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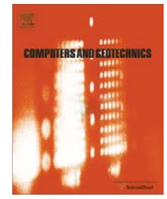

Piles in fully liquefied soils with lateral spread

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ABSTRACT

The paper provides a new analysis procedure for the assessment of the lateral response of isolated piles/drilled shafts in saturated sands as liquefaction and lateral soil spread develop in response to dynamic loading such as that generated by the earthquake shaking. The presented method accounts for: (1) the development of full liquefaction in the free-field soil that could trigger the lateral spread of the overlying crust layer; (2) the driving force exerted by the crust layer based on the interaction between the pile and the upper non-liquefied soil (crust) layer; and (3) the variation of the excess pore water pressure (i.e. post-liquefaction soil strength) in the near-field soil with the progressive pile deflection under lateral soil spread driving force. A constitutive model for fully liquefied sands under monotonic loading and undrained conditions is developed in order to predict the zone of post-liquefaction zero-strength of liquefied sand before it rebounds with the increasing soil strain in the near-field. The analytical and empirical concepts employed in the Strain Wedge (SW) model allow the modeling of such a sophisticated phenomenon of lateral soil spread that could accompany or follow the occurrence of seismic events without using modifying parameters or shape corrections to account for soil liquefaction.

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1. Introduction

In most major earthquakes (San Francisco 1906, Alaska 1964, Niigata 1964, Loma Prieta 1989, Kobe 1995 and Turkey 2004), the development of lateral soil spread and large ground displacements have caused substantial damage to harbor facilities, bridge and structure foundations, buried pipelines, and many infrastructure facilities. Liquefaction-induced lateral spreading is a result of excess pore water pressure build-up in an underlying saturated sand deposit during an earthquake, even with gently sloping ground. The high pore water pressure may yield a substantial degradation in soil strength and stiffness. While the soil is in a full liquefied state suffering a huge drop in its strength, the pile foundation may undergo a substantial amount of lateral displacement. However, this may not be the worst case scenario to which the pile foundation is subjected. After liquefaction, if the shear strength of the liquefied soil is less than the static shear stress caused by the sloping ground, the non-liquefied surface layer (crust) underlain by the liquefied soil deposit could slide with a considerable amount of displacement (lateral spread). During the spreading, the non-liquefied surface layer is carried along with the underlying fully liquefied soil against the pile foundation imposing a large lateral force on the embedded piles. Bridge and structure pile foundations could be severely damaged under such a sophisticated and destructive scenario. It is not necessary to have significant slope in the ground to cause lateral soil spreading. A small slope with a liquefied soil layer overlain by non-liquefied soil surface layer (crust) is enough to trigger such a damaging phenomenon. The formation of a water film at the top of the liquefied soil beneath the crust layer (with low permeability) could keep the lateral spread of the crust layer going due to the unbalanced forces [1,2].

The phenomenon of lateral soil spread and its damaging impact on deep foundations is under investigation via laboratory and field testing, and numerical analysis. The progress to characterize the problem is due to findings from centrifuge, shaking table and laminar shear box tests. A number of studies have been conducted to develop reasonable characterizations for the problem of lateral soil spreading and its impact on the bridge/structure foundations [3–11]. A number of full and model scale tests and case studies were also performed to provide better understanding of the elaborate mechanisms of the problem of lateral soil spreading and its impact on deep foundations [11–17].

The above described lateral spread scenario requires the characterization of the following: (1) the excessive lateral loads from the crust layer against the piles; (2) the post-liquefaction soil displacement under lateral spreading; (3) the soil post-liquefaction mobilized strength; and (4) the influence of sloping ground (static bias). These are major key elements to be considered when evaluating the pile foundation response in liquefied soils with lateral spreading. Great efforts have been made over the past decade to evaluate these key elements from case histories and full/model scale tests.

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