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Theory and practice of cement concrete pavements in Hungary

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Professional paper

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In the late 1990's, various asphalt pavement alternatives did not present the level of deformation resistance that would be sufficient to prevent early rutting on the extremely heavily trafficked motorways in Hungary. This resulted in the reinstatement of concrete pavements, which became once again a technological choice in motorway construction. This paper presents the history of Hungarian concrete pavements, steps for their "revival", technological challenges in the preparation of test sections, and an ongoing research aimed at ensuring long-term preservation of favourable surface properties.

Key words:
concrete pavement, test sections, pavement surface properties, microtexture, macrotexture, pavement behaviour

Stručni rad

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Teorija i praksa u izvođenju betonskih kolnika u Mađarskoj

U Mađarskoj kasnih 90-ih godina prošlog stoljeća različite varijante asfaltnih kolničkih konstrukcija nisu imale dovoljnu otpornost na deformacije koja bi spriječila ranu pojavu kolotraga na iznimno prometnim autocestama. To je uzrokovalo ponovno vraćanje betonskih kolnika kao tehnološkog izbora. U ovom radu prikazana je povijest mađarskih betonskih kolnika, postupci u njihovu "oživljavanju", tehnološki izazovi kod izrade pokusnih dionica te tijek istraživanja betonskih kolnika s ciljem dugoročnog zadržavanja povoljnih površinskih svojstava.

Ključne riječi:
betonski kolnik, pokusne dionice, površinska svojstva kolnika, mikrotekstura, makrotekstura, ponašanje kolnika

Fachbericht

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Theorie und Praxis der Ausführung von Betonfahrbahnen in Ungarn

IIn Ungarn war Ende der 90er Jahre des letzten Jahrhunderts bei verschiedenen Arten von Asphaltbelägen die Beständigkeit gegen Verformungen, die einer frühen Entwicklung von Spurrinnen auf den belebten ungarischen Autobahnen entgegenwirken könnte, nicht ausreichend. Dies führte zur erneuten Einführung von Betonfahrbahnen in die Technologieauswahl für Autobahnen. In dieser Arbeit werden geschichtliche Aspekte ungarischer Betonfahrbahnen, Schritte ihrer "'Wiederbelebung", technologische Herausforderungen bei der Erstellung von Teststrecken sowie der Forschungsablauf bezüglich langfristiger Erhaltung günstiger Oberflächeneigenschaften beschrieben.

Schlüsselwörter:
Betonfahrbahn, Teststrecken, Oberflächeneigenschaften von Fahrbahnen, Mikrotextur, Makrotextur, Fahrbahnverhalten

1. Introduction

The choice of pavement structure type in the national road management practice is a highly important decision that has to be taken by relevant decision makers, typically the transport-related ministry. The most advantageous situation can be the one when all commonly applied (flexible, semi-rigid, rigid, composite) pavement structure types are on the list from which designers of road construction or rehabilitation projects can select.

In 1976, following a Hungarian ministerial decision, the construction of cement concrete pavements (rigid pavement structures) was discontinued for a 25-year period – despite former significant successes of cement-concrete techniques used in Hungary. This action considerably limited the flexibility of road management. The inability of most "deformation resistant" asphalt pavement structures to withstand repeated early rutting on the extremely heavily trafficked Hungarian expressways made it necessary to reinstate concrete pavements as a technological choice for our motorways.

This article summarizes the history of Hungarian cement concrete pavements, the steps for their "revival" in the late 1990's and early 2000's, and technological challenges of concrete test sections, while also outlining an ongoing research on the skid resistance of cement concrete pavement surfaces.

2. History of Hungarian cement concrete pavement before 1976

Concrete pavements have been tested in Hungary since 1911, and constructed since 1927. The first sections had plain concrete pavements 150 mm and later 200 m in thickness, and were laid in two courses. In 1927, a 600 m long main road section was constructed using the Rhoubenit concrete, with a width of 6 m. Cement concrete pavements, mainly laid directly on the sub-grade, were constructed in the total length of 103 km between 1926 and 1933 [1].

The period from 1933 to 1944 can be considered as the "golden age" of cement concrete construction in Hungary (with 1088 km in total length of pavements laid). The pavements were designed to the 30 kN wheel load. Their typical dimensions are: 130 mm in thickness, laid directly onto the sub-grade, 6 m in width, longitudinal joints, transverse joints at 8-12 m intervals, laid mainly in a single course. They performed fairly well; they were improved with asphalt overlay courses n the 50's and 60's.

After World War II, the construction of roads with cement concrete pavements played an important role in the modernisation of the Hungarian main road system. Over 300 km of cement concrete pavements 180 mm in thickness, lying on the sandy gravel base, and varying from 6.50 to 7.00 m in width, were built in that period. The first Hungarian motorway M7 (between Budapest and Lake Balaton), was built using a rigid pavement structure, in the period starting in 1958. The typical pavement structure constructed before 1972 was 200 mm in thickness, which was later increased to 240 mm. It was a jointed plain cement concrete pavement on bituminous base, with stabilization layers of various thicknesses.

The cement concrete pavement at Motorway M7 was typically 8.5 m in width, with a longitudinal joint. The transverse joint spacing was 5.0 m, and no dowels were used in transverse joints. As from 1972, an air-entraining agent was also applied to withstand detrimental effects of de-icing agents.

The total length of cement concrete pavements in Hungary attained 1250 km in 1965 [1]. From that point on, the length has been gradually decreasing due to rehabilitation with asphalt pavements.

Some sections of the M7 Motorway revealed signs of early deterioration due to various construction failures. This was one of the reasons why the Ministry of Transport decided to continue with the motorway programme using exclusively asphalt pavements as from 1976. As a consequence, the construction of cement concrete pavements was also abandoned on other roads. The material supply, the development of machinery, the training of experts, and the research activities, also stopped in this area.

3. Preparation for "renaissance" after 1999

The southern section of the ring road M0 around Budapest was built in the 1980's using a semi-rigid pavement structure, with the polymer modified bitumen SMA wearing course. Due to an extremely heavy traffic characterized by frequent accelerations and decelerations, the pavement structure was frequently affected by rutting, which caused excessive resurfacing costs, and significant user delay costs during such rehabilitation activities. Even the high modulus asphalt layers used in the pavement structure were not sufficiently resistant to deformation. That is why the Ministry of Transport decided to reinstate cement concrete pavements, and to make such pavements once again an option in the Hungarian road management practice, after more than two decades of disuse.

In 1998, the institute KTI (Institute for Transport Sciences Non-Profit Ltd.) from Budapest was commissioned to conduct preparatory works relating to cement concrete trial sections. The researchers first gathered latest foreign experience on the basic materials, formulations, and machinery, design and construction methods, with regard to cement concrete pavements. Several formulations and technical solutions appropriate for Hungarian climate and traffic conditions were selected. After analysis of realistic possibilities, three alternatives were elaborated:

- jointed and dowelled cement concrete pavement,
- jointed and dowelled cement concrete pavement with "exposed aggregate" surface,
- continuously reinforced cement concrete pavement (CRCP).

A PIARC-publication [2] on the design and construction experience, and cement concrete pavement specifications applied in several countries, were used in the selection of the most appropriate formulations for three concrete options. The KTI compressive strength test results, and PIARC recommendations [3], are presented in Table 1.

Table 1. KTI compressive strength test results vs. PIARC recommendations

Source	28-day compressive strength (MPa)		
	Jointed cement concrete	Jointed cement concrete with "exposed aggregate" surface	Continuously rein-forced cement concrete
KTI test results	35,3	42,2	37,2
PIARC recommendations	35,0 - 40,0		min 40,0

The concrete types selected had to be resistant to the expected traffic and environmental loads. That is why the W/C-ratios ranging from 0.40 to 0.42 were chosen as a function of weather conditions and the actual water content of the fine aggregate fraction. The plasticiser and the air-entraining agent were added in the proportion of 0.10 - 0.12 % and 0.04 - 0.08 % of water, respectively.
A heavily trafficked secondary road 7538 was selected as the site for the experiment. Three cement concrete subsections (500 m each) were built between KM 8+600 and KM 10+100, while the control section with the modified bitumen asphalt pavement was constructed between km 14+000 and km 15+000 on the road 7538.
Narrow two-lane pavement sections, with a relatively weak structure, were severely damaged due to an extremely high truck traffic (above 1110 heavy vehicles/day). That is why the decision was made to remove the entire pavement structure before constructing the experimental structures. The following pavement structure variants were subjected to testing (Figure 1).

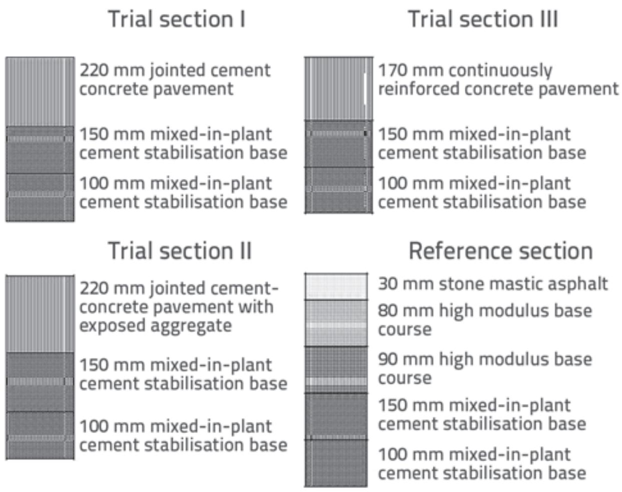

Figure 1. Pavement structures for concrete trial sections and asphalt reference section (road 7538)

The flexible pavement structure for the control section was designed using asphalt layers with high resistance to deformation, and it was considered that its bearing capacity is nearly identical to that of the cement concrete variants. The mix design for the upper asphalt layers was prepared using the SUPERPAVE design method. The pavement width of the trial sections (and the whole road 7538) amounts to 6.00 m. (This width is typical for Hungarian secondary roads).
The construction of the experimental section was basically influenced by the extremely rainy spring and summer of 1999. The requirement was that only one of the traffic lanes could be closed during reconstruction.
Due to frequent rainfalls, the design bearing capacity level of 50 MPa could not be ensured on the surface of the sandy gravel cap layer. The decision was made to stabilise it with cement [4].
The 6 m wide cement concrete pavement was laid as a single layer in two lanes 3 m in width. One of the jointed concrete subsections had the "exposed aggregate" surface in order to decrease the rolling noise and increase macro roughness. In fact, the exposed aggregate concrete is characterised by a specific treatment of the surface: When the concrete has been processed, a setting retarder is applied onto the fresh concrete surface in order to prevent the hydration of cement. After concrete hardening, the non-hydrated mortar at the surface is removed with a high-pressure water jet, so as to expose the coarse aggregate at the surface, and to fully reveal its appearance and colour.
No continuously reinforced cement concrete pavement had been built in Hungary before the experimental section was made on road 7538. The pavement 170 mm in thickness, with 0.67 % of reinforcement, was constructed without transverse joints, i.e. only construction joints were applied at the end of the day's work. A relevant foreign literature [5-7] was used in the design of the subsection (expansion joints, anchor to prevent CRCP end movement, positioning of reinforcement, etc.). After the first winter, a growing number of punch-outs originated on the surface of the continuously reinforced cement concrete pavement section. This "punch-out" in the continuously reinforced concrete pavement is the area enclosed by two closely spaced transverse cracks, a short longitudinal crack, and the edge of the pavement or longitudinal joint, when exhibiting scaling, shattering, or faulting. The following main reasons for the unexpected pavement failure were revealed during subsequent examination:

- excessively thin pavement layer due to application of the early literature data based on limited performance experience (more recent literature suggests 220-250 mm CRCP thickness expecting the benefit of the significantly longer pavement life cycle, compared to that of unreinforced jointed variants),
- narrow (3.0 m) traffic lanes causing overload in the longitudinal joint area due to heavily loaded truck traffic (design of wider traffic lanes on the test sections could have been a serious traffic safety hazard due to the 3.0 m traffic lane width of the road 7538 connecting sections),
- the load bearing capacity of the underlying sandy gravel capping layer locally had an excessively low surface modulus (much lower than the 50 MPa design value).

In the past decade, new motorway sections have already been built using cement concrete pavements. Thus, the cement

Table 2. Major features of Hungarian cement concrete pavement trial sections

Road No.	Construction year	Thickness [mm]	Surface type	Initial texture depth [mm]	Texture depth in 2013 [mm]
7538/I	1999	220	Combed	1,0	0,4
7538/II	1999	220	Exposed	1,8	1,3
7538/III	1999	170	Combed	0,9	0,3
44	2003	250	Combed	0,6	0,4
4	2004	250	Combed	0,6	0,4
5 (whitetopping)	2008	120	Combed	0,5	0,4
4602 Roundabout	2011	230	Combed	0,4	0,2
Whitetopping - is the covering of an existing asphalt pavement with a layer of cement concrete					

concrete pavement was built for the new sections of ring road M0, the most highly trafficked road sections in Hungary based on both the present and predicted data. In addition, a concrete pavement was also adopted for the newly built Motorway 31. Table 2 presents major features of Hungarian cement concrete trial sections, and provides information about the evolution of mean surface texture on trial sections.

There are two different types of documents in the Hungarian road construction specification system: EN standards and Technical Specifications for Roads (UME), which are in fact National Application Documents for EN standards. There are important differences between the two types of documents. One of them is that the application of legal measures is obligatory, while the use of standards is voluntary. Owing to the voluntary nature of standards, they stimulate producers to adapt more up-to-date solutions coming from their recent technical improvements, so that they can be included in a new version of the standard, after approval by an appropriate professional committee. The relevant Hungarian standard [8] does not contain special regulations for cement concrete pavements. It only presents some detailed criteria for the environmental exposure class (abrasion and freeze-thaw resistance). Just a few technical specifications for roads [9-11] are actually used for the cement concrete construction in Hungary.

As a general conclusion based on some 15 years of experience in the use of cement concrete pavements on the Hungarian public road network, it can be stated that the pavement option has proved to be durable and that its surface properties are appropriate, provided that it is build to high quality standards.

4. Use in roundabout

The reappearance of the cement concrete pavements in the Hungarian road management has spurred research on the possibilities for using such pavements in various fields. One of possible options is to use it as a roundabout pavement. In this respect, a targeted research work was initiated at KTI-institute aimed at evaluating resistance of the cement concrete pavement surface to special traffic load due to relatively low radii of roundabouts.

Just like in many countries worldwide, a lot of roundabouts have been built in Hungary in recent decades. Traditionally, they are constructed using asphalt-based flexible pavement structures. The decision was made in 2010 to build a trial roundabout with the cement concrete pavement in order to test the applicability, performance, and efficiency of this pavement type when subjected to special loads originating from traffic at roundabouts. The monitoring of this section – concentrating on its surface characteristics – was also planned to collect information for a future reliable specification on this issue.

The long-term performance of concrete layers is directly linked to its resistance to abrasion. In fact, the term "abrasion" generally refers to dry attrition [12]). It has been reported that a strong concrete has a higher resistance to abrasion than a weak one [13]. The abrasion resistance is inter alia affected by the aggregate type, mix proportion, workmanship, curing, and surface finish or treatment. A hard aggregate is more wear resistant than a soft one. Poor finishing practice can also result in a relatively low abrasion resistance [14]. The abrasion resistance of cement concrete surface basically influences the speed of deterioration of skid resistance, as a consequence of mechanical and environmental loads, as a major traffic safety condition parameter.

Due to lack of relevant Hungarian specifications on roundabouts with the cement concrete pavement, the specified skid resistance values for cement concrete pavements were used. The needed texture depth values are specified in relevant technical specifications for roads [9], where specified values depend on road categories. The texture depth values, measured on the trial cement concrete pavement section constructed at the secondary road 7538, were divided into 4 categories:

- below 0.5 mm,
- 0.5-0.75 mm,
- 0.75-1.00 mm,
- above 1.00 mm.

In the first category, the depth of pavement surface „grooves" produced by the "comb" technique is rather low [15]. Consequently, a relatively slow wear is expected, while deep "grooves" with the texture depth of more than 1.00 mm could result in a much higher wear for the same concrete properties. Figure 1 shows the typical texture depth deterioration curves based on the data time series obtained on the road 7538. Besides the three curves with initial values of 0.65 mm, 0.90 mm, and 1.15 mm, an average texture depth deterioration curve was also introduced. Two conclusions can be drawn from Figure 2:

- texture depth values measured after 2 million vehicle unit passes were almost the same regardless of their initial values,
- above 10 million vehicle unit passes, the wear practically discontinues.

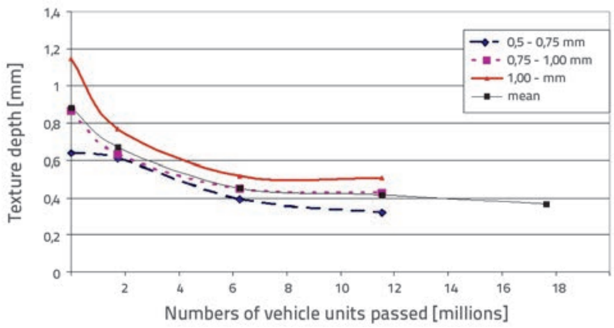

Figure 2. Texture depth deterioration on a cement concrete pavement trial section as a function of vehicle unit passes

Deterioration curves can be approximated by polygons (Figure 3). Three different phases can be identified in the texture depth deterioration due to uniform-speed vehicle movements at straight sections:

- up to 2 million vehicle unit passes (I),
- 2-6 million passes (II),
- above 6 million passes (III).

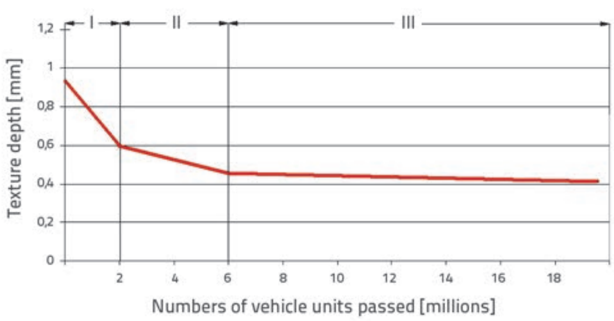

Figure 3. Simplified texture depth deterioration curve

The mathematical equation describing the evolution of texture depth is:

X = D - (e'P)/((AxF)M)

Where:

X - actual texture depth [mm]
D - initial texture depth [mm]
e' - extra loading factor from curved vehicle ride [mm/ axle unit]
P - number of axle units passed
A - wearing factor from abrasion resistance
F - wearing factor from frost-thaw resistance
M - wearing factor from mixture characteristics.

Relationship details are described in a conference paper [16].

5. Micro texture

The micro structure of a road pavement surface can be characterised by several methods and related parameters. The commonly used measuring methodologies are: laser techniques, dynamic procedures for characterisation of road vehicle effects, and static-type devices. The SRT (Skid Resistance Tester) pendulum, the most widely applied measuring apparatus in Hungary, was first investigated [17]. The SRT-value was used as a condition parameter for the qualification of Hungarian new road pavement surfaces, even if specified values were available for expressways only [9].

The change of SRT-values at the pavement surface of two Hungarian cement concrete test sections as a function of time is shown in Figure 4. The typical daily heavy traffic volume at the section of the secondary road 7538 amounts to 1110 heavy vehicle/day, while the similar traffic at the main road 44 amounts to 1420 heavy vehicle/day. The reason for the sudden decline in the SRT-value for the road 7538 can be explained by the fact that a "canalized" heavy traffic uses an excessively narrow pavement, thus causing a quick loss in the initially rather high macro texture, an element of skid resistance.

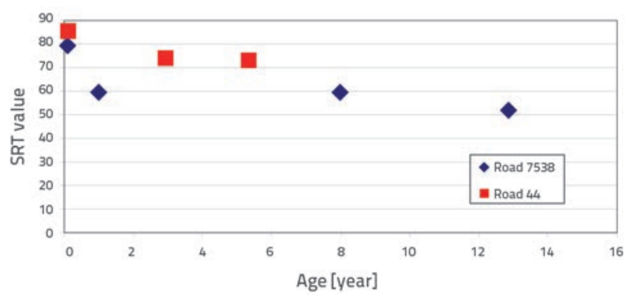

Figure 4. Evolution of SRT-values at cement concrete test surfaces

The evolution of micro texture of a road pavement surface is influenced by several factors. For example, the properties of sand in cement mortar play an important role in this respect [18]. A simple mathematical model can be developed to characterize evolution of micro texture as a function of traffic load, since its mechanism is quite similar to that of the macro texture. Tests were performed to demonstrate the actual change, and the possibility for altering micro roughness of cement concrete surfaces. The idea has come from the rehabilitation of worn cement concrete pavement surfaces when using various pavement milling techniques. The aim is to provide a surface with a certain durable skid resistance level, even though it will later lose its macro roughness due to the wearing effect of highway traffic.

The first step of the experiment was to measure the micro roughness of HPC (high performance concrete) surfaces before and after milling. Then measurements were performed on glass surfaces. There it was undoubtedly revealed that the micro roughness, characterized by SRT-values and simulating the actual skid resistance of a car, can be basically affected by various surface designs.

Characterization of the change in the micro roughness values of pavement wearing surfaces, because of mechanical and environmental loads, can be considered as a rather complicated task. The problem is shown on Figure 5 where it can be seen that, during the life cycle of pavement, the road vehicle tyre is in contact with various materials (S – sand, St – stone) and, as a consequence, the wearing surface with the changing skid features has to be taken into account..

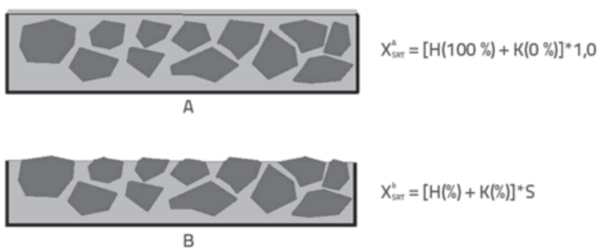

Figure 5. Change of wearing surfaces under combined influence of traffic and weather

So, the micro texture of the surface is the result of the effect of several independent elements. These effects can be summarised in the following simplified algorithm:

$$X_{SRT} = (S + St) * p$$

Where:

S - SRT-value based on the ratio of sandy surfaces

St - SRT-value based on the ratio of stone surfaces

p - SRT-value correction factor as a function of the ratio between aggregate tips and grooves at the skidding plane.

The change of micro texture as a function of time, just like that of the macro texture, can be taken as an arbitrarily wearing and scaling process of an initial surface with incidentally formed features. The evolution of SRT-value can be determined unambiguously as a stochastic phenomenon. The synergic effect of the road-traffic wearing load, and the weather-induced surface alterations, can raise further questions, already investigated by researchers [19-20]. The description of these changes can be explained by the simplified algorithm shown before supposing that the mixture properties coming from the constituents used in concrete recipe change as a function of time. This change occurs in a way that can be predetermined, i.e. the micro texture of the mortar consisting of sand and cement is constant, while the polishing of the stone particles can be predicted.

6. Relationship between macro and micro textures

Development of mathematical background of the theory is followed by its validation. Based on the tests introduced in Figure 6, it can unequivocally be stated that there is a relationship between micro and macro textures. At the same time, it can be seen that the micro texture does not depend on the actual value of macro texture, while macro roughness doesn't depend at all on micro roughness. As a consequence, two interconnected deterioration phenomena cannot be described by a simple mathematical algorithm.

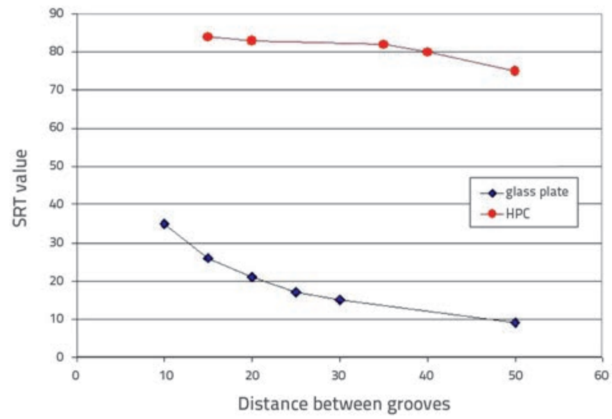

Figure 6. SRT values measured at various distances between glass and HPC surfaces with grooves

After having completed the first test series, the following problem arose: every wearing surface has its own configuration, as a basic property, and it is practically impossible to create the same shape even in laboratory. That is why SRT values are typically interpreted in ranges, since a standard difference of 2.4-2.6 of the SRT value is permitted on the same surface, independently of the temperature [8]. The change in SRT values as a function of temperature is presented in Figure 7.

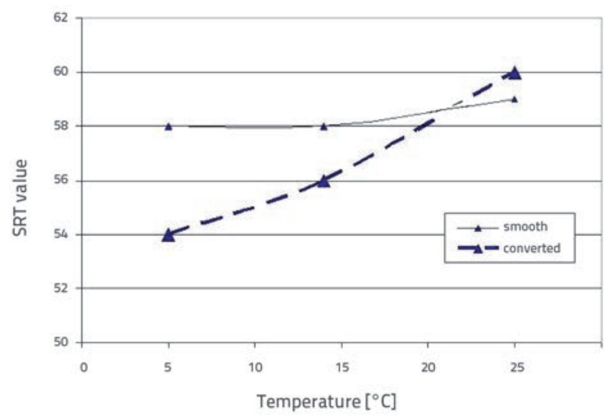

Figure 7. Evolution of SRT values as a function of temperature corrected in accordance with [8]

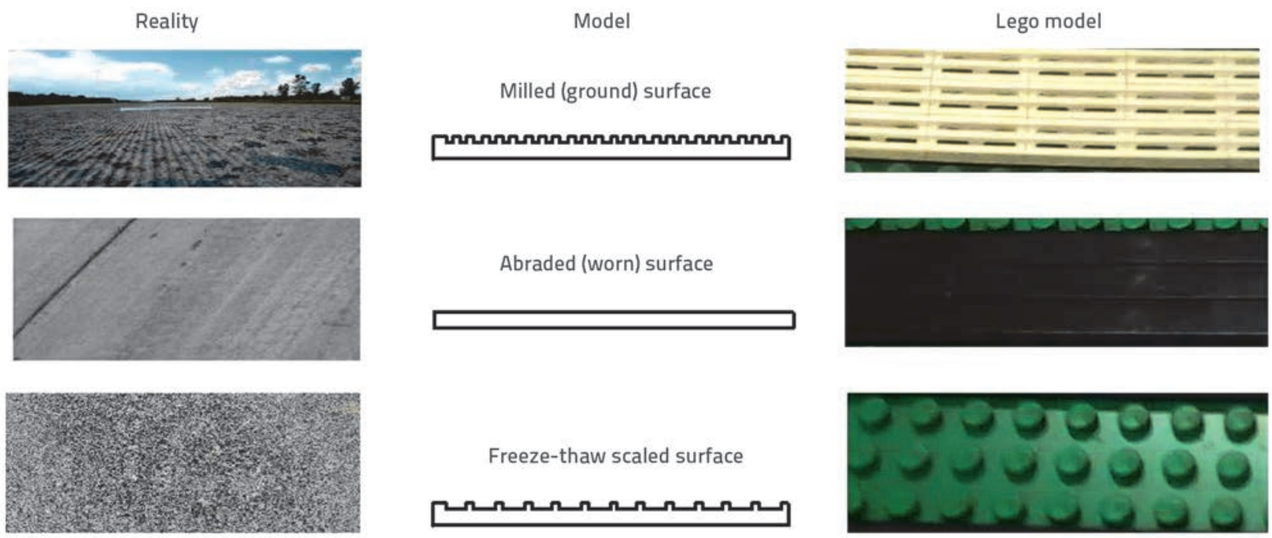

Figure 8. Simulation of milled, worn and freeze-thaw scaled cement concrete pavement surfaces by LEGO® blocks

The simulation was first done on a glass plate because it permitted a spectacular demonstration of the effect of macro texture. It was revealed that the same surface can not be created even on glass plates. After additional unsuccessful attempts with steel and wooden elements, it was established that the best solution can be obtained with plastic surfaces. That is why the well-known LEGO® blocks were used for the *simulation* regardless of their basic differences from the actual road pavement surfaces. The commercially available constant-quality and moisture-resistant LEGO® blocks enabled simulation of the cement concrete pavement surfaces at various ages. The simulation of the "smooth worn" and freeze-thaw scaled surface, as well as the freeze-thaw scaled and milled surfaces, is presented in Figure 8. The aim of this simulation was to identify the influence of various surface ratios on the SRT values of the surface (Figure 9). Once the needed ratios were obtained, the symmetric model could be readily transformed to asymmetric surfaces that approach more realistically the pavement surfaces.

Figure 9. SRT diagram for various proportions of milled, freeze-thaw scaled and milled surfaces

The deterioration of cement concrete pavement surfaces is a natural phenomenon that should also be considered at the pavement design phase. The rehabilitation of a wearing course is typically performed due to its poor macro texture. However, this action "automatically" improves the micro texture properties as well. A relevant example is that of the groove-induced additional SRT value presented on Figure 5. It is suggested that trial pavements should be built on an untrafficked site without any surface roughening design. It could help the road operator to determine the "initial SRT value" and the realistic intervention level of skid resistance. The macro roughness intervention level values given in relevant Hungarian Technical Directives for Roads [9] are generally considered as valid just for the moment of the opening to traffic. However, they are valid for the whole service life of the pavement since the responsibility of the road operator is to provide continuously safe wearing surface. At the same time, the specified micro texture value is valid exclusively for motorways [9]. Thus even the 0 SRT value would theoretically be acceptable on main and secondary roads included in the Hungarian national highway system. Measurement results have shown that no wearing course, even with an absolutely smooth surface, can be produced with an SRT value below 20. Thus, the widely accepted sand patch method for characterization of the pavement surface macro texture is not acceptable below the 0.2 mm texture depth, when some kind of outflow methods should be used.

An American predictive degradation model of skid resistance for in-service asphalt pavement surfaces, based on laboratory polishing test results using asphalt polishing machine, characteristics of aggregate gradation curve, and average daily traffic, can be mentioned as a partly similar effort [21].

7. Conclusions

After recent "re-introduction" of cement concrete pavements into the Hungarian road management practice, several research activities were initiated in this field. Principal findings of the research dealing with the long-term performance of the cement-concrete pavement surface properties are briefly presented. An algorithm was developed for the simplified mathematical description of the change in the micro and macro surface texture during the service life of cement-concrete pavements. As a practical aid, this algorithm can assist road operators in determining relevant intervention levels using simple, rapid, and efficient measuring methods. They can use the algorithm as a decision-making tool for predicting the time of future condition improving interventions based on traffic and environmental loads. In addition, factors influencing evolution of surface characteristics of cement concrete pavements were identified, and these factors point to the limited role of mixture design and laying quality. The significance of geometrical parameters (such as the curvature) is highlighted in case of an accelerated loss of macro texture at the cement-concrete pavement surface on a roundabout.

REFERENCES

[1] Keleti, I., Boromisza, T., Gáspár, L., Karsai-Lukács, K., Kausay, T., Kovács, T., Liptay, A., Táskai-Gáspár, T. & Vörös, Z.: Betonburkolatok, *Magyar Betonburkolat Egyesület*, 2012, 427 p. (In Hungarian)

[2] PIARC Technical committee 7: *Cement Concrete Roads,* 1998, 49 p.

[3] Gáspár, L., Karsai-Lukács, K.: Cement Concrete Pavements in the Hungarian Road Policy, *8th International Conference on Concrete Pavements*, San Francisco, Vol. 1, pp. 39-60, 2005.

[4] Karsai-Lukács, K., Bors, T.: Betonburkolatú kísérleti útszakaszok építése és állapotmegfigyelése, *Betonújság*, 1 (2008), pp. 3-7. (In Hungarian)

[5] Verhasselt, A.: Air-Training Agents in Road Concretes and Characterization of the Air Void System in the Fresh Concrete, *7th International Symposium on Concrete Roads*, Vienna, Session 1, 1994.

[6] Eisenmann, J.: Bemessung und Konstruktion von Betonstrassen. Rückblick und Ausblick., *Strasse und Autobahn*, 12 (1996). (In German)

[7] Goppel, J.M., Cools, P.M.: Scope of the Activities of the Joint Research Programme on Concrete Roads in the Netherlands, *7th International Symposium on Concrete Roads*, Vienna, Session 1, 1994.

[8] MSZ 4798-1:2004 Concrete Part 1: Specification, performance, production, conformity, and rules of application of MSZ EN 206-1 (In Hungarian)

[9] e-UT 06.03.31. (ÚT 2.3-201:2006) Beton pályaburkolatok építése. Építési előírások, követelmények*,* 49 p. (In Hungarian)

[10] e-UT 06.03.35. (ÚT 2.3-213:2008) Hézagaiban vasalt, kétrétegű, mosott felületképzésű, betonburkolatú merev útpályaszerkezet építése, 19 p. (In Hungarian)

[11] e-UT 05.02.54. (ÚT 2.3-210:2006) Pályalemezekből visszanyert beton újrafelhasználása*,* 10 p. (In Hungarian)

[12] Ghafoori, N., Tays, M.W.: Abrasion Resistance of Early-Opening-to Traffic Portland Cement Concrete Pavements, ASCE, Vol 19, 11 (2007), pp. 925-935.

[13] Kosmatka, S.H., Kerkhoff, B., Panarese, W.C.: Design and Control of Concrete Mixtures*,* 14th Edition, *Portland Cement Association*, USA, 2003.

[14] Gebler, S.H., Klieger, P.: Effect of Fly Ash on Some of the Physical Properties of Concrete, *Research and Development Bulletin*, Portland Cement Association, 1986. 48 p.

[15] Bencze, Zs., Karsai-Lukács, K., Gáspár, L.: Hungarian concrete pavements in urban areas using the principles of lifetime engineering. *Central European Congress on Concrete Engineering. Concrete Structures in Urban Areas*, Wroclaw, 2013, pp. 110-113.

[16] Gáspár, L., Bencze, Zs.: Experimental sections in the Hungarian road management. *3rd Inter-national Conference on Road and Railway Infrastructure*, Split, Croatia, 2014, pp. 183-188.

[17] MSZ EN 13036-4 Utak és repülőterek felületi jellemzői – Vizsgálati módszerek 4. rész A felület csúszásellenállásának mérési módszere: ingás vizsgálat, 2012. (In Hungarian)

[18] Wenzl, P.: Dauerhaftigkeit der Oberflächeneigenschaften von texturierten Verkhersflächen aus Beton, *Technische Universität München*, 2008, 144 p. (In German)

[19] Fwa, T.F., Choo, Y.S., Liu, Y.R.: Effect of Aggregate Spacing on Skid Resistance of Asphalt Pavement, *Journal of Transportation Engineering*, Vol. 129, 4 (2003), pp. 420-426, doi: http://dx.doi.org/10.1061/(ASCE)0733-947X(2003)129:4(420)

[20] Lee,Y. P.K., Fwa, T.F., Choo, Y.S.: Effect of pavement surface texture on British pendulum test, *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 6, 2005, pp. 1247–1257.

[21] Wang, H., Liang, R.: Predicting Field Performance of Skid Resistance of Asphalt Concrete Pavements. *Pavement Materials, Structures and Performance,* 2014, pp. 296-305*, http://dx.doi.org/10.1061/9780784413418.030*