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Machine Foundations on Fiber Concrete Tunnel in Reinforced Sand

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ABSTRACT

The superimposing of static and dynamic loads on such as machine foundation which are setting on the tunnels will cause differential and impermissible settlements. These settlements sometimes may reason irreversible damage to financial and human factors. This paper investigates the effects of the soil damping parameters, tunnel lining types and tunnel lining thickness on the circular foundation settlement under the influence of cyclic loads. PLAXIS 2D DYNAMIC is used as the FEM code to analyze models as well as investigating the effects of number of geogrid layers as a reinforcement element on the foundation settlement rested on the bored tunnel to obtain safe condition.

1. Introduction

Recently, the beneficial effects of using geosynthetic reinforcements to increase the bearing capacity of footing located has been clearly demonstrated by several investigators both analytically and numerically (Zidan, 2012; Makkar et al., 2017; Razzazan et al., 2019; Kumar and Ilamparuthi, 2020; Harikumar et al., 2020; Raja and Shukla, 2020; Lingwal and Gupta, 2020). In the past years the structures buried in the soil have received less attention but with the development of transportation and human needs, they have received more attention in recent years, and the effects of these structures under static and dynamic loads have been further studied. Das and Maji (1994) investigated the transient load in relation with the square foundation settlement. Shin and Das (1999) examined the behavior of reinforced sand with geogrid under the low frequency load, 1 cps (cycle per second) and the effects of the geogrid were shown to decrease the foundation settlement. Patra et al. (2005) investigated the bearing capacity of strip footing on reinforced sand and compared it with the Menghong theory and used it with one type of geogrid and uniform density. Zamanian and Sahragard (2006) showed the use of the fiber reinforced concrete shell in a single system of tunnels in the Dorahan-Lavanab railway and the comparisons were made between single-shell and traditional lining systems. Tafreshi and Khalaj (2008) simulated the vehicle load on the embedded pipe of HDPE in sandy soil in strip footing under repeat loading. Boushehrian et al. (2010) investigated the cyclic behavior of geogrid and grid-anchor. The relations between the load amplitude, the dimension of footing, the permanent settlement and the number of cycles were obtained.

In the past years the structures buried in the soil have received less attention but with the development of transportation and human needs, they have received more attention in recent years, and the effects of these structures under static and dynamic loads have been further studied. Boushehrian and Afzali (2016) have found the effect of

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different factors affecting the amount of foundation settlement over reinforced sand with embedded pipe under dynamic loading. This study originates new formula for reinforced soil under dynamic loading to predict the permanent settlement of various pipe depths and load ratio. El-Sawwaf and Nazir (2010) studied the behavior of model strip footings supported on a loose sandy slope and subjected to both monotonic and cyclic loads. The effects of the partial replacement of a compacted sand layer and the inclusion of geosynthetic reinforcement were investigated. Based on the test results, the variation of cumulative settlements with different parameters have been presented and discussed.

Islam and Gnanendran (2013) applied 100,000 loading cycles on a strip foundation next to a sand slope and investigated the effect of the frequency of applied cyclic load on the amount of permanent and resilient vertical and horizontal deformation of the foundation. The results of their research showed that although the application of cyclic loading results in the increased bearing capacity of the foundation on the slope, its improvement effect decreases with the increase of loading frequency. In addition, the loading frequency has a negative effect on the amount of permanent vertical and horizontal deformation. In such a way that with the increase of load frequency under the same conditions of amplitude and the number of loading cycles, the deformations increase. Alam et al. (2018) studied experimentally and numerically the behavior of strip foundations rested on an embankment reinforced with geosynthetics under cyclic loading. They investigated the effect of this kind of loadings on the amount of permanent settlement of the foundation and residual stress accumulated. The effect of utilization of reinforcement layers, the length of the reinforcement, the distance of foundation edge to the slope, the frequency of cyclic load application and the number of loading cycles on the amount of strip foundations settlement have been investigated in their study.

Various problems can be identified for the establishment of footings rested on the soil with substructure elements like tunnels, embedded pipes and power line channels under repeated traffic loads. These are examples of foundations subjected to the cyclic loading with the amplitude well below their allowable bearing capacity. The concern exists for the amount of uniform and non-uniform settlement of such structures. As a review of the previous research indicated, in recent decades, most studies have focused on determination the bearing capacity of shallow footings located on these embedded substructures and there is only a limited amount of information about the foundation settlement under cyclic loading. Thus, the purpose of the present study is to provide a numerical model to determine the effect of the number of reinforcement, the soil damping parameters, tunnel lining thickness and materials on the foundation settlement.

2. Material and Methods

In this article, a sandy soil was modeled according to Tafreshi and Khalaj (2008) work as shown in Table1. For analysis, PLAXIS2D with the hardening soil model was used. The land size was 140×70 m and the circular concrete foundation had a 12 m diameter. Tunnel had an 8m diameter and a height of 15 m below the ground level is shown Fig. 1. The characteristics of the foundation and tunnel are shown in Table 2 which the type of tunnel is bored. The behavior of the tunnel has been analyzed at frequency 1 HZ and above 3000 cycles. The six-node element was used in which the foundation and geogrid were considered as triangle 3 nodal. The load was entered into two phases. The static load due to machinery self weight that is considered as 200 kN/m^2 and the dynamic load is added to the static load that indicating the vibration of machinery considered equal to 50 kN/m^2. The typical history of the cyclic load on the soil surface is shown in Fig. 2.

Table 1. Studied soil's properties

Parameter	Index	Unit	Value
Internal friction	ϕ	Degree	36
Cohesion	C	kN/m^2	0.4
Average wet unit weight	γ_{wet}	kN/m^3	17
Specific gravity	Gs	-	2.65
Dilatancy	ψ	Degree	6.0
Poisson ratio	υ	-	0.3
Elastic normal stiffness of reinforcement	-	kN/m	16
Secant stiffness in standard drained triaxial test	-	kN/m^2	20000
Soil Interface	-	-	0.6

Table 2. Properties of concrete materials in analysis

Structure	E_c (GPa)	EA (kN/m)	EI (kN.m^2/m)	t (mm)	υ
Foundation	20	1.2×10^7	3.6×10^5	600	0.2
Tunnel	20	6.0×10^6	4.5×10^4	300	0.2

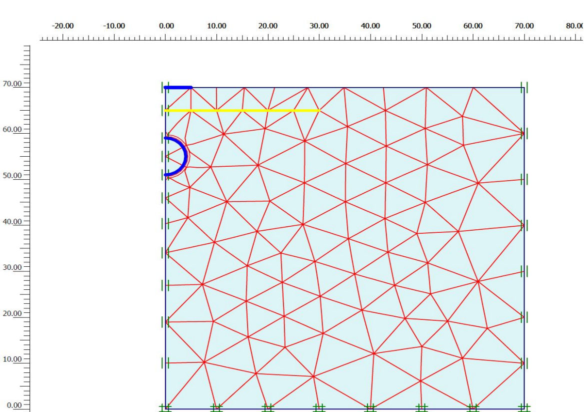

Figure 1. Numerical model for dynamic analyses

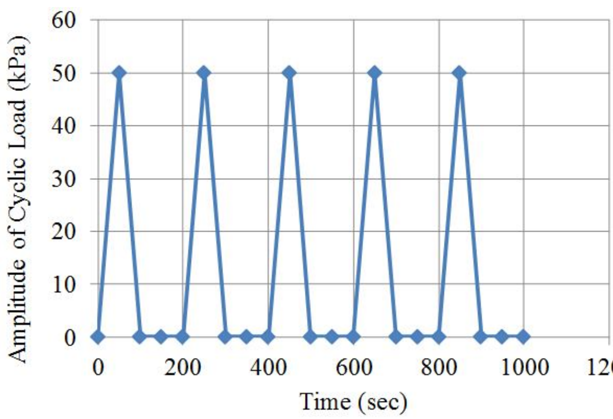

Figure 2. Typical history of the cyclic load on the soil surface

3. Results and Discussions

3.1. Studying the effect of number of reinforcement layers

Due to the traffic or machinery and their repeated action, the settlement occurs on the soil surface of foundation and the top of the embedded tunnels. Since the soil does not bear the tension, the geogrid reinforcement with a high tension capacity is used to strength the soil and reduces its settlement. In this paper the depth of the first layer of reinforcement and the foundation diameter are show by *u* and *D*, respectively. The ratio u/D is considered equal to 0.25. As can be seen in Fig. 3 with the presence of the 4-layer reinforcement, the quantity of foundation settlement is 12% decreased, as compared with the unreinforced condition. This indicates that the geogrid is effective in reducing the foundation settlement and deformation of the tunnel crest.

3.2. Studying the effect of number of damping parameters

Rayleigh damping has been used in this analysis. The Rayleigh relation is as follows:

$$c = \alpha M + \beta K \tag{1}$$

where α=the mass damping, β=damping ratio stiffness. For the effect of damping, two types of analysis are considered:

- Case A: The effect of different α and β,
- Case B: With constant α=0.001 and increasing β=0 to 0.0.

Fig. 4 shows that by increasing β the foundation settlement is increased but the rate of increase for β more than 0.02 is decreased. Table 3 shows that the minimum foundation settlement is obtained at the damping parameter α=0.1 and β=0.1.

Table 3. The variation of damping parameters versus settlement

Variable	α=0 β=0	α=0.001 β=0.05	α=0.01 β=0.1	α=0.1 β=0.1
Settlement(mm)	143.95	144.43	142.68	140.21

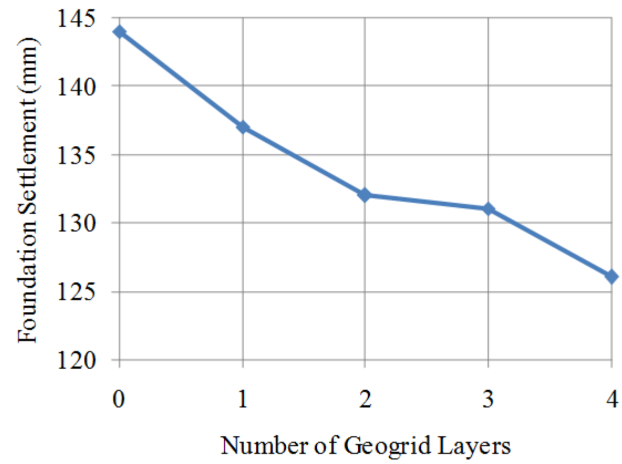

Figure 3. The variation number of geogrid layers versus foundation settlement

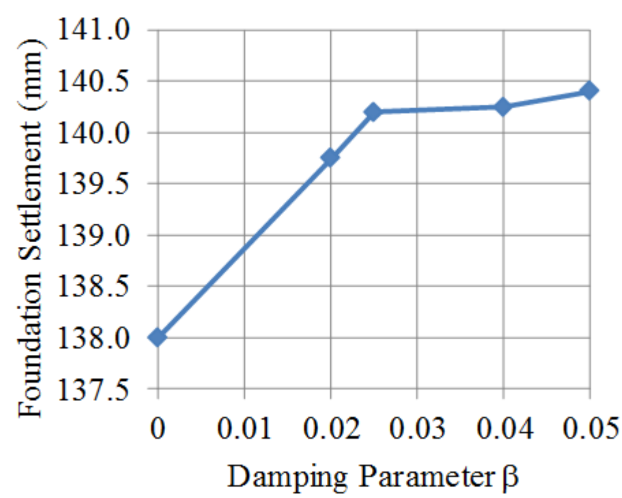

Figure 4. The variation of damping parameter (β) versus foundation settlement when α=0.001

3.3. Studying the effect of lining thickness

The various thicknesses of the concrete equal to 10, 30, 40 and 45cm were used and the results were presented in Fig. 5. As expected, by increasing the thickness of the concrete tunnel lining and increasing its stiffness, the rate of settlement is decreased.

3.4. Studying the effect of fiber concrete as a tunnel lining

Using fiber concrete for the temporary lining and shallow depth tunnels can save the consumption of concrete and increase the speed of operation. The fiber concretes against dynamic and impacts loads have shown much better performance. This advantage has been more effective in the mode of structures failure.

In this part, two types of fiber concrete are used instead of plain concrete to compare their effects on the machine foundation settlement.

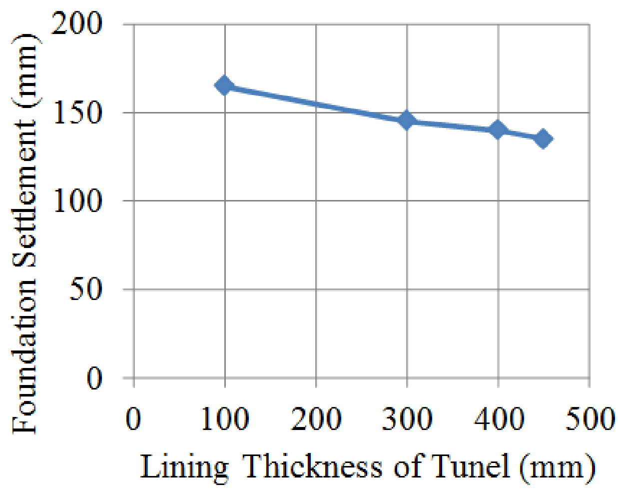

Figure 5. The variation of lining thickness versus the foundation settlement

Fiber concrete I: In this case, the 28-day compression strength of fiber concrete cylinder sample is much more than plain concrete. Marar et al. (2011) studied the toughness of normal strength steel fiber reinforced concrete (NSSFRC). Their tests were carried out on concrete cylinders reinforced with three different aspect ratios of hooked-end steel fibers 60, 75, and 83 and six different percentages of steel fibers L/D (length/diameter of fiber) = 0.5, 1.0, 1.25, 1.5, 1.75, and 2.0%. However compressive strength for the ratio of L/D=1 and 83% fiber volume fraction was 83 MPa.

Fiber concrete II: In this case, the 28-day compression strength of fiber concrete cylinder sample is near to plain concrete. Kandasamy and Murugesan (2011) investigated the influence of the addition of polythene fibers (domestic waste plastics) at a dosage of 0.5% by weight of cement. The compressive strength was of the 28-day sample was 26.03 MPa when 0.5% fiber was mixed in concrete. The specification of fiber concretes show in Table 3.

The analysis was conducted for fiber concrete I and II with 1 to 3 geogrid layers and the results are shown in Fig. 6 and 7. Figure 6 shows that by using 3 reinforcement layers, the amount of foundation settlement decreased 23% for fiber concrete I lining and 14% for fiber concrete II lining, as compared to unreinforced condition. Fig. 7 shows that the foundation settlement by using 3 geogrid layers with fiber concrete as a tunnel lining is less than foundation settlement by using 4 geogrid layers with plain concrete. Result indicates the effectiveness of fiber concrete in reducing settlement compared to plain concrete.

Table 4. Properties of fiber concretes

Structure	f_c (MPa)	EA (kN/m)	EI (kN.m^2/m)	t (mm)	υ
Fiber I	83	9.2×10^6	6.2×10^4	300	0.2
Fiber II	26.03	7.1×10^6	5.3×10^4	300	0.2

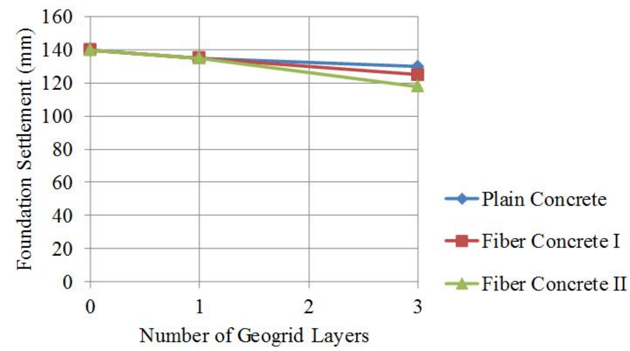

Figure 6. The variation of number of geogrid layers versus foundation settlement for different tunnel lining

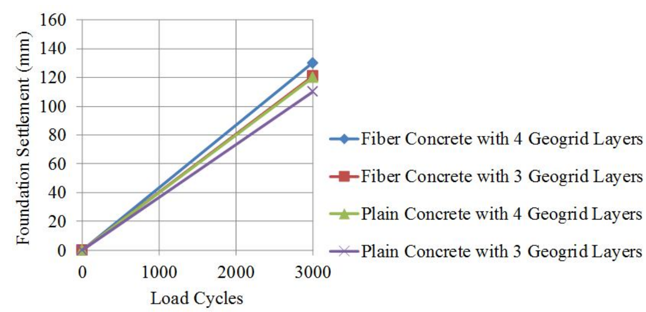

Figure 7. The variation of load cycles versus settlement for two types of tunnel lining

4. Conclusion

In this study the dynamic behavior of the vibration machinery or traffic load in the 3000 cycles is investigated. The tunnel is embedded at a depth of the 15m from ground level. And its results can be written as follows:

1) By increasing the cyclic load, the value of settlement increases, and to reduce it, the geogrid reinforcement is used with 1 to 4 layers. With the 4 layers geogrid, the value of settlement is decreased to 12%, as compared with the non-reinforcement situation.

2) By having the constant α=0.001 and increasing β=0 to 0.05, the rate of foundation settlement increases. In addition, the minimum foundation settlement is obtained at the damping parameter α=0.1 and β=0.1.

3) By increasing the thickness of tunnel lining, the amount of tunnel deformation or foundation settlement decreases. As a result, the amount of axial forces and bending moments of the tunnel increases.

4) Using fiber concrete (the new generation of concrete) for the lining of the tunnel is very effective in reducing the amount of foundation settlement and deformation of tunnel. The settlement is decreased 15% for 3 reinforcement layers and fiber concrete I instead of plain concrete with 3 reinforcement layers. Also, the foundation settlement in tunnel with fiber concrete lining by 3 geogrid layers is decreased more than condition with 4 geogrid layers and plain concrete as a lining.

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