Compaction of Roller-Compacted Concrete

Reported by ACI Committee 309

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Roller-compacted concrete (RCC) is an accepted and economical method for the construction of dams and pavements. Achieving adequate compaction is essential in the development of the desired properties in the hardened material. The compaction depends on many variables, including the materials used, mixture proportions, mixing and transporting methods, discharge and spreading practices, compaction equipment and procedures, and lift thickness. The best performance characteristics are obtained when the concrete is reasonably free of segregation, well-bonded at construction joints, and compacted at, or close to, maximum density.

Compaction equipment and procedures should be appropriate for the work. In dam or massive concrete applications, large, self-propelled, smooth, steel-drum vibratory rollers are used most commonly. The frequency and amplitude of the roller should be suited to the mixture and lift thickness required for the work. Other roller parameters, such as static mass, number of drums, diameter, ratio of frame and drum mass, speed, and drum drive influence the rate and effectiveness of the compaction equipment. Smaller equipment, and possibly thinner compacted lifts, are required for areas where access is limited.

Pavements are generally placed with paving machines that produce a smooth surface and some initial compacted density. Final density is obtained with vibratory rollers. Rubber-tired rollers can also be used where surface tearing and cracks would occur from steel-drum rolling. The rubber-tired rollers close fissures and tighten the surface.

Inspection during placement and compaction is also essential to ensure the concrete is free of segregation before compaction and receives adequate coverage by the compaction equipment. Testing is then performed on the compacted concrete on a regular basis to confirm that satisfactory density is consistently achieved. Corrective action should be taken whenever unsatisfactory results are obtained. RCC offers a rapid and economical method of construction where compaction practices and equipment are a major consideration in both design and construction.

Keywords: compaction; consolidation; dams; pavements; roller-compacted concrete.

CONTENTS

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CHAPTER 1—INTRODUCTION

1.1—General

Roller-compacted concrete (RCC) has become an accepted material for constructing dams and pavements, rehabilitating and modifying existing concrete dams, and providing overflow protection of embankment dams and spillways. Its production provides a rapid method of concrete construction similar in principle to soil-cement and other earthwork construction. RCC technology developed considerably in the 1980s, after early research by Cannon (1972), Dunstan (1977), Hall and Houghton (1974), and the development of the roller-compacted dam (RCD) method in Japan in the 1970s. Also, in the 1980s, RCC was developed as a heavy-duty paving material for log sorting yards, tank hardstands, railroad sorting yards, and other industrial pavements. It also found application in roadways and parking areas. Detailed information on the use of RCC in mass concrete and paving applications is contained in ACI 207.5R and ACI 325.10R, respectively.

1.2—Scope and objective

This report presents a discussion of the equipment and special construction procedures associated with the compaction of RCC. It includes characteristics of the mixture relevant to compaction and the effects of compaction on desired properties of RCC. These properties include various strength parameters, watertightness, and durability. Differentiation is made between RCC used in massive concrete work and that used in pavements. The discussion also includes provisions for measurement of compaction. This report does not cover soil-cement or cement-treated base.

The objective of this report is to summarize experience in compaction of RCC in various applications, to offer guidance in the selection of equipment and procedures for compaction, and in quality control of the work.

1.3—Description

According to ACI 116R, roller-compacted concrete is defined as "concrete compacted by roller compaction that, in its unhardened state, will support a roller while being compacted." ACI 116 further defines roller compaction as "a process for compacting concrete using a roller, often a vibrating roller."

RCC construction involves placement of a no-slump concrete mixture in horizontal lifts ranging from 150 to 600 mm (0.5 to 2 ft) thick and compaction of this mixture, normally with a smooth-drum, vibratory roller. For RCC dams, multiple lifts of concrete, generally 300 mm (1 ft) thick, are continuously placed and compacted to construct a cross section that is similar to a conventional concrete gravity dam. Another RCC placing method is to spread three or more thinner (typically approximately 230 mm [9 in.]) layers with a bull-dozer before compacting them into one thick lift with a vibratory roller. One significant difference between an RCC dam and a conventional concrete dam is the continuous placing of a horizontal lift of concrete from one abutment to the other, rather than constructing the dam in a series of separate monoliths. A horizontal construction joint is produced between each lift in the RCC dam. In paving applications, individual lanes of concrete are placed adjacent to each other to construct a pavement ranging from 150 to 250 mm (6 to 10 in.) thick. The procedure is similar to asphalt-paving techniques. In some instances, two or more lifts of RCC are quickly placed and compacted to construct a thicker, monolithic pavement section for heavy-duty use.

Several steps are required to achieve proper compaction of RCC construction: 1) A trial mixture should be developed using appropriate testing methods to determine the optimum consistency and density for each application; 2) A trial section should be constructed to validate the number of passes and establish the required moisture content and density; 3) The RCC should be placed on freshly compacted material, or, if the surface is not freshly compacted or is the start of a new lift, place a more workable mixture, or place over a bond layer of mortar; 4) For dams, roll from one abutment to the other continuously; 5) For pavements, roll immediately behind the paver and place the next lift within 1 h; 6) Roll the proper number of passes before placing the next lift; 7) Use a tamper or small compactor along edges where a roller cannot operate; and 8) Maintain a site quality-control program. The details of proper compaction and the ramifications of improper compaction are provided in the following chapters.

1.4—Terminology

The terms compaction and consolidation have both been used to describe the densification process of freshly mixed concrete or mortar. In ACI 309R, consolidation is the preferred term used for conventional concrete work. For the purposes of this document on roller-compacted concrete, however, the term compaction will be used for all types of RCC mixtures, because it more appropriately describes the method of densification.

1.5—Importance of compaction

The effect of compaction on the quality of RCC is significant. Higher density relates directly to higher strength, lower permeability, and other important properties. RCC mixtures are generally proportioned near the minimum paste content to fill voids in the aggregate, or at a water content that produces the maximum density when a compactive effort equivalent to the modified Proctor procedure (ASTM D 1557) is applied. The use of RCC in either massive structures or pavement construction needs to address the compaction of each lift because of its influence on performance. Failure to compact the concrete properly can cause potential seepage paths and reduce the stability in RCC dams or reduce the service life of RCC pavements.

In the 1980s, core sampling from RCC dams revealed instances of voids and low density in the lower one-third of lifts of RCC that had been placed and compacted in 300 mm (1 ft) lifts (Drahushak-Crow and Dolen 1988). Lower density at the bottom of lifts can be attributed to lack of compactive effort but is more commonly due to segregation of the mixture during the construction process. This segregation causes excessive voids in the RCC placed just above the previously compacted lift. Segregation is a major concern in dams due to the potential seepage path and the potential for a continuous lift of poorly bonded RCC from one abutment to the other that could affect the sliding stability. RCC dams constructed in earthquake zones can also require tensile strength across the horizontal joints to resist seismic loading. At Willow Creek Dam, seepage through a nonwatertight upstream face, and segregation at lift lines required remedial grouting (U.S. Army Corps 1984). This RCC dam was considered safe, from a sliding stability standpoint, due to its conservative downstream slope of 0.8 horizontal to 1.0 vertical. Recent innovations in South Africa (Hollingworth and Geringer 1992) and China have included the construction of RCC arch-gravity dams with very steep downstream slopes where bonding across lift joints is critical to the stability of these structures.

In pavements, flexural strength is dependent on thorough compaction at the bottom of the pavement section, while durability is dependent on the same degree of compaction at the exposed surface. Furthermore, construction joints between paving lanes are locations of weakness and are particularly susceptible to deterioration caused by freezing and thawing unless good compaction is achieved.

CHAPTER 2—MIXTURE PROPORTIONS

2.1—General

RCC mixtures should be proportioned to produce concrete that will readily and uniformly compact into a dense material with the intended properties when placed at a reasonable lift thickness. Procedures for proportioning RCC mixtures are provided in ACI 211.3R, ACI 207.5R, and ACI 325.10R.

The ability to compact RCC effectively is governed by the mixture proportioning as follows:

- Free-water content;
- Cement plus pozzolan content and cement: pozzolan ratio;
- Sand content, grading, and amount of nonplastic fines (if used);
- Nominal maximum size of aggregate;
- Air-entraining admixtures (if used); and
- Other admixtures (water-reducing, retarding or both).

For a given ratio of cement plus pozzolan, sand, fines (passing the 75µm [No. 2

the workability and ability to compact RCC effectively will be governed by the free-water content. As the water content increases from the optimum level, the workability increases until the mixture will no longer support the mass of a vibrating roller. As the water content decreases from the optimum level, sufficient paste is no longer available to fill voids and lubricate the particles, and compacted density is reduced.

RCC mixtures have no measurable slump, and the consistency is usually measured by Vebe consistency time in accordance with ASTM C 1170. The Vebe time is measured as the time required for a given mass of concrete to be consolidated in a cylindrically shaped mold. A Vebe time of 5 seconds (s) is similar to zero-slump concrete (no-slump concrete), and at such consistency, it is difficult to operate a roller on the surface without weaving, pumping, and sinking. For RCC mixtures used in dam work, a Vebe time of approximately 15 s is suitable for compaction in four to six passes with a dual-drum, 9 tonne (10 ton) vibratory roller. A normal range would be 15 to 20 s. At Victoria Dam Rehabilitation, the Vebe consistency of RCC ranged from approximately 15 to 20 s in the laboratory. In the field, the water content of the RCC was decreased and the Vebe consistency increased to approximately 35 to 45 s (Reynolds, Joyet, and Curtis 1993). The Vebe consistency test was not as reliable an indicator of workability at these consistency levels. Compaction was achieved by up to eight passes with a 9 tonne (10 ton) dual-drum vibratory roller at this consistency. RCC mixtures with a high consistency time, up to 180 s, have been compacted in the laboratory. RCC of this consistency required two to three times more compactive effort to achieve the equivalent percent compaction than mixtures with a lower consistency (Casias, Goldsmith, and Benavidez 1988). A Vebe time of 30 to 40 s appears to be more appropriate for RCC pavement and overtopping protection mixtures.

Lean RCC mixtures can benefit from the addition of nonplastic fines (material passing the 75 µm [No. 200] sieve) to supplement the cementitious paste volume and reduce internal voids between aggregate particles. For these mixtures, the increased fines improve handling and compactability (Schrader 1988). Lean RCC mixtures have no measurable consistency and the optimum water content for compaction is determined by visual inspection during mixing and compaction (Snider and Schrader 1988). If the moisture content is too low or there is insufficient rolling, the density at the bottom of the lifts is reduced and the bond between lifts is usually poor. This problem is easily corrected by first placing a bonding mortar or thin layer of high-slump concrete on the surface of the previously placed and compacted lift to bond the two together.

The fine aggregate content of RCC mixtures can affect compactability of RCC, though to a lesser degree than water content. RCC mixtures are less susceptible to segregation during handling and placing if the fine aggregate content is increased over that which is recommended for conventional concrete mixtures.

Fly ash (Class F or C) and water-reducing and retarding admixtures can be beneficial in the compaction of RCC

se materials, however,