United States Department of Agriculture
Natural Resources Conservation Service

Chapter 13 Roller Compacted Concrete

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645.1300 Introduction

The American Concrete Institute (ACI) defines roller compacted concrete (RCC) as "concrete compacted by roller compaction that, in its unhardened state, will support a roller while being compacted." The term "roller compaction" is defined by the ACI as "a process for compacting concrete using a roller, often a vibrating roller." Properties of hardened RCC are similar to those of conventionally placed concrete.

RCC is batched and mixed onsite using a portable mixing plant. Occasionally, one or more aggregates are obtained on or near the site and graded to conform to the specified aggregate gradation. It is more common to purchase aggregates from an aggregate supplier who delivers and stockpiles them near the batching and mixing plant. Portland cement (hereafter referred to as "cement") and a pozzolan such as fly ash are imported and stored onsite near the batching and mixing plant. After batching and mixing, the RCC mixture is transported, placed, and compacted using earthfill and rockfill-type construction equipment. Ideal RCC projects will involve large placement areas, few or no reinforcement, and no embedded items, such as pipes.

The following construction objectives are recommended to achieve the highest measure of cost effectiveness and a high-quality product:

- use locally produced materials, especially aggregates whenever possible
- consistently produce a uniform mix that conforms to the job mix requirements
- avoid, as much as possible, multiple RCC mixtures on any one job
- minimize complex construction procedures
- limit edge joints
- minimize complexity of lift joint treatment
- limit material segregation
- control RCC temperature where applicable
- convey, place, and compact RCC in a continuous nonstop operation and as quickly as possible
- compact the mix using the fewest compactor passes possible
- use unyielding forms (where forms are used) that can quickly be removed and reset without damaging the RCC
- provide adequate curing and protection of the RCC

645.1301 Installation

The RCC mix is produced onsite specifically for the project being constructed. Aggregates are obtained from local quarries or harvested from onsite materials. The mix design is typically unique to the job at hand. Thus, it is necessary to design the mix and verify that it meets specification requirements before full RCC production can commence. This differs from conventional concrete construction where a mix from a local concrete supplier is typically used.

After the materials and mix proportions have been verified to meet specification requirements, the process of mixing, conveying, and transporting the mixture and placing, spreading, and compaction of the mixture must be established prior to beginning production. This is accomplished in an onsite test section where all of these tasks are demonstrated and refined prior to beginning production. Thus, there is quite a bit of work to be performed up front before the first cubic yard of RCC is ever placed in the structure.

After the RCC mix is designed, the production and installation processes have been established, and the foundation has been prepared to meet specification requirements, then batching and mixing for production can begin.

The construction inspector should be involved in all stages of the construction process from review of submittals related to the selection of materials to inspection of the curing and protection of the in-place RCC.

(a) Materials

An RCC mix is made from the same ingredients as a conventional concrete mix. Cement, pozzolan, aggregates, and water are the four main ingredients. The contractor must select materials that are of the specified quality and proportion them to produce a mix of the specified consistency and strength. This mix is termed the “job mix.”

(1) Cementitious materials

The type, quality, and quantity of cementitious materials in the mix significantly affect the RCC strength and quality. Type II cement is commonly used with RCC because of its relatively low heat generation characteristics at early ages and its longer set times. Type I has been used successfully in less massive structures where heat problems are less likely or where a portion of the cement is replaced with pozzolan.

The use of pozzolan is common in RCC projects and, when substituted for a portion of the cement, generally provides for reduced cost and lowered heat generation. Class F fly ash is the most commonly used pozzolan in RCC. Natural Resources Conservation Service (NRCS) Construction Specification 36—Roller Compacted Concrete, hereafter referred to as Spec 36, requires that pozzolan be used as part of the cementitious materials in the RCC mix.

The inspector must verify that the types of cementitious materials being used conform to the specification and approved job mix. The inspector must check that the temperature of delivered cementitious materials does not exceed the specified maximum. Also, it is important to ensure that cementitious materials are uncontaminated and kept dry until introduced into the mix.

(2) Aggregates

As with conventional concrete, aggregates for RCC should meet the specified standards for quality and gradation. Material Specification 524, Aggregates for Roller Compacted Concrete, specifies that the quality of the aggregate conform to ASTM C33 and be graded within a specific range. The gradation may be different than that normally used for conventional concrete. For instance, the amount of material passing the No. 200 sieve is typically greater for RCC than for conventional concrete. The larger percentage of fines is needed to fill voids in the paste that would otherwise be filled with cementitious materials in conventional concrete. The additional fines are usually made up of naturally occurring nonplastic silt and fine sand or manufactured fines. Plastic fines should not be used, as they result in increased water demand and lower strength.

The project engineer approves the use of the aggregates based on documented evidence from the contractor that the aggregate meets the specification. The inspector must verify and document that only approved aggregates that are graded within the allowable range are being used.

(3) Water

Almost any natural water that is drinkable and has no pronounced taste or odor can be used as mixing water for making concrete. Water not fit for drinking may also be suitable for use in concrete. It is preferable that water used to produce RCC be the same water used in the lab to develop the mix design. However, different water may be used in the field if it meets the requirements of the specification.

The inspector should notify the engineer whenever there is a change in the water source or other water issues relating to quality or availability of water.

(4) Chemical admixtures

Spec 36 allows the use of a water-reducing and retarding admixture in RCC because this type of chemical admixture has proven to be beneficial for extending mix workability, thus increasing the initial time of setting. Extended workability and time of set promotes better lift bond, thus increasing the likelihood of watertight joints. The extended workability is especially beneficial during warmer weather and during RCC startup activities.

The inspector should verify that the admixture used meets the specification and conforms to the approved job mix.

The inspector's responsibilities related to materials include verifying that:

- types of cement and pozzolan used in the RCC mix are in accordance with the job mix
- the temperature of cement and pozzolan at time of delivery is at or below the specified maximum
- cement and pozzolan are maintained in an uncontaminated, dry condition
- the combined (coarse and fine) aggregate used in the mix is graded in accordance with the job mix
- The quality of the mix water complies with specified requirements
- admixture is in accordance with the specification and job mix

(b) RCC mix design

Spec 36 requires the contractor to design the mix. In doing so, the contractor's laboratory must make at least three trial mixes of varied proportions. The consistency and strength of each mix is determined, and the knowledge gained from the trial mixes is used to determine the job mix material proportions.

The contractor must submit documentation that the job mix meets the requirements of the specification. This documentation includes specific detailed information about mix performance and the source, quality, and proportioning of materials used to produce the job mix. The project engineer reviews and concurs with the proposed job mix after it is documented that all mix design requirements have been met and the proposed job mix conforms to the specification. Other than minor adjustments in water content, any change in the job mix requires the engineer's concurrence.

Durability—Durability is dependent on strength, aggregate quality, and density of the in-place RCC. With hard, dense aggregates and a good mix, RCC exhibits excellent resistance to abrasion, erosion, alkali-aggregate reactivity (AAR), and sulfate attack. However, the resistance of RCC to the effects of aggressive water, chemicals, gases, or simple leaching of soluble constituents by water is primarily a function of the permeability of the RCC. A nonsegregated mix that contains enough paste to fill all of the aggregate voids can be relatively impermeable if it is well compacted and bonded to the preceding lift.

Strength—For any given combination of concrete materials, strength is largely dependent on the quality and gradation of the aggregates, the cementitious materials content, and the water content.

Quality well-graded aggregates are needed for an efficient mix. An efficient mix is one with a relatively high strength and relatively low content of cementitious materials. Mix efficiency can be expressed in terms of compressive strength per pound of cementitious material in 1 cubic yard of RCC (psi/lb of cement). This has ranged from 4 to 14 psi/lb of cement.

The cementitious materials content is composed of cement and pozzolan such as fly ash. The dense nature of RCC provides for higher strength per pound of cementitious material than that of conventional concrete. Where conventional concrete may require 500 to 600 pounds of cementitious materials to attain a specified strength, RCC may only need 200 to 300 pounds of cementitious materials to attain the same strength.

The water content of a RCC mix is selected based on the compaction characteristics of the mix at various moisture contents. Because there are less cementitious materials in RCC than in conventional concrete, the water to cementitious materials ratio of RCC is normally higher than that of conventional concrete. Water to cementitious materials ratios as high as 1.0 have been reported in some very strong RCC mixes; whereas, the water to cementitious materials ratio of conventional concrete is typically less than or equal to 0.50. The inspector should be aware that changes in mix moisture content will affect workability and can result in poor compaction characteristics and, thus, adversely impact strength and durability.

Consistency—The consistency of RCC is the property that determines its capacity to be placed and compacted successfully without harmful segregation. It embodies the concepts of compactability and, to some degree, moldability and cohesiveness. It is affected by the same factors that affect the workability of conventional concrete (cement content, water content, the presence of chemical and mineral admixtures and the grading, particle shape, and relative proportions of coarse and fine aggregates).

The consistency of conventional concrete is measured or judged by the slump test. The slump test is not meaningful for roller compacted concrete since the RCC mix has no slump. For RCC mixtures, consistency is measured by the Vebe test (ASTM C1170). Spec 36 requires the job mix to have Vebe consistencies ranging from 15 to 30 seconds. Within this range of Vebe consistency, RCC is generally very workable, is easily placed, and can be fully consolidated. Spec 36 does not require the contractor to perform the Vebe test in the field.

Generation of heat—Whenever cement hydrates, heat is generated that causes the temperature to rise within any concrete structure. Higher temperatures within the structure may result in cracking that occurs as the structure cools. Low cement contents associated with RCC result in less heat being generated than in conventional concrete. Adding pozzolan to the reduced-cement mix allows the strength and durability to be maintained. Thus, Spec 36 requires that pozzolan be substituted for some of the cement in the job mix.

Permeability—The permeability of RCC is greatly influenced by the mix design. To produce relatively impermeable RCC, there must be enough paste in the mix to fill all of the voids in the mortar and enough mortar in the mix to fill all of the voids in the coarse aggregate. For well-graded aggregates, the mortar fraction is generally adequate to fill all of the voids in the coarse aggregate, but additional fines may have to be added to make enough paste to fill all of the voids in the mortar. This supplemental fine material may consist of fly ash, pozzolan, ground slag, or fine sand.

The use of fly ash, pozzolan, or ground slag as supplemental fine material may provide added benefits such as lower cement content and higher strength.

Plastic fines must be avoided. RCC containing plastic or excessive fines will generally have a high water demand, poor durability, low compressive strength, and poor bond between lifts.

Marginal or minimally processed aggregates, such as graded aggregate roadbase materials, may result in poor RCC quality and should not be used unless laboratory results indicate that all project-specific technical and economic requirements are met.

Finish—Whenever RCC is formed, it is desirable to have the finish be as smooth and free of honeycomb and bug holes as possible. The first step in achieving this type of finish is to design a mix that is workable, compactable, and capable of having all of the voids filled. Well-graded aggregates and adequate paste to fill all of the voids in the mortar are essential for producing this kind of mix. The mix must then be proportioned so that the water content can be adjusted to provide for a workable mix with adequate strength.

For formed vertical surfaces, a low Vebe mix (e.g., mix with a 10- to 20-second Vebe time) will likely produce a smooth face, but will be more difficult to place due to rutting and resistance to equipment traveling on or through it. Sometimes, the low Vebe mix is used against the forms, and a higher Vebe mix is used throughout the remainder of the lift. It is typical that the higher Vebe mix be virtually the same mix as the low Vebe mix with the exception of water content. A new job mix is normally not required when only the water content is varied. The higher Vebe mix may be stronger than the low Vebe mix; however, strength will suffer if the mix is so dry that it cannot be effectively compacted. During the performance of the test section, the job mix should be placed and compacted at various water contents and strength-tested to determine the allowable limits on mix water content.

With regards to RCC mix design, the inspector is responsible for verifying that:

- mix proportions are in accordance with the job mix
- other than minor changes in water content, the job mix does not change without the engineer's concurrence

(c) Test section

The test section is designed to demonstrate the contractor's capability to produce the specified quality of RCC. The test section is used to demonstrate the adequacy of:

- construction techniques
- materials
- production plant
- forming
- lift joint preparation
- hauling and conveying
- spreading and compacting
- curing and protecting
- personnel

The test section provides a common basis of knowledge between NRCS and the contractor. It allows the contractor to try both the equipment and procedures planned for the job and to establish an apparent maximum density (AMD) (see below) that can be attained with the production roller. New and innovative construction techniques can be attempted in areas not affecting the safety or function of the project. The test section also provides an opportunity to adjust the RCC mixture proportions.

The AMD is the maximum RCC density of the approved job mix that can be attained by compacting the mix with the production roller. The AMD is not a theoretical value; it can only be determined by measuring the density of the RCC after it is fully compacted by the production roller. The theoretical air free density (TAFD) is the computed maximum wet density that can be attained for a mix assuming there is no air in the mix. Spec 36 requires the AMD to be greater than, or equal to, 98 percent of the TAFD. Thus, the TAFD must be computed prior to beginning the process for determining the AMD.

The TAFD value should be based on the quantities of mix ingredients obtained from the actual mix plant production records. See 645.1303, WS 13.2, Field Mix Evaluation, for a sample TAFD computation.

The process for determining the AMD is explained in detail in Spec 36. See 645.1303, WS 13.3, Apparent Maximum Density Determination, for a sample AMD determination.

Step 1 in the process begins with the placement and spreading of RCC. After the RCC is placed and spread, the production roller begins compaction. After two passes of the production roller, two density measurements are made at separate locations with the nuclear gauge probe set at a depth of 12 inches. The roller makes another pass and two density tests are again taken in two separate locations at a 12-inch depth. This process is repeated until there is no apparent increase in density. The process is continued beyond the point where there is no apparent increase in density. Two roller passes, each followed by density tests, are made beyond the point where apparent maximum density is attained. These tests can be made with the same gauge at both locations or with separate gauges.

Step 2 is to check for variations in density from the bottom to the top of the lift. The density is measured in two locations at depths of 2, 4, 6, 8, 10, and 12 inches. If the difference in the minimum and maximum density values obtained by testing at either of these locations is greater than 2 percent of the maximum density, operations must be modified and the process repeated from the beginning. Modifications may entail changes to the vibration frequency and amplitude of the production roller or changes in the water content of the mix. It may even be necessary to bring in another production roller with compaction characteristics better suited for the job mix to obtain a more uniform density variability from the bottom to the top of the lift.

Step 3 is conducted after the variability requirement has been met. The AMD value is established in this third and final step. The AMD is unique to the nuclear gauge for which it is established so the AMD must be established for each gauge that will be used to monitor compliance during RCC production.

In Step 3, 10-inch depth density measurements are made with each gauge at six locations. If two or more of the density values measured by a specific gauge are less than 96 percent of the TAFD, modifications must be made to the mix or the compaction process in an effort to increase the density. When at least five of the density values measured by a specific gauge are greater than 96 percent of the TAFD, all values (measured by that gauge) that are above 96 percent of the TAFD are averaged. This average value is the AMD for that gauge, provided it is above 98 percent of the TAFD. Otherwise, the mix or the compaction operation must be modified until the AMD is above 98 percent of the TAFD.

Other items demonstrated in the test section, such as forming and lift joint treatment, should be done after the AMD has been established. The air content and density of the mix must be determined according to specified standard test methods, and 15 compressive strength cylinders must be made and weighed. Since it may be necessary to adjust the mix during the process for determining the AMD, these tests and cylinders should be made from the mix after the AMD has been established. Spec 36 also requires that 10 cores be extracted from the test section. These cores should be extracted from a portion of the test section that was compacted to the specified density after the AMD was determined.

One important aspect of RCC that is often overlooked in the test section is curing. Planned curing procedures including wet curing and the application of curing compound, if applicable, should always be demonstrated in the test section.

The inspector's responsibilities related to the test section includes verifying that:

- the contractor's test section plan has been submitted and concurred with by the engineer prior to beginning the test section
- the test section is constructed at the approved location
- the approved job mix is the only mix placed in the test section
- production roller and special compaction equipment used in the test section meet specified requirements and are the same planned for use during RCC production
- compaction equipment is operated at normal operating speeds
- for soil foundations, a minimum of two 12-inch lifts are placed below the lift where the AMD is determined
- the TAFD is accurately determined for the field mix used in the test section
- prior to determining the AMD, all RCC is compacted to a density equal to or greater than 96 percent of the TAFD
- the AMD is determined as per the process specified in Spec 36
- any modifications to the job mix are concurred with by the engineer
- after the AMD is determined, all test section RCC incorporated into the structure is compacted to the specified density
- air content and density of the mix are documented
- 15 cylinders are made from the mix
- 10 cores are made 13 days or more after the RCC is placed in the test section
- curing is demonstrated to conform to Spec 36
- the test section is disposed of as specified if not incorporated into the structure
- all test section operations including the pre- and post-test section briefings are well documented

(d) Mix production

Regardless of the size of the project, the capacities of the batching, mixing, and transporting system must be balanced to keep pace with the placement and compaction operations. The production rate for RCC is the result of the concurrent, coordinated operation of several systems: materials delivery and maintenance of adequate quantities of materials; material batching and mixing; RCC transportation, placing, spreading, and compacting; curing and protecting; quality control testing, and other related operations. Other related operations include bedding placement, facing system placement, and placement adjacent to various structures.

Since segregation is so detrimental to RCC quality, the selection of equipment and procedures used for RCC construction is based, in part, on favorable performance with regard to segregation. Favorable performance of equipment and procedures with regard to segregation usually can be determined by visually observing the mix. It should be obvious that a mix is segregated if there are portions of the mix that contain a lot of coarse aggregate and very little paste relative to other portions of the mix that contain a lot of paste and very little coarse aggregate. A uniform mix cannot be produced when segregation occurs during the mix production, thus the uniformity tests listed in Spec 36 can be conducted to document the capability of the equipment and procedures with regard to segregation.

The RCC production plant includes the aggregate stockpiles, the materials conveyance system, the batching and mixing system, and the discharge system. The plant operator is also an integral part of the mix production. An experienced plant operator is essential to the continuous production of a uniform mix that complies with the job requirements.

The NRCS inspector should ask the mix plant operator to fully explain the entire batching and mixing process prior to beginning production. The inspector should understand:

- how the ingredients are metered
- how the metering is monitored
- possible adjustments that can be made to the plant to achieve better mix uniformity
- how mix plant records and summaries of daily materials used are generated
- how the need for moisture adjustments is determined
- any other items that the plant operator or inspector feels they need to know to verify and document that the approved job mix is being produced, or necessary remedies are being performed when problems occur with mix production

(1) Aggregate stockpiles

It is necessary to accumulate stockpiles of adequate size before starting RCC production and replenish the stockpiles so that materials are available at all times during production. In general, any number of aggregate stockpiles may be used as long as the aggregates are batched accurately and are not allowed to segregate.

Proper storing and handling of aggregates is necessary to reduce the potential for segregation. Blending coarse and fine aggregates is not allowed due to the potential for segregation. Spec 36 requires that coarse and fine aggregates remain separated until introduced into the batch hopper or until dropped onto the belt that delivers the aggregates to the mixing compartment.

When depositing aggregates, especially coarse materials, care should be taken to keep the drop height and pile height and steepness to a minimum to guard against segregation (fig. 13–1). Aggregates that are dropped or allowed to free fall 5 feet or more tend to segregate. If coarse or dry fine aggregates are deposited on a pile so that they roll down the side of the pile, segregation will occur with the larger particles accumulating at the bottom of the pile. Removing materials from the bottom of a pile, especially a tall pile, will result in a steep face. The materials that fall

Figure 13–1 Keep pile height and steepness to a minimum to guard against segregation

from the upper portion of the steep face will segregate (fig. 13–2). Dry, fine aggregates tend to segregate, but moist, fine aggregates tend to clump together, which helps prevent segregation. Therefore, when handling aggregate, it is important to:

- avoid pile heights greater than 5 feet
- avoid depositing aggregates on the top of the pile to prevent materials from rolling down the side of the pile
- extract materials from the top of the pile to avoid creating a steep face
- keep fine aggregates moist to reduce the potential for segregation during handling

Aggregate moisture must be monitored to determine the amount of free water in the aggregates. Dry aggregates will absorb water from the mix making it difficult to accurately control the moisture and consistency of the mix. Dry aggregates should be avoided. On the other hand, aggregates can contain more free water than allowed by the job mix. These very wet aggregates must be dried before being introduced into the mix. The inspector must ensure that aggregate moisture is documented at least once per production shift and whenever a change in moisture is suspected. Mix proportion adjustments must be made whenever there is a significant change in aggregate moisture. See 645.1303, WS 13.2, Record of Aggregate Moisture, for a sample record.

Figure 13–2 Materials that fall from the upper portion of a steep pile will segregate

(2) Materials conveyance system

Aggregates are supplied to the plant by various methods. The simplest method is the use of a front-end loader to remove aggregate from the stockpiles and charge aggregate feed bins at the plant. Continuous feed systems are sometimes used to provide a continuous, uninterrupted flow of material and RCC. A continuous feed system usually includes an initial feed bin or bins that are maintained at a minimum capacity. Material is discharged from these bins through an adjustable gate opening onto a variable-speed conveyor belt. The gate opening and belt speed are varied to achieve a specific rate of aggregate feed.

Cement and pozzolan are pneumatically conveyed into silos at the plant. There will be a silo for the cement and one for the pozzolan, or there will be one silo with two compartments to allow the cement and pozzolan to be stored and metered separately. Separate silos or storage compartments are not needed if a pre-blended cementitious material is used. Occasionally, additional storage silos or containers will be used as needed to keep up with demand on high-production jobs. Silos must be watertight. Cement sometimes tends to cake or set up due to a condition called false set. Silos must be equipped with vibrators or other devices that prevent false set and assure that the material continues to flow freely throughout the batching process.

(3) Batching and mixing system

There are two categories of batching and mixing systems used to produce RCC: one that proportions and mixes continuously and one that proportions and mixes in discrete batches.

(i) Continuous batching and mixing

Continuous batching and mixing is performed by a plant with a continuous-flow, twin-screw pug mill (fig. 13–3). This pug mill has a mixing chamber containing two horizontal, counter-rotating shafts fitted with paddles (fig. 13–3b). The mix components are metered through a certain size opening or volumetric metering device and carried to the mixing chamber on a conveyor belt that runs under the bins and silos. Water is added at a point near the entrance to the mixing chamber.

Changes in material moisture contents and bulking of materials make volumetric batching less accurate than batching by weight. Some sophisticated continuous flow systems are equipped with computers and sensors that monitor the weight of materials and continuously adjust the feed rates. With any continuous flow system, regardless of its sophistication, there is the potential for an ingredient to be improperly metered or left out of the mix. The plant operator must constantly monitor the mix for signs of a change that would indicate a batching problem.

The ingredients are pushed through the mixing chamber by the paddles. The angle of the paddles is fixed so that at the proper rotational speed the ingredients are thoroughly mixed as they are being pushed through the mixing chamber. It only takes a few seconds from the time the ingredients enter the mixing chamber until they exit the chamber. This time interval is referred to as the "mix retention time." Only minor adjustments can be made to shorten or extend the mix retention time, but the few seconds that the mix remains in the mixing chamber are generally adequate for thoroughly mixing the RCC.

There is an optimum rotational speed of the counter rotating shafts. If it is too slow, the ingredients may be pushed through the mixing chamber without being mixed. If it is too fast, segregation can occur. The mix plant operator must adjust the belt speed that feeds the mixing chamber and the rotational speed of the pug mill to those best suited for the mix being produced.

Figure 13–3 Continuous batching and mixing

(a) Plant

(b) Pug mill mixing chamber

(ii) Systems that discretely batch and mix
These systems batch by weight, mix in a drum or pug mill, and discharge a discrete batch. There are two types of systems that discretely batch and mix: the tilting drum mixer and the compulsory mixer. Batching (proportioning) by weight, rather than by volume, has the advantage of being more precise since material bulking has no affect on the amount of material batched. Unlike continuous batching and mixing systems, which have a set mix retention time, discrete batch mixing times can be varied and must be evaluated to ensure complete mixing of the ingredients.

Tilting drum mixers have drums with internal fins. The ingredients are proportioned and fed into the drum where they are repeatedly picked up and dropped similar to the mixing action of a concrete ready-mix truck. When a tilting drum mixer is used, care must be taken not to overcharge the drum, as inadequate mixing and buildup of material on drum surfaces are common problems when the drum is overcharged. The mix must be retained in the drum mixer for a time similar to that for conventional concrete. Too little mixing will result in poor uniformity. Too much mixing can cause heat buildup and drying of the mix. Drum mixers must be cleaned periodically to remove any buildup of concrete that could impair the function of the mixer. RCC is much less workable than conventional concrete, making it almost impossible to discharge from the nontilting drum truck mixer. Thus, the use of nontilting drum truck mixers should be avoided for RCC applications.

Compulsory mixers consist of a pug mill with one or two horizontal shafts with fixed paddles similar to those in a continuous flow twin screw pug mill. The mixing mechanism is contained in an enclosed mixing chamber. The mix can be retained for as long as needed to produce a thoroughly mixed product. The bottom of the mixing chamber opens to drop the mix onto a delivery belt that delivers the RCC to the conveyance system. The horizontal shaft mixers thoroughly mix the ingredients much faster than drum mixers. Mix retention times of less than 20 seconds are generally adequate for thorough mixing with a compulsory mixer.

In both continuous and discrete batch systems, water is metered into the mixing compartment after the cement and aggregates have been added. Admixtures are introduced into the mix in small quantities, and when introduced alone may not be evenly distributed throughout the mix. For better distribution, liquid admixtures are metered into the water prior to the water being metered into the mixing compartment. Since it is normally difficult to detect when an admixture is not properly proportioned, the NRCS inspector must become familiar with and visually inspect the admixture metering mechanism.

The batching and mixing plant should be operated according to the manufacturer's recommendations, maintained in satisfactory operating condition, and cleaned as needed after each production run. During production, all supply bins and silos should be kept sufficiently full to ensure a uniform and constant flow of all materials.

Uniformity of the mix is critical to good quality RCC. A uniform mix is one that is consistent in proportioning and blending. Mix uniformity testing is the primary means of establishing whether consistent mixing of materials is occurring. Mix uniformity should be monitored by continuous visual inspection by the plant operator and by periodic visual inspection by contractor quality control personnel and the NRCS inspector. If a uniformity problem is suspected, the contractor must conduct uniformity tests and take appropriate corrective measures. Spec 36 lists the uniformity tests that must be conducted whenever a uniformity problem is suspected.

Uniformity problems can be caused by one or more malfunctions of the batching and mixing operation such as clogging of bins and silos, inaccurate metering devices, inconsistent feed belt delivery, inconsistent mix retention time, and worn or missing pug mill mixing paddles or mixing drum vanes. Uniformity problems are commonly the result of segregated aggregate or inconsistent aggregate moisture. Segregation of the mix after it leaves the mixing plant should be suspected when uniformity problems are only noted after the mix is conveyed to the point of placement.

To isolate uniformity problems, samples may have to be observed from various locations along the RCC production and conveyance system. Samples may be taken from:

- stockpiles
- aggregate bins and feed belts
- entrance to the mixer
- point of mixer discharge
- points in transit
- placement area

The inspector's responsibilities related to batching and mixing include verifying that:

- the plant operator's experience is documented and the operator exhibits the capability to oversee the batching and mixing operation
- batching equipment is in good condition, has adequate capacity, and hoppers discharge completely
- drums are inspected and cleaned as needed
- specified minimum quantities of aggregates are maintained onsite during production
- adequate quantities of all ingredients (aggregates, cement, pozzolan, water, and admixtures) are available onsite to allow uninterrupted production
- only nonsegregated aggregates are introduced into the mixer
- aggregate moisture is monitored and adjustments made to the mix at least once each production shift
- drum mixers are not overcharged
- nontilting drum truck mixers are not used for mixing RCC
- admixtures are metered at the specified rate

- the plant operator visually inspects the mix for uniformity on a continuous basis
- periodic visual inspections for mix uniformity are being made by quality control personnel
- the mix appears uniform or uniformity testing is conducted to verify uniformity
- causes of uniformity are isolated and corrected
- mix uniformity is documented periodically and before and after uniformity problems are corrected

(4) Discharge system
After the ingredients have been thoroughly mixed, they are discharged from the mixing chamber to the conveyance system. The mixture must be discharged in a manner that limits segregation and protects against excessive wetting or drying.

From a continuous-flow pug mill, the mix is typically discharged onto a short (approximately 20 to 50 feet long) conveyor belt which conveys the mix to another conveyor belt or to a gob hopper. A gob hopper is a hopper typically ranging in size from 1 to 5 cubic yards that collects and temporarily stores the mix (fig. 13–4). With a properly sized gob hopper, the mixing operation may continue without interruption as a loaded truck moves out of the way and an empty truck pulls into position to be loaded.

Gob hoppers are generally positioned below the mixing chamber on plants that discretely batch and mix RCC. In these systems, discrete batches are mixed and discharged directly into the gob hopper. A conveyor belt then conveys the mix to another gob hopper, conveyor belt, or directly into a truck.

(e) Conveying

The mix is conveyed either by belt conveyor or hauling equipment. Hauling equipment is typically used on low-volume jobs, whereas conveyor belts are typically used on high-volume jobs. Occasionally, a combination of conveyors and hauling equipment is used. The main concerns with conveyance of the RCC mixture from the plant to the placement area are segregation, contamination of the mix, drying of the mix, wetting of the mix from rainfall, contamination of the lift surface, and damage to the lift surface from hauling equipment.

Segregation occurs on conveyor belts or chutes that are significantly inclined and at the end of conveyor belts or chutes where the mix is propelled off the end and allowed to fall more than 5 feet. In some cases, baffles can prevent segregation that occurs at the end of a conveyor. A baffle is a piece of wood, steel, or heavy flexible material (like a mud flap behind a truck tire) that is positioned just beyond the end of the conveyor belt (fig. 13–5). The material coming off

Figure 13–4 Gob hopper

Figure 13–5 Wooden baffle

of the belt hits the baffle, temporarily stops, and drops straight down. Otherwise, the material would be propelled off of the end of the conveyor belt and hit the surface below at a relatively high rate of speed, which contributes to segregation. Chutes that tend to cause segregation, such as a significantly inclined chute, should not be used. In general, the use of conveyor belts to deliver the mix to the placement area will result in higher quality lift surfaces than will delivery by trucks or other vehicles. Vehicle conveying systems are more appropriate for placements where lift surface quality and lift bond are not critical.

The mix should be conveyed from mixer to placement area as rapidly as practicable by methods that prevent segregation, contamination, and loss of water. Spec 36 requires that the total length of time from the end of mixing until the mix has been placed, spread, and compacted shall not exceed 45 minutes.

(1) Belt conveyors

When conveyor belts are used, there is the potential for RCC to be exposed to sun, wind, and rain. If the RCC will be exposed for an extended period, the belt should be covered (fig. 13–6).

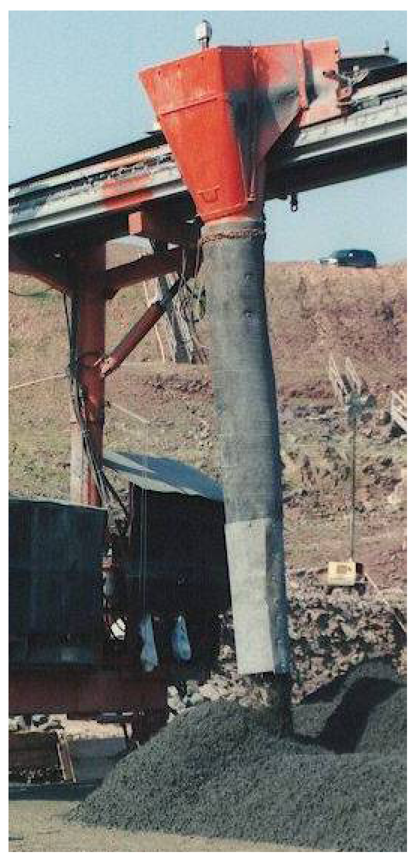
Belts should be of ample width and capable of operating at speeds that meet the production requirements without mixture segregation. A belt that is too narrow will result in the loss of materials as the mixture is being conveyed. Segregation can occur where material is deposited from a belt or transferred from one belt to another. This segregation is more likely to occur when the belt operates at a high speed. The mechanism for cleaning the belts is a key component in conveyor operations. Many conveyors are fitted with a wiper or brush system that removes most of the mortar from the belt. Adjustment and replacement of wipers or brushes may be a frequent operation.

Figure 13–6 Covered conveyor belts

The mix is likely to segregate anytime it is allowed to free fall vertically a distance of 5 feet or more. The potential for segregation is even greater at the end of a fast-moving conveyor if the mix is propelled off the end of the conveyor. Drop chutes, also called elephant trunks or tremies, should be provided at belt discharge points to prevent segregation of the mix (fig. 13–7). Drop chutes must be of sufficient length to limit the free fall to less than 5 feet. They must also be of sufficient diameter to prevent clogging.

Long, inclined chutes similar to those on a ready-mix truck should not be allowed because no-slump mixes tend to segregate when conveyed by a long, inclined chute.

Figure 13–7 Drop chute



Planning and layout of any mix conveyor system is crucial so that in case of a breakdown, critical system components are accessible for machine removal of RCC before it hardens.

(2) Hauling equipment

RCC can be hauled in end-dump trucks, front-end loaders, bottom-dump trucks, and scrapers. The selection of hauling equipment is dependent on road conditions, weather, traffic, and site topography. Hauling equipment should not be permitted to track mud or other contaminants onto previously placed RCC or be allowed to operate directly on uncompacted RCC. Hauling equipment should not be allowed on the RCC surface if it causes rutting of completed RCC surfaces. The contractor should implement necessary measures to prevent contamination or damage of the RCC.

End-dump trucks are commonly used to transport RCC. RCC mixtures may segregate when dumped from an end-dump truck. Hauling and dumping of the mix with end-dump trucks can be effective, provided any segregated mixtures are remixed by dozers or front-end loaders prior to final spreading of the mix.

Front-end loaders have been used for hauling and dumping RCC mixtures in tightly restricted areas. Often, the mix will be deposited onto the lift surface from a truck or conveyor where it is picked up by a front-end loader to be carried elsewhere.

Scrapers and bottom-dump trucks place RCC mixtures while moving in parallel lanes. Segregation is minimized because the fall height of material is much less than from an end-dump truck. A front-end loader is generally needed to further carry the mix into tightly restricted areas that are not accessible by the scrapers or bottom-dump trucks.

The inspector's responsibilities related to conveying the RCC mix includes verifying that:

- the consistency or workability of RCC is maintained during conveyance
- belt conveyors are of ample width
- RCC mixture is protected during conveyance from excessive drying or rain
- conveyor wipers and brushes are maintained in good working order
- drop chutes of sufficient length and diameter are provided where necessary to prevent segregation
- free fall is limited to 5 feet or less
- long, inclined chutes are not used
- hauling equipment does not contaminate or damage recently placed RCC surfaces
- conveyance time does not exceed the maximum specified time

(f) Weather

Various weather conditions present a challenge to the RCC contractor. The costs associated with adverse weather can be great enough to warrant postponing the work until better conditions prevail. If RCC placement is to continue during adverse weather, it is important to understand the problems that can occur.

(1) Wet weather

Wet weather can benefit hardened RCC by attributing to the curing effort, but there are several concerns associated with wet weather placement. During wet weather, there is a greater potential for tracking mud onto the lift surface or contaminating the mix with mud. There is the potential for difficulty in controlling the moisture content of the mix during batching, transporting, and placing. Too much aggregate moisture or variable aggregate moisture can make getting a consistent mix almost impossible. Attention should be given to changes in the consistency (workability) of the mix that would indicate increased quantity of water in the mix. High intensity rainfall can erode the surface. Spec 36 requires the contractor install and maintain a rain gauge that measures the rate and cumulative volume of rainfall and prohibits RCC placement during rain falling at a rate equal to or greater than 0.1 inch in 20 minutes.

The inspector's responsibilities related to wet weather placement include verifying that:

- no mud or standing water is on the bonding surface at the time of placement
- placement ceases if changes in mix consistency indicate a significant increase in mix moisture

- unhardened RCC is protected from erosive high-intensity rainfall
- RCC is not placed in rain falling at a rate equal to or greater than 0.1 inch in 20 minutes

(2) Cold weather

Cold weather is defined by the ACI as a period when for more than 3 successive days, the average daily temperature is less than
40 °F and does not exceed 50 °F for more than half of any 24-hour period. Cold weather presents three main problems:

- Hydration slows and eventually ceases as the RCC gets colder.
- RCC that freezes at an early age can be damaged resulting in low strengths and poor durability.
- Large differences in the surface temperature and that of the RCC beneath the surface can result in thermal cracking.

Spec 36 prevents placement of RCC when the air temperature drops below 35 °F or the RCC mix is less than 40 °F. After placement, when ambient temperatures are expected to be below 32 °F, measures should be implemented to protect the RCC from freezing. The specification requires the temperature of RCC be maintained at or above 35 °F from the time the RCC is placed until 7 days after the curing period. During this protection period, curing blankets or moist sand can be used to insulate the RCC surface. Forms help distribute heat more evenly, protect the surface from cooling effects of wind, and depending on the forming materials, can help insulate the RCC.

All materials, labor, and equipment needed for adequate protection must be on hand and ready for use prior to beginning placement. The surface temperature should be monitored with a high/low thermometer throughout the protection period to verify and document that specification requirements are being met. Protection should remain in place throughout the protection period or until ambient temperatures remain continuously above 35 °F for 24 hours.

Removing forms or insulation in cold weather can result in thermal shock, which can result in thermal cracking. Wind increases the potential for thermal shock. As a general rule, if the air temperature is 25 °F cooler than that of the RCC during the protection period, the RCC should be insulated. After the protection period or whenever the air temperature consistently remains within 25 °F of the RCC temperature, insulation may be removed. At the end of the protection period, RCC should be cooled gradually so that the RCC temperature does not drop more than 20 °F within the first 24 hours after insulation is removed. Waiting for warmer weather before removing forms or insulation may be prudent.

The inspector's responsibilities related to cold weather placement include verifying that:

- RCC is not placed when the air temperature drops below 35 °F or the RCC mix is less than 40 °F
- when there is potential for cold weather, all materials and equipment needed for adequate protection are on hand and ready for use prior to beginning placement
- RCC temperature is maintained at or above 35 °F for a protection period equal to the curing period plus 7 days
- air and RCC temperatures are monitored and documented
- the RCC is insulated if the air temperature is 25 °F cooler than that of the RCC during the protection period
- the RCC temperature does not drop more than 20 °F within the first 24 hours after insulation is removed

(3) Hot weather

Hot weather is defined by the ACI as any combination of the following conditions that tends to impair the quality of freshly mixed or hardened concrete by accelerating the rate of moisture loss and rate of cement hydration or otherwise cause detrimental results:

- high ambient temperature
- high concrete temperature
- low relative humidity
- high wind speed
- high solar radiation

The temperature of the RCC is a function of the temperature of the mix at the time of placement. It is important to control the placement temperature to limit thermal stresses within the RCC that can result in thermal cracking as the RCC cools. The specified maximum allowable temperature varies from job to job as it is determined based on the mean annual temperature in the region. The design engineer will specify the maximum allowable placement temperature in the items of work and construction details located in section 22 of Spec 36.

The temperature of the RCC at the time of placement can be controlled by cooling some of the mix components prior to batching. Cooling the cement and fly ash is generally not practical. It is difficult to add ice to the mix if a continuous flow-through pug mill is used to mix the RCC. Adding ice to RCC mixtures is an uncommon practice, but it may be added to a tilting drum or compulsory mixer as long as the quantity of mix water does not exceed that specified in the job mix. Ice should be shaved or finely crushed so that it will fully melt in the mixing chamber and be distributed throughout the mix.

Cooling the water, the aggregates, or both will help control the mix temperature. Large refrigerator units can be used for cooling the water; however, cooling the aggregates will reduce mix temperature more than cooling the water. Aggregate temperature can be reduced by shading and misting. If misters are used for cooling, the mist should be fine enough so that most of the water evaporates. The evaporation of water will cool the air around the aggregates and prevent adding too much water to them.

Placing the RCC early in the day may be the most economical means of controlling the placement temperature. Regardless of the method used, the inspector must verify and document that the RCC is being placed at or below the maximum placement temperature allowed by the specifications. A concrete thermometer should be inserted into the RCC just prior to compaction to determine the temperature of the mix at the time of placement.

Prompt curing is critical to controlling moisture loss during hot weather. Care must be taken to avoid spraying RCC with large droplets of water before it sets up because this could damage the surface. Also, spraying the RCC so that water collects on the surface before the compaction process is completed can weaken the RCC surface. Applying a fine mist over the RCC during and after the spreading and compaction operation is an ideal way of promptly curing the RCC without damage to the surface. The mist should be fine enough so that it humidifies the air near the RCC surface, but evaporates so that water does not collect on the surface before compaction is completed.

The inspector's responsibilities related to hot weather placement include verifying that:

- if misters are used for cooling, a fine mist is used to avoid adding too much moisture to the fine aggregate
- mix placement temperature is monitored and documented, and RCC is placed at a temperature at or below the maximum specified placement temperature
- all ice added for cooling is melted and distributed throughout the mix before being discharged from the tilting drum or compulsory mixer
- curing is begun immediately after compaction
- when misting the RCC during the compaction and spreading operation, water does not collect on the surface and only a fine mist is allowed so that it does not damage the surface

(g) Foundation preparation

The foundation must be excavated or filled to the specified lines and grades prior to placing RCC. It must be firm and unyielding to minimize settlement or consolidation. For earthen foundations, some settlement will occur, but every effort should be made to ensure that this settlement is uniform across the entire structure foundation.

For rock foundations, the rock should be clean to promote bond between the rock and the RCC. Any specified grouting of the foundation should be completed prior to RCC placement. Surface irregularities should be filled with concrete or grout to remove crevices and cracks that might not otherwise be filled by the stiff RCC mix.

RCC should never be placed on frozen ground. Spec 36 prohibits placing RCC on any surface that is less than 35 °F.

A dry foundation tends to wick moisture from the RCC mix, and standing water will increase the moisture content and weaken the mix. Thus, the foundation should be damp but free of standing water at the time of RCC placement.

The inspector's responsibilities related to foundation preparation include verifying that:

- the foundation is excavated or filled to the specified lines and grades
- the density of earthen foundation is uniform and meets specified requirements
- for rock foundations, all grouting is complete and surface irregularities are filled as specified
- rock foundations are clean
- the foundation temperature is greater than or equal to 35 °F
- the foundation is moist but free of standing water

(h) Forming

Many RCC structures are constructed without forming, but forms are sometimes necessary to attain the desired finish or hydraulic characteristics. Lightweight forming systems may be used for conventional concrete, but are normally not suited for RCC. To produce a finish that is uniform in appearance and relatively free from honeycomb or other voids (fig. 13–8), RCC forms must be unyielding. This means they must be anchored well and be massive enough so that they do not flex as the RCC is being compacted against them. Heavy steel or concrete forms work best. Wooden forms have been used successfully for short form heights, but may require additional anchors and bracing to prevent the flexing that tends to result in a poor surface finish.

The form face must be smooth and may require a coating of form oil to prevent the concrete from sticking to it. Whenever form oil is applied after the forms are set, care must be taken to avoid getting the form oil on any surface where subsequent layers of RCC or conventional concrete are to be bonded.

Forms must be designed so that they can be quickly disassembled and reassembled without damage to the RCC. Damage occurs if the forms are removed too soon, are allowed to bang against the RCC, or lack sufficient form oil. Care must be taken during form removal to prevent damage to the formed surface of the RCC. Forms should first be loosened, then pulled up and away to avoid banging the form against the formed face. Adjustments in time of removal, application of form oil, and form removal techniques may be required to attain the specified finish. Spec 36 specifies that 80 percent of the surface area be free of honeycomb. The design engineer may specify a higher percentage of the surface to be free of honeycomb.

The inspector's responsibilities related to forming include verifying that:

- forms conform to the plan for obtaining vertical surfaces
- forms are set to the planned line and grade and are well anchored and braced
- form oil is uniformly applied, but not allowed to contact any bonding surface
- care is taken in the removal and resetting of forms to avoid damage to the previously placed RCC

Figure 13–8 Finish that is uniform in appearance and relatively free from honeycomb and voids

(i) Placing and spreading

After the foundation or lift surface preparation is complete and if applicable, forms are well anchored, placing and spreading may begin. Equipment that is allowed to operate on the lift surface must not leak fluids. Hydraulic fluid, motor oil, grease, and antifreeze are all detrimental to attaining bond. Equipment that mars and loosens compacted RCC should also be prevented from operating on the lift surface. Any loosened materials or contaminants must be removed prior to covering the lift surface with the next layer of RCC.

As the RCC mix is being deposited, some of the larger aggregate will roll down the side of the pile. This aggregate must then be remixed into the RCC just prior to spreading. If the mix is piled against forms, segregated aggregate will end up against the forms causing rock pockets in the finished surface (fig. 13–9). It is best to deposit the mix away from the forms and then spread it against the forms with the spreading equipment. A better formed finish can be attained by placing nonsegregated mix against the forms using a shovel or loader bucket. It may be possible to blade the mix against the forms with minimal segregation, but never allow the RCC to be dumped or piled against forms (fig. 13–10).

Small dozers can be used to spread and level RCC, but should never operate directly on compacted RCC surfaces if doing so damages the surface. They should spread the uncompacted material in front of them as they extend the lift. When it is necessary to traverse compacted RCC surfaces, protective sheets, such as waste conveyor belts or plywood, should be placed on the surface to protect it from the dozer cleats that would otherwise damage the surface.

RCC should be spread to a uniform thickness. Ruts, bellies, and humps in the uncompacted RCC should be removed. The loose lift thickness must be slightly thicker than the compacted lift thickness. For example, the loose lift thickness may need to be 13 inches to achieve a 12-inch compacted lift thickness. The exact loose lift thickness is dependent on the mix and the amount of compaction and should be determined at the test section.

Some compaction will be caused by the dozer during spreading. It is best to limit this compaction unless it can be uniformly distributed over the entire lift. Otherwise, when the loose lift is leveled and made ready for the compactor, some areas will be denser than others. These areas will end up higher than the other areas after the lift is compacted. It is important to develop a process of depositing and spreading the mix so that

Figure 13–9 Rock pockets in the finished surface

Figure 13–10 Mix piled against form

any premature compaction of the loose lift is minimized or is uniform over the entire lift.

Remixing of the RCC can cause more dozer activity in some areas than others. Limiting segregation prior to spreading will reduce the need for remixing and limit the potential for some areas to be prematurely compacted more than others.

When pushing the mix with a dozer, any mix that flows around the dozer blade will tend to segregate. One way to prevent this is to use a blade with sides. These are often retrofitted in the field by welding a metal plate onto each side of the blade (fig. 13–11).

Figure 13–11 Dozer blade retrofitted with sides

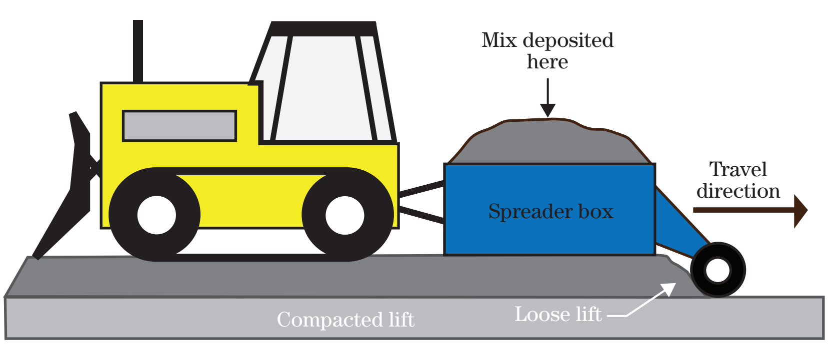
In some instances, a metal box has been used to spread the mix. As illustrated in figure 13–12, the mix is deposited into the box which is attached to a dozer operating on the uncompacted RCC lift. As long as the box contains a sufficient amount of mix, the RCC will be uniformly deposited with minimal segregation. With this process, the amount of compaction caused by the dozer will be sufficiently uniform over the entire loose lift as long as the dozer is not allowed to set running in one place too long.

It is generally more important to spread the RCC to a uniform thickness in as short a time as possible than to spend extra time to perfect the final grade. To quickly spread the RCC to a uniform thickness and also meet the grade tolerances specified in Spec. 36, contractors often employ laser grade control. Rotating beam lasers are ideal for consistent grade control whether the lift surface is level or sloping. Receivers are mounted on the dozer blade for exacting control of the loose lift grade.

The placement of RCC should be performed in as nearly a continuous, nonstop operation as possible. To the extent practicable, the structure should be brought up in level lifts across the entire area. The direction of RCC placement and compaction should be parallel to the main axis of the structure so that the number of lanes and specifically the number of edge joints are minimized.

The RCC mix should be placed as near to its final location as possible. At isolated or confined placement locations, the RCC may be deposited and spread up to a maximum distance of 50 feet provided segregation is

Figure 13–12 Dozer with spreader box



limited, specified spreading time is not exceeded, and the time specified between mixing and completion of compaction is not exceeded.

Spreading of the RCC should be completed within 10 minutes after being deposited. RCC should be spread into an uncompacted, uniform lift thickness that can be compacted to produce a lift of the specified thickness and density. In areas requiring special compaction, such as up against forms, it may be necessary to deposit, spread, and compact the RCC in two or three layers to produce a lift of the specified thickness and density.

Edge joints occur when RCC is placed in parallel lanes and one lane is allowed to set up or harden before the adjacent lane is placed and compacted against it. Edge joints also occur within a lane when placement is stopped before a lane is completed only to resume after the placed RCC has set up. Cracks tend to form at edge joints that contribute to deterioration at the joints over time. Thus, edge joints should be avoided when possible. A plan that allows adjacent lanes of RCC to be compacted simultaneously with both lanes are still compactable should be implemented when possible. Read more on edge joints in NEH 645.1301(k).

Segregation should be corrected by reworking the RCC during spreading operations so that the mix, when compacted, is of the specified uniformity. Reworking should be accomplished in a manner that will not result in damage to previously compacted RCC. If, after remixing, a uniform mix is not achieved, the RCC should be wasted. When uniformity of the RCC is suspect, uniformity tests should be performed on material taken from the placement area after the material has been spread. It may also be necessary to perform uniformity tests on material obtained at other points in the RCC production process to isolate the source of the problem.

The RCC mix should be sampled after spreading to obtain material for testing. Samples are commonly taken for making compressive strength cylinders. Mix consistency (Vebe time), if required by the specifications, should also be determined from material obtained after spreading.

The inspector's responsibilities related to placing and spreading the RCC mix includes verifying that:

- foundation or lift joint preparation is complete as specified
- forms are set to specified line and grade, well anchored, and oiled
- care is taken to prevent damage to previously placed RCC when setting forms or conducting other operations
- lifts are of a uniform thickness to produce the designed grade within allowable tolerances
- equipment does not contaminate or damage the lift surface
- mix is deposited away from forms
- mix is deposited in a manner to limit segregation
- mix is placed as near to its final location as possible
- mix is spread quickly and in a manner to limit segregation
- mix is placed in a configuration that limits edge joints
- segregated mix is remixed or wasted
- tests are conducted to verify and document specification compliance

(j) Compaction

The strength and durability of RCC improves as the density increases, but excessive rolling can actually decrease density of some mixtures and induce surface cracking. Therefore, it is desirable to compact the RCC with a large roller that can attain the specified density in as few passes as possible. This large roller is referred to in Spec 36 as the "production roller." The dynamic force, amplitude, and frequency of vibration of the production roller are specified to ensure that compaction can be attained with a minimum number of roller passes. Typically, four to six passes of the production roller are adequate to achieve desired densities for RCC lifts up to 12 inches thick. The specified density may eventually be attained with a smaller roller, but the number of passes required to compact the full 12-inch lift would likely induce undesirable surface cracking.

Compaction in tight spaces inaccessible to the production roller requires the use of smaller equipment. Special compaction equipment such as walk-behind rollers, power tampers (also known as jumping jacks) and manually directed vibratory plate compactors may be used in confined spaces and up against formwork. It is generally necessary to reduce the lift thickness when using special compaction equipment to prevent overcompaction of the surface. If the surface begins to crack before the specified density is attained or the specified density cannot be attained throughout the entire lift thickness, the lift thickness must be reduced.

Spec 36 requires that the density be not less than 98 percent of the AMD. For example, if the AMD of the mix has been determined to be 153.0 pounds per cubic foot, the minimum density that would meet the specification is:

$$153.0 \quad 0.98 = 149.9\ \text{lb/ft}^3 \qquad \text{(eq. 13–1)}$$

Uniformity of density throughout the full depth of the lift being compacted is a concern. When compaction begins, the upper portion of the lift is compacted first. Once the upper portion of the lift is compacted, compaction energy is transmitted to the lower portion of the lift. Some variation in density is to be expected with the upper portion being denser than the lower portion of the lift. Spec 36 requires that the difference between densities at any two depths shall not exceed 2 percent of the greater of the two values. For example, a density measurement is taken at a depth of 10 inches and another at 4 inches. The density at 10 inches is 150.0 pounds per cubic foot, and the density at 4 inches is 152.0 pounds per cubic foot. The percent difference is:

$$\left[\frac{(152.0-150.0)}{152.0}\right]\times 100 = 1.3\% \qquad \text{(eq. 13–2)}$$

If the difference had been greater than 2 percent, continued compaction would have been needed to meet the requirement for uniformity of density. When the uniformity requirement cannot be met, a reduction in the lift thickness, a change in compaction equipment, or a change in the mix will be necessary. Step 2 in the process of establishing the AMD is conducted to check for variations in density from the bottom to the top of the lift. Read about this process in the discussion about the test section in section 645.1301(c).

Compaction should be accomplished as soon as possible after the RCC is spread, especially in hot weather. Spec 36 specifies that compaction is to be completed within 45 minutes from the time of initial mixing.

The inspector's responsibilities related to compaction includes verifying that:

- the production roller and special compaction equipment meet the specified requirements
- the production roller is used where possible
- special compaction equipment is only used where absolutely necessary
- lift thickness is controlled to prevent surface damage caused by overcompacting
- the RCC is compacted to the specified density
- the requirement for uniformity of density is met
- compaction is accomplished as soon as possible after the RCC is placed, and within the specified time limit

(k) Joints

Joints occur between the RCC and the foundation or between the previously placed and compacted RCC lift and a subsequently placed lift. The type of joint treatment and bond enhancement is dependent on two things: the need for lift bond and the condition of the joint. If the design engineer determines that lift bond is needed, the type of treatment will be dependent on the joint condition. Three joint conditions are defined in Spec 36: fresh joint, intermediate joint, and cold joint.

Specified joint treatment needs to be performed just prior to the placement of the next lift of RCC. Following compaction, lift surfaces should be moistened and kept damp until the next lift is placed or until the end of the required curing period. The lift surface should be cleaned, as necessary, prior to placement of the next lift. The cleanup should include the removal of all loose material, laitance, dirt, debris, standing water, snow, ice, oil, and grease.

Cleaning of previously placed RCC layers should be accomplished by compressed air, low-pressure washing, high-pressure washing, or sand blasting. One or more of these methods may be used, depending on the condition of the lift joint and the specified level of treatment.

All loose materials must be removed from the surface prior to covering it with any material that must be bonded to the previously compacted RCC.

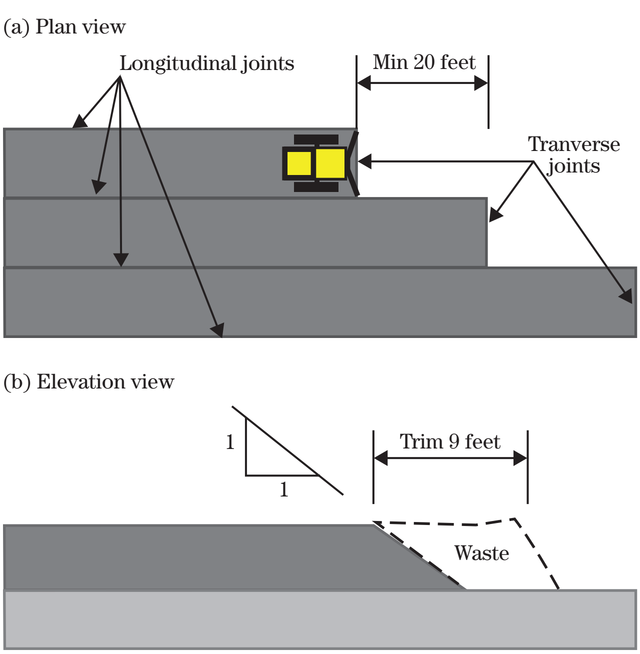
Edge joints are categorized as either longitudinal or transverse. Longitudinal joints are those parallel to the direction of placement. Transverse joints are joints oriented perpendicular to the direction of placement. Both types of edge joints are shown in figure 13–13. Transverse joints must be offset to avoid seepage paths that might occur at the joint. Spec 36 requires all transverse joints be spaced at least 20 feet apart.

Edge joints that are exposed for more than 30 minutes should be trimmed back a minimum of 9 inches and beveled to a 1:1 slope as shown in figure 13–13(b).

Materials removed by trimming should be discarded. As with horizontal lift joints, edge joint treatment should be performed just before placing RCC against it.

The types of bonding materials generally used in RCC are neat cement grout, bonding mortar, and conventional concrete. Bonding mortar is referred to as "bedding mortar" whenever it is placed between the foundation and the RCC. Neat cement grout is made by combining water and cement to make a fluid, but tacky paste. A bonding mortar is a high-slump, high-cement content mix of sand, cement, water, and set retarding admixture. It is used to increase bond and improve water tightness by filling any voids that may occur at the lift joint.

Figure 13–13 Edge joints



Neat cement grout is generally used on jobs where the RCC mix contains enough paste and mortar to fill all of the voids in the RCC. The lift joint for this type of RCC mix would have few, if any, voids, providing for good overall contact between the lifts. The neat cement grout would only serve to bond the joints, not fill voids. The neat cement grout may be mixed before applying it to the lift surface or made by applying dry cement to a moist surface. If dry cement is applied to a moist surface, make sure there is sufficient water to fully hydrate the cement. Otherwise, there may be dry pockets of cement between the lifts that would serve to break rather than enhance the bond. Neat cement grout tends to dry out rapidly, so it is necessary to cover it with the RCC within 10 minutes after it is placed. Care should be taken not to disturb the grout before it is covered with the next lift of RCC. Unless the grout is very liquid, trying to rake or otherwise distribute it after it is placed will result in a nonuniform layer of grout.

Bonding mortar or conventional concrete is often used on jobs where the RCC mix does not contain enough paste and mortar to fill all of the voids in the RCC. With this type of "harsh" or "boney" RCC mix, there will be voids at the lift joint. The lift surface of the previously compacted lift may be relatively free of voids, but there will be voids at the bottom of the next lift due to a lack of adequate paste and mortar in the RCC. The bonding mortar or conventional concrete must be evenly spread on the lift surface in sufficient thickness to fill these voids.

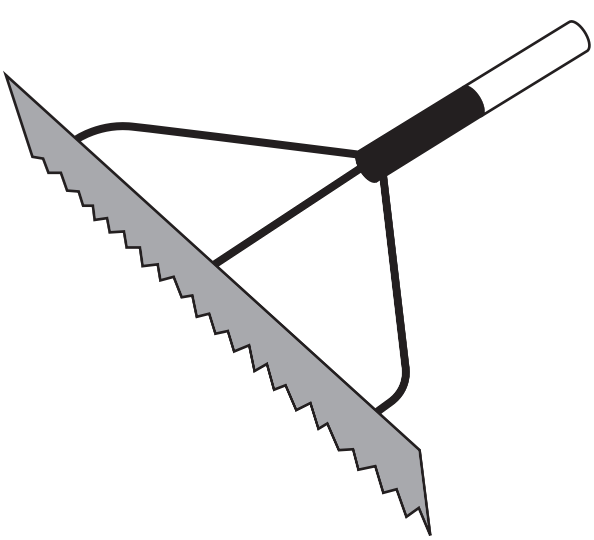
Set retarders should be used to extend the time of setting of the bonding mortar, bonding concrete, and neat cement grout. The time between spreading of the concrete, mortar, or grout and the placement of the RCC should be minimized to ensure the concrete, mortar, or grout does not set up or dry out prior to being covered with the RCC mix. Bonding mortar, bonding concrete, or grout may be deposited onto the lift surface from the chute of a ready-mix truck, a front-end loader bucket, or a concrete bucket. Bonding mortar or grout can then be spread with rakes to the specified thickness.

Serrated rakes made for spreading asphalt, as shown in figure 13–14, should be used and the spreading distance should be limited to prevent segregation. Brooms will result in segregation and should not be allowed. Concrete that is used for bonding lift joints must be spread with shovels because spreading with a broom or rake will result in severe segregation.

The inspector's responsibilities related to joints includes verifying that:

- all transverse edge joints are spaced a minimum of 20 feet apart
- all edge joints are trimmed as specified
- all joints are treated as specified
- all joints are kept moist and clean
- the specified neat cement grout, bonding concrete, or bonding mortar is used
- bonding materials are evenly distributed and spread to the specified thickness
- bonding materials are not disturbed after placement
- bonding materials are not exposed longer than specified
- bonding materials do not set up or dry out before being covered with RCC

Figure 13–14 Asphalt rake



(l) Curing and protection

(1) Curing

RCC, like conventional concrete, must be cured to allow for hydration of the cementitious materials in the mix. Unlike conventional concrete, there is no bleed water to keep the surface moist, so surface drying begins during compaction. Curing cannot begin during compaction, as this would tend to increase the water to cementitious materials ratio of the mix near the surface and weaken the surface, but curing must begin immediately after compaction. It is critical that the surface is not allowed to dry out during the curing period or before being covered with subsequent placements of bonding materials, RCC, or conventional concrete.

Conventional concrete is normally cured for 7 days, but slower strength gains in RCC make longer curing periods necessary. Spec 36 requires that all exposed and completed RCC be cured for a minimum of 14 days at or above 40 ºF. If the temperature of the RCC falls below 40 ºF during the curing period, the curing period must be extended to allow this requirement to be met. For example, consider a scenario where curing begins at noon on March 25th with the surface of the RCC above 40 °F. On the morning of March 28th, the inspector notices that sometime in the night the surface temperature of the RCC fell below 40 °F. The exact length of time that the RCC surface was below 40 °F could not be determined, but the inspector noted that the surface temperature rose above 40 °F by noon on the 25th. Before leaving the site at 5 p.m. the previous day, the inspector had noted in the job diary that the RCC surface temperature was 40 °F. Nineteen hours elapsed from 5 p.m. on the 24th to noon on the 25th. Had the RCC surface temperature remained above 40 °F during the entire curing period, curing could have been terminated at noon on April 8th. But the inspector documented that the surface temperature had fallen below 40 °F for a period of 19 hours during the curing period. Thus, the curing period had to be extended to 7 a.m. on April 9th.

Since repairs are often small or applied in relatively thin layers, they tend to dry out quickly, making it all the more important to begin curing of any repaired area immediately after the repair is completed. Repairs are made with materials that typically gain strength faster than RCC, so Spec 36 only requires repairs be cured for 7 days, not the 14 days required for RCC.

Wet curing—Wet-cured RCC must be maintained in a continuously damp condition for the entire curing period. This can be accomplished by a continuous application of water or water supplemented by a saturated cover material such as sand. Water should initially be applied in a fine mist that does not erode, mar, or otherwise damage the RCC. If sand is used, it should be wetted prior to being placed on the RCC; otherwise, dry sand will wick moisture out of the RCC.

Wet curing often entails the application of water and a covering of plastic. Soaker hoses are typically placed under the plastic cover to replenish any moisture that is lost. Plastic covering must be secured to keep it in place and held tightly against the RCC to limit air movement between the plastic and the RCC. Plastic covering should meet the requirements of ASTM C171. During hot weather, white or reflective coverings should be used.

Curing compound—Areas to be cured with curing compound must be kept continuously moist until the curing compound is applied. All standing water must be removed before applying the curing compound. Curing compound acts as a bond breaker, so it should not be applied to bonding surfaces such as lift joints or areas to be repaired or patched. Some designers specify that a curing compound cannot be used, rather than risk getting it on bonding surfaces. When allowed, only curing compound that meets specification requirements should be used, and it must be reapplied every 7 days during the curing period. The design engineer should specify the type and class of curing compound in the items of work and construction details in section 22 of Spec 36. In areas where the curing compound is damaged, it should be reapplied immediately.

Curing compound cannot be applied in a timely manner using manual hand pump sprayers. Spec 36 prohibits the use of these small sprayers and requires a continuously agitating sprayer. Continuously agitating sprayers typically produce the flow rate needed to quickly and efficiently cover the surface.

Since RCC surfaces are generally rougher than that of conventional concrete, more curing compound must be applied than would be needed for conventional concrete. Spec 36 requires that curing compound be applied at double the manufacturer's recommended rate. The entire surface to be cured with curing compound must be uniformly covered at the specified rate.

The inspector's responsibilities related to curing include verifying that:

- prior to beginning RCC placement, curing equipment and materials are onsite and ready to be deployed
- curing begins immediately after compaction
- curing continues until the RCC has been maintained at or above 40 °F for 14 days
- curing of repairs begins immediately after repair completion
- repair curing continues until the repair has been maintained at or above 40 °F for 7 days
- application of curing water does not erode the surface
- coverings are secured to prevent the movement of air between the RCC and the covering
- only white or reflective coverings are used during hot weather
- curing compounds are not applied to bonding surfaces or areas to be repaired
- curing compounds conform to specification requirements
- the surface is kept continuously moist until the curing compound is applied
- all standing water is removed prior to applying the curing compound
- continuously agitating sprayers are used to apply curing compound
- manual hand pump sprayers are not used
- curing compound is reapplied every 7 days during the curing period
- where curing compound is used, the entire surface is uniformly covered at double the manufacturer's specified rate

(2) Protection

RCC must be protected from rainfall, cold weather, and damage from construction operations. Wet and cold weather is addressed in detail in section 645.1301(f).

Damage from construction operations typically occurs whenever equipment operates on RCC that has not developed sufficient strength to support the equipment or otherwise resist damage. Lack of care in form removal can result in damage to the face of formed vertical surfaces. Another concern might be the potential for damage from flow through a structure should the structure function while under construction.

The contractor is responsible for protecting the work so that the structure conforms to specification requirements, including the quality of the finished surface and specified tolerances in line and grade. Also, performing work in a skillful and workman-like manner is generally a requirement of any construction contract. It is the contractor's responsibility to ensure that the work is adequately protected and not damaged by the contractor's lack of care or protection. If the work is not being adequately protected, the inspector should contact the engineer to request action be taken to correct the problem.

The inspector's responsibilities related to protection of the RCC includes verifying that:

- RCC is protected against erosive rainfall.
- RCC is protected from cold weather damage.
- vehicular traffic is prohibited if it causes damage to the RCC
- form removal is accomplished without damage to the RCC
- flows are diverted from the structure as needed to prevent damage

(m) Repair of RCC

Spec 36 specifies that a repair plan be submitted 10 days prior to beginning the repair and must be approved before any repair, replacement, or patching of RCC can begin. Spec 36 also requires that material and repair methods conform to recommendations in the ACI's Manual of Concrete Inspection.

(1) Repair or replacement

Spec 36 requires the contractor to repair or replace RCC that does not meet specification requirements. A poor-formed finish, poor control of line and grade, low RCC strength, damage caused by equipment, damage caused by rainfall, or lack of curing are some conditions that would be cause for repair or replacement. Repairs to correct surface imperfections may result in a poorer finish (unsightly) than that of the unrepaired surface because it is difficult to match the color of repair materials with the color of RCC. It is for this reason that every effort should be made to avoid the need for repair.

(2) Patching

Spec 36 requires holes caused by form bolts, metal ties, and similar forming restraints to be patched. Because these holes are relatively small and often spaced in a uniform pattern, they can be patched without the adverse visual affects caused by patching large surface imperfections.

The inspector's responsibilities related to repair of RCC include verifying that the:

- repair plan is approved by the engineer prior to beginning the repair
- repair materials and means and methods conform to the approved repair plan

645.1302 Sampling and testing

The sampling and testing of RCC involves sampling and testing of the materials that go into the job mix, the job mix itself, and the compacted RCC. Sampling and testing for bedding mortar, bonding mortar, or neat cement grout involves sampling and testing of the materials and the mix.

Some of the sampling and testing required to verify compliance is performed prior to or during the mix design program. Other sampling and testing must be conducted during RCC production. This section covers tests commonly performed by the NRCS inspector and others for quality control, quality assurance, and for as-built records and contract documentation. The actual procedure for sampling and testing is provided in the applicable ASTM test standards referenced in the specifications. This section focuses on when, where, and by whom the required tests are typically performed.

(a) Cementitious materials

The supplier provides the test results necessary to verify specification compliance for these items. If the quality or type of cement or pozzolan must be verified from a field sample, a representative sample should be sent to a laboratory that is qualified to make the necessary tests. If the contractor is asked to sample and test the cementitious materials, he or she should not have to pay for the sampling and testing unless the results prove that the materials failed to meet specification requirements or the specification requires that cement or pozzolan be tested to verify specification compliance. The contractor should contact the lab to determine the quantities and the sampling and shipping requirements needed to provide samples for testing.

(b) Aggregates

The following is a list of aggregate tests:

- reactivity with alkalis
- soundness
- abrasion of coarse aggregates
- relative density (specific gravity)
- absorption
- mechanical sieve analysis
- fineness modulus of fine aggregate
- tests for deleterious substances such as:
  - wet sieve analysis
  - test for organic impurities in fine aggregates
  - test for clay lumps and friable materials
  - test for the presence of coal and lignite in coarse aggregates
  - test for the presence of chert in coarse aggregates
- bulk density and voids
- aggregate moisture

Aggregate quality must be determined prior to selecting aggregates for the job mix. The NRCS inspector may be asked to sample and test aggregates prior to developing the job mix, but it is more common to rely on recent test results provided by the aggregate supplier or results from tests performed by the laboratory that conducts the mix design program.

Mechanical sieve analysis and aggregate moisture tests are performed both during the mix design program and after the aggregates have been delivered to the jobsite. The mechanical sieve analysis is performed to ensure that aggregates are graded according to the job mix requirements and segregation is held to a minimum. The moisture content of the aggregates is monitored to determine the amount of water the aggregates are absorbing from or contributing to the free water in the mix. Aggregate moisture content values must be determined to compute the theoretical air-free density (TAFD) of the mix.

In arid climates, the inspector should be concerned about aggregates being too dry. Dry aggregates tend to absorb water and make it difficult to control the consistency of the mix. In humid climates, the concern is with too much water in the aggregates. Aggregates, especially fine aggregates, can contain fairly large amounts of free water that cause the mix to be too wet, even before adding additional water.

(1) Aggregate sampling

Aggregate sampling is conducted in accordance with ASTM D75. The main concern with sampling any material is being able to obtain a representative sample. Spec 36 requires that samples from stockpiles be obtained from various parts of the stockpiles, but never from the perimeter of the lower third of the pile. This is because the larger aggregates tend to segregate and roll to the perimeter of the pile.

It is best to sample aggregates just prior to them entering the batch hopper or mixing chamber. When sampling from a belt or stockpile, several samples should be taken and test results averaged to arrive at a value that is representative of a large portion of aggregate.

Aggregates being sampled for moisture testing must immediately be placed into an airtight container to protect against loss of moisture and should be tested as soon as practicable after being collected.

(2) Aggregate testing

Whenever the moisture of the RCC mix is adjusted based on field aggregate moisture tests, it is important to know if the test result represents the total moisture in the aggregate or just the moisture on the surface of the aggregate. For instance, if the moisture is determined according to ASTM D2216, the oven method, the test result will represent the total aggregate moisture (absorbed and surface moisture). The aggregate's absorption is subtracted from this value to determine the free water in the aggregate. If a Speedy (carbide) moisture meter (ASTM D4944) is used, the test result is typically adjusted using a calibration curve to represent the free and absorbed water in the aggregate. Since the oven method results in a true value of total aggregate moisture, results from all other moisture test methods should be compared to results from the oven method to document their accuracy relative to that of the oven method. Other methods for determining aggregate moisture are the:

- nuclear method (ASTM D6938)
- microwave oven method (ASTM D4643)
- direct heat or stovetop method (ASTM D4959)

(c) Water

Generally, water that is safe to drink is good for making RCC. Spec 36 says that water incorporated into the mix or used for curing RCC must be clean and free from injurious amounts of oil, salt, acid, alkali, organic matter, turbidity, or other deleterious substances and conform to the requirements of ASTM C94. Although ASTM C94 allows wash water to be incorporated into the RCC, Spec 36 prohibits the use of wash water for mixing.

If water testing is necessary, samples should be taken in a clean container that will not contaminate the water. Testing is usually done by an independent laboratory. Water testing is not normally required unless there is reason to suspect the water will adversely affect the RCC mix. Cloudy water indicates the presence of suspended particles that could adversely affect the mix. Water with a foul odor might also adversely affect the mix. The contractor should not have to pay for the sampling and testing of water unless the results prove that the water failed to meet specification requirements or the specification requires the water be tested to document specification compliance.

(d) Admixtures

The only admixture allowed by Spec 36 is a water-reducing and set retarding admixture that conforms to ASTM C494, type D. Field sampling and testing of the admixture should not be required; however, it is important to verify that the admixture being used complies with the specifications and the approved job mix. The NRCS inspector should read labels affixed to admixture containers to determine and document compliance.

(e) RCC mix

(1) Sampling

Methods for sampling freshly mixed RCC are provided in ASTM C172. This standard applies to conventional concrete sampling; however, it can also be used for RCC. Specific items to note from this standard are the need to:

- sample and test in a timely manner
- obtain a representative sample
- obtain a sample of adequate size

(2) Consistency and workability

The consistency of conventional concrete is determined by the slump test, ASTM C143. Since RCC is a no-slump mix, the Vebe test, ASTM C1170, is employed to provide a measure of the RCC mix consistency. The Vebe test results in a value of time, in seconds, that it takes for a ring of mortar to appear around the periphery of a surcharged plate while the mix is being vibrated in a cylindrical metal bucket. A low Vebe time (20 seconds or less) indicates the mix is very workable. Low Vebe mixes likely contain adequate paste and when adequately compacted against unyielding forms, produce a smooth finish similar to conventional concrete. A high Vebe time (30 seconds or more) indicates a “harsh” or “boney” mix.

Spec 36 requires the Vebe test be conducted during the mix design program to verify that the job mix is of the specified consistency. Although some specifications require the consistency of the mix be monitored with the Vebe test in the field, many of the quality control firms and most NRCS offices do not own a Vebe apparatus; thus, it is more common on NRCS jobs to visually monitor the mix consistency in the field by observing the actual workability of the mix as it is being spread and compacted. The finish of formed surfaces is another indicator of consistency. A relatively low Vebe mix can have a formed finish that is smooth, free of honey comb and rock pockets, and uniform in appearance. Poor forms, poor compaction, a high Vebe mix, or any combination of these can result in a poor formed finish.

(3) In-place moisture

It is important to measure the moisture content of the mix to verify that the water content of the mix conforms to that called for in the job mix. There are several tests for moisture content of the RCC mix. A drying oven (ASTM D2216), microwave (ASTM D4643), or nuclear moisture/density meter (ASTM D3017) are commonly used onsite to test RCC moisture. These tests are also made to document specification compliance and as part of the tests for mix uniformity required by Spec 36.

When sampling the mix to determine the moisture content, obtain the sample after the mix has been spread. The sample should be tested immediately because the moisture content will change as the cement hydrates.

When testing moisture with a nuclear gauge, the moisture reading on the gauge only represents the average moisture of the material 3 or 4 inches below the gauge. Also, the gauge should be calibrated against a more exacting test, such as the oven test, because there may be elements in the cement that cause the nuclear gauge to give a high moisture reading. Calibration procedures are generally given in the nuclear gauge owners manual. If the results of an oven or other test are to be compared to the results from a nuclear gauge, the sample should be obtained from below the gauge and from the surface down to a depth of no greater than 4 inches.

Testing is necessary to document mix moisture but it is common to base moisture adjustments on a visual observation of the consistency and workability of the mix as it is being spread and compacted. Even though this visual assessment does not yield a numerical value of percent moisture (%M), if all of the ingredients are properly proportioned according to the job mix, it gives a quick indication of whether the moisture is too high or too low for producing a workable mix.

(4) In-place density

RCC density is almost always measured with a nuclear density gauge. The value obtained by the nuclear gauge is only an approximation of the true density of the RCC, but determining the true density is not important. What is important is that specification compliance can be determined from values obtained by the gauge. This can be done as long as the AMD is established for the gauge. Since it is common for different gauges to yield different density values, an AMD value must be determined for each gauge used.

The density reading obtained with the gauge in backscatter mode represents the density near the surface of the RCC. The density reading that is obtained with the nuclear gauge at any depth, say 10 inches, represents the average RCC density between the emitter in the tip of the probe and the detection in the heel of the gauge, not the density at 10 inches (fig. 13–15). Since the density near the surface is generally higher than the density in the lower parts of the lift, the actual density at 10 inches will likely be less than the gauge reading at 10 inches.

Spec 36 requires density measurements be taken at 2, 4, 6, 8, 10, and 12 inches when determining the AMD. Compaction operations must be modified until the minimum value attained from these measurements at various depths is within 2 percent of the maximum value attained. This ensures that the mix placed in the test section is compacted to a relatively uniform density throughout the entire lift depth using the production roller.

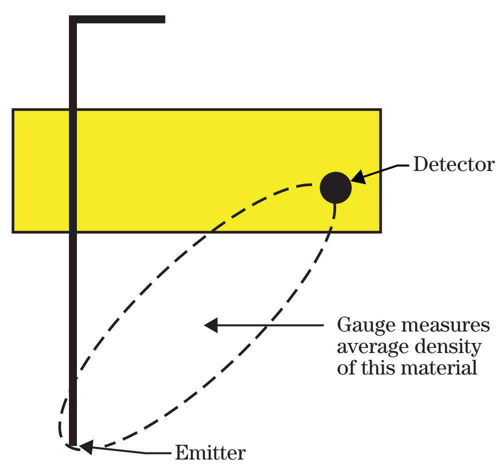
When testing density during RCC production, it is recommended that the density be measured at several depths at each test site to verify that the density is relatively uniform from the bottom to the top of the lift. This is especially important in those areas that cannot be compacted with the production roller, but must be compacted using special compaction techniques. Special compaction techniques employ power tampers and smaller compaction rollers, which do not supply as much compaction energy as the production roller. Thus, a common problem with special compaction techniques is the inability to compact near the bottom of a 12-inch lift. Variations of more than 2 percent in density measurements throughout the lift indicate that thinner lifts are required to attain the specified density in a uniform manner throughout the entire lift depth. Spec 36 requires that the difference in results from two density tests taken at different depths not exceed 2 percent of the greater of the two values.

(5) Temperature
Testing the temperature of the RCC mix at the time of placement is required to verify that mix temperature is within the range specified in Spec 36. The minimum specified mix temperature is 40 °F at the time of placement. The maximum specified mix temperature varies from job to job and is specified in the items of work and construction details in Spec 36. Measurements of RCC mix temperature should be taken at several points across the placement area and at different times during each shift.

In cold weather, it is important to measure the temperature of the RCC after placement during the protection period (the protection period is defined in Spec 36 and discussed in section 645.1301(l)). The temperature should be measured with a surface thermometer that will record the lowest temperature that occurs during a given period. This can be accomplished using a high/low thermometer placed on the surface of the RCC. The thermometer should be placed in a location where the coldest RCC temperature is likely to occur, such as on the edge of a step. Place the thermometer directly on the RCC, and cover it with the same material used to insulate the RCC. If the RCC is not covered, do not cover the thermometer.

The RCC average surface temperature (AST) is multiplied by the time of exposure (TE) to compute joint maturity. Lift surface temperature is measured at several locations on the lift surface each hour that the joint is exposed from the time compaction is completed until the lift is covered with a subsequent layer of RCC or conventional concrete. The surface temperature values are averaged to determine the AST for a specific TE. Measurements are made with a surface thermometer or any thermometer that can be positioned in intimate contact with the surface to attain an accurate reading.

Figure 13–15 Nuclear gauge measures density of material between the tip of the probe and the heel of the meter



(f) RCC compressive strength

(1) Number and frequency of samples
There is no standard frequency for sampling and testing the strength of RCC. The job-specific quality assurance plan (QA plan) should list sampling and testing frequency requirements. Consult with the engineer to develop a schedule for the sampling and testing program that is based on the QA plan. The contractor's sampling and testing schedule should conform to the RCC specification and the specification for quality control.

Initially, frequent sampling and testing are necessary to verify the suitability of the RCC. Most problems should be resolved during the performance of the test section, but extra in-place nuclear density tests and strength specimens in the first few days of RCC production are valuable for early verification of placement procedures and the adequacy of compaction. Test cylinder breaks at 7 or 14 days can be an early indication of the 28-day strength. Frequent tests also may be needed for critical elements of a given structure or when the materials, equipment, weather, or other conditions indicate a need for additional testing.

Compressive strength test results at an early age are not conclusive and should be regarded only as indicators. If early tests indicate relatively low or marginal strength, the contractor may choose to adjust the design mix or, contract permitting, discontinue production and wait to see if tests on more mature specimens prove that the mixture is adequate. The contractor may also perform accelerated strength testing where cylinders are moist cured at a controlled high temperature to accelerate the strength gain. Results of compressive strength tests on these specimens can be used to predict strengths of more mature RCC.

If the mix stays consistent, strength test results should correlate to in-place density. Thus, after the job mix has proven satisfactory and when all manufacturing operations are well controlled, density test results can be used to predict strength. Fewer compressive strength tests will then be needed for quality control and quality assurance.

(2) Molding samples

The procedure for molding test cylinders for compressive strength tests as described in ASTM C31 is not suitable for RCC. ASTM C1435 should be followed to make cylindrical molds using a vibrating hammer, and ASTM C1176 should be followed when using a vibrating table. The vibrating hammer method is more common for making field specimens on NRCS jobs.

Samples need to be handled and shipped as required in the appropriate ASTM standard. Each shipment must have complete identification and sampling data including:

- specimen group number
- specimen dimensions
- number of specimens in group
- date made
- date to be tested
- age to be tested
- standard sampling procedure
- comments including curing information

This information can be recorded on WS 13.6, RCC Compressive Strength Test Results worksheet (see NEH 645.1303). Copies of this form will give the laboratory the information it needs and also provide a record for the contract files.

(g) Hardened RCC

Core samples are obtained in accordance with ASTM C42. The cores should have a minimum length equal to one lift thickness and a minimum nominal diameter of 6 inches. The length of the core should be twice the diameter; otherwise, the results should be adjusted according to C42. Core specimens should not be taken until the RCC has gained sufficient strength to resist damaged during the coring process. The average of test results from two or more cores sampled from the same lift and production shift is taken to represent the concrete strength.

Core specimens are also obtained to test for lift joint strength. These cores are usually sampled with a special core barrel designed to minimize stress on the lift joint. This special equipment is not required by ASTM C42; it must be specified in the items of work for the job. Lift joint testing is not required on all RCC jobs. When it is required, compensation for sampling and testing is generally made under a separate bid item. The items of work and construction details for such an item will be found in Spec 36, section 22 and should include requirements for the type of core barrel, the age of the RCC when cored, curing and handling of the cores, the various ages of cores to be tested, and requirements for filing the hole from where the core was extracted.

Damage in handling and shipping of test specimens may result in test results that are not representative of the in-place RCC. This is particularly true of cores used for evaluating lift joints. Handling and shipping should be carried out in accordance with ASTM D5079, which includes requirements for handling, transportation, and storage.

645.1303 Records and reports

The following records and reports are related to RCC:

- Daily Diary—used to record the day-to-day activities of construction including RCC activities
- WS 13.1—Record of Aggregate Moisture
- WS 13.2—Field Mix Evaluation
- WS 13.3—Apparent Maximum Density (AMD) Determination
- WS 13.4—RCC Lift Summary
- WS 13.5—In-place RCC Density and Moisture Test Results
- WS 13.6—RCC Compressive Strength Test Results

It is best to use all of these documents to facilitate a complete evaluation of RCC production and provide thorough documentation of compliance with Spec 36.

Appendix B contains blank worksheets, guidance on filling out the worksheets, and example worksheets.

Appendix C contains an example of a typical diary entry related to RCC construction.

645.1304 References

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