Dynamic response of water networks in seismic areas

Virginia CORRADO
PhD Student
Federico II University
Napoli, Italy
virginia.corrado@unina.it

Berardino D'ACUNTO
Full Professor
Federico II University
Napoli, Italy
dacunto@unina.it

Nicola FONTANA
Associate Professor
Sannio University
Benevento, Italy
fontana@unisannio.it

Maurizio GIUGNI
Full Professor
Federico II University
Napoli, Italy
giugni@unina.it

Summary

This study aimed at evaluating the dynamic response of continuous buried pipeline. Under the hypothesis that the soil is a Winkler elastic medium and the pipe can be held to be continuous (welded joints), a numerical model is presented. The model makes it possible to evaluate, with reference to specific boundary conditions and at a generic abscissa, the trend over time of the pipe's axial and transverse displacements. These can then be used to define the corresponding trends over time of the strains and, hence, the stresses acting on the pipe.

In this paper emphasis has been placed on the analysis of axial displacements and strains with reference to steel pipes. The effects of the surrounding soil and the pipe length on the seismic behavior of pipelines are also discussed. Numerical results show that the characteristics of soil as well as the pipe length have a remarkable influence on the pipe seismic response.

Keywords: Soil-structure interaction; seismic response; lifelines; buried pipelines; dynamic behaviour; numerical models; partial differential equations.

1. Introduction

Damage and disruption of buried pipelines caused by seismic events may have severe effects on vital lifelines, as telecommunication, water distribution and natural gas supply systems. Even when the structures are not seriously damaged, earthquakes can produce heavy loss of functionality in pipeline networks involving economic and social uneases. As a consequence, studies of seismic analysis and behavior of these structures have been presented in the literature.

Investigating the dynamic behaviour of buried lifelines is a rather complex problem since it includes threedimensional dynamic analysis of the soil–structure system subject to seismic excitation. As a result, different types of modelling of the system are developed using different degrees of simplifications with the aim of evaluating seismic stresses in the pipelines.

Most publications in the literature consider the pipeline to be of infinite length and hence fail to take into account not only its effective length but also the presence of any construction works, such as anchoring blocks, branches and so forth, which inevitably modify its overall behaviour. In this work the authors propose a new approach, which aims to schematize the dynamic behaviour of a finite length pipeline with different boundary conditions at its ends (FLBDWF – Finite Length Beam on Dynamic Winkler Foundation). In particular they consider the dynamical model and analyze the effects of earthquakes on the axial motions of a finite pipe with fixed ends. The pipeline is assumed to be continuous, i.e. any variations between the characteristics of the pipe and those of the joints are held to be negligible, while the soil is assumed to have a linear elastic behaviour. In the applications steel pipes with welded joints are considered.

https://doi.org/10.2749/222137908796294117
Distributed by structurae

2. Numerical analysis

2.1 Numerical model

Under the hypothesis that the soil is a Winkler elastic medium, the equation governing axial motion of the pipe can be written, being U and U_g the displacement of the pipe and the soil:

$$m\frac{\partial^2 U}{\partial T^2} - EA\frac{\partial^2 U}{\partial X^2} + K\left(U - U_g\right) = 0 \qquad (1)$$

where E denotes the Young's modulus of the pipe material, A the area of the cross section, m the mass per unit length and $K=k\pi D_E$, where k is the value of soil's Winkler constant and D_E is the external pipe diameter.

Equation (1), with reference to specific boundary conditions, has been numerically integrated by three finite-difference methods: the MacCormack (MC), Crank-Nicolson (CN) and Courant-Friederichs-Lewy (CFL) methods. By comparing results with the exact solution, the authors emphasized the Courant-Friederichs-Lewy method works very well in treating the discontinuities involved in the partial derivatives of U, while both the MacCormack and Crank-Nicolson methods show undesirable oscillations for the strain close to the discontinuous points. Thus, the Courant-Friederichs-Lewy method has been used for the numerical simulations.

2.2 Numerical results

Numerical simulations have been carried out considering a steel pipe with outer diameter 812.8 mm and thickness 7.1 mm. Different pipe lengths and shear wave speeds have been considered with the aim of highlighting their influence on the pipe dynamic response.

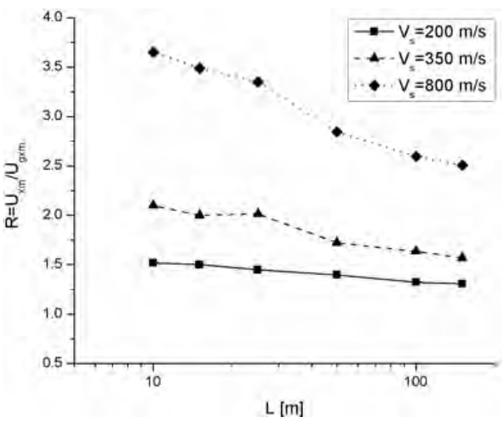

Fig. 1: Ratio R between the maximum axial strain of the pipe and the maximum axial strain of the soil as L varies.

The numerical results show that steel pipe displacements differ slightly from the soil displacements. So a classic BDWF model or a rigid model can be reliably applied to calculate pipe displacements, while for pipe strains a more rigorous approach is needed.

The pipe length and the characteristics of surrounding soil influence the maximum axial strain of the pipe. In particular, Figure 1 show that the ratio R between the maximum axial strain of the pipe and the maximum axial strain of the soil reduces:

- for soft soils, characterized by low values of shear wave speed (V_S),
- with increasing of pipe length (L).

Numerical analysis emphasized that end-constrained finite length pipelines are subject to strains greater than infinite length pipes or free-end finite length pipes. Furthermore, the greatest values of strain significantly decrease with increasing of the pipe length and with decreasing of the soil stiffness. Other situations of engineering interest will be discussed in following works.