strike-slip faults. The vertical fault plane is crossed by the pipeline at an angle ranging between zero and 45 degrees, causing significant plastic deformation in the pipeline. The investigation is numerical, simulating the nonlinear response of the soil-pipeline system rigorously through nonlinear finite elements, accounting for inelastic material behaviour of the pipeline and the pipe and the soil, as well as contact and friction on the soil-pipe interface. Steel pipes with D/t ratio and material grade typical for hydrocarbon pipelines are analyzed, through an incremental application of fault displacement and appropriate pipeline performance criteria, defined within a strain-based design framework, are monitored throughout the analysis. The effects of various soil and linepipe parameters on the structural response of the pipeline are examined. The numerical results from the present investigation determine the fault displacement at which the specified performance criteria are reached, including the effects of internal pressure.

KEY WORDS: Pipeline; buckling; seismic fault; finite elements; strain-based design; performance criteria; soil-structure interaction.

INTRODUCTION

Ground-induced actions due fault movements are responsible for significant damages in oil and gas buried steel pipelines. Those deformations are applied in a quasi-static manner, and are not necessarily associated with high seismic intensity, but the pipeline may be seriously deformed, well beyond the elastic range of pipe material and may cause pipeline failure; high tensile stresses may cause fracture of the pipeline wall, especially at welds or defected locations or welds, whereas compressive stresses may cause buckling, in the form of pipe wall wrinkling, also referred to as “local buckling” or “kinking”.

The pioneering work of Newmark and Hall (1975) has been extended by Kennedy et al. (1977), Wang and Yeh (1985), Wang and Wang (1995) and Takada et al. (2001) through a beam-type approach for describing pipeline deformation. More recent works on this subject have been reported by Karamitros et al. (2007) Liu et al. (2008) and Trifonov & Cherniy (2010). In addition to the above analytical and numerical studies, notable experimental works on the effects of strike-slip faults on buried high-density polyethylene (HDPE) pipelines have been reported in series of recent papers by Ha et al. (2008) and Abdoun et al. (2009).

The analytical works outlined above have modelled soil conditions based on a spring-type approach. A more rigorous approach has been followed in a most recent paper (Vazouras, Karamanos, Dakoulas, 2010) of the present authors, for buried steel pipelines crossing strike-slip faults at right angle with respect to the fault plane, through a finite element modelling of the soil-pipeline system, which accounts rigorously for the inelastic behaviour of the surrounding soil, the interaction and the contact between the soil and the pipe (including friction contact and the development of gap), the development of large inelastic strains in the steel pipeline, the distortion of the pipeline cross-section and the possibility of local buckling, the presence of internal pressure.

The present paper extends the work presented by Vazouras et al. (2010), considering buried steel pipelines crossing the vertical fault plane at various angles. Furthermore, the paper examines the mechanical behaviour of buried steel pipelines with respect to appropriate performance criteria, expressed in terms of local strain or cross sectional deformation. The fault displacements corresponding to those performance criteria are identified, in the framework of a performance-based pipeline design. Pipes from two steel grades (X65 and X80), widely used in buried pipeline applications, are considered for typical values of diameter-to-thickness ratio $D/t$ (ranging from 72 to 144). The performance of pressurized pipes with respect to non pressurized pipes is also examined in terms of each performance criterion. Numerical results are presented in the form of diagrams, depicting the fault displacement corresponding to a specific performance criteria with respect to the crossing angle.

PERFORMANCE CRITERIA FOR STRAIN-BASED DESIGN OF BURIED STEEL PIPELINES

Under strong permanent ground-induced actions, buried steel pipelines exhibit severe deformation beyond the elastic limit. Steel material is quite ductile and capable of sustaining significant amount of