Compressive Creep Analyses for Geocomposite Drainage Products

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ABSTRACT: Compressive deformation of prefabricated geocomposite drains (GCDs) affects the flow capacity and is therefore a significant design issue for many applications. Conceptually, it is understood and recognized that deformation is a function of compressive stress and time (i.e., load duration). This paper presents a methodology for evaluating the combined effect that compressive stress and load duration have on the flow capacity of GCDs. The methodology is used to calculate a "compressive creep reduction factor" that is used as a critical component in evaluating the factor of safety against drainage failure. Compressive creep test data from two commercially available GCD products are presented with a design example to demonstrate the methodology.

INTRODUCTION

There are currently two approaches used to evaluate the anticipated in-service performance of prefabricated geocomposite drains (GCDs). The first approach involves determining the conditions and requirements of the intended application, then conducting long-term performance-oriented hydraulic transmissivity (hereafter referred to as only as transmissivity) testing in an environment that simulates the anticipated conditions. The hydraulic performance of the GCD is measured, and the factor of safety is calculated as the ratio of the measured transmissivity divided by the required transmissivity. This approach may be justifiable for critical applications, but, due to the long-term nature of the tests, it is generally too expensive and time consuming to be performed on a routine basis.

The second approach is more generic in that it allows "reduction factors" to be applied to the transmissivity of the GCD measured in a short-term index-oriented test. The overall factor of safety is evaluated as follows (modified from Koerner, 1990):

$$FS = \frac{\theta_{meas}\ (F_1\ x\ F_2\ x\ \ldots\ x\ F_x)}{\theta_{req}} \qquad (1)$$

where: FS is the factor of safety against drainage failure; Θ_{meas} is the transmissivity of the GCD situated between rigid plates using short-term transmissivity test procedures; Θ_{req} is the required transmissivity of the GCD for the intended application; F_1, F_2 ... F_x are reduction factors to account for conditions such as intrusion of adjacent materials (e.g., the geotextile filter) into the GCD flowpaths, clogging of the GCD due to chemical precipitation or biological growth, and compressive creep of the GCD's core. Although all of these factors are not be completely independent of each other, there is a distinct role that each phenomenon may serve in reducing the actual transmissivity of GCDs.

Some guidance is provided for selecting values of reduction factors (Koerner, 1990), however, supplemental evaluations should be performed to define appropriate values of reduction factors for specific GCD products.

The purpose of this paper is to present a methodology for evaluating the reduction factor to account for compressive creep of the GCD core, F_{CR}. Details of the methodology and examples of test results for two commercially available GCD products are presented below.

PROPOSED METHODOLOGY

The methodology for evaluating the compressive creep of GCDs (i.e., evaluating F_{CR}) involves the following four-step process:

- *Step 1.* Compressive Deformation Testing
- *Step 2.* Compressive Creep Testing
- *Step 3.* Transmissivity Testing
- *Step 4.* Evaluation of F_{CR}

Details of each step are presented below. Actual results obtained from a compressive creep testing program performed on two commercially available GCD products are integrated into the discussion to demonstrate the methodology. The first GCD product (hereafter referred to as Product A) is a 32-mm (1.25-in.) thick polyethylene corrugated cusp. A photograph of Product A is shown in Figure 1A. The second GCD product (hereafter referred to as Product B) is a 45-mm (1.75-in.) thick polyethylene elongation corrugated pipe. A photograph of Product B is shown in Figure 1B. Both products are wrapped with geotextile filters and are typically used in near-surface (i.e., low confining pressure) applications such as pavement edge drains.

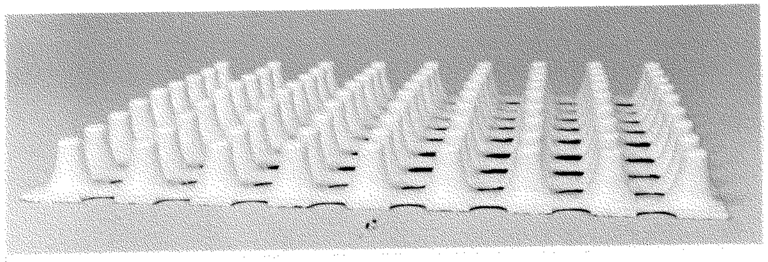

Fig. 1A Photograph of GCD Product A

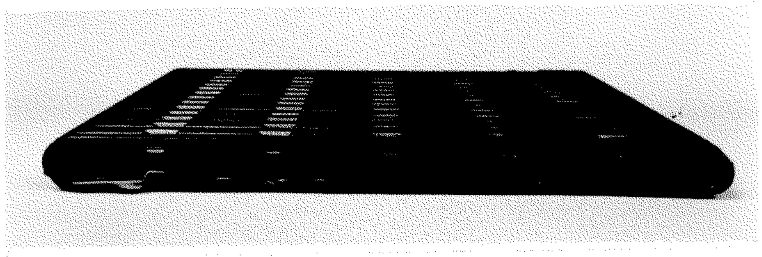

Fig. 1B Photograph of GCD Product B

Step 1. Compressive-Deformation Testing

Short-term compressive deformation testing is performed using the procedures set forth in *Standard Test Method for Compressive Properties of Rigid Cellular Plastics* (ASTM D 1621). The GCD specimen is positioned between two rigid steel plates and compressed at a constant deformation rate of 2.5 mm/min (0.1 in./min); the compressive load is measured at several values of strain. The compressive strain is plotted as a function of compressive stress. The entire duration of the test for most commercially available GCD products is typically 2 to 5 minutes.

Compressive deformation test results for Products A and B are shown in Figure 2. Inspection of this figure reveals that the compressive characteristics of the two GCDs are dissimilar, as would be expected from the inherent geometrical differences between these products.

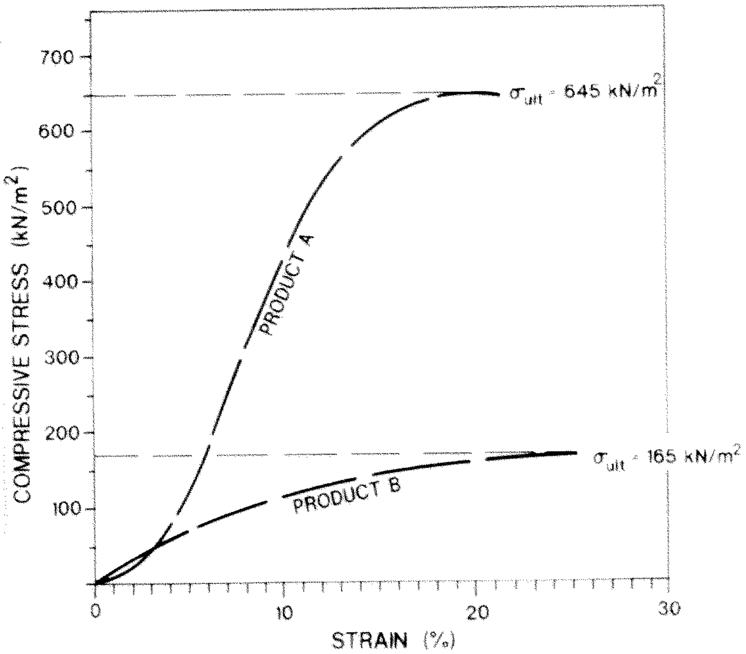

Fig. 2 Short-term stress versus strain relationships from compressive-deformation tests

Step 2. Compressive Creep Testing

The next step is to perform compressive creep testing at various levels of constant compressive stress (i.e., constant load) which should correspond to selected percentages of the ultimate strength determined in Step 1. Guidelines set forth in *Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep Rupture of Plastics* (ASTM D 2990) may be applied, although this test standard was not developed specifically for compressive creep testing of GCDs. Each GCD specimen is positioned between two rigid steel plates, similar to the configuration used for the short-term compressive-deformation tests. A mechanical lever-arm or piston-type loading device is used to apply the normal load (i.e., the level of compressive stress) to each specimen. Several loading stations, as shown in Figure 3, are required to simultaneously test specimens at the various levels of compressive stress. The tests should be conducted in a laboratory which has tightly controlled temperature and humidity conditions. Deformation measurements for each specimen are recorded at regular intervals throughout the duration of the test. The compressive load is sustained on each specimen until a predetermined time duration (typically 10,000 hrs or preferably even longer) is exceeded.

The compressive creep data are plotted as compressive stress versus strain, with a family of isochronous curves depicting the stress-strain relationship after various durations of loading. This was done for Products A and B, as shown in Figures 4A and 4B, respectively. The curve on each graph that is labeled "0 hr" was

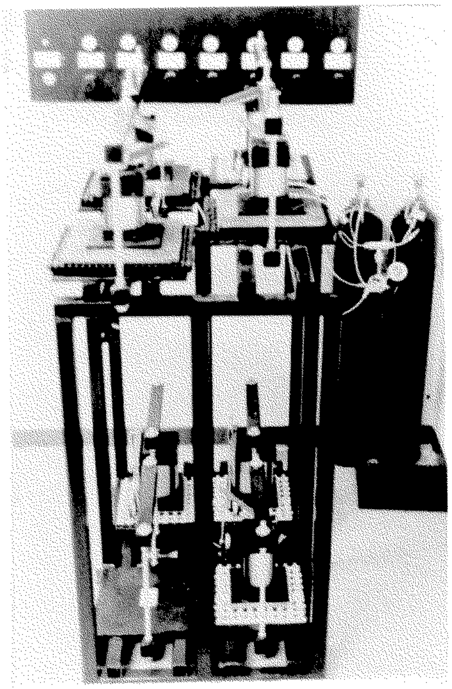

Fig. 3 Photograph of compressive creep test equipment

established from the short-term compressive tests (as described in Step 1). All of the other curves, labeled "10 hr to 10,000 hr", were generated from the creep test data. The general downward trend exhibited by each family of curves shown in Figures 4A and 4B demonstrates the phenomenon known as "stress relaxation" which is typical of thermoplastic materials.

Compressive creep tests on GCDs should continue for as long as possible in order to maximize the evaluation of long-term behavior. The design life of these products could be up to several years, thereby necessitating data that encompasses more than 10,000 hrs (1.15 years). Mathematical models are available to extrapolate creep data beyond the duration of the tests. However, caution must be exercised in applying these models to materials such as GCDs that have unique geometrical shapes.

Step 3. Transmissivity Testing

After completing the compression creep tests, transmissivity testing is conducted in general accordance with the procedures set forth in *Standard Test Method for Constant Head Hydraulic Transmissivity (In-plane Flow) of Geotextiles and Geotextile Related Products* (ASTM D 4716), which requires that the GCD be situated between two rigid plates (typically steel or aluminum). However, the procedures set forth in ASTM D 4716 must be slightly modified such that the transmissivity is measured at several predetermined levels of compressive strain rather than at predetermined levels of compressive stress. This is accomplished by applying a confining pressure (in a direction perpendicular to the plane of flow) until the desired strain is achieved. The transmissivity (i.e., the flowrate) is then measured through the GCD at several hydraulic gradients. The confining pressure is then increased until the next desired level of compressive strain is achieved and the flow is measured again at several hydraulic gradients. This process is repeated until the transmissivity has been measured at several successive predetermined levels of strain (including zero strain) which encompass the strain values encountered in the creep tests in Step 2.

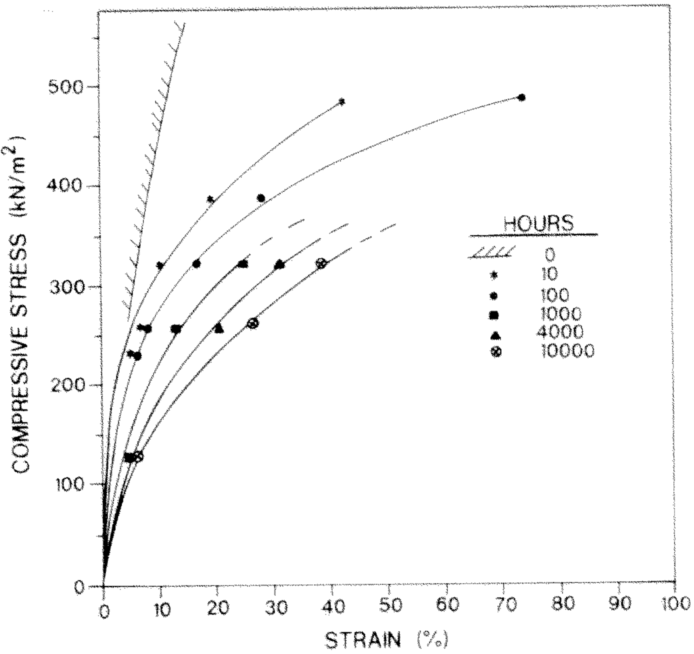

Fig. 4A Isochronous curves for Product A

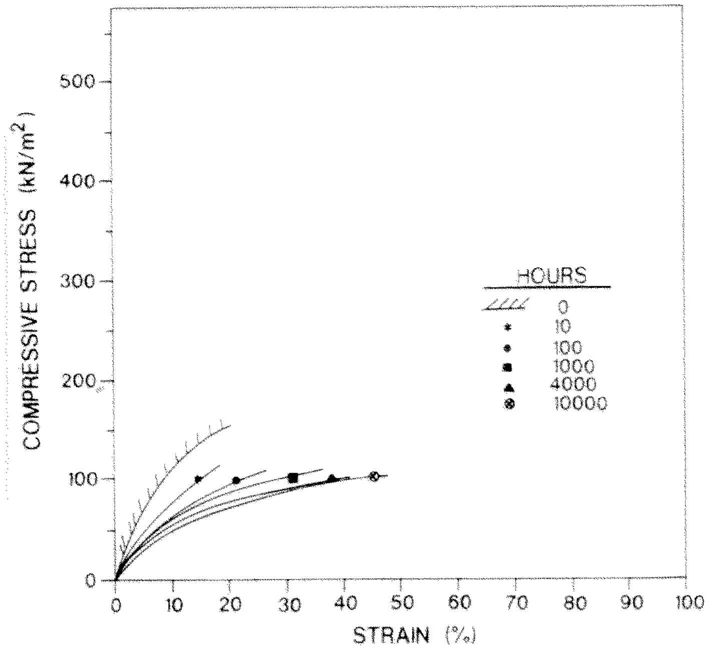

Fig. 4B Isochronous curves for Product B

Step 4. Evaluation of F_{CR}

Evaluating the compressive creep reduction factor involves two tasks. First, the isochronous stress-strain curve from Step 2 corresponding to a load duration of 10,000 hr (or longer if available) is plotted. Next, the transmissivity values measured at each level of compressive strain are normalized with respect to the transmissivity value measured at zero percent strain. Hence, for a given value of hydraulic gradient, each transmissivity value must be divided by the transmissivity value measured at zero strain. These ratios (which will always be less than 1.0) are plotted as a function of compressive strain and are superimposed onto the graph which shows the 10,000-hr isochronous stress-strain curve. This has been done for the transmissivity testing performed on Products A and B, as shown in Figures 5A and 5B, respectively.

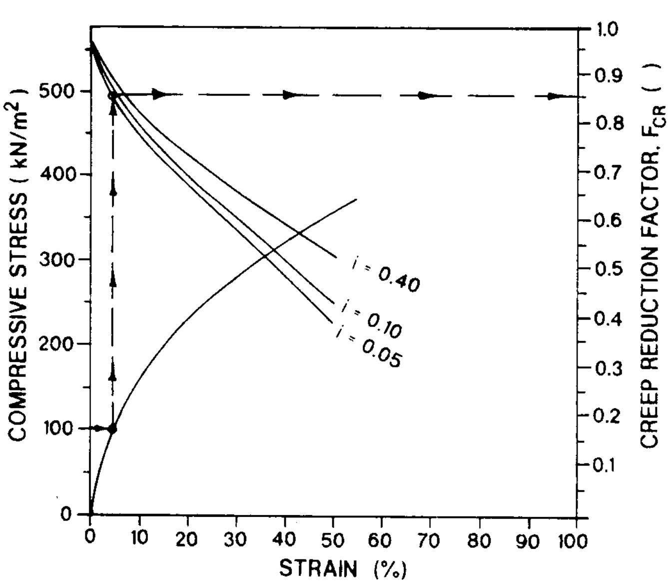

Fig. 5A Creep reduction factor graph for Product A

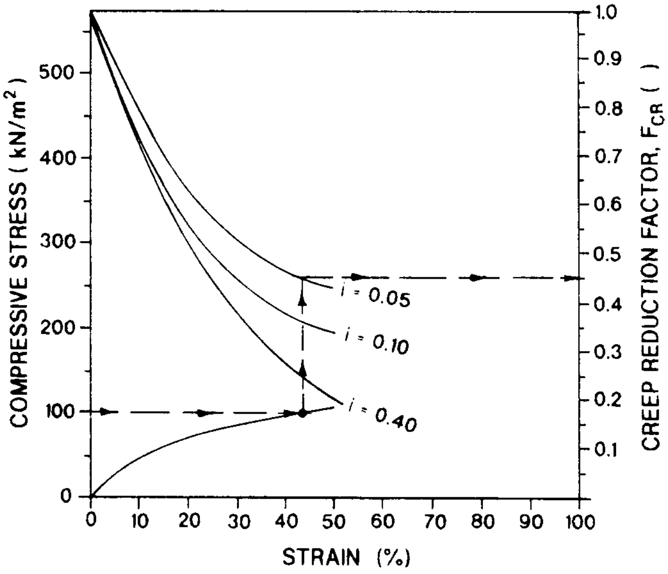

Fig. 5B Creep reduction factor graph for Product B

Comparison of these figures reveals that the effect of hydraulic gradient on the reduction factor is different for the two GCD products. This is due to a more pronounced increase in turbulence that occurs when Product B is compressed than occurs when Product A is compressed. The dissimilar effect is due to the inherent geometrical differences between these two products.

The procedure that should be used by designers to evaluate F_{CR} is demonstrated using an example. Consider an application where the design compressive stress is 100 kN/m^2 (14.5 psi or about 2,000 psf), and the design hydraulic gradient is 0.05. Using Figure 5A for Product A, a horizontal line is extended from a value of 100 kN/m^2 on the compressive stress axis over until it intersects the 10,000-hr stress-strain curve. Again, it should be emphasized that the isochronous curve which most closely corresponds to the required service life of the GCD should ideally be used; for this demonstration, the 10,000-hr curve is used. For Product A the intersection occurs at approximately 5 percent strain. A vertical line is drawn at this value of strain until it intersects the normalized transmissivity curve which corresponds to a hydraulic gradient of 0.05. A horizontal line is then extended from this point until it intersects the creep reduction factor axis, resulting in F_{CR} = 0.85 for this design example. For Product B, F_{CR} = 0.45 is obtained in the same manner as shown in Figure 5B.

CONCLUSIONS

A four-step methodology was presented to evaluate the effect of compressive creep on GCDs. Results of test data from two commercially available GCDs and a design example were presented to demonstrate the methodology. Based on the information provided, it is concluded that: (i) compressive creep reduction factors are specific to each GCD product; and (ii) for any given GCD, the compressive creep reduction factor is a function of the application requirements, namely, the compressive stress, the in-service design life, and the hydraulic gradient.

REFERENCES

ASTM D 1621, *Standard Test Method for Compressive Properties of Rigid Cellular Plastics.*

ASTM D 2990, *Standard Test Methods for Tensile, Compressive, and Flexural Creep of Plastics.*

ASTM D 4716, *Standard Test Method for Constant Head Hydraulic Transmissivity (In-Plan Flow) of Geotextiles and Geotextile Related Products.*

Koerner, R.M., "*Designing with Geosynthetics*", Prentice-Hall, Inc., 1990, 652 p.