Backcalculation of the roller-compacted concrete pavement structure with cement and special additives stabilized base layers

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ABSTRACT: Slip-form concrete (JPCP) has demonstrated reliable performance over many years. An alternative to slip-form concrete is roller-compacted concrete (RCC), which contains a higher proportion of fine aggregates. RCC offers strength and performance equal to or exceeding that of conventional concrete. In Lithuania, RCC pavement structures typically incorporate a base (CTB) and a subbase stabilized with cement and special additives (CTS). The main objective of this research was to evaluate the modulus of the elasticity of CTB and CTS, which is one of the most important mechanical property in the mechanistic–empirical pavement design method. In light of that bearing capacity tests with falling weight deflectometer were performed on local road directly on CTB, CTS and after installation of RCC. Deflections were used in evaluation of the CTB and CTS modulus of elasticity. The results showed increased stability of the E modulus in the CTS and CTB after installation of RCC.

1 GENERAL INSTRUCTIONS

Roller-compacted concrete (RCC) is a dry concrete mix that can be placed using an asphalt paver and compacted with rollers (Vaitkus et al., 2022). Characterized as a no-slump concrete, RCC achieves high strength levels through compaction and aggregate interlock (Chhorn et al., 2018). While its consistency is comparable to that of conventional concrete, RCC differs in its mix proportions (Vaitkus et al., 2021; Rambabu et al., 2023).

To ensure optimal performance of RCC pavements, a strong foundation for the RCC top layer is crucial. In Lithuania, RCC pavement structures typically incorporate a base stabilized with cement and special additives. This stabilized base is designed to endure traffic loads and environmental stresses effectively. The primary goal of stabilization is to enhance the bound layer's performance by incorporating a relatively high cement content, often up to 10% (Yeo, 2011). Additionally, hydrothermal conditions have minimal impact on the bearing capacity of RCC pavement structures with stabilized subbase and base layers when built on a water-permeable subgrade. The bearing capacity tests performed at different times of the year (under neutral and unfavorable hydrothermal regime effects) with a falling weight deflectometer on RCC pavement structure with stabilized subbase and base layers showed that the bearing capacity of the pavement structure in creased over time, since measurements were taken 9 months after the installation of the pavement structure, the deflections decreased, and the equivalent stiffness modulus increased (Vaitkus et al., 2022).

RCC pavements are more cost-effective than traditional concrete pavements and are easier and faster to construct on-site (Sengun et al., 2018; Chhorn et al., 2017). The RCC layer can be installed using a standard asphalt paver equipped with a high-density screed and compacted with rollers. Due to the straightforward installation process, which closely resembles asphalt layer placement, RCC can be laid more efficiently than conventional concrete which reflects in the reduced installation costs up to 30 % (Fardin et al., 2021; Mohammed et al., 2018).

Design of the pavement structures are based on a mechanistic–empirical pavement design method. The procedure incorporates mechanistic components such as load, stresses, deflections and also mechanical properties of the pavement structure. The main pavement structure input data in the mechanistic–empirical pavement design method is thickness of the pavement structure layers and modulus of the elasticity E. Modulus of elasticity E is a property of the stiffness of materials that describes the formation of elastic deformation in a material under the action of axial stress. Modulus of the elasticity of a cement stabilized pavement base is significantly affected by the cement content and the curing duration (Nusit et al., 2015). Typically, modulus of the elasticity of a cement stabilized layer varies from 700 MPa to

3000 MPa (Using Falling…, 2017). It can be obtained from several laboratory tests, such as triaxial and unconfined compression tests or in situ tests like standard penetration tests, pressure meters, plate-load tests and bearing capacity tests using falling weight deflectometers.

Taking all the presented information into account, it can be stated that in pavement design it is vital to use actual mechanical properties of the layers. Only the use of actual properties can lead to rational and cost-effective pavement design solutions. This paper aims to determine the actual modulus of elasticity of CTB and CTS layers, which can be used in mechanistical-empirical pavement design method.

2 EXPERIMENT

2.1 *Test location*

An experimental section of RCC pavement with a cement-stabilized base layer and subbase was constructed on local road No. 130 in Lithuania. he reconstruction of this road took place between June and August 2021. The length of the reconstructed local road No. 130 was 699 m, the width of the concrete pavement 10 m, the unbound shoulders – 1 m.

2.2 *Pavement structure*

The pavement structure of the local road No. 130 is represented in Fig. 1 and consists of:

- 16 cm of RCC layer;
- 40 cm cement and special additives stabilized base layer;
- 20 cm cement and special additives stabilized subbase layer;
- subgrade.

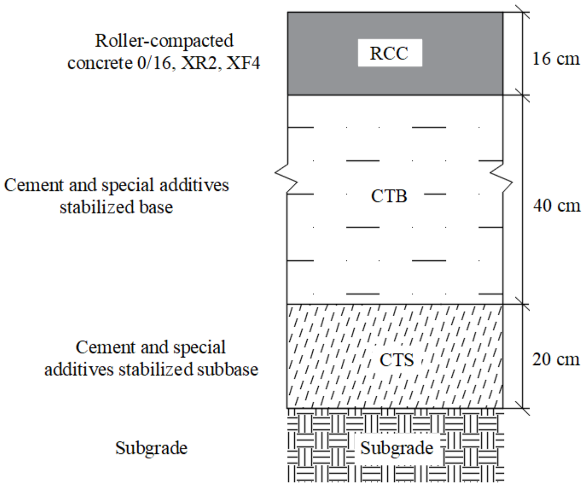

Figure 1. Pavement structure.

RCC mixture was produced in mobile concrete batching plant and consists of:

- 4/16 fraction crushed aggregates (48.8 %);
- 0/4 fraction fine aggregates (30.9 %);
- cement (14.7 %);
- water (5.5 %);
- concrete plasticizer (0.07 %).

Cement and special additives stabilized base and subbase consists of portland cement (5 % for base, and 3 % for subbase), ion exchange enhancing chemical additive (0.2 l per m^3 of soil), water and soil.

Requirements for cement and special additives stabilized base and subbase provided in Table 1.

Table 1 Requirements for cement and special additives stabilized base and subbase.

Requirement	Base	Subbase
Compressive strength after 28 days, MPa	≥1,5	≥1,0
The ratio of compressive strength of samples after refrigeration and thawing cycles to reference samples (after 28 days)	≥0,6	–
Compaction rate, %	≥98	≥98
Deformation modulus E_{v2}, MPa	–	≥100

2.3 *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 and 200 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).

Measurements of the bearing capacity of the pavement structure on the cement and special additives stabilized subbase (CTS) were carried out on June 10, 2021. Within the scope of the study, the bearing capacity was measured at interval of 20 m in each traffic lane (total 48 points) using a falling weight deflectometer (FWD) (more information provided in Fig. 2). Due to the construction the measurements were conducted only on half of the reconstructed section of local road No. 130.

Measurements of the bearing capacity of the pavement structure on the cement and special additives stabilized base (CTB) were carried out on June 23, 2021. Within the scope of the study, the bearing capacity was measured at interval of 20 m in each traffic lane (total 80 points) using a falling weight deflectometer (FWD) (more information provided in Fig. 2).

Measurements of the bearing capacity of the pavement structure on the roller-compacted concrete (RCC) were carried out on July 6, 2021. Within the scope of the study, the bearing capacity was measured at interval of 20 m in each traffic lane (total 80 points) using a falling weight deflectometer (FWD) (more information provided in Fig. 2).

Based on the bearing capacity study, the modulus of elasticity for both CTS and CTB layers was evaluated in two different ways:

- using the deflections from direct measurements on the CTS and CTB (after installation of each layer);
- using the deflections from measurements taken on RCC layer (28 days after installation of the wearing course RCC).

The modulus of elasticity of the CTS and CTB were determined with the automated ELMOD6 software, using the "Deflection Basin Fit" calculation algorithm. The basin fit option methodology starts with a set of estimated moduli for the pavement structure. The theoretical deflection bowl for this pavement structure is calculated. The error between the measured deflections and calculated deflections is then assessed. The moduli in the structure are then increased/decreased by a small amount (typical 10%), and if the error in either of these deflection bowls is less than the original deflection bowl this is taken to be a better solution. This process is iterated until a minimum in error between the calculated and measure deflection bowls are found (Backcalculation of…, 2021). Moreover, the modulus E of CTB and CTS was evaluated from directed

Figure 2. Pavement bearing capacity measurements with FWD.

3 RESULTS AND DISCUSSION

3.1 *CTS backcalculated E modulus*

Taking into account the direct calculations of the E modulus of the CTS layer, it was determined that in the right lane of the examined section of the local road No. 130, the E modulus of the CTS layer varies from 140 MPa to 1013 MPa, the average is 347 MPa, the standard deviation is 233 MPa. In the left lane of the examined section of the local road No. 130, the E modulus of the CTS layer varies from 103 MPa to 816 MPa, the average is 288 MPa, the standard deviation is 139 MPa (more information provided in Fig. 3).

The calculated E modulus of the CTS layer after the installation of the RCC layer showed that in the right lane, the E modulus of the CTS layer varied from 188 MPa to 516 MPa, with an average of 323 MPa and a standard deviation of 52 MPa. In the left lane, the E modulus of the CTS layer varied from 273 MPa to 469 MPa, with an average of 339 MPa and a standard deviation of 49 MPa (more information provided in Fig. 3).

Averages of E modulus of the CTS layer determined in this study are about 50 % lower than typical values of cement treated layer given in literature analysis.

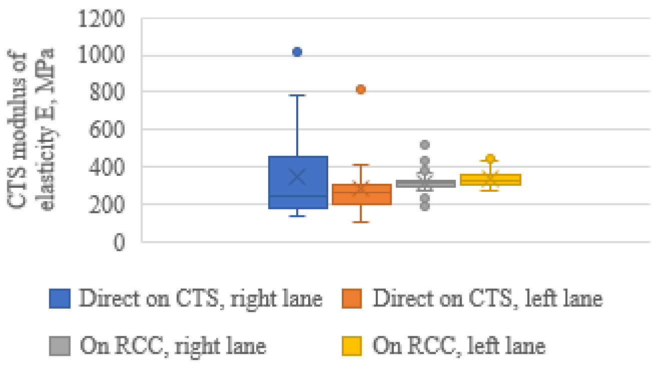

Figure 3. CTS backcalculated E modulus.

3.2 *CTB backcalculated E modulus*

Taking into account the direct calculations of the E modulus of the CTB layer, it was determined that in the right lane of the examined section of the local road No. 130, the E modulus of the CTB layer varies from 725 MPa to 7738 MPa, the average is 3232 MPa, the standard deviation is 2015 MPa. In the left lane of the examined section of the lo-cal road No. 130, the E modulus of the CTB layer varies from 687 MPa to 7581 MPa, the average is 2657 MPa, the standard deviation is 1599 MPa (more information provided in Fig. 4).

The calculated E modulus of the CTB layer after the installation of the RCC layer showed that in the right lane, the E modulus of the CTB layer varied from 542 MPa to 5581 MPa, with an average of 2385 MPa and a standard deviation of 1071 MPa. In the left lane, the E modulus of the CTB layer varied from 514 MPa to 5246 MPa, with an average of 2304 MPa and a standard deviation of 1082 MPa (more information provided in Fig. 4).

Averages of E modulus of the CTB layer determined in this study are similar to the typical values of cement treated layer given in literature analysis.

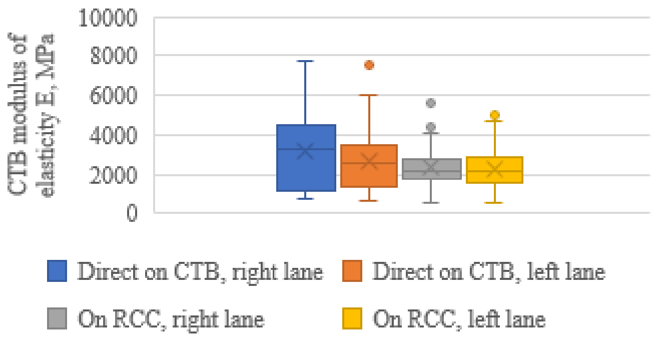

Figure 4. CTB backcalculated E modulus.

4 CONCLUSION

The analysis of FWD data on different pavement layers led to the following conclusions:

- a comparison of the E modulus measurements of the CTS and CTB layers taken directly with those conducted on the RCC layer revealed a more stable E modulus in the underlying layers, along with a smaller standard deviation (CTS right lane 52 MPa, left lane 49 MPa; CTB right lane 1071MPa, left lane 1082 MPa) after the installation of the RCC layer. The increased stability of the E modulus in the CTS and CTB layers may be attributed to the additional compaction of the entire pavement structure following after the installation of RCC layer;
- the analysis of the E modulus measurements for the CTS and CTB layers also showed slight variations between the left and right lanes, particularly during the direct measurements on CTS and CTB. The aforementioned differences could have been influenced by the inhomogeneity of the soils and the lack of uniformity in the technological installation of the layer (water and cement content, soil moisture, compaction etc.).

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