Roller-Compacted Concrete

Course Number: CE-02-115

PDH: 4

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Chapter 1
Introduction

1-1. Purpose

The purpose of this course is to provide information and guidance on the use of roller-compacted concrete (RCC) in dams and other civil works structures. This course does not cover RCC for pavements. Elements discussed include investigation and selection of materials, mixture proportioning, design and construction considerations, construction equipment and techniques, inspection, and performance.

1-2. Applicability

This course applies to all USACE Commands having civil works responsibilities.

1-3. References

Required and related references are listed in Appendix A.

1-4. Definition

The American Concrete Institute (ACI) 116R[1] defines RCC as "concrete compacted by roller compaction; concrete that, in its unhardened state, will support a roller while being compacted." Properties of hardened RCC can be similar to those of conventionally placed concrete. However, RCC can also be made with hardened properties that are outside the range of typical properties of conventionally placed concrete. The term "roller compaction" is also defined by ACI as "a process for compacting concrete using a roller, often a vibrating roller." The terms "rollcrete" and "rolled concrete" are no longer to be used.

1-5. Applications

RCC may be considered for application where no-slump concrete can be transported, placed, and compacted using earth and rock-fill construction equipment. Ideal RCC projects will involve large placement areas, little or no reinforcement, and little or no embedded metal work or other discontinuities such as piles. Application of RCC should be considered when it is economically competitive with other construction methods. It may be considered in lieu of gabions or riprap for bank protection, especially in those areas where riprap is scarce. It may be considered for large work pads, aprons, or paved areas, massive open foundations, base slabs, cofferdams, massive backfill, emergency repairs, and overtopping protection for embankment dams. It may be used in lieu of conventionally placed concrete in concrete gravity and arch-gravity dams. RCC may be considered for use in levees where foundations are adequate and may also be used in caps for jetties to reduce the amount of required rock. For many dam projects, the use of RCC may allow a more economical layout of project features such as an over-the-crest spillway as opposed to a side channel spillway for a comparable embankment dam. A comprehensive summary of RCC dams with heights greater than 15 m (50 ft) has been compiled by Dunstan (1997). A wide range of performance objectives is possible with RCC. Structures designed in a manner similar to those utilizing conventional concrete can be constructed using RCC with many of the same characteristics. It is also possible to design structures requiring less demanding performance, consequently making them more economical.

[1] All ACI references are listed with detailed information in Appendix A.

1-6. Objective of RCC Operations

RCC was initially developed to produce a material exhibiting the structural properties of concrete with the placing characteristics of embankment materials. The result was a material that, when properly designed and constructed as a gravity structure, should be more economical than comparable earth-rockfill and conventional concrete structures. To achieve the highest measure of cost effectiveness and a high-quality product similar to that expected of conventional concrete structures, the following RCC design and construction objectives are desired: RCC should be placed as quickly as possible; RCC operations should include as little manpower as possible; RCC design should avoid, as much as possible, multiple RCC mixtures and other construction or forming requirements that tend to interfere with RCC production; and RCC design should minimize complex construction procedures. RCC structures have been designed for a wide range of performance conditions, from low-strength more massive structures to high-strength less massive structures. It is critical that the design of the structure be coordinated with the performance requirements for the RCC material and the specification requirements for construction.

1-7. Major Advantages

RCC construction techniques have made RCC gravity dams an economically competitive alternative to conventional concrete and embankment dams due to the following factors.

a. Costs. Construction-cost histories of RCC and conventional concrete dams show the unit cost per cubic yard of RCC is considerably less than conventionally placed concrete. Approximate costs of RCC range from 25 to 50 percent less than conventionally placed concrete. The difference in percentage savings usually depends on the cost of aggregate and cementing materials, the complexity of placement, and the total quantities of concrete placed. Savings associated with RCC are primarily due to reduced forming, placement, and compaction costs and reduced construction times. Figure 1-1 shows the relationship of the cost of RCC to the volume of the RCC structure based on RCC projects constructed in the United States.

b. Rapid construction. Rapid construction techniques (compared with those for concrete and embankment dams) and reduced material quantities (compared with those for embankment dams) account for major cost savings in RCC dams. The RCC construction process encourages a near continuous placement of material, making very high production rates possible. These production rates significantly shorten the construction period for a dam. When compared with embankment or conventional concrete dams, construction time for large RCC projects can be reduced by several months to several years. Other benefits from rapid construction include reduced administration costs, earlier project benefits, possible reduction or deletion of diversion facilities, and possible use of dam sites with limited construction seasons. Basically, RCC construction offers economic advantages in all aspects of dam construction that are related to time.

c. Integral spillways and appurtenant structures. As with conventional concrete dams, spillways for RCC dams can be directly incorporated into the structure. A typical layout allows discharging flows over the dam crest and down the downstream face. In contrast, the spillway for an embankment dam is normally constructed in an abutment at one end of the dam or in a nearby natural saddle. An embankment dam with a separate spillway and outlet works is generally more costly than the comparable RCC dam with an integral spillway and outlet works. For projects requiring a multiple-level intake for water quality control or for reservoir sedimentation, the intake structure can be readily anchored to the upstream face of the RCC dam. For an embankment dam, the same type of intake structure would be a freestanding tower in the reservoir or a structure built into or on the reservoir side of the abutment. The cost of an RCC dam intake is considerably lower than the cost of an intake structure for an embankment dam, especially in high seismic areas. The shorter base dimension of an RCC dam, compared with that of an embankment dam, reduces the required size and length of the conduit and penstock for outlet and hydropower works and also reduces foundation preparation costs.

d. Minimized diversion and cofferdam. RCC dams provide cost advantages in river diversion during construction and reduce damages and risks associated with cofferdam overtopping. The diversion conduit for RCC dams will be shorter than for embankment dams. With a shorter construction period, the probability of high water is less, therefore the size of the diversion conduit and cofferdam height can be reduced from that required for both embankment and conventional concrete dams. These structures may need to be designed only for a seasonal peak flow rather than for annual peak flows. With the high erosion resistance of RCC, the potential for a major failure would be minimal, and the resulting damage would be less, even if overtopping of the cofferdam did occur. Significant advantages can be realized using RCC for the construction of cofferdam structures. It offers the benefits of rapid construction, small footprint, and continued operability after overtopping.

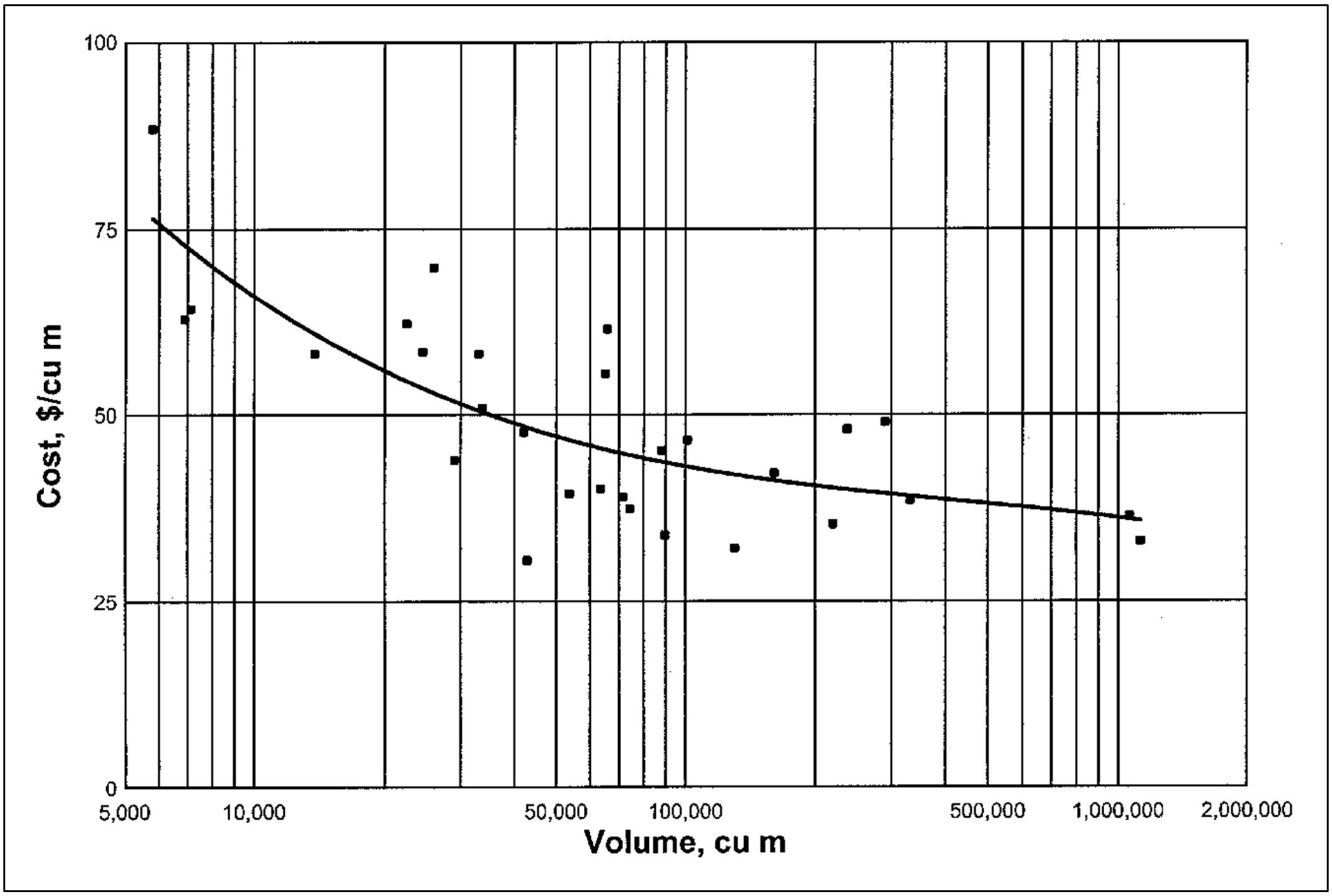

Figure 1-1. RCC costs (1998 price level)

e. Other advantages. When compared with embankment dams, the smaller volume of RCC gravity dams makes the construction material source less of a driving factor in site selection. Furthermore, the borrow source will be considerably smaller and may be more environmentally acceptable. The RCC gravity dam is also inherently more resistant to internal erosion and overtopping.

1-8. Engineering Responsibilities and Requirements

The duties and responsibilities identified in EM 1110-2-2000 apply to RCC structures. During the feasibility stage it may be advantageous to perform a preliminary thermal study to establish gross performance of the structure. Guidance is provided in ETL 1110-2-542, "Thermal Studies of Mass Concrete Structures," for performing these preliminary thermal studies. Later, during the preconstruction engineering and design phase, a more detailed thermal study may be performed to better identify crack control features of the structure. The design team for an RCC project may include many disciplines. As with other mass concrete structures, it is critical that a geologist, engineering geologist, or geotechnical engineer evaluates the foundation conditions, a hydraulic engineer evaluates the spillway and outlet structures, a structural engineer designs the structure, and a materials engineer designs the RCC mixture and coordinates the requisite construction requirements. Coordination by the design team of design requirements, materials requirements, and construction requirements is critical to achieve a cost-effective design.

Chapter 2
Investigation and Selection of Materials

2-1. Policy

Policies for RCC dams regarding the investigation of concrete materials and the scope of the required investigation are the same as for a conventional concrete dam and are discussed in detail in EM 1110-2-2000. It is necessary to assess the availability and suitability of the materials needed to manufacture RCC with qualities meeting the structural and durability requirements. An availability investigation should particularly emphasize the need to meet any high RCC production and placement rates. Additional investigations may be needed for RCC in various applications, as appropriate.

2-2. Cementitious Materials

a. General. The method of investigating cementitious materials for RCC is similar to that used for conventionally placed concrete and should be in accordance with EM 1110-2-2000. The selection of cementitious materials significantly affects the rate of hydration and strength development. The use of pozzolan is quite common for RCC projects and generally provides for reduced cost and lowered heat generation. Pozzolan contents ranging up to 80 percent by volume of the cementitious material have been used by many design organizations.

b. Cement. Type II portland cement is more commonly used with RCC because of its low heat generation characteristics at early ages and its longer set times. The use of Type III portland cement is not practical for most RCC applications because it shortens the time available for compaction and increases heat evolution at early ages. The slower rate of strength development of some cements generally results in greater ultimate strength for a given cement content.

c. Pozzolan. The use of a pozzolan or ground slag may be especially beneficial in RCC as a mineral filler and for its cementitious properties, as well as providing a degree of lubrication during compaction. Pozzolan occupies some of the paste volume otherwise occupied by cement and water. Class F fly ash is most commonly used as a pozzolan or mineral filler for RCC but Class C fly ash has also been used. Class F fly ash contributes to lower heat generation at early ages, may be used to replace cement (generally up to approximately 50 percent by volume), reduces cost, acts as a mineral filler to improve workability, and delays final set. Therefore, RCC mixtures containing Class F fly ash benefit from increased placement time and increased workability. Laboratory testing should be conducted to verify and evaluate the benefits of using pozzolan.

2-3. Aggregates

a. General. One of the most important factors in determining the quality and economy of concrete is the selection of a suitable source of aggregate. This statement is as true for RCC as for conventional concrete. The investigation of aggregates will follow the procedures described in EM 1110-2-2000.

b. Aggregates for RCC. As with conventional concrete, aggregates for RCC should be evaluated for quality and grading. Aggregate for RCC should meet the standards for quality and grading as required by the desired properties for the design structure. The use of lesser quality aggregate may be appropriate for certain circumstances, such as construction during an emergency situation, when the use of a poorer quality aggregate does not affect the design requirements of the RCC, or where specific material properties can be achieved with the use of such aggregates. Changes from the grading or quality requirements must be supported by laboratory or field test results included in a design memorandum. The design memorandum should identify that the concrete produced from the proposed materials fulfills the requirements of the project for strength, durability, water tightness, and economy. The typical nominal maximum size of aggregate (NMSA) particle which has been handled and compacted in Corps of Engineers RCC construction is 75 mm (3 in.). However, the gradings may be significantly different than those normally used for conventional mass concrete. While larger sizes have been successfully used in Japan and at Tarbela Dam, the use of NMSA larger than 75 mm (3 in.) will seldom be technically justified or economically viable in most Corps of Engineers structures. Use of larger aggregate greatly increases the probability of segregation during transporting and spreading RCC and seldom significantly reduces the RCC cost. A proposal to use aggregate larger than 75-mm (3-in.) nominal maximum size should be included in a design memorandum and

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