LEVEE CONSTRUCTION AND REMEDIATION USING ROLLER COMPACTED CONCRETE AND SOIL CEMENT

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ABSTRACT

Roller Compacted Concrete (RCC) was pioneered in the 1970s as a low cost, rapid construction substitute for mass concrete placement primarily for large concrete dams. RCC is placed with earthmoving equipment, and the long-term strength of RCC is similar to concrete.

RCC consists of a zero slump mix of sand, gravel, cement, and water. Fly ash is sometimes used along with cement to reduce material costs and to reduce the heat of hydration. Soil Cement (SC) is similar to RCC but is typically produced with naturally occurring sands and silty sands instead of sand and gravel. While RCC is primarily used for large mass concrete dam construction, SC is typically used for slope and erosion protection for earthen dams and levees.

This paper will address advantages of RCC/SC construction over earthfill, placement methods and techniques, quality management, and contracting issues associated with the use of RCC or SC for levee remediation and construction.

INTRODUCTION

Roller Compacted Concrete (RCC) was pioneered in the 1970s as a low cost, rapid construction substitute for mass concrete placement primarily for large concrete dams. In the past 10 to 15 years it has also been used for overflow protection of spillways, downstream overtop protection of embankment dams, stilling basins, bases for composite pavements of residential roads, parking areas, and foundation construction. One of the more significant reasons that RCC has become a medium of choice for these applications is that it is placed with earthmoving equipment which allows for faster construction at lower costs as compared to placement of conventional concrete. This faster construction may help avoid additional hot seasons, therefore saving on cooling costs. It has hardened, long-term strength similar to concrete with the same basic ingredients with a no slump mix. It is suitable for most site conditions, is erosion resistant, has less maintenance cost, and allows ancillary structures such as drainage systems to be incorporated into the structure.

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Soil Cement (SC), as it is termed, is similar to RCC but is typically produced with naturally occurring sands and silty sands instead of sand and gravel. SC is typically used for slope and erosion protection for earthen dams and levees.

An intermediate type of material is “Hardfill” which is actually a low strength RCC, and can have a percentage of fines, but unlike SC usually has gravel content and a pozzolanic material such as fly ash.

This paper will present a discussion on how RCC and SC may be used in addition to or in place of traditional earthwork, sheet pile walls, or conventional concrete in the remediation or new construction of levees in the New Orleans area or anywhere there are systems of levees in place for flood control.

**Roller Compacted Concrete and Hardfill Standard Applications**

As indicated in the introduction, RCC has been used for large concrete dams and reservoirs in the United States and throughout the world. Two dams recently completed in the US are the Saluda Dam in Columbia, South Carolina and the Taum Sauk Upper Reservoir in southeast Missouri. A third RCC dam, Wyaralong Dam in Australia, was completed in June of 2011. All three of these structures were completed within record time and at a much lower cost than if conventional concrete or embankment dams were constructed. *Figures 1, 2, and 3* show the massive amounts of RCC that were used in construction at these dams. As mentioned above, one can argue that the RCC at Taum Sauk is actually a Hardfill as the design strength was 1500 psi as opposed to 2300 psi at the Saluda Dam and 2500 psi at the Wyaralong Dam.
Figure 2. Taum Sauk Upper Reservoir – Missouri

Figure 3. Wyaralong Dam – Australia
Additionally, other applications include overtopping protection and downstream slope protection of embankment dams and also for roads and parking areas. *Figures 4, 5, and 6* show these different applications.

Figure 4. Overtop Protection, Sandia Watershed – Bernalillo, New Mexico

Figure 5. Stability Berm, Standly Lake Spillway Channel – Westminster, Colorado
Soil Cement Applications
Soil Cement (SC) is similar to RCC but is typically produced with naturally occurring sands and silty sands instead of sand and gravel, along with Portland cement and water. SC has been used on many applications including base course for roads and parking areas, road shoulders, foundation stabilization, and slope protection for earth dams, embankments, and levees. Figures 7, 8, and 9 show where SC was used for slope protection in the United States Air Force Academy in Colorado.
Figure 7. Soil Cement Overtop Protection – Constructing Starter Step, United States Air Force Academy

Figure 8. Soil Cement Overtop Protection – Constructing Reservoir Base - United States Air Force Academy

Figure 9. Compacting Soil Cement Overtop Protection – United States Air Force Academy
RCC Mix Design for Levee Construction and Remediation
RCC or Hardfill consists of a zero slump mix of sand, gravel, cement, water and in most cases a pozzalan such as fly ash. Fly ash is used to reduce material costs and to reduce the heat of hydration. It can be placed with earthmoving equipment, spread in horizontal lifts of 12 inches or less, and then compacted with a vibratory roller. There is flexibility in how a structure can be designed and constructed – the material is durable and erosion resistant, with a relatively low-cost type of construction with proven performance on many applications, therefore making it ideal for levee remediation and construction.

As with any concrete placement project, whether it is conventional, RCC, or Hardfill, a mix design program must be developed, tested, and approved prior to its use in any application. This would be the same for remediation of a levee or in the construction of a new levee system. It has been our protocol to develop a two-phase mix design program. We have on occasion performed a 3rd phase which is strictly a contractor-related program for testing placement schemes and equipment. The following two-phase testing program has been successfully used for RCC as well as SC.

Phase 1 – Laboratory Scale Mix Design Program The primary objectives of the Phase I Test Program for RCC or Hardfill is to determine the relationship between the proportions of cementitious materials (i.e., cement and fly ash) and water on the hardened engineering properties of the RCC or Hardfill. Specifically, the program is aimed at determining the cementitious content, pozzalan content, and water content that would produce the required consistency and strength.

For SC the program is basically the same in terms of determining the relationship between the proportions of cementitious materials.

Aggregate for the program, whether it is RCC, Hardfill, or SC, may be selected from local sources that are convenient to a project. This may mean in-situ materials at the project site or from existing quarries. Pozzalan material such as fly ash for the RCC program can be supplied either through commercial sources or if there is a local plant that produces wet flyash.

Phase II – Construction of a Test Pad The primary objective of Phase II is to establish criteria and guidance in developing the final design parameters for the proposed project, whether it is for an RCC or Hardfill berm or a SC project. The Phase II program typically consists of the following:

- Evaluation of the material sources for the specific project and the storage and stockpiling of the materials;
- Evaluation of the equipment, methods, and procedures for placement, spreading, and compaction; and
- Evaluation of the performance of the materials including fresh and hardened mix properties.

The Phase II Test Pad Program can be constructed and made part of a designed structure in many cases, and would be conducive for levee construction.
**Conceptual Designs for RCC Levee Construction**

It is envisioned that a symmetrical RCC structure could be used for levee construction. The structure would have 1:1 slopes both upstream and downstream, and have a small crest width to accommodate pick-up trucks, maintenance equipment, and inspection vehicles. The Hardfill would have a strength of \( \bar{f_c} = 1000 \text{ psi} \) due to the anticipated soft soil upon which it would be constructed.

It appears that most levees fail due to water seeping under the wall and causing a breach. This would indicate that some form of cutoff wall should be considered under the RCC levee. A cutoff wall such as a Trench Remixing Deep method (TRD) might be a consideration. A TRD wall is currently being used in the construction of the Herbert Hoover Dike in Florida. The cost and efficiency of the construction are reportedly positive. The geology of the foundation may be such that that this type of wall would minimize any effect and virtually stop any seepage of water under the barrier. Permeabilities have been reported to range from \( 1 \times 10^{-6} \) to \( 10^{-8} \text{ cm/sec} \). *(Hayward Baker, TRD Soil Mixing at Herbert Hoover Dike)*. There may be several different profiles of foundation soils and this method of continual mixing of soil from top to bottom will ensure a high quality wall. The equipment used in this type of wall construction would also be conducive to levee construction, as the footprint for the work area and equipment would be minimal compared to other cutoff wall methods of construction *(Hayward Baker, TRD Soil Mixing at Herbert Hoover Dike)*.

Differential settlement and possible related cracking of materials has to be addressed as a design issue. These concerns are valid and therefore constructing levees using a symmetrical cross section and competent foundation conditions is in most cases a must. We have constructed test pads (60 feet long by 40 feet wide by 12 feet high) on several sites where the foundation was compacted soil. There was no evidence of cracking.

The slopes of the levee could be free formed in a step design with RCC and later vegetated for aesthetic value. SC could also be used for a smooth face type construction. Placement methods would be as described in a previous section, again with methods and procedures that allow for work in confined or minimal space areas. Conceptual designs are presented on *Figure 10*. 
Figure 10. Conceptual Designs for RCC Levee Construction
Placement Methods and Procedures for RCC, Hardfill and Soil Cement

The remediation or construction of levees in most areas is usually in confined areas with little space for large equipment. RCC and Hardfill, when used on large dam projects, do require a relatively large area and complex set-up, as show in Figures 11 and 12.

Figure 11. Tower Cranes and Conveyors for RCC – Taum Sauk Upper Reservoir

Figure 12. Placement of RCC using a Crawler Placer – Saluda Dam
Although these projects are large, there are placement schemes that do not require complex set ups but can be adapted to smaller areas such as for levee construction. Some of these schemes may include the following:

- A Creter Crane;
- Super Swingers and small light conveyors; and
- Truck placements.

The Creter Crane, shown in Figure 13, can be used in both large placements as well as in tight and confined areas. The boom travels 200 feet and can be raised up to ~21 degrees, or can be laid out flat. It can be fed from trucks, conveyors or a Gomaco-type mobile paver machine. Although the machine is quite mobile on the site, it does require that the machine be disassembled if it is going to be mobilized any great distances.

Figure 13. Creter Crane Set Up for a Test Pad Placement

Figure 13 shows a Creter Crane in a placement process for a test pad program. The RCC was trucked to the Gomaco machine and then transferred to the Creter Crane for placement. As mentioned previously, the test pad is similar to the construction of a levee. Figures 14 and 15 show the use of a Creter Crane placing in confined and “tight” placement areas.
Super Swinger and Light Mobile Conveyors
One of the more convenient approaches to placing RCC and Hardfill for small structures such as levees is the use of a Super Swinger and light mobile conveyors. A Super Swinger is basically a truck-mounted Creter Crane that is able to be rotated 180° and easily mobilized and set up on virtually any site. The Super Swinger can be accompanied by a system of light weight conveyors and a mobile RCC plant. To better show the methods that may be used during levee
construction, we have included a few photos of the construction of an RCC Test Pad, which in reality are basically small dams that were constructed as test facilities for larger projects. Levee construction would be similar to constructing these test pads. All equipment used for the pads is portable and able to mob and demob within a day to move to a new location.

*Figures 16, 17, 18, and 19* show the placement of RCC Test Pads at the Saluda Dam project in South Carolina and show the versatility of the smaller equipment used for placement and the mobility of the components.

![Figure 16. Super Swinger Placement – Operator Using Remote Control to Move Boom Laterally, Up or Down](image-url)
Figure 17. Portable Continuous Mixing Plant – Feeder Belt has belt scales

Figure 18. RCC Placement Operations – Test Pad construction at Saluda Dam. Construction would be similar to that of Levee Construction
Figure 19. Equipment for Spreading and Compaction Placement – D6 Dozer, 10 Ton Vibratory Roller

**Truck Placements – RCC and Soil Cement**

Truck Placement can also be considered a viable option for the placement of RCC, Hardfill, or SC for the remediation and construction of levees. Placement with trucks has always been in question due to possible segregation, rutting, and surface disturbance due to the size of the trucks, the tires, and also how they are maneuvered on the placement area. These concerns are valid; however, if a lean or dry mix is used and there is a good quality control program in place, these concerns can be minimal. For instance the segregation issue has been remedied by some contractors with the installation of dovetail cowlings that, when used on an ejector truck, force the material to the center of the truck when dumping and ejecting. This does not allow the material to roll off as with a straight end dump. *Figures 20, 21, and 22* show truck placements.
Figure 20. Fabricated Housing on Ejector Trucks to Prevent Segregation

Figure 21. Placing Soil Cement with Trucks
Production Methods
Production methods for RCC, Hardfill and SC may vary from massive Taum Sauk batch plants as shown on Figure 23 to the simple and mobile continuous plant used for the Saluda Test Program, shown on Figure 24. SC may also be produced by in-place mixing methods. Production rates as well as quality concerns would be evaluated for the optimum production method.
Figure 23. Batch Plants used at Taum Sauk

Figure 24. Continuous Mixing Plant used at the Saluda Dam
Cost Comparisons
RCC would prove useful and cost beneficial in situations where the plan area available for construction is limited and slopes steeper than normally used with soil levees cannot be used for that reason. Of course we could make the RCC slopes at or near vertical if the foundation is adequate and a symmetrical section is not necessary. The biggest benefit comes from the actual RCC cost and the ease of placement and the speed of which it can be placed. Conventional concrete requires substantially more formwork, reinforcement and also stringent heat of hydration requirements. We have placed RCC for as little as $18.00 per cubic yard and as high as $120.00 per cubic yard all depending on available material resources, weather and access to the placement areas. The photos within the paper show placement methods used for different site applications.

Quality Management of the Project
Construction or remediation of levees using RCC, Hardfill, or SC, as in any other project, requires total Quality Management. The program philosophy needs to be based on practices that coordinate and direct relevant project resources and activities to achieve quality in an efficient, reliable, and consistent manner. Quality Management is an on-going process, planned and carried out in the Pre-Design, Design, Construction, and Post-Construction phases of the project.

For the actual construction phase it is initially necessary to ensure that the RCC, Hardfill, or SC mix meets the production and placement specifications. This includes:

- Ensuring that the methods and procedures for production and placement of the Contractor are consistent with the approved processes that were determined by the trial testing program;
- Controlling the placement temperature of the RCC, Hardfill, or SC;
- Adhering to the specified curing specifications; and
- Quality is achieved by qualified individuals.

Foundation preparation is of utmost importance, along with quality lift joint preparation, consistent and non-segregating delivery methods, and the proper compaction effort to achieve the desired strength requirements.

Field quality control is supplemented by a laboratory testing program that continues throughout the project to ensure all mix properties are being maintained and that the mix compatibility is on track as forecasted in the mix design program.

CONCLUSION

The previous discussion has presented alternative or innovative ideas for design of levees and their construction, keeping in mind sustainable water management.

The use of Roller Compacted Concrete, Hardfill, and Soil Cement for levee construction is not a new idea but one that should be given more consideration, as these materials can be placed with earthmoving equipment in confined areas which allows for faster construction at lower costs compared to placement of conventional concrete. This faster construction may help avoid additional hot seasons, therefore saving on cooling costs. These materials have hardened, long-
term strength similar to concrete with the same basic ingredients with a no slump mix. They are suitable for most site conditions, are erosion resistant, and have less maintenance cost.

Although, RCC, Hardfill, or SC may never replace the conventional concrete structures or sheet pile walls that are currently being constructed for levees, they are viable alternatives for construction of levee systems.