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28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

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REHABILITATION OF STEEL RAILWAY BRIDGES BY IMPLEMENTATION OF UHPFRC DECK

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Abstract

Nowadays on the existing railway infrastructures many bridges can be found that have been built more than 50 years ago, and which were not designed for current loads and high speed trains. These are mainly bridges from hot rolled steel or cast iron and connected with rivets. The main idea of strengthening existing steel bridges is considering the possibility of adding load bearing deck above the main girders without replacing them. Converting alone metal section to composite cross-section raises the centre of gravity so that section can handle additional loads. In addition, the concrete deck may stiffen upper steel flange and thus eliminates the problem of stability of compressed part of the cross-section. In this paper the research on innovative rehabilitation method for the existing steel bridges is presented. The research has been performed within FP7 SMART RAIL project, and is based on the case study of rehabilitation project of the small non-ballasted steel bridge. The selected bridge ("Buna" bridge in Croatia) was built in 1893, with the first reconstruction in 1953. Since the steel structure of the old Buna Bridge had to be completely replaced, the bridge was dismantled and transported to the laboratory for the experimental assessment and development of the new rehabilitation method. The new design is based on the implementation of the prefabricated ultra-high performance fibre reinforced concrete (UHPFRC) deck. It is expected that this strengthened cross-section will be able to withstand the increased load, as required by contemporary regulations.

Keywords: steel bridge, railways, rehabilitation, ultra-high performance concrete

1 Introduction

Nowadays on the existing railway infrastructures many bridges can be found that have been built more than 50 years ago, and which were not designed for current loads and high speed trains. These are mainly bridges from hot rolled steel or cast iron and mainly connected with rivets. By economic and environmental reasons, it would be a great benefit to extend the service life of these bridges, instead of demolishing or reconstruction. The main idea of strengthening existing steel bridges is considering the possibility of adding load bearing deck above the main girders without replacing them, [1-3]. Converting alone metal section to composite cross-section raises the centre of gravity so that new composite cross-section can carry additional loads. In addition, the concrete deck stiffen upper steel flange and thus eliminates the problem of stability of compressed part of the cross-section.
In this paper the research on innovative rehabilitation method for the existing steel bridges is presented. The research has been performed within FP7 SMART RAIL project, and is based on the case study of rehabilitation project of the non-ballasted steel bridge, [4].

2 Case study: Buna bridge

2.1 Description of the Buna bridge

Buna Bridge in Croatia was built in 1893, with the first reconstruction in 1953 which held up to date. Bridge spans the creek Buna and is located on the Zagreb-Sisak railway line. The bridge is about 9 meters long and 0.9 m high. Cross-section consists of two main girders made of hot rolled steel plates joined with rivets and represents a typical beam construction from the time in which it was created. Main girders are connected by horizontal and vertical grids for stiffening. Because of its location near Zagreb and handling weight of only 8.0 tons, this non-ballasted bridge was a perfect choice for transportation in the testing laboratory.

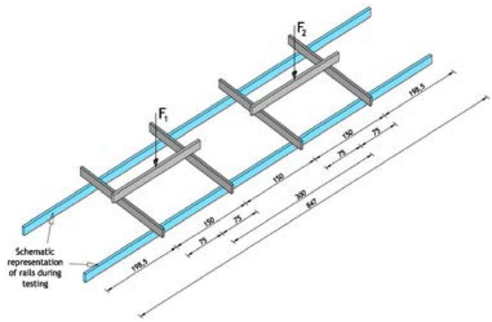
Figure 1 Location of Buna bridge

2.2 Condition assessment of existing bridge in the laboratory

To obtain results for comparison, it was decided that the Buna bridge will be tested before and after strengthening at the Laboratory for Structures at Institute IGH in Zagreb.

Figure 2 Bridge transported into laboratory

It is assumed that the bridge will withstand the load according to EN 1991-2 using Load Model 71 [5]. It is four axle load of 250 kN each at a distance of 1.6 m. The characteristic values are multiplied by a factor α on lines carrying rail traffic which is heavier or lighter than normal rail traffic. The value 1.33 is normally recommended on lines for freight traffic and international lines [6]. Finally, it is necessary to increase the load by dynamic factor for standard maintained track Φ_3. For simply supported girders dynamic factor Φ_3=1.527 for determinant length L_Φ=8.47 m is used so the total force load amounts 1530 kN.

a) 

b) 

Figure 3 a) Schematic representation and b) Load distribution during testing.

During testing following parameters were measured: applied forces; vertical deflection of each girder on elastomeric supports; vertical deflection in the middle of the span; and stresses on upper and lower flange of each girder in the middle of the span. The results are given in diagrams in Figure 4 and Figure 5 and in Table 1. Equipment used for testing was following:

- two load cells – capacity each 1000 kN;
- two hydraulic pistons – capacity each 1000 kN;
- six linear variable differential transformers (LVDT);
- four strain gauges – 120Ω, base length 10 mm;
- National Instruments PXI and SCXI acquisition device.

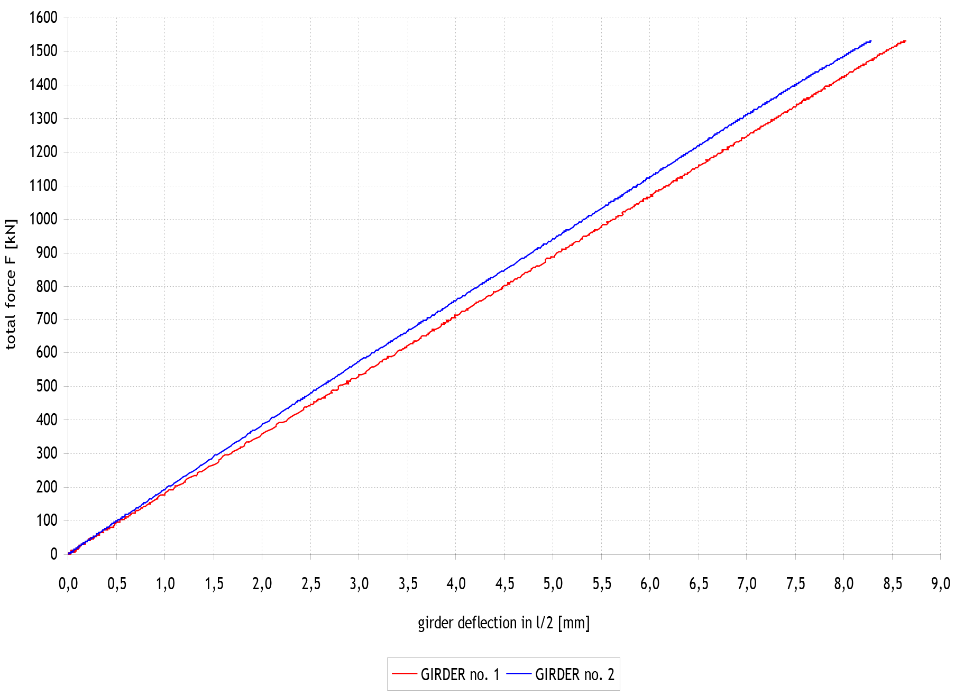


Figure 4 Diagram of girder deflection in l/2 during testing

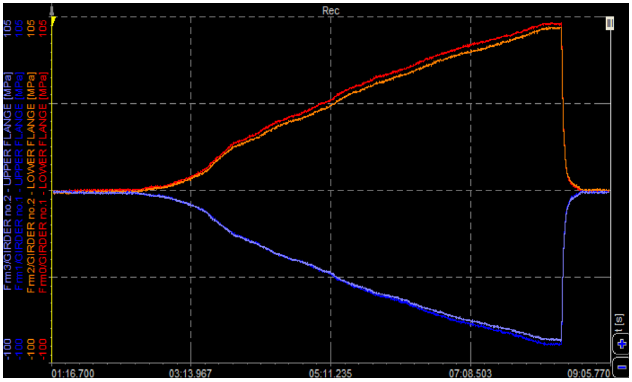


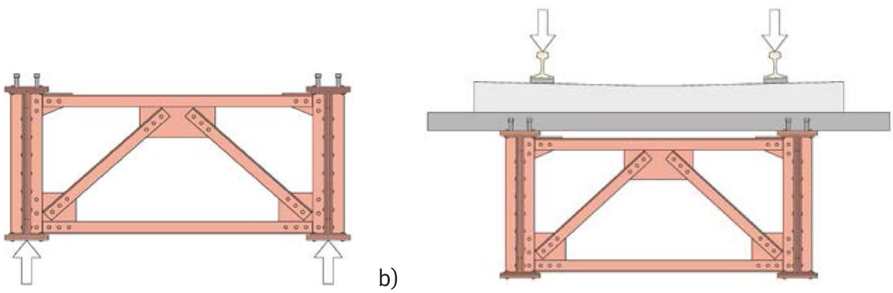
Figure 5 Diagram of stresses during testing

Table 1 Laboratory testing results

Force [kN]			Displacement in l/2 [mm]		Flange stress [MPa]			
F_1	F_2	total (F_1+F_2)	girder no. 1	girder no.2	girder no. 1		girder no. 2	
					upper	lower	upper	lower
756.53	772.52	1529.05	8.64	8.28	-89	101	-87	98

2.3 Design concept of the bridge strengthening

Main idea is to convert alone metal section to composite cross-section. The composite cross-section will increase load bearing capacity and reduce the stress range of live load. The dynamic effects of live loading will also be reduced and concentrated load effects on non-ballasted steel structure would be diminished. Steel structure will be supported during casting in order to increase the bearing capacity of the bridge structure, as schematically presented in Figure 6a, because composite cross-section already carries its own weight and all additional loads.



a) b)

Figure 6 Cross-section a) before and b) after the completion

The new design will be based on the implementation of the cast in situ ultra-high performance fibre reinforced concrete (UHPFRC) deck, as it can be seen in Figure 6b, because of the exceptional mechanical and durability properties of this material.

2.4 Laboratory testing after rehabilitation

Besides testing with the same load arrangement as before rehabilitation, it is planned to test the bridge after rehabilitation with load arrangement and magnitude according to Load

Model SW/2 which represents the static effect of vertical loading due to heavy rail traffic (it is a continuous load of 150kN/m). At the moment of finalizing this paper steel headed dowels are being prepared for welding to the main steel girders, after which ultra-high performance fibre reinforced concrete (UHPFRC) deck will be cast in-situ. Current status of rehabilitation work on the bridge structure can be seen in Figure 7. It is also planned to carry out fatigue testing on bridge after rehabilitation, using cyclic loading with a frequency and duration yet to be contemplated. It is expected that this strengthened cross-section will be able to withstand the increased load, as required by contemporary regulations.

Figure 7 Bridge in process of rehabilitation

3 UHPFRC based rehabilitation methods

Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) is an exceptional cmentitious material characterized by a unique combination of extremely low permeability, high strength and deformation capacity (tensile strain hardening, Figure 8). Extensive R&D works and applications over the last 10 years have demonstrated that cast on site UHPFRC is a fast, efficient and price competitive repair and rehabilitation method for existing structures. UHPFRC provides the structural engineer with a unique combination of extremely low permeability, high strength and tensile strain hardening material. UHPFRC is perfectly suited to the rehabilitation of reinforced concrete structures in critical zones subjected to an aggressive environment and to significant mechanical stresses, to provide a long-term durability and thus avoid multiple interventions on structures during their service life, following maintenance strategy “A” as presented in Figure 9.

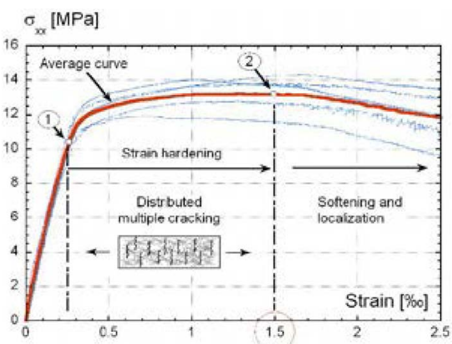


Figure 8 Tensile response of UHPFRC (results from 5 dog bone specimens and average curve, after [7])

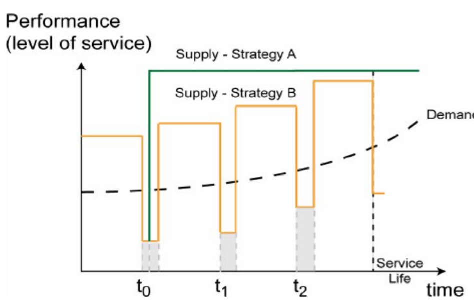


Figure 9 Maintenance strategy of preventing multiple interventions on structures during their service life, [7]

Recent real on-site applications have that UHPFRC can, apart from non-bearing rehabilitations (Log Čezsoški, Ligtening tower), successfully be applied for strengthening of different structures (Strengthening of a 50 year-old reinforced concrete floor of a fire brigade building in Geneva in view of heavier future fire engines(2007), rehabilitation of a 28.5 m span bridge deck of bridge "Dalvazza" (2008)). By introducing an original concept of ECO-UHPFRC with a high dosage of mineral addition, a low clinker content, and a majority of local components, which was within the FP7 research project ARCHES successfully applied for the rehabilitation of a bridge Log Cezsoski in Slovenia, it has been shown, that UHPFRC based rehabilitation methods can also be more sustainable than traditional ones [8]. Based on 10-year on-site experiences a FP7 research project SmartRail has been launched, which goal, among others, was to transfer, apply and prove the UHPFRC based rehabilitation techniques for the rehabilitation of old steel bridges. The advantages of UHPFRC particularly valuable for rehabilitation of railway bridges are high strength and ductility, low added dead load, low added thicknesses, i.e. change in the track vertical alignment, extreme durability. Based on an extensive research work a UHPFRC composition whose main characteristics are listed in Table 2 was chosen to be applied on the old steel railway bridge Buna, Croatia for one-to-one in-lab investigations. The test performed and the results are presented in the next chapter.

Table 2 Main characteristics of UHPFRC used in the investigation

Cement content	540 kg/m^3
Mineral addition	800 kg/m^3
Steel fibres	450 kg/m^3
Superplasticizer	0,9 % on cement
Aggregate 0/2	570 kg/m^3
Compressive strength @ 28 days	150 MPa
Bending strength @ 28 days	35 MPa
Air permeability (Torrent method)	0,01E-16 m^2
Restrain shrinkage	No cracking

4 Conclusion

The majority of the remaining old steel railway bridges will not pass assessment using modern codes of practice. This is because of the extra loading associated with the installation ballasted deck loading, combined with on-going corrosion and fatigue cycles. This is particularly apparent in the deck area due to the lack of drainage and the dynamic impact loadings particularly on non-ballasted bridges. The bridges as a whole may have the capacity to resist the current loading as factored using modern risk and probability factors, however with the desired loading of modern design codes, the requirements of extra deck loading and a desirable extended life of the structure, the bridge will generally fail assessment. This normally occurs because of lack of capacity in the deck with the main load bearing structural elements and other elements either failing by a small percentage or just being sufficient. The UHPFRC composite deck system has been shown to be of significant benefit to this bridge structure. The composite deck has increased the decks capacity and reduced the stress range of live load stress. It has reduced the dynamic factor and concentrated load effects on the previous steel structure.

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