CLOGGING POTENTIAL OF GEOSYNTHETIC BASED REACTIVE CAPS FOR CONTAMINATED SEDIMENT REMEDIATION

Jeffrey S. Melton[1], Rafael Prieto[2] & Kevin H. Gardner[3]

[1] *Civil Engineering, University of New Hampshire, Durham, NH, 03824, USA. (e-mail: jeffrey.melton@unh.edu)*
[2] *Civil Engineering, University of New Hampshire, Durham, NH, 03824, USA. (e-mail: rafael.prieto@unh.edu)*
[3] *Civil Engineering, University of New Hampshire, Durham, NH, 03824, USA. (e-mail: kevin.gardner@unh.edu)*

Abstract: Geosynthetic based reactive capping mats have been used recently as a passive remediation technology for contaminated sediment. These mats are generally comprised of two geosynthetic fabrics bound to a fibrous core that is filled with a reactive material such as activated carbon or apatite to bind the targeted contaminants. The mat is deployed on top of the sediment to trap the contaminants as they migrate out of the sediment via diffusion or advection. The top geosynthetic is generally chosen to act as a filter, preventing sediment migration into the cap while the bottom geosynthetic provides strength to the cap during installation and recovery of the system. The different geosynthetic filter design criteria available generally correlate the grain size distribution of a soil to the suggested apparent opening size (AOS) of the geosynthetic. However, fine grained marine sediment provides a challenge in terms preventing short and long term clogging of the geosynthetic while preventing transport of sediment into the cap. This work evaluated the clogging potential of geosynthetic fabrics and complete cap structures exposed to marine sediments using the gradient ratio test (ASTM D 5101). The tests indicate that no clogging develops in the geosynthetic-sediment and cap-sediment systems, though the AOS was not a good predictor of geosynthetic performance.

Keywords: clogging, geotextile, permeability, groundwater, filter, soft soil.

INTRODUCTION

The presence of industrial contaminants in coastal and estuarine sediments is a world wide problem, and the remediation of those sediments is the subject of extensive research. Ex-situ approaches to sediment remediation are based on removing the sediment from the water for later treatment and disposal on land. However, increasing costs and a decrease in available land for disposal is pushing researchers to find alternative technologies. In-situ reactive capping is a promising new technology that treats the sediment in place, removing the need for an upland disposal site (Palermo 1998, Ramsden and Gardner 2003). The Environmental Research Group at the University of New Hampshire has been investigating the efficacy of this technology.

The key aspect of this reactive capping technology is the use of a geotextile mat which is placed directly on the sediment. The mat is composed of a reactive material (e.g. apatite, activated carbon, organoclay) sandwiched between two geotextile fabrics to form a permeable reactive layer that binds the aqueous phase contaminants as they are transported out of the sediment. The use of a geotextile mat also overcomes several geotechnical issues by allowing the placement of the reactive material on top of the soft, weak sediment and by preventing localized failures and preventing mixing between the sediment and reactive amendments (Palermo 1998, Ling *et al.* 1996). However, this technology is only effective as long as the mat remains permeable and it is unknown if the fine grained sediment will cause clogging of the geotextile fabrics over time. The challenge for cap designers is to find geotextiles that will not clog while minimizing the piping of potentially contaminated sediment through the cap. However, Aydilek *et al.* (2005) found that the pore open size did not necessary relate to the structure of the pore channel, so choosing a geotextile by comparing the apparent opening size (AOS) to the sediment grain size distribution is problematic. In addition, Kossendey and Karam (1996) found that geotextile served as a catalyst for the formation of a soil filter, and that the geotextile properties were not as critical to the filtration properties. The question is then how to choose the appropriate geotextile for use in sediment caps.

This research is evaluating the clogging potential and sediment piping of single geotextile fabrics, new reactive mats and samples of mats retrieved from the field using a modified form of the gradient ratio test – GR test (ASTM D 5101). This paper presents the test results to date on geotextile fabrics and new reactive mats.

MATERIALS AND METHODS

The GR test was used to evaluate the clogging potential of a typical estuarine sediment on different types of geotextiles used in the fabrication of reactive core mats. Figure 1 shows a schematic view of the GR test setup. The numbers 1 through 6 denote the location of manometer ports, which allow measurement of the hydraulic head and the computation of the hydraulic gradient of the sediment and the sediment-geotextile sections. The gradient ratio is defined as the ratio of the hydraulic gradient of the soil-geotextile section to the hydraulic gradient of the soil section, as shown in the following equation.

$$GR = (i_{SG}) / (i_S)$$

Where GR is the unitless gradient ratio, i_{SG} is the average hydraulic gradient measured between ports 4 and 6 and 5 and 6, and i_S is the average hydraulic gradient measured between ports 2 and 4 and ports 3 and 5. The overall system hydraulic gradient *i* is the hydraulic head measured between ports 1 and 6 divided by the height of the sediment sample. The test is carried out at increasing values of *i*, making clogging more likely. Generally, a GR value of one or slightly less than one indicates the absence of clogging. A decrease in GR below one suggests the presence of piping, while a value greater than one indicates clogging. It should be noted that the value of GR with time is a better indication of behavior, rather than the value of GR at a given time.

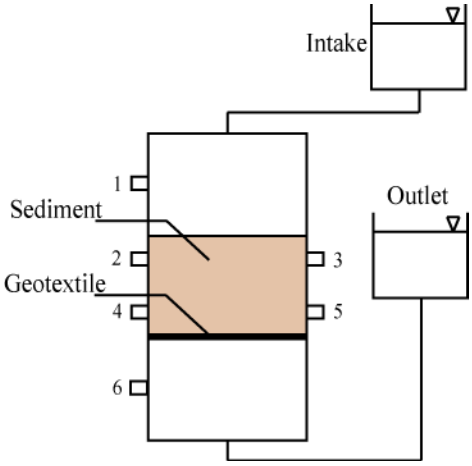

Figure 1. Sketch of the gradient ratio experimental setup

The sediment used in these tests was collected from the Piscataqua River estuary, New Hampshire, USA. Figure 2 shows two sediment grain size distribution curves determined using a hydrometer (ASTM D 422), which indicates the fine grained nature of the material. Previous work on this sediment has shown that typically 90% of the material will pass a 75 µm sieve. The liquid limit of the sediment was 10, and the sediment was classified as a silty clay (CL) according to the USCS (Nourse 2005). The permeability of the sediment was measured as 1.5×10^{-5}cm/s by the falling head test method. It should be noted that the gradient ratio standard provides for the measurement of flow rate every time the gradient ratio is measured, however, the low permeability of the sediment lead to a corresponding low flow of water and the authors were not able to collect sufficient volumes of fluid to accurately measure the flow rate.

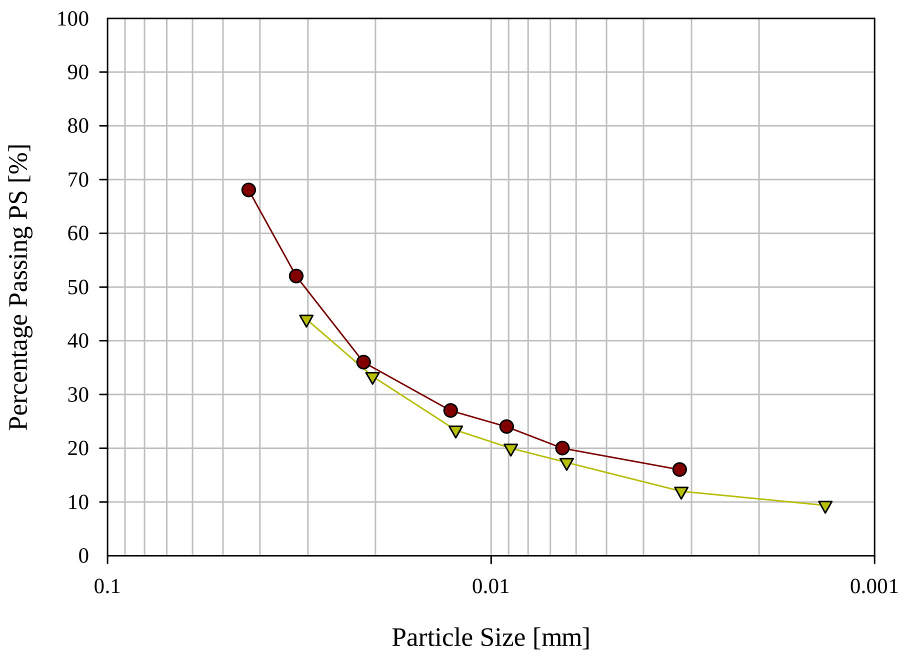

Figure 2. Granulometry of the sediment measured via hydrometer

Three different geotextile fabrics were evaluated for clogging. They were chosen based on the range of apparent opening size (AOS), mass per area and because they may be used to manufacture reactive mats. The AOS and mass values were provided by the manufacturers. Table 1 lists the geotextile properties.

Complete reactive core mats were also tested to evaluate the combined clogging potential of the system. Each mat was composed of a nonwoven geotextile top layer, a fibrous core containing the amendment material, and bottom woven geotextile (AOS 50 mesh, 101 g/m^2). Each mat was approximately 1 cm thick. Table 2 presents the main characteristics and identification of the reactive core mats. The same woven geotextile was used to build all the mats shown in Table 2.

Table 1. Properties of the geotextile fabrics

Mass per unit area g/m^2	**AOS** US Mesh	**Polymer type**	**ID**
170	170	Polyester	G1
203	70	Polypropylene	G2
265	80	Polypropylene	G3

Table 2. Properties of clean and reactive core mats

Non woven geotextile			**ID**
Mass per unit area (Nonwoven layer) g/m^2	**AOS** US Mesh	**Polymer type**	
170	170	Polyester	RCM 1
203	70	Polypropylene	RCM 2
265	80	Polypropylene	RCM 3

RESULTS AND DISCUSSION

Two GR tests were run on each individual geotextile fabric, and two tests have been run on mat RCM 2. In each case, there was some sediment piping through the geotextile while the test stabilized at a system hydraulic gradient i=1. All the sediment was transported in the first 24 hours, with no additional piping evident when the hydraulic gradient was increased. A set of tests was also run with an initial hydraulic gradient of i=0.5 to see if there was any noticeable difference. Figure 3 shows a typical amount of sediment deposited at the base of the GR test system after a test. For scale, the diameter of the sediment circle is 100 mm. It is thought that the sediment transport is due to a bridging effect, where some smaller sediment grains near the geotextile are preferentially oriented such that they are free to move into the geotextile when the hydraulic gradient is applied. The larger grains would then remain in place and form the basis for a filter cake that prevents further piping.

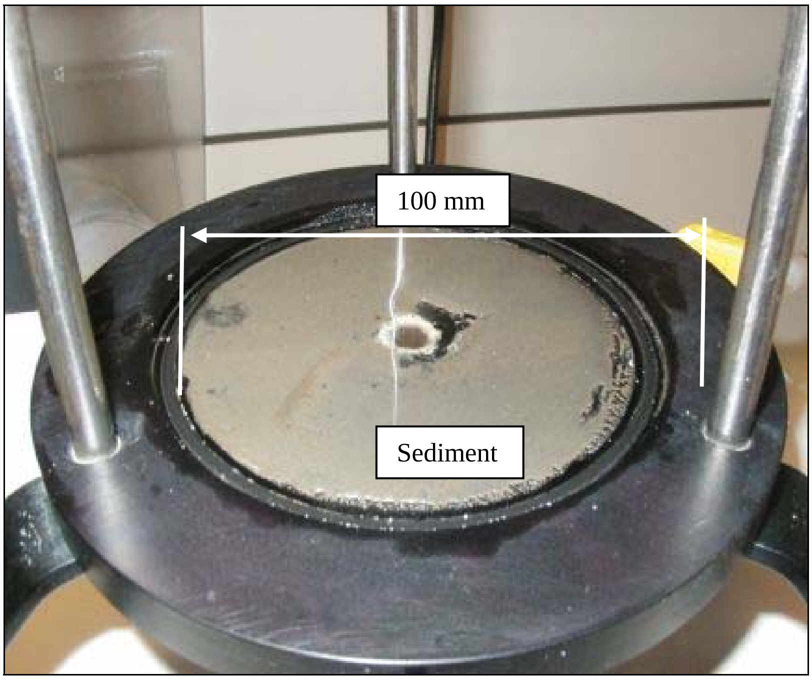

Figure 3. Sediment passing through the geotextile during a GR test

After each test, the sediment was collected, dried and weighed. However, there was not enough sediment to conduct a hydrometer test to evaluate the grain size passing the geotextile. Figure 4 shows mass collected after each test plotted as a function of AOS and mass per area, which is an indicator of thickness. The circles represent tests started at i=1. There does not seem to be any trend in behavior though the data is very scattered. The AOS did not seem to matter with regard to sediment transport, which may be due to the fact that bulk of the material is smaller than the AOS sizes. Geotextile 3 is showed the least overall transport, which may be due to the fact that it is the thickest fabric, and therefore the increased tortuosity of the path through the fabric may have decreased the amount of sediment actually moving all the way through. It should also be noted that the amount of sediment passing through the geotextiles was on the order of 10g, a piping rate of 1274 g/m^2. While less than 2500 g/m^2, the stability limit often used for geotextile filters (Lafleur *et al.* 1989; Bhatia *et al.* 1998), it may be a sufficient mass of material passing the geotextile that cap designers would need to account for it.

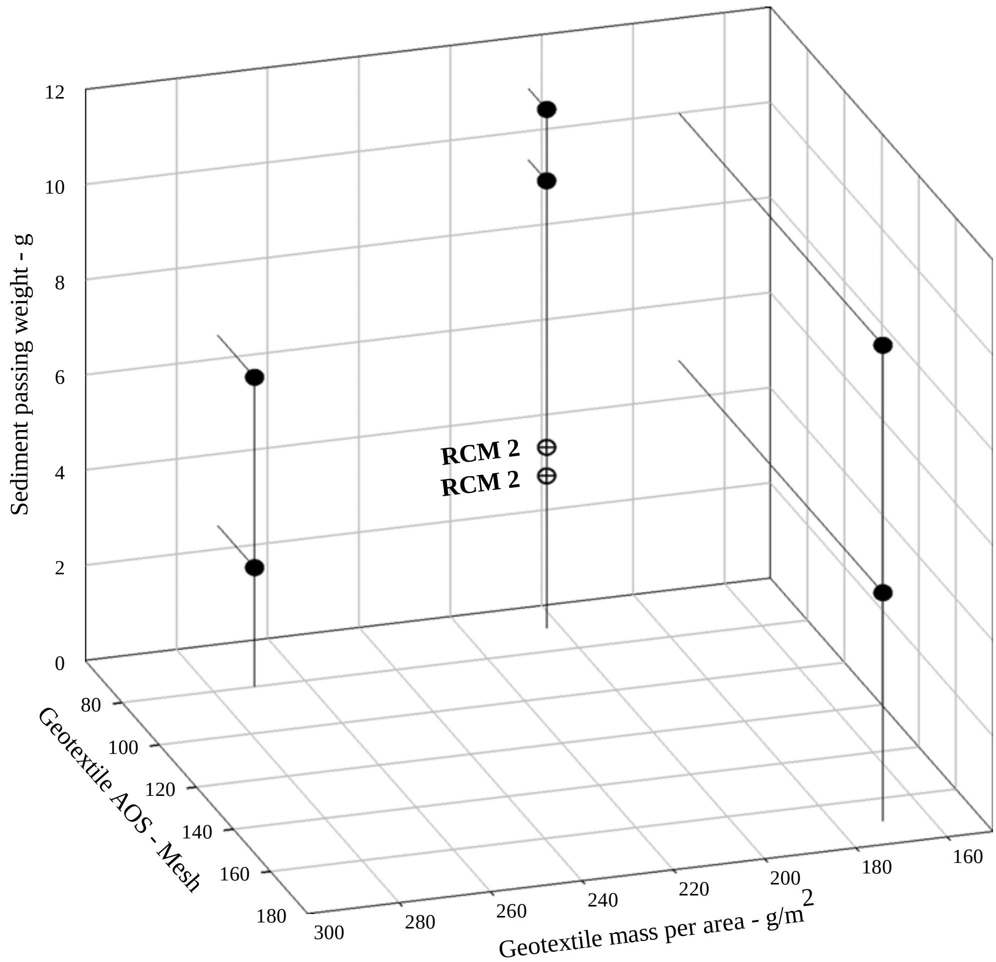

Figure 4. Mass of soil passing through the geotextile vs. AOS vs. mass per area of geotextile

Figures 5, 6 and 7 show the variation of the gradient ratio value over time for geotextiles G1, G2, and G3, respectively.

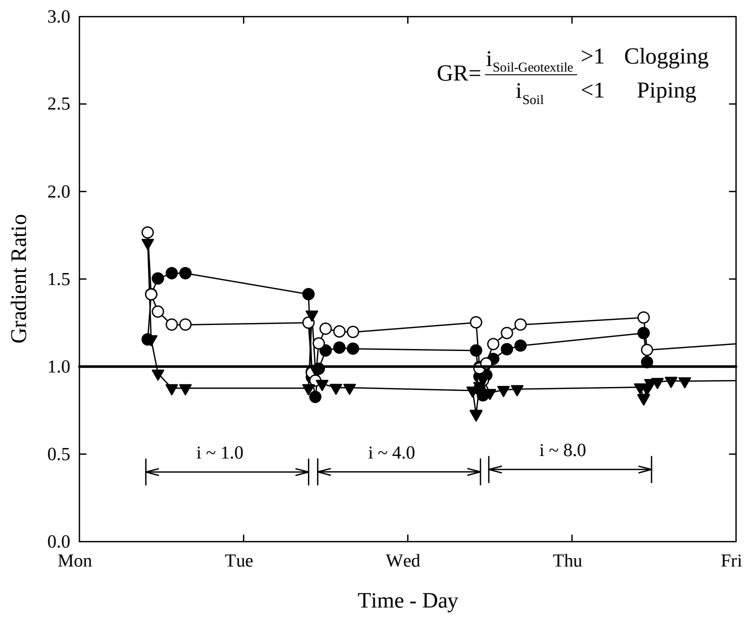

Figure 5. Gradient ratio versus time for geotextile 1 (AOS 170 mesh)

Geotextile 1 had two tests that indicated clogging potential, though the US Army Corps of Engineers criterion for clogging is GR > 3 (Haliburton and Wood 1982), so by that measure geotextile was not actually clogged. However, a GR value in excess of 1 at low hydraulic gradients is concerning because the whole reactive capping concept is based on continued permeability. In addition, field sites may have ground water flow conditions that exceed i=4, and then trend with time of two of the tests is towards more clogging at higher hydraulic gradients.

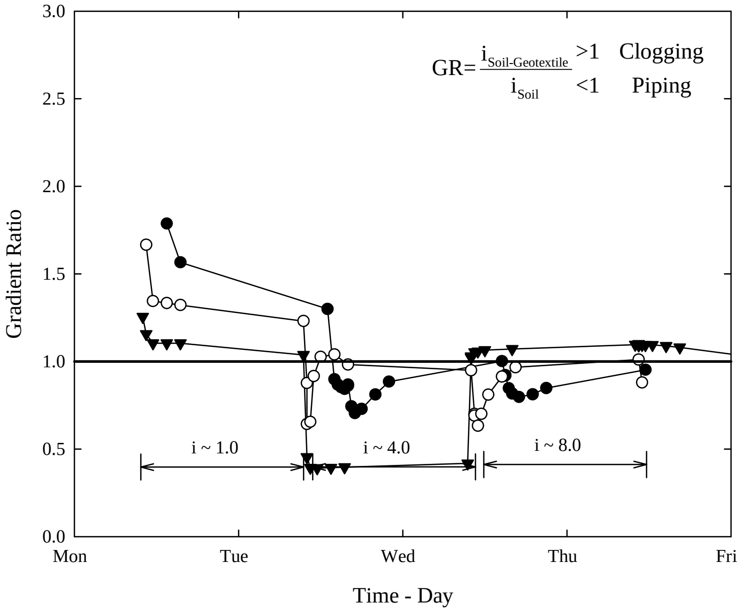

Figure 6. Gradient ratio versus time for geotextile G2 (AOS 70 mesh)

As in the test on fabric G1, there is variability between the results of the three tests conducted on sample G2, though in general the tests began with a GR value greater than unity, and then eventually stabilized around unity toward the end of the test. The key issue is that none of the test results indicate a trend toward increasing GR with time, which may indicate that the system was moving towards a clogged condition.

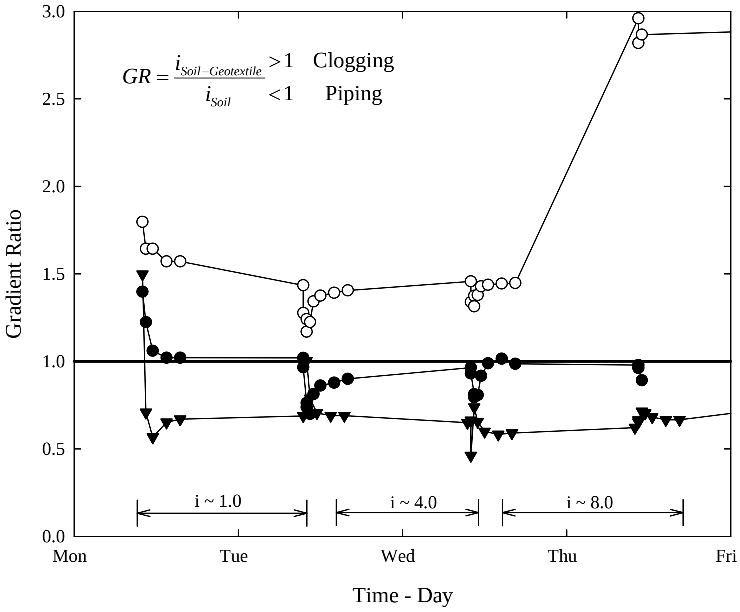

Figure 7. Gradient ratio versus time for geotextile G3 (AOS 80 mesh)

Of the three tests on geotextile G3, two of the data sets (solid symbols in Figure 7) indicate that the soil geotextile system was stable over a range of hydraulic gradients. The drop in GR at the onset of each hydraulic gradient is similar in magnitude and behavior to the results observed for the other geotextiles, and then the GR quickly stabilized. One data set (open symbols in Figure 7) starts at a GR value above 1.5, and remains above 1 for the length of the test, finishing close to GR=3. This suggests clogging, but the authors believe it is a case of piping in the sediment sample, which lowers the hydraulic gradient i_s and causes the GR value to rise. The authors noted early on this research that samples prepared according to the ASTM D 5101 standard often suffered from piping, usually originating near the manometer ports and growing progressively worse as the test progressed. This issue was resolved by placing the sediment as a thick slurry in several lifts, making sure that all bubbles were removed between lifts. The samples were then allowed to consolidate prior to testing. It appears that in this case piping occurred and eventually increased when the hydraulic gradient was increased to 8, though no sidewall piping was observed.

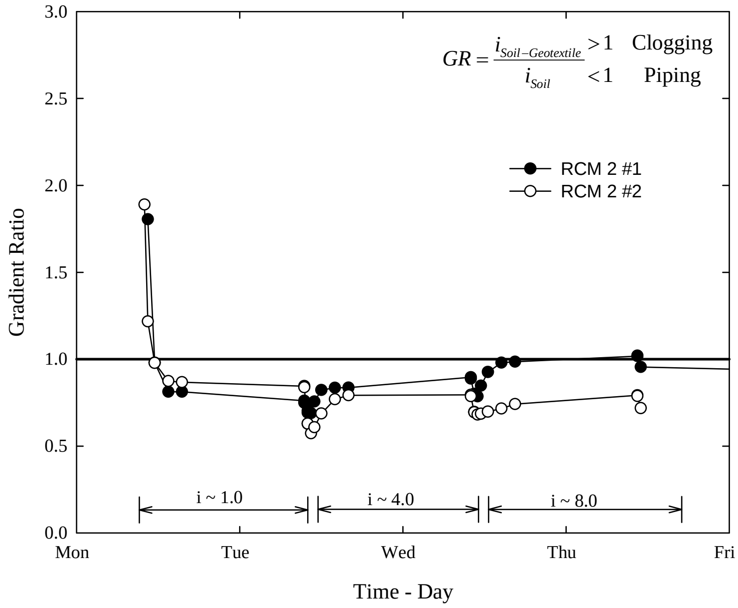

Figure 8. Gradient ratio versus time for clean reactive mats (AOS 70 mesh)

The GR test results for RCM 2 showed similar behavior to the results seen for the tests on geotextiles G2 and G3. There was initial sediment piping, as seen in the other tests (Figure 4), but the amount of sediment actually passing through the mat was about 3g, less than half the amount piped through the single layer. It is likely that some sediment was trapped in the core of the mat but the authors were unable to clearly identify sediment that had mixed with the reactive media. The amount of sediment piped seemed relatively large given that Kutay and Aydilek (2005) conducted GR tests on two layer geotextile systems and observed a piping rate two orders of magnitude less than observed in the research. It appears that the fibrous core and woven backing geotextile provide only marginal filtration properties, and that the nonwoven geotextile layer is primarily responsible for sediment separation. This is not very surprising given that nonwoven geotextiles are traditionally used for filtration. Since the GR behavior of the mat is similar to that of G2, it seems that the nonwoven layer dictates the behavior of the mat system as a whole, and that mat designers should carefully consider the nonwoven layer when balancing sediment piping versus clogging potential.

CONCLUSIONS

Three different geotextile fabrics and one composite geotextile mat were evaluated using the gradient ratio test for clogging potential and sediment piping. Of the samples tested, only geotextile G1 showed trends that indicated the potential for clogging. While the GR value remained less than 1.5, the sample did show a slight trend towards increasing GR with time, which indicates that the behavior was not fully stable and may have moved towards a more clogged state if given more time. The other samples were generally stable with respect to the GR and did not appear to show the potential for clogging.

Sediment piping was observed in all samples and was on the order of 10g per sample or 1274 g/m^2. While this value is less than the commonly used threshold value of 2500 g/m^2, the movement of a kilogram of sediment per meter of geotextile into the cap structure is something that cap designers may need to address, based on the level of sediment contamination.

Acknowledgements: The authors thank the US Navy for supporting this research through agreement N62473-06-R-6045. The authors also thank Jim Olsta at CETCO for providing the geotextile fabrics and mats used to perform the baseline analysis.

Corresponding author: Jeffrey S. Melton, University of New Hampshire, W135 Kingsbury Hall, Durham, NH, 03824, United States of America. Tel: 001 603 862 2107. Email: jeffrey.melton@unh.edu.

REFERENCES

Aydilek, A. Oguz, S., & Edil, T. 2005. Constriction Size of geotextile filters. Journal of Geotechnical and Geoenvironmental Engineering. 131 (1), 28-38.

ASTM D 422. Standard Test Method for Particle-Size Analysis of Soils. ASTM International, West Conshohocken, PA., USA.

ASTM D 5101. Standard Test Method for Measuring the Soil-Geotextile System Clogging Potential by the Gradient Ratio. ASTM International, West Conshohocken, PA., USA.

Bhatia, S. K., Moraille, J., & Smith, J. L. 1998. Performance of granular versus geotextile filters in protecting cohesionless soils. L. N. Reddi and M. V. S. Bonala (Eds.), Filtration and Drainage in Geotechnical and Geoenvironmental Engineering.ASCE, Geotechnical Special Publication 78, 1-29.

Haliburton, T. & Wood, P. 1982. Evaulation of the U.S. Army Corps of Engineers Gradient Ratio Test for Geotextile Performance. Proceedings of the second international conference on geotextiles. Vol. 1. Las Vegas, NV. 97-101.

Kossendey, Th. & Karam, G. 1996. A critical review of the current filter criteria on the basis of the long-term performance test. Proceedings of the First Eurpean Geosynthetics Conference. Geosynthetics: Applications, Design and Construction. Taylor & Francis Ltd.

Kutay, M. & Aydilek, A. 2005. Filtration performance of two-layer geotextile systems. Geotechnical Testing Journal. 28 (1). 1-13.

Lafleur, J., Mlynarek, J., & Rollins, A. L. 1989. Filtration of broadly graded cohesionless soils. Journal of Geotechnical Engineering, 122 (8) 682-690.

Ling, H., Leshchinsky, D., Gilbert, P., & Palermo, M. 1996. In-Situ Capping of Contaminated Sediments: Geotechnical Considerations. Environmental Geotechnics: Proceedings of the Second International Congress OS-Osaka '96. Vol. 1. 575-580.

Nourse, W. 2005. Development and evaluation of a sediment-based flowable fill and the creation of models for key physical properties. MS Thesis. University of New Hampshire, Durham, NH, USA, pp. 78.

Palermo, M. 1998. Design considerations for in-situ capping of contaminated sediments. Water Science and Technology, 37 (6) 315-321.

Ramsden, J. & Gardner, S. 2003. Hydraulic Analyses and Design of a Sediment Cap at a Superfund Site. ASCE Conf. Proc. 147 (56).