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Nonlinear Seismic Analysis of Free Spanning Submarine Pipelines under Spatially Varying Earthquake Ground Motions

Jing Zhou, Xin Li, Xin Feng and Rubo Dong
State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology
Dalian, Liaoning Province, China

ABSTRACT

A study of the nonlinear seismic response of free spanning submarine pipelines subject to a spatially varying earthquake ground motion is carried out. Firstly, an improved method for simulating multiple-station ground motions is proposed. Secondly, the motion equations of the pipeline under multiple-station excitation are derived. The hydrodynamic force applied on the pipeline is simplified as added masses. Thirdly, a nonlinear three-dimensional (3D) finite element model of free spanning submarine pipeline is established. The effects of different material constitutional relationships of steel pipe and soil as well as large displacement are discussed.

KEY WORDS: Free spanning submarine pipeline; nonlinear seismic analysis; spatially varying earthquake.

INTRODUCTION

Submarine Pipelines are used to transport oil and gas from offshore oil fields to onshore terminal facilities or between offshore oil fields. Many offshore oil fields locate in the seismic regions. The seismic load has to be taken into account in the mechanical analysis of the submarine pipeline. Due to the anisotropy and inhomogeneity properties of soil, the seismic ground motions can vary significantly in magnitude, phase angle and frequency along pipeline routes. And the variation of the ground motions can influence the seismic response of the pipeline greatly. Thus, it is of great significance to study the response of the submarine pipeline subjected to multi-support excitation.

In the recent few decades, many numerical simulations and experimental studies have been performed on the dynamic response of submarine pipelines under seismic excitation. Nath and Soh (1978) studied the harmonic and seismic responses of simplified pipeline models in proximity to the seabed using finite element method. Datta and Mashaly (1988, 1990) analyzed the transverse response of both buried and free spanning submarine pipelines under random earthquake excitation in the frequency domain using the spectral approach, which was based on the spatial discretization of the pipeline with nodal lumped masses. Romagnoli and Varvelli (1988) studied the interaction between submarine pipelines and the seabed under earthquake by combining stochastic methods and finite element method. Based on perturbation method Figarov and Kamyshev (1996) evaluated the change of the strained-deformed condition of submarine pipelines. Kalliontzis (1998) examined the problem of random contact between submarine pipelines and seabed under vertical earthquake ground motions with the aid of a finite element model. Kershenbaum et al. (2000) investigated unburied 'snaked' pipeline behavior under various types of seismic faults. Zhou et al. (2001) analyzed the seismic response of submarine pipelines freespan and suggested vibration control methods. Li et al. (2002) employed an experimental study on the response of submarine pipelines under dynamic input using an underwater shaking table. Duan et al. (2004) analyzed the soil-pipeline interaction during earthquakes using the plastic slippage theory.

Among the above studies, in seismic response research, only Datta and Mashaly (1988, 1990) considered the spatial variation of the random earthquake signal. The other researchers were based on the assumption that the ground motions are essentially same alone the pipeline route. In the research of working loads effects, the major issue lied in the buckling problem and static analysis was performed in most cases.

In the study the numerical model of a long-distance buried submarine pipeline with freespan was established and the multi-support excitation seismic response of the pipeline was analyzed. The effects of different material constitutional relationships of steel pipe and soil as well as large displacement were discussed.

SIMULATION OF CORRELATIVE MULTI-POINT EARTHQUAKE GROUND MOTIONS

In recent years, a wide variety of techniques to simulate the spatially variable seismic ground motions have been proposed (Hao et al., 1989; Zerva, 1992; Conte et al., 1992; Ramadan and Novak., 1993). Among them, two commonly used methods are covariance matrix decomposition method (Hao et al., 1989) and spectral representation method (Zerva, 1992). In this paper, an improved method was presented on the base of Hao-Oliveira-Penzien (HOP) method (Hao et al., 1989).

As Hao et al. (1989) suggested, the simulated time histories are a sum of sinusoids, each of which corresponds to the frequency ω_k in the