Soil-pipeline interaction along active fault systems

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ABSTRACT

The problem of soil-pipe interaction along active faults is here numerically taken into consideration by following a displacement based approach. The interaction is analysed by means of lumped coupled elastoplastic springs, whose failure locus is piece-wise linearised and the equations governing their behaviour are set in a form such that a linear complementarity problem can be formulated. The numerical formulation is conceived for taking into account large displacements. The ground motion is controlled; the solution in terms of pipe displacements and internal pipe actions is presented and its dependency on geometrical parameters is discussed. The problem of the axial instability of the pipeline is also studied.

KEY WORDS: pipeline engineering; soil-pipe interaction; active fault systems; numerical modelling; large displacement analyses; displacement based approach; axial instability.

INTRODUCTION

The mechanical interaction between a buried pipeline and the surrounding soil is one of the most important factors that engineers have to account for in pipeline design. Relative soil-pipe displacements induce a change in actions on the external surface of the pipe (Fig. 1), thus resulting in a net additional load distributed along the buried structure.

![Fig. 1 Idealized normal stress distribution over the pipe at rest (a) and after a horizontal rightward pipe displacement (b). After Audibert & Nyman (1977).](image)

When increasing relative soil-pipe displacements, these additional loads modify the pipeline layout, thus increasing actions within the structure and eventually inducing the lost of the serviceability or even the failure of the pipe with consequent leakage of the internal fluid. It derives that the soil-pipeline interaction is a crucial problem from an economic, technical and also environmental point of view.

Relative soil-pipe displacements can be due to several causes: the most common are related to landslides, where buried pipelines cross potentially unstable soil masses (either in mountain regions or in subaqueous environments) that can move several tens of centimetre per year. To these latter we must add relative soil-pipe displacements induced by seismic events. During an earthquake, a buried structure is subject to two different effects: (i) a transient load due to the wave propagation, and (ii) permanent loads due to the permanent ground displacement (PGD). As it is well documented in the literature (see e.g. O’Rourke and Daye, 2004), even though the effects of the wave propagation may affect very wide areas, normally they result in a lower rate of failure per kilometre with respect to the rate of failure caused by PGD. Statistical methods have been developed to study the former ones, as well as analytical approaches based on very simplified hypotheses (Newmark, 1967; Sakurai and Takahashi, 1969; Shimizuoka and Koike, 1979; O’Rourke and El Hmadi, 1988). On the contrary, the effects of PGD normally affect a relatively restricted area, but result in a quite high rate of failure. Permanent ground displacements can be due either to the seismic induced settlement of the soil, or to the liquefaction of the soil and to the consequent buoyancy uplift of the pipe (there exists in the literature a considerable amount of analytical and empirical works on these topics, like those by Tokimatsu and Seed, 1987; Dobry and Baziar, 1990; Bartlett and Youd, 1992). In the following, particular attention will be paid to study the consequences of permanent slip across active faults on pipes.

In the last thirty years several different approaches have been proposed in order to study this problem (Newmark and Hall, 1975; Kennedy et al., 1977; Wang and Yeh, 1985). These methods assign a deformed shape to the pipeline and try to compute the maximum expected strain within the pipe under soil external loads for a given strike-slip offset. An alternative approach consists in assuming that the pipeline will be subject to a non linear behaviour, by introducing two plastic hinges: by minimizing with respect to their position the total virtual work, it is possible to locate them and to define the deformed shape of the pipeline.

Obviously, these methods do not take correctly into account the soil-pipe interaction, and they are unlikely to be adapted to general 3D conditions, or to take into account a non homogeneity of soil mechanical properties.

In this paper a convenient numerical tool based on the discretisation of the pipeline by finite elements of beam type is presented, and a displacement based numerical approach is described. Simple examples