CETRA2010 17–18 May 2010, Opatija, Croatia
First International Conference on Road and Rail Infrastructure

MONITORING AND LOAD TESTING OF THE CETINA BRIDGE

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Abstract

This paper will give detailed overview of monitoring system and load testing of the Cetina bridge near Trilj in south of Croatia. The main superstructure of the bridge is a concrete arch of a box-shaped cross section. The deck's superstructure is a grillage concrete structure over ten spans. The design of the bridge anticipated a permanent observation of the structure in exploitation. Therefore a permanent monitoring system was installed at the bridge. Monitoring system includes the periodic measuring of displacements, dynamic characteristics and reinforcement corrosion, along with continuous measuring of strains, temperature and humidity. The readings of the periodic measurements are supposed to be quarterly conducted. The measuring of strains, temperature and humidity is being performed continuously at 24 locations. All the sensors are being powered continuously over the solar collector installed near the bridge and the data is being stored to the "data logger". Load testing of the bridge was conducted in accordance with the Croatian HRN U.M1.046. norm. Static load testing was conducted through 19 load phases. Seven load phases in which the arch was tested (8 trucks) and 12 load phases of the deck structure (4 trucks). During the loading strains were measured in three arch cross sections (impost, quarter of the arch and apex) and in two deck structure cross sections. Strains were measured by 16 LVDT sensors which are a part of the monitoring system. During the load testing displacements were measured in two lines, above all the supports and in the centres of deck structure span. Dynamic testing was conducted in order to determine dynamic parameters of the structure. Dynamic response of the superstructure was recorded during actual mobile load of a heavy truck weighing approximately 32,0 t. Dynamic parameters are significant for the future diagnostic of structure in exploitation as they are functions of global stiffness of structure and are as such the index of real condition of the structure. Results of experimental testing are compared to theoretical results of FE numerical model.

Keywords: bridge, monitoring, load testing, dynamic testing, displacement, strain.

1 Introduction

1.1 Structure of the bridge

The main superstructure of the bridge is 140,27m concrete arch with 21,50m arch rise [Figure 1]. The fixed arch is of a box-shaped cross section with constant outer contour. Outer dimensions of the arch are 8,0x2,0m. Dimensions of the arch cross section are constant except in the vicinity of the abutments where they are linearly increased from the first columns. Horizontal walls are 40cm and vertical walls are 50cm thick. In the vicinity of the abutment horizontal walls are strenghten to 60cm. Diaphragms are constructed in the heels of the arch (3,00m) and at the connections of the columns to the arch. In the longitudinal section of the bridge they have same tickness as the columns above them.

The deck's superstructure is a grillage concrete structure over ten spans, 21,60m each. Cross section consists of five prefabricated prestressed girders, connected with monolith deck plate (20cm) and cross girders over the supports. Prefabricated girders are of a "T" cross section, 120cm high with flanges of 188cm. They are spaced at 190 cm and subsequently prestressed. Pier sections consist of two piers connected with the head beam. They have rectangular cross section. The width of all columns is 1,80m in the cross section of the bridge. The width of the portal piers in longitudinal section is 2,40m and of the rest of the piers it is 1,50m. Heights of the piers vary between 3,96 – 19,80m. Thickness of the pier walls is 30cm.

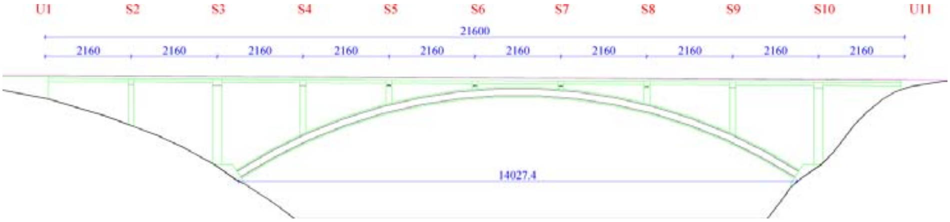

Figure 1 Longitudinal section of the bridge

2 Monitoring system of the bridge

As the main project of the Cetina bridge anticipated a permanent observation of the structure in exploitation the project of bridge monitoring was created by the Faculty of Civil Engineering in Zagreb (Department for Technical Mechanics and Department for Materials). The project of bridge monitoring included long-term monitoring of the mechanical and corrosion behaviour of the entire object at certain specific points of the structure. The monitoring system consists of periodic measurment of displacements, dynamic characteristics and reinforcement corrosion, along with continuous measurment of strains, temperature and humidity. Monitoring system gives the opportunity to permanently control the level of strains in the structure especially in cases of some unexpected events like earthquakes or special loads. Periodical part of bridge monitoring enables us to foresee the progress of corrosion and overlook the displacemnts and to intervene early in order to protect the structure.

2.1 Permanent monitoring

Permanent part of the monitoring system includes continuous measurement of strains, temperature and humidity of the structure. The measuring of strains, temperature and humidity is being performed continuously at 24 locations. All the sensors are being powered continuously over the solar collector installed near the bridge. The recordings are being collected in the monitoring centre located in the arch vertex where all the sensors are connected over A/D convector to the "data logger"[Figure 2].

The primary and the most important part of the measuring system consists of sensors for strain measurement. In this case LVDT sensors (Linear Variable Differential Transformer), which operate on the principle of electric induction. There are 16 LVDT sensors installed at the bridge in three arch cross sections 1, 2 & 3 (impost, quarter of the arch and vertex), and in two deck structure cross sections 4 & 5 [Figure 3]. In each cross section of the arch there are 4 LVDT sensors and in the cross sections of the deck structure there are 2 LVDT's. LVDT's are glued to the surface at the base of 200mm. Temperatures are measured with Pt-100 probes at 7 locations and humidity is measured with a standard electronic moisture meter in cross section 2 [Figure 4].

Figure 2 Monitoring centre

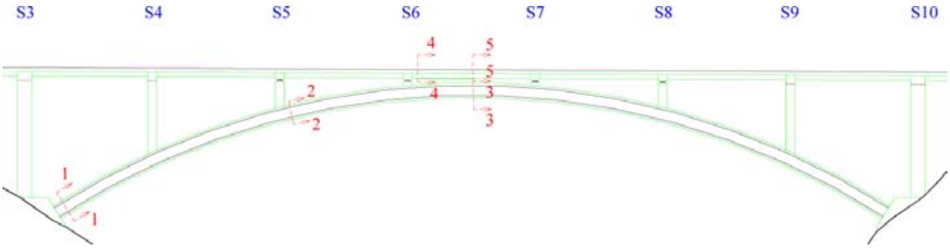

Figure 3 Locations of the cross sections

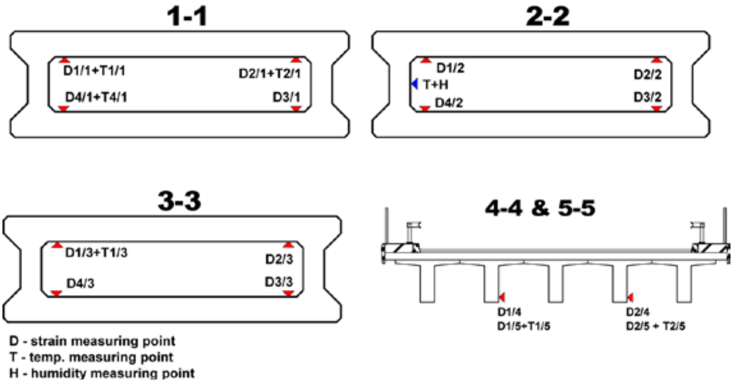

Figure 4 Strain, temperature and humidity measuring points

2.2 Periodical monitoring

Periodical part of the monitoring system consists of displacements, dynamic characteristics and of reinforcement corrosion measurements. For the integral control of the long-lasting displacements of the bridge structure with respect to the stabilized permanent datum marks, the corresponding datum marks were placed in two lines A & B above abutments and all columns [Figure 5. The displacement measurement programme provides for 2 measurements a year on all datum marks. The displacement measurement is carried out with a geodetic method with the use of a precise geometric levelling.

Reinforcement corrosion is being observed at 6 measuring points [Figure 5 over Raupach–Schiesssl sensors embedded into the concrete]. The readings are supposed to be quarterly conducted. The reinforcing steel corrosion state measurement consist of measuring of the following parameters: electric current, voltage, resistance and the temperature of the built-in sensors.

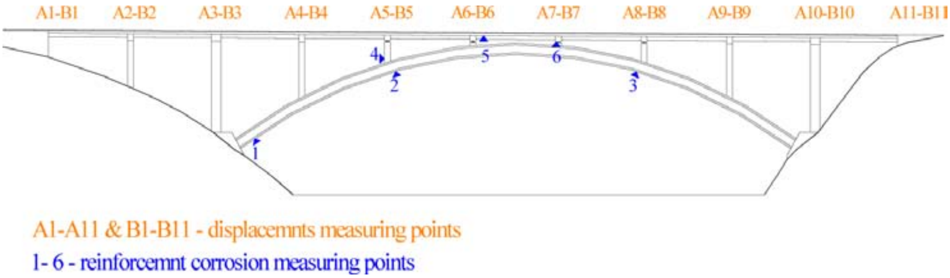

Figure 5 Displacemnet and reinforcemnet corrosion measuring points

3 Load testing

Load testing of the Cetina bridge was carried out in accordance with the regulations of the Croatian standard HRN U.M1.046.

Eight heavy trucks were used as statical load for phases of arch loading and four for single span loading phases. Average weight of each truck was approximately 30,34 tones. The trucks were positioned so to achieve maximum inner forces and displacements corresponding to those from the static bridge calculation. Statical testing was carried out through 19 loading phases and 16 phases of load realeases. Most interesting phases are the first 7 loading phases in which the arch is loaded [Figure 6]. The other 12 loading phases are the phases in which each span was tested with the load of 4 trucks. Span S10-U11 was tested with simetrical and nonsimetrical load to test transverse distribution of strain and deflection.

Figure 6 Fifth load phase of the arch (M_{ymax} at the arch vertex)

During the testing, displacements were measured at the main bearing elements of the structure along the two lines (A and B), over the supports and in the middle of each span. On the arch, horizontal displacements were measured at the columns S5, S6, S7 & S8.

The monitoring system was activated in the course of test loading. During the load testing strains were measured by all LVDT sensors installed as the part of the monitoring system (16 LVDT's).

Dynamic testing of the bridge was carried out with the purpose to determine dynamic parameters of the structure. Bridge was excited with actual traffic load consisting of one heavy truck. Response of the structure was captured in the form of time function, as well as function of frequency spectrum.

3.1 Results of static testing

Maximal deflections measured at the arch for symetrical load consisting of 8 heavy trucks are shown in Table 1 where they are directly compared to corresponding deflections acquired from the FEM model. Figure 7 shows experimental and theoretical deflection lines for the 2nd arch loading phase.

Table 1 Comparison of experimental and numerical deflections

Loading phase	Measuring point (column)	Measured deflection (mm)	Numerical deflection (mm)
1.	S 5	-6,5	-7,4
	S 8	3,7	4,8
2.	S 5	5,9	5,4
	S 8	-8,7	-8,5
3.	S 5	-8,4	-10,1
	S 8	7,3	6,3
4.	S 6	-7,6	-7,2
	S 7	-4,9	-4,1
5.	S 6	-8,2	-8,6
	S 8	5,5	5,1
6.	S 5	6,1	5,8
	S 7	-7,8	-7,8

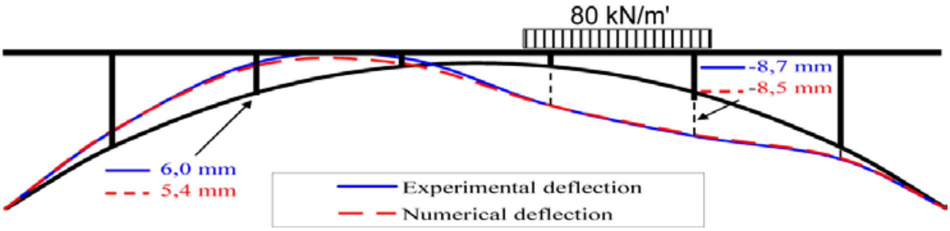

Figure 7 Comparison of experimental and numerical displacements for the 7th loading phase

The most significant values of strains measured at the arch and the bridge deck are shown in table 2. Figure 8 shows strain measurment at cross section 2.

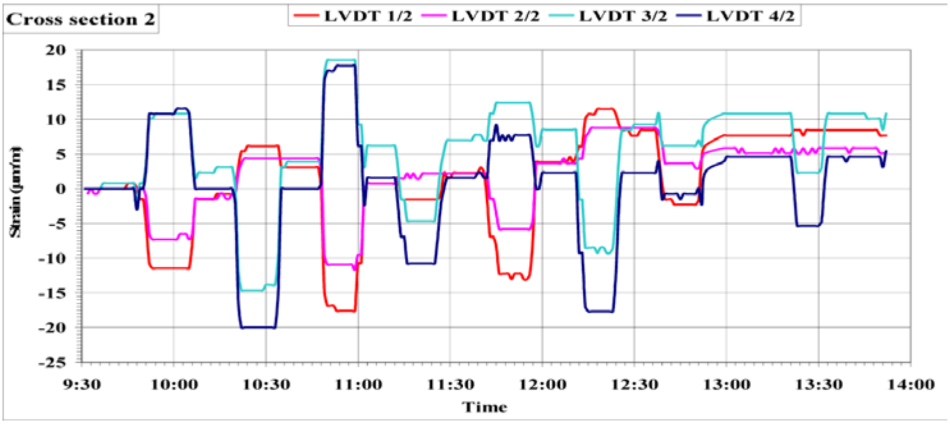

Figure 8 Strain measurment at cross section 2

Table 2 Comparison of experimental and numerical strains

Loading phase	Measuring point (column)	Measured strain $\varepsilon_{exp.}$ (‰)	Numerical strain $\varepsilon_{num.}$ (‰)
1.	D4/1	-0,006	-0,008
	D4/2	0,012	0,013
	D1/3	0,002	0,001
2.	D1/1	-0,009	-0,012
	D4/2	-0,020	-0,024
	D1/3	-0,009	-0,013
3.	D4/1	-0,008	-0,014
	D3/2	0,019	0,020
	D1/3	0,001	0,001
4.	D4/1	-0,007	-0,014
	D4/2	-0,011	-0,015
	D1/3	-0,019	-0,018
	D2/4	-0,046	-0,078
	D1/5	0,055	0,050
5.	D4/1	-0,011	-0,018
	D1/2	-0,013	-0,008
	D1/3	-0,012	-0,015
6.	D1/1	-0,005	-0,011
	D4/2	-0,019	-0,023
	D1/3	-0,009	-0,014

3.2 Results of dynamic testing

In order to continuously monitor the bridge structure's condition dynamic arameters of the structure were determined (natural frequencies, dynamic factors, attenuation).

Table 3 Comparison of experimental and numerical natural frequencies

Oscillation modes	Exper. frequency (Hz)	Num. frequency (Hz)
1. Lateral	1,148	1,084
2. Vertical	1,414	1,343
3. Torsional	2,344	2,302
4. Vertical	2,352	2,303
5. Torsional	3,185	3,123
6. Vertical	3,453	3,426
7. Vertical	4,162	4,128
8. Torsional	4,609	4,654
9. Vertical	5,141	5,072
10. Vertical	5,883	5,788

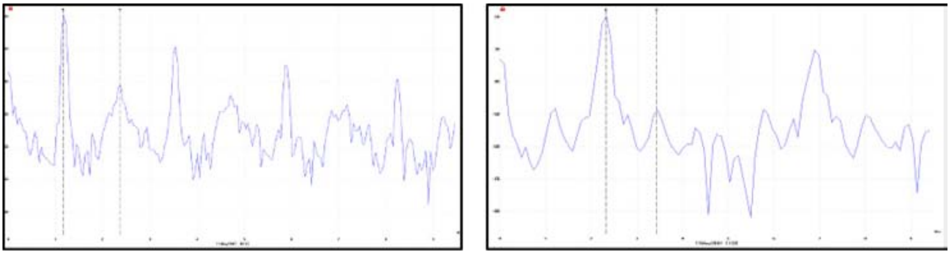

Figure 9 Records of power spectral density response functions

Table 3 shows the comparison of the first 10 experimentally and numerically determined natural frequencies. Figure 9 shows records of the power spectral density functions which lead to identifynatural frequencies. Figure 10 presents several numerical oscillation modes.

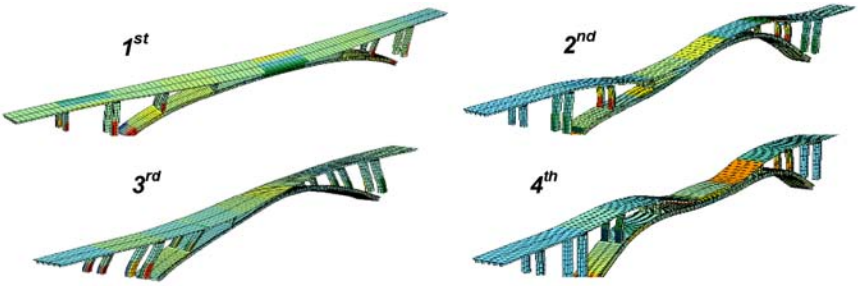

Figure 10 Numerical oscilation modes

4 Conclusion

The installation of the monitoring system on the infrastructure facilities is of great importance enabling thus early damages or even prediction of damages on the structure. The monitoring costs are relatively low compared to total initial investment and maintenance costs, providing that maintenance works were not conducted on time. The cost benefits of such systems will prove to be highly advantageous in future. The test loading of the Cetina bridge was used for checking the part of the monitor system related to observation of structure's relevant characteristics.

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