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Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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IN-SERVICE PERFORMANCE OF ROAD CONCRETE BRIDGES – SET UP OF CASE STUDIES FOR NOVEL PRO-ACTIVE MAINTENANCE METHODOLOGY

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Abstract

Condition assessment of six bridges: Maslenica Bridge, Šibenik Bridge, Adriatic Bridge, Bridge of Youth, Homeland Bridge and Žeinci Bridge are presented in the paper. The bridges are of different type, age, material and traffic demands, but their in-service performance confirms steel corrosion in concrete as main deterioration cause. Influences of age, environment, climate and construction quality on bridge durability are analysed. The presented bridges will be used as case studies for proposed novel methodology of pro-active bridge maintenance based on visual inspection complemented with the non-destructive testing and application of numerical model for service life prediction.

Keywords: bridge, visual inspection, repair, condition assessment, corrosion

1 Introduction

The overwhelming majority of road bridges in Croatia are made of concrete: reinforced (RC) and prestressed (PC), while their main cause of deterioration is steel corrosion in concrete. Existing re-active maintenance policies based on visual inspection do not provide efficient and sustainable bridge management because corrosion induced damage and defects can be detected in advanced stage only. Hence new approach of pro-active maintenance of concrete bridges is proposed including visual inspection complemented with the non-destructive testing (NDT) and application of numerical model for service life prediction [1, 2]. Chosen NDT are simple yet cost efficient methods to evaluate (i) concrete quality and uniformity; (ii) concrete damage and crack geometry; (iii) concrete resistivity and (iv) reinforcement quantity and electrical potential [1, 2].
Numerical models for service life prediction of RC structures have been developed and subsequently improved in the last three decades. Recently developed 3D chemo-hygro-thermo mechanical (3D CHTM) model is one of the most comprehensive models for realistic simulation of transport and corrosion processes before and after depassivation of reinforcement bar in concrete taking into account damage in concrete caused by mechanical loads [3-8]. The 3D CHTM model has proved its ability for realistic simulation of mechanical and corrosion processes on several case studies [9]. However, quantifying the material, mechanical and corrosion

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related parameters and their interactions are still challenging tasks and main objective of the current research project. Application of the 3D CHTM model on existing bridges will contribute to the development of engineering models and formulation of design rules in order to increase the durability of structures and reduce their maintenance costs.

Table 1 Basic data on case studies

Bridge name	Bridge type	Road authority	Opened to traffic
Maslenica Bridge	RC deck arch Superstructure: prestressed continuous T girders + RC slab	Croatian Motorways	1997
Šibenik Bridge	RC deck arch Superstructure: prestressed simple supported T girders + transversely prestressed slab	Croatian Roads	1966
Žeinci Bridge	RC tied arch Superstructure: grillage system of longitudinal and transverse beams	County roads of Krapina-Zagorje County	1913
Adriatic Bridge	Prestressed continuous I girder + RC slab	City of Zagreb	1981
Bridge of Youth	Composite continuous girder: steel box girder + RC slab	City of Zagreb	1974
Homeland Bridge	Externally prestressed continuous box girder + transversely prestressed slab	City of Zagreb	2006

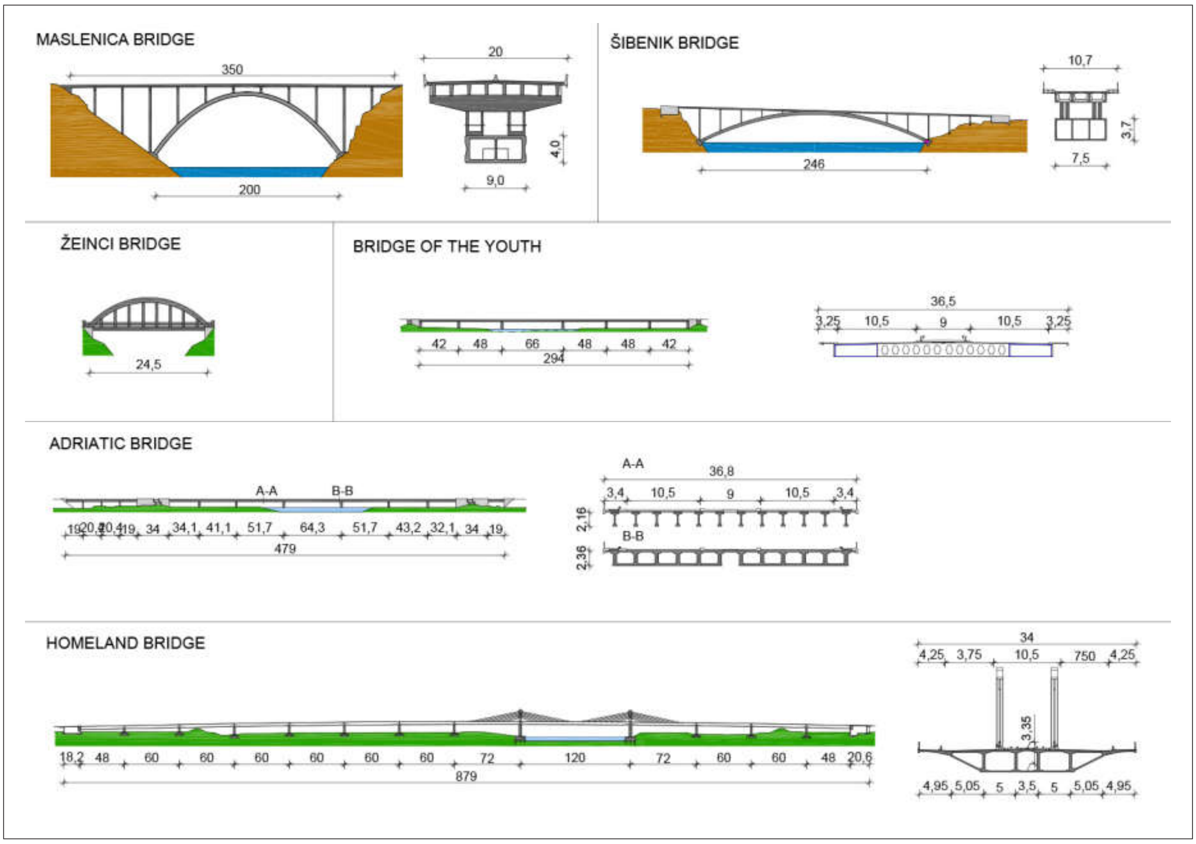

Figure 1 Case studies – bridges layouts

The proposed methodology will be demonstrated on six concrete road bridges of different type, age, material and traffic demands; managed by four different road authorities (Table 1, Figure 1). Maslenica and Šibenik Bridge are exposed to maritime environment, while other bridges are located in continental climate and exposed to de-icing agents during winter period. The oldest among them is Žeinci Bridge, built 105 years ago. Lower exposure to chlorides and reduced traffic demands have contributed to its long life. Unfortunately, there is no available data on design, construction and maintenance of this bridge; hence its overall condition assessment will be given after detailed visual inspection and NDT, planned to be conducted within the current research project [2]. Condition assessment of other five bridges, with available data on maintenance programme, will be provided in next chapter in order to evaluate vulnerability to reinforcement corrosion.

2 Case studies: condition assessment

2.1 Maslenica Bridge

Bridge visual inspection, measuring concrete cover, determining surface hardness by rebound hammer, concrete compressive strength and elasticity modulus on taken samples, as well as chloride content and gas permeability were carried out in 2006 [10]. The results were compared to initial (laboratory) testing from 1995-1996, which showed higher compressive strength than design value, and lower permeability due to continued hydration process and carbonation [11]. Detailed visual inspection of all structural members accompanied by chloride content measurements was conducted in 2010 [12]. It was concluded [13] that the bridge is in good condition; however, there is some localized damage with the areas of exposed corroded reinforcement on arch abutment columns assessed as requiring immediate repair and protection. The concrete cover depth at those locations was smaller than 5 cm prescribed in bridge design specifications. Determination of chloride content was carried out on the total of 120 specimens taken from 24 locations distributed among the arch abutments, the arch itself, the arch abutment columns and the superstructure showing uneven distribution of chloride content, depending on the location from which the specimen was taken, with higher content and deeper penetration on the surfaces facing north.
The testing programme was amended in 2012 [14] with testing concrete strength and homogeneity of concrete, determining the location of reinforcing bars and concrete cover depth, carbonatization depth, adding new positions for chloride content measurements, identifying crack patterns and widths and delamination zones, determining mechanical and chemical properties of concrete and

Figure 2 Repair of Maslenica Bridge after 20 years of service

reinforcing steel, testing concrete permeability (to gases, water absorption, chloride migration / diffusion). Those tests were determined as necessary for developing an appropriate repair design. It was concluded that the concrete compressive strength is approximately 20 % higher than prescribed in design specifications. Unfortunately, the testing related to concrete permeability showed poor results and the chloride content was above critical (0.4 % of cement mass) at approximately 20 % of concrete surfaces.
The repair has started in spring 2016 with 2 types of repair solutions employed depending on the results of corrosion risk assessment [14]. Structural members for which corrosion is

assessed to be still in its initiation period (arch, external main girders, all columns except those at the arch springing up to 35 m a.s.l.) are repaired by corrosion inhibiting impregnation, structural repair mortar and protective coating. Type 2 repair (for columns at the arch springing up to 35 m a.s.l. and arch abutments) includes repair with high strength micro reinforced concrete (with increase of concrete cover depth on columns), subsequently applying surface protection.
At the same time, an effort was made [14] to put in operation corrosion monitoring system installed during bridge construction. 16 corrosion sensors were found to be installed adequately, and subsequently 19 were used for measurements [15].

2.2 Šibenik Bridge

An inspection of Šibenik Bridge carried out in 1989 revealed [16] very poor condition of the superstructure due to water seepage through the joints that have opened in the asphalt as there was no waterproofing layer. Immediate repair was requested, but was not carried out. Detailed inspection was then undertaken in 1995 [16] including NDT of concrete mechanical properties (4 locations), measurements to assess the condition of embedded reinforcing and prestressing steels (crack width measurements by microscope and ultrasonic testing, corrosion potential measurements and check of prestressing tendons by endoscope at 2 locations), determination of concrete compressive strength, chloride content and carbonatization depth (11 specimens from 4 locations), confirming earlier conclusions. The bridge was also damaged by missiles during the War in 1990s (to the arch and the superstructure), which were repaired (est. 1996). In 1985 a finger expansion joint was installed, and the other in 1999, when some repairs on sidewalks were also carried out [17]. Another thorough inspection was in 2005 [16, 18] when chloride ingress and concrete cover testing at 20 locations was carried out showing that the process of corrosion started at the arch abutment on Šibenik side. Geodetic measurements were also conducted at the time as the bridge, constructed by suspended cantilever technique, has in the first 10 years of its service experienced substantially larger creep and shrinkage deformations than expected by the design.
The inspection and testing from 2005 were the basis for repair design. The repair was completed in 2012. It included [19] removing the asphalt layer, placing the waterproofing and new courses with elastic expansion joints at all supports (except at locations of finger joints), complete reconstruction of sidewalks (with lightweight aggregate concrete) and curbs, and repair to cornice, railings and existing expansion joints. Drainage was improved by adding new gutters. The work had to be executed carefully as the roadway slab is transversely prestressed. The repair of the main and cross girders focused to the area close to the supports: poor concrete was removed by water under pressure; the reinforcement appropriately cleaned, amended and protected; and repair mortar applied. The same procedure was used to repair the underside of cantilevers carrying the sidewalks. Localized damage found on all elements was also repaired. External concrete surfaces were subsequently protected with corrosion inhibiting impregnation and crack bridging and anti-carbonation protective coating. The repair of the structure that connects the superstructure and the arch at its crown was treated separately, as large number of wide cracks appeared. This part of structure was thus additionally inspected in detail in 2009 [20]. Finally, the repair design [21] stipulated injection of all cracks and repair using structural repair mortar, as well as subsequently applying surface protection.

2.3 Bridge of Youth

The last main inspection of Bridge of Youth was carried out in 2017 [22] for the whole bridge comprising two viaducts and the main bridge. This comprehensive inspection included investigative work to determine the condition of concrete. South east part of the approach viaduct was rehabilitated in 2010 due to reinforcement corrosion. Inspection determined that most of the bridge is structurally and functionally not compromised. Maintenance work is recommended for restoration of bridge equipment such as drainage, and restoration of corrosion protection. Expansions joints and bearings show most damage, they are to be replaced. Reinforced concrete shows signs of reinforcement corrosion in sidewalks part of the deck, with concrete protective layer cracking and delamination, these are to be repaired. Deck waterproofing does not exist; it needs to be placed during next asphalt replacement. Some of the columns steel envelope is corroded and detached from concrete. The worst condition of the bridge is in its central and west part of the south approach viaduct. This part needs immediate repairs and partly replacement of concrete deck and cantilevers and replacement of the sidewalks, cornice and repairs on parts of the columns.

2.4 Adriatic Bridge

The last main inspection of Adriatic bridge was carried out in 2017 [23] for the whole bridge comprising two viaducts and the main bridge. During inspection, investigative work was done to determine chloride level and strength in concrete. Critical chloride level was determined across 4 cm depth in columns S1, hence these elements need to be repaired. Inspection determined that the damage to structural parts of the bridge are of such a scope that the bearing capacity of the bridge is reduced. The damage is as follows: sidewalks cantilevers concrete delamination due to reinforcement corrosion, asphalt cracking, curb damage, railing corrosion, cornice delamination and cracking, expansion joints blockage, main girders severe reinforcement corrosion and concrete cracking, drainage clogging, columns and abutments reinforcement corrosion, bearings corrosion and misalignment, cracking of concrete bearing pedestals. Box girders of the main central part of the bridge over Sava River are heavily damaged due to reinforcement corrosion, with large parts of the concrete protective layer missing and reinforcement area significantly reduced. Drainage leakage inside box girders is recorded with fills of mud and water. South abutment is severally damaged from water leakage and reinforcement corrosion, with bearings damage. Recommendation is given for the need of extensive rehabilitation.

2.5 Homeland bridge

Repair work on Homeland Bridge was performed in 2012 focusing on rehabilitation of the cable stay anchors due to problems of inadequate drainage around them, which caused water to leak around the anchors inside the box girder. Rehabilitation comprised new waterproofing and concrete layer for inclination towards drains. Main inspection of Homeland bridge was carried out in 2017 [24] and it was concluded that the structure is in good condition. Some minor local cracking around anchor beams was noticed, which is to be monitored for the next 5 years. Cable stay deviators exhibit moderate cracking, but without signs of reinforcement corrosion. Most severe damage was noticed around previously rehabilitated cable stay anchors: water is still leaking around anchor pipe protection inside the box girder, hence new rehabilitation is recommended. Bridge substructure is in relatively good condition. Some cracking is recorded on the abutment foundation plate which should be sealed with injecting. Repairs are needed on most of drains which are clogged through the bridge, and some drainage pipes, to avoid further damage from water.

3 Conclusion

Presented case studies confirm chloride induced corrosion of steel in concrete as main cause of bridge deterioration. Older bridges require greater intervention in maintenance during the fourth and fifth decades of their service life in order to achieve the designed service life of 100 years, e.g. Šibenik Bridge has been recently repaired, while repair of Adriatic Bridge and

Bridge of Youth are in plan. Environment and climate significantly affect bridge durability, contemporary Maslenica Bridge on Adriatic Coast is the most vulnerable to reinforcement corrosion because of aggressive maritime environment with unfavourable combinations of sea salt and strong winds resulting in complex repair after 20 years of service. On the other hand, less use of de-icing agents over the past century contributed to achieving a service life of over 100 years for Žeinci Bridge. Construction quality has important role for bridge durability, since only high-quality and uniform concrete provides sufficient protection for the steel from corrosion, while concrete cracks and damage, inadequate water drainage and lack of waterproofing accelerate deterioration processes. The youngest among the case studies, Homeland Bridge was repaired six years after construction in order to fix errors and imperfection made on site.

Re-active maintenance policy, based on interventions once the bridge is obviously in critical condition, results in lower performance of structures and higher overall costs. In order to achieve efficient and sustainable bridge management new approach of pro-active maintenance of concrete bridges is proposed including visual inspection complemented with the NDT and application of numerical model for service life prediction. Data obtained on the bridges will be used for calibration of the 3D CHTM model in order to precisely predict the remaining service life as a prerequisite for sustainable life cycle cost analysis.

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