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COMPARISON OF THE PERFORMANCE OF FLEXIBLE AND ROLLER-COMPACTED CONCRETE PAVEMENT STRUCTURES

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Abstract. Slip-form concrete (Joint plain concrete pavement) has number of years of good performance experience. As experience showed such technology is cost efficient only for high capacity roads, where very strict requirements for pavement roughness are defined. It also requires special knowledge, experience and mechanisms. An alternative to slip-form concrete is roller-compacted concrete (RCC). RCC mixture has significantly larger amount of fine aggregates, which leads concrete mix to be non-slip. RCC has the strength and performance of conventional concrete with the economy and simplicity of asphalt. Starting from 2016 Lithuania gain experience of RCC pavement structures with cement and special additives bounded base. Asphalt and RCC pavement structures are very competitive. It is very important to make study of the bearing capacity of RCC pavement structures and compare with asphalt pavement structures to know how they perform on the site.

Keywords: falling weight deflectometer (FWD), concrete, roller-compacted concrete, deflection, bearing capacity.

JEL Classification: O30.

Introduction

Roller-compacted concrete (RCC) is dry mix concrete which can be laid down with asphalt paver and can be rolled by rollers for compaction (Vaitkus & Mickevič, 2022; Vineela et al., 2015). RCC is a no-slump concrete that can be designed to achieve high strengths levels due to compaction and aggregate interlock (Chhorn et al., 2018). RCC mixture has same components as conventional concrete mixture but in different mixture proportion (Vaitkus et al., 2021; Rambabu et al., 2023). RCC mixture proportion represented in Figure 1 (National Concrete Pavement Technology Center, 2010).

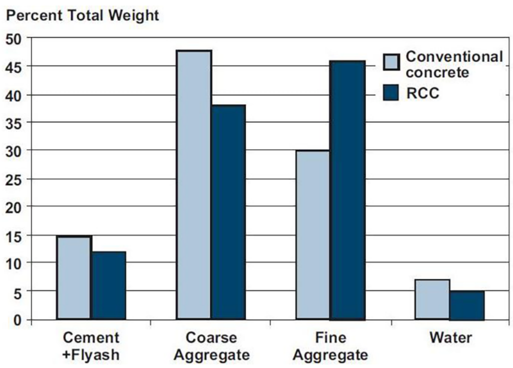

Figure 1. Mixture proportion comparison of RCC and conventional concrete

The need for concrete road pavements is increasing because of materials used in concrete production are more environmentally friendly than those used in flexible pavements. Also, concrete roads have a long life compared to other kinds of pavements (Delatte, 2014; Kici et al., 2018). One of the most important properties of a RCC mixture is its workability, which is a characteristic property that indicates the amount of energy that is required to achieve the maximum density of the aggregates in the mixture (Gagne, 1999; Azizmohammadi et al., 2021). For good performance of RCC pavements it is very important to have strong foundation for the top layer of RCC. In Lithuania RCC pavement structure is usually used with cement and special additives stabilized base. Cement and special additives stabilized base is one of the solutions to have proper base, which could withstand traffic load and environmental conditions. The main aim of stabilization is to obtain a much better performance of the bound layer by adding a relatively high amount of cement (up to 10%) (Yeo, 2011). Modulus of cement-stabilized pavement base course is significantly influenced by cement content and curing time (Nusit et al., 2015). Hydrothermal conditions do not

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affect the bearing capacity of RCC pavement structure with stabilized subbase and base layers which constructed on water permeable subgrade (Vaitkus & Mickevič, 2022). The bearing capacity of such kind of pavement structures usually increases with ages. The main reason is that mechanical properties of hydraulically bounded layers usually increase until they reach their maximum values (Vaitkus & Mickevič, 2022). RCC surface layer lower than 20,3 cm can withstand a significant amount of load (Wu & Mahdi, 2015). Fatigue crack was found to be the primary distress type for a thin RCC (Wu et al., 2016).

RCC pavements are more economical than conventional concrete pavements. It is easier to apply on site and faster to construct (Sengun et al., 2018; Chhorn et al., 2017; Song & Lee, 2015; Owino et al., 2014; American Concrete Institute [ACI], 1995). RCC layer could be laid down with a typical asphalt paver equipped with high-density screed and compacted with rollers. Taking into account simplicity and similarity of RCC installation to the installation of asphalt layers, RCC could be placed in a more time-efficient way than conventional concrete. Using RCC instead of conventional rigid pavement results in lower cost (between 15% and 30% lower than conventional rigid pavement or asphalt pavement), rapid execution process, improves durability, and decreases maintenance (Fardin & dos Santos, 2021; Mohammed & Adamu, 2018; Ramezanianpour et al., 2017; Modarres & Hosseini, 2014). Due to fast construction, in Lithuania popularity of RCC pavements have increased recently. There are over 15 locations in Lithuania where RCC pavement structure with cement and special additives stabilized based was used. RCC pavement structures have been installed in different zones according to traffic loads. It has been used in pedestrians and cyclists areas, local roads, Free Economic Zones and military areas. The use of RCC as an alternative construction material for industrial and heavy-duty pavements has shown initial cost savings in the range of 10–58%, as compared with the use of conventional paving concrete (Pittman, 1994). Asphalt and RCC pavement structures are very competitive, because of that it is very important to make study of the bearing capacity of RCC pavement structures and compare with asphalt pavement structures to know how they perform on the site with the real traffic and weather conditions.

1. Experiment

1.1. Test locations

The experiment of evaluation of the bearing capacity of the different pavement structures was conducted in four different locations. For the experiment there were selected two different RCC pavement and two different asphalt pavement structures. Measurements of the bearing capacity of RCC pavement structures were conducted on Lithuanian local road No. 130 and in heavy duty transport area in Free Economical Zone in Klaipėda. Bearing capacity of the asphalt pavement structures were managed on Lithuanian highway A14 Vilnius-Utena and on regional road No. 195 Kėdainiai-Krekenava-Panevėžys.

1.2. Pavement structures

RCC pavement structure of local road No. 130 is represented in Figure 2 and consists of:

- 16 cm of RCC surface layer (flexural strength 5.5 MPa);
- 40 cm of cement and special additives stabilized base layer (compressive strength 1.5 MPa);
- 20 cm of cement and special additives stabilized subgrade (compressive strength 1.0 MPa);
- subgrade.

RCC pavement structure of heavy-duty transport area in Free Economic Zone in Klaipėda is represented in Figure 2 and consists of:

- 16 cm of RCC surface layer (flexural strength 5.5 MPa);
- 35 cm of cement and special additives stabilized base layer;
- subgrade.

Asphalt pavement structure of Lithuanian highway A14 Vilnius-Utena is represented in Figure 3 and consists of:

- 3 cm of asphalt wearing course (SMA 8 S PMB 45/80-55);
- 9 cm of asphalt binder course (AC 16 AS);
- 10 cm of asphalt base layer (AC 22 PS);
- 20 cm of crushed aggregates base layer;
- 38 cm of subbase layer;
- subgrade.

Asphalt pavement structure of Lithuanian regional road No. 195 Kėdainiai-Krekenava-Panevėžys is represented in Figure 3 and consists of:

- 3 cm of asphalt wearing course (SMA 8 S PMB 45/80-55);
- 5 cm of asphalt binder course (AC 16 AS 50/70);
- 20 cm of cold regenerated base layer;
- 52 cm of subbase layer;
- subgrade.

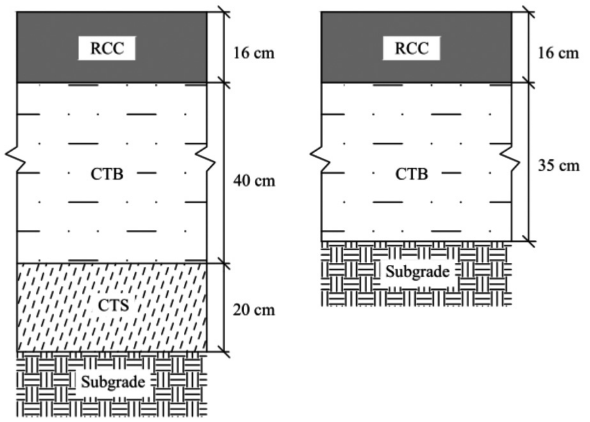

Figure 2. RCC pavement structures used in the bearing capacity test: on the left local road No. 130, on the right Free Economical Zone in Klaipėda

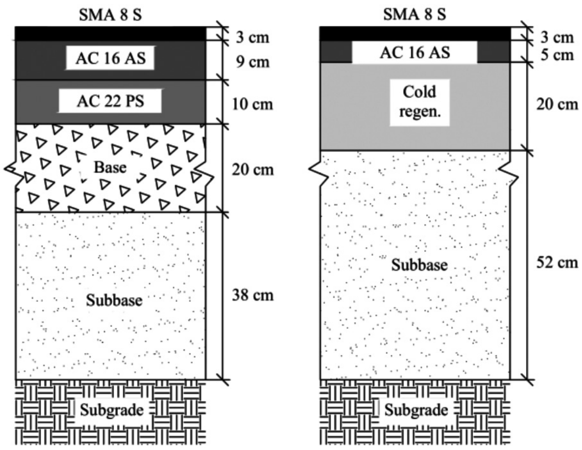

Figure 3. Asphalt pavement structures used in the bearing capacity test: on the left highway A14, on the right regional road No. 195

1.3. Field testing

The bearing capacity of pavement structure was conducted using a falling weight deflectometer (FWD). The falling weight deflectometer (FWD) is non-destructive testing (NDT) device to evaluate the bearing capacity of the pavement, which is use widely all around the world. A FWD transfers a 50 kN load to the road pavement through a 300 mm diameter circular plate, which results in 707 MPa pressure. The generated haversine pulse lasts about 30 ms. Dynamic deflections on the road surface due to applied loads are captured by sensors (geophones), which are positioned at different distances from the center of the loading plate (0, 200, 300, 450, 600, 900, 1200, 1500 and 1800 mm). Testing device is represented in Figure 4.

The bearing capacity of the pavement structure was measured in the middle of right wheel trajectory and at 20 m interval for local road No. 130, highway A14 Vilnius-Utena and regional road No. 195 Kėdainiai-Krekenava-Panevėžys. In Free Economic Zone in Klaipėda the bearing capacity of the pavement structure was measured in the center and in the corners of the RCC slab.

Figure 4. Testing device – falling weight deflectometer (FWD)

2. Results and discussion

The normalized surface deflection w_0 and normalized modulus E_0 measured with FWD with 50 kN load are represented in Figure 5 and Figure 6. Systemized statistical indicators of surface deflection w_0 and normalized modulus E_0 are represented in Table 1 and Table 2.

As seen from Figure 5 and Table 1 normalized surface deflection w_0 measured on Lithuanian regional road No. 195 Kėdainiai-Krekenava-Panevėžys (asphalt pavement structure) with 50 kN load in the middle of the right wheel trajectory varied from 184 µm to 355 µm, average was 277 µm, standard deviation – 40 µm. Normalized surface deflection w_0 measured in heavy duty transport area in Free Economic Zone in Klaipėda (RCC pavement structure) with 50 kN load in the center of the RCC slab varied from 115 µm to 337 µm, average was 182 µm, standard deviation – 62 µm, in the corner of the RCC slab varied from 135 µm to 381 µm, average was 210 µm, standard deviation – 67 µm. On local road No. 130 (RCC pavement structure) normalized surface deflection w_0 measured with 50 kN load in the middle of the right wheel trajectory varied from 63 µm to 385 µm, average was 107 µm, standard deviation – 43 µm. Normalized surface deflection w_0 measured on Lithuanian highway A14 Vilnius-Utena (asphalt pavement structure) with 50 kN load in the middle of the right wheel trajectory varied from 131 µm to 207 µm, average was 168 µm, standard deviation – 14 µm.

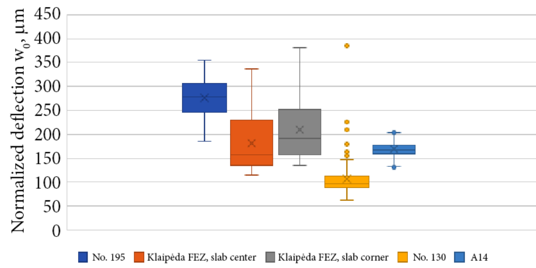

Figure 5. Normalized surface deflection w_0 measured with 50 kN load

Table 1. Systemized statistical indicators of surface deflection w_0 measured with 50 kN load

	No. 195	Klaipėda FEZ, slab center	Klaipėda FEZ, slab corner	No. 130	A14
Min, µm	184	115	135	63	131
Max, µm	355	337	381	385	207
Average, µm	277	182	210	107	168
Stdev, µm	40	62	67	43	14

As seen from Figure 6 and Table 2 normalized modulus E_0 measured on Lithuanian regional road No. 195 Kėdainiai-Krekenava-Panevėžys (asphalt pavement structure) with 50 kN load in the middle of the right wheel trajectory varied from 525 MPa to 1009 MPa, average was 687 MPa, standard deviation – 106 MPa. Normalized modulus E_0 measured in heavy duty transport area in Free Economic Zone in Klaipėda (RCC pavement structure) with 50 kN load in the center of the RCC slab varied from 591 MPa to 1729 MPa, average was 1219 MPa, standard deviation – 340 MPa, in the corner of the RCC slab varied from 522 MPa to 1801 MPa, average was 1074 MPa, standard deviation – 333 MPa. On local road No. 130 (RCC pavement structure) normalized modulus E_0 measured with 50 kN load in the middle of the right wheel trajectory varied from 483 MPa to 2957 MPa, average was 1881 MPa, standard deviation – 431 MPa. Normalized modulus E_0 measured on Lithuanian highway A14 Vilnius-Utena (asphalt pavement structure) with 50 kN load in the middle of the right wheel trajectory varied from 898 MPa to 1423 MPa, average was 1113 MPa, standard deviation – 90 MPa.

Table 2. Systemized statistical indicators of modulus E_0 measured with 50 kN load

	No. 195	Klaipėda FEZ, slab center	Klaipėda FEZ, slab corner	No. 130	A14
Min, MPa	525	591	522	483	898
Max, MPa	1009	1729	1801	2957	1423
Average, MPa	687	1219	1074	1881	1113
Stdev, MPa	106	340	333	431	90

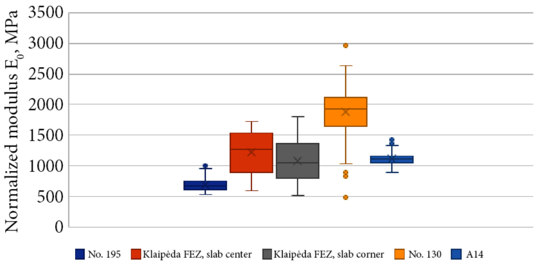

Figure 6. Normalized modulus E_0 measured with 50 kN load

Conclusions

The analysis of FWD data from different pavement structures led to the following conclusions:

- comparison of the bearing capacity of RCC pavement structures with the same thickness of RCC layer but different thickness of cement and special additives stabilized layer has shown different bearing capacity. Pavement structure with 25 cm thicker cement and special additives stabilized layer has about 1.5 times higher bearing capacity than thinner one.
- comparison of the bearing capacity of RCC pavement from local road No. 130 with the bearing capacity of asphalt pavements has shown that RCC pavement from local road No. 130 has about 3 times higher bearing capacity comparing to pavement structure from regional road No. 195 Kėdainiai-Krekenava-Panevėžys and about 1.7 time higher compering to highway A14 Vilnius-Utena.
- taking into account design period of 20 years, RCC pavement structure from local road No. 130 could withstand 2.9 mln ESAs, RCC pavement structure from Free Economic Zone in Klaipeda could withstand 2.4 mln ESAs, asphalt pavement structure from highway A14 Vilnius-Utena could withstand 10 mln ESAs and asphalt pavement structure from regional road No. 195 Kėdainiai-Krekenava-Panevėžys could withstand 1 mln ESAs.
- from the economic perspective, the installation of the pavement structure from local road No. 130, which has the higher bearing capacity is about 6% more expensive than installation of the pavement structure of Free Economic Zone in Klaipėda, about 10% more expensive than pavement structure of regional road No. 195 Kėdainiai-Krekenava-Panevėžys and about 10% cheaper than pavement structure of highway A14.

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