Design considerations for small RCC dams

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The design of small dams constructed of roller compacted concrete (RCC) can be more challenging than the design of a much larger RCC dam. This is especially true when the design engineer has a restricted budget for design and construction of the dam.

Small RCC dams may be a misnomer. By definition, a small RCC dam is one that is less than 15 m high. Some of these low dams can be quite long and may store a considerable volume of water. Many are classified as high hazard dams by dam safety regulators.

Most of the small RCC dams worldwide are located in the USA, where more than 30 such structures have been built. In many cases, the small RCC dams have replaced either timber-crib or earth embankments which had either failed or where the continued reliability or safety was questionable. The RCC structure was considered by the design engineer to provide a higher level of safety and longer service life than the dam being replaced.

Small RCC dams have been built for a variety of purposes in the USA. They include water supply, flood control, irrigation, recreation, or a seismic or hydraulic upgrade. Some of these small RCC dams could be called weirs, as they are basically a long spillway section. To date, no small RCC dam has been built for hydroelectric generation. Because of the low head involved and the cost of permitting, such applications are not generally economically feasible.

View of the Cedar Falls dam in Washington.

1. Design considerations

The basis design considerations such as stability, seepage control, durability as well as aesthetics that apply to higher RCC dams also apply to small RCC dams. There are some exceptions which will be discussed in this article.

1.1 Foundation conditions

While an RCC dam higher than 30 m is invariably founded on a reasonably competent rock foundation, there are a number of examples of low RCC dams being founded on non-rock foundations. Sound rock foundations are preferred for concrete dams because they have a high bearing capacity, a high deformation modulus and a high degree of resistance to erosion and seepage. Nevertheless, if sound engineering principles are applied, an RCC dam can be founded on a non-rock or low modulus foundation material.

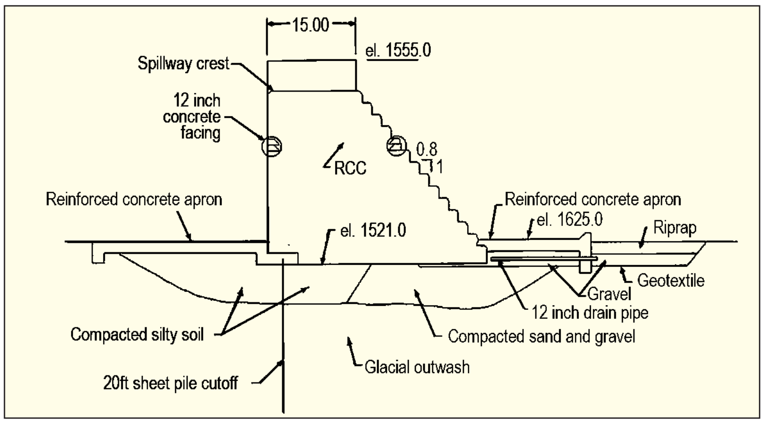
An example for the competent design of a small RCC dam sitting on a non-rock foundation is Cedar Falls dam in the State of Washington. Cedar Falls dam is part of a two dam system which is a main water supply source for the City of Seattle. The existing timber crib dam was deteriorating, leaking, and determined to have an inadequate spillway capacity by current standards. The owner therefore decided the dam should be replaced with a more reliable structure.

Because the dam would be completely inundated when the reservoir from the dam downstream was at a high level, a concrete dam was a logical choice. However, Cedar Falls dam is located in a valley, where glacial sand and gravel deposits up to 180 m deep overlay sound rock.

Obviously, excavation to sound rock and building back up with RCC was not an option. The design engineers therefore had to consider differential settlement, under seepage, and piping potential in their design for placing a 10.4 m-high RCC dam on this mainly sand foundation.

The design solution included replacing the upper 4.9 m of low density sand with compacted fill. This decreased the potential for earthquake-induced liquefaction, decreased the seepage below the RCC dam and reduced settlement of the structure. A 6.1 m-deep sheet-pile cutoff at the heel of the gravity section (see Fig. 1) and an upstream concrete blanket lengthened

Fig. 1. Cross section of the Cedar Falls dam in Washington, USA.



the seepage path beneath the dam. A downstream filter and drain system under the stilling basin slab was designed to collect seepage and to control uplift pressure and piping potential. The completed RCC dam is shown in the photo on the previous page.

There are at least seven other small RCC dams in the USA founded on non-rock materials.

If underseepage of a small RCC dam is not handled properly, a failure could occur. This was case of the failure of the 2 m-high Ferris Ditch diversion dam in Wyoming. In the opinion of the author, the failure was a classical piping failure when the dam had been in service for about five years. There was a differential head from upstream to downstream, an RCC roof over an erodible foundation and an unfiltered downstream exit. The 2 m-high dam was reportedly designed in one day with an upstream cutoff wall. This cutoff wall was omitted by the contractor as a cost-saving measure.

1.2 RCC Section

A number of options are available to the design engineer with respect to cross sections for small RCC dams. Some of the possible cross sections are shown in Fig. 2, with the usual range of dam heights for each option. One consideration is to attempt to minimize the amount of forming required mainly on the downstream face to simply construction and minimize cost. All of these sections have been used on small RCC dams in the USA with the exception of (c), which is an attempt to reduce the volume of RCC. This solution requires forming of the downstream slope steeper than 0.8H:1.0V.

The basic stability of small RCC sections for shear resistance or an overturning calculation is invariably no problem. This is because the minimum crest width of 2.4 m for RCC constructability produces a more than adequate cross section.

The RCC section needs to be designed for full uplift pressures, as no small RCC dam in the USA has included a gallery from which drain holes can be drilled to collect foundation seepage and thus reduce uplift.

1.2.1 Upstream face

Seepage control through the RCC section has become a challenge to designers of small RCC dams. Traditional upstream facing systems such as conventional concrete or membrane-faced pre-cast concrete panels become a major item in the total cost picture. Still, certain owners of water supply dams can absorb this cost, because of the critical nature of the structure.

However, in most cases, designers have had to come up with alternative solutions to keep their designs within limited budgets. Small quantities of conventional concrete can be quite expensive and can slow down the RCC construction process.

Section	Usual height range (h)	Usual crest width (tc)	Usual slope (S)	Downstream facing treatment
(a)	12 to 15 m	3 to 4.9 m	0.8 to 0.9	Formed or exposed
(b)	3 to 15 m	3 to 3.7 m	0.8 to 0.9	Formed or exposed
(c)	3 to 15 m	3 to3.7 m	0.7 to 0.9	Formed - less volume than (b)
(d)	1.5 to 4.6 m	2.4 to 3 m	0.8 to 1	

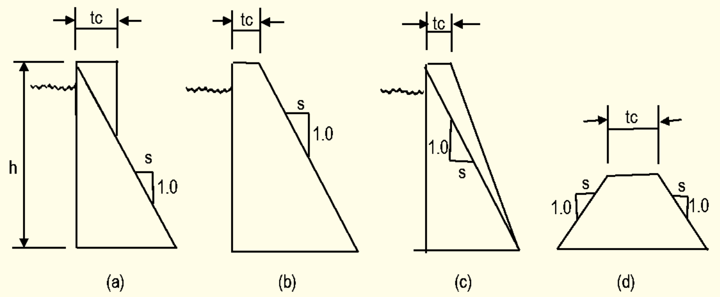


Fig. 2. Possible sections and dimensions for small RCC dams.

The upstream facing solutions have included unformed RCC, formed RCC, and earthfill. Unformed RCC on a slope has been used for a number of low RCC diversion dams, less than 4.3 m high. These low RCC dams are overtopped either frequently or continuously. Thus, seepage reduction is not of great importance.

Formed vertical faces of RCC have found acceptance on some slightly higher RCC gravity dams. For both seepage control and appearance, an RCC mixture with increased cementitious content, reduced maximum size aggregate, and wetter consistency (lower VeBe time) has produced the best results. For these formed RCC faces, as well as for all unformed RCC faces, mortar bedding between each lift of RCC helps improve seepage resistance. In the case of the Atlanta Road dam (see photo below, left) in Georgia, grout-enriched RCC (GERCC) was tried in places to improve appearance at the face and seepage control at the lift lines of this storm water detention dam. It was the first trial of GERCC in the USA on any dam.

Earthfill has been used at the upstream face for a number of small RCC dams. Clay materials adjacent to the RCC are preferred in these cases to aid with seepage control. For the Tobesofkee Creek Replacement dam (see photo below) in Georgia, the RCC layer was placed first and compacted. Then, an earthfill layer was placed and compacted against the 45º edge of the RCC lift. The earth thus acted as a form in addition to providing a seepage barrier upstream of the RCC gravity section.

Far left: the Atlanta Road dam in Georgia, USA.

Left: The Tobesofkee Creek replacement dam, also in Georgia.

The 4th Low Water Street dam in Texas, USA.

1.2.2 Downstream face

Exposed RCC tends to predominate for the sloping downstream faces of the small gravity structures. Again, for the very low dams, unformed RCC eliminates the need for any formwork. Unformed RCC requires of a slope of at least 0.8H:1.0V, preferably 1.0H:1. Formed steps of RCC are then used as the height of the dam increases. The steps can be either 0.3 m or 0.6 m high, depending on the designer's and in some cases contractor's preference. The steps can be visually attractive and hydraulically efficient during overflow situations. If the exposed RCC is located in an area with a large number of freeze-thaw cycles annually, the design engineer should specify an RCC mix that is sufficiently durable for the location.

In some unique applications, the downstream face of the dam has been vertical. This has led to a variety of solutions that are visually attractive. These applications included precast concrete panels for the Great Hills dam located in a business park in Austin, Texas. To maintain the historical appearance of the original Bear Creek dam in Pennsylvania, a rough cut white pine facing covered the RCC for the replacement dam. At Sally's Pond dam in New Jersey, a stone facing was used with some concrete behind to act as a bond between the stone and RCC section.

1.3 Thermal considerations and transverse joints

Thermal-induced cracking in small RCC dams has been less of a problem than in higher, more massive gravity dams constructed by the RCC method. This is because of the smaller volume of concrete to heat up and the fact that a number of these lower dams were constructed on non-rock foundations, which provide no or little restraint to contraction as the concrete cools.

There are a couple of examples to help prove the latter situation. At Cedar Falls dam, a malfunction in metering cement at the proportioning and mixing plant caused an increase in cement content. The calculated 11°C increase in the RCC mixture's maximum temperature produced no more cracking than originally anticipated as a result of the lack of restraint provided by the foundation or abutments. At the 4th Street Low Water dam at Fort Worth, Texas, the author could find no visible cracks in the 46 m-long RCC structure (see photo, left).

The small volume of concrete in these low dams minimizes the potential for cracking caused by a cool exterior being restrained by a warm interior called the mass gradient. Still, design engineers need to be concerned with a thermal related cross canyon shortening, especially if the structure is restrained at its base by being well bonded to a rock foundation.

Waterstopped transverse joints to accommodate these contractions have not been installed in most of the small RCC dams, except those with a conventional concrete face. In these cases, the waterstop can be placed and crack inducers installed by methods similar to those used for higher RCC dams.

For Cache Creek dam in California, transverse joints were installed at 30 m intervals. Measurements of the crack opening varied from 1.5 to 6 mm.

Where no transverse joints are installed, the RCC is allowed to crack. For these low dams, this has not been reported as a problem to date for several reasons. They include earthfill or other seepage barriers upstream of the RCC, the formation of cracks not wide enough to pass water, and no real concern for seepage for frequently overtopped diversion structures or dry flood control dams. For these reasons, design engineers have not specified overly restrictive RCC placement temperatures which would increase cost due to cooling requirements.

1.4 Training walls and stilling basins

As with any dam, flow over the structure should be retrained at its ends in some manner to direct the flow downstream or to prevent erosion of an unprotected abutment. The photo below shows the Bosque River dam in Texas with stepped RCC abutments. The downstream face is also stepped exposed RCC.

The design of stilling basins or other downstream energy dissipators is the same for a small RCC dam as for a higher one. Some floors for stilling basins or downstream aprons have been constructed of RCC rather than conventional concrete for reasons of cost and ease of construction reasons. ◊

The Bosque River dam in Texas.

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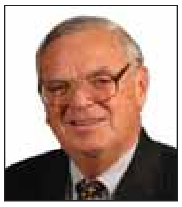

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Ken Hansen is a Senior Consultant with Schnabel Engineering. Before joining the company more than 11 years ago, he worked for the Portland Cement Association (PCA) for nearly 37 years. He is an international recognized author, lecturer, and consultant on the use of roller compacted concrete (RCC) for new dams and the rehabilitation of existing dams. He is the primary author of the book 'Roller Compacted Concrete Dams' published by McGraw-Hill, and he edited or co-edited all three ASCE books on RCC. Mr. Hansen has given more than 400 presentations on RCC dams in the USA and by invitation in 11 other countries, including being the keynote speaker or invited special lecturer at six international conferences on RCC. His consulting assignments now number 70 in 11 countries.

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