Geotextile clogging?

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ABSTRACT
The absence of using existing design methods to mitigate clogging is recognized as a serious problem with the current practice. This paper provides a review of design practice for mitigating the clogging potential of a geotextile filter. Conditions impacting geotextile clogging potential that should be considered in design include geotextile type, soils to be filtered, hydraulic conditions, and the specific application. Design for complex soil and hydraulic conditions that create a high clogging potential are reviewed along with construction procedures required to alleviate the risk of clogging. Recent advances in design and testing, which should be incorporated into current practice, are also discussed. The conclusions section includes a summary of the methods reviewed in the paper that should be used by designers to alleviate and mitigate the concern for geotextile clogging.

1. INTRODUCTION

Geotextiles have been proven through numerous successful applications to provide excellent filtration performance over the past half century. However, there have been a few problems, including clogging failures due to blockage of pores by fine grain soil particles or other particulates, causing a reduction in the seepage flow such that the performance of system is impaired (e.g., see Koerner and Koerner 2015). As a result, some engineers are hesitant to use geosynthetics, especially in critical applications, and they will continue to use granular filters even though conventional graded granular filters may have the same, or even greater potential to clog. Part of the reason for this concern is that conventional filters (e.g., chemical filters as well as automobile and home filters), which in some cases look similar to geotextile filters, are a porous material that removes particulates from a liquid or air and thus will eventually clog. However, geotextiles are not true filters — they are essentially screens that must be designed to allow particles that could clog their pores to pass.

The paper provides a review of the state of the design practice for mitigating the clogging potential of geotextile filters. Design for complex soil and hydraulic conditions that create a high clogging potential will be reviewed along with construction steps required to alleviate the risk of clogging. Recent advances are also discussed which should be incorporated into current practice.

2. CURRENT GEOTEXTILE DESIGN TO MITIGATE CLOGGING POTENTIAL

Designing with geotextiles for filtration is essentially the same as designing graded granular filters. A geotextile is similar to a soil in that it has voids (pores) and particles (filaments and fibers). Because water cannot pass through soil particles, we use the grain size distribution of the soils as a surrogate for the pore sizes. Three simple filtration concepts are used in the design process:

1. If the size of the largest pore in the geotextile filter is smaller than the larger particles of soil, soil particles that tend to move will be retained by the filter. As with graded granular filters, the larger particles of soil will form a *filter bridge* over the hole, which in turn, filters smaller particles of soil, which then retain the soil and prevent piping (Figure 1).
2. If the smaller openings in the geotextile are sufficiently large enough to allow smaller particles of soil to pass through the filter, then the geotextile will not *blind* or *clog* (see Figure 2).
3. A large number of openings should be present in the geotextile so that water flow can be maintained even if some of the openings later become plugged.

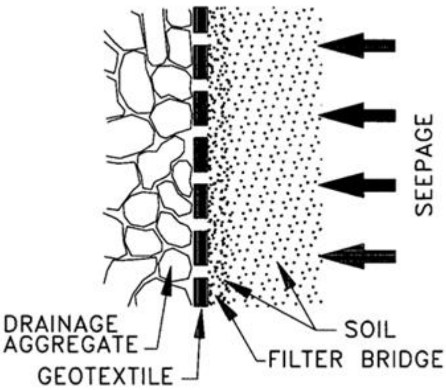

Figure 1. Filter bridge formation (Holtz et al., 2008)

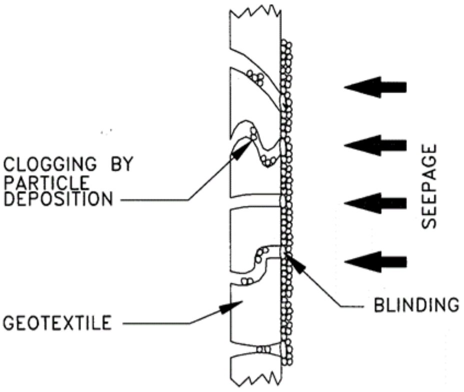

Figure 2. Definitions of clogging and blinding (Bell and Hicks, 1980).

These simple concepts and analogies with soil filter design criteria are used to establish design criteria for geotextiles. Specifically, these criteria are:

- the geotextile must retain the soil particles (*retention* criterion), while
- allowing water to pass (*permeability* criterion),
- throughout the life of the structure (*clogging resistance* criterion and *durability requirements*).

To perform effectively, the geotextile must also survive the installation process (*survivability/constructability* criterion).

Numerous empirical methods have been established for the first, soil retention, and are included in a number of guidelines of practice (e.g., see Fisher et al., 1990 for a list of common criteria). These criteria typically require the geotextile opening size (O) defined by the filtration opening size (FOS) or apparent opening size (AOS) to be smaller than a specific particle diameter (D) with in the grain size distribution of the soil. The permeability criterion requires that the permeability of the geotextile must be greater than or equal to the permeability of the soil that is to be retained (Fisher et al. 1990). This permeability criterion is also related to clogging of the pores in the geotextile, as the permeability of the geotextile is directly related to the intrinsic porosity of the geotextile, which may be reduced by internal clogging of the pores. The permeability criterion also includes an inherent conservatism due to the relatively thin geotextile versus the much thicker soil layer (e.g., Giroud 1982). Even so, an additional factor of safety is often applied (usually a factor of 10 and up to 100), especially where clogging is of concern. However, permeability does not address the mechanisms of clogging (i.e., blinding of the geotextile surface and/or internal clogging of the pores by particle deposition) as it does not relate to the size of the pores versus the size of the particles that could cause clogging. The smaller pores may dominate the intrinsic porosity and, thus define the permeability, but these are the same pores that would more easily blind or clog.

For *less critical/less severe* conditions (Table 1), a simple way to avoid clogging, especially with silty soils, is to allow fine particles already in suspension to pass through the geotextile. Then the ‘bridge network’ (see Figure 1) formed by the larger particles retains the smaller particles. The bridge network should develop rather quickly, and the quantity of fine particles actually passing through the geotextile is usually relatively small. This is why less critical/less severe clogging resistance criteria, as shown in Table 2, usually requires the characteristic opening size (O) for the geotextile filter to be sufficiently larger than the finer soil particles (e.g., D_{15}) such that those particles will pass through the geotextile. Unfortunately, the open size is usually characterized by the largest opening in the geosynthetic (e.g., the filtration opening size, $O_f = O_{90}$ to O_{98}, and the apparent opening size, AOS = O_{95}). Thus, the finer soil particles may still be retained by the smaller openings in the geotextile, and if the porosity of those openings dominate the pore space and there are sufficient fines, a significant reduction in flow rate can occur. Although in some geotextiles the largest openings may dominate the volume of the openings (e.g., monofilament wovens), in many geotextiles (e.g. slit film wovens, heat bonded non-wovens, and some needle punched non-wovens), it does not.

The geotextile characteristics to prevent clogging are controlled by relationships between the particle size to both the diametric and volumetric pore size distribution. Neither of these characteristics, which ultimately control clogging potential, are addressed by the retention, permeability or the Table 2 clogging criteria. A geotextile with only a few large openings but many very small openings can meet the “less than and greater than” opening size required for the retention and clogging criteria, respectively, and still achieve a permeability greater than that of the soil. However, these small pores could easily clog or blind, significantly reducing flow through the geotextile. Consequently, to control the number of holes in the geotextile it is desirable to focus on the relationships between clogging, porosity and pore size distribution. Several theoretical predictions for filtration properties based on these relationships have already been recognized (e.g., Wates, 1980; Rollin, et al., 1982, Gourc and Faure, 1990; Fisher et al., 1990, and Giroud 1996 and 2010). But as reported by Palmeira and Galvis (2017), the accuracies of these methods are still to be properly demonstrated in a wide range of field situations. Thanks to the standardization of the bubble point test method for determining the pore size distribution (ASTM D6767), researchers are now critically evaluating these relationships. Digital image analysis is also being used to determine pore size distribution and quantify the changes in geotextile hydraulic performance and pore structures (e.g., Aydilek et al., 2002).

Table 1. Guidelines for evaluating the critical nature or severity of drainage and erosion control applications. (Holtz et al. 2008 after Carroll 1983)

A. Critical Nature of the Project		
Item	Critical	Less Critical
1. Risk of loss of life and/or structural damage due to drain failure:	High	None
2. Repair costs versus installation costs of drain:	>>>	= or <
3. Evidence of drain clogging before potential catastrophic failure:	None	Yes
B. Severity of the Conditions		
Item	Severe	Less Severe
1. Soil to be drained:	Gap-graded, pipable, or dispersible	Well-graded or uniform
2. Hydraulic gradient:	High	Low
3. Flow conditions:	Dynamic, cyclic, or Pulsating	Steady state

Table 2. Existing clogging criteria in national standards.

A. Critical/ Severe Applications[1]

Perform soil/ fabric filtration tests.
(e.g. Pollici, 1961, Calhoun, 1972; Haliburton, et al. 1982 a and b; Giroud, 1982; Carroll, 1983; Christopher and Holtz, 1985 and 1989; Koerner, 1990)

B. Less Critical/ Non-severe Applications

1. Perform soil-geotextile filtration tests.
    a. Minimum Pore Sizes Alternatives for soils containing fines especially in a non-continuous matrix:
    b. $O_{95} \geq 3 \cdot D_{15}$ for $Cu \geq 3$
       (US FHWA, Christopher and Holtz, 1985 and modified 1989)
    c. $O_f \geq 4 \cdot D_{15}$
       (French Committee of Geotextiles, 1986)
2. For $Cu \leq 3$, geotextiles with maximum opening size from the retention criteria should be specified.
3. Apparent Open Area Qualifiers
   Woven fabrics: Percent Open Area $\geq$ 4% to 6%
   (Calhoun, 1972; Koerner, 1990)
   Nonwoven fabrics: Porosity $\geq$ 30% to to 40%
   (Christopher and Holtz, 1985; Koerner, 1990)

NOTE : 1. Filtration tests are performance tests and cannot be performed by the manufacturer as they depend on specific soil and design conditions. Tests to be performed by specifying agency or their representative.

Palmeira and Galvis (2017) recently used the BP method and hydraulic test to confirm the following expression reported by Giroud (1996) is a useful tool for the prediction of nonwoven geotextiles permeability under virgin and soil contaminated conditions. The Giroud equation for the geotextile filtration opening is:

$$O_F = (d_F)\left[\frac{1}{\sqrt{(1-n_{GT})}} - 1 + \frac{10\,n_{GT}}{(1-n_{GT})\left(\frac{t}{d_F}\right)}\right] \qquad [1]$$

where O_F is the geotextile filtration opening size, d_f is the fiber diameter, *n* is the geotextile porosity, t is the geotextile thickness.

An empirical clogging criterion was advanced by Fisher et al. (1990) and Fisher (1994) based on the BP method, which requires:

$O_{15}/D_{15} > 0.8$ to 1.2 [2]
$O_{50}/D_{50} > 0.2$ to 1.0 [3]

Recent research was perfomed by Abbaspour et al. (2018) using digital analysis to determine the pore size distribution to quantify changes in hydraulic performance and pore structure after long-term gradient ratio tests. They found that these O_{50} and O_{15} relations in Eq. 2 and 3 provided a better prediction of performance that the criterion based on the largest opening (e.g., O_{95}). Additional research using the flexible wall permeameter, discussed in the next section and the BP method is ongoing to validate the empirical clogging criteria advanced by Fisher et al. (1990).

Of course, in the absence of these methods, the fallback for design is still to perform filtration tests (e.g. Table 2).

2.1 Filtration Tests for Critical/Severe Conditions

For critical/severe conditions (Table 1), select geotextiles that meet the retention and permeability criteria. Then perform a filtration test using samples of on-site soils and hydraulic conditions. The following provides a summary of accepted test methods from the US Federal Highway Administration “Geosynthetic Design and Construction Guidelines” (Holtz et al., 2008).

The most widely recommended test method is the gradient ratio test, ASTM D 5101, Measuring the Soil-Geotextile System Clogging Potential by the Gradient Ratio. This test utilizes a rigid-wall soil permeameter with piezometer taps that allow for simultaneous measurement of the head losses in the soil and the head loss across the soil/geotextile interface (Figure 3). The ratio of the head loss across this interface (nominally 25 mm to the head loss across 50 mm of soil) is termed the *gradient ratio*. As fine soil particles adjacent to the geotextile become trapped inside or blind the surface, the gradient ratio will increase. A gradient ratio (GR) less than 3 is recommended by the U.S. Army Corps of Engineers (1977), based upon limited testing with severely gap-graded soils (Haliburton and Wood, 1982). Because the test is conducted in a rigid-wall permeameter, it is most appropriate for sandy soils with $k > 10^6$ m/sec. Although ASTM indicates that the test may be terminated after 24 hours, to obtain meaningful results, the test should be continued until the flow rate has clearly stabilized. This may occur within 24 hours, but could require several weeks, especially if significant fines are present in the soil (e.g., see Maré, 1994).

A gradient ratio of one (or less) is preferred. Less than one is an indication that fine soil particles have passed the filter and that a more open *filter bridge* has developed in the soil adjacent to the geotextile. However, a continued decrease in the gradient ratio below one indicates piping, and an alternate geotextile should be evaluated. On the other hand, a high gradient ratio indicates that a flow reduction has occurred in the geotextile, most likely due to geotextile clogging. If the gradient ratio approaches three (the recommended maximum by the U.S. Army Corps of Engineers, 1977), the flow rate through the system should be carefully evaluated with respect to the design and system performance requirements. A continued increase in the gradient ratio indicates clogging, and the geotextile is unacceptable.

Refinements of the gradient ratio test have been proposed. Fannin et al. (1996) recommended adding additional ports for refining the failure criteria. Later, Fannin and Srikongsri (2007) proposed modifications for performing dynamic cyclic flow tests. Many other researchers have evaluated the long-term filtration performance versus current design practice (e.g., Wayne and Koerner, 1993, Fisher, 1994, Maré, 1994, Aydilek and Edil 2002 and 2003, Palmeira et al., 2010, and Abbaspour et al., 2018).

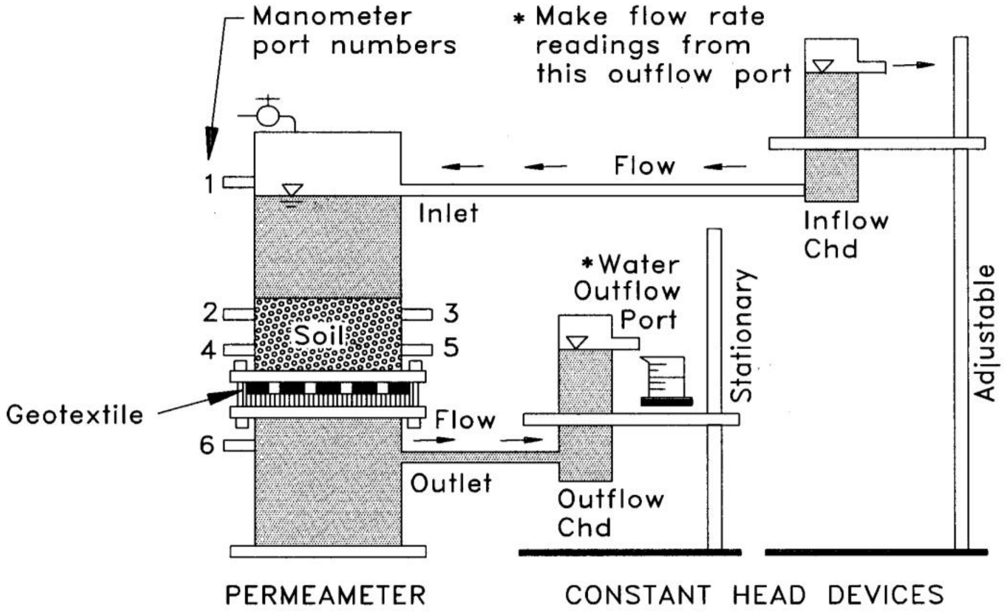

Figure 3. U.S. Army Corps of Engineers gradient ratio test device.

For soils with permeabilities less than about 10^{-6} m/sec, long term filtration tests should be conducted in a flexible wall or triaxial type apparatus to ensure that the specimen is 100% saturated and that flow is through the soil rather than along the sides of the specimen. The soil flexible wall test is ASTM D 5084, while the Hydraulic Conductivity Ratio (HCR) test (ASTM D 5567) currently is the standard test for geotextiles and soils with appreciable fines. In fact, ASTM D 5567 states that it is appropriate for soils with permeabilities hydraulic conductivities) less than 5 x 10^{-4} m/sec. Unfortunately, the HCR has been found to yield inconclusive and inaccurate results for many soils and geotextiles tested. The main problem is that the permeably may be decreasing due to blinding on the surface of the soil or clogging by deposition within the soil matrix, as opposed to the geotextile. Without piezometer ports over the length of the sample, as in the GR test, this phenomenon goes unnoticed.

A recent development is the Flexible Wall GR test (Harney and Holtz, 2001, Bailey et al., 2005, and Harney et al., 2007). This test combines the best features of the GR test (ASTM D 5101) and the flexible wall permeability test (ASTM D 5084). Just as with the GR test, multiple pore water pressure ports are placed along the soil column to accurately determine head losses in the soil and over the soil-geotextile section. Application of back pressure ensures that the specimens are 100% saturated. Research indicated that the FWGR yielded consistent and accurate results, and in significantly less time than the GR, for all geotextiles tested with fine-grained soils. Preliminary indications of the steady-state filtration behavior can be obtained in less than 24 hours and all the FWGR tests in the references above indicated that constant filtration behavior was achieved within five days. The GR test can still be used for filtration testing of coarse-grained soils, but if they contain even a few percent of fines, the FWGR is the preferred test. The FWGR test is currently being evaluated by ASTM for standardization. Fortunately, very fine-grained, low-permeability soils, especially if they have some plasticity, rarely present a filtration problem unless they are dispersive (Sherard and Decker, 1977) or subject to hydraulic fracturing, such as might occur in dams under high hydraulic gradients (Sherard, 1986).

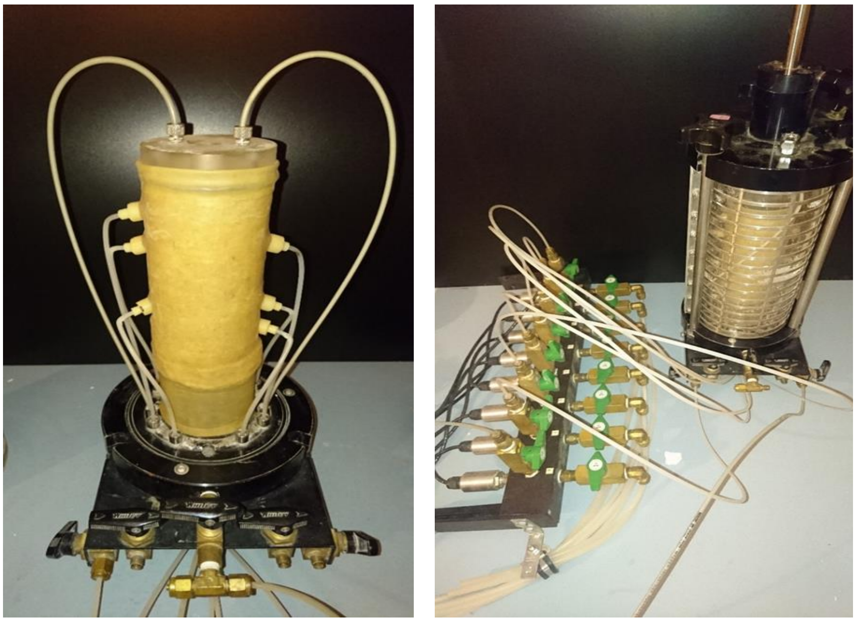

Figure 4. Flexible wall gradient ratio test device.

Again, it should be emphasized that these filtration, or clogging potential tests are *performance tests*. They must be conducted on samples of project site soil by the specifying agency or its representative. These tests are the responsibility of the engineer because manufacturers generally do not have soil laboratories or samples of on-site soils. Therefore, realistically, the manufacturers are unable to certify the clogging resistance of a geotextile.

2.2. Problems with Filtration Tests

The main problem with filtration tests such as the GR test is that these tests are almost never performed. This is because they may require weeks or even months to achieve reliable results, can be relatively expensive, and they only provide results for one specific soil and geotextile system. Because the average designer often lacks the capability of running these tests, she or he cannot prequalify or specify geotextiles by this method. Such testing also poses problems for contractors and manufacturers during bidding and preconstruction as they are not usually equipped to run such tests. As a result, designers often attempt to prequalify a limited number of geotextiles, specify "or equivalents" based on past experience, or ignore the phenomenon of clogging altogether. As a result, filtration tests are usually not performed on less critical applications, and even on critical applications they are rare, unless the project is very significant or after there has been a failure. It should be noted that this is also the case for graded granular filters; filtration tests are also almost never performed, and, as a result, failures do occur in those filters as well.

2.3 Alternate Clogging Test Methods

A relatively simply alternate clogging test is to only evaluate the ability of fines to pass through the geosynthetic basically by placing the finer particles of a soil in suspension and allowing the slurry to flow through the geotextile, measuring the amount of fines that will pass. These tests include the Caltrans slurry filtration test (Hoover, 1982), which was developed by Legge (1990) into the Fine Fraction Filtration (F^3) test (Sansone and Koerner, 1992). The significant disadvantage of these tests is that they only evaluate the most extreme clogging situations and are a "pass only" test (i.e., if the fines go through the geotextile while maintaining flow, the geotextile will not clog). However, because the extreme condition may not match well-constructed field conditions, a geotextile that fails the F^3 may still work if a more realistic gradient ratio test had been performed. In addition, a nonconservative performance factor is the absence of confinement, which reduces pore sizes of the geotextile and may in itself contribute to clogging. In any case, F^3 tests are very rapid to perform, and could be used as a screening test to see if a more rigorous GR or other performance test is required. They can also be used to make quick decisions in the case there is not time for a better performance test.

For this purpose, an even simpler, qualitative form of the F^3 test, the "Jar" test, was developed by Richardson and Christopher (2000) for use either by local municipal engineers, who were using geosynthetics without any evaluation of clogging resistance, or by site engineers, when they are required to make rapid decisions (e.g., due to changing soil conditions).

The jar test is an expedient method to empirically assess the clogging potential of a geotextile filter. It is essentially a fine fraction filtration test that permits a qualitative evaluation of the ability of fines to pass through the geotextile. This test is performed using an ordinary 0.5- to 1-liter jar with a removable inner center lid and an outer screw on ring to secure it (e.g. a Mason jar). A small amount of soil (about ¼ full) is placed in the jar, which is then filled with water and the lid placed on the jar and secured. The jar is then shaken to form a soil-water slurry. The jar is then allowed to stand for about one minute to allow coarser particles to settle. The jar opening is then covered with a sample of the candidate geotextile and secured with the outer ring of the lid. The particles in suspension are by this time fine sands, silts and/or clays, which would potentially clog the geotextile. The liquid from the jar is then poured through the geotextile, tilting the jar such that trapped air does not impede water flow. If the fines pass through the geotextile, it should not clog. If very little fine soil passes and a significant buildup of fines is observed on the surface of the geotextile (i.e., blinding), a clogging potential may exist. In that case, either another geotextile should be evaluated or a more sophisticated filtration test (e.g. Gradient Ratio Test, ASTM D 5101) should be performed.

3. ADDITIONAL FILTER SELECTION CONSIDERATIONS

This section reviews a number of conditions that will impact the clogging potential, which should be considered in the design. These include the type of geotextile, the soils to be filtered, and the severity of the specific application.

3.1 Type of Geotextile

Several different geotextiles, ranging from monofilament wovens to an array of light- to heavy-weight nonwovens, may meet all of the desired design criteria. Monofilament wovens typically provide uniform openings, while non-wovens provide a broad range of openings. In the case of needle punched nonwovens, there is a thickness filtration effect and a potential for lateral movement of water away from a locally clogged area in the geotextile. Depending on the actual soil and hydraulic conditions, as well as the intended function of the filter, it may be preferable to use a particular type of geotextile to enhance system performance. Intuitively, the following observations and selection considerations seem appropriate for these soil conditions (Holtz et al ., 2008):

1. *Graded gravels and coarse sands* -- Very open monofilament or multifilament woven geotextiles may be required to permit high rates of flow and low-risk of blinding.
2. *Sands and gravels with less than 20% fines* -- Open monofilament woven and thin needlepunched nonwoven geotextiles with large openings are preferable to reduce the risk of blinding. For thin, heat-bonded geotextiles and thick, needlepunched nonwoven geotextiles, filtration tests should be performed.
3. *Soils with 20% to 60% fines* -- Filtration tests should be performed on all types of geotextiles especially for critical applications or severe conditions.
4. *Soils with greater than 60% fines* -- Heavy-weight, needlepunched geotextiles and heat-bonded geotextiles tend to work best as fines will not pass. If blinding does occur, the permeability of the blinding cake would equal that of the soil.
5. *Gap-graded cohesionless soils* -- Consider using a uniform sand filter over the soil with a very open geotextile designed to allow fines to pass between the sand filter and drainage aggregate or rip-rap.
6. *Silts with sand seams* -- Consider using a uniform sand filter over the soil with a very open geotextile, designed to allow the silt to pass but to prevent movement of the filter sand; alternatively, consider using a heavy-weight (> 350 g/m^2) needlepunched nonwoven directly against soil so water can flow laterally through the geotextile should it become locally clogged.

Note: in No. 3 and 4 above, the fines are low to non-plastic, Another special consideration for geotextiles in erosion control applications relates to a preference towards felted and rough versus slick surface geotextiles, especially on steeper slopes where there is a potential for the riprap to slide on the geotextile. Such installations must be assessed either through field trials or large-scale laboratory tests.

The above general observations are to help in selecting optimum materials. They are not intended to exclude other possible geotextiles that you may want to consider.

3.2 Stable versus Unstable Soils

Special attention should be given to problematic, unstable, or highly erodible soils. Examples include non-cohesive silts, gap graded soils, alternating sands and silts, dispersive clays, and rock flour. Kenney and Lau (1985, 1986) and LaFluer, et al. (1989) provide methods to determine the internal stability of soil based on grain size distributions and mass fraction analysis. Research by Skempton and Brogan (1994) verified the Kenney and Lau (1985, 1986) procedure. The geotextile recommendations in Section 3.1 should be considered and project specific laboratory testing should be performed especially for critical projects and severe conditions.

Unstable conditions can also exist in materials such as recycled concrete, or dense graded roadway base with erodible fines. Precipitants from leaching of calcium-based ions (aka tufa) from recycled concrete can cause significant problems if the precipitant attaches to the geotextile filaments and accumulates. When using any of these materials, filtration tests should be performed to determine a geotextile filter can even work (e.g., see Abbaspour et al., 2018). If the geotextile filters clog, alternatives include:

- blending the recycled materials with more stable graded natural aggregates to decrease the potential for precipitants to move,
- provide a buffer zone of stable soils between the unstable materials and the drain, or
- do not place the geotextile filter between these unstable materials and the drainage aggregate. (The geotextile still should be used in other sections between natural soil and the drain to prevent infiltration.)

There are also certain applications that may expose the geotextile to chemical or biological activity that could drastically influence its filtration properties or durability. For example, in drains, granular filters and geotextiles can become chemically clogged by iron or carbonate precipitates (similar to tufa). Chemical conditions are often present in mine tailings (see Palmeira et al., 2010). Chemical problems should be addressed as indicated in the previous paragraph on recycled concrete.

Geotextile filters can also be biologically clogged by algae, mosses, etc. Biological clogging is a potential problem when filters and drains are periodically inundated then exposed to air. Biological clogging is a major factor in landfills. Biological clogging potential can be examined with ASTM D 1987, Standard Test Method for Biological Clogging of Geotextile or Soil/Geotextile Filters. Using this method, Koerner and Koerner (1991) found that if the microorganisms can pass through the geotextile, the clogging potential decreases. They also found that if microorganisms are retained in the geotextile, the microbes tend to grow and create bio films that will eventually clog the geotextile. Therefore, if biological clogging is a concern, a higher-porosity geotextile that will allow the microbes to pass should be used, and/or the drain design and operation can include an inspection and maintenance program to flush the drainage system.

3.3 Clogging Resistance for Cyclic or Dynamic Flow

Since erosion control systems are often used on highly erodible soils with reversing and cyclic flow conditions, severe hydraulic and soil conditions often exist. In such cases, the filter bridge may not develop or continually fails due to uplift of the geotextile during storm events. Accordingly, designs should reflect these conditions, and soil-geotextile filtration tests should be conducted.

3.4 Complex Applications that Impact Clogging Potential

The application may also induce a higher potential for clogging or the impact of any clogging may be greater due to blockage of some of the pore space in the geotextile by the structure itself. For example, where a slotted pipe is wrapped with a geotextile, the pore space available for flow into the pipe is only at the holes in the pipe. Therefore, any clogging at all will substantially reduce the flow. Other similar cases include where geotextiles are used to span joints such as between concrete face panels for reinforced soil walls and in erosion control applications where flat block type riprap is used, a portion of the geotextile may not be available for flow. For these applications, the permeability of the geotextile should be increased to account for the area closed off by the system (e.g., see Holtz et al., 2008) and the clogging potential should be critically evaluated using performance tests.

Edge drains in roadway pavements create a special case where the geotextile may be exposed to several different soils, including the subgrade soil, the road base and subbase which may contain fines, and fill material placed on the outer edge to form the shoulder of the road. The geotextile must be checked for compatibility with each of these soils. In addition, there may be dynamic flow conditions due to traffic loading, if the base coarse and/or subbase course becomes saturated. If prefabricated edge drains are used, the compression characteristics (i.e., much less stiff than the base course, may also induce hydrodynamic cyclic loading during trafficking by heavy vehicles.

In some of these applications, the use of geocomposite drains may be appropriate. In order to evaluate the clogging potential of the geotextile, the geocomposite should be tested on and as bonded to the geocomposite. The bonding process as well as the structural blockage from the core geonet or cuspate core will affect the filtration characteristics of the geotextile.

3.5 *Installation Procedures that Impact Clogging Potential*

Several key installation procedures may have a direct impact on the geotextile's performance.

- Surface on which the geotextile will be place placed should be excavated to design grade to provide a smooth, graded surface free of debris and cavities.
- Care should be taken during construction to avoid contamination of the geotextile. It should not be dragged over the soil surface and should not be placed in mud. If it becomes contaminated, it must be removed and replaced with new material.
- In drainage and erosion control systems, the geotextile should be placed with the machine direction following the direction of water flow; for pavements, the geotextile should be parallel to the roadway.
- The geotextile should always be placed in intimate contact with the ground surface. It should be placed loosely (not taut), but with no wrinkles, folds, or void spaces beneath the geotextile.
- The geotextile should be covered with a minimum of 0.2 m of aggregate prior to compaction. High survivability geotextiles should be required unless lift thickness can be increased. Compaction is necessary to seat the drainage system against the natural soil and to reduce settlement within the drain. The aggregate should be compacted with common vibratory equipment.
  - Proper compaction of the soil is extremely important to reduce the movement of particles in the soil. However, spreading and compaction of the soil may itself result in partial contamination after compaction, which should be considered in the design. Palmeira and Galvis (2017) used the bubble point method to assess reduction in the opening characteristics due to partial clogging and recommend opening size reduction factors that should be considered in the design of geotextile filters.
- For trench drains, the two protruding edges of the geotextile should be overlapped at the top of the compacted granular drainage material. A minimum overlap of 0.3 m is recommended to ensure complete coverage of the trench width. The overlap is important because it protects the drainage aggregate from surface contamination. After completing the overlap, backfill should be placed and compacted to the desired final grade.
- For erosion control revetment applications with large (>0.3 m diameter) stone riprap, a 0.15 m thick aggregate bedding layer selected to be compatible with the armor layer should be placed over the geotextile to prevent the geotextile from moving between the riprap and to maintain intimate contact between the geotextile and the subgrade. The bedding layer also reduces the potential for ultraviolet light exposure and provides protection during placement of the larger riprap.

4. CONCLUSIONS

Effective methods to mitigate clogging of geotextile filters include:

- Intuitive judgement based on an assessment of the soil to be filtered, the geosynthetic to be used, and the application of the geotextile filter to determine if the application is severe or critical and if clogging is a potential issue.
- Proper Installation to maintain intimate contact of the geosynthetic and the soil to be filtered throughout the design life of the project.
- Use empirical clogging criteria (along with the retention and permeability criteria) for selection of the geotextile in less critical/less severe applications. Also use for selection of geotextiles for filtration testing in critical and/or severe applications, and for sizing the openings to allow fine materials that will clog the geotextile to pass through it. Consider performing a F^3 test for a rapid, qualitative assessment.
- Perform filtration tests using the latest test methods.
- In the near future, pore size distribution based on the bubble point method will dominate designs and essentially replace the empirical criteria.

Following these methods, designers can certainly mitigate clogging potential. However, for those engineers who are still in doubt, considering running filtration test on granular filters side by side with the selected geotextile filters for a true performance comparison. Without a doubt, this will verity that geotextiles offer a more cost effective, superior alterative to graded granular filters.

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