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Hydraulic compatibility of geotextile containers confining dredged sediments

La compatibilite hydraulique des contenants en géotextiles aux sediments dragués

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ABSTRACT
Geotextile containers have been increasingly used in dewatering of high water content geomaterials. The hydraulic compatibility of a geotextile with the contact soil is an important issue and should be considered in geotextile container design. Clogging becomes especially important in their design, since the physical nature of fine-grained geomaterials that are in contact with these two-layer geotextile systems usually promotes clogging. This paper presents the results of a study conducted to investigate the long-term clogging of two-layer geotextile systems used in designing geotextile containers. The results indicated that the use of a two-layer nonwoven/woven geotextile rather than a single-woven geotextile significantly improved filtration performance of a geotextile container.

RÉSUMÉ
Les contenants en géotextiles sont en traîn d'être utilisés de plus en plus dans le séchage de sédiments à haut pourcentage d'eau. La compatibilité hydraulique d'un géotextile en contact avec le sol est un facteur important et doit être consideré dans la construction d'un contenant en géotextile. Le blocage devient un facteur important dans leur construction, puisque la nature physique des graines fines de géomateriaux qui sont en contact avec ces systèmes de géotextiles à deux couches sont d'habitude de nature à provoquer le blocage. Cet article présente les résultats d'une étude faite à rechercher le blocage à long term des systèmes de gèotextiles à deux couches utilisés dans la construction de contenants en géotextiles. Les résultats ont montré que l'utilisation d'un géotextile tissé ou non-tissé à deux couches au lieu d'un géotextile à couche simple a amélioré de façon importante la filtration d'un contenant en géotextile.

1 INTRODUCTION

Considerable evidence has been provided by the recent studies (Fowler et al. 1996, Pilarczyk 2000, Gaffney 2001) that dewatering of contaminated high water content geomaterials may assist in their further remediation. This dewatering has been traditionally achieved through exposing them to sunlight and allowing for the formation of desiccation crust. A more recent method involves utilization of geotextile containers. The usage of geotextile containers has increased during the last two decades due to their advantages over the traditional dewatering methods. These advantages include; (1) reduced work volume and labor skills, (2) reduced construction time, and (3) reduced cost (Pilarczyk 2000). Even though geotextile containers are mostly used in dewatering and drainage applications, other application areas also exist such as structural applications, erosion and scour protection applications, and containment of contaminated materials. Geotextile containers are tubular structures constructed from either high strength woven geotextiles or a combination of woven and nonwoven geotextiles. Dimensions of the geotextile sheets used in geotextile containers generally range from 4 to 5 meters in width, and from 100 to120 meters in length. Selection of a geotextile mostly depends on the strength requirements and the fill material properties. The reinforcement is an important function expected from a geotextile container for providing sufficient strength during container filling. However, geotextile containers must be permeable enough to allow the passage of water, and tight enough to contain the fill material. As a result, the hydraulic compatibility of a geotextile with the contact soil is an important issue and should be considered in geotextile container design. Clogging becomes especially important in their design, since the physical nature of fine-grained geomaterials that are in contact with these two-layer geotextile systems usually promotes clogging. In order to enhance the anti-clogging performance during consolidation and other fluid movement, hydraulic properties of the geotextile containers comprising two-layer geotextile systems should be satisfactory. Various studies have been conducted to analyze the filtration performance of single-nonwoven or woven geotextiles with various geomaterials (Wayne and Koerner 1993, Fannin et al. 1994, Gabr and Akram 1996, Akram and Gabr 1997, Bhatia et al. 1998, Fischer et al. 1999, Aydilek and Edil 2002, Aydilek and Edil 2003); however, lack of information exists about the filtration performance of two-layer systems such as geotextile containers. Recent advancements in geotextile filter design suggested that the filtration characteristics of these systems can be highly different than those of single-layer systems especially when the fill material contains significant amount of fines (Giroud 1996, Giroud et al. 1998, Mlynarek 1998, Delmas et al. 2000).

The problem of fine particle clogging becomes more cumbersome when industrial by-products or waste materials, such as dredged materials, are in contact with geotextiles. The nature of these geomaterials is different than regular soils, since they contain colloidal particles and are often contaminated with inorganic or organic pollutants. The existing geotextile selection criteria may not be directly applicable to these materials and, in most cases, their filtration or drainage performance with geotextiles should be investigated by conducting laboratory tests.

The objective of this study is to investigate the hydraulic compatibility of the bottom sea dredged sediments with various geotextiles. To meet this objective, a testing program was implemented which included gradient ratio tests. Results of these tests were used to develop recommendations for the dewatering applications using geotextile containers confining dredged sediments.

2 MATERIALS AND TEST PROCEDURES

Dredged sediments used in the study were obtained from Tolchester Channel located in Baltimore Harbor, Maryland. The material was black in color and had some odor. One woven and four nonwoven geotextiles were used in the study. Different combinations of these geotextiles were employed in the testing program to evaluate the efficiency of two-layer geotextile filters. The geotextiles were selected from the ones most often used in filter applications and had a wide range of apparent opening size (*AOS* or O_{95}) and permittivity (ψ) values. All two-layer systems included the geotextile W5, since this geotextile is commonly used by engineers in geotextile container design. The properties of the dredges sediments and geosynthetics are summarized in Tables 1 and 2, respectively.

Table 1. Geotechnical Properties of Dredged Sediments

Property	
Water Content (%)	1600
Solid Content (%)	18-26
Specific Gravity	2.6
Liquid Limit (%)	85
Plastic Limit (%)	50
USCS Classification	CH
Fines Content (grains < 0.075 mm) (%)	95
Coefficient of uniformity	11.7
Hydraulic conductivity (m/s)	1×10^{-7}

Table 2. Hydraulic Properties of Geosynthetics

Geotextile ID: W5	
Structure, polymer type	MF, PP
Apparent opening size, *AOS* (mm)	0.6
Permittivity, Ψ(s^{-1})	0.4
Mass/unit area (g/m^2)	490
Geotextile ID: NW1	
Structure, polymer type	NP, PP
Apparent opening size, *AOS* (mm)	0.15
Permittivity, Ψ(s^{-1})	1.5
Mass/unit area (g/m^2)	406
Geotextile ID: NW2	
Structure, polymer type	NP, PP
Apparent opening size, *AOS* (mm)	0.21
Permittivity, Ψ(s^{-1})	2.0
Mass/unit area (g/m^2)	331
Geotextile ID: NW3	
Structure, polymer type	NP, PP
Apparent opening size, *AOS* (mm)	0.3
Permittivity, Ψ(s^{-1})	2.5
Mass/unit area (g/m^2)	123
Geotextile ID: NW4	
Structure, polymer type	NP, HB
Apparent opening size, *AOS* (mm)	0.3
Permittivity, Ψ(s^{-1})	1.1
Mass/unit area (g/m^2)	140

Note: MF: monofilament, NP=needle-punched, HB= heat-bonded, PP= polypropylene.

Gradient ratio tests were conducted to determine the clogging performance of soil-geotextile combinations. Figure 1 shows the gradient ratio test permeameter used in the study. Methods described in ASTM D 5101 were followed for the specimen preparation, with few exceptions. Two geotextiles were glued at their edges to prevent any lateral drainage and were placed at the bottom of the dredged sediments. The flow was maintained from top to bottom. Inflow and outflow devices (not shown herein) provided a constant head on the specimen. Contrary to the 24-hour procedure prescribed in the standard method, the tests were continued for 4 to 6.5 months to understand the long-term clogging performance of these systems. The stabilization criterion adopted called for the last five gradient ratios and hydraulic conductivities to vary less than 25%. The specimen preparation technique described in ASTM D 5101 was slightly modified for the dredged sediments due to their high water content. Reverse filling of the permeameter was eliminated, and sediments were placed directly on the geotextile. Due to the gases in sediments, back-saturation of the specimens was slow. To speed-up the process, a Tygon tube was connected to the bottom of the specimens with its other end open to air. The specimens were then back-saturated for 24 hours. Along with the suggestions of Fischer et al. (1999), filters with openings of 1 μm were used to filter the tap water in order to remove any suspended solids, and the carbon dioxide gas was not used for back-saturation. Additionally, hydraulic gradients of 1.5, 3, 6, and 8 were used in the tests. In all tests, a fully automated water de-airing system continuously supplied the test water. The dissolved oxygen content of the water was regularly checked and maintained between 3.5 and 4 mg/L, less than a limit of 6 mg/L set by the ASTM D 5101.

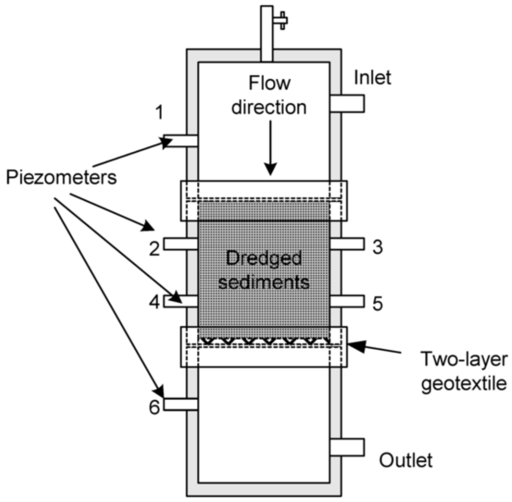

Figure 1. ASTM D 5101 gradient ratio test device

ASTM D 5101 defines gradient ratio, *GR*, as the ratio of hydraulic gradient in the contact zone to hydraulic gradient in the soil:

$$GR = i_{\text{sediment-GT interface}} / i_{\text{soil}} \qquad (1)$$

ASTM D 5101 gives a *GR* of 1 as the limit for clogging whereas the U.S Army Corps of Engineers considers *GR* values of up to 3 acceptable. Previous research has shown that the 24-hr time period is usually not enough to achieve a stabilized gradient ratio (Akram 1995), and long-term testing is recommended. Fischer (1994) also showed that *GR*=1 may not be representative due to analysis of a relatively small soil-geotextile contact zone in the gradient ratio apparatus. This is specifically true for dredged sediments, since a clod-like structure occasionally formed after sediment placement with visible voids between these clods. This structure may dramatically increase gradient ratios, since blocking of a manometer port by a clod would change the head registered in that particular manometer. Therefore, similar to the U.S. Army of Corps of Engineers' criterion, *GR* =3 may be considered as the limit for acceptable clogging of sediment-geotextile systems.

3 DISCUSSION OF THE RESULTS

The values of *GR* and system hydraulic conductivity for each dredged sediment-geotextile system are shown in Figures 2 and 3. As seen in the figures, *GR* values are generally higher than the ASTM D 5101 limit of 1.0, which may suggest that the geotextiles or combinations clogged. However, the hydraulic conductivities measured at different depths inside the soil specimen (not shown herein) were comparable and did not support this conclusion. The comparable hydraulic conductivities implied that the geotextile did not significantly affect the permeability of the system. These observations indicated that the geotextiles or combinations usually did not clog since they did not have a significant effect on the flow regime of the overall system.

Figures 2 and 3 suggest that the *GR* is relatively lower for combinations as compared to those obtained for single-woven geotextile W5, when the end-of-testing conditions are considered (i.e., i=6 for all geotextiles and combinations). The low *GR* values indicate lower hydraulic gradients and, in turn, lower seepage forces ($F_{seepage} = i\gamma_w$) at the soil-geotextile interface. This clearly shows the benefit of using a nonwoven geotextile.

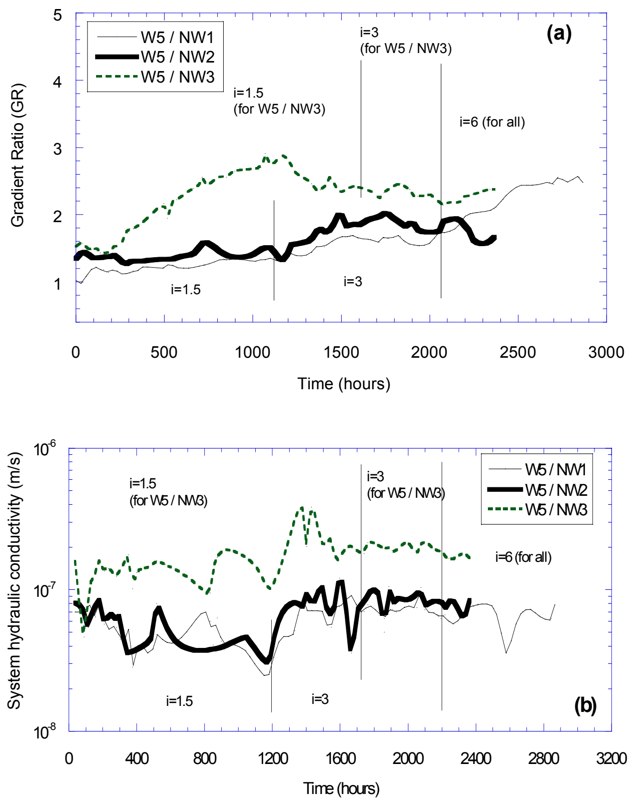

Figure 2. Temporal characteristics of gradient ratio and system hydraulic conductivity for the combinations W5/NW1, W5/NW2, and W5/NW3

Rollin et al. (1985) observed three different flow patterns during long-term filtration tests (Figure 4). Each group was defined by the following criteria: (1) blinding/blocking behavior where soil particles move through geotextile increasing the density of the soil just above the geotextile thus reducing permeability, (2) piping behavior, which occurs after some normal behavior, where fine soil particles pipe through the geotextile resulting in an increase in permeability, and (3) mixed behavior where loss of soil particles is followed by a filter cake formation at the soil geotextile interface.

For all woven/nonwoven combinations, the gradient ratio stayed almost constant during the first 300 hours, ranging from 1.2 to 1.5. After that time, two distinct phases were observed: blocking/blinding and a mixed pattern. Figure 2 demonstrates these two phases. For instance, a blocking/blinding pattern is observed for the combination W5/NW1 under the initial hydraulic gradient (i.e., i=1.5). At this stage, the hydraulic conductivity decreases from 7 x 10^{-8} m/s to 2 x 10^{-8} m/s and is accompanied by an increase in gradient ratio from 1.0 to 1.3. A mixed behavior is observed at i=3 and i=6. At the hydraulic gradient of 3 (between 1200 to 2000 hours), *GR* increases slightly from 1.3 to 1.56 and the hydraulic conductivity increases from 2 x 10^{-8} m/s to 7.9 x 10^{-8} m/s. When the hydraulic gradient is increased to 6 after 2000 hours of flow, the *GR* rapidly increases to about 2.5 and stays at that value; however, the hydraulic conductivity does not change significantly. A continuous piping phenomenon (i.e., decreasing *GR* and increasing system hydraulic conductivity with time) cannot be observed in testing of dredged sediments.

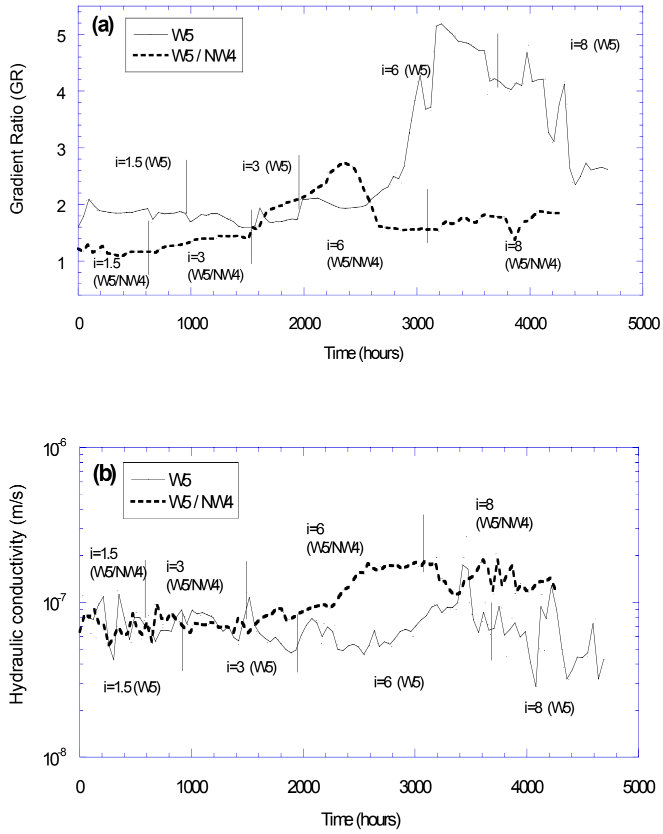

Figure 3. Temporal characteristics of gradient ratio and system hydraulic conductivity for the geotextile W5 and combination W5/NW4.

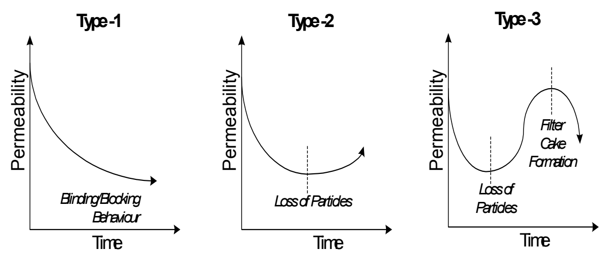

Figure 4. Long-term filtration behavior of soil geotextile systems (After Rollin et al. 1985)

Stabilized values of the gradient ratio are plotted versus each applied hydraulic gradient in Figure 5. The *GR* values range from 1.2 to 4.2. A clear-cut relationship cannot be observed; however, the *GR* tends to increase slightly with increasing hydraulic gradient.

Attempts are made in Figure 6 to relate the *GR* to apparent opening size (*AOS* or O_{95}) of the geotextile in contact with the geomaterial. The results indicate that a significant relationship does not exist between these variables. Similar observations

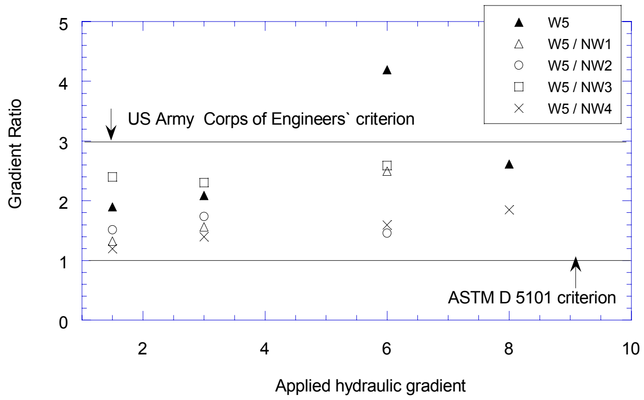

Figure 5. The effect of hydraulic gradient on gradient ratio of geotextiles exposed to filtration with dredge sediments

were made by previous researchers that *AOS* is a poor indicator of the clogging performance and other parameters, such as median opening sizes (O_{50}) or pore channel constriction sizes should be considered when relating the filtration behavior to pore structure (Giroud 1996, Aydilek and Edil 2002).

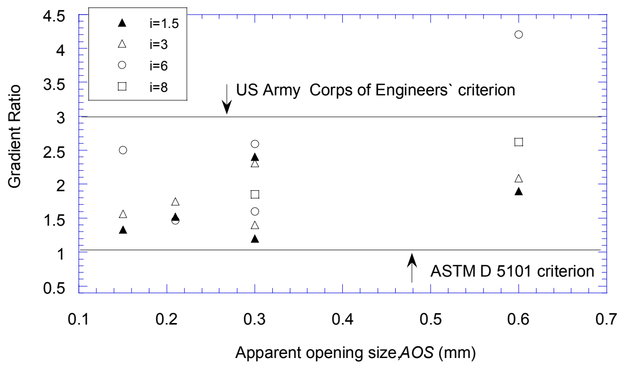

Figure 6. The effect of *AOS* on gradient ratio of geotextiles exposed to filtration with dredge sediments

4 SUMMARY

In designing geotextile containers, a nonwoven geotextile filter may not have the required mechanical properties to withstand deformations, and an additional woven geotextile is usually employed in design. A battery of laboratory long-term gradient ratio tests was conducted to evaluate the filtration performance of four different woven/nonwoven geotextile combinations with bottom-sea dredged sediments. For comparison, the sediments were also tested with a single-woven geotextile. The results indicated that the use of a two-layer nonwoven/woven geotextile rather than a single-woven geotextile significantly improved filtration performance of a geotextile container. Two-layer geotextile systems, in most cases, exhibited lower *GR* values when tested with cohesive dredged sediments.

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