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ROLLER COMPACTED CEMENT CONCRETE (RCC) PAVEMENT

Abstract

Introduction. Construction of Roller Compacted Concrete or Rolling Compacted Concrete (RCC) road pavements is well-spread in many countries all over the world. (Its name comes from the heavy steel drum rollers, which compact the concrete into final form).

Problem statement. It has several advantages but its technique is different from that of „traditional" cement concrete pavement.

Purpose. The article presents the specialities of RCC techniques and the international application experiences emphasizing the Hungarian ones in order to support the introduction of the technology in other countries.

Materials and methods. The RCC consists of the same ingredients as conventional concrete does, but it has a higher percentage of fine aggregates and is stiff enough to remain stable under compaction having sufficient water for distributing the paste without segregation. RCC pavements can be constructed without forms, dowels or reinforcing steel. The article will supply with an introduction to and updated review of RCC and its many paving applications. Previous relevant research works and the results of laboratory test series will be summarized which were done partly in Hungary and partly in other countries. The importance of the following of strict technological rules in producing high-quality material is also emphasized. Besides the main points of recently published Hungarian Road Technical Directives are presented. Finally, some long-term performance data of Roller Compacted Concrete experimental (test) sections are discussed.

Results. This technology gives a favourable economical alternative for several layers in rigid and semi-rigid pavement structures, pavements carrying heavy loads in low-speed areas, as well as dams. Its trial use and later the introduction of the technology into the so-called "technological choice" is recommended in every country, included Ukraine.

Keywords: pavements, concrete pavements, roller compacted concrete, trial sections, concrete mix design, concrete pavement construction.

Introduction

Roller compacted concrete (RCC) is an economical, fast-construction candidate for many pavement applications. It has traditionally been used for pavements carrying heavy loads in low-speed areas because of its relatively coarse surface. However, in recent years its use in commercial areas and for local streets and highways has been increasing. Based on current research and best practices, the paper describes RCC and how it works as a paving material, especially compared to concrete pavement, as well as its common uses and its benefits and potential limitations compared to other paving materials. It provides detailed overview of RCC properties and materials, mixture proportioning, structural design issues, and production and construction considerations, plus troubleshooting guidelines.

The name of Roller Compacted Concrete Pavement comes from the heavy steel drum rollers which compact the concrete into final form. The RCC consists of the same ingredients as conventional concrete does, but it has a higher percentage of fine aggregates and is stiff enough to remain stable under compaction having sufficient water for distributing the paste without segregation [1].

After having shown various previous research works and the documents of completed RCC constructions, the relevant Hungarian activities will be outlined. First, an appropriate mixture recipe was planned. In the laboratory of KTI Institute for Transport Sciences Non-Profit Ltd., Budapest, Hungary numerous test cubes, cylinders and beams were made for testing the strength properties, freeze-thaw durability, water permeability, abrasion wear and air void characteristics for hardened concrete [2]. The results obtained proved that RCC can have the same properties (quality) as conventional concrete has. Using the available mixtures, a test (trial) section was planned, and organized in order to evaluate the quality of placement (laying) and compaction operations, to fine-tune eventually the mixture composition, and to bore core samples to perform testing on the constructed RCC.

It has been shown that RCC with basic ingredients and proper recipe (mixture proportions) can be made with similar strength and durability as conventional concrete, but unlike conventional pavements. This technology gives a favourable economical alternative for many types of civil engineering facilities.

Application areas

Multi-layer pavement systems for high-speed uses

For roadways carrying traffic at highway speeds, RCC is primarily used as a base under a thin asphalt wearing course for better rideability. Another option is its use under a conventional concrete pavement. This case, the roller compacted cement layer provides an excellent construction platform and allows the thickness of the final cement concrete pavement to be reduced. A separation layer between the two concrete layers is needed for separate layer movement and to create a shear plane that relieves stress and helps prevent cracks from reflecting up from the base into the concrete pavement surface. The separation layer could be an asphalt layer or a geotextile fabric layer. The RCC base is typically not sawed when used under a conventional concrete pavement. If they sawed to minimize crack spacing and improve load transfer, transvers joints should be spaced at 4.5 to 6.0 m intervals for pavements less than 20 cm thick, in other cases, the interval could be 6.0 to 9.0 m depending on the actual pavement thickness. Longitudinal joints should be spaced 6.0 to 7.5 m. This multi-layer system could be used cost-effectively in highway, airport and heavy industrial applications, and should provide excellent long-term performance.

Local streets

Speed of construction, economy and early opening to traffic are key reasons to use RCC for streets and local roads. For new residential developments provides a strong working platform during site work and construction. When traffic speeds are greater than 50 km/h, surface evenness is important. That is why high-density paver and/or diamond grinding should be applied. A thin asphalt wearing course placed on top of RCC is another option. Light traffic could be placed on top of the RCC pavement within 24 hours after construction to accommodate nearby businesses. Sawed joints may be desired to initiate crack locations or for aesthetic reasons in residential areas (see Figure 1).

Widening and shoulders

Widening roadways is a common way to meet lane and edge drop-off criteria. The strength of RCC and its speed of construction make it particularly suited to road widening applications. The material provides a stable foundation that can be surfaced with asphalt or concrete for highway traffic and that provides a long, low-maintenance life. Distressed pavement in shoulders can also be replaced with RCC. Sawed joint are typically not required for widening and shoulders.

***Figure 1* —** RCC pavement on a local road

Other application areas

Some other application areas where RCC pavements can be favourably constructed: ports, intermodal facilities, light and heavy industrial facilities, airport facilities (maintenance areas, parking lots, snow storage areas, etc.), logging facilities, storage yards, dams [7].

RCC properties and materials

The main characteristics (properties) of RCC are as follows:

- compressive strength (28 to 48 MPa);
- flexural strength (3.5 to 7.0 MPa);
- bond strength (usually appropriate if pavement lifts are placed within an hour of each other);
- freeze-thaw durability (minimum air void spacing factor of 250 μm is needed for a durable concrete);
- shrinkage (the volume change associated with drying shrinkage is normally less than that in comparable conventional concrete mixtures due to the lower water content of RCC);
- permeability (hardened RCC permeability is comparable to that of conventional concrete);
- the process of RCC itself will reduce your construction costs as there is no need to use rebars or forms, and the application process is very easy and can be done quickly [4, 5].

RCC contains the same basic materials as conventional concrete–coarse and fine aggregates, cementitious materials (cement, fly ash, silica fume, etc.), water, and, when appropriate, chemical admixtures — but they are used in different proportions. The cost of materials used in RCC is generally comparable to the cost of materials used in conventional concrete. RCC typically has a slightly lower cement content than conventional concrete of similar strength. The lower cement content can lead to some savings in material costs [6].

Aggregate

Aggregate grading of RCC-mixtures differs from that of traditional concretes because partly RCC mixture will be denser under paver, steel and pneumatic-tyre rollers, partly fine fraction ratio should be increased for the total saturation of concrete mixture. Figure 2 presents the selected aggregate grading compared to the upper and lower bounds coming from averaging the relevant Hungarian and some foreign boundaries.

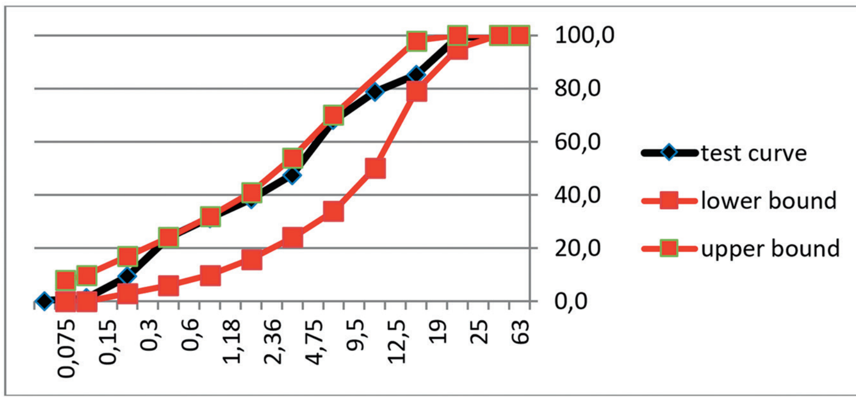

Figure 2 **—** The selected aggregate grading compared to boundaries obtained by averaging bounderies in Hungarian and some foreign specifications

Binders

RCC mixtures can be produced using any cement type meeting specification requirements [8] in Hungary. Selection of optimal cement type is influenced by environmental effects (sulphate resistance, resistance to thawing salts, abrasion resistance). It is advised to use cement types with limited hydration heat since the mixture uses low water content, and proper hydration does need sufficient water.

Water

Water needed for hydration is originated partly from the water content of aggregate, partly from the water added at mixing plant. Water used should meet the quality requirements of relevant standard [9]. RCC technique needs the highest possible density of concrete; that is why the optimal water content of mixture should be determined in accordance of the relevant standard [10].

Admixtures

Also the admixtures used for traditional concrete mixture (plasticizers, set retarders, accelerators, air entrainers, etc.) can be applied. Due to the limited water amount in RCC mixture, dosages of various admixtures can be multiple of the common ones. Set retarder can be needed if laying in 45–60 minutes after mixing is questionable, especially in warm time. Based on foreign experiences, two recipes were selected for the test sections with different cement contents.

Construction rules

Subgrade

Subgrade density should be min. 95 % of Proctor density. For avoiding bearing capacity loss due to eventual subgrade wetting, a granular capping layer is recommended.

Concrete mixing

Batch or continuous concrete mixing plants can be used. Batch plants are appropriate for small projects when mixture is transported by covered trucks to the site. Mixer has to be fully emptied after each mixing cycle before mixing next batch. Continuous mixing for big projects allows the production of cement concrete mixture of constant quality. Properly homogenous concrete mixture of needed quantity and quality should arrive to the paver. Because of the dryness of RCC mixtures, the appropriate mixing at batch type production necessitates more energy reducing mixing plant capacity. The same dosage tolerances are to be used for RCC as for traditional concrete; however, it is important here to apply moisture meter for avoiding segregation.

Laboratory tests

The laboratory tests in relevant Road Technical Instructions [11, 12] and in foreign literature were carried out. For fresh concrete, aggregate moisture content, compaction [13] and water/cement ratio should be measured, and maximal wet density [14] designed. For hardened concrete, compressive strength [15], splitting tensile strength [16], density [17], distance factor [18], frost resistance [19], water permeability [20] and abrasion resistance [21] were tested.

Transportation

Generally, trucks with dump bodies are used. Concrete mixture has to be poured in 60 minutes since the mixtures with low water/cement ratio harden much quicker than the more flexible ones. Number and capacity of trucks to be applied have to ensure the continuous laying of concrete mixture. The mixture should be covered during transportation to protect it from evaporation or raining. Mixture has to be loaded directly from lorry to the finisher. For allowing to the evaporation loss during transportation, slightly increased water content can be selected.

Laying

RCC is usually laid by an asphalt paver the edge compactors of which compact the mixture, and so, rollers can move on a pre-compacted surface. Pre-compaction should reach 85 % of maximum wet density. Paver could lay min. 1.5 times output capacity of mixing plant. In order to avoid the segregation during concrete pouring, paver should not be emptied completely during laying, spreading screws are to be covered continuously by mixture. Paver speed has to be selected to ensure the continuous paving to avoid surface unevenness.

Compaction

Some general rules of RCC compaction:

- Compaction has to be commenced immediately after concrete pouring. Primary compaction should be performed using 10 ton double drum vibratory roller. Secondary compaction is to be done by static roller passes, while the even surface can be attained using pneumatic-tyre rollers. In tight places where space is limited for heavy rollers, small plate compactor or rammer (jumping jack compactor) can be applied. Compaction has to be completed in 15 minutes after laying, and 60 minutes after the end of concrete mixing.
- Ideally, no water enters from below on the surface of freshly compacted RCC course. The compaction rate of rolled compacted concrete pavement can be readily assessed by scrutinizing concrete mixture behaviour under static roller passes. Uniform deformation under compaction proves appropriate concrete consistency. If concrete is too wet for compaction, layer surface becomes pasty and shining after rolling, and it behaves elastically, even under pedestrian traffic. If concrete is too dry, surface is granular and dusty, or even cracked. In the latter cases, water content of the mixture is to be changed, grading to be checked or weighing balance calibrated.
- Freshly laid concrete layers can be compacted relatively quickly and easily, however, some special rules are to be followed. Compaction rules are rather similar to those of hot laid asphalt layers. In both cases, the most important rules are to use continuously low (about 3 km/h) rolling speed, to change directions just gradually, and to accelerate after changing directions also gradually. No turning is allowed

during roller passes. Changing rolling lanes, starting new lane or turning have to be done just at the back, on the already compacted and hardened pavement section.

- In case of RCC-layers with 151–250 mm thickness, the needed 98 % density can be reached by 4–6 passes of a 10 ton vibrating compactor. Over-compaction can reduce the density of upper layer or edges can crack.

Jointing

The joint types used are: tight, contraction and expansion joints.

The planned tight joint is built between a new cement concrete layer and an „old" concrete pavement. However, RCC pavements' shrinkage, due to their low water contents, is just minimal, some cracking can be developed. These cracks can be fully avoided if contraction joints are formed. It is suggested to saw pavements to a depth of one-quarter of the slab thickness at 6–18 m intervals. No sealing is needed for joints below 6 mm width.

As for traditional concrete pavements, expansion joints should be placed to allow movement of the RCC pavement without damaging adjacent pavements, intersecting streets or other fixed objects (buildings, public utilities shaft, etc.).

Site tests

At the RCC construction site, pavement compaction [13], as well as density and water content [22] are to be controlled. The aim of RCC compaction test is identical with that of consistency test for conventional concrete pavements. The test results inform about if the mixture can still pored after transport, and it can be compacted appropriately. The test results of pavement density and water content after laying point towards the attained percentage of maximal laboratory dry density which was obtained using the Proctor test.

Curing and protection

Since the water content of RCC is very low, and evaporation and hydration heat quickly reduce further its water content; if water is not retrieving it, shrinkage cracking and/or lower strength could be caused. That is why curing should be started just after the completion of pavement compaction; aftercare has to be done for at least 7 days. Curing can be performed using watering-cart or fixed sprinkler.

Construction troubleshooting

Problems occurring in RCC pavements are generally related to materials and construction practices; therefore, adequate prequalification, testing, and evaluation are necessary [3]. Understanding the integration of raw and produced concrete materials with construction practices under certain weather conditions is a good starting point for assessing and pinpointing the exact origin of problems. At times, various undesirable effects are caused by the constituent materials and their interactions with climate and weather conditions. In many cases, there are several factors at play, making it challenging to isolate a specific cause.

Because RCC can be constructed in both in hot and cold weather, it is important to appreciate the differences in the behaviour of mixtures in different weather conditions. Problems can arise during production, transportation, paving, compaction, and curing and at later ages in terms of long-term performance of RCC mixtures. A general strategy to determine the cause of a problem is to look for patterns that may connect cause and effect. When a particular problem occurs frequently, individual causes can be eliminated in a step-by-step manner. Broadly, problems can be associated with weather changes, changes in the material source or consistency, and staffing-related changes. Occasionally, problems may also be associated with a combination of factors, including design, detailing, material source, batching, and construction practices. Sometimes a minor change in one factor can result in disproportionate consequences.

Hungarian Road Technical Instructions

In 2019, the e-UT 06.03.36 Road Technical Instructions (UME) entitled "Design and construction of roller compacted cement concrete pavements" was published in Hungary [23]. Some details of the specification will be presented.

Application areas and conditions

The following application areas are suggested: light and very light trafficked roads, pavement of their bus stops,, roads loaded by slow, heavy vehicles, agricultural roads, cycle roads and lanes, pavement of industrial areas, pavements of storage areas, parking places, port pavements, airport service areas, paved shoulder.

Suggested RCC pavement thicknesses

Supposing 20 years of pavement life and depending on the actual traffic load, the following RCC pavement thicknesses are recommended:

– very light traffic (max. 30,000 equivalent 100kN-axle load repetitions) 120 mm,
– light traffic (30,000–100,000 equivalent 100kN-axle load repetitions) 160 mm,
– moderate traffic (100,000–300,000 equivalent 100kN-axle load repetitions) 180 mm,
– cycle path, parking area, paved shoulder 120 mm,
– other areas mentioned earlier max. 200 mm.

Underlying layer types

Roller compacted concrete pavements can be built on flexible and semi-rigid pavement structures of good condition and sufficient bearing capacity. The underlying layer can be unbound, hydraulically bound, flexible or remixed base course. In the case of hydraulically bound base course, a separation layer (bituminous emulsion, surface dressing, thin asphalt concrete layer, polyethylene foil, geotextile) is also used to avoid the so-called wild cracking of RCC.

Basic materials of RCC

Aggregate types to be used: natural sand, gravel, gravel and sand, crushed sand, crushed gravel, crushed stone, chippings. Hydraulically binder types: Portland cement, blast furnace slag cement, fly ash cement, trass cement. Admixtures (additives): air training concrete admixture, gas forming admixture, concrete plasticizer, flow additive.

Design requirements for the mixture

Two mixture types (RCC 3 and RCC 4) are specified as a function of splitting tensile strength (N/mm^2). Minimum cement content: 340 kg/m^3, optimum water content: 5–7 %, max. w/c (water/cement) ratio: 0.35 ± 0.02, max. aggregate size: 22 mm, air content of fresh concrete: 4–5 vol %.

Laying and compaction

The surface of underlying layer could be wetted if needed. Max. 250 mm loose thickness of concrete can be applied. The time interval between the laying of two neighbouring RCC courses should not exceed 60 minutes. Pavers of high compacting ability with one or two edge rammers and vibrating plate should be used. A rate of 90–93 % compaction degree is to be attained. The actual compaction is performed using steel or pneumatic-tyre rollers of at least 10 tons. The 30–50 m wide pavement edge should be compacted by road shoulder compactor or vibratory plate.

Trial sections

In the research work mentioned [2], various recipes were designed in order to select the most suitable one for the planned RCC trial section on the access road of gravel pit in Bugyi. The loading of the two 100 m-long sections are radically different depending upon whether the sections are used by loaded vehicles or empty ones. KTI-institute prepared a Technological Instruction and a Sampling and Qualification Plan for the field trial, it had technical surveillance, besides carried out fresh concrete and tested cored samples taken from the pavement. The degree of compaction of the very well-compacted subgrade has reached 100 % compared to Proctor density during the several-year intensive truck loading. The Young's soil modulus measured by plate-bearing test amounted to a rather high (129.9 MP) value. That is why the trial section was designed without capping layer, just 50 mm 0/4 chippings were laid below the roller compacted concrete pavement for levelling and ensuring the planned cross fall. On the trial section with lower traffic size, RCC pavement was 150 mm thick, while its thickness on the relatively highly-trafficked section amounted to 200 mm. 50–50 % of both sections were built using two different recipes for a later comparison of their performances.

Before the field trial, among others, the Proctor-tests of the aggregates of the two mixtures were carried out, with the following results: w_{opt} = 4.7 %; ρ_{dmax} = 2.39 Mg/m^3; w_{opt} = 4.7 %; ρ_{dmax} = 2.37 Mg/m^3. The site quality control data of RCC were in the following ranges: water content between 4.9 and 5.8 %, dry density between 2.30 and 2.37 g/cm^3, wet density between 2.43 and 2.50 g/cm^3; degree of compaction between 96 % and 100 %.

The performance of the access road of gravel pit in Bugyi, the first Hungarian RCC trial section proved to be favourable after 6 years of heavy traffic.

Meanwhile other experimental sections were built, among others, a forest road in Kaposvár used also by cyclists; another forest road in Barcs-Drávaszentes, agricultural roads in Drávaszentes.

Conclusions

In many countries, Roller Compacted Concrete pavements have proved to be an efficient and environmental-friendly pavement type, especially for slow heavy traffic. Research works and laboratory test series carried out in KTI-laboratory also provided favourable results that were validated further by the good performance of trial sections constructed. The technological details given in the paper can contribute to the experimentation and then introduction of RCC technique in any country.

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ПОКРИТТЯ З УКОЧУВАНОГО ЦЕМЕНТОБЕТОНУ

Анотація

Вступ. Будівництво дорожніх покриттів з ущільненого за допомогою укочення бетону або дорожніх покриттів з укоченого бетону (Roller Compacted Concrete — RCC) є широко поширеним у багатьох країнах світу. (Його назва походить від важких сталевих барабанних котків, які ущільнюють бетон, укочуючи його до остаточної форми).

Постановка проблеми. Ця технологія має кілька переваг, але вона відрізняється від «традиційної» технології улаштування цементобетонного покриття.

Мета. У статті представлені особливості технології RCC та міжнародний досвід її застосування, з особливим акцентом на угорському досвіді, щоб підтримати впровадження цієї технології в інших країнах.

Матеріали та методи. Технологія RCC передбачає наявність тих же інгредієнтів, що і звичайний бетон, але вона передбачає також більш високий відсоток фракцій дрібного заповнювача, та таке покриття є достатньо жорстким, щоб залишатися стабільним під час ущільнення, маючи достатню кількість води для розподілення цементного тіста, уникаючи розшарування. Покриття за технологією RCC може бути укладено без використання опалубки, стрижнів або армуючої сталі. У статті буде представлено вступ до оновленого огляду технології RCC та її багатьох застосувань під час укладання. Буде представлено узагальнені попередні відповідні науково-дослідні роботи та результати лабораторних випробувань, які було виконано частково в Угорщині та частково — в інших країнах. Підкреслюється також важливість дотримання суворих технологічних правил під час виготовлення високоякісного матеріалу. Окрім того, надаються основні положення з нещодавно опублікованих Угорських технічних дорожніх директив. Нарешті, обговорюються деякі дані багаторічних досліджень експлуатаційних характеристик, отриманих з експериментальних (випробувальних) ділянок, влаштованих за технологією укочуваного бетону.

Результати. Ця технологія є вигідною економічною альтернативою під час увлаштування конструкцій покриття жорсткого та напівжорсткого типу з декількох шарів; для покриттів, що піддаються великим транспортним навантаженням на ділянках з низькою швидкістю транспортного руху, а також для ділянок дамб. Дослідне використання та подальше впровадження технології в так званій "технологічний вибір" рекомендовано для кожної країни, включаючи Україну.

Ключові слова: дорожні покриття, бетонне покриття, укочуваний бетон, дослідні ділянки, підбір бетонної суміші, конструкція бетонного покриття.