Seismic performance of Mid-rise Buildings on Geogrid Reinforced Sand

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ABSTRACT: Reinforcing soils with geogrid material is an effective method to improve seismic performance of the soils. In this study, a series of finite element analyses were performed to determine the seismic performance of the medium rise building constructed on the reinforced sand. Two dimensional plain strain analysis was performed with PLAXIS 2D finite element program. Geogrids with varied number of layers were used as a reinforcing material. The effects of the depth to the first layer of the reinforcement layers and the number of reinforcement layers under earthquake loadings were investigated. Numerical models were subjected to the 1999 Kocaeli Earthquake. The results of seismic analysis of unreinforced and reinforced soil models were compared. The numerical studies indicated a substantial improvement in terms of acceleration, shear stresses and settlement values due to the inclusion of geogrid layers. Furthermore, it has been found that the reinforcement depth has an important effect on the seismic performance of the building model.

Keywords: Geogrid reinforcement, Seismic performance, Finite element analysis.

1 INTRODUCTION

In the last decades, reinforced soil foundations have been widely used in various geotechnical engineering applications, such as bridge approach slab, bridge abutment, building footings, and embankment. Previous studies have shown that the inclusion of reinforcement in soil foundations is a cost-effective solution to increase the bearing capacity and decrease the settlement of footings compared to the conventional methods such as replacing natural soils or increasing the dimensions of the footings. The most common type of reinforcement used in soil foundation applications are geogrids.

It is a well-known fact that geosynthetics are synthetic products which are generally used to solve civil engineering problems. Significant advancements have been made in our understanding of the behavior of geosynthetic-soil systems under static loads. On the other hand, the seismic response of facilities that incorporate geosynthetics has not been adequately addressed.

The use of geosynthetics under foundations can absorb seismic energy and mitigate excitation transmitting to upper layers of soils and foundation of overlying structures. The interface between soil and geosynthetic material increases shear resistance of soil against dynamic loadings. The depth to the first layer of reinforcement, vertical spacing of reinforcement layers, number of reinforcement layers and the size of the reinforcement are other important factors affect the bearing capacity under static and dynamic loads..

In recent years, significant improvements were achieved on understanding the dynamic interface shear properties of geosynthetic materials. Yegian et al. (1995a,b) conducted researches on geosynthetic reinforced soils. Kavazanjian et al. (1991), Yegian and Lahlaf (1992), and Zimmie et al. (1994) have shown that the seismic energy dissipated along the slip deformations occurred on geosynthetic interfaces.

Yetimoglu et al. (1994) performed a study on the bearing capacity of footings on geogrid-reinforced sand. It is indicated that there is an optimum reinforcement spacing for multi-layer reinforced sand. The optimum depth would be larger for settlement ratios greater than 6 and the highest bearing capacity occurs at embedment depth of approximately 0.3B.

Adams and Collin (1997) investigated the effects of reinforcement parameters of foundations on carrying load and settlement. Reinforcement parameters such as vertical space between reinforcement layers, dimension and number of reinforcement layers and degree of compactness were selected. It is found that when the number of reinforcement was N = 3, maximum carrying capacity was obtained and it was determined that soil improvement was not only dependent on number of layers but also varied with total reinforcement depth and vertical space between reinforcements.

Yildiz et al. (2006) investigated the bearing capacity of circular foundations settled on geogrid reinforced sand by using PLAXIS program. Bearing capacity was increased when the first reinforcement layer was selected as 0.3D and the number of reinforcement layers were selected as N= 4. Alamshahi and Hataf (2009) demonstrated that the inclusion of geogrid layers increases bearing capacity of foundation and decreases the settlement. Demiroz and Tan (2010) declared similar results with an experimental study performed on design factors affecting the settlement of strip foundation on geogrid-reinforced sand. It is revealed that the settlement increases until the number of reinforcement is N = 3. The amount of settlement increases until 2nd level of reinforcement depth rate (u = 0.5B) and it decreases after this level. Mahboubi and Keyghobadi (2012) developed a numerical model to investigate the bearing capacity of a strip foundation on geogrid reinforced sand. It is found that increasing number of geogrid layers has a positive effect in bearing capacity, Marto et al. (2013) conducted a parametric study on effect of geogrid reinforcement on bearing capacity of a soil under static loading. It is seen that the improvement in ultimate bearing capacity increases and settlement decreases with the increase of reinforcement layers.

Geosynthetics have been widely used for various geotechnical engineering applications. Especially it has been used in seismic regions for reinforcing slopes and embankments with geogrid materials for stabilization against earthquake hazards. The aim of this preliminary study is to determine the effectiveness of number of geogrid layers on seismic performance of mid-rise building constructed on the reinforced sand.

2 NUMERICAL STUDY

2.1 *Geometry of model*

A medium-rise building with a basement on unreinforced and reinforced soils was modelled. Geogrids with different number of layers were used to reinforce the soil. PLAXIS 2D software program was used for finite element analysis of models. The building consists of five -storey with a basement and dimensions of the building are B= 10 m, storey height was 2 m and 3 m for basement and normal storeys, respectively. The first layer of geogrid is located at a depth of 3 m below the foundation and the vertical distance selected as 2 m between consecutive layers. As it can be seen in numerical models, the total reinforcement depth is expressed with '*d'* and it can be calculated as $d = u + (N-1).h$, where h is the vertical distance between geogrid layers and equals to 2 m in each cases (Figure1).

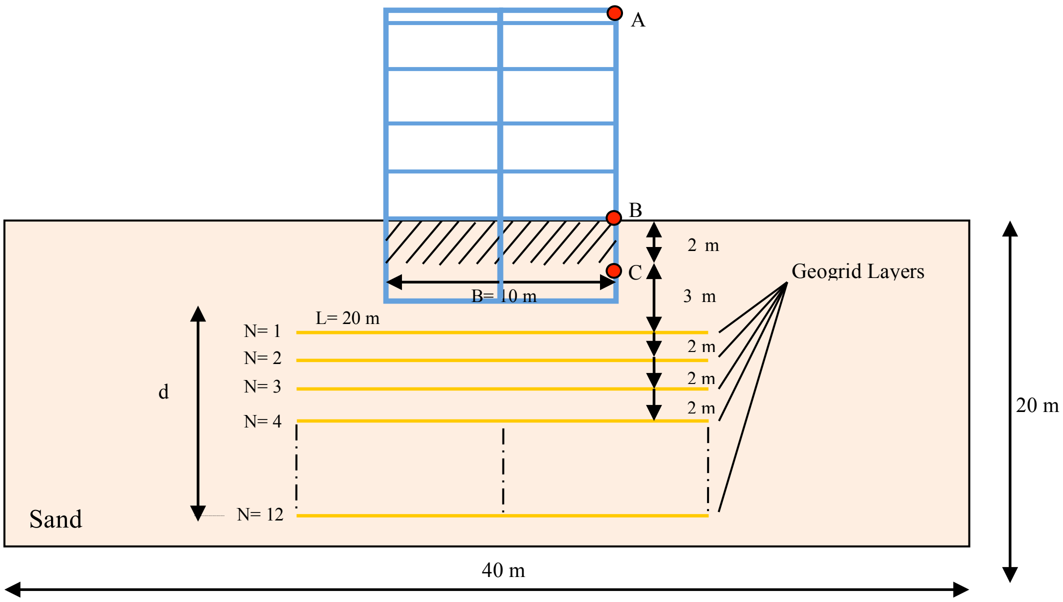

Figure 1. Numerical model.

2.2. Material properties

The behavior of sand material was selected as hardening soil model. The material properties of sand is given in Table 1. The structural elements were categorized in two groups as foundation and building materials. The materials were assumed to be concrete and selected as a plate element. The material properties are shown in Table 2.

Table 1. Parameters of soil.

Parameter	Sand
Behaviour Model	Hardening Soil
γ_{unsat}	17 kN/m^3
γ_{sat}	17 kN/m^3
c'_{ref}	0 kN/m^2
Ø	30°
ψ	3°
E	15.000 kN/m^2

Table 2. Material properties of building elements.

Parameter	Foundation	Plate Elements
Material Type	Isotropic-Elastic	Isotropic-Elastic
EA_1	12.00E6 kN/m^2	9.00E6 kN/m^2
EA_2	12.00E6 kN/m^2	9.00E6 kN/m^2
EI	400.0E3 kN/ m$^{2/}$m	67.0E3 kN/ m$^{2/}$m

The uniaxial geogrids have been used to reinforce the sand material. Numbers of layers N= 0, 3, 6, 9 and 12 were used for reinforcing the soil. The length of each layers are 20 m. The horizontal symmetry axis of geogrid layers and foundation coincidence with each other. The numerical model was designed with maximum number of layers (N= 12) and then they are eliminated for models with reducing number of geogrid layers. The physical properties of geogrid material is shown in Table 3.

Table 3. Material properties of geogrid.

Material Type	Isotropic-Elastic
EA_1	500.000 kN/m^2
EA_2	500.000 kN/m^2

2.3 Dynamic loading

The 1999 Kocaeli earthquake record (PGA=0.23g) was taken as an input motion (Figure 2). Records are obtained from BU-KOERI-BDTIM and used after baseline corrected and filtered from noise contamination. The numerical models were fine meshed. Deformed mesh of the dynamically loaded model is given in Figure 3.

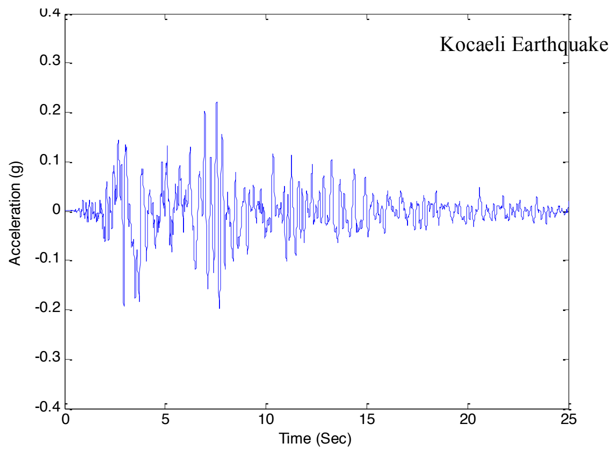

Figure 2. Acceleration-time history of the 1999 Kocaeli Earthquake.

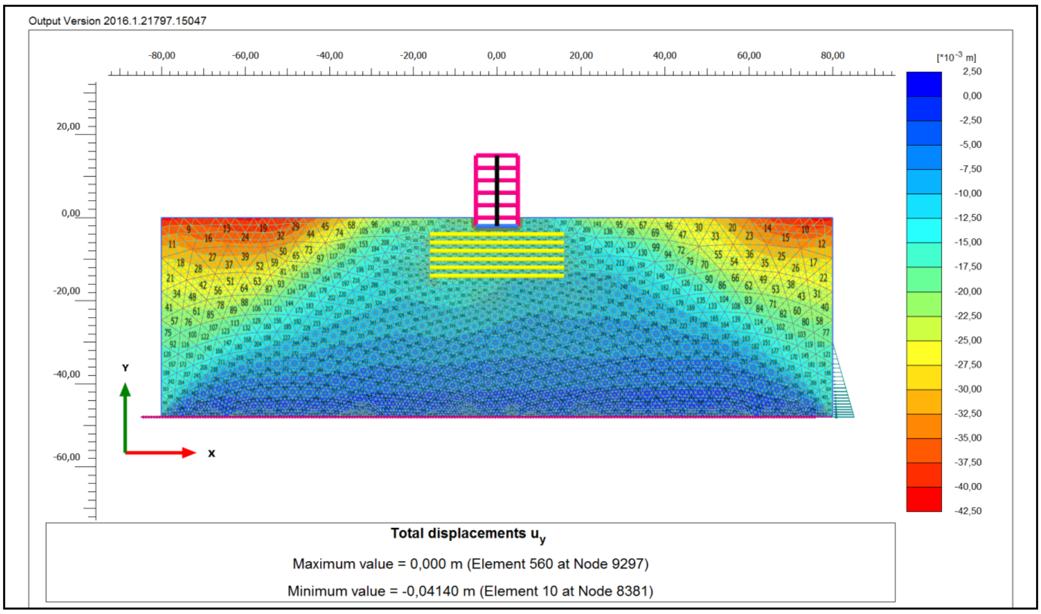

Figure 3. Deformed mesh of dynamically loaded numerical model.

3 RESULTS

Numerical results of foundation on sand are represented in terms of total displacements, acceleration responses and shear stresses.

3.1 Total displacements

The displacement time histories of unreinforced sand (N= 0) and reinforced sand models with varied numbers of geogrid layers are shown in Figure 4.

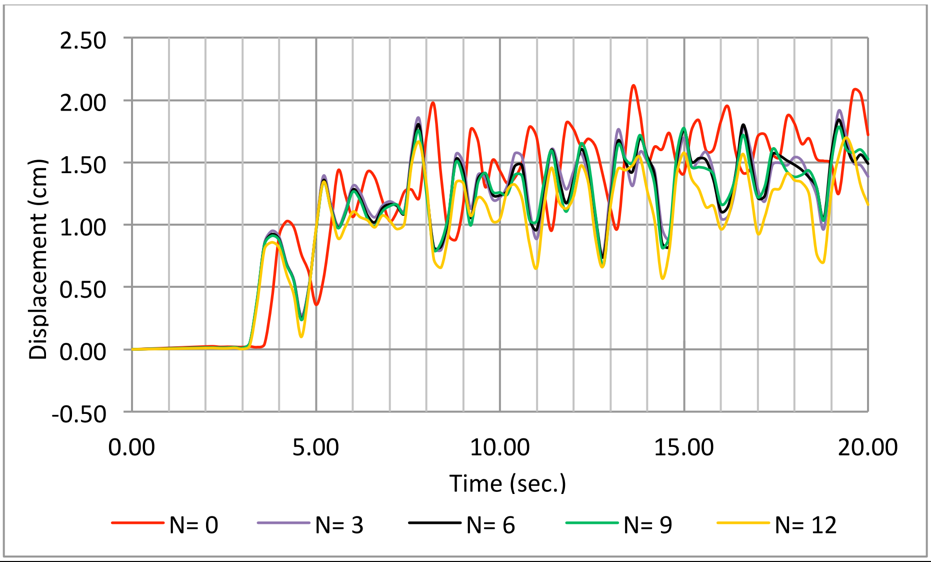

Figure 4. Displacement time histories of numerical models.

The maximum total displacement value of model for N=0 obtained as 2.18 cm. The increase in reinforcing layers have a reducing effect on displacements. As number of geogrid layers increases, the displacement values gradually decreases. The minimum total displacement occurred for N= 12 layers of geogrid as 1.70 cm. The maximum displacement values are summarized in Table 4. The maximum change in reduction of displacements occurred in sand reinforced with N= 12 layers of geogrid as - 19%. The minimum reduction occurred with N= 3 layers of reinforcement as - 9.5%.

Table 4. Maximum displacement values of numerical models.

Number of Geogrid Layers (N)	Max. Displacement (cm)	Change (%)
0	2.18	-
3	1.91	- 9.50
6	1.84	- 12.80
9	1.79	- 15.20
12	1.70	- 19.40

3.2 Displacements of building

The vertical displacement of top height of building is shown in Figure 5. The displacement value for unreinforced sand measured as 2.80 cm. When the soil model reinforced with N= 3 layers of geogrid, the vertical displacement value reduces to 2.20 cm. The reinforcement layers greater than three reduces the displacement values to 2.10 cm which equals to 25 % reduction (Table 5).

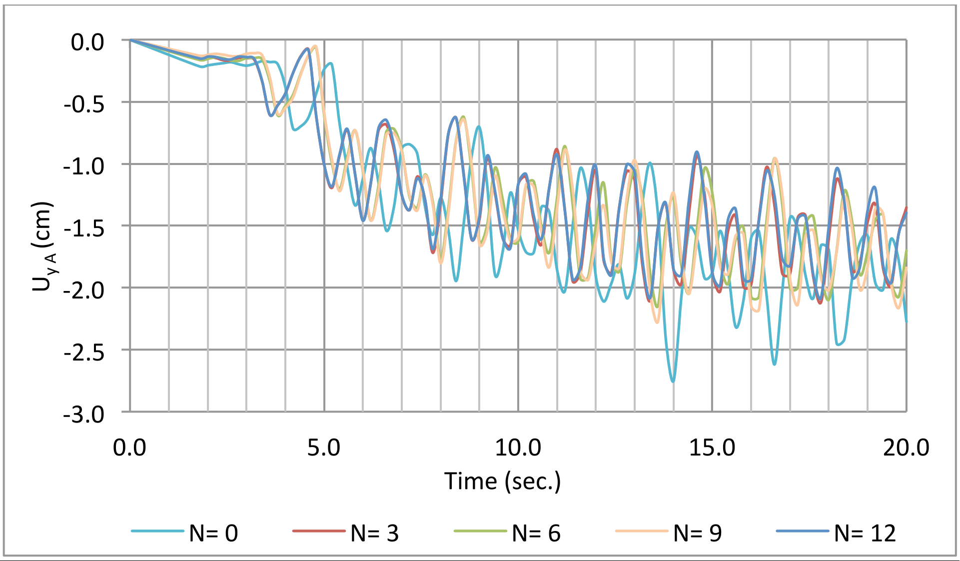

Figure 5. Displacement time history at the top of building.

Table 5. Vertical displacement change calculated for the top of building.

Number of Geogrid Layers (N)	Max. Disp. (cm)	Change (%)
0	2.80	-
3	2.30	- 18
6	2.20	- 21
9	2.20	- 21
12	2.10	- 25

3.3 Acceleration time histories

The PGA values for unreinforced and reinforced sand is given in Table 6. It is seen that increasing numbers of geogrid layers cause decrease in PGA values. Minimum acceleration value observed from the model with N=12. In y-direction the maximum decrease observed for N= 9. It is seen that the increasing reinforcement depth decreases the acceleration values and causes deamplification. The maximum reduction occurred for N=9 and N=12 layers of geogrids as 50 % and 44 % for y- and x- directions respectively.

Table 6. The percent change in acceleration values of numerical models.

Number of Geogrid Layers (N)	Max. $Acc._x$ (g)	Change (%)	Max. $Acc._y$ (g)	Change (%)
0	0.154	-	0.100	
3	0.104	-32.50	0.096	-4
6	0.110	-28.60	0.060	-40
9	0.098	-36.40	0.050	-50
12	0.086	-44.20	0.068	-32

The acceleration time histories are given Figure 6. The transmitted acceleration value measured as 0.12g for unreinforced sand. When it is reinforced with N=9 layers of geogrid, the acceleration value decreased to 0.102g which means 15 % reduction (Table 7).

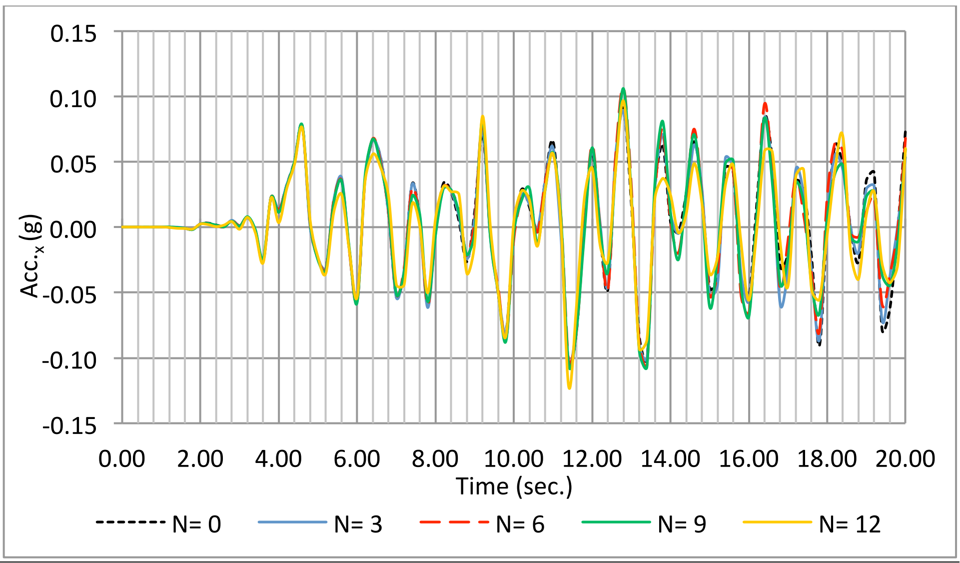

Figure 6. Acceleration time history of top height of building.

Table 7. The percent change in acceleration response of building.

Number of Geogrid Layers (N)	Max. Acc.$_x$ (g)	Change (%)
0	0,121	-
3	0,104	13
6	0,104	13
9	0,102	15
12	0,105	12,5

The acceleration time histories on the ground surface is given in Figure 7. For the unreinforced and N=12 cases, PGA was obtained as 0.07g and 0.039g which equals to 44% reduction with respect to the unreinforced sand (Table 8).

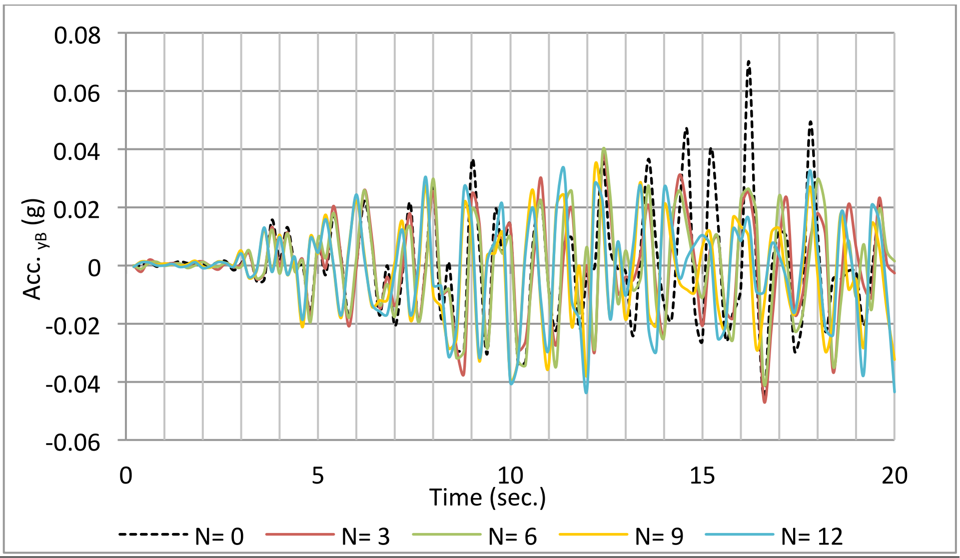

Figure 7. Acceleration time history of ground surface.

Table 8. Acceleration values of ground surface of soil.

Number of Geogrid Layers (N)	Max. Acc $_{yB}$. (g)	Change (%)
0	0,070	-
3	0,046	- 34,30
6	0,040	- 43
9	0,042	- 40
12	0,039	- 44

3.4 Shear stresses

Shear stress values under dynamic loadings are compared. At a depth of 2 m, the maximum shear stress was measured as 20 kN/m^2 for unreinforced sand (Figure 8). The placement of geogrid layers causes gradual reduction in shear stresses. The soil reinforcement with N=12 geogrid layers decreased the shear stress to 16,70 kN/m^2 which corresponds to almost 17 % reduction (Table 9).

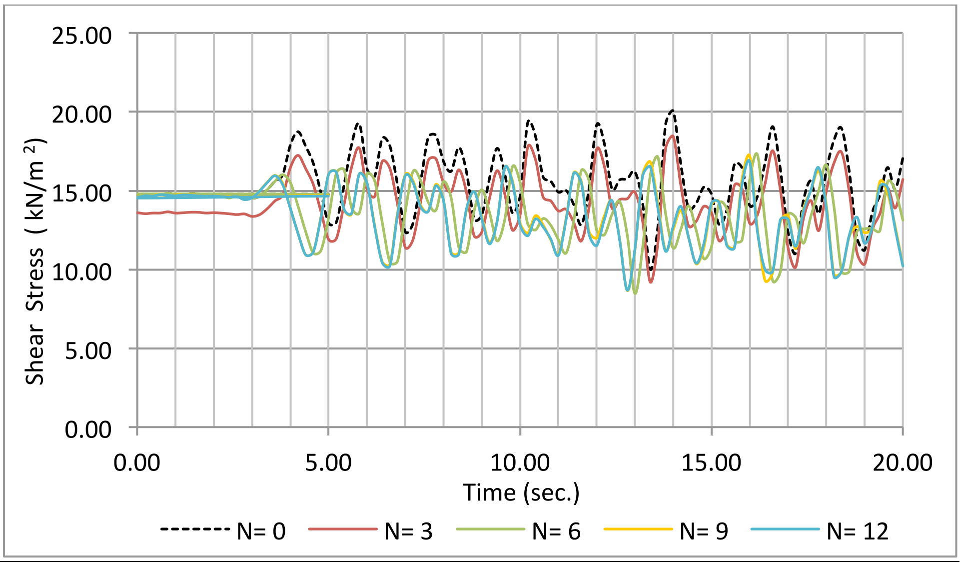

Figure 8. Shear stress of dynamically loaded soil.

Table 9. The percent change in shear stress values.

Number of Geogrid Layers (N)	Max. Shear stress (kN/m^2)	Change (%)
0	20,06	-
3	18,50	- 7.8
6	17,30	- 13.8
9	17,20	- 14.3
12	16,70	- 16.7

4 CONCLUSIONS

The main objective of this study is to investigate the effect of the depth of geogrid reinforcement on the seismic performance of soils. A medium-rise building with a basement constructed on unreinforced sand and geogrid reinforced sand with four different numbers of layers (N= 3, 6, 9 and 12) was modelled. The 1999 Kocaeli earthquake which is known as one of the destructive earthquake in the world was applied to numerical models and finite element analyses were performed with PLAXIS 2D software program. The result of this study reveals that the geogrid reinforced sand is an effective method to reduce the seismic energy transmitted to the mid-rise building. A remarkable difference occurred in total displacements between the reinforced and unreinforced soils. Calculated shear stresses were lowered substantially with inclusion of reinforcement layers. With increasing number of reinforcing layers, total displacements decreased. There is an optimum number of reinforcement layers for multi-layer reinforced sand. The bearing capacity of the reinforced sand was also found to increase with reinforcement layer number when the reinforcement was placed within a certain effective zone.

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