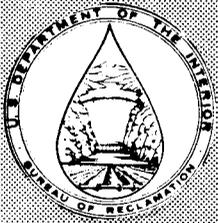


R-90-04



GRADATION ANALYSIS OF SOILS TEST PROCEDURES



March 1990

U.S. DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Denver Office
Research and Laboratory Services Division
Geotechnical Services Branch

R-90-04

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by

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Geotechnical Services Branch
Research and Laboratory Services Division
Denver Office
Denver, Colorado

March 1990



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INTRODUCTION

This report documents the rationale used in preparing the following test procedures for gradation analysis of soils as presented in the Third Edition of the *Earth Manual* (Bureau of Reclamation, in preparation):

- USBR 5325 "Performing Gradation Analysis of Gravel-Size Fraction of Soils"
- USBR 5330 "Performing Gradation Analysis of Fines and Sand-Size Fraction of Soils, Including Hydrometer Analysis"
- USBR 5335 "Performing Gradation Analysis of Soils Without Hydrometer - Wet Sieve"
- USBR 1405 "Calibrating Hydrometers"

Copies of these procedures are included in appendix B.

Volume II of the Third Edition of the *Earth Manual* was developed during 1986-87. That volume is a compilation of the procedures used by the Bureau of Reclamation for investigating, sampling, testing, and construction quality control of soils. The procedures are written and presented in a significantly different format than used in the Second Edition of the *Earth Manual* (Bureau of Reclamation, 1974).

During the writing of these procedures, many decisions were made to either (1) modify or expand the previously published version or (2) prepare a new procedure not included in the Second Edition. The procedures were written to conform, as much as possible, with ASTM (American Society for Testing and Materials) Standards and to reflect current soil mechanics technology and concepts. This report serves as a background reference for requirements of the test procedures for gradation analysis as presented in the Third Edition.

Previous versions of procedures discussed in this report were Designation E-5, "Preparation of Soil Samples for Testing," and Designation E-6, "Gradation Analysis of Soils" (Bureau of Reclamation, 1974).

Designations E-5 and E-6 were incorporated into the following procedures in the Third Edition (Bureau of Reclamation, in preparation):

- USBR 1405 "Calibrating Hydrometers"
- USBR 5205 "Preparing Soil Samples by Splitting or Quartering"
- USBR 5325 "Performing Gradation Analysis of Gravel-Size Fraction of Soils"
- USBR 5330 "Performing Gradation Analysis of Fines and Sand-Size Fraction of Soils, Including Hydrometer Analysis"
- USBR 5335 "Performing Gradation Analysis of Soils Without Hydrometer - Wet Sieve"

Terminology and symbols were standardized in USBR 3900, "Standard Definitions of Terms and Symbols Relating to Soil Mechanics."

Related ASTM Standards used in the development of these procedures were:

- C 117 "Standard Test Method for Materials Finer Than 75- μ m (No. 200) Sieve in Mineral Aggregates by Washing," Designation C 117-84 (ASTM, 1985a)
- C 136 "Standard Method for Sieve Analysis of Fine and Coarse Aggregates," Designation C 136-84a (ASTM, 1985a)
- D 421 "Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants," Designation D 421-85 (ASTM, 1986b)
- D 422 "Standard Method for Particle-Size Analysis of Soils," Designation D 422-63 (reapproved 1972) (ASTM, 1986b)
- D 653 "Terms and Symbols Relating to Soil and Rock," Designation D 653-85 (ASTM, 1986b)
- D 1140 "Standard Test Method for Amount of Material in Soils Finer than the No. 200 (75- μ m) Sieve," Designation D 1140-54 (reapproved 1971) (ASTM, 1986b)

The following ASTM standard specifications are referred to and used as part of USBR procedures:

- E 1 "ASTM Thermometers," Designation E 1-86 (ASTM, 1986c)
- E 11 "Standard Specification for Wire-Cloth Sieves for Testing Purposes," Designation E 11-81 (ASTM, 1986a)
- E 100 "Specification for ASTM Hydrometers," Designation E 100-81 (reapproved 1986) (ASTM, 1986c)
- E 323 "Standard Specification for Perforated-Plate Sieves for Testing Purposes," Designation E 323-80 (ASTM, 1986d)

A list of soil testing manuals and books that were reviewed in conjunction with the preparation of these gradation analysis procedures is included at the end of the bibliography as "Related References."

USBR 5325

Performing Gradation Analysis of Gravel-Size Fraction of Soils

This test procedure was previously a part of Designation E-5, "Preparation of Soil Samples for Testing," in the Second Edition of the *Earth Manual*.

The following summarizes the differences in this procedure between the Second and Third Editions of the *Earth Manual*. A detailed discussion of each item follows the summary list.

Changes to the procedure as presented in the Second Edition were:

1. The gravel gradation procedure was removed from Designation E-5, "Preparation of Soil Samples for Testing," and was made into a separate procedure.
2. The moisture content of plus No. 4 particles must be determined (or assumed) because the gradation of plus No. 4 particles should be based on dry mass.

The following are items that were added to USBR 5325 that were not mentioned in Designation E-5:

3. Minimum test specimen mass required, based on maximum particle size.
4. Criteria to avoid overloading the sieves.
5. Provisions for determining the mass retained on the sieves on a cumulative basis.
6. Minimum time of sieving with criterion for when sieving is considered complete.
7. Use of a mechanical sieving device or shaker.

Rationale

Item 1. - The gravel gradation procedure was removed from Designation E-5 and was made into a separate procedure.

As presented in Designation E-5, the gradation analysis of the fraction of a soil larger than the No. 4 sieve size was part of a means of separating the minus No. 4 sieve-size and plus No. 4 sieve-size particles in order to obtain minus No. 4 material samples for testing.

Since the gradation analysis of the gravel-size fraction is as important as the gradation of sand and fines, it was decided to give the gravel gradation analysis as much emphasis as the rest of the gradation and make it a separate procedure. Since an error in the determination of gradation percentages of particles larger than the No. 4 sieve size affects calculations for the rest of the gradation, a separate procedure will stress the care that must be taken in performing this portion of the gradation analysis. As previously presented in Designation E-5, the gravel gradation was not even mentioned in the title and was presented as almost an incidental step.

Designation E-5 included a 5-inch (125-mm) sieve as part of the gradation analysis of plus No. 4 sieve size material. However, USBR 5325 was restricted to only the gravel size and finer fractions because (1) the minus 3-inch (75-mm) fraction of a soil is the portion that is needed for classifying soils according to the Unified Soil Classification System, and (2) a more complete gradation is often required for the plus 3-inch sieve size fraction. It is planned to write a test procedure for plus 3-inch sieve-size particles to complement the other gradation analysis procedures. When that procedure is completed, USBR 5325 will require a reference to that designation.

Other information presented in Designation E-5 not integral to gradation of gravel was incorporated into other test procedures in the Third Edition. The portion of Designation E-5 related to splitting and quartering was expanded and made a separate procedure since these activities are necessary for sample or specimen preparation in many of the test procedures.

Therefore, Designation E-5, as presented in the 1974 Second Edition of the *Earth Manual*, is now basically covered in two procedures: USBR 5205, "Procedure for Preparing Soil Samples by Splitting or Quartering," and USBR 5325, "Procedure for Performing Gradation Analysis of Gravel-Size Fraction of Soils," with some portions covered in other separate test procedures.

Item 2. - The moisture content of plus No. 4 particles must be determined (or assumed) because the gradation of plus No. 4 particles should be based on dry mass.

As stated in Designation E-5, the soil is normally air dried in preparation for sieving. The mass of the air-dried particles is determined in performance of the test. This must be considered as "wet" mass since the soil has not been oven-dried. A note was added to USBR 5325 to emphasize this distinction as follows:

"NOTE 2. - In this designation, 'wet mass' refers to material that has not been oven-dried and 'dry mass' to material that has been oven-dried or the dry mass calculated."

Designation E-5 further states that, if the moisture content of the soil is estimated to be less than 5 percent, the moisture content need not be determined, and the gradation percentages are based on wet mass measurements. If the moisture content is deemed to be 5 percent or more, the moisture content of the plus No. 4 and the minus No. 4 must be determined, the dry mass calculated, and the gradation percentages based on the dry mass. Thus, the gradation analysis is based on either the wet basis or the dry basis depending on the estimated moisture content of the soil. This difference can account for variations in gradation percentages in excess of plus or minus 1 percent.

The example in Designation E-5, figure 5-3, shows data for a test for which the moisture content of the plus No. 4 and minus No. 4 fraction had been determined (fig. 1). The moisture content of the total sample would be 5.0 percent [using equation (10) on page 33 of the Second Edition of the *Earth Manual*]. If the moisture content had been estimated to be less than 5 percent, the test would have been performed on the wet basis and the gradation percentages, as shown on figure 2, would have differed by 0.2 percent. In rounding the percentages to whole numbers, the percent passing the 1-1/2-inch (37.5-mm) sieve, the No. 4 sieve, and the No. 100 sieve would have differed by 1 percentage point. This example had about 5 percent plus No. 4 particles.

FORM 7-1451
(8-62)

BUREAU OF RECLAMATION

SAMPLE PREPARATION AND GRADATION ANALYSIS

LABORATORY SAMPLE NO. 11J-23

FEATURE EXAMPLE ARFA A EXC. NO. 203 DEPTH 0.0 to 5.0'

SAMPLE PREPARATION							
PREPARED BY _____	% MOIST - NO. 4 <u>1.8</u>		WET WT. TOTAL SAMPLE <u>47.75</u>				
DATE _____	% MOIST - NO. 5 <u>5.2</u>		DRY WT. TOTAL SAMPLE <u>45.47</u>				
SIEVE SIZE	5"	2"	1-1/2"	3/4"	3/8"	NO. 4	TOTAL WT. PASSING NO. 4
WT. PAN + RETAINED MATERIAL							
WT. PAN							
WET WT. RETAINED		<u>0</u>	<u>1.68</u>	<u>0.25</u>	<u>0.43</u>	<u>0.27</u>	<u>45.12</u> WET
DRY WT. RETAINED		<u>0</u>	<u>1.65</u>	<u>0.25</u>	<u>0.42</u>	<u>0.26</u>	<u>42.89</u> DRY
DRY WT. PASSING		<u>45.47</u>	<u>43.82</u>	<u>43.57</u>	<u>43.15</u>	<u>42.89</u>	
% OF TOTAL PASSING		<u>100.0</u>	<u>96.4</u>	<u>95.8</u>	<u>94.9</u>	<u>94.3</u>	- ^W

SIEVE AND HYDROMETER ANALYSIS

DISH NO. <u>18</u>	DRY WT. OF SAMPLE (W) <u>50.0</u> gms.	FACTOR (F) = $\frac{W}{W'} = \frac{50.0}{34.3} = 1.886$				
DRY WT. OF SAMPLE (SIEVED) <u>21.4 gms.</u>						
SIEVING TIME <u>15 min.</u>	DATE _____					
SIEVE NO.	WEIGHT RETAINED	WEIGHT PASSING	F x WEIGHT PASSING = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIA (mm)	REMARKS
8	<u>0.2</u>	<u>49.8</u>		<u>93.9</u>	2.360	
16	<u>0.4</u>	<u>49.6</u>		<u>93.5</u>	1.190	
30	<u>1.1</u>	<u>48.9</u>		<u>92.2</u>	0.590	
50	<u>3.3</u>	<u>46.7</u>		<u>88.1</u>	0.297	
100	<u>11.6</u>	<u>38.4</u>		<u>72.4</u>	0.149	
200	<u>21.4</u>	<u>28.6</u>		<u>53.9</u>	0.074	
PAN	<u>0.0</u>					
TOTAL	<u>21.4</u>					TESTED AND COMPUTED BY _____ CHECKED BY _____ DATE _____

HYDROMETER ANALYSIS

HYDROMETER NO. <u>320584</u>	DISPERSING AGENT <u>Sodium Metaphosphate</u>								
STARTING TIME <u>8:00</u>	DATE _____	AMOUNT <u>125</u> ml							
TIME	TEMP C°	HYD READ	HYD CORR	CORR READ	F x CORRECT READ = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIA (mm)	REMARKS	
.5 MIN"								0.050	
1 MIN		<u>16.4</u>	<u>+3.2</u>	<u>19.6</u>			<u>37.0</u>	0.037	
4 MIN	<u>26.8</u>	<u>10.1</u>	<u>+3.2</u>	<u>13.3</u>			<u>25.1</u>	0.019	
10 MIN	<u>26.8</u>	<u>6.9</u>	<u>+3.2</u>	<u>10.1</u>			<u>19.0</u>	0.009	
60 MIN	<u>27.0</u>	<u>4.9</u>	<u>+3.2</u>	<u>8.1</u>			<u>15.3</u>	0.005	
7 HR. 15 MIN"								0.002	
25 HR. 45 MIN"								0.001	
TESTED AND COMPUTED BY _____ CHECKED BY _____ DATE _____									

Figure 5-3.—Sample preparation and gradation analysis data form. 101-D-329.

Figure 1. - Example data sheet from Designation E-5.

7-1451 (9-86) Bureau of Reclamation	GRADATION ANALYSIS		Designation USBR 5325-__ Designation USBR 5330-__ Designation USBR 5335-__
SAMPLE NO. EXAMPLE	PROJECT	FEATURE	
AREA FROM FIG 5-3	EXC. NO.	DEPTH	

GRADATION OF GRAVEL SIZES							
TESTED AND COMPUTED BY <i>ash</i>	DATE	% MOISTURE CONTENT OF + NO. 4				WET MASS OF TOTAL SPECIMEN 47.75	
CHECKED BY	DATE	% MOISTURE CONTENT OF - NO. 4				TOTAL DRY MASS OF SPECIMEN	
SIEVE SIZE		3" (75 mm)	1-1/2" (37.5 mm)	3/4" (19.0 mm)	3/8" (9.5 mm)	NO. 4 (4.75 mm)	PAN
MASS OF CONTAINER AND RETAINED MATERIAL							
MASS OF CONTAINER							
WET MASS RETAINED			1.68	0.25	0.43	0.27	45.12
DRY MASS RETAINED							
WET DRY MASS PASSING		47.75	46.07	45.82	45.39	45.12	<input checked="" type="checkbox"/> lbm <input type="checkbox"/> kg <input type="checkbox"/> g
% OF TOTAL PASSING		100.0	96.5	96.0	95.1	94.5	

GRADATION OF SAND SIZES							
DRY MASS OF SPECIMEN		50.0	g FACTOR = $\frac{\% \text{ TOTAL PASSING NO. 4}}{\text{DRY MASS OF SPECIMEN}}$		$\frac{94.5}{50.0}$	- 1.890	
DISH NO.		DRY MASS OF SPECIMEN (SIEVED)					
SIEVING TIME				DATE			
SIEVE NO.	MASS RETAINED (g)	MASS PASSING (g)	FACTOR X MASS PASSING = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS	
8	0.2	49.8		94.1	2.36 mm		
16	0.4	49.6		93.7	1.18 mm		
30	1.1	48.9		92.4	600 μm		
50	3.3	46.7		88.3	300 μm		
100	11.6	38.4		72.6	150 μm		
200	21.4	28.6		54.1	75 μm		
PAN			TESTED AND COMPUTED BY	DATE	CHECKED BY	DATE	
TOTAL							

HYDROMETER ANALYSIS								
HYDROMETER NO.				DISPERSING AGENT				
STARTING TIME			DATE		AMOUNT mL			
TIME	TEMP °C	HYD READ	HYD CORR	CORR READ	FACTOR X CORRECT READ = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
1 min							37 μm	
4 min							19 μm	
19 min							9 μm	
60 min							5 μm	AUXILIARY TESTS: USBR 5205-__ USBR 5300-__
7 h 15 min*							2 μm	
25 h 45 min*							1 μm	
TESTED AND COMPUTED BY			DATE	CHECKED BY			DATE	

*Not required for standard test.

Figure 2. - Wet mass determination.

Figures 3 and 4 show a comparison for a soil with about 90 percent plus No. 4 particles. If the moisture content of the plus No. 4 particles was 2.0 percent and the moisture content of the minus No. 4 particles was 8.0 percent, the moisture content of the total soil would be 2.6 percent (fig. 4). The test, according to Designation E-5, would have been performed on the wet basis with the results as shown on figure 3. Had the moisture contents been determined, the gradation analysis would be as shown on figure 4, based on dry mass. The differences are as high as 0.5 percentage point, and the percent passing the 3/8-inch (9.5-mm) sieve and the No. 4 sieve would have been reported as 1 percentage point difference.

Other examples can show that the difference in performing the test on a wet basis or on a dry basis can affect results in excess of 1 percentage point when rounded to the nearest whole percent. Although these differences are normally small, for the test to be accurate it should be based on dry masses. The definitions of gradation or gradation analysis (USBR 3900, ASTM D 653) do not specify that the percentages are based on dry mass. However, most test procedures used by others do specify that gradation analysis be on a dry basis.

As stated in USBR 5325, the plus No. 4 moisture may be either determined or assumed. Since the moisture content of sound, durable gravel particles usually ranges from 1 to 3 percent, if the moisture content has been determined on similar plus No. 4 particles from the same area, a value of moisture can be assumed without significantly affecting test results. For plus No. 4 particles that are more absorbent, the moisture content should be determined for each test.

Item 3. - Minimum test specimen mass required, based on maximum particle size.

A. As stated in USBR 5325:

"9. Sampling, Test Specimens, and Test Units

"9.1 Sample preparation. -

"9.1.1 Prepare a test sample of minus 3-inch (75-mm) material in accordance with USBR 5205. The mass of the specimen to be tested depends on the maximum particle size present in the soil as follows:

7-1451 (9-86) Bureau of Reclamation	GRADATION ANALYSIS		Designation USBR 5325 --- Designation USBR 5330 --- Designation USBR 5335 ---
SAMPLE NO. WET MASS	PROJECT	FEATURE	
AREA DETERMINATION	EXC. NO.	DEPTH	

GRADATION OF GRAVEL SIZES						
TESTED AND COMPUTED BY	DATE	% MOISTURE CONTENT OF + NO. 4			WET MASS OF TOTAL SPECIMEN 102.6	
CHECKED BY	DATE	% MOISTURE CONTENT OF - NO. 4			TOTAL DRY MASS OF SPECIMEN	
SIEVE SIZE	3" (75 mm)	1-1/2" (37.5 mm)	3/4" (19.0 mm)	3/8" (9.5 mm)	NO. 4 (4.75 mm)	PAN
MASS OF CONTAINER AND RETAINED MATERIAL						
MASS OF CONTAINER						
WET MASS RETAINED		40.80	61.20	81.60	91.80	10.8
DRY MASS RETAINED						
WET DRY MASS PASSING		102.6	61.8	41.4	21.0	10.8
% OF TOTAL PASSING		100	60.2	40.4	20.5	10.5

GRADATION OF SAND SIZES						
DRY MASS OF SPECIMEN		% TOTAL PASSING NO. 4				
DISH NO.		DRY MASS OF SPECIMEN (SIEVED)				
SIEVING TIME				DATE		
SIEVE NO.	MASS RETAINED (g)	MASS PASSING (g)	FACTOR X MASS PASSING = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
8					2.36 mm	
16					1.18 mm	
30					600 μm	
50					300 μm	
100					150 μm	
200					75 μm	
PAN	TESTED AND COMPUTED BY		DATE	CHECKED BY		DATE
TOTAL						

HYDROMETER ANALYSIS								
HYDROMETER NO.			DISPERSING AGENT					
STARTING TIME		DATE	AMOUNT mL					
TIME	TEMP °C	HYD READ	HYD CORR	CORR READ	FACTOR X CORRECT READ = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
1 min							37 μm	
4 min							19 μm	
19 min							9 μm	
60 min							5 μm	AUXILIARY TESTS: USBR 5205 --- USBR 5300 ---
7 h 15 min*							2 μm	
25 h 45 min*							1 μm	
TESTED AND COMPUTED BY		DATE	CHECKED BY		DATE			

* Not required for standard test.

Figure 3. - Determination using wet mass.

7-1451 (9-86) Bureau of Reclamation		GRADATION ANALYSIS		Designation USBK 5325 ___ Designation USBK 5330 ___ Designation USBK 5335 ___	
SAMPLE NO. DRY MASS		PROJECT		FEATURE	
AREA DETERMINATION		EXC. NO.		DEPTH	

GRADATION OF GRAVEL SIZES							
TESTED AND COMPUTED BY	DATE	% MOISTURE CONTENT OF + NO. 4			WET MASS OF TOTAL SPECIMEN		
		2.0			102.6		
CHECKED BY	DATE	% MOISTURE CONTENT OF - NO. 4			TOTAL DRY MASS OF SPECIMEN		
		8.0			100.0		
SIEVE SIZE		3" (75 mm)	1-1/2" (37.5 mm)	3/4" (19.0 mm)	3/8" (9.5 mm)	NO. 4 (4.75 mm)	PAN
MASS OF CONTAINER AND RETAINED MATERIAL							
MASS OF CONTAINER							
WET MASS RETAINED			40.80	61.20	81.60	91.80	10.8
DRY MASS RETAINED			40.0	60.0	80.0	90.0	10.0
DRY MASS PASSING			100.0	60.0	40.0	20.0	10.0
% OF TOTAL PASSING			100.0	60.0	40.0	20.0	10.0

GRADATION OF SAND SIZES						
DRY MASS OF SPECIMEN			FACTOR = $\frac{\% \text{ TOTAL PASSING NO. 4}}{\text{DRY MASS OF SPECIMEN}}$			
DISH NO.			DRY MASS OF SPECIMEN (SIEVED)			
SIEVING TIME			DATE			
SIEVE NO.	MASS RETAINED (g)	MASS PASSING (g)	FACTOR X MASS PASSING = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
8					2.36 mm	
16					1.18 mm	$w_{total} = 90(0.02) + 10(0.08)$ $= 1.8 + 0.8$ $= 2.6\%$
30					600 μ m	
50					300 μ m	
100					150 μ m	
200					75 μ m	
PAN		TESTED AND COMPUTED BY		DATE	CHECKED BY	
TOTAL						

HYDROMETER ANALYSIS								
HYDROMETER NO.			DISPERSING AGENT					
STARTING TIME			DATE					
			AMOUNT					
TIME	TEMP °C	HYD READ	HYD CORR	CORR READ	FACTOR X CORRECT READ = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
1 min							37 μ m	
4 min							19 μ m	
19 min							9 μ m	
60 min							5 μ m	AUXILIARY TESTS: USBR 5205 ___ USBR 5300 ___
7 h 15 min*							2 μ m	
25 h 45 min*							1 μ m	
TESTED AND COMPUTED BY			DATE		CHECKED BY			DATE

*Not required for standard test.

Figure 4. - Determination using dry mass.

<u>Maximum particle size</u>		<u>Minimum dry mass of test specimen</u>	
<u>in</u>	<u>mm</u>	<u>lbm</u>	<u>kg</u>
3/8	9.5	*0.5	*0.25
3/4	19.0	*2.5	*1.1
1-1/2	37.5	20	10
3	75	150	70

* For the equipment typically used in this procedure, a test specimen mass of at least 10 lbm (4.5 kg) is recommended (see subpar. 12.2.2).

"These values are in terms of dry mass. Values for wet mass of the specimen will have to be adjusted based on an estimated moisture content."

B. Discussion

Designation E-5 did not give specific information as to required or recommended test specimen size. These changes to the test specimen mass were based on information in a separate report, GR-88-2, "Minimum Test Specimen Mass for Gradation Analysis" (Howard, 1988).

Item 4. - Criteria to avoid overloading the sieves.

A. As stated in USBR 5325:

"8.2.2 Care must be taken to prevent overloading of the sieves.

"8.2.2.1 The total quantity of material to be sieved must be limited so that on a given sieve all the particles have an opportunity to reach sieve openings a number of times during the sieving operation. As a rule, if the material retained on a sieve at the completion of testing is spread out evenly over the area of the sieve, the layer of material should not be more than one particle thick.

"8.2.2.2 For wire cloth sieves, the load on the cloth must never be so great that permanent deformation of the cloth occurs. This should be checked visually to avoid overloading the sieve."

* * * * *

"12.4 Separation of specimen prior to sieving:

"12.4.1 If the amount of material to be tested is greater than the capacity of the sieving equipment (do not overload the sieves), divide the specimen into appropriate portions for testing. For each portion, follow the steps in

subparagraphs 12.5 through 12.11. Calculate the sum of the wet masses retained on each sieve and in the pan, and record as wet mass retained for each sieve size and in the pan and proceed with subparagraph 12.12.

"12.4.2 Alternately, if the amount of material to be tested is greater than the capacity of the sieving equipment or to not overload the sieves, the specimen may be separated using a No. 4 sieve prior to testing. Separation on the No. 4 sieve also may be necessary for (1) testing the minus No. 4 portion of a soil before or during the testing of the plus No. 4, (2) convenience of test scheduling, or (3) when the plus No. 4 particles need to be soaked in water (see subpar. 12.7.1). The wet mass of the separated minus No. 4 material must be determined and then added to the wet mass of any minus No. 4 particles collected and measured during the sieving of the plus No. 4 material.

"12.5 Assemble the set (nest) of sieves to be used in order of decreasing size of opening from top to bottom and place in the sieving device. The sieves may be the standard set as described in subparagraph 7.3, or others as required by the specifications covering the material to be tested. If desired, sieves coarser than the maximum particle size may be omitted from the set. However, a sieve at least one size larger than the anticipated maximum size should be included in the set. Additional sieve sizes may be added to restrict the amount of material on a particular sieve (see subpar. 12.4.1) or to protect individual sieves from excessive wear.

"12.6 Place the soil specimen on the top sieve and turn on the sieving device. To avoid overloading the top sieve, it may be necessary to feed the soil onto the top sieve gradually. Sieve the material for about 15 minutes, or longer if necessary, to separate all the material. A satisfactory end-point is considered to have been reached when an additional 1 minute of sieving does not change the mass on any individual sieve by more than 1.0 percent."

B. Literature review of criteria on overloading sieves:

ASTM C 136-84a, "Standard Method for Sieve Analysis of Fine and Coarse Aggregates"

"7.3 Limit the quantity of material on a given sieve so that all particles have opportunity to reach sieve openings a number of times during the sieving operation. For sieves with openings smaller than 4.75-mm (No. 4), the weight retained on any sieve at the completion of the sieving operation shall not exceed 6 kg/m^2 (4 g/in^2) of sieving surface. For sieves with openings 4.75 mm (No. 4) and larger, the weight in kg/m^2 of sieving surface shall not exceed the product of 2.5X (sieve opening in mm). In no case shall the weight be so great as to cause permanent deformation of the sieve cloth.

"NOTE 5. - The 6 kg/m^2 amounts to 194 grams for the usual 203-mm (8-in) diameter sieve. The amount of material retained on a sieve may be regulated

by (1) the introduction of a sieve with larger openings immediately above the given sieve, or (2) testing the sample in a number of increments."

Manual on Test Sieving Methods, Publication No. STP 447B (ASTM, 1985b)

"5.14 Sample weight limits. - In determining the suitable size of the test sample, the weight per cubic unit of the material is very important. For example, as may be seen from table 5, a 100-cm³ sample of powdered iron would weigh approximately 390 g, while the same volume of diatomaceous earth would weigh only 50 g. The volume of the test sample should be such that no sieve is overloaded to a point where there is a crowding of oversize and near-mesh particles on the sieve surface. Overloading is most likely to occur in tests of materials which have a concentration of particles close to one size, or where the entire sample is within a narrow size range, for example, if a large proportion of the particle sizes would be between a 2-mm sieve and a 500- μ m sieve. In such a case, the size of the sample should be determined by the capacity (without overloading) of the sieve retaining the largest amount of the sample. At the same time, the sampling must be large enough to permit a measurable amount of the material to be retained on each sieve, particularly on the control sieves. In making a sieve analysis of medium or fine material, it is best not to use too large a sample. A smaller sample properly taken and carefully reduced will usually give more accurate and consistent results than a larger sample which might overload one or more of the sieves. The reverse may be true when testing coarse materials, such as coarse aggregates where larger samples are required to constitute a representative portion.

"5.15 Determination of test sample size. - As a check method to determine the correct size of a sample, the following procedure is suggested. With a sample splitter, accurately split samples of varying weights, such as 25, 50, 100, and 200 g. Then run these various samples on the sieves selected for a period of approximately 5 minutes, preferable on a mechanical sieve shaker. A comparison of these results will show the most suitable size sample to use. For example, if the test with the 100-g sample shows approximately the same percentage passing the finer sieves as the 50-g sample, whereas the 150-g sample shows a lower percentage through the finest sieve, this would be an indication that a 150-g sample would be too large, but a 100-g sample would be satisfactory. Once the correct size sample is determined for a particular test, this same size sample should be used for all such tests.

"5.16 Table of suggested sample sizes. - A useful table of recommended sample sizes for tests with 8-inch or 200-mm sieves is given in table 5. Note that the table gives sample sizes by volume. Recommended sample weights (in grams) can be determined by multiplying the values in columns 3 and 4 by the bulk density (in grams per cubic centimeter) of the material to be tested, rounded out within a tolerance of ± 25 percent. If the actual bulk density of the material being tested has not been determined, the typical density factor for the most nearly similar material listed in table 5 may be

used. The values in table 5 are a useful guide where standard test sample sizes have not already been established, but it is suggested that the sample sizes obtained by the use of table 5 be verified by the procedure outlined above before adopting them as standard."

NOTE. - Table numbers have been corrected in quoted 5.16 because of typographical errors in the original.

"Table 5. - Suggested bulk volume of test sample for sieve analysis with 8-in and 200-mm round sieves*

<u>Standard sieve designation</u>		<u>Bulk volume of material</u>	
Standard	Alternate	Recommended volume of material for test sample	Maximum permitted volume on sieve on completion of sieving
1	2	3	4
25.0 mm	1 in	1,800 cm ³	900 cm ³
22.4	7/8	1,600	800
19.0	3/4	1,400	700
16.0	5/8	1,000	500
12.5	1/2	800	400
11.2	7/16	800	400
9.5	3/8	600	300
8.0	5/16	500	250
6.3	1/4	400	200
5.6	No. 3-1/2	400	200
4.0	No. 5	350	150
2.8	No. 7	240	120
2.0	No. 10	200	100
1.40	No. 14	160	80
1.0	No. 18	140	70
710 μm	No. 25	120	60
500	No. 35	100	50
355	No. 45	80	40
250	No. 60	70	35
180	No. 80	60	30
125	No. 120	50	25
90	No. 170	40	20
63	No. 230	35	17
45	No. 325	30	15
38	No. 400	25	12

* The recommended weight of material for a sieve test sample is calculated by multiplying the bulk volume figure in column 3 by the particular bulk density in grams per cubic centimeter of the material, rounded out within a tolerance of ±25 percent. If the density figure for the material being testing is not readily available, use the factor of the nearest similar material shown in Table 6."

Gilson Laboratory Particle Size Equipment, Catalog 84-1 (Gilson Company, 1984)

"In the absence of applicable specifications, or for mass separation screening jobs, it may be useful to estimate the screening capacity of various models for a specific situation. Machine capacities are impossible to state in absolute terms since they depend upon wire cloth sizes used in the machine and properties of the test material as well as the physical limitations of the machine itself. We recommend maximum loading at completion of screening on coarse series sizes of 6 inches to No. 4 (150 mm to 4.75 mm) equivalent to one layer of spherical particles of diameter of wire cloth openings. Compute load volume from sphere volume ($4.189 r^3$) times estimated number of spheres. Then specific gravity of test material will determine maximum loading on a weight basis. For fine series sizes No. 4 to No. 200 (4.75 mm to 75 μm), use maximum loading of 4 g/in² of wire cloth surface at completion of sieving for material of 2.4 specific gravity. Then ratio result according to specific gravity of material to be tested. Keep in mind that these calculated limits will apply to only the ONE tray or sieve which actually is limiting in a given test, and other loads will be reduced depending on the size distribution of the sample. Actual screening capacity may therefore be 50 percent or less of the sum of calculated limits for a given set of trays or sieves. When one tray or sieve severely limits overall sample capacity, an additional size may be inserted ahead of the limiting size to divide the load and increase overall capacity."

C. Discussion

Overloading the sieves creates two separate problems. The first is permanent deformation of the wire cloth resulting from too much material on the cloth in the initial loading of the soil onto the sieves. Secondly, during the test, all the particles must have ample opportunity to reach the sieve openings.

To address both problems, provisions were added to USBR 5325 for separating the soil to be tested into portions, adding additional sieves, or feeding the soil into the sieves gradually.

Avoiding deformation of the wire cloth is difficult to assess in specific terms and is left to the judgment of the operator.

The criterion recommended in the Gilson catalog was used to give all the particles an opportunity to reach sieve openings a number of times during the sieving action. At the completion of testing, the layer of soil on the sieve should not be more than one particle thick. This results in about the same criterion as used in ASTM C 136 of "the weight in kg/m² of sieving surface shall not exceed the product of 2.5 x (sieve opening in mm)."

Item 5. - Provisions for determining the mass retained on the sieves on a cumulative basis.

A. As stated in USBR 5325:

"12.9 Starting with the coarsest sieve, remove all particles retained on each sieve and place in the container(s). Determine and record the mass of container and

retained material. The mass may be determined and recorded as the mass for individual sieve size (fig. 3) or as the mass on a cumulative basis (fig. 4)."

B. Discussion

As presented in Designation E-5, the mass retained on each gravel-size sieve is determined separately. However, this test is commonly performed by determining the mass on a cumulative basis. In addition, the gradation of the sand-size particles is determined on a cumulative basis (see Designation E-6 in the Second Edition of the *Earth Manual*, and USBR 5330 and 5335). Therefore, the procedure was written to permit determining the mass on either an individual sieve basis or a cumulative basis. Examples are shown that illustrate each method.

Item 6. - Minimum time of sieving with criterion for when sieving is considered complete.

A. As stated in USBR 5325:

"12.6 Place the soil specimen on the top sieve and turn on the sieving device. To avoid overloading the top sieve, it may be necessary to feed the soil onto the top sieve gradually. Sieve the material for about 15 minutes, or longer if necessary, to separate all the material. A satisfactory end-point is considered to have been reached when an additional one minute of sieving does not change the mass on any individual sieve by more than 1.0 percent."

B. Discussion

Designation E-5 did not discuss sieving time at all.

A minimum sieving time of 15 minutes was added to the new procedure with further provision when sieving is considered complete. The criterion from ASTM C 136 was used and reworded as follows: "A satisfactory end-point is considered to have been reached when an additional 1 minute of sieving does not change the mass on any individual sieve by more than 1.0 percent." This is also the criterion recommended in ASTM STP 447B.

The 15-minute minimum time was added to parallel Designation E-6 and USBR 5330.

Item 7. - Use of a mechanical sieving device or shaker.

A. As stated in USBR 5325:

"7. Apparatus"

* * * * *

"7.5 Sieving device. - A mechanical sieve shaker (fig. 1) that causes the particles to bounce and turn so that all particles have ample opportunities in various orientations to reach the sieve openings. The agitation of particles must be such that adequate sieving is reached within a reasonable time.

Adequate sieving is reached when an additional 1 minute of sieving does not change the mass on any of the sieves by more than 1.0 percent.

"The sieving device illustrated in USBR 5330 may be used except that it is generally impractical for maximum particle sizes of 1-1/2 inch (37.5 mm) and larger. Care must be taken not to overload the sieves (see subpar. 8.2.2)."

* * * * *

"12.0 Procedure"

* * * * *

"12.6.1 Hand sieving may be used; however, use of a mechanical sieving device is the most common and accepted method of performing this procedure. Hand sieving must be done in accordance with the directions in USBR 4136 or ASTM C 136. If hand sieving is used for part or all of this procedure, it should be noted on the data forms."

B. Discussion

Designation E-5 did not mention use of a mechanical device for sieving, although this is now the device most commonly used. Most other gradation procedures allow the use of a mechanical shaker although hand sieving is still regarded as the standard or "referee method" (ASTM, 1985b).

With mechanical devices for sieving readily available and commonly used, the art of hand sieving is most likely extinct and, with the attitude of today's worker, would be performed carefully and correctly only by the most diligent, conscientious person. Therefore, use of a mechanical sieving device is considered the standard method with hand sieving allowed for those circumstances when a mechanical device is not available.

The mechanical apparatus most commonly used is the Gilson type as illustrated in figure 1 in USBR 5325. The Gilson catalog describes the motion as essentially a vertical vibration. This is not the same action as obtained using the hand sieving method as described in ASTM STP 447B or in ASTM C 136. It is also not the same action as imparted by the device used for sieving sand-size particles such as the Ro-tap where a circular motion is combined with a tapping action, which is an action closer to the hand sieving procedure.

The only reference that describes a required action for a mechanical device is ASTM C 136, which states in 5.3: "A mechanical sieve shaker, if used, shall impart a vertical, or lateral and vertical, motion to the sieve, causing the particles thereon to bounce and turn so as to present different orientations to the sieving surface."

In ASTM D 422, C 136, and STP 447B, the adequacy of a mechanical device is judged by checking test results against hand sieving.

The rotary mechanical sieving device used for gradation analysis by the Geotechnical Branch at the Denver Office for many years, illustrated in figure 2 in USBR 5325, does not impart a vertical vibration to the soil particles. Further, the "mechanical sieving device" uses square aperture perforated steel plate for the sieve material rather than wire cloth as specified in all of the standards for gradation analysis of soil or concrete aggregates. There are no records of comparison of gradation results from this device with results from hand sieving or from a Gilson-type device.

There is an ASTM Standard (E 323, "Standard Specification for Perforated-Plate Sieves for Testing Purposes") which specifies plate opening dimensions so that perforated plate openings can be checked against standard values (ASTM, 1986d). However, the opening dimensions and allowable tolerances are different from those specified in ASTM E 11 for wire-cloth sieves (ASTM, 1986a).

Since the device used in the Denver Office is unique, the gradation results may not duplicate results obtained in other laboratories.

Discussions during the preparation of USBR 5325 led to the decision that the rotary mechanical sieving device in the Denver Office laboratory may only be used to separate soil into plus No. 4 and minus No. 4 sieve-size quantities and that gradation of the gravel-size particles will be determined using a Gilson-type sieving device.

USBR 5330

Performing Gradation Analysis of Fines and Sand-Size Fraction of Soils, Including Hydrometer Analysis

Designation E-6, "Gradation Analysis of Soils," in the Second Edition of the *Earth Manual* was the previous version of this test procedure. The following lists summarize the differences in the procedure as presented in the Second and Third Editions. A detailed discussion of each item follows the summary.

Changes to the procedure as presented in the Second Edition were:

1. Hydrometer calibration presented in separate procedure USBR 1405, "Calibrating Hydrometers."
2. Dispersing agent and its preparation changed.
3. Minimum soaking time changed from 18 to 16 hours.
4. Synthetic analysis incorporated into USBR 5205.
5. Gradation plot reversed and particle diameters changed.

The following are items that were added to USBR 5330 that were not mentioned in Designation E-6:

6. Apparatus and fluids must remain at fairly constant temperature during test.
7. Discussion of when and why to use air-dispersion method.
8. Use of a constant temperature water bath.
9. Use of different concentrations of dispersing agent.
10. Removed 0.5-minute reading from data sheet.
11. Established criteria for 7-hour 15-minute and 25-hour 45-minute readings.
12. Use alcohol to reduce foam when reading hydrometer.

Item 1. - Hydrometer calibration presented in separate procedure USBR 1405, "Calibrating Hydrometers."

The discussion in Designation E-6 on calibrating the hydrometers is presented in a separate procedure (USBR 1405), as were most calibrations, to emphasize the importance of calibration. A detailed discussion of USBR 1405 is presented later in this report.

Item 2. - Dispersing agent and its preparation changed.

A. Elimination of "Calgon"

Although a dispersing agent was not listed under "Apparatus" in Designation E-6, the use of sodium metaphosphate or sodium hexametaphosphate was described in the procedure. However, in Designation E-4, "Lists of Laboratory Equipment," item 112 is described as "Dispersing agent, sodium metaphosphate, in granular or flaky form, commonly available in food stores under the trade name of Calgon." The use of Calgon was common and was discussed in Reclamation training classes in connection with Designation E-6.

In 1979, the use of Calgon was prohibited for Reclamation use when it was realized that its chemical composition had been modified from its earlier formulation (Bureau of Reclamation, 1979). A reagent grade of sodium hexametaphosphate available from chemical supply firms was specified in its place. A collection of documents related to the use of sodium hexametaphosphate as a dispersant is included as appendix A to this report.

B. Elimination of pH adjustment and setting maximum storage time of dispersing agent solution

Designation E-6 stated: "The stock solution should be prepared frequently (at least once a month) or adjusted to a pH (hydrogen-ion concentration) of 8 or 9 by adding sodium carbonate."

Although it is unclear why the pH of the dispersing agent was to be adjusted to 8 or 9 after a month's storage, it was probably due to chemical change with time. Some Reclamation field laboratories reported that the pH could never be adjusted to 8 or 9 because of the water they were using. Taken literally, the dispersing agent solution could be stored and used indefinitely as long as the pH was constantly adjusted. It is not known what effect adding sodium carbonate would have over a long period of time, but it was felt that the dispersing agent solution should be more standardized.

In a study conducted by the Geotechnical Branch at the Denver Office, it was determined (based on not adjusting the pH) that the dispersing agent solution should be stored no longer than 21 days if the storage temperature remained near 73 °F and no longer than 7 days if the storage temperature exceeded 73 °F (Rocklin, 1981).

Elimination of pH adjustment and setting of specified maximum storage times were directed to all Reclamation laboratories in 1981 (Bureau of Reclamation, 1981).

Item 3. - Minimum soaking time changed from 18 to 16 hours.

A. As stated in USBR 5330:

"10. Sampling, Test Specimens, and Test Units"

* * * * *

"10.5 Dispersion of soil specimen (mechanical stirring). -

"10.5.1 Place the soil specimen in an evaporating dish.

"10.5.2 Add 125 mL of a 4-percent sodium hexametaphosphate solution and enough distilled water to cover the soil.

"10.5.3 Soak the soil specimen in the sodium hexametaphosphate solution for a period of at least 16 hours.

"10.6 Dispersion of soil specimen (air dispersion). -

"10.6.1 Place the soil specimen into a hydrometer cylinder.

"10.6.2 Add 125 mL of 4-percent sodium hexametaphosphate solution to the hydrometer cylinder.

"10.6.3 Add enough distilled water to hydrometer cylinder to bring the volume to about 250 mL and stir.

"10.6.4 Soak the soil specimen in the sodium hexametaphosphate solution for a period of at least 16 hours."

B. Discussion

Designation E-6 stated that the soil specimen should soak in the dispersing agent solution for at least 18 hours. This was changed to 16 hours to conform with normal workday hours and with ASTM D 422. No reason for requiring 18 hours of soaking could be determined. A period of 16 hours is typically the difference between the end of an 8-hour workday and the beginning of the next. The soaking time requirement was therefore changed so that the next step in the procedure could begin immediately the next workday.

Item 4. - Synthetic analysis incorporated into USBR 5205.

Since synthetic gradation analysis (mathematically combining two or more gradation analyses or removal of a fraction of a gradation analysis) is used more for the preparation of soil for testing, it was more appropriate to include the discussion and instructions for synthetic analysis in USBR 5205.

Item 5. - Gradation plot reversed and particle diameters changed.

The gradation test plot was reversed so particle diameter values decrease from left to right, rather than increase as the trend in the technical literature seems to be in this fashion.

The diameters of the sieve-size openings in millimeters were changed to correspond with ASTM E 11-81, which was changed from E 11-70.

Item 6. - Apparatus and fluids must remain at a fairly constant temperature during test.

A. As stated in USBR 5330:

"7. Apparatus"

* * * * *

"7.5 Water bath (optional). - A water bath for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory constant temperature bath is an insulated tank with automatic temperature control that maintains the soil suspension at a convenient constant temperature at or near 68 °F (20 °C). Such a device is shown in figure 2. If a constant temperature water bath is not used, a water-filled container (such as an additional hydrometer cylinder) must be used to store the hydrometer between readings. The water in this storage cylinder must be at the same temperature as the solution in the test hydrometer cylinder."

* * * * *

"9. Precautions"

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"9.1.4 A temperature differential may create convection currents in the solution - in the hydrometer cylinder - that would affect the hydrometer reading. When the hydrometer is read during the test, it is important that the equipment and the fluids are all at the same temperature. The test should be performed away from sources of heat and/or cold such as direct sunlight or heating/air conditioning ducts."

* * * * *

"13. Procedure"

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"13.3 Place the dispersed soil specimen that was prepared according to subparagraph 10.5 into a hydrometer cylinder or take the hydrometer cylinder containing the specimen as prepared in subparagraph 10.6 and fill the cylinder

to a level approximately 2 inches (50 mm) below the 1000-mL mark with distilled water. The hydrometer cylinder and its contents, the constant temperature water bath (or extra hydrometer cylinder filled with water), and the hydrometer must all be at the same temperature before starting the test."

* * * * *

"13.8 Record the temperature of the liquid in the hydrometer cylinder to the nearest 0.5 °C at each hydrometer reading interval. Over the period of 60 minutes the temperature of the solution in the hydrometer cylinder must not vary by more than ± 2 °C. If it does, the test must be abandoned and started over.

"13.9 After the 4-minute reading, remove the hydrometer from the hydrometer cylinder after each reading and wash off the hydrometer in the constant temperature water bath. Place the hydrometer in the constant temperature water bath until it is needed for the next reading.

"NOTE 2. - If a constant temperature water bath is not available, the hydrometer is to be stored between readings in a water-filled hydrometer cylinder. The water is to be of the quality described in subparagraph 8.1. The water must be at the same temperature as the solution in the test hydrometer cylinder.

"13.10 Place the hydrometer in the hydrometer cylinder approximately 30 seconds before subsequent readings are to be taken.

"13.11 If the 60-minute reading indicates that 40 percent or more of the specimen is smaller than the 0.005-mm size, continue the test by taking temperature and hydrometer readings at 7-hour 15-minute and 25-hour 45-minute time intervals. If the 60-minute reading indicates that less than 40 percent of the specimen is smaller than the 0.005-mm size, the test is complete. (See subpars. 14.3 and 14.4 for the necessary calculations.) If the temperature is more than ± 2 °C from the last temperature reading, keep taking temperature readings over the next 30 minutes to ascertain whether the system was at equilibrium when the hydrometer reading was made. If more than ± 2 °C temperature change occurred in the 30-minute period, do not use the reading."

B. Discussion

Although most of the other standards and procedures reviewed (see Related References) stated that temperature fluctuation must be controlled during the test, an explanation of why this is important was presented in a laboratory manual (Casagrande and Fadum, 1940). On page 13 of this manual, it states: "Unsymmetrical heating causes convection currents which obviously affect the sedimentation process. It is important to keep the suspension out of direct sunlight and away from any local source of heat."

To prevent the possibility of convection currents, maintaining a constant temperature of all equipment and liquids for the duration of a test was emphasized in the procedure. Casagrande also stated on page 13: "The average temperature over a period of the test should not differ from the mean temperature by more than ± 2 °C in order not to cause an error in the determination of the grain diameter of more than 2%."

This advice was incorporated into the procedure by restricting the allowable temperature change of the liquid during the first 60 minutes (subpar. 13.8) and observing any temperature change during the time the 7-hour 15-minute and the 25-hour 45-minute readings were determined to ensure that these readings did not occur during a rapid temperature change.

The difference between a temperature change and a rapid temperature change must be clearly understood. If the apparatus and liquids are at a constant temperature when the reading is taken, the calibration of the hydrometer will take into account a different constant temperature than might exist at a different reading. What is to be prevented is a rapid temperature change that would cause convection currents to occur while the hydrometer is being read.

Although the temperature change of plus or minus 2 °C was based on Casagrande's comment, the time periods of the first 60 minutes and for a 30-minute period around the 7-hour 15-minute and 25-hour 45-minute reading were logical assumptions.

Item 7. - Discussion of when and why to use air-dispersion method.

A. As stated in USBR 5330:

"1. Scope"

* * * * *

"1.5 Two methods of dispersing the soil are provided (1) a mechanical stirring device, and (2) an air-dispersion tube. The air dispersion method must be specially requested or specified and its use noted on the test form (see subpar. 5.3)."

* * * * *

"5. Significance and Use"

* * * * *

"5.3 Normally, the mechanical stirring device is used to disperse the soil specimen. Its use may cause degradation of some soil particles. Performing the gradation analysis on a mechanically dispersed specimen and on an air-dispersed specimen may be useful in evaluating the durability and hardness of sand-size particles."

B. Discussion

Although Designation E-6 described the air-dispersion procedure, there is no mention of when or why air dispersion should be used. Comments were added to USBR 5330 under "Significance and Use" based on information in ASTM D 422 and Reclamation Report EM-618 (West and Jones, 1961).

Item 8. - Use of a constant temperature water bath.

A. As stated in USBR 5330:

"7. Apparatus"

* * * * *

"7.5 Water Bath (optional). - A water bath for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory constant temperature bath is an insulated tank with automatic temperature control that maintains the temperature of the suspension at a convenient constant temperature at or near 68 °F (20 °C). Such a device is shown on figure 2.

"If a constant temperature water bath is not used, a water- filled container (such as an additional hydrometer cylinder) must be used to store the hydrometer between readings. The water in this storage cylinder must be at the same temperature as the solution in the test hydrometer cylinder."

B. Discussion

Since a constant temperature water bath is used in the Geotechnical Branch laboratory at the Denver Office and its use is mentioned in ASTM D 422, it was added to the list of apparatus and mentioned during the procedure. The constant temperature water bath was made optional because most field laboratories do not have one; and with proper precautions as stated in this procedure (see item 8) and in USBR 1405, "Calibrating Hydrometers," it is convenient but not absolutely necessary.

Item 9. - Use of different concentrations of dispersing agent.

A. As stated in USBR 5330:

"8. Reagents and Materials"

* * * * *

"8.2 A 4-percent sodium hexametaphosphate solution is used to disperse the representative soil sample."

* * * * *

"8.4 In some circumstances, an 8- or 12-percent solution may be required as a dispersing agent. The following amounts of sodium hexametaphosphate are to be used for the required percent solution of sodium hexametaphosphate.

<u>"Solution desired, percent</u>	<u>Sodium hexametaphosphate required, g</u>
4	40
8	80
12	120

"8.5 If an 8- or 12-percent solution is required, the procedure outlined in subparagraph 8.3 is to be used along with the appropriate amount of sodium hexametaphosphate is given in subparagraph 8.4."

B. Discussion

During testing of soils for the Riverbank Stabilization Program for Grand Coulee Dam, significant anomalies were encountered for the hydrometer portion of the gradation analysis such as percent passing was greater than 100 percent and the minus No. 200 sieve gradation values did not match the plus No. 200 sieve gradation curve values. Some of the anomalies were taken care of by calculating the percent passing using Stokes law as presented in ASTM D 422 and others by using 8 and 12 percent solutions of dispersing agent. The justification for using these methods to address anomalies or if any comparative studies were performed was not documented.

However, other literature sources mention that different concentrations of dispersing agents or different dispersing agents may be necessary to properly disperse the soil before testing (Department of the Army, 1970; British Standards Institution, 1975).

C. Future changes

When or why different concentrations of dispersing agent should be used is not discussed in USBR 5330. Even though it is not commonly needed, possible use of different concentrations or different dispersing agents should be discussed briefly in the procedure and a more detailed discussion, along with information as stated in subparagraph 8.4 on procedure, should be covered in an appendix. These items will be addressed when USBR 5330-86 is revised.

Item 10. - Removed 0.5-minute reading from data sheet.

On the data sheet shown in Designation E-5 and referred to in Designation E-6, there is a space for a 0.5-minute reading, although neither Designation E-6 nor USBR 5330 procedure makes

reference to a 0.5-minute reading being required. ASTM D 422 does not require a 0.5-minute reading although it is mentioned in other procedures.

No documentation was located which discussed requirements for the 0.5-minute reading nor could anyone in the Geotechnical Branch recall having requested or needed the 0.5-minute reading. Reference to the 0.5-minute reading was, therefore, removed from the data sheet. If it is ever needed, it should be requested as a modification to the test.

Item 11. - Established criteria for 7-hour 15-minute and 25-hour 45-minute readings.

A. As stated in USBR 5330:

"13. Procedure"

* * * * *

"13.11 If the 60-minute reading indicates that 40 percent or more of the specimen is smaller than the 0.005-mm size, continue the test by taking temperature and hydrometer readings at 7-hour 15-minute and 25-hour 45-minute time intervals. If the 60-minute reading indicates that less than 40 percent of the specimen is smaller than the 0.005-mm size, the test is complete."

B. Discussion

The 40-percent passing 0.005-mm size at the 60-minute reading criterion was not included in Designation E-6. The decision to add this statement to USBR 5330 was made several years before the writing of this report, and although no one could remember exactly why it was added, it is much more economical to obtain the 7-hour 15-minute and 25-hour 45-minute data at that point in the test, since it is already set up and in progress, than to have to go back and obtain the data later.

The only data analysis involving determination of particle sizes smaller than 0.005 mm is for investigations of potentially expansive soil (see table 3, page 212 in Second Edition of the *Earth Manual*). If a soil is being tested for expansive potential, the 25-hour 45-minute reading is usually requested before the test starts.

Item 12. - Use alcohol to reduce foam when reading hydrometer.

A. As stated in USBR 5330:

"13. Procedure

"NOTE 1. - When the hydrometer is initially placed in the dispersed soil specimen, foam may appear round the hydrometer stem making it difficult to read. A few drops of alcohol can be added to remove the foam and aid in making an accurate reading of the hydrometer."

B. Discussion

This was not mentioned in Designation E-6, but its use has been practiced as long as personnel in the Geotechnical Branch could remember.

This comment was not found in any other discussion or test procedure reviewed.

USBR 5335

Performing Gradation Analysis of Soils Without Hydrometer - Wet Sieve

The instructions in Designation E-6 indicated that performing a hydrometer analysis on minus No. 4 material was a standard, routine part of the test procedure. However, the test is often performed to obtain the gradation of the sand sizes and to determine the percent passing the No. 200 sieve without obtaining gradation percentages of the soil smaller than the No. 200 sieve. While an exception to the procedure as described in Designation E-6 could be requested, the frequency of the exception would be such that it was deemed appropriate to prepare a separate test procedure.

The procedure is similar to USBR 5330 except that after the soil has soaked in the dispersing agent and has been dispersed, it is washed on a No. 200 sieve without performing the hydrometer analysis. The sand-size gradation is then obtained as described in USBR 5330.

The minimum soaking time in the dispersing agent was reduced from the 16 hours required in USBR 5330 to 2 hours for USBR 5335. The longer period is more desirable to help disperse the minus No. 200 sieve-size particles and is not necessary if the gradation of the minus No. 200 particles is not required.

Part B of Designation E-6, "Percentage of Gravel and Fines in Soil" was not included in USBR 5335. The Part B procedure in Designation E-6 is identical to Designation 16 in the Eighth Edition of the *Concrete Manual* except that a No. 4 sieve was added in order to determine gravel content (Bureau of Reclamation, 1975). This method of determining the percent of fines is also similar to ASTM C 117, D 1140, and AASHTO T 11. Rather than just reproduce one of these methods, it was felt appropriate to specify use of one of the ASTM methods or the AASHTO method when the need for such a test arises. It should be noted that C 117 is basically for concrete aggregates that contain few fines, and it prohibits the use of a dispersing agent. AASHTO T 11 is the same procedure but requires a dispersing agent. ASTM D 1140 does not mention a dispersing agent, and it addresses testing soils with much higher percentage of fines.

USBR 1405

Calibrating Hydrometers

The procedure for calibrating the hydrometer had been included in Designation E-6, "Gradation Analysis of Soils," in the Second Edition of the *Earth Manual*. As discussed in this report in USBR 5330, "Performing Gradation Analysis of Fines and Sand-Size Fraction of Soils, Including Hydrometer Analysis," a separate procedure (USBR 1405) for calibrating the hydrometer was prepared for the Third Edition. A draft version of the calibration procedure had been issued in an internal working document (Kaufman, 1984). There are some differences between the draft version and the Third Edition version, but these will not be addressed in this report.

The following lists summarize the differences in the procedure as presented in the Second and the Third Editions. A detailed discussion of each item follows the summary. Changes to the procedure as presented in the Second Edition were:

1. Eliminated correction for meniscus.
2. Eliminated calibrating hydrometer in distilled water to get separate temperature correction curve.
3. Defined calibration curve as straight line.
4. Made four determinations to establish calibration curve used instead of "several."
5. Made and recorded thermometer and hydrometer readings to the nearest 0.5 unit rather than 0.1.

The following are items that were added to USBR 1405 that were not mentioned in Designation E-6.

6. Hydrometer zero reading check.
7. Determination of table of calibration values.
8. Criteria for acceptability of calibration values.
9. Frequency of calibration.

Item 1. - Eliminated correction for meniscus.

Soil hydrometers are marked to read in grams of soil in suspension per liter of soil and distilled water. The hydrometer is graduated to read zero at the surface of distilled water at 20 °C. The water surface would be at the bottom of the meniscus formed by the water on the stem of the hydrometer. Since a solution of water and soil is generally opaque, the graduated mark on the stem of the hydrometer corresponding to the bottom of the meniscus cannot be read, and readings must be made at the top of the meniscus. In Designation E-6, a correction was determined to

account for the difference in the top and bottom of the meniscus, and that correction was applied to hydrometer readings made during the test.

However, the value used to calculate the amount of soil in suspension is a relative value between individual hydrometer readings with and without the soil in suspension. The value of the hydrometer reading without the soil in suspension is determined before the test by methods described in this calibration procedure. Since this value is subtracted from readings made during the test, both readings can be made at the top of the meniscus and a meniscus correction need not be made. The calibration procedure and the test procedure were both written so that all the readings are made at the top of the meniscus. This is also the approach used in ASTM D 422.

Item 2. - Eliminated calibrating hydrometer in distilled water to get separate temperature correction curve.

Designation E-6 describes obtaining separate "corrections" for temperature variation and for the dispersing agent. The two corrections (along with the meniscus correction described in item 1) were then combined for a total correction. However, the correction for temperature variation and dispersing agent can be obtained as one value without distinguishing between the two. Since the total correction is applied to hydrometer readings determined during the test, identifying separate corrections for temperature variation and dispersing agent is not necessary. This is also the approach used in ASTM D 422.

Thus, the calibration procedure consists of obtaining hydrometer readings at the top of the meniscus for a solution of dispersing agent in distilled water at different temperatures.

A calibration curve (or table) is then prepared relating hydrometer correction to temperature. The hydrometer correction value corresponding to the temperature during the test is then subtracted from the test hydrometer reading.

Item 3. - Defined calibration curve defined as straight line.

Designation E-6 described determining calibration "curves." The relationship between temperature and hydrometer correction is essentially nearly linear over the typical range of temperatures existing during the test. A constructed smooth curve will vary according to the individual drawing the curve. Since the hydrometer is only read to the nearest 0.5 unit (see item 5 discussion below), a straight line assumption results in correction values just as reliable as constructing a smooth curve. ASTM D 422 also assumes a straight-line relationship.

The straight line may either be constructed visually or by performing a linear regression analysis on the data.

Item 4. - Made four determinations to establish calibration curve used instead of "several."

Designation E-6 described obtaining "several" sets of temperature-hydrometer correction values in order to establish a calibration curve. ASTM D 422 requires that only two points be determined since only two are required to define a straight line. However, if one of the points is in error for some reason, an inaccurate calibration line would result. If three points are determined and they do not fall in a straight line, it is not known which point may be in error, and a fourth point would

be required to identify the error. Since the calibration temperatures cover the expected test temperature range, the fourth point would then have to be between the minimum and maximum temperatures used. Since a water bath is used to control the temperature of the hydrometer cylinder and its contents, it was felt that it would be simpler to require four data points initially so that the temperature could be raised in equal increments and thus eliminate the time involved to reduce the temperature to obtain a fourth and intermediate reading, particularly when an automatic temperature-controlled water bath is used.

Item 5. - Made and recorded thermometer and hydrometer readings to the nearest 0.5 unit rather than 0.1.

Designation E-6 contained an inconsistency. In the procedure, it was stated that the hydrometer was to be read to the nearest 0.5 gram per liter. However, figure 5-3 in Designation E-5, used to show example data for E-6, indicates hydrometer readings to the nearest 0.1 gram per liter. Also, in figure 5-3 the temperature is shown recorded to the nearest 0.1 °C; however, the apparatus section of Designation E-6 lists a thermometer graduated in 0.5 °C increments.

The hydrometer is graduated to 1 gram per liter. It is inappropriate to estimate the reading to 0.1 gram per liter; however, the reading can be reasonably estimated to 0.5 gram per liter. Since the thermometer recommended for this test is graduated to 0.5 °C, it is inappropriate to estimate the temperature to 0.1 °C.

Item 6. - Hydrometer zero reading check.

The soil hydrometer used by the Bureau of Reclamation (ASTM hydrometer No. 152H) is calibrated by the manufacturer to read 0 gram per liter in distilled water at 20 °C. The graduations are marked on a piece of paper inside the stem held in place with a spot of glue. However, with time this paper might slip up and down inside the stem. Since the hydrometer reading reflects how much of the stem is in the solution, a slipped paper results in erroneous readings.

Therefore, the zero reading of the hydrometer must be checked to ascertain whether the graduations are in the correct position. This is discussed in USBR 1405-86 in subparagraph 10.2.

ASTM E 100, "Specification for ASTM Hydrometers," states that the allowable error for the zero reading is plus or minus 1 graduation (± 1 g/mL). Theoretically, the hydrometer should float with the zero mark on the stem at the water surface when in distilled water at 20.0 °C; however, the zero reading could be from plus 1.0 to minus 1.0.

Since in the Reclamation procedure the zero reading check is made at the top of the meniscus (which is about 0.5 graduation mark above the water surface), the "zero reading check" reading must then be between plus 0.5 and minus 1.5. This should be checked upon receipt of the hydrometer to see if the hydrometer was properly calibrated by the manufacturer.

To check whether or not the paper may have slipped in the stem, the "zero reading check" must be performed annually or at any time the hydrometer readings are suspect.

Item 7. - Determination of table of calibration values.

Designation E-6 discusses the preparation of "correction" curves to obtain a hydrometer correction value for a given test temperature. It is more expedient for the test person to have a table of correction values prepared (see table 1 in USBR 1405). To calculate the values for the table, it is necessary to obtain the equation of the calibration line. The equation can be obtained if a linear regression analysis is performed on the data; or if the straight line was visually constructed, instructions are given in the calculations paragraph on how to determine the equation of the line.

The table of hydrometer corrections can be prepared using the directions in the calculations paragraph.

Item 8. - Criteria for acceptability of calibration values.

In case of an error in the determination of the data points needed to plot the calibration line, criteria were established to evaluate the validity of the data.

Since the hydrometer is read to the nearest 0.5 gram per liter, a reading should be accurate to plus or minus 0.5 gram per liter. Thus, the constructed straight line should pass within 0.5 gram per liter of any of the data points. A linear regression analysis would result in a correlation coefficient of plus or minus 0.95 or higher. If one point is in error and the criterion is not met, then the procedure states that the one point can be discarded (leaving three points) and the calibration line reconstructed and again evaluated for acceptability. If the criterion is still not met, the calibration procedure has probably been performed incorrectly and the whole procedure must be repeated until the criterion is met.

Item 9. - Frequency of calibration.

When a hydrometer is initially received, it should be calibrated to see if it is working properly.

The dispersing agent has the largest effect on the calibration. Therefore, the calibration must be performed for different dispersing agents, different concentrations of dispersing agent, or possibly when a new supply of dispersing agent is received, particularly if it is obtained from a different supplier.

If a temperature range is to be used during performance of the test that is outside the range previously calibrated, the calibration procedure should be performed in the new temperature range rather than extrapolating the previously determined curve.

BIBLIOGRAPHY

American Society for Testing and Materials, *Annual Book of ASTM Standards*, Section 4, Volume 04.02, Philadelphia, Pennsylvania, 1985a.

_____, *Manual on Test Sieving Methods*, Publication No. STP 447B, Philadelphia, Pennsylvania, 1985b.

_____, *Annual Book of ASTM Standards*, Section 4, Volume 04.02, Philadelphia, Pennsylvania, 1986a.

_____, *Annual Book of ASTM Standards*, Section 4, Volume 04.08, Philadelphia, Pennsylvania, 1986b.

_____, *Annual Book of ASTM Standards*, Section 14, Volume 14.01, Philadelphia, Pennsylvania, 1986c.

_____, *Annual Book of ASTM Standards*, Section 14, Volume 14.02, Philadelphia, Pennsylvania, 1986d.

British Standards Institution, *Methods of Test for Soils for Civil Engineering Purposes*, BS 1377:1975, London, 1975.

Bureau of Reclamation, Designation 16, "Percentage of Aggregate Passing No. 200 Screen," *Concrete Manual*, Eighth Edition, U.S. Government Printing Office, Washington, D.C., 1975.

_____, *Earth Manual*, 2d Ed., U.S. Government Printing Office, Washington, D.C., 1974.

_____, *Earth Manual*, 3d Ed., vol. II, U.S. Government Printing Office, Washington, D.C. (in preparation).

_____, Memorandum to All Regional Directors, Project Managers, Project Construction Engineers, Construction Engineers, from Acting Assistant Commissioner, E&R Center,. Subject: "Dispersing Agent for Use in the Gradation Analysis of Soils, Designation E-6, *Earth Manual*, Second Edition, 1974," August 1, 1979.

_____, "Revised Procedure for the Preparation and Storage of the Dispersing Solution for use in the Hydrometer Analysis," Technical Note No. 26, Denver, Colorado, October 20, 1981.

Casagrande, A. and R. E. Fadum, *Notes on Soil Testing for Engineering Purposes*, Soil Mechanics Series No. 8, Graduate School of Engineering Publication No. 268, January 1940.

Department of the Army, Laboratory Soils Testing, Appendix V: "Grain-Size Analysis," Engineering Manual EM 1110-2-1906, Office of the Chief of Engineers, Washington, D.C., November 1970.

Gilson Company, Inc., Gilson Laboratory Particle Size Equipment, Catalog 84-1, 1984.

Howard, A. K., *Minimum Test Specimen Mass for Gradation Analysis*, Report No. GR-88-2, Bureau of Reclamation, Denver, Colorado, January 1988. Also published in *Geotechnical Testing Journal*, GTJODJ, vol. 11, No. 3, September 1988.

Kaufman, L., "Calibration of Field Laboratory Soils Testing Equipment," Internal Document, U.S. Bureau of Reclamation, Denver, Colorado, January 1984.

Rocklin, Rob C., "Revised Procedure for the Preparation and Storage of the Dispersing Solution for use in the Hydrometer Analysis," Geotechnical Branch Reference No. 81-58, Internal Memorandum, Bureau of Reclamation, Denver, Colorado, September 15, 1981.

West, M. B., and C. W. Jones, *Comparison of Dispersion Methods for Soil Gradation Analysis*, Report No. EM-618, Bureau of Reclamation, Denver, Colorado, May 26, 1961.

RELATED REFERENCES

Bowles, J. E., *Engineering Properties of Soils and Their Measurements*, 2d Ed., McGraw-Hill Book Company, New York, 1978.

Dawson, R. F., *Laboratory Manual in Soil Mechanics*, Pitman Publishing Corporation, New York, 1954.

Head, K. H., *Manual of Soil Laboratory Testing*, Volume 1: Soil Classification and Compaction Tests, John Wiley & Sons, Inc., New York, 1980.

Lambe, T. W., *Soil Testing for Engineers*, John Wiley & Sons, Inc., New York, 1951.

APPENDIX A

**Documents relating to use of sodium hexametaphosphate as a dispersing agent
in the Bureau of Reclamation**

Comments and Letters to the Editor (Retyped from original)

"Calgon" No Longer Suitable

I would like to sound a warning regarding the continuous use of Calgon as the dispersing agent in grain size analyses of soils as it may cause serious errors (Tyner, E. H., 1939. Soil Sci. Soc. Am. Proc. 4:106-113.), technical grade Na-hexametaphosphate (NaPO_3)₆ was marketed under the commercial name of Calgon. As such it was cheaper than reagent grade chemicals and the small amounts of Na_2CO_3 added to it assured the desired high pH of the dispersing solution.

Being a slowly decomposing detergent, Calgon was eventually forced to change its formula, and did so without changing name or packaging. The currently marketed Calgon does not contain any soluble phosphates, and is hence no longer as effective for dispersing soils. Where such Calgon continues to be used for dispersion, and I have found several laboratories not being aware of the change in the content of the package, and the clay percentages obtained may be seriously in error and should be viewed with suspicion.

As pyrophosphates have been shown equally effective in dispersing soils (Lameris, C. L., 1964. Neth. J. Agric. Sci. 12:40-56), it is recommended that the more easily available Na-pyrophosphate ($\text{Na}_4\text{P}_2\text{O}_7$) be adopted for common use in mechanical analysis of soils and that the name Calgon be dropped from all instruction manuals. A solution concentration of 0.02N with regard to Na^+ and adjusted to pH 9.5-10.0 is suitable for most soils.

Received 11 Nov. 1975.

D. H. Yaalon

Department of Geology
The Hebrew University
Jerusalem, Israel

Soil Science Society of America Journal Vol. 41, p 450, 1977

Comments and Letters to the Editor (Retyped from original)

"Calgon" Still Suitable

Yaalon (1976) recently published a warning regarding the use of Calgon as a dispersing agent in mechanical analyses. It was correctly observed that the product sold under the commercial name of "Calgon" was unsuitable as a dispersant.

However, his conclusion that the formula was abandoned but that the name was retained is somewhat misleading. The old Calgon is still commercially available, but under the new trade name of "Instant-Calgon" (Calgon Company, P.O. Box 1346, Pittsburgh, PA 15230). This product contains over 90% Na-hexametaphosphate (NaPO_3)₆ and a small amount of Na_2CO_3 - NaHCO_3 buffer to assure a high pH.

It is available in 100 lb. bags which are more economical than the pyrophosphates recommended by Yaalon.

Received 27 Sept. 1976

P.L.M. Veneman

Department of Soil Science
University of Wisconsin
Madison, Wisconsin 53706

Literature Cited

1. Yaalon, D. H. 1976. "Calgon" No Longer Suitable. Soil Sci. Soc. Am. J. 40:333

(Retyped from original)

August 1, 1979

D-1541

Memorandum

To: All Regional Directors, Project Managers, Project Construction Engineers, Construction Engineers

From: Acting Assistant Commissioner - Engineering and Research, E&R Center

Subject: Dispersing Agent for Use in the Gradation Analysis of Soils, Designation E-6, Earth Manual, Second Edition, 1974

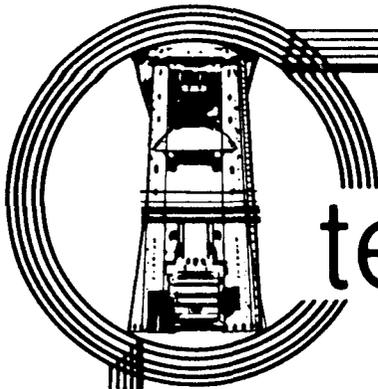
In 1961, the E&R Center issued a report entitled, "Investigation of Dispersing Agents for Gradation Analysis of Soils," Earth Laboratory Report No. EM-617, in which sodium hexametaphosphate was recommended for use as the dispersing agent for gradation analysis of soils. At that time, the chemical was readily available under the trade name of Calgon. Recently, it has come to our attention that the formula of Calgon has been changed to include sodium carbonate. Therefore, in order to conform with the requirements of Designation E-6, Gradation Analysis of Soils, all laboratories are hereby directed to discontinue the use of Calgon and use only the chemical, sodium hexamataphosphate.

Sodium hexametaphosphate is available in 100-pound bags from chemical and laboratory supply companies for about \$50 which would be sufficient for performing approximately 9,000 laboratory gradation tests. For laboratories requiring smaller quantities, the Geotechnical Branch, D-1540, at the E&R Center, Denver, Colorado, will supply the amount desired. Prior to using the chemical, the laboratory hydrometers will have to be recalibrated.

It is requested that copies of this letter be made available to field personnel engaged in soil testing. Any additional information can be obtained by contacting the E&R Center, attention: code D-1540, (303-234-3780).

(Signed) D. J. Duck

Copy to: Regional Engineers
Regional Geologists
Regional Planning Officers



technical note

Division of Research

Bureau of Reclamation

Technical Note No. 26

October 20, 1981

Revised Procedure for the Preparation and Storage of the Dispersing Solution for Use in the Hydrometer Analyses

At present, a 4 percent solution of sodium hexametaphosphate in distilled water is used as a dispersing agent when performing the hydrometer portion of the gradation procedure. The Earth Manual (Designation E-6) requires that the dispersing solution be prepared frequently or adjusted to a pH of 8 or 9 by adding sodium carbonate. This requirement was instituted because a solution of sodium hexametaphosphate in distilled water loses effectiveness as a dispersing agent when stored for long periods of time. Recent research conducted by the Geotechnical Branch indicates that the effectiveness of the dispersing solution is directly related to the storage time and to the temperature at which it is stored:

- When the dispersing solution is stored at room temperature (approximately 73 °F), the hydrometer analysis gives consistent results if the dispersing solution is stored for no more than 21 days prior to the testing.
- When the dispersing solution is stored at a high temperature (approximately 120 °F), the hydrometer analysis gives consistent results only if the solution is stored for 7 days or less.

As a result of this research, it is recommended that:

1. All laboratories store the dispersing solution for the hydrometer analysis no more than 21 days if the storage temperature will remain near room temperature (73 °F);
2. The dispersing solution be stored for no more than 7 days if the temperature will consistently exceed 73 °F;
3. Bottles containing the dispersing solution have the date of preparation marked on them;

4. The pH of the dispersing solution not be adjusted; and
5. Because sodium hexametaphosphate in powder, granular, or crystalline form is hygroscopic (absorbs moisture), the material should be stored in airtight containers.

Any questions or comments concerning the above guidelines should be directed to Robin C. Rocklin, E&R Center, Code D-1542, FTS 234-3299.

APPENDIX B

Copies of test procedures



PROCEDURE FOR PERFORMING GRADATION ANALYSIS OF GRAVEL SIZE FRACTION OF SOILS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 5325. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for performing gradation analysis of the gravel size fraction of soils. The term "gravel" refers to particles of rock that will pass a 3-inch (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve. The sieve sizes included in this designation are noted.

U.S.A. Standard series sieve	
mm	in
75	3
37.5	1-1/2
19.0	3/4
9.5	3/8
4.75	(No. 4)

2. Auxiliary Tests

2.1 A sample must be obtained in accordance with USBR 5205 prior to performing this procedure. The moisture content of the soil must be determined in accordance with USBR 5300 as part of this procedure.

3. Applicable Documents

- 3.1 *USBR Procedures:*
- USBR 1012 Calibrating Balances or Scales
 - USBR 1025 Checking Sieves
 - USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
 - USBR *4136 Sieve Analysis of Fine and Coarse Aggregates
 - USBR 5205 Preparing Soil Samples by Splitting or Quartering
 - USBR 5300 Determining Moisture Content of Soil and Rock by the Oven Method
 - USBR 5330 Performing Gradation Analysis of Fines and Sand Size Fraction of Soils, Including Hydrometer Analysis
 - USBR 5335 Performing Gradation Analysis of Soils Without Hydrometer-Wet Sieve

* *Concrete Manual*, Bureau of Reclamation, vol. 2, in press.

3.2 *ASTM Standards:*

- C 136 Standard Method for Sieve Analysis of Fine and Coarse Aggregates
- E 11 Specification for Wire-Cloth Sieves for Testing Purposes
- E 323 Specification for Perforated-Plate Sieves for Testing Purposes

4. Summary of Method

4.1 Soil is separated in sizes by a series of sieves of progressively smaller openings. The mass retained on each sieve is determined and the percent of the total sample mass passing each sieve is calculated.

5. Significance and Use

5.1 The percentage and distribution of particle sizes influence the strength, permeability, and compressibility of a soil mass. The amount of fines, sand (USBR 5330), and gravel (USBR 5325) are used to obtain gradation curves. These curves are widely used for identification and classification of soils and in the assessment of in-place characteristics of a soil mass.

6. Terminology

6.1 Definitions are in accordance with USBR 3900. Terms of particular significance are:

6.1.1 *Gradation.*—The proportions by mass of a soil or fragmented rock distributed in specified particle-size ranges (ASTM definition).

6.1.2 *Gradation Analysis.*—The process of determining gradation (ASTM).

6.1.3 *Gravel.*—Particles of rock that will pass a 3-inch (75-mm) U.S.A. Standard sieve and be retained on a No. 4 (4.75-mm) sieve.

6.2 Terms not included in USBR 3900 specific to this designation are:

6.2.1 *Maximum Particle Size.*—The largest particle in a soil sample as related to sieve openings of 3-, 1-1/2-, 3/4-, 3/8-inch or the No. 4 sieve. A maximum particle size of 1-1/2-inch means the largest particle passes a 1-1/2-inch sieve, but is retained on a 3/4-inch sieve.

6.2.2 *Pan*.— A pan used in a set (nest) of sieves placed beneath the smallest sieve size and used to collect the particles that pass the smallest sieve opening.

7. Apparatus

7.1 *Balance or Scale*.—A balance or scale of appropriate capacity for determining moisture content. The mass of the specimen can range from 200 g up to 35 kg or more depending on:

- Maximum particle size present
- Entire sample is tested
- Representative portion of sample tested

NOTE 1.—A typical set of balances or scales that would cover the requirements of this designation are:

Readable to	Approximate capacity
0.01 g	200 g*
0.1 g	1000 g*
1 g	20 kg
0.01 lbm	150 lbm

*Often same apparatus.

7.2 *Balance or Scale*.—A typical balance or scale used to measure the mass of soil particles retained on each sieve must be readable to 0.01 lbm (0.1 kg or 10 g) and have a capacity of about 150 lbm (80 kg).

7.3 *Sieves*.—U.S.A. Standard series 3-, 1-1/2-, 3/4-, 3/8-inch, and No. 4 (75-, 37.5-, 19.0-, 9.5-, 4.75-mm) sieves, conforming to the requirements of ASTM E 11 or ASTM E 323.

7.4 *Cans, Containers, or Bags*.—Suitable metal can, container, or bag for sample storage and containers for measurements of mass, as required.

7.5 *Sieving Device*.—A mechanical sieve shaker (fig. 1) that causes the particles to bounce and turn so that all particles have ample opportunities in various orientations to reach the sieve openings. The agitation of particles must be such that adequate sieving is reached within a reasonable time. Adequate sieving is reached when an additional 1 minute of sieving does not change the mass on any of the sieves by more than 1.0 percent.

The sieving device illustrated in USBR 5330 may be used except that it is generally impractical for maximum particle sizes of 1-1/2 inch and larger. Care must be taken not to overload the sieves (see subpar. 8.2.2).

7.6 *Separating Device* (Optional).—A device such as shown on figure 2 may be used for separating soils on the No. 4 sieve. This device should not be used to perform a gradation analysis.

8. Precautions

8.1 Safety Precautions:

8.1.1 Appropriate personal protective apparel are to be worn when handling the sample and during operation of the sieving device.

8.1.2 Ear protection should be worn during operation of the mechanical sieving device.

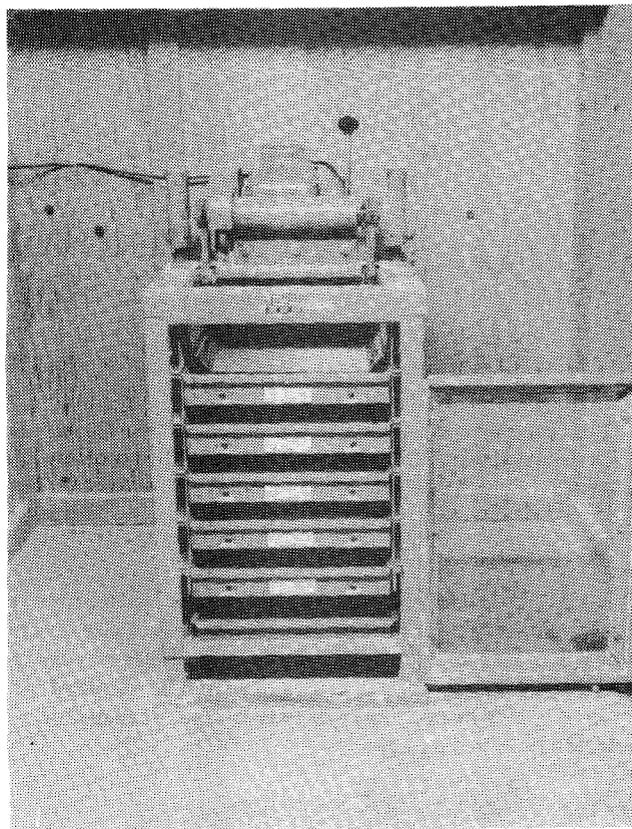


Figure 1. — Mechanical sieve shaker.

8.2 Technical Precautions.—

8.2.1 Due to the effects of sampling, handling, processing, and testing on some materials, results of this test may not reflect in-place conditions or the properties of the material caused by processing and placement during construction. Of particular concern are materials such as soft and/or friable decomposed granite, sandstone, shale, limestone, claystone, etc., or soils affected by air and/or oven drying. Such materials must be identified before processing and the person requesting the test should verify whether standard procedures are to be followed, whether modifications are appropriate, or whether the material should be processed and tested at all. Cautionary statements must be made on data forms and in reporting the test data.

8.2.2 Care must be taken to prevent overloading the sieves.

8.2.2.1 The total quantity of material to be sieved must be limited so that on a given sieve all the particles have an opportunity to reach sieve openings a number of times during the sieving operation. As a rule, if the material retained on a sieve at the completion of testing is spread out evenly over the area of the sieve, the layer of material should not be more than one particle thick.

8.2.2.2 For wire cloth sieves, the load on the cloth must never be so great that permanent deformation of the cloth occurs. This should be checked visually to avoid overloading the sieve.

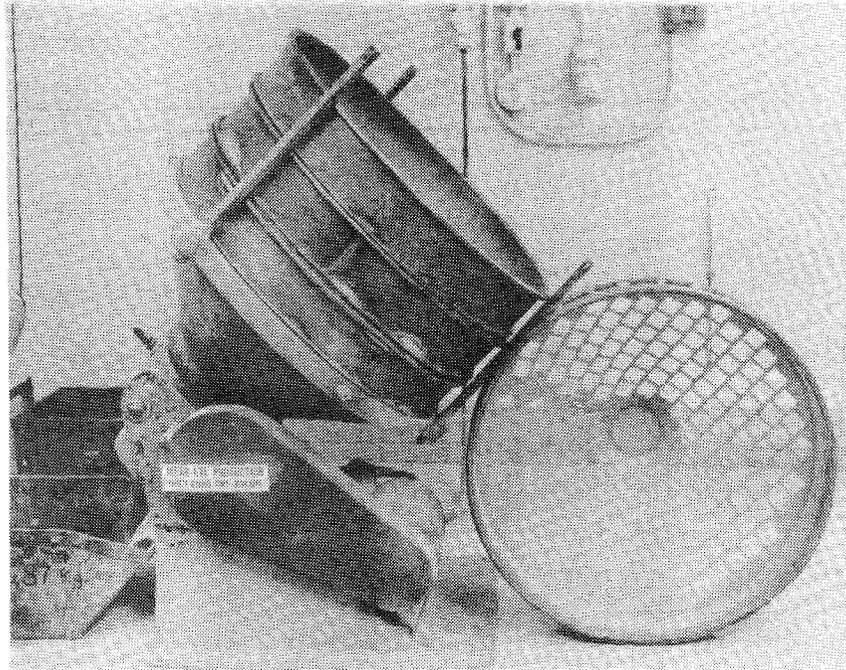


Figure 2. – Separating device.

9. Sampling, Test Specimens, and Test Units

9.1 Sample Preparation:

9.1.1 Prepare a test sample of minus 3-inch material in accordance with USBR 5205. The mass of the specimen to be tested depends on the maximum particle size present in the soil as follows:

Maximum particle size		Minimum dry mass of test specimen	
in	mm	lbm	kg
3/8	9.5	0.5*	0.25*
3/4	19.0	2.5*	1.1*
1-1/2	37.5	20	10
3	75	150	70

* For the equipment typically used in this procedure, a test specimen mass of at least 10 lbm (4.5 kg) is recommended (see sub-par. 12.2.2).

These values are in terms of dry mass. Values for wet mass of the specimen will have to be adjusted based on an estimated moisture content.

10. Calibration and Standardization

10.1 Verify that equipment is currently calibrated in accordance with the applicable calibration procedure. If the calibration is not current, perform the calibration before using the equipment for this procedure.

USBR 1012 Calibrating Balances or Scales

USBR 1025 Checking Sieves

11. Conditioning

11.1 Before a soil can be separated by sieving, it must be at a moisture content such that soil lumps and/or

individual soil particles will be free flowing and such that the soil can be separated by the sieving process.

11.1.1 Preparation of a sample in accordance with USBR 5205 will normally result in an appropriate moisture content for sieving.

11.1.2 If the entire amount of soil available is to be tested and is not reduced in size in accordance with USBR 5205, the soil must be conditioned to the appropriate moisture content in accordance with USBR 5205.

11.1.3 For soils to be tested at their natural moisture content, the test specimen should be separated on a No. 4 sieve with the minus No. 4 material not allowed to become drier than the natural moisture content. The plus No. 4 material can then be conditioned and tested in accordance with this designation. However, the dry mass of the minus No. 4 material must be determined and added to the dry mass of the total specimen as determined in this procedure.

12. Procedure

12.1 All data are to be recorded on a "Gradation Analysis" form as shown on figure 3 or 4.

12.2 For a specimen mass of 10 lbm (4.5 kg) or larger, all measurements of mass are to be determined and recorded to the nearest 0.01 lbm (0.01 kg).

12.2.1 A minimum specimen mass of 10 lbm (4.5 kg) is recommended when the mechanical sieving device, shown on figure 1, is used in combination with a balance or scale readable to 0.01 lbm (0.01 kg).

12.2.2 The required minimum specimen mass is 0.5 lbm for soil having a maximum particle size of 3/8-inch, and 2.5 lbm for a maximum particle size of 3/4 inch. If for some reason the specimen mass for these soils is less than 10 lbm, other combinations of sieving equipment (such as described in USBR 5330) and balances and scales

7-1451 (9-86) Bureau of Reclamation	GRADATION ANALYSIS	Designation USBR 5325-89 Designation USBR 5330- Designation USBR 5335- ---
SAMPLE NO. Example	PROJECT	FEATURE
AREA (individual)	EXC. NO.	DEPTH

GRADATION OF GRAVEL SIZES							
TESTED AND COMPUTED BY	DATE	% MOISTURE CONTENT OF + NO. 4 assumed 1.8			WET MASS OF TOTAL SPECIMEN 162.07		
CHECKED BY	DATE	% MOISTURE CONTENT OF - NO. 4 12.3			TOTAL DRY MASS OF SPECIMEN 149.47		
SIEVE SIZE		3" (75 mm)	1-1/2" (37.5 mm)	3/4" (19.0 mm)	3/8" (9.5 mm)	NO. 4 (4.75 mm)	PAN
MASS OF CONTAINER AND RETAINED MATERIAL			18.94	33.33	24.23	28.28	124.94
MASS OF CONTAINER			12.21	12.21	12.21	12.21	18.81
WET MASS RETAINED			6.73	21.12	12.02	16.07	106.13
DRY MASS RETAINED			6.61	20.75	11.81	15.79	94.51
DRY MASS PASSING		149.47	142.86	122.11	110.30	94.51	<input checked="" type="checkbox"/> lbm <input type="checkbox"/> kg <input type="checkbox"/> g
% OF TOTAL PASSING		100.0	95.6	81.7	73.8	63.2	

GRADATION OF SAND SIZES							
DRY MASS OF SPECIMEN		g		FACTOR = $\frac{\% \text{ TOTAL PASSING NO. 4}}{\text{DRY MASS OF SPECIMEN}}$			
DISH NO.		DRY MASS OF SPECIMEN (SIEVED)					
SIEVING TIME			DATE				
SIEVE NO.	MASS RETAINED (g)	MASS PASSING (g)	FACTOR X MASS PASSING = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS	
8						2.36 mm	
16						1.18 mm	
30						600 μm	
50						300 μm	
100						150 μm	
200						75 μm	
PAN			TESTED AND COMPUTED BY		DATE	CHECKED BY	DATE
TOTAL							

HYDROMETER ANALYSIS									
HYDROMETER NO.				DISPERSING AGENT					
STARTING TIME			DATE		AMOUNT mL				
TIME	TEMP °C	HYD READ	HYD CORR	CORR READ	FACTOR X CORRECT READ = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS	
1 min								37 μm	
4 min								19 μm	
19 min								9 μm	
60 min								5 μm	AUXILIARY TESTS: USBR 5205-8 9 USBR 5300-8 9
7 h 15 min*								2 μm	
25 h 45 min*								1 μm	
TESTED AND COMPUTED BY			DATE		CHECKED BY		DATE		

*Not required for standard test.

Figure 3. - Gradation analysis (individual method) — example.

7-1451 (9-86) Bureau of Reclamation		GRADATION ANALYSIS				Designation USBR 5325-89 Designation USBR 5330- Designation USBR 5335-		
SAMPLE NO. Example		PROJECT		FEATURE				
AREA (cumulative)		EXC. NO.		DEPTH				
GRADATION OF GRAVEL SIZES								
TESTED AND COMPUTED BY		DATE	% MOISTURE CONTENT OF + NO. 4 assumed 1.8			WET MASS OF TOTAL SPECIMEN 162.07		
CHECKED BY		DATE	% MOISTURE CONTENT OF - NO. 4 12.3			TOTAL DRY MASS OF SPECIMEN 149.47		
SIEVE SIZE		3" (75 mm)	1-1/2" (37.5 mm)	3/4" (19.0 mm)	3/8" (9.5 mm)	NO. 4 (4.75 mm)	PAN	
MASS OF CONTAINER AND RETAINED MATERIAL			18.94	40.06	52.08	68.15	124.94	
MASS OF CONTAINER			12.21	12.21	12.21	12.21	18.81	
WET MASS RETAINED			6.73	27.85	39.87	55.94	106.13	
DRY MASS RETAINED			6.61	27.36	39.17	54.95	94.51	
DRY MASS PASSING		149.47	142.86	122.11	110.30	94.52	<input checked="" type="checkbox"/> lbm <input type="checkbox"/> kg <input type="checkbox"/> g	
% OF TOTAL PASSING		100.0	95.6	81.7	73.8	63.2		
GRADATION OF SAND SIZES								
DRY MASS OF SPECIMEN		g FACTOR = $\frac{\% \text{ TOTAL PASSING NO. 4}}{\text{DRY MASS OF SPECIMEN}}$ =						
DISH NO.		DRY MASS OF SPECIMEN (SIEVED)						
SIEVING TIME				DATE				
SIEVE NO.	MASS RETAINED (g)	MASS PASSING (g)	FACTOR X MASS PASSING = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS		
8					2.36 mm			
16					1.18 mm			
30					600 μm			
50					300 μm			
100					150 μm			
200					75 μm			
PAN			TESTED AND COMPUTED BY		DATE	CHECKED BY		
TOTAL					DATE			
HYDROMETER ANALYSIS								
HYDROMETER NO.				DISPERSING AGENT				
STARTING TIME			DATE	AMOUNT mL				
TIME	TEMP °C	HYD READ	HYD CORR	CORR READ	FACTOR X CORRECT READ = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
1 min							37 μm	
4 min							19 μm	
19 min							9 μm	
60 min							5 μm	AUXILIARY TESTS: USBR 5205-89 USBR 5300-89
7 h 15 min*							2 μm	
25 h 45 min*							1 μm	
TESTED AND COMPUTED BY			DATE	CHECKED BY			DATE	

*Not required for standard test.

Figure 4. - Gradation analysis (cumulative method) — example.

may be used. In this case, a balance or scale must be used such that the mass is determined and recorded to at least 0.1 percent of the total specimen mass.

12.3 Determine and record the *wet mass of total specimen* (or dry mass, if appropriate — see notes 2 and 3).

NOTE 2.—In this designation, “wet mass” refers to material that has not been oven-dried and “dry mass” to material that has been oven-dried or the dry mass calculated.

NOTE 3.—The gradation analysis may be performed on oven-dried material. In this case, substitute “dry mass” for “wet mass” in this designation and disregard the steps pertaining to determining moisture content and calculating the dry mass. The data should be recorded in the spaces on the form for “dry mass.”

12.4 Separation of specimen prior to sieving:

12.4.1 If the amount of material to be tested is greater than the capacity of the sieving equipment (do not overload the sieves), divide the specimen into appropriate portions for testing. For each portion, follow the steps in subparagraphs 12.5 through 12.11. Calculate the sum of the wet masses retained on each sieve and in the pan, and record as wet mass retained for each sieve size and in the pan and proceed with subparagraph 12.12.

12.4.2 Alternately, if the amount of material to be tested is greater than the capacity of the sieving equipment or to not overload the sieves, the specimen may be separated using a No. 4 sieve prior to testing. Separation on the No. 4 sieve also may be necessary for (1) testing the minus No. 4 portion of a soil before or during the testing of the plus No. 4, (2) convenience of test scheduling, or (3) when the plus No. 4 particles need to be soaked in water (see subpar. 12.7.1). The wet mass of the separated minus No. 4 material must be determined and then added to the wet mass of any minus No. 4 particles collected and measured during the sieving of the plus No. 4 material.

12.5 Assemble the set (nest) of sieves to be used in order of decreasing size of opening from top to bottom and place in the sieving device. The sieves may be the standard set as described in subparagraph 7.3, or others as required by the specifications covering the material to be tested. If desired, sieves coarser than the maximum particle size may be omitted from the set. However, a sieve at least one size larger than the anticipated maximum particle size should be included in the set. Additional sieve sizes may be added to restrict the amount of material on a particular sieve (see subpar. 12.4.1) or to protect individual sieves from excessive wear.

12.6 Place the soil specimen on the top sieve and turn on the sieving device. To avoid overloading the top sieve, it may be necessary to feed the soil onto the top sieve gradually. Sieve the material for about 15 minutes, or longer if necessary, to separate all the material. A satisfactory end-point is considered to have been reached when an additional one minute of sieving does not change the mass on any individual sieve by more than 1.0 percent.

12.6.1 Hand sieving may be used; however, use of a mechanical sieving device is the most common and accepted method of performing this procedure. Hand

sieving must be done in accordance with the directions in USBR 4136 or ASTM C 136. If hand sieving is used for part or all of this procedure, it should be noted on the data forms.

12.7 Any significant amount of minus No. 4 particles adhering to the plus No. 4 particles must be brushed or wiped off and placed in the minus No. 4 fraction.

12.7.1 If the minus No. 4 material cannot be easily removed from the plus No. 4 particles, the plus No. 4 particles should be soaked and/or washed on a No. 4 sieve until all minus No. 4 material is removed. If tests are to be performed on the minus No. 4 material, the minus No. 4 particles must be collected and added to the minus No. 4 material and thoroughly mixed in. The plus No. 4 material must then be rescreened.

12.8 Determine and record the *mass of container(s)* to be used.

12.9 Starting with the coarsest sieve, remove all particles retained on each sieve and place in the container(s). Determine and record the *mass of container and retained material*. The mass may be determined and recorded as the mass for each individual sieve size (fig. 3) or as the mass on a cumulative basis (fig. 4). When removing the particles, take care to avoid permanent deformation of sieve openings or the sieve cloth.

12.10 Remove all particles retained in the pan and place into a container. Determine and record the *mass of container and retained material*.

12.11 Calculate and record the *wet mass retained* on each sieve size (individual or cumulative) and in the pan by subtracting the *mass of container* from the *mass of container and retained material*.

NOTE 4.—As a check, the sum of the *wet mass retained* on each sieve (or cumulative on the No. 4 sieve) and the *wet mass retained* in the pan should be about equal to the *wet mass of total specimen*.

12.12 Determine and record to the nearest 0.1 percent the moisture content of the plus No. 4 material and the moisture content of the minus No. 4 material in accordance with USBR 5300.

12.12.1 A moisture content may be assumed for the plus No. 4 material if previous tests on similar material have been performed and the value is relatively constant. Note on the form that the value is *assumed*.

12.13 Using the moisture content of the plus No. 4 material and the wet mass retained, calculate and record the *dry mass retained* on each sieve (individual or cumulative).

12.14 Using the moisture content of the minus No. 4 material and the wet mass of soil retained in the pan (passing the No. 4 sieve), calculate and record the *dry mass retained* in the pan.

12.15 Calculate and record the *total dry mass of specimen* by one of the following methods:

12.15.1 Mass determined for each individual sieve (fig. 3).—Calculate the sum of the *dry mass retained* on each sieve and in the pan. Also, record this value as *dry mass passing* under the 3-inch sieve size column (or under

the column for the next larger sieve size than the sieve size on which particles were retained).

12.15.2 Mass determined on cumulative basis (fig. 4).—Calculate the sum of the *dry mass retained* on the No. 4 sieve and the *dry mass retained* in the pan.

12.16 Calculate and record the *dry mass passing* each sieve by one of the following methods.

12.16.1 Mass determined for each individual sieve (fig. 3).—Starting with the coarsest sieve on which particles were retained, calculate the *dry mass passing* each sieve by subtracting the *dry mass retained* from the *dry mass passing* the next larger size sieve.

12.16.2 Mass determined on cumulative basis (fig. 4).—Calculate the *dry mass passing* each sieve by subtracting the *dry mass retained* from the *dry mass of total specimen*.

NOTE 5.—As a check, the *dry mass passing* the No. 4 sieve must equal (± 0.01 lbm or kg) the *dry mass retained* in the pan.

12.17 Calculate and record to the nearest 0.1 percent the *percent of total passing* each sieve. Record 100.0 percent in the sieve size column that is one sieve size larger than the coarsest sieve size on which material was retained.

12.18 If required, plot the results as shown on figure 5. Typically, this procedure is performed in conjunction with USBR 5330 or 5335 to determine the gradation of the minus No. 4 material and the plot is prepared after the minus No. 4 gradation has been determined.

13. Calculations

13.1 Calculate the percent of total passing for each sieve using the following expression:

$$\text{Percent of total passing} = 100 \left(\frac{\text{dry mass passing}}{\text{total dry mass of specimen}} \right)$$

14. Report

14.1 The report is to consist of a completed and checked "Gradation Analysis" form (fig. 3 or 4).

14.2 All calculations are to show a checkmark.

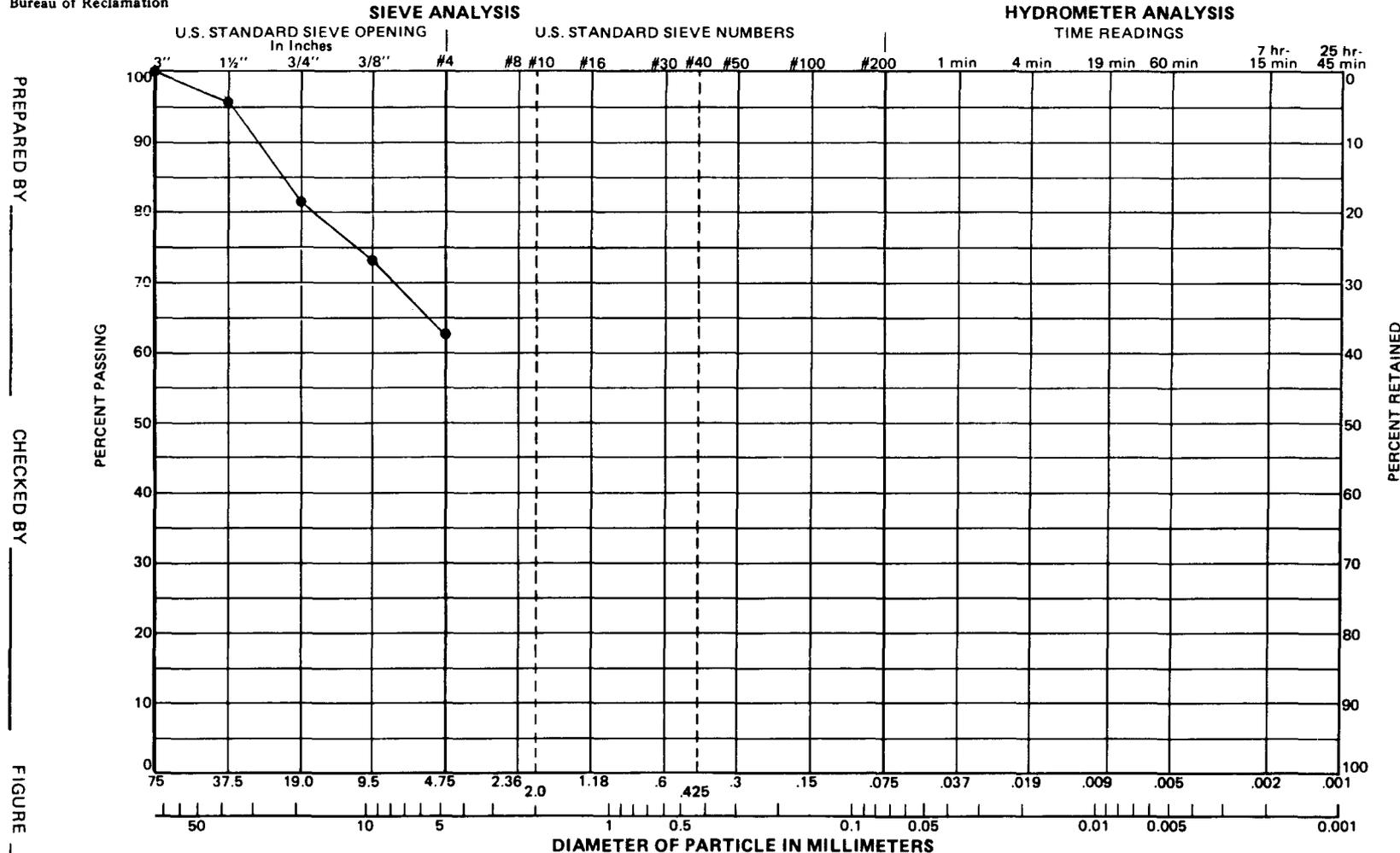
14.3 If required, the results are to be plotted as shown on the "Gradation Test" form (fig. 5).

14.4 For reports, summary tables, etc., the gradation percentages are generally reported to the nearest 1 percent. The percentages may be reported as either percent passing or percent retained.

14.5 In many cases, the gradation is reported in terms of percent gravel, percent sand, and percent fines. The percentages must add to 100 percent. Due to rounding, the total may be either 99 or 101 percent; 1 percent must be added to or subtracted from the component (gravel, sand, or fines) with the largest percentage so the total is 100 percent. If the percentages, when rounded to the nearest 1 percent are equal, make the adjustment to the coarser component.

GRADATION TEST

Designation USBR 5325- 89



PREPARED BY _____
 CHECKED BY _____
 FIGURE _____

GRAVEL		SAND			FINES
COARSE	FINE	COARSE	MEDIUM	FINE	

SAMPLE NO.	HOLE NO.	ELEV. OR DEPTH <input type="checkbox"/> ft <input type="checkbox"/> m	UNIFIED SOIL CLASSIFICATION			ATTERBERG LIMITS			SPECIFIC GRAVITY		NOTES: Example
			GROUP SYMBOL	% GRAVEL	% SAND	% FINES	LL (%)	PI (%)	SL (%)	MINUS NO. 4	

Figure 5. - Gradation test — example plot.



PROCEDURE FOR

PERFORMING GRADATION ANALYSIS OF FINES AND SAND SIZE FRACTION OF SOILS, INCLUDING HYDROMETER ANALYSIS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, Code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 5330. The number immediately following the designation indicates the year of acceptance or the year of last revision.

The method is similar to ASTM D 422-63, the principal difference being the sieve sizes used and the separation on the No. 4 instead of No. 10 sieve (4.75 and 2.00 mm) for the hydrometer test.

1. Scope

1.1 This designation outlines the procedure for performing gradation analysis of fines and sand size fraction of soils, including hydrometer analysis. It is used for the quantitative determination of distribution of particle sizes in soils.

1.2 The distribution of particle sizes larger than retained on the No. 200 sieve (75 μm) is determined by sieving, while the distribution of particle sizes smaller than No. 200 is determined by a sedimentation process, using a hydrometer to secure the necessary data.

1.3 If gravel size particles were present in the original soil sample, this test is usually performed in conjunction with USBR 5325.

1.4 If the particle size distribution of the minus No. 200 (75 μm) sieve size soil is not required, USBR 5335 may be used in place of this designation.

1.5 Two methods of dispersing the soil are provided (1) a mechanical stirring device, and (2) an air dispersion tube. The air dispersion method must be specially requested or specified and its use noted on the test form (see subpar. 5.3).

2. Auxiliary Tests

2.1 A soil sample must be prepared in accordance with USBR 5205 prior to performing this procedure.

3. Applicable Documents

3.1 *USBR Procedures:*

- USBR 1012 Calibrating Balances or Scales
- USBR 1020 Calibrating Ovens
- USBR 1025 Checking Sieves
- USBR 1405 Calibrating Hydrometers
- USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
- USBR *4136 Sieve Analysis of Fine and Coarse Aggregates

USBR 5205 Preparing Soil Samples by Splitting or Quartering

USBR 5325 Performing Gradation Analysis of Gravel Size Fraction of Soils

USBR 5335 Performing Gradation Analysis of Soils Without Hydrometer-Wet Sieve

3.2 *ASTM Standards:*

C 136 Standard Method for Sieve Analysis of Fine and Coarse Aggregates

E 1 ASTM Thermometers

E 11 Specification for Wire-Cloth Sieves for Testing Purposes

E 100 Specification for ASTM Hydrometers

D 422 Standard Method for Particle-Size Analysis of Soils

4. Summary of Method

4.1 A sample of minus No. 4 (4.75-mm) material is prepared and placed in a dispersing agent (usually sodium hexametaphosphate) for a period of at least 16 hours. Then it is mixed thoroughly and placed in a 1000-mL hydrometer cylinder and filled with distilled water. Hydrometer readings are taken at time intervals of 1, 4, 19, and 60 minutes after the beginning of sedimentation.

For soils with a high percentage of very small particles, readings are also taken at time intervals of 7 hours 15 minutes, and 25 hours 45 minutes after the beginning of sedimentation.

4.2 After completion of the hydrometer analysis, the material is washed on a 200-mesh sieve. The fraction retained on the No. 200 sieve is oven-dried and separated on the following sieves. (The sieving is done using a powered sieve shaker.)

U.S.A. Standard series sieves

No. 8	2.36 mm
No. 16	1.18 mm
No. 30	600 μm
No. 50	300 μm
No. 100	150 μm
No. 200	75 μm

* *Concrete Manual*, Bureau of Reclamation, vol. 2, in press.

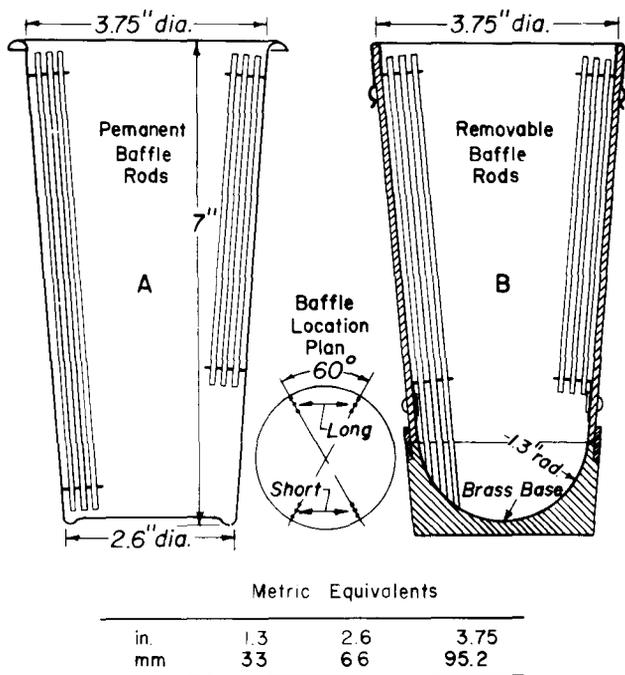


Figure 1. - Dispersion cup designs [ASTM D 422].

in the air line when not in use. Otherwise, the water must be blown out of the air line before using for dispersion purposes.

7.18 *Graduated Cylinder*.—250 mL capacity, graduated in 2 mL divisions or other suitable container or method to measure 125 mL of the dispersing agent solution.

8. Reagents and Materials

8.1 Distilled water is to be used whenever water is called for in this procedure except for water in the water bath or when washing the specimen on a No. 200 sieve. Tapwater that is free of acids, alkalies, or oils and suitable for drinking may be used to fill the tank, provided the water is changed regularly (about once per week).

8.2 A 4-percent sodium hexametaphosphate solution is used to disperse the representative soil sample.

8.3 To prepare a 4-percent sodium hexametaphosphate solution, the following procedure is to be followed:

8.3.1 Fill a 1000-mL hydrometer cylinder with distilled water to approximately 750 mL.

8.3.2 Obtain 40 grams of sodium hexametaphosphate and place into the dispersion cup. Add approximately 100 mL of distilled water to the sodium hexametaphosphate. Mix the sodium hexametaphosphate and water for 5 minutes using the malt mixer or until the sodium hexametaphosphate is completely dissolved.

8.3.3 Add the solution from the dispersion cup to the hydrometer cylinder. Fill the hydrometer cylinder to the 1000-mL line with distilled water. Insert the rubber stopper and securely place it on top of the hydrometer cylinder. With one hand over the top of the hydrometer cylinder and the other on the bottom, shake the hydrometer cylinder to thoroughly mix the solution.

8.4 In some instances, an 8- or 12-percent solution may be required as a dispersing agent. The following amounts of sodium hexametaphosphate are used for the required percent solution of sodium hexametaphosphate.

Solution required, percent	Sodium hexametaphosphate required, grams
4	40
8	80
12	120

8.5 If an 8- or 12-percent solution is required, the procedure outlined in subparagraph 8.3 is to be used along with the appropriate amount of sodium hexametaphosphate as given in subparagraph 8.4.

8.6 A prepared sodium hexametaphosphate solution may be stored for no more than 21 days if the storage temperature remains near room temperature of 73 °F (23 °C), and for no more than 7 days if the temperature of the storage area consistently exceeds 73 °F.

8.7 All containers of the dispersing solution must have the date of preparation and percent solution marked on them.

9. Precautions

9.1 Technical Precautions:

9.1.1 Ensure that the hydrometer is clean, especially the reading portion of the stem, by washing the hydrometer with soapy water, then rinsing it with alcohol and again in clean water.

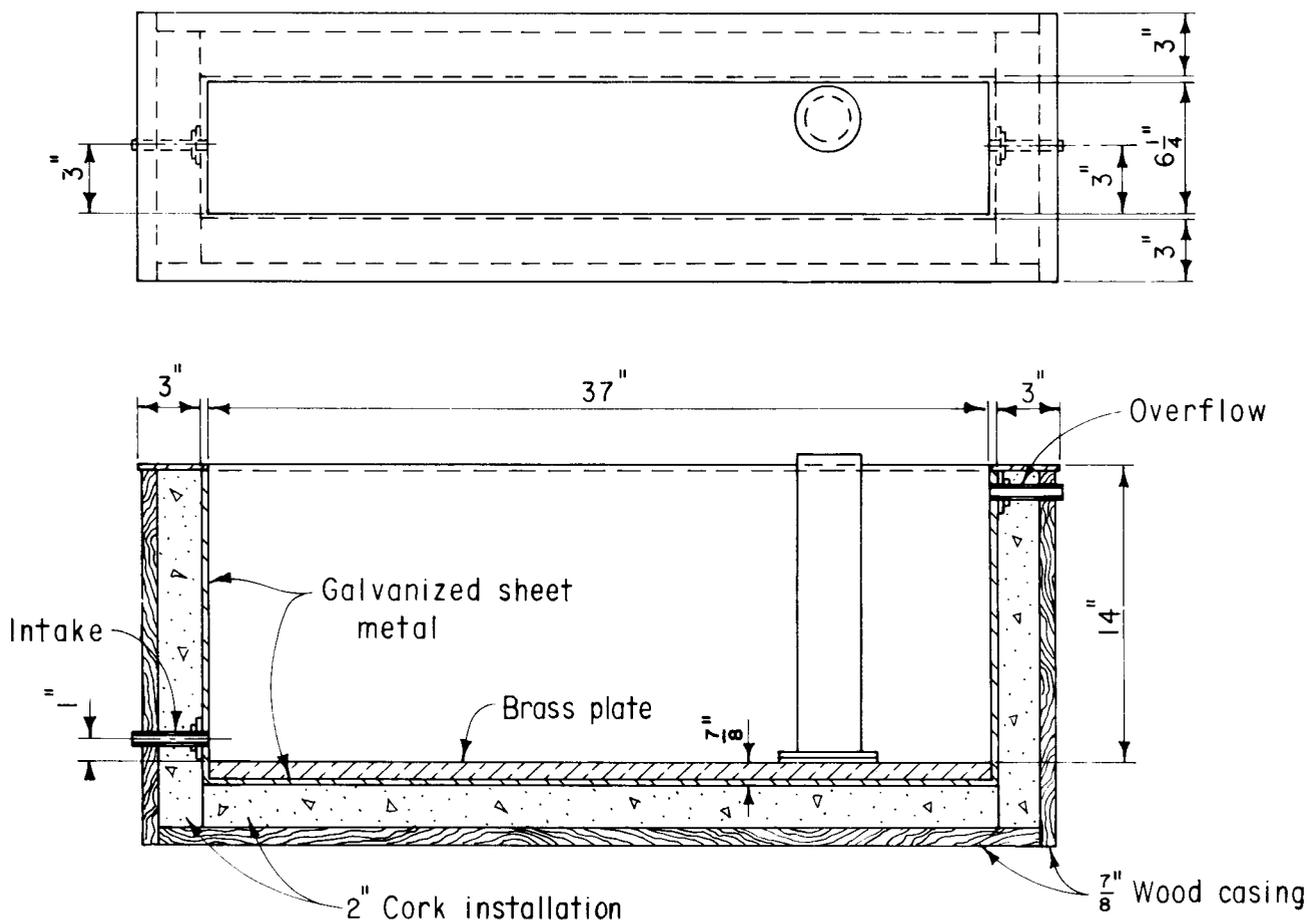
9.1.2 Because sodium hexametaphosphate in powder, granular, or crystalline form absorbs moisture, the material must be stored in airtight containers.

9.1.3 Due to the effects of sampling, handling, processing, and testing on some materials, results of this test may not reflect in-place conditions or the properties of the material caused by processing and placement during construction. Of particular concern are materials such as soft and/or friable decomposed granite, sandstone, shale, limestone, claystone, etc., or soils affected by air and/or overdrying. Such materials must be identified before processing and the person requesting the test should verify whether standard procedures are to be followed, whether modifications are appropriate, or whether the material should be processed and tested at all. Cautionary statements must be made on test data forms and in reporting the test data.

9.1.4 A temperature differential may create convection currents in the solution—in the hydrometer cylinder—that would affect the hydrometer reading. When the hydrometer is read during the test, it is important that the equipment and the fluids are all at the same temperature. The test should be performed away from sources of heat or cold such as direct sunlight or heating/air conditioning vents.

10. Sampling, Test Specimens, and Test Units

10.1 Prepare a test sample of approximately 500 grams of minus No. 4 (4.75-mm) material in accordance with



Metric Equivalents

in.	$\frac{7}{8}$	1	3	$6\frac{1}{4}$	14	37
mm	22.2	25.4	76.2	158.2	356	940

Figure 2. - Constant temperature bath [ASTM D 422].

USBR 5205. If 500 grams of soil is not available, obtain at least enough soil to have an oven-dried test specimen that meets the requirements of subparagraph 10.3.

10.2 Place the test sample into a suitable container and oven-dry the sample for a minimum of 16 hours.

10.3 Thoroughly mix the soil and obtain a specimen of approximately 100 grams for sandy soils and about 50 grams for silty or clayey soils by splitting in accordance with USBR 5205. Determine the mass of the specimen to the nearest 0.1 g and record on the "Gradation Analysis" form as shown on figure 5.

10.4 The test specimen must be dispersed in accordance with either subparagraph 10.5 or 10.6 (see subpar. 5.3). If the air dispersion method is used, it must be noted on the test form.

10.5 *Dispersion of Soil Specimen (mechanical stirring):*

10.5.1 Place the soil specimen in an evaporating dish.

10.5.2 Add 125 mL of 4-percent sodium hexametaphosphate solution and enough distilled water to cover the soil.

10.5.3 Soak the soil specimen in the sodium hexametaphosphate solution for a period of at least 16 hours.

10.5.4 Wash the specimen into a dispersion cup with distilled water.

10.5.5 Continue adding distilled water until the dispersion cup is within 2 inches (50 mm) of being filled.

10.5.6 Mix the contents of the dispersion cup using the malt mixer for 1 minute.

10.6 *Dispersion of Soil Specimen (air dispersion):*

4.3 After sedimentation and sieving, the percentage of particles passing specified sizes are calculated, recorded, and plotted.

5. Significance and Use

5.1 Gradation is a descriptive term which refers to the proportions by dry mass of a soil or fragmented rock distributed in specified particle-size ranges.

5.2 The gradation of a soil gives an indication of the engineering properties of the soil. Permeability, compressibility, and shear strength are all influenced by the gradation characteristics of a soil mass. Therefore, reliable determination of the amount of fines, sand, and gravel in a representative soil sample is of extreme importance for design considerations.

5.3 Normally, the mechanical stirring device is used to disperse the soil specimen. Its use may cause degradation of some soil particles. Performing the gradation analysis on a mechanically dispersed specimen and on an air-dispersed specimen may be useful in evaluating the durability and hardness of sand size particles.

6. Terminology

6.1 Definitions are in accordance with USBR 3900. Terms of particular significance are:

6.1.1 *Dispersing Agent*.—An agent used to assist in separating individual fine soil particles and to prevent them from flocculating when in suspension.

6.1.2 *Fines*.—Portion of soil finer than a No. 200 (75 μm) U.S.A. Standard sieve (ASTM definition).

6.1.3 *Gradation*.—The proportions by mass of a soil or fragmented rock distributed in specified particle-size ranges (ASTM).

6.1.4 *Gradation Analysis*.—The process of determining gradation (ASTM).

7. Apparatus

7.1 *Balance or Scale*.—A typical balance or scale used for this designation must be readable to 0.1 g and have a capacity of about 500 g.

7.2 *Soil Hydrometer*.—A soil hydrometer, graduated to read in grams per liter of suspension and conforming to the requirements for hydrometer 152H in ASTM E 100.

7.3 *Hydrometer Cylinder*.—A glass cylinder essentially 18 inches in height and 2-1/2 inches (457- by 64-mm) in diameter, and marked for a volume of 1000 mL. The inside diameter is to be such that the 1000-mL mark is 14 ± 1 inch (355 ± 25 mm) from the bottom of the inside.

7.4 *Stirring Apparatus* (malt mixer).—A mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10,000 revolutions per minute without load. The shaft should be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber. The shaft is to be of such a length that the stirring paddle will operate not less than 1-1/2 inches (38 mm) above the bottom of the

dispersion cup. A special dispersion cup conforming to either of the designs shown on figure 1 should be used.

7.5 *Water Bath* (optional).—A water bath for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory constant temperature bath is an insulated tank with automatic temperature control that maintains the soil suspension at a convenient constant temperature at or near 68 °F (20 °C). Such a device is shown on figure 2. If a constant temperature water bath is not used, a water-filled container (such as an additional hydrometer cylinder) must be used to store the hydrometer between readings. The water in this storage cylinder must be at the same temperature as the solution in the test hydrometer cylinder.

7.6 *Thermometer*.—0 to 50 °C range, 0.5° divisions, conforming to the requirements of ASTM E 1.

7.7 *Rubber Stopper*.—An appropriate size rubber stopper to adequately seal the hydrometer cylinder.

7.8 *Sodium Hexametaphosphate*.—A chemical agent in powder, crystal, or granular form, used as a dispersing agent, of technical grade or better.

7.9 *Evaporating Dish*.—A porcelain evaporating dish, 300-mL capacity, approximately 4-1/2 inches in diameter by 2 inches (115 by 50 mm) deep.

7.10 *Tubing*.—Flexible tubing of sufficient length and diameter to direct the flow of water for washing the soil specimen through a No. 200 (75- μm) sieve.

7.11 *Timing Device*.—A clock or stopwatch with a second hand.

7.12 *Sieve Set*.—A set of sieves, of square-mesh, woven-wire cloth, conforming to the requirements of ASTM E 11. A full set of sieves includes the following:

A lid	
No. 8	2.36 mm
No. 16	1.18 mm
No. 30	600 μm
No. 50	300 μm
No. 100	150 μm
No. 200	75 μm
A pan	

7.13 *Washing Sieve*.—No. 200 washing sieve may be fabricated, or 8-inch (203-mm) brass No. 200 sieve may be used.

7.14 *Sieve Shaker*.—A motor-driven electric sieve shaker, equipped with timer as shown on figure 3, should be used.

7.15 *Brush*.—A fine brass wire brush used for removing soil from the sieves and pan.

7.16 *Drying Oven*.—An oven, thermostatically controlled, preferably of the forced-draft type, and capable of maintaining a uniform temperature of 230 ± 9 °F (110 ± 5 °C) throughout the drying chamber.

7.17 *Air Dispersion Tube and Air Supply*.—An air dispersion tube conforming to the requirements of figure 4. The air supply must be capable of producing 2 cubic feet per minute for each dispersion tube. A water trap on the air line may be useful to remove water that condenses

7-1451 (9-86) Bureau of Reclamation	GRADATION ANALYSIS	Designation USBR 5325-__ Designation USBR 5330- 89 Designation USBR 5335-__
SAMPLE NO.	PROJECT	FEATURE
AREA	EXC. NO.	DEPTH

GRADATION OF GRAVEL SIZES						
TESTED AND COMPUTED BY	DATE	% MOISTURE CONTENT OF + NO. 4			WET MASS OF TOTAL SPECIMEN	
CHECKED BY	DATE	% MOISTURE CONTENT OF - NO. 4			TOTAL DRY MASS OF SPECIMEN	
SIEVE SIZE		3" (75 mm)	1-1/2" (37.5 mm)	3/4" (19.0 mm)	3/8" (9.5 mm)	NO. 4 (4.75 mm)
MASS OF CONTAINER AND RETAINED MATERIAL						
MASS OF CONTAINER						
WET MASS RETAINED						
DRY MASS RETAINED						
DRY MASS PASSING		(example from U.S.B.R. 5325)				<input type="checkbox"/> lbm <input type="checkbox"/> kg <input type="checkbox"/> g
% OF TOTAL PASSING		100.0	95.6	81.7	73.8	63.2

GRADATION OF SAND SIZES						
DRY MASS OF SPECIMEN		59.1	g	FACTOR =	% TOTAL PASSING NO. 4	63.2
					DRY MASS OF SPECIMEN	59.1
						1.069
DISH NO.	17	DRY MASS OF SPECIMEN (SIEVED)				
		39.2				
SIEVING TIME	15 min.			DATE		
SIEVE NO.	MASS RETAINED (g)	MASS PASSING (g)	FACTOR X MASS PASSING = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS
8	3.4	55.7		59.5	2.36 mm	
16	8.3	50.8		54.3	1.18 mm	
30	14.2	44.9		48.0	600 μm	
50	22.1	37.0		39.6	300 μm	
100	30.8	28.3		30.3	150 μm	
200	39.0	20.1		21.5	75 μm	
PAN	0.1			TESTED AND COMPUTED BY	DATE	CHECKED BY
						DATE
TOTAL	39.1					

HYDROMETER ANALYSIS							
HYDROMETER NO.			DISPERSING AGENT				
189			Sodium Hexametaphosphate 4%				
STARTING TIME		DATE			AMOUNT		
10:15					125 mL		
TIME	TEMP °C	HYD READ	HYD CORR	CORR READ	FACTOR X CORRECT READ = % OF TOTAL PASSING	% OF TOTAL PASSING	
						PARTICLE DIAMETER	REMARKS
1 min	27.0	16.5	3.5	13.0		13.9	37 μm
4 min	27.0	11.0	3.5	7.5		8.0	19 μm
19 min	27.0	8.0	3.5	4.5		4.8	9 μm
60 min	27.0	6.5	3.5	3.0		3.2	5 μm
7 h 15 min*							2 μm
25 h 45 min*						1 μm	
TESTED AND COMPUTED BY		DATE		CHECKED BY			
				DATE			

*Not required for standard test.

Figure 5. - Gradation analysis — example.

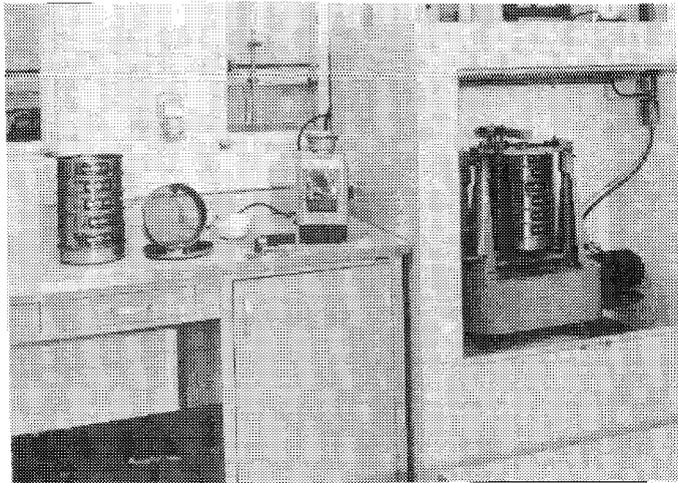


Figure 3. – Sieve analysis equipment.

10.6.1 Place the soil specimen into a hydrometer cylinder.

10.6.2 Add 125 mL of 4-percent sodium hexametaphosphate solution to the hydrometer cylinder.

10.6.3 Add enough distilled water to the hydrometer cylinder to bring the volume to about 250 mL and stir.

10.6.4 Soak the soil specimen in the sodium hexametaphosphate solution for a period of at least 16 hours.

10.6.5 Turn on the air supply to the air dispersion tube so there is a small air pressure (about 1 to 2 lbf/in²) and insert the tube into the hydrometer cylinder.

10.6.6 Increase the air pressure to about 15 lbf/in² and let the mixture disperse for 10 minutes. Occasionally rinse the sides of the cylinder with distilled water. For some soils containing coarse sand particles, it may be necessary to increase the air pressure to adequately agitate and disperse the particles.

10.6.7 Decrease the air pressure to a very low pressure and slowly withdraw the air dispersion tube. Rinse the tube with distilled water as it is being withdrawn and rinse the sides of the hydrometer cylinder.

11. Calibration and Standardization

11.1 Verify that equipment is currently calibrated in accordance with the applicable calibration procedure. If the calibration is not current, perform the calibration before using the equipment for this procedure.

USBR 1012 Calibrating Balance or Scales

USBR 1020 Calibrating Ovens

USBR 1025 Checking Sieves

USBR 1405 Calibrating Hydrometers

12. Conditioning

12.1 A water bath is recommended for maintaining the soil suspension at a constant temperature during the hydrometer analysis.

12.2 The temperature of the soil suspension and water bath should be checked to ensure that they remain within

the range of temperatures bracketed during calibration of the hydrometer (USBR 1405).

13. Procedure

13.1 All data are to be recorded on the "Gradation Analysis" form as shown on figure 5.

13.2 Record the hydrometer number.

13.3 Place the dispersed soil specimen that was prepared according to subparagraph 10.5 into a hydrometer cylinder or take the hydrometer cylinder containing the specimen as prepared in subparagraph 10.6 and fill the cylinder to a level approximately 2 inches (50 mm) below the 1000-mL mark with distilled water. The hydrometer cylinder and its contents, the constant temperature water bath (or extra hydrometer cylinder filled with water), and the hydrometer must all be at the same temperature before starting the test.

13.4 Place a rubber stopper over the mouth of the hydrometer cylinder. With one hand over the top of the hydrometer cylinder and the other on the hydrometer cylinder bottom, thoroughly mix the contents by turning the cylinder end over end for 1 minute.

13.5 Place the hydrometer cylinder into the constant temperature water bath (if available) and start the timing device.

13.6 Remove the stopper and quickly and carefully wash into the cylinder—with distilled water—any soil that may be present on the stopper or along the top of hydrometer cylinder. The water level should be approximately at the 1000-mL mark.

13.7 Carefully place the hydrometer into the hydrometer cylinder. Record hydrometer readings after elapsed times of 1, 4, 19, and 60 minutes. The hydrometer is read to the nearest 0.5 gram per liter at the top of the meniscus formed by the suspension around its stem.

NOTE 1.—When the hydrometer is initially placed in the dispersed soil specimen, foam may appear round the hydrometer stem making it difficult to read. A few drops of alcohol can be added to remove the foam and aid in making an accurate reading of the hydrometer.

13.8 Record the temperature of the liquid in the hydrometer cylinder to the nearest 0.5 °C at each hydrometer reading interval. Over the period of 60 minutes the temperature of the solution in the hydrometer cylinder must not vary by more than ±2 °C. If it does, the test must be abandoned and started over.

13.9 After the 4-minute reading, remove the hydrometer from the hydrometer cylinder after each reading and wash off the hydrometer in the constant temperature water bath. Place the hydrometer in the constant temperature water bath until it is needed for the next reading.

NOTE 2.—If a constant temperature water bath is not available, the hydrometer is to be stored between readings in a water-filled hydrometer cylinder. The water is to be of the quality described in subparagraph 8.1. The water must be at the same temperature as the solution in the test hydrometer cylinder.

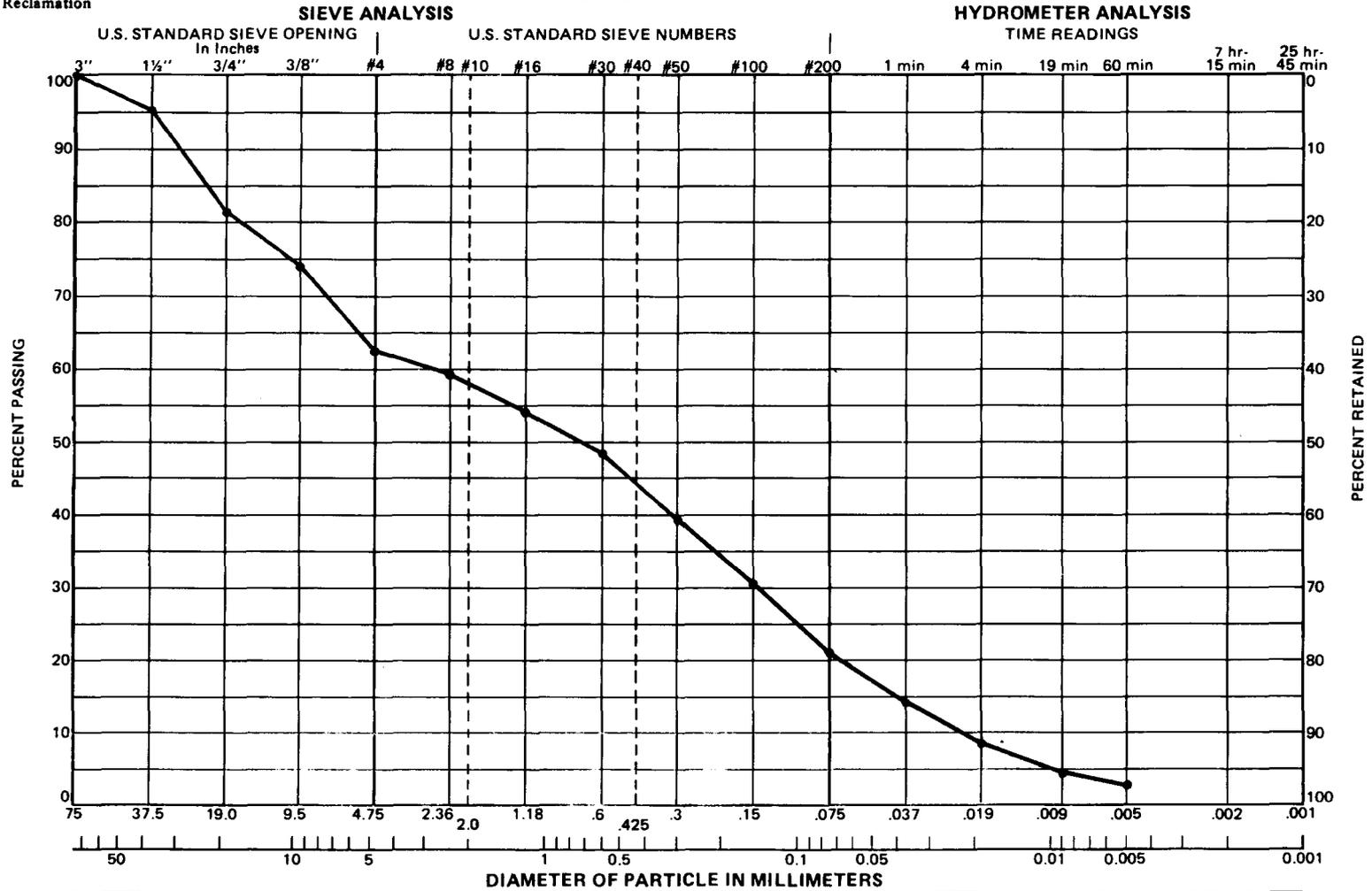
GRADATION TEST

Designation USBR 5330 - 89

PREPARED BY _____

CHECKED BY _____

FIGURE _____



GRAVEL		SAND			FINES	
COARSE	FINE	COARSE	MEDIUM	FINE		

SAMPLE NO.	HOLE NO.	ELEV. OR DEPTH □ft □m	UNIFIED SOIL CLASSIFICATION			ATTERBERG LIMITS			SPECIFIC GRAVITY		NOTES: Example
			GROUP SYMBOL	% GRAVEL	% SAND	% FINES	LL (%)	PI (%)	SL (%)	MINUS NO. 4	

Figure 6. - Gradation test — gradation analysis data plot — example.

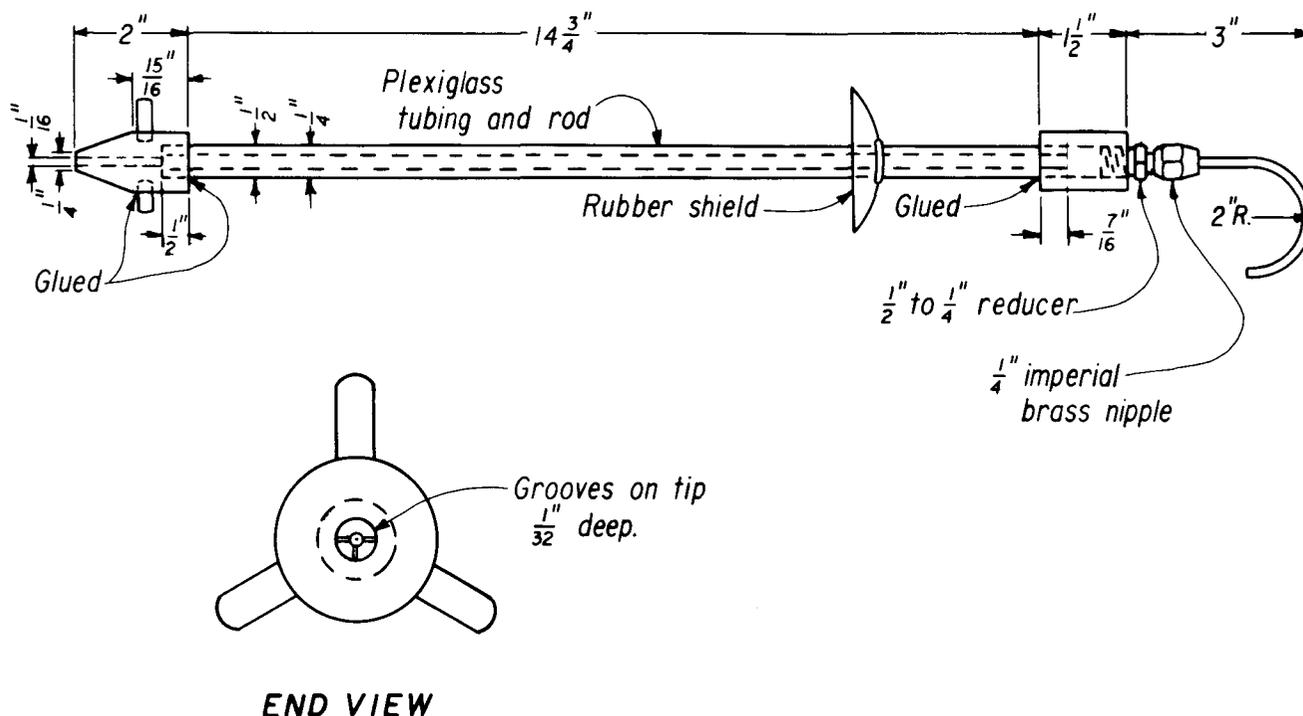


Figure 4. - Air dispersion tube. 101-D-523

13.10 Place the hydrometer in the hydrometer cylinder approximately 30 seconds before subsequent readings are to be taken.

13.11 If the 60-minute reading indicates that 40 percent or more of the specimen is smaller than the 0.005-mm size, continue the test by taking temperature and hydrometer readings at 7-hour 15-minute and 25-hour and 45-minute time intervals. If the 60-minute reading indicates that less than 40 percent of the specimen is smaller than the 0.005-mm size, the test is complete. (See subpars. 14.3 and 14.4 for the necessary calculations.) If the temperature is more than ± 2 °C from the last temperature reading, keep taking temperature readings over the next 30 minutes to ascertain whether the system was at equilibrium when the hydrometer reading was made. If more than ± 2 °C temperature change occurred in the 30-minute period, do not use the reading.

13.12 After the hydrometer readings have been completed, carefully wash the soil specimen on a No. 200 sieve until all fines are removed.

13.13 Pour the remaining soil into an evaporating dish and decant excess water.

13.14 Place the evaporating dish into an oven at 230 ± 9 °F (110 ± 5 °C) and dry for 16 hours.

13.15 Remove the specimen from the oven after 16 hours and obtain the dry mass of the specimen.

13.16 Place the specimen into the top sieve of a sieve set and place the lid on the top sieve. Place the sieve set into a sieve shaker. The sieve set should consist of the six sizes noted in subparagraph 7.12.

13.16.1 Hand sieving may be used; however, use of a mechanical sieving device is the most common and

accepted method of performing this procedure. Hand sieving must be done in accordance with the directions in USBR 4136 or ASTM C 136. If hand sieving is used for part or all of this procedure, it should be noted on the data forms.

13.17 Sieve the soil specimen for approximately 15 minutes using the powered sieve shaker and record the mass of the soil retained on each sieve to the nearest 0.1 gram as shown on figure 5.

13.18 Calculate and record to 0.1 percent the percent of total soil mass passing each size for both the hydrometer and sieve analysis.

13.19 Plot the percent of total mass passing versus the particle diameter as shown on figure 6.

14. Calculations

14.1 Computations required on the "Gradation Analysis" form are divided into three parts:

- Gradation of gravel sizes
- Gradation of sand sizes
- Hydrometer analysis

14.2 *Gradation of Gravel Sizes.*—The method and calculations required to determine the percentages and distribution of particles larger than the No. 4 sieve size are outlined in USBR 5325.

14.3 *Gradation of Sand Sizes:*

14.3.1 Calculate the factor used to compute the percentage of the total sample mass passing a given sieve or the percentage of the total sample mass smaller than a given particle size as follows:

$$F = \frac{W_1 \%}{W} \quad (1)$$

where:

- F = percent factor, %/g (record to 0.001)
- W_1 % = percent of total sample mass passing the No. 4 (4.75-mm) sieve
- W = total dry mass of minus No. 4 sample, g

14.3.2 Calculate the mass of soil passing each sieve using the following expression:

$$\text{Dry mass passing, g} = \frac{\text{dry mass of sample, g} - \text{dry mass retained, g}}{F} \quad (2)$$

14.3.3 Calculate the “% of total passing” each sieve by multiplying the mass passing each sieve, “mass passing,” on the form by the factor F calculated in accordance with subparagraph 14.3.1.

14.4 *Hydrometer Analysis:*

14.4.1 The hydrometer reading obtained is corrected using the following expression:

$$(1) = (2) - (3) \quad (3)$$

where:

- (1) = corrected hydrometer reading
- (2) = hydrometer reading obtained from test
- (3) = hydrometer correction obtained from USBR 1405

NOTE 3.—The hydrometer correction value can be either positive or negative. Care should be taken when applying this correction to ensure that the proper mathematical sign is used.

14.4.2 Calculate the percentage of the total sample mass smaller than a given particle size.

$$(4) = F(1) \quad (4)$$

where:

- (4) = percent of total mass passing, %
- F = factor calculated in accordance with subparagraph 14.3.1
- (1) = corrected hydrometer reading

NOTE 4.—The results of several hundred tests on widely different soil types indicated that the maximum size particles in suspension for any given time of sedimentation varied over a comparatively narrow range, and was sufficiently independent of temperature, hydrometer reading, and soil type that the determination of the maximum particle size in suspension—based on hydrometer reading times—is sufficiently accurate for analyzing soils for construction purposes. If a more accurate particle size determination is desired, the method given in ASTM D 422 may be used.

15. Report

15.1 The report is to consist of the completed and checked:

- “Gradation Analysis” form (fig. 5).
- “Gradation Test” plot (fig. 6).

15.2 All calculations are to show a checkmark and all plotting must be checked.

15.3 For reports, summary tables, etc., the gradation percentages are generally reported to the nearest 1 percent. The percentages may be reported as either percent passing or percent retained.

15.4 In many cases, the gradation is reported in terms of percent gravel, percent sand, and percent fines. The percentages must add to 100 percent. Due to rounding, the total may be either 99 or 101 percent; 1 percent must be added to or subtracted from the component (gravel, sand, or fines) with the largest percentage so the total is 100 percent. If the percentages, when rounded to the nearest 1 percent are equal, make the adjustment to the coarser component.

APPENDIX

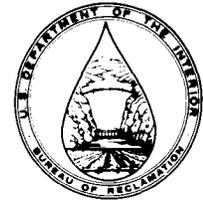
X1. COMMENTS ON CERTAIN ASPECTS OF THE HYDROMETER TEST

X1.1 A review of procedures and standards published by various sources revealed a variety of recommended reading times for the hydrometer test. The times traditionally used by the Bureau of Reclamation (and continued with this procedure) were selected based on the following rationale.

X1.2 It has been found to be convenient to assume a value of specific gravity for the hydrometer test. The value assumed is 2.65. This is a reasonable assumption, and moderate variations from this value have only a small effect on test results. By assuming a value of specific gravity, it was possible to print gradation forms with both particle diameter and time of reading values on the abscissa. This eliminates the need to calculate Stoke’s Law (or use a nomograph) for each reading, thus reducing the chance for error. The particular times selected — at which readings are to be taken — were based on both convenience in performing the test, and in obtaining data points which

have approximately equal spacing when plotted on the form. The three longer time readings (60 min, 7 h 15 min, and 25 h 45 min) correspond to particular particle sizes of interest (0.005, 0.002, and 0.001 mm, respectively).

X1.3 There are various recommendations concerning storage of the hydrometer between readings. These recommendations range from placing in clean water to distilled or demineralized water. While distilled water is required for preparing the soil suspension, the hydrometer may be stored between readings in either distilled water or tapwater that is free of acids, alkalies, or oils and is suitable for drinking. The tapwater will not cause a flocculating reaction with the soil, and allows laboratories that use water baths for controlling hydrometer test temperatures to store the hydrometer in the water bath between readings. Test results are not affected as long as the hydrometer bath water is changed regularly (about once per week).



PROCEDURE FOR PERFORMING GRADATION ANALYSIS OF SOILS WITHOUT HYDROMETER-WET SIEVE

INTRODUCTION

This procedure is under the jurisdiction of Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 5335. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for determining the amount of soil finer than the No. 200 (75 μm) sieve and performing gradation analysis of the sand size fraction.

1.2 The amount of material finer than the No. 200 (75 μm) sieve is determined by wet sieving and the distribution of particle sizes larger than 75 μm (retained on the No. 200 sieve) is determined by dry sieving.

1.3 If gravel size particles were present in the original soil sample, this test is usually performed in conjunction with USBR 5325.

1.4 Two methods of dispersing the soil are provided (1) a mechanical stirring device, and (2) an air dispersion tube. The air dispersion method must be specially requested or specified and its use noted on the test form (see subpar. 5.3).

1.5 This procedure is used when a standard gradation analysis is required. When a quick, approximate determination of the percent fines in a soil is needed, USBR 4117, ASTM C 117, or ASTM D 1140 may be used.

2. Auxiliary Tests

2.1 A soil sample must be prepared in accordance with USBR 5205 prior to performing this procedure.

3. Applicable Documents

- 3.1 *USBR procedures:*
- USBR 1012 Calibrating Balances or Scales
 - USBR 1020 Calibrating Ovens
 - USBR 1025 Checking Sieves
 - USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
 - USBR *4117 Materials Finer Than No. 200 (75- μm) Sieve in Mineral Aggregates by Washing
 - USBR *4136 Sieve Analysis of Fine and Coarse Aggregates
 - USBR 5205 Preparing Soil Samples by Splitting or Quartering
 - USBR 5325 Performing Gradation Analysis of Gravel Size Fraction of Soils

3.2 *ASTM Standard:*

E 11 Specification for Wire-Cloth Sieves for Testing Purposes

C 117 Standard Test Method C for Materials Finer Than 75- μm (No. 200) Sieve in Mineral Aggregates by Washing
D 1140 Standard Test Method for Amount of Material in Soils Finer Than the No. 200 (75- μm) Sieve.

4. Summary of Method

4.1 A sample of minus No. 4 (4.75 mm) material is prepared and placed in a dispersive agent (usually sodium hexametaphosphate) for a period of at least 2 hours. Then it is thoroughly mixed and washed on a No. 200 sieve. The fraction retained on the No. 200 (75 μm) sieve is oven-dried and separated on U.S.A. Standard sieves No. 8, 16, 30, 50, 100, and 200 (2.36 mm, 1.18 mm, 600 μm , 300 μm , 150 μm , and 75 μm , respectively). The sieving is done using a powered sieve shaker.

4.2 After sieving, the percentage of particles passing specified sizes are calculated, recorded, and plotted.

5. Significance and Use

5.1 Gradation is a descriptive term which refers to the proportions by dry mass of a soil or fragmented rock distributed in specified particle-size ranges.

5.2 The gradation of a soil gives an indication of the engineering properties of the soil. Permeability, compressibility, and shear strength are all influenced by the gradation characteristics of a soil mass. Therefore, reliable determination of the amount of fines, sand, and gravel in a representative soil sample is of extreme importance for design considerations.

5.3 Normally, the mechanical stirring device is used to disperse the soil specimen. Its use may cause degradation of some soil particles. Performing the gradation analysis on a mechanically dispersed specimen and on an air dispersed specimen may be useful in evaluating the durability and hardness of sand size particles.

6. Terminology

6.1 Definitions are in accordance with USBR 3900. Terms of particular significance are:

* *Concrete Manual*, Bureau of Reclamation, vol. 2, in press.

6.1.1 *Dispersing Agent.*—An agent used to assist in separating individual fine soil particles and to prevent them from flocculating when in suspension.

6.1.2 *Fines.*—Portions of soil finer than a No. 200 (75 μm) U.S.A. Standard sieve (ASTM definition).

6.1.3 *Gradation.*—The proportions by dry mass of a soil or fragmented rock distributed in specified particle-size ranges (ASTM definition).

6.1.4 *Gradation Analysis.*—The process of determining gradation (ASTM).

7. Apparatus

7.1 *Balance or Scale.*—A typical balance or scale used for this designation must be readable to 0.1 g and have a capacity of about 500 g.

7.2 *Stirring Apparatus* (malt mixer).—A mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10,000 revolutions per minute without load. The shaft should be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber. The shaft is to be of such a length that the stirring paddle will operate not less than 1-1/2 inches (38 mm) above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown on figure 1 should be provided.

7.3 *Sodium Hexametaphosphate.*—A chemical agent in powder, crystal, or granular form, used as a dispersing agent, of technical grade or better.

7.4 *Evaporating Dish.*—A porcelain evaporating dish, 300-mL capacity, approximately 4-1/2 inches (115 mm) in diameter by 2 inches (50 mm) deep.

7.5 *Hydrometer Cylinder.*—A glass cylinder 18 inches (457 mm) in height and 2-1/2 inches (63.5 mm) in diameter, and marked for a volume of 1000 mL. The inside diameter is to be such that the 1000-mL mark is 14±1 inch (360±20 mm) from the bottom on the inside.

7.6 *Rubber Stopper.*—An appropriate size rubber stopper to seal the hydrometer cylinder.

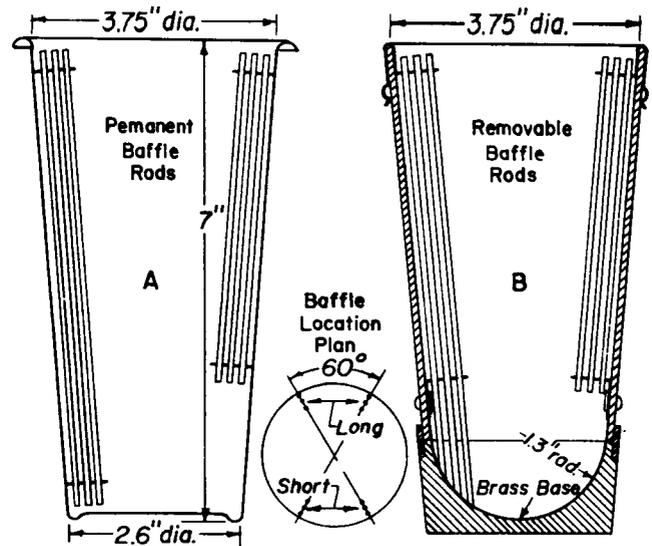
7.7 *Tubing.*—Flexible rubber tubing of sufficient length and diameter to be used for washing the soil specimen through a No. 200 (75 μm) sieve.

7.8 *Sieve Set.*—A set of sieves of square-mesh woven-wire cloth, conforming to the requirements of ASTM E 11. A set of sieves includes the following:

A lid		
No. 8	2.36 mm	
No. 16	1.18 mm	
No. 30	600 μm	
No. 50	300 μm	
No. 100	150 μm	
No. 200	75 μm	
A pan		

7.9 *Washing Sieve.*—No. 200 washing sieve may be fabricated, or an 8-inch diameter (203-mm) brass No. 200 sieve may be used.

7.10 *Sieve Shaker.*—A motor-driven electric sieve shaker, equipped with timer as shown on figure 2 should be used.



Metric Equivalents			
in.	1.3	2.6	3.75
mm	33	66	95.2

Figure 1. - Dispersion cup designs [ASTM D 422].

7.11 *Brush.*—A fine brass wire brush used for removing soil from the sieves and pan.

7.12 *Drying Oven.*—An oven, thermostatically controlled, preferably of the forced-draft type, and capable of maintaining a uniform temperature of 230±9 °F (110±5 °C) throughout the drying chamber.

7.13 *Air Dispersion Tube and Air Supply.*—An air dispersion tube conforming to the requirements of figure 3. The air supply must be capable of producing 2 cubic feet per minute for each dispersion tube. A water trap on the air line may be useful to remove water that condenses in the air line when not in use. Otherwise, the water must be blown out of the air line before using for dispersion purposes.

7.14 *Graduated Cylinder.*—250 mL capacity, graduated in 2 mL divisions or other suitable container or method to measure 125 mL of the dispersing agent solution.

8. Reagents and Materials

8.1 Tapwater that is free of acids, alkalis, or oils and is suitable for drinking may be used for washing the sample.

8.2 A 4-percent sodium hexametaphosphate solution is used to disperse the representative soil sample.

8.3 To prepare a 4-percent sodium hexametaphosphate solution, the following procedure is to be followed:

8.3.1 Fill a 1000-mL hydrometer cylinder with distilled water to approximately 750 mL.

8.3.2 Obtain 40 grams of sodium hexametaphosphate and place into the dispersion cup. Add approximately 100 mL of distilled water to the sodium hexametaphosphate. Mix the sodium hexametaphosphate and water for about 5 minutes using the malt mixer or until the sodium hexametaphosphate completely dissolves.

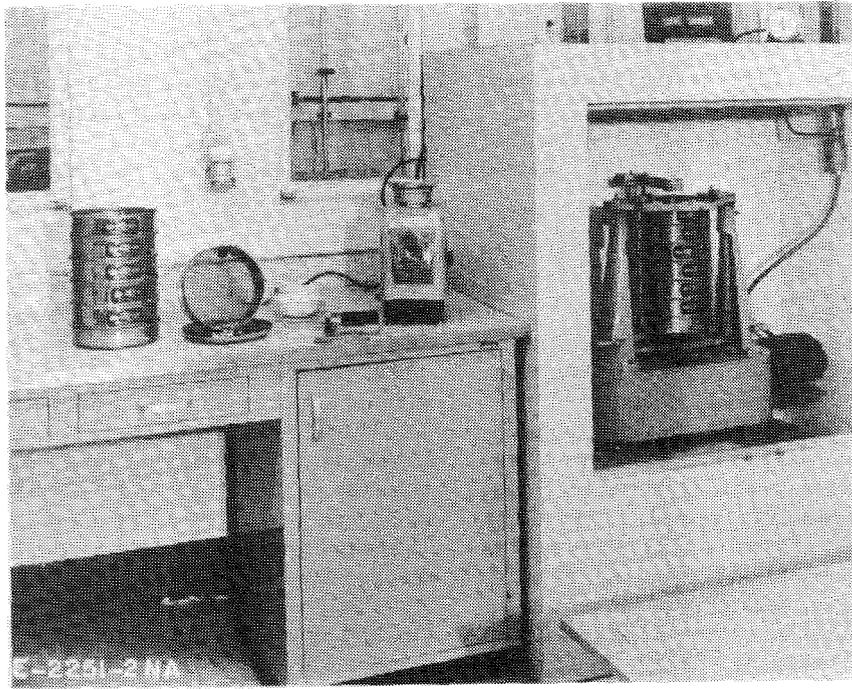


Figure 2. - Sieve analysis equipment.

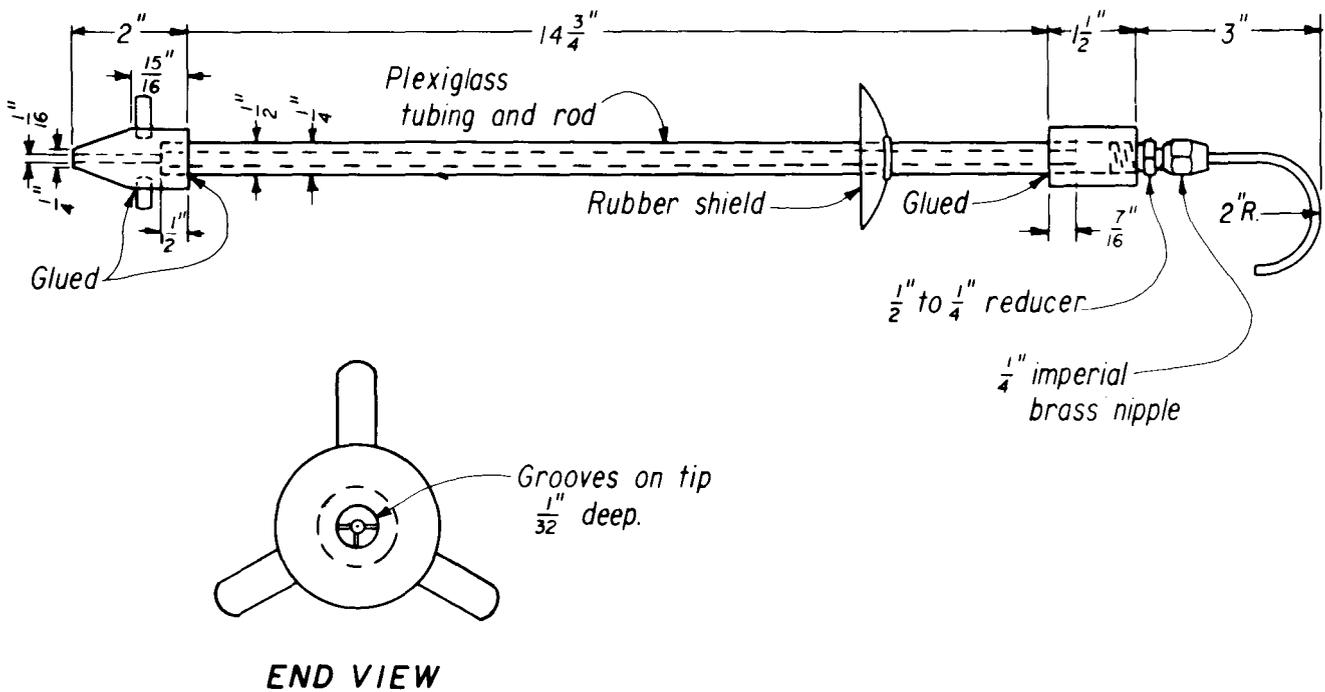


Figure 3. - Air dispersion tube. 101-D-523

8.3.3 Add the solution from the dispersion cup to the hydrometer cylinder. Fill the hydrometer cylinder to the 1000-mL line with distilled water. Securely place the rubber stopper on top of the hydrometer cylinder. With one hand over the top of the hydrometer cylinder and

the other on the bottom, shake the hydrometer cylinder to thoroughly mix the solution.

8.4 A prepared sodium hexametaphosphate solution may be stored for no more than 21 days if the storage temperature remains near 73 °F (23 °C), and for no more

than 7 days if the temperature of the storage area consistently exceeds 73 °F (23 °C).

8.5 All bottles containing the dispersing solution must have the date of preparation and percent solution marked on them.

9. Precautions

9.1 Technical Precautions:

9.1.1 Because sodium hexametaphosphate in powder, granular, or crystalline form absorbs moisture, the material must be stored in airtight containers.

9.1.2 Due to the effects of sampling, handling, processing, and testing on some materials, results of this test may not reflect in-place conditions or the properties of the material caused by processing and placement during construction. Of particular concern are materials such as soft and/or friable decomposed granite, sandstone, shale, limestone, claystone, etc., or soils affected by air and/or over-drying. Such materials must be identified before processing and the person requesting the test should verify whether standard procedures are to be followed, whether modifications are appropriate, or whether the material should be processed and tested at all. Cautionary statements must be made on test data forms and in reporting the test data.

10. Sampling, Test Specimens, and Test Units

10.1 Prepare a test sample of approximately 500 grams of minus No. 4 (4.75-mm) material in accordance with USBR 5205. If 500 g of soil is not available, obtain at least enough soil to have an oven-dried test specimen that meets the requirements of subparagraph 10.3.

10.2 Place the test sample into a suitable container and oven-dry the sample for a minimum of 16 hours.

10.3 Thoroughly mix the soil and obtain a specimen of approximately 100 grams for sandy soils and approximately 50 grams for silty or clayey soils by splitting in accordance with USBR 5205. Determine the mass of the specimen to the nearest 0.1 g and record on the "Gradation Analysis" form as shown on figure 4.

10.4 The test specimen must be dispersed in accordance with either subparagraph 10.5 or 10.6 (see subpara. 5.3). If the air dispersion method is used, it must be noted on the test form.

10.5 *Dispersion of Soil Specimen* (mechanical stirring):

10.5.1 Place the soil specimen in an evaporating dish.

10.5.2 Add 125 mL of 4 percent sodium hexametaphosphate solution and enough water to cover the soil.

10.5.3 Soak the soil specimen in the sodium hexametaphosphate solution for a period of at least 2 hours.

10.5.4 Wash the specimen into a dispersion cup with distilled water.

10.5.5 Continue adding distilled water until the dispersion cup is within 2 inches (50 mm) of being filled.

10.5.6 Mix the contents of the dispersion cup using the malt mixer for 1 minute.

10.6 *Dispersion of Soil Specimen* (air dispersion):

10.6.1 Place the soil specimen into a hydrometer cylinder.

10.6.2 Add 125 mL of 4-percent sodium hexametaphosphate solution to the hydrometer cylinder.

10.6.3 Add enough distilled water to the hydrometer cylinder to bring the volume to about 250 mL and stir.

10.6.4 Soak the soil specimen in the sodium hexametaphosphate solution for a period of at least 2 hours.

10.6.5 Turn on the air supply to the air dispersion tube so there is a small air pressure (about 1 to 2 lbf/in²) and insert the tube into the hydrometer cylinder.

10.6.6 Increase the air pressure to about 15 lbf/in² and let the mixture disperse for 10 minutes. Occasionally rinse the sides of the cylinder with distilled water. For some soils containing coarse sand particles, it may be necessary to increase the air pressure to adequately agitate and disperse the particles.

10.6.7 Decrease the air pressure to a very low pressure and slowly withdraw the air dispersion tube. Rinse the tube with distilled water as it is being withdrawn and rinse the sides of the hydrometer cylinder.

11. Calibration and Standardization

11.1 Verify that equipment is currently calibrated in accordance with the applicable calibration procedure. If the calibration is not current, perform the calibration before using the equipment for this procedure.

USBR 1012 Calibrating Balance or Scales

USBR 1020 Calibrating Ovens

USBR 1025 Checking Sieves

12. Conditioning

12.1 After dispersion and mixing as outlined in either subparagraph 10.5 or 10.6, the specimen is ready for testing.

13. Procedure

13.1 All data are to be recorded on the "Gradation Analysis" form as shown on figure 4.

13.2 Pour the dispersed soil specimen prepared according to subparagraph 10.5 or 10.6 onto a No. 200 sieve and carefully wash the specimen until all fines are removed.

13.3 Pour the remaining soil into an evaporating dish and decant excess water.

13.4 Place the evaporating dish into an oven at 230±9 °F (110±5 °C) and dry for 16 hours.

13.5 Remove the specimen from the oven after 16 hours and obtain the dry mass of the specimen. Record the mass as shown on figure 4.

13.6 Place the specimen into the top sieve of a sieve set and place the lid on the top sieve. Place the sieve set into a sieve shaker. The sieve set should consist of six sizes noted in subparagraph 7.8.

13.6.1 Hand sieving may be used; however, use of a mechanical sieving device is the most common and

accepted method of performing this procedure. Hand sieving must be done in accordance with the directions in USBR 4136 or ASTM C 136. If hand sieving is used for part or all of this procedure, it should be noted on the data forms.

13.7 Sieve the soil specimen for about 15 minutes using the powered sieve shaker and record cumulative masses of the soil retained on each sieve to the nearest 0.1 gram as shown on figure 4.

13.8 Calculate and record to 0.1 percent the percent of total passing of soil mass for each sieve.

13.9 Plot the percent of total mass passing versus the diameter of particle as shown on figure 5.

14. Calculations

14.1 Computations required on the "Gradation Analysis" form are divided into three parts:

- Gradation of gravel sizes
- Gradation of sand sizes
- Hydrometer analysis

14.2 *Gradation of Gravel Sizes.*—The method and calculations required to determine the percentages and distribution of particles larger than the No. 4 sieve size are outlined in USBR 5325.

14.3 *Gradation of Sand Sizes:*

14.3.1 Calculate the factor used to compute the percentage of the total sample mass passing a given sieve or the percentage of the total sample mass smaller than a given particle size as follows:

$$F = \frac{W, \%}{W} \quad (1)$$

where:

F = percentage factor, %/g (record to 0.001)

$W, \%$ = percent of total sample mass passing the No. 4 (4.75-mm) sieve

W = total dry mass of minus No. 4 sample, g

14.3.2 Calculate the dry mass of soil passing each sieve using the following expression:

$$\text{Dry mass passing, g} = \text{total dry mass of sample, g} - \text{dry mass retained, g} \quad (2)$$

14.3.3 Calculate the "% of total mass passing" each sieve by multiplying the mass passing each sieve, "mass passing," on the test form by the factor F calculated in accordance with subparagraph 14.3.1.

14.4 *Hydrometer Analysis.*—The hydrometer analysis portion of the form is not used as a part of this procedure.

15. Report

15.1 The report is to consist of the following completed and checked:

"Gradation Analysis" test form (fig. 4).

"Gradation Test" plot (fig. 5).

15.2 All calculations are to show a checkmark and all plotting must be checked.

15.3 For reports, summary tables, etc., the gradation percentages are generally reported to the nearest 1 percent. The percentages may be reported as either percent passing or percent retained.

15.4 In many cases, the gradation is reported in terms of percent gravel, percent sand, and percent fines. The percentages must add to 100 percent. Due to rounding, the total may be either 99 or 101 percent; 1 percent must be added to or subtracted from the component (gravel, sand, or fines) with the largest percentage so the total is 100 percent. If the percentages, when rounded to the nearest 1 percent are equal, make the adjustment to the coarser component.

7-1451 (9-86) Bureau of Reclamation	GRADATION ANALYSIS	Designation USBR 5325-__ Designation USBR 5330-__ Designation USBR 5335-89
SAMPLE NO. Example	PROJECT	FEATURE
AREA	EXC. NO.	DEPTH

GRADATION OF GRAVEL SIZES									
TESTED AND COMPUTED BY	DATE	% MOISTURE CONTENT OF + NO. 4			WET MASS OF TOTAL SPECIMEN				
CHECKED BY	DATE	% MOISTURE CONTENT OF - NO. 4			TOTAL DRY MASS OF SPECIMEN				
SIEVE SIZE		3" (75 mm)	1-1/2" (37.5 mm)	3/4" (19.0 mm)	3/8" (9.5 mm)	NO. 4 (4.75 mm)	PAN		
MASS OF CONTAINER AND RETAINED MATERIAL									
MASS OF CONTAINER									
WET MASS RETAINED									
DRY MASS RETAINED									
DRY MASS PASSING		(example from U.S.B.R. 5325)					<input type="checkbox"/> lbm	<input type="checkbox"/> kg	<input type="checkbox"/> g
% OF TOTAL PASSING		100.0	95.6	81.7	73.8	63.2			

GRADATION OF SAND SIZES							
DRY MASS OF SPECIMEN		59.1 g	FACTOR = $\frac{\% \text{ TOTAL PASSING NO. 4}}{\text{DRY MASS OF SPECIMEN}} = \frac{63.2}{59.1} = 1.069$				
DISH NO.	18	DRY MASS OF SPECIMEN (SIEVED)		39.2			
SIEVING TIME		15 min.		DATE			
SIEVE NO.	MASS RETAINED (g)	MASS PASSING (g)	FACTOR X MASS PASSING = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS	
8	3.4	55.7		59.5	2.36 mm	125 ml 4% Sod. Hexametaphosphate	
16	8.3	50.8		54.3	1.18 mm	dispersing agent used.	
30	14.2	44.9		48.0	600 μm		
50	22.1	37.0		39.6	300 μm		
100	30.8	28.3		30.3	150 μm		
200	39.0	20.1		21.5	75 μm		
PAN	0.1	TESTED AND COMPUTED BY		DATE	CHECKED BY		DATE
TOTAL	39.1						

HYDROMETER ANALYSIS									
HYDROMETER NO.				DISPERSING AGENT					
STARTING TIME			DATE		AMOUNT			mL	
TIME	TEMP °C	HYD READ	HYD CORR	CORR READ	FACTOR X CORRECT READ = % OF TOTAL PASSING	% OF TOTAL PASSING	PARTICLE DIAMETER	REMARKS	
1 min								37 μm	
4 min								19 μm	
19 min								9 μm	
60 min								5 μm	AUXILIARY TESTS: USBR 5205-8 9 USBR 5300-__
7 h 15 min*								2 μm	
25 h 45 min*								1 μm	
TESTED AND COMPUTED BY			DATE		CHECKED BY			DATE	

*Not required for standard test.

Figure 4. - Gradation analysis — example.

GRADATION TEST

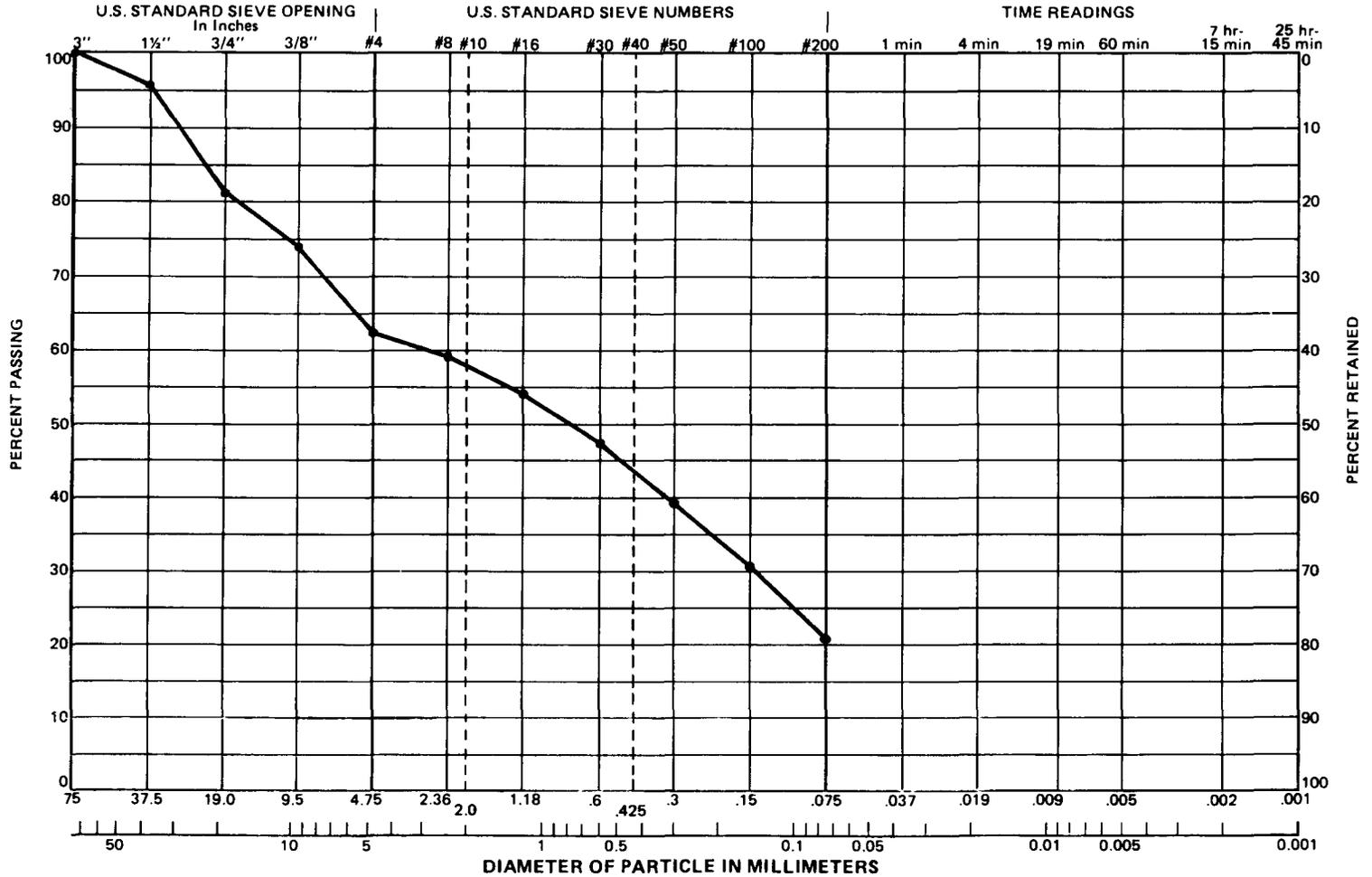
SIEVE ANALYSIS

HYDROMETER ANALYSIS

PREPARED BY _____

CHECKED BY _____

FIGURE _____



GRAVEL		SAND			FINES	
COARSE	FINE	COARSE	MEDIUM	FINE		

SAMPLE NO.	HOLE NO.	ELEV. OR DEPTH <input type="checkbox"/> ft <input type="checkbox"/> m	UNIFIED SOIL CLASSIFICATION			ATTERBERG LIMITS			SPECIFIC GRAVITY		NOTES. Example
			GROUP SYMBOL	% GRAVEL	% SAND	% FINES	LL (%)	PI (%)	SL (%)	MINUS NO. 4	

Figure 5. - Gradation test — gradation analysis data plot example.



PROCEDURE FOR CALIBRATING HYDROMETERS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1405. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating the hydrometer used for gradation analysis of soils as performed in accordance with USBR 5330.

1.2 This calibration procedure is used to determine the hydrometer correction to compensate for the temperature of the water and the type of dispersing agent used.

2. Applicable Documents

2.1 *USBR Procedures:*

USBR 1012 Calibrating Balances or Scales
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
USBR 5330 Performing Gradation Analysis of Fines and Sand Size Fraction of Soils, Including Hydrometer Analysis

2.2 *ASTM Standards:*

E 1 ASTM Thermometers
E 100 Specification for ASTM Hydrometers

3. Summary of Method

3.1 A hydrometer cylinder is filled with either distilled water or a sodium hexametaphosphate solution of given concentration and is placed in a water bath. A hydrometer is placed into the cylinder and sufficient time is allowed for the hydrometer, hydrometer cylinder, cylinder fluid, and water bath to reach a temperature equilibrium. Hydrometer readings are taken at temperatures spanning the range of expected test temperatures, and corrections for intermediate temperatures are calculated.

4. Significance and Use

4.1 Soil hydrometers are used in gradation analysis of soils to determine the distribution of particles smaller than the U.S.A. Standard series No. 200 (75- μ m) sieve. The ASTM soil hydrometers used by the Bureau are marked to read in grams of soil in suspension per liter of mixture of soil and distilled water at 20 °C. Since the temperature of the water used in the test may not be exactly 20 °C and because either distilled water or a solution of distilled water and dispersing agent is used, it is necessary to prepare hydrometer correction charts to compensate for the effects

of temperature variation and dispersing agent. The hydrometer corrections are subtracted from the hydrometer readings obtained during the gradation analysis test to give a corrected hydrometer reading.

4.2 The hydrometer correction values obtained from this procedure are unique to the individual hydrometer, dispersing agent, percent solution of the agent, and temperature range in which the calibration procedure is performed. If any one of these is changed, new individual hydrometer correction values must be obtained.

4.3 This calibration procedure is to be performed upon receipt of the hydrometer as an acceptance check.

4.4 The hydrometer zero reading (see subpar. 10.2) must be checked upon receipt of the hydrometer and annually thereafter or anytime hydrometer readings are suspect.

5. Terminology

5.1 Definitions are in accordance with USBR 3900. Terms of particular significance are:

5.1.1 *Dispersing Agent.*—An agent used to assist in separating individual fine soil particles and to prevent them from flocculating when in suspension.

5.1.2 *Gradation Analysis.*—The process of determining gradation (ASTM definition).

6. Apparatus

6.1 *Soil Hydrometer.*—An ASTM soil hydrometer, graduated to read in grams per liter of suspension and conforming to the requirements for hydrometer 152H in ASTM E 100.

6.2 *Hydrometer Cylinder.*—A glass cylinder essentially 18 inches in height and 2-1/2 inches in diameter (457 by 64 mm) and marked for a volume of 1000 mL. The inside diameter is to be such that the 1000-mL mark is 14 \pm 1 inch (355 \pm 25 mm) from the bottom on the inside.

6.3 *Stirring Apparatus* (malt mixer).—A mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10,000 revolutions per minute without load. The shaft should be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber. The shaft is to be of such a length that the stirring paddle will operate not less than 1-1/2 inches (38 mm) above the bottom of the

dispersion cup. A special dispersion cup conforming to either of the designs shown on figure 1 should be provided.

6.4 *Thermometer*.—0 to 50 °C, 0.5 °C divisions, conforming to the requirements of ASTM E 1.

6.5 *Balance or Scale*.—A typical balance or scale used for this designation must be readable to 0.1 g and have a capacity of about 500 g.

6.6 *Rubber Stopper*.—An appropriate size rubber stopper to adequately seal the hydrometer cylinder.

6.7 *Water Bath*.—An automatic temperature-controlled water tank or an insulated container large enough to hold the hydrometer cylinder is required. It is important that the water bath, hydrometer, and the hydrometer cylinder and its contents be maintained at a constant temperature for each hydrometer reading.

6.8 *Sodium Hexametaphosphate*.—A chemical agent in powder, crystal, or granular form, used as a dispersing agent.

6.9 *Graduated Cylinder*.—1000 mL capacity, graduated to 10 mL.

6.10 *Graduated Cylinder*.—250 mL capacity, graduated to 2 mL or other suitable container or method to measure 125 mL of the dispersing agent solution.

7. Reagents and Materials

7.1 Distilled water is to be used for obtaining hydrometer corrections for gradation analysis that will be performed using distilled water as the fluid medium.

7.2 A sodium hexametaphosphate and distilled water solution is to be used for obtaining hydrometer corrections for gradation analysis that will be performed using sodium hexametaphosphate as a dispersing agent.

7.3 In general, a 4-percent solution of sodium hexametaphosphate is used in performing the calibration procedure stated in subparagraph 7.2 (see subpar. 7.4 for preparing 8 and 12 percent solutions). To prepare a 4-percent solution, the following procedure is to be followed:

7.3.1 Fill a 1000-mL graduated cylinder with distilled water to approximately 750 mL.

7.3.2 Obtain 40 grams of reagent grade or better sodium hexametaphosphate and place it into the dispersion cup. Add approximately 100 mL of distilled water to the sodium hexametaphosphate. Mix the sodium hexametaphosphate and water using the malt mixer until the sodium hexametaphosphate is dissolved. To dissolve the sodium hexametaphosphate into solution typically requires approximately 5 minutes of mixing in the malt mixer.

7.3.3 Add the solution from the dispersion cup to the graduated cylinder. Fill the graduated cylinder to the 1000-mL line with distilled water. Take the rubber stopper and securely place it on top of the graduated cylinder. With one hand over the top of the graduated cylinder and the other on the bottom, shake the graduated cylinder to thoroughly mix the solution.

7.4 In some circumstances, an 8- or 12-percent solution may be desired as a dispersing agent. The following amounts of sodium hexametaphosphate are to be used for the desired percent solution of sodium hexametaphosphate:

Solution desired, %	Sodium hexameta- phosphate required, g
4	40
8	80
12	120

7.5 If an 8- or 12-percent solution is desired, the procedure outlined in subparagraph 7.3 is to be used along with the appropriate amount of sodium hexametaphosphate as given in subparagraph 7.4.

7.6 A prepared sodium hexametaphosphate dispersing solution may be stored for no more than 21 days if the storage temperature remains near room temperature (73 °F), and for no more than 7 days if the temperature of the storage area consistently exceeds 73 °F.

7.7 All containers of the dispersing solution must have the date of preparation and percent solution marked on them.

8. Precautions

8.1 Technical Precautions:

8.1.1 Sufficient time should be allowed for the hydrometer and liquids to reach a temperature equilibrium. Usually 30 minutes are required for the hydrometer to reach equilibrium after the liquids have attained the desired temperature.

8.1.2 Because sodium hexametaphosphate in powder, granular, or crystalline form absorbs moisture, the material must be stored in airtight containers.

9. Preparation of Apparatus

9.1 The hydrometer is to be cleaned, especially the reading portion of the stem, by washing the hydrometer

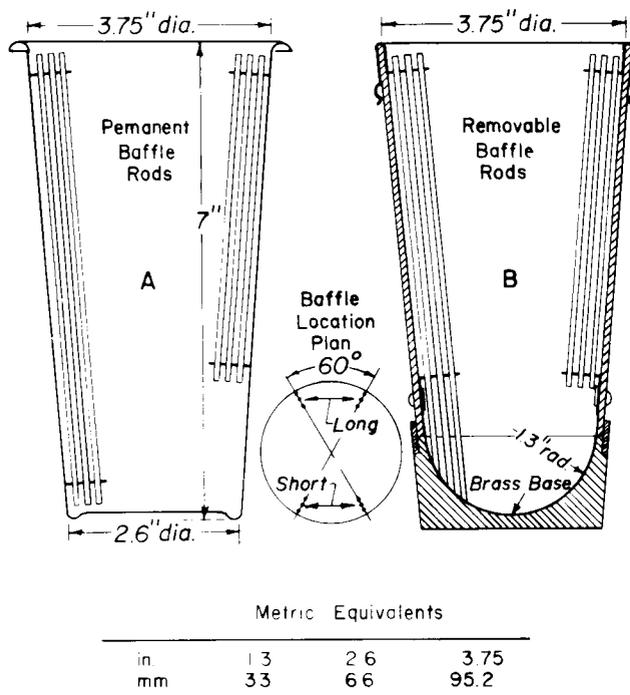


Figure 1. — Dispersion cup designs [ASTM D 422].

with soapy water and then rinsing it with alcohol and again in clean water.

10. Calibration and Standardization

10.1 Verify that the balance or scale used is currently calibrated in accordance with USBR 1012. If the calibration is not current, perform the calibration before using the balance or scale for this procedure.

10.2 *Hydrometer Zero Reading Check.*—The zero reading must be checked upon receipt of the hydrometer and annually thereafter or anytime hydrometer readings are suspect.

10.2.1 Fill a clean hydrometer cylinder to the calibration mark with 1 liter of distilled water.

10.2.2 Prepare a water bath at 20 °C and place the hydrometer cylinder and distilled water in the bath. Stir the water in the cylinder occasionally and allow sufficient time for the temperature of the water in the cylinder to come to equilibrium with the bath temperature.

10.2.3 Wash the hydrometer to be calibrated with soap and distilled water and clean the neck with alcohol. Rinse the hydrometer in distilled water and dry it with a clean towel.

10.2.4 Place the hydrometer in the cylinder and allow adequate time for the temperature of the hydrometer and water to stabilize.

10.2.5 Take the reading of the hydrometer at the top of the meniscus (see note 1) to the nearest 0.5 unit and record as shown on figure 2. This reading should be between +0.5 and -1.5. Insert the thermometer so that the tip is about 8 inches (200 mm) into the hydrometer cylinder, and check that the water temperature has remained at 20 °C. The thermometer should be read to the nearest 0.5 °C.

NOTE 1.—Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top. By calibrating the hydrometer, using the top of the meniscus, this correction is automatically accounted.

10.2.6 If the hydrometer reading does not fall within the required range, the hydrometer is to be rejected for laboratory use.

11. Conditioning

11.1 Perform this calibration procedure in an area where there will not be a large temperature fluctuation while performing the procedure.

12. Procedure

12.1 All data are to be recorded on the "Hydrometer Calibration for Gradation Analysis" form as shown on figure 2.

12.2 Locate and record the hydrometer number.

12.3 Record the type of and percent solution of dispersing agent to be used for the calibration procedure.

This will either be distilled water or a solution of sodium hexametaphosphate, as described in subparagraph 7.3 or 7.4.

12.4 The hydrometer is calibrated by taking hydrometer readings at four different temperatures covering the range of expected test temperatures.

12.5 Adjust the temperature of the water bath to the lowest calibration temperature desired.

12.6 Place 125 mL of dispersing agent solution into the hydrometer cylinder.

12.7 Fill the hydrometer cylinder to 1000 mL with distilled water.

12.8 Apply a rubber stopper and securely place it on top of the hydrometer cylinder. With one hand over the top of the hydrometer cylinder and the other on the hydrometer cylinder bottom, shake the hydrometer cylinder until the dispersing agent and distilled water are thoroughly mixed.

12.9 Place the hydrometer cylinder into the water bath.

12.10 Dry the hydrometer, if necessary; carefully place the hydrometer into the hydrometer cylinder and wait at least 30 minutes to allow the temperature of the hydrometer, hydrometer cylinder, and liquids to equalize.

12.11 Record the temperature of the liquid in the hydrometer cylinder to the nearest 0.5 °C.

12.12 Determine and record the water level at the top of the meniscus on the hydrometer to the nearest 0.5 unit. If the water level is above the zero mark on the hydrometer, then the hydrometer correction is recorded as a negative value of that reading. If the water level is below the zero marking on the hydrometer, then the hydrometer correction is recorded as a positive value of that reading (see fig. 3).

12.13 Verify the hydrometer reading by removing the hydrometer, drying it, and replacing the hydrometer into the hydrometer cylinder. If the hydrometer readings are not the same, remove the hydrometer and repeat subparagraphs 12.10 through 12.12 until a reading can be verified.

12.14 Remove the hydrometer and elevate the temperature of the water bath to the next desired calibration temperature. Allow the temperatures of the water bath, the hydrometer cylinder, and the dispersing agent solution to equalize.

12.15 Repeat subparagraphs 12.10 through 12.14 until hydrometer readings at four different temperatures covering the range of expected test temperatures have been obtained and verified.

12.16 Determine the calibration equation.

12.16.1 Plot the temperature versus hydrometer reading data pairs on a graph similar to that shown on figure 4.

12.16.2 Draw a best-fit straight line through the plotted points (or perform a linear regression analysis and construct the resulting best-fit straight line on the graph).

12.16.3 Compare the data points to the straight line for acceptability.

12.16.3.1 All data points should plot within ± 0.5 hydrometer unit of the straight line (or the correlation coefficient for the linear regression should be equal to or greater than ± 0.95).

7-2309 (12-86) Bureau of Reclamation	HYDROMETER CALIBRATION FOR GRADATION ANALYSIS	Designation USBR 1405. 89										
HYDROMETER NO. 189	ZERO READING 0.5											
DISPERSING AGENT Sodium Hexametaphosphate	PERCENT SOLUTION 4%											
CALIBRATION PERFORMED BY _____ DATE _____	CHECKED BY _____ DATE _____											
CALIBRATION DATA												
<table border="1" style="margin: auto; border-collapse: collapse;"> <thead> <tr> <th style="padding: 5px;">TEMPERATURE °C</th> <th style="padding: 5px;">HYDROMETER READING</th> </tr> </thead> <tbody> <tr> <td style="text-align: center; padding: 5px;">18.0</td> <td style="text-align: center; padding: 5px;">6.5</td> </tr> <tr> <td style="text-align: center; padding: 5px;">21.0</td> <td style="text-align: center; padding: 5px;">5.5</td> </tr> <tr> <td style="text-align: center; padding: 5px;">25.0</td> <td style="text-align: center; padding: 5px;">4.0</td> </tr> <tr> <td style="text-align: center; padding: 5px;">28.0</td> <td style="text-align: center; padding: 5px;">3.0</td> </tr> </tbody> </table>			TEMPERATURE °C	HYDROMETER READING	18.0	6.5	21.0	5.5	25.0	4.0	28.0	3.0
TEMPERATURE °C	HYDROMETER READING											
18.0	6.5											
21.0	5.5											
25.0	4.0											
28.0	3.0											
DETERMINATION OF CALIBRATION EQUATION												
SELECTED POINTS												
<table border="1" style="margin: auto; border-collapse: collapse;"> <thead> <tr> <th style="padding: 5px;">TEMPERATURE °C</th> <th style="padding: 5px;">HYDROMETER READING</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">(1) 18.0</td> <td style="padding: 5px;">(3) 6.5</td> </tr> <tr> <td style="padding: 5px;">(2) 28.0</td> <td style="padding: 5px;">(4) 3.0</td> </tr> </tbody> </table>			TEMPERATURE °C	HYDROMETER READING	(1) 18.0	(3) 6.5	(2) 28.0	(4) 3.0				
TEMPERATURE °C	HYDROMETER READING											
(1) 18.0	(3) 6.5											
(2) 28.0	(4) 3.0											
HYDROMETER CALIBRATION EQUATION												
$y = mx + b$												
$(2) - (1) = \frac{10.0}{-3.5} \quad (A)$												
$(4) - (3) = \frac{-3.5}{-3.5} \quad (B)$												
$m = \frac{(B)}{(A)} = \frac{-0.35}{-3.5}$												
$b = y - mx \quad b = (3) - (m)(1) = 12.8$												
<table border="1" style="margin: auto; border-collapse: collapse;"> <tr> <td style="padding: 5px;">CALIBRATION EQUATION $y = -0.35(x) + 12.8$</td> </tr> </table>			CALIBRATION EQUATION $y = -0.35(x) + 12.8$									
CALIBRATION EQUATION $y = -0.35(x) + 12.8$												

GPO 852 - 933

Figure 2. - Hydrometer calibration for gradation analysis — example.

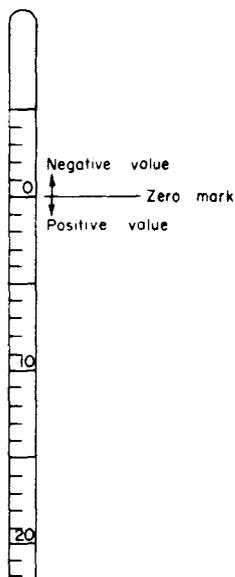


Figure 3. - Soil hydrometer stem sketch.

12.16.3.2 If the criteria in subparagraph 12.16.3.1 are not met, discard the data point that appears to be farthest from the straight line and repeat subparagraphs 12.16.1 through 12.16.3. If the criteria still cannot be met, the calibration procedure must be repeated until the criteria have been satisfied.

12.16.4 Determine and record the equation of the calibration line.

12.17 Use the calibration equation to obtain a table of temperature-hydrometer corrections as shown in table 1.

13. Calculations

13.1 Determine the linear equation of the hydrometer calibration line and calculate the hydrometer corrections for the temperature range calibrated.

13.2 Select the two data pairs closest to the straight line and calculate the equation of the straight line. The equation of the calibration line is determined in the form:

$$y = mx + b$$

where:

y = hydrometer correction

m = slope of line

x = temperature, °C

b = hydrometer correction intercept

13.3 The "Hydrometer Calibration for Gradation Analysis" form illustrates an example calculation of the slope of the calibration line, m , and the intercept, b .

13.4 Calculate hydrometer corrections using the calibration equation in subparagraph 13.2 and substituting the appropriate temperatures. The temperature range is generally between 18 and 28 °C, using 0.5 °C increments. These hydrometer corrections are to be rounded to the nearest 0.5 unit as shown in table 1 for the example calibration equation.

13.5 Calculation of the hydrometer corrections shown in table 1 is performed as follows:

$$y = -0.35 x + 12.8 \quad (\text{Calibration equation, fig. 2})$$

substitute 18 °C into the calibration equation:

$$y = -0.35 (18.0) + 12.8$$

$$y = 6.5$$

Therefore, the hydrometer correction, y , (for the temperature of 18 °C) is recorded in the table as 6.5. This substitution procedure is continued for the entire temperature range calibrated.

14. Report

14.1 The report is to consist of the following completed and checked form, plot, and table:

"Hydrometer Calibration for Gradation Analysis" form (fig. 2).

Plot of calibration equation (fig. 4).

Table of hydrometer corrections (table 1).

14.2 All calculations are to show a checkmark and all plotting must be checked.

Table 1. - Hydrometer corrections.

Hydrometer number 189 Dispersing agent <i>Sodium hexametaphosphate</i> Percent solution 4% Calibration date Computed by Checked by	
Temperature, °C	Hydrometer correction
18.0	6.5
18.5	6.5
19.0	6.0
19.5	6.0
20.0	6.0
20.5	5.5
21.0	5.5
21.5	5.5
22.0	5.0
22.5	5.0
23.0	5.0
23.5	4.5
24.0	4.5
24.5	4.0
25.0	4.0
25.5	4.0
26.0	3.5
26.5	3.5
27.0	3.5
27.5	3.0
28.0	3.0

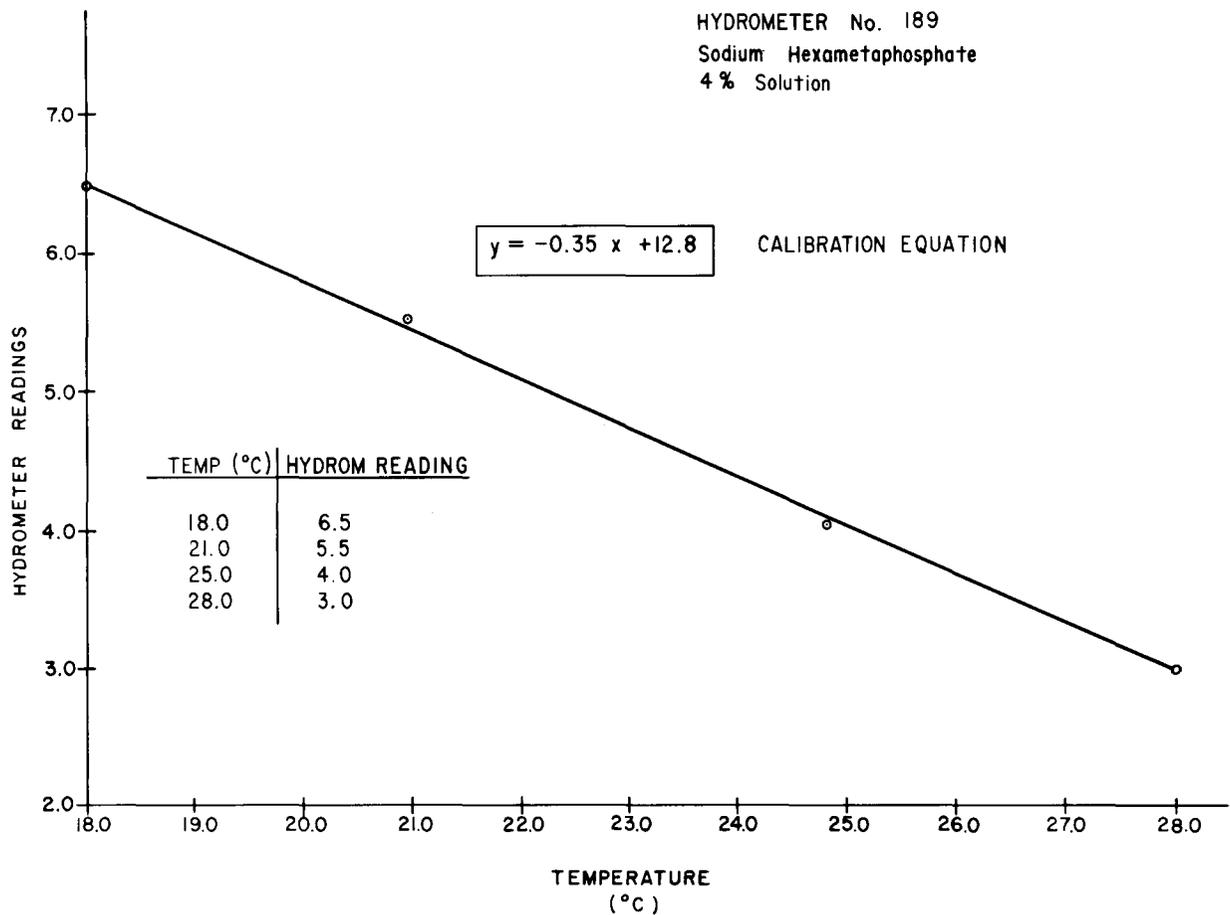


Figure 4. - Hydrometer calibration equation.

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-7923A, PO Box 25007, Denver Federal Center, Denver CO 80225-0007.