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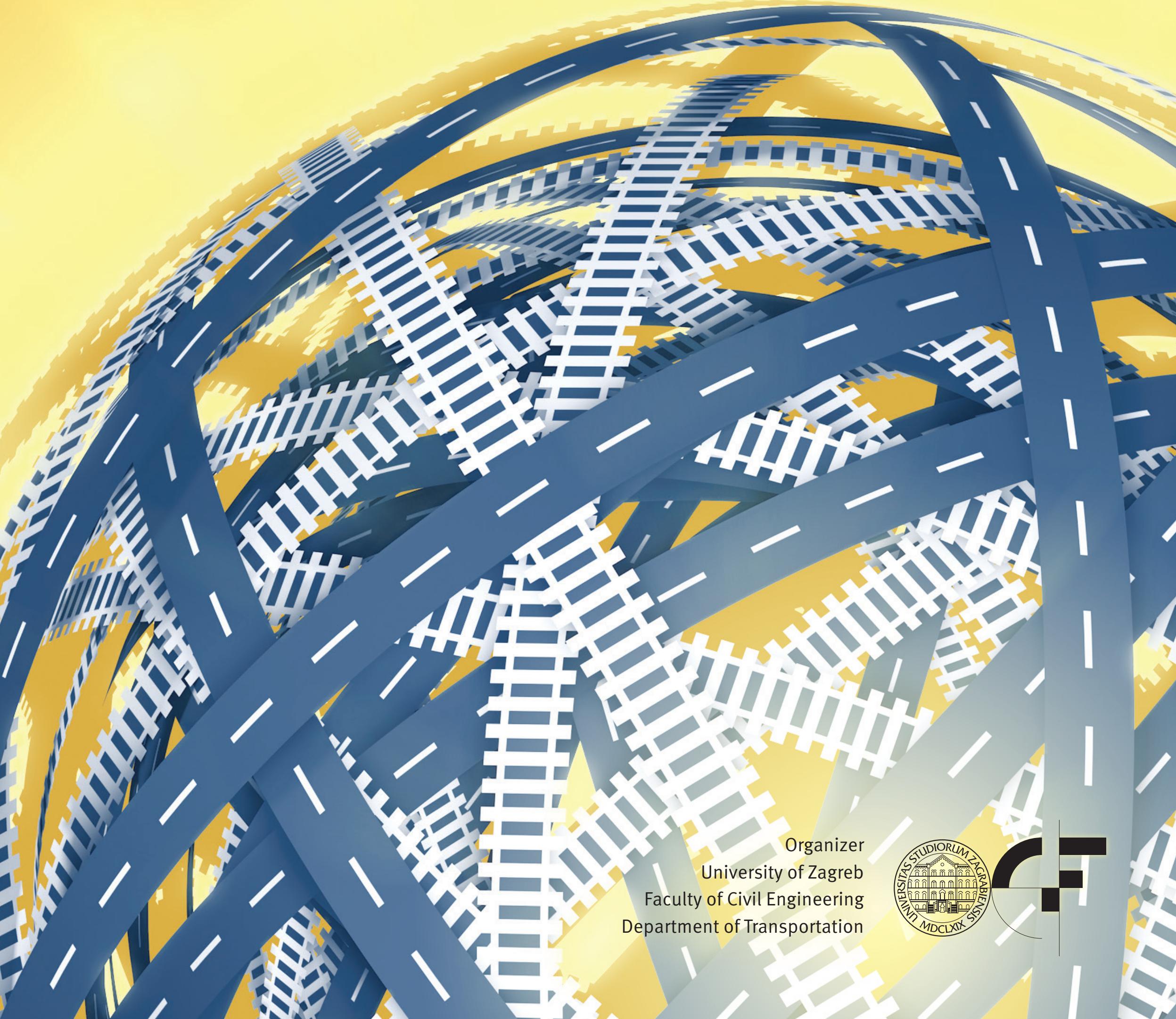
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure IV

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ROLLED COMPACTED CONCRETE PAVEMENTS

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Abstract

Roller-Compacted Concrete (RCC) road pavement is well-spread in the USA and in several European countries due to its strength, density and durability, economic advantages and high construction speed. Its name 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. After having studied different previous research works and the documents of completed RCC constructions, a mixture was planned following the main prin-ciples from the examples taking the available components into consideration. In KTI laboratory, 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. 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, and 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, RCC pavements can be con-structed without forms, dowels or reinforcing steel. This technology gives a favourable economical alternative for pavements carrying heavy loads in low-speed areas such as industrial plant access roads, shipping yards, posts, loading docks, large commercial parking lots, and it can also be used as base course for semi-rigid pavement structures. The Hungarian trial section built is still in good shape after 2-year heavy traffic load.

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

1 Introduction

RCC (Roller Compacted Concrete) road pavements have been built in several countries all over the world, primarily for slow moving heavy traffic. The main feature of its technology is the compaction of laid fresh cement concrete mixture using vibratory heavy steel-drum compactors and pneumatic-tyre rollers. The use of the construction technology in Hungary was preceded by the research works and tests to be briefly presented. KTI Non-Profit Ltd., Budapest performed – on behalf of CEMEX Hungária Ltd. – literature survey, research, mixture design on RCC, besides prepared the construction of a trial section and monitored it [1].

2 Some related literature sources

The main potential advantages of RCC roads compared to other road types are the smaller carbon footprint (less environmental impact), singular material con-struction (in-situ materials) and faster construction time (faster compacting than with finisher). RCC techniques are the perfect solution for low-cost cement concrete road or dam constructions [2, 7]. The use of RCC in public and private applications has been increasing steadily in various countries all over the world in recent years particularly in the construction of low-volume roads and parking lots [2]. RCC pavements are strong, dense, and durable. These characteristics, com-bined with construction speed and economy, make RCC pavements an excellent alternative for parking and storage areas; port, intermodal, and military facilities; highway shoulders; streets; and highways. RCC can also be used in composite systems as base material [3]. In-situ materials have become more and more relevant in construction nowadays [4]. Some guideline and specification were developed for roller compacted concrete (RCC) as an exposed RCC pavement surface, that may or may not be diamond ground for smoothness and/or texture [5]. Some studies related to secondary materials in RCC provided favourable results from the point of view of compaction and long-term performance. Using natural pozzolan or fly ash in massive concrete dam construction, it is possible to achieve a temperature rise reduction without any undesirable effects such as bleeding, tendency to segregate and tendency to increase permeability [6].

3 RCC mix design

Roller compacted concrete mixture has the same ingredients as traditional concrete mix has; just the ratios of fractions are different. Its construction cost practically does not differ from that of conventional concrete; the extra costs of more fine fractions and eventual additional additives are compensated by the cost saving coming from reduced cement need.

3.1 Aggregate

Aggregate grading of RCC-mixtures differs from that of traditional concretes be-cause 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 1 presents the selected aggregate grading compared to the upper and lower bounds coming from averaging the relevant Hungarian and some foreign boundaries.

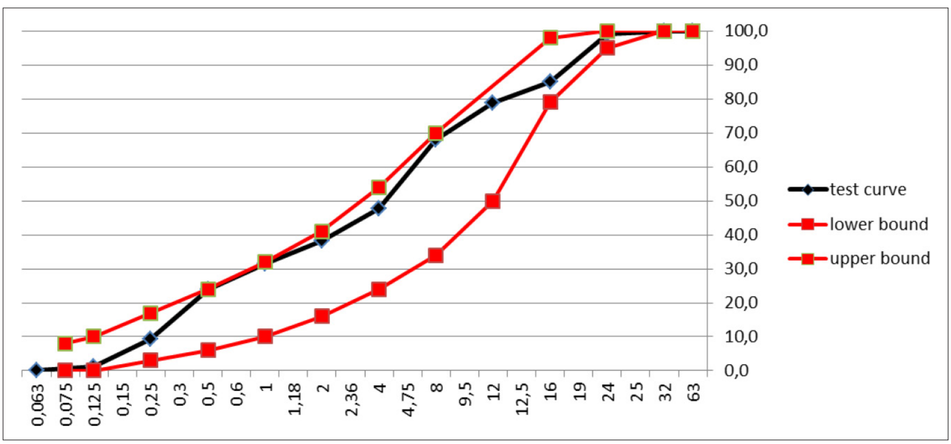

Figure 1 The selected aggregate grading compared to bondaries obtained by averaging bounderies in Hungarian and some foreign specifications

3.2 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.

3.3 Water

Water needed for hydration is originated partly from the water content of agg-regate, 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].

3.4 Admixtures

Also the admixtures used for traditional concrete mixture (plasticizers, set re-tarders, 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.

4 Construction rules

4.1 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.

4.2 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 conc-rete mixture of constant quality. Properly homogenous concrete mixture of need-ed 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.

4.3 Laboratory tests

The laboratory tests in relevant Road Technical Directives [11, 12] and in foreign literature were carried out. For fresh concrete, aggregate moisture content, com-paction [13] and water/cement ratio should be measured, and maximal wet den-sity [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.

4.4 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

4.5 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. Precom-paction 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, spread-ing screws are to be covered continuously by mixture. Paver speed has to be selected to ensure the continuous paving to avoid surface unevenness.

4.6 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 pave-ment 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 pave-ment 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.

4.7 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, inter-secting streets or other fixed objects (buildings, public utilities shaft, etc.).

4.8 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 iden-tical with that of consistency test for conventional concrete pavements. The test results informs 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.

4.9 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 retrieve it, shrinkage crack-ing 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.

5 Field trial

5.1 Principles of a field trial

Before an RCC project, a field trial is strongly advised to demonstrate the suitability of the mix recipe, design, paving machinery, curing and joint forming. A trial PCC pavement should be constructed on dense and strong subgrade using the construction technique of the planned project. The dimensions of the trial area would be sufficient for supplying the following information types:
- Subgrade quality (grading, density, moisture content, etc.);
- Quality parameters of RCC ingredients, mixture and pavement, com-pared to relevant specification requirements;
- Suitability of mixing plant to produce continuously homogeneous RCC mixture and to feed basic materials accurately;
- Suitability of mix composition (recipe) for fulfilling relevant requirements;
- Quality of laying and compaction (compaction plan, number of passes);
- Shaping of construction lanes (timing, layout);
- Assessment of pavement surface features (texture, homogeneity, etc.);
- Testing concrete cube specimens made during field trial, comparison of their strength values with relevant requirements of type test.

Coming from the site tests and laying experiences results of field trial, originally planned technology can be modified.

5.2 Trial sections

5.2.1 Some features of trial sections

In the research work mentioned in section 1 [1], 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 com-parison of their performances.

5.2.2 Some test results obtained on trial sections

Table 1 shows the main strength results of cement concrete mixtures with the same aggregate grading and different cement content.

Table 1 Strength values of concrete mixes using two different recipes

	Recipe 1 (350 kg/m³ CEM I+III)						Recipe 2 (320 kg/m³ CEM I+III)					
	7-day beam	28-day cube	28-day cylinder (150x300 mm)	28-day beam	7-day bored cylinder	28-day bored cylinder	7-day beam	28-day cube	28-day cylinder (150x300 mm)	28-day beam	7-day bored cylinder	28-day bored cylinder
Bend force [kN]	34.5			47.5			32.3			41.4		
Bend strength [N/mm²]	4.56			6.20			4.26			5.40		
Splitting force [kN]	126.8		260.0			147.0	121.3		279.1			140.6
Splitting strength [N/mm²]	3.55		3.65			3.55	3.39		3.90			3.35
Compressive force [kN]	995.8	1339.8			180.4	180.7	898.4	1306.0			135.1	195.2
Compressive strength [N/mm²]	44.26	59.20			23.38	38.70	39.93	57.60			17.51	36.70

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/m³; w_{opt} = 4,7%; ρ_{dmax} = 2,37 Mg/m³. 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/cm³, wet density between 2.43 and 2.50 g/cm³; degree of compaction between 96 and 100%.

6 Some concluding remarks

In a lot of countries, Roller Compacted Concrete pavements have proved to be an efficient and environmentally-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 further validated by the good perform-ance of trial section constructed. The legislation of this perspective pavement technology in Hungary is expected soon.

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