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Behavior of a model shallow foundation on reinforced sandy sloped fill under cyclic loading

M.J.I. Alam, C. T. Gnanendran & S.R. Lo
School of Engineering and Information Technology (SEIT), The University of New South Wales (UNSW), Canberra, ACT-2600, Australia

ABSTRACT: Investigations of shallow foundations with geogrid reinforcement under cyclic loading conditions are rather limited. In this study, an attempt has been made to experimentally investigate the behavior of a model shallow foundation on dense sandy sloped fill under cyclic loading. Special placement and compaction techniques were used to ensure a consistent and uniform soil density representative of the field condition. A high tenacity polyester geogrid reinforcement was embedded into the foundation soil mass using the wrap-around technique. Laboratory testing program covered a wide range of cyclic loading amplitudes. A large number of loading cycles, considering hold periods, were applied to the strip footing. The vertical soil stress at different depth was also measured using five individual earth pressure cells. The test results suggested that the cyclic loading amplitude had a significant effect on both the vertical and horizontal permanent deformation behavior of the soil. For a particular loading amplitude and frequency, permanent deformations showed negligible effect of hold periods when the load was held at the minimum value of the cyclic loading amplitude. However, significant increases of permanent deformations were observed after the hold periods when the load was totally released during the hold periods. Similar observations, as of permanent deformations, were also found for residual soil stresses.

1 INTRODUCTION

Loading is one of the most important design factors for a foundation. The static load due to the self-weight of the structure is the dominant contributor of the loads acting on a foundation. However, in addition to the static loads, the foundation is often subjected to live loads of different types such as cyclic loading. The strength and deformation characteristics of a foundation soil mass are significantly affected by cyclic loading due to stress repetitions (Seed et al. 1967). The number of loading cycles, amplitude and frequency are the most important factors that affect the behavior of foundation soil mass under cyclic loading (Diyaljee & Raymond 1982).

The materials used to support foundations may vary but, generally, well-graded granular materials such as sand and gravel are used due to their high bearing capacity, good drainage quality and frictional characteristics. In many practical cases shallow foundations may need to be constructed on or near the crest of a sloped soil mass. The behavior of a shallow foundation near slope of a granular soil mass becomes very complicated when it is subjected to cyclic loading in addition to the static loading due to its non-linear elasto-plastic behavior. Bridge abutment constructed on embankment slope under traffic loading is one of the common examples of such type of foundations which are subjected to a large number of loading cycles. To avoid potential complexity, deep foundations are normally preferred by the design engineers (Bauer et al. 1981). However, the use of shallow foundations may be necessary due to the type of structure and cost effectiveness in many practical conditions.

In practice, the design of a shallow foundation is often based on approximations of the bearing capacity under static loading conditions, despite the foundation experiencing cyclic loading. These approximations lead to the use of a large factor of safety and excessive cost. The main reason behind this practice is the lack of experimental and theoretical studies and understanding of the actual behavior of shallow foundation under cyclic loading conditions.

At present geogrids are widely used as soil reinforcement to improve the stability of the foundation soil mass. Related experimental studies considering single or multiple layers of geogrid reinforcement embedded in a sloped soil mass available in the literature are mainly focused on the investigations of the bearing capacity under static loading conditions (Bathurst et al. 2003; Choudhary et al. 2010; Gnanendran &

Selvadurai 2001; Lee & Manjunath 2000; Sawwaf 2007). Experimental studies on the behavior of foundation on geogrid reinforced sandy flat ground under cyclic loading can also be found in the literature (Boushehrian et al. 2011; Puri et al. 1993; Sawwaf & Nazir 2010; Yeo et al. 1993). However, experimental investigations on the behavior of shallow foundation on geogrid reinforced sloped granular fill under cyclic loading conditions are rather limited in the literature except some recent studies reported by Sawwaf & Nazir (2012) and Islam & Gnanendran (2013). Furthermore, shallow foundations (such as bridge abutment) also experience interruptions of cyclic loading due to the absence of vehicles on the road for an extended period of time. These interruptions may affect the deformation and residual stress behavior of the foundation soil mass. Nevertheless, at the time of conducting this research, the authors are not aware of any study which discusses the effect of any load interruptions during the cyclic loading period which experience a shallow foundation in practical conditions.

The objective of this research work is to experimentally investigate the behavior of a model shallow foundation on geogrid reinforced sandy sloped fill under cyclic loading conditions. The permanent deformation behavior and residual soil stress at different depth of the foundation soil mass subjected to cyclic loading were investigated. The effect of any load interruption on deformation and stress behavior was also investigated by providing hold periods during cyclic loading.

2 TESTED MATERIALS

2.1 *Tested soil*

A well-graded sand with about 5% of non-plastic fines was used for this study. The particle size distribution curve of the tested soil is shown in Figure 1. The maximum dry density (MDD) and optimum moisture content (OMC) of the soil were determined from Standard Proctor compaction test and found to be 1819.5 kg/m^3 and 4.75% respectively. A series of monotonic triaxial tests were also conducted at different confining pressures ranging from 50 to 200 kPa to determine the soil strength and deformation parameters. The measured friction angle (ϕ), dilation angle (ψ) and cohesion (c) was found to be 44^0, 13^0 and 8.2 kPa respectively. It should be noted that all the triaxial specimens were prepared maintaining the MDD and OMC which were consistent with the large scale laboratory model foundation tests as described later.

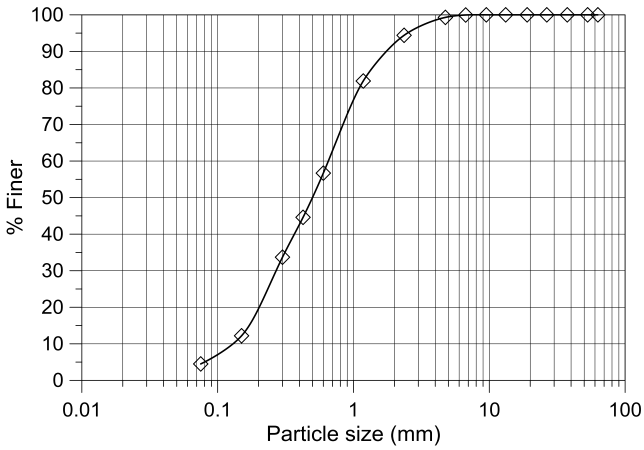

Figure 1. Particle size distribution curve of the tested soil

2.2 *Reinforcement*

A polyester geogrid was used in this experimental study as the reinforcing element. The geogrid, named as Miragrid 8XT, was manufactured by Tencate Geosynthetics. The geogrid was composed of high molecular weight with high tenacity multifilament yarns with a PVC coating to resist the geogrid from biological degradation. The width of the longitudinal and transverse members of the geogrid was 8 mm and 4 mm respectively with a thickness of 1 mm. The longitudinal members were placed at a spacing of 20 mm whereas the transverse members were placed at 30 mm spacing. A pictorial view of the geogrid reinforcement used in this study is shown in Figure 2. According to the manufacturer the tensile strength of the geogrid was 108 kN/m.

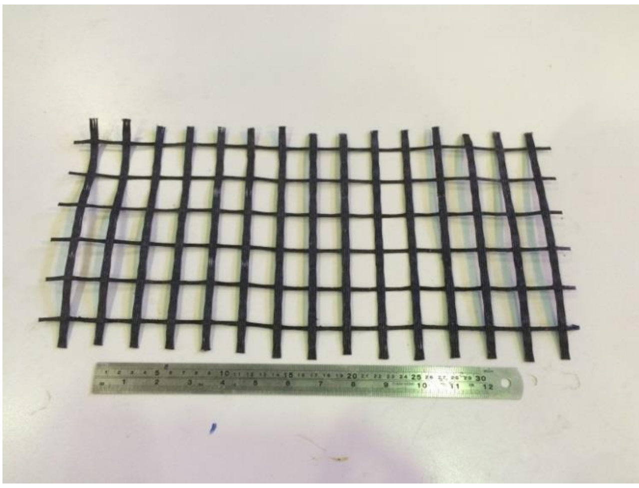

Figure 2. Pictorial view of the geogrid reinforcement

3 TEST CONFIGURATION

The testing arrangement used for this laboratory experiment comprised of a rectangular box, a strip footing, a polyester geogrid reinforcement, hydraulic actuator, load cell, displacement transducers, pressure cells and data acquisition system. The rectangular box was made of steel with dimensions of 2 m long, 1 m wide and 1 m height. Steel made strip footing of 1 m long and 0.2 m wide was used to apply cyclic loading on the soil mass. To replicate practical conditions, the base of the footing was roughened by cementing a thin layer of sand to it using epoxy glue. A schematic diagram of the laboratory testing arrangement is shown in Figure 3.

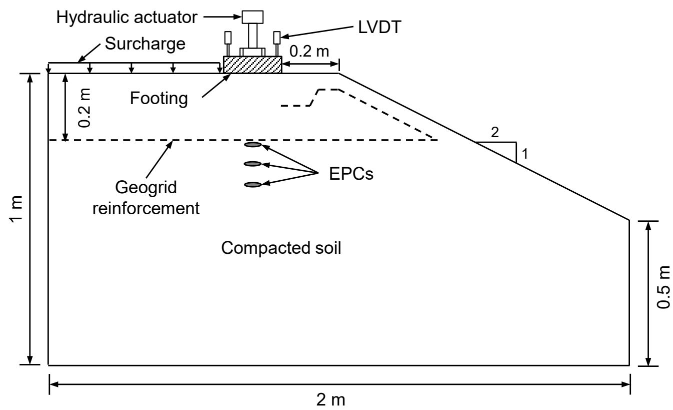

Figure 3. Schematic diagram of the model shallow foundation testing system

The tested soil was collected and stored in big air tight containers. To achieve desired moisture content, required amount of water was added to the soil during specimen preparation. Pre-weighted soil sample was placed in the box and compacted maintaining the MDD and OMC which were consistent with the triaxial tests as explained earlier. The whole compaction process was performed using a percussion compactor with 10 compaction layers maintaining the desired thickness to achieve target dry density. After filling the bottom eight layers, the geogrid reinforcement was placed. As the reinforcement was placed using wrap-around technique (as shown in Figure 3) on the sloping side, the top two layers were compacted very carefully using an additional drop hammer ensuring the uniform compaction around the reinforcement. It is to be noted that five individual earth pressure cells (EPCs) were placed in the soil mass at different depths of 200, 300 and 400 mm from the top surface to measure the vertical soil stresses under the footing as shown in Figure 3. After compacting all the layers, a slope of 1V:2H was made on one side of the foundation. The strip footing was then placed on the soil mass with a setback distance of 0.2 m from the crest of the slope (see Figure 3). A surcharge pressure of 8 kPa was also applied on non-slope side of the soil mass to replicate the static structural load. An external load cell was placed on top of the footing to measure the applied loading amplitude whereas eight individual linear variable differential transformers (LVDTs) were mounted directly on top of the footing to measure both the vertical and horizontal displacements. This ensured that the measured displacements were not be affected by compliance in the loading train.

Cyclic loading amplitude with a desired frequency was applied on the footing in load controlled mode using a hydraulic actuator which was connected to a strong reaction frame. The cyclic load was applied in such a way that a ramp-up load at a very slow rate up to the minimum value of the cyclic loading amplitude was applied first. Then the load was varied between the minimum and maximum values using a sinusoidal wave with the desired frequency of equal to 0.5 Hz for a total of 20000 cycles. To investigate the effect of any loading interruption, the applied cyclic loading was held for two hours at the minimum value of the loading amplitude after each 5000 cycles. The A data acquisition system was used to collect and store data from the measuring devices.

4 RESULTS AND DISCUSSIONS

A total of five large scale model foundation tests were conducted under cyclic loading conditions. A model foundation test is identified by a standardized naming system of F-XX-YY&ZZ. Letters ‘F’ represents large scale model foundation tests. The following letters ‘XX’ represent the frequency of the applied cyclic loading. The letters ‘YY’ and ‘ZZ’ indicate the minimum and maximum values of the cyclic loading amplitudes respectively. For example, F-0.5-27&45 indicates large scale cyclic load model foundation test performed at a frequency of 0.5 Hz with minimum and maximum values of the loading amplitude of 27 and 45 kN respectively. It is to be noted that, as the effect of cyclic loading amplitude is more prominent than the loading frequency, for this study, tests were performed at a constant frequency of 0.5 Hz.

4.1 *Permanent deformation behavior*

The vertical and horizontal permanent deformations occurred in each loading cycle were calculated for each test. The cumulative values of the vertical and horizontal permanent deformations were also calculated and plotted against the number of load cycle (N) to investigate their variation. It is to be noted that, for the plot of cumulative permanent deformations the deformation value started from the first loading cycle and the deformation occurred during virgin loading (ramp-up and a cycle) was not considered. As the tests were performed in four different stages (5000 cycles in each stage) considering hold periods, test results were presented for each stage. Figure 4a and b represent the variation of the cumulative vertical and horizontal deformations with N obtained from the test of F-0.5-27&45. The four different plots in Figure 4a and b represent the variation of cumulative permanent deformations in those corresponding stages. According to the Figure 4, both the cumulative vertical and horizontal permanent deformations increased with the increase of N. In a particular loading stage, the increment rate was high within the first few thousand loading cycles and after about 2000 cycles, the curve remained almost constant up to the end of the cycle as considered. It is also evident that, for both the cumulative vertical and horizontal permanent deformations the values were significant for the first 5000 loading cycles (i.e., stage-1). However, after the first 5000 loading cycles, the permanent deformations decreased significantly (stage-2 to 4).

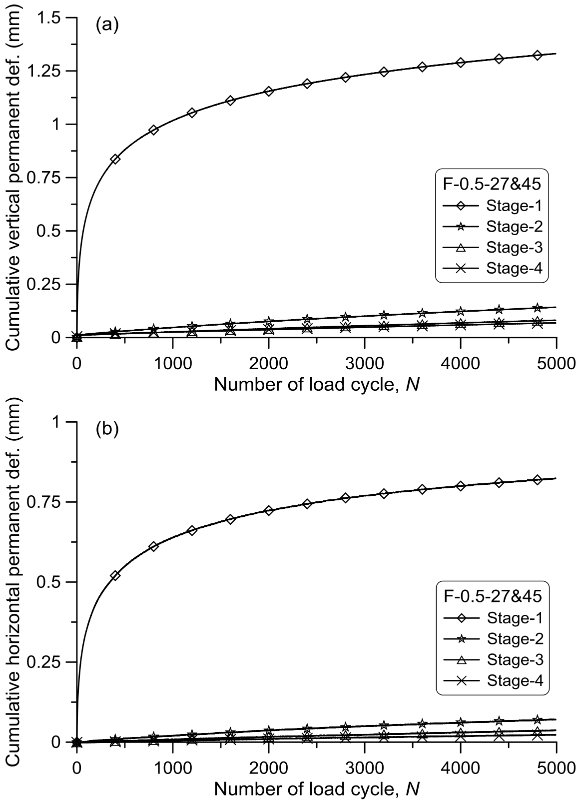

Figure 4. Variation of cumulative permanent deformations with N for F-0.5-27&45; (a) vertical permanent deformation and (b) horizontal permanent deformation

The effect of hold periods during the tests, where the load was held at the minimum value of the cyclic loading amplitude, were also investigated by summarizing the permanent deformations calculated in each stage. Figure 5 shows the cumulative vertical and horizontal deformations occurred in the entire test (20000 cycles) for all the tests as performed. Evidently, for both the vertical and horizontal permanent deformations, the curves did not show any deflection during the hold periods for all the tests which was indicative of a negligible effect of hold periods on the permanent deformations when the load was held at the minimum value of the cyclic loading amplitudes.

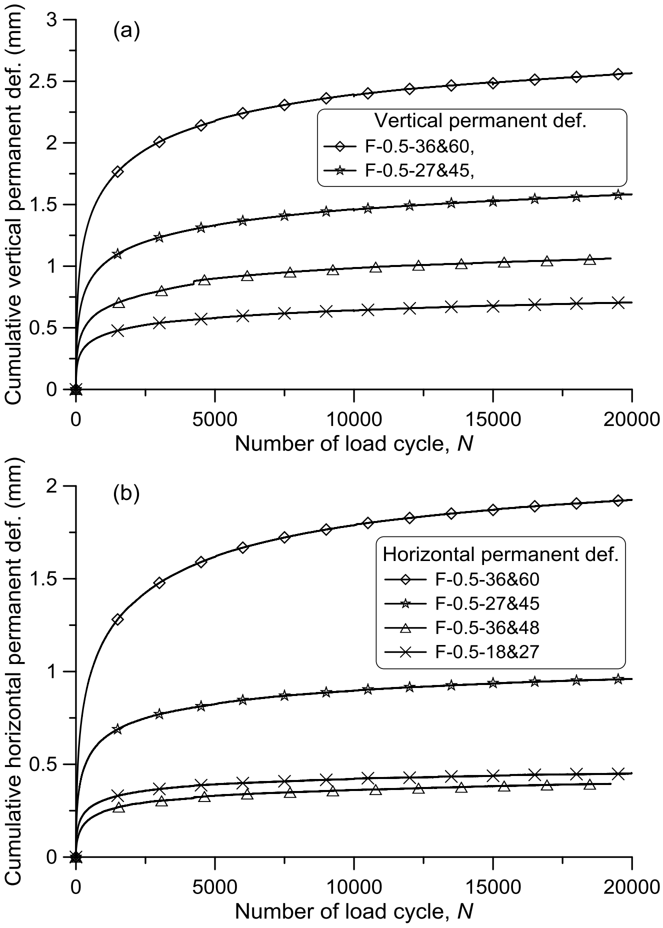

Figure 5. Variation of cumulative permanent deformations with N; (a) vertical permanent deformation and (b) horizontal permanent deformation

To further investigate the effect of hold period on permanent deformation, test F-0.5-27&45 was repeated (named as F-0.5-27&45*) with a different loading path where the load was totally released during the hold periods. A total of 30000 loading cycles were applied for this test maintaining hold periods after each 10000 cycles. It is to be noted that, after each hold period, the cyclic load was applied considering ramp-up followed by load cycles. The test results for the variation of cumulative vertical and horizontal permanent deformations for F-0.5-27&45* are shown in Figure 6.

It is pertinent to note that, for these plots the permanent deformation values started from the first loading cycle for stage-1 as consistent with F-0.5-27&45, and the deformations occurred in the ramp-up periods for stage-2 and 3 were not considered. Evidently, for this particular test, the hold period had a significant effect on the permanent deformations where sudden increases of both the vertical and horizontal permanent deformations were observed after each hold periods. This behavior of permanent deformations was expected to be due to the release of all loads on the soil mass during hold periods and the reloading acted as virgin loading for the next stage.

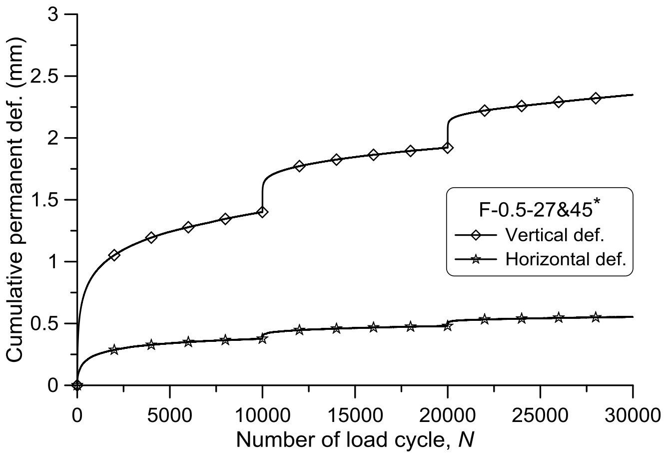

Figure 6. Variation of cumulative permanent deformations with *N* for F-0.5-27&45*

4.2 *Residual soil stress behavior*

The residual soil stresses at different depths (200, 300 and 400 mm) of the foundation soil mass were also observed and plotted against *N* to investigate their variation. A representative plot of the residual soil stress vs. *N* obtained at different depths for F-0.5-27&45 is shown in Figure 7a. Evidently, the residual soil stress increased with the increase of *N*. However, the increment rate was high at the first stage (i.e., first 5000 cycles) of the test and after that the soil stress remained almost consistent up to the end of the test. The residual soil stress was found to be maximum at a depth of 200 mm (i.e., at the geogrid reinforcement level) and reduced with the increment of depth. It is also evident that, the hold periods had almost negligible effect on the residual soil stress when the load was held at the minimum value of the cyclic loading amplitude.

The residual soil stresses at different depths of the foundation soil mass were also investigated for the test of F-0.5-27&45* where the load was entirely released during the hold periods. The variation of the residual soil stresses with *N* for the test of F-0.5-27&45* is shown in Figure 7b. A similar observation as of test F-0.5-27&45 was found where the residual stress increased with the increase of *N* and the maximum stress was found at 200 mm depth (i.e., at the geogrid reinforcement level). However, the reloading after each hold period showed significant increase of residual soil stress at every EPC level. This variation of residual soil stress is believed to be due to the release of load during the hold periods which releases all the stresses in the foundation soil mass. The reloading after hold periods acted as virgin loading in the soil mass which caused the sudden increase of residual soil stresses at the beginning of each stage.

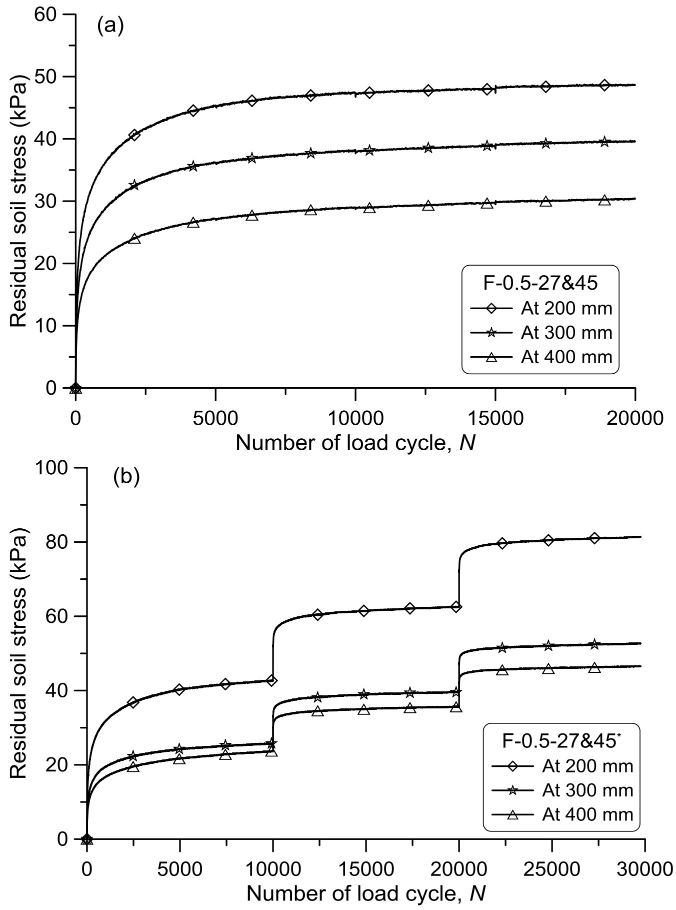

Figure 7. Variation of residual soil stresses with *N*; (a) for F-0.5-27&45 and (b) for F-0.5-27&45*

5 CONCLUSIONS

A comprehensive series of large scale experiments were performed in this study to investigate the behavior of a model shallow foundation on reinforced sandy sloped fill under cyclic loading conditions. A widely used geogrid reinforcement was embedded in to the foundation soil mass to improve stability. The main conclusions from this experimental study can be summarized as follows.

1. The cumulative vertical and horizontal deformations increased with the increase of N and the majority of the permanent deformations occurred within first few thousand loading cycles.

2. The hold periods showed negligible effect on permanent deformations when the load was held at the minimum value of the cyclic loading amplitude.

3. Significant increases of vertical and horizontal permanent deformations were observed in each stage when the load was entirely released during hold periods.

4. The residual soil stresses at different depth of the soil mass increased with the increase of N for first few thousand loading cycles and after that the stress remained almost constant up to the end of the test.

5. A negligible effect of hold periods on residual soil stresses was observed when the load was held at the minimum value of the cyclic loading amplitude. However, significant increase of residual soil stresses was evident for the test where the load was entirely released during hold periods.

6 REFERENCES

Bathurst, R.J., Blatz, J.A. & Burger, M.H. 2003. Performance of instrumented large-scale unreinforced and reinforced embankments loaded by a strip footing to failure. *Canadian Geotechnical Journal* 40 (6): 1067-1083.

Bauer, G.E., Shields, D.H., Scott, J.D. & Gruspier, J.E. 1981. Bearing capacity of footings in granular slopes. *Proceedings of the 10th International Conference on Soil Mechanics and Foundation Engineering, Stockholm, Sweden*, 33-36.

Boushehrian, A.H., Hataf, N. & Ghahramani, A. 2011. Modeling of the cyclic behavior of shallow foundations resting on geomesh and grid-anchor reinforced sand. *Geotextiles and Geomembranes* 29 (3): 242-248.

Choudhary, A.K., Jha, J.N. & Gill, K.S. 2010. Laboratory investigation of bearing capacity behaviour of strip footing on reinforced flyash slope. *Geotextiles and Geomembranes* 28 (4): 393-402.

Diyaljee, V.A. & Raymond, G.P. 1982. Repetitive load deformation of cohesionless soil. *Journal of Geotechnical Engineering Division, ASCE* 108 (10): 1215-1229.

Gnanendran, C.T. & Selvadurai, A.P.S. 2001. Strain measurement and interpretation of stabilising force in geogrid reinforcement. *Geotextiles and Geomembranes* 19 (3): 177-194.

Islam, M.A. & Gnanendran, C.T. 2013. Slope stability under cyclic foundation loading-Effect of loading frequency. *Stability and Performance of Slopes and Embankments III (Geo-Congress 2013), San Diego, California, USA*, 750-761.

Lee, K.M. & Manjunath, V.R. 2000. Experimental and numerical studies of geosynthetic-reinforced sand slopes loaded with a footing. *Canadian Geotechnical Journal* 37 (4): 828-842.

Puri, V.K., Yen, S.C., Das, B.M. & Yeo, B. 1993. Cyclic Load-Induced Settlement of a Square Foundation on Geogrid-Reinforced Sand. *Geotextiles and Geomembranes 12* 12: 587-597.

Sawwaf, M.A.E. 2007. Behavior of strip footing on geogrid-reinforced sand over a soft clay slope. *Geotextiles and Geomembranes* 25 (1): 50-60.

Sawwaf, M.E. & Nazir, A.K. 2010. Behavior of repeatedly loaded rectangular footings resting on reinforced sand. *Alexandria Engineering Journal* 49: 349-356.

Sawwaf, M.A.E. & Nazir, A.K. 2012. Cyclic settlement behavior of strip footings resting on reinforced layered sand slope. *Journal of Advanced Research* 3: 315-324.

Seed, H.B., Mitry, F.G., Monismith, C.L. & Chan, C.K. 1967. Prediction of flexible pavement deflections from laboratory repeated-load tests. National Cooperative Highway Research Program Report No. 35, Highway Research Board, Washington DC.

Yeo, B., Yen, S.C., Puri, V.K., Das, B.M. & Wright, M.A. 1993. A laboratory investigation into the settlement of a foundation on geogrid-reinforced sand due to cyclic load. *Geotechnical & Geological Engineering* 11 (1): 1-14.