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Parametric Analysis of Effective Factors on the Seismic Rehabilitation of the Foundations by Network Micropile

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***Abstract*—**The main objective of seismic rehabilitation in the foundations is decreasing the range of horizontal and vertical vibrations and omitting high frequencies contents under the seismic loading. In this regard, the advantages of micropiles network is utilized. Reduction in vibration range of foundation can be achieved by using high dynamic rigidness module such as deep foundations. In addition, natural frequency of pile and soil system increases in regard to rising of system rigidness. Accordingly, the main strategy is decreasing of horizontal and vertical seismic vibrations of the structure. In this case, considering the impact of foundation, pile and improved soil foundation is a primary concern. Therefore, in this paper, effective factors are studied on the seismic rehabilitation of foundations applying network micropiles in sandy soils with nonlinear reaction.

***Keywords*—**Micropile network, rehabilitation, vibration, seismic load.

I. Introduction

EVALUATION of site response is one of the most important issues in geotechnical earthquake. Every earthquake may cause some irregular damages and these irregularities indicate the features of earthquake source, seismic wave dissemination, type of structure and situations and site response. Site's seismic response is remarkably affected by conditions and features of the site itself. Therefore designing the foundation is dependent on axial loads, critical stiffness and lateral stresses and it is mostly dependent on the soil.

Generally in order to control seismic vibrations in site especially for problematic soils, we get use of soil reinforcement methods. By having micropile injected in the site, natural frequency of micropile system and the soil will be increased due to increase of their stiffness. As a result, we can decrease vibration amplitude in foundation, through type of foundation or dynamic hardness modulus enlargement such as foundation depth or improved soil block [10]. Shahrour et al indicated that structure's frequency is the result of inertial interaction between the soil system and the structure. When frequency is increased or is close to frequency loads of the soil, lateral shift, bending moment and shear force will be increased topside of the micropile [2]. These results show the importance of structure's frequency in designing the micropile foundation system.

In soft soils, if the construction is located on foundation with low-dynamical hardness modulus, we may witness high inertial interaction. And if the structure is located on deep foundations, due to high dynamic stiffness, we may not have any inertial interaction [5]. Deep foundations have low inertial interaction in horizontal direction compared to the vertical direction in which the reason is petrifaction changes around the micropile.

Construction on instable, heterogeneous, or soft grounds has got many risks; for this reason, most of the time the utilized models are complicated and there are no easy ways of calculation for them. Static studies cannot be applied in solving such problems; as a result, it is necessary to get use of parametric studies in order to identify unfavorable conditions. Wong 2004 indicated that structure's response to seismic loads is dependent on features of the site, external loads, mechanical features of surrounding soil and the structure itself [17].

Generally, in order to identify structure's vibrations, we need to consider and compare three different models:

1. Free field effect
2. Inertial interaction between the soil and foundation
3. Inertial interaction

Decrease of vibration amplitude in the foundation can be gained through high stiffness dynamic moduli for example in deep foundations such as pile and micropile foundations, and improved soil block. It is suitable to get use of vertical micropiles in order to decrease vibration amplitudes caused by vertical excitations and also it is suitable to use inclined micropiles for decreasing vibration amplitudes caused by horizontal excitations. In short, the purpose of this article has been identifying an angle to which inclined micropile causes decrease of vertical and horizontal vibrations in the structure.

The purpose of this research has been identifying a strategy for decreasing vertical and horizontal vibrations in the structures. For this purpose Flac 3D finite-difference software has been used to simulate dynamic behavior of the soil system and the structure. Through studying effective parameters in decreasing seismic vibrations of structures located on surface foundations, micropiles and micropile foundations, this article has attempted to identify positive and negative points in these

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kinds of foundations, and by considering their advantages and disadvantages, it is going to introduce the most suitable option for decreasing vertical and horizontal vibrations in structures.

II. Site Modeling Hypotheses

In order to analyze the model, we got use of Flac 3D finite-difference software. The model was formed of one-layer sandy site in which the utilized soil is indicated in Table I. The structure which has been used in the model represents a tall structure with 10 meters altitude above the foundation. For the sake of modeling the structure we utilized the system of one degree of freedom (pillar and mass).

The mass applied on pillar was 5e5 kg, and it was installed in 10 meters altitude on the pillar. Fig. 1 indicates acceleration of applied earthquake to the model of Bam (2003) earthquake. The interface features of lower layer of foundation with soil are indicated in Table II.

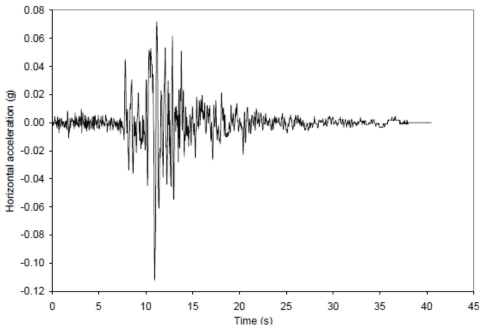

Fig. 1 Horizontal acceleration of the Bam 2003 earthquake

Due to the fact that bending moment is predominant in tall structures, the shift of topside of the structure might be more. For controlling and decreasing this shift, we got use of network micropile under the foundation with axis of the center of foundation. Network micropile is located around a circle with 2 meters diameter, 8 times in degrees of 135, 90, 45, 0, 180, 225, 270 and 315. The length of the utilized micropile is 10 meters in inclined angles of 20, 30, 40, 50 and 60 degrees to vertical axis.

TABLE I
Property of Soil

Symbol	Property		
ρ	Density	2500	kg/m3
Bu	Bulk	1.00E+08	Pa
G	Shear	4.60E+07	Pa
C	Cohesion	2.00E+06	Pa
T	Tension	1.00E+06	Pa
f	Friction	4.50E+01	degree
di	Dilation	1.00E+01	degree

III. Numerical Model of the Soil in Structure's Micropile

In fact, the following parameters are needed for having a complete and general definition of a site: shear wave velocity, Poisson's ratio, soil density, shear stiffness decrease ration, amplitude changes of secant modulus, damping, radius of under-studying region, and plastic modulus of the soil.

According to Wilson and Ghosh, if the radius of under-studying region from the center of the structure is 3-4 times the radius of the foundation in horizontal direction and 2-3 times the equivalent radius of the foundation in vertical direction, the effect of the reflection of seismic waves will be so trivial into the model. As a result, according to the dimension of rectangular studied foundation which is 10 in 8 meters, by getting use of (1), equivalent radius of rectangular foundation of the site in horizontal direction is 80 meters and in vertical direction is 30 meters.

$$r = \sqrt{\frac{B \times L}{\pi}} \tag{1}$$

Fig. 2 of the site indicates one-degree-of-freedom system and network micropile used in the model.

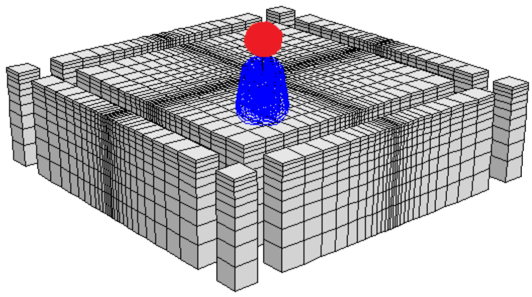

Fig. 2 Soil model of structure's micropile (one degree of freedom)

The purpose of applying network micropile is to change the inclination angle of micropile and to put the foundation under pressure in order to create dilation state and enough friction all over the lower layer of the foundation [4]. In this condition, sand effectively occupies all over the micropile and wall friction of the micropile will be increased, and as a result, horizontal shift of the foundation especially in topside of it will be decreased. In this case, by changing the angle of inclination of micropile we can control the shift of topside of the structure according to its height and lowness, and also applied acceleration to the structure. In Table III, features of the structure's pillar with one degree of freedom and applied micropile in the model are indicated.

IV. The Changes of Shear and Damping Moduli of the Site Affected by Applying Micropile

In general, by applying injection pressure of cement slurry into soil layers of the lower surfaces of the foundation, cement slurry penetrates in between soil grains and make the soil stiffer; hence soil strain will decrease compared to the state before injection. By hardening and decreasing soil strains, changes coefficient of shear modulus will be decreased and the average of seismic acceleration will increase significantly, but by increase or decrease of soil damping changes coefficient, the acceleration of the earthquake will have very little changes [11]. Also by changing Poisson's ratio of soil we will witness no change in the average of seismic acceleration.

Therefore the only parameter by which through changing it we can increase the average seismic acceleration in the soil is shear modulus. By increasing shear modulus we can increase seismic acceleration in the soil and decrease site's PGA.

TABLE II
PROPERTY OF INTERFACE SOIL-FOUNDATION

Symbol	Property		
Kn	Normal Resistance	1.66E+08	Pa
Ks	Shear Resistance	1.66E+08	Pa
C	Cohesion	1.34E+06	Pa
T	Tension	1.00E+06	Pa
f	Friction	2.20E+01	degree

Generally, increasing damping changes has no effect on the average of transfer function. And it is only the increase of changes in shear modulus that causes decrease in the average of transfer function. Shear modulus depends on fine grain percentage (more than 30%), grains shape, stress between grains and frequency loads; damping of the soil depends on friction between grains, the force between grains, soil adhesion and vacuolar adhesion resulting from fluids [13].

By applying micropile, due to increase of confining stresses resulting from injection pressure, the soil will turn from isotropic to non-isotropic state, which leads to increase of shear modulus [12]. Fig. 3 indicates a 3D profile of network micropile in compressive state.

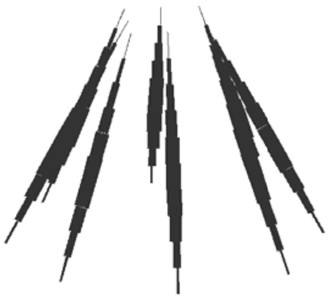

Fig. 3 3D profile of network micropile in compressive state

By increasing injection pressure and decreasing distance between the micropiles, the amplitude of shear strains will be decreased and the effective vertical stress and relative density in the soil will be increased. It is worth noting that shear modulus in soils with 5% or more fine grain will be increased by having frequency loads increased [13]. Increasing frequency leads to decrease of shear strains and more cohesion in the soil and finally leads to increase of shear modulus of the soil [15]. Small loading frequencies create large shear shifts in each loading cycle. When frequency is increased, shear strains will be decreased. The more the number of loading cycles, the more increase we shall witness in shear modulus. Also the effective vertical stress and density ratio increase through having increase in number of loading cycles [19].

The velocity of shear wave in the soil is considered to be a function of confining stresses [14], porosity ratio and shear modulus of soil [13]. Therefore by increasing the pressure resulting from cement slurry injection and by decreasing the distance between micropiles, we can increase confining stresses and decrease the porosity ratio in the soil. This process can lead to increase of shear modulus, cycle shear stress and increase of shear wave velocity in the soil. Cyclic shear stress depends on density, confining pressure, stress history, grain structures, frequency loads, and cyclic shape of the wave [16].

TABLE III
PROPERTY OF MICROPILE AND COLUMN

Symbol	Property	micropile	column
ρ	Density	2200	2500
E	Elasticity	2.90E+10	2.50E+10
ν	Nu	0.3	0.3
D	Diameter	0.1	1.5
	Yeild comperssion	2.38E+05	-
	Yeild tension	2.38E+05	-
	Grout RESISTANCE	2.19E+08	-
	Grout cohesion	6.28E+03	-
	Grout friction	4.50E+01	-

V. The Effect of Wave Shape on Shear Modulus of the Site

In high confining pressures, shear modulus will be slightly affected by the wave shape, so that shear modulus in low confining pressures in sinusoidal waves is greater than triangular waves. The shape of sinusoidal and triangular waves has insignificant effect on shear and damping moduli; these amounts in sinusoidal state are greater than triangular one [13]. By increasing vibration magnitude, strain in soil is increased and shear modulus is decreased. The more the magnitude of the vibration, the more the soil stiffness will be decreased [23].

VI. The Stiffness of Soil System and Micropile Foundation

Generally, the stiffness of soil system and micropile is a function of elasticity ratio Ep/Es and micropile's angle of inclination [3]. Horizontal stiffness of the soil depends on deviation angle of pile which is sensitive to pile's narrowness ratio [1]. Generally, by increasing pile's angle of inclination to a given extent, shift in pile cap is decreased, and in contrast, bending moment and axial force are increased. It is expected that by applying micropile and decreasing the horizontal shift of the foundation, the amplitude of seismic vibration in soil is decreased; this depends on foundation type and the magnitude of dynamic stiffness modulus of the soil [9]. Therefore, horizontal response of the foundation is independent of pile type and depends on soil response. Horizontal stiffness of the foundation depends on elasticity modulus, Poisson's ratio, and size and shape of the foundation which include bottom surface, size and depth of the foundation, and micropile's diameter [20].

If we do not pay attention to the system of the group of inclined micropile and soil, problems may occur, which include: 1- decrease of the capacity of bending moment caused by tensile forces of seismic loads, 2- pile cap's angle of rotation caused by asymmetric application of inclined micropiles, 3- increase of structure's shear caused by the increase of system stiffness.

VII. Effective Parameters in Considering Micropile in Site

In non-linear analysis, using high-capacity micropiles as narrow piles will lead to the decrease of horizontal and vertical response of the foundation as well as the control of the response of its upper structure. This happens when micropiles put the foundation under pressure. Therefore, the main mechanism of soil interaction and micropile is soil resistivity in passive state. In Fig. 4, the distribution of passive pressure of the soil under the effect of dilation state and sand contraction is shown.

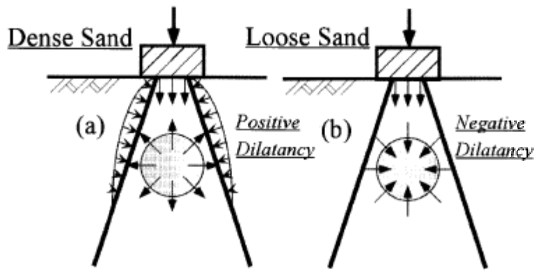

Fig. 4 Distribution of passive pressure of soil under the effect of dilation state and sand contraction

During transportation, micropile improves properties of its adjacent soil by injecting cement slurry [8]. In flexible micropiles with small diameters, relative motion between soil and micropile will increase the ultimate lateral pressure of the earth sufficiently, in which paying attention to the angle of placing micropile in soil, sand state, the distance between micropiles and sand can have a significant role in decreasing horizontal shift of the foundation and increasing lateral pressure between soil and micropile. The mechanism of load transportation is the frictional micropile, and it depends on the procedure, excavation and injection, the state of internal stresses, engineering properties of soil including density, permeability, shear stress, grain size, soil porosity, grout permeability, and the soil surrounding the pile [21].

VIII. Considering the Effective Parameters in Soil System Shift and Micropile Foundation

The effect of micropile group's shift in sandy soils depends on state parameter. This parameter is used to determine the ratio of porosity and confining stress of the soil, and without it, we cannot evaluate the condition of the site. Therefore, considering the plasticity of the soil for creating dilation angle by means of micropile for the purpose of increasing the friction between foundation's bottom surface and soil is very important. By increasing soil dilation angle due to the increase of wall friction, micropile shift along the pile is decreased, but in plastic soils, by considering dilation angle and narrowness of distance between micropiles, the plasticity around the pile is increased. By increasing soil plasticity, topside shift of the micropile will be increased as well. And the more the soil materials proceed from elastic state to medium and high non-linearity, the more the shift in micropile's topside will be. Therefore, by increasing the distance between micropiles in pile group, the system rigidity will be increased and site's PGA in plastic soils will be decreased.

Generally, micropile foundation shift depends on EP/ES ratio. Therefore, when elastic modulus of the micropile is greater than elastic modulus of the soil, rigidity in the site will be disoriented which leads to the increase of micropile's topside shift. Thus, the more the elastic modulus of the soil is increased, the more the amount of topside shift in micropile is decreased. And the more the elastic modulus of the micropile is decreased, the more the bending moment in micropile, which is created for compensating this shift, is increased. However, by increasing the distance between micropiles, system rigidity is increased, and subsequently, the enlargement of micropile shift is decreased and bending moment is increased. Fig. 5 shows the effect of increasing elastic modulus of the micropile relative to the elastic modulus of the soil on the increase of shift in micropile's topside. In dilating soils, more use of micropiles with lesser diameters is much better than use of less number of micropiles with more diameters [18]. In this case, using more micropiles will decrease the bending moment in each micropile. But in general, in soils with no adhesion, for an excitation frequency, the more the distance between micropiles is decreased or the more the micropiles' diameter is increased, the more the bending moment and micropile group's shift is decreased. Increasing micropile flexibility will also increase the shift in micropile topside.

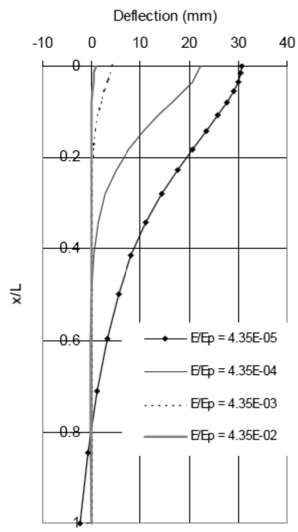

Fig. 5 Effect of increasing micropile's elastic modulus relative to the elastic modulus of the soil on the increase of shift in micropile's topside

Diameter and distance between micropiles have a very significant effect on transportation capacity of the foundation [26]. The more the diameter of the micropile is decreased, the more the shift in micropile topside is decreased. Since the diameter of the micropile is small, there is no bending strength in micropile. Therefore, this parameter is only dependent on micropile diameter and the thickness of steel sheath. Increasing micropile diameter will increase the contact surface of the micropile with soil, and because damping in soil is of radiation damping type, damping ratio will be increased. This kind of damping is dependent on excitation frequency as well, and will be increased by increasing frequency.

IX. Considering the Effect of Micropile on the Interface Properties of Soil and Foundation

In micropile foundations, by increasing subsidence, the friction between soil and the lower surface of the foundation will be increased, and subsequently, the transportation capacity is increased [22]. The more the angle of inclination of micropile is increased, the more the horizontal transportation capacity will increase. By increasing the inclination angle of micropile group, modulus of horizontal response of the lower soil of the foundation is increased, but the modulus of its vertical response is decreased. In micropile foundations, since micropiles tolerate the major load of the structure, it will not allow more loads and subsidence to the foundation [6]. As a result, the friction between foundation's bottom and sand will not be expanded fully, and the modulus of the soil horizontal response is less than the modulus of the vertical response in surface foundation. Therefore, in designing micropile foundation, by appropriate distribution of load between foundation and micropile we can allow the foundation to have sufficient subsidence so that the friction between foundation and soil which covers a large area is expanded along the foundation.

X. The Effect of Micropile's Angle of Inclination on Horizontal Shift of the Foundation

When the angle of inclination of micropile is increased, lateral stiffness, bending moment and axial force are increased, but shear force and lateral acceleration in micropile's topside are decreased [7]. In this case, lateral pressure coefficient changes from K0 to Kp, which prevents micropile's topside shift. Generally, network micropiles increase the horizontal component of soil resistivity [17]. Fig. 6 shows the distribution of soil lateral pressure on network micropile resulting from applying bending moment into pile cap.

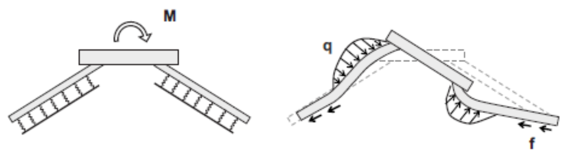

Fig. 6 Distribution of soil lateral pressure on network micropile resulting from applying bending moment

XI. The Effect of Loading Angle on Transportation Capacity of Micropile Foundation

Vertical loading will have more transportation capacity in vertical micropile group than network micropile group. But in horizontal loading, network micropile group will have more transportation capacity than the vertical group [24]. Furthermore, when the inclination angle of applied loads' consequence to foundation is increased, horizontal transportation capacity of the foundation is increased as well, and the horizontal shift of the foundation is decreased, but this increase in the angle of inclination will lead to decrease of the modulus of horizontal and vertical responses in micropile foundation [25].

XII. Considering Horizontal Shift and the Angle of Rotation of Tall and Short Structures by Applying Micropile

In tall structures, due to the increase of their height, overturning moment is dominant over all other forces, while in short structures, shear inertial force and pile cap rotation will be dominant over shift [25]. Due to the rotation in pile cap, bending moment will have no significance. Fig. 7 shows the effect of structure's height and lowness on shift and pile cap rotation of micropile in two modes of network micropile and vertical micropile.

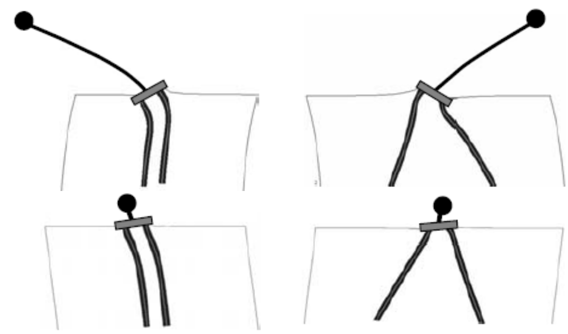

Fig. 7 Shift and rotation of pile cap in tall and short structures

By increasing the angle of inclination, bending moment in micropile will be very high due to the increase of soil stiffness. Created transformations and inclination angle in micropile depend on loading type. In tall structures, by increasing the inclination angle of micropile, bending moment and axial force in micropile will increase and decrease respectively, while in short structures, bending moment will have insignificant decrease and axial force will be increased. Generally, by increasing the angle of inclination of inclined micropiles, horizontal shift of pile cap resulting from earthquake will be decreased, but an amount of rotation will be created in pile cap. Fig. 8 shows the effect of axial force and bending moment resulting from tall and short structures on the shift and the angle of rotation of pile cap.

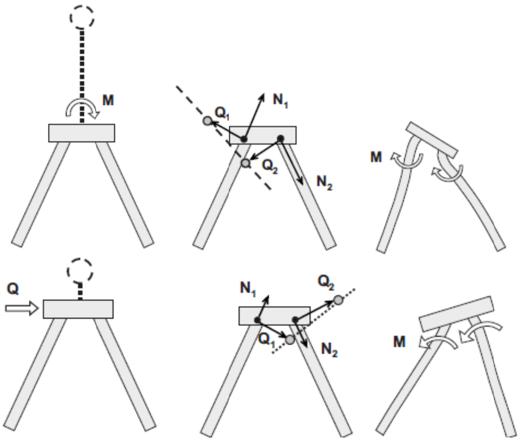

Fig. 8 Effect of axial force and bending moment on shift and the angle of rotation in tall and short structures

The more the angle of inclination is increased, the more the topside shift of the structure in tall structures compared to short ones is limited. And finally, PGA of the site structure will be decreased by increasing the angle of inclination of micropile in tall and short structures.

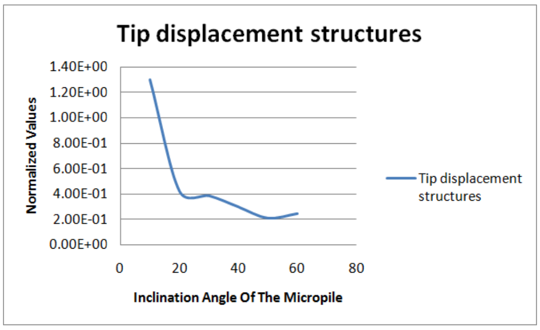

Fig. 9 The effect of increasing the angle of inclination of the lower micropile vertex displacement structures

XIII. Discussion and Results Analysis

In general, the purpose of applying network micropile in constructed model, is to figure out an angle from inclination of the micropile which through putting the foundation under the pressure and creating dilation state we can provide enough friction for the lower layer of the foundation in contact with the soil so that vertical or horizontal shift of the foundation become decreased and the response modulus of the soil remains in its current position. In this case, finally the loading capacity of the foundation can vertically and horizontally be increased and PGA of the site on which the structure has been located, can be decreased.

As it was already mentioned in previous discussions, occurrence of the situation mentioned above is dependent on many different parameters and the most important of them are shear modulus or shear wave velocity of the site, horizontal shift of the foundation, subsidence of the foundation, velocity of the wave toward dispersing seismic acceleration of the site and finally pick ground acceleration of the site on which the structure is located. As it was already indicated, the structure was modeled in 6 groups of micropiles in different angles of inclination, for each of which the following things were calculated:

Shear wave velocity, horizontal shift of the foundation, subsidence of the foundation, horizontal velocity of seismic wave in the site and PGA of the site.

By increasing inclination angle of the micropile from the vertical axis, seismic features of the site would be improved, but this amount is different in tall or short structures. It is in a way that in tall structures, by increasing the height of the structure, the bending moment will be increased, also for preventing many shifts we are in need of a length of the micropile which can increase lateral pressure of the soil and get use of passive condition of the soil to decrease lateral shifts of the foundation.

Fig. 10 indicates the most important normalized seismic parameters in different inclination angles of modeled network micropiles. This is useful for choosing the most suitable inclination angle of the micropile for the model of analyzed structure. Of course it is worth mentioning that all presented values in the diagram have been normalized without applying micropile, and these values have been achieved by dividing parameter through applying micropile by the state without applying micropile.

It is observed that subsidence of the foundation in all inclination angles of the micropile is being decreased. Here inclination angle of 60 degrees of micropile may have the minimum amount of subsidence of the foundation, but all of the indicated amounts for subsidence of the foundation are more than 1. Therefore it can show the increase of subsidence in foundation due to applying network micropile, yet it is without applying network micropile against the foundation. As a result for the sake of decreasing subsidence, we can only use vertical micropile. This is a main defect in using network micropiles in the foundation comparing with vertical micropile. As it is shown in Fig. 10, in inclination angle of 50 degrees, horizontal lateral shift of the foundation will be decreased, horizontal velocity of the seismic wave is increased and the PGA of the structure would have the minimum amount. Shear force velocity in different angles of inclination has very little changes, but this amount will be increased in inclination angles of 50 degrees to 0.01. Therefore, according to the points mentioned above, 50degrees of inclination angle in modeled structure is the best and the most suitable site.

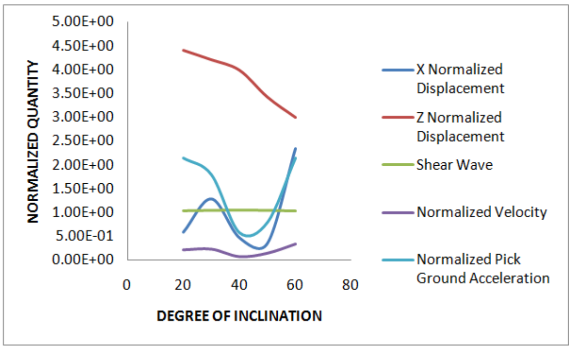

Fig. 10 Normalized seismic parameters of the site in different angles of inclination of the micropile

XIV. Conclusion

The purpose of applying network micropile is to obtain an inclination angle of the micropile which through putting the foundation under pressure and creating dilation state we can provide enough friction for lower layers of the foundation, so that the lateral shift of the foundation become decreased and the response modulus of the soil get increased, and finally the maximum loading capacity of the foundation is increased and PGA of the site on which the structure is placed becomes decreased.

Increase of pressure of cement slurry injection can cause the slurry to be absorbed into the dry grains and strains to become decreased in the soil. This decrease leads to changing the state of the soil from isotropic to non-isotropic which finally can lead to hardening of the soil and increasing shear modulus and also leads to increasing the average of seismic acceleration in the soil and at last to decreasing PGA of the structure. The pressure resulting from cement injection increases the stresses in the soil and causes decrease in porosity ratio which can increase shear wave velocity in the site. The amount of input seismic frequency and the number of loading cycles in decrease or increase of amount of shear modulus are very effective. This is so much that small frequencies create big shifts and big frequencies create small shifts in the soil.

In flexible micropiles with small diameter, the relative motion between the soil and the micropile enlarges enough the lateral pressure of the ground; in this status according to the angle that micropile is located in the soil, the position of the sand, the distance between micropiles, etc. would have a significant effect on decreasing horizontal shift of the foundation. By increasing the angle of inclination, the micropile will be increased in a determined amount of horizontal stiffness of the soil. This determined amount is dependent on different parameters such as the amount of bending moment, axial force and shift of the topside of the micropile. In fact this amount is dependent on the elasticity ratio Ep/Es. Decrease of horizontal shift in the foundation is dependent on largeness of dynamic hardness modulus of the soil. Therefore horizontal shift of the foundation is not dependent on the type of the micropile but the micropile would be considered as a means of changing the features of the soil. As a result the horizontal hardness of the foundation is dependent on elasticity modulus, Poisson’s ratio and the size or shape of the foundation such as lower layer of the foundation and the depth of foundation installation in the soil.

In general, it is totally essential to pay attention to elasticity modulus of the soil to determine elasticity modulus of the micropile, in a way that micropile foundation shift is dependent on Ep/Es ratio and by increasing elasticity modulus, rigidity of the system would be decreased in the site and shift would become increased. Having elasticity in the site can lead to increase of shift in the topside of the micropile. As a result, by having a decrease in the distance between micropiles, the effect of elasticity will be dominant in the soil and micropile shift will be increased, but by having the distance between the micropiles increased, we will witness that rigidity of the system will be increased, the effect of plasticity is decreased and finally PGA of the site will be decreased.

Increasing horizontal shift can lead to decrease of horizontal loading capacity and increasing vertical shift can cause decrease of loading capacity vertically. By increasing inclination angle of micropile due to the increase of horizontal hardness of the soil, the horizontal response modulus of the soil will be increased, but the vertical response modulus will become decreased. Therefore increasing the inclination angle in micropile can only be used for increasing horizontal loading capacity and decreasing horizontal shift of the foundation. Also increase of inclination angle can lead to increase of subsidence and decrease of vertical loading capacity of the foundation. In this case we need to get use of vertical micropile to increase it.

Loading angle has got a deep effect on the shifts of the foundation. Hence vertical loading can cause decrease of vertical shift and horizontal loading may also cause decrease of horizontal shift. Yet horizontal loading can increase vertical shift of the foundation. By increasing loading angle to vertical axis of the modulus, the vertical and horizontal responses of the soil will be decreased, but this amount for the vertical response modulus is more than the horizontal one.

In tall structures, overturning moment will be dominant due to high altitude; therefore the horizontal shift of the foundation will be increased. Yet in small structures the dominant shear inertial force and revolving rotation of the foundation will be increased. Due to increase of rotational angle, bending moment of small structures is not very important. In general by increasing inclination angle in micropile, the horizontal shift due to earthquake will be decreased because of the increase of soil stiffness, but a little rotation will be remained in the foundation. The increase in micropile’s inclination angle will confine the shift of topside of the tall structures more than the short ones. In fact PGA of the site in tall structures will be decreased more than the short ones. Therefore seismic upgrading of the foundation by getting use of network micropile through applying horizontal accelerations is suitable. And in case vertical seismic accelerations are dominant, using vertical micropiles is better. If both vertical and horizontal accelerations are applying force to the site, getting use of a combination of network and vertical micropile is suggested.

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