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Dynamic Response Of Foundations Using Reinforced Technique Under Earthquake Effect-Numerical Study

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Abstract— The structures are subjected to additional loads due to earthquakes may lead to failures in soil and superstructure. Consequently, this research aims at studying the behaviour of large scale foundations and structures constructed on unreinforced and geosynthetic reinforced sand under seismic loads. The effect of geotextile on controlling lateral deformation of soil and decreasing pore water pressure beneath the foundation during earthquake is investigated. A two dimensional plain strain program PLAXIS (dynamic version) is used for the present numerical modeling. A ten story reinforced concrete building with basement rests on a raft foundation is idealized as two-dimensional model with and without geotextile reinforcement. In this research, three types of geotextile with varying tensile modulus were analyzed to examine the influence of their tensile modulus from the perspective of the horizontal displacement, acceleration, and footing settlement. The effect of vertical spacing between geotextile is also investigated. The results indicated that the inclusion of geotextile decreased both the vertical and horizontal displacement; it significantly reduced the foundation subgrade acceleration by 47%, 52% and 73% in case of dense, medium and loose soil respectively at (E = 35000 kN/m) and horizontal displacement by 50%, 57% and 63% for dense, medium and loose soil respectively at (E = 35000 kN/m). It can be concluded that geotextile reinforcement is increase subgrade stiffness and considered a good method to increase the subgrade stability during the earthquake shaking. The lateral soil deformation is reduced with the decreasing the vertical spacing between the first reinforcement layer and the building foundation. The reduction in the horizontal displacement and lateral acceleration in case of loose sand is considered a very good value when we compared it with the other two cases for dense and medium soil. The reduction reached to 62% and 70% respectively at (U/B= 0.3).

Keywords—seismic loads, Geotextile, Foundation, Numerical Analysis

I. INTRODUCTION

Vibration and dynamic responses produced from earthquakes can cause extensive damage to both the foundation and the superstructure. Earthquake motions initiated in the soil are instantaneously transmitted to foundations causing adverse effect on both the supporting soil and the superstructures. Damages may occur due to instability of soil which results in extensive ground movements including differential movement. The initiating cause can be often identified as the adverse response of the soil foundation system under seismic forces. Soil reinforcement is considered one of the modern methods in the field of Foundation Engineering which aims to raise the soil resistance to excess loads. The meaning of reinforcing the soil is strengthen the soil by adding new materials Performed the same purpose, which Played by steel in concrete. Soil reinforcement performed by using different elements in the form of strips (Geosynthetic). These materials have high resistance to chemical and biological degradation and can be processed to meet the requirements of resistance, tensile deformation, providing good adherence with the reinforced soil. In this research, it has been used as a new tool to increase bearing capacity of the soil and decreasing the settlement of the foundation as stated by [1], [2], [3], and [4]. The soil reinforcement technique was also used to improve the soil resistance against dynamic loads as reported by ([5], [6], [7], [8], [9], [10], and [11]).

The previous technique of using soil reinforcement was mainly focused only on studying the behavior of foundation without considering its effect on the performance of the both foundation and structure. Therefore, the present paper was aimed at studying the effect of increasing the subgrade stiffness using soil reinforcement on the deformation characteristics of foundation performance plus superstructure under earthquake loading.

In order to avoid the scale effect and the problem of shaking table, full-scale testes were used to simulate the actual foundation building behavior. The finite element analysis using Plaxis dynamic version, was adopted to model the earthquake and the structure**.**

II. NUMERICAL MODELING AND SELECTION OF PARAMETERS:

The plane strain model was used with the six node element. For the mesh generation, the global coarseness is set to 'coarse' and the clusters inside the building are refined twice. This is because of the high concentration of stresses that can be expected just in and under the building elements. The subsoil is consisted of a deposit of sand layer of 40 m thickness. It assumed to be Mohr-coulomb in dynamic analysis. The properties of the adopted sand (γ =16.5 kN/m3, v = 0.2, E_{ref} = 38000 kN/m^2, C_{ref} = 0.0, φ= 35° , Ψ = 5, the Raleigh damping is considered at vertical boundaries and with α, ß = 0.01). The Rayleigh damping is considered at vertical boundaries with α, β = 0.01 in order to resist the Rayleigh waves. While the plastic properties of soil (viscous properties) are defined by using material damping, which is defined in Plaxis by Rayleigh (α and β), where a damping term is assumed which is proportional to the mass and stiffness of the system (Rayleigh damping) such that: C = α M + βM, C damping coefficient, M mass, K stiffness and. (α and β) Rayleigh coefficient. 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 building foundation is assumed a reinforced concrete raft, it modeled as an elastic beam element, the raft is 1 m thickness its plate properties are (EA = 2.2 x 107 kN/m and EI = 1.833 x 106 kN/m^2/m with weight of 25 KN/m/m and Poisson's ratio ν = 0.15) .

Geosynthetic material as geotextile of polypropylene (PP) is used. For all the models analyzed, the values of (h/B), and (d/B) were taken as, 0.1 and 0.2 respectively, (L/B) was taken 3 and N was 3layers. Where B is the foundation width, h is the vertical spacing of consecutive geotextile layers, L is the geotextile length and N is the number of geotextile layers. The geotextile properties are (EA was taken = 15000, 25000 and 35000 KN/m).

The earthquake is modeled by imposing a prescribed horizontal displacement at the bottom of boundary in contrast to standard unit length (Ux = 0.01m and Uy = 0) as used in manual default. The geometry of finite element model adopted for the analysis is shown in “Fig. 1,” The selected monitored points along building and foundation was used to identify the performance of both foundation and building during earthquake. These points are selected on the top of the building, at foundation level and within and under the reinforced zone.

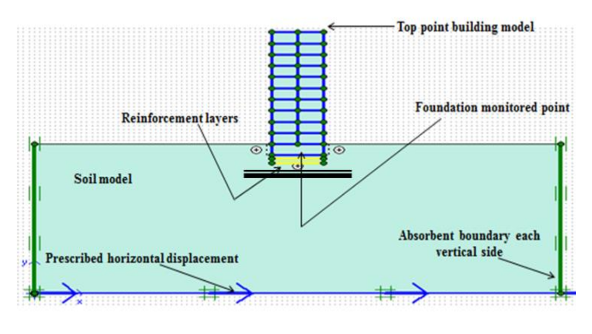

Fig. 1. *Geometry model with standard earthquake boundary conditions*

A. *Analysis Procedures*

A series of dynamic numerical models were run for the problem under investigation using different values for geotextile tensile model and U/B ratio. The calculation procedure involves two phase. The first one is a normal plastic calculation in which the building is constructed. The second is a dynamic analysis in which the earthquake is simulated. In this phase the displacement are reset to zero and the time interval 10 sec, the acceleration of the input earthquake is chosen from the default acceleration data file in program (225smc) (SMC, Strong Motion CD-ROM). The acceleration time history used as a default in program with maximum horizontal acceleration of 2.3 m/sec^2 at time of 2.53. Before the mesh generation, the water pressure can be activated for considering the pore water pressure.

III. RESULTS AND ANALYSIS

A. *Effect of Reinforcent Tensile Modulus on the Behaviour of Foundation Subgrade*

The existence of geotextile in the sand is considered a good method to increase the subgrade stiffness during seismic loading. It can significantly limit and control the lateral deformation of the soil underneath the foundation and increase the soil stability. For the current research, it has been found that, in the free field, an earthquake will cause soil displacement in both horizontal and vertical direction. If the foundation and structure on the surface, or embedded in a soil, the geotextiles can increase the subgrade stiffness, and prevents the subgrade soil from flowing in horizontal component of free field displacement. Tensile modulus is one of the most important properties of geotextile, which have significant influence on the performance of footing and structure on reinforced soils. The results show that Regardless of the number of reinforcement layers, the footing with geotextiles of higher tensile modulus has a larger bearing capacity than that with weaker geotextile. On the other hand, the Settlement, and lateral deformations of the soil decreases with the increase in reinforcement tensile modulus, at a gradually reducing rate. In general, “Fig. 2”, “Fig. 3” and “Fig. 4”, indicates the reduction of horizontal displacement, acceleration and settlement for the three type of sandy soil (dense, medium, and loose sand).

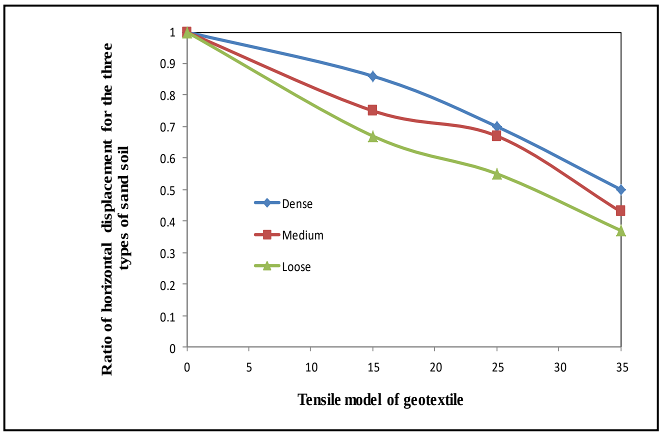

Fig. 2. *The relation between horizontal displacement and tensile model of geotextile layers at N=3 and L/B=2*

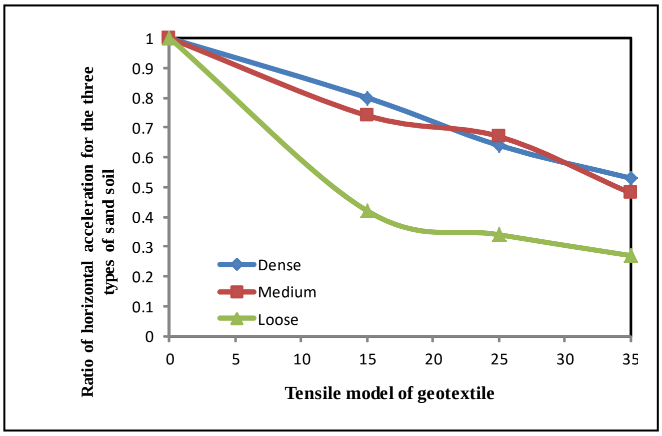

Fig. 3. *The relation between horizontal acceleration and the tensile model of geotextile layers at N =3 and L/B =2*

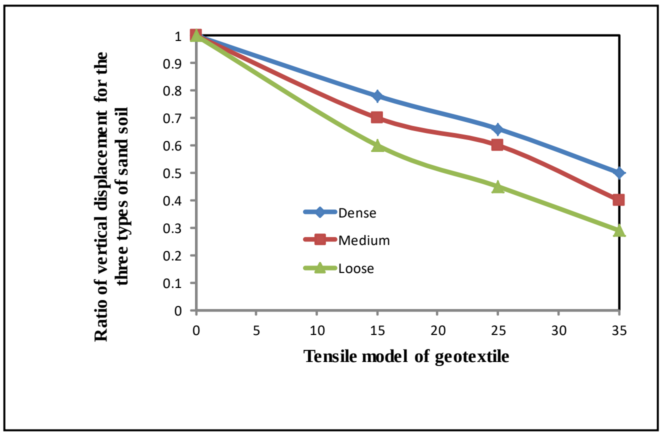

Fig. 4. *The relation between vertical displacement and the tensile model of geotextile layers at N =3 and L/B =2*

The results indicate that when using the geotextile with a higher tensile model the reduction ratio reached its highest value compared to the two other types of geotextile. For dense sand case the reduction of horizontal displacement and acceleration was 50% and 47% respectively, in addition to the reduction of vertical displacement was also50% like the ratio of the horizontal displacement. Moving to the case of medium sand case the reduction of both the horizontal displacement and acceleration was 57% and 52% respectively, and the reduction of vertical displacement was 60%. Finally the case of loose sand, the reduction ratio of lateral displacement and acceleration was 63% and 73% respectively, as well as the reduction of the vertical displacement was 71%, and it considered a good ratio compared to the ratios extracted when using the two other types of geotextile with lower tensile model. At the end we can say that a better reinforcement effect can be achieved when the geotextile has higher tensile modulus. For the soil studied herein, a geotextile with a tensile modulus ranging from 15,000 to 25,000 kN/m will maximize the benefits of the reinforced soil footing. No more significant improvement is achieved when the tensile modulus of geotextile exceeds 35,000 kN/m.

B. OPTIMUM LOCATION OF FIRST REINFORCEMNT LAYER

The influence of the location of first reinforcement layer (u) on the lateral deformation, lateral acceleration, at the foundation level is discussed in this section, based on the numerical analyses for the footing placed on geotextile-reinforced soil systems at varying depth ratios(u/B). The typical variations of the horizontal displacement, acceleration with varied depth ratios (u/B) are shown in “Fig. 5” and “Fig. 6”. First in the case of dense sand when using single-layer reinforcement, the reduction of horizontal displacement and acceleration increases first with the increase of the depth ratio (u/B) the reduction was 62% and 53% respectively at U/B = 0.3. Then it decreases after a threshold value of u/B, this threshold depth ratio (u/B) is around 0.3, where the horizontal displacement and horizontal acceleration was the lowest. Second the case of medium sand when using single-layer reinforcement, the reduction of the horizontal displacement and acceleration reached to 52% and 50% respectively at U/B = 0.3. Finally for the case of loose sand there is a good effect for the using of geotextile layers in the loose sand the value of the reduction in the horizontal displacement and acceleration in this case is considered a very good value when we compared it with the other two cases. The reduction ratio for both the horizontal displacement and acceleration was reached to 62% and 70% respectively at U/B = 0.3. The variation of horizontal displacement and acceleration with depth ratios (u/B) is similar in the two-layer and three-layer reinforcement cases. The findings of the present study on the effect of the depth ratio are similar to those reported by other researchers (Yetimoglu et al, 1994, Maharaj, 2003), in which the optimum location of multi-layer reinforced clay under square footing is 0.25-0.3 B (Yetimoglu et al., 1994) and the optimum location of single-layer reinforced clay under strip footing is about 0.5 B.

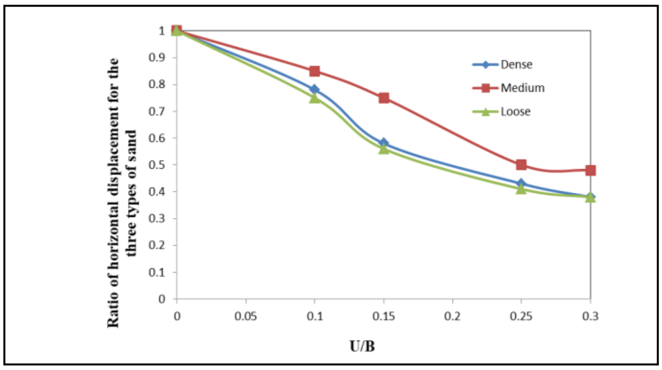

Fig. 5. *The relation between horizontal displacement and the vertical distance between the bottom of the footing and the top most geotextile layer (U) at N =3 and L/B =2*

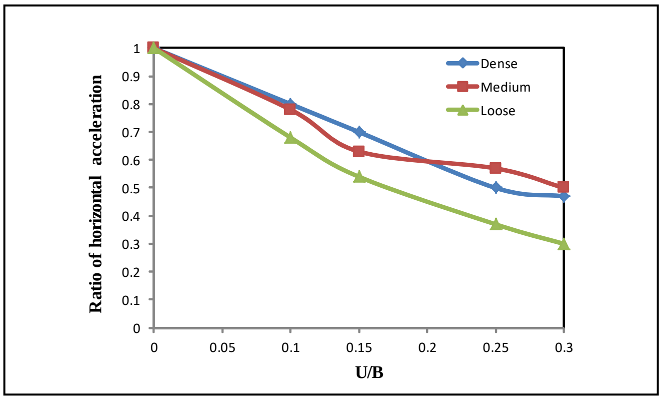

Fig. 6. *The relation between horizontal acceleration and the vertical distance between the bottom of the footing and the top most geotextile layer (U) at N =3 and L/B =2*

IV. CONCLUSION

Based on the finite element analysis for reinforced foundation soil system subjected to an earthquake, the benefits of using geosynthetic-reinforced sand foundations were demonstrated in this paper through increasing the soil's bearing capacity and reducing the footing settlement.

The following conclusions can be drawn:

The existence of geotextile in the sand is considered a good method to increase the subgrade stiffness during seismic loading. It can significantly limit and control the lateral deformation of the soil underneath the foundation and increase the soil stability.

The increase in the geo-grid tensile modulus (or stiffness) results in significant reduction of permanent deformation; however, the geo-grid stiffness effect decreases with the increase in the thickness of the reinforced base course layer and the strength of subgrade layer.

Increasing the tensile model of the geotextile decreasing the vertical displacement of the foundation subgrade. The reduction reached to 50% in case of dense sand like the ratio of the horizontal displacement, and 60%, 71% in case of medium and loose sand respectively When the tensile model was equal to 35000kn/m.

Also the lateral displacement and acceleration decreased with increasing the geotextile tensile strength. The reduction reached to 50% , 57% and 63% for horizontal displacement in case of dense, medium and loose sand respectively. In addition the reduction in horizontal acceleration was 47%, 52% and 73% for dense , medium and loose sand respectively.

Changing the vertical distance of the top most geotextile layer (U/B) affect the lateral deformation for the foundation subgrade the reduction of horizontal displacement and acceleration for dense soil reached to 62% and 53% respectively under foundation level at N =3 layers and L/B = 2.

REFERENCES

The template will number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use “Ref. [3]” or “reference [3]” except at the beginning of a sentence: “Reference [3] was the first .” G. Eason, B. Noble, and I.N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529-551, April 1955. (*references*)

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