інколи й переходять на їх сторону, повівшись на красиву обгортку. Кожному із нас необхідно пам'ятати те, що кремль грає на наших слабкостях, головне – не підігравати йому.

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Секція 4-5. ВПЛИВ ВОЄННИХ КОНФЛІКТІВ ТА ТЕХНОГЕННИХ КАТАСТРОФ НА БЕЗПЕКУ ЖИТТЄДІЯЛЬНОСТІ, ЛОКАЛЬНІ ТА ГЛОБАЛЬНІ ЕКОСИСТЕМИ

НОВІТНІ ПІДХОДИ ДО МІНІМІЗАЦІЇ ЕКОНОМІЧНИХ, ЕКОЛОГІЧНИХ ТА СОЦІАЛЬНИХ НАСЛІДКІВ ВІЙСЬКОВИХ КОНФЛІКТІВ

UDC-62

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THE POTENTIAL OF USING ROLLER COMPACTED CONCRETE TECHNOLOGY IN LOCAL ROAD CONSTRUCTION

The aim of the article is to show the possibility of applying the technology of Roller Compacted Concrete on local roads and to indicate the economic benefits resulting from it. Local governments have limited infrastructure budgets. It would be good, if they could build durable roads for years, while minimizing their costs. Especially nowadays, when the crude oil market is extremely volatile, using of Roller Compacted Concrete technology on local roads should be considered.

Referring to historical data, Roller Compacted Concrete technology was first used on pavement in the 1930s in Sweden. Then, it gradually spread in both infrastructural and hydrotechnical construction, primarily in the US, Canada, China and Western Europe.[1] According to the *Ogólna Specyfikacja Techniczna*, Roller Compacted Concrete is made of a concrete mix with optimal moisture (similar to the natural moisture of the soil), determined by the modified Proctor method, laid and compacted similar to asphalt concrete pavements. "Roller Compacted Concrete or RCC, takes its name from the construction method used to build it. It is placed with conventional or high-density asphalt paving

[1] ACI 325.10R-95, Report on Roller-Compacted Concrete Pavements, 2001.

equipment, and then compacted with rollers. Roller Compacted Concrete has the same basics ingredients as conventional concrete: cement, water and aggregates, such as gravel or crushed stone. But unlike conventional concrete, it is a drier mix-stiff enough to be compacted by vibratory rollers. Typically, Roller Compacted Concrete can be constructed with or without joints. It needs neither forms nor finishing, nor does it contain dowels or steel reinforcing. These characteristics make Roller Compacted Concrete simple, fast and economical."[2] It is characterized by a quick increase in strength and a short time of putting the investment into public use. As mentioned Roller Compacted Concrete technology is characterized by a special paving method, which consists that the relatively dry concrete mix is pave with a typical asphalt paver and then compacted with a typical road roller and Roller Compacted Concrete mixture is characterized by zero slump consistency. This technology combines the advantages of concrete roads, such as durability, rutting resistance, low environmental impact and low operating costs, with the speed of laying and short commissioning time, characteristic of asphalt concrete roads. The most important parameter for the pavement is that the concrete mix should be in the optimal moisture condition, which is characterized by the zero slump consistency. It means that there is a minimal amount of mixing water in the Roller Compacted Concrete mix (passive water is practically eliminated). Therefore, even small fluctuations in the amount of mixing water can have an impact on the quality of the surface. When the mixture is too dry, problems with obtaining the appropriate compaction index may appear, while when the mixture is too wet, the surface may not withstand the pressure of the rollers, which according to the polish specifications should have a minimum weight of 8 tons.[3] As mentioned, the most important step in the production of Roller Compacted Concrete mix is to achieve and maintain optimal moisture content, while the most important step of paving is the appropriate compaction. During the compaction process, we obtain the appropriate wedging of aggregates, which affects the final strength of the pavement. According to the *Ogólna Specyfikacja Techniczna*[3], a single layer of roller compacted concrete pavement should have a thickness of not less than 12 cm and not more than 20 cm after compaction.

According to the to the *Ogólna Specyfikacja Techniczna* [3] for Roller Compacted Concrete, this technology is dedicated to:

– Surfaces not exposed to de-icing salts - moderately used (such as storage yards under a shelter) - made of minimum class C20/25 concrete.

– The surfaces of the roads of the KR1-KR2 traffic category - made of concrete, at least C25/30 class.

– Pavements of technological roads (access roads, detours or service roads), internal roads, maneuvering yards, etc. (with a load corresponding to the KR3-KR4 traffic categories on national roads) - made of minimum class C30/37 concrete.

– Substructures of roads of the KR1-KR7 traffic category - in accordance with *WT-5 2010 Mieszanki związane spoiwem hydraulicznym do dróg krajowych* guidelines.

Local governments are currently facing difficult decisions regarding the choice of technology for the construction of their roads. Of course, the most common technology is asphalt technology. But is it really the best choice for such investors? Local governments need inexpensive and durable roads that are characterized by high durability and low financial outlays for their maintenance.

[2] Hemant S., Mishra S.P., DEVELOPING ECONOMICAL ROLLER COMPACTED CONCRETE MIX FOR PAVEMENTS, International Journal of Civil Structural Environmental And Infrastructure Engineering Research

[3] Ogólne Specyfikacje Techniczne, Rozdział III PRACE KONSTRUKCYJNE, Dział 06 Nawierzchnie betonowe, 06.02 Nawierzchnia z betonu wałowanego.

„There is no perfect and precise procedure when selecting the type of road pavement, but you must take many factors into account when choosing the type of street pavement, here are some of them: traffic density, cost, type of soil, climate conditions, materials, durability, repair and maintenance, and environmental issues."[4]

Comparing the properties of roller compacted concrete pavements with asphalt concrete pavements, it is easy to see that:

Roller Compacted Concrete pavement is characterized by high ability to retain its properties over time (durability). A properly constructed roller compacted concrete road without major obstacles achieves 30, 40 or even 50 years of use, when in the case of bituminous pavements, often 20 years of use could be a problem.

Roller Compacted Concrete pavement requires the necessity to maintain a high technological regime, starting with maintaining optimal moisture throughout the entire process, and ending with achieving appropriate compaction, where in the case of asphalt pavements, the technological regime is lower.

Roller Compacted Concrete pavements have high compressive strength, and thus high load carrying capacity, regardless of the weather conditions of use.

There is no rutting phenomenon in Roller Compacted Concrete pavements, which is one of the most common damages to asphalt roads.

The Roller Compacted Concrete roads have a bright surface color, which significantly reduces lighting costs. This aspect is of particular importance in times when electricity is very expensive.

Environmental effect - concrete carbonation (binding of CO^2 by the Roller Compacted Concrete pavement).[5]

Fig. 1. Comparison of the brightness (visibility) of a cement concrete and asphalt concrete road.

Source: P. Kijowski, 2011, Doświadczenia europejskie i krajowe w budowie nawierzchni betonowych, p. 6.

- Roller Compacted Concrete is characterized by the following basic parameters:
- Low w/c ratio (around 0.3).
- The content of dusty fractions 2-8%.
- Reduced cement content compared to typical concrete mixtures.

[4] Babagoli R., Abbaspour K., Mohammadi Z., Ameli A.R., Technical and Economical Comparison between Roller Compacted Concrete and Asphalt Pavement and Prioritizing Effective Parameters Using Hierarchy Analysis Model and Fuzzy Hierarchical Analysis Model, Journal of transportation Research, Vol. 16, Issue 1, 2019.

- The durability of the surface depends on the correct compaction and optimal moisture.
- Minimum density of 98%.
- Possibility of making expansion joints at greater distances than normally accepted.

Fig. 2. Roller Compacted Concrete mixture.
Source: private collection.

To determine the basic parameters of Roller Compacted Concrete, samples were made according to the *ASTM C1176-1992* method and the following tests were carried out:

- The compressive strength.
- The splitting tensile strength.
- Slab Test - Freeze/Thaw Resistance of Concrete (3% NaCl).

The compressive strength test is determined according to the *PN-EN 12390-3* standard. Concrete qualifies for a given class of compressive strength if the criteria for average and minimum strength are met, in accordance with the requirements of *PN-EN 206-1* for a given class of compressive strength.

Choosing the right materials and the right proportions is very important for the production of a high-quality Roller Compacted Concrete. The mixture design process should be based on a scientific approach that takes into account the desired technical properties, design requirements and economy.

There are many methods to design a Roller Compacted Concrete mix composition. Consequently, it is difficult to identify one procedure as the reference procedure. However, the two most common methods of designing a blend composition are based on the following two general approaches:

- USACE Recommended Method - Concrete Consistency Method: The c/w ratio and consistency remain constant and the mixture is determined by absolute volume.
- Soil Compaction Method: This approach is based on a cement-aggregate ratio, with the mixture determined by the optimum moisture and the maximum dry mixture density.

The composition of the Roller Compacted Concrete mix was selected with Concrete Consistency Method. Optimum moisture was determined using the modified Proctor method as described in *ASTM D 1557-2000 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort.*

Table 1. The composition of the mixture for 1 m^3 of Roller Compacted Concrete.

Ingredient	**Weight [kg]**
Sand 0/2	920
Gravel 2/8	491

Gravel 8/16	634
CEM I 32,5 R	270
Water	95
Plasticizer	1,06
Total	**2411,06**

Laboratory results:

Table 2. Roller Compacted Concrete laboratory results.

Test	**Average result**
Compressive strength	**34,57 MPa**
Splitting tensile strength	**2,77 MPa**
Slab Test - Freeze/Thaw Resistance of Concrete	**0,41** $\frac{kg}{m^2}$

Fig. 3. Roller Compacted Concrete splitting tensile strength.
Source: private collection.

Fig. 4. Prepared sample before Slab Test - Freeze/Thaw Resistance of Roller Compacted Concrete.
Source: private collection.

The analyzed Roller Compacted Concrete achieved the required compressive strength, which was 34,57 MPa. The requirement for the concrete splitting tensile strength parameter is at least 2,5 MPa (for KR1-KR2). The obtained test results (2,77 MPa) showed that the analyzed samples achieved the required strength level.

The typical content of cement, with the lack of the possibility of air-entraining the mixture, raise concerns as to ensuring an adequate level of frost resistance. On the other hand,

the dry consistency and high degree of compaction change the pore structure, which allows for good frost resistance parameters.

5 cm thick Roller Compacted Concrete slices cut from cubic samples were subjected to 56 freeze cycles. The test surface was covered with a layer of 3% NaCl solution. After 56 freeze cycles, the exfoliated material is collected from the surface of the test sample by washing it into the vessel. The exfoliated material is washed with water and dried for 24 hours at 105°C, then weighed. The acceptable amount of exfoliation is 1,0 $\frac{kg}{m^2}$ for 56 cycles or 0,5 $\frac{kg}{m^2}$ for 28 cycles. The obtained results confirmed that Roller Compacted Concrete is characterized by good frost resistance, which was similar to that of paving stones, and its value is much lower than the permissible value.

Economic aspects comparison of Roller Compacted Concrete pavement and asphalt concrete pavement.

Both scientific publications and contractors inform that the construction of the road in Roller Compacted Concrete technology is economically advantageous, both compared to standard road cement concrete and asphalt concrete. Therefore, a comparison of the cost simulations of the construction of a road section of the load capacity category KR1 in two technologies was carried out: Roller Compacted Concrete and asphalt concrete. It was assumed that both surfaces have the same subbase, therefore its costs as well as the costs of additional works were omitted. The pavement constructions were selected on the basis of polish roads specifications *Katalog typowych nawierzchni sztywnych* and *Katalog typowych nawierzchni podatnych i półsztywnych.* Nowadays, the crude oil market is characterized by high dynamics of price changes, and therefore, for general contractors it is a technology with a higher production risk. The cement market is more stable and allows reducing the risk associated with price changes.

The adopted technical assumptions for the cost analysis:

– The lower construction layers are the same.
– The secondary deformation modulus E2 on the upper surface of the subbase is 120 MPa.
– Service life - 30 years.
– Road class L (local), KR1, 1000 m long, 7 m wide.
– Costs based on Q2 2022 price information.
– Unit prices of road maintenance processes and operating cost analysis were estimated using the "Road calculator" program developed by DROCAD and the Cracow University of Technology. The discount rate was adopted at the level of 5%.

Table 2. Comparison of the analyzed pavements.

Roller Compacted Concrete	**Asphalt concrete**
RCC C30/37 – 15 cm	AC 8 S 50/70 – 5 cm
	AC 16 W 50/70 – 7 cm

Table 3. Quantity of the mixtures.

Roller Compacted Concrete	**Asphalt concrete**
RCC C30/37 – 1050 m^3	AC 8 S 50/70 – 350 m^3
	AC 16 W 50/70 – 490 m^3

Table 4. Density of the mixtures.

Roller Compacted Concrete	**Asphalt concrete**
RCC C30/37 – 2,41 t/m^3 2 530 t total	AC 8 S 50/70 – 2,52 t/m^3 882 t total
	AC 16 W 50/70 – 2,43 t/m^3 1 176 t total

Table 5. Binder and cement content.

Roller Compacted Concrete	**Asphalt concrete**
RCC C30/37 – 11% – 278,4 t	AC 8 S 50/70 – 5,8 % – 51,2 t
	AC 16 W 50/70 – 5,1 % – 60,7 t

Table 6. Binder and cement price.

CEM I 32,5 R	**Bitumen 50/70**
411 PLN/t	3 190 PLN/t

Source: Cement Ożarów (CRH group) and Orlen Asfalt offers.

Table 7. Total cost of binder and cement.

CEM I 32,5 R	**Bitumen 50/70**
114 422 PLN	356 961 PLN
100%	**312%**

Table 8. Cost of the mixtures.

Roller Compacted Concrete	**Asphalt concrete**
RCC C30/37 – 175 PLN/t	AC 8 S 50/70 –315 PLN/t
	AC 16 W 50/70 – 295 PLN/t

Source: Own calculation.

Table 9. Total cost of the mixtures.

Roller Compacted Concrete	**Asphalt concrete**
RCC C30/37 – 442 750 PLN	AC 8 S 50/70 –277 830 PLN
	AC 16 W 50/70 – 346 920 PLN
100%	**141%**

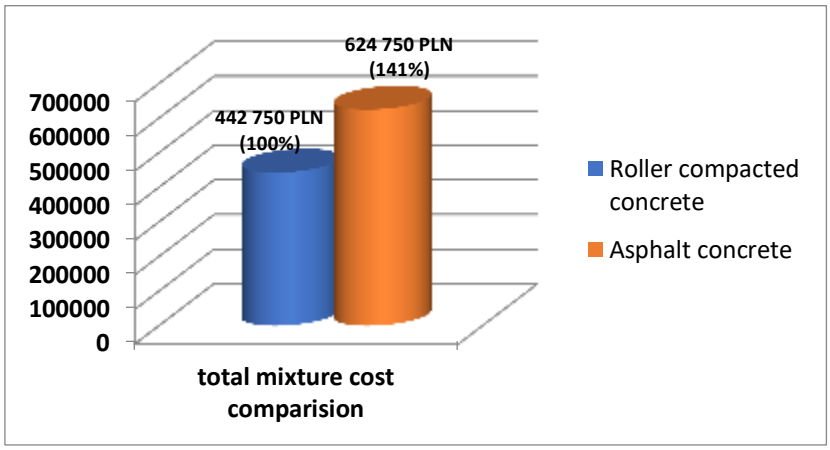

Fig. 5. Comparison of the total mixture cost.

The adopted maintenance assumptions for the cost:

– Road with lighting.
– Winter maintenance.
– Assumed replacement of the wearing course of the bituminous pavement after 10 years of maintenance.

Table 9. Total cost of the road maintenance processes.

	Roller Compacted Concrete	**Asphalt concrete**
Cost of maintenance, repair, reconstruction and modernization	1 824 833 PLN	4 362 774 PLN
Service life	30 years	30 years

Source: "Road calculator" by DROCAD and the Cracow University of Technology.

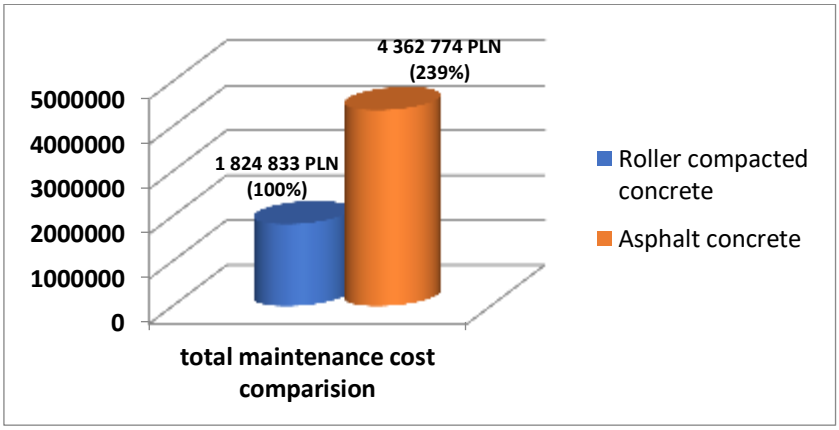

Fig. 6. Comparison of the total maintenance cost.

The analysis shows that in the case of the KR1 local road, the Roller Compacted Concrete technology is a more advantageous solution. When analyzing the total life-cycle costing (LCC) of a road investment, it is noticeable that Roller Compacted Concrete is a solution that requires both less financial outlays during construction and during maintenance.

If we are dealing with a technology whose difficulty of construction is comparable with the implementation of asphalt concrete pavements, but the end product is not only more economically advantageous, but also more durable and ecological (concrete carbonation and more environmentally friendly production process), the conclusions are obvious.

The above analyzes show that even in the case of the construction of a local road, low category KR1, the more advantageous solution is to make it in the technology of Roller Compacted Concrete. In addition, the road made in Roller Compacted Concrete technology meets all technical requirements for such surfaces.

Concrete roads are more durable and, in particular, for small investors such as municipalities, they ensure that the money once invested will allow the road to be used for years.

The conducted research gives a lot of optimism when it comes to introducing a real alternative to asphalt concrete roads on the local road market. An important barrier to entry is certainly the ignorance of this technology by investors.

Roller Compacted Concrete pavements should be of particular interest to local government investors, such as, for example, municipalities. They constitute an inexpensive,

durable and ecological structure for many years. The possibility of using local materials, the simplicity of construction and low interference in the natural environment, as well as lower maintenance costs are ideally in line with sustainable economic development.

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