APPLICATION OF ROLLER COMPACTED CONCRETE FOR PAVEMENT STRUCTURES

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Summary: *Roller compacted concrete was first used in the 1930s and 1940s for construction of dams, while the first application in the field of roads was recorded in the 1970s. In the last ten years, roller compacted concrete has been primarily used for military purposes, industrial carts, in the construction of ports, but also in commercial projects for pedestrian and bicycle paths, local streets, emergency lanes of motorways, parking lots. The paper presents the basic characteristics of the roller compacted concrete and requirements for its application as a material for pavement structures.*
Key words: *roller compacted concrete, concrete, cement stabilization, pavement structures, application*

1. INTRODUCTION

Nowadays, the mixtures of aggregates and bitumen known as asphalt or flexible pavement structures are most commonly used for construction of pavement structures worldwide. On the other hand, concrete pavements (rigid pavement structures) are significantly less represented, despite the undoubted advantages in the area of load transfer, sustainability and maintenance costs, mainly due to significantly higher costs during construction and longer time to commissioning. Only about 5% of the world roads have a concrete surface [1].
As one alternative to conventional concrete, Roller Compacted Concrete (RCC) started to be used in the 1930s and 1940s, when building dams. The first major project for the use of RCC was in 1974 when one of the tunnels of the Tarbel Dam outlets in Pakistan was restored. After that, the RCC was mostly used for the construction of dams in the United States of America (USA), where the regulations and norms show the most rapid development. One of the largest dams in the USA built with RCC is the Willow Creek which was built from 1981 to 1983.
Since the 1970s, RCC was used for other projects as well, so in Canada it has been applied for the fast placement of cheap pavements and manipulative surfaces. Until

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1990, more than 50 projects with over 2 million m^2 of RCC pavements were made in the USA.

Over the following ten years, there was slight stagnation just to find its wider application again during the last few years. By 2012, over 70 projects were carried out with an amount exceeding 7.5 million m^2 of pavements made of RCC (Figures 1 and 2), mostly for the needs of army, industrial pavements, for the construction of ports, and increasingly for various other commercial purposes such as pedestrian and biking paths, local streets, emergency lanes on motorways, parking lots. There is a growing use of RCC in other countries, especially in European states.

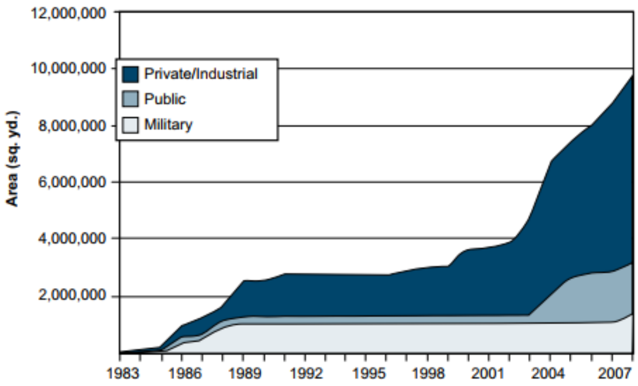

Figure 1. Increase of RCC use until 2007 [2]

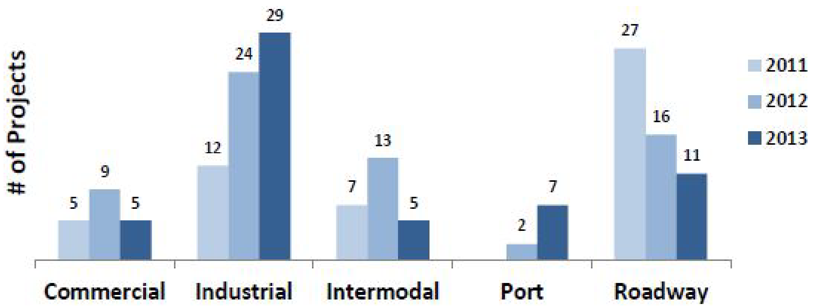

Figure 2. Increase of RCC use for industrial purpose [2]

2. BASIC CHARACTERISTICS OF ROLLER COMPACTED CONCRETE

As material, RCC is a type of concrete that, apart from the composition (Figure 3), mixture and properties, differs from conventional concrete by its placement technology into the pavement structure, that is, instead of vibrating, it is incorporated by compacting and rolling (similar to asphalt pavements) [1, 3, 4, 5].

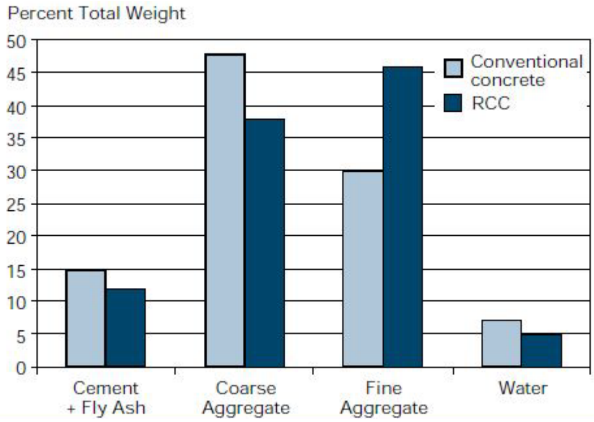

Figure 3. General comparison of the composition of mixtures of conventional and RCC [6]

RCC is by its physical and mechanical properties very similar to ordinary concrete, it has the same composition, but in other proportions. The biggest difference in the composition between the RCC and “plain” concrete is that the RCC contains larger quantity of fine particles of aggregate and less cement (Figure 4). Recently, in addition to aggregates, cement and water, additives for concrete are used, such as air entraining admixtures for higher resistance of concrete to freezing and defrosting salts, bonding retardant additives, certain chemicals for the special finishing of the concrete surface required for individual projects. Minerals, such as fly ash, are increasingly used. The addition of fly ash significantly influences the later strength of the concrete, the improvement of the workability and reduction in the permeability of the concrete, the savings in production and the suitability for the construction of massive concrete structures. The addition of fly ash increases the ability of the concrete to compact due to the increase in the amount of fine particles, and also improves the quality of finishing the surface of the roller compacted concrete.

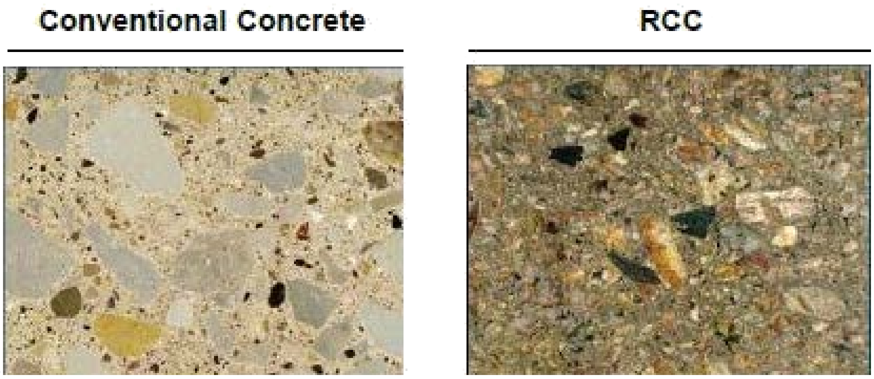

Figure 4. Visual difference between conventional concrete and RCC [2]

The pavement structure of RCC is a type of concrete pavement structure, which is placed by compacting concrete with machines and equipment for placement of asphalt (pavers and rollers) or, more recently, special finishing machines for the placement of RCC.
Compaction is the most important stage in the construction of pavements made of roller compacted concrete because it ensures density, strength and surface texture and should be carried out with great care with adequate quality control during performance.

2.1. Roller compacted concrete - conventional concrete - cement stabilization

The difference between the RCC and the conventional concrete is in consistency, which is conditioned by the need for efficient compacting. RCC must be sufficiently dry to carry the weight of the equipment, but also sufficiently humid to allow the appropriate distribution of binder through the mass during the mixing and vibration process. The placement speed is much higher, and the price is much lower compared to conventional concrete. From cement stabilized gravel, RCC is primarily different because it contains a coarser aggregate and develops properties similar to conventional concrete.
In case of conventional concrete, the aggregate makes 60 to 75% of mixture volume, while the water-cement factor is in the range of 0.4 to 0.45, which ensures a sufficiently moist mixture to shut in all the grains of the aggregate and fill well the space between the particles. For RCC, the aggregate content is from 75 to 85%. The granulometric curve contains larger quantity of fine particles and with a maximum grain size of up to 16 mm. Crushed aggregate is more suitable for pavements. The RCC mixture has a lower content of water and cement compared to the classical.
In the fresh state, RCC should be sufficiently rigid i.e. dry, to enable placement of the concrete without sinking of the placement equipment, but it should also contain enough water to allow the homogeneous distribution of the cement paste during the process of mixing and compacting of concrete, as well as to ensure hydration of the cement. Placement of RCC is made exclusively by machines.
The mixture of conventional concrete is placed on the base in front of a paver that pushes and distributes concrete over the entire width of the pavement, compacting concrete by vibrating and flattening the upper surface. The RCC mixture is transported to the construction site, poured into a paver (for asphalt), and using the vibrating plate the mass is compacted across the entire surface and height of the pavement. The paver should be operated continuously to acquire consistent form and quality of the surface.
Concrete compaction is performed by the action of vibrating machines, resulting in the settling and thick depositing of particles of cement and aggregates releading the excess air. The final compacting of the RCC is performed using the rollers, and it is recommended to do it within 60 minutes from the beginning of mixing the concrete. Achieving the required density is the basic precondition for ensuring all other physical and mechanical properties of the concrete built in the pavement.
After the placement of the concrete (mechanical or manual), mechanical surface roughing is performed in order to improve the adhesive properties of the vehicle’s tires to the surface of the pavement and to increase friction in order to improve slip resistance and to achieve shorter stopping distance of the vehicle (Figure 5). The upper surface of the pavement made of RCC usually has relatively rough texture that remains after the final rolling, but it is also possible to obtain a finer texture by using a greater amount of

fine particles of aggregates, cement or mineral additives. The surface can also be treated with diamond grinding, which reduces the noise of the pavement, or by the coating with the asphalt layer, which increases the speed of vehicles.
Proper hydration of the mixture of conventional concrete, as well as the mixture of RCC is very important for the durability of the concrete pavement, and therefore the proper care of the concrete in the early stage of hardening is very important.

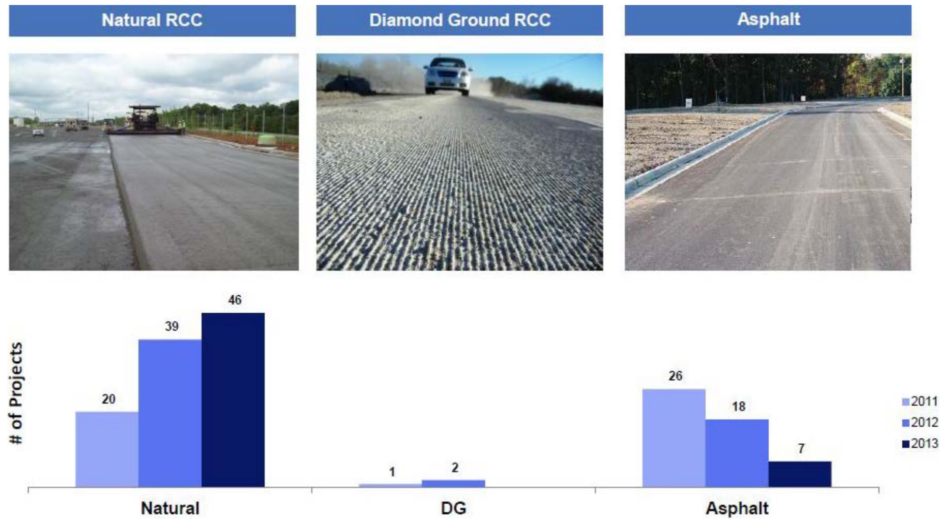

Figure 5. Display of top surface types [2]

Cracks in conventional concrete are controlled by joints, reinforcements, dowels and anchors. Distance between joints is defined by the structure design. Also, it is possible to work with apparent joints if this is specified by the design or is required for aesthetic reasons and for the sake of durability. Due to the technology of compaction of RCC, the dowels and anchors cannot be placed in the pavement, which is one of the advantages of the pavement made of RCC, increasing the cost efficiency and speed of construction.

3. ADVANTAGES OF ROLLER COMPACTED CONCRETE APPLICATION

The basic advantages of the application of RCC compared to other materials used for the construction of pavement structures include a number of aspects which are listed below [1-5].

(i) Safety
- improved visibility - concrete reflects 33 to 50% more light than, for example, asphalt, which is good for a night ride
- the possibility of quick commissioning of completed section
- good slip resistance
- reduced possibility of water retention on pavement (water absorption);

- good adhesion - the texture of the upper surface of the pavement made of RCC ensures good friction in contact with the tire
- pavement of RCC is not deformed during the use, avoiding appearance of ruts
- long-lasting flatness - the rigidity of the roadway made of RCC makes it possible to maintain flatness that ensures safer and more comfortable driving surface over a longer lifetime;

(ii) Durability
- The life span of the RCC pavement, if properly executed, is as long as the pavement of conventional concrete, and the need for maintenance, repairs and reconstruction is reduced
- maintenance and repair procedures are easy
- if properly designed and constructed, RCC pavements have high resistance to wear, freezing, resistance to frost and defrosting salt, resistance to oil and fuel performance and have greater resistance to different climatic changes compared to other materials
- concrete becomes more solid over time (the cement hydration process continues)
- RCC pavements save fuel, which is confirmed by numerous studies, as a rigid pavement structure has fewer deformations;

(iii) Price, energy and economic characteristics
- the highest profitability - the RCC pavements are, compared to other solutions, the most cost-effective due to low initial construction costs, long service life and low maintenance costs throughout the lifetime
- execution of works with minimum work force, no formwork, reinforcement, dowels, anchors and surface finishing works
- possible execution of works even in cold weather
- reduced public lighting costs due to the light surface of the concrete
- concrete pavements are very acceptable in terms of energy, they are less heated than other types of pavements, summer temperatures are reduced in cities, the need for air conditioning of the space for residential, commercial and industrial buildings is lower
- high speed of execution enabling the completed sections of road to be put in service in a short time
- RCC can be used as a lower bearing layer (base course), which directly affects the lower price of the entire pavement structure;

(iv) Environmental impacts
- concrete is environmentally acceptable, it can be recycled and reused as building material
- production and placement of RCC require lower energy consumption, thus reducing CO_2 emission, directly and indirectly
- concrete production plants cause lesser pollution to the environment than the asphalt production plants
- it is possible to use reclaimed water (in the production and for the care of concrete)
- surface texture of carriageway (diamond grinding) can reduce the development of noise
- reducing the emissions of harmful gases from vehicles due to the continuous travel speed and traffic flow and the reduced need for carriageway maintenance.

4. RECOMMENDATIONS AND LIMITATIONS OF APPLICATION

RCC has certain application limitations that actually result from the advantages of this type of concrete, but it is necessary to know how to use them [2-4].
During the production, transport and placement of RCC, the following should be taken into account:
- due to a very dry mixture, the mixing process must be carried out with greater care to obtain a homogeneous mixture;
- due to increased resistance while mixing the amount of material during the mixing should be lesser than usual;
- it is necessary to pay extra attention and undertake measures to avoid loss of moisture during the transportation of the prepared mixture;
- due to the very dry mixture, the need for higher dosage of additives in the concrete compared to the usual dosage amounts is possible;
- during the placement of RCC it is necessary to pay attention to the time limit requirements due to sensitivity of RCC to the loss of moisture;
- the edges of the pavement are more difficult to compact, thus require additional attention and control of the process.

When it comes to the use of RCC, there are certain recommendations related to the traffic surfaces for which it is used [2-4]:
- RCC pavement is mainly used for surfaces where lower speeds are achieved, such as access streets and access roads, agricultural and industrial roads, terminals, warehouses, parking lots, etc.;
- RCC pavement can be applied for fast-moving traffic roads if the upper surface is treated with diamond grinding or other methods for achieving the appropriate flatness on the surface (asphalt or other finishing layer).

5. TECHNOLOGY OF APPLICATION AND CARE OF ROLLED compacted CONCRETE

The basic stages of the application of RCC pavements are:
- preparation of the base;
- production and transport of RCC to the construction site with tipper trucks;
- placement of RCC by stretching and initial compacting with pavers;
- final compaction for which various types of rollers are used;
- timely cutting of pavement and performing apparent couplings;
- care of applied concrete.

Regardless of the advantages, taking into account the aforementioned limitations, during the placement of RCC pavement structures, it must be ensured that the contractor has the appropriate experience, as well as the appropriate process of quality assurance and quality control (not only the mixture, but also the process of work and the finished product itself). A quality RCC pavement, which should provide a level of service that is appropriate for the road in which it is applied, can be provided if the principles and recommendations listed below are followed [1-5].

5.1. Preparation of base

The quality of the base for the RCC pavement has the same requirements as for pavement made of conventional concrete. Of great importance for the construction of high-quality pavement structure is a well-prepared subbase, and the base should provide sufficient resistance to ensure complete compacting of the RCC through a complete cross-section of the pavement.
The lower bearing layer of the concrete pavement structure can be made of unbound, mechanically compacted rock material and from aggregate stabilized with hydraulic or bitumen binder. The lower bearing layer of the pavement structure, before the placement of the concrete, should meet the requirements regarding the degree of compactness, flatness of the surface and the thickness of the layer. The base should be uniformly moist, and all standing water, residues of ice and the like should be removed from the base prior to placement. The uniform moisture should be maintained during the execution of the subject section of the carriageway.

5.2. Transport of concrete to the site

Fresh concrete is transported to the construction site with tipper trucks, without mixing, with obligatory covering of the mixture in order to prevent moisture loss from fresh concrete, and as protection against the impact of sudden rain and other atmospheric conditions. It is recommended that the transport time should not be longer than 60 minutes, even if the bonding retardant additives are added to the mixture. The delivery dynamics must be determined to provide continuous feeding of the paver.

5.3. Concrete placement and compacting equipment

Placement is performed by compacting the concrete with equipment for asphalt placement, or more recently with special machines for placement of RCC.
When placing this concrete, the paver performs so called pre-vibration of the material, achieving up to 90% of requested density of the concrete, while final density is achieved by rolling with various types of rollers. Recently, special pavers have been emerging on the market, intended for placement of RCC. These are highly modernized high-power machines, the so called “high density pavers” that can be used both in dam construction and in traffic infrastructure construction.
For rolling or compacting, the most common are static and vibration rollers with steel or rubber wheels, and for more demanding and inaccessible surfaces, various vibrating plates and rams for compaction of RCC.

5.4. Placement of roller compacted concrete

Upon the delivery of fresh concrete to the construction site, placement of concrete should start immediately. All equipment, machines and staff should be prepared until the concrete has reached the site. All stages of construction should start with the placement of concrete, which should be planned in such a way that the placement is performed in favourable weather conditions, with sufficient work force, sufficient number of machines and other equipment.

Paver (Fig. 6) should work to ensure a continuous flat surface without cracks, signs of surface pulling, tearing, pushing, etc. The speed of execution of works should be in accordance with the requirements of the project and the requirements for ensuring the maximum required compaction that can be achieved by the paver.

Figure 6. Installation of RCC using asphalt paver [3]

Concrete rolling (Fig. 7) during the placement of RCC pavement is one of the most important stages because rolling enables final compaction of the concrete. The rolling of concrete should begin immediately after the concrete placement process is finished and should be completed within 60 minutes from the beginning of concrete mixing at the concrete base. Using the cement-bonding retarder the time of concrete placement and rolling can be extended. Rolling should be done using suitable rollers, in phases, similar to asphalt pavement structures. For thinner layers (100-150 mm), initial rolling is done with a 4 t lightweight roller and for thicker layers with vibratory roller up to 10 t. The main rolling is performed with a 10 t pneumatic roller, and the final rolling with a 10 t static roller.

Figure 7. Compaction of RCC with roller [3]

5.5. Final treatment

Final treatment of the pavement in most projects is completed by rolling the concrete, after which no procedures for roughening or smoothing the pavement are applied. The surface is very similar to that of asphalt pavement except that it is gray (Figures 8 and 9). The upper surface of the RC pavement is usually of relatively rough texture that remains after the final rolling and as such provides sufficient adhesion of the tire to the pavement surface with increased friction which improves the slip resistance and allows a shorter stopping distance of the vehicle.

Figure 8. Final treatment of RCC surface [3]

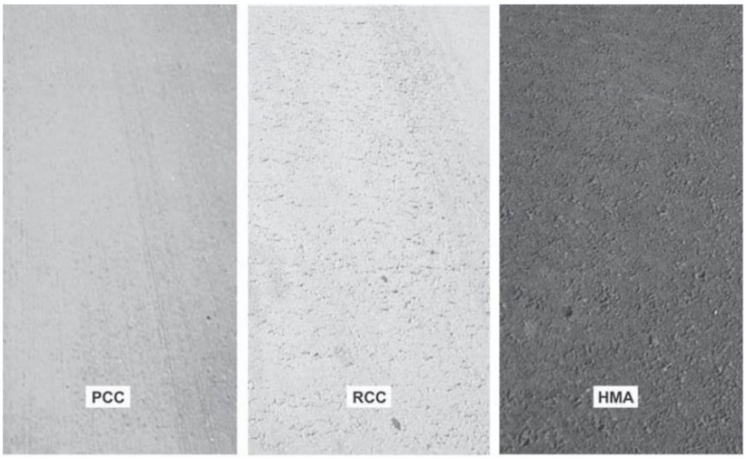

Figure 9. The appearance of road surface of conventional concrete, RCC and asphalt [6]

A smooth surface can be achieved by using a large amount of fine particles of aggregates, cements or mineral additives in the mixture. The surface can also be treated with diamond grinding, which reduces the noise, or by the coating of the asphalt layer, which increases the speed of vehicles.

5.6. Care

Since RCC has low water content and therefore there is no water extraction, they are prone to drying and must be properly cared of. RCC is very sensitive to the loss of moisture, which should be taken into account when transporting RCC to the construction site, but also during the placement.
Concrete care is efficiently performed by chemical agents (Figure 10), rather than by spraying with water, because due to inadvertent and irregular watering there is possibility of drying between the sprayings.

Figure 10. Care of RCC with chemicals [3]

6. CONCLUSION

Although in our country, even in the surrounding countries, concrete pavements generally have never gained much popularity (except in bus station zones and stops, and fuel stations), RCC as a material for the construction of pavement structures deserves due attention due to all its favourable characteristics (safety, durability, price, ecological aspect). Due to the surface texture characteristics, RCC pavements are mostly used in conditions of reduced traffic speed, most of them in industrial access roads, warehouses, terminals, parking lots, ports, etc. As a suitable alternative to asphalt pavements or conventional concrete pavements, RCC pavements can have significant application in our conditions, especially for roads with low traffic loads such as, for example, local or agricultural roads, as well as access roads in low-traffic zones (residential areas, education, health facilities, bicycle and pedestrian areas, etc.).

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