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Deflocculating Agents for Mechanical Analysis of Soils

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Soil samples from different parts of the United States were used in mechanical analysis experiments for comparing the effectiveness of several chemicals as deflocculating agents. Sodium metaphosphate was found most promising. Since different varieties of this chemical are manufactured, experiments were conducted to evaluate compounds available through chemical supply houses.

The recommended compound was further studied to determine the effect of amount and age of the deflocculating solution used on efficiency of dispersion. Experiments were also performed to determine the change in viscosity and density of a soil suspension due to the use of sodium metaphosphate.

The viscosity of the soil suspension in the standard methods of mechanical analysis is assumed to be that of water. Viscosity measurements in this study indicate that correction factors for the influence of both the deflocculating agent and soil fines are desirable. The effect of sodium metaphosphate on the density of the soil suspension was also found to be appreciable, and a method for determining a correction factor is presented.

● ADEQUATE and stable dispersion of a soil sample is important for an accurate mechanical or particle-size analysis. Since most soils are difficult to disperse in water and tend to flocculate after being dispersed, the chemicals used as deflocculating or dispersing agents are added to the soil-water mixture to obtain satisfactory dispersion.

The addition of a deflocculating agent to a soil-water mixture affects the degree of dispersion of the soil sample and may also affect the specific gravity of the soil particles and the viscosity and specific gravity of the suspending medium. The experiments described in this paper were conducted: (1) to compare the effectiveness of several chemicals as deflocculating agents for the dispersion of soils and (2) to determine the effect of one of the deflocculating agents on the specific gravity of the soil dispersed and on the viscosity and specific gravity of the suspending medium.

Soil samples from different parts of the United States were used in the experiments. Table 1 gives the sources and some properties of the soil samples.

EFFECTIVENESS OF DEFLOCCULATING AGENTS

The theory of soil dispersion has been discussed in a previous paper (1). The effectiveness of a deflocculating agent can be rated on the degree of dispersion of a soil sample with the deflocculating agent. The degree of dispersion can be determined especially by particle-size measurements of the fractions finer than 0.005 mm. and 0.001 mm. For example, the higher the content of material finer than 0.005 mm. and 0.001 mm., the higher the degree of dispersion.

Two types of dispersion apparatus were used in the mechanical analysis experiments reported in this paper. The first is the mechanical stirrer specified by both the American Society for Testing Materials and the American Association of State Highway Officials; the second is the Soil Dispersion Tube (S. D. T.). The dispersion procedure with the mechanical stirrer is given in the ASTM and AASHO standard methods of mechanical analysis (2, 3). The S. D. T. apparatus and its use have been described (4).

Hydrometer tests were performed essentially according to the standard methods of mechanical analysis, except that corrections were applied to hydrometer readings, to compensate for the change in the specific gravity of the suspending medium due to the addition of a deflocculating agent.

The determination of correction constants is discussed later in this paper. Particle-size measurements reported in this paper are the average of results from duplicate tests.

COMPARISON OF SODIUM SILICATE, SODIUM PYROPHOSPHATE, AND SODIUM METAPHOSPHATE AS DEFLOCCULATING AGENTS

Sodium silicate is specified as the deflocculating agent in the present ASTM and AASHO standard methods of mechanical analysis. Sodium pyrophosphate and sodium metaphosphate have been found effective as deflocculating agents for many types of soil (1, 5, 6). These three chemicals were evaluated as deflocculating agents for the soil samples listed in Table 1.

TABLE 1

SOURCE AND SOME PROPERTIES OF SOIL SAMPLES

Sample No.	Source	Textural Classification	Plasticity Index	Organic Matter Content, Percent	Content of Carbonates, Percent	pH
1	Iowa	Clay	51.7	1.2	2.5	5.3
2	Virginia	Clay	35.3	0.7	2.5	6.7
3	California	Clay	38.7	0.3	6.8	8.5
4	New York	Clay	13.1	0.6	14.9	8.1
5	Texas	Clay loam	3.6	0.2	81.3	8.2
6	Iowa	Silty loam	6.2	0.3	11.6	8.3
7	Virginia	Sand	N. P.	0.3	40.8	7.4
8	Texas	Clay	42.4	0.3	13.6	7.5

Note: Only material passing No. 10 sieve was used in this study. Textural classifications are based upon the Bureau of Public Roads system except that 0.074 mm. was used as the lower limit of the sand fraction.

In all experiments reported in this paper, deflocculating agents in solution were added to the soil-water mixture. The concentration of sodium silicate solution prepared from sodium metasilicate crystals was 3 deg. Baumé. The concentration of sodium pyrophosphate[1] solution and of sodium metaphosphate solution[2] was 0.5 N.

The degree of dispersion of a soil sample usually varies with the amount of deflocculating agent used. The trend of variation depends on the type of soil dispersed, the type of deflocculating agent used, and the apparatus and procedure of dispersion. Soil Samples 1 and 6 were used to determine the relation between degree of dispersion and amount of each deflocculating solution.

[1] The chemical used is also known as tetrasodium pyrophosphate ($Na_4P_2O_7 \cdot 10H_2O$).

[2] Sodium metaphosphate B was used to prepare the solution. The description of this chemical is given in Table 3.

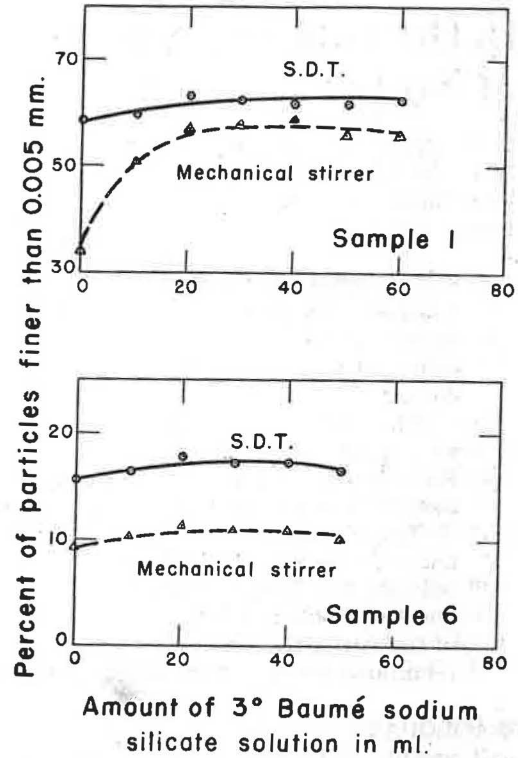

Figure 1. Relation between amount of sodium silicate solution and degree of dispersion obtained with different dispersion apparatus.

Both the mechanical stirrer and the S. D. T. were used in dispersing the soils.

As mentioned before, the degree of dispersion obtained by different methods of dispersion can be compared by means of particle-size measurements. This approach was followed in comparing the degree of dispersion obtained with different amounts of the three deflocculating solutions. The relations between the amount of each deflocculating solution and the degree of dispersion of the two samples, as represented by the percent of particles finer than 0.005 mm., are shown in Figures 1, 2 and 3. The curves for percentages finer than 0.001 mm. are similar.

Note that for equal amounts of solution the S. D. T. gave a higher degree of dispersion than the mechanical stirrer and that the amount of deflocculating agent used in the S. D. T. procedure was of less importance than in the mechanical stirrer procedure. For example, Figure 3 shows that the degree of dispersion of Sample 1 varied only slightly with the amount of sodium metaphosphate solution when the soil

TABLE 2

COMPARISON OF EFFECTIVENESS OF DEFLOCCULATING AGENTS IN SOIL DISPERSION

Dispersion Apparatus	Deflocculating Agent: Type	Concentration of Solution	Amount[a] (ml.)	Sample 1: 0.005mm.	Sample 1: 0.001mm.	Sample 2: 0.005mm.	Sample 2: 0.001mm.	Sample 3: 0.005mm.	Sample 3: 0.001mm.	Sample 4: 0.005mm.	Sample 4: 0.001mm.
				Percent[b] of Particles Finer Than							
S. D. T.	No deflocculating agent			58.2	38.6	54.9	34.6	Flocculated		Flocculated	
	Sodium Silicate	3° Baume	20	63.1	51.1	58.6	45.9	53.7	40.8	56.9	29.8
	Sodium Pyrophosphate	0.5N	40	62.7	51.5	62.4	49.6	53.5	44.1	53.7	28.9
	Sodium Metaphosphate	0.5N	40	63.7	53.3	62.9	50.6	56.0	52.1	57.1	30.2
Mechanical Stirrer	No deflocculating agent			34.0	13.5	35.0	9.8	Flocculated		Flocculated	
	Sodium Silicate	3° Baume	20	57.0	34.8	51.8	25.4	43.9	16.8	55.3	27.3
	Sodium Pyrophosphate	0.5N	40	59.6	48.4	59.5	48.2	54.2	42.7	53.3	28.4
	Sodium Metaphosphate	0.5N	40	62.8	51.0	59.9	48.0	54.8	43.0	56.3	29.6

[a] Refers to the amount of deflocculating solution used in dispersing a sample of 50g. or 100g. into a one liter soil suspension.

[b] All percentages are the average of results from duplicate tests.

Dispersion Apparatus	Deflocculating Agent: Type	Concentration of Solution	Amount[a] (ml.)	Sample 5: 0.005mm.	Sample 5: 0.001mm.	Sample 6: 0.005mm.	Sample 6: 0.001mm.	Sample 7: 0.005mm.	Sample 7: 0.001mm.	Sample 8: 0.005mm.	Sample 8: 0.001mm.
				Percent[b] of Particles Finer Than							
S. D. T.	No deflocculating agent			Flocculated		15.7	6.0	Flocculated		Flocculated	
	Sodium Silicate	3° Baume	20	28.8	7.1	17.8	10.4	4.8	2.7	Flocculated	
	Sodium Pyrophosphate	0.5N	40	30.1	7.4	20.6	13.6	5.5	3.5	65.6	50.6
	Sodium Metaphosphate	0.5N	40	30.7	8.8	18.8	12.7	6.6	4.0	65.7	52.3
Mechanical Stirrer	No deflocculating agent			Flocculated		9.4	4.1	Flocculated		Flocculated	
	Sodium Silicate	3° Baume	20	20.1	2.6	11.3	4.2	3.8	1.8	Flocculated	
	Sodium Pyrophosphate	0.5N	40	29.6	7.5	17.9	11.0	5.5	3.5	63.6	47.7
	Sodium Metaphosphate	0.5N	40	29.4	9.1	16.2	9.9	6.0	3.8	64.6	51.3

was dispersed with the S. D. T. As a contrast, when dispersed with the mechanical stirrer, the degree of dispersion changed substantially as the amount of sodium metaphosphate solution was varied from 10 to 30 ml.

The data in the three figures further indicate that, regardless of the type of dispersion apparatus used, the degree of dispersion of each sample practically remained unchanged when the amount of deflocculating solution used was about 20 ml. or more, as is shown in Figures 1 and 2, and was about 40 ml. or more in Figure 3.

The three deflocculating agents were further compared in the dispersion of samples 2, 3, 4, 5, 7 and 8 with both types of dispersion apparatus. The amounts of deflocculating solutions used for these samples were 20 ml. of sodium silicate solution[3], 40 ml. of sodium pyrophosphate solution, and 40 ml. of sodium metaphosphate solution. Results are given in Table 2. With most of the samples, sodium silicate was found inferior to the other two deflocculating agents, and sodium metaphosphate gave slightly better results than sodium pyrophosphate. Therefore sodium metaphosphate was chosen for more detailed studies.

[3] As specified in ASTM Method D422-51 and AASHO Method T88-49.

COMPARISON OF DIFFERENT VARIETIES OF SODIUM METAPHOSPHATE

The sodium metaphosphate used in the foregoing experiments is one variety of the complex chemical also known as sodium hexametaphosphate or Graham's salt. The nomenclature of this group of chemicals is discussed in the appendix.

Since the different varieties of sodium metaphosphate sold by chemical supply companies may differ in their dispersing actions, experiments were made to compare the six varieties listed in Table 3. Variety B was used in the previously discussed experiments to compare sodium metaphosphate with sodium silicate and sodium pyrophosphate. The source and

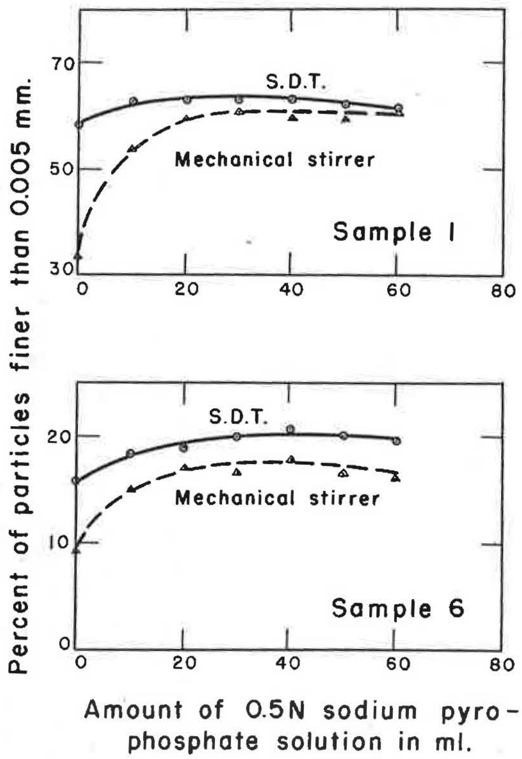

Figure 2. Relation between amount of sodium pyrophosphate solution and degree of dispersion obtained with different dispersion apparatus.

structure or crystallinity of each variety are given in the table. The significance of the structure of sodium metaphosphate with respect to its dispersing action is discussed by Tyner (5), who suggests that only the glassy form be used for soil dispersion purposes.

Soils 1 and 6 were chosen for the experiments. The S. D. T. was the only dispersion apparatus used. Since the amount of deflocculating solution needed for maximum dispersion may be different for different varieties of sodium metaphosphate, a number of solutions in the range from 30 to 60 ml. of 0. 5N solution were tested to compare the six varieties (see Table 4).

The mechanical analysis results given in Table 4 indicate that the degree of dispersion varies only slightly with the varieties and amounts of sodium metaphosphate tested. The type of structure of sodium metaphosphate appears to be of little consequence.

Because the mechanical analysis data for Samples 1 and 6 showed no significant difference in the effectiveness of the six

TABLE 3

SOURCE AND STRUCTURE OF DIFFERENT VARIETIES OF SODIUM METAPHOSPHATE

Variety of Sodium Metaphosphate	Source	Structure[a]
A	Made by Calgon, Inc., Pittsburgh, Pa. and distributed under the trade name "Calgon"	Partially Microcrystalline
B	Made by Blockson Chemical Co., Joliet, Ill., available at Fisher Scientific Co., St. Louis, Mo. as sodium metaphosphate, C. P.	Glassy
C	Distributed by Fisher Scientific Co., St. Louis, Mo. as sodium hexametaphosphate	Crystalline
D	Prepared at Iowa Engr. Exp. Sta. Laboratory from sodium dihydrogen phosphate according to Tyner (5)	Glassy
E	Made by Rumford Chemical Works, Rumford, R. I., and sold under the trade name "Quadrafos"	Glassy
F	Made by Rumford Chemical Works, Rumford, R. I., and sold under the trade name "Metafos"	Glassy

[a] Based on examination with a petrographic microscope.

varieties of sodium metaphosphate, only two types, B and F, were used with the other six soil samples. Types B and F were selected mainly because of their comparative purity. The amounts of these two de-

TABLE 4

COMPARISON OF EFFECTIVENESS OF DIFFERENT VARIETIES OF SODIUM METAPHOSPHATE IN SOIL DISPERSION

Deflocculating Agent (Sodium Metaphosphate)		Sample No. 1		Sample No. 6	
		Percent of Particles Finer Than[b]			
Variety	Amount[a] (ml.)	0.005mm.	0.001mm.	0.005mm.	0.001mm.
A	30	61.9	51.1	18.2	12.3
	40	63.1	52.1	19.0	13.3
	50	62.9	51.5	19.7	14.2
	60	63.6	51.3	18.9	13.5
B	30	62.4	51.3	19.1	11.7
	40	63.7	53.3	18.8	12.7
	50	61.7	52.0	18.4	11.9
	60	62.0	51.7	18.9	13.3
C	30	63.0	51.7	20.3	11.8
	40	62.6	52.2	18.9	12.2
	50	62.8	52.6	19.2	11.3
	60	62.9	52.1	18.2	11.7
D	30	62.5	50.8	20.3	11.2
	40	63.6	52.3	19.6	10.6
	50	62.8	51.4	19.3	10.6
	60	63.5	52.3	20.8	10.0
E	30	63.4	51.8	19.1	12.2
	40	63.0	51.6	18.7	14.[illegible]
	50	62.2	50.8	18.4	11.9
	60	64.4	53.2	18.4	12.8
F	30	62.6	51.5	18.1	15.0
	40	63.4	52.0	19.0	13.0
	50	61.5	51.6	18.5	13.4
	60	64.4	52.3	18.3	15.2

[a] Refers to the amount of 0. 5N deflocculating solution used in dispersing a sample of 50g. into a one liter soil suspension.

[b] All percentages are the average of results from duplicate tests.

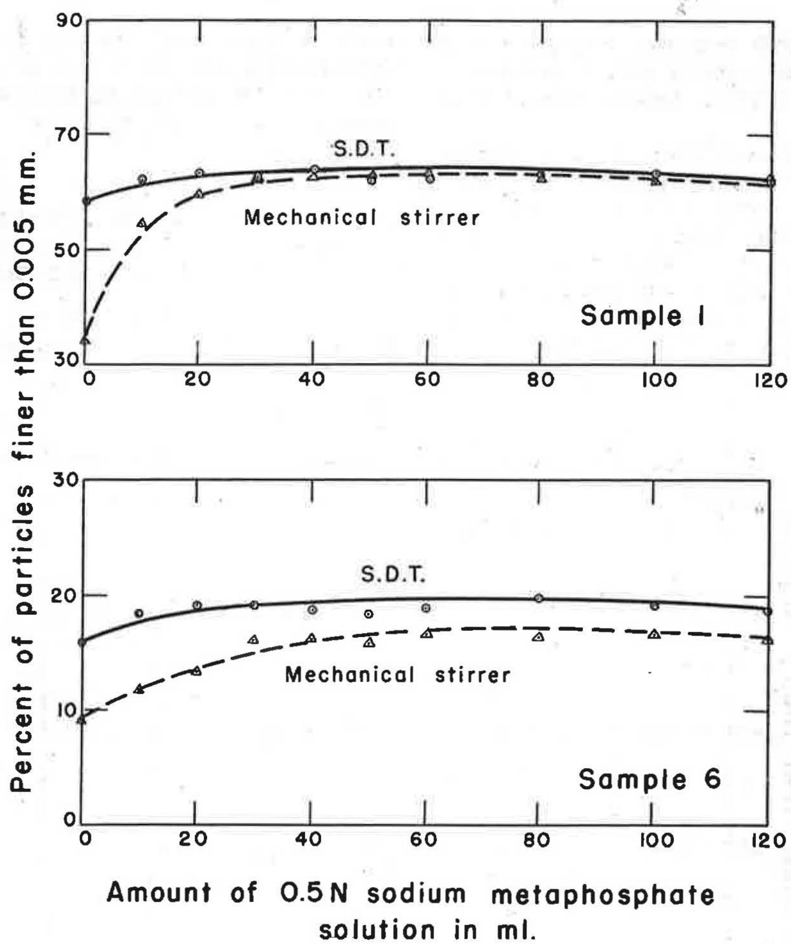

Figure 3. Relation between amount of sodium metaphosphate solution and degree of dispersion obtained with different dispersion apparatus.

flocculating solutions to be used with Samples 2, 3, 4, 5, 7 and 8 were chosen on the basis of the data shown in Figures 3 and 4. The curves representing dispersion with the S. D. T. show that when the amount of either B or F solution is within the range from 20 to 120 ml., the degree of dispersion is nearly independent of the amount of deflocculating solution. For this reason, two amounts, 40 ml. and 100 ml., were used to cover this comparatively wide range. In these experiments only the S. D. T. dispersion apparatus was used.

Mechanical-analysis data representing the degree of dispersion obtained with the two varieties of sodium metaphosphate are presented in Table 5. Types B and F appear equally effective. An analysis of the

TABLE 5

COMPARISON OF TWO VARIETIES OF SODIUM METAPHOSPHATE IN SOIL DISPERSION

Deflocculating Agent (Sodium Metaphosphate)		Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6		Sample 7		Sample 8	
		Percent of Particles Finer Than [b]															
Variety	Amount[a] (ml.)	0.005 mm.	0.001 mm.	0.005 mm.	0.001 mm.	0.005 mm.	0.001 mm.	0.005 mm.	0.001 mm.	0.005 mm.	0.001 mm.	0.005 mm.	0.001 mm.	0.005 mm.	0.001 mm.	0.005 mm.	0.001 mm.
B	40	63.7	53.3	62.9	50.6	56.0	52.1	57.1	30.2	30.7	8.8	18.8	12.7	6.6	4.0	65.7	52.3
	100	63.0	52.0	62.5	52.9	55.2	48.2	57.0	30.3	30.2	10.3	19.1	12.5	6.5	4.3	66.2	54.0
F	40	63.4	52.0	59.0	46.0	56.3	48.1	56.6	32.0	30.8	8.3	19.0	13.0	7.4	4.0	67.1	52.1
	100	62.2	53.1	60.8	50.3	55.7	51.0	57.8	30.5	31.5	10.0	19.3	14.5	6.6	4.0	67.6	54.6

[a] Refers to the amount of 0.5N deflocculating solution used in dispersing a sample of 50g. or 100g. into a one liter soil suspension.

[b] All percentages are the average of results from duplicate tests.

data in the table indicates that the use of 100 ml. of both kinds of sodium metaphosphate gives slightly better results than 40 ml.

Although all varieties of sodium metaphosphate were equally effective in dispersing the soils used in the preceding experiments, this might not be true with a greater variety of soils. Because of this, it seems desirable to recommend one kind of sodium metaphosphate in a standard method of mechanical analysis. Among sodium metaphosphates of equal effectiveness as deflocculating agents, preference should be given to a kind, such as B, which is comparatively pure and readily available.

In a standard method of mechanical analysis, the recommendation of an amount of deflocculating solution that will give adequate dispersion to a great variety of soils is desirable. On the basis of the experiments described in this paper, 100 ml. of 0.5N sodium metaphosphate (B) solution seems to be a safe amount to recommend.

EFFECT OF AGE OF SODIUM METAPHOSPHATE B SOLUTION ON ITS DISPERSIVE ACTION

Tyner (5) points out that sodium metaphosphate solutions may slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive action. Because of this possibility, experiments were made to determine the effect of aging on the dispersing action of 0.5N sodium metaphosphate (B) solution. The pH of the solution used was 6.8, and its temperature during storage was about 70 to 80F. Both pH and temp-

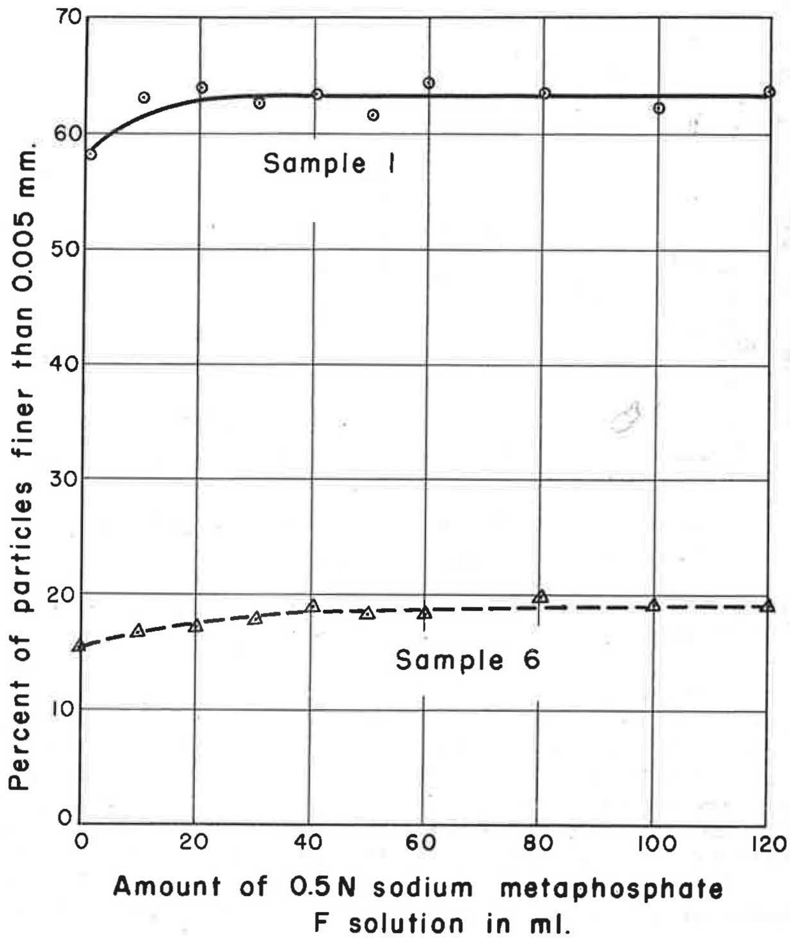

Figure 4. Relation between amount of sodium metaphosphate F solution and degree of dispersion obtained with the S.D.T. apparatus.

erature may affect the rate of reversion.

Two amounts of the solution, 40 and 100 ml., were used in dispersing Samples 1 and 6 with the S. D. T. apparatus. Results given in Table 6 indicate that aging over a period of eight weeks had no appreciable effect on the dispersing action of the B solution. Because of the limited extent of this experiment, no definite conclusion should be drawn. It appears safe to say, however, that aging of a solution up to one month will not decrease the dispersive action of sodium metaphosphate Type B.

SECONDARY EFFECTS OF A DEFLOCCULATING AGENT ON RESULTS

In addition to affecting the degree of dispersion of a soil sample, a deflocculating agent may have other important effects on mechanical-analysis results. These effects, which will be referred to as secondary effects, include the changes in the specific gravity of the soil particles and in the viscosity and specific gravity of the suspending medium.

In the standard methods[4] of mechanical analysis, the percentage and the diameter of soil particles remaining in suspension after a given sedimentation period are computed by the following equations:[5]

$$P = \frac{Ra}{W} \times 100 \qquad (1)$$

Where:

P = percentage of originally dispersed soil remaining in suspension.
R = hydrometer reading (temperature correction should be applied if necessary).
W = weight in grams of soil originally dispersed minus the hygroscopic moisture.
a = constant depending on the specific gravity of soil dispersed and the specific gravity of the suspending medium.

$$d = \sqrt{\frac{30\ nL}{980\ (G - G_1)\ T}} \qquad (2)$$

Where:

d = maximum particle diameter in mm.
n = coefficient of viscosity of the suspending medium in poises.
L = distance in cm. through which soil particles settle in a given period of time.
T = time in minutes, period of sedimentation.
G = specific gravity of soil particles.
G_1 = specific gravity of the suspending medium

In computing the percentage and the diameter of soil particles remaining in suspension from Equations 1 and 2, it is usually assumed that values of R and a in Equation 1 and of n, G, and G_1 in Equation 2 are not significantly affected by the use of a deflocculating agent. Actually these values may be substantially affected,

TABLE 6

EFFECT OF VARIATION IN AGE OF SODIUM METAPHOSPHATE B SOLUTION ON ITS EFFECTIVENESS IN SOIL DISPERSION

Soil	Deflocculating Agent (sodium metaphosphate B)		Percent of Particles Finer Than[c]	
	Amount[a] (ml.)	Age[b] (weeks)	0.005mm.	0.001mm.
Sample 1	40	0	63.7	53.3
		2	62.1	52.0
		4	63.0	52.0
		6	62.8	51.4
		8	62.6	51.0
	100	0	63.0	52.0
		2	62.2	51.5
		4	62.7	53.1
		6	64.3	52.5
		8	62.3	51.3
Sample 6	40	0	18.8	12.7
		2	20.2	13.8
		4	18.4	14.2
		6	20.4	13.3
		8	19.5	13.1
	100	0	19.1	12.5
		2	19.7	14.3
		4	18.9	15.0
		6	20.0	13.9
		8	18.9	13.5

[a] Refers to the amount of 0.5N deflocculating solution used in dispersing a 50g. sample into a one liter soil suspension.

[b] Age refers to the time period after the solution is prepared.

[c] All percentages are the average of results from duplicate tests.

TABLE 7

COMPARISON OF SPECIFIC GRAVITIES OF SOILS BEFORE AND AFTER DISPERSION WITH 100 ML. 0.5N SODIUM METAPHOSPHATE (B) SOLUTION

Sample No.	Specific Gravity[a], 20C/20C	
	Before Dispersion	After Dispersion
1	2.714	2.711
6	2.729	2.724

[a] Specific gravity values are the average of the data from triplicate tests.

[4] ASTM Method D422-51, AASHO Method T88-49.

[5] Equation 1 is for tests using Bouyoucos hydrometer. When specific gravity hydrometers are used, the equation for computing the percentage of soil in suspension will be slightly different but the same variables are involved.

especially when a relatively large quantity of deflocculating solution is used.

Experiments described in this part of the paper were conducted to determine the secondary effects resulting from the use of sodium metaphosphate(B). In these experiments the S. D. T. dispersion apparatus was used for Samples 1 and 6.

TABLE 8

COMPARISON OF VISCOSITIES OF DISTILLED WATER, DISTILLED WATER WITH DEFLOCCULATING AGENTS, AND SOIL SUSPENSIONS

Liquid	Viscosity at 68 F (centipoise)
A (Distilled water)	1.004
B (20 ml. 3 deg. Baume sodium silicate solution mixed with 961 ml. distilled water)	1.018
C (40 ml. 0.5N sodium metaphosphate B solution mixed with 941 ml. distilled water)	1.025
D (100 ml. 0.5N sodium metaphosphate B solution mixed with 881 ml. distilled water)	1.038
Soil suspension[a] prepared from fraction finer than 0.001 mm. in Sample 1 with the following suspending medium:	
Liquid A	1.026
Liquid B	1.031
Liquid C	1.056
Liquid D	1.097
Soil suspension[a] prepared from fraction finer than 0.001 mm. in Sample 6 with the following suspending medium:	
Liquid A	1.116
Liquid B	1.195
Liquid C	1.251
Liquid D	1.274

[a] The soil suspension prepared from the fraction finer than 0.001 mm. in Sample 1 contains about 20 g. in 1000 ml. suspension; that prepared from the fraction finer than 0.001 mm. in Sample 6 contains about 3 g. in 1000 ml. suspension.

EFFECT ON SPECIFIC GRAVITY OF SOIL DISPERSED

Winterkorn, et. al. (7), in experiments with homoionic soils, found that the specific gravity of a soil varies with the kind of adsorbed cation. Since exchange of cations, as well as other chemical changes, may take place when a deflocculating agent is added to a soil-water mixture, there is a possibility for a change to occur in the specific gravity of the soil particles.

The exchangeable cations in Sample 6 are mainly sodium, potassium, and calcium, with the latter cation occupying about 80 percent of the exchange positions. Those in Sample 1 were not determined analytically but are estimated to be mainly hydrogen. The cation exchange capacities of Samples 6 and 1 are 40.0 and 13.4 m.e. per 100 g., respectively.

Experiments to determine the effect of sodium metaphosphate (B) on the specific gravity of Samples 1 and 6 consisted of specific gravity measurements (ASTM Standard Method D854-45T) before and after dispersion. Following dispersion with 100 ml. of 0.5N solution, the soil suspension was left undisturbed for 24 hours, filtered, washed with distilled water, and then dried. Results given in Table 7 indicate that no significant change in specific gravity occurred.

EFFECT ON VISCOSITY OF SUSPENDING MEDIUM

The relation between the viscosity of the suspending medium and the diameter of soil particles in suspension is shown by Equation 2. In the AASHO and ASTM methods of mechanical analysis, the viscosity of distilled water is taken as the viscosity of the suspending medium. Actually, when a deflocculating agent is used, the suspending medium will be a combination of water and the deflocculating solution, and the viscosity of the resulting suspending medium may be appreciably different from that of water. This is illustrated by the viscosity measurements given in Table 8 of Liquids A, B, C, and D representing different kinds of suspending medium. A Cannon-Fenske-Ostwald-type viscometer was used, and the test procedure recommended in ASTM Method D445-46T was followed. Note that the viscosity of Liquid D is about 3.4 percent higher than that of distilled water (Liquid A). Such a difference in viscosity will result in a relative difference of about 1.7 percent in the diameter of soil particles computed by Equation 2.

Theoretically, neither the viscosity of water nor that of water mixed with a deflocculating agent should be used as n in Equation 2. Consider a soil suspension containing silt-size and clay-size particles. Since the silt-size material settles much faster than the clay-size, especially the sizes finer than 0.001 mm., the medium through which silt-size material settles is a soil suspension comprised of clay-size material, deflocculating agent, and water. The viscosities of soil suspensions prepared from the fraction finer than 0.001 mm. in Samples 1 and 6 are also given in Table 8. Note that the viscosity of such suspending mediums may be

as much as 27 percent higher than that of pure water. In using Equation 2, this would result in a difference of about 13 percent in the diameter of soil particles.

From the somewhat-limited experimental results discussed above, for an accurate mechanical analysis it appears that the viscosity value used in computing particle diameters should be as nearly as possible that of the actual suspending medium. The most-practical approach in routine tests might be to apply corrections to the diameters as computed in the conventional manner. The correction will vary not only with the temperature of the soil suspension but also with the particle size composition of the soil sample and the value of the particle diameter. One way to obtain the correction values for routine testing purposes is to arbitrarily divide the common types of soil into several groups and to determine the corrections needed for the different particle-size ranges in each group. The temperature correction can either be included in these correction values or can be applied separately.

EFFECT ON SPECIFIC GRAVITY OF SUSPENDING MEDIUM

The addition of a deflocculating agent to a soil-water mixture will change the density or specific gravity of the suspending medium, which will affect particle-size determinations in two ways. The value of a in Equation 1 and that of G_1 in Equation 2 may be significantly affected. The hydrometer reading R in Equation 1 is influenced in the following manner. Regardless of the type of hydrometer used, hydrometer readings give the difference between the specific gravity of the soil suspension and that of water. If the suspending medium is water only, the hydrometer reading R represents the increase in specific gravity due to the presence of suspended soil particles. If water mixed with a deflocculating agent is the suspending medium, the hydrometer reading R represents the increase in the specific gravity due to the presence of both the suspended soil particles and the deflocculating agent.

The change in the values of a and G_1 can be determined by measuring the specific gravity of the actual suspending medium, water containing a deflocculating agent. For example, when 100 ml. of 0.5N sodium metaphosphate (B) solution is contained in one liter of soil suspension, the specific gravity of the suspending medium at 67 F. will be about 1.003, which is approximately 0.5 percent higher than the specific gravity of water at the same temperature. A difference of this amount will result only in a change of about 0.3 percent in the percentage values and of about 0.2 percent in the diameter values obtained from Equation 1 and 2, respectively. These small changes can probably be overlooked in routine mechanical analyses.

The idea of correcting the hydrometer reading R for the presence of a deflocculating agent is not new. Many laboratories apply such a correction when the quantity of deflocculating solution used is relatively large.

Hydrometer readings may be corrected by subtracting the hydrometer reading[6] of the suspending medium (water plus a deflocculating agent) from the reading taken in the soil suspension. The hydrometer reading of the suspending medium can be determined by a hydrometer measurement in water containing the amount of deflocculating agent in the soil suspension. The correction constant can be determined from the hydrometer reading (in the use of the Bouyoucos hydrometer, the reading is the constant).

When different amounts of a given deflocculating solution are being investigated, the following equations may simplify the determination of correction constants.

For Bouyoucos hydrometer

$$C = \frac{m\ R_d}{1000 - \frac{W}{G}} \quad (3)$$

For specific gravity hydrometer

$$C = \frac{m\ (R_d - 1)}{1000 - \frac{W}{G}} \quad (4)$$

Where:

C = correction constant.

m = amount of deflocculating solution in ml. contained in one liter of soil suspension.

R_d = hydrometer reading of deflocculating solution at specified temperature.

W = weight in grams of soil originally dis-

[6] With specific gravity hydrometers, only the decimal portion of the hydrometer reading will be subtracted.

TABLE 9

COMPARISON OF EXPERIMENTAL AND COMPUTED CORRECTION CONSTANTS FOR HYDROMETER READINGS

Soil	Deflocculating Agent		Hydrometer reading of soil suspension at the elapsed time indicated [b]		Difference in hydrometer readings of soil suspension with and without deflocculating agent [c]		Correction constant determined by Equation 3
	Type	Amount [a] (ml.)	15 min.	60 min.	15 min.	60 min.	
Sample 1, fraction finer than 0.0005 mm.	No deflocculating agent		14.5	14.5	0	0	--
	Sodium metaphosphate B	40	17.0	17.0	2.5	2.5	2.5
		100	21.0	21.0	6.5	6.5	6.4
Sample 6, fraction finer than 0.005 mm.	No deflocculating agent		6.5	Not taken	0	--	--
	Sodium metaphosphate B	40	9.0	Not taken	2.5	--	2.5
		100	13.0	Not taken	6.5	--	6.4

[a] Refers to the amount of 0.5N deflocculating solution used in preparing one liter of soil suspension.

[b] Bouyoucos type hydrometer was used in all tests. The temperature of soil suspension was maintained at 67F. during the hydrometer test.

[c] Example: Hydrometer reading of suspension without deflocculating agent = 14.5, hydrometer reading of suspension with 40 ml. deflocculating solution = 17.0, difference in hydrometer readings = 17.0 - 14.5 = 2.5.

persed minus the hygroscopic moisture.

G = specific gravity of soil dispersed.

In deriving Equations 3 and 4, the Bouyoucos and the specific gravity hydrometer readings for water at the specified temperature (usually 67 F. or 68 F.) are assumed to be zero and one respectively. For practical applications of the two equations, the specific gravity G can be assumed as 2.65 because it has little effect on the correction constant computed. It should also be mentioned that the correction constant computed from either Equation 3 or 4 is always positive in value and should be subtracted from hydrometer readings taken in the soil suspension.

The method of determining correction constants discussed above is valid only if it can be assumed that chemical changes caused by the addition of a deflocculating agent to a soil-water mixture do not significantly affect hydrometer readings taken in the soil suspension.

A direct test of the validity of this assumption is to compare the correction constant determined by Equations 3 or 4 with the required correction as determined experimentally. The required correction equals the difference between the hydrometer reading taken in a soil suspension containing a deflocculating agent and that taken in a similar soil suspension without the deflocculating agent. Since the degree of dispersion of a soil sample may be greatly affected by the use of a deflocculating agent, the experimental determination of the required correction must be accomplished in such a way that any change in the degree of dispersion of the soil sample will not significantly affect hydrometer readings taken in the soil suspension. This can be done by using clay-size soil samples. A description of two such determinations follows.

The clay-size material was collected by the layer method (8) from Samples 1 and 6. The clay separated from Sample 1 was finer than 0.0005 mm. in size, and that from Sample 6 was finer than 0.005 mm. Samples of each separated clay material were soaked for over 18 hours in either distilled water or distilled water containing sodium metaphosphate B (Table 9) before being dispersed with the S. D. T. for the hydrometer test. The hydrometer tests were conducted in essentially the same manner specified in the AASHO and ASTM standard methods of mechanical analysis.

As mentioned, the purpose of using such clay-size material was to eliminate the degree of dispersion variable from the tests. Thus, any variation in the degree of dispersion of a sample consisting of particles finer than 0.0005 mm. will not significantly affect hydrometer readings taken within an hour after the beginning of sedimentation. Similarly, hydrometer readings in a soil suspension consisting of minus-0.005-mm. material will not be significantly affected by a variation in the degree of dispersion, if the readings are taken within 15 minutes after the beginning of sedimentation.

Carbonates in a soil sample may influence chemical changes taking place in a soil suspension in which sodium metaphosphate is the deflocculating agent. The minus-0.0005-mm. clay material used in the tests contained a negligible amount of carbonates; the 0.005-mm. clay contained about 8 percent of carbonates, principally calcium carbonate.

Hydrometer readings of the prepared soil suspensions taken at different sedi-

mentation times are given in Table 9. The readings taken before 15 minutes are not shown in the table, since they were the same as those taken at 15 minutes due to the smallness of the particle sizes contained in the suspensions. To eliminate the effect of variation in degree of dispersion on hydrometer readings, no readings were taken after 60 minutes of sedimentation in the soil suspensions prepared with minus-0.0005-mm. material and none after 15 minutes in suspensions prepared with the minus-0.005-mm. material.

The required correction constant for each suspension containing sodium metaphosphate (B), obtained by subtracting the hydrometer reading of the suspension from the hydrometer reading of a similar suspension containing no deflocculating agent, is given in the table together with the correction constants computed by Equation 3. Considering that hydrometer readings were taken to the nearest half division, the required and the computed corrections are practically in complete agreement. According to this experiment, the assumption made in developing Equations 3 or 4 seems valid.

CONCLUSIONS

1. Among the three chemicals compared, sodium metaphosphate is the most-promising deflocculating agent.

2. Among the different varieties of sodium metaphosphate compared, variety B appears to be well suited for adoption as a deflocculating agent in standard methods of mechanical analysis.

3. On the basis of the results with the soils tested, the use of 100 ml. of 0.5N Sodium Metaphosphate B solution in making one liter of soil suspension is recommended.

4. To avoid a possible decrease in its dispersive action, it seems advisable to make up fresh B solutions about every 30 days.

5. The effect of B solution on the specific gravity of soils tested was found to be insignificant.

6. The viscosity of water is used as that of the suspending medium on the present standard methods of mechanical analysis in computing particle diameters. A correction should be applied to the computed diameter for accurate mechanical analysis results to compensate for the difference between the viscosity of water and that of the actual suspending medium.

7. The suggested method for determining the correction constant to compensate for the change in specific gravity of the suspending medium due to the use of a deflocculating agent appears to be valid.

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Appendix

NOMENCLATURE OF SODIUM POLYPHOSPHATES

There is no universally adopted nomenclature for the sodium polyphosphates at the present time. The following is one method of classifying the different sodium polyphosphates.

The sodium polyphosphates may be classified according to their structure into two groups: the crystals and the glasses. The crystalline sodium polyphosphates include sodium metaphosphate, sodium pyrophosphate, and sodium tripolyphosphate. The glassy sodium polyphosphates include sodium tetraphosphate, sodium hexametaphosphate, and also sodium metaphosphate. The two names, sodium hexametaphosphate and sodium metaphosphate, are often used interchangeably. Manufacturers use trade names (e. g. Calgon, Sodium Polyphos, Quadrafos, Metaphos) in referring to their glassy sodium polyphosphate products.

As r ioned, sodium metaphosphate can be either crystalline or glassy. Different varieties of this chemical are available from chemical supply companies. The complicated properties of this group of chemicals were discussed by Thorne and Roberts (9) as follows:

"Metaphosphoric acid, HPO_3, and its salts possess the most complicated properties of all the acids of phosphorus, because, on the one hand, they have a strong tendency to polymerize, when varied products of high molecular weight can be formed, while, on the other hand, these products show isomerism through different arrangements within the individual molecules, so that varying constitutions may appear with the same molecular complexity. The relations of the metaphosphates are still so confused, in spite of numerous investigations, that the practice of giving definite formulae for the products must be given up for the present."