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HIGHWAY RESEARCH REPORT

METHODS OF CONTROLLING GROUT FOR PRESTRESSED, POST-TENSIONED STRUCTURES

INTERIM REPORT

71-23

STATE OF | IALS AND RESEARCH DEPARTMENT

BUSINESS AND TRA

RESEARCH REPORT

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

NO. M & R 635117-3

Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration November, 1971

STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

November, 1971
Interim Report
M&R No. 635117-3
FHWA D03-12

Mr. R. J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is an interim report titled:

METHODS OF CONTROLLING GROUT FOR

PRESTRESSED, POST-TENSIONED STRUCTURES

By

J. L. McCormick, W. A. Winter,
and R. L. Watkins

Under the Direction of

D. L. Spellman
Principal Investigator

Under the Supervision of

R. F. Stratfull
Co-Principal Investigator

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Attachment

REFERENCE: McCormick, J. L., Winter, W. A., and Watkins, R. L., "Methods of Controlling Grout for Prestressed, Post-Tensioned Structures", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report No. 635117-3, FHWA No. D03-12, November 1971.

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KEY WORDS: Grout, grouting, cement, prestressed concrete, post-tensioning, bridges, corrosion, statistics.

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ACKNOWLEDGMENT

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This project was performed in cooperation with the U.S. Department of Transportation, Federal Highway Administration, Agreement No. D03-12.

The opinions, findings, and conclusions expressed in this report are those of the authors and are not necessarily those held by the Federal Highway Administration.

METHODS OF CONTROLLING GROUT FOR
PRESTRESSED, POST-TENSIONED STRUCTURES

INTRODUCTION

The corrosion of high-strength, prestressing steels in concrete became of serious concern with the increased use of prestressed concrete coupled with the fact that the grouting of ducts was not trouble-free. If the ducts were not completely filled with grout, then some degree of corrosion of the steel could be anticipated.

At the outset of this study it was believed that an ideal grout (for grouting prestressing ducts) (1) should have a low viscosity and remain low all during the pumping operation; (2) should have no plastic shrinkage or volume reduction due to settlement (no bleeding); (3) should not shrink after hardening; (4) should be slightly expansive in nature during the plastic stage; and (5) should have reasonably good strength after curing.

This report deals with determining what the necessary steps are as far as mixing techniques to produce grout with the aforementioned qualities.

During the course of this study, steel and fiberglass flow cones were compared. Flow cone efflux time as a measure of viscosity and mixing energy as a criterion of grout quality were examined.

As a result of this study, fiberglass flow cones are now used throughout the State of California as a tool for grout quality control.

Statistical methods are used throughout this report in comparing the steel and fiberglass flow cones as well as determining the effects of mixing energy.

OBJECTIVES

This study was initiated to establish a more effective control of corrosion of mild and high strength steel used in highway bridge concrete by insuring that the steel will be completely encased in neat cement grout.

This work was intended to (1) determine the effect of variable grout mixing techniques on grout quality, and (2) develop simple field procedures to control the quality of neat cement grout.

SUMMARY AND CONCLUSIONS

1. Flow Cones

a. Types of Flow Cones

A comparison of fiberglass to metal flow cones demonstrated that fiberglass flow cones performed as well in field situations as metal flow cones. It was also found that fiberglass cones were more desirable because they could be fabricated economically to more accurate tolerances.

b. Grout Efflux Time

It was found that if the mixing energy and the cement brand were known for a given grout, relatively accurate predictions could be made of the initial efflux time and confined shrinkage. It was determined that an important control in field grout testing was the efflux time immediately after mixing and after a quiescent period. Any changes from the initial efflux time measurement of a grout would indicate that the mixing energy at the mixer has either increased or decreased, or an error was made in the grout water-cement ratio.

The quiescent period efflux time indicated that additional mixing water as well as increased mixing energy could be used to obtain a more initially fluid grout. However, to a great degree, grout bleeding increases with mixing water.

Grout bleeding and settlement shrinkage increases with increasing time of "set" of the grout. Therefore, the longer the grout remains plastic, the greater the bleeding.

2. Mixing Energy

Numerous tests showed that high energy mixing and in some cases speed over and above that usually required for ordinary mixing was beneficial in that (1) grout viscosity both at the initial and after the 20-minute quiescent time was at a minimum, and (2) bleeding and shrinkage were reduced.

Because of the difficulty in measuring mixing energy with methods presently available, it is doubtful at this time that mixing energy per se would be a useful field criteria. However, it was also observed that indications of adequate effective total mixing energy could be observed by means of the flow cone. It was found that with increasing mixing time, up to a point, the initial efflux time of the grout would decrease. Therefore, it appears that the minimum required time for grout mixing with any mixer would be sufficiently indicated by a lack of change in the initial efflux time of the grout with added mixing time.

In summary, it can be concluded that an ideal grout for grouting prestressing ducts (1) should have a low viscosity and remain low all during the pumping operation; (2) should have no plastic shrinkage or volume reduction due to settlement (no bleeding); (3) should not shrink after hardening; (4) should have reasonably good strength after curing.

TEST RESULTS

A. Flow Cones

1. Purpose:

Due to unavailability and fabrication problems, an alternate to metal flow cones was considered. The search for a new material resulted in fiberglass flow cones. The purpose of this test series was to determine if the flow times measured with fiberglass flow cones were reliable. The design of the cones conformed to the design presented in the Corps of Engineers test method CRD-C79-58.

2. Test Procedure:

In this test series, 12 fiberglass and six metal flow cones were compared and evaluated using grout, water, and oils of two different viscosities. The two oils used were No. 15 white oil and No. 3 white oil.

The efflux times were measured with a hand operated stop watch and temperatures were taken at the end of each efflux time test. Test data obtained from batches of oil and water having a temperature outside the range of 70°F to 75°F were omitted from the group.

Before beginning a test using oil, the flow cones were coated with the particular oil to be used. When water or grout efflux times were measured, the flow cones were wetted with water before use. The water and the oils were allowed to stabilize for 30 seconds in the flow cones before allowing flow to begin and they were allowed to drain for 15 seconds before making the final time measurement. The grout efflux time measurement began immediately after the flow cones were filled for an initial efflux time. The remaining grout was washed from the flow cones after each efflux time was measured. The reason for the immediate initial flow time measurement of the grout was in order to obtain the efflux time before any cement settled within the mixture. The grout used for this test series was mixed for 10 minutes at 900 rpm with a water-cement ratio of 4.75 gallons per sack of cement, and the initial temperatures fell between 77°F and 85°F.

The fiberglass cones were divided into two groups according to their fabrication process. Group 1 differed from Group 2 in that the cones had very smooth interiors, obtained at a significant cost difference. It was the purpose of this series of tests to determine (1) were the fiberglass cones as accurate as steel cones, and (2) what refinements in design of the fiberglass cones were justified from an economic standpoint. Micrometer measurements were taken of the orifice and nozzle of each cone. The mean orifice and nozzle measurements are shown in Table 1. For purposes of definition, the opening of the 1 1/2" tube inside the cone is referred to as the orifice, the outside opening the nozzle.

From Table 1, it can be seen that the wider range of the orifice and nozzle measurements of the efflux times of the first six would produce a better correlation than the narrower range of the second group of six. For further comparison, it was necessary to refer to the standard deviations shown in Table 2. They are used to determine if the difference between metal and fiberglass flow cones is significant. Using grout as the medium, the first comparison was computed between the efflux times of the first six fiberglass flow cones and the metal flow cones. This produced a t-statistic of 1.815 compared with the t-statistic at the 10% level of significance of 2.015. This indicated that there was no significant difference between the efflux times of the first six fiberglass flow cones and the metal flow cones. A comparison of their standard deviations produced an F-statistic of 3.11 and at the 5% level of significance, the F-statistic was 5.05. This also indicated that there was no significant difference between the fiberglass flow cones and the metal flow cones. The F-statistic for the second six and the metal flow cones was 2.19 which again indicated that there was no significant difference between the two. Since the testing of grout was our objective, the above comparison is the most important comparison (see Table 2).

Water and oil were considered for adoption as a calibration fluid. Water was eliminated because it often developed a vortex. The efflux times for the No. 15 white oil were too long to be compared with grout, so the No. 3 white oil was chosen as the calibration fluid.

It should be noted that the metal flow cones had previously been calibrated to produce an efflux time of 11.00 seconds as a

Table 1

Micrometer Measurements and Efflux Times for
Fiberglass Flow Cones
(Means of 6 Recordings)

	Micrometer Measurements			Efflux Time, Seconds			
				Oils			
	Fiber Glass Cone Number	Orifice Diameter	Nozzle Diameter	No. 3 Mineral	No. 15 Mineral	Grout	Water
Group 1	1	.516	.505	10.77	17.03	11.18	8.00
	2	.514	.504	10.90	17.23	11.02	7.93
	3	.512	.505	10.83	17.22	11.11	8.00
	4	.504	.503	11.13	17.73	11.44	8.25
	5	.507	.506	10.87	17.15	11.26	8.05
	6	.506	.505	10.92	17.35	11.22	8.18
Group 2	7	.513	.506	10.75	17.02	11.38	7.98
	8	.509	.505	10.78	17.30	11.45	7.95
	9	.514	.506	10.77	17.07	11.28	7.95
	10	.505	.504	10.87	17.62	11.35	7.98
	11	.509	.505	10.85	17.48	10.95	8.00
	12	.512	.506	10.80	17.32	11.33	8.00

Table 2

Standard Deviation of Flow Times
for both Fiberglass and Metal Flow Cone

Cones	Efflux Times in Seconds		
	Water	#3 White Oil	Grout
1-6	.122	.123	.148
7-12	.023	.047	.176
Metal	.191	.284	.261

"standard." Due to fabrication irregularities, the volumes of the metal cones had to be adjusted, and the adjustment was as high as 325 millitiers above the standard volume of 1725 milliliters. The volumes for the fiberglass flow cones did not need adjustment.

In other respects, such as ease of cleaning and field durability, the fiberglass cones were found to be equal in quality to the metal cones.

B. Mixing Energy

1. Test Series I

In the first test series, 20 batches of grout having the same Type II cement and an identical water/cement ratio of 4.50 gallons per sack of cement were mixed using various mixer blades, mixer speeds, and mixing times in an attempt to determine what constituted good mixing.

In this test series, Phase II of the Laboratory Test Procedures in Part C of test results was followed (see page 15). The Jiffy and quad epoxy blades were used for a large percentage of the test batches, although all of the blades shown in Figure 1 and in the laboratory test procedure discussion were evaluated. The mixer speeds varied from 362 to 511 rpm, and the mixing times varied from 5 to 40 minutes.

Efflux time (initial and after quiescence period), bleeding, and shrinkage were plotted against the specific energy input of the mixer in watt-minutes per kilogram of grout. There was considerable scatter in the data, but there was a definite tendency for grouts subjected to high energy mixing to be less viscous initially and more stable over a quiescent period, and to bleed and shrink less.

2. Test Series II

In the second test series, 18 batches of grout were mixed with a 1/2-inch, 5.5-amp hand operated drill, using Type II cement, a water-cement ratio of 4.5 gal./sack of cement, and no admixture. This test series was designed to use nine different mixing times ranging from 5 to 40 minutes, 2 mixer speeds of 382 and 491 rpm, two different blades, a mixer bucket with and without stationary baffles, and three different cement batch sizes of 8.4, 12.6, and 16.8 kilograms.

At 1-minute intervals during mixing, the mixer speed was adjusted by means of a variac and the voltage and current drawn by the motor were recorded. The voltage and current required to turn the motor and blade at the same speed with no load (no grout) had been determined previously, permitting calculation of the net apparent power used to mix each batch. There was no adjustment for power factors, therefore, the exact amount of power input could not be determined, but the relative values used are considered adequate for the purpose. The sum of the net volt-amps recorded each minute during mixing, divided by the mass of the batch, is then the net specific apparent energy input in watts per kilogram of grout. The results are presented in Table 3.

Table 3

Summary of Test Series II Mixing Energy Data

Specific[1] Energy	No. of Batches	Shrinkage[2] Percent	Bleeding[2] at 3 hrs. Percent	Quiescent Time, Min.[3] 0	5	10	15	20	30
				Time of Efflux, Seconds[2]					
14-20	2	1		-----Too viscous to test----					
24-26	2	1.82	1.7	20.4	26.0	27.0	31.0	36.0	48.2
33-40	4	1.69	1.7	21.6	22.1	23.4	26.6	30.2	38.7
49-56	4	1.58	0.9	20.2	20.8	21.9	25.1	27.4	36.4
64-99	6	1.42	1.1	18.8	19.8	20.4	23.7	27.0	31.4

[1]Specific energy - volt-amp, minutes per kilogram of grout

[2]Average values

[3]Time of grout standing in flow cone at time of measurement

3. Test Series III

In the third test series, three batches of grout were mixed for up to 5 hours and 40 minutes each using the 1/2-inch hand operated drill motor and the quad epoxy blade at a mixer speed of about 525 rpm in an attempt to determine the mixing time required to produce grout with the shortest possible initial efflux time. The initial efflux times indicate that for the particular mixer and speeds employed, the optimum mixing time is between 2 and 3 hours, and the accompanying temperature rise of the grout is between 15°F and 20°F. For the test series in which the grout was mixed for 5 hours and 40 minutes, the average 28-day compressive strength for three cylinders was 8536 psi.

4. Test Series IV

In the fourth test series, six batches were mixed at different speeds using the 1/2-inch drill press mixer. The cement, water-cement ratio (4.75 gals./sack of cement), mixer and mixing time (10 minutes), were held constant and the blade speed was varied from 500 to 1600 rpm.

The stiffening rate was dramatically reduced by mixing at higher speeds which indicated that the grout fluidity became more stable with increased mixing speed. Grout mixed at 500 rpm for 10 minutes had a 21-second time of efflux from the flow cone after 20 minutes of quiescence. Grout mixed at 1600 rpm for 10 minutes had a 12-second efflux time after the same 20-minute quiescent period. The 21-second grout would probably be too viscous to pump through any commonly used prestressing duct, whereas the 12-second grout should be pumpable in most any system.

The efflux time of the grout after 20 minutes of quiescence, was more effectively reduced by increasing the mixer speed from 500 to 1600 rpm than it was in previous tests by increasing the water-cement ratio from 4.25 to 4.75 gallons per sack of cement. At lower speeds, and resulting longer efflux time, the most likely way of increasing fluidity would be the addition of water.

Perhaps more important is the fact that bleeding, shrinkage, and compressive strength, as well as efflux time and stiffening time were all apparently improved by mixing at higher speeds. To reduce the viscosity and stiffening rate by increasing the water-cement ratio would result in a grout which is inferior in the other properties (lower strength, more bleeding, greater shrinkage). It is, therefore, preferable to mix with the highest energy possible and the lowest water-cement ratio which will give a pumpable grout.

In the first four test series, an attempt was made to compare one test series to another using the grout properties as the common denominators. It was decided that to progress further, a test series was needed to study the relationships of all of the properties. With this type of analysis, it was assumed that the properties which influenced the quality of grout the most, could be determined. Knowing this, a better prediction of the quality of a particular grout could be made.

5. Test Series V

a. Test Procedure

In the fifth test series, it was assumed that the product of the mixing speed and the length of time the grout was mixed was a function of the total mixing energy.

Three mixing speeds and five mixing times were chosen making a total of 15 variables. The mixing speeds were 600, 900, and 1200 rpm, and the mixing times were 2, 4, 8, 16, and 32 minutes. The approximate amounts of power used in mixing the grout at the various mixing speeds were 600 rpm, 165 watts; 900 rpm, 270 watts; and 1200 rpm, 520 watts. Each batch was mixed in triplicate for a total of 45 batches.

The evaluation and comparison of each of the 45 batches of grout were based on the results of five different laboratory tests which were (1) initial efflux time, (2) efflux time after 20 minutes of quiescence, (3) unconfined bleeding, (4) confined volume change, and (5) compressive strength.

A water-cement ratio of 4.75 gals./sk. of cement was used for all of the 45 batches. The batches were standardized by using 16 kilograms of cement plus 6.741 kilograms of water for a total batch size of 22.741 kilograms. Phase III of the test procedures was used as the mixing procedure for the fifth test series. The mixing system was the three rod blade and the bucket containing three baffles. The batch temperature was 70°F ± 3°F.

b. Analysis

Equation (1) was derived to test the effect mixing energy and batch temperature on the confined shrinkage.

$$S = 4.7036 - 0.1131\ E - 0.02915T_b \qquad (1)$$

Where: S = confined shrinkage (% by volume)

E = mixing energy (kilowatt/minute/22.7 kg batch)

T_b = batch temperature (°F)

Number of sets of values = 46

The t-statistics indicate that mixing energy is the largest contributor to the correlation. Plots of actual against calculated values of the one variable against another, failed to reveal any nonlinear functions.

As previously mentioned, the mixing energy and batch temperature were used as independent variables in further correlation studies. Multiple regression equations were, therefore, calculated to test the effect of these independent variables on the dependent test variables.

Since confined shrinkage is one of the more important grout properties relative to grouting of prestress tendons, mixing requi... for grout would be expected to receive considerable attention in specifications.

C. Laboratory Testing Procedure

1. Phase I

It should be noted that the grout mixer was modified several times in the early laboratory grout mixing operations. As a result, some modifications to the mixing procedures were necessary.

The first mixer used was a 1/2-gallon Hobart mixer; however, due to the lack of consistency, the data could not be reasonably correlated to the more recent data. Trends in the data were used to establish the initial guidelines for improving future mixing techniques.

2. Phase II

a. Mixing Equipment

The mixer used in this phase was a 1/2-inch hand operated electric drill connected to a variac to control the speed (see Figure 1).

an ammeter and a voltmeter were used to record power consumption for both load and no-load conditions. The no-load amperage and voltage were measured to permit the calculation of the net apparent power required to mix each batch. No adjustment for power factor loss was made.

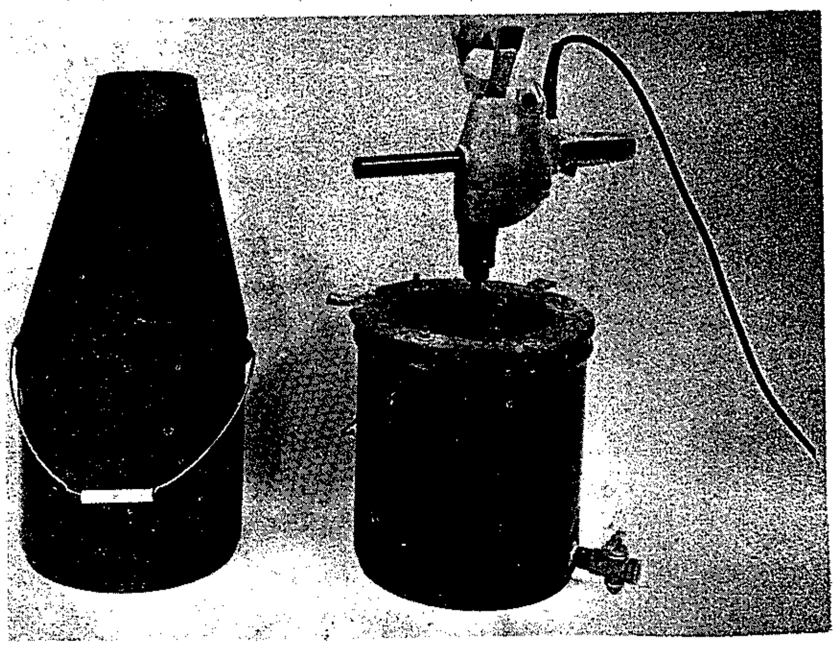

Figure 1

Phase II Mixing equipment

During this phase of development, four experimental and one 3-rod epoxy mixing blades were used; the Experimental No. 1 and No. 2, the Jiffy, and the quad-epoxy. All four blades are shown in Figure 2. The Experimental No. 1 and No. 2 and the quad-epoxy blades were constructed by the Laboratory. The Jiffy was a commercially developed paint mixing blade. The quad-epoxy was used in two versions. The first version had only one of the rectangular propellers shown in Figure 2.

The Experimental No. 1 and No. 2 blades were of preliminary design and the data that was obtained during their use was not used in any analysis.

The mixing bucket was a standard 5-gallon bucket with a specially developed insert to which baffles could be attached. There were two different systems of baffles: (1) eight 1/2-inch rods attached to the insert parallel with the sides of the bucket, and (2) four 1-1/2-inch wide, 1/4-inch thick vanes attached to the insert parallel with the sides of the bucket. The insert with three vanes attached is shown in Figure 3.

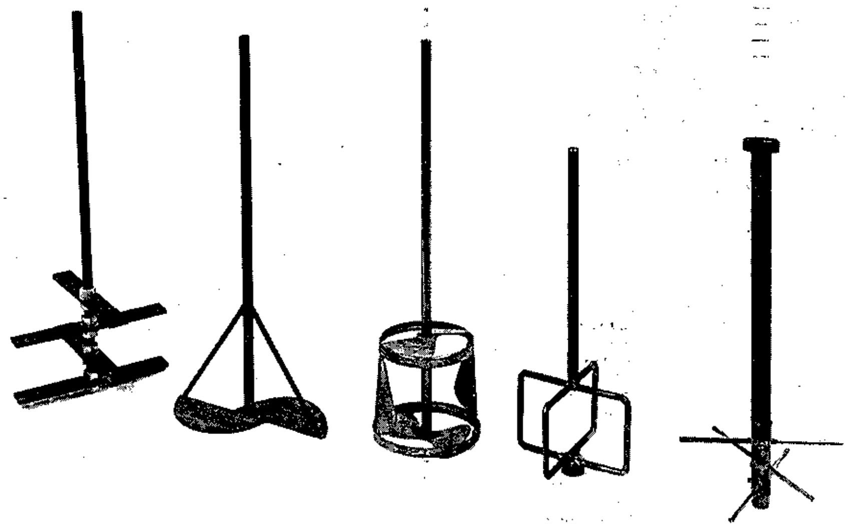

Figure 2

From left to right Experimental No. 1, Experimental No. 2, Jiffy, quad-epoxy and 3-rod blade.

b. Mixing Procedure

After the water-cement ratio, the batch size, the type of cement, the mixing time, and the mixing speed were chosen for a batch, these were recorded on the data sheet along with the date and batch number. Then the cement and water, and admixture (if used) were batched (see Figure 4).

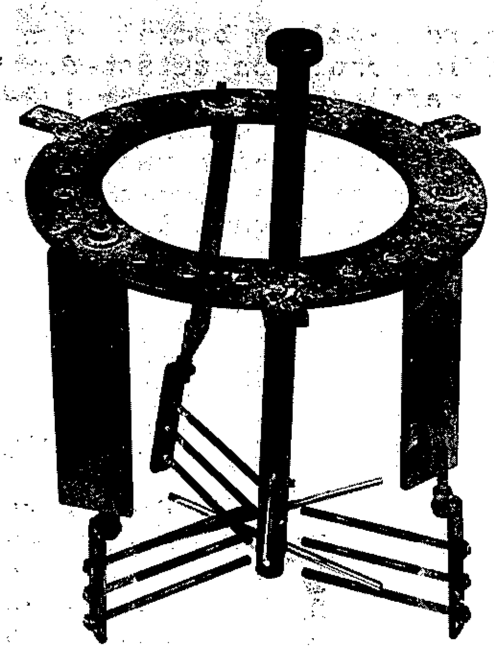

Figure 3

Mixer Rod and baffle assembly

To start the mixing procedure, the water was poured into the mixing bucket, and low rpm agitation was started. The cement was then added to the water, and the mixing speed increased to a predetermined value. The mixing time was started the moment the mixer reached the predetermined test speed.

Temperatures were taken of the mixing water before mixing and of the grout after each quiescent period.

The power (wattage) consumption of the mixer was recorded for each minute during the entire mixing time.

c. Laboratory Tests

The flow cones used in the flow cone test generally conformed to the specifications described by the Corps of Engineers in Test Method CRD-C79-58 (see Figure 5). The flow, or efflux times of the grout were recorded to one-tenth of a second.

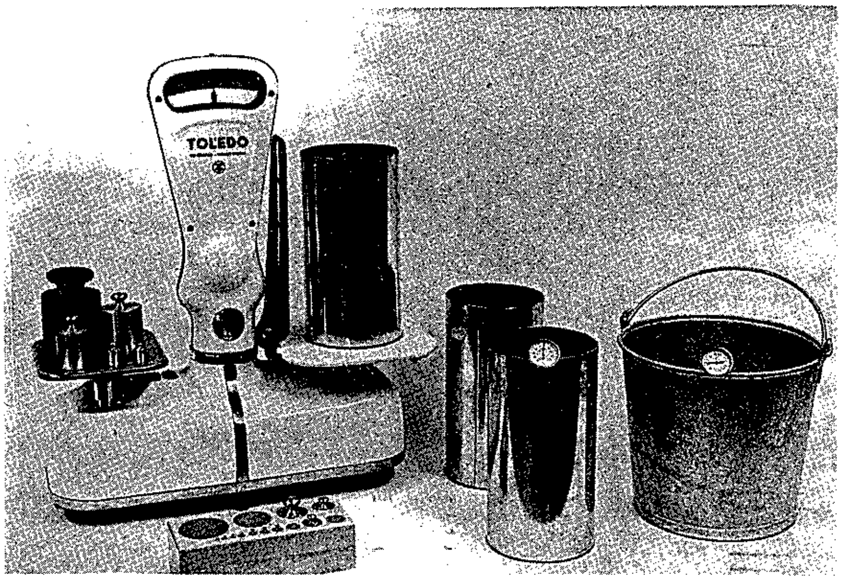

Figure 4

Mix batching and testing equipment

There were two different efflux times measured for each batch in most of the test series: initial, and after 20 minutes of quiescence. For these efflux times, 1725 mls of grout were used. Temperature of the grout was taken at the end of each efflux time test.

For the Unconfined Bleeding Test, 1-inch PVC (polyvinyl chloride) tubes 10 inches long were used. The tubes were capped on one end, placed in a rack, and filled with grout (see Figure 6). The grout was then leveled off on top and an extension approximately 1-1/2 inches long was added to the end.

Following the addition of the extension, 10 milliliters of carbon tetrachloride was poured from an automatic measuring device into the extension and a cover glass was placed on the extension. The use of the carbon tetrachloride was based on a CCl_4 displacement method in ASTM Proceedings, Vol. 49, 1949.

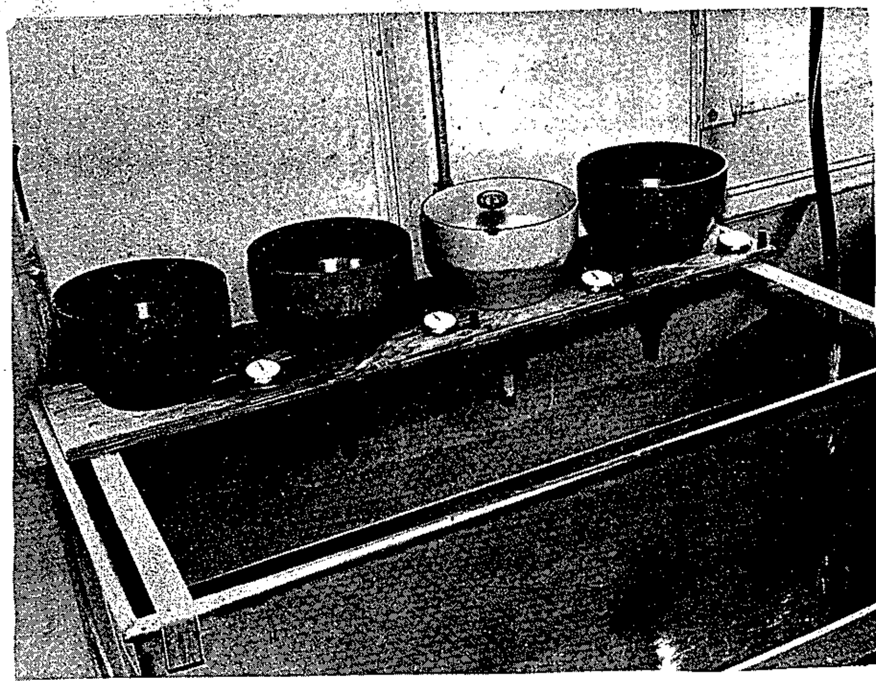

Figure 5

Modified Corps of Engineers flow cones

For the Unconfined Volume Change Tests, PVC tubes 1-inch in diameter and 10 inches in length were filled with grout. Then a 1-inch extension was placed on the top of the tubes, and a cover glass was placed on the extension. The volume change was measured taking depth micrometer readings in three places on the surface, averaging the three readings, and converting the average depth to a volume. The unconfined volume change measurements were taken at various intervals of time from a few minutes to 7 days after the grout was poured into the tubes. The maximum change of the grout from the original dimension was recorded as the volume change.

In the Confined Shrinkage Test, cylindrical metal molds of 2-inch diameter and 4 inches in height were filled with grout and capped with a device to prevent loss of grout and water (see Figure 7).

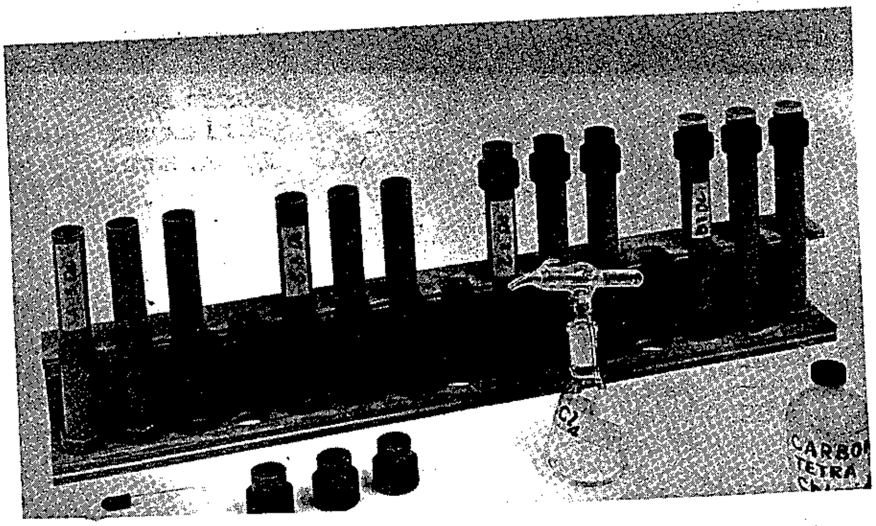

Figure 6

Grout bleeding test apparatus

Twenty-four hours after the cylinders were cast, the confining caps were removed. The shrinkage was then measured with a depth micrometer. The average of three readings in each mold was used to compute the shrinkage.

The hardened grout was later extracted from the molds and used in the compressive strength test. The compressive strength was measured after various curing periods. In general, the curing periods were either 1, 2, and 7 days, or 7, 14, and 28 days. The 2, 7, 14, and 28 day curing periods were in a fog room at about 72°F. The 1-day curing was at room temperature (about 70-75°F). Compressive strength was measured immediately after the specimens were extracted from the molds and capped.

The load rate for testing of the compressive strength of the capped cylinders was 15,000 pounds per minute, or approximately 5000 pounds per square inch per minute.

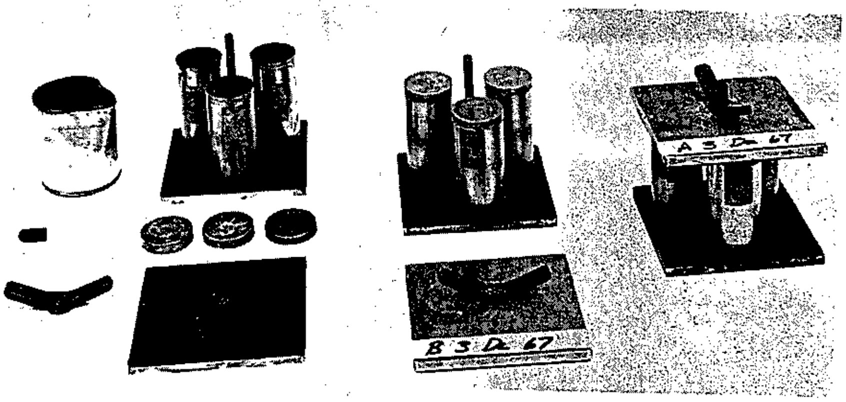

Figure 7

Confined Shrinkage Apparatus

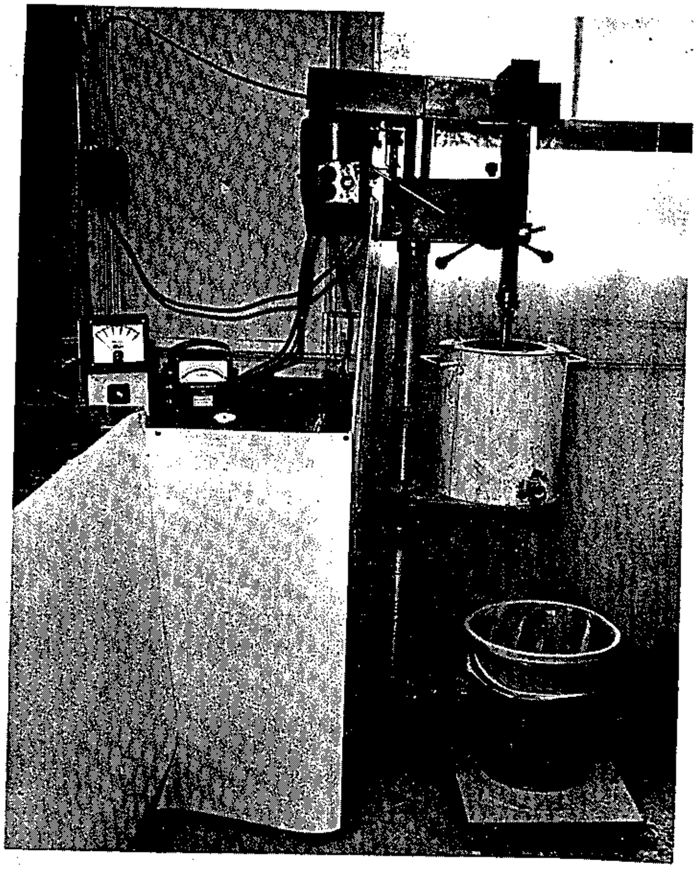

Figure 8

Phase III mixing equipment

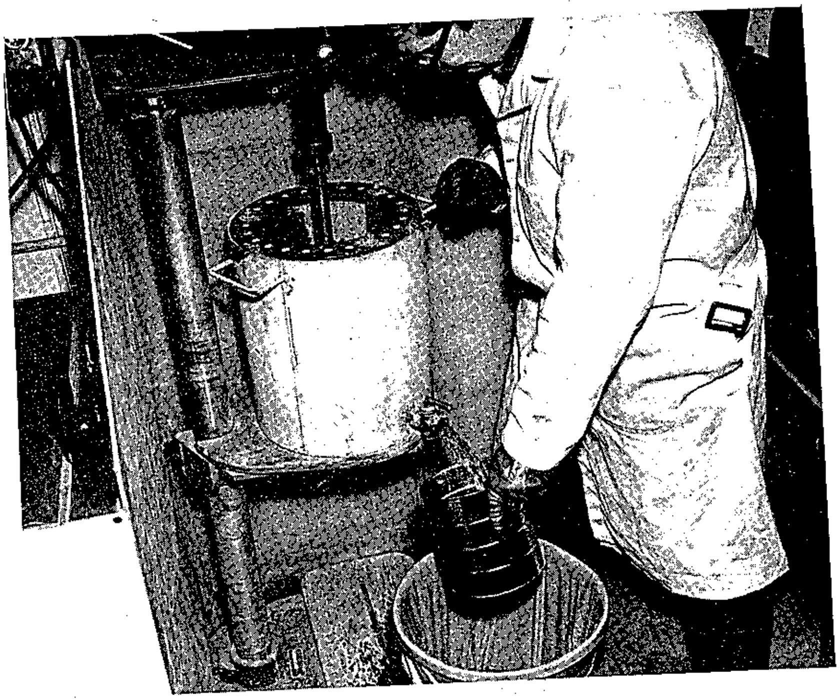

Figure 9

Removal of Liquid without interrupting mixing

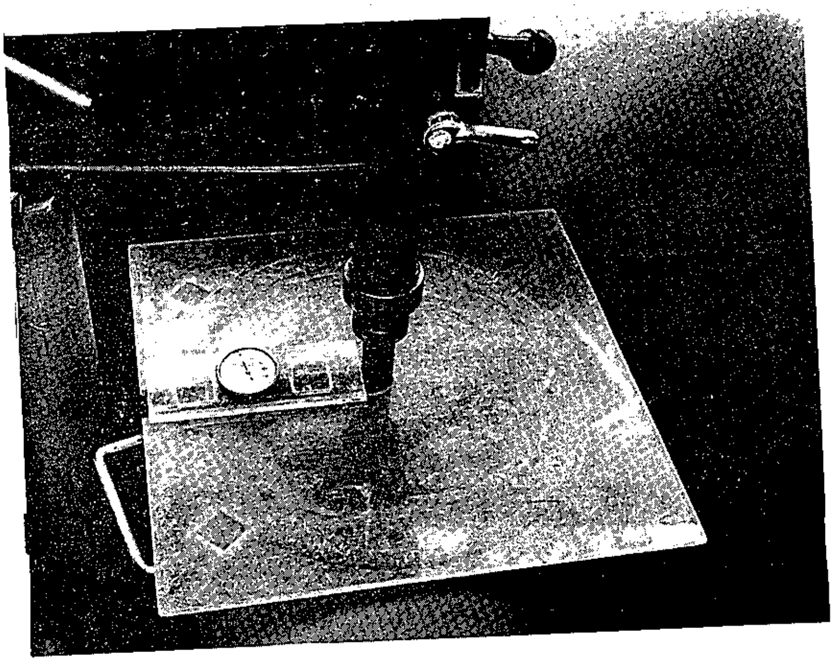

Figure 10

Mixer cover plate and thermometer

3. Phase III

a. Mixing Equipment

The mixer consisted of a 12-inch I.D. bucket 13 inches deep mounted on the table of a floor model drill press with a 1/2-horsepower DC motor providing power (Figure 8). The speed of the drill shaft was varied with a silicon controlled rectifier. A specially designed 5-gallon bucket was fitted with a valve near the bottom for drawing samples without interrupting mixing (Figure 9). A nylon bushing in the bottom restrained the lateral movement of the rotor shaft.

The stirring or baffle system consisted of an assembly that could be inserted inside the mixing bucket (see Figure 3). Two separate systems of baffles and blades were used.

The first system of baffles consisted of four vertical vanes which deflected the grout toward the center of the bucket, and a quad epoxy blade (Figure 2).

The second system of baffles consisted of three vertical vanes. Connected to the bottom of each vane was a set of three 1/4-inch rods which extended horizontally from the circumference of the bucket to within 1 inch of the center of rotation of the mixing rotor or blade. The rotor consisted of a 7/8-inch shaft containing three 1/4-inch rods 7 inches long mounted normal to the shaft, 1-inch apart, and offset 60° axially. The baffle vane rods were spaced between the rotor rods, leaving a clear space of only 1/4-inch between the two. This arrangement provided a high shearing action on the grout.

b. Mixing Procedure

The mixing procedure used was the same as that used in Part B, Phase II, except that mixing speeds were more precisely controlled and additional temperatures were taken (see Figures 9 and 10).

The agitation of the batch before and after mixing was carefully controlled to within ± 10 rpm as indicated by an electronic tachometer.

Temperatures of the water, cement, and ambient air were recorded before mixing. The batch temperature was recorded at the start of mixing and checked periodically during mixing. The grout temperature was recorded at the beginning of each efflux time measurement and after the 20-minute efflux time.

c. Laboratory Tests

The flow cone test for this mixing method was the same as that used in Phase II except that for each test, four flow cones were used (see Figure 5), and at the end of the predetermined mixing time, the mixing speed was reduced to 400 rpm to keep the cement in suspension.

At the completion of the four initial efflux time tests, stoppers were placed in the four cones for the 20-minute quiescent period test measurement and filled. After filling each cone, a timer was started. After 20 minutes of quiescence, the corks were pulled, and the efflux was timed and recorded to 1/10 of a second.

In general, the confined shrinkage test was the same as the test method used in Phase II except that the shrinkage was measured by pouring water from a graduated cylinder into the void on top of the cylinder until the water was level with the edges of the mold. The amount of water needed to fill the void was recorded in milliliters. The absorption of the measuring water by the grout was considered negligible.

Figure 11

Cement Funnel

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