

# Influence of using Micropiles as Retrofitting Method for Bridge Shallow Footing: Numerical Study



Hassan. A. Abas, M.A. Ismaeil

**Abstract:** *Seismic retrofitting of the existing bridges, which was not properly constructed for seismic loading, is necessary. This paper examines and evaluates the effect of using micropiles as retrofitting method to improve seismic performance for bridge shallow footing. Numerical simulations using Plaxis-3D have been performed to study the effect of using micropiles to mitigate the seismic hazard and enhance the deformation characteristic of bridge shallow footing. Displacement and acceleration induced by seismic loading before and after retrofitting were assessed and compared. The results showed a significant influence of the micropiles on the control of the displacement and acceleration during the seismic period.*

**Keywords:** *Dynamic analysis; Micropile, Plaxis-3D, Shallow footing, Seismic retrofitting.*

## I. INTRODUCTION

Bridge structures are becoming extremely prevalent due to rapid population growth, especially in urban areas. Consequently, the design of such constructions must include not only static loading, but also seismic loading. Higher ground accelerations due to seismic have not only influenced the bridge structure in terms of increased lateral pressure but also contributed to a greater potential for geotechnical seismic hazards, involving liquefaction, embankment instability and seismic settlement, which could potentially have an impact on the stability of bridge structure [1]. The bridge response was highly dependent on amount of stress generated by earthquake, bridge types, foundation types and the engineering properties of underlying soil [2]. Seismic retrofitting of the existing bridges, which was not properly constructed for seismic loading, is essential. The seismic resistance of bridge is usually strengthened by the retrofitting of its piers and abutments, but the foundations must also be retrofitted. The techniques available for retrofitting the bridge foundation may be classified into two parts: first, ground improvement to reduce geotechnical seismic risks, and second, rehabilitation of the foundation to enhance the efficiency of the foundation [3]. Various ground improvement

is available such as: 1) Vibro-compaction, 2) jet grouting, 3) Stone Columns, 4) deep soil mixing, and 5) removal and recompaction soil around foundation. Ground improvement techniques are usually invasive, require a large site to operate and create considerable amounts of vibration. However, most of them have many limitations and is very costly and may not be feasible in limited spaces where traffic has to be maintained [1]. On the other side, numerous foundations retrofit methods of the foundation are considered, such as: 1) elongation footing size, 2) underpinning with higher capacity piles, and 3) elongation footing size with micropiles. The extension of the foundation with new piles was expensive and the construction of the pile could cause a traffic disturbance [4]. In certain cases, insufficient space under the bridge deck slab makes it impossible to drive new piles to retrofit the bridge foundations. Seismic retrofitting of the existing bridge foundation is a method of work might be done under restrictive conditions of execution because the bridge girders are low [5]. Hence, micropiles are progressively being used to retrofit bridge foundations where only limited space is available. This situation was often extremely critical in the choice of the retrofit process. The micropiles has a wide range of construction techniques that can satisfy the small access available under bridge [6]. In addition, the system of micropiles can provide tension and compression capacities. [7]. This is important for the seismic retrofit of the foundation because an uplifting resistance is necessary due to seismic hazard. Previous numerical studies have almost exclusively focused on improving bearing capacity and reducing settlement using micropiles. Moreover, few studies have focussed on seismic behaviour of micropiles. The literature review shows that the seismic behavior of utilizing micropiles as a retrofitting method for existing shallow foundation is not fully understood. Kishishita et al. (2000) conducted a two-dimensional finite element analysis of vertical and inclined micropiles subject to seismic load. The findings show that the vertical micropiles were horizontally displaced more than the inclined micropiles [8]. Shahrour et al. (2001) performed a three-dimensional finite element analysis of a single micropile as well as a micropile group utilizing PECPLAS software. These micropiles were modeled on a homogeneous soil layer that overlays a rigid rock. Their findings show that as the mass of the superstructure increased, the horizontal displacement, the shearing force, and the bending moment of the micropile head increased. The findings also show that the bending moment rises as micropile spacing increases [9]. Wang et al.

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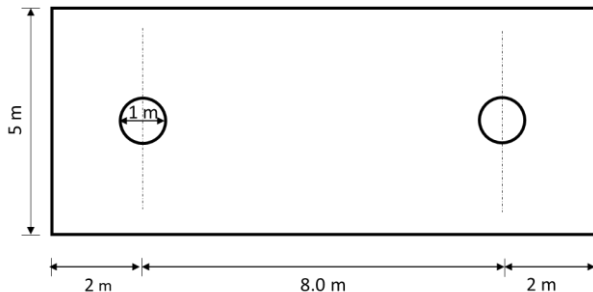
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(2009) used PLAXIS software to conduct analysis of the impact of micropile strengthening soil under seismic load. It has been found that the increased amplitude of the acceleration increases horizontal displacement, axial force, bending moments, and shear force.

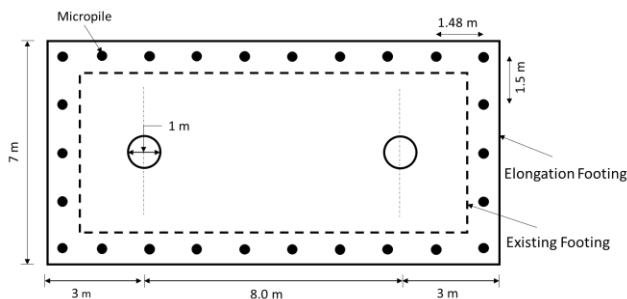
The analysis also shows that Rayleigh damping causes a decrease in seismic horizontal displacement and acceleration of micropile cap. [10]. Wang and Han (2010) performed a numerical analysis to examine the effect of micropile inclination and seismic magnitude on micropile seismic behavior on liquefiable soil. The research was conducted out by the FLIP program. The findings showed that the greater the inclination of micropile the smaller horizontal displacement and bending moments [11]. In this paper, the micropiles and bridge shallow foundation responses were investigated before and after retrofitting. A series of full-scale models using PLAXIS-3D were used to simulate the actual shallow foundation behaviour and construction process.

## II. MODEL GEOMETRY

The field data from the as build drawings were initially used to develop 3D geometric model to represent the actual construction process. The design data considered in this study were collected from the existing bridge constructed west-north Saudi Arabia. Fig.1. illustrates the layout of the foundation and piers constructed at depth 2 m from ground surface. Seismic strengthening of existing footing by installation numbers of micropile Type B and elongation footing size as shown in Fig.2. All micropiles will be embedded into extended concrete footing that will be monolithically connected to the existing footing using new concrete ring around existing footing.



**Fig. 1. Existing Foundation before Retrofitting.**

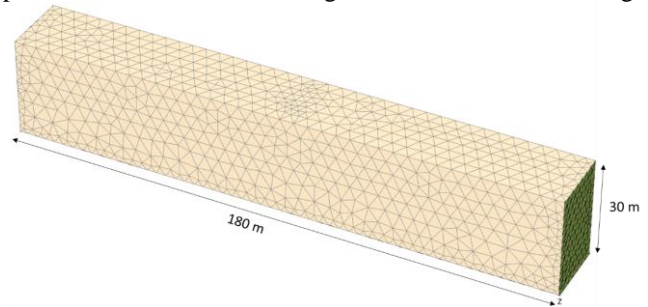


**Fig. 2. Strengthening of existing footing by installation numbers of micropiles and elongation footing size.**

## III. NUMERICAL MODELLING

A series of numerical models using non-linear time history dynamic analysis was performed using Plaxis 3D software. A bridge shallow footing is idealized as a three-dimensional

model before and after installation of micropiles. The foundation rest on relatively stiff silty sand. The overall depth from ground surface to the bedrock is 30 m. A sufficient distance is given to the vertical boundaries on both ends to mitigate the effects of the boundary condition. Based on previous studies done by Brandt (2014); Magar (2016), the most appropriate boundary condition for dynamic analysis is chosen [12], [13]. Popular practice is to have three times the depth of the soil profile (3H) on each side. The model has a length of 90 m on each side (total 180 m) and a depth of 30 m. The groundwater table is assumed at depth 5 m. The finite element model geometry used for the analysis is shown in Fig.3. Mesh refining was set to fine the whole volume of soil layers and refined further in the zone around the foundation. The selected points along the model were used to detect the performance of shallow footing before and after retrofitting.



**Fig. 3. Finite Element Model.**

In this analysis, the Hardening soil model with small strain stiffness (HS small) model was chosen to define the soil layer. HS small model captures the far field seismic effect better than any other model in PLAXIS [14]. The soil characteristics are shown in Table-I. The foundation is simulated as plate elements and the micropiles are simulated as embedded beam elements. The materials properties of foundation and micropiles are given in Table-I I and Table-I I I.

**Table- I: Soil Parameters for HS small Model.**

Parameter	Unit	Value
Soil unit weight, saturated ( $\gamma_{sat}$ )	$kN/m^3$	20
Soil unit weight, unsaturated ( $\gamma$ )	$kN/m^3$	18
Secant stiffness in standard drained triaxial test ( $E_{50}^{ref}$ )	MPa	30
Tangent stiffness for primary oedometer loading ( $E_{oed}^{ref}$ )	MPa	36.01
Unloading/reloading stiffness ( $E_{ur}^{ref}$ )	MPa	110.8
Stress-level dependency power (m)		1
Cohesion (effective) ( $C'$ )	KPa	5
Angle of internal friction ( $\phi$ )		28
Dilatancy angle ( $\psi$ )		0
Shear strain at $G_s = 0.722 G_0$ ( $\gamma_{0.7}$ )		$0.15 \times 10^{-3}$
Shear Modulus at very small Strain ( $G_0^{ref}$ )	MPa	100
Poisson's Ratio ( $\nu_{un}$ )	-	0.2

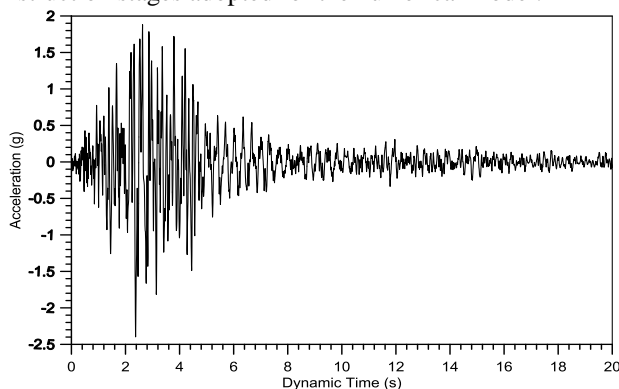
**Table- I I: Material Properties of concrete foundation.**

Parameter	Unit	Value
Young's modulus, E	KPa	$30 \times 10^6$
Footing thickness, D	m	1
Unit weight, $\gamma$	$kN/m^3$	24
Raleigh Damping, $\alpha$	-	0.2320
Raleigh Damping, $\beta$	-	$8 \times 10^{-3}$

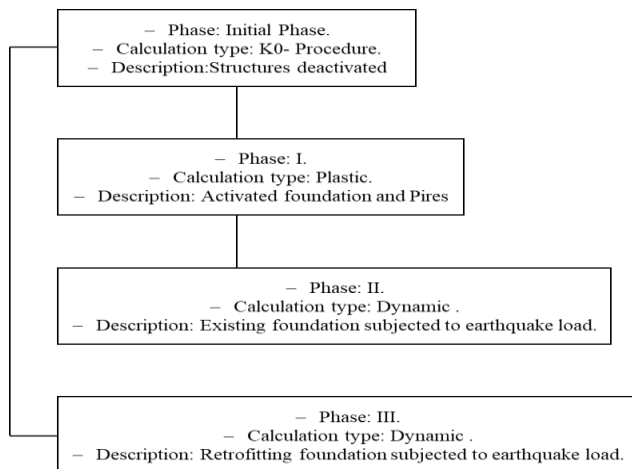
**Table- I I I: Input parameters of micropile Elements.**

Parameter	Unit	Value
Embedded Beam Element		
Young's modulus, E	KPa	$30 \times 10^6$
Unit weight, $\gamma$	$kN/m^3$	25
Diameter, d	m	0.25
Anchor Element		
Axial Stiffness, EA	kN	$650 \times 10^3$

The acceleration of earthquake is selected from the default acceleration data file in the Plaxis 3D software as shown in Fig.4. At the bottom of the model, the earthquake load is performed as a dynamic multiplier [14]. The bottom boundary of the model is considered to be rigid, so the seismic signal stuck in the soil and unable to move through the underlying boundary. The x-direction of the surface displacement of the bottom boundary is prescribed with a uniform value of 0.5 m. A series of dynamic simulations have been implemented for foundation before and after retrofitting, Fig.5. show the construction stages adopted for the numerical model.



**Fig. 4. Time accelerogram of earthquake Plaxis 3D Code.**



**Fig. 5. Construction Stages adopted for the numerical model.**

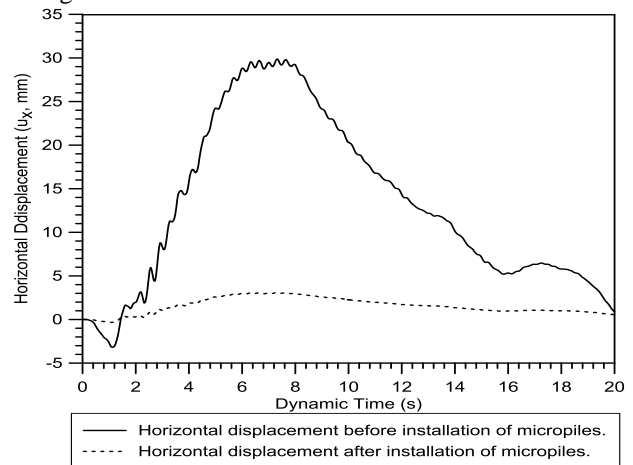
#### IV. ANALYSIS AND RESULTS

In order to obtain the response of the shallow foundation

before and after retrofitting, acceleration, horizontal displacement and internal force in micropiles were presented and discussed in this section.

##### A. Horizontal Displacement

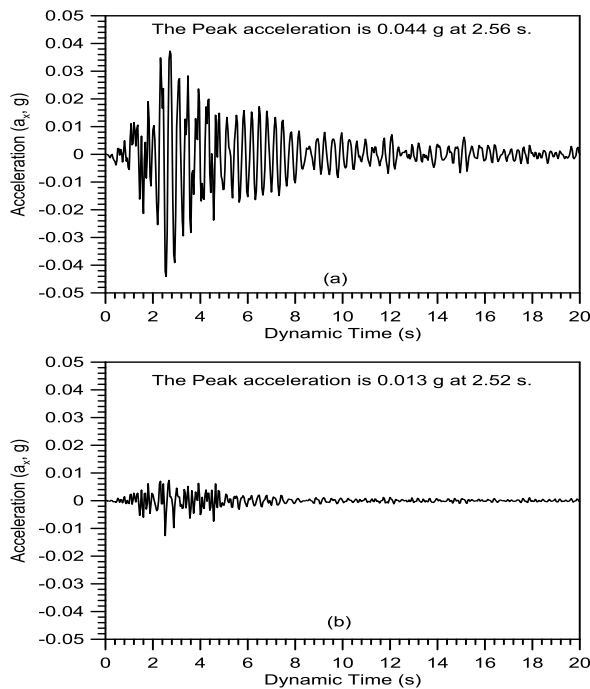
The change of the horizontal displacement with seismic time at the top point on footing model was determined before and after installation of micropiles. Fig.6. demonstrates the efficacy of the micropiles in minimizing horizontal displacement during the seismic time. The maximum horizontal displacement of the foundation before retrofitting is found 29.88 mm that occurs at  $t = 7.32$  s, after installation micropiles horizontal displacement decrease to 3.067 mm that occurs at  $t = 7.28$  s. It was found that the micropile could substantially reduce the horizontal displacement of the footing; the reduction in horizontal displacement is 89.7 percent. This behaviour is exhibited that, the presence of micropiles along the foundation edge is a successful method to increase the stability of the foundation during earthquake loading.



**Fig. 6. Horizontal displacement at the top point of footing before and after installation of micropiles..**

##### B. Acceleration

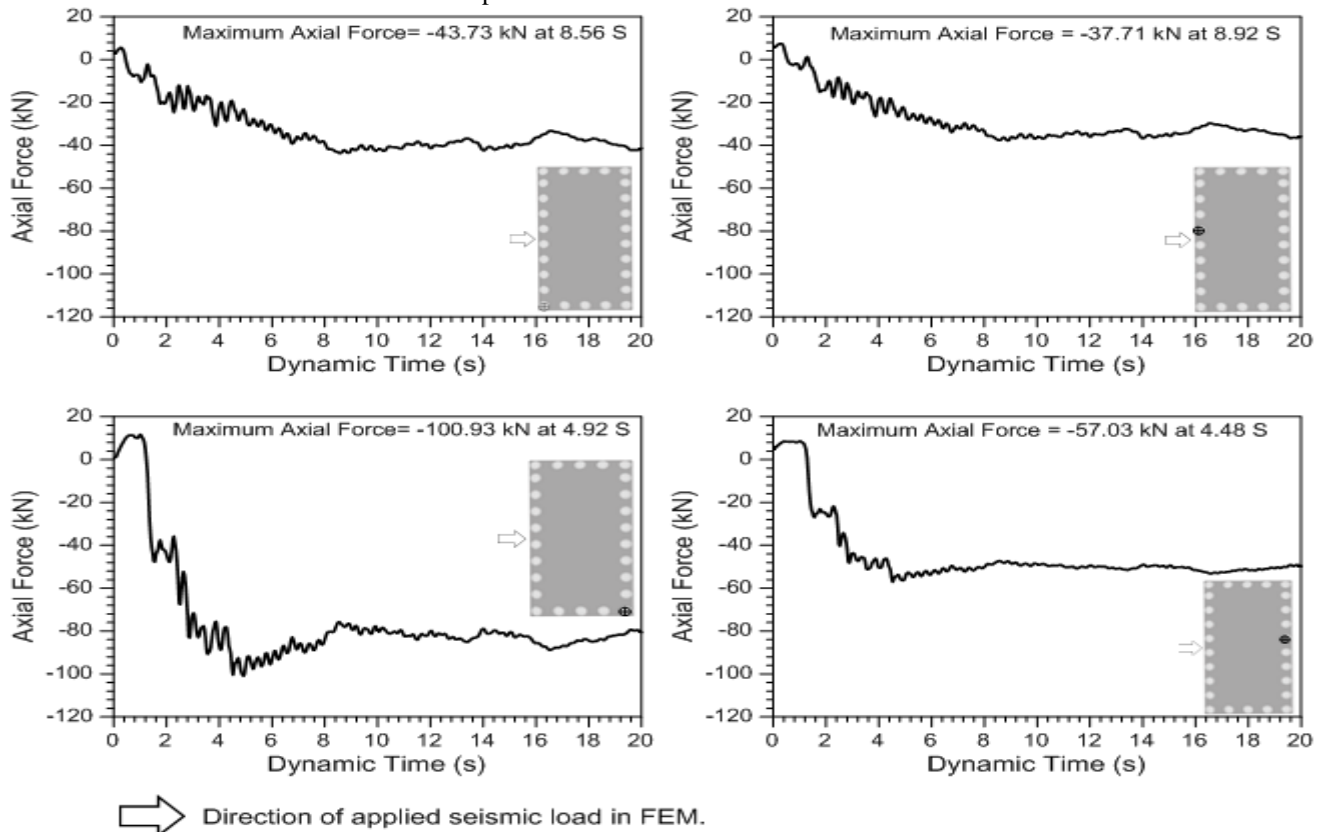
Earthquake acceleration was applied at the bottom boundary and the output acceleration was measured at the control point chosen at the top of the footing. The relationship between the maximum acceleration of the foundation before and after retrofitting was measured as shown in the Fig.7. It is observed that the acceleration of the foundation was significantly reduced in comparison to the situation prior to the installation of micropiles. The Peak acceleration at the top of foundation is 0.044 g after 2.56 seconds, while after installation of micropiles is 0.013 g after 2.52 seconds. Compared to the foundation without retrofitting, the reduction in acceleration is 70 percent. The micropiles increases the interaction between the shallow footing and the underlying soil, hence the deformation behavior has been improved. Also, the shallow footing and the confined soil between the micropiles acted as a coherent volume that improves the stability of the foundation and absorbs the seismic hazard. This coherent volume restricts the acceleration of the amplification from arising.



**Fig. 7. Acceleration versus dynamic time at top of footing, (a) for existing footing and (b) after installation of Micropiles.**

## C. Axial Force in Micropiles

Fig. 8. show axial force in selected micropile with seismic time. It can be seen that the axial force in micropiles fluctuates



**Fig. 8. axial force in selected micropile during seismic time.**

between tension and compression at the start of the earthquake. Subsequently, the micropiles have tension force only to prevent uplifting deformation. The high flexibility of micropile is important for the seismic retrofit because an uplifting resistance is necessary due to seismic events. The location of the micropile under a shallow foundation affects the number of axial forces. In other words, seismic loading is not equally distributed in the micropiles group. The results showed that the axial force in the corner micropiles is higher than that in the middle micropile. A similar pattern of findings was obtained from the experimental data of Juran et al. (2001) and from the numerical analyzes of Shahrour et al. (2001), which strongly indicates that the loads taken from the corner micropiles are higher than those taken from the middle micropile [9], [15].



## V. CONCLUSION

In this paper, three-dimensional finite element modeling was conducted to evaluate the effect of using micropiles to mitigate the seismic hazard and improve the deformation characteristic of bridge shallow footing. The earthquake acceleration is chosen from the default data file in Plaxis 3D software. Considerable attention has been given to horizontal displacement and acceleration caused by seismic loading before and after retrofitting, as well as a change in axial force in the micropiles during the seismic time. The proposed method is a seismic retrofit technique which can be considered in the shallow bridge retrofit project, especially if the site is very restricted. The advantages of high-tension capacity of tieback anchors and compression and lateral capacity of traditional piles are combined with the Micropile method. This is one of the reasons why micropillars are the most appropriate method for retrofit construction.

The results showed a significant impact of the micropiles on the control of the acceleration during the seismic period. It is noted that the acceleration of the footing was substantially reduced relative to the situation prior to the implementation of the micropiles. Compared to a non-retrofit foundation, the decrease in acceleration is 70 percent.

Once the micropiles were implemented with elongation of existing footing, the lateral displacements decreased by up to 89.7 percent. This behavior shows that the existence of micropiles along the edge of the footing is an effective method to increase the stability of the footing during seismic loading. The micropiles increase the stiffness and the interaction between the shallow footing and the underlying soil, thus enhancing the deformation behavior. The shallow footing and the confined soil between the micropiles also operate as a cohesive volume that enhances the foundation's stability and absorbs the seismic hazard. The location of the micropile under a shallow foundation affects the amount of axial forces. The results showed that the axial force in the corner micropiles is higher than that in the middle micropile.

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