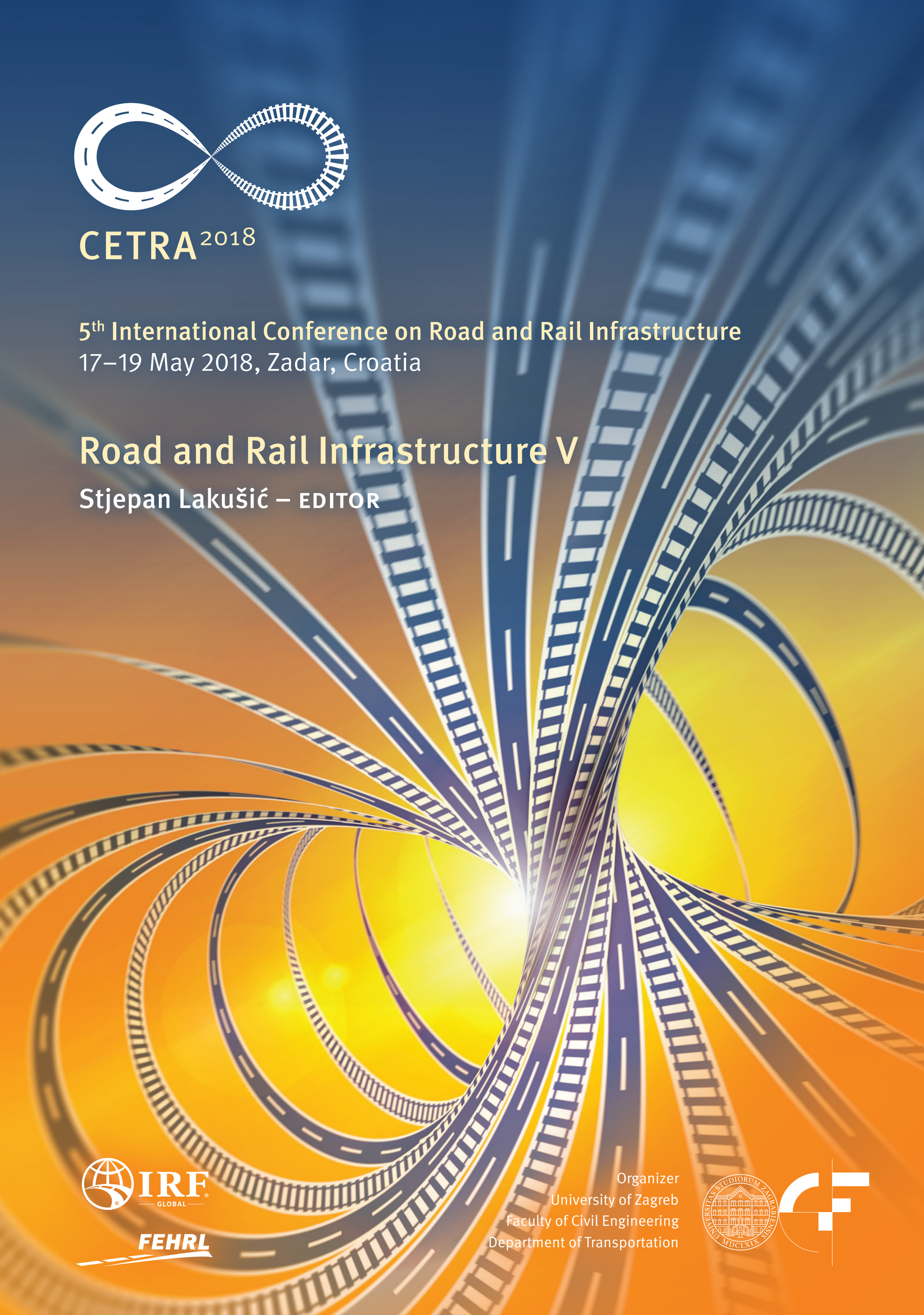

CETRA 2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – **EDITOR**

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THE FIRST BRIDGE WITH POLYMER FIBRE REINFORCED CONCRETE RIDING SURFACE IN THE CZECH REPUBLIC

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Abstract

In Central European conditions, a deck of a concrete bridge usually consists of several layers with specialized functions: load-bearing reinforced concrete slab, adjusting layer, waterproofing layers (asphalt or polymer) and riding layers (bitumen or concrete). The concept where all the functions are integrated into one layer (called “unprotected concrete bridge deck – UCBD” in this paper) is rarely used. This is mainly due to lack of experience with materials and structural solutions suitable for this type of structures. This paper deals with the development and pilot application of a material for UCBD structure in the Czech Republic. Considering the requirements on the structure and the material, polymer fibre reinforced concrete (PFRC) was selected as the most suitable alternative. The composition of the material was optimized during an extensive experimental program, which included tests of slump, air content, compressive strength, flexural strength, elastic modulus, resistance to water with deicing chemicals, depth of penetration of water under pressure, abrasion resistance, chloride ingress and shrinkage. The developed material was then applied on a small-span bridge on a local motorway. The structure and the construction process are also briefly described in the article. The pilot structure will be subjected to long-term monitoring with the aim to verify the reliability of UCBD concept with the use of the developed PFRC. Life-cycle costs analysis will be carried out to assess the economic efficiency of the solution.

Keywords: polymer fibres, fibre reinforced concrete, riding surface, unprotected bridge deck

1 Introduction

In Central European conditions, a typical structure of a concrete bridge deck consists of several layers with specialized functions: load-bearing reinforced concrete slab, adjusting layer, waterproofing layers (asphalt or polymer) and wearing/riding layers (usually asphalt). Another possibility is to use so called unprotected concrete bridge deck (UCBD), where all the functions are integrated into one layer. Load-bearing structure is not protected against environmental and traffic loads. This approach is rarely used in European countries.

The pilot structure presented in this paper exploits polymer fibre reinforced concrete (PFRC) for UCBD. It is the first structure of its kind in the Czech Republic and according to the knowledge of the authors, PFRC has not been used for UCBD anywhere else in Europe before.

UCBD concept has many technological and economic advantages arising from its simplicity. Thanks to the exclusion of several structural layers, the construction process is simpler, faster, less demanding in terms of required machinery and coordination of subcontractors. The risk of many defects and failures such as delamination of structural layers or rutting is eliminated. On the other hand, some additional technological requirements have to be taken into account as a result of missing protection of the load-bearing structure. The directive for concrete bridges of the Ministry of Transport of the Czech Republic [1] requires secondary corrosion

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protection of reinforcement in case that all the load-bearing structures are built without waterproofing. There are increased demands on the quality of concrete; besides high strength, very good resistance to abrasion, freeze-thaw cycling, water with deicing chemicals and penetration of water under pressure is required. A very good work discipline on the construction site is crucial as potential defects of the surface of the load-bearing structure (unevenness, scaling etc.) cannot be corrected in the additional layers.

The objective of the presented work was to develop a suitable material for UCBD, to apply it on a pilot structure and to verify its applicability in Central European climate conditions.

2 Polymer fibre reinforced concrete

Fibre reinforced concrete was selected as a prospective material for UCBD. The dispersed reinforcement limits the width of potential cracks and therefore increases the resistance of the material to all environmental loads. The fibres also improve the abrasion resistance of concrete. The aim was to design a concrete mix complying with all the requirements of the valid standards and directives, mainly TKP18 [1] and TP260 [2].

The process of optimization of PFRC mixture was described in detail elsewhere [3]. Based on the professional experience of the authors, polypropylene fibres Forta Ferro were selected as the most appropriate dispersed reinforcement. The use of steel fibres was considered, but rejected by the infrastructure operator due to his worries about surface corrosion and possibility of damage of tyres of passing vehicles. The final composition of the PFRC mix that was applied in the pilot structure is given in table 1.

Table 1 Composition of the PFRC mixture

Compound	Specification	Quantity [kg/m^3]
cement	CEM II/A 42.5 R	425
water	-	170
water to cement ratio (w/c)	-	0.4
aggregate	0/4 fraction	800
	4/8 fraction	160
	8/16 fraction	490
	11/22 fraction	280
air-entrainer	Microporan 2	0.51
superplasticizer	Stachement S33	2.60
fibers	Forta Ferro 54 mm	3

The material was subjected to a set of tests that proved its sufficient mechanical properties and durability. The applied testing methods were described in [3]; the results for the final mixture are summarized in table 2. In cases when two directives demanded different value of a parameter, the stricter one was considered.

TP260 [2] specifies two additional requirements that couldn´t be verified by direct experiments. These were analysed by deterministic numerical simulations.

The difference in shrinkage of the precast and monolithic part of the structure after 28 days should be max. 150 μm/m. The shrinkage of the applied PFRC mixture after 28 days was determined on 100x100x500 mm samples according to ČSN 73 1320 [5] as 289 μm/m. By calculation in CaS software [6] based on B3 model [7], shrinkage of 273 μm/m was obtained for 100x100x500 mm samples when 50 % ambient relative humidity was considered. This confirmed that the material behaves in accordance with B3 model and that the CaS software can be used to estimate the shrinkage of the PFRC UCBD structure. The calculation resulted in the value of shrinkage of the monolithic PFRC layer of the deck of 52 μm/m (the values of shrinkage of the sample and the real structure differ significantly due to different ratio of cross-sectional area to naked surface exposed to drying), which was considered as a proof that the structure will comply with the given requirement.

The diffusion coefficient of chlorides into concrete at the age of 10 years $D_{c,3650} < 2.5\text{x}10^{-12}$ m^2/s is required. By calculation in CarboChlorCon software [8] based on model by Kwon et al. [9], diffusion coefficient of $D_{c,3650} = 1.2\text{x}10^{-13}$ m^2/s was determined. This value would be satisfactory even for uncoated carbon steel reinforcement (requirement: $D_{c,3650} < 1.5\text{x}10^{-12}$ m^2/s), while in the given case the secondary protection of reinforcement of upper surface of the structure by 0.3 mm thermoplastic coating was designed due to the requirements of TKP18 [1].

Table 2 PFRC mixture test results

Requirement	Source	Required value	Measured value	Met?
Cement content	TP260 [2]	min. 350 kg/m^3	425 kg/m^3	YES
Water/cement ratio	TP260 [2]	max. 0.4	0.40	YES
Slump-test	TKP18 [1]	min. S3	S4-190 mm	YES
Air content	TKP18 [1]	min. 4.0 %	4.2 %	YES
Compressive strength	TKP18 [1]	min. C 30/37	C 35/45	YES
Flexural strength	TKP18 [1]	min. 3 MPa	4.7 MPa	YES
Abrasion resistance	EN 206-1/Z3 [4]	min. C 30/37	C 35/45	YES
Exposure class	TP260 [2]	XC4, XD3, XF4, XM2	XC4, XD3, XF4, XM3	YES
Resistance to water and deicing chemicals	TKP18 [1]	max. 1000 g/m^2 after 100 cycles, meth. A	714 g/m^2	YES
Depth of penetration of water under pressure	TKP18 [1]	max. 20 mm	13 mm	YES

3 Structure

The developed material was used for the reconstruction of Na Kácku bridge in Sázava town near Prague in the Czech Republic. The structure was a small-span one-lane bridge connecting Sázava town with an island in Sázava river where a hotel, a restaurant, a camping ground and various sports facilities are located. The original structure was heavily damaged by repeated floods in the last 15 years, therefore its complete removal and replacement was necessary.

Reinforced concrete slab bridge with UCBD made from PFRC was designed with the parameters described in figures 1 and 2. The structure was found on two triplets of 7800 mm long micropiles (steel tubes TR89/100 S355 filled with cement grout) with 5000 mm long root of 200 mm diameter. The bridge deck was connected to the micropile foundation by 800x880 mm reinforced concrete crossbeam.

Load model LM1 and traffic class 2 according to EN 1991-2 were considered for the structural analysis that was performed according to EN 1992-1-1, EN 1992-2 and EN 1990. UCBD was designed as a composite structure consisting of precast permanent formwork panels of 120 mm thickness and monolithic PFRC deck of 330 mm thickness to speed up the construction process. The two parts of the deck were connected by diagonals of filigran reinforcement of the panels. The main reinforcement of the deck was as follows:

- Lower surface: 7x 25 mm B500B steel bars per 1 m in longitudinal direction, 7x 12 mm B500B steel bars per 1 m in transversal direction (in the precast panels);
- Upper surface: 7x 12 mm B500B steel bars per 1 m in both directions, 7x 14 mm additional B500B steel bars per 1 m above the supports in longitudinal direction. Reinforcement of the upper surface was protected by 0.3 mm thick thermoplastic coating.

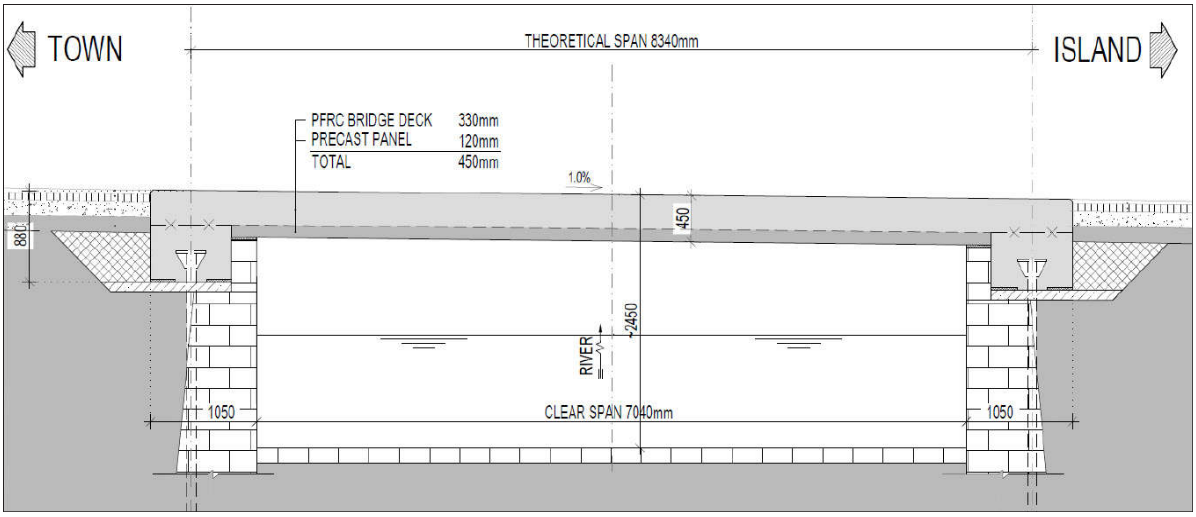

Figure 1 Simplified longitudinal section

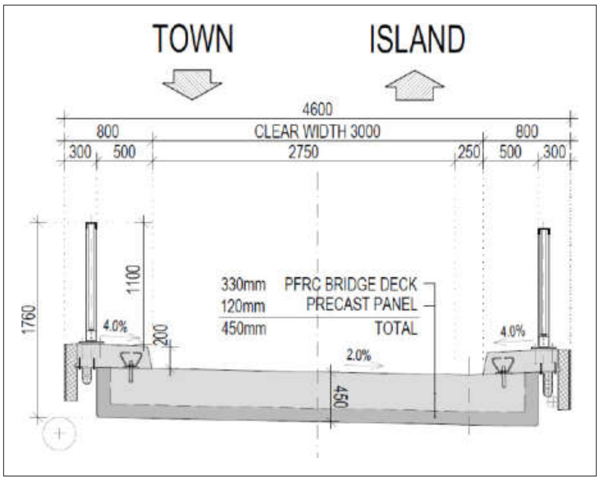

Figure 2 Simplified transversal section

Additional requirements of TP260 [2] directive for structures with UCBD were checked:

- Crack width: Width of cracks of the wearing surface of UCBD from frequent load combination is limited to 0.15 mm. Maximum bending moment on the upper surface of the bridge deck (at supports) was 55.9 kNm/m, while the cracking moment was 112.5 kNm/m. No cracks should occur from frequent load combination.
- Minimum UCBD thickness: 130 mm is required. Monolithic part of the deck has the thickness of 330 mm.
- Shrinkage reinforcement of UCBD: At least 12 mm bars per 150 mm in both directions are required on the wearing surface. The provided reinforcement is sufficient.
- Cornices: Minimum height of the cornices should be 150 mm, maximum spacing of expansion joints should be 6 m. The height of the cornices was 200 mm and the spacing of the joints was 5.2 m in the given structure.

4 Construction

At first, the original bridge was removed, then the micropiles were concreted, abutments were repaired, permanent formwork panels were placed on the abutments and supported by adjustable steel props, formwork for crossbeams was prepared and the reinforcement was placed into the formwork. Concreting of the PFRC UCBD followed. The surface of concrete was levelled and dragged by burlap (figure 3).

Figure 4 demonstrates that high quality of PFRC surface of the UCBD was reached. There are no significant non-homogeneities and no cracks on the surface. Small non-homogeneities together with scarifying secure sufficient roughness of the surface that is necessary for good anti-skid properties.

Figure 3 Left: Levelling of concrete surface. Right: Surface of fresh concrete after burlap dragging.

Figure 4 demonstrates that high quality of PFRC surface of the UCBD was reached. There are no significant non-homogeneities and no cracks on the surface. Small non-homogeneities together with scarifying secure sufficient roughness of the surface that is necessary for good anti-skid properties.

Figure 4 Left: The new bridge. Right: The surface of PFRC UCBD.

5 Cost analysis

The following savings were identified for Na Kácku bridge in comparison with traditional solution with the use of special waterproofing and wearing layers:
- Elimination of primer and waterproofing layers: 1130 EUR;
- Elimination of asphalt surface and protection of waterproofing: 1580 EUR;
- Elimination of the future repairs of asphalt wearing surface: 740 EUR;
- Shortening of construction time by 15 days: 1250 EUR.

On the other hand, the following additional costs arose due to the use of the UCBD technology:
- Thermoplastic coating of upper reinforcement of UCBD: 1380 EUR;
- Forta Ferro polymer fibres: 740 EUR.

The total savings reached 5 % of the total costs of the project. Similar savings can be expected for all bridges of the same type and size. For different types of bridges, the economic balance may be different based on the ratio of the costs of the bridge deck and the total costs of the project. The shortening of the construction time had positive effect also on the economic subjects on the Sázava island (hotel, restaurant etc.) as the public access was very limited during the reconstruction. The owners did not provide the exact amounts of the savings, but their estimation was in the order of several thousand EUR. The structure will be monitored in the following years in order to assess operation and maintenance costs. More detailed life cycle costs analysis will be performed once relevant data is gathered.

6 Conclusions

The technology of PFRC UCBD is applicable for construction or reconstruction of both roadway and railway bridges. It is especially suitable for small-span slab bridges on roads with lower traffic load or pedestrian bridges. Despite many technological and economic advantages, the technology of unprotected concrete bridge deck is rarely used in Europe, mainly due to very limited experience of the designers. The construction of the pilot structure of Na Kácku bridge has proved some of the benefits of the technology. In the future, it will help to verify the behaviour of the unprotected bridge deck in the long-term scope, to enable application of the technology on more structures of the similar type and – in the ideal case – to provide support for its application on larger bridges as well.

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References

[1] Ministry of Transport of the Czech Republic, Technical guidelines for roadways – Part 18: Concrete structures and bridges (TKP18), Prague, Czech Republic, 2016.

[2] Ministry of Transport of the Czech Republic, Directly runned roadway bridges (TP260), Prague, Czech Republic, 2016.

[3] Fládr, J., Bílý, P., Ryjáček, P., Vodička, J.: Development of special fibre reinforced concrete for exposed concrete pavements on bridges, Proceedings of Fibre Concrete 2015 – Technology, Design, Application, Prague, Czech Republic, 2015.

[4] Czech office for standards, metrology and testing, ČSN EN 206-1/Z3 Concrete – Part 1: Specification, performance, production and conformity, Prague, Czech Republic, 2008.

[5] Czech office for standards, metrology and testing, ČSN 73 1320 Determination of volume changes of concrete, Prague, Czech Republic, 1987.

[6] Vráblík, L.: CaS – Software for determination of effects of creep and shrinkage of concrete using B3 model, http://people.fsv.cvut.cz/www/vrablluk/Veda.htm, 28.02.2017.

[7] Bažant, Z. P.; Baweja, S.: Creep and Shrinkage Prediction Model for Analysis and Design of Concrete Structures: Model B3, Adam Neville Symposium: Creep and Shrinkage – Structural Design Effects, Farmington Hills, Michigan, USA, 2000.

[8] Šmilauer, V., Pohl, K.: CarboChlorCon 1.0 – software for concrete carbonation and chloride ingress, https://mech.fsv.cvut.cz/~smilauer/index.php?id=software, 15.03.2017.

[9] Kwon, S.J., Na, U.J., Park, S.S., Jung, S.H.: Service life prediction of concrete wharves with early-aged crack: Probabilistic approach for chloride diffusion, Structural Safety Vol. 31(1) (2009), pp. 75-83.