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Nonlinear Three-Dimensional Numerical Study of Pile Seismic Behavior: Effect of Pile Geometrical Parameters

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ABSTRACT: The behavior of soil-pile systems subjected to earthquake loading depends on many parameters. These parameters can be categorized into three main groups: geometrical parameters of the pile, soil mechanical properties, and loading characteristics. The purpose of this study is to investigate the effect of pile geometrical parameters on the seismic response of soil-pile systems considering soil nonlinear behavior. To this aim, a set of fully nonlinear three-dimensional analyses in the time domain was conducted using the finite difference computer program FLAC^{3D}. The focus of the paper is on the seismic response of the floating single pile embedded in clayey soil, and the parametric study was performed to investigate the effect of pile geometrical parameters on its seismic response. To consider soil nonlinear behavior during seismic events, an elastoplastic constitutive law was applied to the soil medium. Also, soil shear modulus reduction with the increase in soil shear strain level was simulated. The results of this study showed that an increase in pile diameter causes an increase in the maximum kinematic bending moment. This increase is proportional to the pile diameter powered by a value. Also, the results showed that effect of pile length on the magnitude of maximum bending moment in pile was not significant. However, the shape of the bending moment distribution diagram and location of the maximum bending moment are strongly affected by pile length.

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1- Introduction

Several researchers found that kinematic interaction is the main factor in the induced damages to piles during severe earthquakes, e.g., Mexico City 1985, Kobe 1995, and Chi Chi 1999 [1,2].

The main purpose of the current study is to investigate the pile geometrical properties affecting kinematic soil-pile interaction considering more realistic assumptions. To this end, based on the continuum mechanics approach, fully nonlinear three-dimensional analyses were conducted in the time domain. The explicit scheme finite difference program, FLAC^{3D} (Fast Lagrangian Analysis of Continua in 3D), was employed. A parametric study has been performed to investigate the effects of the diameter and length of the pile on the seismic behavior of a single pile in a clayey stratum.

2- Numerical Modeling

The schematic section view of the single pile embedded in the clayey layer and the three-dimensional model developed in FLAC^{3D} is shown in Fig. 1. A single pile with a length of L and a diameter of D embedded in a clayey stratum was modeled. The soil medium was simulated using eight-noded cubical elements, with each node having three translational degrees of freedom (in X, Y, and Z coordinates). Two-noded flexural elements were selected for modeling the piles in the parametric study carried out in this research. The assumed properties for the soil layer and the pile are listed in Table 1 and Table 2, respectively. Horizontal input motion, consisting of 9 sinusoidal cycles with an amplitude of 0.2g and a frequency of 5 Hz was applied to the model base.

3- Results and Discussion

The distribution of the bending moment envelope along the pile is presented in Fig. 2. The graphs present the results for pile lengths of 10.0 m, 15.0 m, and 20.0 m. Fig. 6 illustrates that the bending moment increases along the pile length as the pile diameter increases; however, in most cases, this increase in bending moment is more significant along the upper two-thirds of the pile length.

The distribution of the bending moment envelope for the single piles having different lengths is shown in Fig. 3. It is observed that diagrams of the distribution of the bending moment envelope along the piles can be characterized by two completely different shapes: “S-shaped” diagrams and “monotonic” diagrams.

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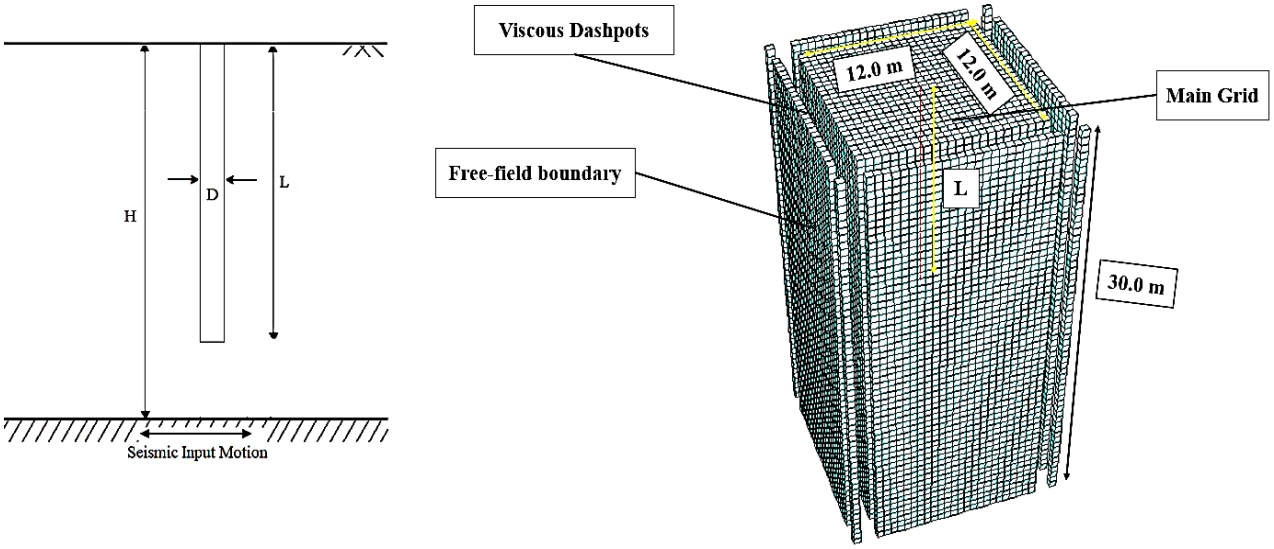

Fig. 1. Schematic view and the three-dimensional model developed in this study

Table 1. Adopted properties for soil in analyses performed in this study

Property	Values
Layer height (m)	30
Unit weight (kN/m^3)	18
Poisson's ratio	0.45
Strength ratio (α=$\frac{c_u}{\sigma_v}$)	0.3
Initial stiffness ratio (β=$\frac{E}{c_u}$)	150

Table 2. Geometrical and mechanical properties of piles adopted in this study

Property	Values
Diameter (m)	0.5, 0.8, 1. 0, 1.2
Length (m)	10, 15, 20
Unit Weight (kN/m^3)	24
Elastic Modulus (GPa)	20
Poisson's ratio	0.15

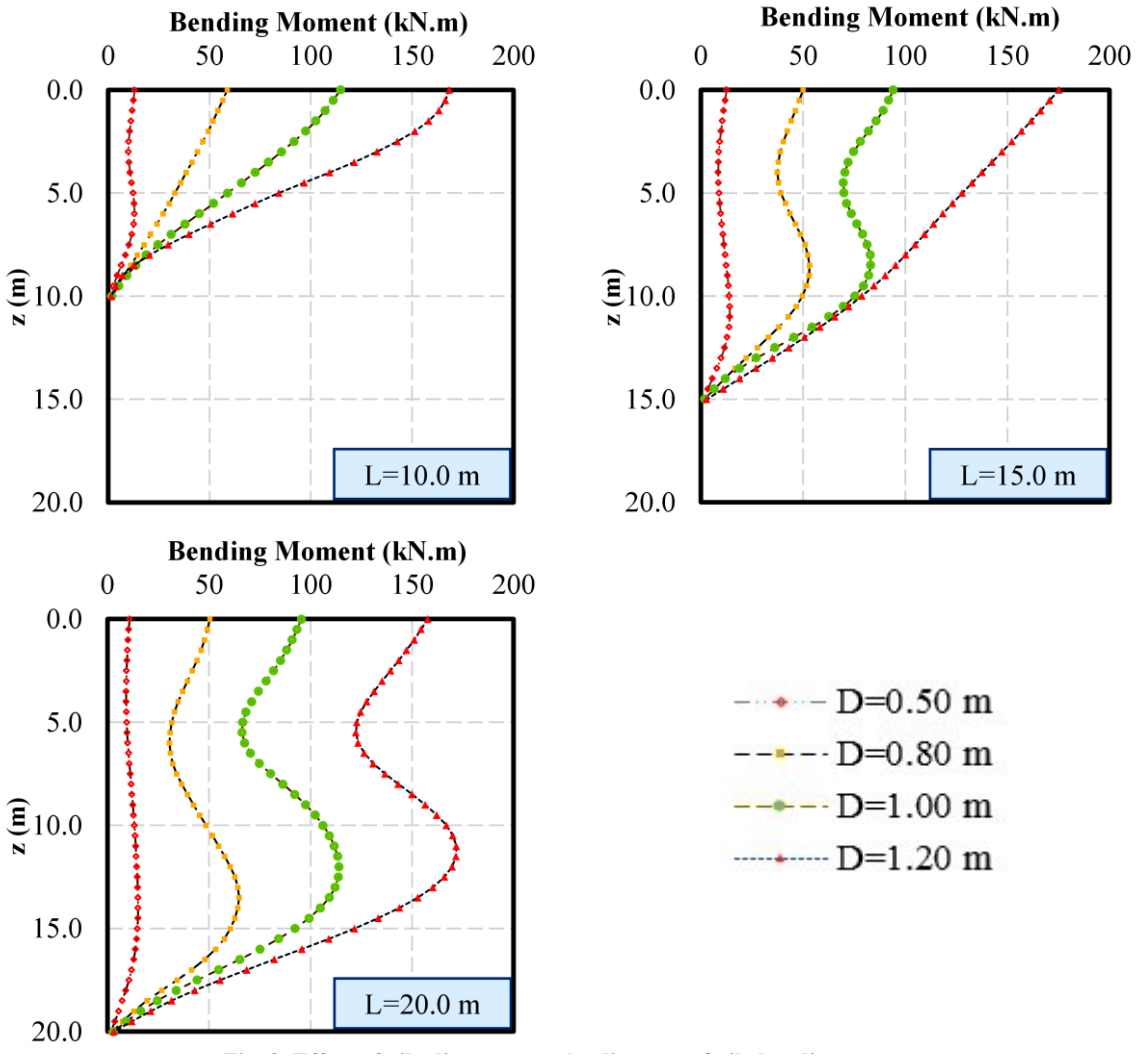

Fig. 2. Effect of pile diameter on the diagram of pile bending moment

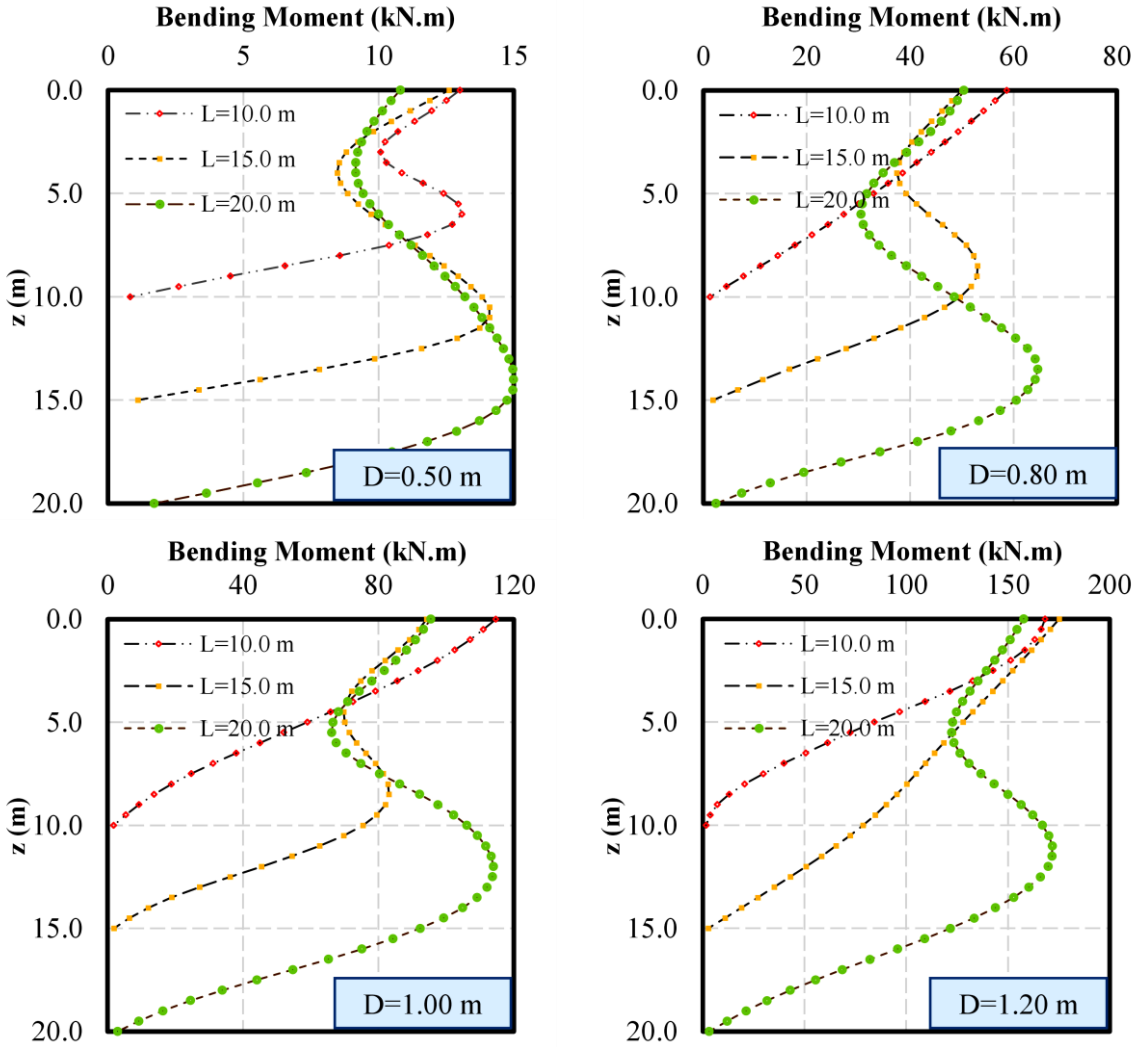

Fig. 3. Effect of pile length on the diagram of pile bending moment

4- Conclusions

In this research, the seismic behavior of floating single piles embedded in a clayey stratum was studied. The main conclusions obtained from this research are as below:

- The bending moment increases along the pile length as the pile diameter increases, especially along the upper two-thirds of the pile length.
- The shape of the diagram of bending moment distribution can be categorized into two groups: "S-shaped" diagrams and "monotonic" diagrams.

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