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Utilization of Soil Nailing Technique to Improve Sand Slopes under Seismic Loading

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ABSTRACT

Soil nailing is a soil stabilization technique which is used as a remedial measure in order to treat the unstable natural or artificial soil slopes. This study aims to investigate the factor of safety of sandy slopes using soil nailing under seismic loading. A series of numerical models were studied using elastic plastic Finite Element program as (2D PLAXIS). The studied parameters include the slope angle, shear strength of the sandy slope, soil nailing length, number of soil nailing and the stiffness soil nailing. The results indicated that using soil nailing on the sandy slopes under cycling loading has a significant effect in improving the factor of safety of the slope and reduce the slope deformation. It can be concluded that this improvement technique has a significant effect in modifying the failure pattern of sandy slope.

Keywords: *Soil nailing, Sandy slope, Finite Element program and (c-φ) reduction method.*

INTRODUCTION

Soil nailing is a soil stabilization technique which is used as a remedial measure in order to treat the unstable natural or artificial soil slopes. This technique is also used in order to allow the safe over-steepening of new or existing soil slopes. In this method of slope stabilization, a relatively slender reinforcing element is driven into the soil slope[1]. Reinforcing elements generally used in this technique generally consists of HYSD steel bars or steel hollow tubes depending upon the requirement. A nail is fundamental element in soil nailing and estimation of nails (lengths and spacing) forms the major parts of the design procedure for soil nailing. It is widely known that a nail force, by friction or bond to surrounding soil, can decrease the principal strain in soil and hence improve the stability and decrease the displacements of the soil [1,2].
Soil nailing is a useful, economic technique for the construction of new steep cuts or the strengthening of existing slopes [2-4]. While the basic concept of reinforcing soil with tensile elements is reasonably straightforward, the exact mechanism by which nails strengthen and stabilise a slope cannot be modelled easily. A number of assumptions and simplifications must be made to define required properties of the nails and their spacing. The details of the installation of the nails can have a significant effect on their performance and design requires a good deal of information and experienced engineering judgement. The use of soil nailing has increased rapidly in Europe and North America since the early 1970s. The first recorded application of soil nailing in Europe was in 1972 for an 18 m high 70° cutting as part of a railway widening project near Versailles, France. Extensive researcher studied the behavioue and concept of soil nailing by experimental model test and numerical analysis. The experimental tests for such technique are limited due to scaling effect and difficulty to simulate the problem in the laboratory therefore numerical analysis is more reliable and widely adopted. The numerical analysis of soil nailing technique has been done for investigating the effect of reinforcing the

loose fill slope under different loading system by different researchers [5-7] . Also, Numerical analyses that have been conducted to examine the influence of soil nail orientations on the behaviour of the ground nail–facing system [8]. Based on the available research findings, it is suggested that the use of soil nails to upgrade loose fill slopes is feasible and recommended a design methodology that has been described [9] . Further guidance on designing soil nails in loose fill slopes has been provided with details [10]. On the other hand the stability analysis for soil nailed walls is applied as an application for nailing technology [11]. Based on the Varity of investigation in literature, it has been found that the soil nailing is widely acceptable technique to reinforce the steeper slope and cut. So the most paper in literature deals with studying the slope behavior or walls under static loading by limit equilibrium method. But the behavior of soil nailing to reinforce the slopes under earthquake loading can not be thoroughly investigated. Except for minor investigation like exploration on the dynamic behavior of soil nail walls is considered [12]
Therefore the present research aimed at studying the application of using reinforced element in the form of soil nailing method to resist the additional loading resulting from earthquake and increase the stability of slopes. This analysis is based on using two dimensional analysis by Plaxis 2d dynamic version [13] in order to clarify and identify the beneficial effect of such nailing in decreasing the earthquake hazard for slope.

NUMERICAL ANALYSIS and VALIDATION

In this analysis, the plane strain model was used to describe the current problem using finit element commercial program Plaxis. So in order to check the program validity to solve this problem, the verification example should be considered. The numerical model that adopted in plaxis has been validated using results reported by Pradel et al., 2010 [1], that used a 3D FLAC (Itasca, 2008) program as a Finite Difference Method (FDM) to model piles – slope system and evaluate the F.O.S. The stabilized slope geometry and properties are shown in the Fig. 1. They modeled a row of closely spaced stabilizing piles will act as a wall with an elastic modulus E = 2*107 kPa, a cross-sectional area A = 1 m2/m, and moment of inertia I = 1 m4/m. And it located at S = 10.45 m from the toe of the slope (S/L = 0.44).
From there results, it was shown that the F.O.S of theses slope was equal to 1.68 and the displacements of it become very large, which means that the slope is yielding. Also, the position of the slope failure was located above the stabilizing piles as shown in the Fig. 2.
The F.O.S of the stabilized slope was equal to 1.66 using the numerical FEM modeling. And the position of the slope failure was also located above the piles as shown in the Fig. 3 and Fig. 4.

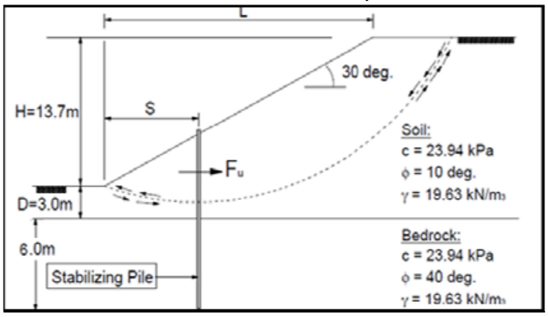

Fig. 1 Stabilized slope geometry and its material properties (After Pradel et al., 2010)

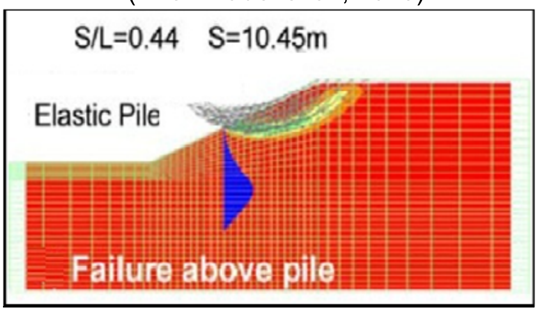

Fig. 2 The shape of the slip surface of the stabilized slope using the 3D FLAC program (After Pradel et al., 2010)

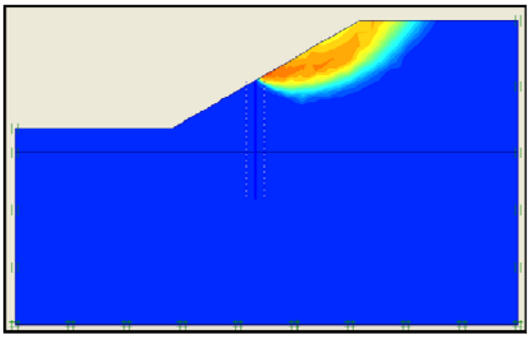

Fig. 3 The shape of the slip surface of the stabilized slope using the numerical 2D PLAXIS modeling

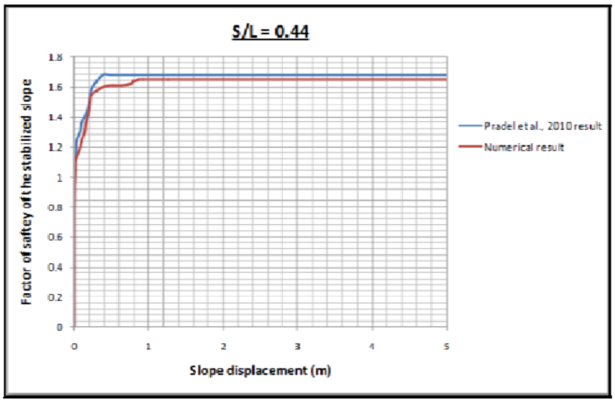

Fig. 4 Comparison of 3D FLAC program results with the 2D PLAXIS modeling results for S/L =0.44, (After Pradel et al., 2010)

SAND SOIL PARAMETERS ESTIMATION

The plane strain model was used with the 6 node element. The mesh was generated by the program. In this study, the (MC) was used to model the three drained sandy soils. The linear elastic perfectly-plastic Mohr-Coulomb model involves five input parameters: which are Es and υ for soil elasticity; ϕ and c for soil plasticity and Ψ angle of dilatancy.
Kishida and Nakai (1977) introduced empirical formulae to calculate stiffness parameters of sand soil. The soil stiffness parameters presented were function of N_{SPT} number and were related to the relative density (Dr) of sand soils.

$$Es = 1.6 * N_{SPT}$$

A nonlinear analysis was assumed, so that (Es) represent a secant modulus for low load level.
The Mohr-Coulomb model was considered to model elastic- plastic behavior of sand soils. These parameters in this model are soil cohesion (c), angle of internal friction (ϕ) and soil dilatancy (ψ). Since we considered sand soils in this study in the drained case, soil cohesion was set to 1*10-3 kPa to avoid errors as shown in Table 1.

Table 1: Estimation of Young modulus (Es) of sandy soils

Soil code	Angle of Friction (ϕ)	Young modulus (Es) kPa	Poisson's ratio (υ)
Soil 1	25	12800	0.33
Soil 2	30	40000	0.3
Soil 3	35	72000	0.26
Soil 4	40	90000	0.24

Now the dilatancy angle can be computed according to the following empirical formula:-

$$\Psi = \phi - 30^0$$

Also Table 2 represents the estimated values of internal friction angle and dilatancy angle for the selected soils.

Table 2: Estimation of Dilatancy angle of sandy soils

Soil code	Angle of Friction (ϕ)	Sand Density	Dilatancy angle (ψ)
Soil 1	25	Loose condition	0
Soil 2	30	Medium condition	0
Soil 3	35	Dense condition	5
Soil 4	40	Very Dense condition	10

Interfaces are special elements particularly thought for the soil-foundation interaction in 2D programs. Therefore, interface elements allow relative displacements between structure and subsoil. The interface strength was defined by the parameter (Rint). For real soil-anchored interaction, the interface is weaker and more flexible than the surrounding soil, which means that the value should be less than 1. Suitable values of Rint the interaction between sandy soils and nailing was found to be 0.8 (After Gomes, 2013)

ANCHORED PARAMETERS ESTIMATION

The input properties of the used Anchored in 2D PLAXIS program were summarized in the Table 3.

Table 3: The Anchored adopted in 2D PLAXIS program

No.	Length of Anchored (L) m	Axial Stiffness (EA) kN/m
1	30	1e*3
2	30	1e*6
3	30	1e*9

SEISMC LOADING PARAMETERS

The Rayleigh damping is considered at vertical boundaries and taken as a, b= 0.01 in order to resist the Rayleigh waves. The plastic properties of soil (viscous properties) are defined by using material damping which was defined in Plaxis by Rayleigh (a and b), where a damping term is assumed which is proportional to the mass and stiffness of the system (Rayleigh damping) such that: C=aM+bM, C is the damping coefficient, M is the mass, K is stiffness and a and b are Rayleigh coefficients. The Rayleigh damping is considered to be object dependent in material data set to consider the plastic properties of soil during the dynamic analysis in Plaxis. The earthquake is modeled by imposing a prescribed horizontal displacement at the bottom of boundary in contrast to standard unit length (Ux= _0.01 m and Uy= 0). Absorbent boundary conditions are applied at vertical boundaries to absorb the outgoing waves. The default setting to generate boundary calculations for earthquake loads is by using SMC files (strong Motion CD rom).

A safety analysis in PLAXIS can be executed by reducing the strength parameters of the soil. (c-ϕ) reduction should be selected when it is desired to calculate a global safety factor for any problems. It can be performed after each individual calculation phase and thus for each construction stage. However, note that a (c-ϕ) reduction phase cannot be used as a staring condition for another calculation phase, because it ends in the state of failure. When performing a safety analysis, no loads can be increased simultaneously.

STUDIED PARAMETERS

The soil domain of the studied geometries of sandy slopes with nailed element was shown as following. The boundary condition in all cases was evaluated to relief its effect on the results of the numerical model. The input of 2D PLAXIS program was the global factor of slope (Σ Msf) in each case. A numerous numerical modeling tests in different cases of sandy slopes were carried out using 2D PLAXIS program. The studied parameters include the slope angle (θ), shear strength of the sandy slope (friction angle) (Φ), soil nailing length ratio (L/H), number of soil nailing (N), soil nailing spacing (S) and the stiffness soil nailing (EA) as shown in Fig. 5 and Fig. 6. A series of numerical models were run to study the factor of safety of sandy slopes using soil nailing technique under Seismic loading. Each series was run to study the effect of one parameter while other parameters were kept constant as shown in Table 4.

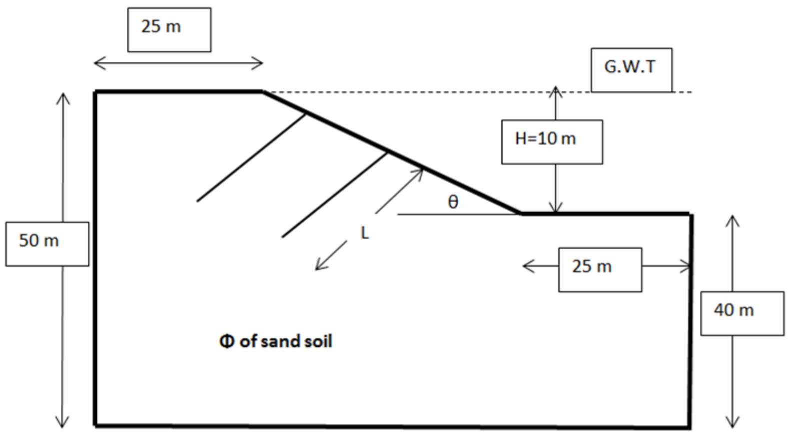

Fig. 5 The geometry model for different studied parameters in 2D PLAXIS model

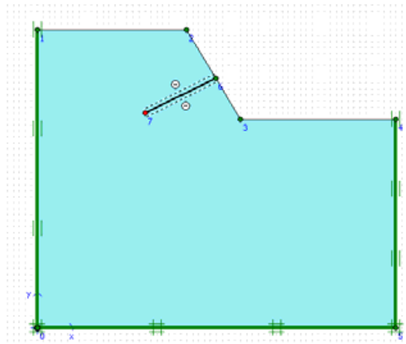

Fig. 6 Numerical modeling in 2D PLAXIS program

Table 4 Numerical model and studied parameters

Series	Constant parameters	Variable parameters	Case
1	Φ =25	θ =30,40,60	Without soil Nailing
2	Φ =30	θ =30,40,60	
3	Φ =35	θ =30,40,60	
4	Φ =40	θ =30,40,60	
5	Φ =25, L/H =1, N =3 , EA =1e*9, S=3m	θ =30,40,60	With soil Nailing
6	Φ =30, L/H =1, N =3 , EA =1e*9, S=3m	θ =30,40,60	
7	Φ =35, L/H =1, N =3 , EA =1e*9, S=3m	θ =30,40,60	
8	Φ =40, L/H =1, N =3 , EA =1e*9, S=3m	θ =30,40,60	
9	θ =40, Φ =25, N =3 , EA =1e*9, S=3m	L/H =0.5,1,1.5,2	
10	θ =40, Φ =25, L/H=1 , EA =1e*9, S=3m	N =1,2,3,4	
11	θ =40, Φ =25, N =3 , L/H =1, S=3m	EA =1e*3, 1e*6, 1e*9	
12	θ =40, Φ =25, N =3 , EA =1e*9, L/H =1	S =2,3,4	

RESULTS AND DISCUSSIONS

Factor of safety of slope without/with soil nailing

The factor of sfaty against shear failure for investigated slope without/ with soil nailing elemnt ispresnted in Fig. (7and 8) for different slope inclination angle and angle of shear resistance. For non reinforce case, It can be seen that, the factor of safety against shear failure is affect by both slope angle and angle of internal friction of slope. It is noticed that the increase of shear angle significantly improve the factor of safety with lower values of slope inclination angle. For maximum friction angle of (ϕ =40^o) and at (θ= 30^o) the factor of safety is found to be as much as 1.2. while this value is decrsed to 0.58 at friction angle of (ϕ =25^o). it is also found that the factor of sfaty is less than 1 and the shear failure is took place at shear angle < 35o for both inclination angle of (40^o and 60^o) as confirmed by relevant figure.

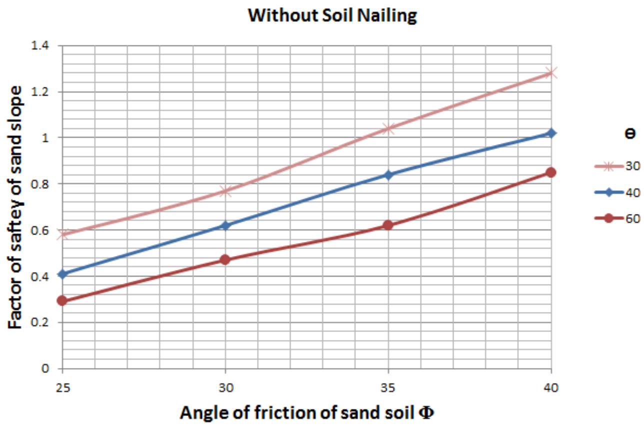

Fig. 7 Factor of safety of sand slope under earthquake loading without soil nailing versus different angle of friction and the slope angle

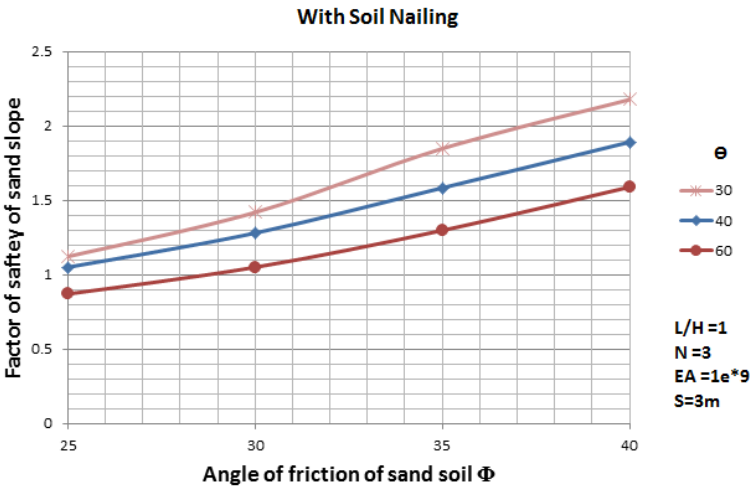

Fig. 8 Factor of safety of sand slope under earthquake loading with soil nailing versus different angle of friction and the slope angle

From this figure it can be seen that a flow failure occurs at a defined sliding surface. Due to this failure, the displacements become very large with a maximum value at the toe of slope. The failure surface of the slope is just induced by the shear failure associated with earthquakes and higher slope angle as confirmed by the Fig. 7

On the other hand the existence of reinforced element in the form of soil nailing, the factor of safety is considerable improved as shown in Fig. (8). It has been found that the placing 3 element with sufficient stiffness can increase the factor of safety especially for steeper slope in case of (θ =30^o and 40^o) in loose sand (ϕ =25^o). It can be also seen that at (ϕ =35^o)L/H=1, N =3 and S =3) the factor of safety is reached to (1.25, 1.6 and 1.8) for slope angle of (θ =60^o , 40^o and 30^o) respectively. Wearase these values of factors of safety are found to be (1.6, 1.80 and 2.4) for sand slope with friction angle (ϕ =40^o).
Furthermore, the nails can decrease the slope deformation, which shows that the factor of safety has a maximum value compared with the slope without nails. The reinforced element/nails can also limit and considerably reduce the vertical slope deformation. In general the nails were effective in reducing the slope disturbance and induced strains from the earthquake. It prevented the weakening instability phenomena of a slope that occurs during an earthquake, hence, control the slope deformation. The weakening instability can occur when the reduced strength drops below the static and dynamic shear stresses induced in the slope.

Effect of soil nailing number and spacing

In order to study the effect of soil nailing number and spacing, Fig.9 shows the variation of the obtained factor of safety against numbers of soil nailing within the slopes at different nailing spacing. It is found that the installation of reinforcing element within the slope with minimum spacing and sufficient number can appreciably increased slope stability against shear failure when the slope subjected to earthquake loading specially in loose sand. It is Cleary established that the existence of single element can increase the factor of safety by 2.75, 2.25 and 1.75 times of its initial value at spacing of (2, 3 and 4m)respectively. While for N = 2 ,these values is found to be 3.37, 2.9 and 2.25 time of non reinforced slope at the same order of spacing. It can be concluded that the increase of number of soil nailing elements leads to higher stability for loose slope when the spacing is decreased. Because of the shear strength of studied slope is increased due to induced interaction between the soil and nailing elements at minimum spacing. Since the soil mass in a slope is restrained on three sides, the soil particles can only move down and outwards as resistance is reduced. The form of movement is dependent on the nature of the soil. A granular material will tend to move as a translational block parallel to the slope surface. Therefore the existence of such reinforced element within the slope Skelton can appreciably increase the shear strength and limited the subgrade movement when the slope subjected to earthquake movement. It also can provided a restraint obstacle that resist the additional movement form earthquake. A more loose material may move as blocks form along zones of weakness within the mass. This movement of the soil induces load into the embedded reinforcements. The level of load imposed on the nail and the mechanisms set up to redistribute that load are dependent on the response of the soil nail system. The initial movement is small and minimised by the axial stiffness of the nail as confirmed by Fig. (10). A nail is relatively stiff compared to the soil structure and hence its bending stiffness may also be mobilized. Moderate soil movements, however, result in a small contribution from bending stiffness. Thus for the most part, the load induced by the unstable mass is transferred along the nail in axial tension and redistributed to the stable mass as a result the factor of safety against shear failure is increased. With increasing ground movements due to earthquake, the tensile load in a nail increases. If the movements are very large then, depending on nail properties and geometry, the bending resistance of the nail may provide some small resistance in addition to the tensile component. Depending on the soil, geometry of the slope and nail inclination, this may induce a cantilever effect at the front of the nail, or possibly a deformed S shape within the zone of high strain (i.e. a failure plane or zone).
This complex loading condition occurs at large displacements, usually well beyond serviceability limits for the slope. Finally the installation of such nails through slopes can modified the prevented the shear failure from occurrence and decreasing the distortion rate in higher starin zone due to soil nails interaction which is took place in case of highr nails stiffness as confirmed by Fig. (10) and justified by [15] that reports that the beneficial effects arising from bending stiffness are a post serviceability phenomenon and therefore should not be relied upon in design Also the bending contribution is not achieved until displacements have taken place that are at least an order of magnitude greater than those required to generate maximum axial

resistance. Thus, the only contribution from bending resistance is at ultimate limit state, where the nails may provide shear or bending resistance at large displacement
Finall the Ultimate failure occurs when the nail itself ruptures or installed with higher spacing and low axial stiffness, where the soil moves around the nail, or the nail is 'pulled out'.

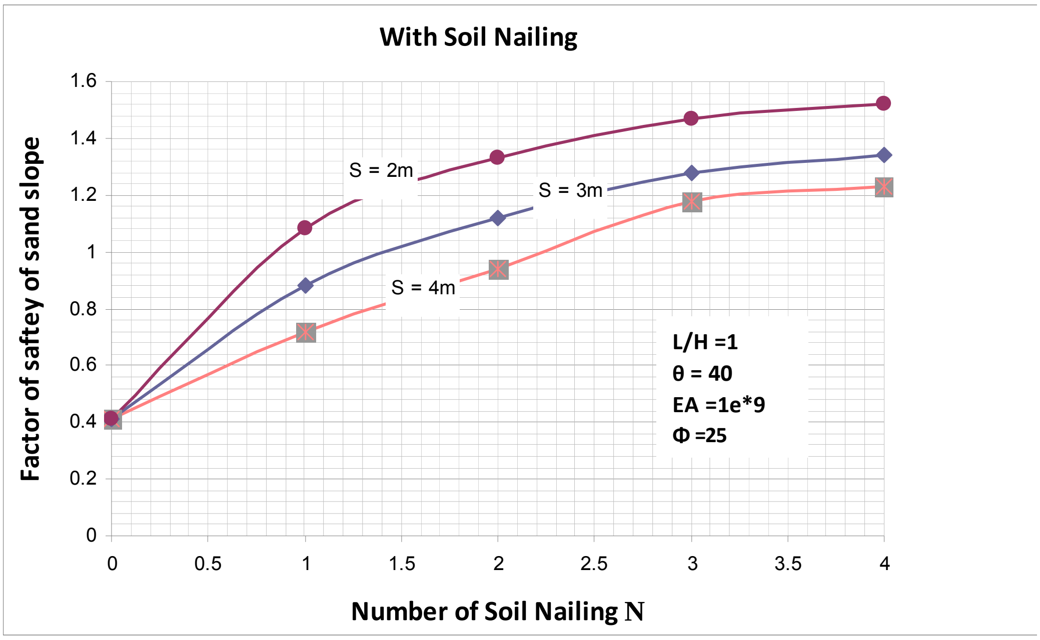

Fig. 9 Factor of safety of sand slope under earthquake loading with soil nailing versus different number of soil nailing and the horizontal spacing in the long direction

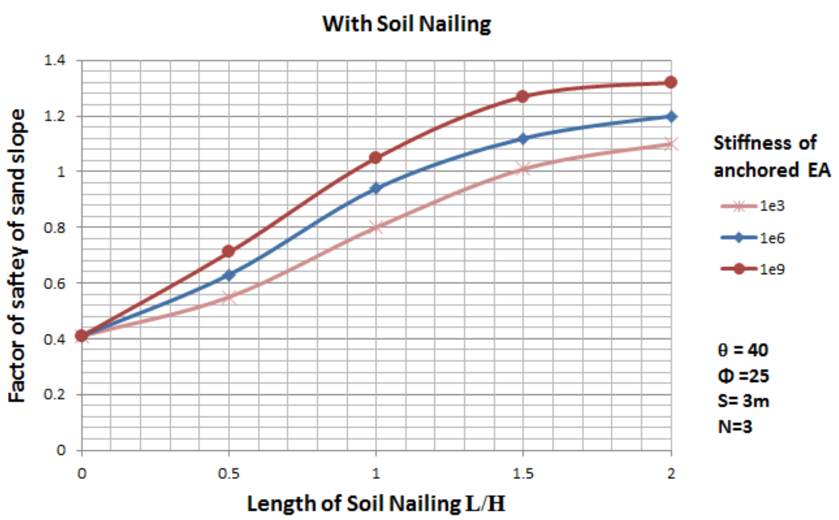

Fig. 9 Factor of safety of sand slope under earthquake loading with soil nailing versus different length of soil nailing and the stiffness of anchored

CONCLUSIONS

Extensive numerical models of different sand soil slopes with soil nailing under seismic loading were performed to study the effect of diversity of parameters on the factor of safety. From the discussion of the previous results, it can be concluded the following:

(1) Using soil nailing technology with a slope is a good method to safeguard slopes from collapsing during an earthquake and to control the lateral deformation of a slope.

(2) The factor of safety of a seismic slope stabilized by nailing method is related to soil shear strength, nailing number, spacing and stiffness different from cases of foundations without.

(3) The existence of such soil nailing effectively increase the inertial stability of a slope by decreasing the slope deformation and increasing the factor of safety against shear failure.

(4) Placing 3 element with sufficient stiffness can increase the factor of safety especially for steeper slope in case of (θ =30^{o} and 40^{o}) in loose sand (ϕ =25^{o}).

(5) The factor of safety is reached to (1.25, 1.6 and 1.8) times of normal slope without nails at slope angle of (θ =60^{o} , 40^{o} and 30^{o}) respectively. Whereas these values of factors of safety are found to be (1.6, 1.80 and 2.4) for sand slope with friction angle (ϕ =40^{o}).

(6) The existence of single element can increase the factor of safety by 2.75, times of its initial value at spacing of 2m. While for two nailed element, N = 2 ,the factor of safty is found to be 3.37time of non reinforced slope at the same order of spacing.

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In response to these concerns, research work has been conducted to shed light on the behaviour of loosely compacted decomposed rock and its interaction with soil nails (e.g., Cheuk et al. 2005).

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