UNIVERSITY OF EAST SARAJEVO
FACULTY OF TECHNOLOGY ZVORNIK

PROCEEDINGS

ZBORNIK RADOVA

IV INTERNATIONAL CONGRESS

ENGINEERING, ECOLOGY AND MATERIALS IN THE PROCESSING INDUSTRY

IV MEĐUNARODNI KONGRES

INŽENJERSTVO, EKOLOGIJA I MATERIJALI U PROCESNOJ INDUSTRIJI

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TEHNOLOŠKI FAKULTET ZVORNIK
UZ PODRŠKU
SAVEZA INŽENJERA I TEHNIČARA SRBIJE

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UNDER AUSPICIES OF
THE MINISTRY OF SCIENCE AND TECHNOLOGY OF REPUBLIC OF SRPSKA
THE ACADEMY OF SCIENCE AND ART OF REPUBLIC OF SRPSKA

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Review

ROLLER COMPACTED CONCRETE FOR PAVEMENTS

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Abstract**:** Roller compacted concrete pavement has a wide range of uses – from the pedestrian pathways to the infrastructural buildings. This type of concrete is primarily intended for the roundabouts and industrial pavements bearing heavy loads, but not high speeds. It can be used for construction of pedestrian and bicycle lanes, parking lots etc. Concrete pavement is more durable than the other types of pavements, it is more resistant to wear and its maintenance is simpler, not requiring frequent closures for traffic in order to maintain it. Its durability, longevity, noninflamability is accompanied by the low cost It has a light color, so less lighting is required at night. The construction process of roller compacted concrete is simple: the concrete is produced in the concrete factory, transported to the construction site in a mixer-truck and placed with the available technology – pavers and if needed, by vibrating rollers. The pavement can be used very shortly after construction. Owing to the raw materials used in fabrication, the roller compacted concrete pavement has considerably lower cost of construction in comparison to asphalt-concrete.

Key words: *roller compacted concrete, fast construction, longevity*

VALJANI BETON ZA KOLOVOZ

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Izvod**:** Kolovoz od valjanog betona ima široko polje primene - od pešačkih staza pa sve do infrastrukturnih objekata. Ova vrsta betona je prevashodno namenjena izgradnji kružnih tokova i industrijskih kolovoza koji podnose velike terete, ali ne i velike brzine. Može se primeniti i za izgradnju pešačkih staza, biciklističkih staza, parkirališta i drugo. Betonski kolovoz je dugotrajniji od ostalih kolovoza, otporniji je na habanje, a njegovo je održavanje jednostavnije tako da ne zahteva česta zatvaranja za sobraćaj. Uz otpornost, dugotrajnost i nezapaljivost, odlikuje se i povoljnom cenom. . Ima svetlu boju te je noću potrebno manje rasvete. Valjani beton je moguće ugraditi i na podlogu bez posebne pripreme. Proces izrade betonskog kolovoza od valjanog betona je jednostavan: beton se proizvodi u fabrici betona, kamionom-kiperom se prevozi na gradilište i ugrađuje postojećom tehnologijom – finišerima a, po potrebi, i vibrovaljcima. Kolovoz je moguće koristiti vrlo brzo nakon ugradnje. Zahvaljujući sirovinama koje se koriste u proizvodnji, kolovoz od valjanog betona ima znatno niže troškove ugradnje u odnosu na asfalt beton.

Ključne reči: *valjani beton, kolovoz, brza izrada, dugotrajnost*

1. ROLLER COMPACTED CONCRETE FOR PAVEMENTS - DEFINITION AND PROPERTIES

The American Concrete Institute (ACI) in *Cement and Concrete Terminology* (ACI 1 16R-99) defines roller-compacted concrete (RCC) as, "concrete compacted by roller compaction; concrete that, in its unhardened state, will support a roller while being compacted [1].
RCC can further be defined as a stiff, extremely dry concrete that has the consistency of damp gravel. Large vibratory rollers are used to externally consolidate or compact the roller-compacted concrete. Properties of fully compacted, hardened RCC are similar to those of conventionally placed concrete [2]

Guide for roller – compacted concrete pavements, **National Concrete Pavement Technology Center, Institute for Transportation, Iowa State University**, August 2010 [3], gives an answer to a question:" What is Roller-Compacted Concrete Pavement?" Roller-compacted concrete (RCC) gets its name from the heavy vibratory steel drum and rubber-tired rollers used to compact it into its final form. RCC has similar strength properties and consists of the same basic ingredients as conventional concrete—well-graded aggregates, cementitious materials, and water—but has different mixture proportions. The largest difference between RCC mixtures and conventional concrete mixtures is that RCC has a higher percentage of fine aggregates, which allows for tight packing and consolidation.

Fresh RCC is stiffer than typical zero-slump conventional concrete. Its consistency is stiff enough to remain stable under vibratory rollers, yet wet enough to permit adequate mixing and distribution of paste without segregation. Unlike conventional concrete pavements, RCC pavements are constructed without forms, dowels, or reinforcing steel. Joint sawing is not required, but when sawing is specified, transverse joints are spaced farther apart than with conventional concrete pavements. RCC pavements are strong, dense, and durable. These characteristics, combined with construction speed and economy [3].
Figure 1. Shows construction of a road made of RCC, and the appearance of the placed concrete

Figure 1. Construction of a road made of RCC and the appearance of the placed concrete

The following are typical applications:

• Industrial plant access roads and parking lots
• Intermodal shipping yards, ports, and loading docks
• Truck/freight terminals, bulk commodity storage, and distribution centers
• Low-volume urban and rural roads
• Aircraft parking areas
• Military long- or short-term loading zones, forward or rearward bases of operation, and airfields
• Recreational vehicle pad storage
• Vehicle maintenance areas or compost areas
• Large commercial parking lots
• Roadways in public parks
• Roadways for timber and logging operations
• Highway shoulders
• Temporary travel lanes that must be constructed quickly to divert traffic [4].

2. HISTORY OF ROLLER COMPACTED CONCRETE

Figure 2.a 1930s:A form of RCC paving is performed in Sweden

Figure 2.b. 1970s:RCC pavements become common for log-sorting yards in Canada

Figure 2.c. Late 1980s–early 1990s: RCC pavements are constructed for automotive, port, and intermodal facilities in the U.S.

Figure 2 a,b,c. History of roller compacted concrete

While some early examples of RCC dating back to the 1930's and 1940's have been reported [5], the first widespread use of RCC was in the 1970's by the Canadian logging industry when the new land-based log sorting methods needed a strong, fast but economic paving system that could take the massive loads and handling equipment. RCC provided the solution. As appearance was not in this case a primary concern, they did not even provide joints but let the concrete crack, and this made RCC an even more economic solution.
From the 1980's onwards the use of RCC has increased for technical and economical reasons. In the USA, data from Pittman [6] showed that in 1998 about 2.5 million square meters of RCC was constructed and by 2008 this had increased to 8 million m^2, i.e. more than tripled in ten years.

3. ADVANTAGES OF ROLLER COMPACTED CONCRETE

The primary advantage of RCC over conventional construction is in the speed of construction and cost savings. Trafficking at much earlier ages than with conventional pavement concrete is possible due to its rapid gain of strength. Other benefits of RCC for pavements are:

- Durability
- Low maintenance
- Light surface reduces lighting requirements and Urban Heat Island effects (RCC pavements have a solar reflectance index (SRI) greater than the minimum 29 required for Leadership in Energy and Environmental Design (LEED) points under LEED Credit 7.1: "Heat Island Effect" [7].
- The lower paste content in RCC results in less concrete shrinkage and reduced cracking from shrinkage-related stresses.
- RCC can be designed to have high flexural, compressive, and shear strengths, which allow it to support heavy, repetitive loads without failure—such as in heavy industrial, mining,and military applications—and to withstand highly concentrated loads and impacts.
- With its low permeability, RCC provides excellent durability and resistance to chemical attack, even under freeze-thaw conditions.
- RCC resists abrasion, similar to conventional concrete pavement, even under heavy loadsand high traffic volumes.
- Freeze-thaw durability of RCC is high, even without the use of air entrainment.
- The possible limitations and challenges associated with RCC pavements, such as the following:
- Without diamond grinding, RCC's profile and smoothness may not be desirable for pavements carrying high-speed traffic.
- The amount of RCC that can be mixed in a transit mixer or ready mix truck is typically lower than for conventional concrete, due to the dryness of the RCC mix
- Due to relatively low water content, hot-weather RCC paving requires extra vigilance to minimize water loss to evaporation.
- Due to the dryness of the RCC mixture, admixture dosage requirements can be higher for RCC than for conventional concrete [8].

Table 1 shows a comparison of conventional concrete and RCC materials [9].

Table 1 Comparison of conventional concrete and RCC materials

General Materials and Practices	Conventional Concrete Pavements	RCC Pavements
Mix materials proportions	Well-graded coarse and fine aggregates typically account for 60 to 75 percent of the mixture by volume. A typical waterto-cementitious materials (w/cm) ratio is 0.40 to	Dense- and well-graded coarse and fine aggregates typically comprise 75 to 85 percent of RCC mixtures by volume. RCC mixtures are drier than

	0.45, which makes a cement paste wet enough to thoroughly coat the aggregate particles and fill spaces between the particles.	conventional concrete due to their higher fines content and lower cement and water contents.
Workability	The mixture is plastic and flowable, so that it can be manipulated by the paving machine, and relatively stiff (slump is generally about 5 cm to hold shape after being extruded from the paving machine.	The mixture has the consistency of damp, dense-graded aggregates. RCC's relatively dry and stiff (less than zero slump) mixture is not fluid enough to be manipulated by traditional concrete paving machines.

Figure 3. Illustrates surface texture of RCC, PCC and HMA.

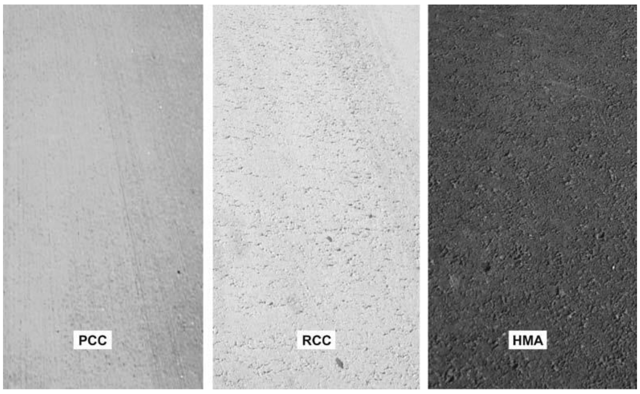

Figure 3. Surface texture of RCC compared to conventional concrete (PCC) and asphalt (HMA)

RCC mixtures typically have a lower volume of cementitious materials, coarse aggregates, and water than conventional concrete mixes and a higher volume of fine aggregates, which fill the air voids in the pavement system. The fine aggregates in RCC are more closely packed than in conventional concrete. This close packing initially provides high friction (aggregate interlock) between the particles and contributes to the pavement's initial load carrying capacity. The construction of all concrete pavements involves mechanical (consolidation) and chemical (hydration) processes. For conventional concrete pavement, consolidation occurs through internal paving machine vibrators. Through the hydration process, the paste hardens to bind the aggregate particles together. For RCC pavements, consolidation occurs through conventional or high-density paving screeds followed by steel drum and rubbertired rollers. As with conventional concrete, the paste hardens through hydration to bind aggregate particles together within the RCC mixture. The result is a dense pavement that has properties similar to those of conventional concrete pavement [10].

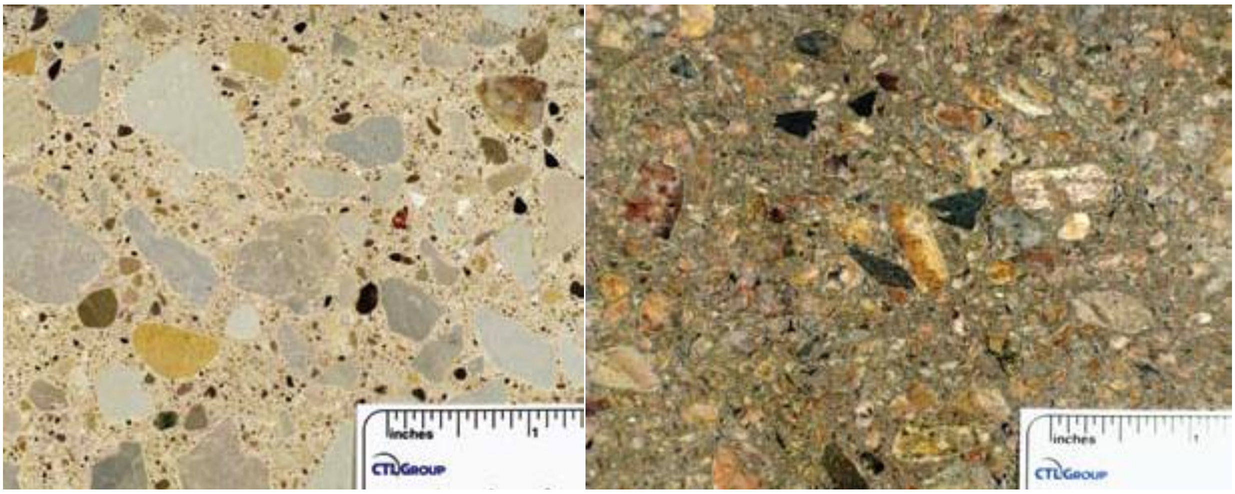

Figure 4. Comparison of aggregate distribution of conventional Portland cement concrete (PCC, left) and RCC (right)

4. MIXTURE PROPORTIONING

The cement and addition, if any, have to achieve the required compressive strength and there must be sufficient binder to coat the aggregate particles and give a closed structure. Too much paste causes the RCC to form a wave in front of the roller wheel. Consequently there is a need to find the cement content that is sufficient to give a closed structure, but is not excessive. North American experience [11] indicates that to meet this requirement the cement content of RCC is lower than with conventional pavement concrete.

There are several methods of mix proportioning [12] and the soil compaction method is the most commonly used at present. In the future, more use is likely to be made of "particle packing" models [12] to determine the maximum dry density as this saves on laboratory time and quickly allows a range of materials to be assessed. The soil compaction model is similar in approach to the design of hydraulically bound materials and for soil stabilization; once the optimum grading and binder contents are determined, the mixture is tested at different moisture contents to determine the moisture content that gives the maximum dry density. For practical reasons the plastic density is also recorded as this is measured when checking if the RCC has been adequately compacted.

The required compressive characteristic strength (including the margin) needs to be achieved at the design plastic density. If it is not being achieved, it may be necessary to do one or more of the following:

● use water-reducing admixtures to lower the w/c ratio;
● if an addition is being used, increase the proportion of cement in relation to the addition;
● increase the cement content.

Experience has indicated that batching at a slightly higher moisture content than that needed to achieve the maximum dry density gives a better finish. This increase may be up to 0.5% but it will depend upon the travel time and weather conditions.

Some of the methods of design of RCC for pavement are:

Corps of Engineers Method - This proportioning method is based on w/c and strength relationship. The method calculates mixture quantities from solid volume determinations, as used in proportioning most conventional concrete. The approximate water demand is based on nominal maximum size aggregate and desired modified Vebe time. A recommended fine aggregate as a percentage of the total aggregate volume is based on the nominal maximum size and nature of the course aggregate. Once the volume of each ingredient is calculated, a comparison of the mortar content to recommended values maybe made to check the proportions.

High Paste Method - This method results in mixtures that generally contain high proportions of cementitious materials, high pozzolan contents, clean and normally graded aggregates and high workability. The optimum water, fine aggregate, and coarse aggregate ratios are determined by trial batches Vebe consistencies are typically determined in accordance with ASTM Test Method for Determining the Consistency and Density of Roller-Compacted Concrete (C 1170). The major advantage of the high paste method is to provide excellent lift-joint bond strength and low joint permeability by providing sufficient cementitious paste in the mixture to enhance performance at the lift joints.

Roller-Compacted Dam Method - The roller-compacted dam (RCD) method is used primarily in Japan. The method is similar to proportioning conventional concrete in accordance with ACI 2 1 1.1 except that it incorporates the use of a consistency meter. The procedure consists of determining relationships between the consistency, termed VC value, and the water content, sand-aggregate ratio, unit weight of mortar, and compressive strength. Because of the consistency test equipment requirements and differences in the nature of RCD design and construction, this method is not widely used in proportioning RCC mixtures outside of Japan.

Maximum Density Method - This method is a geotechnical approach similar to that used for selecting soil-cement and cement stabilized base mixtures. Proportioning by this approach is also covered in Appendix 4 of ACI 21 1.3. Instead of determining the water content by Vebe time or visual performance, the desired water content is determined by moisture-density relationship of compacted specimens, using ASTM Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (D 1557). Another method for proportioning nonair-entrained RCCP mixtures is referred to as the optimal paste volume method. The premise behind the method is that workability and strength requirements are treated in two independent steps. The method is based on the assumption that an optimal RCC should have just enough paste to completely fill the interstices remaining when the granular skeleton has reached its maximum density under compaction [13].

5. RCC PROPERTIES – COMPRESSIVE STRENGTHS AND FLEXURAL STRENGTH

The properties of RCC are similar to those of conventional concrete pavement but are achieved using different mixture proportions and construction techniques. Data describing the engineering properties of RCC pavements are based on tests of cylinders from actual paving projects as well as full-scale test sections.

5.1. COMPRESSIVE STRENGTHS

A major advantage of RCC over pavement quality concrete is the ability to open it to traffic at a relatively early age. A "rule of thumb" used in the USA [14] is to open it to traffic when the compressive in-situ strength reaches about 20 N/mm^2 cylinder strength. The rate of gain of strength is highly dependent upon a number of factors including cement type, RCC strength and the ambient conditions, all of which are site specific. In practice the requirement of 20 N/mm^2 is achieved in about 2 days in warm weather and about 4 days in cooler weather. The model specification has the more onerous requirement of 7 days after construction before trafficking. In most cases, a shorter period is not needed, but where it is an issue, the achievement of an in-situ strength of 20 N/mm^2 is the fundamental criterion. These requirements relate to trafficking by the public and not to trafficking by the contractor. The RCC will have been compacted by heavy machinery and therefore occasional site traffic is unlikely to harm the RCC. The compressive strength of RCC is comparable to that of conventional concrete, typically ranging from 28 to 41 N/mm^2. Some projects have reached compressive strengths higher than 48 MPa N/mm^2.

5.2. FLEXURAL STRENGTH

Flexural strength is directly related to the density and compressive strength of the concrete mixture. In properly constructed RCC pavements, the aggregates are densely packed and minimize the development of fatigue cracking. The density of the paste and the strength of its bond to the aggregate particles are high due to its low w/cm ratio. As a result, the flexural strength of RCC, depending on the mix design, is generally high—ranging from 3.5 to 7 N/mm^2.

6. CONCLUSION

Over the past 30 years, roller-compacted concrete has advanced significantly as a viable construction technique. Primary applications are for dams, spillways, overtopping protection, and pavements. The main advantage of RCC over conventional construction is in the speed of construction and cost savings. Performance of RCC has been very good even under free~ethaw conditions. Additional research and development is needed to:

1.) improve surface texture, skid resistance, and joint construction methods in pavements;

2.) establish standardized joint design spacing;
3.) establish standardize rnixture design methods;
4.) develop representative freeze -thaw durability test procedures;
5.) determine methods - for air-entrainment,
6.) improve mixing efficiency using conventional concrete mixing equipment; and
7.) expand the use of admixtures including retarders and water reducers to extend working time and enhance performance [14].

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