Analysis of new road construction technologies in Ukraine and abroad

Kateryna Pushkariova[1] , Vitaliy Tchaikovsky[2], Dmitry Borisenko[3]

[1, 2, 3] Kyiv National University of Construction and Architecture
31, Air Force Avenue, Kyiv, Ukraine, 03037
[1] chaikovskyi_vv-2023@knuba.edu.ua, , https://orcid.org/0009-0009-4424-0878
[2] pushkarova.kk@knuba.edu.ua, https://orcid.org/0000-0001-7640-8625
[3]borysenko_ds-2023@knuba.edu.ua

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Abstract This article discusses the long-term and short-term benefits and disadvantages of using cement concrete roads compared to asphalt roads. Modern technologies of cement concrete pavements are listed, including: exposed aggregate concrete, whitetopping and the technology of roller compacted concrete pavement is considered in detail. The expedient spheres of use of roller compacted concrete, advantages and problems of studying this technology are determined.

Keywords: cement concrete pavement, roller compacted concrete, concrete roads

INTRODUCTION

Nowadays, roads play a key role in the country's transport network and have a direct impact on the prosperity, welfare and development of society. There are two types of pavements in use in Ukraine: rigid (cement concrete) and non-rigid (e.g. bitumen concrete). Properly designed and constructed rigid pavements can ensure long-term use of a road without significant maintenance and operating costs. For example, one of the world's first cement concrete roads was built in 1872 in Inverness, Scotland, and is still in use today [1].

ADVANTAGES OF CONCRETE PAVEMENTS OVER ASPHALT PAVEMENTS

Currently, the percentage of cement concrete roads in Ukraine is about 2%, but concrete roads are more common abroad [1, 2].

Ekaterina Pushkareva
Head of the Department
Doctor of Technical Sciences, prof.

Vitaly Tchaikovsky
Postgraduate student of the Department of Building Materials

Dmitry Borisenko
5th year student

In Germany, in the 70s of the last century, 30% of cement concrete pavements were built, in the 80s about 60%, and in the second half of the 90s already 62% [2, 3]. In the Czech Republic, about 65% of new motorways have cement concrete surfaces. Other examples of European countries where the percentage of cement concrete roads is systematically increasing include: Austria and the UK (50%). In Belgium, concrete motorways are made of 40%, and in local roads they use concrete in 60% cases [3]. The amount of cement concrete pavements in the total number of roads in different countries is shown in Figure 1.

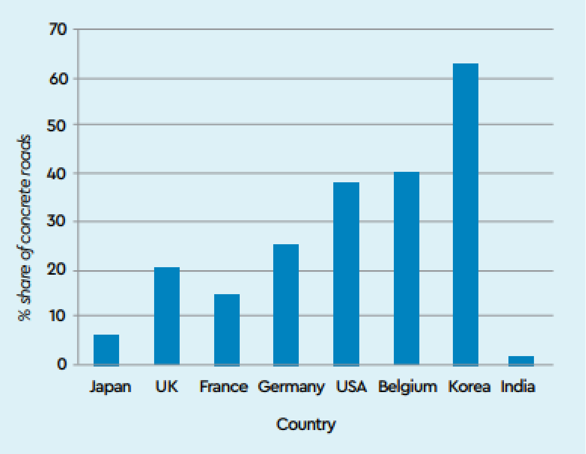

Figure 1. Amount of concrete roads in the total number of motorways in different countries of the world (2022)

The length of public roads in Ukraine with different types of pavement is shown in Figure 2 [4]. In recent years, new projects with cement concrete pavements have been launched in Ukraine: roads H14, H31, M14 bypass around Zhytomyr and others.

For many years, in Ukraine and around the world, traffic intensity has been increased significantly (more than double in ten years). Asphalt pavements cannot withstand such loads. Therefore, the construction of cement concrete pavements, which have better properties than bitumen concrete pavements, is particularly appropriate in Ukraine [3].

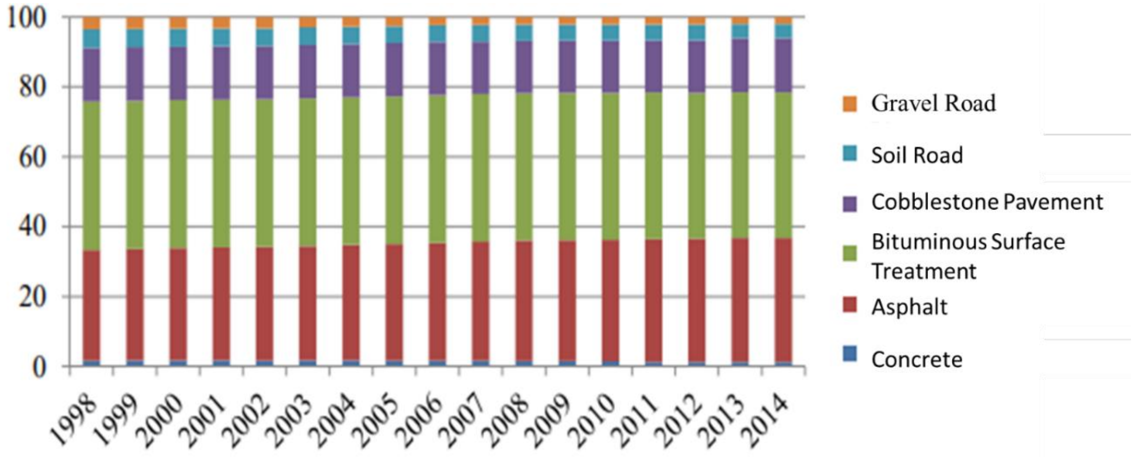

Figure 2. Length of public roads in Ukraine with different types of pavement

THE URGENCY OF REPLACING BITUMEN PAVEMENTS

Each type of road pavement (cement concrete and bitumen) has its advantages and disadvantages. The publication [1] discusses the short-term and long-term benefits of cement concrete pavements, but does not mention the disadvantages faced by specialists during road construction and operation.

Short-term benefits of using cement concrete pavements compared to bituminous road:

- High stiffness, negligible wear & tear (due to abrasion), and higher durability.

- Fuel efficiency: Heavy vehicular movement on concrete roads can lead to higher fuel efficiency.

- Due to its grey colour, the concrete surface reflects heat, whereas asphalt pavements absorb and store this heat for longer durations leading to an increase in the surrounding air temperature (urban heat islands).

- Bituminous / Asphalt roads bleed at high ambient temperatures whereas concrete roads are unaffected.

Disadvantages of concrete roads:

- The opening of traffic on asphalt roads occurs much earlier than in the construction of cement concrete roads;

- Cement concrete roads require a higher production culture, special equipment, qualified stuff and strict adherence to the construction technology;

- The issue of the cost of a cement concrete road compared to an asphalt pavement remains open;

- During operation of the concrete pavement, there is an increase in noise, which requires the use of special noise protection screens.

The advantages of cement concrete roads are more obvious in the **long term:**

- Durability: the minimum service life of cement concrete roads in most cases is 20...30 years with very low maintenance costs;

- Concrete roads do not require constant maintenance (replacement of the worn-out layer); this significantly reduces the downtime of roads;

- No rutting of the cement-concrete pavement, due to its increased strength and the absence of a negative impact of high air temperatures on the elasticity of the pavement;

- The economic efficiency of cement concrete roads, taking into account the service life, reaches 30...40%;

- The ability to recycle destroyed cement concrete roads to produce recycled aggregate that can be used for the construction of lower road layers.

Disadvantages:

- Repairs of cement concrete roads are extremely rare, but repair work takes a longer time, as it is necessary for the concrete to reach sufficient strength to allow traffic to move;

- In the case of a cement concrete road on a low-quality base, the pavement slabs may be displaced;

- Cement concrete roads require the use of special anti-icing agents that do not cause corrosion of the concrete pavement.

The urgency of replacing asphalt roads with cement concrete roads was driven by the price competitiveness of cement concrete pavements due to a significant increase in the price of bitumen and a slight change in the cost of cement. On the other hand, with the increase in traffic on motorways and the number of heavy vehicles in the traffic flow, there are objectively higher requirements for the strength and durability of pavements, vehicle safety and their minimal impact on the environment. Cement concrete pavements meet these requirements to the greatest extent. However, recent events have made it necessary to put another reason in the first place in justifying the relevance of this article - the energy security of the state, which is ensured by the partial replacement of imported bitumen or oil as raw materials for its production with local cement [4].

In times of war, concrete is one of the most effective materials for protecting structures from destruction by shells. For example, Antonivskyi Bridge successfully withstood shelling from heavy weapons. The situation with concrete roads is similar. Concrete pavement can withstand direct hits from various weapons, but there can be significant damage to the road surface if the pavement is hit under the pavement or from the side (Figure 3 and Figure 4).

Figure 3. Damage to concrete pavement caused by direct shell hits

Figure 4. Damage to concrete pavement caused by shells hitting the side of the pavement

In view of the above, the construction of concrete roads is extremely important for Ukraine, where hostilities have been going on for quite some time. Destroyed asphalt pavements should be immediately replaced with more durable concrete pavements made using various technologies, which will be discussed below. In addition, changing climatic conditions and ongoing "warming" are another argument for the feasibility of building concrete roads.

TECHNOLOGY OF CONCRETE PAVEMENT CONSTRUCTION

Monolithic cement concrete pavements can be classified according to various criteria. According to DSTU B V.2.7-96-2000, concrete mixtures can be divided into ultra-hard, hard and cast concrete mixtures depending on the workability.

In turn, cast concrete mixtures are divided into [2,5,6] low workability (OK = 5...9 cm); medium workability (9-15 cm) and cast or high workability (more than 16 cm). Low workability concrete mixtures are used for the construction of concrete pavements in slipform with partial immediate unmolding. Medium workability and cast-in-place mixtures are advisable to use when constructing concrete pavements in formwork with small-scale mechanisation and in bridge construction.

Semidry concrete mixtures are used in the construction of roller compacted concrete.

World experience shows that cement concrete pavements can be divided into three types according to the technology of construction [7,8] (Fig. 5):

1. Jointed plain concrete pavement - abbreviated as JPCP.
2. Jointed reinforced concrete pavement (JRCP).
3. Continuously reinforced concrete pavement (CRCP).

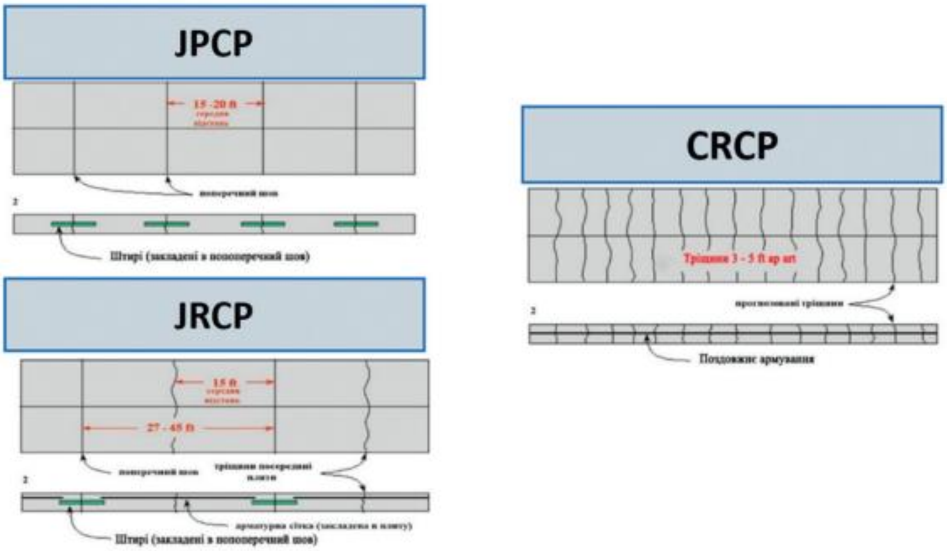

Figure 5. Types of cement concrete pavements used around the world

There are a number of different types of concrete pavements that have been built. The term “conventional concrete pavements” is generally taken to mean either jointed plain, jointed reinforced, or continuously reinforced concrete pavements [7,8].

The most common is “Jointed plain concrete pavement” with compression joints spaced at approximately 4...6 m, without reinforcing mesh in the slab (JPCP). The thinner the concrete slab, the shorter the distance between the transverse joints. It should exceed the slab thickness by 20...25 times [8].

The second type of road concrete structure (JRCP) has a reinforced concrete pavement with transverse joints every 7...9 m, even up to 12 m. In Ukraine, Reinforcement is used in slabs when constructing pavements on weak soils, on roads of I-III categories [7].

The third type of road construction (CRCP) with continuous pavement reinforcement has longitudinal reinforcement along the entire length. Transverse joints are not arranged [8].

In most cases, JPCP pavements have rods in the transverse joints to transfer part of the load to the adjacent slab, but in some cases, rods are not used. The bars are made of smooth steel. They are coated with stainless steel or protected against corrosion with epoxy resin. One half of the rod is treated with bitumen, paint or other substance to create a film and eliminate adhesion to the concrete: the rods should not interfere with the temperature longitudinal movement of the slabs.

In the USA, a rod diameter of 25 mm is used for pavements up to 20 cm thick, a diameter of 32 mm for pavements 20...25 cm thick and a diameter of 38 mm for pavements over 25 cm thick.

In Germany, the diameter of the rods is 25 mm, regardless of the thickness of the road, and the length of the rods is 50 cm. Anchor rods are installed in the longitudinal joint, which ensures that both slabs have a good grip on the concrete.

In Ukraine, the diameter and length of the bars are determined by the calculation method according to GBN B.2.3-37641918-557:2016. Typically, the diameter of the rods is 22...25 mm, the length of the rod for transverse joints is 50 cm, and for longitudinal joints - 80 cm [7,8].

The second type of road structure (JRCP) has a reinforced concrete pavement with transverse joints every 7...9 m, even up to 12m. The mesh reinforcement allows to increase the length of the slab, i.e. to reduce the number of transverse joints - the most labour-intensive and weakest structural element. The percentage of longitudinal reinforcement ranges from 0.10% to 0.25%. Despite the fact that such structures have fewer joints than the first type of structures, this advantage is conditional and is offset by the high cost of metal mesh [7,8].

The third type of road structure (CRCP) with continuous reinforcement of the pavement has longitudinal reinforcement along its entire length. There are no transverse joints. The percentage of longitudinal reinforcement ranges from 0.4 % to 0.8 %. The longitudinal reinforcement is located inside the slab. Temperature cracks in such coatings occur in increments of 0.9...1.5m. The reinforcement tightens these cracks and prevents them from opening more than 0.5 mm. Continuously reinforced pavements are more expensive, but they have a smoother surface than pavements with seams and can last longer. In Ukraine, continuously reinforced cement concrete pavements are allowed to be installed subject to an appropriate feasibility study [8].

According to the construction method, cement concrete pavements can be:

- single-layer;
- two-layer with the simultaneous placement of two layers; in this case, the composition of concrete layers can often differ.

There are different types of monolithic concrete pavements in the construction technology:

-concrete pavement with exposed aggregate (Waschbeton);

-whitetopping;

-roller compacted concrete (RCC or Walzbeton).

In Germany, the technology of concrete pavements with exposed aggregate is quite widespread, which helps to reduce the noise level of traditional cement concrete roads [9].

The whitetopping technology involves the elimination of surface defects in asphalt or cement concrete pavements, as well as the reinforcement of the existing pavement by applying an additional layer of concrete [9].

The technology of constructing a road pavement of roller compacted concrete (RCC) is being actively implemented in the USA, Canada, Germany, Sweden and other countries, but in Ukraine this technology is new and there are only a few test sections made by different contractors [3]. At the same time, the arrangement of road base layers by rolling concrete is widely used in road construction in Ukraine.

On the other hand, for example, in Germany, roller compacted concrete (Walzbeton) is defined as concrete of class WB25 and above and limits the use of such concrete to either the top layer of a road pavement or the bottom layer of a two-layer pavement and “lean concrete” does not match the definition known in Germany as "Walzbeton" [9].

Compared to traditional road pavements, roller compacted concrete has a number of advantages. Firstly, the use of ultra-hard concrete mixes helps to reduce the cost of the road. Secondly, it can be installed using widely available equipment, such as asphalt pavers and rollers. Thirdly, the speed of traffic opening - ultra-hard concrete mixtures are characterized by higher strength kinetics, and the compacted pavement is ready for use in just a few days. It is also very important for Ukraine to be energy independent, so using local materials is good choice. All these factors contribute to the introduction of this technology for the construction of local roads in Ukraine, but a number of challenges need to be addressed to implement RCC in Ukraine.

ACTUAL PROBLEMS IN ROLLER COMPACTED CONCRETE TECKNOLOGY

A number of issues arise on the way to the introduction of roller compacted concrete in Ukraine.

1. Inconsistent regulatory frameworks and test methods. A number of countries have developed guidelines for the roller compacted concrete (RCC), but these documents often have significant differences and are based on different standards and quality control systems. The standards developed by the American Concrete Institute (ACI) use special test methods for roller compacted concrete that differ from traditional concrete and asphalt C1170M, C1176, C1435, etc. These standards provide for a different form of specimens and methods of their manufacture than, for example, the German recommendations [9,10].

In Ukraine, there is currently no standard for roller compacted concrete. The question of the test methodology and what test methods will be introduced in Ukraine remains open, as there is an intertwining of concrete and asphalt technology (roller compacting).

In many works, the question of how tests flexural tensile strength - remains open, on the other hand it is the key parameter for road concrete. The test results of conventional prisms will obviously depend to a large extent on the quality of the specimens. Of course, it is always possible to test concrete using specimens taken from structures.

2. Uncertainty of the technological parameters of roller compacted concrete pavements. In many countries, there are restrictions on the thickness of the roller compacted concrete layer, as it is quite difficult to lay a homogeneous monolithic concrete pavement that is evenly compacted over the entire height. For example, in Germany, the maximum thickness of a Walzbeton layer is 200 mm. Therefore, it is necessary to design compaction methods that will achieve the required homogeneity of the concrete structure throughout its thickness [11, 12, 13].

It is clear that the technological parameters of compaction will be determined by both the composition of used concrete mixtures and the equipment for rolling concrete layers. The solution to this problem requires additional scientific and practical research, taking into account the specifics of the construction of such roads.

3. Predictive assessment of the durability of roller compacted concrete and development of methods for its determination.

The question of the durability of roller compacted concrete in the current climatic conditions of Ukraine remains open, as, firstly, there is no long-term experience of using these concretes, and secondly, the climate in Ukraine is becoming sharply continental: quite high temperatures are possible in summer and unpredictable temperature drops in winter; also, the frost resistance of such concretes can be significantly reduced due to the current practice of widespread use of de-icing salts. Waterproofness will obviously depend on the quality of the pavement and the degree of compaction of the concrete mix. In connection with the above, it is necessary to explore the possibilities of increasing the durability of roller compaccted concrete (RCC) by optimising their formulations, including the use of modern chemical additives, and the possible application of hydrophobic coatings.

Roller compacted concrete is typically used for low-traffic intensity roads to prevent mechanical destruction of the pavement. The question of the durability of RCC concrete and whether this parameter can be assessed by the abrasion index as for conventional concrete remains open.

CONCLUSIONS

1. New technologies of road construction in Ukraine and abroad are analyzed. The experience of constructing concrete pavements with different technologies of reinforcement and connection of road slabs is considered. New trends in the development of road cement concrete construction technology are highlighted: concretes with exposed aggregate, "witetopping", and rolled concrete. New technologies are gradually being introduced in Ukraine.

2. The article proves the purpose of using roller compacted concrete in Ukraine for the construction of local roads using available raw materials and equipment**.**

3. The problems and ways to eliminate obstacles to the implementation of the technology of rolled concrete in Ukraine are identified.

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Аналіз нових технологій дорожнього будівництва в Україні та за кордоном

Катерина ПУШКАРЬОВА, Віталій ЧАЙКОВСЬКИЙ, Дмитро БОРИСЕНКО

Анотація В даній статті розглянуто довгострокові та короткострокові переваги та недоліки у використанні цементобетонних доріг порівняно з асфальтобетонними.

Перелічено сучасні технології влаштування цементобетонних покриттів включаючи: бетони із оголеним заповнювачем, «whitetopping» та детально розглянуто технологію влаштування укочуваного бетону. Визначено доцільні сфери викоритання укочуваого бетону, переваги та проблематику вивчення даної технології.

Ключові слова: дорожнє жорстке покриття, цементобетон, укочуваний бетон, цементобетонні дороги