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Evaluation of the reliability of buried gas pipelines exposed to ground movement in the perspective of their use for hydrogen transportation: A state-of-art review

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Hydrogen (H2) has been recognized as having the potential to become the cornerstone of a low-carbon energy system. As a result, it has garnered much interest from policymakers and industry as a focus for future infrastructure.

In its race towards climate neutrality by 2050, the European Union seems to be betting on green hydrogen as a high-potential energy source. Europe envisages to develop more than 11,000 km of pipelines transporting hydrogen in 2030 [2]. The French government seems to prioritize the reuse of gas networks for the transport and storage of H2 [4]. On the other hand, the substitution of gas by hydrogen leads to an evolution of the mechanical characteristics of steel pipelines, and consequently, increases their vulnerability vis-à-vis external stresses (loads, ground movements, natural hazards, etc.). It has been shown that pipeline steel could lose up to 40% of its ductility after exposure to 100 bar H2 [3]. Thus, the reuse of the existing gas networks for the hydrogen transport raises today a set of scientific and technical questions. The problematic of pipelines vulnerability is getting even more serious by both the climate change and the evolution of human activities associated with the ecological transition.

In the framework of a thesis that we recently started (October 2022), we aim to understand the interaction between buried networks (gas networks reused for hydrogen transport) and ground movements, with a purpose to enhance risk prevention and to reduce the associated consequences. The aim is to establish a reliable analytical model enabling sensitivity studies to be performed and the influence of the uncertainties on the results to be assessed. The outcomes will be also valued by developing fragility curves that constitute operational approaches when assessing damages in an uncertain context.

The aim of this study is to synthesize the existing research work available in the literature addressing the behaviour of buried pipelines subjected to various ground motion phenomena. This review covers the various modelling approaches and simulation techniques for the soil-pipe system found in the literature. The main limitations of the existing methods are also stated.These studies encompass a diversity of ground motion sources including, but not limited to: Fault movements (strike-slip, normal-slip), soil settlements due to tunnelling, differential ground settlements related to groundwater lowering, and soil liquefaction. The main research methodologies employed are analytical analysis, numerical simulation and experimental testing.

One way to study the behaviour of the buried pipelines is the analytical modelling based on theoretical analysis [6, 7, 8]. For this approach, reasonable assumptions and simplification are necessary when simulating the pipe-soil system but also the ground movement. Soil-pipe interaction models found in previous study are mainly based on Winkler model, Pasternak model and others. The pipeline material behaviour was considered to have either elastic, bilinear or tri-linear stress-strain response. The adopted simplifying assumptions in the abovementioned studies can be prominent in certain cases of practical interest.

Analytical models based upon empirical curve fits have also been employed in some studies. The fitted functions can be derived from a numerical parametric analysis, by performing regression analyses on data obtained from a large number of configurations covering different values of the input parameters, such as pipe diameter, burial depth, soil subgrade modulus, pipe elasticity, and

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maximum displacement of the soil [11]. The derived empirical expressions can be used to directly estimate pipe response induced by a soil settlement.

Another major way to investigate this topic is the numerical simulation. Numerous studies were carried out using numerical finite element models [10, 12]. The results of these computational methods are becoming increasingly accurate as currently available numerical analysis techniques allow this problem to be solved in a rigorous manner, minimizing the number of required approximations. However, the non-linear behaviour of the pipeline steel, the soil-pipeline interaction and the second-order effects induced by large displacements make these analyses quite challenging.

Apart from the above analytical and numerical methodologies, there have been a growing number of papers involving the experimental simulation of buried pipes under ground motion. These investigations were based on centrifuge tests [1, 5] and other designed testing apparatus [9].

However, despite the advancement of modelling techniques, there are still some limitations when examining the behaviour of buried pipelines subjected to ground settlement such as the need for accurate soil and pipe parameters and the lack of consideration of external loads.

Contributor statement

Mariam Joundi : Investigation, Writing – Original draft; Rasool Mehdizadeh : Supervision, Writing – Review & Editing; Olivier Deck : Supervision, Writing – Review & Editing; Keith Mateo : Writing – Original draft.

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