# EVALUATION OF IMPACT OF DENSITY ON FILTERING PROPERTIES OF NARROW VERTICAL FILTERS

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## ABSTRACT

Filters are necessary in embankment dams to provide protection from internal erosion. Design and performance criteria for typical filters (chimney drains, blanket drains, toe drains, conduit collars, etc.) is well established and the authors are advocating following the standard of practice for these facilities. However, it can be difficult to appropriately compact filter materials in deep vertical filter trenches. Examples of deep vertical filter trenches include center filters installed in dry-earth dams with unsupported narrow excavations and in downstream filters installed in embankment dams and foundations with bio-polymer slurry supported excavation. Based on the authors' research, very limited information has been published related to the impact of filter material density on the performance of the filtering characteristics.

Extensive laboratory testing was performed by Sherard, Dunnigan, and Talbot (ASCE, 1984) to identify criteria for filter design for clay and silt soils in embankment dams. These analyses consisted of a test apparatus that contained a compacted specimen of the base soil of interest. This specimen was created with a defect simulating a crack or other opening. Beneath the soil specimen was sand carefully graded and compacted to serve as a filter material, which prevented the loss of the base soil with water running through the defect at a pressure of 40 pounds per square inch.

The Authors performed filter tests to evaluate the impact of filter density on filter performance using a specific clayey base soil utilizing methods that generally replicated the method by Sherard, Dunnigan, and Talbot (ASCE, 1984).

## INTRODUCTION

Narrow vertical filters for dams have become more prevalent in recent years including installation of central filters in dry earth dams in the southwestern United States and the use of bio-polymers supported trenches to install filters at the toes of dams. Both of these installation methods allow for limited compaction of the filter materials. The Authors are

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not proposing a change to the current standard of practice which recommends compacting filters (FEMA, 2011). However, for the above conditions and technologies, compaction and consolidation of a filter can be difficult.

The goal of the testing was to identify if the density of the filter material impacts the filter properties related to the retention of a particular base soil. This paper will present the results of filter testing performed for a specific clayey base soil using methods that generally replicated the method by Sherard, Dunnigan, and Talbot (ASCE, 1984).

## PREVIOUS RESEARCH AND CURRENT DESIGN PRACTICE

The basis for current filter design criteria is primarily rooted in work performed by Sherard, Dunnigan, and Talbot (ASCE, 1984 and 1984A). The guidelines proposed by Sherard, Dunnigan, and Talbot resulted in a factor of safety of at least 2 for clayey base soils with at least 85 percent fines (passing the No. 200 sieve). It should be noted that this testing showed a wide scatter for the boundary between success and failure for clay soils, but the criteria for filter design was set so the factor of safety was at least 2 for the most critical soils. This work used filters that were compacted in a saturated condition on a vibrating table with a 10 kg. surcharge weight. Filter densities were not measured, but likely exceeded 70% relative density. Subsequent testing to verify this work found that relative densities of about 60% produced similar results (personal communication, Talbot, 2014). The Federal Emergency Management Agency (FEMA) guidelines for Filters for Embankments Dams (FEMA, 2011) recommends compacting filters to at least 70 percent relative density according to ASTM D4253 and ASTM D4254 (ASTM, 2014).

The Authors only identified one reference where a similar type of filter test was performed to evaluate the impact of density of a filter on the ability to retain particles. Research by Park (Park, et. al, 2004) performed a modified type of filter test that included a crack along the side of the test apparatus. Water under pressure was applied to the base soil and filter material. Tests were performed with filter materials compacted between 18 percent and 70 percent relative density and all tests resulted in successful retention of the base soil. The filter design criteria used by Park et. al. was United States Bureau of Reclamation Standards (USBR, 1994), which are similar to FEMA criteria (FEMA, 2011).

## TEST METHODLOGY

### Base Soil and Filter Material Properties

The selected base soil was classified as a Category 1 soil according FEMA because it contained more than 85 percent fines. The particle size for the $D_{85}B$ ($D_{85}B$ = the particle size of the base soil where 85 percent by weight of soil particles are finer) for the selected base soil was 0.063mm. The liquid limit was 48 and the plasticity index was 36. Based on a crumb test (USBR, 1990), the soil was classified as non dispersive. Using the FEMA (FEMA, 2011) guidelines a filter design was performed and the maximum $D_{15}F$

was calculated to be 0.5 mm. The base soil and required filter gradation using FEMA guidelines are shown on Figure 1.

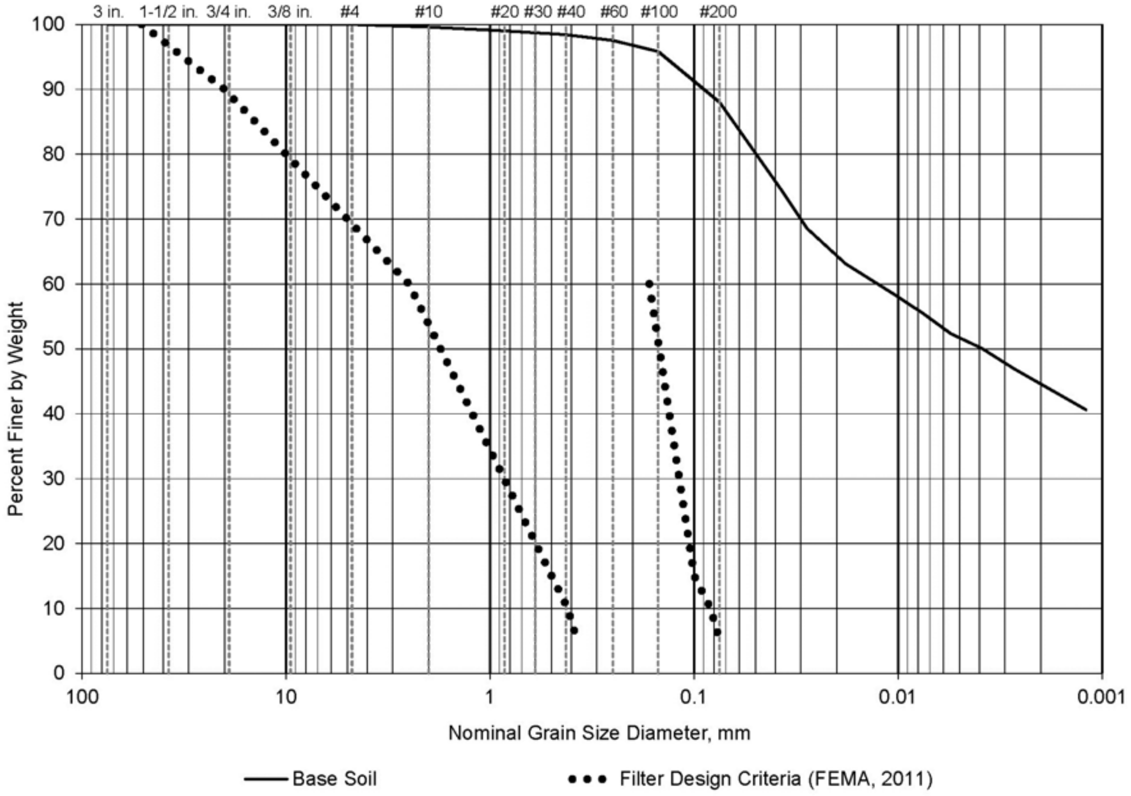

Figure 1. Base Soil and Filter Design Gradations

Filter materials were developed using subrounded to rounded quartz well screen sands. Well screen sands are very poorly graded and therefore mathematical estimates could be performed to developed ratios using various sands to prepare a filter material that would have the desired $D_{15}F$ ($D_{15}F$ = the particle size of the filter where 15 percent by weight of soil particles are finer).

After completion of successful filter tests, grain size tests were performed on the base soil to confirm the material was similar to the initially evaluated base soil. Grain size tests and relative densities were performed on the filter material to identify the actual $D_{15}F$ and relative density for each specific test.

## Test Apparatus and Sample Preparation

The tests performed used an apparatus similar to the apparatus used by Sherard, Dunnigan, and Talbot, as shown in Figure 2.

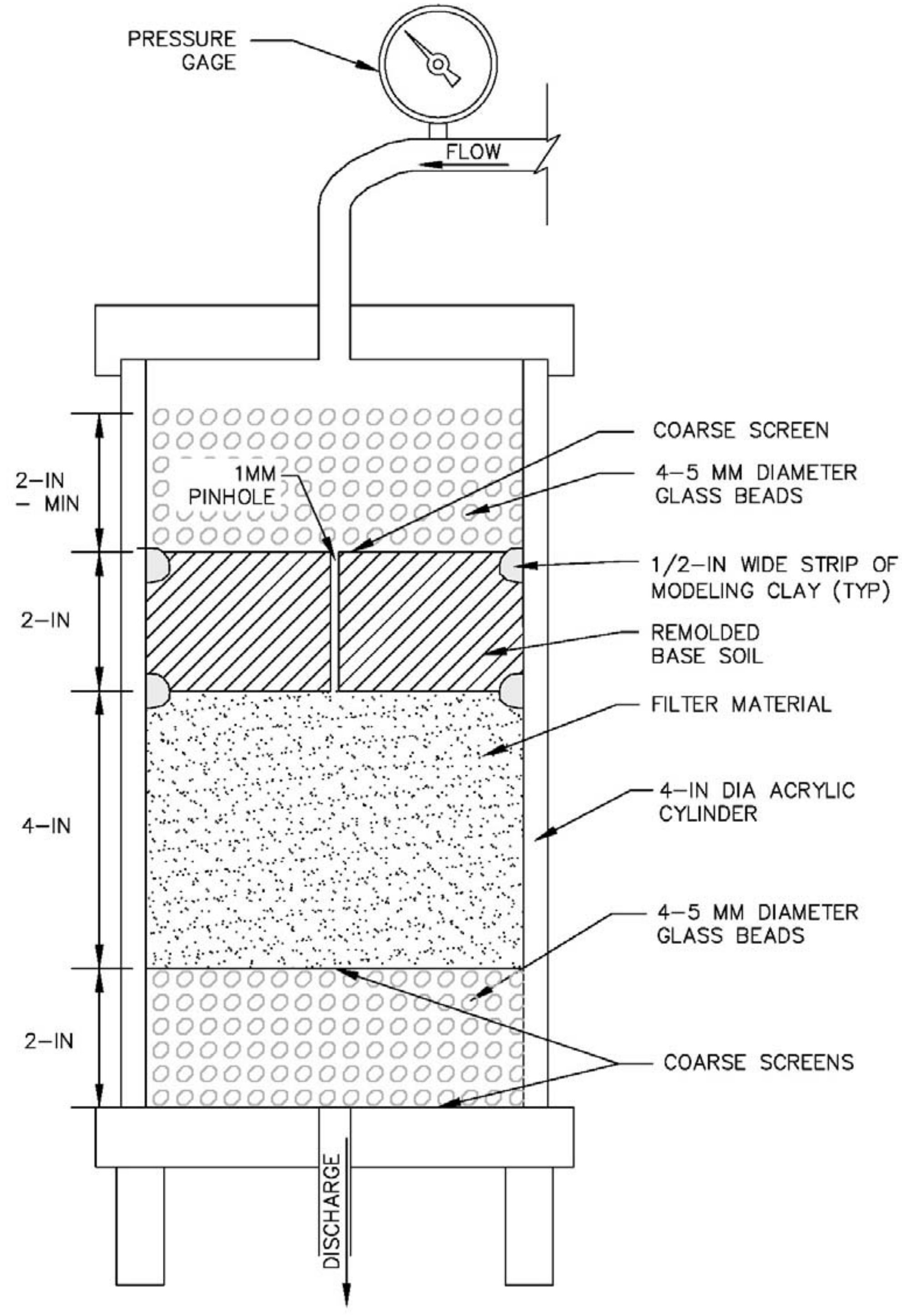

Figure 2. Test Apparatus

The sample was remolded within the test apparatus with the test apparatus placed vertically as follows:

1. Blocks were inserted into the apparatus that set on a solid surface.
2. The base soil was placed over the blocks in two, one-inch lifts and were lightly compacted with minimal effort. The contact between the first and second lift was scored prior to placement of the second lift.
3. Modeling clay was placed around the inside of the cylinder wall at the top and bottom of the base soil.
4. The apparatus was turned 180 degrees and blocks were inserted into the opposite side of the apparatus to maintain the position of the base soil in the apparatus. The blocks were set on a solid surface.
5. Filter material was placed into the cylinder. Two methods of placement were used to control density of the filter material:
    a. For dense samples – filter material was placed into the apparatus while rodding the filter material and striking the outside of the test apparatus with a rubber mallet.
    b. For low density samples – filter material was placed with methods similar to ASTM D4253 (ASTM, 2014) for placement at minimum relative density.
6. A 1-mm diameter pin hole was introduced into the base soil and extended into the filter material
7. Coarse screens were placed between the glass beads and the base soil and between the glass beads and the bottom of the apparatus so that the glass beads would not plug the pin hole or discharge outlet. A coarse screen was also included between the filter material and the glass beads to aid in disassembly of the test apparatus.
8. Glass beads were placed above the base soil and below the filter material. Care was taken to not modify the density of the filter material during assembly.

## General Test Results

Tests were performed with the cylinder orientated vertically. Water was supplied to the apparatus at 40 pounds per square inch (psi). A valve was opened to allow the pressurized water to enter the apparatus. Discharge water was collected in glass beakers to visually evaluate turbidity. A surge of discolored water that would progressively become more turbid and cloudy was observed within about the first minute of all tests.

For successful tests, after the initial surge of turbid water, either flow completely stopped or the flow greatly diminished and eventually would become clear with no observable fines. A successful test was usually identified within the first one to five minutes. Upon disassembly of the test apparatus there was very limited widening of the pin hole and no other cracks or pipes were identified in the base soil. It is the opinion of the authors that the flow either completely stopped or was greatly diminished because the filter performed properly and retained the fines, which created a filter cake that reduced or stopped flow.

For unsuccessful tests, the water flow would generally continue at about the same rate throughout the test. Varying degrees of discolored water would continue throughout the duration of these tests and between six and seven liters of water flowed through the apparatus for each unsuccessful test. At the end of several tests (after six to seven liters of flow), the water was mostly clear, but fines were observable in the bottom of the beakers about 10 to 15 minutes after completion of the tests. It appears that for this particular clay, when the pipe was of sufficient size to convey the seepage allowed by the filter, erosion was significantly reduced, but not halted. Upon disassembly of the test apparatus, generally the pin hole had eroded (widened) and other cracks or pipes had formed during testing.

Care needs to be taken with assembly of the test apparatus and particularly with the placement width of the modeling clay. Based on observations, the void space is larger at the contact between the filter material and the side of the test apparatus. Several failed tests occurred because the modeling clay was not adequately adhered to the side of the test apparatus or the width of the modeling clay was to narrow. This condition resulted in fines bypassing the filter material and flowing along the side of the test apparatus where the void space was larger and not through the center of the filter material.

## Variation of Density

After the test apparatus was assembled with the base soil and filter material, several tests were performed with a compacted sample of filter material to identify the $D_{15}F$ required to retain the base soil. The $D_{15}F$ was varied by about 0.1mm to 0.3mm until the successful $D_{15}F$ was identified. Initial filter material gradations were prepared based on maximum $D_{15}F$ for a successful test identified by Sherard, Dunnigan, and Talbot (ASCE, 1984). After a successful test was performed for compacted filter material, the test was repeated with low density filter material and the $D_{15}F$ was varied by about 0.1 mm until a successful test was performed with the low density filter material.

## RESULTS

The successful $D_{15}F$ for the compacted filter material with a relative density of 55 percent was 1.1 mm, which results in a factor of safety of about 2.2 when compared to the maximum $D_{15}F$ according to FEMA criteria. This is similar to factors of safeties identified by Sherard, Dunnigan, and Talbot (ASCE, 1984) for Category 1 base soils. The successful $D_{15}F$ for the low density filter material with a relative density of 17 percent was 0.7 mm, which results in a factor of safety of about 1.4 when compared to the maximum $D_{15}F$ according to FEMA criteria. The base soil gradation, required filter gradation using FEMA guidelines, the filter material gradations, and respective $D_{15}Fs$ are show on Figure 3.

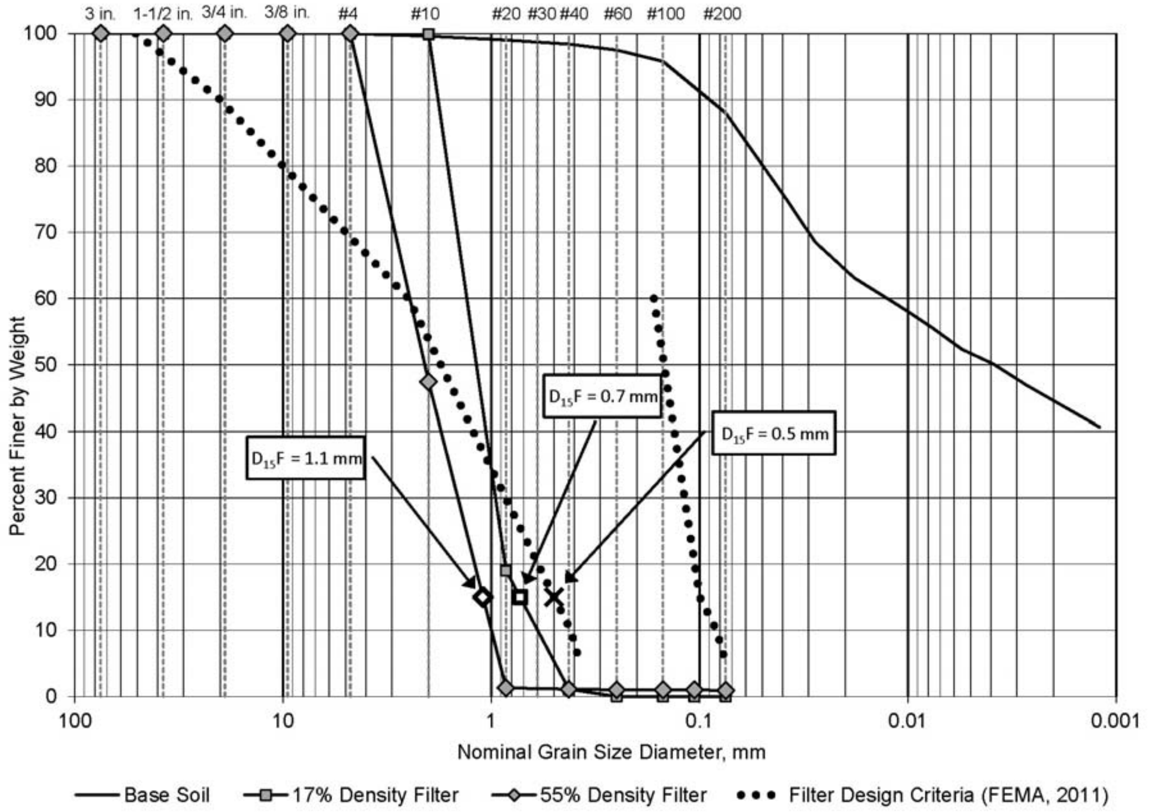

Figure 3. Filter Testing Gradations

## CONCLUSIONS

The Authors reiterate that the standard practice of compacting filters should be adhered to when possible. The purpose of this paper was to present a test method to evaluate the impact of density on the filter material properties (ability to retain the base soil) for a specific base soil and is not intended to be design guidance. Based on the results of the tests performed we offer the following conclusions that pertain to the tested materials:

- Density does impact filter material's ability to retain the base soil.
- Low density filter materials would meet the intent of the FEMA guidelines, but with a lower factor of safety.
- The factor of safety of the $D_{15}F$ at failure versus the design guideline $D_{15}F$ was reduced from 2.2 to 1.4.
- Erosion of the tested base soil continued throughout the unsuccessful tests, however erosion appeared to significantly reduce after a sufficient pipe size was developed to convey the flow accepted by the filter material. It should be noted that this particular clay soil has a high plasticity index (near the upper limit for a liquid limit of 48). This would result in a rather high resistance to erosion in the simulated crack (pin hole). Silt or clay soils with lower plasticity indexes would likely erode more in unsuccessful tests and test durations would likely be shorter.

## RECOMMENDATIONS

For situations where compaction cannot be performed, as in narrow vertical trenches and bio-polymers supported trenches we recommend performing a filter test on the site specific base soils and intended filters to confirm the design guidelines are met. As shown in Sherard, Dunnigan, and Talbot (ASCE, 1984), the factor of safety for filters varies widely for Category 1 soils and a filter test would provide site specific test data to confirm impact on density to specific base soils.

Proper setup of the test apparatus is critical to test accuracy, particularly the modeling clay separating the base soil and filter material.

The duration of the filter tests needs to be sufficient to confirm the lack of fines in the discharge water. Several unsuccessful tests had initial appearance of successful tests, but upon review, a small quantity of fines were visible in the discharge water.

Gradations, and relative densities should be performed on each successful test to obtain actual $D_{15}F$ and relative densities.

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