



Roller Compacted Concrete



Concept and significance

- The development of Roller Compacted Concrete (RCC) caused a major shift in the construction practice of mass concrete dams and locks. The traditional method of placing, compacting, and consolidating mass concrete is at best a slow process. Improvements in earth-moving equipment made the construction of earth and rock-filled dams speedier and, therefore, more cost-effective.



Early Developments

- The first successful application of RCC technology was demonstrated in 1974. The repair of the collapsed intake tunnel of Tarbela Dam proved that the material had more than adequate strength and durability. The maximum placement of 18,000 m³ of RCC in one day, which is still the world's record, was a clear evidence of the potential of this new construction method.



Definition

- ACI 207.5R-89 defines **roller compacted concrete** (RCC) as concrete compacted by roller compaction. The concrete mixture in its unhardened state must support a roller while being compacted.
- Thus RCC differs from conventional concrete principally in its consistency requirement. For effective consolidation, the concrete mixture must be dry enough to prevent sinking of the vibratory roller equipment but wet enough to permit adequate distribution of the binder mortar in concrete during the mixing and vibratory compaction operations



Advantages

- By 1997, 150 projects using RCC, including 46 new dams, were completed in the United States.
- The U.S. Army Corps of Engineers list the following advantages of using RCC:
- Costs: Depending on the complexity of the structure, RCC costs 25 to 50% less than conventional concrete.



Advantages

- **Rapid Construction:** For large projects, RCC dams can be finished 1 to 2 years earlier compared to regular mass concrete dams.
- **Spillways:** Compared to embankment dams which normally require that spillways be constructed in an abutment, RCC dams offer the attractive and cost-effective alternative of constructing the spillway in the main structure of the dam.



Japanese Experience

- Cement consumption is lower because much leaner concrete mixtures can be used.
- Formwork costs are lower because of the layer placement method.
- Pipe cooling is unnecessary because of the low temperature rise.
- Cost of transporting, placement, and compaction of concrete is lower, because concrete can be hauled by end dump trucks; spread by bulldozers and compacted by vibratory rollers.

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Sequence of placement



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Sequence of placement



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Sequence of placement



Roller Compacted Concrete Compaction





Materials -- Cement

- The consolidation by a roller does not require special cements; however, when RCC is to be used in mass concrete, the recommendation of selecting cements with lower heat generation should be followed.



Mineral Admixtures

- Mineral admixtures are used extensively in RCC mixtures. The use of large amounts of mineral admixtures reduces both the adiabatic temperature rise of concrete and costs, and improves durability. In the United States, Class F fly ash is the most common mineral admixture used in dams, however, in other parts of the world Class C fly ash, slag, and natural pozzolan have also been used.



Chemical Admixtures

- Air-entraining and water-reducing admixtures are used in RCC compositions that contains higher volume of paste.
- Set-retarding admixtures can extend the time up to which the concrete lift should remain unhardened, reducing the risk of cold joints with the subsequence lift. In RCC mixtures of dry consistency, however, chemical admixtures show rather a limited effectiveness.



Aggregates

- Aggregates greater than 76 mm in diameter (3 in.) are seldom used in RCC because they can cause problems in spreading and compacting the layer.
- The size of coarse aggregate has a significant influence on the degree of compaction in small layers. This influence is less marked in relatively thicker layers specially when large vibratory rollers are employed.
- The use of material finer than 75 mm (No. 200 mesh sieve) produces a more cohesive mixture by reducing the volume of voids.

Concrete Mixture Proportioning

- Method I
- Uses the principles of soil compaction to produce a lean RCC, where the optimum water content of the concrete is the one that produces the maximum dry density of the mixture.
- This method does not utilize the conventional concept of minimizing the water-to-cement ratio to maximize the concrete strength; the best compaction gives the best strength, and the best compaction occurs at the most wet mix that will support the operating vibrating roller.
- The overriding criteria for these mixtures are the compressive and shear strength since the dam using this type of concrete typically will have an impermeable upstream face made either by traditional mass concrete or precast panels.



Concrete Mixture Proportioning

- Method II
- Uses traditional concrete technology methods to produce high-paste RCC mixtures. Upper Stillwater and Elk Creek Dams are examples of dams that were built using this approach. The overriding criteria for these mixtures are the shear strength between the lifts and low permeability of concrete since no protective, impermeable face is used upstream .



Laboratory Testing

- RCC is a zero-slump concrete whose properties are strongly dependent on the mixture proportions and on the quality of compaction. Concrete is consolidated in the field using vibrating rollers.
- Despite extensive research on this subject, there is as yet no unanimously accepted methodology to simulate the field condition in preparing laboratory samples.



Strength

- For RCC mixtures made according to the concrete technology approach, where the volume of the paste exceeds the volume of the voids between the aggregate, the compressive strength follows the dependence on the water-to-cement ratio as predicted by Abram's rule.
- For RCC mixtures made according to the soil mechanics approach, where the cement paste may not fill the voids between the aggregate, Abram's rule does not apply, and strength is often plotted as a function of the moisture content.



Elastic Modulus and Poisson's ratio

- The thermal stresses generated by heat of hydration are proportional to the elastic modulus of concrete. Therefore, lean RCC mixtures, which produce concrete with low elastic modulus, are attractive to designers.
- As with regular concrete, the elastic modulus of RCC depends on the degree of hydration, volume and type of aggregate, and water-to-cement ratio.
- Poisson's ratio for CCR typically ranges from 0.15 to 0.20.



Creep

- The long-term deformation of RCC depends on the amount and the type of aggregate, the water-to-cement ratio, the age of loading, and the duration of loading.
- RCC with lower compressive strength and lower elastic modulus will normally show high creep which is a critical factor in determining the stress relaxation when thermal strain is restrained.
- Lean concrete with large amounts of fines also shows high creep.



Thermal properties

- The adiabatic temperature rise of RCC is similar to conventional mass concrete mixtures and depends on the amount and type of cementitious material used in the mixture.
- The specific heat, conductivity, and coefficient of thermal expansion are a function of the type and amount of aggregate used in the mixture.



Durability

- The coefficient of permeability of RCC is a critical parameter for long-term performance of dams, particularly if no impermeable membrane has been used at the upstream face of the dam.
- The construction process of RCC generates porous zones between the lifts where water can percolate. Depending on the mixture proportions and construction process, the coefficient of permeability can vary over 8 orders of magnitude.
- For instance, the lean concrete at Willow Creek dam had a coefficient of permeability of 2×10^{-4} m/s, while the coefficient of permeability at Upper Stillwater Dam was 4×10^{-12} m/s. Willow Creek Dam, however, has an impermeable membrane at its upstream face.



Durability

- If the moisture content in concrete goes beyond the critical saturation point, the performance of non-air entrained RCC to cycles of freezing and thawing will be poor; however, if the structure does not become saturated, the frost resistance of RCC is satisfactory.
- Air-entrainment of very lean RCC mixtures has not been very successful.



Construction Practice

- The overall planning of a RCC dam is conceptually different from a gravity dam. To minimize thermal stresses, traditional mass concrete is built in separate, monolith blocks.
- This process is slow but allows great flexibility; if a problem develops in one of the blocks, the construction front moves to another block. RCC dams do not have such luxury.
- The operation is continuous, building one horizontal lift at a time.



Construction Practice

- There are no special requirements for batching and mixing of RCC which can be produced using the same equipment as for conventional mass concrete.
- Ready-mixed concrete trucks cannot be used to transport RCC because the zero-slump concrete is too dry and cannot be discharged.
- To obtain significant economical benefits, special care must be taken in the selection of equipment and construction methods for fast placement and consolidation of RCC.
- Conveyor systems can be an efficient method of transporting RCC.

Construction Practice

- The success of a RCC dam is often contingent on the correct selection of lift thickness, which depends on the mixture proportions and on the equipment available.
- If the lift is too thin, the placement rates will be small, thereby reducing the advantages of using RCC.
- If the lift is too thick, the compaction will not be adequate, creating horizontal layers of higher porosity, thereby compromising the strength and durability of the structure.
- Normally, the thickness of the lifts ranges from 0.15 to 0.90 m; in the U.S. a lift thickness of 0.3 m is often used.



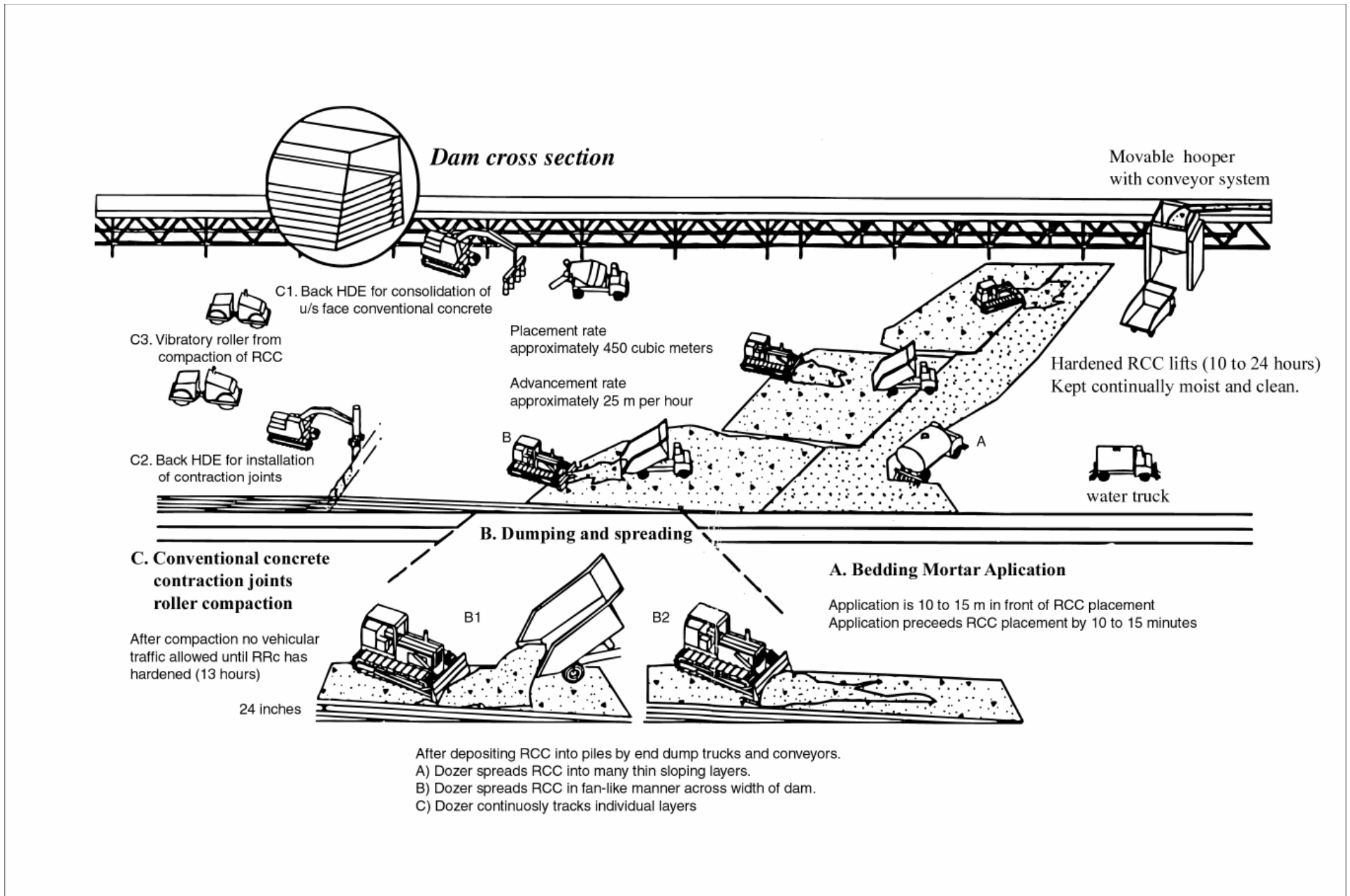
Construction Practice

- Compaction of the lift is achieved by using a vibrating steel-wheel roller.
- Compaction of the lift should be performed as soon as possible, typically within 10 minutes after spreading and no more than 40 minutes after mixing.
- Once adequate compaction is achieved, good curing conditions for the finished surface are essential; the surface should be kept in a moistened condition until the next lift is placed.



Construction Practice

- The dry consistency of RCC results in difficulty in bonding fresh concrete to hardened concrete.
- This bond can be improved between the lifts by reducing the time of casting the lifts or by increasing the paste content in the mixture.
- Typically, bedding mixtures contain 360 to 460 kg/m³ of cement, 170 to 220 kg/m³ of fly ash, and 4.75-mm maximum size aggregate.



Typical work layout for RCC placement