CRD-C 161-92

**Standard Practice for Selecting Proportions for Roller-Compacted
Concrete (RCC) Pavement Mixtures Using Soil Compaction Concepts**

## 1. Scope

1.1 This practice covers procedures for selecting proportions for roller-compacted concrete (RCC) pavement mixtures made with normal-weight aggregates and having a workability suitable for placement with asphalt paving machines having vibratory screeds.

1.2 The method provides a first approximation for air-entrained or nonair-entrained RCC pavement mixture proportions. These proportions should be checked by trial batches in the laboratory or field and adjusted, as necessary, to produce the desired RCC characteristics.

NOTE 1 - This practice is considered applicable to RCC containing 19.0-mm (3/4-in.) nominal maximum size aggregate (NMSA) or smaller.

## 2. Referenced Documents

2.1 Handbook Items:

CRD-C 4 Practice for Sampling Freshly Mixed Concrete (ASTM C 172)

CRD-C 10 Practice for Making and Curing Concrete Test Specimens in the Laboratory (ASTM C 192)

CRD-C 20 Test Method for Resistance of Concrete to Rapid Freezing and Thawing

CRD-C 41 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method (ASTM C 231)

CRD-C 106 Test Method for Unit Weight and Voids in Aggregate (ASTM C 29)

CRD-C 107 Test Method for Specific Gravity and Absorption of Coarse Aggregate (ASTM C 127)

CRD-C 108 Test Method for Specific Gravity and Absorption of Fine Aggregate (ASTM C 128)

CRD-C 160 Practice for Making Roller Compacted Concrete Specimens in Cylindrical Molds Using a Vibrating Table (ASTM C 1176)

CRD-C 162 Test Methods for Moisture-Density Relations of Soils and Soil Aggregate Mixtures Using 10-lb (4.54-kg) Rammer and 18-in. (457-mm) Drop (ASTM D 1557)

2.2 Other References.

Ragan, S. A., Pittman, D. W., and Grogan, W. P. 1990 (Sep). "An investigation of the Frost Resistance of Air-Entrained and Nonair-Entrained Roller-Compacted Concrete (RCC) Mixtures for Pavement Applications," Technical Report GL-90-18, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

## 3. Apparatus

3.1 *Molds.* The 6.0-in. (152.4-mm) molds shall be as described in CRD-C 160.

3.2 *Rammer.* The rammer shall be the manually operated rammer described in CRD-C 160.

3.3 *Sample Extruder* (optional). A jack, frame, or other device adapted for the purpose of extruding compacted specimens from the mold.

3.4 *Scales or Balances.* Scales and balances having capacities of 500 lb (227 kg), 20 kg, and 2 kg with an accuracy of 0.01 percent of the test load at any point within the range of use, and meeting the requirements for sensitivity and tolerances prescribed in CRD-C 10.

3.5 *Drying Apparatus.* A hot plate capable of heating to at least $230 \pm 9$ °F ($110 \pm 5$ °C), a drying pan, and a spatula; or a suitable microwave oven with oven glass containers. A suitable microwave oven is one capable of drying 1500 g samples of RCC to constant mass in a time period of not more than 48 min. Constant mass is achieved when the mass of a sample does not change by more than 0.1 percent of the original mass on successive determinations of mass.

3.6 *Straightedge.* A stiff metal straight edge as described in CRD-C 160.

3.7 *Mixer.* A power-driven revolving pan or revolving paddle mixer capable of thoroughly mixing batches of RCC of the prescribed size. A revolving drum mixer is not suitable for mixing concrete having a very dry consistency such as RCC.

## 4. Introduction

4.1 The proper selection of mixture proportions is an important step in obtaining an economical, durable

RCC pavement. RCC pavement mixture proportions, like those of conventional concrete pavement mixtures, depend largely upon the placeability, compactibility, strength, and durability requirements of the pavement.

4.2 Conventional concrete cannot generally be re-proportioned for use as RCC by any single action such as altering the proportions of mortar and coarse aggregate, reducing the water content, or changing the water-cement ratio (w/c). Differences in conventional concrete and RCC pavement mixture proportioning methods are essentially due to the relatively stiff consistency of fresh RCC.

## 5. Basic Considerations

5.1 *Durability.* The frost resistance of nonair-entrained RCC that is exposed to cycles of freezing and thawing while critically saturated with water is usually poor when tested in accordance with ASTM C 666. However, the service record of nonair-entrained RCC when used in freezing and thawing situations and in extremely cold situations has usually been good. Research indicates that air-entrained RCC pavement mixtures can be successfully produced in the laboratory; however, field production and placement have only been tried on a very limited basis. None of the ASTM standard methods has proven satisfactory for determining the air content of fresh RCC. The pressure method described in CRD-C 41 has been used, however the RCC sample cannot be consolidated into the measuring bowl by rodding or internal vibration. Application of a surcharge to the sample top surface along with external vibration has been successfully used to properly consolidate the RCC samples. The US Army Engineer Waterways Experiment Station (WES) conducted research on air-entrained RCC and used a 52.5-lb (23.8-kg) surcharge, and a vibrating table having a frequency of approximately 3.600 vibrations per minute (60 Hz) and amplitude of approximately 0.0170 in. (0.43 mm) to effectively consolidate air content test samples in two layers. Each layer was vibrated until a ring of mortar was formed around the complete periphery of the measuring bowl. This research was reported by Ragan et al in the report listed in 2.2. If air-entrained RCC is specified. extensive laboratory and field testing should be planned to determine the effectiveness and proper dosage rates of selected air-entraining admixtures, the specific effects of air on RCC workability and mixing water demand, the effects of RCC handling and compaction operations on parameters of the air-void system.

and the extent of testing needed to ensure the required RCC quality is achieved.

5.2 *Strength.* As with conventional concrete, the strength of RCC is largely dependent on the w/c. For a given cementitious materials content, the strength of RCC at a given age will be a maximum when the minimum paste volume required to till the aggregate voids is used. Strength will be reduced if the paste volume is not sufficient to till the space among the aggregate particles or if the water content of the mixture is increased to a point which creates excess paste and a higher w/c. Differences in strength for a given w/c may result from changes in aggregate characteristics, cement types and sources, and air content. CRD-C 160 describes a procedure for molding cylinders. No procedure has been standardized for fabricating RCC beam test specimens, such as those used to determine concrete flexural strength. However, some success has been achieved by tilling beam molds in layers and consolidating each layer of RCC using external vibration in conjunction with a surcharge. One procedure successfully used by WES involved molding 6- by 6- by 20-in. (152- by 152- by 508-mm) flexural strength beams in two layers by vibrating each layer on a vibrating table under a surcharge of 125 lb as reported by Ragan et al (1990). The surcharge was uniformly distributed over the entire specimen area during molding, and vibration continued until a ring of mortar formed around the complete periphery of the mold. A different procedure successfully used by the North Pacific Division of the CE involves tamping the RCC in the beam mold. Unless previous data are available showing the relationship between w/c or equivalent cement content and flexural strength. the approximate w/c or equivalent cement content for various flexural strengths of beams having cross sectional dimensions of 6 by 6 in. (152 by 152 mm) can be estimated using the information in Table 1. The equivalent cement content is that mass of portland cement having an absolute volume equivalent to that of cementitious materials to be used in the mixture. For most pavements the equivalent cement content will range between 10 and 17 percent, by mass of dry aggregate. The values in Table 1 represent data from a variety of RCC pavement mixtures which primarily contained 19.0-mm (3/4-in.) NMSA and 20 to 30 percent Class F fly ash by absolute volume of cementitious material. Values estimated from the table should be verified by trial batches to ensure that the required average flexural strength is achieved.

**Table 1.  Approximate Relationships Between W/C or Equivalent Cement Contents and 28-Day Flexural Strength of RCC Pavement Mixtures**

| Specified Flexural Strength psi (MPa) | Nonair-entrained RCC | | Air-entrained RCC | |
|---|---|---|---|---|
| | w/c | Equivalent Cement Content, percent | w/c | Equivalent Cement Content, percent |
| 600 (4.1) | 0.57 | 10 | 0.50 | 11 |
| 700 (4.8) | 0.51 | 13 | 0.44 | 14 |
| 800 (5.5) | 0.46 | 16 | 0.38 | 17 |

5.3 *Workability.* The workability of RCC is that property which determines its capacity to be placed and compacted successfully without harmful segregation. It embodies the concepts of compactibility and to some degree moldability and cohesiveness. It is affected by the same factors that affect the workability of conventional concrete. i.e., the grading, particle shape, and proportion of the aggregate; the cementitious material content of the mixture; the presence of chemical and mineral admixtures in the mixture; and the water content of the mixture. However, the magnitude of the effect of each factor will not necessarily be the same for RCC as for conventional concrete. The consistency of RCC cannot be measured or judged in the same way that the consistency of conventional concrete is indexed to the slump test. The slump test is not meaningful for RCC since it has no slump. Preliminary judgment of the workability, placeability, and compactibility of RCC pavement mixtures should be made during mixture proportioning studies by determining the optimum moisture content using soil compaction concepts. The soil compaction procedures described in 7.1 through 7.6 should be used to determine the optimum moisture content of an RCC mixture. Experience with RCC pavement mixtures placed in the field indicates that the actual RCC water content used may need to be slightly greater than that which is calculated using the optimum moisture content determined for the mixture. This is probably due to the loss of water from the mixture due to evaporation during the transporting and placing operations or to different compaction in the field. The degree to which the water content of the mixture should be increased will vary depending on ambient conditions. however it is typically equivalent to a moisture content increase of 0.1 to 0.5 percent above optimum. Pavement test sections under project conditions should be constructed so that mixture proportions can be adjusted as necessary to achieve the required workability.

5.4 *Aggregates.* Fine and coarse aggregate should be proportioned to create a well-graded combined aggregate. Recommended combined grading limits are given in Table 2. The addition of material finer than the 75-μm (No. 200) sieve may be necessary to supplement fine aggregate in order to reduce the volume of voids within the fine aggregate and to produce a more cohesive mixture. This supplemental fine material may consist of fly ash, natural pozzolan, ground granulated blast-furnace slag (GGBF slag), or natural fine sand. The use of fly ash, natural pozzolan, or GGBF slag as supplemental fine material may provide added benefits as a result of reduced overall water demand, lower water to cementitious material ratio, and higher ultimate strength. RCC containing minimally processed pit- or quarry-run aggregate may require a greater water content, be less durable, have a lower flexural strength, and experience less bond between lifts than RCC containing properly processed aggregate.

**Table 2. Recommended Combined Aggregate Grading Limits**

| Sieve Size | Cumulative Percent Passing |
|---|---|
| 19.0-mm (3/4-in.) | 83-100 |
| 12.5-mm (1/2-in.) | 72-93 |
| 9.5-mm (3/8-in.) | 66-85 |
| 4.75-mm (No. 4) | 51-69 |
| 2.36-mm (No. 8) | 38-56 |
| 1.18-mm (No. 16) | 28-46 |
| 600-μm (No. 30) | 18-36 |
| 300-μm (No. 50) | 11-27 |
| 150-μm (No. 100) | 6-18 |
| 75-μm (No. 200) | 2-8 |

5.5 *Water Content.* The optimum moisture content of an RCC mixture is defined as the peak of the moisture content-wet density curve, and for a given compactive effort is dependent on the aggregate properties and the cementitious materials content. It is also dependent on the use of air-entraining admixture (AEA) and other chemical admixtures if used. The use of an AEA may reduce the optimum moisture content of a mixture by as much as 0.5 percent depending on the AEA type and dosage, and the aggregate and cementitious material properties and proportions. Moisture content - wet density relationships should be established over a range of cementitious material contents in order to determine the minimum cementitious material content, or maximum w/c, which will produce RCC of the required average strength and durability.

5.6 *Air Content.* Laboratory research indicates that air-entrained RCC pavement mixtures having a 19.0-mm (3/4-in.) NMSA have a satisfactory air-void system to be frost resistant when their air contents range from 4.0 to 6.0 percent. However, the AEA dosage required to achieve this range of air contents will typically be five to ten times greater than that required for conventional concrete, depending on the type AEA used.

5.7 *Cementitious Material Content.* The cementitious material content of an RCC pavement mixture is determined by the w/c needed to satisfy strength and durability requirements. It is usually expressed as a percentage of the dry mass of aggregate and typically ranges from 10 to 17 percent. This range corresponds to approximately 350 to 600 lb per yd$^3$ (208 to 356 kg per m$^3$) of cementitious material, of which typically 25 to 40 percent will be fly ash or GGBF slag.

**6. Background Data**

6.1 An RCC pavement mixture must be stable enough to support the weight of a vibratory roller immediately after laydown without shoving or rutting. Yet, it must also be workable enough to allow some aggregate reorientation and paste migration during the compaction operations so that voids between aggregate particles become essentially filled with paste. Selection of RCC pavement mixture proportions should be based on test data or experience with the materials actually to be used. Where such data or experience are limited or not available, estimates given in this practice may be used. Trial batches and, where required, test sections should be made.

6.2 The following information for the available materials will be useful in arriving at the preliminary mixture proportions.

6.2.1 Sieve analysis of fine and coarse aggregates

6.2.2 Bulk specific gravities and absorptions of aggregates

6.2.3 Estimated mixing water requirements of RCC developed from experience with available aggregates

6.2.4 Approximate relationships between strength and w/c, or strength and equivalent cement contents, for available combinations of cements, pozzolans if considered, and aggregates

6.2.5 Specific gravities (densities) of portland cement, other cements, and pozzolans if used

**7. Procedure**

7.1 Estimating the proportions for RCC pavement mixtures involves a sequence of logical, straightforward steps which, in effect, fit the characteristics of the available materials into a mixture suitable for the work. Some or all of the following may be stipulated for proportioning the mixture:

7.1.1 Maximum w/c

7.1.2 Minimum cement content

7.1.3 Range of pozzolan contents, expressed as a percentage by absolute volume of cementitious materials used in the mixture

7.1.4 Air content

7.1.5  NMSA

7.1.6  Flexural strength

7.2 *Step 1*. Determine the proportion of fine and coarse aggregate which will result in a combined aggregate grading as close to the median of the combined aggregate grading limits given in Table 2 as possible. If finer aggregate sizes are not available, pozzolan, GGBF slag, or other nondeleterious fines supplied may be used to supplement the fine aggregate.

7.3   *Step 2*. Using past experience or information in Table 1, select an initial equivalent cement content based upon the desired flexural strength.

7.4 *Step 3*.

7.4.1 Determine the optimum moisture content according to ASTM D 1557.

7.4.2 Using the aggregate proportions determined in Step 1, add approximately 20 lb (9 kg) of combined aggregate and the appropriate mass of cementitious material, based upon the cementitious material content selected in Step 2, to the mixing bowl or pan of a small mechanical mixer. Vigorous mixing of the materials is essential to produce uniform RCC for the compaction and moisture content test specimens. This is particularly important if the RCC is to be air entrained. Prepare a series of at least four specimens by increasing amounts of water to each sample so that moisture contents vary by approximately 0.5 percent. If the mixture is to be air entrained, the AEA should be first added to the water, and then the water/AEA mixture added to the dry materials. The moisture contents selected should bracket the anticipated optimum moisture content, thus providing specimens that, when compacted will decrease in void content to the maximum density and then decrease in density. The optimum moisture content for most RCC pavement mixtures will be within a range of 4.5 to 6.5 percent, by dry mass of RCC. Thoroughly mix the materials to ensure uniform distribution of all ingredients,  moisture, and entrained air bubbles throughout.

7.4.3   Attach the mold extension collar to the mold, and compact each specimen in five layers of approximately equal height. Each layer should receive 56 blows from the rammer. The total amount of material used should be such that the fifth compacted layer is slightly above the top of the mold, but not exceeding 1/4 in. (6 mm). During compaction the mold should rest on a uniform rigid foundation, such as provided by

a cylinder or cube of concrete having a mass of not less than 200 lb (90 kg). In operating the rammer, care should be taken to avoid rebound of the rammer from the top end of the guidesleeve. The guidesleeve should be held steady and within 5 deg of the vertical. The blow should be applied at a uniform rate not exceeding approximately 1.4 sec per blow and in such a manner as to provide complete and uniform coverage of the specimen surface. Following compaction, remove the extension collar; carefully screed the compacted specimen even with the top of the mold by means of a straightedge and determine the mass of the specimen. Divide the mass of the compacted specimen and mold, minus the mass of the mold, by the volume of the mold. Record the result as the wet density,    $\gamma_{m}$,  , in lb/ft$^3$ (kg/m$^3$). of the compacted specimen. Remove the material from the mold and slice vertically through the center. Take a representative sample of the material, weighing not less than 1500 g, from the full height of one of the cut faces, weigh immediately, and dry until constant mass is achieved. Calculate the moisture content as follows:

$$w = [(A-B)/(B-C)] \times 100$$

where:

w = percentage of moisture in the specimen

A = mass of moisture tare and wet RCC

B = mass of moisture tare and dry RCC

C = mass of moisture tare

Repeat the procedure in step 4 for each specimen prepared.

7.5   *Step 4*. From the data obtained in Step 3, plot the wet density ($\gamma_{m}$) values as ordinates with corresponding moisture contents as abscissas.   Draw a smooth curve connecting the plotted points. The moisture content corresponding to the peak of the curve is termed the optimum moisture content, and the wet density of the RCC mixture at optimum moisture content is termed maximum wet density under the compaction prescribed in this practice.

7.6 *Step 5*. Following determination of the optimum moisture content, the saturated surface-dry (SSD) batch weights of materials for 1 yd$^3$ (or 1 m$^3$) of RCC are calculated. The masses of materials used in preparing compaction and moisture content specimens, along with the moisture content corresponding to approximately 0.1 to 0.5 percent above the optimum serve as the basis for the 1 yd$^3$ or 1 m$^3$ SSD batch weights. The

aggregate masses are converted to SSD masses as follows:

If aggregates are wetter than SSD,
SSD mass, lb (kg) = [mass, lb (kg)] / [(100 - (moisture content - absorption)) / 100]

If aggregates are drier than SSD,
SSD mass, lb (kg) = [mass, lb (kg)] / [(100 + (moisture content - absorption))/100]

NOTE 2 - When using aggregates with low absorptions in oven-dry condition the amount of water that will be absorbed by the aggregates before the concrete sets may be assumed to be 80% of the 24-hr absorption of the aggregates determined by CRD-C 107 or 108.

The water content is then reduced or increased by an amount equal to the total increase or reduction in aggregate mass in order to compensate for the difference in the actual aggregate moisture condition and the SSD condition. The absolute volume of each material is determined as follows:

$$A_b = SSD\ mass,\ lb/(G_{SSD} \times 62.4\ lb/ft^3)$$

$$(A_b = SSD\ mass,\ kg/(G_{SSD} \times 1,000\ kg/m^3))$$

where:

$A_b$ = absolute volume of each material which would be used in an RCC batch for moisture and compaction test, $ft^3 (m^3)$

$G_{SSD}$ = bulk specific gravity, saturated surface-dry basis.

The absolute volume of each material, SSD basis, to be used in 1 yd³ (or 1 m³) of RCC is then calculated as follows:

$$A_{cy} = [(27.000\ cu\ ft/\ \Sigma\ A_b) \times A_b]$$

$$(A_{cy} = [(m^3/\ \Sigma\ A_b) \times A_b])$$

where:

$A_{cy}$ = absolute volume of each material, SSD basis, to be used in one yd³ of RCC, $ft^3$ (or $1\ m^3$, $m^3$)

The SSD mass of each material to be used in one yd³ (or one m³) is calculated as follows:

$$W_{cy} = A_{cy} \times (G_{SSD} \times 62.4\ lb/cu\ ft)$$

$$W_{cy} = A_{cy} \times (G_{SSD} \times 1,000\ kg/m^3))$$

where:

$W_{cy}$ = mass of each material, SSD basis, to be used in 1 yd³ of RCC, lb (or 1 m³, kg)

7.7 *Step 6.* The procedures described in 7.3 through 7.5 should be repeated for cementitious material contents approximately 2 percent above and below that initially selected.

7.8 *Step 7.* The proportions for each mixture should be checked by means of trial batches. Test specimens should be prepared in accordance with CRD-C 10, except that a revolving drum mixer should not be used. Thorough mixing, such as that achieved in a revolving pan or revolving-paddle mixer, is needed for RCC pavement mixtures. This is even more critical if the mixture is to be air entrained. The concrete produced in each trial batch should be checked for wet density and moisture content as described in Step 3. If the RCC is air entrained it should be tested for air content in accordance with CRD-C 41, except that the sample should be molded as described in 5.1. If the desired air content was not achieved, the AEA dosage should be reestimated. The optimum moisture content at the new AEA dosage should be determined and the mixture proportions adjusted as necessary before a subsequent trial batch is produced. Whether the procedures described in 5.2 are used to mold flexural test specimens, or others are followed, they should be consistent throughout any given mixture proportioning study and should be well documented.

## 8. Sample Computations

8.1    The following example problem will be used to illustrate application of the proportioning procedures. The following conditions are assumed:

8.1.1    Type I portland cement having a density of 3.15 Mg/m³ will be used.

8.1.2 Coarse and tine aggregates are of satisfactory quality and are capable of being proportioned such that the combined grading is approximately at the median of the limits given in Table 2 .

8.1.3    The coarse aggregate has a bulk specific gravity, SSD basis, of 2.72 and an absorption of 0.5 percent.

8.1.4 The tine aggregate has a bulk specific gravity, SSD basis, of 2.62 and an absorption of 0.8 percent.

8.1.5 Twenty-five percent of the total cementitious material will consist of Class F fly ash having a specific gravity of 2.45.

8.1.6 A commercially available AEA which has been demonstrated effective for entraining air in RCC will be used. Based upon past experience a dosage rate of 6.0 fl oz/cwt (3.9 mL/Kg) will be used.

8.2 *Example.* An RCC pavement is required for a large storage terminal located in a severe freezing and thawing environment. The specified flexural strength is 650 psi (4.5 MPa) at 28-days age, and the specified air content is 5.0 ± 1.0 percent. Local aggregate sources are capable of producing ample supplies of coarse and fine aggregate which, when properly proportioned, will result in a well-graded blend. A 19.0-mm (3/4-in.) NMSA is selected for use based upon past experience with the type of modified asphalt paving equipment which is anticipated for use. Using the sequence of steps outlined in 7.2 through 7.9, the SSD batch weights per cubic yard of RCC are calculated as follows.

8.3 *Step 1.* Aggregates for the project are supplied in two size groups: 4.75 to 19.0 mm (No. 4 to 3/4 in.) and 75μm to 4.75 mm (No. 200 to No. 4). The results of sieve analysis tests indicate that if 46 percent of the coarse aggregate is combined with 54 percent of the fine aggregate, combined aggregate is produced having a grading near the median of the limits of Table 2. Four 20.0-lb (9.07-kg) batches of the combined oven-dried aggregates, each containing 10.8 lb (4.90 kg) of coarse aggregate and 9.2 lb (4.17 kg) of fine aggregate are produced in preparation for the production of compaction and moisture content test specimens.

8.4 *Step 2.* An equivalent cement content of 13 percent, by dry weight of aggregate, is initially selected for use. A fly ash content of 25 percent, by absolute volume of cementitious materials, is also selected. Therefore, the absolute volume of cementitious material to be added to the 20.0 lb (9.07 kg) of dry combined aggregates is:

$$V_{cm} = (20.0 \ lb \ \times \ 0.13)/(3.15 \ Mg/m^3 \times 62.4 \ lb/ft^3) =$$
$$2.40 \ lb/196.56 \ lb/ft^3 = 0.0132 \ ft^3$$

$$(V_{cm} = (9.07 \ kg \ \times \ 0.13)/(3.15 \ \times \ 1,000 \ kg/m^3) =$$
$$1.17 \ kg/3,150 \ kg/m^3 = 0.00037 \ m^3)$$

The mass of cement to be added is:

$$W_c = (0.0132 \ ft^3 \times 0.75) \ \times \ 196.56 \ lb/ft^3 = 1.95 \ lb$$
$$(W_c = (0.00037 \ m^3 \times 0.75) \ \times \ 3,150 \ kg/m^3 = 0.884 \ kg)$$

And the mass of fly ash to be added is:

$$W_{fa} = (0.0132 \ \times \ 0.25) \ \times \ (2.45 \ \times \ 62.4 \ lb/ft^3) = 0.50 \ lb$$
$$(W_{fa} = (0.00037 \ \times \ 0.25) \ \times \ (2.45 \ \times \ 1,000 \ kg/m^3) = 0.227 \ kg)$$

8.5 *Steps 3, 4, and 5.* Compaction and moisture content tests are conducted on samples taken from the four RCC batches following procedures described in 7.4 through 7.6. The initial batch is proportioned to have a moisture content of 5.0 percent. The moisture content of each subsequent batch is increased by 0.5 percent. The moisture content-wet density curve shown in Figure 1, indicates that the optimum moisture content is 5.8 percent and the maximum wet density is 147.5 lb/ft³ (2,363 kg/m³). An RCC moisture content of 6.0 percent will be used as the basis for determining the water content of the first mixture from which flexural strength specimens are molded.

8.6 *Step 6.* The SSD weights for a batch of RCC having a moisture content of 6.0 percent and of a size comparable to those used for the compaction and moisture content test specimens are as follows:

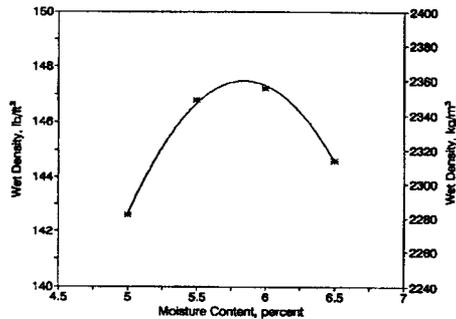cement = 1.95 lb (0.884 kg)

fly ash = 0.50 lb (0.227 kg)



Figure 1. Relationship between RCC moisture content and wet density

fine aggregate = 9.20 lb x [(100 + (0.8 x 0.8))/100] = 9.26 lb

(fine aggregate = 4.17 kg x [(100 + (0.8 x 0.8))/100] = 4.197 kg)

coarse aggregate = 10.80 lb x [(100 + (0.8 x 0.5))/100] = 10.84 lb

(coarse aggregate = 4.90 kg x [(100 + (0.8 x 0.5))/100] = 4.919 kg)

water + AEA = [(1.95 + 0.50 + 9.20 + 10.80) x 0.06] - (9.26 - 9.20) - (10.84 - 10.80) = 1.25 lb

(water + AEA = [(0.884 + 0.227 + 4.170 + 4.900) x 0.06] - (4.197 - 4.170) - (4.919 - 4.900) = 0.565 kg)

The quantity of AEA to be used is

[(1.95 *lb* + 0.50 lb)/100 *lb]* x 6.0 *fl oz/cwt* = 0.147 *oz* ((0.884 *kg* + 0.227 *kg)* x 3.9 *mL/kg* = 4.3 *mL)*

The absolute volume of each material in this batch is:

cement = 1.95 lb / (196.56 lb/ft$^3$) = 0.0099 ft$^3$

(cement = 0.884 kg / (3,150 kg/m$^3$) = 0.00028 m$^3$)

fly ash = 0.50 lb / (2.45 x 62.4 lb/ft$^3$) = 0.0033 ft$^3$

(fly ash = 0.227 kg/(2.45 x 1,000 kg/m$^3$) = 0.00009 m$^3$)

fine aggregate = 9.26 lb / (2.62 x 62.4 lb/ft$^3$) = 0.0566 ft$^3$

(fine aggregate = 4.197 kg / (2.62 x 1,000 kg/m$^3$) = 0.00160 m$^3$)

coarse aggregate = 10.84 / (2.72 x 62.4 lb/ft$^3$) = 0.0639 ft$^3$

(coarse aggregate = 4.919 kg / (2.72 x 1,000 kg/m$^3$) = 0.00181 m$^3$)

water + AEA = 1.25 lb / (62.4 lb/ft$^3$) = 0.0200 ft$^3$

(water + AEA = 0.565 kg / (1,000 kg/m$^3$ = 0.00057 m$^3$))

total air-free batch volume = 0.1538 ft$^3$ (0.00435 m$^3$)

total batch volume = 0.1538 ft$^3$/ 0.95 = 0.1619 ft$^3$

(total batch volume = 0.00435 m$^3$/0.95 = 0.00458 m$^3$)

The absolute volume of each material, SSD basis, to be used in one yd$^3$ (or one m$^3$) of RCC is:

cement = (27 ft$^3$/0.1619 ft$^3$) x 0.0099 ft$^3$ = 1.651 ft$^3$

(cement = (1 m$^3$/0.00458 m$^3$) x 0.00028 m$^3$ = 0.0611 m$^3$)

fly ash = (27 ft$^3$/0.1619 ft$^3$) x 0.0033 ft$^3$ = 0.550 ft$^3$

(fly ash = (1 m$^3$/0.00458 m$^3$) x 0.00009 m$^3$ = 0.0197 m$^3$)

fine aggregate = (27 ft$^3$/0.1619 ft$^3$) x 0.0566 ft$^3$ = 9.456 ft$^3$

(fine aggregate = (1 m$^3$/0.00458 m$^3$) x 0.00160 m$^3$ = 0.3494 m$^3$)

coarse aggregate = (27 ft$^3$/0.1619 ft$^3$) x 0.0639 ft$^3$ = 10.657 ft$^3$

(coarse aggregate = (1 m$^3$/0.00458 m$^3$) x 0.00181 m$^3$ = 0.3953 m$^3$)

water + AEA = (27 ft$^3$/0.1619 ft$^3$) x 0.0200 ft$^3$ = 3.336 ft$^3$

(water + AEA = (1 m$^3$/0.00458 m$^3$) x 0.00057 m$^3$ = 0.1245 m$^3$)

air = 27 ft$^3$ x 0.05 = 1.350 ft$^3$

(air = 1 m$^3$ x 0.05 = 0.0500 m$^3$)

The SSD weight of each material to be used in one yd$^3$ (or one m$^3$) of RCC is:

cement = 1.651 ft$^3$ x (3.15 x 62.4 lb/ft$^3$) = 324.5 lb

(cement = 0.0611 m$^3$ x (3.15 x 1,000 kg/m$^3$) = 192.5 kg)

fly ash = 0.550 ft$^3$ x (2.45 x 62.4 lb/ft$^3$) = 84.1 lb

(fly ash = 0.0197 m$^3$ x (2.45 x 1,000 kg/m$^3$) = 48.3 kg)

fine aggregate = 9.456 ft$^3$ x (2.62 x 62.4 lb/ft$^3$) = 1,545.9 lb

(fine aggregate = 0.3494 m$^3$ x (2.62 x 1,000 kg/m$^3$) = 915.4 kg)

coarse aggregate = 10.657 ft$^3$ x (2.72 x 62.4 lb/ft$^3$) = 1,808.9 lb

(coarse aggregate = 0.3953 m$^3$x (2.72 x 1,000 kg/m$^3$)
= 1,075.2 kg)

water + AEA = 3.336 ft$^3$x 62.4 lb/ft$^3$= 208.2 lb

(water + AEA = 0.1245 m$^3$x 1.000 kg/m$^3$= 124.5 kg)

AEA = (324.5 lb + 84.1 lb/100 lb) x 6.0 fl oz/cwt =
24.5 fl oz

(AEA = (192.5 kg + 48.3 kg) x 3.9 mL/kg = 939 mL)

water = 208.2 lb - (24.5 fl oz/16 fl oz/lb*) = 206.7 lb

(water = 124.5 kg - (939 mL/1,000 mL/kg*) =
123.6  kg)

8.7 *Step 7.* Steps 2 through 6 are repeated for equivalent cement contents of 11 and 15 percent.

8.8 *Step 8.* The batch masses for each of the three mixtures are scaled down to produce trial batches having volumes of approximately 3 ft$^3$(0.08 m$^3$). After each trial batch is produced a sample is taken and tested for air content. The air content of each batch is within the specification limits and therefore beams are molded for testing at both 7- and 28-days age.

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*       approximate  conversion