COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

HENRY WARD
COMMISSIONER OF HIGHWAYS

April 17, 1961

ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
MATERIALS RESEARCH LABORATORY
132 GRAHAM AVENUE
LEXINGTON 29, KENTUCKY

A. 1. 9.

MEMO TO: A. O. Neiser
Assistant State Highway Engineer

SUBJECT: Special Specification for
Lightweight Concrete

We have prepared the attached proposed Special Specification for "Lightweight Concrete" for consideration of the Specification Committee as requested in your letter of December 12, 1960.

I am, also, attaching Mr. J. H. Havens' memorandum of April 14, 1961, ASTM C 330-59T, "Specification for Lightweight Aggregates for Structural Concrete," and "Recommended Practice for Selecting Proportions of Structural Lightweight Concrete," ACI.

Due to the limited experience with Kenlite aggregate concrete (three highway structures noted in my memorandum of November 2, 1960) and information derived from laboratory freeze-thaw durability studies, we would recommend that its use in exposed structural concrete be on an experimental basis. It would appear that prefabricated and possibly prestressed structural members would be ideal for realizing any economic advantage of lightweight concrete.

Respectfully submitted,

W. B. Drake
Director of Research

WBD:dl
Encs.

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April 14, 1961

ADDRESS REPLY TO
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MATERIALS RESEARCH LABORATORY
132 GRAHAM AVENUE
LEXINGTON 29, KENTUCKY

A.1.9.

MEMO TO: W. B. Drake
Director of Research

SUBJECT: Proposed Special Specifications for Lightweight Concrete

REFERENCES: Memo to A.O.Neiser, 11-2-60, per W. B. Drake, Transmitting: "A Discussion on the Durability of Expanded Shale Aggregate for Exposed Concrete Structures (Bridges)," by James H. Havens.
Memo per A. O. Neiser, 12-12-60, Requesting Appropriate Specifications.

Attached hereto are copies of our preliminary proposal for a special specification covering lightweight concrete. The specification parallels Article 5.6.0 of the Department's Standard Specifications... insofar as practicable, and, when invoked, would supersede 5.6.0. It would not directly supersede any part of Article 5.1.0 (Concrete Bridges) inasmuch as specific uses of the lightweight concrete are not designated. Hence, the use of the concrete would have to be designated by special provisions to Article 5.1.0 or by plan notes.

Although the specification largely anticipates the use of local, expanded shale aggregates, ASTM C 330, which covers the material requirements for the aggregates, does not so limit the aggregate as to type.

Further, it is anticipated that the mixes will be designed according to "Recommended Practice for Selecting Proportions for Structural Lightweight Concrete," Proceedings, A.C.I., Vol. 55, September 1958. The A.C.I. criterion suggests that trial mixes be made and that an effective apparent specific gravity (specific gravity factor) of the aggregate be computed from it. It also proposes that any adjustments in water, for control of consistency, be made by adding both cement and water in proportion to the water-cement ratio specified.

Ordinarily and heretofore, cement factors have been selected as that amount which will assure a safe margin of strength. It is suggested here that higher cement factors may be desirable from the standpoint of durability. Of course, air-entrainment should be mandatory, and all near-level surfaces should have sufficient slope to promote drainage. Protective coatings might well be considered for exposed, lightweight, concrete if used in major structures.

The criterion recommends that the air content be determined by the volumetric method, ASTM C173; although the pressure method may be used with certain precautions. It is intended, of course, that the amount of entrained air be between 4.5 and 6.5 percent. The amount of entrapped air seems to run between 2 and 4 percent (this may be confirmed by measuring the air in a mix containing no air-entraining agent); then, by measuring the total air in a mix containing the air-entraining agent and deducting from this the amount of entrapped air, the amount of entrained air may be determined.

It appears to be the practice in the use of expanded shales to deliver them to the work in a less-than-saturated condition (Kenlite -75% of about 9% water by weight) and to maintain this condition until mixing. This attempts to minimize the robbing of the mix-water by the aggregate during and following mixing. Some absorption is unavoidable, and it is because of this that straight-forward volumetric calculations are usually not as reliable as they are in normal concrete. The use of the aggregate in a less-than-saturated condition is desirable from the standpoint of resistance to freeze-thaw.

Jas. H. Havens
Assistant Director of Research

JHH:dl
Encs. 1. Proposed Special Specification for Lightweight Concrete
2. ASTM C330-59T
3. "Recommended Practice for Selecting Proportions for Structural Lightweight Concrete," ACI.

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COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

SPECIAL SPECIFICATION NO.________

LIGHTWEIGHT CONCRETE
(Class "L", and Class "L" Modified)

This Special Specification No.___, covers the materials and construction requirements for lightweight concrete for highway structures (bridges), pavements, and other uses as may be designated. It shall be applicable when indicated on plans, proposals, and bidding invitations; and, when so indicated, it shall supersede all conflicting requirements of the Department's current Standard Specification...

A. DESCRIPTION

Lightweight concrete as provided herein shall consist of portland cement, lightweight fine and coarse aggregates, water, and air-entraining admixture, combined and mixed in prescribed proportions. The placement and forming thereof shall be in a ccordance with plans and as directed by the Engineer.

B. MATERIALS

The ingredient materials shall comply with the following requirements:

1. Cement - Articles 7.1.1, 7.1.2, and 7.1.3
2. Water - Article 7.2.0
3. Air-Entraining Admixture - Article 7.39.0
4. Aggregates - ASTM C330-59T

5. Care and Storage of Concrete Aggregate - The fine and coarse aggregates shall be furnished, stocked, and handled on the job so that uniformity of grading and moisture content will be maintained. Aggregate shall be maintained free of all contaminants and foreign matter. Expanded shale aggregates shall be delivered to the job at a uniform moisture content of 6 to 8 percent and shall be maintained so through the period of storage and prior to mixing.

6. Admixtures for Improvement of Workability - Article 5.6.2-G.

C. CONSTRUCTION METHODS

1. Proportions, Classes, and Strengths - The Engineer shall stipulate the precise proportions of the ingredients, and adjustments thereof, as may be necessary to obtain a satisfactory mixture. The general requirements for the mixture shall be as follows:

Minimum Cement Factors (bbls.per cu. yd.)	
Class "L"	1.75
Class "L" Modified	2.00
Air Content, total(entrapped and entrained)(% by vol.) (Method: ASTM C173)	
Minimum	6.5
Maximum	10.5
Maximum Wt. per cu.ft. (theoretical, dry basis)	
Class "L"	110
Class "L" Modified	115
Slump (in inches)	2 to 5
Max. Free Water(gals/sack of cement)	6.00

(Note: If the desired consistency, "slump", is not achieved within the limits determined by the minimum cement factor and maximum free water allowed in terms of gals/sack of cement, the mixture shall be adjusted by adding both cement and water in the ratio of 6 gals/sack of cement.)

Minimum Compressive Strength
Class "L" - 3500 psi, 28 days
Class "L" Modified - 4000 psi, 7 days

2. Proportioning and Mixing

   a. Measuring: Article 5.6.3.B-1 (applicable portions thereof)

   b. Consistency: Article 5.6.3.B-2

   c. Mixing Conditions: Article 5.6.3.B-3

   d. Mixing Concrete: Article 5.6.3.B-4

3. Placing Concrete: Article 5.6.3.D.

4. Construction Joints: Article 5.6.3.D

5. False Work and Forms: Article 5.6.3.E

6. Expansion Joints: Article 5.6.3.F

7. Curing Concrete: Article 5.6.3.G

8. Surface Finish: Article 5.6.3.H

D. METHOD OF MEASUREMENT: Article 5.6.4

E. METHOD OF PAYMENT: Article 5.6.5

Tentative Specifications for

LIGHTWEIGHT AGGREGATES FOR STRUCTURAL CONCRETE[1]

ASTM Designation: C 330 – 59 T

ISSUED, 1953; REVISED, 1959.[2]

These Tentative Specifications have been approved by the sponsoring committee and accepted by the Society in accordance with established procedures, for use pending adoption as standard. Suggestions for revisions should be addressed to the Society at 1916 Race St., Philadelphia 3, Pa.

Scope

1. These specifications cover lightweight aggregates intended for use in structural concrete in which prime considerations are lightness in weight and compressive strength of the concrete.

NOTE.—Concrete for such purposes as fireproofing and fill, and for concrete constructions the use of which is based upon load tests and not conventional design procedures, is not covered by these specifications.

General Characteristics

2. (*a*) Two general types of lightweight aggregates are covered by these specifications, as follows:

Aggregates prepared by expanding, calcining, or sintering products such as blast furnace slag, clay, diatomite, fly ash, shale, or slate.

Aggregates prepared by processing natural materials, such as pumice, scoria, or tuff.

(*b*) The aggregates shall be composed predominately of lightweight cellular and granular inorganic material.

Grading

3. (*a*) The grading shall conform to the requirements shown in Table I.

(*b*) *Uniformity of Grading*.—To assure reasonable uniformity in the gradation of successive shipments of lightweight aggregate, fineness modulus shall be determined on samples taken from shipments at intervals stipulated by the purchaser. If the fineness modulus of the aggregate in any shipment differs by more than 7 per cent from that of the sample submitted for acceptance tests, the aggregate in the shipment shall be rejected, unless it can be demonstrated that it will produce concrete of the required characteristics.

Unit Weight

4. (*a*) The unit weight of lightweight aggregates shall conform to the requirements shown in Table II.

[1] Under the standardization procedure of the Society, these specifications are under the jurisdiction of the ASTM Committee C-9 on Concrete and Concrete Aggregates.

[2] Revision accepted by the Society at the Annual Meeting, June, 1959.

These specifications, together with the Tentative Specifications for Lightweight Aggregates for Concrete Masonry Units (C 331) and the Tentative Specifications for Lightweight Aggregates for Insulating Concrete (C 332), replace the former Standard Specifications for Lightweight Aggregates for Concrete (C 130 – 42).

(*b*) *Uniformity of Weight.*—The unit weight of successive shipments of lightweight aggregate shall not differ by more than 10 per cent from that of the sample submitted for acceptance tests.

Deleterious Substances

5. Lightweight aggregates shall not contain excessive amounts of deleterious substances, as determined by the following limits:

TABLE I.—GRADING REQUIREMENTS FOR LIGHTWEIGHT AGGREGATES FOR STRUCTURAL CONCRETE.

Size Designation	Percentages (by Weight) Passing Sieves Having Square Openings								
	1 in.	¾ in	½ in.	⅜ in.	No. 4 (4760-micron)	No. 8 (2380-micron)	No. 16 (1190-micron)	No. 50 (297-micron)	No. 100 (149-micron)
Fine Aggregate:									
No. 4 to 0. . . .	....	....	....	100	85 to 100	....	40 to 80	10 to 35	5 to 25
Coarse Aggregate:									
1 in. to ½ in. .	95 to 100	....	0 to 10	....	....	....	....	....	....
1 in. to No. 4. .	95 to 100	....	25 to 60	....	0 to 10	....	....	....	....
¾ in. to No. 4.	100	90 to 100	....	20 to 60	0 to 10	....	....	....	....
½ in. to No. 4.	....	100	90 to 100	40 to 80	0 to 20	0 to 10	....	....	....
⅜ in. to No. 8.	....	....	100	80 to 100	5 to 40	0 to 20	....	....	....
Combined Fine and Coarse Aggregate:									
½ in. to 0.	....	100	95 to 100	....	50 to 80	....	....	5 to 20	2 to 15
⅜ in. to 0.	....	....	100	90 to 100	65 to 90	35 to 65	....	10 to 25	5 to 15

TABLE II.—UNIT WEIGHT REQUIREMENTS OF LIGHTWEIGHT AGGREGATES FOR STRUCTURAL CONCRETE.

Size Designation	Dry Loose Weight, max, lb per cu ft
Fine aggregate.	70
Coarse aggregate.	55
Combined fine and coarse aggregate.	65

(*a*) *Organic Impurities.*—Lightweight aggregates that, upon being subjected to the test for organic impurities, produce a color darker than the standard shall be rejected, unless it can be demonstrated that the discoloration is due to small quantities of materials not harmful to the concrete.

(*b*) *Staining.*—Lightweight aggregates that, upon being subjected to the test for staining materials, are classified as "heavy stain" or darker by the visual staining test, shall be tested by the chemical procedure, and aggregates that contain 1.5 mg or more of ferric oxide (Fe_2O_3) shall be rejected for use in structural concrete.

NOTE. 1—This requirement is designed as a means of defining the degree of staining to be expected from lightweight aggregates containing iron compounds which may or may not produce stains on the surface of the concrete.

(*c*) *Clay Lumps.*—The amount of clay lumps shall not exceed 2 per cent by dry weight.

(*d*) *Loss on Ignition.*—The loss on ignition of lightweight aggregates shall not exceed 5 per cent.

NOTE 2.—Certain processed aggregates may be hydraulic in character, and may be partially hydrated during production; if so, the quality of the product is not reduced thereby. Other aggregates may in their natural states contain innocuous carbonates or water of crystallization, which will contribute to the loss on ignition. Therefore, consideration should be given to the type of material when evaluating the product in terms of ignition loss.

(*e*) *Durability.*—In the absence of a proven record of satisfactory durability in structural concrete, lightweight aggregates may be required to pass an accelerated soundness test or a concrete freezing and thawing test satisfactory to the purchaser.

Concrete-Making Properties

6. Concrete specimens containing lightweight aggregate under test shall meet the following requirements:

(*a*) *Compressive Strength and Unit Weight.*—It shall be possible to produce structural concrete, using the lightweight aggregates under test, such that one or more of the compressive strength requirements in the following table will be satisfied without exceeding the corresponding maximum unit weight values. Intermediate values for strength, and corresponding unit weight values, may be established by interpolation.

Average 28-Day Compressive Strength min, psi	Average Unit Weight, max, lb per cu ft
4000	115
3000	110
2000	105

(*b*) *Drying Shrinkage.*—The drying shrinkage of concrete specimens prepared and tested in accordance with Section 8 (*c*) shall not exceed 0.10 per cent.

(*c*) *Popouts.*—Concrete specimens prepared and tested in accordance with Section 8 (*d*) shall show no surface popouts.

Methods of Sampling and Testing for Aggregate Properties

7. Lightweight aggregates shall be sampled and the properties enumerated in these specifications shall be determined in accordance with the following methods:

(*a*) *Sampling.*—Standard Methods of Sampling Stone, Slag, Gravel, Sand, and Stone Block for Use as Highway Materials (ASTM Designation: D 75).[3]

(*b*) *Grading.*—Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates (ASTM Designation: C 136),[3] except that the weight of the test sample for fine aggregate shall be in accordance with Table III, and the aggregate when mechanically sieved shall be sieved for only 5 min. The test sample for coarse aggregate shall consist of 0.1 cu ft or more of the material used for the determination of unit weight.

TABLE III.—WEIGHT OF SIEVE TEST SAMPLE FOR FINE LIGHTWEIGHT AGGREGATES.

Nominal Weight of Aggregate, lb per cu ft	Weight of Test Sample, g
5 to 15	50
15 to 25	100
25 to 35	150
35 to 45	200
45 to 55	250
55 to 65	300
65 to 70	350

(*c*) *Unit Weight* (*Loose*).—Tentative Method of Test for Unit Weight of Aggregate (ASTM Designation: C 29),[3] utilizing the shoveling procedure described in Section 7 of Method C 29 except that the aggregate shall be tested in an oven-dry condition.

(*d*) *Organic Impurities.*—Tentative Method of Test for Organic Impurities in Sands for Concrete (ASTM Designation: C 40).[3]

(*e*) *Fineness Modulus.*—Standard Definitions of Terms Relating to Concrete and Concrete Aggregates (ASTM Designation: C 125).[3]

(*f*) *Clay Lumps in Aggregates.*—Tentative Method of Test for Clay Lumps in Natural Aggregates (ASTM Designation: C 142).[3]

(*g*) *Loss on Ignition.*—Standard Methods of Chemical Analysis of Portland Cement (ASTM Designation: C 114–58),[3] Section 20, Method A or B.

(*h*) *Soundness.*—Tentative Method of Test for Soundness of Aggregates by Use

[3] 1958 Book of ASTM Standards, Part 4.

of Sodium Sulfate or Magnesium Sulfate (ASTM Designation: C 88).[3a]

(*i*) *Test for Staining Materials.*—Select a 100-g sample of the aggregate graded to pass the ⅜-in. sieve and be retained on the No. 30 (590-micron) sieve.[4] Crimp the edge of a 25-cm diameter white filter paper to form a cup-shape receptacle, approximately 5 in. in diameter and 2½ in. in depth, and place the aggregate sample approximately ½ in. in depth in the filter paper cup. Fold the sides of the cup to the center and press in that position. Prepare a second portion of the sample in the same manner. Place both portions of the sample, one on top of the other, in a cheesecloth bag, saturate with water, and expose to steam in a steam bath for 16 hr. At the end of this period, remove from the steam bath and carefully remove the aggregate from the filter paper. Wash both papers with tap water, and oven-dry at a temperature of 212 to 220 F (100 to 104.4 C). The insoluble products of the decomposition of iron compounds in the aggregate will be deposited on the filter paper as red, green, or black stains. The quantity of such products shall be determined by one of the two following methods:

(*1*) *Visual Classification Method.*—Evaluate the extent and intensity of the stains on the filter paper in accordance with the following table and the photographic reference standards shown in Fig. 1:

Extent and Intensity of Stain	Stain Index
Very heavy stain	100
Heavy stain	80
Moderate stain	60
Light stain	40
Very light stain	20
No stain	0

(*2*) *Chemical Analysis Method.*—Digest the washed and dried filter papers from which the visual stain observations were made in 3 *N* hydrochloric acid to dissolve the iron compounds. Filter the solution and wash the residue of filter pulp thoroughly with hot distilled water. Precipitate the iron compounds in the filtrate as ferric hydroxide; then redissolve and determine quantitatively by standard titration procedures. Report the results as milligrams of ferric oxide (Fe_2O_3) deposited on the filter papers from 200 g of the aggregate tested.

Methods of Testing for Concrete-Making Properties

8. The concrete-making properties of lightweight aggregates shall be determined in accordance with the following methods, using the same ratio of fine to coarse lightweight aggregate as is proposed for use, and using three specimens for each type of test:

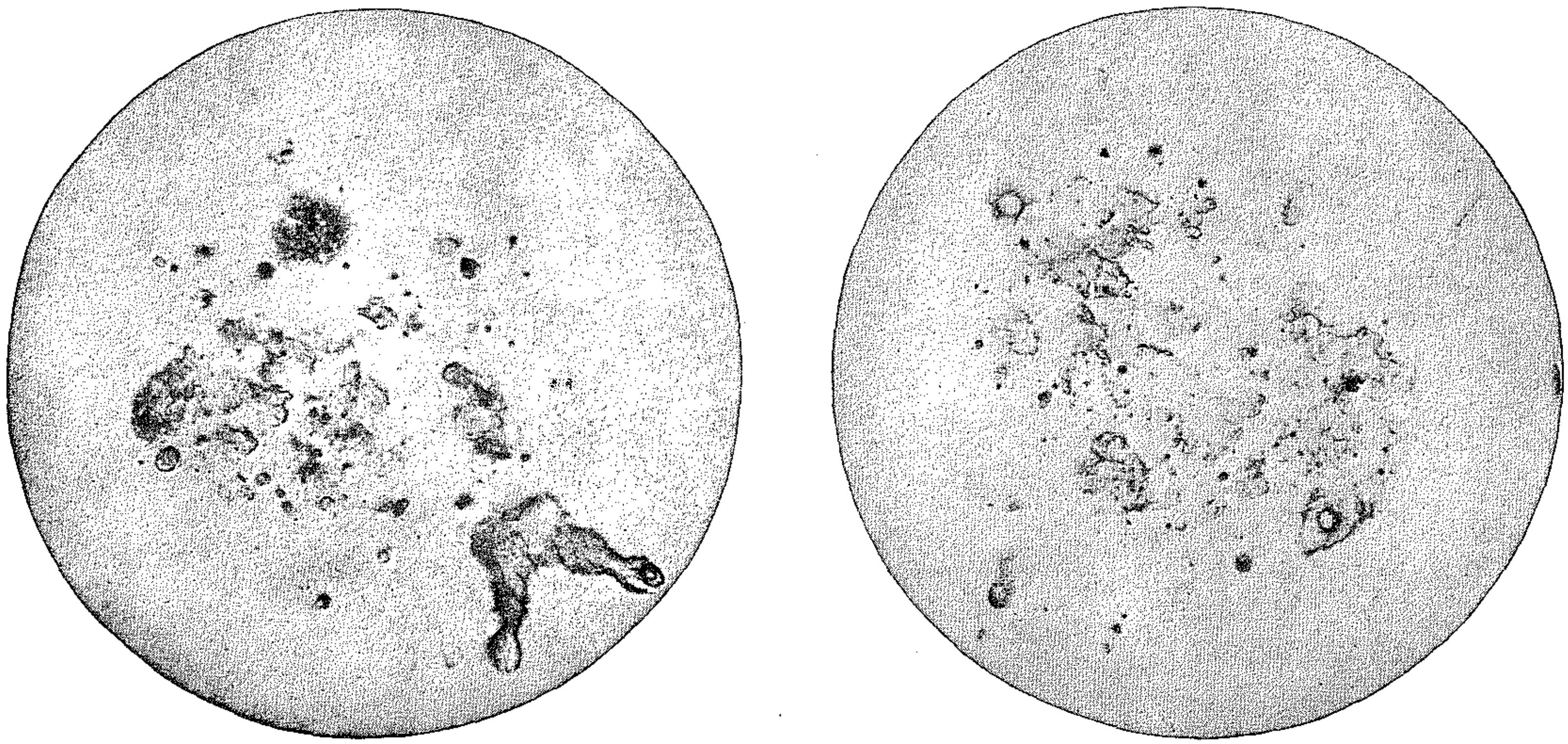
(*a*) *Compressive Strength.*—Standard Method of Test for Compressive Strength of Molded Concrete Cylinders (ASTM Designation: C 39).[3] Test specimens shall be made in accordance with the Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (ASTM Designation: C 192),[3a] with the following exception:

At the age of 7 days, the specimens shall be removed from the moist room and stored in a temperature of 73.4 ± 2 F (23 ± 1.1 C) and a relative humidity of 50 ± 2 per cent until time of test.

(*b*) *Unit Weight of Concrete.*—Using cylinders molded and cured as prescribed for the compression test specimens in Paragraph (*a*), determine the weight of concrete per cu ft, at the age of 28 days, by the following procedure: Determine the weight of the cylinders as cured; then completely immerse the cylinders in water at 73.4 ± 2 F (23 ± 1.1 C) for 24 hr, and determine the immersed weight and the saturated, surface-dry weight of

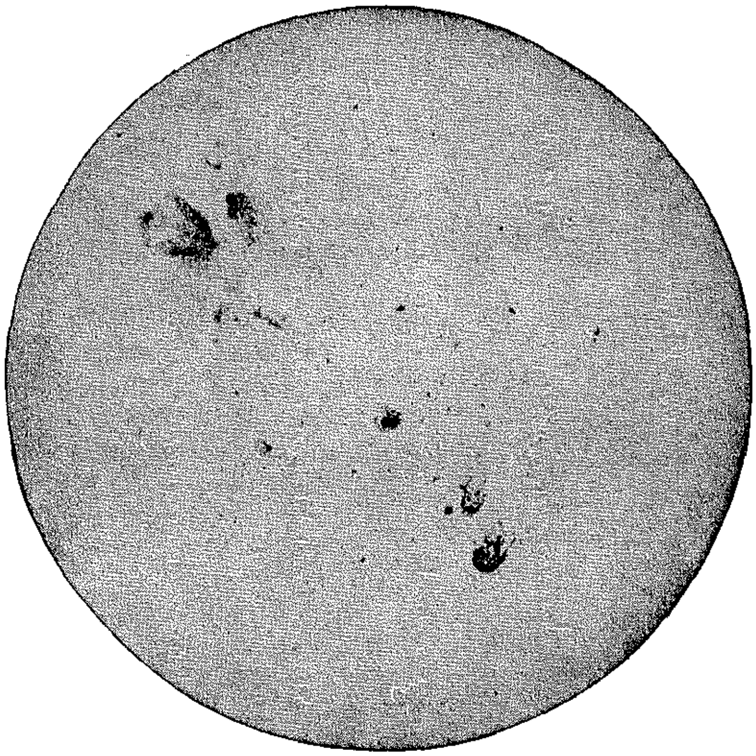
[3a] Appears in this publication, see Contents in Numeric Sequence of ASTM Designations at front of book.

[4] Detailed requirements for these sieves are given in the Tentative Specifications for Sieves for Testing Purposes (ASTM Designation: E 11), which appears in the 1958 Book of ASTM Standards, Part 4.

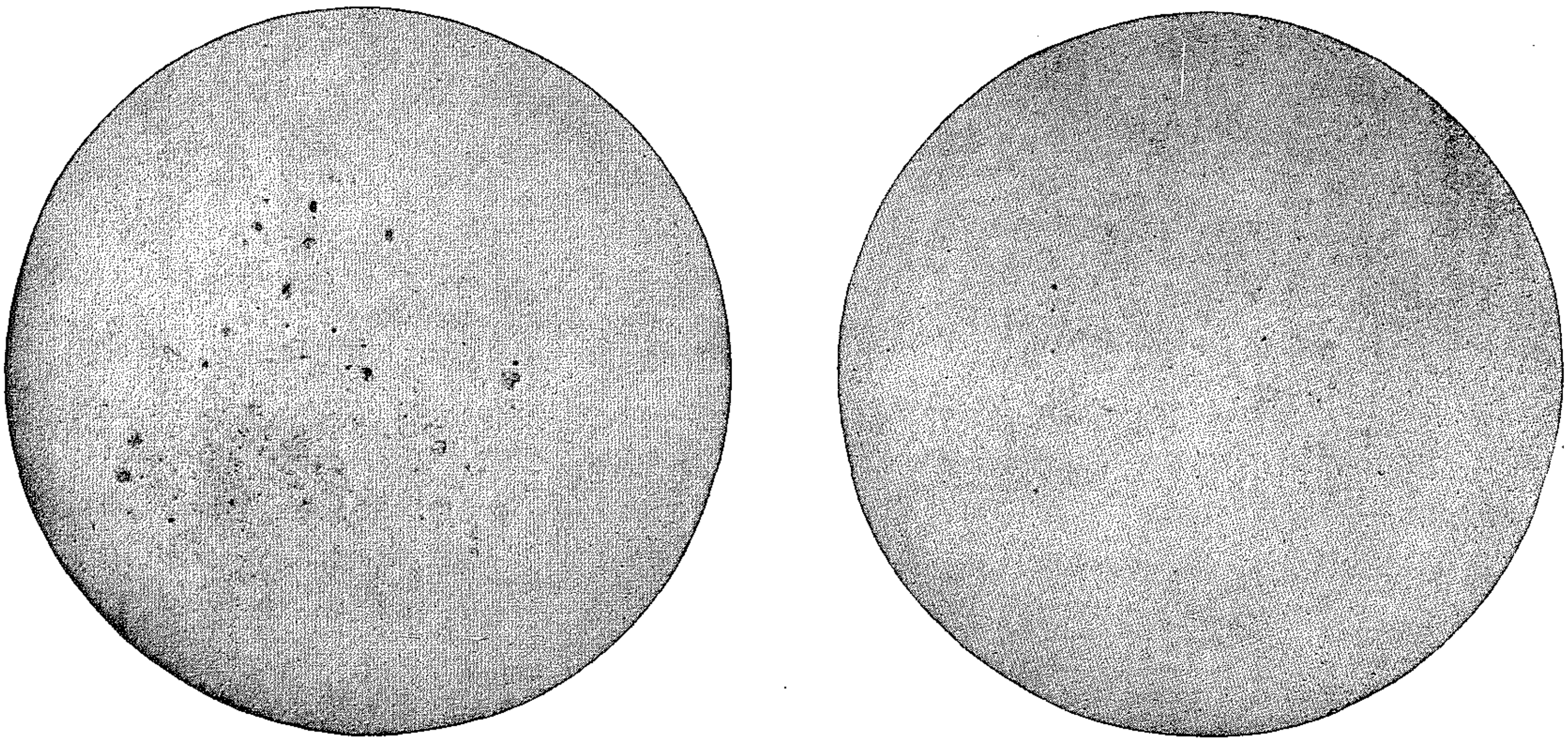


Very Heavy Heavy

Fig. 1.—Degree of Staining Caused by Impurities in Lightweight Aggregate.



Moderate



Light

Very Light

FIG. 1.—Degree of Staining Caused by Impurities in Lightweight Aggregate (*Concluded*).

the cylinders. Calculate the weight per cubic foot of concrete, as cured, in accordance with the following formula:

$$\text{Weight per cubic foot} = \frac{A \times 62.4}{B - C}$$

where:

A = 28-day weight of concrete cylinder, as cured,

B = saturated, surface-dry weight of cylinder, and

C = immersed weight of cylinder.

(c) *Shrinkage of Concrete.*—Tentative Method of Test for Volume Change of Cement Mortar and Concrete (ASTM Designation: C 157),[3] with the following exceptions:

(1) Prepare the concrete mix in the proportions of one part of portland cement to six parts of combined aggregates, measured by dry loose volume. Adjust the water content so as to produce a slump of 2 to 3 in. and thoroughly consolidate the concrete in steel molds 2 by 2 by 11¼ in. for aggregates having ½ in. or less maximum size designation. The surface of the concrete shall be steel-troweled.

(2) Cure the test specimens as prescribed for the compression test specimens in Paragraph (a). Make initial length measurements immediately after removal of specimens from moist storage. Make subsequent measurements at 28 and 100 days.

(3) Calculate the difference in length of the specimens, when removed from moist storage at the age of 7 days and at the final measurement at the age of 100 days, to the nearest 0.01 per cent of the effective gage length, and report as the drying shrinkage of the specimen. Report the average drying shrinkage of the specimens as the drying shrinkage of the concrete.

(d) *Test for Popout Materials.*—Prepare concrete specimens for the test for popout materials in accordance with Paragraph (c), Item (1). Cure and autoclave the specimens in accordance with the Standard Method of Test for Autoclave Expansion of Portland Cement (ASTM Designation: C 151).[3a] Visually inspect the autoclaved specimens for the number of popouts that have developed on the surface. Report the average number of popouts per specimen.

(e) *Freezing and Thawing.*—Make freezing and thawing tests of concrete, when required, in accordance with one of the following methods: Tentative Method of Test for Resistance of Concrete Specimens to Rapid Freezing and Thawing in Water (ASTM Designation: C 290),[3] Tentative Method of Test for Resistance of Concrete Specimens to Rapid Freezing in Air and Thawing in Water (ASTM Designation: C 291),[3] Tentative Method of Test for Resistance of Concrete Specimens to Slow Freezing and Thawing in Water or Brine (ASTM Designation: C 292),[3] and Tentative Method of Test for Resistance of Concrete Specimens to Slow Freezing in Air and Thawing in Water (ASTM Designation: C 310).[3]

Title No. 55-18

Proposed

Recommended Practice for Selecting Proportions for Structural Lightweight Concrete*

Reported by Subcommittee on Proportioning Lightweight Aggregate Concrete, ACI Committee 613

J. J. SHIDELER
Chairman

ROBERT K. DUEY
FRANK ERSKINE
RICHARD J. FRAZIER
FRED HUBBARD
HENRY L. KENNEDY†
THOMAS B. KENNEDY
GEORGE H. NELSON
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PAUL M. WOODWORTH

SYNOPSIS

This subcommittee report is intended as a supplement to ACI Standard "Recommended Practice for Selecting Proportions for Concrete (ACI 613-54)" and describes a procedure for proportioning structural grade concrete containing lightweight aggregates. This procedure does not require the use of values for specific gravity or absorption of the aggregates but utilizes a "specific gravity factor." Use of this factor is illustrated and examples are included for proportioning both air-entrained and non-air-entrained mixes.

CHAPTER 1—INTRODUCTION

101—Scope and limits

(*a*) Under this title the subcommittee has limited its discussion and recommendations to structural grade lightweight aggregate concrete. Structural lightweight concrete is defined as having a 28-day compressive strength in excess of 2000 psi and an air dry unit weight less than 115 lb per cu ft. Many expanded shales, slates, clays, slags, and some natural aggregates, such as scoria, are used in this class of concrete. Proportioning of very lightweight concrete used primarily for insulation is not included.

*Title No. 55-18 is a part of copyrighted JOURNAL OF THE AMERICAN CONCRETE INSTITUTE, V. 30, No. 3, Sept. 1958, *Proceedings* V. 55. Separate prints are available at 50 cents each. **Discussion** (copies in **triplicate**) should reach the Institute not later than Dec. 1, 1958. Address P. O. Box 4754, Redford Station, Detroit 19, Mich.

This report was prepared as a part of the work of ACI Committee 613, Recommended Practice for Proportioning Concrete Mixes. The report was submitted to the main committee (26 members) with 17 voting affirmatively and none negatively. It is released by the Standards Committee for publication and discussion with view to its consideration for adoption as an Institute Standard at the 55th annual convention, Los Angeles, Calif., Feb. 23-27, 1959.

†Deceased.

(*b*) The principles of normal weight concrete proportioning as established by ACI Standard "Recommended Practice for Selecting Proportions for Concrete (ACI 613-54)" apply directly to lightweight aggregate concretes, but generally the application of these principles is difficult. However, conventional procedures may be used with good results for such lightweight aggregates as are generally characterized by rounded particle shape, coated or sealed surfaces, and relatively low values of absorption.

CHAPTER 2—FACTORS AFFECTING PROPORTIONS OF LIGHTWEIGHT CONCRETES

201—General

(*a*) Some lightweight aggregates have absorption values of more than 12 percent and so may have more than 200 lb of absorbed water per cu yd of concrete. The question of how much water is absorbed and how much water actually occupies space in the concrete is the principal difficulty in proportioning by absolute volume procedures, when applied to this class of lightweight aggregates. The high values of absorption and the fact that the absorption may continue at an appreciable rate for several days make it difficult to determine correct values of absorption and specific gravity of the aggregate. Because of these complications the established relationships cannot be applied with the same confidence as for normal weight aggregates.

(*b*) The net water-cement ratio of most lightweight aggregate concretes can *not* be established with sufficient accuracy for use as a basis of mix proportioning. Lightweight aggregate concrete mixes are established by a series of trial mixes proportioned on a cement content basis at the required consistency.

202—Aggregate

(*a*) Several investigators[1,2,3,4] have determined that the moisture content of the aggregate immediately prior to mixing has little effect on the compressive strength of the concrete. Whether the aggregates are dry or have free surface moisture makes little difference as long as the moisture content is known and accounted for at the time the aggregates are batched. Dry aggregates produce concrete of lower unit weights than wet aggregates and allow easier control of batch quantities. Concrete made with saturated aggregate will be more vulnerable to damage by freezing and thawing than concrete made with dry aggregate. However, it is desirable that the aggregates be damp at the time of mixing to reduce the amount of water absorbed from the mix and so reduce the rate of loss of slump. Damp materials also show less tendency to segregate during storage and transportation than dry materials. When the aggregate is in a less than saturated condition, it is desirable to mix the aggregate with about two-thirds of the required mixing water for a short period prior to introduction of cement and air-entraining admixture. This reduces the effective loss of cement into the vesicles in the surface of porous aggregates.

(*b*) The grading of the fine and coarse aggregate and the proportions used have an important effect on the concrete. A well graded aggregate will have a minimum void content and so will require a minimum amount of paste to fill these voids. This will result in the most economical use of cement and will provide maximum strength with minimum volume change due to drying shrinkage and temperature changes.

(*c*) For sand-and-gravel aggregates the bulk specific gravities of materials retained on the different sieve sizes are nearly equal, so the fineness modulus, on a weight basis, gives a true indication of the volumes occupied by each size of material. However, the bulk specific gravity of the various size fractions of lightweight aggregate increases as the particle size diminishes. Some coarse aggregate particles may float in water while the particles finer than the No. 100 sieve have a specific gravity approaching that of sand and gravel. It is the *volume* occupied by each size fraction and *not the weight* of material retained on each sieve that determines the final void content, paste content, and workability of the concrete. The fineness modulus by weight and by volume for a lightweight aggregate are computed in the following example.

Sieve size	Percent retained, by weight	Cumulative percent retained, by weight	Specific gravity	Percent retained, by volume	Cumulative percent retained, by volume
4	0	—	1.40	—	—
8	21.6	21.6	1.55	25.9	25.9
16	24.4	46.0	1.78	25.4	51.3
30	18.9	64.9	1.90	18.5	69.8
50	14.0	78.9	2.01	13.0	82.8
100	11.6	90.5	2.16	9.9	92.7
Pan	9.5	100.0	2.40	7.3	100.0

Fineness modulus (by weight) = 3.02 Fineness modulus (by volume) = 3.23

(*d*) The fineness modulus (by volume) of 3.23 indicates a considerably coarser grading than that normally associated with the fineness modulus of 3.02 by weight. From data presented by Richart and Jensen[1] on another lightweight aggregate, the fineness modulus of 2.83 on a weight basis converts to 3.21 on a volume basis. Therefore, lightweight aggregates require a larger percentage of material retained on the finer sieve sizes, on a weight basis, than do the heavier aggregates to provide an equal void content. Grading and other properties of lightweight aggregate for structural concrete are specified in ASTM C 330.

203—Air entrainment

(*a*) Air entrainment is desirable in most concrete. It improves workability and resistance to weathering, and it decreases bleeding and obscures grading deficiencies. Strength is generally reduced, but the reduction is not great with normal air contents, particularly when cement content is maintained, and becomes important only with richer mixes. The advantages of air entrainment are most apparent in lean or otherwise harsh mixes where strengths may actually be increased. Most lightweight aggregate concretes will contain from 2 to 4 percent entrapped air, but this has negligible effect on workability and durability and additional entrained air is desirable. The durability of lightweight aggregate concretes has generally been considered to be very good even without air entrainment.[2,6] However, where air entrainment is required to provide protection against freezing and thawing, it is recommended that all lightweight aggregate concretes contain not less than 6 percent total (entrapped plus entrained) air. T. C. Powers[7] and others have shown that the spacing of the air bubbles is more important than the total quantity of air entrained. But since this factor cannot be readily determined in the field, adequate weathering protection can only be assured by the use of recognized air-entraining admixtures and by obtaining the recommended quantities of entrained air.

(*b*) There are several methods of determining the amount of entrained air. It is indicated by the difference in unit weights of similar concrete mixes with and without an air-entraining admixture and with the water adjusted to provide a given slump. It can be computed from these mixes since the difference in volumes of the two batches plus the volume difference in water requirement equals the volume of purposely entrained air. It can also be computed by use of the "specific gravity factor" which is discussed later in this report. The pressure type meter can be used if it is properly calibrated, although with many air-entrained lightweight concretes it must be used at reduced pressure. The volumetric method described in ASTM C 173-55T gives the most reliable results and this method is recommended. It has the advantage that the air content of both air-entrained and non-air-entrained concrete can be measured.

CHAPTER 3—ESTIMATING PROPORTIONS

301—Proportions of fine and coarse aggregate

(*a*) A good estimate of the proportions of fine and coarse aggregate may be obtained by the maximum density method. The proportions are adjusted to produce a maximum unit weight of the combined aggregate. Due to the difference in the specific gravities of the fine and coarse fractions the curve may not show a maximum at a point below 100 percent of the fine fraction; however, a rather sharp change in curvature will be observed. This change in curvature is indicative of the region of minimum void content, and can be verified by computation if values of the apparent specific gravities of the coarse and fine aggregate fractions are known. Results of such procedure are illustrated in Fig. 301(a).

(*b*) This procedure will generally indicate that, for ¾-in. maximum size aggregate, material passing the No. 4 sieve should be between 40 and 60 percent of the total aggregate, based on dry loose volume. As the maximum size of aggregate decreases the proportion of fine aggregate increases. With air entrainment and richer mixes a lower percentage of fines is normally used. The void content changes only slightly between limits of 40 and 60 percent. The amount of fine aggregate is generally kept as low as possible while still providing a margin of safety for good workability. However, some producers of lightweight aggregate concrete have found that maximum strengths are not obtained by using the largest quantity of coarse aggregate. The relatively weak physical structure of the large size aggregate reduces the concrete strength if an excessive amount of coarse aggregate is used.

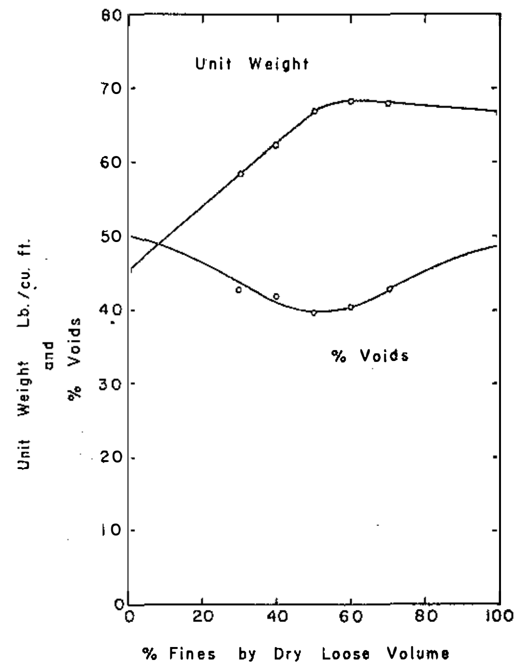

Fig. 301(a)

302—Estimate of cement and water requirements

(*a*) Some lightweight aggregates are rounded with relatively smooth surfaces, others are extremely angular with very rough surfaces. These characteristics account for the wide range in amount of net water required to produce a concrete of a given consistency with different *saturated* aggregates. The *net* water required to produce a 2-in. slump in non-air-entrained concrete averages about 390 lb per cu yd of concrete. However, amounts varying from 300 to 450 lb per cu yd are encountered with different aggregates. This wide range in water requirement is reflected in a corresponding range of cement contents to produce a given strength. The structural strength of different aggregates also has an important effect on the cement requirement, particularly for higher strength concretes.

(*b*) Producers of the various lightweight aggregates have devoted considerable time to studies of their particular aggregates. Their recommendations provide the best estimate of the required cement content and other mix proportions and should be given first consideration. Because of the wide range of cement contents required to produce concrete of the same compressive strength with the various lightweight aggregates, the subcom-

TABLE 302(b)—APPROXIMATE RELATIONSHIP BETWEEN STRENGTH AND CEMENT CONTENT

Compressive strength, psi	Cement content bags per cu yd*
2000	4 to 7
3000	5 to 8
4000	6 to 9
5000	7 to 10

*U. S. standard bag of cement weighing 94 lb. The Canadian standard bag of cement weighs 87.5 lb.

mittee was reluctant to provide any indication of the compressive strength to be associated with a certain cement factor. However, Table 302(b) provides this relationship within broad limits.

(*c*) These values are suggested only as a guide in proportioning the first trial mixes. A number of references to published data which might also be used as a guide are included at the end of this report. As with heavier concretes, the minimum amount of mixing water should be used that will allow the concrete to be adequately placed. The use of wetter mixes increases the opportunity for segregation and lowers the bond and compressive strengths and the resistance to weathering action. Under most conditions, slumps less than 4 in. will be satisfactory.

CHAPTER 4—TRIAL MIXES

(*a*) Due to the difficulties involved in the determination of a satisfactory value for specific gravity and absorption of the aggregate, a method of proportioning is suggested which does not require the use of these values. The first step in preparation for a trial mix is to determine the dry loose unit weights (ASTM C 330) and moisture contents of the fine and coarse aggregate fractions. Trial mixes are then made with at least three different cement contents. The first mix is made with estimated quantities of the various materials and the water is added to produce the required slump. The quantities for this first mix might be estimated in the following manner:

Assume that the mix is to contain 6 bags of cement per cu yd, and that the dry loose unit weights for the fine and coarse aggregates are 56 and 45 lb per cu ft, respectively. A slump of about 2 in. is required. About 32 cu ft of dry loose aggregate (sum of uncombined fine and coarse volumes) are required to produce a cubic yard of concrete. Most lightweight aggregates will require from 31 to 33 cu ft, but values as low as 28 cu ft may occur with particularly well graded and rounded aggregates. If the aggregate is produced in two sizes, fine and coarse, these are proportioned in equal volumes. Water is added to produce the required slump. A trial batch of approximately 1 cu ft would then require:

$$\text{Cement} \quad \frac{6 \times 94}{27} = 20.9 \text{ lb}$$

$$\text{Fine aggregate} \quad \frac{16 \times 56}{27} = 33.2 \text{ lb}$$

$$\text{Coarse aggregate} \quad \frac{16 \times 45}{27} = 26.7 \text{ lb}$$

$$\text{Water} \quad \frac{480}{27} \ \text{(includes water absorbed during mixing)} = 17.8 \text{ lb}$$

$$\text{Total weight} \quad 98.6 \text{ lb}$$

The wet unit weight is 97.0 lb per cu ft and the air content test indicates 2.5 percent entrapped air. The yield 98.6/97 = 1.016 cu ft. Quantities per cubic yard of concrete are obtained by multiplying the batch quantities by the ratio of cubic feet in a yard to cubic foot of batch 27/1.016 = 26.6.

Cement	556 lb per cu yd = 5.91 bags per cu yd
Fine aggregate	882 lb per cu yd
Coarse aggregate	710 lb per cu yd
Water	473 lb per cu yd

(*b*) Additional trial mixes could be made by estimating cement and aggregate quantities and establishing the yield, cement and water content, and other fundamental relationships. However, by the use of a "specific gravity factor"[11] for the aggregate, all other trial mixes with this aggregate can be proportioned with considerable confidence. The specific gravity factor is obtained in the following manner:

Solid volume of cement $\frac{556}{62.4 \times 3.15} = 2.83$ cu ft

Volume of water $\frac{473}{62.4} = 7.58$ cu ft

Volume of entrapped air 2.5 percent = 0.67 cu ft

11.08 cu ft

The aggregate then occupies 27 − 11.08 = 15.92 cu ft. The coarse and fine aggregate were used in equal parts by volume, so they each occupy 7.96 cu ft. This is not precisely correct, but the error becomes unimportant when the specific gravity factor method is used. The specific gravity factor expresses the relationship between the dry weight of the aggregate and the space it occupies, assuming that no water is absorbed during mixing.

Specific gravity factor, fine aggregate $\frac{882}{62.4 \times 7.96} = 1.78$

Specific gravity factor, coarse aggregate $\frac{710}{62.4 \times 7.96} = 1.43$

(*c*) This is only a *factor* and not a specific gravity value defined by ASTM because the method does not account for any water absorbed during mixing. However, in subsequent mixes with this aggregate in the same moisture condition, the volume of water absorbed during mixing is nearly constant. The specific gravity factor can then be used as though it were the apparent specific gravity and additional mixes can be proportioned by a procedure similar to the absolute volume method outlined in ACI 613-54.

(*d*) The first trial batch may appear harsh and need a higher percentage of fine materials. Additional trial mixes are made using less coarse aggregate until the desired workability is obtained. These and other mixes can be proportioned by the method outlined in the following example.

Assume the 5.91-bag trial batch is judged to have the desired workability and no further adjustments are required. We now want to proportion an 8-bag mix at the same consistency. *The quantity of coarse aggregate is maintained constant. The water requirement also is considered to remain constant.*

$$\text{Solid volume of cement} = \frac{752}{62.4 \times 3.15} = 3.83 \text{ cu ft}$$

$$\text{Volume of water} = \frac{473}{62.4} = 7.58 \text{ cu ft}$$

$$\text{Solid volume of coarse aggregate} = \frac{710}{62.4 \times 1.43} = 7.96 \text{ cu ft}$$

$$\text{Air} \quad 2.5 \text{ percent} = 0.67 \text{ cu ft}$$

$$\text{Total volume of ingredients except fine aggregate} = 20.04 \text{ cu ft}$$

$$\text{Volume of fine aggregate} = 27 - 20.04 = 6.96 \text{ cu ft}$$

$$\text{Weight of fine aggregate} = 6.96 \times 62.4 \times 1.78 = 773 \text{ lb}$$

A trial mix is made using these proportions although the quantity of water may require minor adjustment. The unit weight and air measurement are taken and the actual quantities of material per cubic yard are computed.

(*e*) Air-entrained concrete mixes are proportioned in the same manner. However, the water content is generally reduced 2 to 3 percent for each 1 percent of entrained air. For example, if we want to repeat the 5.91-bag mix but include 4 percent purposely entrained air:

$$\text{Solid volume of cement} = \frac{556}{62.4 \times 3.15} = 2.83 \text{ cu ft}$$

$$\text{Volume of water} = \frac{426}{62.4} = 6.83 \text{ cu ft}$$

$$\text{Solid volume of coarse aggregate} = \frac{710}{62.4 \times 1.43} = 7.96 \text{ cu ft}$$

$$\text{Volume of air (2.5 percent + 4 percent)} = 0.065 \times 27 = 1.76 \text{ cu ft}$$

$$19.38 \text{ cu ft}$$

$$\text{Volume of fine aggregate} = 27 - 19.38 = 7.62 \text{ cu ft}$$

$$\text{Weight of fine aggregate} = 7.62 \times 62.4 \times 1.78 = 846 \text{ lb}$$

(*f*) Additional trial mixes should be made which include at least three cement contents both with and without air entrainment. Graphs may be prepared relating the cement content and unit weight to the 28-day compressive strengths for use in proportioning mixes at other strength levels.

JOB CONTROL

(*a*) Job control of lightweight aggregate concrete is not within the scope of this subcommittee, but to make effective use of this proposed recommended practice the following fundamentals for lightweight concrete control are suggested.

(*b*) Job control is obtained by keeping constant the cement content, slump, and *volume of dry aggregate* per cubic yard of concrete regardless of variations in absorbed or surface moisture. If the density of the aggregate does not vary, constant *volume* can be maintained by keeping the *dry weight* of aggregate constant. *Unit weight* of the *fresh concrete* should be determined at *frequent* intervals. *A change in unit weight indicates a change in air content or change in weight of aggregate.* An air content determination will establish whether or not the correct amount of air is entrained. If the weight of aggregate has changed, it is due to a change in moisture, a change in gradation, or a change in density of the aggregate. Checks of moisture content, gradation, and unit weight can be easily made, and these will reveal the cause of the change. If the *moisture* content has changed, the aggregate weight is adjusted to keep the *weight of dry aggregate* constant. If the *density* of the aggregate has changed, the weight of dry aggregate is adjusted to keep the *volume of dry aggregate* constant.

(*c*) It must be remembered that the principle of the water-cement ratio law applies to lightweight aggregate concrete. When mixes are proportioned on a cement content basis, the compressive strength associated with a certain cement content is obtained only at a given consistency. If it is found necessary to increase the slump, the increase in water content should be accompanied by a proportionate increase in cement content.

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10. Shideler, J. J., "Lightweight-Aggregate Concrete for Structural Use," ACI JOURNAL, Oct. 1957, *Proc.* V. 54, pp. 299-328.

11. Nelson, G. H. and Frei, O. C. "Proportioning and Control of Lightweight Structural Concrete," ACI JOURNAL, Jan. 1958, *Proc.* V 54, pp. 605-622.

12. The following standards and tentatives of the American Society for Testing Materials are particularly applicable to structural lightweight concrete:

ASTM C 330 Tentative Specifications for Lightweight Aggregates for Structural Concrete

ASTM C 136 Method of Test for Sieve Analysis of Fine and Coarse Aggregates (limits in C 330)

ASTM C 29 Tentative Method of Test for Unit Weight of Aggregate (shoveling procedure)

ASTM C 173 Tentative Method of Test for Air Content of Freshly Mixed Concrete by the Volumetric Method

Discussion of this report should reach ACI headquarters in triplicate by Dec. 1, 1958, for publication in the March 1959 JOURNAL.