Creep Performance of Geosynthetic Reinforcements

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Abstract—**Most geosynthetic materials exhibit rheological properties that lead to creep strain response when subjected to sustained loads, and consequently it is necessary to evaluate their long-term creep deformation before any real application. This paper presents the results of sustained loading tests conducted on large-scale geogrid soil reinforcement. The purpose of these laboratory tests was to identify the appropriate design parameters for geosynthetic-reinforced systems. The results of these tests demonstrate the continuous creep deformation characteristic of geogrid materials under constant sustained loading. The increase in the applied load led to a continuous increase in the amount and rate of the geogrid creep deformation. The data analysis method used in this investigation enabled the possibility of predicting the load-deformation-time behavior and the ultimate load of geosynthetic reinforcements.**

Keywords-soil reinforcement; geosynthetics; geogrid; creep

I. INTRODUCTION

The use of geosynthetic materials has increased significantly over the last three decades in different geotechnical aspects such as retaining walls, slops' stability, pavements, and railway embankments. Their applications have proven to offer cost-effective and environmentally friendly solutions to many unstable ground problems where the use of conventional construction methods would be limited or considerably expensive. However, identification of the design parameters for geosynthetic reinforcements is complicated when compared to conventional materials. It requires the designer to have a good understanding of the material load-strain and strength behavior and the changes in this behavior with time, temperature, and loading conditions. It is recognized that geosynthetic materials display rheological properties that exhibit creep strains and stress relaxation response when subjected to axial constant loads. Such phenomena may influence the long-term behavior of the geosynthetic reinforcement and can cause potential damage to the corresponding structural system [1-2]. Creep, defined as the time-dependent increase in the geosynthetic accumulative strain resulting from a constant applied load, is considered one of the most important properties that should be properly estimated and integrated in the design process of geosynthetic-reinforced structures [3-4]. The mechanics of creep is not completely understood. Creep may be simply described as the phenomenon that occurs when the geosynthetic reinforcement held under sustained load continues to deform with time increase. Standard laboratory creep tests were developed to compute the tensile strength and elongation parameters of geosynthetics in isolation [5-6]. Similarly, in-soil creep tests were also performed using special equipment in an attempt to better simulate the effect of soil confinement on the creep behavior of geosynthetics [7-9]. However, the results of these tests were somewhat inconclusive and until now there is a lack of a thorough understanding of the time-dependent response of geosynthetic soil reinforcements due to the absence of comprehensive and conclusive studies. More recently, numerous constitutive models have been developed to simulate the load-strain-time behavior of geosynthetic materials. The majority of these models have been applied for in isolation geogrids and geotextiles [10-11]. Moreover, several sophisticated finite element codes have been developed to simulate the response of geosynthetic materials to different loading and environmental conditions in order to provide appropriate design parameters for geosynthetic-reinforced soil systems [12-14].

This paper presents the results of sustained loading tests carried out on SR2 Tensar geogrid reinforcements. The purpose of these large scale laboratory tests is to examine the load-strain-time response of geosynthetic reinforcements in order to develop design parameters for geosynthetic reinforced systems.

II. TEST EQUIPMENT, MATERIALS, AND PROCEDURE

A. Equipment and Materials

Figure 1 shows the experimental pullout apparatus used in this study. It consists of a rigid sand container of 4.0×0.3×0.3m inside dimensions, a loading system to apply static axial loads to the reinforcement and a confining pressure system to apply surcharge pressures of up to 300kPa (Figure 2). It was designed

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according to the recommendation of ASTM D6706-01 [15] which prescribes the standard method for computing the pullout resistance of geosynthetic reinforcements.

Fig. 1. Pull-out apparatus.

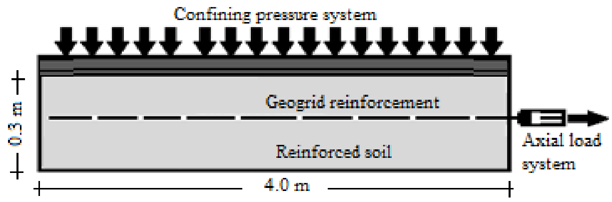

Fig. 2. Schematic view of the test apparatus.

The experimental apparatus permits for the testing of different types of soil reinforcing materials and the application of different values of axial loads and surcharge pressure on the reinforcement. The load was applied to the reinforcement by adding incremental dead weights to the load hanger situated at the rear end of the sand container. The confining stress was applied to the top of the reinforced soil sample via a pressure plate loaded through a water bag and connected to an air compressor. The pullout device was equipped with a number of dial gauges and load cells to compute the applied load, confining pressure and reinforcement movement. The geogrid specimen was placed in the middle of the soil mass and was connected to the loading system with a special clamp as shown in Figure 3. More details about the experimental apparatus can be found in [16].

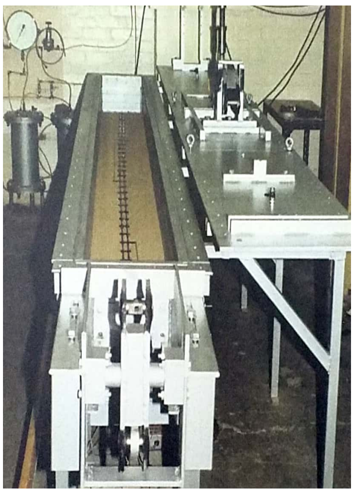

Fig. 3. Pull-out apparatus.

The reinforcement used in testing is formed by cutting Tensar SR2 geogrid into a row of two ribs in width and 35 bars length (approximately 4m). Physical and mechanical properties of the geogrid are taken from manufactures' data and are shown in Figure 4 and Table I. The distribution of axial strain in the geogrid was measured using axial movement gauges provided at different locations along the reinforcement. The applied load levels were expressed as a percentage of the index load (Pur) of the geogrid, defined as the ultimate rupture load of an identical geogrid in air (Figure 5).

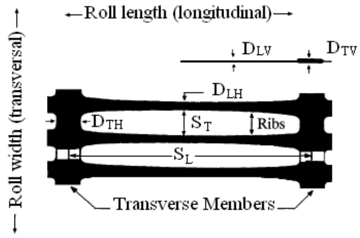

Fig. 4. Geogrid (SR2) dimensional properties.

TABLE I. GEOGRID (SR2) PHYSICAL PROPERTIES

Geogrid properties	Mean values
Product width (S_L)	100mm
Transverse bar width (D_{TH})	12.69mm
Maximum transverse bar thickness (D_{TV})	4.56mm
Minimum transverse bar thickness (D_{TV})	4.36mm
Rib width (D_{LH})	5.72mm
Rib thickness (D_{LV})	1.34mm
Number of ribs	44/m
Mass per unit area	972g/m^2

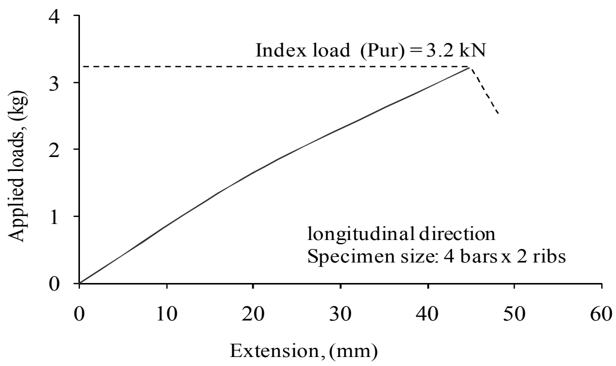

Fig. 5. Geogrid material tensile strength.

The soil used in this study was a uniformly graded sand of medium size with the properties given in Table II. The sand samples were prepared in the pullout box by raining method to an average and repeated medium bulk density of 1.59Mg/m^3.

TABLE II. SOIL PROPERTIES

Parameter	Mean value
Uniformity coefficient, C_u	1. 9
Specific gravity of solids, G_s	2. 67
Friction angle, φ (^{o})	39.4
Max/Min densities, ρ_{max}/ρ_{min} (Mg/m^3)	1.78/1.42
Max/Min void ratios, e_{max}/e_{min}	0.872/0.491

B. Test Procedure

Two series of sustained loading tests, short-term and long-term tests, were conducted throughout this investigation. The test procedure included 4 steps: (i) formation of the sand bed, (ii) placement of the geogrid reinforcement, (iii) application of the surcharge confining pressure, and (iv) application of the static load. These tests were performed under very small variation in temperature to reduce its effect on the test results. The temperature recorded during the tests was 18±1^{o}C. Silicone grease was smeared on the container inside walls in a thin layer to minimize the friction effect and ensure uniform distribution of the normal stress all over the soil mass. After the preparation of the experimental arrangement the test started by monitoring the surcharge pressure and applying gradual sustained loads to the reinforcement.

III. RESULTS AND DISCUSSION

A series of sustained loading tests were conducted to obtain the load-strain-time characteristics of the geogrid reinforcement. The tests involved monitoring the normal stress first and then applying the axial load to the reinforcement incrementally. In all these tests the normal pressure was kept constant at 100kPa during the pullout process. In the short-term test series, a loading increment of 5% Pur was applied every 60min during which the creep deformations of the geogrid were recorded at 1, 2, 5, 10, 20, 40 and 60min. For the long-term tests, the sustained loads were held for a period of 2000h and the creep strains of the geogrid were recorded each hour. The data collected during each test included the measurements of axial pullout loads and creep strains of the geogrid reinforcement with time. Figure 6 shows the total displacement of the geogrid versus time data in which the sustained loads were incrementally increased every 60min. It can be seen that there is a significant increase in the geogrid creep displacement with time increase and this is more apparent at high loading increments. The test results clearly demonstrate the continuous extension characteristic of the geogrid reinforcement when subjected to sustained load as shown in Figure 7. This deformation was mainly close to the point of load application which consisted only of an extension of the front part of the geogrid. To illustrate further the effect of time on the creep behavior of the geogrid, the above data are re-plotted in a semi-log form. Figure 8 shows the creep deformation-log time relationships for the 35 bar length geogrid reinforcement under 100kPa confining stress. Both the instantaneous displacement and the creep displacement are given for a series of loading levels over a period of 1h. These curves demonstrate the effect of time on the deformation of the geogrid under sustained loading. It can be seen that for most of the loading levels, the relationship between creep displacement and time when plotted on a semi-log scale produces approximately straight lines the slope of which, defined as the creep coefficient, increases with the increase of load increment. This finding is somewhat in contrast with the result of the creep rate which showed no dependency of the stress levels. However, both plots indicated clearly the effect of time on the creep behavior of the geogrid material.

The relationships between creep rate and time are shown in Figure 9 in a log-log scale. The visual impression from these plots is that at any constant applied load the creep rate decreases linearly with time giving approximately same slopes.

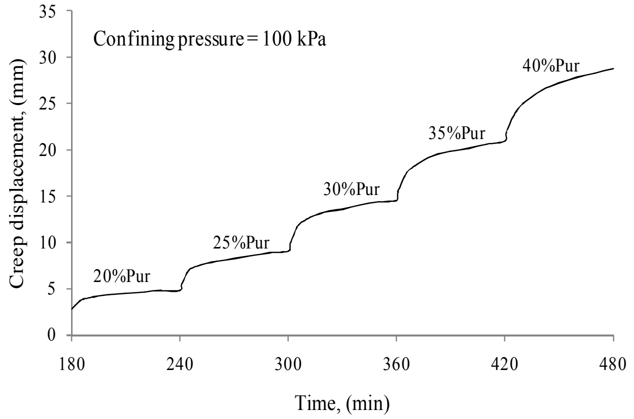

Fig. 6. Load-creep-time relationships.

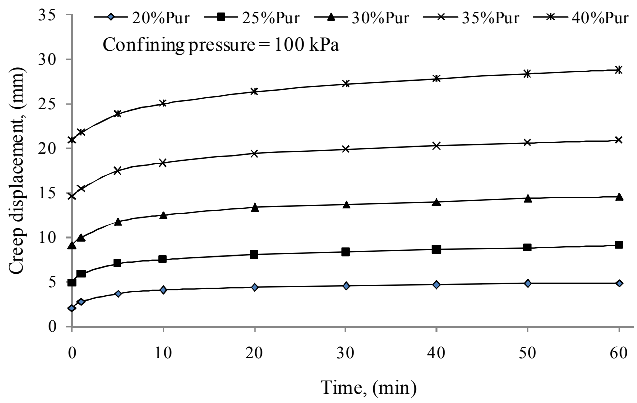

Fig. 7. Creep displacement-time relationships.

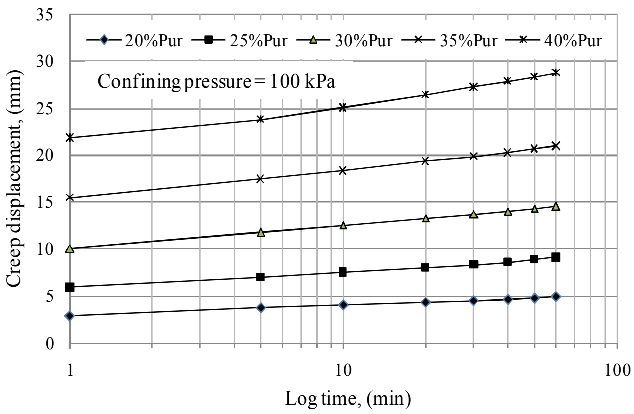

Fig. 8. Creep displacement-log time relationships.

For additional examination of the stress-strain-time effects on the geogrid behavior, a "long-term" creep test series was undertaken. Two sustained loads, namely 25% Pur and 35% Pur, were chosen to be held for a duration of 2000h while the creep deformation of the geogrid was recorded at specified time intervals. Throughout these tests the surcharge stress was kept constant at 100 kPa. Figure 10 shows the creep strain of the geogrid reinforcement against log time.

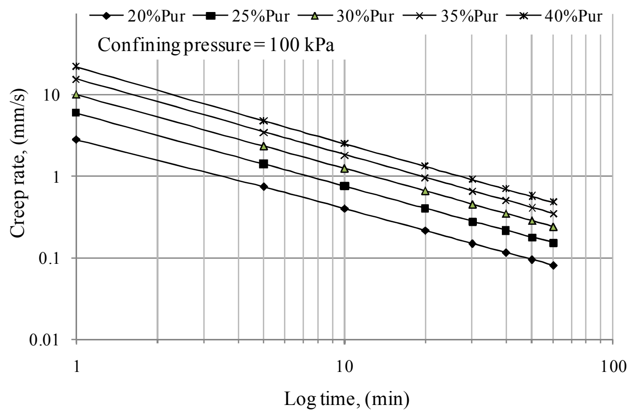

Fig. 9. Creep rate-log time relationships.

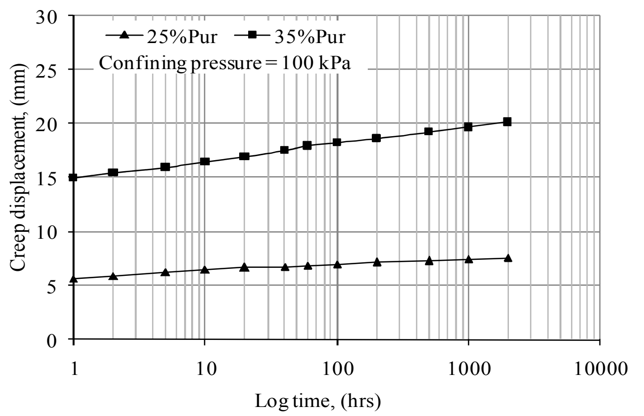

Fig. 10. Long-term creep behavior of the geogrid.

It can be clearly noted from these diagrams that the increase in the applied sustained load leads to a continuous increase in the amount and rate of the geogrid deformation. A remarkable aspect is that the rate of the deformation-log time diagrams remained almost steady during the first weeks and then started to decrease. This result indicates that retaining the load constant for long periods may lead to significant creep deformations of the geogrid materials. Similar observations were also reported by the authors of [17] in their centrifuge study performed to investigate the time-dependent behavior of geotextile-reinforced soil walls. Their test results indicated considerable time-dependent deformations of the geotextile reinforcement during the long-term tests. It is evident from this analysis that the use of geosynthetics as soil reinforcements may not play a significant role in the long-term stability of reinforced soil structures. In order to estimate the ultimate load of the geogrid reinforcement, the short-term sustained loading tests were analyzed in accordance with the recommendations of the German code of practice DIN 4125 [18] for permanent anchorage in loose stone. This code recommends a method to estimate the future creep displacement of an anchor and predict its ultimate and safe working loads. According to this standard, the general relationship between creep displacement and time is an exponential function which gives a straight line when plotted to a semi-log scale. For each load increment a graph is plotted between the creep displacement and log-time and the slope of the creep curve, defined as the stabilization coefficient (α), is calculated. The values of α are then plotted against the applied loads and the value of the critical load is identified as that load at which there is a bend in the α-load relationship. Figure 11 shows the creep coefficient-load relationship of the geogrid under 100kPa surcharge pressure. As can be seen, the value of the critical load corresponds to the load at which a bend in the plot α-load starts. This method of analysis may provide the possibility of predicting the ultimate load of geosynthetics by taking into consideration their long-term creep characteristic.

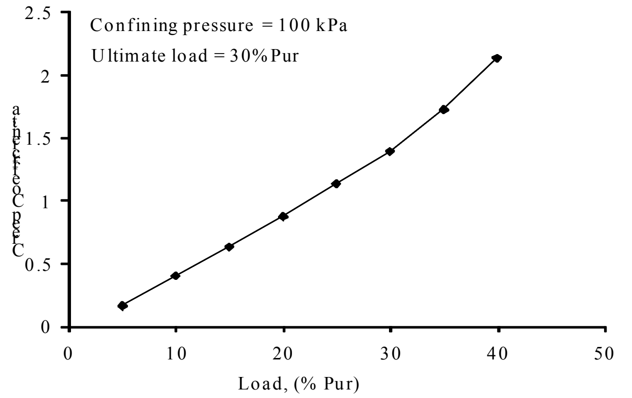

Fig. 11. Prediction of the ultimate load.

IV. CONCLUSION

This study investigated the creep behavior and performance of geosynthetic soil-reinforcements. A series of pullout tests were conducted on geogrid reinforcements embedded in uniformly graded sand and subjected to a constant vertical confining pressure. The results obtained from this experimental and analytical investigation demonstrate that the identification of the appropriate design parameters for geosynthetic reinforcement requires a thorough examination of the load-strain and strength behavior of the material, as well as the change in this behavior with time and load levels. The analysis method used in this investigation enabled the possibility of predicting the load-deformation-time behavior of the geogrid material and the estimation of its ultimate load. The tests' results indicated that maintaining the applied load constant for long periods results in a continuous creep deformation of the geogrid reinforcement without cessation. It is clear from these findings that geosynthetic reinforcing materials may play a significant role in the long-term stability of reinforced-soil structures and, therefore, care is required in ensuring that appropriate factors of safety are applied to control the resulting creep deformation of geosynthetic-reinforce structures.

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