Chapter 3
Mixture Proportioning

3-1. General

The proper selection of mass or structural RCC mixture proportions is an important step in obtaining an economical, durable concrete and should be accomplished in the laboratory under the direction of a materials engineer with previous RCC mixture proportioning and project experience. RCC mixture proportions depend largely upon the strength and durability requirements of the structure. However, RCC proportions may also be greatly influenced by project-specific requirements such as material availability, hauling and conveying methods, spreading and compaction equipment, etc. The RCC mixture proportioning procedure that is presented in paragraph 3-3 of this chapter is one of several methods that have been used successfully covering a broad range of mixtures and performance requirements.

3-2. Basic Considerations

a. Durability. RCC durability is dependent on strength, cementitious material content, aggregate quality, and percent compaction. With hard, dense aggregates and an appropriately selected type and quantity of cementitious material, RCC exhibits excellent resistance to abrasion and erosion, alkali-aggregate reactivity, and sulfate attack. However, the resistance of RCC to the effects of aggressive waters, chemicals, gases, or simple leaching of soluble constituents by water is primarily a function of the permeability of the concrete, and, since lean mass RCC mixtures are designed with low cementitious contents, they are relatively permeable. For lean interior mass mixes, durability protection is often enhanced by the use of exterior zone mixes with higher cementitious contents, incorporation of conventional concrete facings, use of impermeable membranes, and sometimes oversized sections allowing for some deterioration. The frost resistance of non-air-entrained RCC is poor when exposed to freezing and thawing while critically saturated. However, when RCC is not critically saturated, it is relatively frost resistant, even in areas of severe climate. In laboratory applications, significant improvement in resistance to freezing and thawing of RCC has been realized by use of certain air-entraining admixtures. However, consistent production of air-entrained RCC in actual production conditions has been less reliable. If air entrainment is specified for the RCC, laboratory and field testing should be performed using project materials to determine: (1) the effectiveness and proper dosage rates of the selected air-entraining admixtures, (2) the effects of air on RCC workability and water demand, (3) the effects of RCC handling and compaction operations on the air-void system parameters, and (4) the effects of aggregate and cementitious material fines on entrained air content. The pressure method described in ASTM C 231 is typically used to measure the air content of RCC. Since the RCC cannot be consolidated by rodding or internal vibration, it is consolidated in the air meter bowl by external vibration (using the Vebe table) or tamping (using a pneumatic tamper, electric hammer, etc.). The top surface of the consolidated or compacted RCC can be struck off while the specimen is still on the Vebe table using a steel plate, or it can be leveled off using a plywood plate and tamping. After the RCC is consolidated or compacted and struck off flush with the top of the air meter bowl, the unit weight and air content of the sample may be determined following the procedures of ASTM C 138 and C 231. The unit weight of mixtures containing NMSA greater than 37.5 mm will require a larger unit weight measure, and electric or pneumatic tamping may be the only means to effectively consolidate the RCC.

b. Strength. As with the design of conventional concrete structures, the required RCC strength is determined by the design of the structure. RCC is different than conventional concrete in that material properties are affected by the workability level of the mixture, the fines content, and the moisture content relative to the optimum moisture content. Consequently, it is extremely difficult to state general relationships. In most situations, for any given combination of concreting materials, strength is largely dependent on cement content. The moisture content of the mixture is a function of the aggregate and the desired RCC workability level. The necessary proportions of materials, including cement and pozzolan, must be determined by laboratory evaluation. Figures 3-1 and 3-2 and Table 3-3 provide a starting point for establishing cement contents and water contents, respectively. The effect of pozzolan on RCC strength development cannot be assumed; it must be determined in the laboratory. Figures 3-1 and 3-2 provide relationships between cement content and compressive strength for various equivalent cement contents with and without pozzolan. These curves represent average data from a variety of RCC mixtures ranging from 19.0- to 75-mm (3/4 to 3 in.) NMSA and batched with and without Class F fly ash. Values estimated from the curves should be verified by trial batches to ensure that the required average compressive strength (f_{cr}) is achieved.

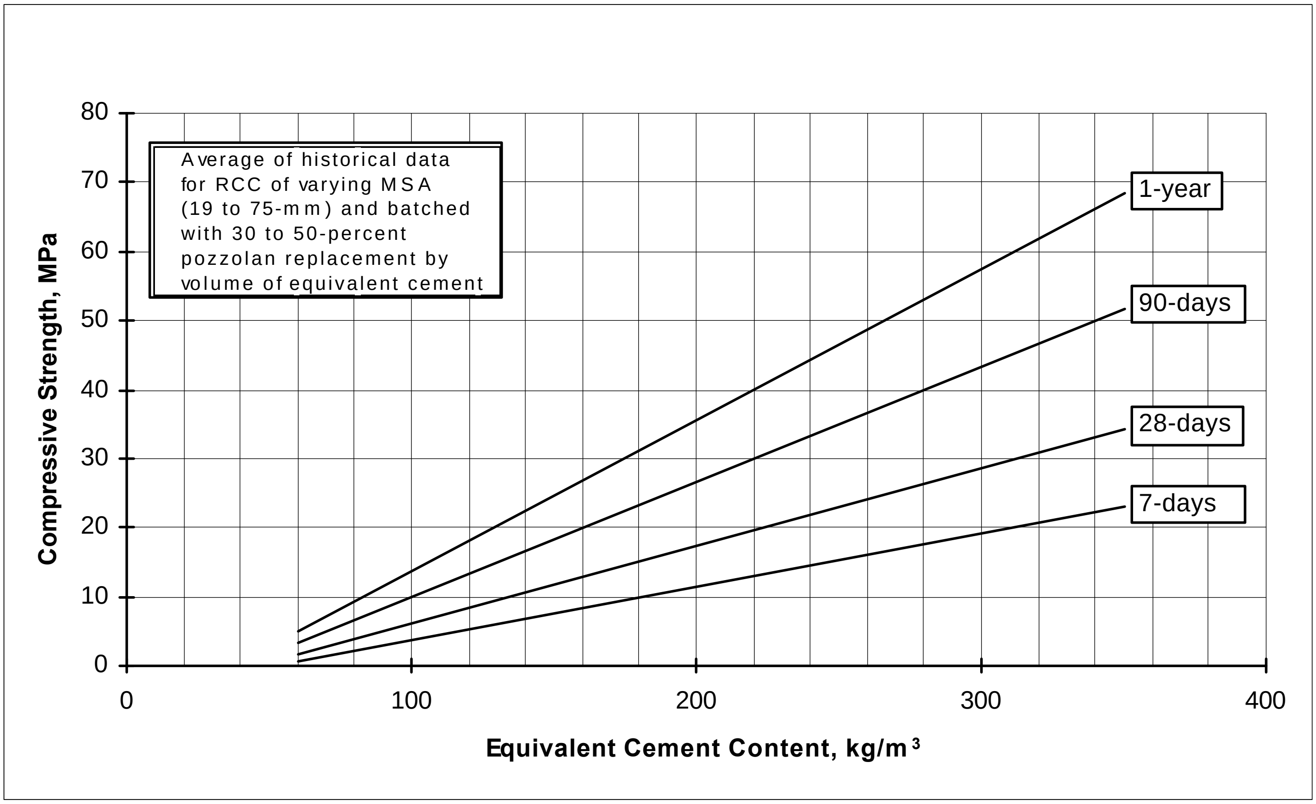

Figure 3-1. Equivalent cement content versus compressive strength; average historical data for RCC batched with pozzolan

(1) Calculating equivalent cement contents. The calculation of equivalent cement contents used in this manual is based on the absolute volume equivalency computation method commonly used throughout the Corps of Engineers. Using the volume equivalency method, the equivalent cement content is calculated using the equivalent mass of cement that would occupy the same volume as the cement and pozzolan combined. Many commercial laboratories calculate this in a slightly different manner using a mass equivalency method as described in ACI 211. The materials engineer should be aware that the different methods used for computing cement equivalency will result in slightly different values.

(2) Compaction. CRD-C 10 (ASTM C 192) describes a procedure for molding cylinders by using external vibration and surface surcharge for concretes that have low water contents. For RCC mixtures designed at a Vebe consistency of less than 30 sec, the RCC can be easily consolidated on the Vebe table using plastic cylinder molds and a surcharge as described in CRD-C 10. For RCC mixtures designed at Vebe consistencies greater than approximately 30 sec, tamping procedures are required to fabricate specimens. Tamping can be performed using pneumatic pole tampers or electric tamping hammers, and either steel molds or plastic molds with steel sleeves that can resist pressures exerted by the tamping equipment can be used for fabrication. Be aware that the selection of the appropriate compaction method is dependent on the workability level of the mixture.

c. Workability. The workability of RCC is the property that determines the RCC's capacity to be placed and compacted successfully without harmful segregation. It embodies the concepts of compactability and, to some degree, moldability and cohesiveness. It is affected by the same factors that affect the workability of conventional concrete (i.e., cement content, water content, the presence of chemical and mineral admixtures, and the grading, particle shape, and relative proportions of coarse and fine aggregates). However, the effect of each factor will not be the same for RCC as for conventional concrete. The workability of RCC cannot be measured or judged in the same way that the placeability of conventional concrete is indexed to the slump test. The slump test is not meaningful for concrete intended for roller compaction since the correct mixture has no slump. A critical step in the design of RCC mixtures is to establish the desired workability level of the RCC.

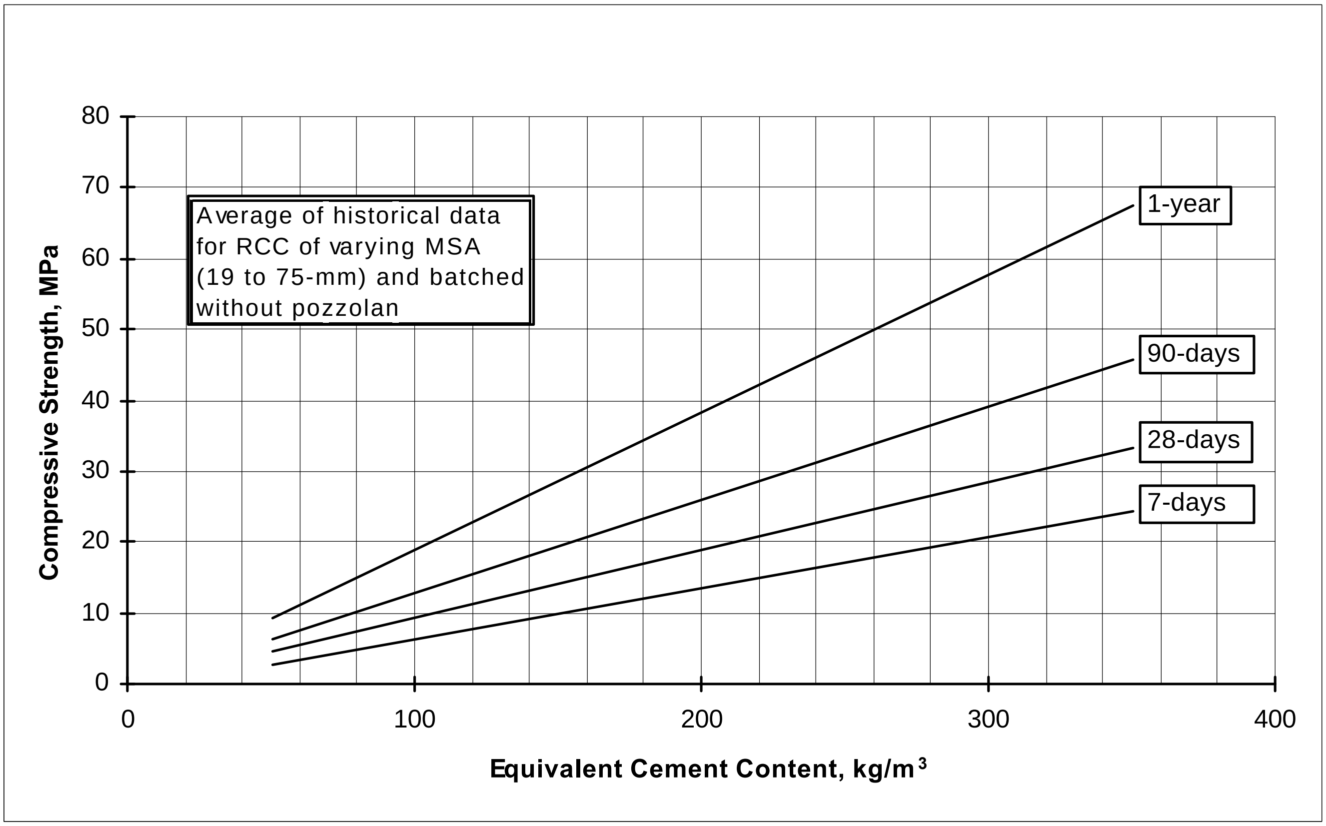

Figure 3-2. Equivalent cement content versus compressive strength; average historical data for RCC batched without pozzolan

For more workable mixtures, consistency of the mixture may be measured using a modified Vebe apparatus. The apparatus and test method are described in CRD-C 53. Most Corps of Engineers mass RCC applications have used RCC mixtures proportioned with Vebe consistencies ranging from approximately 12 to 25 sec. Within this range of Vebe consistency, RCC is generally very workable, is easily placed, and can be fully consolidated, especially at lift joints. However, RCC mixtures with Vebe consistencies of greater than approximately 30 sec have also been used successfully. Advantages of the drier consistency mixtures include somewhat greater economy through more efficient use of cementing materials and less surface rutting and deformation during placement. A walk-behind roller is useful to evaluate mixture workability in small laboratory test sections. On larger test sections, the use of full-size transporting, spreading, and compaction equipment is required. These test strips and sections must be large enough to accommodate the full-size equipment and also have sufficient area for the operation to stabilize. Mixture proportions may then be further adjusted, if necessary, and, final modified Vebe times may be established to control RCC production.

d. Generation of heat. Low water contents associated with mass RCC make possible the use of very low cement contents. The maximum amount of pozzolan or ground slag consistent with strength, durability, and economic and construction requirements should be used to further minimize the portland cement content. During the preconstruction engineering and design (PED) stage of the project, the designer and laboratory personnel must work together in close co-ordination to ensure that parameters used for mixture proportioning studies necessary at this stage agree with the design assumptions selected. From these studies, a range should be selected for the total cementitious material content as well as the amount of pozzolan or slag or both to be used. Later, the project specifications will be based on the range of selected cementitious material content, and the laboratory will make the final contract mixture proportioning studies using materials supplied by the contractor. Placement temperatures, which are expected to affect the fresh and hardened properties of the RCC, should be taken into consideration as much as possible during the mixture proportioning studies.

e. Aggregate. The largest practical NMSA should be used in RCC. However, the larger the aggregate size used in the RCC mixture, the more likely that problems related to segregation during handling, spreading, and compaction operations will occur. The number of aggregate stockpiles used is usually determined based on a variety of factors, including: (1) the available space at the batch plant, (2) the aggregate sizes normally produced and available in the local area, (3) the inherent tendency for the specific aggregate to segregate, and (4) the number of individual materials that can reasonably be handled at the batch plant. In general, any number of aggregate stockpiles may be used as long as the aggregates are batched accurately and are not allowed to segregate. The grading limits of individual coarse aggregate size fractions should comply with those used for conventional concrete for civil works structures. Individual coarse aggregate size groups should be combined to produce gradings approaching the ideal gradings shown in Table 3-1. For mass RCC mixtures, fine aggregate will normally contain somewhat higher percentages of sizes smaller than the 600-µm sieve. This is primarily to reduce the volume of voids within the mortar matrix, decrease the tendency for bleeding, and generally produce a more cohesive and workable mixture. The addition of supplemental material, primarily material finer than the 75-µm sieve, is sometimes needed to supplement the locally available project materials that may not contain sufficient fines. This supplemental fine material may consist of fly ash, natural pozzolan, ground slag, or natural fine blend sand. The use of fly ash, natural pozzolan, or ground slag as supplemental fine material may provide added benefits as a result of a reduced overall water demand, lower cement content, and higher ultimate strength. Fine aggregate gradings within the limits shown in Table 3-2 have performed satisfactorily; approximate fine aggregate contents, expressed as a percentage of the total aggregate volume, are given in Table 3-3. RCC containing softer aggregates, and perhaps clayey or excessive fines, will generally have a greater water demand, be less durable, achieve lower compressive strengths, and experience less bond between lifts. Marginal or minimally processed pit-run aggregates may result in poor concrete performance and should not be used unless laboratory results indicate that all project technical and economic requirements are met.

Table 3-1
Ideal Coarse Aggregate Grading

	Cumulative Percent Passing		
Sieve Size	4.75 to 75 mm (No. 4 to 3 in.)	4.75 to 50 mm (No. 4 to 2 in.)	4.75 to 19.0 mm (No. 4 to 3/4 in.)
75 mm (3 in.)	100		
63 mm (2-1/2 in.)	88		
50 mm (2 in.)	76	100	
37.5 mm (1-1/2 in.)	61	81	
25.0 mm (1 in.)	44	58	
19.0 mm (3/4 in.)	33	44	100
12.5 mm (1/2 in.)	21	28	63
9.5 mm (3/8 in.)	14	18	41
4.75 mm (No. 4)	--	--	--

Table 3-2
Fine Aggregate Grading Limits

Sieve Size	Cumulative Percent Passing
9.5 mm (3/8 in.)	100
4.75 mm (No. 4)	95-100
2.36 mm (No. 8)	75-95
1.18 mm (No. 16)	55-80
600 µm (No. 30)	35-60
300 µm (No. 50)	24-40
150 µm (No. 100)	12-28
75 µm (No. 200)	6-18
Fineness modulus	2.10-2.75

f. Water content. Approximate mixing water requirements and entrapped air contents (for non-air-entrained RCC) are shown in Table 3-3 for various NMSA. The water contents shown are averages from structural and mass concrete mixtures made with both natural and manufactured aggregate. Unit water demand for RCC containing a specific aggregate combination will generally show little change over a wide range of cementitious material contents. Also shown in Table 3-3 are approximate ranges of modified Vebe times corresponding to ranges of water contents and approximate mortar contents for RCC mixtures having varying nominal maximum aggregate sizes.

Table 3-3
Water Content, Sand Content, Mortar Content, Paste-Mortar Ratio, and Entrapped Air Content for Various Nominal Size Aggregates. Typical Values for Use in Estimating RCC Trial Mixture Proportions

	Nominal Maximum Size of Aggregate[a]					
	19.0 mm		50 mm		75 mm	
Contents	Average	Range	Average	Range	Average	Range
Water content[b], kg/m^3						
a) Vebe <30 sec	150	133-181	122	107-140	107	85-128
b) Vebe >30 sec	134	110-154	119	104-125	100	97-112
Sand content, % of total aggregate volume						
a) crushed aggregate	55	49-59	43	32-49	34	29-35
b) rounded aggregate	43	38-45	41	35-45	31	27-34
Mortar content, % by volume						
a) crushed aggregate	70	63-73	55	43-67	45	39-50
b) rounded aggregate	55	53-57	51	47-59	43	39-48
Paste: mortar ratio, Vp/Vm, by volume	0.41	0.27-0.55	0.41	0.31-0.56	0.44	0.33-0.59
Entrapped air content on -1 1/2 in. (37.5-mm) fraction, %	1.5	0.1-4.2	1.1	0.2-4.1	1.1	0.5-3.3

[a] Quantities for use in estimating water, sand, mortar, and entrapped air content for trial RCC mixture proportioning studies.
[b] Lower range of values should be used for natural rounded aggregates and mixtures with low cementitious material or aggregate fines content.

3-3. Procedure for Selecting RCC Mixture Proportions

Laboratories should proportion RCC mixtures using materials that are representative of those to be used on the project. RCC mixture proportioning procedures are very similar to those of conventional concrete. The primary differences are due to the relatively low water content and no-slump consistency of RCC. An RCC mixture must be stable enough to support the weight of a vibratory roller and other heavy equipment, yet workable enough to allow some aggregate reorientation. This reorientation allows the voids between aggregate particles to become filled with paste or mortar during the compaction operations. The following is a step-by-step procedure for proportioning RCC for structural or mass concrete applications. After proportions are established for a proposed mixture, it is intended that the workability and strength of the RCC mixture be verified in the laboratory by trial batching. All of the data presented in the figures and tables are a compilation of over 150 RCC mixture proportions formulated in the laboratory and used on various projects throughout the world. After proportions are selected, minor adjustments during laboratory trial batching are normally required and should be expected.

Step 1: Determine all requirements related to the properties of the RCC mixture, including:

a. required/specified strength and age

b. expected exposure time and condition

c. cementitious materials limitations

d. admixture requirements

e. maximum size, source, and quality of aggregate

Note: Special concrete properties, such as stress-strain characteristics, thermal properties, creep, etc., should be considered during the material selection process and ultimately evaluated after the concrete proportions are established. A comprehensive laboratory test program would normally include a series of mixtures spanning the specified strength requirements with specialized tests on selected mixtures in order to provide a comprehensive evaluation of the materials. The mixture proportioning procedure herein is based on the assumption that the concrete materials are suitable for the intended use. For structural applications, the required average compressive strength (f_{cr}) should be determined using procedures described in EM 1110-2-2000 or ACI 214. However, for normal mass concrete applications, these procedures may be somewhat overly conservative, and a modified approach to establishing an over design factor and the required average strength may be considered.

Step 2: Determine the essential properties of the materials. Obtain representative samples of all materials in sufficient quantities to provide verification tests by trial batching. For estimating purposes, a single RCC mixture proportion will require sufficient materials in the laboratory to produce approximately 0.5 m^3 (0.7 yd^3) of concrete. Proportion RCC with the determined (Steps 3 and 4) or specified amount of pozzolan or cement replacement materials that will satisfy strength, durability, and economic requirements. From the materials submitted for the test program, determine the grading, specific gravity, and absorption of aggregates and the specific gravities of the cementitious materials. The grading of the aggregates submitted for mixture proportioning studies should also be verified to ensure that the aggregate is truly representative of the source.

Step 3: From Table 3-3, estimate the water requirement and entrapped air content for the maximum size aggregate being used.

Step 4: Compute the required equivalent mass of cement from the required compressive strength shown in the relationship on Figure 3-1. If the use of pozzolan is anticipated, compute the cement and pozzolan mass based on the equivalent absolute volume of required cement.

Step 5: Compute the required coarse aggregate proportions that best approximate the ideal coarse aggregate grading shown in Table 3-1.

Step 6: Compare the available fine aggregate grading to the recommended fine aggregate grading shown in Table 3-2. If the fine aggregate is lacking minus 75-µm (No. 200) fines, pozzolan or other nondeleterious natural fines may be used as a supplement. From Table 3-3, select the fine aggregate (sand) content for the maximum size and type (crushed or rounded) aggregate being used.

Step 7: Compute the absolute volumes and masses for all of the mixture ingredients from the information obtained in Steps 2 through 6.

Step 8: Compute the mortar content and compare with values given in Table 3-3. Mortar volume includes the volume of all aggregate smaller than the 4.75-mm (No. 4) sieve, cementitious materials, water, and entrapped air. Adjust fine aggregate content, if required, to increase or decrease mortar volume of the mixture.

Step 9: Compute the volume of paste and the ratio of paste volume to mortar volume, Vp/Vm. For paste, include the volume of all aggregate and mineral filler finer than the 75-µm (No. 200) sieve, cementitious materials, water, and entrapped air. The minimum Vp/Vm ratio should be greater than approximately 0.42 to ensure that all voids are filled. If required, adjust cementitious material content or increase quantity of aggregate and mineral filler finer than 75-µm (No. 200) sieve.

Note: The minimum Vp/Vm ratio of 0.42 is recommended to ensure that voids are filled. However, RCC has been proportioned satisfactorily with a Vp/Vm as low as approximately 0.30 (Table 3-3). Paste to mortar volume (Vp/Vm) ratios less than 0.42 may indicate that the mixture has insufficient paste to fill voids. This condition may adversely affect strength and result in higher entrapped air content, increased permeability, and decreased workability.

Step 10: Evaluate the workability and strength of the RCC mixture by trial batching. For RCC containing large aggregate, test for density ("unit weight") and then wet sieve over the 38-mm (1-1/2 in.) sieve and test for modified Vebe time (if applicable) and air content. Mold specimens for compression and other strength tests as appropriate. All RCC laboratory cast and in situ specimens should meet the minimum size and dimensional requirements as specified in the ASTM testing standards for conventional concrete. In general, cylinders, cores, beams, and blocks will preferably have a minimum dimension of at least three times the nominal maximum size of coarse aggregate in the concrete. All RCC laboratory-cast specimens should be moist cured, and in situ samples should be moisture conditioned the same as for conventional concrete.

Note: For RCC mixtures proportioned at Vebe consistencies greater then approximately 30 sec, the Vebe apparatus and external vibration do not provide sufficient energy to fully consolidate the concrete. For these mixtures, consolidation is accomplished by tamping with pneumatic or electric rammers.

3-4. Example Problem

RCC is required for a flood control structure in a moderate climate. The required average compressive strength is 17.5 MPa (2500 psi) at 1 year, and the required minimum shear cohesion is 193 kPa (28 psi). Placement conditions allow for the use of large aggregate, and a quarry that can produce 75-mm (3-in.) NMSA is nearby. A Class F fly ash is available.

Step 1:

a. The required average compressive strength is 17.5 MPa (2500 psi) at age 1 year. RCC is for mass placement with no limiting requirements for cement content.

b. The mixtures are to be proportioned at a modified Vebe consistency of 15 to 25 sec.

c. Portland cement Type II, low alkali, will be specified. Class F fly ash is available and will initially be used at 40 percent replacement by volume of equivalent cement to reduce cement costs and lower heat generation. Later, supplemental mixture proportioning studies may be conducted to evaluate the performance of mixtures with 30 and 50 percent cement volume replacement.

d. Service records indicate good to excellent performance for concrete batched with aggregate from the local quarry source. Aggregate quality tests indicate the rock is a hard, dense, durable basalt that is well suited for use as concrete aggregate. The aggregate meets conventional concrete grading requirements, but the producer is not able to meet the recommended RCC fine aggregate grading. The fine aggregate must be supplemented to meet the recommended RCC grading band shown in Table 3-2.

e. Adjacent to the local quarry source is a deposit of very fine sand. Petrographic examination indicates the material is primarily ash and pumice fragments. Tests on the fine sand indicate that it is suitable for concrete and can be used to supplement fine aggregate in order to meet the required RCC grading band.

f. It has been determined that a Type D admixture will be used at the rate of 0.3 L per 50 kg of equivalent cement to retard the RCC mixture in order to facilitate placing and bonding at lift joints. Later, supplemental mixture proportioning studies may be performed to evaluate the effect of varying admixture dosage.

g. The mixture proportioning program will consist of selecting initial proportions for the mixture, then making additional mixtures at higher and lower cementitious material contents. Selection of final mixture proportions will be based upon compressive strength versus equivalent cement content curves. Shear strength tests will be performed on laboratory-simulated lift joints after properties of the RCC mixture are established.

Step 2:

Density of the Type I-II cement and Class F fly ash are determined to be 3.15 and 2.26 Mg/m^3, respectively. Samples from the project rock quarry and from the fine sand deposit are available for RCC mixture proportioning studies. Gradings, specific gravities, and absorption tests on the aggregate samples are performed and detailed in Table 3-4.

Step 3:

For the 75-mm (3-in.) maximum size aggregate, a water content of 107 kg/m^3 (180 lb/yd^3) and an air content of 1.0 percent are selected from Table 3-3.

Step 4:

For the required average compressive strength of 17.5 MPa (2500 psi) at age 1 year, Figure 3-1 indicates the required cement content is approximately 120 kg/m^3 (200 lb/yd^3). Class F fly ash is to be used at 40 percent replacement by volume of equivalent cement. Densities of cement and fly ash are from Step 2. Volume and weight of the cement and fly ash are calculated as follows:

$$\text{Volume of equivalent cement} = \frac{120 \text{ kg}}{(3.15)\,(1000 \text{ kg/m}^3)}$$

$$= 0.0381 \text{ m}^3$$

Table 3-4
Summary of Aggregate Grading Blend Used for Example RCC Mixture Proportions

	Percent Passing, Nominal Size Groups									
	Coarse Aggregate					Fine Aggregate				Total
Sieve Size	75 to 38 mm	38 to 19.0 mm	19 to 4.75 mm	RCC[a] Blend 40-26-34	Table 3-1 Ideal	Sand	Fine Sand	RCC[a] Blend 88-12	Table 3-2 Ideal	Aggregate[a] Blend 66-34
75 mm	100			100	100					100
63 mm	90			96	88					97
50 mm	46	100		78	76					85
37.5 mm	4	95		60	61					74
25. 0 mm		34	100	43	44					62
19.0 mm		8	98	35	33					57
12.5 mm		1	59	20	21					47
9.5 mm		1	29	10	14	100		100	100	41
4.75 mm			4	1		98		98	95-100	34
2.36 mm			1			85		87	75-95	30
1.18 mm						67		71	55-80	24
600 µm						42	100	49	35-60	17
300 µm						22	98	31	24-40	11
150 µm						8	86	17	12-28	6
75 µm						2.6	72.1	10.9	6-18	3.7
Fineness modulus						2.78		2.47	2.10-2.75	
Specific Gravity, BSSD	2.79	2.77	2.76			2.77	2.56			
Absorption, (%)	0.7	1.0	1.4			1.6	1.9			

[a] Blend proposed for RCC trial mixture proportions as follows:
coarse aggregate: 40% 75 to 38 mm, 26% 38 to 19.0 mm, and 34% 19.0 to 4.75 mm size groups
fine aggregate: 88% fine aggregate and 12% fine sand sizes
total aggregate: 66% coarse aggregate and 34% fine aggregate

Volume of fly ash = (0.40) (0.0381)

= 0.0152 m^3

Volume of cement = (0.60) (0.0381)

= 0.0229 m^3

Mass of fly ash = (0.0152 m^3) (1000 kg/m^3) (2.26)

= 34.4 kg/m^3

Mass of cement = (0.0229 m^3) (1000 kg/m^3) (3.15)

= 72.1 kg/m^3

Steps 5 and 6:

Ideal coarse aggregate gradings for several maximum size aggregates and the recommended fine aggregate grading band are shown in Tables 3-1 and 3-2. From Table 3-3, a total sand content of 34 percent is selected. Results of the calculations for proportioning coarse and fine aggregates are shown in Table 3-4. The total coarse and fine aggregate is blended to provide the desired 34 percent fine aggregate content in the overall total aggregate grading. The proportions of each individual nominal aggregate size group is calculated:

75 to 37.5 mm = 0.40 (0.66) (100) = 26.4%

37.5 to 19.0 mm = 0.26 (0.66) (100) = 17.2%

19.0 to 4.75 mm = 0.34 (0.66) (100) = 22.4%

Fine aggregate = 0.88 (0.34) (100) = 29.9%

Fine sand = 0.12 (0.34) (100) = 4.1%

Total aggregate = 100.0%

Step 7:

Compute absolute volumes and masses for each mixture ingredient:

a. From Steps 3 and 4:

Cement = 72.1 kg/m^3 = 0.0229 m^3
Fly ash = 34.4 kg/m^3 = 0.0152 m^3
Water = 107.0 kg/m^3 = 0.1070 m^3
Total = 0.1451 m^3

b. Air content is estimated to be 1.0 percent of the minus 37.5-mm portion of the mixture. The determination of air content volume is a trial and error procedure as follows:

Air content of total mixture = 0.0085 m^3 (estimate)
Volume of air, cement,
fly ash, and water = 0.0085 + 0.1451
= 0.1536 m^3

Volume of aggregate = 1.0000 - 0.1536
= 0.8464 m^3

From Steps 5 and 6 and Table 3-4; 74 percent of total aggregate is minus 37.5 mm, 26 percent is plus 37.5 mm (Table 3-4); therefore, the volume of the minus 37.5-mm portion of the mixture is:

1.0000 - (0.26)(0.8464) = 0.7799 m^3
or
(0.74) (0.8464) + 0.1536 = 0.7799 m^3

Estimated air content = 1.0% of minus 37.5-mm portion of mixture
= (0.01) (0.7802 m^3)
= 0.0078 m^3

Change estimated air content and repeat computation until estimated value and computed value converge, as follows:

Air content of total mixture = 0.0078 m^3 (changed estimate)
Volume of air, cement,
fly ash, and water = 0.0078 + 0.1451
= 0.1529 m^3

Volume of aggregate = 1.0000 - 0.1529
= 0.8471 m^3

Again, from Steps 5 and 6 and Table 3-4; 74 percent of total aggregate is minus 37.5 mm, 26 percent is plus 37.5 mm (Table 3-4); therefore, the volume of the minus 37.5 mm portion of the mixture is:

1.0000 - (0.26) (0.8471) = 0.7798 m^3
or
(0.74) (0.8471) + 0.1529 = 0.7798 m^3

Estimated air content = 1.0% of minus 37.5-mm portion of mixture
= (0.01) (0.7798)
= 0.0078 m^3

Therefore, estimated air content volume (1% of minus 37.5-mm portion of mixture) is 0.0078 m^3.

c. Absolute volumes and weights for each mixture ingredient, including total aggregate volumes, can now be calculated as shown in Table 3-5.

Step 8:

Compute mortar volume:

Mortar volume = volume cement + volume fly ash
+ volume water + volume air
+ volume minus 4.75-mm aggregate

= 0.0229 + 0.0152 + 0.1070 + 0.0078
+ (0.04) (0.1898) + (0.98) (0.2533)
+ 0.0347

= 0.4434 m^3 = 44.3%

From Table 3-3, mortar content is within typical limits.

Table 3-5
Summary of Example RCC Mixture Proportions

Material	Aggregate, %	Volume, m^3	Specific Gravity	Weight, kg/m^3
Coarse aggregate				
75 - 37.5 mm	26.4	0.2236	2.79	624
37.5 - 19.0 mm	17.2	0.1457	2.77	404
19.0 - 4.75 mm	22.4	0.1898	2.76	524
Sand	29.9	0.2533	2.77	702
Fine sand	4.1	0.0347	2.56	89
Cement		0.0229	3.15	72.1
Fly ash		0.0152	2.26	34.4
Water		0.1070	1.00	107.0
Air		0.0078	--	--
Type D admixture		--	--	(0.72 ℓ/m^3)[a]
		1.0000		2556.5

[a] (120 kg/m^3 cementitious material) (0.3 ℓ/50 kg cementitious material).

Step 9:

Compute paste volume:

Paste Volume = volume cement + volume fly ash
+ volume water + volume air
+ volume minus 75-µm aggregate fines

= 0.0229 + 0. 0152 + 0.1070 + 0.0078
+ (0.026) (0.2533) + (0.721) (0.0347)

= 0.1845 m^3

Check paste/mortar volume ratio:

$$\frac{Vp}{Vm} = \frac{\text{Volume Paste}}{\text{Volume Mortar}} = \frac{0.1854\ m^3}{0.4434\ m^3}$$

= 0.416

The ratio is within typical limits, Table 3-3.

Step 10:

Compute masses for a trial batch from mass and volume information in Step 7 and as shown in Table 3-5. Results of tests on the trial batch are as follows:

Air content = 0.9%
Vebe consistency = 8 sec

The mixture appears well proportioned but slightly wet as indicated by the low Vebe time. Air content is close to the 1.0 percent assumed and does not require adjustment. For adjustment in mixing water, assume $\pm$ 3 percent change in mixing water = $\pm$ 10-sec change in Vebe consistency. Therefore, recompute second trial mixture following same procedures as outlined in Steps 2 through 10, making the following adjustments:

Mixing water: decrease approximately 3 percent to 103.8 kg/m^3 (175 lb/yd^3).

Cementitious material content: maintain equivalent cement content of 120 kg/m^3 (200 lb/yd^3).

Aggregate: maintain coarse and fine aggregate relative proportions, but increase total aggregate volume equal to the water volume decrease.

Strength performance: evaluate required strength parameters and make further mixture proportion adjustments if necessary.

3-5. Field Adjustment of Mixture Proportions

The mixtures developed using the steps listed have proven to be placeable; however, minor field adjustments to the proportions should be expected. Advantage should be taken of the preliminary and project test sections to make the necessary field adjustments. They should be made on the basis of visual observation, the modified Vebe, and nuclear density test results. Once a determination is made that a mixture is too dry or too wet, the adjustment is made only by adding or deleting water in the mixture until the concrete can be completely compacted in three or four passes of the vibratory roller with the vibrator on. Routine minor adjustments in water content will be required daily or more often due primarily to changes in the aggregate moisture condition. Minor adjustments to cement content can be made using mixture proportioning concepts described in the preceding paragraphs and verified by observed performance.