RECLAMATION

Managing Water in the West

Report DSO-11-04

Binding Agents in Embankment Dam Protective Filters

Dam Safety Technology Development Program

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

March 2011

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14. ABSTRACT

Granular filters are used in embankment dams to protect against soil that may erode through cracks in the embankment core. It is required that the filter material itself not be able to sustain a crack. Design recommendations exist to limit cohesive behavior of filters. However, based on the observation of cemented behavior of filter materials in the field, it became clear that requirements beyond the existing ones related to grain size and plasticity were needed. The goal of the present research is to evaluate a new index test method to quantify the cementation potential for candidate filter materials for use in embankment dams. This report describes a modified sand castle test method and apparatus, test results for 12 different materials, conclusions from the research, as well as recommendations for future study.

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Embankment dam protective filter, filter cementation, filter cracking, sand castle test, Vaughan test, sand equivalency value

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Dam Safety Technology Development Program

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Denver, Colorado

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Dam Safety Technology Development Program
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Report DSO-11-04

Binding Agents in Embankment Dam Protective Filters

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Date	Description	Prepared	Checked	Technical Approval	Peer Review

Acronyms

AOR	angle of repose
C_u	coefficient of uniformity
DFC	Denver Federal Center
FM	fineness modulus
pcf	pounds per cubic foot
Reclamation	Bureau of Reclamation
SEV	sand equivalency value
°C	degrees Celsius
°F	degrees Fahrenheit

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1.0 Introduction and Project Description

Granular filters are used in embankment dams to protect against soil that may erode through cracks in the embankment core. It is required that the filter material itself not be able to sustain a crack. Early consideration of this issue led to a requirement that filter material not contain more than five percent fines[1] and be non-plastic.[2] This requirement results in soils that are "cohesionless." While the requirement does limit the potential for cohesive behavior, it is now known that other agents can results in a filter sustaining a crack. These agents, which are not detected by the earlier tests, are usually soluble minerals or other precipitates. In the Western U.S. it had been noticed that filter material that had passed the earlier tests would exhibit brittle or "crispy" behavior several days after being placed and compacted. Closer examination of this in-place material indicated that some form of cementation occurred. In one extreme example, filter material was undercut during a forensic investigation and water flowed through the overhanging material with no sand grains detaching. This indicated the cemented filter had gained a good deal of strength (cohesion). As illustrated on figure 1, similar behavior was observed in an undercut stockpile of recycled (crushed) concrete on the Denver Federal Center campus. Based on this observed behavior, it became clear that test procedures beyond the original grain size and plasticity tests were needed to ensure that filter material will perform as desired and not exhibit cementitious behavior.

Figure 1.—Undercut recycled concrete material exhibiting cemented (cohesive) behavior.

[1] Fines are soil particles that are finer than (i.e., which pass) the No. 200 sieve (75-micrometer opening size) as determined by ASTM D 6913.

[2] A non-plastic soil is a soil with a plasticity index equal to zero as determined by ASTM D 4318.

The goal of the present research is to evaluate a new index test method to quantify the cementation potential for candidate filter materials for use in embankment dams. Originally, a test known as the sand castle test was developed to measure this potential. The test was developed by P.R. Vaughan at the University of London in the 1970s (Vaughan 1978, Vaughan and Soares 1982) and involved submerging a compacted specimen, allowing it to collapse, and subsequently comparing the resulting "submerged" angle of repose (AOR) to the AOR in air. When materials collapse with a submerged AOR larger than the AOR in air, they are classified as cohesive and generally considered unsuitable for use as filter materials. However, the test is only loosely described in the literature. Compaction parameters are unclear, and precise criteria for evaluating the results are not established. Several other researchers, including some funded by the Bureau of Reclamation (Reclamation), have attempted to modify the sand castle test to make it more rigorous and to quantify how the results might be used to judge filter material quality (e.g., Yamaguchi 2001, Park 2003, Bolton et al. 2005).

It is suspected that the original sand castle test and the subsequent modified tests are not sensitive enough to distinguish small amounts of cementation potential. The results might lead to an unsuitable material being identified as suitable for filter applications. Of particular concern is that fact that cementation has not been given the opportunity to develop. It is likely that in the field a filter could be compacted in a moist condition and then allowed to dry in ambient air temperatures in excess of 100 °F (38 °C), especially in the Western U.S. These conditions are suspected to be favorable for development of cementation, and it is therefore desirable to develop an index test that takes these conditions into account. The following describes a modified sand castle test method and apparatus, test results for 12 different materials, conclusions from the research, as well as recommendations for future study.

2.0 Materials and Sample Preparation

As shown in table 1, 12 materials were tested in this trial program. Several of the materials were commercially available ASTM C 33 concrete sands[3] (Index Nos. 36F-1138, 1139, 1140, 1141, 71Z-3, 4, 5, 6). Two other materials were pit run materials that required processing in order to meet the concrete sand gradation requirements (36F-1137, 71Z-2). One material consisted of recycled (crushed) concrete obtained from Denver Federal Center grounds (71Z-1), and another material consisted of a mixture of two different gradations of silica sand (36F-1136). These last two materials served as high and low cementation potential controls for the testing. All materials were processed (crushed, excess fines

[3] Since concrete sand is readily available and found to be acceptable in many filter applications, it was selected as the gradation for this study.

Table 1.—Summary of materials tested

Index No.	Description/Source	Meet C33 gradation as received?	USCS class of as-tested material	Average dry density (pcf)	Sand equivalency value	Coefficient of uniformity, $C_u = D_{60}/D_{10}$	Fineness modulus[1]
36F-1136	CO Silica Sand	NA[2]	SP	111.3	97	2.34	2.41
36F-1137	Basalt Hill	NO[3]	SP	117.2	95	6.1	2.68
36F-1138	Teichert Aggregate	YES	SP	119.7	77	7.26	2.98
36F-1139	Mark & Son (CEMEX)	YES	SP	115.0	78	6.28	3.01
36F-1140	Triangle Rock Products	NO[3]	SP	116.5	81	5.92	3.29
36F-1141	Granite Rock	YES	SW	123.7	71	6.8	2.86
71Z-1	DFC Recycled Concrete	NO[3]	SW	100.4	41	6.01	3.10
71Z-2	Ochoco Dam	NO[3]	SP	115.6	61	5.02	3.07
71Z-3	Redi-Mix/Lone Pine	YES	SP	109.3	82	4.45	2.50
71Z-4	Shevlin Sand & Gravel	NO[4]	SP	110.8	71	7.61	2.84
71Z-5	Grizzly Rock Products	YES	SP	106.6	87	3.75	2.37
71Z-6	Rock Products Mfg.	YES	SP	106.7	85	4.2	2.58

[1] Computed as the sum of the cumulative percent retained on sieve Nos. 4, 8, 16, 30, 50, and 100 divided by 100.
[2] Portions 10-20 and 20-40 silica sands combined to meet gradation requirement of C-33 sand.
[3] Excess coarse material removed to meet gradation requirements of C-33 sand.
[4] Excess fine material removed to meet gradation requirements of C-33 sand.

removed, etc.) as required (see table 1) to meet the gradation requirements set forth in ASTM C 33 for fine aggregate with the additional requirement of fines content of less than 2 percent before placement and 5 percent after placement (see Reclamation DS No. 13, Chapter 5, Protective Filters). None of the materials were washed to remove fines or other cementitious material. Gradations for each material, both as-received and as-tested, are provided in appendix A.

Each specimen was compacted to 100 percent relative density with a vibrating hammer according to ASTM D 7382 (see figure 2). This approach is preferred to impact (Proctor) compaction as it subjects the soil to less particle degradation and more closely mimics the way filter materials are compacted in the field (e.g., via vibratory rollers). The specimens were compacted in a saturated condition. A split mold was used, allowing for easier sample extraction. Once compacted, the specimens were immediately removed from the compaction mold and dried to constant mass in a 120 °F (49 °C) oven. Two to four specimens were prepared for each soil type depending on the amount of material available. Table 1 summarizes the characteristics of the 12 materials.

The sand equivalency value (SEV) was determined for each material according to ASTM D 2419 (as shown in table 1). The sand equivalency test is commonly used to assign an empirical value (SEV) to the relative amount, fineness, and character of claylike material present in the test specimen.

Figure 2.—Vibratory hammer compaction apparatus.

The individual test results are provided in appendix B. The SEV has been proposed by other researchers as a filter quality test (e.g., McCook 2005, Draft FEMA Filter Manual) and was investigated here to determine if it could be used as a predictive test. It is not anticipated that the SEV alone could be used to determine a filter material's suitability, but could be used along with other tests to those ends. It should be noted that, based on experience, manufacturer-provided SEVs are more favorable (i.e., higher) than those performed by independent laboratories.

3.0 Modified Sand Castle Test Apparatus and Procedure

An existing test apparatus was modified to accommodate the modified sand castle test. As shown on figure 3, an acrylic chamber with plumbing allowing the introduction of water from the bottom of the chamber was partially filled with gravel. This gravel served to evenly distribute the flow of water into the chamber and acted as a base for the specimens. Each specimen was placed on a perforated acrylic disc atop the gravel.

Figure 3.—Modified sand castle test apparatus.

Once the specimen was placed inside the chamber, water was introduced to a depth of 1 inch above the bottom of the specimen. The water level was maintained constant throughout testing. Specimens absorbed water via capillary action, and typical behavior involved the specimen crumbling from the bottom towards the top. The time required to reach several milestones was recorded, including the time required for (1) crumbling to progress to the water line (i.e., 1 inch up the specimen), (2) crumbling to progress to the mid-height of the specimen, (3) water to be absorbed to the top of the specimen, and (4) the specimen to completely collapse. In some cases, the specimen collapsed before it had crumbled to mid-height. Figure 4 presents photographs of some of these milestones.

4.0 Modified Sand Castle Test Results

The modified sand castle test was performed on all 12 materials (as summarized in table 2). The wide range of times observed indicates that the test is sensitive to cementation and holds promise as an index type test to indicate cementation potential for candidate filter materials. As anticipated, the two control materials, silica sand and recycled concrete, established the upper and lower bounds for 100 percent disintegration, respectively. At the time when the recycled concrete tests were stopped, very little to no crumbling had occurred – it is therefore inferred that it would have defined the upper bound.

Table 2.—Summary of results

Index No.	Description/Source	Average time to 100% disintegration (minutes)
36F-1136	CO Silica Sand	8.3
36F-1137	Basalt Hill	4.2
36F-1138	Teichert Aggregate	2,077.5
36F-1139	Mark & Son (CEMEX)	18.0
36F-1140	Triangle Rock Products	68.9
36F-1141	Granite Rock	85.5
71Z-1	DFC Recycled Concrete	>30,240[1]
71Z-2	Ochoco Dam, Zone 2 Pit Run	>60,480[2]
71Z-3	Redi-Mix/Lone Pine	53.1
71Z-4	Shevlin Sand & Gravel	>123,840[2]
71Z-5	Grizzly Rock Products	16.2
71Z-6	Rock Products Mfg.	82.5

[1] Test terminated before collapse – material had shown no signs of disintegration after 3 weeks.
[2] Test terminated before collapse – material had reached 50 percent disintegration, but had not collapsed after more than 1 month.

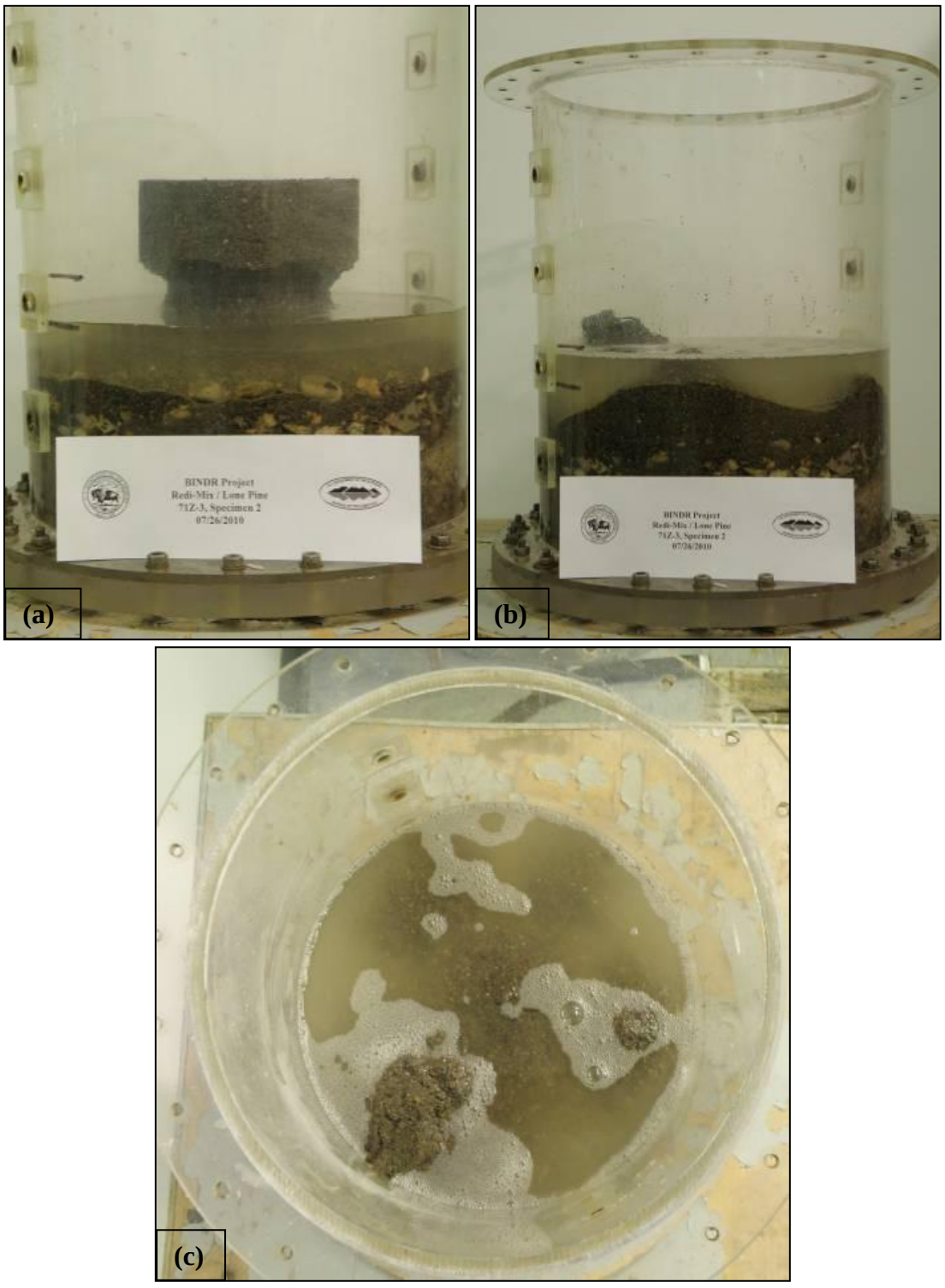

Figure 4.—Test photographs illustrating typical behavior: profile view of (a) 50 percent disintegration, (b) 100 percent disintegration, and top view of (c) 100 % disintegration.

Several interesting trends were found in the results. First, figure 5 shows that there is a decreasing trend for time to 100 percent disintegration, T_{100}, with respect to SEV. It is likely that even a small deviation in the clay (or other mineral) content of any given sand could have a significant impact on the cementation potential. As discussed by Hurcomb (2001), clay particles can form "bridges" between larger sand particles, effectively binding them together. Only a small amount of clay is needed for this behavior to be observed. It should be noted that no discernable trend was observed between the percentages passing the No. 100 or No. 200 sieve and T_{100}. This is likely due to varying degrees of the "fines" (i.e., minus No. 200 sieve size particles) being composed of clay-size sand grains (i.e., rock flour) rather than true clayey type particles. For this reason, the SEV is a better indicator of cementation potential than the percent passing the No. 100 or No. 200 sieves.

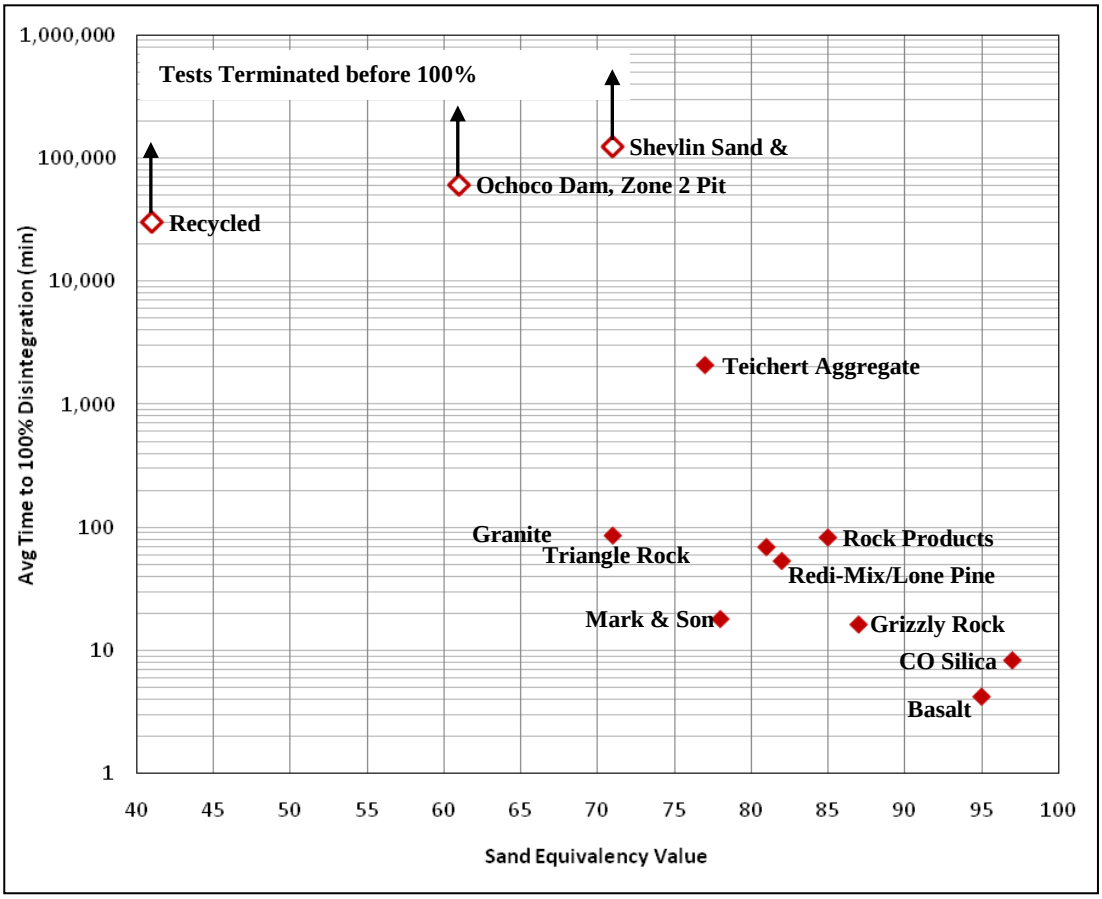

Figure 5.—Variation of average time to 100 percent disintegration with SEV. (Note that the y-axis [time] is log scale.)

Further, the results indicate that there is some degree of correlation between T_{100} and the gradation of the filter material. Figures 6a and 6b show the variation of T_{100} with the coefficient of uniformity (C_u) and the fineness modulus (FM), respectively. A weak increasing trend can be observed for both characteristics of the gradation. The results indicate that, in general, a more well-graded material has a higher potential to cement. This is likely due to the increased amount of grain-to-grain contact area and is in accordance with classic concrete design theory – the lowest cement content for a given strength comes from well-graded aggregates.

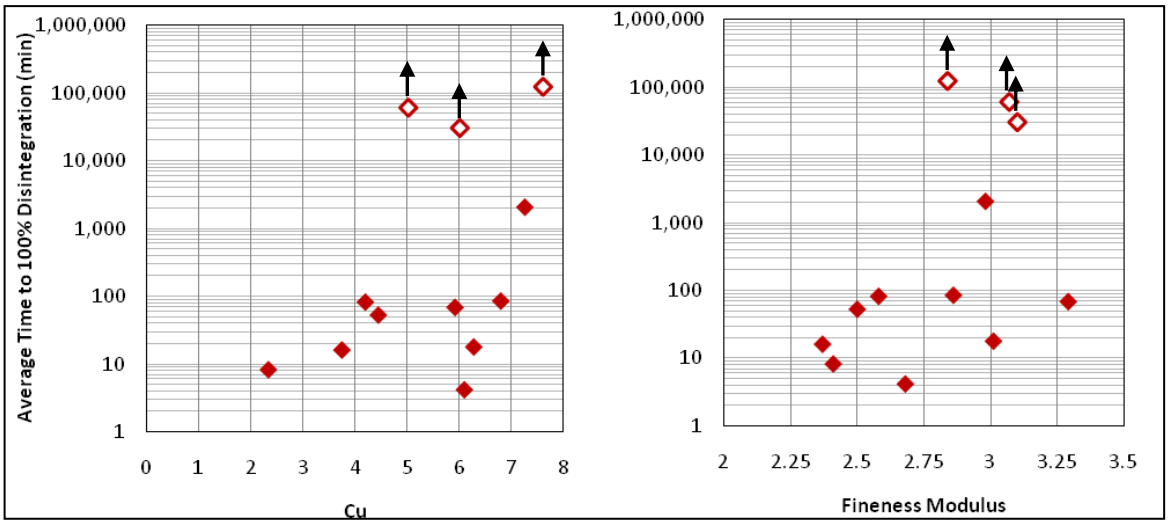

Figure 6.—Variation of average time to 100 percent disintegration with (a) C_u and (b) FM. (Note that the y-axis [time] is log scale.)

5.0 Conclusions

The research has resulted in the following conclusions:

- The modified sand castle test shows promise as an indicator of cementation potential. With modification (discussed below) and further research, an index value indicating cementation potential for candidate filter materials could be developed.

- Increasing SEV tends to indicate decreased collapse time (i.e., decreased cementation potential). A small amount of clay or other minerals may contribute significantly to cementation (Hurcomb 2001). Given that the fines content of sand can be composed of both clay-type and clay-sized particles (i.e., rock flour), the sand equivalency test may be a better indicator of cementation potential than the gradations alone.

- It should be recognized that the geologic origin of the material and its location relative to the recent water table may be as important as gradation, if not more so. The gradation-based tests (e.g., percent fines, SEV, C_u, FM) are not influenced by geologic origin or nearness to the water table. The modified sand castle test, on the other hand, inherently includes effects due to the geologic origin and location of the material.

- Samples with SEV > 95 took less than 10 minutes to collapse, and samples with SEV > 80 took less than 100 minutes to collapse. The typical minimum required SEV for concrete sand is 70-80, and the FEMA Filter Manual (draft) recommends that, for filters, SEV be greater than 80. Based on the present findings, the SEV > 80 criterion seems appropriate. However, the modified sand castle test is relatively inexpensive and should be run in conjunction with the sand equivalency test.

- Increasing C_u and FM tend to lead to increased collapse time. More well-graded sands tend to show increased ability to cement.

- Recycled (crushed) concrete should never be used as a filter material.

- It is not anticipated that either the modified sand castle test or the SEV test would ever be used alone to differentiate between suitable and non-suitable filter materials. Based on the results of the research described here, these tests do show merit as additional tools to help evaluate potential filter materials.

6.0 Future Research

In moving towards a standardized index for cementation potential, future research should include the following:

- Several improvements to the current test method should be investigated. First, the test should be made more rapid. This could be accomplished by increasing the depth of water from 1 inch to 2 inches. Further, a surcharge load (e.g., 5-pound disc) could be placed on top of the specimen to mimic the stress state of an in-place filter.

- The effect of cure time (both in the oven and before being placed in the oven) should be investigated. If the binding agents are primarily mineral salts, the cure time likely does not matter; however, if the binding is due to pozzolanic action, the cure time may be an important parameter.

- The effect of geologic origin should be examined (e.g., alluvium from below a recent water table should be compared with alluvium from above any recent water table and crushed bedrock). These results could have a significant effect on the ability of a correlation based on gradation to predict filter performance.

- Once a final test method has been established, the repeatability of the method should be verified for a range of soils.

- After the repeatability has been verified, a range of soils should be investigated to determine an appropriate index system (i.e., range and increment).

- It may also be of interest to investigate the variation of cementation within the range of relative densities that Reclamation specifies for typical filter installations. The testing here was performed at 100 percent relative density per ASTM D 7382.

- The unconfined compressive strength should be determined on specimens after curing.

7.0 References

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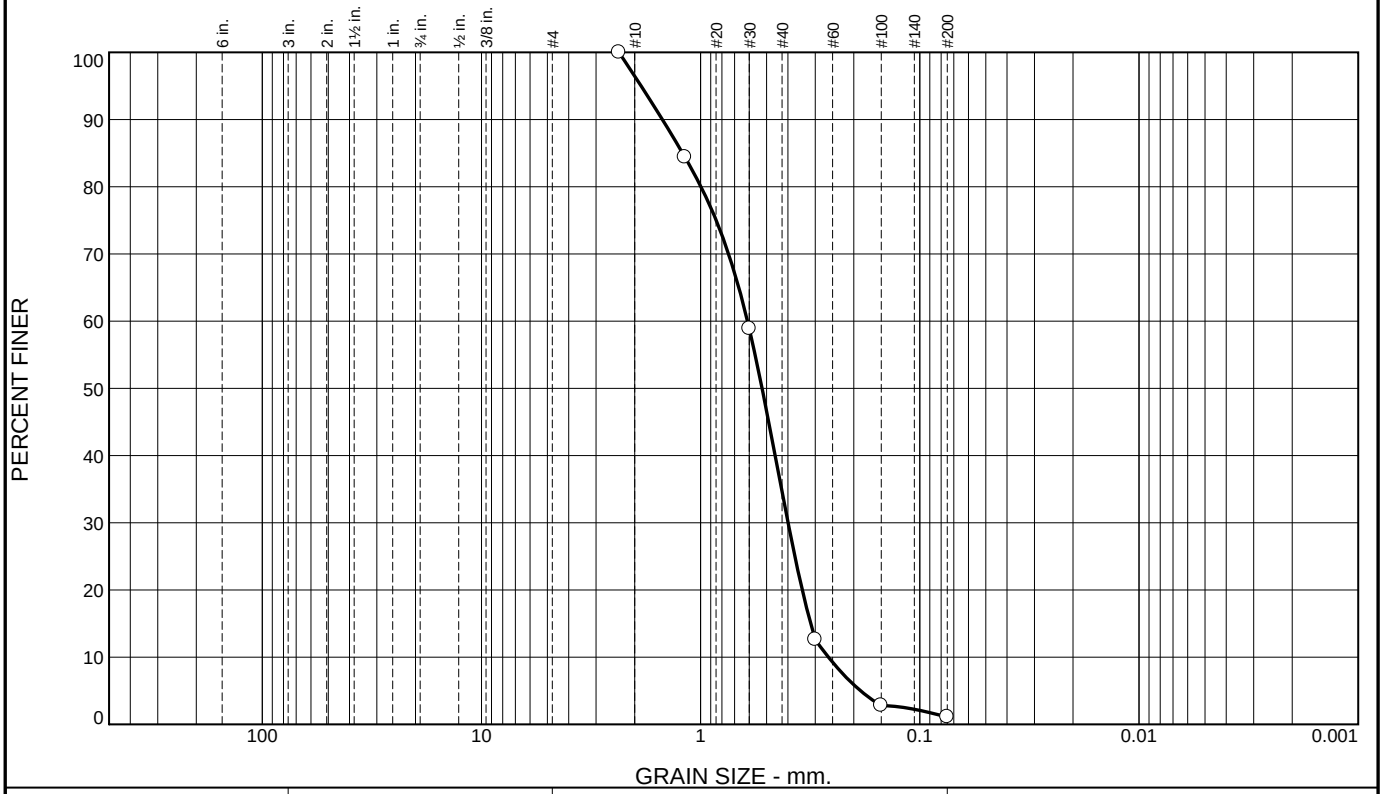
Appendix A

Gradation Analysis Reports

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	3.6	61.8	33.5	1.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#8	100.0	80.0 - 100.0	
#16	84.4	50.0 - 85.0	
#30	58.9	25.0 - 60.0	
#50	12.6	5.0 - 30.0	
#100	2.8	0.0 - 10.0	
#200	1.1		

* ASTM C 33 - Sand

Material Description

10-20 and 20-40 silica sands mixed in-house to meet requirements of C-33 sand

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 1.4948 D_{85}= 1.2092 D_{60}= 0.6111
D_{50}= 0.5244 D_{30}= 0.3992 D_{15}= 0.3151
D_{10}= 0.2613 C_u= 2.34 C_c= 1.00

Classification

USCS= SP AASHTO= A-1-b

Remarks

fines assumed to be non-plastic

Location: Colorado Silica Sand
Sample Number: 36F-1136

Date: 7/22/2010

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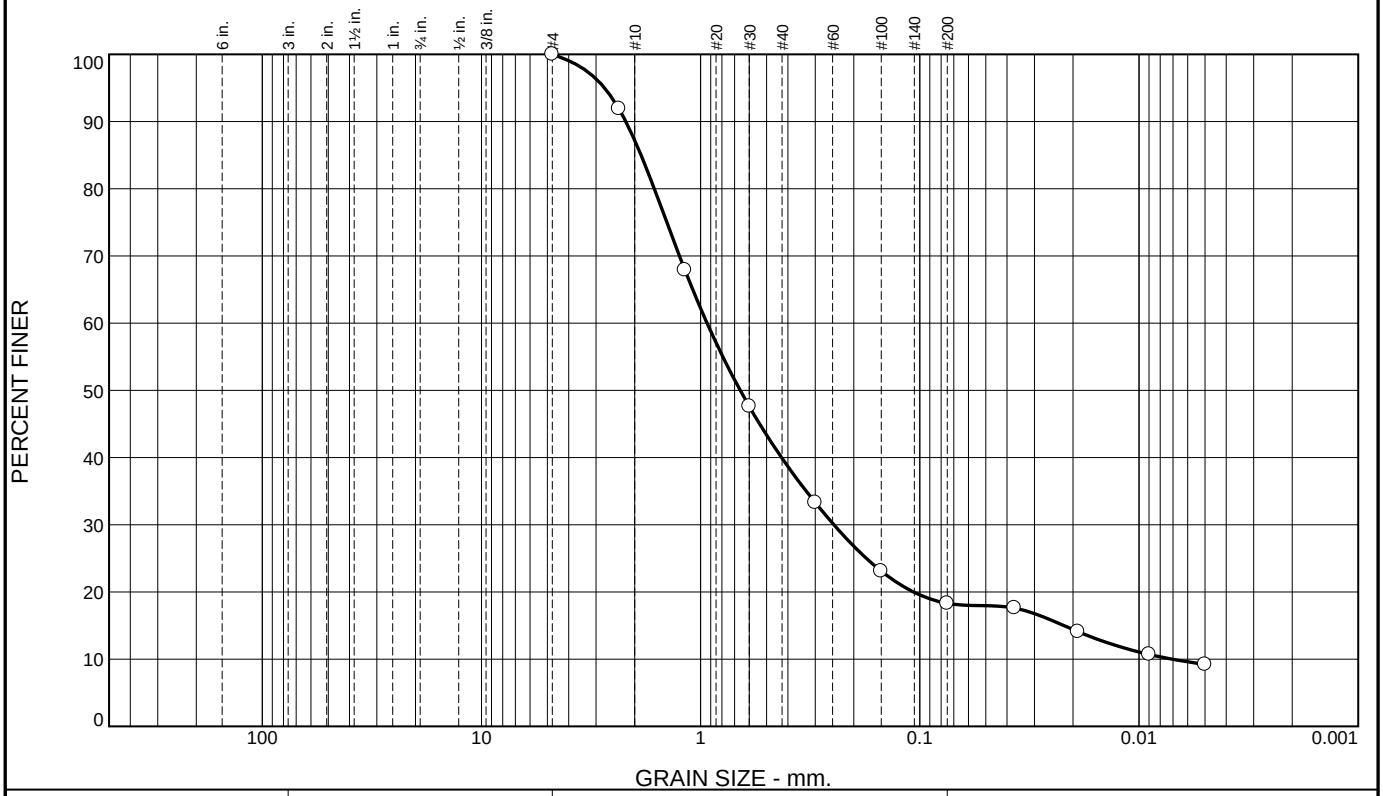
Client:
Project: Binders in Filter Material
Project No: 36F, 71Z **Figure**

Tested By: P.Irey **Checked By:** R.Rinehart

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	12.8	47.3	21.6	9.1	9.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0	95.0 - 100.0	
#8	91.9	80.0 - 100.0	
#16	67.9	50.0 - 85.0	
#30	47.6	25.0 - 60.0	
#50	33.3	5.0 - 30.0	X
#100	23.1	0.0 - 10.0	X
#200	18.3		
0.037 mm	17.6		
.019 mm	14.1		
0.009 mm	10.7		
0.005 mm	9.2		

* ASTM C 33 - Sand

Material Description

As used in Sand Castle test. Shows a discrepancy with the results of the Gilson processing to make C-33 material.

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 2.1951 D_{85}= 1.8711 D_{60}= 0.9347
D_{50}= 0.6598 D_{30}= 0.2468 D_{15}= 0.0220
D_{10}= 0.0070 C_u= 132.63 C_c= 9.24

Classification

USCS= SM AASHTO= A-1-b

Remarks

Fines assumed to be non-plastic

Location: Basalt Hill
Sample Number: 36F-1137*

Date: 8-9-2010

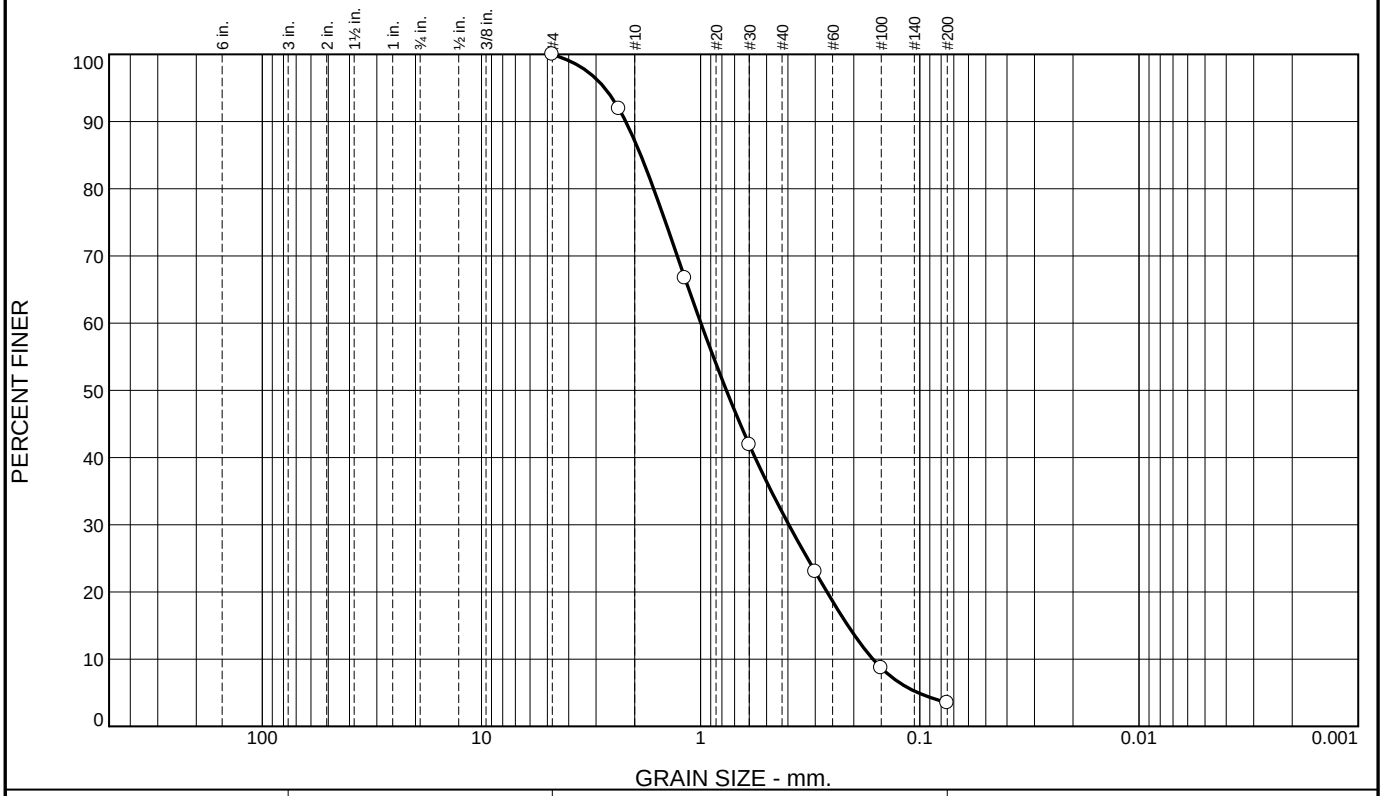
BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z

Figure

Tested By: R.Rinehart

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	12.9	55.2	28.4	3.5	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0	95.0 - 100.0	
#8	91.9	80.0 - 100.0	
#16	66.7	50.0 - 85.0	
#30	41.9	25.0 - 60.0	
#50	23.0	5.0 - 30.0	
#100	8.7	0.0 - 10.0	
#200	3.5		

* ASTM C 33 - Sand

Material Description

Material from borrow area used to supply 1980 repair crushed in-house to meet requirements of C-33 sand

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 2.1965 D_{85}= 1.8766 D_{60}= 0.9975
D_{50}= 0.7632 D_{30}= 0.3960 D_{15}= 0.2128
D_{10}= 0.1635 C_u= 6.10 C_c= 0.96

Classification

USCS= SP AASHTO= A-1-b

Remarks

fines assumed to be non-plastic

Location: Basalt Hill
Sample Number: 36F-1137

Date: 7/22/2010

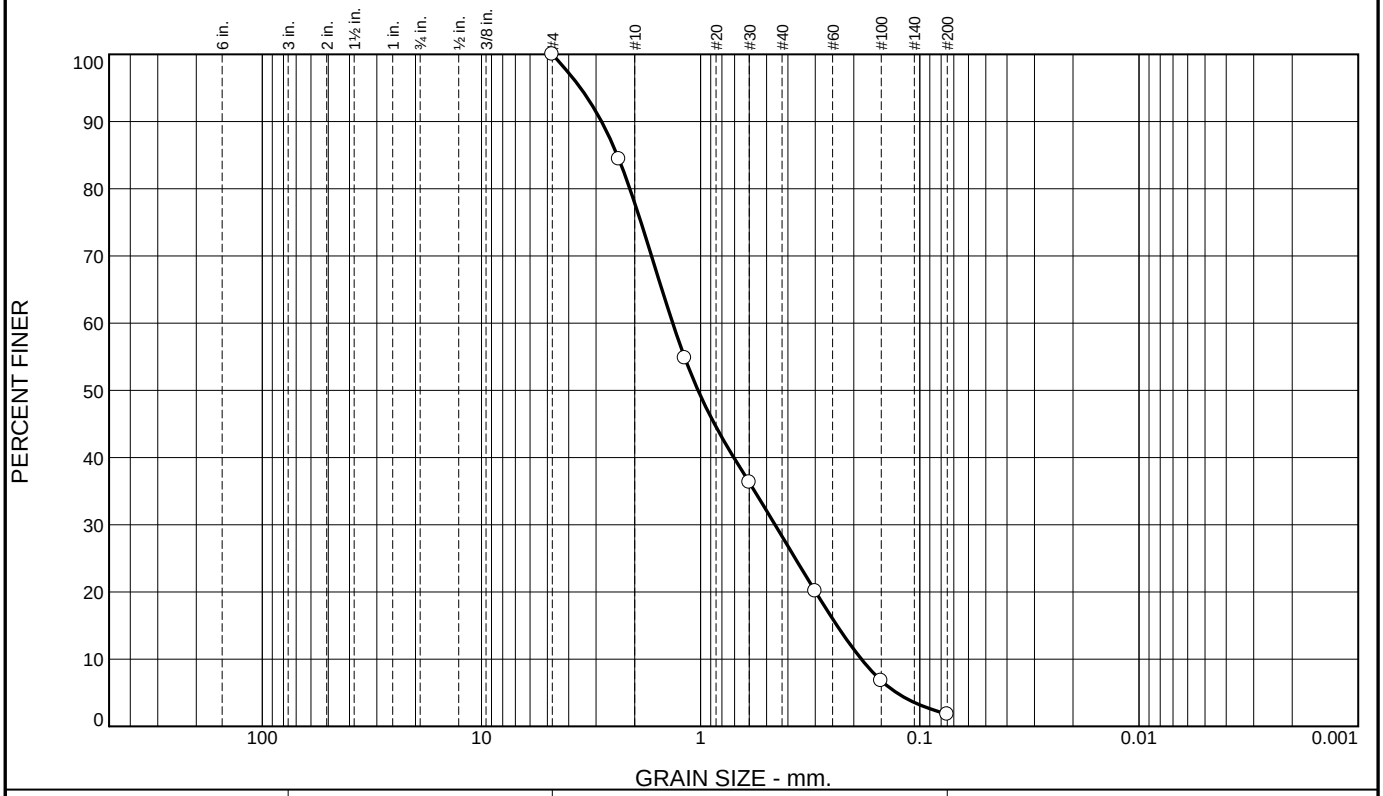
BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z

Figure

Tested By: P.Irey **Checked By:** R.Rinehart

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	22.1	49.6	26.5	1.8	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0	95.0 - 100.0	
#8	84.4	80.0 - 100.0	
#16	54.8	50.0 - 85.0	
#30	36.3	25.0 - 60.0	
#50	20.1	5.0 - 30.0	
#100	6.8	0.0 - 10.0	
#200	1.8		

* ASTM C 33 - Sand

Material Description

Concrete Sand, as received

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 2.8320 D_{85}= 2.4009 D_{60}= 1.3412
D_{50}= 1.0278 D_{30}= 0.4576 D_{15}= 0.2386
D_{10}= 0.1848 C_u= 7.26 C_c= 0.85

Classification

USCS= SP AASHTO= A-1-b

Remarks

fines assumed to be non-plastic

Location: Teichert Aggregate
Sample Number: 36F-1138

Date: 7/22/2010

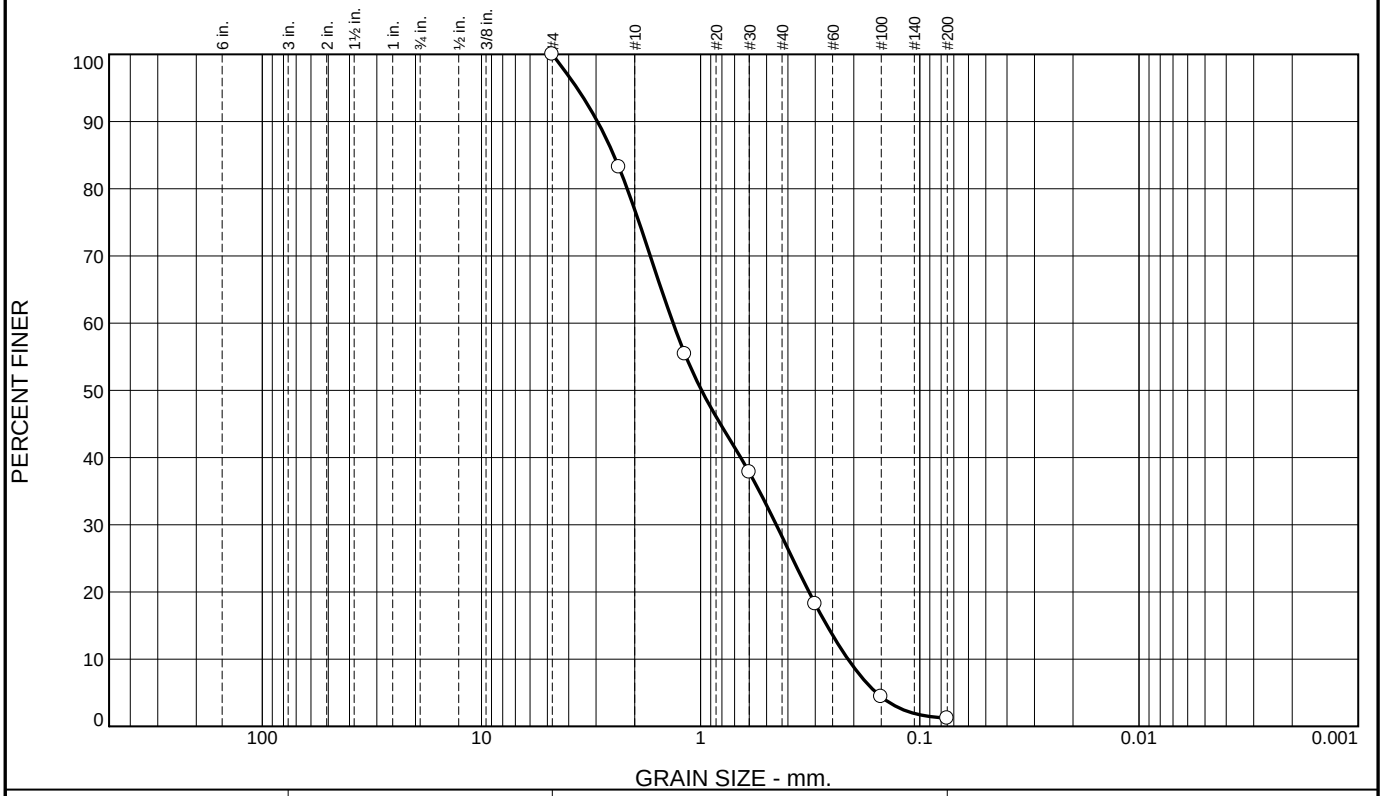
BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z

Figure

Tested By: P.Irey **Checked By:** R.Rinehart

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	23.1	48.7	27.0	1.2	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0	95.0 - 100.0	
#8	83.2	80.0 - 100.0	
#16	55.4	50.0 - 85.0	
#30	37.8	25.0 - 60.0	
#50	18.2	5.0 - 30.0	
#100	4.4	0.0 - 10.0	
#200	1.2		

* ASTM C 33 - Sand

Material Description

Concrete Sand, as received

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 2.9562 D_{85}= 2.4896 D_{60}= 1.3359
D_{50}= 0.9901 D_{30}= 0.4521 D_{15}= 0.2652
D_{10}= 0.2127 C_u= 6.28 C_c= 0.72

Classification

USCS= SP AASHTO= A-1-b

Remarks

fines assumed to be non-plastic

Location: Marks & Son (Cemex)
Sample Number: 36F-1139

Date: 7/22/2010

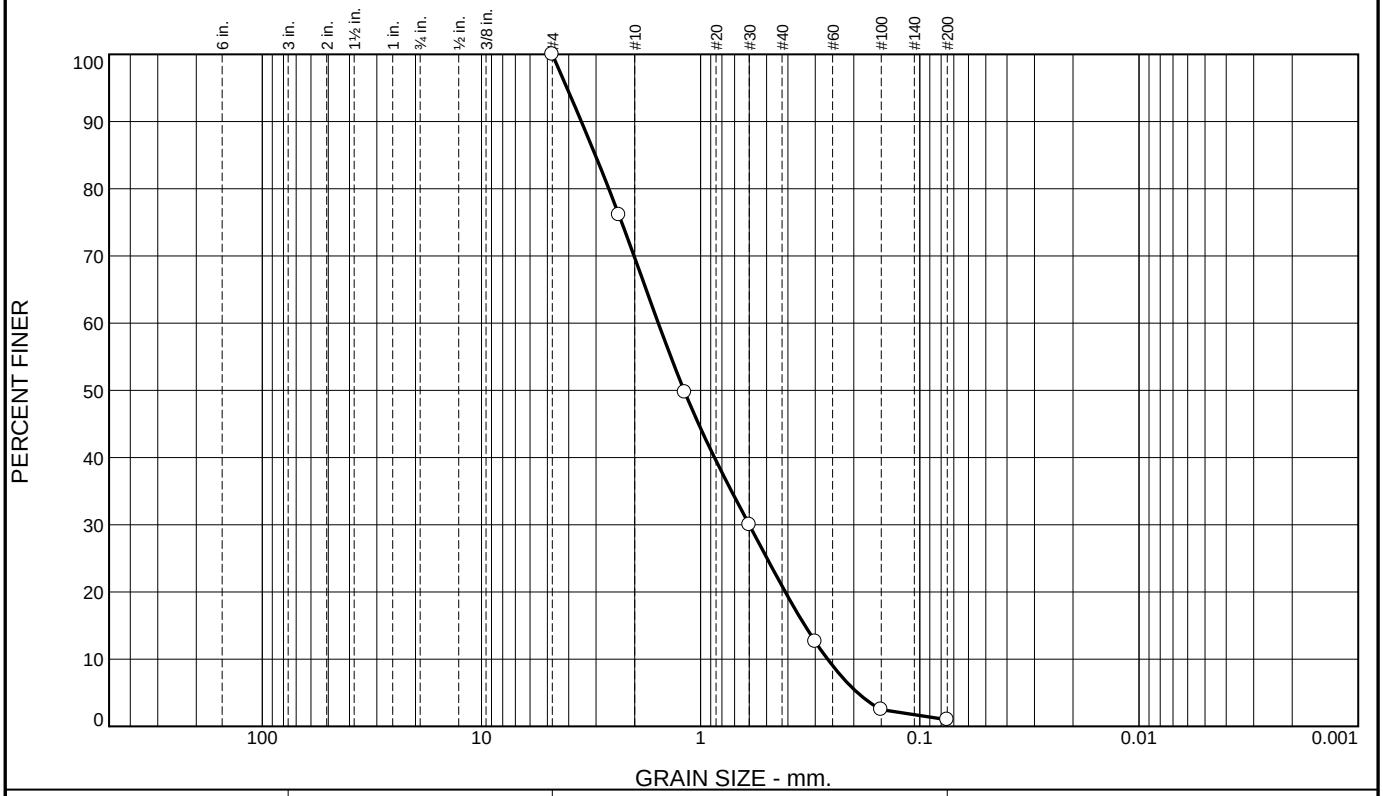
BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z

Figure

Tested By: P.Irey **Checked By:** R.Rinehart

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	30.3	48.8	19.9	1.0	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0	95.0 - 100.0	
#8	76.1	80.0 - 100.0	X
#16	49.7	50.0 - 85.0	X
#30	30.0	25.0 - 60.0	
#50	12.6	5.0 - 30.0	
#100	2.5	0.0 - 10.0	
#200	1.0		

* ASTM C 33 - Sand

Material Description

Concrete Sand, as received

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 3.5023 D_{85}= 3.0231 D_{60}= 1.5603
D_{50}= 1.1903 D_{30}= 0.6000 D_{15}= 0.3344
D_{10}= 0.2635 C_u= 5.92 C_c= 0.88

Classification

USCS= SP AASHTO= A-1-b

Remarks

fines assumed to be non-plastic

Location: Triangle Rock Products
Sample Number: 36F-1140

Date: 7/22/2010

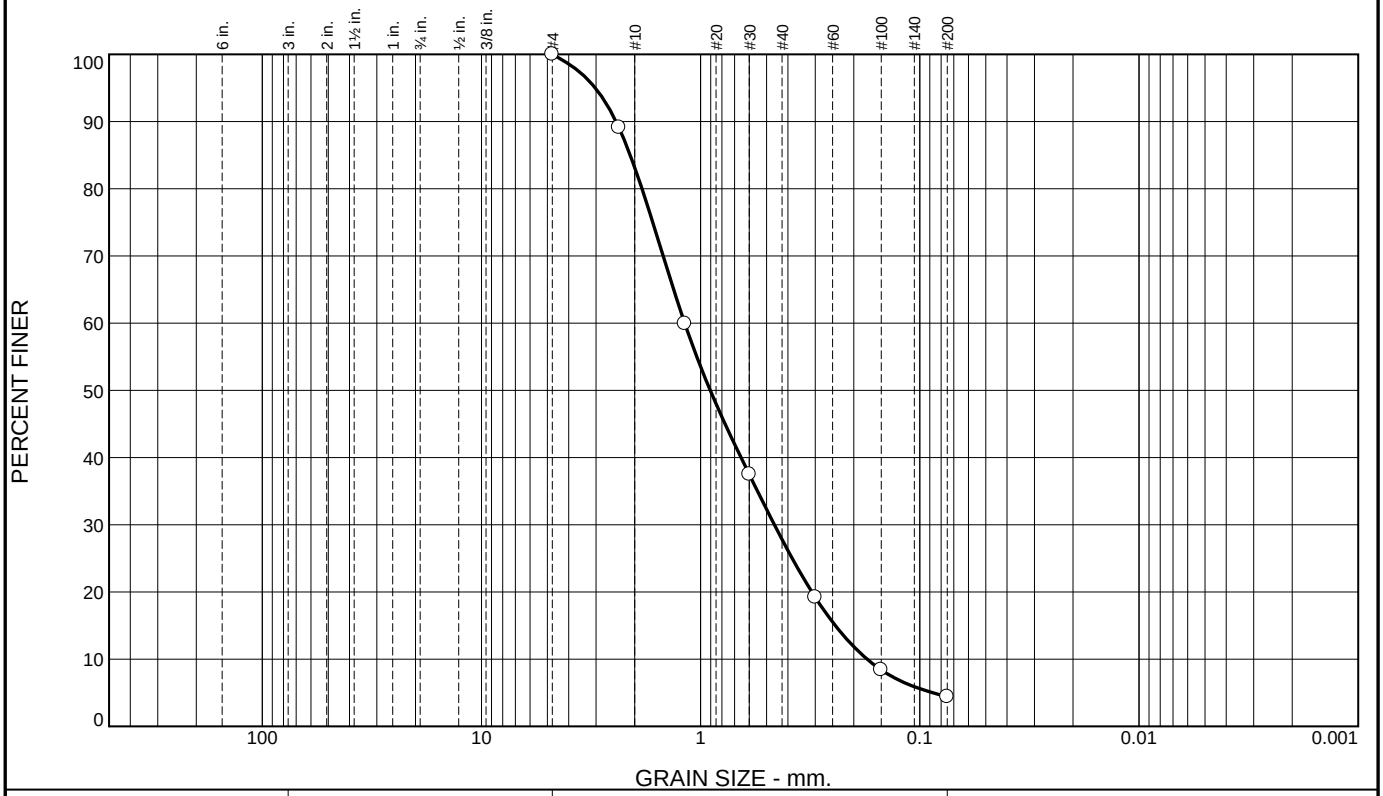
BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z

Figure

Tested By: P.Irey **Checked By:** R.Rinehart

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	16.8	55.4	23.4	4.4	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0	95.0 - 100.0	
#8	89.1	80.0 - 100.0	
#16	59.9	50.0 - 85.0	
#30	37.5	25.0 - 60.0	
#50	19.2	5.0 - 30.0	
#100	8.4	0.0 - 10.0	
#200	4.4		

* ASTM C 33 - Sand

Material Description

Concrete Sand, as received

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 2.4318 D_{85}= 2.0962 D_{60}= 1.1829
D_{50}= 0.9042 D_{30}= 0.4607 D_{15}= 0.2429
D_{10}= 0.1739 C_u= 6.80 C_c= 1.03

Classification

USCS= SW AASHTO= A-1-b

Remarks

fines assumed to be non-plastic

Location: Granite Rock
Sample Number: 36F-1141

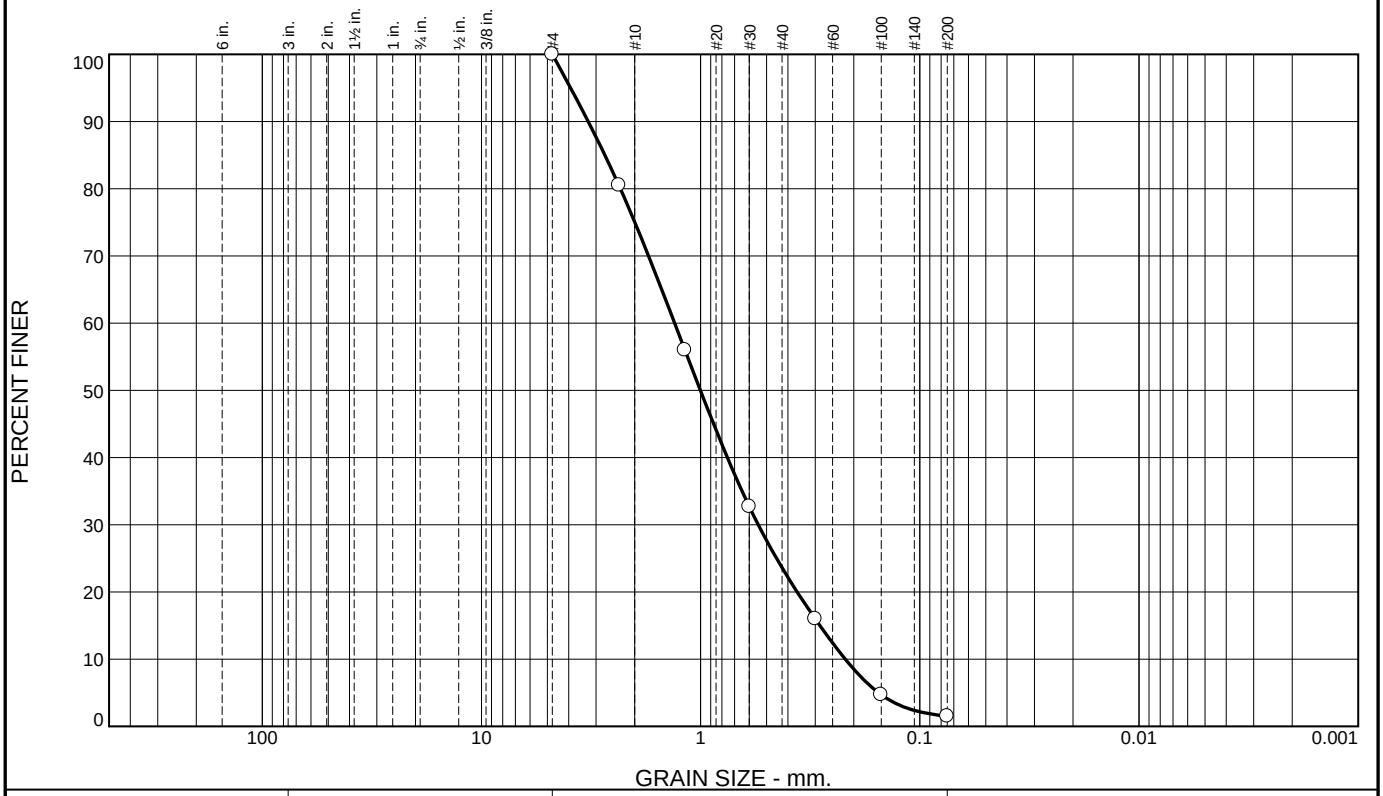
Date: 7/22/2010

BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z **Figure**

Tested By: P.Irey **Checked By:** R.Rinehart

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	24.9	51.5	22.1	1.5	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0	95.0 - 100.0	
#8	80.5	80.0 - 100.0	
#16	56.0	50.0 - 85.0	
#30	32.7	25.0 - 60.0	
#50	16.0	5.0 - 30.0	
#100	4.7	0.0 - 10.0	
#200	1.5		

* ASTM C 33 - Sand

Material Description

Recycled concrete from Federal Center stockpile, processed in house to meet requirements of C-33 sand

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 3.2583 D_{85}= 2.7343 D_{60}= 1.3146
D_{50}= 1.0026 D_{30}= 0.5460 D_{15}= 0.2855
D_{10}= 0.2189 C_u= 6.01 C_c= 1.04

Classification

USCS= SW AASHTO= A-1-b

Remarks

fines assumed to be non-plastic

Location: Denver Federal Center
Sample Number: 71Z-1*

Date: 7/21/2010

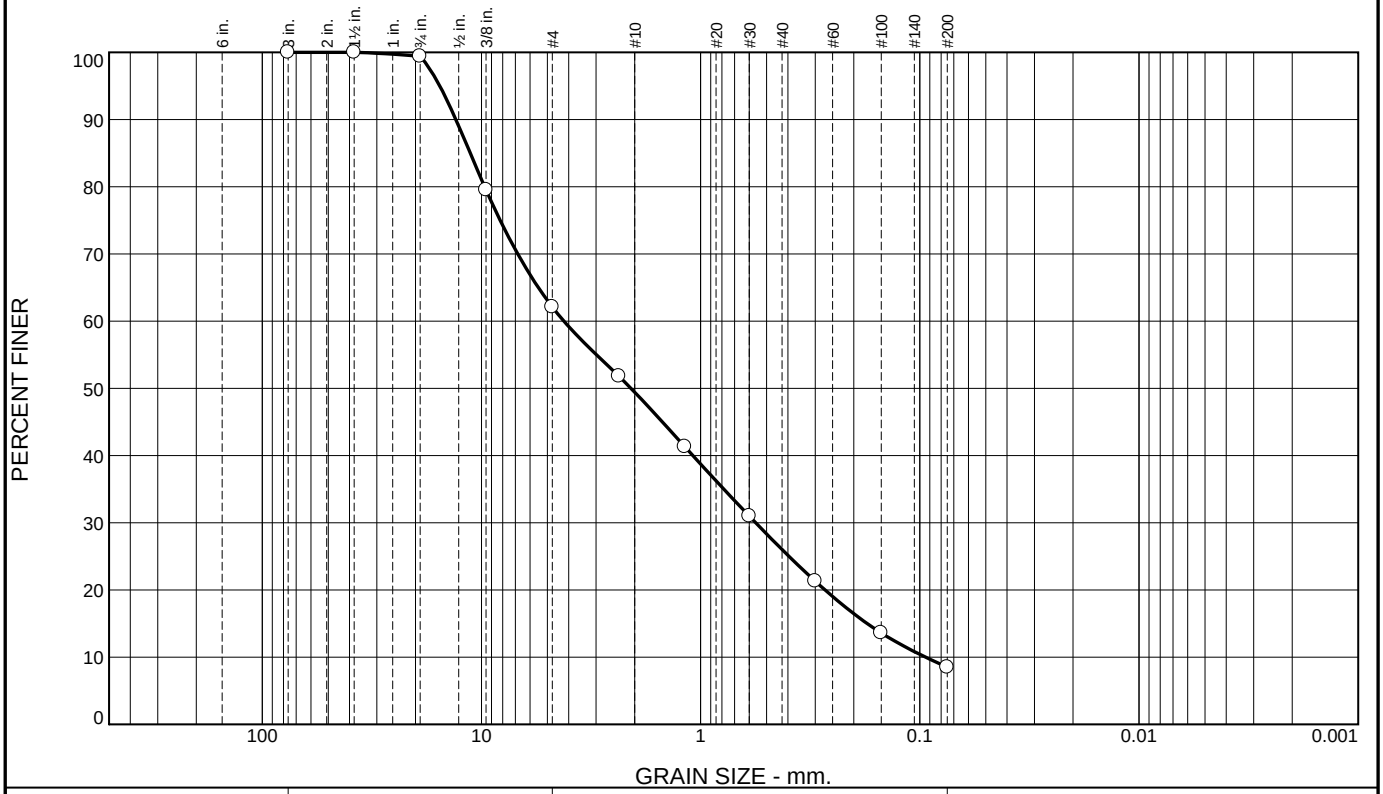
BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z

Figure

Tested By: C.Dowling **Checked By:** R.Rinehart

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.6	37.3	12.7	23.4	17.5	8.5	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3	100.0		
1.5	100.0		
.75	99.4		
.375	79.5	100.0 - 100.0	X
#4	62.1	95.0 - 100.0	X
#8	51.8	80.0 - 100.0	X
#16	41.3	50.0 - 85.0	X
#30	31.0	25.0 - 60.0	
#50	21.3	5.0 - 30.0	
#100	13.6	0.0 - 10.0	X
#200	8.5		

* ASTM C 33 - Sand

Material Description

Recycled Concrete from Federal Center stockpile, as received

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 13.0886 D_{85}= 11.2492 D_{60}= 4.2074
D_{50}= 2.0802 D_{30}= 0.5607 D_{15}= 0.1738
D_{10}= 0.0941 C_u= 44.73 C_c= 0.79

Classification

USCS= SP-SM AASHTO= A-1-a

Remarks

fines assumed non-plastic

Location: Denver Federal Center
Sample Number: 71Z-1

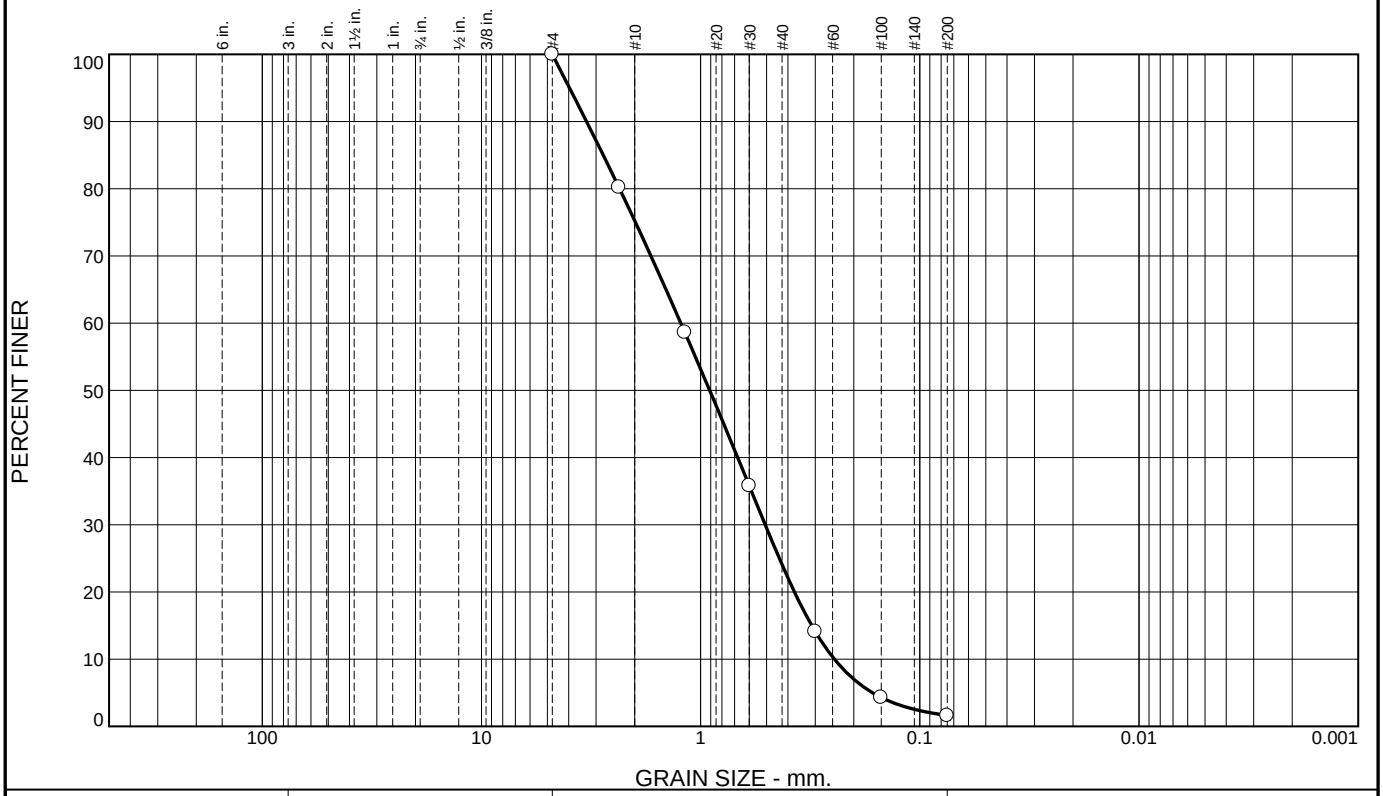
Date: 6/11/2010

BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z **Figure**

Tested By: R.Rinehart **Checked By:** J.Fahy

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	24.8	51.2	22.4	1.6	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0	95.0 - 100.0	
#8	80.2	80.0 - 100.0	
#16	58.6	50.0 - 85.0	
#30	35.8	25.0 - 60.0	
#50	14.1	5.0 - 30.0	
#100	4.3	0.0 - 10.0	
#200	1.6		

* ASTM C 33 - Sand

Material Description

Zone 2 Pit Run, processed in-house to meet requirements of C-33 sand

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 3.3173 D_{85}= 2.7827 D_{60}= 1.2319
D_{50}= 0.9097 D_{30}= 0.5075 D_{15}= 0.3113
D_{10}= 0.2454 C_u= 5.02 C_c= 0.85

Classification

USCS= SP AASHTO= A-1-b

Remarks

fines assumed to be non-plastic

Location: Ochoco Dam
Sample Number: 71Z-2*

Date: 7/21/2010

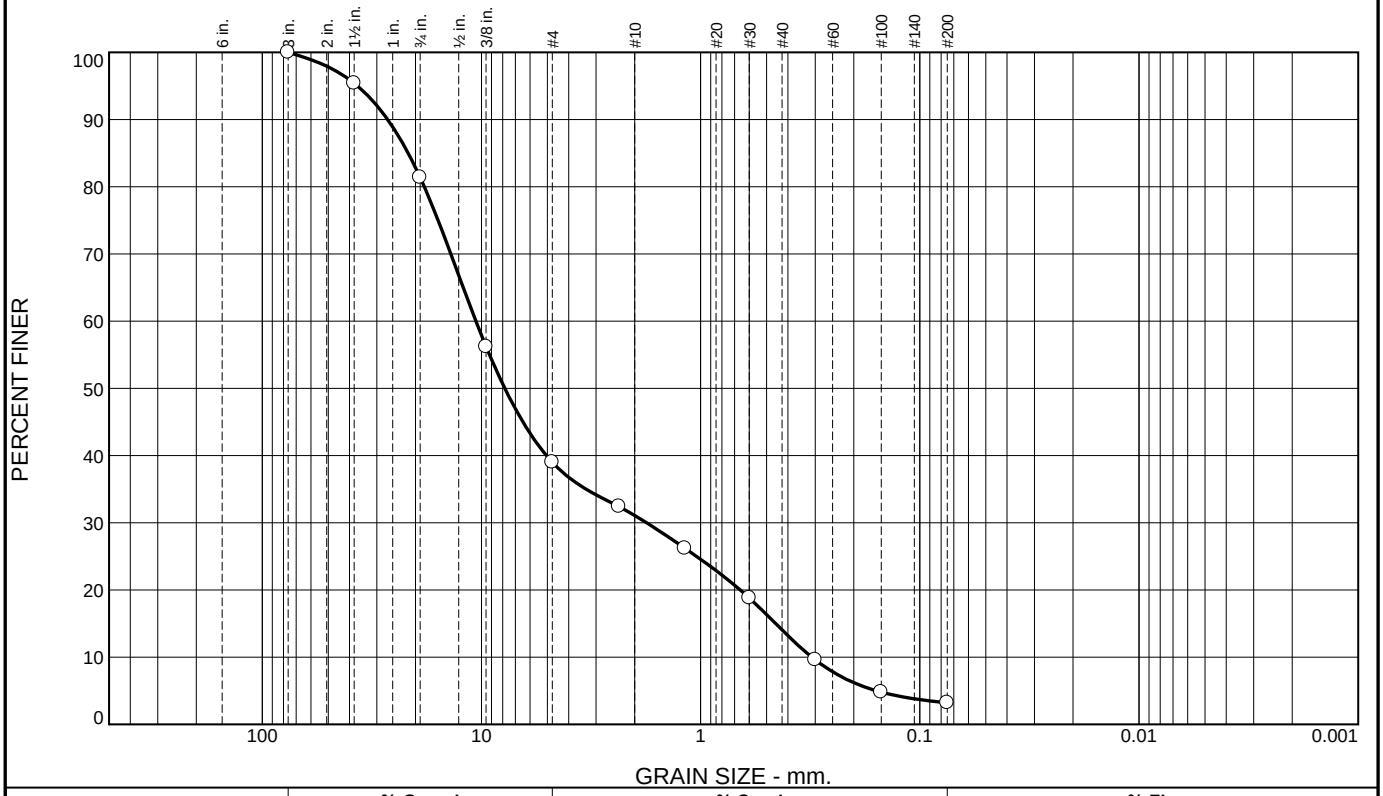
BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z

Figure

Tested By: C.Dowling **Checked By:** R.Rinehart

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	18.6	42.4	7.9	17.0	10.9	3.2	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3	100.0		
1.5	95.4		
.75	81.4		
.375	56.2	100.0 - 100.0	X
#4	39.0	95.0 - 100.0	X
#8	32.4	80.0 - 100.0	X
#16	26.2	50.0 - 85.0	X
#30	18.8	25.0 - 60.0	X
#50	9.6	5.0 - 30.0	
#100	4.8	0.0 - 10.0	
#200	3.2		

* ASTM C 33 - Sand

Material Description

Zone 2 Pit Run, as received

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 26.7918 D_{85}= 21.5876 D_{60}= 10.5994
D_{50}= 7.8267 D_{30}= 1.7654 D_{15}= 0.4548
D_{10}= 0.3109 C_u= 34.09 C_c= 0.95

Classification

USCS= GP AASHTO= A-1-a

Remarks

fines assumed to be non-plastic

Location: Ochoco Dam
Sample Number: 71Z-2

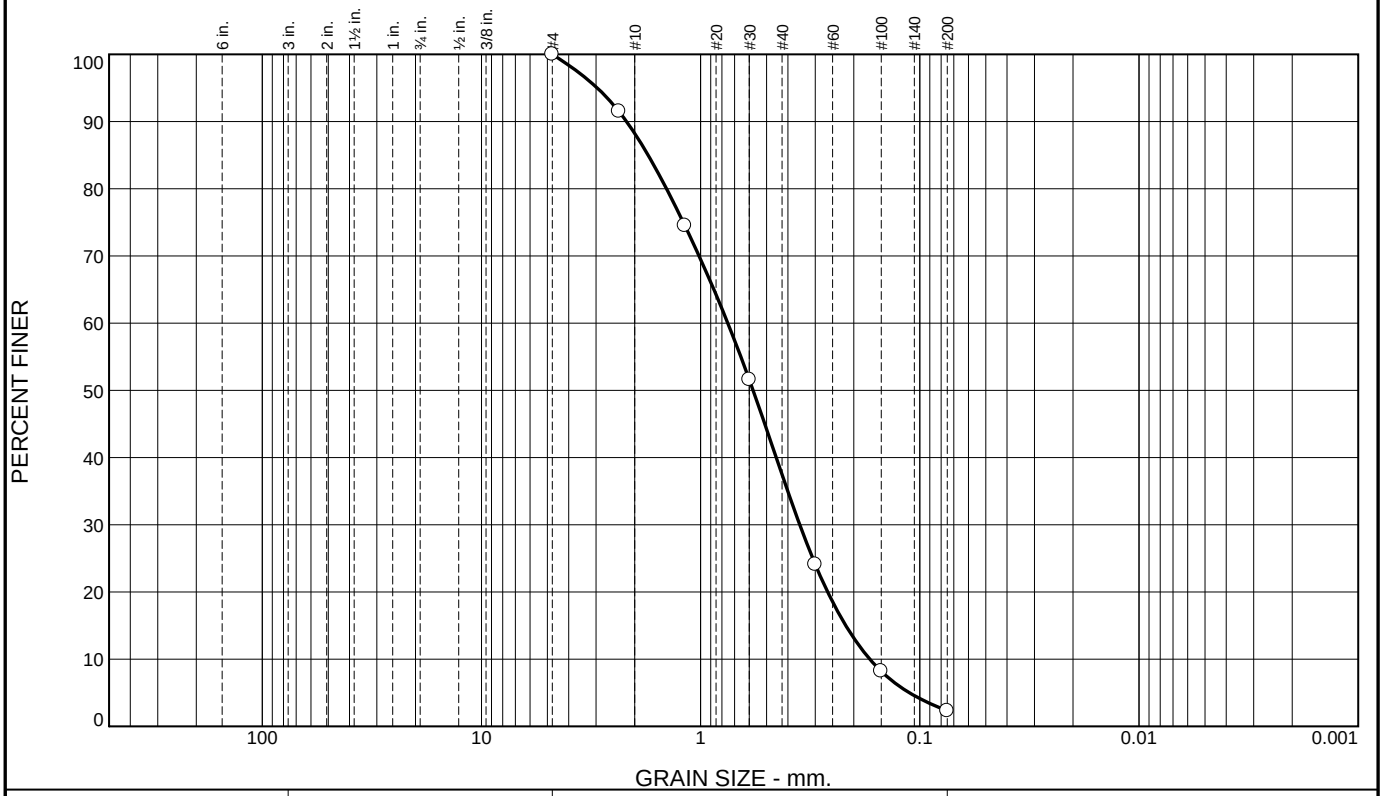
Date: 6/11/2010

BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z **Figure**

Tested By: R.Rinehart **Checked By:** J.Fahy

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	11.8	50.8	35.1	2.3	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0	95.0 - 100.0	
#8	91.5	80.0 - 100.0	
#16	74.5	50.0 - 85.0	
#30	51.6	25.0 - 60.0	
#50	24.1	5.0 - 30.0	
#100	8.2	0.0 - 10.0	
#200	2.3		

* ASTM C 33 - Sand

Material Description

Manufactured Concrete Sand, as received

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 2.1787 D_{85}= 1.7369 D_{60}= 0.7518
D_{50}= 0.5763 D_{30}= 0.3530 D_{15}= 0.2176
D_{10}= 0.1690 C_u= 4.45 C_c= 0.98

Classification

USCS= SP AASHTO= A-1-b

Remarks

fines assumed to be non-plastic

Location: Central Oregon Redi-Mix/Lone Pine
Sample Number: 71Z-3

Date: 6/11/2010

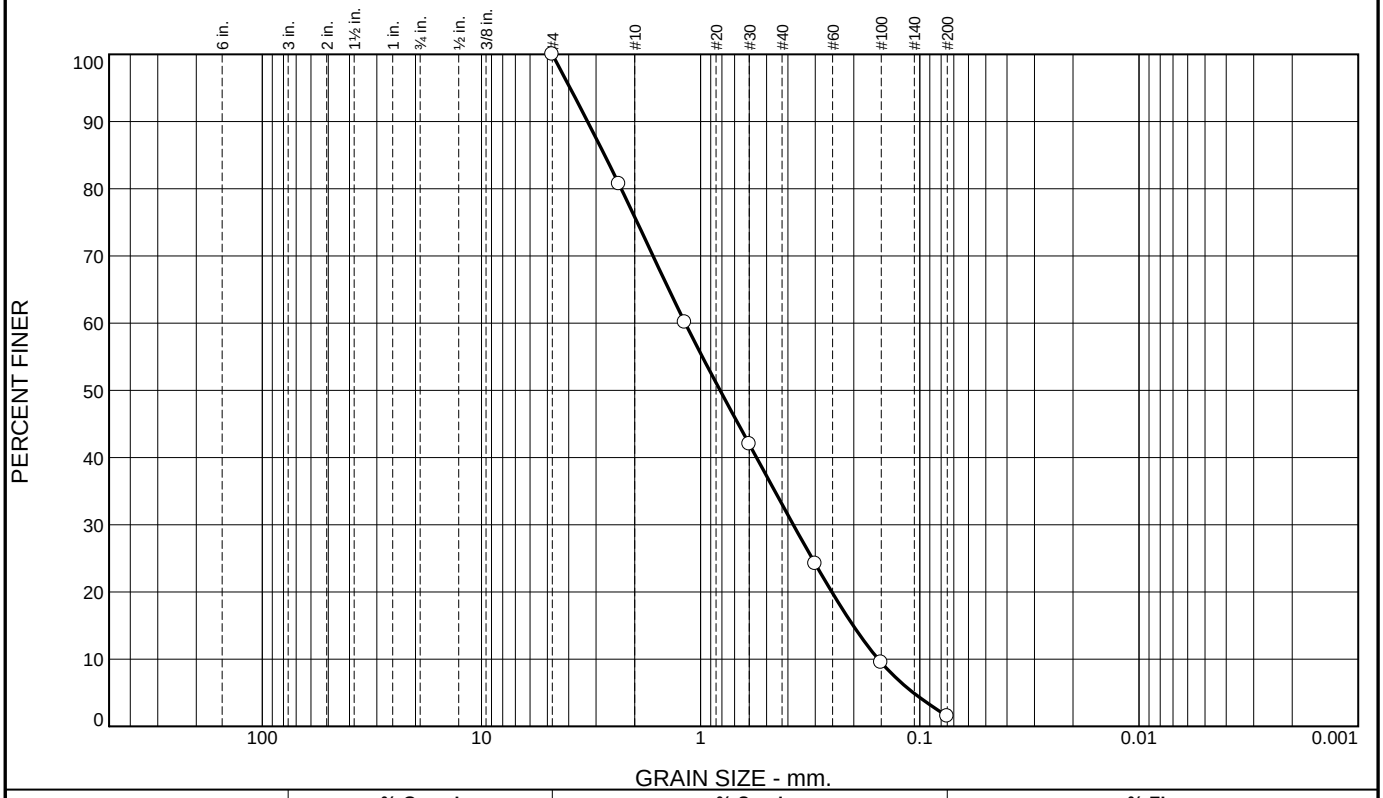
BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z

Figure

Tested By: R.Rinehart **Checked By:** J.Fahy

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	24.2	42.8	31.5	1.5	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0	95.0 - 100.0	
#8	80.7	80.0 - 100.0	
#16	60.1	50.0 - 85.0	
#30	42.0	25.0 - 60.0	
#50	24.2	5.0 - 30.0	
#100	9.5	0.0 - 10.0	
#200	1.5		

* ASTM C 33 - Sand

Material Description

As received concrete sand processed to remove excess -#100 material

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 3.2812 D_{85}= 2.7417 D_{60}= 1.1759
D_{50}= 0.8152 D_{30}= 0.3779 D_{15}= 0.2014
D_{10}= 0.1546 C_u= 7.60 C_c= 0.79

Classification

USCS= SP AASHTO= A-1-b

Remarks

fines assumed to be non-plastic

Location: Shevlin Sand & Gravel
Sample Number: 71Z-4*

Date: 7/22/2010

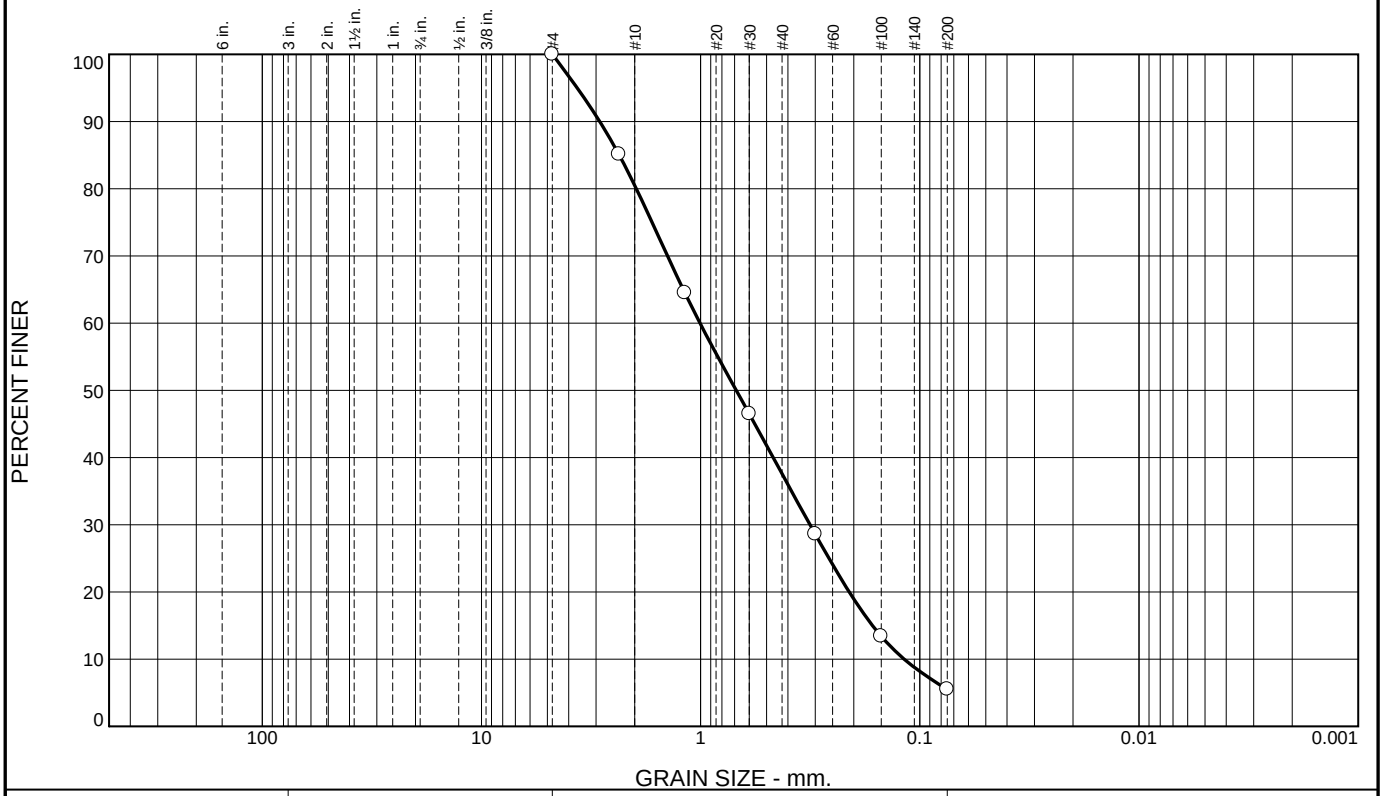
BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z

Figure

Tested By: C.Dowling **Checked By:** R.Rinehart

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	19.5	42.9	32.1	5.5	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0	95.0 - 100.0	
#8	85.1	80.0 - 100.0	
#16	64.5	50.0 - 85.0	
#30	46.5	25.0 - 60.0	
#50	28.6	5.0 - 30.0	
#100	13.4	0.0 - 10.0	X
#200	5.5		

* ASTM C 33 - Sand

Material Description

Fine Aggregate Sand for Concrete, as received

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 2.8865 D_{85}= 2.3510 D_{60}= 1.0066
D_{50}= 0.6879 D_{30}= 0.3170 D_{15}= 0.1644
D_{10}= 0.1179 C_u= 8.54 C_c= 0.85

Classification

USCS= SP-SM AASHTO= A-1-b

Remarks

fines assumed to be non-plastic

Location: Shevlin Sand and Gravel
Sample Number: 71Z-4

Date: 6/11/2010

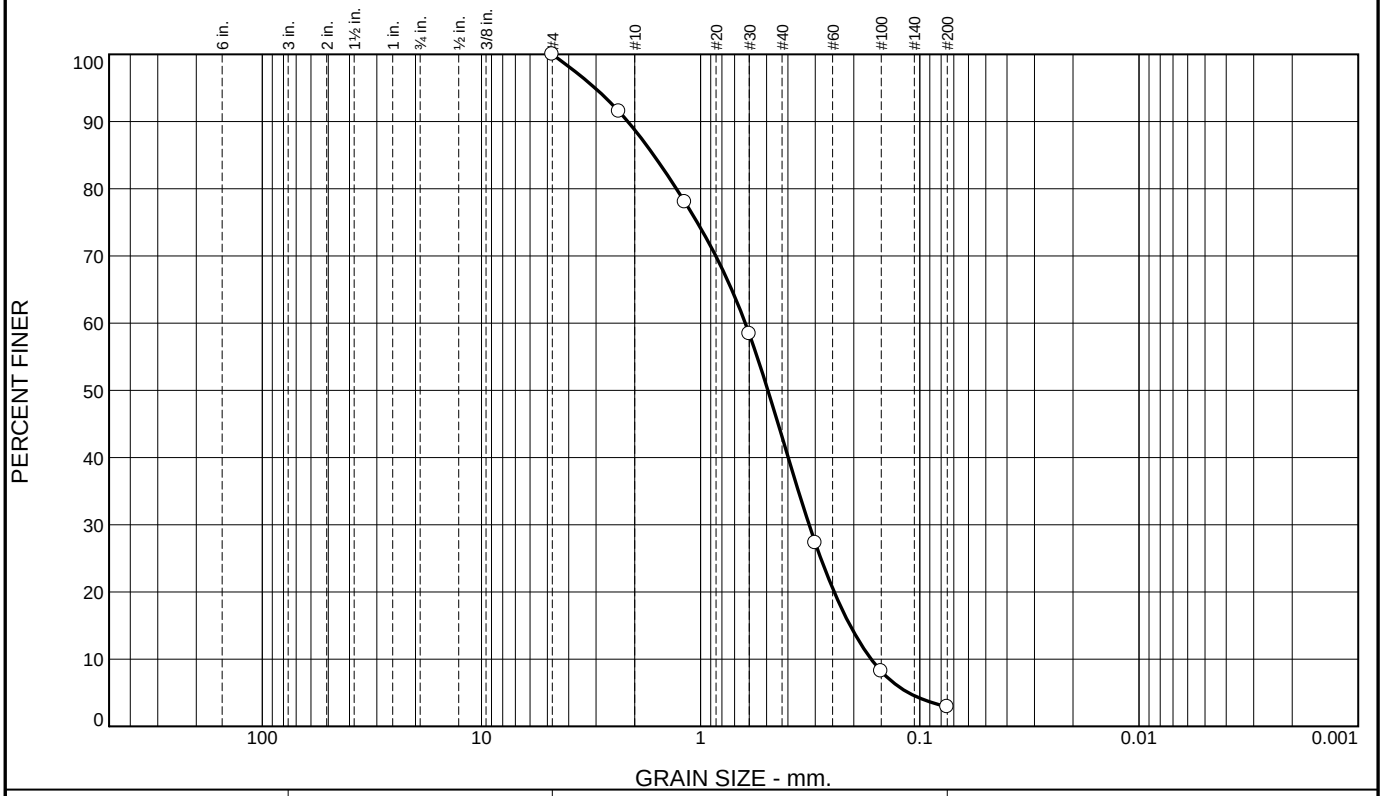
BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z

Figure

Tested By: R.Rinehart **Checked By:** J.Fahy

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	11.2	45.8	40.1	2.9	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0	95.0 - 100.0	
#8	91.5	80.0 - 100.0	
#16	78.0	50.0 - 85.0	
#30	58.4	25.0 - 60.0	
#50	27.3	5.0 - 30.0	
#100	8.2	0.0 - 10.0	
#200	2.9		

* ASTM C 33 - Sand

Material Description

Concrete Sand, as received

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 2.1500 D_{85}= 1.6378 D_{60}= 0.6254
D_{50}= 0.4934 D_{30}= 0.3200 D_{15}= 0.2078
D_{10}= 0.1667 C_u= 3.75 C_c= 0.98

Classification

USCS= SP AASHTO= A-1-b

Remarks

fines assumed to be non-plastic

Location: Grizzly Rock Products
Sample Number: 71Z-5

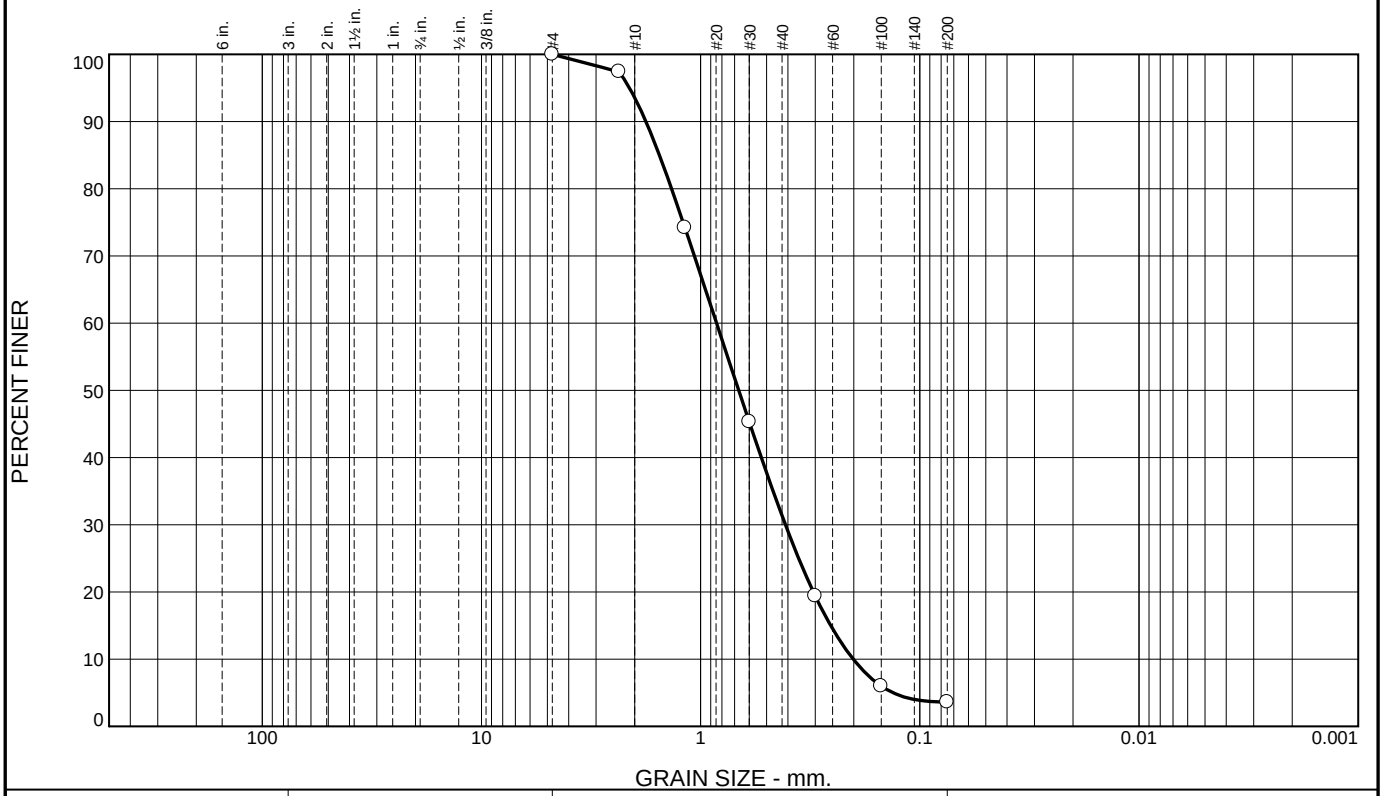
Date: 6/11/2010

BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z **Figure**

Tested By: R.Rinehart **Checked By:** J.Fahy

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	6.4	62.3	27.7	3.6	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0	95.0 - 100.0	
#8	97.4	80.0 - 100.0	
#16	74.2	50.0 - 85.0	
#30	45.3	25.0 - 60.0	
#50	19.4	5.0 - 30.0	
#100	6.0	0.0 - 10.0	
#200	3.6		

* ASTM C 33 - Sand

Material Description

Concrete Sand, as received

Atterberg Limits

PL= NP LL= NV PI= NP

Coefficients

D_{90}= 1.7776 D_{85}= 1.5428 D_{60}= 0.8461
D_{50}= 0.6703 D_{30}= 0.4104 D_{15}= 0.2550
D_{10}= 0.2013 C_u= 4.20 C_c= 0.99

Classification

USCS= SP AASHTO= A-1-b

Remarks

fines assumed to be non-plastic

Location: Rock Products Mfg. Inc./Prineville Sand & Gravel
Sample Number: 71Z-6

Date: 6/11/2010

BUREAU OF RECLAMATION

Client:
Project: Binders in Filter Material
Project No: 36F, 71Z

Figure

Tested By: R.Rinehart **Checked By:** J.Fahy

Appendix B

Sand Equivalent Test Reports

ASTM D 2419

Standard Test Method of Sand Equivalent Value of Soils and Fine Aggregate

Sample Identification Colorado Silica Sand (36F-1136)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 1				
Test 1	4.3	14.2	97.7	98
Test 2	4.3	14.2	97.7	98
Test 3	4.2	14.1	97.6	98
Sample Average				98

Sample Identification Colorado Silica Sand (36F-1136)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 2				
Test 1	4.4	14.2	95.5	96
Test 2	4.4	14.2	95.5	96
Test 2	4.4	14.2	95.5	96
Sample Average				96

Sample Identification Colorado Silica Sand (36F-1136)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 3				
Test 1	4.4	14.2	95.5	96
Test 2	4.4	14.1	93.2	94
Test 3	4.3	14.2	97.7	98
Sample Average				96

ASTM D 2419

Standard Test Method of Sand Equivalent Value of Soils and Fine Aggregate

Sample Identification Basalt Hill Quarry (36F-1137)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 1				
Test 1	4.4	14.0	90.1	91
Test 2	4.3	14.0	93.0	93
Test 3	4.4	14.2	95.5	96
Sample Average				94

Sample Identification Basalt Hill Quarry (36F-1137)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 2				
Test 1	4.1	13.8	92.7	93
Test 2	4.1	14.0	97.6	98
Test 2	4.0	13.8	95.0	95
Sample Average				96

Sample Identification Basalt Hill Quarry (36F-1137)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 3				
Test 1	4.1	13.8	92.7	93
Test 2	3.9	13.7	94.9	95
Test 3	4.1	13.8	92.7	93
Sample Average				94

ASTM D 2419

Standard Test Method of Sand Equivalent Value of Soils and Fine Aggregate

Sample Identification Tiechert (36F-1138)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 1				
Test 1	5.4	13.7	68.5	69
Test 2	5.3	13.8	73.6	74
Test 3	5.2	13.8	73.1	74
Sample Average				73

Sample Identification Tiechert (36F-1138)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 2				
Test 1	4.8	14.0	83.3	84
Test 2	5.2	14.0	76.9	77
Test 2	5.5	14.0	72.7	73
Sample Average				78

Sample Identification Tiechert (36F-1138)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 3				
Test 1	4.7	13.9	83.0	83
Test 2	4.9	14.0	81.6	82
Test 3	5.4	13.9	72.2	73
Sample Average				80

ASTM D 2419

Standard Test Method of Sand Equivalent Value of Soils and Fine Aggregate

Sample Identification Cemex (36F-1139)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 1				
Test 1	5.5	14.2	76.4	77
Test 2	5.5	14.0	72.7	73
Test 3	5.4	14.1	75.9	76
Sample Average				76

Sample Identification Cemex (36F-1139)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 2				
Test 1	5.5	14.1	74.5	75
Test 2	5.0	14.1	82.0	82
Test 2	5.3	14.1	77.4	78
Sample Average				79

Sample Identification Cemex (36F-1139)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 3				
Test 1	5.4	14.3	79.6	80
Test 2	5.4	14.2	77.8	78
Test 3	5.4	14.1	75.9	76
Sample Average				78

ASTM D 2419

Standard Test Method of Sand Equivalent Value of Soils and Fine Aggregate

Sample Identification Triangle Rock Prod. (36F-1140)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 1				
Test 1	4.9	13.9	79.6	80
Test 2	4.9	13.9	79.6	80
Test 3	4.8	14.0	83.3	84
Sample Average				82

Sample Identification Triangle Rock Prod. (36F-1140)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 2				
Test 1	5.1	14.0	78.4	79
Test 2	5.0	14.0	80.0	80
Test 2	4.9	13.9	80.0	80
Sample Average				80

Sample Identification Triangle Rock Prod. (36F-1140)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 3				
Test 1	5.1	14.0	78.4	79
Test 2	5.0	14.0	80.0	80
Test 3	4.6	13.9	84.8	85
Sample Average				82

ASTM D 2419

Standard Test Method of Sand Equivalent Value of Soils and Fine Aggregate

Sample Identification Granite Rock (36F-1141)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 1				
Test 1	5.6	13.8	67.9	68
Test 2	5.5	13.9	70.9	71
Test 3	5.3	13.9	73.6	74
Sample Average				71

Sample Identification Granite Rock (36F-1141)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 2				
Test 1	5.4	13.8	70.4	70.4
Test 2	5.4	13.7	68.5	68.5
Test 2	5.3	13.7	69.8	69.8
Sample Average				69

Sample Identification Granite Rock (36F-1141)	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 3				
Test 1	5.3	13.7	69.8	70
Test 2	5.3	13.8	71.7	72
Test 3	5.2	13.7	71.2	72
Sample Average				72

ASTM D 2419

Standard Test Method of Sand Equivalent Value of Soils and Fine Aggregate

Sample Identification 71 Z-1	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 1				
Test 1	9.0	13.1	34.4	35
Test 2	8.5	13.3	38.8	39
Test 3	7.2	13.4	47.2	48
Sample Average				41

Sample Identification 71 Z-2	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 1				
Test 1	6.0	13.8	63.3	64
Test 2	7.1	14.0	56.3	57
Test 2	6.5	13.9	60.0	60
Sample Average				61

Sample Identification 71 Z-3	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 2				
Test 1	5.1	14.1	80.4	81
Test 2	5.0	14.2	84.0	84
Test 3	5.1	14.0	78.4	79
Sample Average				82

ASTM D 2419

Standard Test Method of Sand Equivalent Value of Soils and Fine Aggregate

Sample Identification 71 Z-4	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 1				
Test 1	5.6	13.8	67.9	68
Test 2	5.4	13.9	72.2	73
Test 3	5.6	14.0	71.4	72
Sample Average				71

Sample Identification 71 Z-5	Clay Reading	Sand Reading	Sand Equivalent	Actual Sand Equivalent
Sample 1				
Test 1	4.9	14.2	85.7	88
Test 2	4.7	14.2	89.4	90
Test 2	5.0	14.2	84.0	84
Sample Average				87

Sample Identification 71 Z-6	Clay Reading	Sand Reading	San	Actual Sand Equivalent
Sample 2				
Test 1	5.2	14.2	80.8	81
Test 2	5.3	14.2	79.2	90
Test 3	4.8	14.0	83.3	84
Sample Average				85