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Creep behaviors and constitutive model for high density polyethylene geogrid and its application to reinforced soil retaining wall on soft soil foundation

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HIGHLIGHTS

- Creep behavior and stress relaxation of geogrids have been investigated.
- Constitutive model for simulating creep behaviors and stress relaxation of geogrids.
- Working stress of geogrids should be less than 40% of ultimate tensile strength.
- Piles treated deep soft soil foundation can ignore creep behavior of soft soil.

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ABSTRACT

The reinforced soil retaining wall has been applied extensively with its numerous advantages. However, the performance of geogrids reinforced soil retaining wall was affected by creep behavior of geogrids and soft soil foundation as well as stress relaxation of geogrids. In this paper, the creep behavior and stress relaxation of high density polyethylene geogrids have been investigated in a laboratory. Four different sustained load levels of 20%, 40%, 50% and 60% of ultimate tensile strength were employed as load levels for creep tests. A constitutive model, which was capable of simulating creep behaviors and stress relaxation of geogrids, was established based on experimental data and verified. Numerical modeling using finite element method has also been used to assess the impact of creep behavior and stress relaxation of geogrids on the long-term performance of reinforced soil retaining wall on the deep soft soil foundation. The results show that the constitutive model for creep behavior and stress relaxation of geogrids was in good qualitative agreement with experimental data under different load levels. To ensure the stability of the retaining wall, the working stress of geogrids should be less than 40% of ultimate tensile strength, and the high strength geogrids should be adopted in the middle of the wall or the spacing of geogrid reinforced layers should be reduced. The deep soft soil foundation which is treated by piles can ignore the creep behavior of soft soil.

1. Introduction

Plastics geogrids, a type of geosynthetic, refer to high strength and durability polymer materials developed for reinforced retaining wall on the soft soil foundation [1]. For reinforced soil, geogrids provide tension strength to bound soil and restrain excessive lateral displacement of soil. However, geogrids are subjected to time-dependent creep behavior and stress relaxation in a stretched state in actual projects, leading to variational internal stress and affect the long-term performance in reinforced structures such as loss of overall stability and excessive deformation [2]. Therefore, the long-term creep strain of geogrids must not exceed the allowable value and the reinforced structures should be restricted to a limited deformation to keep long-term stability [3]. In addition, the creep deformation of soft soil induced by secondary consolidation has influence on the creep behavior and stress relaxation of geogrids through friction and adhesion [32]. All of these key factors influence the long-term performance of reinforced soil retaining wall.

Numerous studies have been conducted on the performance of reinforced retaining walls on the solid foundation [4–9]. The different wall and backfill materials, the reinforced intensity and length, and geometry of reinforced soil structures were reported based on

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reinforced mechanism and design methods of reinforced retaining wall. The soil pressure, displacement and stress distribution at base of reinforced retaining walls have been previously summarized. Based on the results of these studies, the design methods of present specifications for reinforced retaining walls were formed gradually [10,11].

This is not the case with reinforced retaining walls on the soft soil foundation, where the settlement or differential settlement are taken place in most reinforced soils [12–15]. However, reinforced retaining walls sustained almost no damage and the strain of reinforcement materials did not exceed the design standards. Therefore, current design methods for reinforced retaining walls on the solid foundation were not suitable for soft soil foundation.

For the creep model of geogrids, linear [17,18], hyperbolic [19] and polynomial [20] constitutive relations, which did not consider time-dependent behavior [16], were used commonly in most early numerical analysis of geogrids reinforced retaining wall. Currently, creep models used in finite element analysis including component models, rheological models and empirical models, and empirical models based on test data were widely adopted. Finnigan and Findley [18,21] developed an empirical equation based on experiments that both short-term and long-term creep behaviors of geosynthetics have been considered. Das [22] proposed an empirical equation of strain rate for geogrids which was modified from the empirical rheological models of soil developed by Singh and Mitchell [29]. Additionally, rheological models which combined of creep and stress relaxation have been widely used to study the stress relaxation of geosynthetics. Sawicki [23,24] developed a three parameters‘ creep model based on linear solid model comprised of a spring and Kelvin‘s model, and proposed a four parameters‘ rheological model by adding a plastic slider.

In this study, creep tests of geogrids have been conducted and the creep behavior and stress relaxation of geogrids subjected to different loadings were investigated. In addition, a constitutive model, which was capable of simulating creep behaviors and stress relaxation of geogrids, was established based on experimental data and verified by comparing experimental and calculated results. The model was then incorporated into a finite element model to simulate the long-term performance of a reinforced retaining wall on the deep soft soil foundation. The results provide useful information for analysis and evaluation of the long-term performance of geogrids reinforced structure on the deep soft soil foundation.

2. Materials and apparatus

2.1. Properties of geogrid

Tensile properties of high density polyethylene geogrid were evaluated according to the test procedure described in ASTM D 6637 [25]. Ten longitudinal and transverse ribs cut from geogrids were tested at a constant displacement rate of 20 mm/min, respectively, and the typical load-deformation curves are shown in Fig. 1. The average ultimate tensile strength is 39.91 kN/m for longitudinal ribs and 36.79 kN/m for transverse ribs, and the average elongation rate under the ultimate tensile strength is 9.53% on longitudinal direction and 11.27% on transverse direction. Therefore, loads were applied on longitudinal ribs of geogrids in creep tests, and the properties of specimens in longitudinal direction are listed in Table 1.

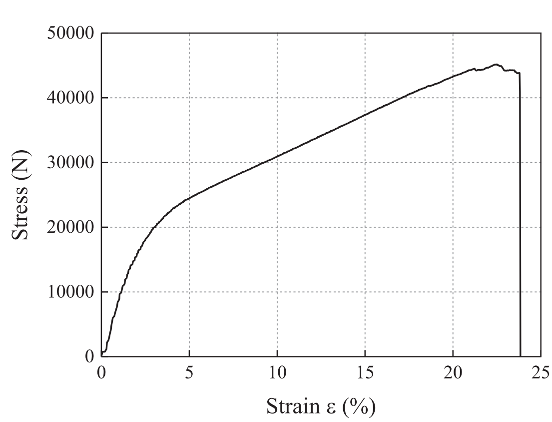

Fig. 1. Typical tensile behavior of geogrids.

Table 1
Longitudinal properties of specimens.

Properties	Specimen
Tensile strength (kN/m)	39.91
Strength at 2% strain (kN/m)	13.45
Strength at 5% strain (kN/m)	28.96
Width	3 ribs
Unit weight (kg/m^2)	0.6

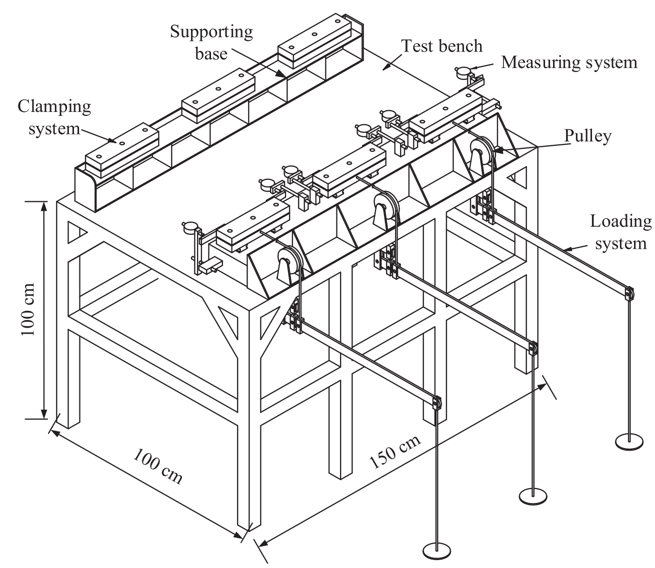

Fig. 2. Apparatus sketch for creep tests.

2.2. Description of apparatus

The test apparatus used in creep tests was developed by authors, which consisted of test bench, clamping system, loading system and measuring system, as shown in Fig. 2.

2.2.1. Test bench

The dimension of test bench is 1.5 × 1.0 × 1.0 m. Two stationary supporting bases were installed on each side of the test bench respectively, and one of them connected with pulley, which was used to convert vertical load to horizontal load.

2.2.2. Clamping system

Clamping system consisted of fixed fixtures and free fixtures, as shown in Fig. 3. All the fixtures were 30-cm-wide to ensure wider than specimens. It was easy to clamp the geogrid which has a thickness of 5 mm. However, clamping method was important to ensure the accuracy of test data. A non-slip treatment was used inside fixtures, and a row of bolts was set to provide clamping power. Fixtures connected with pulley were free to slide on the supporting base, and the other fixtures on another side of test bench were fixed. The specimen with three longitudinal parallel ribs was mounted inside the fixtures.

2.2.3. Loading system

Considering the difficulty of massive load application in the test, the principle of leverage with a scaling-down ratio of 1:8 was used to reduce the applied load. The load was applied to the specimens using weights, which were hung on the lever system as tensile load.

2.2.4. Measuring system

Two dial gauges were used for measuring the displacement of free fixtures to obtain deformation of specimen. Dial gauges, which have an accuracy of 0.01 mm, were mounted on both sides of the fixtures, as shown in Fig. 4.