Monitoring performance of large Croatian bridges

Jelena Bleiziffer and Jure Radic
Institute IGH, Faculty of Civil Engineering, Croatia University of Zagreb, Zagreb, Croatia

ABSTRACT: The paper discusses monitoring performance of seven reinforced concrete arch bridges in Croatia. The bridges are vital links in road network system. Systematic approach in planning of bridge maintenance activities is essential for efficient bridge management. Structural health monitoring techniques may be implemented to improve maintenance management. Monitoring systems for long-term control of stresses, strains and corrosion progress have been installed on three major Croatian reinforced concrete arch bridges. Further research is required to develop monitoring strategy addressing the entire bridge stock.

1 INTRODUCTION

1.1 Croatian road network

As in most European countries, road network is by far the most important element of land transport in Croatia. According to Croatian legislation, public roads are classified as (Official Gazette RoC, 2008):

(1) motorways (1.200 km);
(2) state roads (6.800 km);
(3) county roads (10.800 km);
(3) local roads (10.300 km).

Generally, motorway network contributes most to the efficiency of transport, which in turn is of utmost importance for economic and social development of a country. Over the last decades Croatia made large investments in construction of motorways (Fig.1), which would integrate the most distant parts of the country and provide for quick, easy and comfortable transportation of people, goods and services.

With the total planned length of 1.500 km, the Croatian motorway network may not seem long, but it is worth mentioning that Croatia already has more kilometres of motorways per 100.000 citizens than, for instance, UK, Ireland, Greece or Italy.

Of the total 1.200 km of motorway network currently in service in Croatia, distribution by length by number of lanes is as follows (HUKA, 2009a):

(1) single carriageway (175 km);
(2) dual two-lane carriageway (1.003 km);
(3) dual three-lane carriageway (21 km).

The Croatian network of tolled motorways (Fig.2) is operated by 4 companies (HUKA, 2009a):

(1) Hrvatske autoceste d.o.o. (816 km);
(2) Autocesta Rijeka-Zagreb d.d. (182 km);
(3) Bina-Istra d.d. (141 km of single carriageway);
(4) Autocesta Zagreb-Macelj d.o.o. (60 km).

1.2 Investments into existing sections

Even though investments in new construction in Croatia are still high (Fig.3), the attention of bridge owners and professional community is starting to turn to methods and techniques for preserving the safety and serviceability of their assets.

Of major concern are some of the oldest motorway sections, namely 183 km of Zagreb bypass and motorway from Zagreb to Slavonski Brod (refer to Fig.2) where no regular maintenance was conducted ever since their completion in the 1980's. It was impossible to carry out maintenance in 1990's due to war activities in the region. Major rehabilitation works started in 2003 comprising pavement repair (replacement of the wearing course, and bonding layer as necessary), equipment replacement, drainage rehabilitation as well as technically demanding and costly repairs or even replacement of severely deteriorated motorway structures (Fig.4).

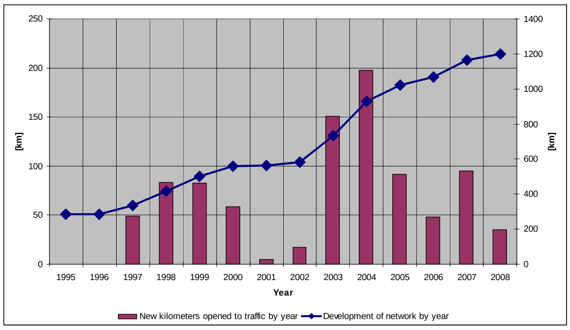

Figure 1 : Development of Croatian motorway network by years

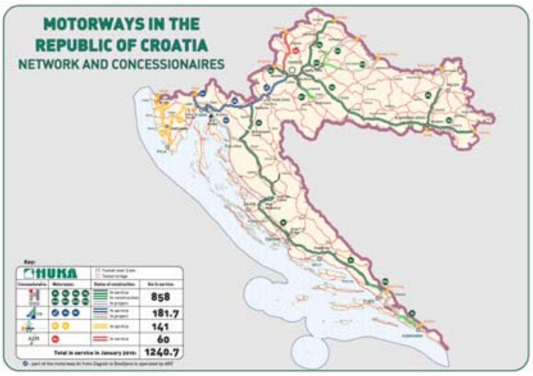

Figure 2 : Croatian motorway network in 2009 (HUKA, 2009b)

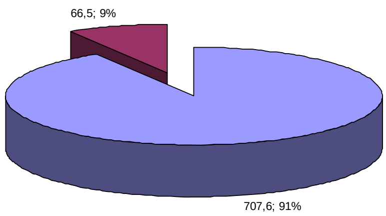

Figure 3 : Distribution of investments between new (in blue) / existing (in red) sections of motorways in Croatia in 2008

Figure 4 : Reconstruction of a severely deteriorated motorway overpass

2 MONITORING PERFORMANCE OF LARGE CROATIAN BRIDGES

In the last fifteen years health monitoring technologies emerge as a new approach to collect data about critical structural elements using attached or embedded sensors to provide indicators when some anomalies are detected in a structure.

According to COST 345 report, monitoring can be defined as any periodic or continuous operation where the behaviour of a structure or structural components is quantified in some way so that its serviceability and stability can be evaluated. Observations and measurements are taken to:

(1) compare the predicted and the actual in-service performance (check the validity of design assumptions);

(2) detect defects as they occur in service (as they may affect serviceability or safety);

(3) provide data for assessing the level of serviceability or safety.

Monitoring works may be implemented:

(1) before construction (to determine the effect of construction works);

(2) during construction (in response to a problem that arises, or a change in some construction detail);

(3) in-service (as a part of assessment condition).

There are seven major reinforced concrete arch bridges in Croatia located on Adriatic coastline, with spans ranging from 200 m to almost 400 m. These are, in chronological order of the construction:

(1) Sibenik Bridge completed in 1966 across Sibenik Bay in central Dalmatia;

(2) Pag Bridge completed in 1968 to link the Island of Pag with the mainland;

(3) Krk Bridge (two arch bridges) completed in 1980 to link the Island of Krk with the mainland;

(4) Maslenica Bridge completed in 1997 to carry new motorway across Novsko strait;

(5) Skradin Bridge completed in 2005 to carry new motorway across Krka River canyon;

(6) Cetina Bridge completed in 2006.

Four Adriatic arch bridges – the Sibenik Bridge, the Pag Bridge and the Krk Bridges are usually referred to as the first generation of Croatian Adriatic arches, while Maslenica, Skradin and Cetina Bridges were completed much more recently.

2.1 The first generation of Croatian Adriatic arches: In-service performance

As opposed to the bridges discussed in the next chapter, the durability design of the first generation of large reinforced concrete arch bridges was generally treated as that of secondary importance. These were ground breaking engineering structures, both in terms of span length and construction technique, and much effort was put into assuring stability. The threat of chloride attack on reinforced concrete structures was not highly regarded risk at the time of their design and construction, i.e. in the 1960's, as it is today.

Repair works on the Pag Bridge started already after a decade of its service, but did not prove efficient in terms of stopping the corrosion process. Major reconstruction started in 1991 with the repair of the arch and was finally finished in 1999 when the original concrete superstructure was dismantled and replaced by a completely new structure in steel. Columns were repaired by encasing in steel and concrete. Bridge inspection was carried out in 2009 and the condition of the steel portion of the structure was assessed as satisfactory, although minor local defects were detected. However, the inspection and limited testing revealed that more detailed investigation is required to draw final conclusions on the condition of the arch as disturbing delamination and chloride content levels were found.

The repair works on the Krk Bridge started several years after its completion focusing on superstructure supports. In the 1990s the works were broadened to include the repair of columns at the smaller arch. Different repair techniques had to be devised for spandrel and approach columns. The smaller arch has been recently repaired by removal of the contaminated concrete, its subsequent replacement with shotcrete and adding protective coating. The repair of the larger arch presents major challenge to engineers. The arch is actually supported on submerged inclined struts. After many years of research and testing of various corrosion protection systems, cathodic protection method was selected for this part of the structure (Beslac et al., 2007). All of these repair works are not only expensive, but technically demanding tasks and very difficult to perform.

Figure 5 : Sibenik (left), Pag (center) and Krk (right) Bridges:deterioration of bridge superstructure

Figure 6 : Sibenik (left), Pag (center) and Krk (right) Bridges: deterioration of columns

Sibenik Bridge is somewhat less exposed to aggressive maritime environment and, although the oldest among the large Croatian bridges, only minor rehabilitation work was performed so far. The bridge was thoroughly inspected in 2005, and development of repair design is currently underway.

2.2 The second generation of Croatian Adriatic arches: Structural health monitoring

Recent advances in sensing and information technologies paved the way to bridge instrumentation and structural health monitoring aimed at monitoring and evaluating structural performance and environmental impact, coupled with serviceability level and incidents.

For the first time in Croatia, bridge monitoring system for long-term control of stresses, strains and corrosion progress was installed on Maslenica bridge. The intention was to closely monitor both structural performance and durability related performance in order to facilitate the future maintenance activities by triggering timely adjustments and interventions.

Maslenica Motorway Bridge (Candrlic et al., 1999) was completed in 1997. The bridge comprises a reinforced concrete arch structure spanning 200 m. The cross section of the fixed arch is a double-cell box of constant depth. The bridge superstructure comprises eight simply-span precast prestressed girders made continuous over intermediate supports and interconnected by deck-plate cast in place, with cross-girders provided only at supports. The arch of Maslenica Motorway Bridge was constructed by free cantilevering on traveling formwork carriages, utilizing stays and auxiliary steel pylons.

The monitoring system (Simunic et al., 1999) was used to record the stresses and strains at various construction stages and under load-testing prior to opening the bridge to the service (Fig. 7). Additionally, monitoring the environmental parameters such as air temperature, wind speed and direction was anticipated.

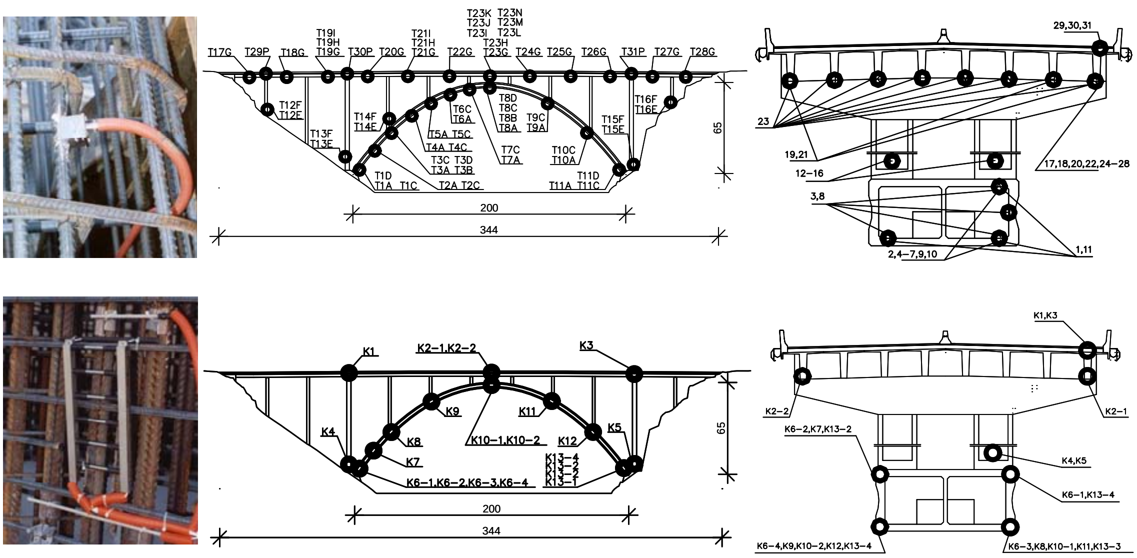

Figure 7 : Location of strain-gauges (top) and corrosion sensors (bottom) installed on the Maslenica Bridge

The system consists of 92 strain-gauges, 40 temperature sensors and 21 corrosion sensors (anode-ladder) mounted at carefully chosen spots on the arch and girders of the superstructure. These documented the initial condition of the structure needed as a reference for future measurements. Unfortunately, the monitoring project was stopped soon afterwards.

Skradin Bridge monitoring comprises structural and durability performance monitoring, with a smaller number of gauges than installed on the Maslenica Bridge.

Skradin Bridge is a reinforced concrete arch bridge spanning 204 m with a rise of 52 m completed in the year 2005. Instead of a conventional prestressed concrete superstructure made of precast girders and a cast-in-place slab, a composite superstructure (spans of 28 to 32 m) was selected. It consists of steel girders and reinforced concrete deck-plate. Bridge deck serves two two-lane carriageways. The arch was constructed by free cantilevering on traveling formwork carriages in 5.25 m long segments. The steel superstructure was erected by longitudinal launching in three phases.

The concrete deck is formed by full depth precast slabs interconnected by on-site concreting of longitudinal and transverse joints above shear connectors.

The monitoring system includes continuous monitoring of strain, temperature and humidity on the structure, periodic displacement measurements, and periodic measurements to evaluate the corrosion progress (Fig. 8 and 9) (Rak et al., 2006).

The superstructure is instrumented with 16 strain gauges, 12 temperature sensors, and 1 humidity sensor.

The arch is instrumented with 6 corrosion sensors (anode-ladder), 12 strain gauges, 9 temperature sensors, and 1 humidity sensor.

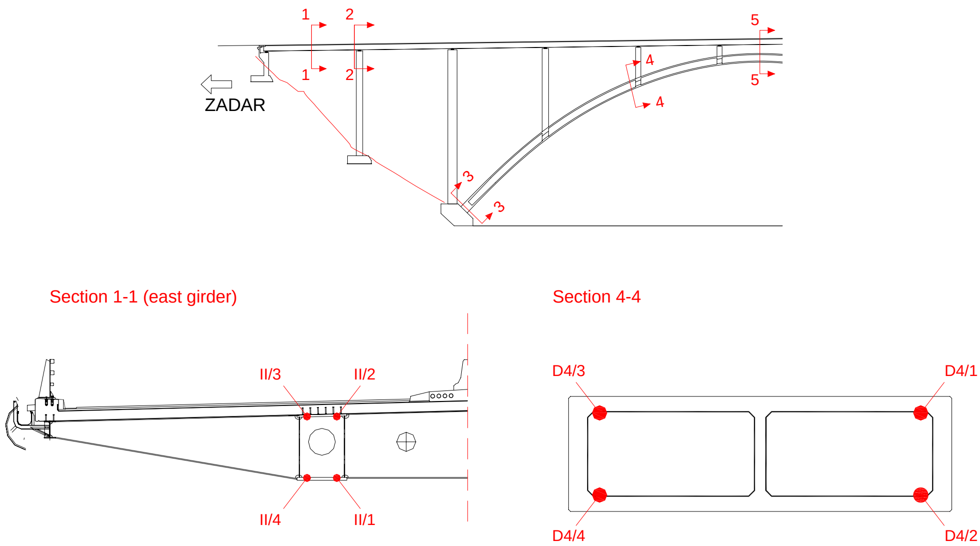

Figure 8 : Location of strain gauges and temperature sensors

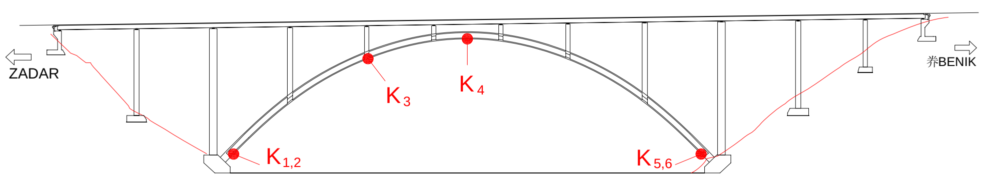

Figure 9 : Location of corrosion sensors installed on Skradin Bridge

Displacement control is performed twice a year at 13 spots in 4 lanes (each edge of each carriageway). Measuring points are located at abutments and over each pier.

Strain monitoring started during proof load testing in June 2005. Initial corrosion measurements were performed in May 2004. The expected frequency of the corrosion sensors readings is 2 to 4 times a year.

Cetina Bridge monitoring system is similar to system installed on Skradin Bridge. Cetina Bridge (Zderic et al., 2007) is a reinforced concrete arch bridge spanning 140 m with a rise of 21.50 m completed in the year 2006. The bridge superstructure comprises five simply supported precast prestressed girders in each span.

The monitoring system includes continuous monitoring of strain, temperature and humidity on the structure, periodic displacement measurements, and periodic measurements to evaluate the corrosion progress (Fig.10 and 11) (Rak et al., 2005).

The superstructure is instrumented with 16 strain gauges (D), 2 temperature sensors (T), and 1 combined humidity + temperature sensor (T+V).

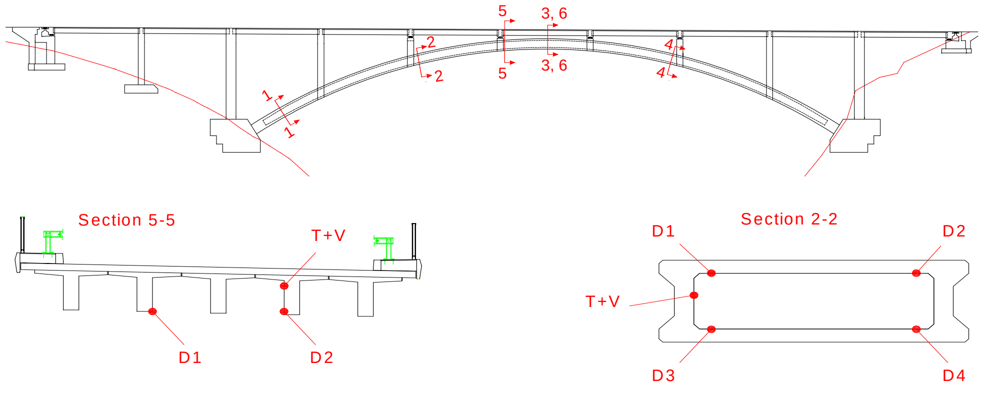

Figure 10 : Location of strain gauges and temperature sensors

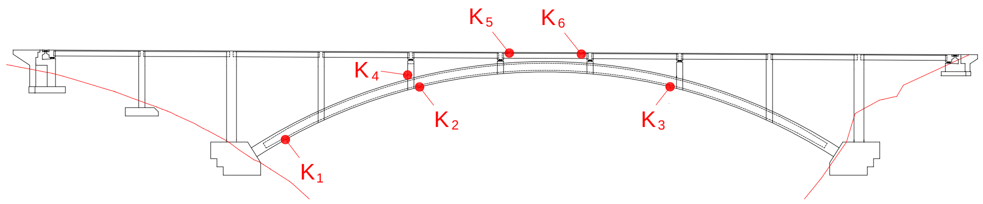

Figure 11 : Location of corrosion sensors installed on Cetina Bridge

The arch is instrumented with 6 corrosion sensors (anode-ladder) (K1 – K6), 12 strain gauges (D), 4 temperature sensors (T), and 1 combined humidity + temperature sensor (T+V). The expected frequency of the corrosion sensors reading is 2 to 4 times a year.

Displacement control is performed twice a year at 11 spots in 2 lanes (each edge of carriageway). Measuring points are located at abutments and at each pier.

3 CONCLUSIONS

Installation of a monitoring system is recommended on all bridges falling into the category of particular (out-of-ordinary) structures to ensure the longevity and safety as well as optimize its management on a project level. Appropriate planning, design and execution of a bridge monitoring system is most important for its proper functioning and further interpretation of results. In order to enable the integration of recorded data into a bridge management system, it is necessary to define critical value of key parameters that are monitored as well as degradation models to facilitate future deterioration prediction. Experience from inspection and assessment of large Adriatic bridges may be used as a starting point, while in time the instrumented bridges should provide sufficient data to determine more precisely the critical values and deterioration curves corresponding to different environmental conditions. Further research is required to develop monitoring strategy addressing the entire bridge stock.

REFERENCES

Candrlic V., Radic J. and Savor Z., 1999. Design and construction of the Maslenica Highway Bridge. In Proceedings of the fib Symposium Structural Concrete – the Bridge Between People, Vol.II, p.551-555.

COST 345 Procedures Required for Assessing Highway Structures, Joint Report of Working Groups 2 and 3: methods used in European States to inspect and assess the condition of highway structures. 2004. http://cost345.zag.si/ (18-05-08).

HUKA (Croatian Association of Toll Motorways Concessionaires), 2009. Key Figures. Zagreb: HUKA.

HUKA (Croatian Association of Toll Motorways Concessionaires website), 2009. http://www.huka.hr/ (12-03-10).

Official Gazette of Republic of Croatia, 122/08, 2008. http://www.nn.hr/ (12-03-10).

Simunic Z., Gasparac I. and Pavlovic B., 1999. Monitoring of Maslenica Bridge during Construction. In Proceedings of IABSE Symposium Structures for the Future – The Search for Quality: CD-ROM. Rio de Janeiro: IABSE.

Rak M., Bjegovic D., Krolo J. and Stipanovic I., 2005. Monitoring project of Cetina bridge (Projekt monitoringa mosta preko rijeke Cetine). Zagreb: Faculty of Civil Engineering, University of Zagreb.

Rak M., Bjegovic D., Kapovic Z., Stipanovic I. and Damjanovic D., 2006. Durability monitoring system on the bridge over Krka river. In J. Radic (Ed.) Bridges: p1137-1146. Zagreb. SECON HDGK.

Zderic Z., Runjic A. and Hrelja G., 2007. In P.B. Lourenço D.V. Oliveria and A. Portela (eds.) Proceedings of the 5th International Conference on Arch Bridges ARCH'07: 745-750. Guimarães: Multicomp, Lda.