Creep behaviour of geosynthetics under cyclic and sustained loading

Etudue du fluage des géosynthetiques sous l'effet des chargements cycliques et permanents

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ABSTRACT: This paper examines the creep behaviour of SR2 geogrid reinforcement under cyclic and sustained loading. Large amount of test data has been generated in order to assess the long-term behaviour of geosynthetics under different loading conditions. Attention has been concentrated on the accumulation of reinforcement deformation induced by the different types of applied load, the mechanism of failure and the characteristics of load mobilisation along the reinforcement. Under cyclic loading the geogrid exhibited a gradual forward movement with increase in the number of load repetitions and showed no sign of imminent pullout failure for all the applied loads. Under sustained loading the geogrid exhibited also a continuous deformation without cessation. The test results showed that most of the creep deformation occurred close to the point of loading. Under the same loading level the geogrid exhibited more deformation when subjected to cyclic loading than when it was subjected to sustained loading.

RÉSUMÉ: Cet article examine la déformation due au fluage des éléments de renforcement de type SR2 geogrid sous l'effet des chargements cycliques et permanents. Un nombre important de données a été produit afin d'evaluer le comportement à long terme des géosynthétics sous différentes conditions de chargement. Une attention particulière a été donnée à l'accumulation de la déformation du renforcement induite par les différents types de chargement, au mécanisme de la rupture et aux caractéristiques de la mobilisation de chargement le long du renforcement. Sous l'effet de chargement cyclique le geogrid performait une déformation progressive et il n'a montré aucun signe d'arrachement total du sol. Sous le chargement permanent le geogrid a montré aussi un mouvement continu sans cessation. Les resultants ont montré que la majeure partie du déformation due au fluage du renforcement s'est produit près du point de chargement. Sous le même nivau de chargement le geogrid a montré plus de déformation une fois soumis au chargement cyclique que quand il a été soumis au chargement permanent.

1 INTRODUCTION

The rapid emergence and utilisation of geosynthetics in geotechnical applications has been one of the major developments in the past two decades. Use of geosynthetics as reinforcing elements in earth retaining structures is rather attractive because of their low cost and uncomplicated installation. However, identification of the design parameters for these types of soil reinforcement is complicated when compared to conventional materials. It requires the designer to become intimately involved with the details of the load-strain and strength behaviour, as well as changes in this behaviour with time, temperature and load level. Recent research on the use of geosynthetics has made significant contributions to our understanding of the static behaviour of the geosynthetic-soil system (McGown et al. 1984; Palmeira and Milligan 1989; Jewell 1990; Bergado et al. 1993; Palmeira et al. 1996; Long et al. 1997). However, the cyclic behaviour of these systems has not yet been adequately addressed in design or in research. There are many uncertainties concerning the design of the maximum pullout resistance and the load transfer mechanism governing the deformation behaviour of geosynthetics when subjected to repeated loading. With regard to static loading, it is widely recognised that one of the most important properties of the geosynthetics is their continuous deformation with the passage of time. The cumulative effects of cyclic loading on the long-term behaviour of geosynthetics is still unknown. The development and evaluation of reliable design methods for this type of structures requires a good understanding of the mechanism of soil-reinforcement interaction under different loading conditions. This paper examines the creep behaviour of SR2 geogrid reinforcing elements under cyclic and sustained loading. Attention has been concentrated on the accumulation of reinforcement deformation induced by the different types of applied load, the mechanism of failure and the characteristics of load mobilisation along the elements. Efforts were made to work at large laboratory scale to avoid errors associated with model testing.

2 TESTING APPARATUS

The main testing apparatus and loading system used in this investigation are shown in Figure 1. The major considerations taken into account in designing this apparatus were the rigidity of the test rig and the stress condition on the boundaries.

The rig consisted of a sand container of inside dimensions 0.3 x 0.3 x 4.0 m. The internal walls of the container are smeared with a frictionless grease allowing a surcharge pressure, applied via a pressure plate loaded through a water bag, to be transmitted through the sand mass. The surcharge pressure could be controlled from 0 to 300 kN/m^2 without causing any significant straining of the test rig. The sand was used in a dry state being of medium size and uniformly graded ($D_{60}/D_{10} = 1.9$). The specific gravity was 2.67; maximum and minimum densities were 1.78 and 1.42 Mg/m^3 respectively with corresponding void rations of 0.87 and 0.49. A raining method of sand placement gave an av-

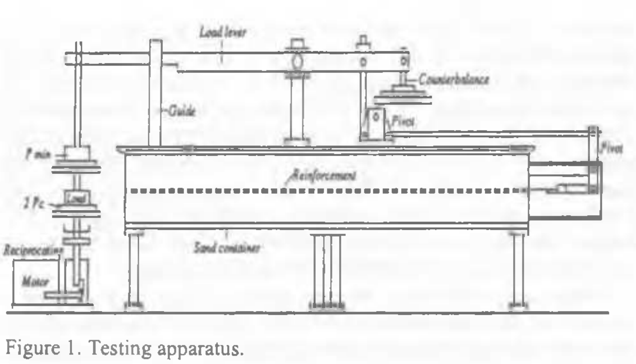

Figure 1. Testing apparatus.

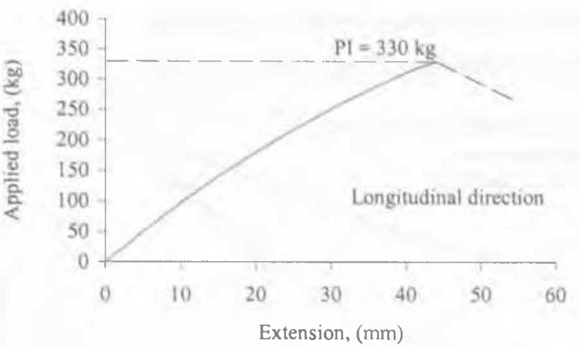

Figure 2. SR2 geogrid tensile strength extension relationship.

Table 1. Typical dimension of Tensar (SR2) geogrid

Dimensional Properties	Means
Product width:	1000 *mm*
Mass per unit area:	971.6 g/m^2
Number of ribs:	44 per *m*
Aperture length:	90.73 *mm*
Transverse bar width:	12.69 *mm*
Transverse bar thickness (maximum):	4.56 *mm*
Transverse bar thickness (minimum):	4.36 *mm*
Rib width:	5.72 *mm*
Rib Thickness:	1.34 *mm*

erage and repeatable density of 1.57 Mg/m^3 with a relative density of 0.53. The geosynthtic reinforcement selected for testing was a Tensar SR2 geogrid. The reinforcement was formed by cutting the geogrid into a row of two ribs in width and 35 bars in length (approximately 4 m). The strip was provided with special axial movement gauges at five locations along the reinforcement. The reinforcing element is located within the sand mass, emerging through the end of the sand box where it is connected to a special loading level system with the capacity to apply either static loads or slow cyclic loading (see Figure 1). For the cyclic loading the load was changed every 20 seconds to give a square-shaped pattern between an upper and a lower load level. The load levels were related to index load (PI) of the geogrid strip defined as the ultimate tensile strength load of an identical geogrid strip in air (McGown at al., 1984). An Instron tensile testing machine was employed to determine the index load of the tested strips. The load was applied gradually to the sample in the longitudinal direction till rupture took place. A typical tensile strength-extension relationship of the SR2 geogrid strip is shown in Figure 2 and Table 1 gives typical dimensions of the Tensar SR2 geogrids.

3 DEFORMATION OF STRIP DUE TO CYCLIC LOADING

A wide range of loading levels and amplitudes was chosen to assess their effect on the behaviour and performance of the geogrid reinforcement. In some cases the tests were taken to 10^5 load cycles while the confining stress was kept constant at 100 kN/m^2. The cumulative displacement of the reinforcements versus the number of loading cycles is presented in Figure 3. As shown, the general behaviour of the reinforcement was characterised by a continual increase in displacements with increase in loading cycles from the starting till the end of the test with no indication of sudden pullout. All the strips were gradually pulling through the ground, as the number of load repetitions increased, showing no sign of absolute failure. It can be seen that the behaviour of the reinforcements was highly dependent upon the magnitude of the repeated loading, with higher amplitude of cyclic loads causing a rapid deterioration of the reinforcement performance.

These observations are best illustrated in the form of a plot between the rate of displacement/cycle against the number of cycles on a log-log scale as shown in Figure 4. In all the tests of

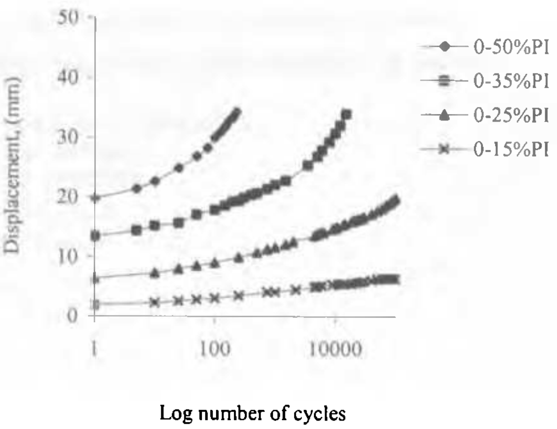

Figure 3. Load-displacement relationships due to cyclic loading.

this series the rate of displacement was observed to decrease from the commencement of the strip displacement till the end of the test by following an approximately linear relationship with the number of load cycles. The effect of the loading condition is further clarified in this diagram, where different load levels gave different straight lines, which are virtually parallel. Such behaviour defines a region along the deformation curve known as transient creep, in so far the strain is time and stress dependent. Also, the figure reflects the behaviour of the geogrid reinforcement under repeated loading, namely that all the strips gradually pull through the sand mass, with load repetitions, showing no change in the state from the beginning till the end of the test.

The total deformation at any section along the geogrid and its variation with load reversals was also examined under a wide range of loading conditions. A consistent trend of load transmission along the reinforcing strips was observed, and therefore typical tests have been selected to demonstrate this phenomenon.

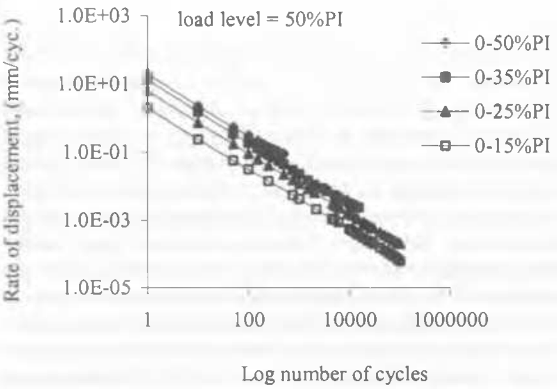

Figure 4. Rate of displacement-load cycles relationships.

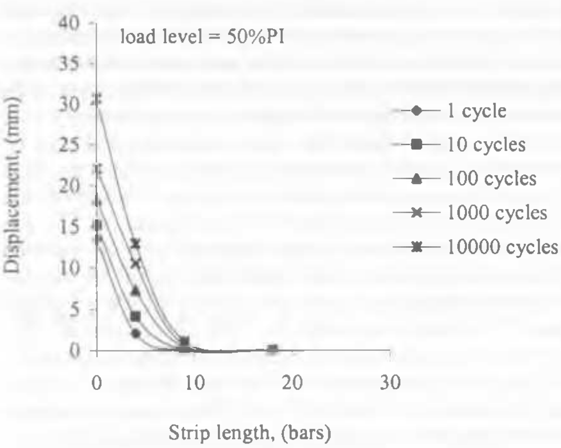

Figure 5. Strain variation due to cyclic loading.

Figure 5 shows the recorded displacement along the geogrid reinforcement at specified loading cycles. The total deformation consists only of an extension of the front segments and neither slip nor extension along the distal end of the strip were observed. This observation would indicate that unless a very low confining stress is used it would be impossible to pullout the geogrid strip.

4 EFFECT OF SUSTAINED LOADING

To obtain a better understanding of creep behaviour of SR2 geogrids when used as soil reinforcement, three series of creep tests namely, short-term, medium-term and long-term were conducted throughout this investigation. These tests were carried out under a very small changes in temperature to minimise the effect of temperature variation on the experimental results. The temperature recorded throughout all the tests by the temperature probe were 18 ± 1°C with maximum variation of 2°C. The effect of such variation is believed to be insignificant on the test results (McGown et al., 1984). The short-term sustained loading tests were performed using the recommendation of the German Code of Practice DIN 4125, due to the common nature of loading characteristics of anchor structures and reinforced earth structures. A loading increment of 5%PI, where PI is the index load or rupture load of an identical strip in air, is applied each 60 minutes during which the creep deformation are recorded at 1, 2, 5, 10, 20, 40 and 60 minutes. For the medium-term sustained loading tests the loading levels were held for 10000 minutes (equivalent to 7 days) and for the long-term tests the loading levels were held for 2000 hours (equivalent to 12 weeks) and the creep deformations were recorded at 1, 2, 5, 10, 20, 40, 60 minutes and then after each hour. During all these tests the surcharge pressure was kept constant at 100 kN/m².

Figure 6 shows the total displacement versus time data, in which the reinforcement is subjected to a series of incremental loads. The dashed line shows the creep displacement curve where the immediate displacement that occurs at the beginning of each load application is subtracted. It can be seen that there is a significant increase in the geogrid creep deformation with time increase and being more apparent at high loading increments. Generally, the results of these tests indicated that, despite none of the reinforcement failed by pulling through the sand mass, their creep deformation did not cease throughout the test period and showed a significant increase with time increase.

These observations are best illustrated by the form of a plot between creep deformation rate and time. It may be seen from Figure 7 that at any sustained stress level, the logarithm of creep deformation rate decreases linearly with the logarithm of time. Furthermore, the slope of this relationship is essentially independent of the stress level, and increases in stress serve only to shift the line vertically upwards. Based on these diagrams the creep deformation of the geogrid reinforcement at any time can be expressed by:

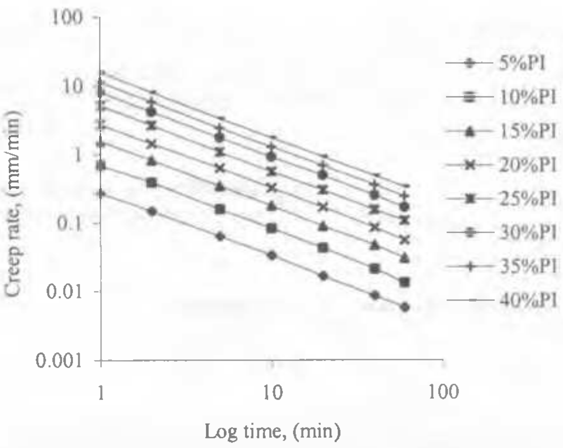

Figure 7. Creep deformation rate-time relationships.

$$\delta_c(t) = \delta_1 t^{a+1} \qquad (1)$$

where: $\delta_c(t)$ is the creep deformation at any time t; δ_1 is the rate of deformation at the first minute; and a is the slope of the creep deformation-time relationship.

The medium-term sustained loading tests results are presented in Figure 8. This plot shows the creep displacement-log time relationship for the geogrid strip under the same confining stress and applied load levels of 10%PI, 20%PI, 30%PI and 40%PI over a period of 10000 minutes. It is clear from this diagram that the increase in the applied load levels has a significant effect on the amount and rate of displacements. High values of creep displacement were measured under a load level of 40%PI accompanied by an increasing rate of displacement-log time. The plot indicates also that the relationship between creep displacement and log-time is linear for the sustained loading levels of up to 30%PI whish is, in fact, in line with the conclusion of short-term sustained loading test results. However, the most of the creep deformation of the geogrid occurred close to the point of loading. This can be seen in figure 9 which illustrate the relationship between the displacement and log time for various sections along the 35 bars length strip. As shown, a constant rate of displacement log time was obtained at internal section of the reinforcement, which indicate that only instantaneous displacement took place throughout the test period. This phenomenon can be attributed to the high axial load concentration near the point of load application which may be caused by the high extensibility and low tensile strength of the geogrid and by the relatively high applied confining stress.

Figure 10 presents the results of the long-term sustained load-

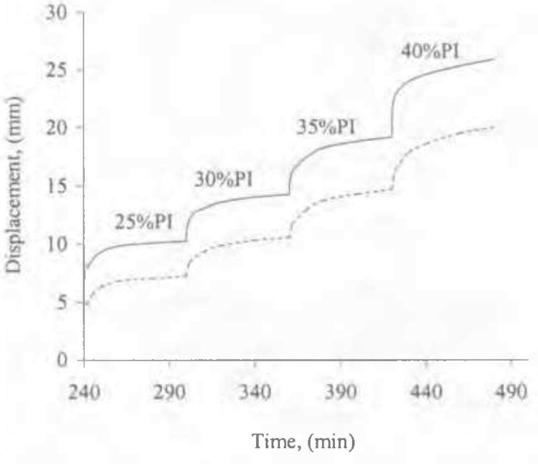

Figure 6. Total deformation-time relationships with applied load.

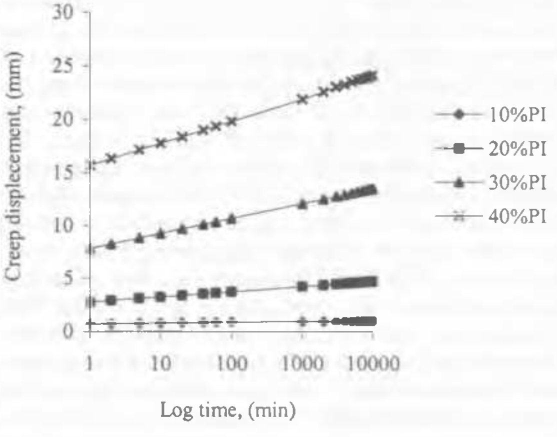

Figure 8. Medium-term creep displacement-log time relationships.

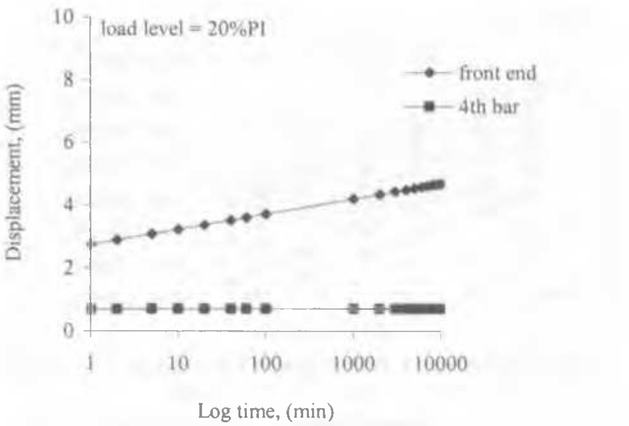

Figure 9. Creep displacement-log time relationships at various sections.

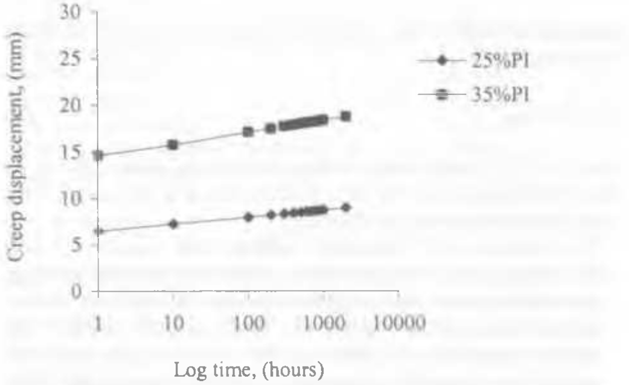

Figure 10. Long-term creep displacement-time relationships.

ing tests of the geogrid strip subjected to 25%PI and 35%PI axial loads. The illustration shows no cessation of creep displacement of the strip throughout the testing period of 2000 hours. This indicates that maintaining the applied load constant for several weeks results in a continuous deformation of the strip. An interesting feature is that the rate of displacement-log time was constant during the first few weeks and started to decrease slightly toward the end of the test.

5 CONCLUSIONS

The cyclic loading test results indicated that the rate of accumulation of the geogrid reinforcement movement increases with increase in the number of load repetitions and load levels. The reinforcement exhibited a gradual forward movement with increase in the number of load cycles and showed no pullout failure for all levels of applied load. The rate of the strip movement kept decreasing approximately linearly with the log number of loading cycles, showing no sign of cessation. At all load levels the geogrid deformation consisted only of an extension of the front part of the strip and neither slip nor extension along the rear segment of the strip length were observed. Unless a very low confining stress is used, it would be impossible to pull the strip out of the soil. The sustained loading test data indicated that maintaining the applied load constant for several weeks results in a continuous deformation of the geogrid reinforcement without cessation. It was noted that for most of the loading levels, the relationship between creep displacement and time when plotted on a semi-log scale produced approximately straight lines. The slope of these lines, defined as the creep coefficient, increased with increase of load increment. The logarithm of the creep rates was found to decrease linearly with the logarithm of time, giving approximately constant slopes for all loading levels. However, Under the same loading level, the geogrid exhibited more deformation when subjected to cyclic loading than when it was subjected to sustained loading.

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