APPENDIX A

1. Application. Procedures and criteria described herein are applicable to the design and construction of roller-compacted concrete (RCC) pavement.

2. Conversion Factors. The non-SI units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	25.4	millimeters
pounds (mass) per cubic yard	144.16614	kilograms per cubic meter
square yards	0.8361274	square meters
pounds	0.4535924	kilograms
tons per hour	907.1847	kilograms per hour
pounds (force) per cubic inch	6.894757	kilopascals

The equivalent metric size of the wire—cloth sieves given in non—SI units are as follows:

Sieve	SI Equivalent
1 in.	25.0 mm
3/4 in.	19.0 mm
½ in.	12.5 mm
3/8 in.	9.5 mm
No. 4	4.75 mm
No. 8	2.36 mm
No. 16	1.18 mm
No. 30	600 μm
No. 50	300 μm
No. 100	150 μm
No. 200	75 μm

3. General. Roller-compacted concrete pavements are the product of a relatively new concrete paving process that involves laydown and compaction of a no-slump portland cement concrete mixture using techniques similar to that used for asphaltic concrete pavement. RCC pavement does not originate from an entirely unique paving technique or material, because it combines the existing asphaltic concrete paving and/or cement-treated base construction procedures with the final product of a portland cement concrete pavement. By using this construction technique, a large amount of concrete may be placed quickly with no forms, dowels, or reinforcing steel. Construction cost savings of 10 to 30 percent, or even more, of the cost of slip-formed or fixed-formed concrete pavements have been realized (Table 1). The surface smoothness and surface texture of RCC pavement is somewhat rougher and coarser than conventional concrete pavement and this has tended to limit RCC pavement applications to areas where low-speed, heavy-load traffic is the primary user of the pavement.

a. Other nonpavement applications that employ a similar construction method include slope protection of embankment or dams, providing an impermeable lining for sludge-drying basins or waste water lagoons, platforms for handling containerized freight, for recycling yards, for composting yards, for log sorting yards, for mine storage areas, etc.

b. The typical RCC pavement construction process is illustrated in Figure 1. RCC is typically mixed in a continuously-mixing pugmill plant (1) located near the paving site. In the plant, the aggregates, cement, and flyash are weighed with belt scales or volumetrically proportioned on a continuous conveyer belt, which dumps the dry materials in the pugmill, where the water is added. The pugmill provides the vigorous mixing action necessary to evenly distribute the relatively small amount of water through-out the relatively stiff, no-slump concrete mixture. The freshly mixed RCC is then discharged into dump trucks equipped with protective covers, which haul the RCC to the paving site (2).

c. At the paving site, the base course material is graded and compacted (3) to form a smooth, firm working platform for the RCC pavement. The surface of the base course is moistened with water just before the RCC is placed (4), and stringlines are set up along the paving lanes to guide the height of the paving screed during placement (5). The RCC is placed with a paving machine to a uniform density and smoothness (6). Immediately after placement, the fresh RCC is compacted with several passes of a dual-drum vibratory roller to the specified final densities (7).

After the compaction is completed, several passes of a rubber-tired roller are made to tighten the surface texture of the pavement (8). In some instances, finish rolling with steel-drum rollers may be required to remove roller marks. When the rubber-tire rolling is completed, the surface of the RCC is kept moist by the use of water trucks equipped with fogger-spray bars (9), until an irrigation sprinkler system can be set up, usually by the end of the day (10). The sprinkler system is used to keep the surface of the RCC pavement continuously moist for the duration of the curing period, usually 7 days (although 14 days is always better). Membrane-forming curing compounds and asphalt emulsions have also been used successfully.

d. Cold joints are construction joints formed between paving lanes placed more than 1 hour apart and always between two separate days' paving. Perpendicular cold joints (11) are formed between lanes placed perpendicular to each other; longitudinal cold joints (12) are oriented in the direction of paving, and transverse cold joints (13) are located perpendicular to the direction of paving, between lanes oriented in the same direction. Transverse cold joints are constructed by sawing across the ends of the paving lanes which have been rounded off from rolling and removing the excess material. Finally, transverse contraction joints may be cut with a concrete saw (14) within 4 to 20 hours after the RCC is placed and compacted. Historically, the standard practice has been to allow the RCC pavement to crack; however, current practice is to saw cut contraction joints to improve pavement aesthetics and ease the application and maintenance of joint sealants.

4. Subgrade and Base Coarse Preparation. The subgrade and base course requirements for RCC pavement are essentially the same as those for conventional concrete pavement. They should conform to the requirements outlined in TM 5-822-5/AFM 88-7, Chapter 1, or TM 5-825-3/AFM 88-6, Chapter 3. The subgrade and base course should also meet the requirements given in ETL 1110-3-435. The subgrade and base course should be prepared to ensure sufficient support to permit uniform consolidation of the RCC pavement through its entire thickness upon compaction.

5. Selection of Materials.

a. Aggregates. As with other types of concrete, selection of a suitable aggregate source is one of the most important factors in determining the quality and economy of RCC.

(1) The aggregates used should generally meet the

requirements given in ASTM C 33. The recommended RCC gradation is shown in Figure 2. This gradation is similar to gradations used for asphalt concrete. This gradation should produce an RCC pavement surface with relatively few surface voids. Conventional portland cement concrete mixtures are generally obtained by combining coarse and fine groups of aggregates. The well-graded blend of aggregates given in Figure 2 may be difficult to produce from two groups due to problems with segregation of the different sized aggregate particles. When possible, the use of more than two aggregate groups (coarse and fine) at the plant will provide for more flexibility in blending the aggregates to control the gradation of the RCC.

(2) Aggregate can be classified into two size groups, coarse and fine. The coarse aggregate consists of at least 90 percent by weight retained on the No. 4 sieve and the fine aggregate consists of at least 90 percent by weight passing the No. 4 sieve. Aggregate for RCC should be evaluated for quality and grading, and should generally comply with the provisions outlined in TM 5-822-7/AFM 88-6, Chapter 8, Paragraph 5, and CEGS 02520 Paragraph AGGREGATES. The coarse aggregate may consist of crushed or uncrushed gravel, recycled concrete, crushed stone, or a combination thereof. Local state highway department coarse aggregate grading limits, for example, should generally be acceptable. A primary consideration should be that, regardless of the grading limits imposed, the grading of the aggregate delivered to the project site be relatively consistent throughout the production of RCC. This is an important factor in maintaining control of the workability of the concrete mixture. The nominal maximum aggregate size normally should not exceed 3/4 in., particularly if pavement surface texture is important. Limiting the nominal maximum aggregate size to 3/4 of an in. or less usually results in less segregation of the coarse aggregate from the mix, and rock pockets are less likely to occur. The fine aggregate may consist of natural sand, manufactured sand, or a combination of the two. Sands with higher quantities of nonplastic silt particles may be beneficial as a mineral filler and may allow some reduction in the amount of cement required. However, mixtures made with fine aggregates having an excessive amount of clay may have a high water demand with attendant shrinkage, cracking and reduced strength. Determination of the specific gravity and absorption of these sands with high quantities of fines should be made according to ASTM C 128, Note 3. Expedient construction with RCC can utilize minimally processed aggregates such as pit- or quarry-run

aggregates to produce an RCC pavement. This RCC pavement may require a greater water content, be less durable, and have a lower flexible strength.

b. Cement. The portland cement investigated for use shall meet the requirements of ASTM C 150. The use of Type III, or "high early strength" cement will almost never be justified or practical for use in RCC due to shortened working times with this cement.

c. Admixtures. A proper air-void system normally must be provided to prevent frost damage in concrete which freezes when critically saturated. 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. The most widely used method to minimize freezing and thawing damage to RCC pavement is to combine a low water-cement ratio with a highly compacted RCC. The low water-cement ratio and good compaction ensure that the concrete has a minimum amount of freezable water in the capillaries and that it has low permeability. This makes it difficult for sufficient water to enter the RCC and for it to reach critical saturation. A free-draining base under the RCC pavement will further prevent water from saturating the RCC pavement. As long as the RCC pavement is not critically saturated, it will not be damaged by freezing and thawing. Laboratory studies have also shown that water-reducing or retarding admixtures may be used successfully with RCC. However, they may not be as effective in RCC as in conventional concrete because they effect the paste content of the mixture. The amount of paste is less in RCC than in conventional PCC mixtures. If the use of these admixtures is proposed, such use should be based on investigations which show them to produce benefits greater than their cost.

6. Proportioning Methods.

a. General. The basic mixture proportioning procedures and properties of conventional concrete and RCC are essentially the same. However, conventional concrete cannot be reproportioned for use as RCC by any single action such as (1) altering proportions of the mortar and concrete aggregates, (2) reducing the water content, (3) changing the water-cement ratio, or (4) increasing the fine aggregate content. Differences in mixture proportioning procedures and properties are mainly due to the relatively dry consistency of the fresh RCC and the selected use of nonconventionally graded aggregates and compaction procedures. The primary differences in the properties of RCC are

(1) RCC often is not air entrained, (2) RCC has a lower water content, (3) RCC has a lower paste content, and (4) RCC generally requires a higher fine aggregate content. Table 2 provides the RCC pavement mixture proportions used at various locations. A number of methods have been used to proportion RCC pavement mixtures, including those found in CRD-C 161, ASTM D 558, EM 1110-2-2006, ACI 211.3, and ACI 207.5R. The first two of these methods treat the material as a cement stabilized soil rather than a concrete and establish a relationship between moisture and density obtained from a particular compactive effort. The latter three methods follow an approach used in conventional concrete. Currently, CRD-C 161 is the method recommended for RCC pavement mix design. The procedures for RCC pavement mixture proportioning are not as well defined as for conventional concrete, as evidenced by the five different methods being used to obtain the mixtures. The key to the successful selection of a trial batch of RCC in the laboratory that is close to that which performs best in the field is the experience of the one conducting the proportioning study. For this reason, CEGS 02520 requires that the government be responsible for the selection of mixture proportions for military pavement projects.

b. CRD-C 161 Method. This method was developed at WES and covers procedures for selecting proportions for roller RCC pavement mixtures with normal-weight 3/4 in. nominal maximum size aggregates and having a workability suitable for placement with asphalt paving machines having vibratory screeds. 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 provide 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.

c. ASTM D 558 Method. WES and other Corps laboratories have used a proportioning method similar to ASTM D 558 for RCC pavement mixtures. Such a method would produce the optimum moisture content necessary to obtain maximum density for a particular set of materials and compaction procedures. Previous experience indicates that the optimum moisture content obtained by Method 100 (CE 55) of MIL-STD-621 is usually close to that required to allow efficient operation of a vibratory roller.

d. ACI 207.5R Method. The U.S. Army Engineer Waterways Experiment Station (WES) has used the method described in

ACI 207.5R, with some modification, on some RCC pavement mixture proportioning studies (further information on this procedure may be obtained at CEWES-GP-SC, 3909 Halls Ferry Road, Vicksburg, MS, 39180-6199). The primary consideration when using this method is proper selection of the ratio (P^v) of the air-free volume of paste (V^p) to the air free mortar (V^m). This selection is based primarily on the grading and the particle shape of the fine aggregate. The P^v affects both the compatibility of the mixture and the resulting surface texture of the pavement. Ratios of 0.36 to 0.41 have been found to be satisfactory for mixtures having a nominal maximum size aggregate of 3/4 in. The fraction of the fine aggregate passing the No. 200 sieve should be included in v~ when calculations are made using P^v.

7. Mixture Properties.

a. Handling Characteristics. The workability of RCC is that property which determines its capacity to be mixed, placed, and compacted successfully. It embodies the concepts of compatibility and to some degree moldability and cohesiveness. RCC 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; and the presence of chemical and mineral admixtures in the mixture. However, the magnitude of the effect on each factor will not necessarily be the same for RCC as for conventional concrete. When placing RCC or conventional concrete the consistency of the mixture is very important. The slump test is used to measure the consistency of conventional concrete. The slump test is not meaningful for RCC since it has no slump. Preliminary judgement of the workability, placability, and compatibility 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 CRD-C 161, Paragraphs 7.1 through 7.6 should be used to determine the optimum moisture content of an RCC mixture. Experience with RCC pavement mixtures, as well as other soil or aggregate cement stabilized materials, placed in the field indicates that the actual RCC water content used may need to be slightly greater than the optimum moisture content determined for the mixture. This is probably due to the loss of water from the mixture due to evaporation during transport and placement operations or to different compaction in the field. The degree to which the water content of the mixture will vary depends on ambient conditions. Typically, the moisture increase will be 0.1 to 0.5 percent above the optimum. A test section should be constructed for each RCC project so that the mixture proportions can be adjusted as necessary to achieve the required workability.

b. Sample Fabrication. The strength of an RCC mixture is controlled primarily by the water-cement ratio and the degree of compaction attained. All RCC pavement mixtures placed by the Corps of Engineers to date have had water-cement ratios ranging from 0.30 to 0.40. The fabrication of cylindrical laboratory test specimens for strength determinations can be made with ASTM C 1176 or CRD-C 160. No procedure has been standardized for fabricating RCC beam specimens such as those used to determine concrete flexural strength. However, as described in CRD-C 161, some success has been achieved by filling beam molds in two layers. Each layer is consolidated by vibrating each layer on a vibrating table having a frequency of 3,600 vibrations per minute, under a surcharge of 125 pounds (57 kilograms). The surcharge is uniformly distributed over the entire specimen area during molding, and vibration continued until a ring of mortar forms around the complete periphery of the mold. All specimens fabricated in the laboratory are to be cured according to ASTM C 192.

c. Strength Results. Test specimens fabricated and cured in the laboratory generally exhibit higher strengths than those cored or sawn from an RCC pavement. This is probably due to the higher unit weights normally obtained with the fabricated specimens and the more efficient laboratory moist curing. Laboratory test specimens generally have unit weights which are 98 to 99 percent of the theoretical (air-free) weight of the mixture, while core samples taken from RCC pavement normally have unit weights ranging from 95 to 98 percent of the theoretical weight. Therefore, fabrication of a companion set of test specimens having the lowest relative density allowed by the contract specimens should be considered during laboratory mixture proportioning studies.

8. Considerations.

a. General. The thickness design procedure for RCC pavement is outlined in Army ETL 1110-1-141. The primary difference in the approaches to RCC pavement and plain concrete pavement thickness design is the assumption of no load transfer at any joint or crack in the RCC pavement. Limited load transfer tests conducted at Ft. Hood, TX, and Ft. Stewart, GA, revealed average load transfer at transverse contraction cracks of 16 to 19 percent. The load transfer at longitudinal and construction joints will be lower and all were less than the 25 percent used for plain concrete pavement design for parking areas, open storage areas, and airfields. placement of RCC pavement immediately adjacent to existing structure is not practical. Conventional formed concrete should be used between the structure and the RCC pavement. The RCC pavement can be placed first and cut back to the desired line or the RCC can be placed against the previously placed formed concrete.

b. Lift Thickness. The maximum thickness of a lift of RCC pavement is governed by the ability of the pavers to place the concrete in a smooth and continuous fashion. This maximum uncompacted thickness is usually 10 in. (250 mm). The compacted thickness will be 10 to 20 percent less than this, depending on the degree of compaction obtained. The minimum compacted thickness of any lift should be 4 in. (100 mm).

c. Two-lift Construction. If the total uncompacted thickness exceeds the capacity of the paver, the RCC pavement should be placed in two or more lifts, thus creating a horizontal joint (or horizontal plane between the layers) in the pavement. Sufficient bond should develop at the horizontal joint in RCC pavement if the underlying RCC is fresh. The time frame involved with this can vary from just a few minutes to 30 minutes depending on ambient conditions. If the top lift is not placed while the bottom lift is fresh, CEGS 02520 requires that a layer of bonding mortar must first be applied. The surface of the lower lift should be kept moist and clean until the upper lift is placed, and the upper lift should be placed and compacted within the time frame allowed by existing ambient conditions. In two-lift construction, the uncompacted thickness of the first lift should be about two-thirds the total uncompacted height of the pavement (or the maximum lift thickness the paver can handle, whichever is smaller). The thinner section in the upper lift aids in creating a smoother final surface, and because of the smaller volume of material, allows the paver placing the second lift to move quicker than, and follow closer behind the paver placing the first lift.

9. Test Section.

a. General. A test section must be constructed to determine the ability of the contractor to mix, haul, place, compact, and cure RCC pavement. The test section must be constructed of the same material using the same equipment that is intended to be used in production placement. The test section must be constructed at a location near the jobsite at least 10 days prior to the construction of the RCC pavement. The test section should be large enough to establish the rolling pattern for the vibratory and finish rollers, the correlation between laboratory and nuclear gage densities, and the correlation between the number of passes and relative density. The test section should contain both longitudinal and transverse cold joints, and a fresh joint. A suggested minimum size is two 12 to 14 ft wide lanes (4 meters), each 375 ft (115 meters) long, with one and one-half lanes placed the first day and the rest placed the next day (see Figure 3).

b. Optimum Number of Rolling Passes. During the test section construction, a nuclear gage operated in the direct transmission mode and standardized with a calibration block should be used to determine the optimum number of passes with the vibratory roller to reach maximum density. The density should be measured by inserting the nuclear gage probe into the same hole after each pass of the vibratory roller. The hole should be made with an instrument specifically designed for the purpose, and should be formed using the same method throughout the test section and main construction. This rolling and measuring procedure should be continued until there is less than a 1 percent change in successive readings. These data may be used in conjunction with correlation between the nuclear gage and the laboratory density to determine the minimum number of passes needed to achieve or slightly exceed the specified density during the pavement construction. However, a minimum of four vibratory passes should be used, and this minimum will probably prevail in most cases.

c. Calibration Block for the Nuclear Density Gauge. A calibration block should be used each day before paving begins to calibrate the full-depth readings of the nuclear density gages. The block should be fabricated, from the RCC mixture to be used in the project, before the test section construction begins. The block size should be 18 in. by 18 in. (450 mm by 450 mm) by the maximum thickness of one lift, plus 1 in. (25 mm). The block should be compacted to between 98 and 100 percent of the maximum wet density determined in accordance with ASTM D 1557. The block should be measured and weighed to determine the actual density (unit weight) and shall be used to check the calibration of the nuclear density gauge. After drilling a hole in the block to accommodate the nuclear density gage probe, three full-depth nuclear density gauge tests should be performed in the direct transmission mode and the results averaged. This average nuclear density gauge reading should then be compared with the measured unit weight of the block and the difference used as a correction factor for all readings taken that day. If the adjusted nuclear gauge density is less than the specified density, additional passes with the vibratory roller should be made on the fresh RCC until the specified density is reached. Two nuclear density gauges should be calibrated (using the same holes) during the test section construction, so that an extra one is available during construction.

d. Strength Tests. CEGS 02520 does not require strength testing for quality control or quality assurance of the in-situ RCC pavement. However, the pavement strength should be determined from samples obtained from the test section. The testing should determine the flexural and splitting tensile strength of the RCC pavement. If the design strength requirements are not met, the mix proportions should be adjusted (or the compaction procedure or curing altered, and another test section built), until the strength results are satisfactory.

10. Batching. Mixing. and Transporting. RCC requires a vigorous mixing action to disperse the relatively small amount of water evenly throughout the matrix. This action has been best achieved by using a twin-shaft pugmill mixer as is commonly used in asphalt concrete mixing. RCC may be produced successfully in either a continuous-mixing or a batch-type plant. The continuous-mixing plant is recommended for mixing RCC because it is easier to transport to the site, takes less time to set up, and has a greater output (or production) capacity than the batch-type plant. The batch-type plant allows more accurate control over the proportions of material in each batch, but generally does not have enough output capacity for larger paving jobs. The most widely used and recommended equipment is a continuous plant with weigh controls (belt scales) for the materials. The output of the plant should be such that the smooth, continuous operation of the paver(s) is not interrupted. Generally, for all but the smaller jobs (1,000 square yards or meters or smaller), the capacity of the plant should be no less than 250 tons per hour (230,000 kilograms per hour). The output of the plant should match the laydown capacity of the paver(s) and the rollers. The plant should be located as close as possible to the paving site, but in no case should the haul time between the batch plant and the paver(s) exceed 15 minutes. The RCC should be hauled from the mixer to the paver(s) in dump trucks. These trucks should be equipped with protective covers to guard against adverse environmental effects on the RCC, such as rain, or extreme cold or heat. The truck should dump the concrete directly into the paver hopper.

11. Placing. For most pavement applications, RCC should be placed with a paving machine. The paver should be equipped with automatic grade-control devices such as a traveling ski or

electronic stringline grade-control device. Satisfactory performance has been obtained using modified asphalt type pavers having a vibratory screed and at least one tamping bar. These machines have provided a satisfactory surface texture and some initial compaction when the RCC is placed. Necessary adjustments on the paver to handle the RCC include enlarging the feeding gates between the feed hopper and the screed to accommodate the large volume of stiff material moving through the paver, and adjusting the spreading screws in front of the screed to insure that the RCC is spread uniformly across the width of the paving lane. Care should be taken to keep the paver hopper from becoming empty to prevent any gaps or other discontinuities from forming in the pavement. The concrete should be placed and compacted within 45 minutes after water has been added to the batch. When paving adjacent lanes, the new concrete should be placed within 60 minutes of placing the first lane to form a fresh joint. This time may have to be reduced depending on ambient conditions. If these time restraints can not be met then a cold joint is formed. The height of the screed should be set even with the uncompacted height of the adjacent lane, thus allowing simultaneous compaction of the edges of the adjacent lanes into a fresh joint. Two or more pavers operating in echelon may reduce the number of cold joints by one half or greater, and are especially recommended in road construction where the entire width of the road can be placed at the same time.

12. Compaction.

a. General. RCC pavement has generally been compacted with a dual-drum (10 ton static weight) vibratory roller making four or more passes over the surface to achieve the design density (one back-and-forth motion is two passes). The primary compaction should be followed with two or more passes of a 20 to 30 ton rubber-tired roller. This serves to tighten the surface texture by closing the small voids and fissures left by the vibratory rolling process. The use of a static (nonvibratory) dual drum roller may be required to remove any roller marks left by the vibratory or rubber-tired roller. A single-drum (10 ton) vibratory roller has been used successfully to compact RCC pavement, but may require the use of a rubber-tired or dual-drum static roller to remove tire marks.

b. Proper Time for Rolling. The consistency of the RCC when placed should be such that it may be compacted immediately behind the paver without undue displacement of the RCC pavement surface. If rolling has to be delayed, the cause should be investigated and the problem corrected. In no case should more than 10 minutes pass between placement and the beginning of the rolling procedure. The rolling should be completed within 45 minutes of the time the water was added at the mixing plant. A good indication that the RCC is ready for compaction is obtained by observing the displacement of the surface after two static passes with the 10 ton vibratory roller. A mixture that is too wet may appear "rubbery" under the roller, or even spread to form a deep rut after two passes. A mixture that is too dry will hardly consolidate at all under the first passes. In either case, only minor changes in the design water content should be made at the plant to correct the problem; otherwise, a new mix design may be needed. With practice, the roller operator should be able to tell whether the consistency of the RCC is satisfactory for compaction.

c. Rolling Pattern. After making two static passes over the entire surface (except the joint), the vibratory roller should make four passes on the RCC pavement using the following pattern: two passes on the exterior edge of the first paving lane (the perimeter of the parking area or the edge of a road) so that the rolling wheel extends over the edge of the pavement 1 to 2 in. (25 to 50 mm) (done to confine the RCC to help prevent excessive lateral displacement of the lane upon further rolling), followed by two passes within 12 to 18 in. (300 to 500 mm) of the interior edge (Figure 4). The uncompacted edge may then be used to set the height of the paver screed when placing the adjacent lane, and allows both lanes of the fresh joint to be compacted simultaneously. Any remaining uncompacted material in the center of the lane should be compacted with two passes of the roller. This pattern should be repeated once to make a total of four passes on the lane (or more if the specified density is not achieved). If the interior edge will be used to form a cold joint, it should be rolled exactly as the exterior edge was rolled, taking care to maintain a level surface at the joint and not round the edge (see Figure 5(1)). When the adjacent lane is placed, two passes should be made about 12 to 18 in. (300 to 500 mm) from the outer edge of the lane (again, to confine the concrete), followed by two passes on the fresh joint (Figure 4). The first two passes should extend 1 to 2 in. (25 to 50 mm) over the outer edge of this lane if the lane will form an outer edge of the completed pavement. Any remaining uncompacted material in the lane should be compacted with two passes of the roller. This pattern should be repeated to make a total of four passes over the RCC pavement. Additional passes may be necessary along the fresh joint to insure smoothness and density across the joint (see Figure 4).

d. Compacting the End of a Lane. When the end of a lane is reached, the roller should roll of f the end of the lane creating a rounded ramp. The recommended procedure is to cut the ramp with a power saw full-depth to form a vertical face. This will eliminate hand work and lessen the possibility of damage to the in-place RCC pavement. Another method is to saw the concrete to at least one-half the depth of the pavement. Then the lower portion of the joint should be trimmed by hand to form a nearly vertical face, clean from debris and loose particles.

e. Proper Roller Operation. During the course of the vibratory compaction, the roller should never stop on the pavement with the vibrator on. Instead, the vibrator should be turned on only after the roller is in motion and should be turned off several feet before the roller stops moving. The stopping points of successive rolling passes should be staggered to avoid forming depressions in the fresh pavement surface. The roller should be operated at the proper speed, amplitude, and frequency to achieve optimum compaction. Experience has shown that the best compaction will probably occur at a high amplitude and low frequency (because of the thick lifts) and a speed not exceeding 1.5 miles per hour. A low amplitude/high frequency combination may be necessary if the surface is disturbed during the high amplitude rolling.

f. Finish Rolling. The vibratory compaction should be followed immediately with two or more passes of the rubber-tired roller so that the surface voids and fissures close to form a tight surface texture. This rolling may be followed by a light dual-drum roller to remove any roller marks on the surface, but this will probably not be necessary. It is very important that all exposed surfaces of the RCC pavement be kept moist with a light water spray after the rolling process until curing is started.

13. Cold Joints.

a. General. A cold joint in RCC pavement is somewhat analogous to a construction joint in conventional concrete pavement. It is formed between two adjacent lanes of RCC when the first lane has hardened to such an extent that the uncompacted edge cannot be consolidated with the fresher second lane. This happens when there is some time delay between placement of adjacent lanes such as at the end of the days construction. This hardening normally takes approximately 1 hour depending on properties of the concrete and environmental conditions. The adjacent lane should be placed against the first lane and be compacted within this time frame. Otherwise, the joint between the two lanes should be considered a cold joint.

b. Cold Joint Construction. Before placing fresh concrete against hardened in-place pavement to form a longitudinal cold joint, the edge of the in-place pavement should be cut with a power concrete saw. As discussed in paragraph 12.d., the recommended procedure is to saw full-depth with a power concrete saw to form a vertical face. This will eliminate hand work and lessen the possibility of damage to the in-place pavement. Another method is to saw to at least one-half the depth of the pavement. Then the lower unsawed portion of the joint should be trimmed by hand to form a nearly vertical face, clean of debris and loose particles. Care should be taken to avoid undercutting of the pavement edge. This vertical face should be dampened before the placement of the fresh lane begins. The height of the screed should be set to a sufficient elevation to compensate for the reduction in thickness due to compaction. The screed should overlap the edge of the hardened concrete surface 1 to 3 in. (25 to 75 mm). The excess fresh concrete should be pushed back to the edge of the fresh concrete with rakes or lutes and rounded off so that no fresh material is left on the surface of the hardened concrete before compacting the joint. The loose material should not be broadcast over the area to be compacted; this may leave a rough surface texture after rolling. The edge of the fresh lane adjacent to the hardened concrete should be rolled first in the static mode, with about 1 ft (300 mm) of the roller on the fresh concrete, to form a smooth longitudinal joint (see Figure 5). Transverse cold joints are constructed in a similar manner. After cutting back the rounded-off edge and wetting the vertical face, the paver is backed into place and the screed set to the proper elevation using shims sitting on top of the hardened concrete. The excess material should be pushed back as mentioned before, and a static pass made in the transverse direction across the first 1 ft (300 mm) of the freshly placed lane. The joint should be carefully rolled to insure a smooth surface transition across the joint.

c. Sawing of Contraction Joints. RCC pavement has been allowed to crack naturally in many previous projects to save the cost of sawing joints. However, this has probably resulted in larger crack openings, increased raveling, and higher maintenance costs than if cracking was controlled. Contraction joints may be sawn in RCC pavement to induce controlled crack formation. The weakened plane should be sawn at least one-fourth the slab depth using a 1/8 in. (3 mm) blade. Sawing of joints can commence when the concrete strength is sufficient to enable the saw to cut through the concrete with a minimum of spalling, tearing, or aggregate pullouts. The use of special green-cut saws which penetrate the pavement surface to only a depth of about 1 in. (25 mm) have been shown to be effective on at least one RCC paving project. The time of sawing is very important and usually ranges from 4 to 20 hrs after compaction, depending on weather conditions and other factors. To date, sawn transverse contraction joints in RCC pavement have typically been spaced from 30 to 60 ft (9 to 18 meters). These spacings may vary with different materials and thicker pavements, so optimum contraction joint spacing should be determined during test section construction. Local service records may also be helpful in establishing a joint spacing that will effectively control transverse cracking. Joint spacing greater than 40 ft (12 meters) should never be used without backup data.

d. Sealing Joints and Cracks. Rigid pavements that do not receive adequate joint and crack seal maintenance will rapidly deteriorate due to the intrusion of water and incompressible materials that migrate through and into the pavement joints and cracks. Incompressible materials lodge between the individual pavement slabs and parts of slabs restricting movement that allows for expansion and contraction. This restriction of movement causes spalling and cracking along the edges of the joints and cracks and can result in breakage and blowup of entire slabs. Water in the subgrade material causes a migration of fines that eventually results in loss of support under the edge of the pavement slab. Preparation and sealing of joints and cracks in RCC pavement should be done in accordance with CEGS-02580.

e. Load-Transfer Devices. The stiff consistency of RCC does not lend itself to application of load-transfer devices such as dowels or keyed joints. Until an efficient method is developed to insert and align dowels properly in RCC, the use of dowels should be limited.

f. Vertical Joints in Two Lift Construction. In two lift construction, care should be taken to align the transverse and longitudinal joints in the upper and lower lifts to form a uniform, vertical face through the depth of the pavement along the joint. If the edge of the upper lift is not even with the edge of the lower lift, the lower lift should be cut back even with the edge of the upper lift (Figure 6).

14. Curing.

a. General. The relatively rough or open surface texture of the compacted RCC pavement will tend to dry very quickly. To prevent this moist curing has been commonly recommended to prevent drying and scaling of the RCC pavement surface. For moist curing, the pavement surface should be kept continuously moist after final rolling for at least 7 days by means of a water spray truck, sprinkler (fog spray) system, wet burlap, or cotton mat covering. If burlap mats are used, they should be thoroughly wetted, placed on the RCC pavement so that the entire surface and exposed edges are covered, and kept continuously wet. An irrigation sprinkler system has been used to cure RCC pavement on some projects, but caution should be exercised so that the fines in the surface of the RCC pavement are not washed away by excessive pressure, particularly in the first few hours. Curing RCC pavement with water can generate considerable runoff and if not properly handled, can cause erosion or saturation of exposed subgrade. Curing with membrane-forming curing compound and asphalt emulsion applied at double the rates used on conventional concrete have been used successfully.

b. Effect of Moist Curing on Frost Resistance. Preliminary results of laboratory freezing and thawing tests indicate that RCC which has a sufficiently low water-cement ratio and has been moist cured for an extended period tends to be more frost-resistant. The improved frost resistance may be due to more complete hydration resulting in a reduction in fractional volume of freezable water at saturation, and/or by reducing the permeability of the RCC, making it more difficult to saturate under wet conditions.

c. Early Loading. All vehicular traffic should be kept off the RCC until the end of the curing period. If it is absolutely necessary, a water-spraying truck may be driven onto the pavement before that age, but any turns must be kept to a minimum. Water-spraying trucks or any other traffic should be kept to a minimum.

15. Quality Control and Assurance.

a. General. Quality control and quality assurance operations for RCC pavement are outlined in CEGS 02520. The philosophy behind the guide specification is a mixture of the "how-to-build" and "final product" philosophies. This type of specification provides some guidance to the contractor on the construction method, while outlining what is expected in terms of density, smoothness, thickness, and surface texture. No strength is specified because the Government is responsible for providing mixture proportions that, if mixed to the proper tolerances, compacted to the proper density and cured properly, will yield the desired strength. However, strength samples should be obtained and tested by the Government to insure that the desired strength was obtained.

b. Quality Control Operations. According to CEGS 02520, quality control operations for military RCC pavement projects are the responsibility of the contractor. Quality control consists of sampling, gradation, quality, and moisture testing of aggregates going into the concrete; checking the plant calibration regularly; conducting moisture-density relationship tests (ASTM D 1557) on the fresh RCC; measuring the in-place density and moisture content of the RCC by using a nuclear gage; checking the smoothness of the finished RCC with a straightedge; taking core samples from the RCC for measurement of density, strength, and thickness; and, if desired, fabricating RCC cylinders and beams.

c. Quality Assurance Operations. Quality assurance consists of providing the RCC mixture proportions, testing of cementitious materials and aggregates for quality, and testing in-place density, smoothness, surface texture, and thickness for acceptance. Quality assurance testing by the Government may also consist of randomly duplicating any quality control test to determine if consistent results are being obtained. Payment is based on the results of the quality assurance tests (density, smoothness, surface texture, and thickness) for each lot, which represents a days placement of pavement. If the quality assurance test results show deficiencies in any of these four areas, the payment for the lot is reduced, and the lot is rejected if the deficiency is too great.

d. Tests at Plant. Moisture content of the fine and coarse aggregates should be determined daily as necessary and appropriate changes made in the amount of mixing water. Washed sieve analysis tests should normally be performed on the combined aggregates each day at the beginning of the shift. The samples should be taken from the conveyor belt before the cement and fly ash is added to the combined aggregates. The amount of materials passing the No. 100 sieve should be determined during this analysis. Whenever the characteristics of the mixture change or a check on the ingredients is required, a proportioning check can be performed using, a washout test according to procedures in ASTM C 685 (Para. 6.5). This test may be performed on the combined dry ingredients on samples taken from the conveyor belt between the cement and fly ash hoppers and pugmill. By washing the dry ingredients over the No. 4 and No. 100 sieves and weighing the material in each size category, the approximate proportions of course aggregate, fine aggregate, cement and fly ash combined may be determined and checked against predetermined limits.

e. Field Density Tests. Field density tests should be performed on the RCC pavement using a nuclear density gage operated in the direct transmission mode according to ASTM D 2922, with the full-depth reading being used for control and acceptance. At least one field reading should be taken for every 100 ft (30 meters) of each paving lane. The readings should be taken as closely behind the rolling operation as possible. The reading should be adjusted using the correlation determined in the test section construction and checked against a specified density. Areas that indicate a deficient density should be rolled again with the vibratory roller until the specified density is achieved.

f. Obtaining Core Samples. The acceptance criteria for the thickness of the RCC pavement shall be based on appropriate tests conducted on cores taken from the pavement. Cores should be taken from the pavement when it is no less than 7 days old. One core should be taken at a random location selected within each sublot, which is one-fourth the size of a lot, and the thickness measured. The density and splitting tensile strength of the cores should be determined by the Government according to ASTM C 496 when the cores are 28 days old.

g. Smoothness. The finished surface of the RCC pavement should conform to the tolerances outlined in Table IV of CEGS 02520 when tested with a 12 ft straight edge. Smoothness should be checked as closely behind the finish roller as possible, and any excessive variations in the surface shall be corrected with the finish roller. particular attention should be paid to the smoothness across fresh and cold joints because this is usually a critical area for surface variations. A skilled vibratory roller operator is essential in minimizing smoothness problems.

h. Surface Texture. The final surface texture of an RCC pavement typically resembles that of an asphalt concrete pavement surface: a coarse surface texture with regularly spaced voids and inter-connected fissures. The final surface texture should be devoid of surface tears, check cracking, segregation, or rock pockets, surface patches, pumped areas, aggregate drag marks, loose aggregate, or exposed aggregate from washed fines.

I. Cylinder and Beam Fabrication. The fabrication of cylinders and beams during RCC pavement construction would be highly desirable as (1) an aid to the coring operation in checking the RCC strength and density, and (2) a means of establishing a database for developing future quality control criteria. If fabricated cylinders and beams are to be used as a quality control aid during construction, a correlation between their strength and density and that obtained from cores and sawed beams should be made during the test section construction. Results of this correlation should be sent to CEWES-GP-GT, 3909 Halls Ferry Road, Vicksburg, MS, 39180-6199, for addition to the above mentioned database.

j. Method of Cylinder and Beam Fabrication. Cylinders should be fabricated in the field by filling cylinder molds in three equal layers. Each layer is consolidated by vibrating each layer on a vibrating table having a frequency of 3,600 vibrations per minute, under a surcharge of 20 lbs (9 kg). Each layer should be vibrated until a mortar ring is visible around the entire periphery of the surcharge. Eight cylinders should be fabricated for every 300 cu yds (225 cu m) of RCC placed. Two cylinders should be tested each at 7, 14, 28, and 90 days. The cylinders should be tested for splitting tensile strength according to ASTM C 496. No procedure has been standardized for fabricating RCC beam specimens such as those used to determine concrete flexural strength. However, CRD-C-161 details a procedure that fills beam molds in two layers. Each layer is consolidated by vibrating each layer on a vibrating table having a frequency of 3,600 vibrations per minute, under a surcharge of 125 lbs (57 kg). The surcharge is uniformly distributed over the entire specimen area during molding and vibration continued until a ring of mortar forms around the complete periphery of the mold. Four beams should be fabricated during each shift of construction, two to be tested at 14 days and two at 28 days. The beams should be tested for flexural strength according to ASTM C 78.

k. Inspectors. Inspectors are vital in the quality control operations. At least one inspector should be stationed at the mixing plant and one at the job site to insure that a quality pavement is being built. At the mixing plant, the inspector should check mixing times occasionally and spot-check the consistency and appearance of the mix coming out of the plant. He/she should also coordinate the aggregate moisture content tests, the gradation tests, calibration of the plant, and washout tests to see that they are performed properly and at the correct frequency. At the job site, the inspector should make sure that the base course and cold joints are moistened before the RCC is placed against them and that the RCC is placed and compacted within the proper time limitations. He/she should check the paver operation to insure that proper grade control is continuously maintained, and to make sure no gaps or discontinuities are left in the pavement before rolling. The inspector should make sure the roller begins compaction at the proper time and that the proper rolling pattern and number of passes is used. He/she should make sure adequate smoothness across joints is achieved and that the surface texture is tight after final rolling. The final compacted pavement thickness should be spot-checked by the inspector and corrected accordingly, if appropriate. He/she should make sure that the curing procedures are implemented as specified. He should also insure that all exposed surfaces of the RCC pavement are kept moist at all times. He/she should also coordinate the nuclear gage density test, the coring procedures, cylinder and beam fabrication, and the surface smoothness tests to see that they are performed properly and at the required frequency.

Table 1
RCC Pavement Projects in the United States

Location	Application(s)	Date of Construction	Area (sq yd)	Thickness (in.)	RCC Cost ($/sq yd)	Savings[1] (% PCC)
1. Vicksburg, MS	test section	Sep 1975	140	6 & 10	---	---
2. Vicksburg, MS	test section	Dec 1976	970	4 & 6	---	---
3. Ft. Stewart, GA	tank trail	Jul 1983	470	9 to 13	---	---
4. Ft. Gordan, GA	tank trail	1983	590	10 to 13	---	---
5. Ft. Hood, TX	tank hardstand	Jul 1984	20,000	10.0	16.11	---
6. Ft. Stewart, GA	tank trail	Sep 1984	783	4/6/8/10	---	---
7. Ft. Lewis, WA	test section	Oct 1984	1,788	8.5	---	---
8. Hanover, NH	test section	Nov 1984	50	8.0	---	---
9. Austin, TX	hike/bike trails	1984	12,000	8 to 10	---	---
10. Ft. Lewis, WA	tank road	1984	2,667	9.5	---	---
11. Houston, TX	intermodal yard	Jan 1985	53,666	18.0	37.73	58
12. Tacoma, WA	shipping yard	Apr 1985	45,000	12/17	50.40	22
13. Portland, OR	county road	Nov 1985	4,000	7.0	---	20
14. Austin, TX	municipal street	1985	2,720	8.0	---	---
15. Colorado Springs, CO	ready mix plant	1985	11,860	8.5	---	---
16. Ft. Lewis, WA	rocket facility	Jun 1986	15,700	8.5	13.69	---
17. Wright-Patterson AFB, OH	parking area	Oct 1985	27,000	8.0	---	---
18. Denver, CO	shipping yard	Apr 1986	136,000	15/20	---	10
19. Boston, MA	port facilities	Jun 1986	27,000	18.0	---	---

[1] The savings reported may be somewhat exaggerated, because the allowance for thinner sections of conventional concrete due to load transfer was not considered in all cases.

(Sheet 1 of 3)

Table 1
(Continued)

Location	Application(s)	Date of Construction	Area (sq yd)	Thickness (in.)	RCC Cost ($/sq yd)	Savings[1] (% PCC)
20. Ft. Bliss, TX	tank hardstand	Jul 1986	87,900	8.0	15.43	14
21. Ft. Lewis, WA	Equipment shop	Jul 1986	15,700	8.5	13.69	41
22. Ft. Bragg, NC	vehicle maint.	Jul 1986	11,600	8.0	17.85	22
23. Tooele Depot, UT	ammunition storage	Oct 1986	3,333	15.0	45.80	---
24. Ft. Benning, GA	maintenance yard	Nov 1986	23,630	7.5	14.71	33
25. Tacoma, WA	shipping yard	1986	55,000	15.0	50.40	22
26. Portland, OR	aircraft apron	1986	40,970	14.0	15.84	32 (AC)
27. Denver, CO	railroad trailer lot	1986	32,000	6.0	---	---
28. Hugo, OK	Co-op coal yard	1986	37,400	13.0	---	---
29. Joliet, IL	coke storage pad	1986	11,100	10/14	---	---
30. Boston, MA	port facilities	1986	54,000	18.0	---	---
31. Boston, MA	port facilities	1986	75,000	15.0	---	---
32. Austin, TX	shipping terminal	Apr 1987	90,000	7/8	8.00	25 (AC)
33. Aberdeen PG., MD	instruction yard	May 1987	21,160	8.5	---	---
34. Ft. Campbell, KY	equipment shop	Jul 1987	66,500	7.5	13.84	33
35. Austin, TX	municipal street	Aug 1987	14,670	7.0	10.75	---
36. Ft. Hood, TX	tank hardstand	Oct 1987	63,900	8.0	10.44	---
37. Ft. Drum, NY	tank hardstands	Jun 88/Oct 89	420,000	10.0	17.25	30

[1] The savings reported may be somewhat exaggerated, because the allowance for thinner sections of conventional concrete due to load transfer was not considered in all cases.

(Sheet 2 of 3)

Table 1
(Concluded)

Location	Application(s)	Date of Construction	Area (sq yd)	Thickness (in.)	RCC Cost ($/sq yd)	Savings[1] (% PCC)
38. Ft. Hood, TX	tank hardstand	Aug 1988	18,600	9.0	17.88	---
39. Springhill, TN	automobile plant	Nov 88/Jul 89	650,000	6/8/10	9.00	---
40. Ft. Hood, TX	wash facility	Sep 1989	20,000	9.0	17.38	---
41. Ft. Hood, TX	tank trail	Sep 1989	5,200	9.0	---	---
42. Camp Lejeune, NC	hardstands	1989	24,975	8.0	---	---
43. Camp Lejeune, NC	HQ complex	1989	12,700	8.0	---	---
44. Ft. Benning, GA	tank trail/wash	1989	45,000	9.0	---	---
45. Last Chance, CO	roads/parking	1989	50,000	5.5/7/10	---	---
46. Tacoma, WA	log sort yard	1989	48,000	9/15	---	---
47. Bartow, FL	roads/parking	1990	5,555	6.0	18.00	---
48. Tracy, CA	distribution center	Sep 1991	270,000	7/8	---	---
49. Hollister CA	haul road	Apr 1992	4,667	7/8/9/10	---	---

[1] The savings reported may be somewhat exaggerated, because the allowance for thinner sections of conventional concrete due to load transfer was not considered in all cases.

(Sheet 3 of 3)

Table 2
RCC Pavement Mixture Proportions

Location	Area	Cement		Flyash		Water Weight[1]	W/ (C+F)[2]	RCC Flexural Strength[3]	Coarse Aggregate		Fine Aggregate	
		Type	Weight[1]	Class	Weight[1]				Max. Size	Weight[4]	Max. Size	Weight[4]
Austin, TX	Central Freight	I	260	C	260	182	0.35	550	3/4 in.	1610	No. 4	1610
	Tuscany Way	I	260	C	260	182	0.35	550	3/4 in.	1610	No. 4	1610
Ft. Campbell, KY	63rd Chem. Co.	I	400	F	212	205	0.34	760	3/4 in.	1785	No. 4	1465
Ft. Drum, NY	PN69A	I	450	F	150	210	0.35	8205	3/4 in.	2321	NYDOT 1B	988
	PN69B	I	450	F	150	210	0.35	8205	3/4 in.	2321	NYDOT 1B	988
	PN187	I	450	F	150	210	0.35	8205	3/4 in.	2321	NYDOT 1B	988
	PN203	I	450	F	150	210	0.35	8205	3/4 in.	2321	NYDOT 1B	988

[1] Weight in pounds per cubic yard.
[2] Water/(Cement + Flyash) ratio, by weight.
[3] 28-day, third point loading.
[4] Weight in pounds per cubic yard, saturated surface-dry.
[5] Flexural tests on beam samples cut from the RCC approximately one year after placement had average flexural strengths of 851 psi and 598 psi in the top and bottom halves of the pavement, respectively.

(Sheet 1 of 2)

Table 2
RCC Pavement Mixture Proportions

Location	Area	Cement		Flyash		Water Weight[2]	W/ (C+F)[2]	RCC Flexural Strength[3]	Coarse Aggregate		Fine Aggregate	
		Type	Weight[1]	Class	Weight[1]				Max. Size	Weight[4]	Max. Size	Weight[4]
Ft. Hood, TX	Bldg 26027											
	Mix 1	I	312	C	155	158	0.34	830	1 1/2 in.	2275	No. 4	1372
	Mix 2	I	376	C	186	130	0.23	830	3/4 in.	2165	No. 4	1366
	Bldg 38033	I	293	F	146	176	0.40	800	7/8 in.	2006		
	Wash Rack	I	293	F	146	176	0.40	800	7/8 in.	2006	No. 4	1669
	Tank Trail	I	293	F	146	176	0.40	800	7/8 in.	2006	No. 4	1669
Spring Hill, TN (Saturn Plant)	Zenith Road	I	400	F	150	192	0.35	600	3/4 in.	1890	No. 4	1550

1 Weight in pounds per cubic yard.
2 Water/(Cement + Flyash) ratio, by weight.
3 28-day, third point loading.
4 Weight in pounds per cubic yard, saturated surface-dry.
5 Flexural tests on beam samples cut from the RCC approximately one year after placement had average flexural strengths of 851 psi and 598 psi in the top and bottom halves of the pavement, respectively.

(Sheet 2 of 2)

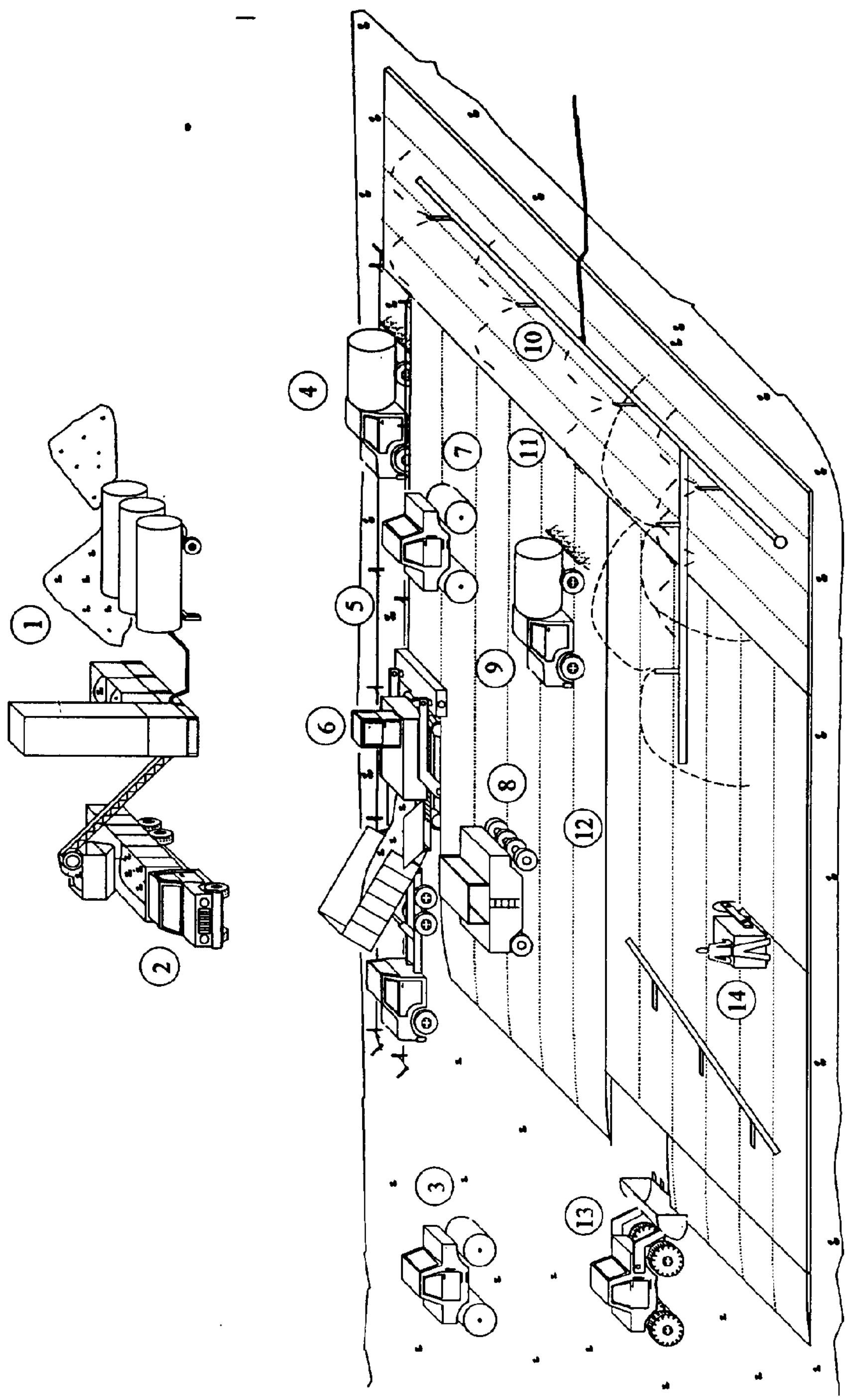


Figure 1. Typical RCC Pavement Construction Process

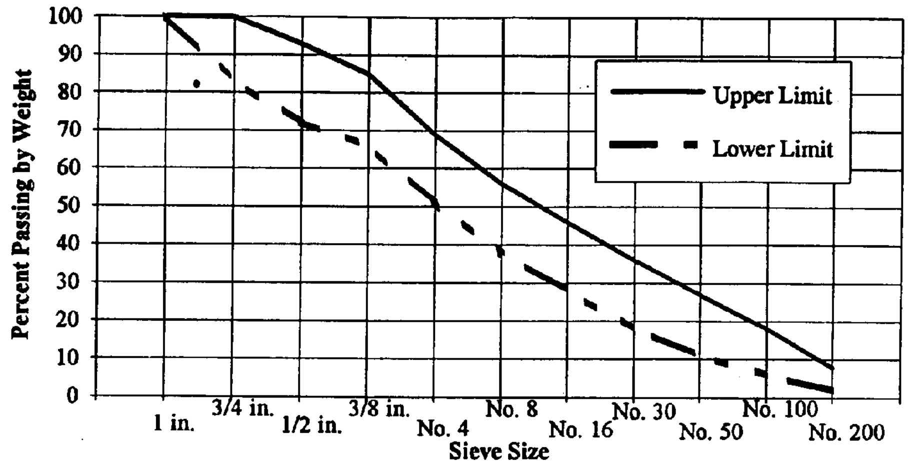


Figure 2. Recommended Gradation Band for RCC Pavements

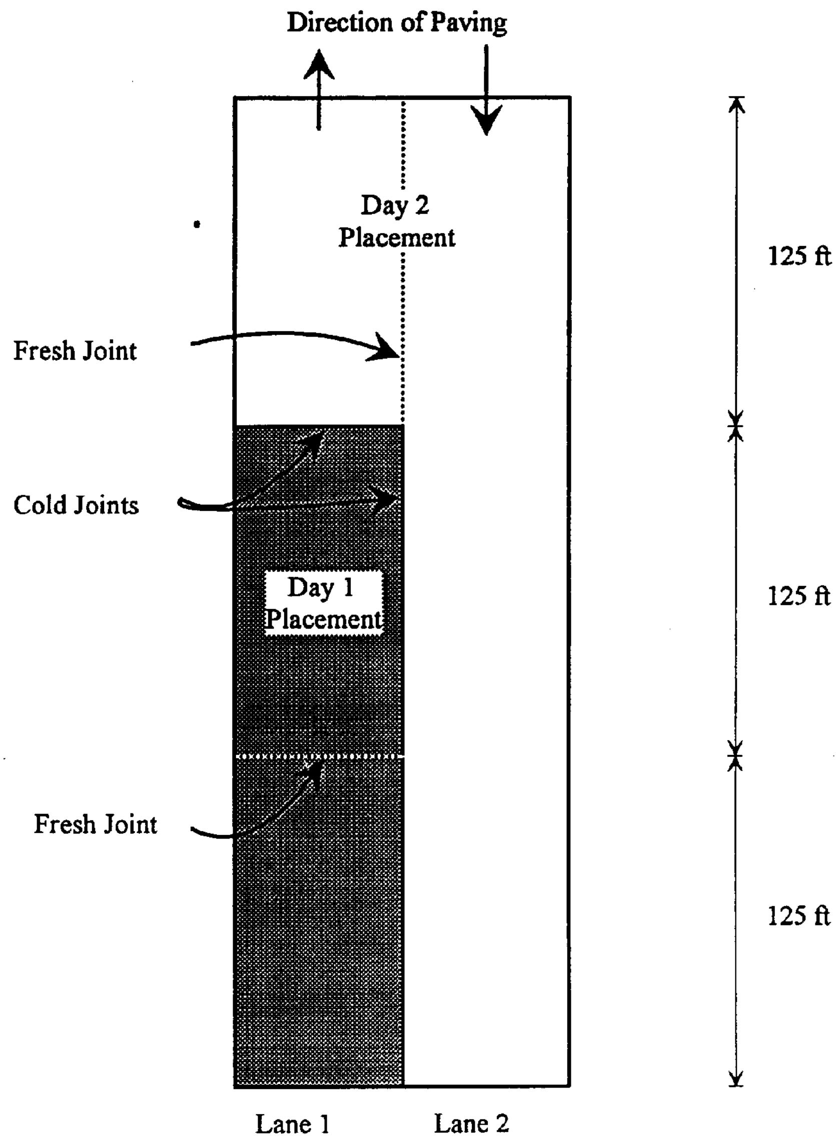


Figure 3. Recommended Layout of Test Section

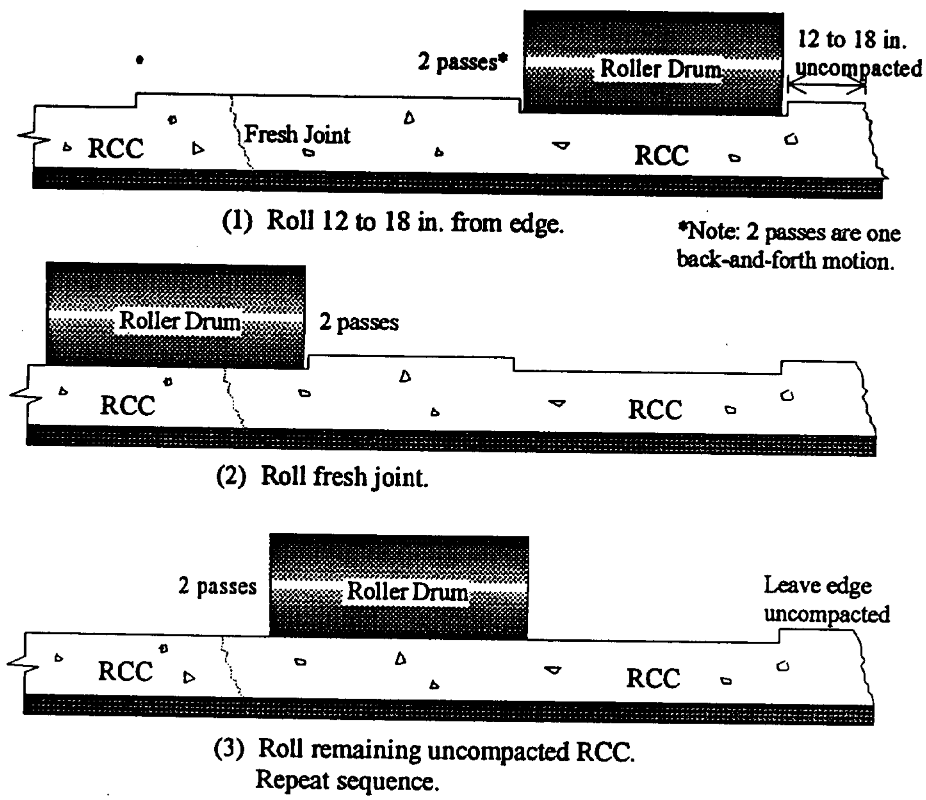
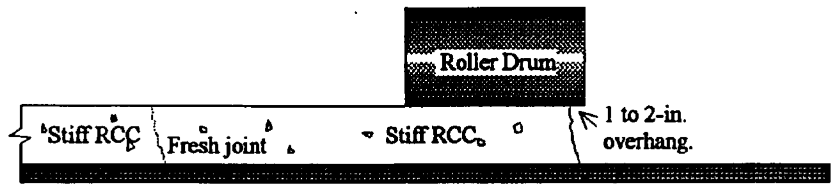
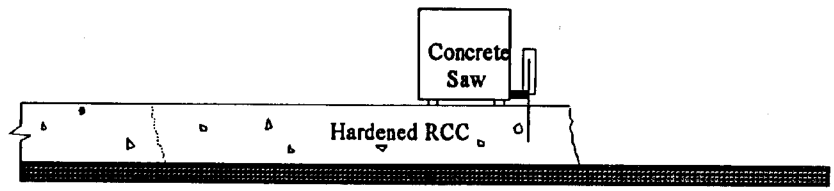


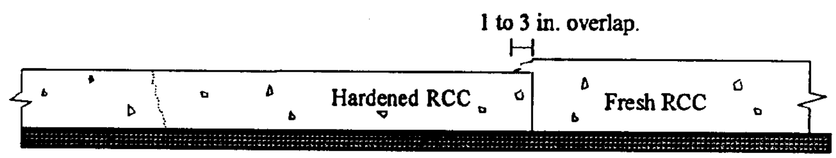
Figure 4. Compaction Process for Fresh Joints



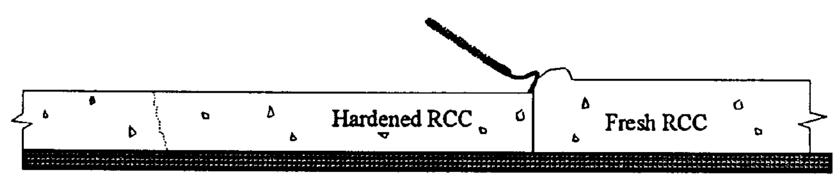
(1) Roll outer lane of last lane.



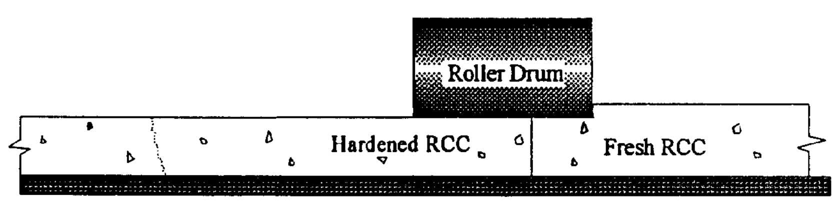
(2) Trim edge with concrete saw, either partial or full depth cut.



(3) Wet hardened RCC edge, then place adjacent lane.



(4) Push back fresh RCC with rakes.



(5) Roll cold joint with two or more static passes.

Figure 5. Compaction Process for Cold Joints

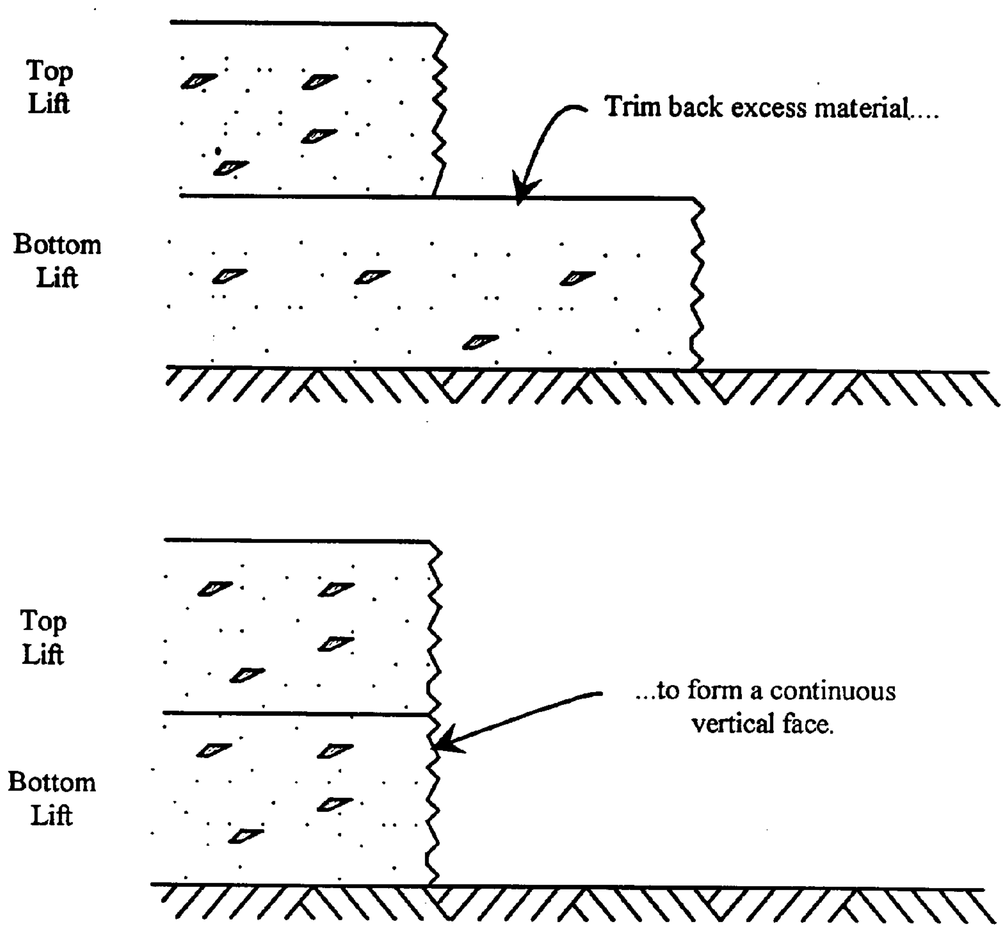


Figure 6. Vertical Joints for Two Lift Construction