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The effect of farfield and nearfield earthquakes on the seismic behavior of micropile group in loose and dense granular soils

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ABSTRACT: Studying the performance of micropile system as an effective, practical and affordable method for seismic retrofitting of the site and foundation and considering the different characteristics and effects of nearfield and farfield earthquakes on structures, justifies the need to study the performance of micropile group under nearfield and farfield earthquakes. In this research, using Opensees software, two types of loose (Dr =40%) and dense (Dr = 80%) granular soils with elastoplastic behavior and two reinforcement models including vertical and inclined micropiles with elastic behavior and concrete material were affected by three sets of farfield and nearfield earthquakes due to the shear wave velocity of the site (Vs30). The responses of the micropile group, including horizontal displacement, acceleration and internal forces, were studied and compared and important results were presented to use the micropile group in order to seismic retrofitting of areas close to and far from the epicenter. The results showed that the effect of near-fault records significantly increases the horizontal displacement, especially in the loose granular site. The increase in lateral displacement due to near earthquakes compared to far earthquakes is 125% and 124% for the vertical and inclined micropile group in the loose granular structure and 15% and 13% for the vertical and inclined micropile group in the dense granular site, respectively. Also, the inclined micropile group shows almost similar performance in controlling horizontal displacements and better performance in controlling internal forces than the vertical micropile group.

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1- Introduction

Micropiles are piles with a diameter of less than 300 mm that are accompanied by light steel reinforcement and grout injection. Micropiles are used for a variety of purposes, including bearing axial and lateral loads, enhancing soil or foundation performance, and generally as part of a soil-micropile system, depending on the design purpose [1].

Numerous laboratory and numerical studies were conducted on the seismic performance of vertical and inclined micropiles. The study of Shahrour et al. (2012) and Ghorbani et al. (2013) confirmed that inclined micropiles have a completely positive effect on seismic performance and a significant reduction effect on the amount of shear and bending forces [2, 3]. In addition, using physical models, the seismic performance of the micropile group was studied on a laboratory scale by Jalilian et al. (2018). The study clearly showed the positive effect of micropile group performance, especially inclined ones [4].

The above studies indicate the efficiency of the micropile group and also show the important differences between farfield and nearfield earthquakes in the frequency content and the formation of surface deformations despite the inherent similarities. Also, the study of Moradi Moghaddam et al. (2021) using laboratory physical modeling showed that the different percentages of relative densities in granular soils could cause a significant difference in the load-bearing capacity of micropiles [5]. Based on the facts, two types of granular elastoplastic soils with different mechanical characteristics, including loose granular soils (Dr = 40%) and dense granular soils (Dr = 80%) were reinforced by two groups of vertical and inclined concrete micropiles with linear elastic behavior. The responses of the micropile group, including horizontal displacement, acceleration and internal forces, were examined and compared and important points were presented for using the micropiles group for seismic improvement in areas close to and far from the epicenter.

2- Materials and Methodology

A homogeneous soil mass consisting of eight-node Brick u-p elements was considered for soil modeling. The nodes of this element have four degrees of freedom, which includes three degrees of freedom for transitional movement and one degree of freedom for pore water pressure. Pressure Depend Multi Yield (PDMY) material was used to define granular soil

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Table 1. Characteristics of granular soil [7]

Parameters	*Nevada Sand*	
Relative density (%)	40	**80**
Saturated mass density ρ (ton/m^3)	1.96	**2.03**
Reference shear modulus *Gr* (MPa)	46.2	**88.4**
Reference bulk modulus *Br* (MPa)	123.3	**236**
Friction angle φ°	32	**36.5**
Peak Shear Strain γmax	0.1	**0.1**
Void Ratio	0.73	**0.618**

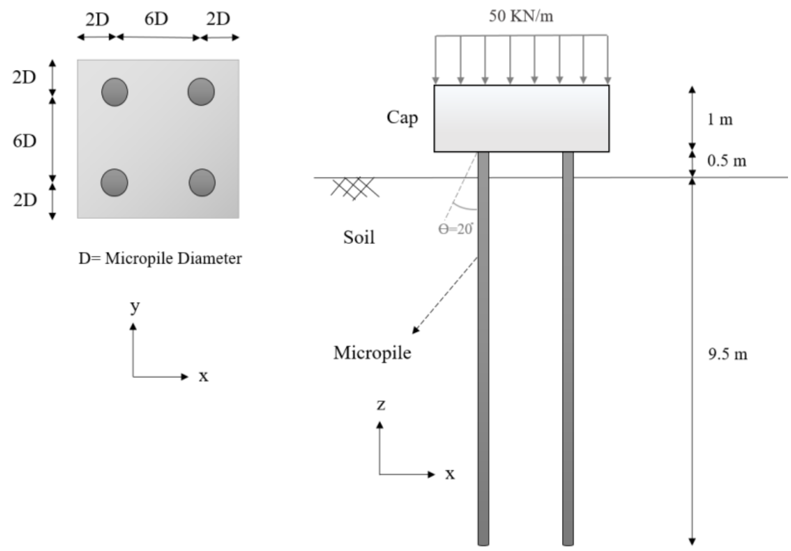

Fig. 1. Details of modeling of micropile and concrete cap

materials [6]. Two types of granular materials with different mechanical properties were considered for soil block. Soil characteristics are given in Table 1.

Displacement-Based Beam-Column element was selected for micropiles and cap modeling. This element has the ability to produce beam-column with prismatic or non-prismatic sections by considering the effect of plasticity. The micropiles are made of concrete and have a diameter of 0.2 meters

According to the research topic, two categories of farfield and nearfield earthquakes are required to apply earthquakes to the model floor (bedrock). For this purpose, farfield and nearfield earthquakes, according to the shear wave velocity (Vs30) based on the classification method of Verdugo et al. (2018) [8], were selected from the proposed accelerogram of P695-Femma instruction [9]. Thus, the farfield and nearfield records of the Imperial Valley, Kocaeli, and Chi-Chi earthquakes were considered for the loose site and the farfield and nearfield records of the Northridge, Loma Prieta and Landers earthquakes were considered for the dense site.

3- Results and Discussion

The results show a significant effect of nearfield earthquakes on increasing lateral displacement in both vertical and inclined micropile groups compared to farfield earthquakes in the loose granular sites. The increase in lateral displacement due to nearfield earthquakes compared to farfield earthquakes is 125% and 124% for the vertical and inclined micropile group in the loose granular site and 15% and 13% for the vertical and inclined micropile group in the dense granular site, respectively.

In dense granular sites, nearfield earthquakes have increased lateral displacement in both vertical and inclined

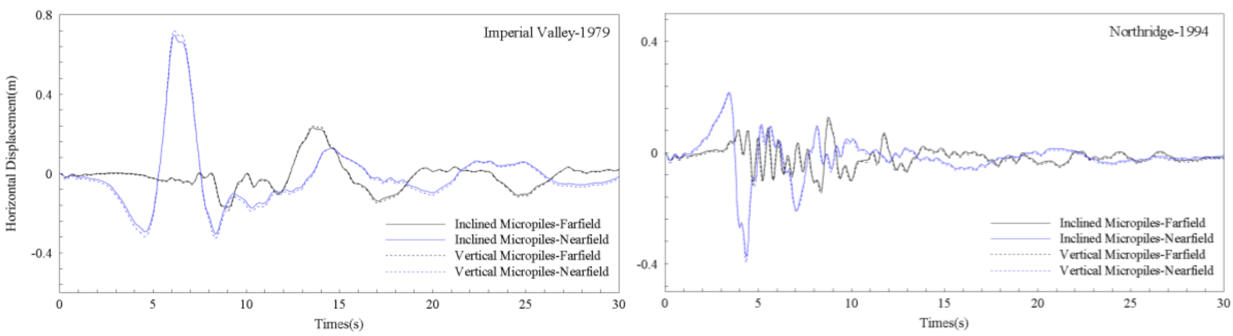

Fig. 2. History of horizontal displacement of the vertical and inclined micropile group
(a): Loose granular site (b): Dense granular site

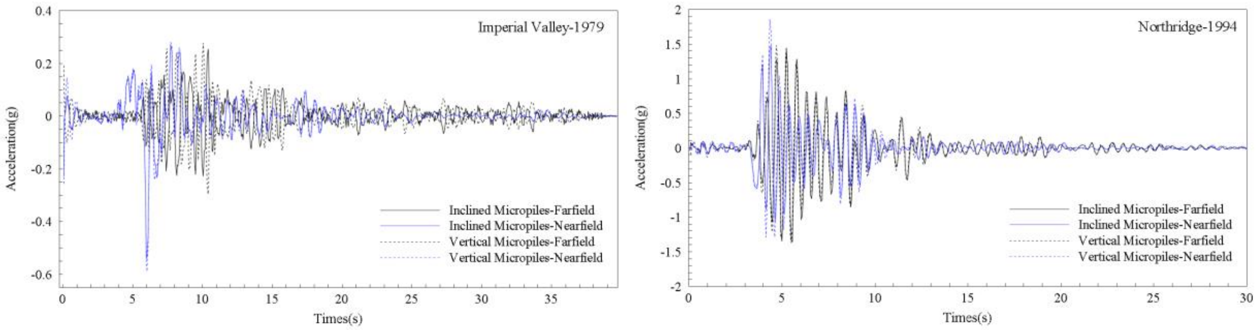

Fig. 3. Acceleration history of vertical and inclined micropile group
(a): Loose granular site (b): dense granular site

micropile groups, which is far less than similar values for the loose sites. The ratio of values in the two groups of earthquakes shows that the effect of nearfield records on increasing lateral displacement in loose granular soils is on average about 96% and 98% more than dense granular soils for vertical and inclined micropiles. It seems that the increase of Riley damping which is due to the increase of shear wave in the dense site, plays a decreasing role in the enhancing effect of near-fault records on the lateral displacement of the micropile group.

In general, the increase in maximum acceleration of the vertical and inclined micropile group due to near-fault records in both loose and dense sites is significant and the effect of these records should be considered in the design of the soil-micropile-cap system. The increase in acceleration due to nearfield earthquakes compared to farfield earthquakes is 35% and 33% for the vertical and inclined micropile group in the loose granular site and 36% and 21% for the vertical and inclined micropile group in the dense granular site, respectively.

The acceleration of the vertical and inclined micropile group in the dense sites and in nearfield earthquakes recorded larger numbers. This seems reasonable considering the larger input acceleration in these earthquakes and confirms the results of previous studies in increasing system acceleration due to increased input acceleration [4].

4- Conclusion

Since the effect of three components affecting the system, including the type of site, the type of input record and the micropile reinforcement model was seen simultaneously in this study, it was possible to make comprehensive conclusions about the seismic performance of the micropile group in a variety of possible conditions during farfield and nearfield earthquake.

1) The results showed that the studied parameters in the micropile group including displacement, acceleration,

bending and shear force are a function of one of the three characteristics of site type, input record and reinforcement model and other factors have less effect on responses. In a general view, it can be said that the shear and bending forces of micropile depend on the type of reinforcement and the type of site and input earthquake have less effect on these responses while the acceleration and displacement of the system are more affected by the site type and input earthquake.

2) The effect of nearfield earthquakes on the increase of lateral displacement and acceleration in both vertical and inclined micropile groups is significant especially in loose granular sites, which have weaker mechanical properties. Therefore, the effect of near-fault records should be considered in the design and deformation control of foundations or sites reinforced with a group of micropiles.

3) The acceleration changes of the vertical and inclined micropile groups are a function of the two components of the earthquake, input acceleration and magnification coefficient of the site. The system acceleration recorded larger numbers in dense sites and in nearfield earthquakes and in conditions of reinforcement with vertical micropile groups.

4) From the point of view of comparing the performance of vertical and inclined micropile groups in two granular sites, it can be concluded that the inclined micropile group has almost the same performance in controlling lateral displacements and system acceleration and better performance in controlling internal forces than vertical micropile group. Also, the results showed that the performance of both micropile groups is better in reducing acceleration and lateral displacement in dense sites. This feature was more clearly observed in inclined micropiles.

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