# ALTERNATIVE DAM CONSTRUCTION TECHNIQUES

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## INTRODUCTION

Water resources management in Georgia has taken on new importance over the last few years because of a series of years where below-normal rainfall has occurred. Georgia on the average receives approximately 49 inches of rainfall a year (NOAA, 1988). Thus the problem is not one of quantity but of collection and storage. Man-made reservoirs are an important source for water supply but are becoming more difficult to site because of environmental regulations. Today's planners and designers must be innovative in their approach with designing dams and the operation of the reservoirs.

During the last decade a relatively new technology has been adapted for use in new gravity dam construction and for the rehabilitation of existing dams and spillways. This technology, called roller compacted concrete (RCC), although still in its infancy, is growing rapidly. Because RCC is a relatively new technique in dam construction, its technology is currently being developed and tested by various private and government organizations.

RCC is defined as a no-slump consistency concrete that is placed in thin horizontal lifts and compacted by vibratory rollers. RCC should not be confused with soil cement or cement-treated graded aggregate base. Although similar, RCC, as used in dam construction, must have engineering properties that are very similar to cast-in-place concrete after it has set and cured.

Major differences still exist among designers as to the best methods for placing the material, treatment of cold joints, mix consistency and proportions. Efforts are underway to develop standards, particularly test procedures, for determining mix density and consistency. As of the date of this paper, each designer of an RCC dam project develops his own technique, drawing from the successful experiences of previous projects.

## ADVANTAGES AND LIMITATIONS OF RCC

Excellent opportunities for positive economic benefits are available through the use of RCC-constructed dams. A typical RCC dam will consist of a vertical upstream slope with a steep (1V:0.7H) downstream slope. Because of its slim profile, the material volumes required for construction are substantially less than for either an earthfill or rockfill dam (Figure 1). Also, RCC has a much lower unit cost per cubic yard than conventional mass concrete because RCC uses less cement per cubic yard, requires little formwork and is placed with standard earthwork techniques. In place RCC for dam construction is averaging between \$30-\$40 per cubic yard (Hansen, 1988). By examination of Figure II it can be seen that for increasing dam heights there is almost an exponential increase in volume requirements. From a purely economic perspective, an RCC dam as compared to an earthfill dam generally becomes more economical as the height of the dam increases.

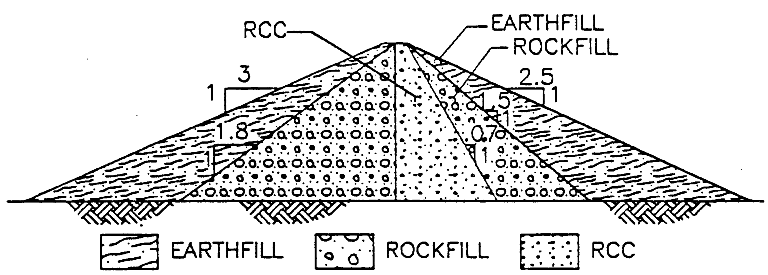


FIGURE 1. COMPARISON OF CROSS SECTIONS

The reduced foundation footprint of an RCC dam offers several distinct advantages. Because of the narrow base width of an RCC gravity dam, a shorter (i.e., less expensive) outlet conduit is possible and less foundation treatment is necessary. Also environmental damage, such as impact on wetlands, destruction of forests and encroachment on endangered or threaten species can be reduced due to less area occupied by the dam and spillway structures. For example a typical earthfill dam 100 feet in height by 1,000 feet in length would occupy a space of 15 acres while an RCC dam with the same dimensions would only require 2 acres. This comparison does not even consider the acreage required for an earthfill dam's emergency spillway.

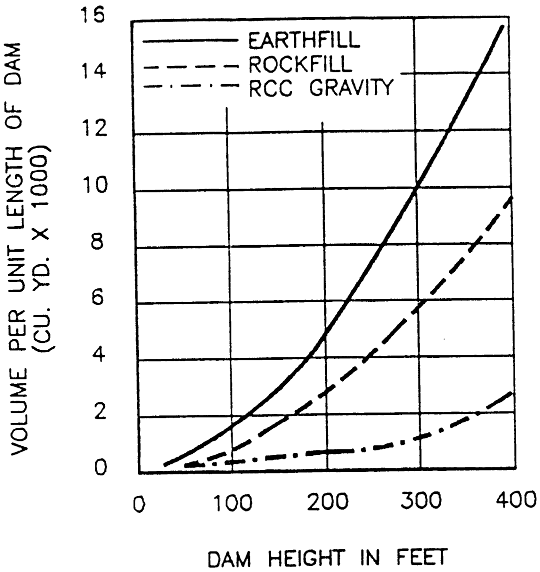


FIGURE 2. COMPARISON OF MATERIAL VOLUMES

Dams constructed across streams located on large watersheds will be expected to safely pass project design storms which can produce tremendous flows. Most RCC dams designed to-date incorporate both the principal and emergency spillways over the dam. Because of this arrangement, the difference between the normal pool and flood pool elevations can be minimized, requiring less land to be acquired above the normal pool elevation. This also affords opportunities for positive economic benefits when optimizing dam height versus spillway width when considering probable maximum precipitation (PMP) design criteria. Because RCC gravity structures are not erodible, wave run-up freeboard is not required. Appurtenant structures location and design requirements provided by RCC offer further economic advantages in spillways, energy dissipators, and intake structures. Most designs incorporate a multiport intake structure which can easily be attached to the vertical upstream slope. Energy dissipation of the flows over the dam can be accomplished by stair-stepping the downstream slope which has been found to dissipate up to 70 percent of the energy in the water (Hansen, 1985). This reduction in energy translates into small stilling basins and lower costs. Because the entire crest length of an RCC dam can be used as a spillway, the emergency spillway can usually be eliminated which can typically constitute significant line items in the construction budget. Spillway costs for an earthfill dam on a wasteshed large enough to support an on stream water supply reservoir can typically exceed the costs of the dam.

Another advantage is the short time required for construction of an RCC dam. This means having a project on line much sooner, thus saving interest costs. Because an RCC dam can be constructed in a matter of months, diversion capacity and upstream cofferdams can be smaller for RCC projects. The contractor is not subject to as much liability concerning the chances of a storm which could wash out an earthfill dam that was partially constructed, whereas an RCC could sustain overtopping with little to no damage.

A cost not associated with construction is the annual maintenance expenses. Experience has shown that the maintenances and upkeep of a earthfill dam exceeds that of a concrete structure. Also, concrete dams are inherently safer than earthfill dams in the areas of stability, internal seepage forces, overtopping, and earthquake forces.

RCC dams are not suited for all sites for a number of reasons. First and foremost is the geology of the area. RCC dams, as with conventual concrete dams, require, in most cases, a sound rock foundation. In Georgia, above the Fall Line, rock underlines the residual soils but its depth may make the costs of excavating the overburden uneconomical. Because the material which comprise RCC are approximately 90 percent process aggregate a source for the aggregate must be on or near the site. If a quarry cannot be establish on site or one is not within a reasonable haul distance, the cost of materials can contribute to an RCC dam being an uneconomical alternative.

In most cases, even if the site is favorable to RCC, if the dam is small and located on a small watershed a RCC dam will not be cost competitive with an earthfill dam.

## CONSTRUCTION PROCEDURES

Each recently constructed RCC dam has used different methods of placement and for reducing the permeability between lifts. Some of these differences are related to site-specific conditions while others are based on the opinions of the various designers. What is consistent among designers is the design criteria which is similar to conventional concrete gravity dams.

The first use of RCC in the United States for dam construction was on the Willow Creek Dam in Oregon by the Corps of Engineers in 1982. Over 12 RCC dams have since been constructed in the United States with multiple uses of RCC used in the rehabilitation of existing dams and spillways. Internationally, RCC dams have been constructed in Japan, China, Australia, and South America.

RCC designs are influenced in a large part by material availability. Since 90 percent of the material used in an RCC mix is the fine and coarse aggregate, the quality and source of available aggregate play a significant role in deciding if an RCC design will be economical for a selected site. If a quality source of rock is available on-site, a portable crushing plant can be set up to produce the appropriate gradation of both fine and coarse aggregate.

## MIX DESIGN

Once an aggregate source is identified, a mix design is developed which will possess both the strength and permeability properties which are necessary for gravity dam design. A typical mix design will contain approximately, by weight, 5-6 percent water, 5-10 percent cement and fly ash, 30-35 percent fine aggregate and 60-65 percent coarse aggregate (Crow, 1984). The moisture content and cement/fly ash percentages are varied to obtain consistency measurements which can be obtained in the field during construction. Some designs will specify more than one design mix for different sections of the dam and spillway depending on what properties need to be modified.

## PLACEMENT CONTROLS

Because of the low moisture and cement content of the mix, the problems normally associated with heat of hydration of conventional mass concrete are significantly reduced with RCC. Still, measures should be employed before placement, to keep the RCC mix cool (below 70 degrees F.). Typical measures include chilling the mixing water, spraying the aggregate piles, and even applying liquid nitrogen. Where practical, the aggregate should be processed and stockpiled during the winter months so that the temperature of the material will be as low as possible for spring or summer construction. When concrete cures, the cement portion hydrates when mixed with water. Heat is given off during the hydrating process which causes the concrete to contract when it cools down to ambient temperatures. When concrete contracts cracks can develop which, in dams, can lead to seepage. Generally, seepage through concrete dams does not cause safety problems but does cause a loss of storage water and is aesthetically unsightly. The rate of seepage in all RCC dams that leak has reduced exponentially with time due primarily to siltation and calcification (Webber, 1987). Several dams were pressured grouted after completion when seepage volumes exceeded permissible limits.

A typical plant to blend the various components of the RCC mix can either be a drum batch plant or a continuous-type pugmill. A continuous mixing plant is advantageous when large quantities of mix are being placed, but on small jobs, a single or dual drum batch plant can be best suited for assuring proper mix proportions and moisture content (McLean, 1985). The continuous pugmills can produce up to 450 tons per hour of RCC mix. Regardless of the type of mixing plant specified, an adequate volume of materials must be on site to prevent a non-mechanical shutdown leading to an unexpected cold joint.

As with conventional concrete dams, the foundation for an RCC dam must be properly prepared. The preparation for an RCC dam includes a thin, leveling layer of conventional concrete. This is necessary to help achieve good bonding between the foundation and the dam. The RCC mix is then placed in one to two foot lifts. One foot lifts are used most often but Japan has experimented with two foot lifts. The placement of the lifts can be by scrapers or dozers spreading the mix after initial placement by dump trucks or by pans, if space permits. A conveyer system, which can place the mix on the working surface, has been found to be very efficient. Because the RCC is repeatedly handled and re-mixed, segregation is limited because of the dryness of the mix. After a uniform lift is applied, a vibratory roller will make a predetermined number of passes to consolidate the mix. It is important that each lift be kept moist and clean of all foreign materials. Water trucks and vacuum trucks have been used successfully to accomplish these tasks.

## SEEPAGE CONTROLS

The upstream slope can be constructed in a variety of ways all of which incorporate some positive measures to reduce seepage along lift lines. The two most popular options are precast concrete panels which have a synthetic geomembrane attached or conventional concrete cast against forms. Those incorporating the geomembrane liners also use some conventional concrete as a secondary seepage prevention system. To keep from developing cold joints, placement of RCC should be placed 24 hours a day, six to seven days a week. If a cold joint develops, a typical joint surface treatment would consist of a thin layer of slurry grout to bond the old and new lifts.

The downstream spillway face can either be slip formed with conventional concrete or be left as an RCC surface. In colder climates the RCC surfaces, if left unprotected, can experience some spalling during freeze and thaw cycles. If required in the future a conventional concrete overlay can be applied.

## CONCLUSIONS

When a project is proposed for water supply, flood control and/or hydroelectric generation, owners should be well aware of economic and environmental constraints. RCC dams are proving to be a viable alternative to earthfill, rockfill, and conventional concrete dams because of cost savings and due to dam safety considerations. Over a dozen new RCC dams have been built in the United States in the last decade and many more are proposed. While the western portions of the United States has seen most of the activity, several have been designed in the southeast and are awaiting the necessary permits for construction. In Georgia, the Soil Conservation Service are studying the possibility of a rural water supply project in Banks County which appears to support an RCC type dam. Studies have also been completed or are underway for water supply reservoirs in Habersham and Henry Counties which would use RCC dams. Spartenburg, South Carolina has a RCC dam designed to impound a water supply reservoir, but construction is delayed until all necessary permits are secured.

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