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Three dimensional vibration analysis of a buried pipeline with slip conditions

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ABSTRACT

Based on the three-dimensional (3D) elasticity theories, an analytical solution for the infinite pipeline surrounded by the infinite soil medium subjected to an incident plane wave is derived. The Coulomb frictional force is applied at the pipeline–soil interface to represent the slip condition between the pipeline and the soil medium. This applied interface interaction can be considered as the viscous damping with some considerations. The normal and shear stress distributions along the cross-section of the pipeline are obtained by solving the obtained equations analytically. Furthermore, the superposition and the corresponding principles are used to obtain the von Misses strains. The critical and maximum amplitude ranges of the incident wave for which slipping and yielding, respectively, occur are estimated. The solutions are presented for ranges of soil densities and pipe thicknesses with perfect/imperfect bonds and different incident wave angles.

1. Introduction

Buried pipelines are one of the most important components of lifeline systems which are greatly related to the daily lives of citizens and industrial production. Some of the recent earthquakes such as Kobe (1995) and Chi-Chi (1999) caused extensive failure in the underground structures such as buried pipelines and tunnels [1–3]. Therefore, proper design of these structures becomes crucially important in saving human lives and increasing the efficiency in the serviceability.

Several numerical and analytical methods have been used in the literature to investigate the seismic behavior of cylindrical underground structures [4–6]. The major deficiency of the numerical methods such as finite element method (FEM) is that they usually assume a finite size medium instead of semi-infinite one to decrease the computational cost. Although several investigations have been done to allow the energy radiation at the end of the FE meshes, 3D dynamic analysis of these problems using FE methods require enormous computational cost such that the accurate modeling of 3D problems becomes practically impossible in some cases [7].

Analytical methods were primarily developed to solve the wave propagation and scattering problems of buried structures by considering these structures as discontinuities in either infinite or semi-infinite homogenous medium [7]. These methods have been successfully applied to investigate the dynamic behavior of 2D and/or 3D underground cylindrical structures by considering elastic behavior for both soil and the structures [8–17]. However, the majority of the 2D/3D analytical works have used shell or beam theories to model the pipeline. A careful review of the papers on modeling of the imperfect bonding at the pipeline–soil interface reveals that the shell or beam theory is usually used to model the pipe; whereas, the 3D elasticity theories are used to model the soil medium. Akiyoshi and Fuchida [10,11] used the frictional interface model during the earthquake to represent the soil–pipeline interaction. They modeled the buried pipeline using the beam on an elastic foundation concept and the surrounding soil using the 3D elasticity theories. Furthermore, they considered only the slippage of the pipe and the surrounding soil without taking into account the possibility of the angular slippage of the pipe with respect to the soil which is likely to happen during the complex mechanism of pipe failures subjected to earthquakes loading. Added to the mentioned deficiencies, the beam model does not yield adequate accuracy for pipes with large diameters which limits the application of this theory to a range of pipe diameters. Later on, researchers have used cylindrical shell models for the buried pipes. Most of these researches, however, modeled the buried pipes and surrounding soil as 2D axi-symmetric by neglecting the effect of imperfect bonding between the soil and the pipe [12–14].

To the best of the author's knowledge, Dwivedi and Upadhyay are the only ones who investigated the dynamic response of an

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