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Evaluation of the U.S. Army Corps of Engineer Gradient Ratio Test for Geotextile Performance

Etude de l'essai du rapport de gradient du Corps des Ingénieurs de l'US Army pour l'évaluation des géotextiles

Gradient Ratio testing, following U. S. Army Corps of Engineer test procedures, was conducted on six geotextiles (four woven, two nonwoven) to evaluate their clogging potential. Gap-graded test soil mixtures of ASTM C-190 Ottawa Sand and Vicksburg silt loess were used to simulate worst-ca͏s͏e soil behavior. Gradient Ratio values were found to increase slowly with increasing soil silt content until a value of approximately 3 was obtained, and then increase rapidly with further small increases in soil silt content. The Corps of Engineer maximum acceptable test value of 3.0 was thus confirmed by the testing program. Geotextile EOS was not found to relate to geotextile clogging resistance, but woven geotextile percent open area was found to be directly related to geotextile clogging resistance.

L'essai du "rapport de gradient", selon la procédure du Corps des Ingénieurs de l'US Army, a été fait sur six géotextiles (quatre tissés, deux nontissés) pour évaluer leur tendance au colmatage. Des mélanges à granulométrie discontinue de sable d'Ottawa (ASTM C-190) et de silt de Vicksburg ont été utilisés pour simuler les pires conditions. On a trouvé que les valeurs du rapport de gradient augmentaient lentement, avec l'accroissement de la teneur en silt, jusqu' à une valeur de 3 et ensuite augmentaient rapidement. La valeur maximale de 3 acceptée par le Corps des Ingénieurs se trouve ainsi confirmée. La dimension des ouvertures du géotextile n'apparaît pas reliée à la résistance au colmatage, mais l'aire relative des ouvertures de tissés apparaît directement reliée à la résistance au colmatage.

BACKGROUND INFORMATION

Conventional soil used in filters, drains, and erosion control to protect existing cohesionless soil from water-caused internal piping or external erosion must satisfy two criteria to be effective (1):

a. The protective (filter, drain, etc.) soil void spaces must be small enough to prevent piping of existing (protected) soil into or through the filter, and

b. The protective soil must be more permeable than the protected soil, such that hydraulic head loss and seepage forces in the protective soil will be relatively small.

Any geotextile used as a substitute for one or more granular layers in a conventional protective soil system must satisfy these same criteria. Geotextile openings must be small enough to prevent piping or erosion of the protected soil, but the geotextile must maintain a higher permeability than the protected soil. If the geotextile clogs, it may no longer satisfy the higher permeability criterion.

In 1972, C. C. Calhoun, Jr., of the U. S. Army Corps of Engineers studied in-service geotextile piping and clogging potential by measuring head loss at various points through a laboratory-simulated soil-geotextile system (2). The apparatus used by Calhoun consisted of constant head permeameters, each with 8 piezometers, as shown in Figure 1. Piezometer No. 1 measured the tailwater or standpipe elevation, Piezometer Nos. 2-7 measured hydraulic head at locations inside the soil, and Piezometer No. 8 measured the constant head reservoir elevation. Soils used by Calhoun were selected to provide a worst case condition for internal soil piping and fines migration. Uniform Ottawa 20-30 Sand (ASTM C-190) was used as the coarse fraction, with a low plasticity Vicksburg, Mississippi, silt loess as the fine fraction. The Ottawa Sand, with D_{15} of 0.6 mm, could not be used as a protective filter for the Vicksburg loess, with D_{85} of 0.06 mm, because the D_{15}/D_{85} Ratio of 10 exceeds acceptable limits of 4 to 5 (1). Resulting sand-silt soil mixtures thus had maximum potential for internal fines migration and allowed evaluation of fabric performance under worst case conditions. The Corps testing was initiated to determine geotextile performance requirements for critical use applications under severe hydraulic loadings.

As a result of Calhoun's work, the Corps established a piping/erosion loss criterion based on fabric Equivalent Opening Size (EOS), the U. S. Bureau of Standards sieve size of the D_5 geotextile openings, and a clogging/head loss criterion based on geotextile percent open area.

Later (1977) research conducted by the Corps using Calhoun's apparatus established a direct measure of geotextile clogging potential, called the Gradient Ratio (GR), defined (for tests run with the Calhoun apparatus) as the hydraulic gradient through the lower 25 mm (1 in.) of soil plus geotextile divided by the hydraulic gradient through the adjacent 50 mm (2 in.) of soil [between 25 mm (1 in.) and 75 mm (3 in.) above the geotextile]. Gradient Ratio values exceeding 3 were found to signify excessive geotextile clogging, and a limiting value of 3.0 was established by Corps geotextile acceptance specifications (3), for testing with the soil, geotextile, and hydraulic conditions of interest.

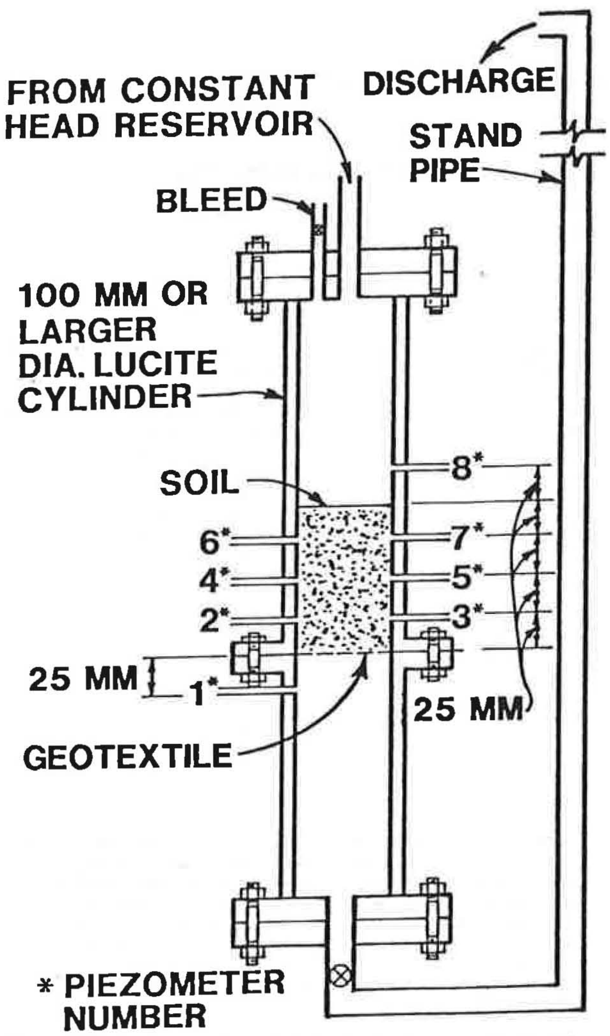

Figure 1. Cross-section detail of U. S. Army Corps of Engineer Gradient Ratio test permeameter.

TESTING PROGRAM

The testing program was designed to evaluate the comparative hydraulic performance of geotextiles, with primary emphasis on geotextile clogging potential. Six geotextiles, representing the basic types of standard geotextiles on the market, were used in the test program. Geotextile trade names, characteristics, and relevant properties are given in Table 1.

The EOS of each geotextile was determined using the glass bead sieving procedure given in Corps of Engineer Specification CW-02215 (3). Successively coarser beads were sieved until 5% or less by weight passed the cloth. The EOS is the "retained on" size of that bead diameter, expressed as a U. S. Bureau of Standards sieve number. Percent open area of the woven geotextiles was determined by projecting each geotextile image onto a screen, tracing the open area outlines, and taking the ratio of the area of the openings to the total geotextile area, expressed in percent. A precise percent open area value cannot be obtained for nonwoven geotextiles.

In order to compare geotextile clogging resistance using accepted Corps of Engineer criteria, four units of the Calhoun test apparatus (Figure 1) were constructed for the test program. Gap-graded ASTM C-190 Ottawa sand and Vicksburg silt loess test soil mixtures of 0%, 5%, 10%, 15%, 20%, 25%, 30%, 40%, 50%, 60%, 70%, and 80% silt by weight were prepared.

The D_{85} of tested soils corresponded to a U. S. Bureau of Standards sieve number between 20 and 30. All geotextiles satisfied both the original 1972 Calhoun and current Corps of Engineer piping criterion, which specifies that the EOS of a geotextile must be less than the D_{85} size of the soil it protects.

Four Calhoun-type test units (Figure 2) were used to evaluate clogging potential of the six geotextiles with increasing soil silt content, using recommended Corps of Engineer GR test procedures (3). Four replicates of each percent soil-geotextile type system were tested. Soil mixtures were tremmied in dry and placed to 100-mm (4-in.) thickness. Each unit was then slowly filled from the bottom with ordinary tap water, to minimize soil disturbance.

The outflow standpipe elevation remained constant for all geotextiles at each silt percentage and was changed with silt percentage. Hydraulic gradients used were those necessary to obtain enough flow for rapid (5 min) soil-geotextile system permeability determinations, ranging from near unity (1) at low silt percentages to over 10 at high silt percentages. Similar operating gradients were used by Calhoun (2) to maximize silt migration and geotextile silt loading. Piezometer

TABLE 1. PROPERTIES OF GEOTEXTILES USED IN TEST PROGRAM

Geotextiles Tested	Manufacturer	Description	EOS (US Bureau of Standards Sieve No.)	% Open Area (%)
Typar 3401	E.I. DuPont de Nemours & Co., Inc.	Gray, nonwoven heat-bonded polypropylene continuous filament	70-100	—
Bidim C-34	Monsanto Textiles Co.	Gray, nonwoven mechanically entangled (needle-punched) polyester continuous filament	70	—
Mirafi 500X	Celanese Corporation	Off-white, woven polypropylene slit film	70-100	1
Poly-Filter X	Carthage Mills	Black, woven polypropylene monofilament	70	5
Nicolon 70/20	Nicolon Corporation	Black, woven polypropylene monofilament	70	20
Poly-Filter GB	Carthage Mills	Black, woven polypropylene monofilament	40	30

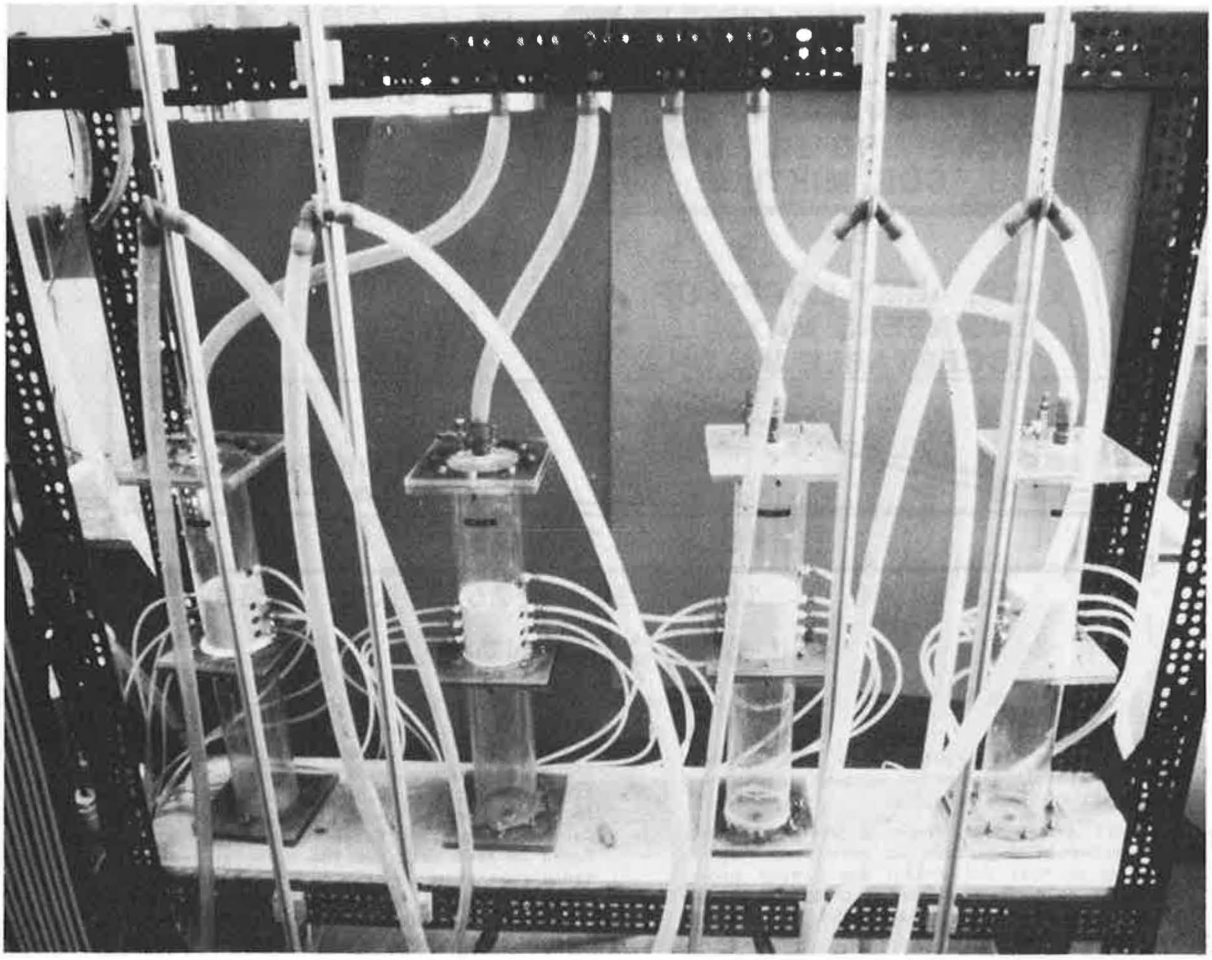

Figure 2. Four Calhoun-type permeameters used in Gradient Ratio test program.

readings were taken every 15 min until they stabilized (1 hr-2 hr) and flow rate measurements were recorded periodically. The GR was determined after 24 hr of testing (3).

After testing, soil samples were taken from each test unit, over intervals of 0 mm-6 mm (0 in.-0.25 in.), 6 mm-25 mm (0.25 in.-1 in.), 25 mm-50 mm (1 in.-2 in.), and 50 mm-75 mm (2 in.-3 in.) above the geotextile, and the final silt percentage distribution determined.

TEST RESULTS AND EVALUATION

The test system GR, defined previously, was used to quantitatively evaluate geotextile performance at each soil-silt content. Corps of Engineer Specification No. CW-02215 allows a maximum Gradient Ratio of 3.0.

Gradient Ratio values for each soil-geotextile combination were computed as the average of four individual tests and are plotted versus percent silt in Figure 3. The various geotextiles exceeded the maximum GR of 3.0 at the following silt percentages:

Geotextile	Maximum Allowable Soil Silt Percentage (GR $\leq$ 3.0)
Mirafi 500X	0% (Clean Sand)
Typar 3401	0.5%
Bidim C-34	18.5%
Poly-Filter X	25%
Nicolon 70/20	60%
Poly-Filter GB	Could not clog, maximum GR = 1.1 at 80% silt

Review of the various test data indicated that:

a. Except for the slit-film Mirafi 500X, which exceeded an allowable GR of 3.0 at 0% silt, and the 30% open area woven monofilament Poly-Filter GB, which did not exceed the maximum allowable GR of 3.0 at the highest silt percentage tested, the remaining four geotextiles showed a small increase in GR with increasing percent silt content until a GR of 3.0 was exceeded, followed by an extremely rapid increase in GR with fairly small further increases in silt percentage. These findings tend to confirm the limiting GR of 3.0 used by

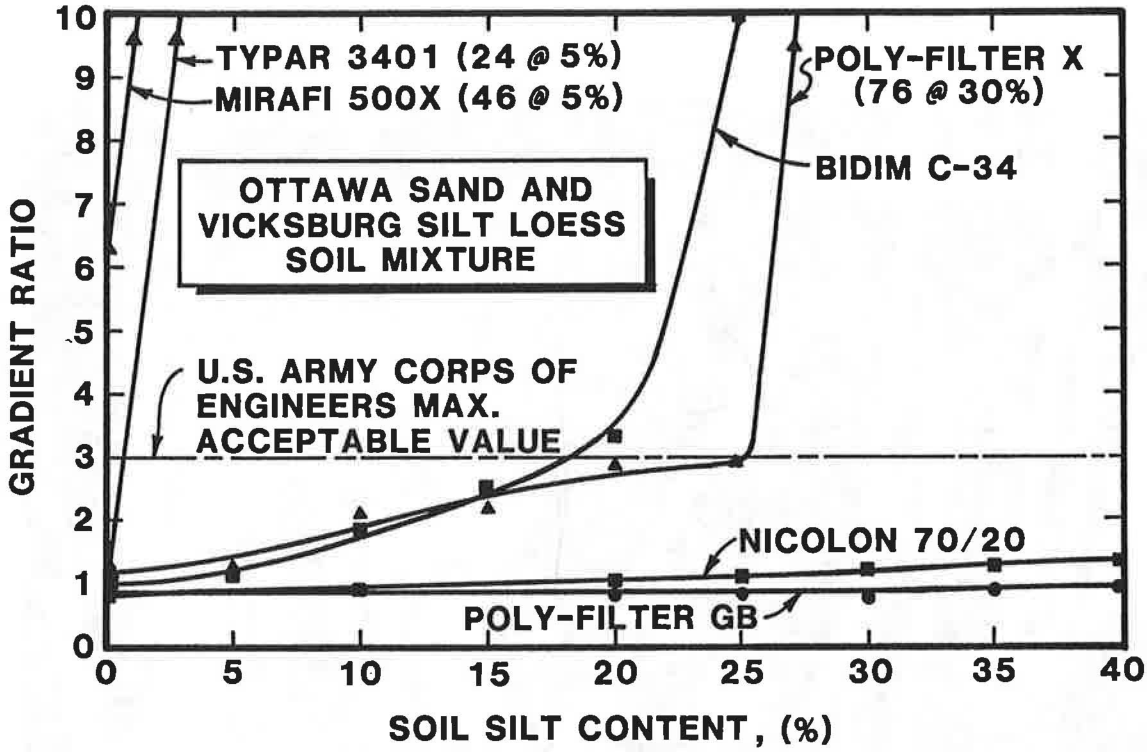

Figure 3. Gradient Ratio as a function of soil silt content for geotextiles tested.

the U. S. Army Corps of Engineers as the boundary between the minimal soil-geotextile system clogging and high soil-geotextile system clogging.

b. For all geotextiles, once a GR of 3.0 was exceeded, an order of magnitude or more reduction in system beginning of test and end of test Darcy permeability was noted to occur, indicating that the clogged geotextile had become the least permeable part of the soil-geotextile system.

c. Once a GR of 3.0 was exceeded, noticeable amounts of silt were found deposited on or in all geotextiles. However, despite the gap-graded nature of the Calhoun test soils, significant changes in soil silt content were found to occur only in the 6 mm (0.25 in.) above the geotextile, increasing slightly (2%-4% silt) for the Mirafi 500X and Typar 3401 geotextiles, and decreasing approximately the same amount for all other geotextiles tested, with the percentage of silt loss remaining essentially constant, even at higher test silt percentages. For all samples and all silt percentages where silt loss occurred, loss (noted through discoloration of test water) occurred only during the initial 10 min-15 min of the test, with the majority of loss occurring in the first 5 min. When the GR was less than or equal to 3.0, a slight (less than one order of magnitude) increase in soil-geotextile system permeability was noted to accompany the soil loss. It is believed these data tend to indirectly confirm the formation of a "mini-graded filter" in the soil immediately behind the geotextile, as originally suggested by Calhoun (2).

d. For the nonwoven needle-punched geotextile (Bidim C-34), flow occurred through the needle-punched EOS 70 holes even when the felt-like portion of the geotextile became clogged with silt.

e. The three monofilament woven geotextiles had the best clogging resistance among the six geotextiles tested, and clogging resistance increased with increase in woven fabric percent open area, substantiating Calhoun's original Corps of Engineer conclusions (2). Based on test data for the woven geotextiles, the silt percentage which caused a GR of 3.0 is plotted versus woven geotextile percent open area in Figure 4. This Figure may be used to estimate the minimum woven geotextile percent open area required for acceptable clogging resistance at the various silt percentages noted, and for the critical/severe conditions the GR test is designed to simulate.

f. For the geotextiles tested, geotextile EOS was found to have no relationship to geotextile clogging behavior.

CONCLUSIONS

Based on the test program conducted and discussed herein, it may be concluded that:

a. The 1977 U. S. Army Corps of Engineer Gradient Ratio test is an acceptable method to evaluate and quantify clogging potential of geotextiles. Geotextiles definitely should not be used in severe/critical design applications where the soil-geotextile system Gradient Ratio exceeds 3.0.

b. All tested geotextiles satisfied both the 1972 and 1977 U. S. Army Corps of Engineer EOS piping criteria, and minimal soil piping was noted for any soil-geotextile combination.

c. Geotextile EOS was found to have no relationship to geotextile clogging behavior. Woven geotextile percent open area was almost directly related to geotextile clogging potential.

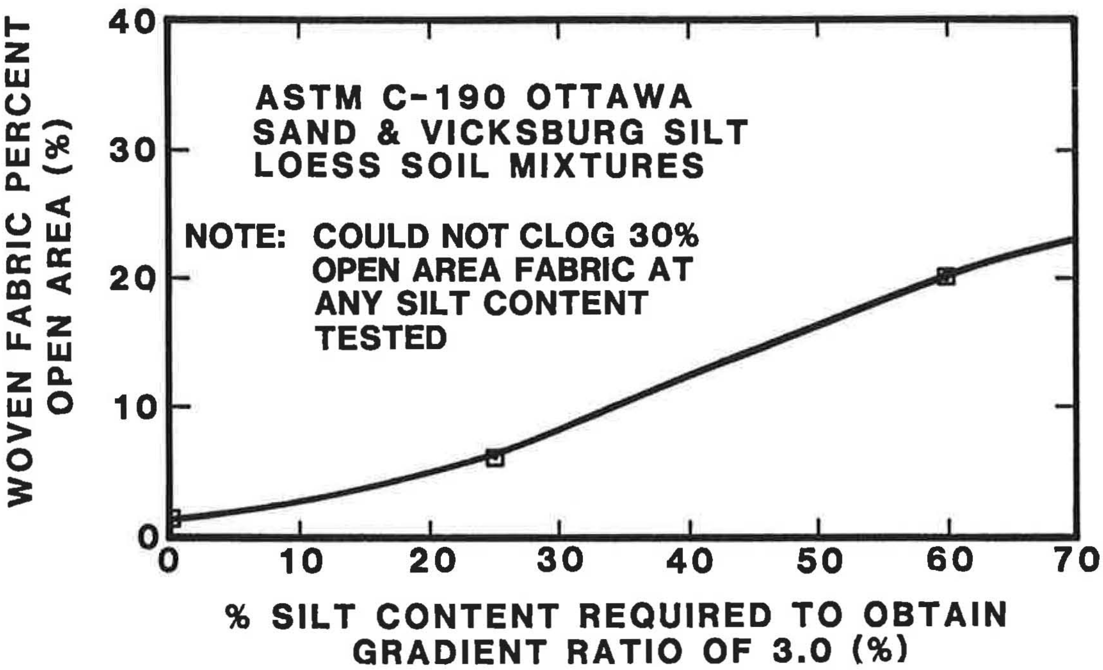

Figure 4. Woven geotextile percent open area vs. percent silt to develop Gradient Ratio of 3.0

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