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Uplift response of buried pipelines in saturated sand deposit under earthquake loading

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ABSTRACT

Pipelines buried in saturated sand deposits, during earthquake loading could damage from resulting uplift due to excess pore water pressure generation. Several studies have been made to better understand the uplift mechanism and evaluate the effectiveness of mitigating techniques through experiment, but little numerical works have been done to assess the influence of soil properties and field conditions in pipeline floatation. Especially for previously buried pipelines, in order to set the priority for seismic retrofit, evaluating the risk of floatation in each region could be a concern. In this paper, effects of several parameters including dilatancy angle and density ratio of natural soil, diameter and burial depth of pipe, underground water table and thickness of the saturated soil layer on uplift of pipe have been investigated. Results show the prominent role of burial depth in pipe response and that there exits an optimum level for drop of water table to reduce floatation.

1. Introduction

There are several lifeline utilities in urban and non-urban areas that could suffer severe damages from intensive earthquakes. Oil and gas transferring pipelines, water supply and sewage system and traffic tunnels are examples of these lifelines that their failure could exacerbate the damages of earthquakes. For petroleum transferring pipelines, aside from economic loss and contamination of the ecosystem, leakage of gas from damaged pipelines would cause fires in the case of electricity sparks [1]. Moreover, destruction of water pipelines could prevent fire fighter's activities in restraining these fires. The 1989 Loma Prieta earthquake [2], 1994 earthquake of Northridge [3] and 1995 earthquake of Kobe [4] were the well-known examples of lifeline failures, which drew more attention towards investigation of circumstances that cause pipeline failures. The underground tunnels that act like large diameter pipes could experience the same problems. Urban subway system of Taipei in 1999 earthquake of Chi-Chi encountered damages, as reported by Chou et al. [5].

In literature, seismic behavior of buried pipelines under earthquake excitations has been investigated by several researchers [6–9]. Moreover, for pipelines crossing active faults, series of centrifuge tests have been performed to evaluate the effects of several soil and pipe parameters on the structural response of buried pipelines [10,11] and a remediation technique of using expanded polystyrene geofoam block as a low density backfill to reduce soil restraint and pipeline strains has been proposed [12]. Also, there are the results of studied effects of wave and soil characteristics and pipe geometry on excess pore pressure generation for seabed installation of pipelines [13,14]. A rather newly arisen phenomenon for scientists to investigate in the past decade was the floatation of buried pipelines in saturated deposits during intensive earthquakes, which can be defined as follows.

Under earthquake loading, granular materials such as sands are susceptible to compaction. In saturated deposits, reduction in volume is prevented by the presence of pore fluids. Lack of drainage due to low permeability and short duration of loading result in a nearly undrained condition. This undrained condition that is accompanied by tendency to reduction in volume of soil skeleton builds up the pore fluid pressure. Consequently, the effective stress and so the shear resistance of these cohesionless soils reduces. By continuing generation of excess pore fluid pressure, gradually the effective stress diminishes, the process in which liquefaction could occur. Generation of excess pore water pressure beneath the pipeline and shear resistance reduction of soil above it, results in floatation of pipeline. Uplift resistance of offshore pipelines buried in liquefied clay was assessed by Bransby et al. [15] and Cheuk et al. [16]. Studies have been conducted on liquefaction-induced uplift of tunnels and two measures of secondary injection grouting and application of cutoff walls proposed [5,17,18]. Additionally, Mohri et al. [19,20] proposed a mitigation technique for buried pipelines, which consisted of confined gravels by geogrid layers as an integrated body around the pipe, resisting floatation by increasing

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