



# Analysis of buried pipelines subjected to reverse fault motion

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## ABSTRACT

Presently available simplified analytical methods and semi-empirical methods for the analysis of buried pipelines subjected to fault motion are suitable only for the strike-slip and the normal-slip type fault motions, and cannot be used for the reverse fault crossing case. A simple finite element model, which uses beam elements for the pipeline and discrete nonlinear springs for the soil, has been proposed to analyse buried pipeline subjected to reverse fault motion. The material nonlinearities associated with pipe-material and soil, and geometric nonlinearity associated with large deformations were incorporated in the analysis. Complex reverse fault motion was simulated using suitable constraints between pipe-nodes and ground ends of the soil spring. Results of the parametric study suggest that the pipeline's capacity to accommodate reverse fault offset can be increased significantly by choosing a near-parallel orientation in plan with respect to the fault line. Further improvement in the response of the pipeline is possible by adopting loose backfill, smooth and hard surface coating, and shallow burial depth in the fault crossing region. For normal or near normal orientations, pipeline is expected to fail due to beam buckling at very small fault offsets.

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## 1. Introduction

Buried steel pipelines with continuous joints are commonly used for transporting oil, gas and water over long distances. Such a pipeline crossing an active fault zone may be subjected to large, abrupt differential ground movement due to the fault rupture. Several major pipeline systems have been identified with the pipelines passing through active fault regions [1]. Reverse faults result from compressional plate tectonic environment and are abundantly present throughout the world. In India, major active faults are of reverse or thrust type and mainly distributed in Kachchh (Western India) and Himalayan frontal (North-western India) regions [2,3]. Some of these reverse faults can potentially produce large fault offset, as high as several metres. Many cases of pipeline damage due to fault rupture have been recorded during recent major earthquakes [4–6]. For example, a case of severe pipeline damage was reported due to the rupture of Chelungpu fault during 1999, Chi-Chi (Taiwan) earthquake [4]. The fault was steep reverse type (total length of about 105 km), and fault offsets of 4–10 m were observed along its length during the earthquake. The damaged portion of this pipeline went through local buckling

and large section deformations near the fault crossing point. Hence, it is necessary to design the pipeline which can safely accommodate large fault offsets without being ruptured or buckled.

Faults are most commonly classified based on the direction of relative slip. Portion of the ground, which remains stationary during the slip is referred to as foot wall, and the other portion that slips over the foot wall is referred to as hanging wall. The hanging wall in normal-slip faults moves downward and in reverse-slip faults upward with respect to the foot wall. A low dip angle (less than 45°) reverse fault is called a thrust fault. In strike-slip fault, the slip takes place in the horizontal direction. Response of buried pipeline is significantly influenced by the type of fault motion and orientation of the pipeline with respect to the fault line [7]. In general, a steel pipeline strained in direct tension due to fault rupture can safely accommodate a larger fault offset value compared to when it is strained in direct compression [8,9].

Pioneering work in the analysis of pipeline subjected to fault motion was done by Newmark and Hall [10]. They developed a simplified method for analysis of pipeline subjected to fault motion. This method assumed the pipeline to be subjected to direct tension due to the fault motion and ignored lateral resistance of the soil. Hence, the analysis of the pipeline was performed by assuming it to be a cable deforming in straight line. Kennedy et al. [8] revised the Newmark–Hall method by incorporating bending of the pipeline near the fault crossing point and considering the soil lateral forces. However, the formulae for

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