Buried pipeline analysis subjected to strike-slip fault

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Introduction

An understanding of pipeline response to lateral ground movements is essential in pipeline design. These movements may arise from offshore slope failures, earthquake-induced faulting, landslide, liquefaction, tunneling and excessive ground settlement. For pipelines that are above the ground and flexibly supported, the fault movement can often be accommodated by the flexibility of the pipeline. However, when the pipeline is required to be buried in the ground for security or environmental reasons, the pipe is confined by surrounding soil to a varying degree depending on the rigidity of the soil. Therefore, it is essential that a pipeline carrying oil or gas has to accommodate fault, without direct rupture (bursting) during fault movement as it carries hazardous material. A buried pipeline crossing the strike slip fault or normal fault is strained in direct tension and bending since the hanging wall moves away from the foot wall, hence it is of utmost importance to keep it safely operational. In the past, pioneering research has been carried out on buried pipeline crossing different types of faults. P. Vazouras, S.A. Karamanos, P. Dakoulas, 2010; investigated the mechanical behavior of buried steel pipeline crossing an active strike-slip tectonic fault, the work focused on the effects of various soil and pipeline parameters on the structural response of the pipe. S. Joshi et al, 2011; analyzed buried pipeline crossing reverse fault motion for deformation which was used for the conveyance of water supply. T.H. Abdoun & X. Xie, 2011; analyzed the offset rate parameter and the effect it would have on induced strain within the pipeline. L. Zhang et al, 2016; proposed a new finite element model considering soil springs to simulate pipe-soil interaction more sufficiently. The results show that local buckling occurs more easily under smaller fault displacements, while the tensile failure tends to occur under larger fault displacements.

In the present study, the mechanical behaviour of a buried steel pipe crossing an active strike-slip fault is assessed for different burial depths of 2, 6 and 10. The fault is normal to the direction of the pipeline, moving in the horizontal direction, causing stresses, strains and deflection in the pipeline. The pipe-soil interaction (PSI) system is modeled using 2D finite elements PSI and JOINTC simulating the strike-slip fault using commercial finite element software Abaqus. The finite element analysis is conducted for fixed diameter-to-thickness ratio of 48 for different fault offsets (200mm, 400mm, 600mm, 800mm and 1000mm) using different sand (Loose, Medium and Dense) types. The paper focuses on the effects of various sand types and fault offsets on the structural response of the pipeline with particular emphasis on identifying deformation, bending strain and axial stress. The deflection, bending strain and axial stress are analysed using PSI element. The results are then verified numerically using JOINT-C element. The results from the present investigation are useful for the pipeline design purposes.

Materials and Methods

Steel pipeline API-5L, X65 grade of length 60m having a wall thickness of 0.0127m with Poisson's ratio of 0.30 is used. The pipeline behaves as elastic perfectly plastic material. The soil used is sand, having a unit weight of 17kN/m^3 with Poisson's ratio of 0.25 is made of PSI24 element. In this work, the pipe is modelled using PIPE 21 element which is a 2 noded element with 3 degrees of freedom i.e. translation in X, Y directions and rotation along Z direction. The pipe-soil interaction is established using PIPE 24 element which is a 4 noded element with 1 displacement degree of freedom.

To simulate the experimental model into numerical model the parameters essential for numerical modelling such as element type, number of elements, boundary conditions, fault offset loading are adopted properly as described below. The pipeline has been divided into three regions 14m in the middle and 23m on either sides. The middle 14m region is subjected to the fault motion; remaining adjacent regions do not experience the direct fault motion. The middle third 14m part is densely meshed with 60 elements and the either sides each of 23m part is meshed into 30 elements each.

A fixed boundary condition is assigned to the pipe at the ends which constrains its translational and rotational displacements (U1, U2, and UR3). As per the design, the middle portion of the pipeline is made to simulate the strike-slip fault by applying the fault offsets from 200mm to 1000mm with an increment step of 200mm. The displacement boundary condition is assigned to the soil which undergoes strike slip fault motion and the remaining soil portion of PSI24 elements were restrained to translation and rotational displacements (U2).

The main objective is to determine the bending strain (EE11), axial stress (S11) induced in the pipeline due to fault movement which are the main factor causing buckling, rupture and tensile or compressive failure. Deformation (U) of the pipeline is the other output determined which helps in studying the deformation profile of the pipeline.

Results and Concluding Remarks

The analysis was conducted for different burial depths of 2, 6 and 10. However, the results for H/D ratio 2 for a fault offset of 200mm and 1000mm is only demonstrated below. The results obtained by using PSI element is numerically verified by JOINTC element.

Table 1. Results for H/D ratio 2

H/D ratio	fault offset	Output parameter	Loose sand		Medium sand		Dense sand	
			PSI	JOINTC	PSI	JOINTC	PSI	JOINTC
2	200	U(mm)	78.18	78.17	84.72	84.70	89.70	89.68
		EE11(mε)	494.20	493.70	587.80	587.20	673.50	672.90
		S11(MPa)	101.80	101.70	121.10	121.00	138.70	138.60
	1000	U(mm)	373.40	373.40	403.90	403.90	426.90	426.90
		EE11(mε)	2184	2184	2184	2184	2184	2184
		S11(MPa)	450	450	450	450	450	450

The following are the main conclusions drawn,

- The pipeline remains in the elastic region for a longer duration and reaches plastic zone at the maximum fault offset under the influence of fault offset rate effect.
- The pipeline reaches the plastic region at a very early stage for all sand types under the influence of pipe burial depth.
- The displacement values increase with increase in the fault offset rate irrespective of the sand type at a fixed depth-to-thickness ratio.
- The results of bending strain and axial stress increases with increase in fault offset rate up to the yield point and thereafter both bending strain and axial stress remains constant for any increase in the fault offset rate indicating that the pipeline has reached the plastic region.
- It is observed that the pipeline embedded in loose sand undergoes less displacement and reaches the yield point at a later stage when compared to other sand types. However, the pipeline buried in dense sand is most vulnerable under seismic calamities.

References

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