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THE CRACKS ON THE OLD BRIDGE IN MOSTAR

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Abstract: The Old Bridge in Mostar was restored in mid-2004. The first cracks were observed in 2007. The cracking process has been ongoing since then. This paper presents the process of cracking and comments on the vertical deflection of measurement points on the bridge since construction of the new bridge. The analysis of these phenomena has been carried out and some possible causes of their emergence have been addressed.

Keywords: Old Bridge in Mostar, cracks, vertical deflection of the stone arch, causes of the stone bridge cracking

NAPRSLINE NA STAROM MOSTU U MOSTARU

Sažetak: Stari most u Mostaru je obnovljen sredinom 2004. godine. Prve naprsline su opažene 2007. godine. Proces nastajanja naprslina traje od tada neprekidno. U radu je predstavljen proces nastanka naprslina i komentirano je vertikalno pomicanje mjernih točaka na mostu od izgradnje novog mosta. Izvršena ja analiza ovih pojava i obrađeni su neki mogući uzroci njihovom nastanku.

Ključne riječi : Stari most u Mostaru, naprsline, vertikalna pomicanja kamenog luka, uzroci pucanja kamenog luka mosta

1. The occurrence of cracks

Cracks were observed on the arch of the Old Bridge in Mostar at the end of November 2007. Significant cracks were observed in several places on the bridge arch. They were found on the north and south sides of the stone arch on the east bank of the bridge at about half the arch height (S1 and J1), while on the west bank cracks were only on the south side of the bridge arch at one fifth of the arch height (J2). Also, on the south side there were cracks slightly lower than the arch crown towards the west bank (J3)(1). Cracks were not observed on the intrados of the bridge. All the cracks extend over several stone blocks of the arch and do not go only over joints.

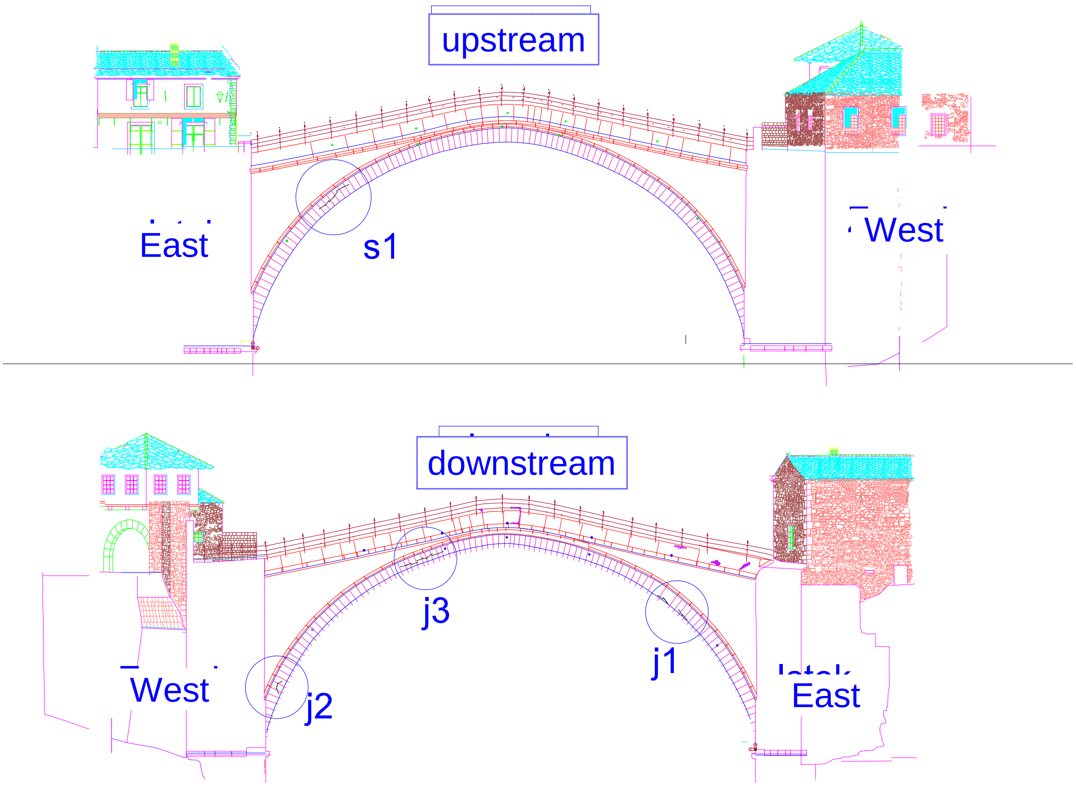

Figure 1. Cracks from 2008 (1)

2. The condition around 2010

In the next several years, cracks on the bridge were distributed on a larger area of the bridge arch, and already in 2008 they also appeared on the intrados of the bridge. In mid-2010, a spatial recording of the bridge was carried out and a drawing of cracks on the intrados of the bridge vault was made (3).

Figure 2. Cracks on the bridge intrados on 9 November 2008.

3. Development of cracks from 2010 to 2018

In the following years, new cracks were appearing and the existing ones were becoming increasingly visible. In the period since the cracks were detected on the bridge, I took photographs of the bridge in the summer hot and winter cold periods of the year. Based on analysis of these photographs, a drawing of the existing cracks was made, on which the cracks on intrados recorded in 2010 are marked in red and the cracks that appeared afterwards up until the beginning of December 2018 are marked in green color. It is evident that the number of new cracks has significantly increased. A drawing of the development of cracks on the sides of the bridge vault was also made. On the downstream and upstream sides, cracks are marked through a number of time intervals from 2007 to the end of 2018.

The period of development of new cracks from the photograph in the spring of 2018 to the recent photographs in early December is particularly interesting. A significant number of new cracks appeared on sides of the bridge vault in this half-year period.

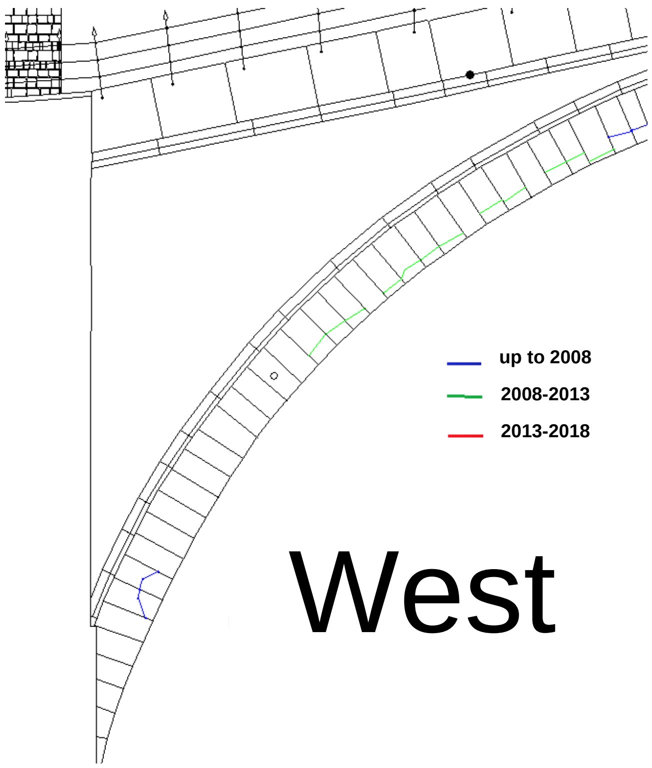

Figure 3. A sketch of the cracks on the downstream side of the bridge arch - west

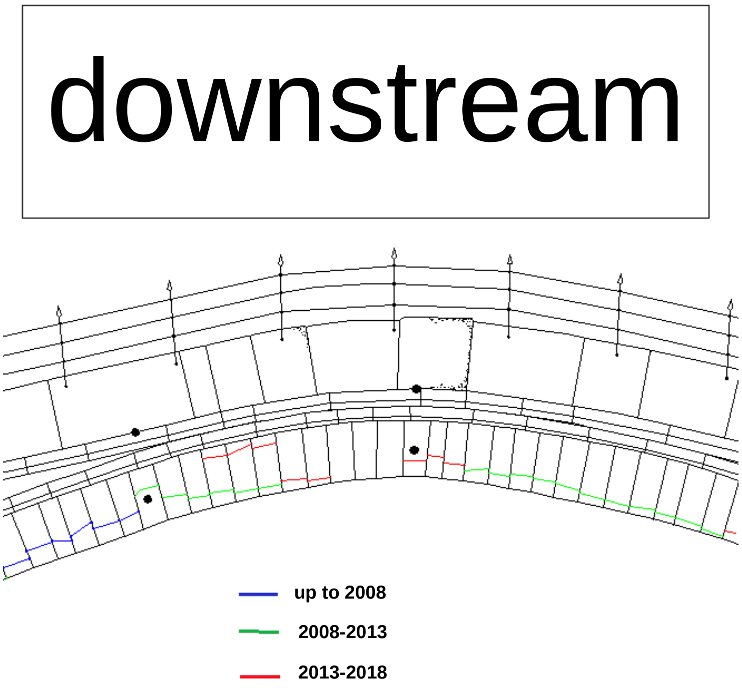

Figure 4. A sketch of the cracks on the downstream side of the bridge arch - center

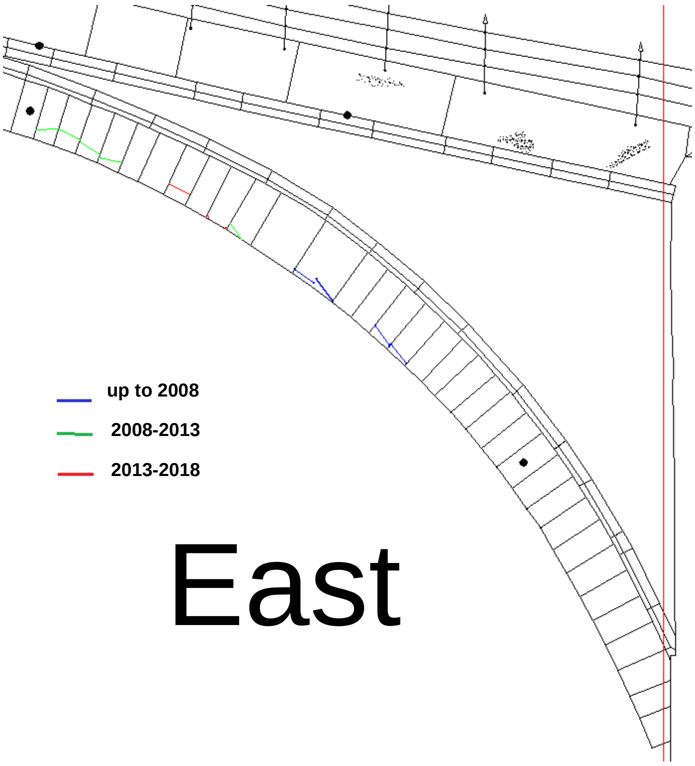

Figure 5. A sketch of the cracks on the downstream side of the bridge arch – east

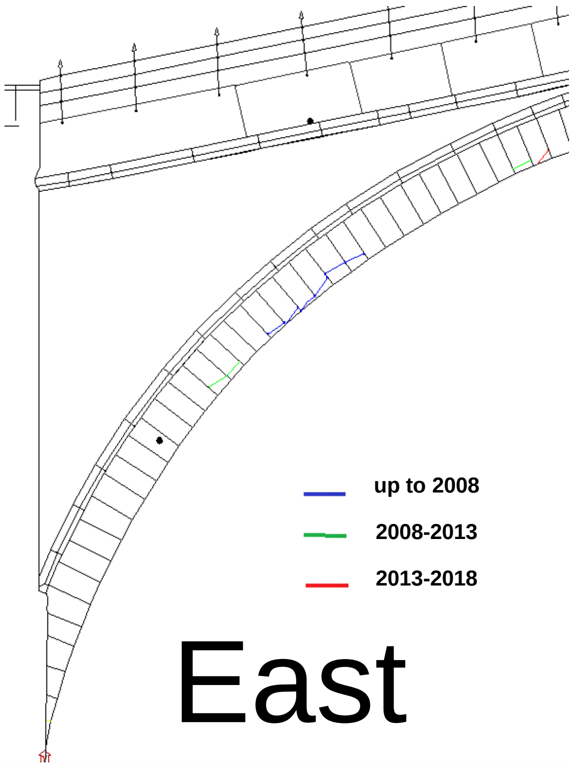

Figure 6. A sketch of the cracks on the upstream side of the bridge arch - east

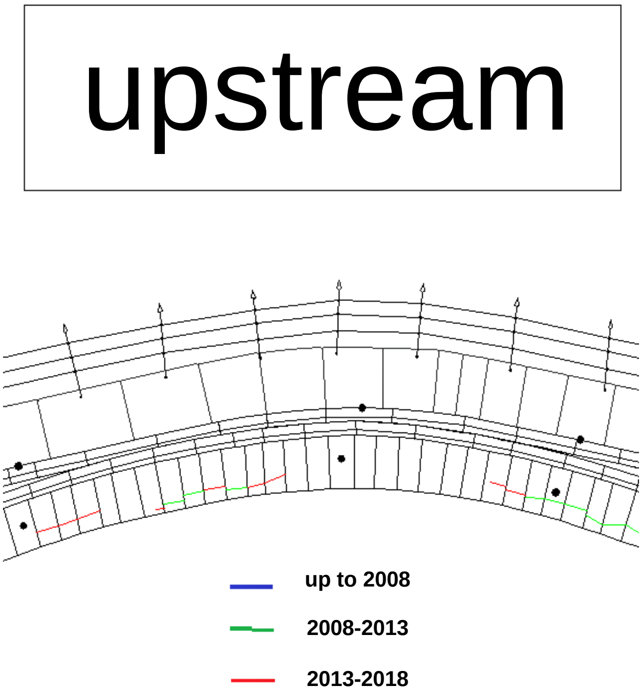

Figure 7. A sketch of the cracks on the upstream side of the bridge arch - center

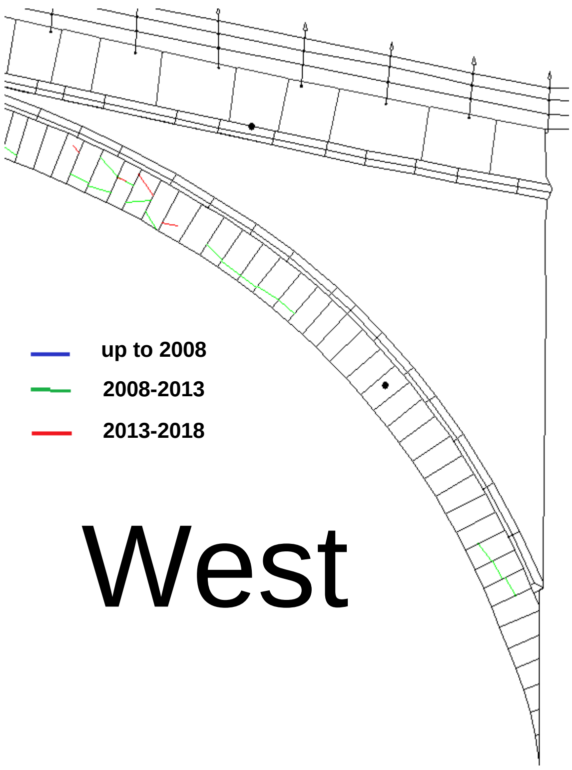

Figure 8. A sketch of the cracks on the upstream side of the bridge arch - west

Figure 9. Cracks on the downstream side of the arch from 2013 and 2018. Visible new cracks to the right of the benchmark

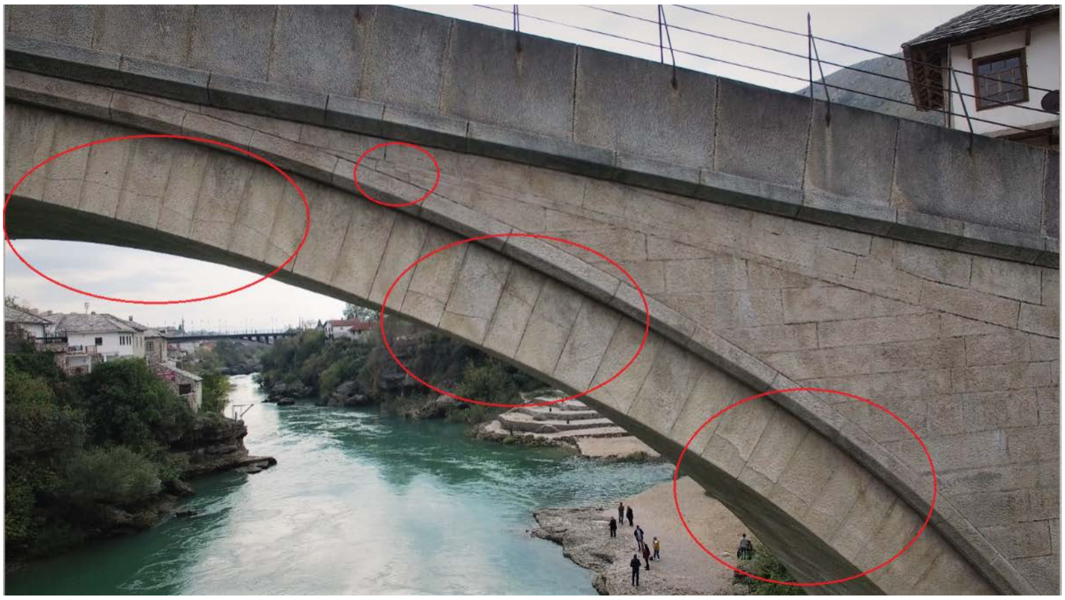

Figure 10. Cracks on the upstream side of the arch in 2018

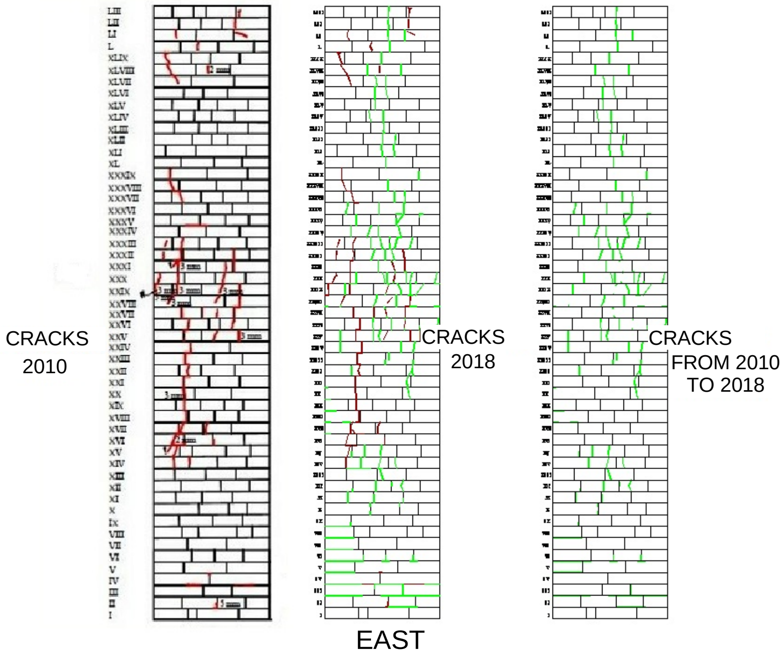

Figure 11. A sketch of the cracks of the bridge vault intrados towards the east side

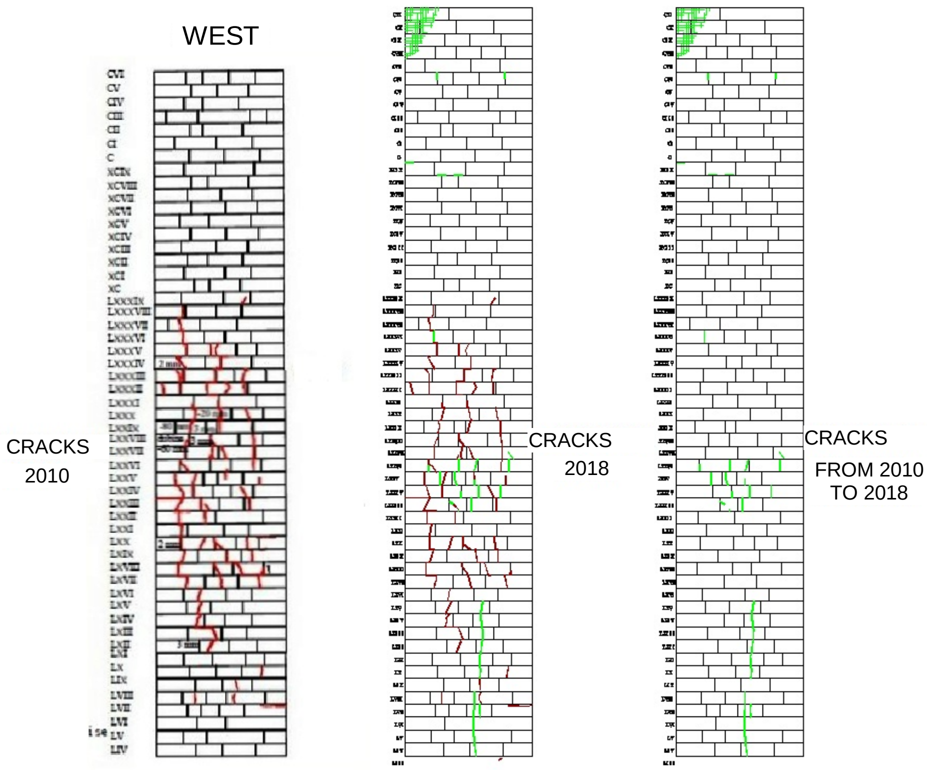

Figure 12. A sketch of the cracks of the bridge vault intrados towards the west side

Figure 13. Cracks on the bridge intrados east side, 2018

4. Analysis of the development of cracks

The cracks on the bridge have several characteristic features:

a) The cracks develop over a number of years and the cracking process has not been completed.
b) The cracks develop on almost the entire surface of the bridge vault intrados.
c) The cracks result from a compressive stress greater than compressive bearing capacity of bridge vault stone.

Cracks on the bridge were observed in late 2007, three years after completion of the bridge. Since then, constant development of new cracks has been observed and this process has not been completed. It is obvious that the cracking is caused by long-term processes rather than short-term loads of the bridge. For this reason, these short-term loads have not caused the cracking: earthquakes, wind, impact of high water of Neretva, settlement of abutments, application of a rigid scaffold and contact stress grouting of abutments during construction. The loads acting over a longer period of time are dead weight, service load and the effect of temperature change. Dead weight is the dominant load, but the fact that cracks did not occur in the first three years of age of the new bridge shows that the cause of cracking is not this load alone.

A service load of 5 kN/m2, which rarely occurred at its highest value, is too small relative to the dead weight of the bridge to be a reason of cracking.

The most suspicious cause of cracking on the bridge remains, a it is the effect of bridge temperature changes. Here we have two types of temperature change as loads on the bridge. The first type is the annual change of air temperature in Mostar, while the second one is the temperature change in different parts of the bridge, which has a daily character.

Mostar is known for moderate climate over the winter but with exceptionally hot summers. Winter air temperatures do not drop below -10 °C, while in summer temperatures exceed 40 °C.

The temperature of the bridge walls that are exposed to direct sunlight exceeds 55 °C. It can be confidently accepted that the maximum annual temperature difference to which the bridge structure is subjected exceeds 50 °C.

The temperature change of internal parts of the bridge is considerably lower, but a daily difference between internal and external part of the bridge in the summer can be up to 20 °C.

The reconstructed Old Bridge was made at a considerably higher level of quality than the demolished bridge. High-quality selection of materials, professional performance, application of modern technology, professional and continuous control of works and incomparably higher level of professional knowledge are the reasons why the new bridge is superior as compared to the old one. A consequence of that is that we have a much more rigid bridge than it was before. For this reason, the temperature changes cause greater stresses in the load-bearing structure of the bridge than the old Old Bridge had for four centuries. The main load-bearing structure of the bridge begins to feel temperature effects from the moment the scaffold is removed. That was in the spring of 2004 when the temperature was about 10 °C. The effect of temperature increase on the bridge is highest in the summer months (July and August), while the effect of temperature decrease is highest during January.

A possible cause of long-term cracking may be the joint effect of large dead weight, more rigid structure of the new bridge along with the temperature stress of the bridge and the possible lower quality of stone of the bridge vault. This last reason must be analyzed because all the cracks resulted from compressive stress and stone splitting. There are no significant cracks through mortar joints as a consequence of tensile stresses.

5. Deflections of benchmarks

Benchmark points were fixed on the bridge cornice on the upstream (north) and downstream (south) side still during the bridge construction. Coordinates of the benchmark points were surveyed since the scaffolding was removed from the bridge in 2004 until 2018.

Analysis of the deformation values shows that the values at the benchmark points RV3 (bridge center) increase upward (negative deflection) as time passes, while the values at the benchmark points RV1 and RV5 increase negatively (deflection). These increases in absolute deformation values appear both in winter and summer measurements. Absolute elevation values of the benchmark points RV3 in the summer are greater than the winter ones, while it is the opposite for the outlying benchmark points RV1 and RV5.

Similar results can also be obtained by analyzing the images taken by 3D recording of the bridge in 2004, 2010 and 2018. Spatial displacements of sections are visible in both directions and rotation of bridge sections is also present. An indirect indicator of the bridge rotation is the widening of joints between paving stones.

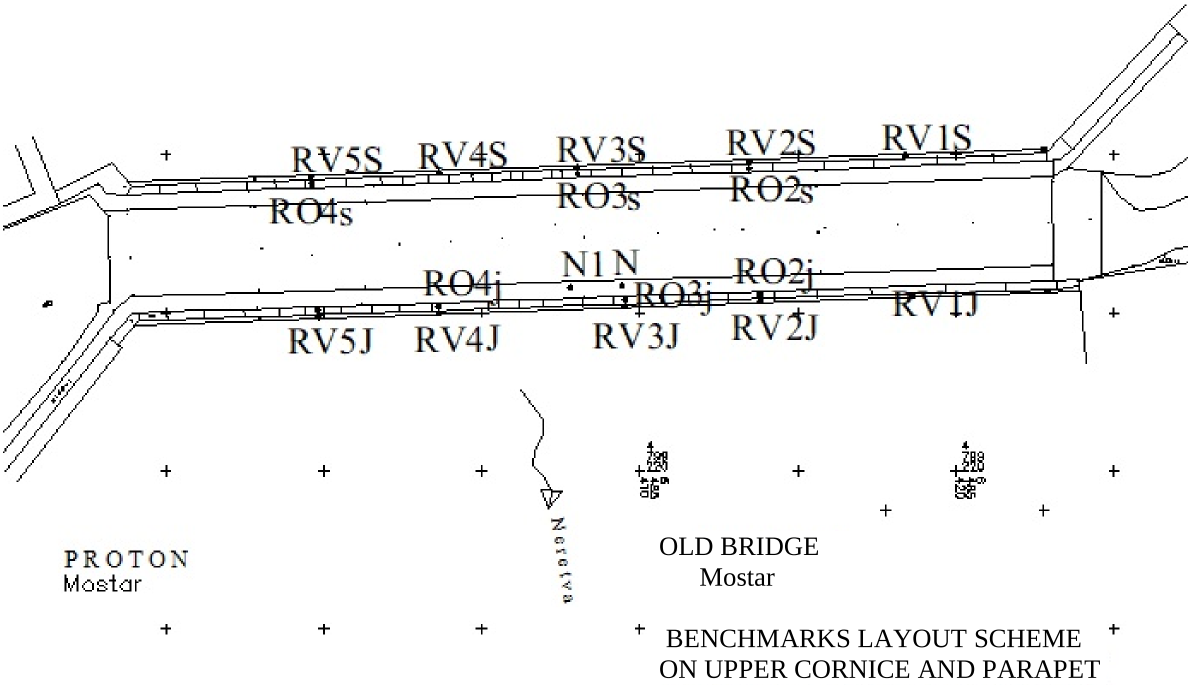

Figure 14. Positions of benchmark points

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
TOČKA	Mjerenje	Mjerenje	ΔV	Mjerenje	ΔV	Mjerenje	ΔV	Mjerenje	ΔV	Mjerenje	ΔV	Mjerenje	ΔV	Mjerenje	ΔV	Mjerenje	ΔV	Mjerenje	ΔV
Mjerenje	0	1		4		5		6		7		8		9		10		11	
Datum	01.02.'04	07.02.2004.		29.03.2004.		20.04.2004.		27.04.2004.		08.01.2008.		07.01.2011.		21.06.2014.		14.12.2014.		12.09.2015.	
sjever																			mm
RV1s	58,1498	58,1498	0,0	58,1492	-0,6	58,1492	0,0	58,1492	-0,6	58,1487	-1,1	58,1496	-0,2	58,1464	-3,4	58,1458	-4,0	58,1462	-3,6
RV2s	59,1669	59,1669	0,0	59,1664	-0,5	59,1664	-0,5	59,1658	-1,1	59,1662	-0,7	59,1646	-2,3	59,1677	0,8	59,1660	-0,9	59,1684	1,5
RV3s	60,1231	60,1231	0,0	60,1234	0,3	60,1234	0,3	60,1231	0,0	60,1268	3,7	60,1269	3,8	60,1333	10,2	60,1305	7,4	60,1350	11,9
RV4s	59,6502	59,6502	0,0	59,6501	-0,1	59,6501	-0,1	59,6492	-1,0	59,6518	1,6	59,6505	0,3	59,6541	3,9	59,6517	1,5	59,6552	5,0
RV5s	58,5110	58,5110	0,0	58,5103	-0,7	58,5103	-0,7	58,5099	-1,1	58,5099	-1,1	58,5069	-4,1	58,5079	-3,1	58,5069	-4,1	58,5078	-3,2
jug																			
RV1j	58,1396	58,1396	0,0	58,1388	-0,8	58,1388	-0,8	58,1382	-1,4	58,1382	-1,4	58,1394	-0,2	58,1359	-3,7	58,1355	-4,1	58,1360	-3,6
RV2j	59,1791	59,1791	0,0	59,1789	-0,2	59,1789	-0,2	59,1773	-1,8	59,1782	-0,9	59,1768	-2,3	59,1799	0,8	59,1785	-0,6	59,1810	1,9
RV3j	60,0390	60,0390	0,0	60,0390	0,0	60,0390	0,0	60,0381	-0,9	60,0414	2,4	60,0413	2,3	60,0478	8,8	60,0455	6,5	60,0501	11,1
RV4j	59,4440	59,4439	-0,1	59,4430	-1,0	59,4430	-1,0	59,4425	-1,5	59,4438	-0,2	59,4425	-1,5	59,4455	1,5	59,4438	-0,2	59,4470	3,0
RV5j	58,4366	58,4365	-0,1	58,4361	-0,5	58,4361	-0,5	58,4355	-1,1	58,4355	-1,1	58,4314	-5,2	58,4325	-4,1	58,4315	-5,1	58,4325	-4,1

TOČKA	Mjerenje	Mjerenje	ΔV	Mjerenje	ΔV	Mjerenje	ΔV	Mjerenje	ΔV	Mjerenje	ΔV
Mjerenje	0	12		13		14		15		16	
Datum	01.02.'04	14.07.2016.		19.12.2016.		15.07.2017.		12.12.2017.		10.06.2018.	
sjever											
RV1s	58,1498	58,1476	-2,2	58,1472	-2,6	58,1463	-3,5	58,1454	-4,4	58,1461	-3,7
RV2s	59,1669	59,1690	2,1	59,1664	-0,5	59,1687	1,8	59,1661	-0,8	59,1681	1,2
RV3s	60,1231	60,1373	14,2	60,1316	8,5	60,1357	12,6	60,1314	8,3	60,1348	11,7
RV4s	59,6502	59,6558	5,6	59,6558	5,6	59,6571	6,9	59,6525	2,3	59,6565	6,3
RV5s	58,5110	58,5090	-2,0	58,5081	-2,9	58,5084	-2,6	58,5064	-4,6	58,5074	-3,6
jug											
RV1j	58,1396	58,1338	-5,8	58,1371	-2,5	58,1360	-3,6	58,1338	-5,8	58,1352	-4,4
RV2j	59,1791	59,1823	3,2	59,1795	0,4	59,1812	2,1	59,1787	-0,4	59,1808	1,7
RV3j	60,0390	60,0520	13,0	60,0474	8,4	60,0506	11,6	60,0468	7,8	60,0498	10,8
RV4j	59,4440	59,4439	-0,1	59,4439	-0,1	59,4475	3,5	59,4445	0,5	59,4468	2,8
RV5j	58,4366	58,4343	-2,3	58,4326	-4,0	58,4320	-4,6	58,4307	-5,9	58,4317	-4,9

Figure 15. Table of measurements of benchmark point coordinates

6. Analysis of deflections and cracks

The presented values of deflections and photographs of cracks show that both phenomena increase as the bridge ages. The absolute values of deformations increase and the development of new cracks has not completed. The cracks on the bridge vault stones decrease structural rigidity, which leads to increasing deformation values. Heating of the bridge structure leads to elevation of the bridge center, the value of which increases as the bridge rigidity decreases. The cracks on the bridge vault are due to compressive stresses that cause the stone to split. The extent to which the cracks have reduced the bridge rigidity can be found by measuring the dynamic properties of the bridge and comparing with the measured values from 2007 (2). Eigenfrequencies of the bridge were measured that year, while the bridge still did not have cracks. Studies conducted in 2007 include determining the dynamic characteristics of the Old Bridge in Mostar experimentally using the test method of measuring ambient vibrations. The measurements were conducted by the:
INSTITUTE OF EARTHQUAKE ENGINEERING AND ENGINEERING SEISMOLOGY - IZIIS from Skopje Macedonia.
The measured values were in good agreement with the calculation values from the bridge reconstruction project (4).
There is a real risk of stone blocks locally falling out of the bridge vault in winter, when precipitation water freezes in cracks.

7. Conclusion

The cracks developing in the bridge vault in the last ten years certainly reduce safety of the bridge structure. The formation of new cracks indicates that the process has not completed yet and that cracks increasingly compromise the bearing capacity of the bridge. This is why it is urgently necessary to take action that will define the real causes of cracking on the bridge. It is necessary to propose the measures for repair of the existing cracks and measures that will eliminate the possibility of occurrence of new ones. Our time is running out.

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