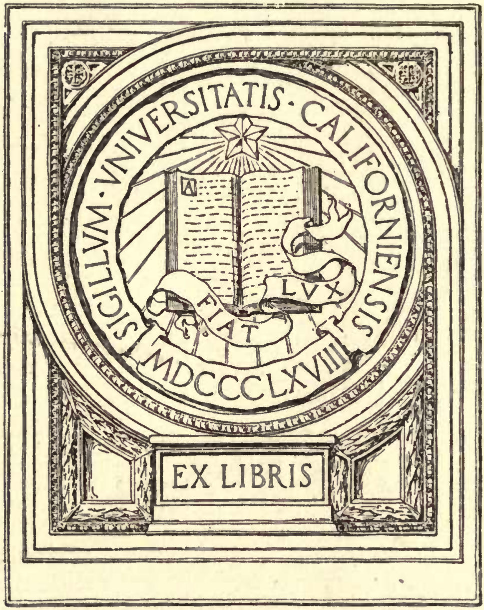
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UNIVERSITY OF CALIFORNIA
DEPARTMENT OF CIVIL ENGINEERING
TESTING LABORATORY

LABORATORY INSTRUCTIONS FOR TESTS OF CEMENT, MORTAR AND CONCRETE

BY

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AND

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PREFACE

This manual has been prepared for Civil Engineering students who take the course in cement testing at the University of California. Its purpose is to relieve the instructor from the detailed direction of students and so afford more time for emphasizing the theory and principles involved.

The chief objects of the course are to acquaint the student with the methods of testing cement and cement products, and to cultivate habits of accurate observation and clear description of phenomena. It must be remembered, however, that skill for the production of uniformly satisfactory results in testing can be acquired only after considerable practice.

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GENERAL RULES FOR LABORATORY WORK

Prompt and regular attendance is required of every student.

The assignment to tests is posted on the bulletin board.

Before coming to the laboratory read the directions for the assigned test carefully; be prepared to perform the operations promptly. Follow the directions closely.

When the required specimens or tests have been made, thoroughly clean, washing if necessary, all apparatus used. Remove all waste from the tables, floor or testing machines. Dry and oil all polished surfaces of metal to prevent rust.

Should any apparatus be broken, it should be reported immediately. Breakages due to carelessness will be charged to the student responsible for the damage.

In performing tests, students working together should share alike; but reports are to be written independently.

Keep, for your own reference, all original data of tests in neat tabular form in a special laboratory log book. This book will be inspected from time to time and called for at the end of the term.

OPERATION OF TESTING MACHINES

Study the operation of the testing machines at every opportunity until you are thoroughly familiar with their principle and mechanism. The machines in the laboratory are in operation daily and students are welcome to witness the tests at any time.

Do not operate a machine for the first time without the assistance of the instructor.

Do not start a machine without determining the direction and speed with which it will move.

Do not start a machine too suddenly as there is danger of stripping a gear or throwing a belt.

Do not change the direction or speed of motion without first stopping the machine.

Always accurately center a specimen in a testing machine as the weighing apparatus records correctly for this position only.

Always use a spherical seated base-plate for compression tests so that the bearing surface of the specimen may be made parallel to the upper compression plate of the machine.

Before applying the load in any test, balance the weighing apparatus with the poise at zero and the test piece in the machine. Adjust the recoil nuts to be just loose.

The speed of applying the load should be such that the poise arm may be kept balanced. Readings upon a test piece for a certain load should be taken only when the poise arm is balanced at that load.

Before leaving a machine or when a test is finished be sure that the clutches are properly thrown out and that the machine has stopped running.

CAUTION.—At times machines have been left running by operators with the result that usually some part of the machine was broken. *You* will be charged for repairs necessitated by careless handling of machines.

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Caution.—At times machines have been left running by operators with the result that usually some part of the machine was broken. You will be charged for repairs necessitated by careless handling of machines.

WRITING OF REPORTS

Follow strictly the "General Rules for Notes, Problems, Reports and Theses" adopted by the Department of Civil Engineering and printed in the standard manila folder.

Clearness, order of presentation, legibility of writing and neatness will receive due consideration in grading the report. Lack of neatness is sufficient cause for rejecting a report.

Observe the following order in arranging the report:

Title. This should indicate at a glance the scope of the test.

Purpose. Give briefly the object and significance of the test.

Material. Describe the materials tested. Give scale sketches or photographs of the specimens before and after failure.

Apparatus. Name all apparatus. Describe all special apparatus and testing machines used for the first time. Supplement descriptions with scale sketches.

Method of Test. Describe all operations which have any bearing on the performance or success of the test.

Data. Submit a tabular transcript of the essential data from the laboratory log book. Describe the behavior of the material when tested; state observations of unusual phenomena.

Computations. Derive all formulas involved. Indicate the numerical work. Ordinarily the computations may be made with a slide rule. Give a tabular summary of the final results.

Conclusions. State the conclusions to be drawn from the results. Compare the results with those in standard text-books and specifications; discuss the reasons for any discrepancies.

Each report must be submitted in a standard manila folder within one week of date of performance of test. Reports returned for correction are due one week from date of return.

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Conclusions. State the conclusions to be drawn from the results. Compare the results with those in standard text-books and specifications; discuss the reasons for any discrepancies.

Each report must be submitted in a standard manila folder within one week of date of performance of test. Reports returned for correction are due one week from date of return.

FINENESS OF PORTLAND CEMENT

Apparatus. Chemical balance, one set of weights, two sets of sieves—no. 30, no. 100 and no. 200 with pan and cover, trowel, spatula, two pans, brush for cleaning sieves, some steel shot to facilitate sieving, four small sheets of paper for weighing cement.

Operations. Place about 300 grams of the cement sample assigned in a pan and dry in the oven at 212° F. for at least thirty minutes. Break any caked lumps with the trowel. Screen the dried sample through the no. 30 sieve and discard any residue. Weigh out carefully 50.00 grams of the screened sample; place it with some shot on the no. 200 sieve with the pan attached.

Cover the sieve and shake at a convenient rate according to the directions in paragraph 25, "Standard Methods of Testing Cement." If the cement clogs the meshes of the sieve it has not been sufficiently dried. The sieve must always be kept perfectly dry.

The shot is separated from the residue by shaking on a no. 30 sieve.

Record the following weights: 1. Weight of cement passing no. 200 sieve. 2. Weight of residue rejected by no. 200 sieve. 3. Weight of residue passing no. 100 sieve. 4. Weight of residue rejected by no. 100 sieve. (Check the weights by 1 + 2 = 50 grams and 1 + 3 + 4 = 50 grams.)

Repeat the determination using 100.00 grams of cement. Each student will thus make two independent tests of the fineness of the sample assigned.

Students are cautioned to handle the no. 100 and especially the no. 200 sieves with extreme care to prevent injury to the mesh. In making weight determinations brush both the sieve and the pan free of all cement dust. In cleaning, use only the small brush provided, and that very lightly.

TEST No. 1

FINENESS OF PORTLAND CEMENT

Apparatus. Chemical balance, one set of weights, two sets of sieves—no. 30, no. 100 and no. 200 with pan and cover, trowel, spatula, two pans, brush for cleaning sieves, some steel shot to facilitate sieving, four small sheets of paper for weighing cement.

Operations. Place about 200 grams of the cement sample assigned in a pan and dry in the oven at 212° F. for at least thirty minutes. Break any caked lumps with the trowel. Screen the dried sample through the no. 30 sieve and discard any residue. Weigh out carefully 50.00 grams of the screened sample; place it with some shot on the no. 200 sieve with the pan attached.

Cover the sieve and shake at a convenient rate according to the directions in paragraph 25, "Standard Methods of Testing Cement." If the cement clogs the meshes of the sieve it has not been sufficiently dried. The sieve must always be kept perfectly dry.

The shot is separated from the residue by shaking on a no. 30 sieve.

Record the following weights: 1. Weight of cement passing no. 200 sieve. 2. Weight of residue rejected by no. 200 sieve. 3. Weight of residue passing no. 100 sieve. 4. Weight of residue rejected by no. 100 sieve. Check the weights by $1 + 2 = 50$ grams and $1 + 3 + 4 = 50$ grams.

Repeat the determination using 100.00 grams of cement. Each student will thus make two independent tests of the fineness of the sample assigned.

Students are cautioned to handle the no. 100 and especially the no. 200 sieves with extreme care to prevent injury to the mesh. In making weight determinations brush both the sieve and the pan free of all cement dust. In cleaning, use only the small brush provided, and that very lightly.

Submit results in tabular form, giving the amounts of cement by weight and by percentage which pass and are rejected by the sieves.

What is the significance of fineness of grinding of a cement? What are the standard requirements concerning the fineness of Portland cement?

References. Fineness of Cement. 1. Practical Cement Testing, by W. P. Taylor, pages 63–80. 2. Cements, Limes and Plasters, by E. C. Eckel. 3. Portland Cement, by R. K. Meade, pages 291–298. 4. Concrete—Plain and Reinforced, by Taylor and Thompson, pages 82–87. 5. The Materials of Construction, by Johnson, pages 409–413. 6. Proceedings of the American Society for Testing Materials.

TEST No. 1

SPECIFIC GRAVITY OF PORTLAND CEMENT

Apparatus. Chemical balance, one set of weights, two Le Chateliers specific gravity flasks, two battery jars, two small funnels, two glass tubes for pipettes, two short pieces of brass wire, two stands and clamps, two spatulae, one large funnel with filter paper, two small brushes, two pans, vessel for waste kerosene and cement, supply of kerosene.

Operations. Place about 200 grams of the cement sample assigned in a pan, breaking any caked lumps with a trowel, and dry in the oven at 212° F. for at least thirty minutes. Allow the dried sample to cool.

Determine the specific gravity in both ways mentioned in paragraphs 8–16, "Standard Methods of Testing Cement." Each student will make two independent determinations, thus obtaining four values for the specific gravity of the sample.

To insure accurate results the following details should be observed: After kerosene has drained from the sides of the upper stem, adjust exact height at E by adding or drawing out the liquid with a pipette. When this has been accomplished do not run any wire or glass tube into the liquid again, since doing so lowers its level. Use large funnel only for filling flask with kerosene. Facilitate the passage of the cement through the small funnel by warming it in the oven when drying the cement; then polish its inside surfaces, especially the stem, with a piece of clean cotton waste. Avoid any tendency of the cement to accumulate at the lower portion of the bulb C by shaking the flask gently.

CAUTIONS. Handle the apparatus with great care. **Do not allow any water to get into the flask.** To wash the cement out and clean the flask use kerosene only. Provide a 1-inch sand cushion in the bottom of the battery jar. Do not raise and drop the funnel against the top of the flask, but use a short wire when cement clogs in the funnel.

TEST No. 2

SPECIFIC GRAVITY OF PORTLAND CEMENT

Apparatus. Chemical balance, one set of weights, two Le Chateliers specific gravity flasks, two battery jars, two small funnels, two glass tubes for pipettes, two short pieces of brass wire, two stands and clamps, two spatulae, one large funnel with filter paper, two small brushes, two pans, vessel for waste kerosene and cement, supply of kerosene.

Operations. Place about 200 grams of the cement sample assigned in a pan, breaking any caked lumps with a trowel, and dry in the oven at 212° F. for at least thirty minutes. Allow the dried sample to cool.

Determine the specific gravity in both ways mentioned in paragraphs 8–16, "Standard Methods of Testing Cement." Each student will make two independent determinations, thus obtaining four values for the specific gravity of the sample.

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References. Specific Gravity of Cement. 1. Practical Cement Testing by W. P. Taylor, pages 46-62. 2. Portland Cement, by R. K. Meade, pages 278-291. 3. Concrete—Plain and Reinforced, by Taylor and Thompson, page 81. 4. A Treatise on Masonry Construction, by Baker, pages 00-61. 5. Proceedings of the American Society for Testing Materials.

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TEST No. 3

DETERMINATION OF VOIDS IN CONCRETE AGGREGATES

Apparatus. One 1000 c.c. or 500 c.c. graduate, one balance with scoop and counterweight, one set of metric weights, one wooden measuring box, one water pail, one galvanized iron measuring cylinder with bottom inlet and tube, scale graduated to tenths of an inch, scales sensitive to one-quarter of an ounce.

Operations. The party will determine the voids in the sand, gravel and broken stone samples separately by each of the methods mentioned. Method 1 will give approximate results only where the particles are less than one-quarter inch in size, since all the air is not expelled by the entering water. It is, however, well adapted for rough determinations in the field, where special apparatus is not always at hand.

In both method 1 and method 2, immerse any aggregate which is absorbent, for thirty minutes, then remove and allow the water to drain well from the surfaces before making the void determination.

Method 1. Determine the volume of the water pail by weighing it first empty, then filled to the very rim with water, and dividing the difference in weight in pounds by 62.4.

Fill the pail with material and after shaking to cause settlement, scrape the top off evenly with a straight edge. Weigh the amount of water which can be added to exactly fill the pail and calculate its volume.

The per cent of voids equals the ratio of the volume of water added to the volume of the pail, times 100.

Method 2. Determine the volume of the cylinder by measuring its average diameter and height to the nearest tenth of an inch.

Place the funnel attached to the rubber tube which leads to the bottom of the measuring cylinder in the lower rack which is level with the bottom of the cylinder. Fill the tube and funnel with water to the bottom level of the cylinder. Fill the measuring cylinder with aggregate. Raise the funnel to the upper rack. Weigh the water which must be added: 1. to reach the top level of the aggregate if the material settles; 2. to fill the cylinder.

Calculate the per cent of voids as in method 1.

For any aggregate which settles, obtain also the ratio of the volume of water, added to reach the top level of the aggregate, to the actual volume of the settled aggregate.

Method 2 is slightly more accurate than method 1, since less air is entrained when small particles make up the aggregate. The per cent of moisture greatly influences the per cent of voids in sands. For sand and in general, method 3 will give more reliable results.

Method 3. Specific Gravity Method. Determine the specific gravity of each of the materials in the following manner: Weigh the glass graduate first empty, then half filled with water. Check the increase in weight with the volume. Weigh out about the same volume of dry aggregate, add and agitate, if necessary to remove any air bubbles. Quickly note the exact rise of the water level before the material absorbs any appreciable amount of water.

The specific gravity of the material equals the weight of aggregate added, divided by the weight of displaced water.

Weigh the wooden measuring box. Fill even full with aggregate; shake to cause settlement and weigh again. Calculate the per cent of voids by using the specific gravity above obtained. If the material is not dry, its weight must be corrected for the per cent of moisture present. Determine the per cent of moisture by weighing out about 50 grams, then thoroughly drying in the oven and reweighing.

Mix thoroughly an amount of dry sand and broken stone in the proportions 1:2, by volume shaken, sufficient to slightly more than fill the wooden measuring box. Fill the box even full the bottom of the measuring cylinder in the lower rack which is level with the bottom of the cylinder. Fill the tube and funnel with water to the bottom level of the cylinder. Fill the measuring cylinder with aggregate. Raise the funnel to the upper rack. Weigh the water which must be added: 1. to reach the top level of the aggregate if the material settles; 2. to fill the cylinder.

Calculate the per cent of voids as in method 1.

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The specific gravity of the material equals the weight of aggregate added, divided by the weight of displaced water.

Weigh the wooden measuring box. Fill even full with aggregate; shake to cause settlement and weigh again. Calculate the per cent of voids by using the specific gravity above obtained. If the material is not dry, its weight must be corrected for the per cent of moisture present. Determine the per cent of moisture by weighing out about 50 grams, then thoroughly drying in the oven and reweighing.

Mix thoroughly an amount of dry sand and broken stone in the proportions 1:2, by volume shaken, sufficient to slightly more than fill the wooden measuring box. Fill the box even full

with this mixture, shake slightly to cause settlement, and obtain its net weight. Calculate the per cent of voids in the mixture.

Tabulate the results of the several determinations.

References. Determination of Voids. 1. Concrete—Plain and Reinforced, by Taylor and Thompson, pages 160–168. 2. A Treatise on Masonry Construction, by Baker, pages 143–146, 101–102, 91–94. 3. Bulletin 23, University of Illinois Engineering Experiment Station, by I. O. Baker.

TENSILE STRENGTH OF NEAT CEMENT AND STANDARD CEMENT MORTAR

Apparatus. Balance with scoop and counterweight, one set of weights, Vicat needle apparatus, thirty standard briquette moulds, five six-mould gang clamps, six surface plates, one 100 cc. graduate, thermometer, two small trowels, two scraping knives, two pans, one water pitcher.

Operations. Determination of Normal Consistency. Since the strength of neat cement and cement mortars at early periods varies greatly with the amount of water used in mixing, to obtain comparable results for various cements, it is necessary to make the mixture of a standard consistency. The method for determining this consistency is given in the "Standard Methods of Testing Cement," pages 13–15.

Determine the normal consistency for the cement sample assigned, using 500 grams for each trial batch. Add the whole of the trial per cent of water at once; use a new batch of cement for each trial. "Penetration of the needle" is construed to mean its position of final rest after one or two minutes, there being no vibration of the apparatus. After the normal consistency for the cement paste is determined, the per cent of water for standard sand mortars is determined empirically from the table on page 15.

Moulding of Briquettes. Following the directions on pages 17–21, "Standard Methods for Testing Cement," each student will mould independently nine neat and six mortar briquettes. For the neat briquettes mix two batches of 800 grams each; for the mortar mix one batch of 300 grams of cement with 900 grams of standard sand.

Each student should carefully put a small identifying mark near the end of each of his briquettes; do not change nor injure the middle section of a briquette by the marking. Place the

TEST No. 4

TENSILE STRENGTH OF NEAT CEMENT AND STANDARD CEMENT MORTAR

Apparatus. Balance with scoop and counterweight, one set of weights, Vicat needle apparatus, thirty standard briquette moulds, five six-mould gang clamps, six surface plates, one 100 cc. graduate, thermometer, two small trowels, two scraping knives, two pans, one water pitcher.

Operations. Determination of Normal Consistency. Since the strength of neat cement and cement mortars at early periods varies greatly with the amount of water used in mixing, to obtain comparable results for various cements, it is necessary to make the mixture of a standard consistency. The method for determining this consistency is given in the "Standard Methods of Testing Cement," pages 13–15.

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Each student should carefully put a small identifying mark near the end of each of his briquettes; do not change nor injure the middle section of a briquette by the marking. Place the finished briquettes in the moist closet, together with a card indicating the party number.

The temperature of the room should be as near 70° F. as possible, since lower temperatures retard the setting of cement and hence decrease its strength at early periods.

The laboratory data for each batch mixed should be presented in tabular form and contain the following items: Batch number, brand of cement, temperatures of room and water, weights and percentages of various ingredients, number of briquettes moulded, date made, identification marks.

Testing of Briquettes. In order to fulfill the conditions of the standard methods of testing cement it will be necessary for students to come to the laboratory to make the first tensile test as nearly twenty-four hours after the moulding of the briquettes as possible. The tests at seven and twenty-eight days can be made at the regular laboratory periods in addition to the assignment for those days. Failure to test at the proper time will make it necessary to repeat the whole test. The report should be submitted after making the twenty-eight day test.

Fairbank's automatic cement testing machine will be used.

Before testing the briquettes, check the rate of application of the load as follows: Support the poise arm and allow the shot to run into the bucket for sixty seconds. Transfer the bucket with shot to the opposite end of the arm, put counterweight in its place and weigh out. If the machine does not record 600 lbs. adjust the valve regulating the flow of shot and repeat until the load is applied at the rate of 600 lbs. per minute.

Briquettes should be tested as soon as they are removed from the water. Before testing, dry each briquette with a cloth and weigh.

With the shot basket empty and the poise set at zero, close the clips of the machine together with the fast motion and insert the briquette. See that the briquette is accurately centered and bears uniformly against the clips at the surfaces of contact. Tighten with the fast motion until the poise arm is balanced.

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Briquettes should be tested as soon as they are removed from the water. Before testing, dry each briquette with a cloth and weigh.

With the shot bucket empty and the poise set at zero bring the clips of the machine together with the fast motion and insert the briquette. See that the briquette is accurately centered and bears uniformly against the clips at the surfaces of contact. Tighten with the fast motion until the poise arm is balanced:

then transfer to the slow motion. Release the shot and keep the poise arm balanced by turning the slow motion wheel until the briquette breaks. Note the time of shot flow. Weigh out as above.

Each student will test three neat cement briquettes at ages of twenty-four hours, seven days and twenty-eight days, and three mortar briquettes at ages of seven days and twenty-eight days.

Submit the test results in a tabular form including the following items: Number of briquette, batch number, mixture, weight, age, tensile strength, remarks.

References. **Tensile Strength of Cement.** 1. A Treatise on Masonry Construction, by Baker, pages 71-86, 121-124. 2. The Elasticity and Resistance of the Materials of Engineering, by Bovey, pages 352-374. 3. Practical Cement Testing, by W. P. Taylor, pages 101-158. 4. Portland Cement, by Meade, pages 316-350. 5. Cements, Limes and Plasters, by Eckel. 6. Concrete—Plain and Reinforced, by Taylor and Thompson.

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References. Tensile Strength of Cement. 1. A Treatise on Masonry Construction, by Baker, pages 71–84, 121–124. 2. The Elasticity and Resistance of the Materials of Engineering, by Burr, pages 352–378. 3. Practical Cement Testing, by W. P. Taylor, pages 101–156. 4. Portland Cement, by Meade, pages 316–350. 5. Cements, Limes and Plasters, by Eckel. 6. Concrete—Plain and Reinforced, by Taylor and Thompson.

TEST No. 5

MOULDING CUBES FOR COMPRESSION TESTS OF CEMENT MORTAR

Apparatus. Balance with scoop and counterweight, one set of metric weights, sixteen two-inch cast iron cube moulds, two 250 c.c. graduates, two mixing pans, two slate slabs, two trowels, two scraping knives, two small pans, one water pitcher, Vicat needle apparatus.

Operations. Determine as in test 4 the amount of water required for a cement paste of normal consistency. All mixtures are to be of normal consistency, which for mortars is obtained empirically from the following table:

Percentages of Water for Standard Mixtures

Neat	1:1	1:2	1:3	1:4	1:5	1:6
18	12.0	10.0	9.0	8.4	8.0	7.6
19	12.3	10.2	9.2	8.5	8.1	7.7
20	12.7	10.4	9.3	8.7	8.2	7.8
21	13.0	10.7	9.5	8.8	8.3	7.9
22	13.3	10.9	9.7	8.9	8.4	8.0
23	13.7	11.1	9.8	9.1	8.5	8.1
24	14.0	11.3	10.0	9.2	8.6	8.2

If the sand is damp the per cent of moisture should be determined as in test 3, so that proper allowance can be made for it.

Using the sands and cement provided, each student will mix independently four batches of mortar. For each batch use 600 grams of dry material. Mould two cubes from each batch and carefully weigh the mortar left over. Student 1 will make mixtures: neat, 1:1, 1:2, 1:3, using ordinary sand; student 2 will make mixtures 1:4, 1:5, 1:6, using ordinary sand, and 1:3, using standard sand. All proportions are to be determined by weighing.

First thoroughly mix the sand and cement dry. With the

thumb or trowel, but without ramming, carefully press the mortar into the corners and completely fill the moulds. Smooth the top off evenly. Place an identifying mark on each cube and leave a card with the party number on each slate slab.

Using the specific gravity for cement and sand as determined in tests 2 and 3 calculate the density of the mortar of each batch.

For each batch mixed tabulate the following data: Batch number, brand of cement, kind of sand, weights and proportions of various ingredients, density of mortar, size of cubes, number of cubes, marks on cubes, date made.

References. Density of Mortar. 1. Concrete—Plain and Reinforced, by Taylor and Thompson, pages 134–140. 2. A Treatise on Masonry Construction, by Baker, pages 108–110.

MOULDING SPECIMENS FOR COMPRESSION TEST OF CONCRETE

Apparatus. Two 6-in. cylinder moulds 12 in. long with bottom plates, one 8-in. cylinder mould 16 in. long, one 6×6×6 in. cube mould, one set of measuring boxes of capacities ½ cu. ft., ¼ cu. ft., and ⅛ cu. ft., one mixing pan, two shovels, two trowels, two tamping rods, one water pail. Note:—The sectional areas of the 6-in. and 8-in. cylinders are respectively 30 sq. in. and 50 sq. in.

Operations. Mix two batches of concrete of proportions 1:2:4 by volume shaken. Use for each batch ½ cu. ft. of rock, ¼ cu. ft. of sand and ⅛ cu. ft. of cement. See that the boxes are even full after shaking. Weigh each measure of materials used and calculate its average weight per cubic foot. Allow for any moisture present.

First spread the broken stone in an even layer in the mixing pan; place the sand next and the cement on top. Thoroughly mix the cement, sand and rock dry. Add water gradually and mix until the mass is uniformly incorporated and of a rather wet plastic consistency. Weigh the amount of water used for each batch.

In filling the moulds put some of the richer portions of the mix at the bottom so as to form an even bearing surface. Add the concrete gradually and tamp continually to force out air bubbles and to obtain a uniformly dense specimen. Heap the material slightly on top and when the water has settled smooth the surface off evenly and level with the mould.

Stamp the party number on each specimen. Weigh the concrete left over.

Calculate the average density of the concrete made.

The data for each batch should contain the following items

TEST No. 6

MOULDING SPECIMENS FOR COMPRESSION TEST OF CONCRETE

Apparatus. Two 6-in. cylinder moulds 12 in. long with bottom plates, one 8-in. cylinder mould 16 in. long, one 6 × 6 × 6 in. cube mould, one set of measuring boxes of capacities ½ cu. ft., ¼ cu. ft., and ⅛ cu. ft., one mixing pan, two shovels, two trowels, two tamping rods, one water pail. Note:—The sectional areas of the 6-in. and 8-in. cylinders are respectively 30 sq. in. and 50 sq. in.

Operations. Mix two batches of concrete of proportions 1:2:4 by volume shaken. Use for each batch ½ cu. ft. of rock, ¼ cu. ft. of sand and ⅛ cu. ft. of cement. See that the boxes are even full after shaking. Weigh each measure of materials used and calculate its average weight per cubic foot. Allow for any moisture present.

First spread the broken stone in an even layer in the mixing pan; place the sand next and the cement on top. Thoroughly mix the cement, sand and rock dry. Add water gradually and mix until the mass is uniformly incorporated and of a rather wet plastic consistency. Weigh the amount of water used for each batch.

In filling the moulds put some of the richer portions of the mix at the bottom so as to form an even bearing surface. Add the concrete gradually and tamp continually to force out air bubbles and to obtain a uniformly dense specimen. Heap the material slightly on top and when the water has settled smooth the surface off evenly and level with the mould.

Stamp the party number on each specimen. Weigh the concrete left over.

Calculate the average density of the concrete made.

The data for each batch should contain the following items

in tabular form: Batch number, kinds of material, weights of materials per cubic foot, amounts and proportions of materials by volume and weight, number of specimens made, dimensions of specimens, date made.

References. Density of Concrete. 1. A Treatise on Masonry Construction, by Baker, pages 137–139. 2. The Laws of Proportioning Concrete: Transactions American Society of Civil Engineers, vol. 59, page 67.

TEST No. 7

MOULDING SPECIMENS FOR TENSION TEST OF CONCRETE

Apparatus. Three 6-in. cylinder moulds 27 in. long with end plates and bolts, one set of measuring boxes of capacities 1 cu. ft., ½ cu. ft. and ¼ cu ft., one mixing pan, two shovels, two trowels, two tamping rods, one water pail.

Operations. Mix two batches of concrete of rather wet consistency according to the directions of paragraphs 1 and 2 under Operations in test 6.

Arrange the bolts in the lower plate so that their heads extend alternately about three inches and five inches into the mould. Clamp the shell squarely about the lower plate. Fill the mould to about one inch above the bolt heads with a 1:1 mortar tempered to a soft-plastic consistency. Tamp the mortar about the bolts, being careful not to disturb the position of the bottom plate. Add the concrete gradually up to a point five inches below the top of the mould, tamping continually. Adjust the top plate squarely in place with the bolt heads extending into the mould. Through the opening in the top plate fill in 1:1 mortar of a semi-fluid consistency, so that it will completely fill the mould. After settlement of the material remove any excess above the lower surface of the top plate. Leave a card with the party number on each specimen.

The ends are made of a richer mixture to make them stronger than the body of the specimen.

The data for each batch should be tabulated and contain batch number, kinds of material, weights of materials per cubic foot, amounts and proportions of materials by volume and weight, number of specimens made, dimensions of specimens, date made.

TEST No. 7

MOULDING SPECIMENS FOR TENSION TEST OF CONCRETE

Apparatus. Three 6-in. cylinder moulds 27 in. long with end plates and bolts, one set of measuring boxes of capacities ½ cu. ft., ¼ cu. ft., and ⅛ cu ft., one mixing pan, two shovels, two trowels, two tamping rods, one water pail.

Operations. Mix two batches of concrete of rather wet consistency according to the directions of paragraphs 1 and 2 under Operations in test 6.

Arrange the bolts in the lower plate so that their heads extend alternately about three inches and five inches into the mould. Clamp the shell squarely about the lower plate. Fill the mould to about one inch above the bolt heads with a 1:1 mortar tempered to a soft plastic consistency. Tamp the mortar about the bolts, being careful not to disturb the position of the bottom plate. Add the concrete gradually up to a point five inches below the top of the mould, tamping continually. Adjust the top plate squarely in place with the bolt heads extending into the mould. Through the opening in the top plate fill in 1:1 mortar of a semi-fluid consistency, so that it will completely fill the mould. After settlement of the material remove any excess above the lower surface of the top plate. Leave a card with the party number on each specimen.

The ends are made of a richer mixture to make them stronger than the body of the specimen.

The data for each batch should be tabulated and contain: Batch number, kinds of material, weights of materials per cubic foot, amounts and proportions of materials by volume and weight, number of specimens made, dimensions of specimens, date made.

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TEST No. 8

MOULDING SPECIMENS FOR TEST OF BOND BETWEEN STEEL AND CONCRETE

Apparatus. Six moulds 4 × 6 × 6 in., two threaded specimens each of plain round, twisted square and corrugated steel reinforcement bars, one set of measuring boxes of capacities ½ cu. ft., ¼ cu. ft., and ⅛ cu. ft., one mixing pan, two shovels, two trowels, two tamping rods, one water pail.

Operations. Mix a batch of concrete of a rather wet consistency according to the directions of paragraphs 1 and 2 under Operations in test 6.

Carefully adjust the steel rods in the moulds. Add the concrete slowly and tamp continually, but be careful not to displace the rods, as their axes must be perpendicular to the front faces of the specimens. Fill the moulds completely. After the material has settled smooth the top off evenly and stamp the party number on each specimen.

The data for each batch should be tabulated and contain: Batch number, kinds of materials, weights of materials per cubic foot, amounts and proportions of materials by volume and weight, number of specimens made, dimensions of specimens, sizes of rods, imbedded length of rods, areas of bond surface of rods, date made.

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TEST No. 9

MOULDING REINFORCED CONCRETE BEAMS FOR FLEXURE TEST OF CONCRETE

Apparatus. Two beam moulds 4 × 6 × 72 in., two plain round reinforcement bars, two deformed reinforcement bars, one set of measuring boxes of capacities ½ cu ft., ¼ cu. ft., and ⅛ cu. ft., two mixing pans, two shovels, two trowels, two water pails, two tamping rods.

Operations. Mix four batches of concrete of rather wet consistency according to the directions of paragraphs 1 and 2 under Operations in test 6.

First tamp into the mould a layer of concrete one inch thick; then insert the bars through the holes in the ends of the mould. See that the bars are straight when in position. Fill the mould gradually, tamping continually. After the concrete has settled, smooth the top off even with the mould. Stamp the party number at each end of the beam.

Two beams will be moulded. Use the plain bars in one and the deformed bars in the other.

The data for each batch should be tabulated and contain: Batch number, kinds of material, weights of materials per cubic foot, amounts and proportions of materials by volume and weight, number of specimens made, dimensions of specimens, sizes and sectional areas of rods, per cent of reinforcement, date made.

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COMPRESSION TEST OF CEMENT MORTAR CUBES

Apparatus. Testing machine equipped for compression with spherical seated base-plate; one balance, one set of metric weights, pan for broken cubes.

Materials. Mortar cubes previously made by the party.

Operations. Dry each cube with a cloth and weigh just before testing. Apply the pressure on the moulded faces; if these are uneven bed them with blotting paper.

Read the directions for operation of testing machines on page 5.

After accurately centering the specimen in the machine lower the movable head until it just clears the cube. Adjust base-plate so that the bearing surface of the cube is parallel to the upper plate; this insures a uniform pressure over the entire cross-section when the load is applied.

Use the slowest speed of the machine to apply the load. Keep the poise arm floating throughout the test. Record the maximum load. Note the character of the failures.

Each student will test his own cubes independently, alternating in the use of the machine with other students assigned to the same test.

Report. Submit results in tabular form, giving the following facts for each cube: batch number, kinds and proportions of materials, age, dimensions, total weight, weight in pounds per cubic foot, density, total crushing load, crushing strength in pounds per square inch.

Using the average results of both members of the party, construct a diagram on coördinate paper using crushing strengths as ordinates and percentages of cement by weight as abscissas.

References. 1. Principles of Reinforced Concrete Construction, by

TEST No. 10

COMPRESSION TEST OF CEMENT MORTAR CUBES

Apparatus. Testing machine equipped for compression, with spherical seated base-plate, one balance, one set of metric weights, pan for broken cubes.

Materials. Mortar cubes previously made by the party.

Operations. Dry each cube with a cloth and weigh just before testing. Apply the pressure on the moulded faces; if these are uneven bed them with blotting paper.

Read the directions for operation of testing machines on page 5.

After accurately centering the specimen in the machine lower the movable head until it just clears the cube. Adjust base-plate so that the bearing surface of the cube is parallel to the upper plate; this insures a uniform pressure over the entire cross-section when the load is applied.

Use the slowest speed of the machine to apply the load. Keep the poise arm floating throughout the test. Record the maximum load. Note the character of the failures.

Each student will test his own cubes independently, alternating in the use of the machine with other students assigned to the same test.

Report. Submit results in tabular form, giving the following facts for each cube: Batch number, kinds and proportions of materials, age, dimensions, total weight, weight in pounds per cubic foot, density, total crushing load, crushing strength in pounds per square inch.

Using the average results of both members of the party construct a diagram on coördinate paper using crushing strengths as ordinates and percentages of cement by weight as abscissae.

References. 1. Principles of Reinforced Concrete Construction, by

Turneaure and Maurer, pages 12–13. 2. Concrete—Plain and Reinforced, by Taylor and Thompson, page 136. 3. Tests of Metals.

TEST No. 11

COMPRESSION TEST OF CONCRETE

Apparatus. Testing machine equipped for compression, with spherical seated base-plate, scales, plaster of Paris, water pitcher, trowel, mixing pan, circular cast iron capping plates.

Materials. Concrete compression specimens previously made by the party, except one small cylinder.

Operations. Weigh each specimen. Bed the end surfaces with a thin layer of plaster of paris. Cap these with the iron plates when the plaster is still soft. Press the plates firmly against the plaster and be careful to place them perpendicular to the axis of the specimen.

Read the directions for operation of testing machines on page 5.

Center the specimen, with its ends thus prepared, in the testing machine. Adjust the base-plate for parallelism of top bearing surface and upper plate of the machine. Use the slowest speed for applying the load. Keep the poise arm floating throughout the test. Record the load when the first crack appears and the maximum load. Sketch the failures.

Report. Give the following results for each specimen: Each number, shape and dimensions, kinds and proportions of materials, age, total weight, weight per cubic foot, density, total loads at first crack and maximum, strengths at first crack and maximum in pounds per square inch.

References. 1. A Treatise on Masonry Construction, by Baker, pages 184-185. 2. Principles of Reinforced Concrete Construction, by Turneaure and Maurer, pages 11-15. 3. Tests of Metals.

TEST No. 11

COMPRESSION TEST OF CONCRETE

Apparatus. Testing machine equipped for compression, with spherical seated base-plate, scales, plaster of Paris, water pitcher, trowel, mixing pan, circular cast iron capping plates.

Materials. Concrete compression specimens previously made by the party, except one small cylinder.

Operations. Weigh each specimen. Bed the end surfaces with a thin layer of plaster of paris. Cap these with the iron plates when the plaster is still soft. Press the plates firmly against the plaster and be careful to place them perpendicular to the axis of the specimen.

Read the directions for operation of testing machines on page 5.

Center the specimen, with its ends thus prepared, in the testing machine. Adjust the base-plate for parallelism of top bearing surface and upper plate of the machine. Use the slowest speed for applying the load. Keep the poise arm floating throughout the test. Record the load when the first crack appears and the maximum load. Sketch the failures.

Report. Give the following results for each specimen: Batch number, shape and dimensions, kinds and proportions of materials, age, total weight, weight per cubic foot, density, total loads at first crack and maximum, strengths at first crack and maximum in pounds per square inch.

References. 1. A Treatise on Masonry Construction, by Baker, pages 194–208. 2. Principles of Reinforced Concrete Construction, by Turneaure and Maurer, pages 11–15. 3. Tests of Metals.

TEST No. 12

TENSION TEST OF CONCRETE

Apparatus. Testing machine equipped for tension, with spherical seated tension head, flanged grips, nuts and spacing rods for concrete tension tests, small wrench.

Materials. Concrete tension cylinders previously made by the party.

Operations. Bolt a grip on the bottom of each cylinder; then bolt the top grip against the three spacing rods placed in their proper position between the grips. Screw the nuts uniformly, but not too tightly. This method of attaching the grips insures that the applied tension is axial.

Read the directions for operation of testing machines on page 5.

Insert the specimen in the machine. Apply the load by the slowest speed and keep the poise arm floating throughout the test. Record the maximum load; sketch the failure.

Report. Tabulate the following quantities for each specimen: Batch number, dimensions, kinds and proportions of materials, age; total load, strength in pounds per square inch.

References. 1. A Treatise on Masonry Construction, by Baker, page 202. 2. Principles of Reinforced Concrete Construction, by Turneaure and Maurer, pages 15-17.

TEST No. 12

TENSION TEST OF CONCRETE

Apparatus. Testing machine equipped for tension, with spherical seated tension head, flanged grips, nuts and spacing rods for concrete tension tests, small wrench.

Materials. Concrete tension cylinders previously made by the party.

Operations. Bolt a grip on the bottom of each cylinder; then bolt the top grip against the three spacing rods placed in their proper position between the grips. Screw the nuts uniformly, but not too tightly. This method of attaching the grips insures that the applied tension is axial.

Read the directions for operation of testing machines on page 5.

Insert the specimen in the machine. Apply the load by the slowest speed and keep the poise arm floating throughout the test. Record the maximum load; sketch the failure.

Report. Tabulate the following quantities for each specimen: Batch number, dimensions, kinds and proportions of materials, age, total load, strength in pounds per square inch.

References. 1. A Treatise on Masonry Construction, by Baker, page 202. 2. Principles of Reinforced Concrete Construction, by Turneaure and Maurer, pages 15–17.

TEST OF BOND BETWEEN CONCRETE AND STEEL

Apparatus. Testing machine equipped for bond test, with spherical seated tension head.

Materials. Specimens for bond tests previously made by the party.

Operations. Read the directions for operation of testing machines on page 5.

Pass the rod of the test specimen through the opening in the movable head of the testing machine and screw the tension grip on to it. Adjust the specimen so that the concrete bearing surface is parallel to the lower surface of movable head. If the concrete surface is uneven it should be bedded with plaster of Paris and capped with a special perforated plate.

Apply the load with the slowest speed and keep the poise arm floating throughout the test. Record the maximum load and the frictional resistance after the maximum is reached.

Report. Give the following results for each specimen: Batch number, dimensions, kinds and proportions of materials, age, kind and size of bar, bond area, maximum load, frictional resistance, maximum and frictional bond strength in pounds per square inch of bond area.

Give the ratio of average bond strengths of deformed and plain bars.

References. 1. Principles of Reinforced Concrete Construction, by Turneaure and Maurer, pages 33–40. 2. Bulletin no. 8, Engineering Experiment Station, University of Illinois. 3. Bulletin no. 321, University of Wisconsin.

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REINFORCED CONCRETE BEAM TEST

Apparatus. Testing machine equipped for flexure test, with box channel beam, beam supports, third point loading apparatus, deflection measuring apparatus, scale, small square.

Materials. Two reinforced concrete beams previously made by the same party.

Operations. Weigh the beam and measure its dimensions. Support the beam on a 60-in. span, with its middle under the center of the movable head. Draw vertical lines on both sides of the beam at the supports, center and third points. Apply the load at the third points; if the top of the beam is uneven at these points, bed the plates of the loading apparatus in plaster of Paris.

Read the directions for operation of testing machines on page 9.

Attach the deflection measuring apparatus and obtain its zero reading for an initial load of 100 lbs. Record the deflection for each 100-lb. load increment up to a total load of 1000 lbs.; for each 200-lb. increment thereafter. Note the deflection and load when the first crack appears, also the position of the crack. Keep the poise arm floating throughout the test. Record the maximum load. Make a scale sketch of the failure on cross-section paper.

Demolish the beam and return the reinforcement bars to their proper place.

Report. For each test construct a diagram on coordinate paper with loads in pounds as ordinates and deflections in inches as abscissae. Join the plotted points with a smooth, not a sinuous curve. Mark as the elastic limit that point on the curve where the deflection ceases to be proportional to the load. Submit curve in pencil to the instructor for approval before inking.

Give the following quantities for each beam: Batch number, kinds and proportions of materials, kind, disposition and per cent

TEST No. 14

REINFORCED CONCRETE BEAM TEST

Apparatus. Testing machine equipped for flexure test, with box channel beam, beam supports, third point loading apparatus, deflection measuring apparatus, scale, small square.

Materials. Two reinforced concrete beams previously made by the same party.

Operations. Weigh the beam and measure its dimensions. Support the beam on a 60-in. span, with its middle under the center of the movable head. Draw vertical lines on both sides of the beam at the supports, center and third points. Apply the load at the third points; if the top of the beam is uneven at these points, bed the plates of the loading apparatus in plaster of Paris.

Read the directions for operation of testing machines on page 5.

Attach the deflection measuring apparatus and obtain its zero for reading for an initial load of 100 lbs. Record the deflection for each 100-lb. load increment up to a total load of 1000 lbs.; for each 200-lb. increment thereafter. Note the deflection and load when the first crack appears, also the position of the crack. Keep the poise arm floating throughout the test. Record the maximum load. Make a scale sketch of the failure on cross-section paper.

Demolish the beam and return the reinforcement bars to their proper place.

Report. For each test construct a diagram on coördinate paper with loads in pounds as ordinates and deflections in inches as abscissae. Join the plotted points with a smooth, not a sinuous curve. Mark as the elastic limit that point on the curve where the deflection ceases to be proportional to the load. Submit curve in pencil to the instructor for approval before inking.

Give the following quantities for each beam: Batch number, kinds and proportions of materials, kind, disposition and per cent

of reinforcement, age, dimensions, total weight, weight in pounds per cubic foot, manner of loading, loads at first crack, elastic limit and maximum.

Calculate the following quantities for each beam: Case 1—Neglect tension in concrete and assume that compression in concrete varies lineally. Position of neutral surface. Fiber stresses in concrete and steel, bond developed between concrete and steel and maximum shear in concrete at the elastic limit and maximum load. Case 2—Neglect tension in concrete and assume that compression in concrete varies parabolically. The same quantities as in case 1. In both cases assume the ratio of the coefficients of elasticity of steel and concrete as 15.

References. 1. Principles of Reinforced Concrete Construction, by Turneaure and Maurer, pages 56–72; 108–112. 2. A Treatise on Masonry Construction, by Baker, pages 224–236.

SIEVE ANALYSIS OF CONCRETE AGGREGATES

Purpose. To obtain the granulometric composition of the component parts of a concrete aggregate.

Apparatus. Sand shaker; balance with scoop and counter-weights; the following sizes of sand sieves: Nos. 4, 10, 20, 30, 40, 50, 80, 100 and 200; also perforated rock screens of the following diameters: $\frac{1}{4}$ in., $\frac{3}{8}$ in., $\frac{1}{2}$ in., $\frac{5}{8}$ in., $\frac{3}{4}$ in., $\frac{7}{8}$ in., 1 in., $1\frac{1}{4}$ in.. $1\frac{1}{2}$ in.. 2 in., and $2\frac{1}{2}$ in.; measuring box.

Materials. *Group 1.* A fine sand, a coarse sand, several assortments of crusher run of broken stone ranging in size from $\frac{1}{4}$ in. to $1\frac{3}{4}$ in. *Group 2.* A fine sand, a coarse sand, several assortments of screened river gravel ranging in size from $\frac{1}{4}$ in. to $1\frac{1}{2}$ in.

Operations.

Sieve Analysis of Sand

Make a sieve analysis of each of the sands of group 1 or 2, as directed, in the following manner.

From a representative portion of bin material select, by a quartering process, a sample of approximately 1500 gm. Dry this thoroughly in the oven; then determine its weight in pounds per cubic foot.

Arrange the sand sieves in order with the largest size on top and the pan at the bottom. Place the nest of sieves in the shaker.

Place 1000 gm. of the dried sample in the top sieve, cover the sieve, clamp the nest in the shaker and shake for 1000 complete oscillations at a uniform rate of 333 per minute. Weigh the residue on each sieve and in the pan.

Sieve Analysis of Gravel or Crushed Rock

Make a sieve analysis of each of the gravels or broken stones of group 1 or 2, as directed, in the following manner:

From a representative portion of bin material, select, by a quartering process, a sample of about 3500 gm. Dry this thoroughly in the oven; then determine its weight in pounds per cubic foot.

Weigh out accurately a portion as close to 3000 gm. as practicable. Shake this by hand successively through all the rock screens, starting with the largest size. Shake on each sieve until complete rejection occurs. Weigh the amount which passes each screen, and, as a check, the amount rejected.

Report. The separation size of a sieve is the distance in the clear between its meshes. The effective separation size of a sieve is defined as that separation size which is computed to be numerically equal to the diameter of a sphere whose volume is equal to the average of the volumes of angular sand or rock particles which just pass the sieve. The effective size of a sieve, therefore, must be determined experimentally and it varies slightly according to the general form of the sand or rock particles analyzed.

The following table gives the effective separation sizes of the above sieves.

Effective Separation Sizes of Sand Sieves		Effective Separation Sizes of Rock Screens	
Sieve No.	Size in inches	Screen size	Effective size in inches
4	0.231	$\frac{1}{4}$ in.	0.213
10	0.077	$\frac{3}{8}$	0.34
20	0.050	$\frac{1}{2}$	0.45
30	0.024	$\frac{5}{8}$	0.56
40	0.018	$\frac{3}{4}$	0.68
50	0.014	$\frac{7}{8}$	
80	0.0061	1	0.87
100	0.0059	$1\frac{1}{4}$	
200	0.0036	$1\frac{1}{2}$	1.34
		2	1.68
		$2\frac{1}{2}$	1.98

Describe each material and give its weight in pounds per cubic foot. Submit the results of each sieve analysis in tabular form, giving actual separation size of sieve or screen, its effective size, weight passing, percentage passing. Indicate checks in weighing.

References.

1. Concrete, Plain and Reinforced, by Taylor and Thompson (1909 edition), pp. 193–200.
2. The Modern Asphalt Pavement, by Richardson (1912 edition), pp. 59–72.

TEST No. 16

GRANULOMETRIC PROPORTIONING OF CONCRETE AGGREGATES

Purpose. To determine the relative amounts of separately screened materials of various sizes ranging from fine sand to a given maximum size of rock, required to produce a concrete of the greatest density possible with the given materials.

Materials. The same as those used in Test No. 15.

Operations. Plot the sieve analysis curves of all the materials analyzed in Test No. 15 on a sheet of tracing cross-section paper 11 x 36 in. Plot "percentage passing" as ordinates and "effective sizes" as abscissas. Using the data at the bottom of page 203, Concrete, Plain and Reinforced, by Taylor and Thompson (1909 edition), draw in pencil on the cross-section paper the ideal curve for a practical mix.

Following the methods outlined in Appendix IV of Taylor and Thompson, determine the relative amounts of the several materials, so that the sieve analysis curve of their combination approaches, throughout its entire length, the ideal curve as nearly as is practicably possible. Draw in pencil the curves of several trial combinations. Submit for approval by instructor before inking the trial curve which is finally selected as the best. Compute the proportions of the several materials for a 1 : and for a 1 :9 concrete, where the components of the aggregate are measured by volume separately.

Report. Explain in detail the method of solution. Include all computations. Ink and label all curves in black. In the lower right corner of the diagram place a title giving a statement of the problem, the kinds, sizes and proportions by volume, of materials.

References.

1. Concrete, Plain and Reinforced, by Taylor and Thompson (1909 edition), pp. 200–210.
2. "The Laws of Proportioning Concrete," by W. B. Fuller and S. E. Thompson, Transactions of the American Society of Civil Engineers, vol. 59, p. 67.

TEST No. 6A

DENSITY OF CONCRETE

Purpose. To determine the density of concrete to be used for compression specimens.

Materials. $\frac{1}{2}$ cubic foot dry crushed rock, $\frac{1}{4}$ cubic foot of dry sand, $\frac{1}{8}$ cubic foot of cement.

Apparatus. 8×16-in. cylindrical measuring mould with piston, one set of measuring boxes of capacities $\frac{1}{2}$ cubic foot, $\frac{1}{4}$ cubic foot, and $\frac{1}{8}$ cubic foot, one mixing pan, one shovel, one trowel, one tamping rod, one water pail.

Operations. Before mixing any concrete, weigh dry, the mixing pan, the shovel, the trowel and the tamping rod. Use no other tools than these for mixing. Weigh out $\frac{1}{2}$ cubic foot of dry crushed rock, $\frac{1}{4}$ cubic foot of dry sand, and $\frac{1}{8}$ cubic foot of cement. Jar the materials in the measuring boxes and scrape off the top level with the top of the box before weighing.

Spread the broken stone in an even layer in the mixing pan; place the sand next and the cement on top. Thoroughly mix the cement, sand and rock dry. Add water gradually and mix until the mass is uniformly incorporated and of a quaking consistency. Weigh the amount of water used. The mixture should not be too wet. Take great care not to lose any of the ingredients either during mixing or while filling into the measuring cylinder.

Measure accurately the mean diameter and height of the measuring cylinder. Weigh it including the piston. Place the bottom of the cylinder on a truly level surface and fill it with concrete in about 2-inch layers, tamping each layer before adding the next. Occasionally while filling the cylinder stir the concrete remaining in the mixing pan to keep it uniformly incorporated. Fill the cylinder to about one inch of the top. See that the top surface of the concrete is truly level. The tamping should not be so vigorous as to force an excess of water to the surface. Insert the piston and allow it to rest without added pressure on the concrete. Measure from top of cylinder to top of piston at the 120 degree points of the cross-section of the cylinder. To obtain the depth of the concrete add the circumferential thickness of the piston to the mean of these three measurements. Weigh the cylinder with concrete and piston. Calculate the volume of the concrete.

Weigh the mixing box with remaining concrete, together with uncleaned shovel, trowel and tamping rod. Check the difference in weight between the measuring cylinder empty and filled with concrete with the difference in weights of materials used and remaining.

Calculate the density of the concrete, assuming that the ratio of ingredients in the concrete remaining is the same as the ratio of their original weights. For the specific gravities of the sand and crushed rock use the values posted on the bulletin board. Consult reference No. 1 under Test No. 6 for the method of making the computation of density.

All other conditions being the same, the density of concrete having a given percentage of cement indicates how effectively the voids in a set concrete have been reduced by granulometric proportioning of the aggregate. The denser a concrete, the stronger it is. For given materials, density determinations are useful to give an immediate clue as to the best concrete the materials can produce without waiting for such concrete to age for compression tests, but compression tests alone can determine what the actual strength of such a concrete is. For given materials small variations in density produce large variations in strength. An increase of 1 per cent in the density constant may produce an increase of 20 per cent in the compressive strength of a 1c : 2s : 4r concrete in the form of cubes at the age of three months. It therefore follows that great care must be exercised in making density determinations, particularly in regard to weights of ingredients, in regard to moisture (all surface of the concrete is truly level. The tamping should not be so vigorous as to force an excess of water to the surface. Insert the piston and allow it to rest without added pressure on the concrete. Measure from top of cylinder to top of piston at the 120 degree points of the cross-section of the cylinder. To obtain the depth of the concrete add the circumferential thickness of the piston to the mean of these three measurements. Weigh the cylinder with concrete and piston. Calculate the volume of the concrete.

Weigh the mixing box with remaining concrete, together with uncleaned shovel, trowel and tamping rod. Check the difference in weight between the measuring cylinder empty and filled with concrete with the difference in weights of materials used and remaining.

Calculate the density of the concrete, assuming that the ratio of ingredients in the concrete remaining is the same as the ratio of their original weights. For the specific gravities of the sand and crushed rock use the values posted on the bulletin board. Consult reference No. 1 under Test No. 6 for the method of making the computation of density.

All other conditions being the same, the density of concrete having a given percentage of cement indicates how effectively the voids in a set concrete have been reduced by granulometric proportioning of the aggregate. The denser a concrete, the stronger it is. For given materials, density determinations are useful to give an immediate clue as to the best concrete the materials can produce without waiting for such concrete to age for compression tests, but compression tests alone can determine what the actual strength of such a concrete is. For given materials small variations in density produce large variations in strength. An increase of 1 per cent in the density constant may produce an increase of 20 per cent in the compressive strength of a 1c : 2s : 4r concrete in the form of cubes at the age of three months. It therefore follows that great care must be exercised in making density determinations, particularly in regard to weights of ingredients, in regard to moisture (all

ingredients must be dry before mixing) and in regard to accounting for all ingredients originally weighed. The density should be obtained to the nearest tenth of a per cent.

Describe all the ingredient materials. Report all quantities and calculations in tabular form.

References.

1. A Treatise on Masonry Construction, by Baker, pp. 137–139 (1909 edition).
2. The Laws of Proportioning Concrete: Transactions American Society of Civil Engineers, vol. 59, p. 67 on.

TEST No. 3

SPECIFIC GRAVITY OF SAND AND CRUSHED ROCK VOIDS IN CONCRETE AGGREGATES

Purposes. To determine the specific gravity of sand, of crushed rock. To determine the percentage of voids in sand, in crushed rock and in a mixture of sand and crushed rock.

Apparatus. One 1000 cc. glass graduate, one 500 cc. glass graduate, one balance with scoop and counterweight, table and overhanging arm, one set of metric weights, one wooden measuring box of $\frac{1}{2}$ cubic foot capacity, one water pail, one galvanized iron measuring cylinder with bottom inlet, weighing scales sensitive to one-quarter of an ounce, scale graduated to tenths of an inch, some thread, battery jar, a large square pan.

Materials. Two cubic feet of crushed concrete rock, one cubic foot of concrete sand, both thoroughly dry.

Operations. Make the following determinations:

1. Specific gravity of sand.
2. Specific gravity of crushed rock.
3. Percentage of voids in sand by two methods.
4. Percentage of voids in crushed rock by two methods.
5. Percentage of voids in a mixture of sand and crushed rock by two methods.

1. Specific Gravity of Sand.

Weigh in grams the 1000cc. graduate first empty, then about half filled with water. Check increase in weight with volume of water. Weigh about 500 grams of dry sand. Note exact weight. Pour the weighed sand into the graduate; agitate to remove air bubbles. Quickly note exact rise in water level before the sand, if other than siliceous, can absorb any appreciable amount of water.

The specific gravity of the sand equals its weight in air divided by the weight of displaced water.

2. **Specific Gravity of Crushed Rock.**

Make trial weighings first in air, then in water, of a dry rock particle which is approximately cubical and weighs in air between 29 and 31 gm. This is to determine approximately the loss in weight on immersion. The determination is approximate because of absorption by the stone during weighing.

Carefully weigh in air another dry rock particle of similar size and shape and from the previous weighings calculate the approximate weight of the second particle when immersed in water. Set the scale at this calculated weight. With the thread suspend the rock from the scale pan so as to completely immerse it and quickly determine its exact weight when immersed.

The apparent specific gravity of the rock is given by the expression $\frac{W}{W - W_1}$, where W equals the weight in grams of the dry rock particle in air and W_1 equals its weight in grams just after immersion.

3. **Percentage of Voids in Sand by Two Methods.**

Method 1. By Direct Measurement with Water.—Weigh in grams the 1000 cc. graduate first empty, then about half filled with water. Note the height of water surface. Check increase in weight with volume of water. Measure out 500 cc. of dry sand in the smaller graduate. Jar graduate gently to settle sand. Pour sand into large graduate. Agitate to remove air bubbles. Quickly note new height of water surface.

The difference between 500 cc. and the displaced volume of water in the graduate equals the voids in cubic centimeters in 500 cc. of sand. Calculate the percentage of voids. Note the volume of the settled sand in the large graduate. Account for the change in volume.

Method 2. Indirectly by Measurement of the Solid Contents of the Sand.—Weigh in grams the 1000 cc. graduate first empty, then filled with dry sand. Jar very gently to settle the sand. The volume of solid sand particles in the graduate equals the increase in weight divided by the specific gravity of the sand. The volume of voids in cubic centimeters in 1000 cc. of sand equals 1000 cc. minus the volume of solid sand particles. Calculate the percentage of voids in the sand. Compare with the result of Method 1. Give reasons for difference.

4. Percentage of Voids in Crushed Rock by Two Methods.

Method 1. An Approximate Field Method.—Determine the volume of the water pail by weighing it first empty, then completely filled with water. Its volume in cubic feet equals the difference in weight in pounds divided by 62.24.

Soak in water for thirty minutes enough crushed rock to fill the pail. Then remove the rock from the water and set it aside in the large square pan to drain. When its surfaces have become free of surplus water place it in the pail, shake it to cause settlement and level it even with the top of the pail. Weigh the amount of water which can be added to fill the pail completely. Calculate its volume by dividing this weight in pounds by 62.24. This equals the volume of voids in a volume of crushed rock equal to that of the water pail. Calculate the percentage of voids in the crushed rock.

Method 2. By Direct Measurement with Water.—In this method the water is introduced into the container from below so as to reduce the inclusion of air to a minimum.

Determine the volume of the galvanized iron cylinder by measuring its mean diameter and height. Place the funnel attached to the rubber tube which leads to the bottom of the cylinder in the lower rack which is level with the bottom of the cylinder. Fill the tube and funnel with water to the level of the bottom of the cylinder. Then weigh the cylinder to the nearest quarter of an ounce.

Fill the cylinder with dry crushed rock. Shake to cause settlement. Level the rock even with the rim of the cylinder. Weigh the cylinder filled with rock. Place the funnel in the upper rack. Pour water into the cylinder through the funnel, measuring with a graduate the amount required to fill it completely. Note the length of time required. Weigh the cylinder when it is completely filled with water. Check increase in weight with measured volume of water added.

equals 1000 cc. minus the volume of solid sand particles. Calculate the percentage of voids in the sand. Compare with the result of Method 1. Give reasons for difference.

4. **Percentage of Voids in Crushed Rock by Two Methods.**

Method 1. An Approximate Field Method.—Determine the volume of the water pail by weighing it first empty, then completely filled with water. Its volume in cubic feet equals the difference in weight in pounds divided by 62.24.

Soak in water for thirty minutes enough crushed rock to fill the pail. Then remove the rock from the water and set it aside in the large square pan to drain. When its surfaces have become free of surplus water place it in the pail, shake it to cause settlement and level it even with the top of the pail. Weigh the amount of water which can be added to fill the pail completely. Calculate its volume by dividing this weight in pounds by 62.24. This equals the volume of voids in a volume of crushed rock equal to that of the water pail. Calculate the percentage of voids in the crushed rock.

Method 2. By Direct Measurement with Water.—In this method the water is introduced into the container from below so as to reduce the inclusion of air to a minimum.

Determine the volume of the galvanized iron cylinder by measuring its mean diameter and height. Place the funnel attached to the rubber tube which leads to the bottom of the cylinder in the lower rack which is level with the bottom of the cylinder. Fill the tube and funnel with water to the level of the bottom of the cylinder. Then weigh the cylinder to the nearest quarter of an ounce.

Fill the cylinder with dry crushed rock. Shake to cause settlement. Level the rock even with the rim of the cylinder. Weigh the cylinder filled with rock. Place the funnel in the upper rack. Pour water into the cylinder through the funnel, measuring with a graduate the amount required to fill it completely. Note the length of time required. Weigh the cylinder when it is completely filled with water. Check increase in weight with measured volume of water added.

Since the rock absorbs water, a correction must be made for the percentage of absorption of the rock for the time required to fill the cylinder. Determine the percentage of absorption of the rock as follows:

Percentage of Absorption of Rock

Determine exact weights in air and on immersion of a dried rock particle which is approximately cubical in shape and weighs in air between 29 and 31 gm. To do this, follow in detail the directions given in the first two paragraphs in subdivision 2 above, entitled, "Specific Gravity of Crushed Rock." After determining the exact weight on immersion allow the particle to remain immersed for the time required to fill the cylinder when making the determination of voids and then again weigh the particle while it is still immersed.

The water absorbed in pounds per cubic foot of solid rock is given by the expression, $\frac{W_2 - W_1}{W - W_1} \times 62.24$, where W equals the weight in grams of the dried sample in air; W_1, the weight in grams of the sample in water just after immersion and W_2, the final weight in grams of the sample while it is still immersed. The weight of distilled water in pounds per cubic foot at temperature of 77° Fahr. is 62.24 lbs. The percentage of absorption by weight is given by the expression $\frac{W_2 - W_1}{W} \times 100$.

Calculate the percentage of voids in the crushed rock, making the correction for absorption.

5. Percentage of Voids in a Mixture of Sand and Crushed Rock by Two Methods.

Method 1. By Direct Measurement with Water.—In the wooden measuring box measure off and weigh $\frac{1}{2}$ cubic foot of dry crushed rock which has been slightly shaken to cause settlement. Place the rock in the pan. Measure off similarly an amount of dry sand equal in volume to $\frac{1}{2}$ cubic foot multiplied by the percentage of voids in the crushed rock as determined by Method 2 of subdivision 4 above, entitled, "Percentage of Voids in Crushed Rock by Two Methods."

Weigh this amount of sand. Add the sand to the crushed rock in the pan and mix these thoroughly. Determine the percentage of voids in the mixture by Method 2 of subdivision 4 above, entitled, "Percentage of Voids in Crushed Rock by Two Methods."

To do this, weigh the amount of thoroughly settled mixture required to fill the cylinder. Measure by volume and check by weight the amount of water required to fill the cylinder. Calculate the percentage of voids in the mixture, making the correction for absorption. In computing this correction for absorption, assume that the ratio of sand to rock by weight in the cylinder is the same as the ratio of their weights before mixing. The correction for absorption need not be made for sand when it is siliceous.

Assuming the percentage of voids in the sand as given by the average of the two methods in subdivision 3 above, entitled, "Percentage of Voids in Sand by Two Methods," compute the percentage of voids in the above mixture of sand and crushed rock, assuming that the sand completely fills the voids in the crushed rock as they existed before addition of the sand. Compare this computed quantity with the measured percentage of voids. Draw conclusions.

Method 2. Indirectly by Measurement of the Solid Contents of the Mixture.—Make a mixture of dry crushed rock and dry sand of the same proportions and amounts as for Method 1 above. Weigh the amount of this mixture required to fill the $\frac{1}{2}$ cubic foot measuring box. Before levelling top surface of mixture even with the rim of the box, jar slightly to cause settlement. Assume the ratio of sand to crushed rock by weight in the box to be the same as the ratio of their weights before mixing.

The volume in cubic centimeters of either solid sand or solid rock particles in the box equals its weight in grams divided by its specific gravity. This volume in cubic feet equals the weight in pounds divided by the quantity, (specific gravity multiplied by 62.24). Compute separately the volumes of solid sand and of solid rock particles in the box. Compute the percentage of voids in the mixture.

Compare Methods 1 and 2 of subdivision 5.

Tabulate the results of all determinations.

When only two materials are available for concrete, a sand and a coarse aggregate, gravel or crushed rock, void determinations are useful to give a first approximate proportion for a mixture of the sand and rock which will produce a concrete with minimum voids. The exact proportions of sand and rock are then determined as follows: Using the above proportion as a basis, various concrete mixtures are made in which these proportions are varied slightly either way, the percentage of cement by weight in terms of the total dry aggregate in each case being the same and the amount of mixing water used in each case being such as to produce the same consistency in all cases. The density of each of these concrete mixes is then determined. That mixture is selected as best whose density is greatest.

When there is a variety of available sands of different sizes and a variety of available coarse aggregates of different sizes the most direct method of proportioning so as to produce the densest concrete is outlined in Test No. 16.

Tabulate the results of all determinations.

When only two materials are available for concrete, a sand and a coarse aggregate, gravel or crushed rock, void determinations are useful to give a first approximate proportion for a mixture of the sand and rock which will produce a concrete with minimum voids. The exact proportions of sand and rock are then determined as follows: Using the above proportion as a basis, various concrete mixtures are made in which these proportions are varied slightly either way, the percentage of cement by weight in terms of the total dry aggregate in each case being the same and the amount of mixing water used in each mix being such as to produce the same consistency in all cases. The density of each of these concrete mixes is then determined. That mixture is selected as best whose density is greatest.

When there is a variety of available sands of different sizes and a variety of available coarse aggregates of different sizes, the most direct method of proportioning so as to produce the densest concrete is outlined in Test No. 16.