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Designer's Guide for UFGS 32 13 16.16 Roller Compacted Concrete (RCC) Pavement

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DESIGNER'S GUIDE FOR UFGS-32 13 16.16

ROLLER COMPACTED CONCRETE (RCC) PAVEMENT

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1. INTRODUCTION

Roller Compacted Concrete

Roller-Compacted Concrete (RCC) is a no-slump concrete that is placed using asphalt concrete paving machines and compacted by vibratory rollers. The RCC pavements are lower cost alternative to conventional jointed concrete pavements and generally provide structural performance that is equivalent to that of conventional jointed concrete pavements for equal design features. However, the RCC pavement does not incorporate all the features of conventional jointed concrete pavement. The primary features that cannot be considered in RCC pavements include the following:

1. Use of dowel bars and tie-bars at joints
2. Use of reinforcement
3. Use of an air-entraining admixture to develop an entrained air-void system in the concrete
4. Hand finishing or hand tooling of the final surface
5. Texturing of the surface (e.g., tining)
6. Highway type pavement smoothness requirements
7. Highway type surface friction properties.

Diamond grinding RCC pavements can provide the surface smoothness and surface friction properties comparable to conventional concrete pavements.

RCC is placed in a single lift when the compacted thickness of the RCC is 8 in. or less. For compacted thickness greater than 8 in, RCC is typically placed in two or more lifts that are bonded, so as to behave monolithically. The cementitious materials used in the RCC mixture (about 13 to 15% by total weight of the concrete) are of the same order as that used for conventional paving concrete. RCC requires use of dense graded aggregates that contain a higher percentage of fine aggregate than for conventional paving concrete. The fine aggregate facilitates dense compaction and produces a tight surface under rolling. RCC is not air-entrained. The freeze-thaw durability of well constructed RCC is considered adequate for military applications for most continental US locations. For military applications, transverse contraction joints may be required on most projects.

Military Applications and Performance

The use of RCC pavements is of reasonably recent origin. Most of the larger RCC pavements in the US have been constructed since the early 1980s. Most of the early applications were for off-highway facilities, such as log sorting yards, forest haul roads and port facilities. Recently, there has been a renewed interest for considering RCC for highway application, including use for highway shoulders and rural highways.

The military applications of roller compacted concrete (RCC) pavements is of recent origin too. The oldest large scale applications of RCC pavements were about 25 years ago at Fort Hood. During 1988, over 400,000 square yards of RCC pavement was constructed for the hardstand facility at Fort Drum. The early military RCC pavement projects were designed and constructed using the state of technology existing then. As a result, many of the early RCC pavements did not exhibit good performance, primarily with respect to surface durability. The RCC pavement construction technology has improved considerably over the last 20 years and new well designed and well constructed projects can be expected to provide the desirable performance for a range of military applications, including hardstands and tank trails. The military continues to use RCC pavements for a wide range of applications, including tank hardstands, equipment shop facilities, tank trails, and parking areas. A recent application of RCC pavement was at Fort Carson, Colorado, during 2008.

When a RCC pavement is considered for military applications, it is important that the agency be aware of the limitations of the RCC pavement with regards to the surface finishing (texture) and the appearance of cracking if transverse joints are not provided. In addition, there should be appreciable cost benefit for considering a RCC pavement compared to a conventional jointed concrete pavement. The project size may also influence the economic viability of considering RCC pavement as the project size may determine whether it is cost-effective to mobilize the specialized equipment needed to construct RCC pavements, especially if experienced RCC pavement contractors are not available locally.

UFGS 32 13 16.16 Specification

The UFGS 32 13 16.16 specification covers the requirements for construction of RCC pavement for Army, Navy and Air Force heavy-duty roads and hardstands. The guide specification is edited, as necessary, for project specific requirements by adding, deleting, or revising text. The specification provides the necessary language to specify the items to construct a durable RCC pavement conforming to the lines, grades, thickness, and typical cross sections shown on the plans.

A primary assumption of the UFGS 32 13 16.16 specifications is that the constructed RCC pavement will exhibit failure at the end of the project life due to anticipated traffic loadings and not due to material deficiencies that are a result of construction quality and soundness of materials used. Thus, <u>durable roller compacted concrete is that concrete that will not exhibit materials or construction related failures during the service life of the pavement</u>.

The design and construction of RCC pavements should involve the same level of engineering competency as for conventional concrete pavements. Except for the method of construction, RCC pavements are expected to perform almost similar to jointed concrete pavements and the service life expectations should be similar. The RCC pavements, as constructed, do not provide smoothness, surface finish and texture comparable to conventional jointed concrete pavements.

Construction End Product Requirements

All work and all materials furnished for the construction of the roller concrete pavements for military applications should be in reasonably close conformity with the lines, grades, grading sections, cross sections, dimensions, material requirements, and testing requirements that are specified (including specified tolerances) in the contract, plans or the UFGS 32 13 11 specification. A concern with RCC pavement construction is that both the process control testing and acceptance testing deal primarily with the as-delivered concrete. There is little testing performed to characterize the properties of the as-placed concrete. Therefore, there is a need to ensure that the fresh concrete that is accepted for placement can be placed and compacted without segregation or excessive surface tear due to the rolling operation.

The end product requirements related to the concrete and RCC pavement, as specified in USGS 32 13 16.16, are listed below:

1. Requirements that do not incorporate a payment adjustment
    a. Surface finish
    b. Concrete strength
2. Requirements that incorporate a payment deduction
    a. Concrete compaction
    b. Surface smoothness
    c. Concrete thickness

It is important that all parties involved in the RCC Pavement construction project have a common understanding about the surface finish that needs to be achieved. The acceptable surface finish is one that is accepted at the test section (discussed later). Typical examples of the variability of the RCC pavement surface finish are given in Figure 1.

Figure 1 – Examples of RCC Pavement Surface Finish

In addition to the end product requirements listed above, the contractor is responsible for ensuring that all materials, equipment, and processes used during the construction of the RCC pavement meet the requirements of the USGS 32 13 16.16 specification.

2. PLANNING ITEMS

RCC for Military Pavement Applications

The RCC pavement behavior under traffic loading is similar to that of jointed concrete pavements. Joints may or may not be specified. When joints are not specified, transverse cracking will develop in the RCC pavement at spacing of 20 to 40 ft. The load transfer at the cracking locations is achieved by means of aggregate interlock. Also, when joints are specified, the load transfer at the transverse joints is provided by aggregate interlock. With respect to the longitudinal joints, there are two types of joints – fresh joints and cold joints. Fresh joints result when the two adjacent lanes are constructed within a short time period and longitudinal joint can be rolled in tandem. Cold joints result when there is a larger delay in placing two adjacent lanes. For this case, the longitudinal edge of the first lane is typically trimmed back about 6 to 12 in. There is effectively very little load transfer across cold longitudinal joints.

RCC can be proportioned to achieve strength levels comparable to conventional paving concrete, typically, compressive strength of 4,000 to 5,000 psi and corresponding flexural strength of 600 to 700 psi. Because of the dry nature of the RCC mixture and the method of production, air cannot be entrained effectively in RCC mixtures. However, the hardened RCC has a dense matrix and very low permeability. As a result, the RCC pavements have been successfully used in a range of environmental conditions without impacting on pavement durability or serviceability.

RCC Pavement Thickness Requirements

For military applications, primarily hardstands and tank trails, the RCC pavement thickness can be determined in accordance with the procedure presented in Chapter 17 of UFC 3-250-01FA – Pavement Design for Roads, Streets, Walks, and Open Storage Areas, January 2004. When transverse jointing is not used and the RCC is allowed to crack naturally, the RCC pavement is typically designed on the basis of a free edge condition, that is, it is assumed that no load transfer is available at transverse joints and cracks and across longitudinal joints. This is based on limited tests conducted at several army installations that indicate that load transfer across cracks, spaced at 40 to 60 ft, was less than about 18%. When transverse joints, at short spacing of about 30 to 40 ft, are specified, it can be assumed that there will be good load transfer across these joints. As a result, the thickness determined in accordance with the procedure of Chapter 17 of UFC 3-250-01FA, can be reduced by about 10% to account for about 25% load transfer across the transverse joints.

Also, it is generally assumed (and enforced by specification) that when the RCC is placed in multiple lifts, there are no unbonded interfaces between the lifts and that the RCC behaves as a single layer, that is, monolithically.

The RCC pavement lane width should not exceed 20 ft. If RCC paving width is greater than 20 ft, intermediate longitudinal contraction joints should be provided at a spacing not less than 10 ft. For military applications, transverse contraction joints maybe required at spacing not to exceed 40 ft, depending on RCC pavement (slab) thickness.

Thickness design procedures, specifically for off-highway RCC pavements, have also been developed by the Portland Cement Association (PCA). These procedures typically result in RCC pavement thickness that is about 10 to 15 % more than using conventional jointed pavement design procedures to account for the higher variability of the RCC material and poor load transfer along longitudinal construction joints.

Construction Equipment Availability

Before considering the use of RCC pavements, it is advisable to determine availability of qualified contractors and equipment in the local area. Well constructed RCC pavement require the use of high density asphalt pavers that are capable of imparting compactive force as the concrete is extruded out of the paver. It is necessary to achieve a high density for the concrete and the high density pavers should be capable of producing concrete with a density of 90 to 92% for the full lift thickness. An example of an extruded RCC from a high density asphalt paver is shown in Figure 2. The additional densification, upto 96 to 98%, is then achieved using steel drum vibratory rollers with 10 ton minimum static weight. Rubber-tired rollers are used for the final rolling to achieve a smooth and tightly closed surface. It should be noted that there are only a few contractors in the U.S. with the equipment and experience to construct RCC pavements.

Figure 2 – Extruded RCC from a High Density Asphalt Paver

The attributes of various paving machines that can be used for RCC placement are summarized below:

1. High density asphalt pavers:
    a. Tamping bars used to densify the concrete
    b. High density (90 to 92%) achieved for material exiting the paver
    c. High volume placement
    d. Smoother RCC surface
    e. Good surface texture
2. Conventional asphalt pavers
    a. Density of 85 to 90% achieved for material exiting the paver
    b. Relatively smooth RCC surface
    c. Relatively good surface texture
3. Aggregate spreaders
    a. Low initial compaction for material exiting the spreader
    b. Variable (typically poor) surface smoothness and texture

The use of aggregate spreaders for placing the concrete should not be allowed for military projects and use of conventional asphalt paving machines is not recommended for RCC that has compacted lift thickness greater than 6 in.

In addition to the placement equipment, high production RCC placement necessitates use of a continuous mixing concrete plant, typically, pug mills that are capable of producing concrete at a rate of 250 cy/hour. For smaller projects, requiring less than about 5,000 cy of RCC, conventional batch type concrete plants may be adequate. In any case, concrete production must match the concrete placement rate. Stop and go operation in RCC placement are not acceptable.

3. GETTING READY FOR RCC PLACEMENT

Subgrade/Subbase/Base

The preparation of the subgrade, subbase, and base is very critical for RCC placement. Because RCC is roller compacted, it cannot be effectively compacted to the desired density if the layers under the concrete are not adequately compacted and do not have adequate strength. The base layer should be compacted uniformly to 95% or greater of the maximum dry density, in accordance with ASTM D 1557. It is generally expected that the compacted base layer will have a CBR value greater than 40. This can be achieved using a granular based that meets the rigid base gradation or the flexible subbase gradation in UGFS 32 11 16.

Grade Protection

The completed base should be protected before placement of RCC. Any areas of the base that are damaged due to use by construction or other traffic should be repaired.

There should be no standing water on the base before placement of the RCC. The base surface should be kept moist, but without standing water, just prior to placement of the RCC.

Drainage Considerations

RCC pavement design should incorporate drainage considerations similar to conventional jointed concrete pavements. Since permeable bases cannot be used with RCC pavements, it is necessary that the granular base be free draining and non-erodible and that the RCC surface be graded to accommodate rainwater drainage at the surface.

4. CONCRETE MATERIALS AND MIXTURE

Basic Considerations

The concrete used for RCC has several different attributes compared to conventional paving concrete. These attributes are:

1. The roller compacted concrete is a very dry mixture and the conventional concepts of concrete workability and water/cementitious materials ratio do not apply to RCC mixtures.
2. The RCC is compacted. Therefore, the potential for aggregate segregation needs to be eliminated as segregated aggregates will not allow dense compaction of the drier concrete mixture. The aggregate segregation risk is minimized by requiring use of dense graded aggregates. A single aggregate is typically used with gradation similar to that used for asphalt concrete.
3. The aggregate maximum size for RCC is 5/8 in. or ¾ in. The smaller maximum size aggregate produces a very tight finish at the surface.
4. The RCC mixture has a higher portion of finer aggregate. This ensures that the compacted concrete matrix is dense and also aids in producing a tight surface finish.

Aggregates

Aggregates are a key component of concrete and can affect the properties of fresh and hardened concrete. Aggregate selection should allow for maximizing the volume of aggregate in the concrete mixture in order to minimize the volume of cementitious paste without compromising the strength, durability and the roller-compactibility of the concrete mixture.

Aggregates should meet the quality requirements stated in UFGS-32 13 16.16.These requirements are based on ASTM C 33 requirements to ensure that the concrete will not exhibit any materials related issues and that the concrete will be durable for the service conditions.

The maximum aggregate size needs to be as small as possible to ensure a tight surface finish. For military applications, the recommended nominal maximum size of aggregates is ¾ in. Use of larger size maximum aggregate will result in a coarser surface texture that may exhibit early surface wear. As stated, the aggregate needs to be well-graded (dense-graded) to ensure that the RCC can be densely compacted. When a pugmill is used to produce the RCC, a single-sized aggregate is typically used. When a batch plant is use for RCC production, two or more aggregate sizes may be blended together to produce the well-graded aggregate.

Cementitious Materials

Cementitious materials include hydraulic cements such as portland cement and slag cement (also often referred to as ground granulated blast furnace slag (GGBFS) but slag cement is increasingly becoming the preferred term for this product) and pozzolanic materials such as fly ash, natural pozzolans, and silica fume. Slag cement and pozzolanic materials are also referred to as supplementary cementitious materials (SCMs). The cementitious binder for the concrete mixtures may consist of portland cement alone or a combination of portland cement with one or more supplementary cementitious materials. The portland cement and SCM may be combined at the plant during concrete production, or they may be purchased as a blended hydraulic cement from the producer.

The use of supplementary cementitious materials may offer the potential for improved performance of concrete and/or reduced cost. These materials, as partial replacement of portland cement, may provide some benefits more economically and sometimes more effectively than use of 100% portland cement. Military airfield concrete pavements have routinely used SCMs for decades.

A key concern with use of certain aggregates is the development of alkali-silica reaction (ASR) in the concrete. The development of ASR is very detrimental to the performance of concrete pavements, including RCC pavements. For guidance on ASR related testing and guidance, the reader is referred to the procedures and criteria included in USGS 3213 11 specification.

The common cementitious materials used for RCC include the following:

1. Portland Cement

    a. ASTM C 150 – Portland cement
    b. ASTM C 595 – Blended cement
        i. Type IS cement – containing ground granulated blast furnace slag
        ii. Type IP – containing pozzolan (flyash or natural pozzolan)
2. Supplementary Cementitious Materials
    a. Flyash (as per ASTM C 618)
        i. Type F (preferred)
        ii. Type C (if ASR is not a consideration)

   b. Slag (as per ASTM C 989)
   c. Natural pozzolans (as per ASTM C 618) (not used for pavement applications in continental US)
   d. Silica fume (not used for pavement applications in continental US)

The supplementary cementitious material (SCM) use is common in conventional paving concrete and its use is encouraged for RCC. No special precaution need to be taken when using the SCM. The use of the SCM may affect the water requirement. However, the optimum water content to be used is as determined during the mixture proportioning studies.

<u>Notes:</u>

1. Cementitious material sources should be identified for each cement load. A change in cementitious material source should require submittal of new concrete mixture proportions. Cementitious materials from different manufacturers, even if meeting the same ASTM type designation, may still vary significantly.
2. The Government quality assurance program may want to retain samples of the portland cement and SCMs used in the project, and if questions concerning these materials arise, they may be independently tested by an approved laboratory.

The supplementary cementitious content for military RCC pavements should conform to requirements given in Table 2 in the UFGS 32 13 11 specification.

Chemical Admixtures

Chemical admixtures are commonly used in conventional paving concrete to manipulate the properties of the fresh and hardened concrete and their use is well established. These admixtures are used to provide entrained air in the concrete and to change the set time of the concrete. However, for RCC pavement applications, air entrainment is typically not specified and therefore no attempt is made to entrain air. Roller compacted concrete has been used successfully without air entrainment at projects in northern US and in Canada. The primary distress due to lack of air entrainment is the loss of a thin layer (about ¼ in. thick) of the surface paste/mortar during the early years for projects constructed in the freeze environment.

Water reducing and retarding admixtures (WRRA) (Type A or Type D, as per ASTM C 494) are sometimes used by contractors to extend the time available for concrete placement and roller compaction. The WRRA use if not effective when a pugmill is used for concrete production.

Water

The water quality requirements are the same as for conventional paving concrete.

Concrete Requirements

The two most important attributes of the RCC are strength and in-place density. RCC can be designed so that it can achieve the desired strength (flexural or compressive) after it has been compacted and cured. Concrete pavements (conventional and RCC) are designed on the basis of flexural strength. However, field acceptance of concrete for military pavement application is on the basis of compressive strength.

For a given cementitious content, the most economical design of the RCC is achieved when the mixture is compacted close to its maximum compactable density. The RCC construction specifications typically require RCC to be compacted to an average dry density of 98% of the maximum dry density. The maximum dry density is determined using the modified Proctor test (ASTM D 1557). The in-place maximum density under roller compaction is typically achieved when the RCC mixture is just a little wet of the optimum moisture content as determined using the ASTM D 1557 procedure. The maximum density for RCC is obtained when a dense graded aggregate is used and the mixture has just enough paste to coat all aggregates in the mixture and fill any voids that may exist between aggregates. It is therefore important for aggregates to achieve point to point contact and not exhibit segregation.

Concrete Mixture Proportioning

The RCC mixture delivered to the paving machine and exiting the paver must be dry enough to be able to support a vibratory roller without significant settlement and be wet enough to allow the paste and aggregates to be redistributed under roller vibratory roller compaction to achieve high density.

As indicated, the most economical mixture to be used for RCC is one that requires the least amount of the cementitious materials to achieve the require strength levels. For RCC, this requires that concrete must be able to be compacted as densely as possible. The mixture proportioning methods for RCC take into account both of these considerations.

The two most common methods for the proportioning of the RCC are the following:

1. Concrete Consistency Method, as typically specified by the Corps of Engineers for military RCC pavement applications
2. Soil Compaction Method

The fundamental assumption in both these method is that the resulting concrete mixture can be roller compacted to achieve the maximum density possible. For the specified design strength (flexural or compressive), the mixture proportioning study in the laboratory provides the following:

1. Acceptable aggregate – establish combined aggregate gradation and maximum aggregate size

2. Cementitious material content
3. Water content (just wet of the optimum water content required to produce concrete with a maximum density)

In the Concrete Consistency Method, the concrete ingredients are selected to meet a specified consistency as determined by the Vebe apparatus. The method is based on ASTM C1170 / C1170M - 08 Standard Test Method for Determining Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table (Procedure A). The test principle is to measure the time for the concrete to be consolidated by vibrating in a cylindrically shaped mold. The longer the time, the drier/lesser workable is the concrete. Vebe times of RCC mixtures is generally from 20 to 40 seconds

The Soil Compaction Method attempts to simulate the compaction energy imparted by vibratory rollers. The method incorporates the ASTM D 1557 procedure, commonly referred to as the modified Proctor method. The use of the standard Proctor method (ASTM D 698) is not recommended for RCC pavement applications. The modified Proctor method determines an optimum water content that results in the maximum dry density of the compacted concrete for a given proportion of the cementitious materials and the selected aggregate. The mixture proportioning steps are as follows:

1. Select the cementitious materials, the proportion of each material and the total material to be used per cubic yard of the RCC
2. Select a water content. Typically, four to five water contents will be required to establish the Proctor curve shown in Figure 4.
3. For each water content, select the amount of concrete that will result in one cubic yard of concrete when mixed with the cementitious materials and the water, assuming zero air content in the mixture.
4. Mix the concrete ingredients thoroughly.
5. Compact the mixture in the 6 in. diameter Proctor test mold, using the compactive effort specified in ASTM D 1557.
6. Measure the wet density of the compacted mixture and determine the dry density.
7. Repeat Steps 2 to 5 using different water contents.
8. Plot the water content against the computed dry density, as shown in Figure 3.
9. Determine the maximum dry density and the optimum water content that will produce the maximum dry density.
10. Prepare at least three compressive strength cylinders using the concrete mixture at optimum moisture content following the procedure of ASTM C 1435. In this procedure, a standard vibratory hammer is used to compact the concrete in the cylinder mold, as shown in Figure 4.
11. Repeat steps 1 to 10 using different total cementitious content.
12. Test the moist-cured compressive strength cylinders at the specified age, typically 28 days.
13. Plot cementitious content versus average compressive strength.
14. Select the cementitious content that will produce the desired concrete compressive strength at the specified age. This cementitious content is the

design cementitious content. Determine the associated water content. For field placement, the water content should be about ½ to 1% wet of this water content.

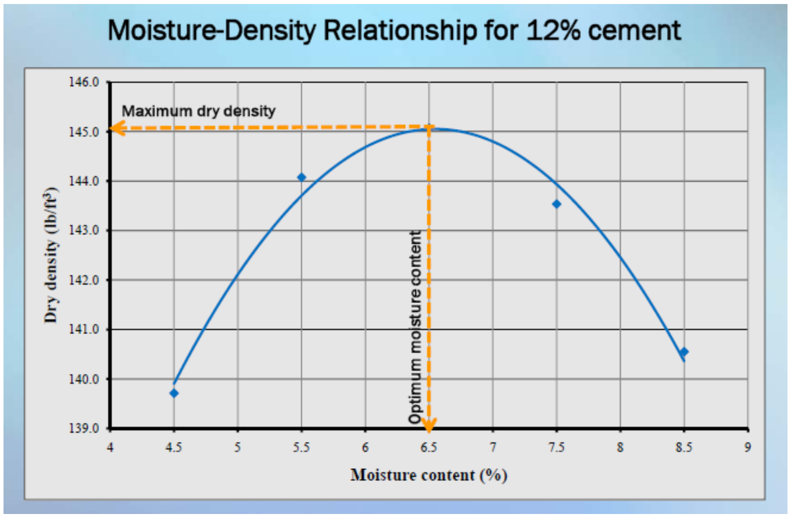

Figure 3 – Proctor Curve for RCC Mixtures

Figure 4 – Preparation of a Strength Test Cylinder using a Vibratory Rammer

The concrete that is produced in the laboratory in accordance with the above procedure can be placed by a high density paving machine and roller compacted to achieve in-place density of 98% or higher. THE USGS 32 13 16.16 specification requires the average in-place density for a lot to be 98%, with no measured density values to be less than 96%.

5. CONCRETE PRODUCTION AND TRANSPORT

The RCC mixture may be produced using a central batch plant or a pugmill that produce the mixture on a continuous basis. For military applications, use of a pugmill is recommended for projects that require 10,000 or more cubic yards of RCC. Pugmills can produce RCC mixtures at a rate of 200 to 300 cubic yards per hour and this high production rate is necessary to ensure continuous placement of RCC.

Continuous Pugmills

Pugmills are stationary plants with a twin-shaft mixer equipped with synchronized metering sensors that allow introduction of the correct proportions the materials used for the RCC production. The RCC-making materials are metered and continuously charged into the pugmill at one end and the well-mixed mixtures exits at the other end of the pugmill. The mixing time in the pugmill typically ranges from 20 to 50 seconds. The exiting mixture is continuously collected in a gob-hopper from where it is transferred onto dump trucks, as shown in Figure 5. Items to consider for inspection/approval of the pugmill:

1. Calibration of the material metering devices
2. Aggregate management plan that will minimize the risk of aggregate contamination and aggregate segregation
3. Aggregate moisture measurement plan to ensure the RCC is produced at the desired water content consistently. RCC mixture that is too dry or too wet will not produce a dense compacted mixture
4. RCC uniformity testing.

Typically, a single-sized aggregate is used with pugmill RCC production.

Figure 5 – A Pugmill Plant with a Gob Hopper

Central Batch Plants

When a central batch plant is used to produce the RCC mixture, the procedures used is similar to the production of conventional paving concrete. The aggregate may be single sized or two or more aggregates may be used. Because the mixture will be on the dry side compared to conventional concrete, it is necessary to use at least one minute of mixing to ensure proper mixing of all constituents. The batch size should be about 60 to 70% of the plant batch capacity to ensure proper mixing of the drier mixture. As a result, the production rate is limited to about 150 to 200 cubic yard per hour for a plant with a rated batch capacity of 10 cubic yards.

The central batch plants do allow for more accurate proportioning of the constituent materials than is possible for the continuous mixing pugmills. However, because of the lower production rate, use of batch plants should be limited to smaller projects requiring 10,000 cy or less of RCC.

Transit Mixing of RCC

Transit mixing of RCC is not allowed for military projects.

Concrete Transport

Concrete is transported in dump trucks. Sufficient number of dump trucks must be available to support the concrete production rate and maintain continuous delivery to the paving machines.

The truck haul times must be regulated, especially in hot weather. This is because the time between the end of mixing and completion of the roller compaction should not exceed 45 minutes when the air temperature is less than 85 F and should not exceed 30 minutes when the air temperature is equal to or greater than 85 F. When a water reducing and retarding admixture (WRRA) is used, an increase in the haul time may be permitted. In addition, in hot weather, the trucks must be equipped with covers to prevent the drying out of the RCC mixture.

6. CONCRETE PLACEMENT AND COMPACTION

Test Section

A test section at the project site should be constructed prior to production paving. The test section will allow observation of the Contractor’s procedures for RCC production, transporting RCC, needed haul time, RCC placement and compaction, longitudinal cold construction joint edge treatment, curing, and joint sawing. This is the time to identify problem areas and to make adjustments before full-scale production and placement begins. The test section should be closely observed by all of the appropriate QC/QA staff. A full suite of the required QC and acceptance tests should be run to verify compliance with specification requirements. Many future issues can be rectified at the test section stage which if left unresolved will lead to ongoing controversy, future rejections of work, claims and counterclaims by all parties, and possibly ultimately legal actions between the parties.

The following items are necessary at the time of test section construction:

1. Site storage of cementitious materials and aggregate to be used for the project
2. Operational and calibrated concrete plant (pugmill or central batch plant)
3. Paving machines and rollers in good working condition
4. Test section paving plan
5. Test section quality control plan
6. Test section acceptance testing plan
7. Test equipment, including concrete coring equipment
8. Availability of prepared site, with the base graded and compacted as per specification.

The test section can be used to demonstrate the contractor's ability to construct an RCC pavement that meets the project requirements and to fine-tune any of his processes. The test section will help establish the RCC mixture proportions, the RCC mixing time, the RCC placement pattern with a single paver or multiple pavers, the rolling pattern, the longitudinal edge treatment, the timing of joint sawing, acceptable surface, and testing logistics. The test section should include at least two adjacent lanes, each about 100 ft long, to demonstrate the treatment of a fresh and a cold longitudinal joints.

It is necessary that the test section meet all specified acceptance test requirements - RCC density, thickness, and surface smoothness. If the section cannot be constructed without corrective work and without payment adjustments, it is unlikely that the Contractor will be able to construct a quality RCC pavement in accordance with this specification. A reduction in payment reflects failure to meet specification requirements and a reduction in quality in the final product. <u>For the Government, the most successful outcome is full compliance with the specification and full payment to the Contractor for work performed. Work that results in payment reduction is as undesirable for the Government as it is for the Contractor</u>. Therefore, it is important that the Contractor demonstrate during the test section construction that a quality RCC pavement can be constructed in accordance with the requirements of this specification. Additional test sections should be constructed at the contractor's expense until the test section meets the specified acceptance test requirements.

The test section should also be used to establish the surface texture that is acceptable to the Government.

Production RCC placement should not begin until an acceptable test section has been constructed.

Readiness

The following critical elements should be in place before production paving of RCC starts:

1. The RCC plant (pugmill or central batch plant) has been inspected, approved and testing for optimum mixing time been determined.
2. A RCC placement and roller compaction plan has been developed.
3. All paving machines and rollers are in operational condition.
4. An acceptable length of grade for RCC paving is available. Verify all base materials conform to project plans and specification requirements.
5. Test reports for all materials are on file at the job site and at the plant site.
6. Backup testing equipment is available.
7. Ensure that the needed haul trucks are available.
8. A weather management plan has been developed and measures have been taken to mitigate extreme weather conditions during paving.
9. Weather forecast for each day of paving is available and checked daily.

The variability of the base layer grade will affect the variability of the compacted RCC grade. In addition, the variability of the base compaction will affect the compactibility of the RCC. Therefore, it is important that the base layer variability (grade and compaction) be minimized. Just as with conventional concrete pavements, the performance of the RCC pavement in service will be affected by the quality of the base. If a granular base is disturbed during the trimming or other construction activity, the base surface must be reworked, graded and leveled to proper elevation, and re-compacted to specified density.

RCC Placing and Construction Sequence

The RCC placement should be done in accordance with the contractor's submitted RCC placement plan. The RCC is placed by the asphalt paving machines in long strips (lanes). Depending on the project size, a single paver may be used or two pavers may be used to place adjacent lanes in a staggered manner, the second paver positioned a little bit behind the first paver.

Multi-lift Construction

The limitations on RCC lift thickness are as follows:

1. Minimum compacted lift thickness – 4 in.
2. Maximum compacted lift thickness for conventional asphalt pavers – 8 in.
3. Maximum lift thickness for high density asphalt pavers – 10 in.

When the required RCC layer thickness exceeds the maximum recommended compacted lift thicknesses noted above, the RCC should be placed in two or more lifts, preferably of equal thickness. The following should be noted:

1. Each lift thickness should meet the specified density requirements.
2. A subsequent lift must be placed within 60 minutes of placement of the previous lift to ensure good bond between the lifts. The multiple lifts must behave as a monolithic layer. If the lifts become separated, early failure of the RCC pavement

will result. The USGS specification requires that each lift of a multiple-lift construction should be placed with a separate paver.

3. If more than 60 minutes elapse between placements of successive lifts, a cementitious bonding grout will need to be applied on the previously placed lift to ensure bonding between the successive lifts. Also, the previously placed lift surface needs to be kept moist by use of fog sprays.
4. Cores should be examined for potential for delamination at the interface of successively placed lifts.

Multi-Lane Construction

By necessity, the construction of the RCC pavement will involve placement of adjacent lanes of RCC. Multi-lane RCC placement results in two types of longitudinal joints:

1. Fresh Longitudinal Joints – these joints result when any adjacent two lanes are placed within 60 minutes.
   a. When two pavers are used to place adjacent lanes. The pavers should be staggered and the lane lengths kept short enough so that most lanes can be placed with fresh longitudinal joints.
   b. When the paving lane is short and the single paver can be used to place the adjacent lane within 60 minutes.
2. Cold Longitudinal Joint – these joints result when the placement of an adjacent lane is done after 60 minutes of the placement of the previous lane.

Compacting

Roller compaction is the most important step in the construction of the RCC pavement. As discussed previously, the in-place RCC density is a key attribute of the RCC and will impact the durability and strength properties of the RCC. The USGS specifications require the following:

1. Rolling to be started within 10 minutes of placement by the paver and to be completed within 45 minutes of mixing at the plant. These time limits are reduced for hot-weather conditions.
2. The average lot dry density to be 98% or greater of the ASTM D 1157 maximum dry density
3. No lot density to be less than 96% of the ASTM D 1157 maximum dry density

The RCC material that extrudes out of the asphalt paver is at about 85% to about 95% of the ASTM D 1157 maximum dry density, depending on the paving machine. The roller compaction further densifies the RCC to achieve a final compacted dry density exceeding 96% of the ASTM D 1157 maximum dry density. Two types of rollers are used:

1. Vibratory Steel Drum Roller – A self-propelled steel drum vibratory roller with a minimum static weight of 10 tons. The roller may be used in a non-vibratory

mode for the final finishing pass over the RCC. The vibratory mode should be used only while the roller is moving. A common type of a vibratory roller is shown in Figure 7.

2. Rubber Tired Roller – A self-propelled rubber –tire roller for the final finishing passes. These rollers have two axles with at least 3 wheels per axle and the wheels offset so that the front and back tires do not track in the same path. The use of the rubber-tire roller results in a tight surface texture. The rubber-tire roller does not further densify the RCC. A common type of a rubber-tire roller is shown in Figure 6.

The rolling pattern and the number of passes required to achieve the desired compaction are established by the contractor during the test section construction. The USGS specification requires use of four passes to achieve the desired level of compaction. A round trip by the vibratory roller over the same material is considered as two complete passes

Light, walk-behind, or similar sized vibratory rollers and mechanical plate vibrators may be used for compacting areas inaccessible to the large rollers.

Figure 6 – Examples of a Vibratory Roller and a Rubber-tire Roller

Longitudinal Edge Compaction

For fresh longitudinal joints, the vibratory roller should not be operated within 12 inches of the lane edge until after the adjacent lane is placed. The non-compacted portion along the edge of the previous lane is compacted together with the adjacent lane. This allows achievement of the same high level of density as in the lane interior areas.

The edge area along a planned cold longitudinal construction joint should be compacted carefully using fewer passes of the vibratory roller so as not to damage or displace the edge area. However, this action leaves the narrow strip along the edge less compacted and not meeting the density requirements. For these joints, a strip, about 6 to 10 in. wide is sawcut full depth after the RCC has hardened, but no earlier than 12 hours after final compaction, and removed. Use of wheel cutters or motor graders is not allowed for removal the non-compacted edge.

Asphalt paving machines equipped with an edge compactor are capable of producing a well compacted edge that can be further compacted by the vibratory roller. This process can produce a cold longitudinal construction joint edge that may meet the project's density requirements. The effectiveness of this process can be verified during the test section construction. Use of this process can eliminate the need to remove the 6 to 10 in. lower density strip along the cold joint. In any case, the concrete density along the free edge must be verified in accordance with the specification requirements.

When an edge compactor is not used or the edge compactor is determined to be not effective in adequately compacting the edge, the contractor may consider extending the edge strip beyond the plan limit at no cost to the Government. With this option, all RCC within the plan limits would be compacted as per the specification requirements and the additional width beyond the plan limits is left in place in lieu of sawing of the poorly compacted edge.

7. JOINTING AND CURING

Jointing

Transverse Contraction Joints

RCC pavements may be constructed with or without sawed transverse joints. When joint sawing is not used, uncontrolled random transverse cracking will develop at a spacing of 20 to 50 ft. These cracks are difficult to maintain well and may not look aesthetically pleasing. For military applications, sawing of transverse joints is typically specified at a spacing of not more than 40 ft. Joints should be sawed to a depth of a fourth of the total compacted RCC thickness within 24 hours of compaction, preferably as early as possible without chipping, tearing, raveling or damaging the joint face. The timing of this initial sawing will depend on the weather condition and should be such as to prevent uncontrolled cracking of the RCC pavement.

A second sawcut is required at all transverse joints to serve as the sealant reservoir, as per the details shown in the plans. This sawcut is made after the RCC has hardened sufficiently so as not to damage the joint face, typically not before three days after the final compaction of the RCC.

Transverse Construction Joints

A transverse construction joint is provided at the end of each lane. The RCC placement and roller compaction is continued beyond the planned location of the transverse construction joint. The construction joint is then formed by making a full-depth sawcut after at least 12 hours of RCC compaction and removing the excess RCC material.

Cold Longitudinal Construction Joints

Cold longitudinal construction joints are formed as previously discussed. If longitudinal joint sealing is specified, a partial depth saw cut is made along longitudinal construction joints between the two adjacent lanes to serve as the sealant reservoir, as per the details shown in the plans. This sawcut is made after the RCC has hardened sufficiently so as not to damage the joint face, typically not before three days after the final compaction of the RCC along the joint.

Curing

The curing of the compacted RCC is another critical process in the construction of the RCC pavement. Because the RCC material is a drier mixture, any significant loss of moisture at the RCC surface will impact the durability of the RCC surface and the strength of the RCC material. The compacted RCC may be moist-cured continuously for up to seven days or may be covered with a concrete curing membrane soon after compaction.

Membrane Curing

Membrane curing is similar to the process used for conventional concrete pavements. A white-pigmented curing compound is used and is applied to the finished RCC surface by means of an automatic self-propelled spraying machine. The curing membrane must be protected for a period of at least 7 days. If the membrane is damaged, the curing compound should be re-applied.

Moist Curing

Moist curing of the RCC is a very effective curing procedure for RCC pavements. Moist curing requires placement of burlap over all exposed surface areas of the RCC pavement and keeping the burlap wet for a period of at least 7 days. The burlap is kept wet by regularly spraying the burlap by water trucks or using a sprinkling system.

Other Curing Methods

The use of plastic sheets or application of asphalt emulsion is not allowed for military applications.

8. CONTRACTOR PROCESS (QUALITY) CONTROL ITEMS

It is in the interest of both the Government and the Contractor to ensure that the RCC pavement is constructed in accordance with the USGS specification and that the end product meets the specification requirements. For the contractor, it is necessary that a compressive program of process (quality) control be established and implemented for the RCC pavement construction project. In accordance with the USGS specification, the Contractor is responsible for sampling and testing aggregates, cementitious materials, and RCC to determine compliance with the specifications. The specific items to consider for effective process control include the following:

1. Aggregate quality, gradation and aggregate moisture control
2. Plant calibration
3. Vibratory roller compactive effort (frequency and amplitude)
4. Adverse weather mitigation plan and implementation readiness
5. RCC mixture uniformity testing
6. Density testing using a nuclear gage
7. Surface smoothness
8. Surface texture
9. Thickness control
10. Strength

9. ACCEPTANCE TESTING ITEMS

The USGS specification incorporates pay adjustments for the following items:

1. In-place density of the compacted RCC
    a. In the lane interior areas
    b. Along a fresh longitudinal joint
    c. Along a cold longitudinal construction joint
2. Surface smoothness
3. RCC thickness

The specific procedures for determination of the pay adjustments are given in the UFGS 32 13 16 16 specifications. Figure 7 shows the testing for density and smoothness.

Figure 7 – Density and Smoothness Testing

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