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INTERACTION MECHANISMS OF SOIL-GEOSYNTHETIC REINFORCEMENT

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ABSTRACT: The pullout performance of geosynthetic reinforcements under static and sustained loading is described in this paper. Laboratory tests were conducted to investigate the cumulative effects of loading on the pullout capacity and behaviour of geogrid reinforcements. The test methods and procedures for analyzing and interpreting the data are presented. The mechanics of load transfer and reinforcement displacement are also examined. In general, the results showed that under static loading applications the geogrid experienced a gradual deformation with load increase. No peak load was observed with the system of loading used and the deformation of the geogrid was mainly close to the point of load application. The sustained loading tests showed no cessation of creep displacement of the geogrid throughout the testing periods of this investigation.

Keywords: Geosynthetics; Geogrids; Soil Reinforcement; Static Loading; Creep

1. INTRODUCTION

Over the past three decades, geosynthetics have become a significant part of civil and environmental engineering practice in most part of the world. Various types of geosynthetic products have been used extensively in a range of engineering applications such as in road and highways, railways, soil reinforcement, drainage and erosion control, waste containment, retaining structures, slops stability and embankments stabilization, and in some of these applications they have entirely replaced the conventional construction materials. The use of geosynthetics has proven to offer cost-effective environmentally sustainable alternative solutions to many soft and unstable ground problems, where the use of conventional construction materials would be restricted or significantly expensive.

However, the rapid development of geosynthetics technology has been accompanied by relatively slower development in methods of analysis and design. The selection of appropriate design parameters for geosynthetics reinforced soil systems has remained variable and sometimes confusing, due to the lack of data form field and laboratory models that can optimize current design methods [1]. Up to now, there are many uncertainties concerning the structural or load-carrying capacity of geosynthetic-reinforced soil systems. Perceptions by users concerning the durability of geosynthetic materials have caused a number of designers to be hesitant to use geosynthetics for long-term reinforcement applications. Although many research studies have been carried out in recent years to investigate the interaction properties of soils-geosynthetics [2],[3], [4], there is still a lack of understanding about the long-term interaction mechanism of the composite system due to the absence of comprehensive and conclusive studies. Geosynthetics are widely used in structures which are subjected to constant loads throughout their service life. Under these loading conditions, geosynthetics would exhibit creep strains which may potentially cause damage to the corresponding structural system [5], [6]. Creep is the time-dependent increase in accumulative strain or elongation in the geogrid resulting from a constant applied load. Thus, the creep behaviour of geosynthetics should be properly evaluated so that the appropriate factor of safety can be incorporated into the long-term design of structural systems.

The main objective of this research was to evaluate the pullout performance of geogrid soil reinforcements under different loading conditions. Large-scale experimental program was conducted aimed at the improvement of the understanding of the interaction behaviour of soil-geosynthetic composite systems. This paper presents an examination of the pull-out performance and failure machanisms of geogrid reinforcements under static and sustained loading.

2. TEST EQUIPMENT AND MATERIALS

For the examination of the interaction mechanism of soil-geogrid composite systems, a large scale laboratory pullout device was developed. The testing program was designed to evaluate the interlock capacity of the soil-geogrid and to analyse the failure mode of the composite system.

The main testing apparatus used in this investigation is shown in Fig. 1. It consisted of a rigid sand container of inside dimensions 4.0 m x 0.3 m x 0.3 m, a loading system with the capacity to apply axial pullout loads and a surcharge pressure system. The confining stresses, which could be controlled from up to 300 kPa safely, were applied to the top of the soil sample via a pressure plate loaded through a water bag and connected to an air compressor through a pressure regulator. Instrumentations were used to measure pullout forces, pullout displacements and surcharge pressures. All instrumentations were recorded and monitored by a computer based data acquisition system connected to the apparatus.

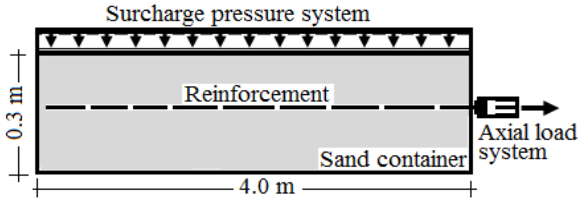

Fig. 1 Test apparatus

The reinforcements tested in this investigation were formed by cutting SR2 geogrids into a row of two ribs in width and 4 m in length. SR2 geogrid is a uniaxial geogrid type manufactured from co-polymer grade high density polyethylene. Physical and mechanical properties of SR2 geogrids are reported from manufactures' data in Fig. 2 and Table 1. The index load (PI) of the geogrid, defined as the ultimate rupture load of an identical geogrid in air, is shown in Fig. 3.

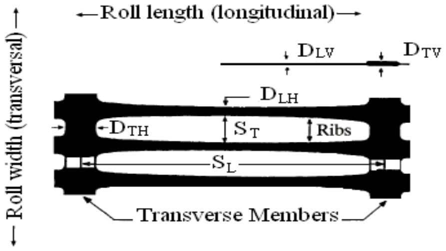

Fig. 2 Geometry of uniaxial SR2 geogrid

Table 1 Physical properties of SR2 geogrid

Dimensional Properties	Mean
Product width (S_L)	100 mm
Transverse bar width (D_{TH})	12.69 mm
Max bar thickness (D_{TV})	4.56 mm
Min bar thickness (D_{TV})	4.36 mm
Rib width (D_{LH})	5.72 mm
Rib thickness (D_{LV})	1.34 mm
Number of ribs	44 / m
Mass per unit area	972 g/m^2

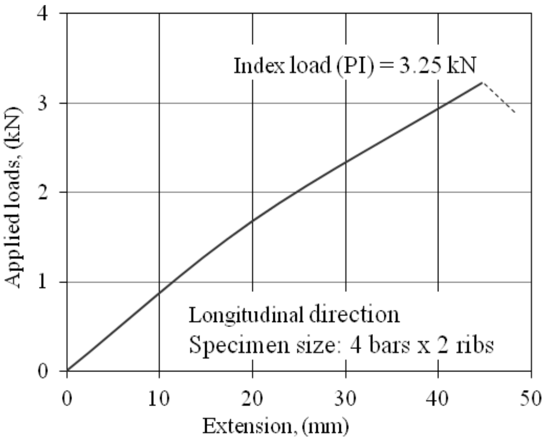

Fig. 3 Typical tensile strength extension of the geogrid (SR2)

The test specimen was located at the mid-height of the soil sample and connected to the loading levels system with a special end clamp. The displacements along the geogrid were measured using inextensible steel wires connected to the specimen, in at least eight different locations, and to LVDTs fixed to the external back side of the box.

The soil used in testing was a uniformly graded dry sand of medium size with a coefficient of uniformity C_u = 1.9; a specific gravity G_s = 2.67; a friction angle φ = 39.4; maximum and minimum densities of 1.78 Mg/m3 and 1.42 Mg/m3 respectively (Fig. 4). The sand samples were prepared in the pullout box by raining method to a targeted relative density Dr = 53%. To obtain a uniform density of sand throughout the filling operation, the sand was placed in equal layers of 50 mm thickness.

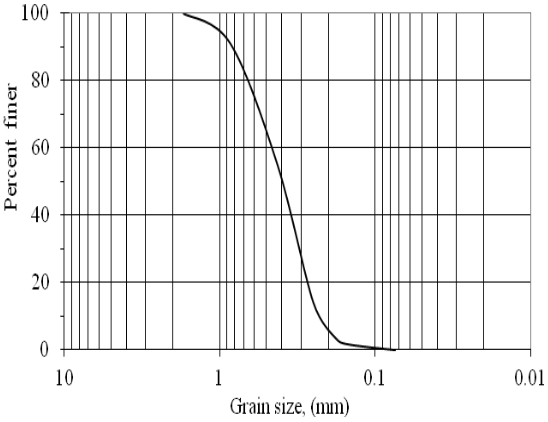

Fig. 4 Particle size distribution of the sand

3. PULL-OUT BEHAVIOUR OF GEOGRIDS

A series of static pull-out tests were carried out to investigate the pullout performance of the geogrid. The static loading of the reinforcements were carried out by applying dead weights of 20 kg each 5 minutes and then reduced to 10 kg each 5 minutes at high extension.

Figure 5 shows the load-displacement relationships for the 4 m geogrid reinforcement buried under 2 different normal stresses of 50 and 100 kPa.

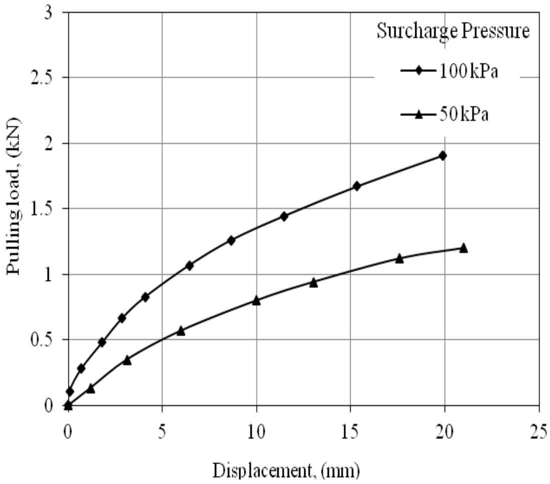

Fig. 5 Pullout load–displacement relationships of the geogrid at different confining stresses

As can be seen, the general pattern of these relationships is characterized by a rapid increase of load with an initial small increase in the strip movement up to a certain level after which the displacement continues to increase with load increase till the end of the test. No peak load could be observed with the system of loading used and the relationship between load and deformation became linear at large displacements. The surcharge pressure was found to have a great effect on the deformation of the geogrid. The reinforcement mobilized greater resistance to pulling load when the surcharge pressure increased and that is clearly visible under high loading increments.

The recorded movements along the length of the geogrid reinforcement are given in Fig. 6. These movements were expected to be a combination of two components; the extension induced in the reinforcement together with the slip movement of the reinforcement. However, as can be seen, the total displacement of the reinforcement consists only of an extension of the front half part of the geogrid reinforcement and neither slip nor extension along the rear segment of the specimen length was observed. This means that no load was absorbed by the lattermost half length of the reinforcement and hence no frictional or bearing resistances were mobilized along that part of the strip. This observation would indicate that unless a very low confining stress be used it would be impossible to pull out the reinforcement. Consequently, failure of these reinforcements by rupture appears to be an easier mode.

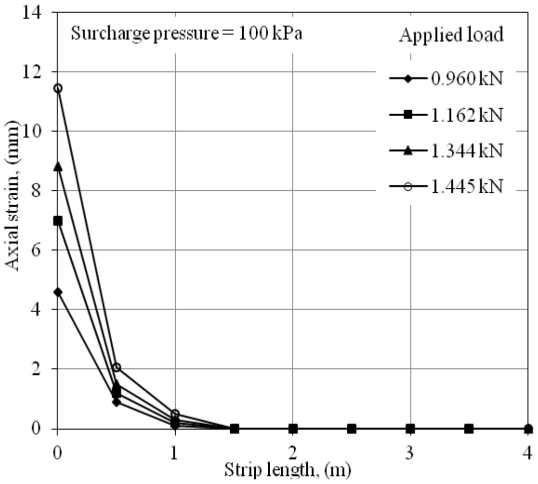

Fig. 6 Axial displacement of the geogrid with applied loads

4. CREEP BEHAVIOUR OF THE GEOGRID

To examine the creep behavior of the SR2 geogrid reinforcement a series of short and long-term sustained loading tests were conducted throughout this investigation. For the short-term creep test a loading increment of 5% PI was applied each 60 minutes during which the creep deformations are recorded at 1, 2, 5, 10, 20, 40 and 60 minutes. For the long-term creep test, two loading levels, namely 25% PI and 35% PI, were chosen to be held for tweleve weeks (2000 hours) time duration while the creep deformations of the geogrid reinforcement 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 kPa. These tests were carried out under very small changes in temperature to minimize the effect of temperature variation on the experimental results. The temperature recorded throughout the tests was 18 ± 1^o C with a maximum variation of 2^o C.

The results of these tests showed no cessation of creep displacement of the geogrid reinforcement throughout the testing period. This trend can be clearly seen in Fig. 7 which illustrates the relationships between creep displacements and time. 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 and applied load increase.

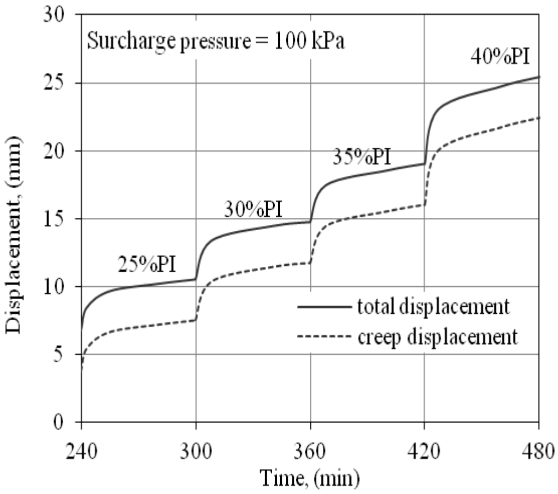

Fig. 7 Deformation-time relationships with applied load of the geogrid

These observations are best illustrated by the form of a plot between creep deformation rate and time. It may be seen in Fig. 8 that at any sustained stress level the logarithm of the 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.

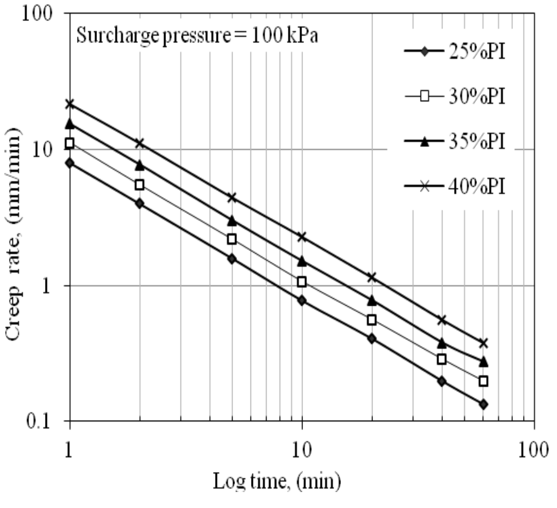

Fig. 8 Creep rate-time relationships of the geogrid

Figure 9 shows the time-dependent deformation relationships of the geogrid on a semi-log scale plot for the long-term sustained tensile loading. This Figure indicates that maintaining the applied load constant for several weeks results in a continuous deformation of the geogrid reinforcement. An interesting feature is that the rate of displacement-log time was constant during the first few weeks and started to decrease slightly towards the end of the test.

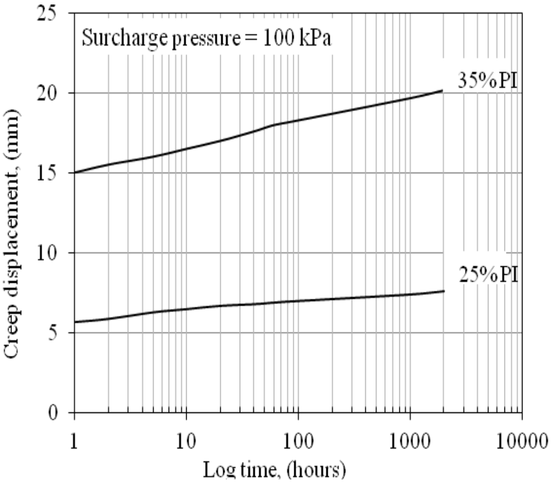

Fig. 9 Creep deformation–log time relationships of the geogrid

5. CONCLUSION

The pull-out performance of the geogrid reinforcement under static and sustained loading is described in this paper. The laboratory tests results demonstrated that the geogrid reinforcement can be used in most loading conditions, although care will be required in ensuring that appropriate factors of safety are applied to control the resulting deformation.

Under static loading applications the geogrid reinforcement experienced a gradual deformation with load increase. No peak load was observed with the system of loading used and the relationship between load and deformation became almost linear at larger displacements. The total displacement of the reinforcement consists only of an extension of the front half part of the geogrid reinforcement and neither slip nor extension along the rear segment of the specimen length was observed

The sustained loading tests data indicated that maintaining the applied load constant for several weeks results in a continuous deformation of the geogrid reinforcement without cessation. This deformation was mainly close to the point of load application. 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 and applied load increase.

6. ACKNOWLEDGEMENTS

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