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Crack monitoring in the Baptistery of the Euphrasian Basilica in Poreč

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ABSTRACT: In this paper we present six-month results of an ongoing structural monitoring of the Baptistery in the Episcopal Complex of the Euphrasian Basilica in the historic centre of Poreč, which is under UNESCO's protection as one of the best preserved complexes of early Christian architecture in the world. The complex is located by the sea and is partially still being used for its original function. Two wide and more than five meters long vertical cracks have been present for some time in the Baptistery, so the authorities decided to undertake a continuous crack width measurement. Automatic static monitoring system was installed with the aim to determine (i) if the cracks are active and (ii) if there is a correlation between the crack opening and the environmental parameters or the sea level oscillations. Such a continuous structural monitoring is a good way of getting necessary data in order to properly assess and extend the life time of heritage structures.

1 INTRODUCTION

The Episcopal Complex of the Euphrasian Basilica in the historic centre of Poreč, Croatia, has been inscribed on the World Heritage List in the 1997 as one of the best preserved early Christian complexes in the world. The Cathedral complex consisting of the Basilica, Atrium, Episcopal Palace and the memorial chapel originates from the mid sixth century (built by Bishop Euphrasius), while the Baptistery and numerous archaeological remains (like the floor mosaics of the older churches) are a testimony of two earlier building phases from: (i) the late fourth century and (ii) the fifth century (Matejčić, 2014).

In this work we focus on the Baptistery, which originates from the fifth century (Figure 1). It has an octagonal plan with internal side length of 3.4 m and floor slightly above the see level. In the middle of the floor there is a hexagonal pool which was used for the baptism. The masonry walls (stone in lime mortar) are 12 m high, 70-75 cm thick and have a window at the top of each side. According to drawings from the mid nineteenth century the upper part of the Baptistery was in ruins and without roof (Šonje, 1971), what consequently must have caused some deterioration of the material properties of the walls. The upper part of the walls with the windows and the timber roof has been reconstructed twice (Terry and Gilmore Eaves, 2001): first in the 1881 (Austrian period) and afterwards in the 1935 (Italian period). Two wide and more than five meters long vertical cracks reaching the windows (figure 2) have been present for some time in the Baptistery (already existed in the 1971, as reported by Šonje), so the authorities decided to undertake a continuous crack width measurement in order to assess more in detail the structural safety of the structure. The details of the structural monitoring will be showed in the next chapter.

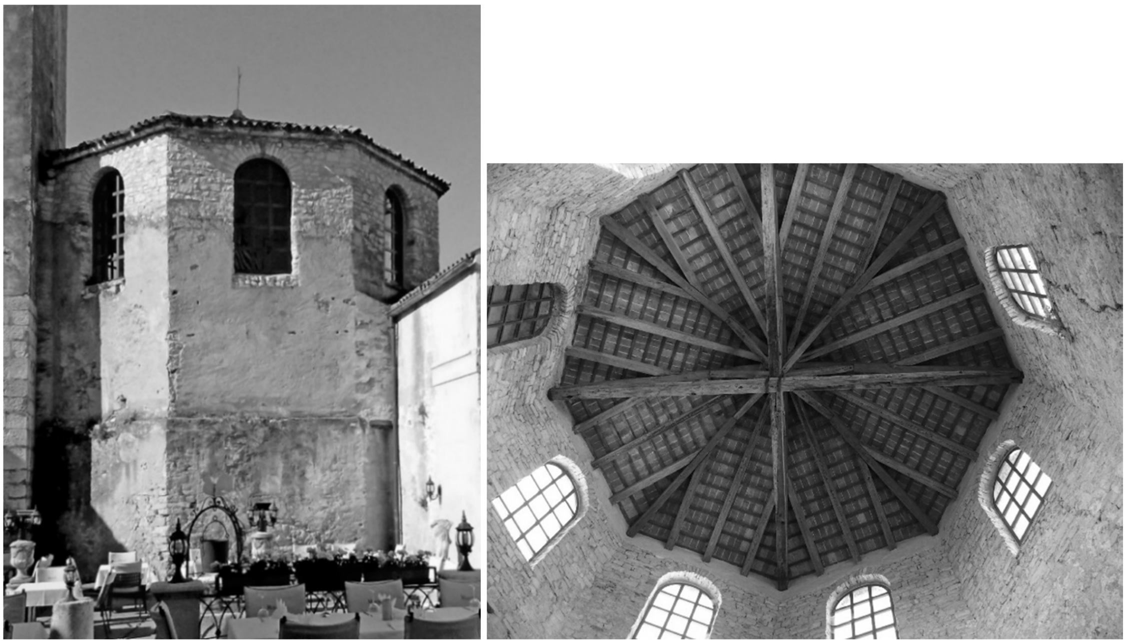

Figure 1. Octagonal Baptistery: south side view and view of the roof structure.

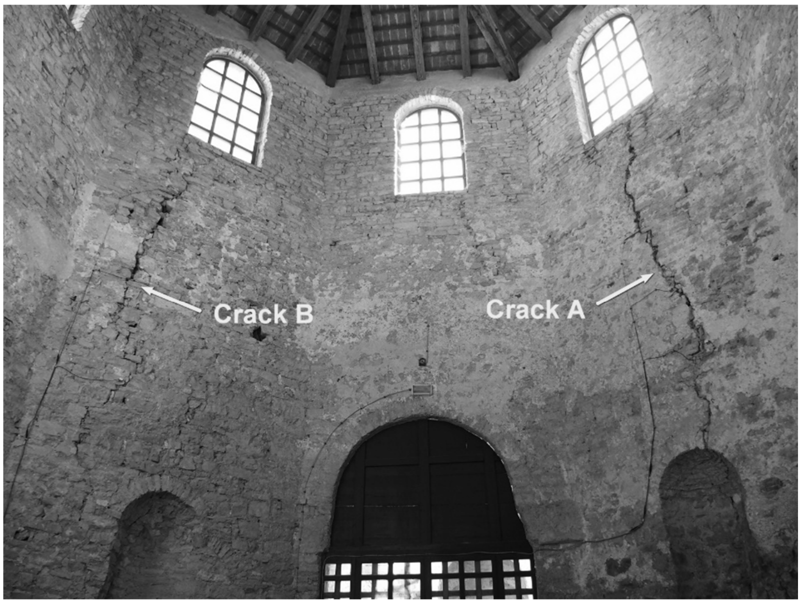

Figure 2. Two wide and long cracks in the Baptistery.

2 STATIC MONITORING SYSTEM

Automatic static monitoring system was installed in July 2018 with the aim to determine (i) if the two cracks are active and (ii) if there is a correlation between the crack opening and the environmental parameters (temperature and relative humidity) or the sea level oscillations. The monitoring system consisted of: six linear variable differential transformers (LVDT) – three per each crack, two combined temperature and relative humidity sensors (for measuring both indoor and outdoor conditions) and one water level logger (pressure sensor) for measuring the groundwater/sea level oscillations (figure 3). Data sampling for displacement, temperature and relative humidity was set to 15 min. Data from LVDT were collected via 16-bit AD converter, which was together with a PC with the remote control option located inside a protection box in the Baptistery.

Two types of LVDT were installed (Figure 4 and 5): (i) LVDT with a measurement range of ±25 mm (A1 and B1) and (ii) LVDT with a measurement range of ±2.5 mm (A2, A3, B2 and B3). They both have high linearity (<0.3% FSO). They were connected to the masonry wall with the adhesive without damaging the wall, and secured from falling on the ground or on visitors of the Baptistery.

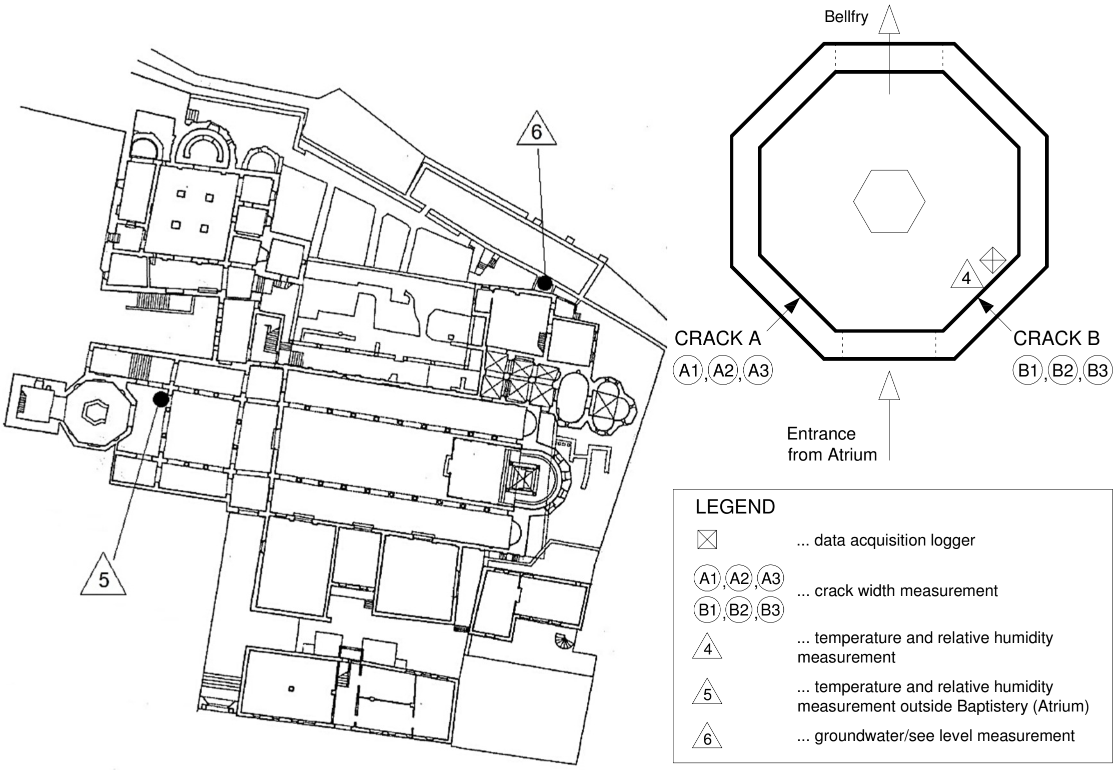

Figure 3. Ground plan of the Episcopal Complex (adopted from Terry and Gilmore Eaves, 2001) with enlarged plan of the baptistery showing the layout of the static monitoring system.

Figure 4. Two types of LVDT used with measurement range of: (i) ± 25 mm and (ii) ± 2.5 mm.

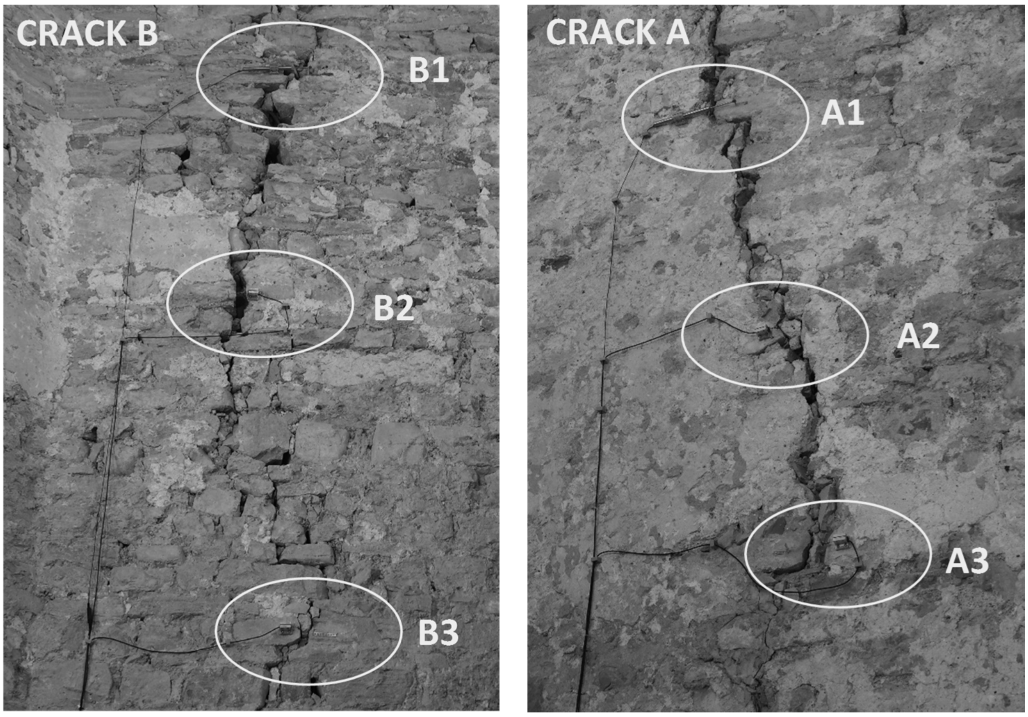

Figure 5. Crack width measurement points.

Since the Complex is located by the sea, and some parts are being flooded during the winter period it was especially important to measure the groundwater oscillations. For that purpose a CTD-Diver was installed to measure the groundwater level, temperature and conductivity. The acquisition time was set to 30 min. Depending on the measured temperature, pressure, and electrical conductivity, the current salinity of water or presence of sea water may be determined. Figure 6 shows the position of the installed sensor bellow the water level in a monitoring duct.

Figure 6. Position of the groundwater/sea level measurement sensor.

3 RESULTS AND DISCUSSION

Here we present results of the first six-month measuring period from July 2018 till January 2019. Figure 7 reports the temperature and relative humidity measurements inside and outside the Baptistery. It may be noticed that for most of the measured period the maximum temperature inside Baptistery is mostly equal or greater than the temperature outside (except for Sundays and holidays when the Baptistery is closed for visitors, therefore during sunny days higher temperatures are measured outside). In addition, since the Baptistery is closed during the night, there are much smaller fluctuations of the temperature inside than outside, meaning that during the night there is no cooling as outside. In the period from 6th September till 15th October a sudden jump may be noticed on both inside temperature and relative humidity measurements, which is affected by sunlight passing through windows and falling on the sensor causing sudden temperature increase and relative humidity decrease. This occurs only at a certain time during the year and is due to the different angles of the sunlight. These extreme results have therefore been neglected from the further analysis.

Very high values of relative humidity inside Baptistery have been recorded almost through the whole six-month measuring period. During the summer it was mainly above 70%, while during autumn and winter bigger fluctuations have been noticed with the values often above 80%.

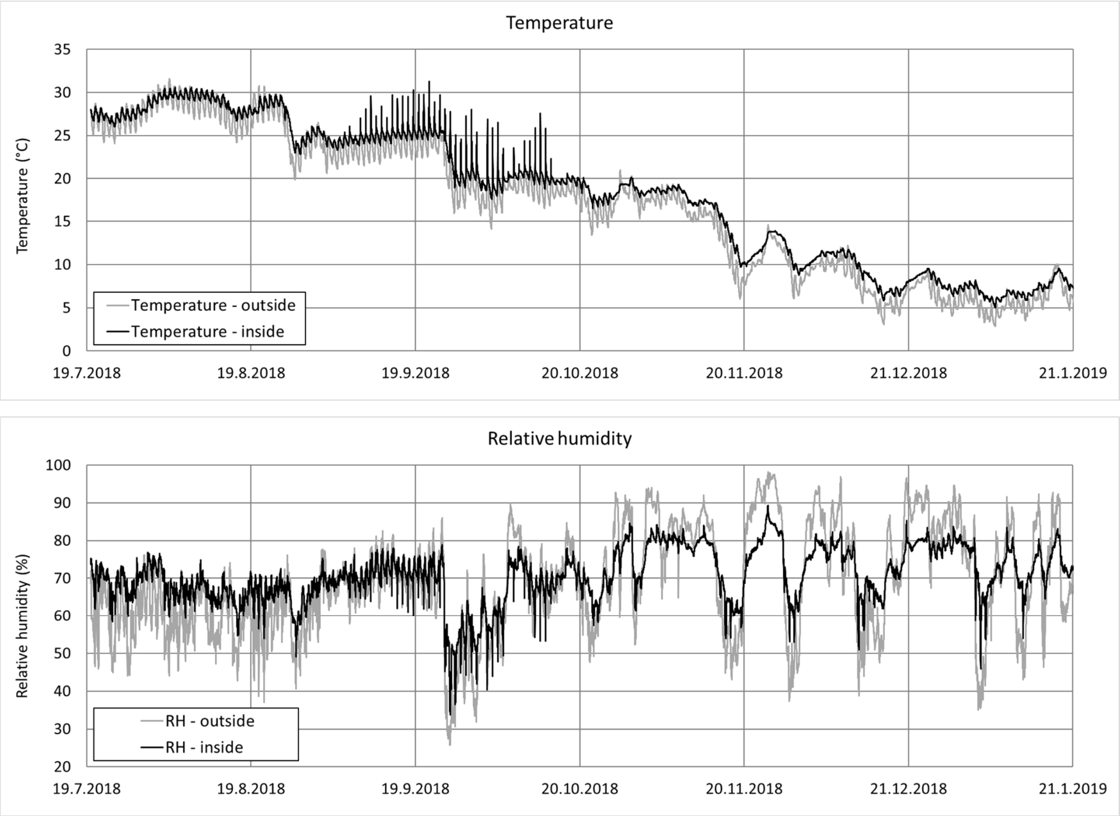

Figure 7. Temperature and relative humidity measurements.

Figure 8 presents crack width changes (displacement) related to the outside temperature for the considered six-month period. Note that the measured crack width changes are extremely small in size: width of crack A is within 0.15 mm, while width of crack B is within 0.2 mm.

From Figure 8 we may establish a correlation between the crack width change and temperature, especially for measuring point A1 and B1: with the temperature decrease the crack width decreases, i.e. the cracks close. We expect the crack widths would return to previous measured values with temperature increase in the next six-month period.

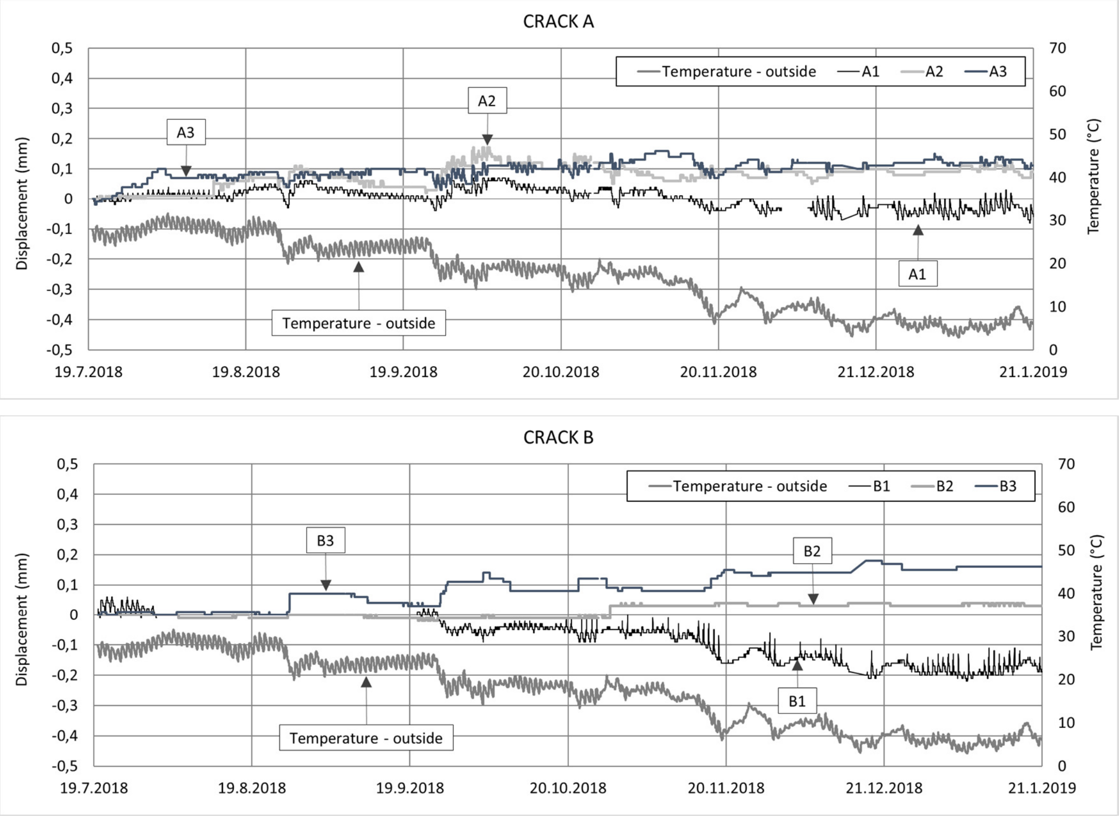

Figure 8. Crack width in relation to outside temperature.

The correlation between the crack width A change and the temperature is better investigated in Figure 9, where the results are compared for the period from 27th September till 4th October. It may be clearly noticed that daily temperature fluctuations cause the crack width change accordingly (for all three measuring points). This is something that happens on daily basis due to the whole day exposure of the south wall (where crack A is located) to direct sunlight. This was not observed for crack B since that wall is not exposed to direct sunlight.

Figure 10 shows the crack width change in relation to relative humidity, where no significant correlation has been observed.

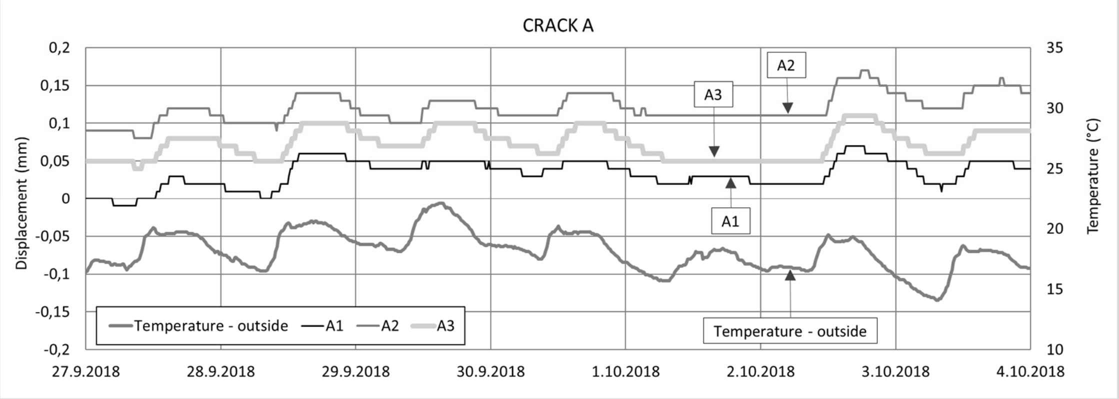

Figure 9. Crack width A in relation to outside temperature from 27th September till 4th October.

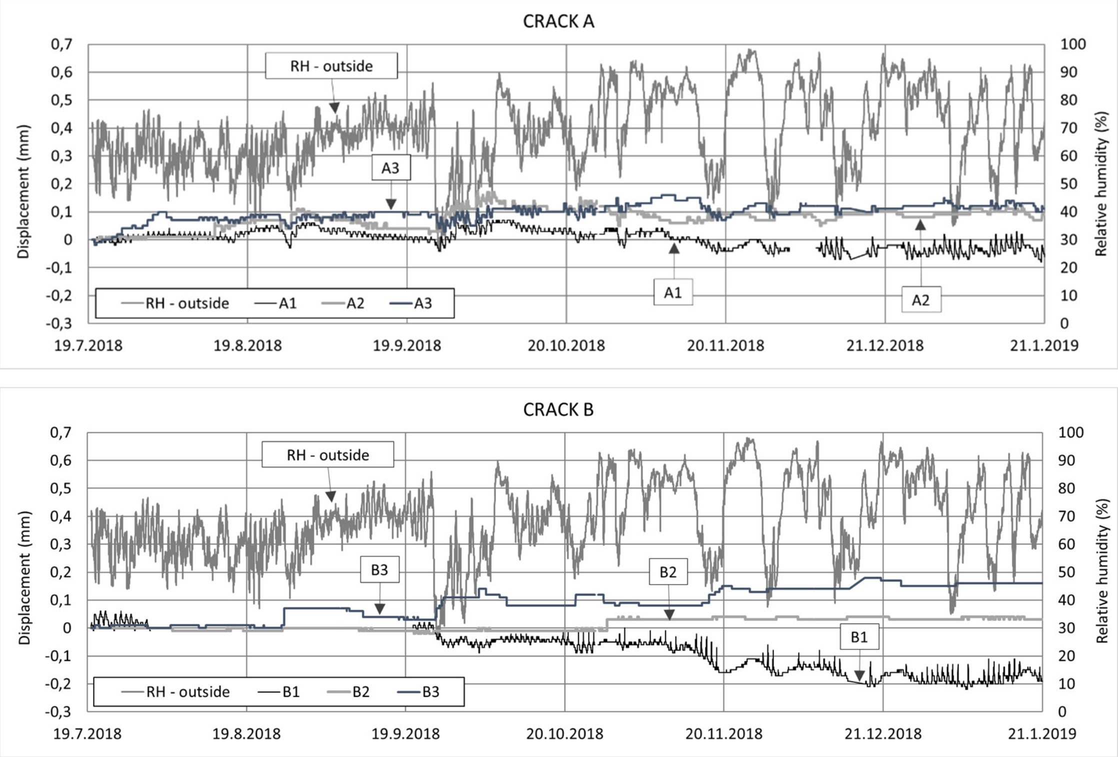

Figure 10. Crack width in relation to relative humidity.

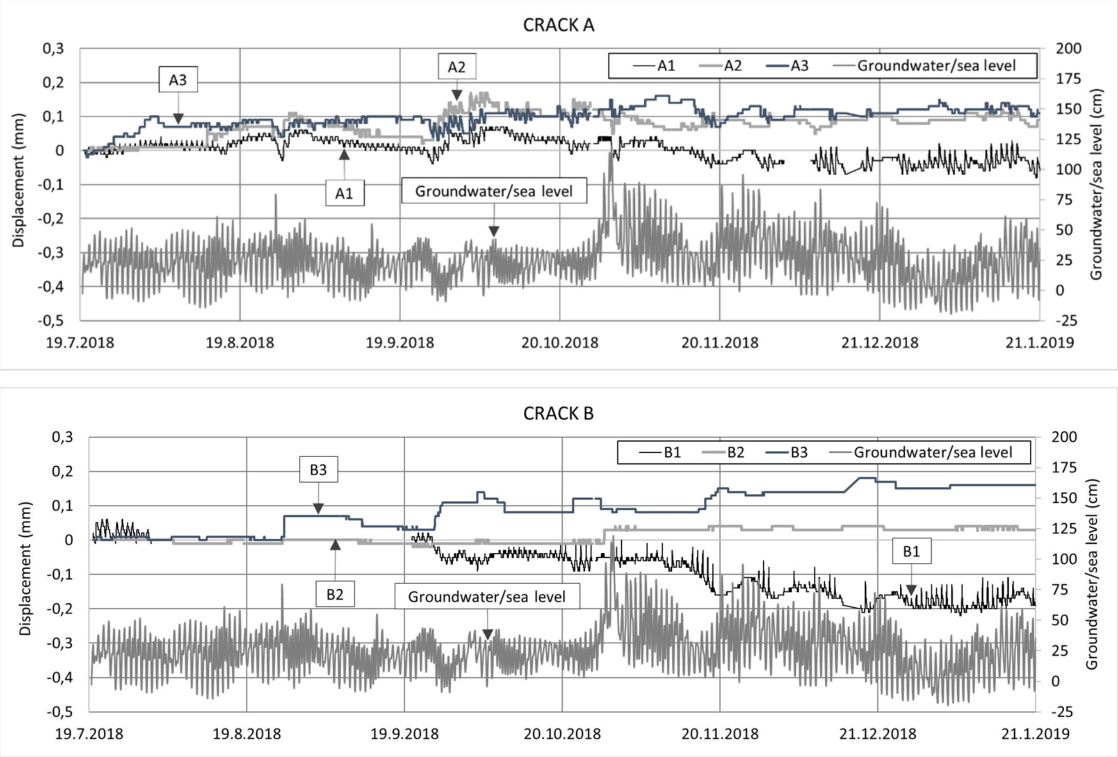

Figure 11. Crack width in relation to groundwater/sea level.

On Figure 11 crack widths are related to groundwater/sea level measurements, displayed as absolute levels. Measured levels mainly correspond to sea levels, which was confirmed by electro-conductivity measurements. Sea levels are higher during low air pressure and rainy weather, when the salinity decreases. The most frequently recorded levels are from +30 to +50 cm above sea level, while the high levels over +100 cm above sea level are very rarely recorded. Average value of groundwater/sea level during the observed period was equal to +26.4 cm above sea level, while maximum and minimum were +119.0 cm and -19.6 cm above sea level, respectively. So far no correlation was observed between the crack width change and groundwater/sea level measurements.

4 CONCLUSION

This paper presents preliminary results of an ongoing structural monitoring in the Baptistery of the Euphrasian Basilica in the historic centre of Poreč. Based on the first six-month measuring period the following conclusions may be summarised:

(i) measured displacements (crack width change) are extremely small in size: all measured crack width opening/closing are within ±0.2 mm,

(ii) change of crack width may be related to change of temperature: both in the entire measurement period (global) as well as on the daily level (local),

(iii) measured groundwater levels mainly correspond to sea levels, which was confirmed by electro-conductivity measurements.

The aim of this paper is to show that a long term continuous structural monitoring is a good way of getting necessary data in order to properly assess, preserve and extend the life time of heritage structures. Based on the results obtained so far no general trend of crack width increase or decrease in time was observed. Therefore it may be concluded that the monitored cracks are not active. The correlation between the crack closure with temperature decrease has been established, while no correlation has been observed between the crack width change and sea level oscillations. The structural monitoring will be continued to at least six more months to get a whole year response.

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6 REFERENCES

Matejčić, I. 2014. Euphrasiana – Cathedral in Poreč, Pula, Region of Istria. (downloadable at: http://www.expoaus.org/listalice/en/Eufraz_ENG_WEB.pdf).

Šonje, A. 1971. Protection issues of the Euphrasian Basilica's Baptistery in Poreč (in Croatian), Zbornik Poreštine, Zavičajni muzej Poreštine, Croatia.

Terry, A. and Gilmore Eaves, F. 2001. Retrieving the record – A century of archaeology at Poreč (1847-1947). University of Zagreb – International Research Center for Late Antiquity and the Middle Ages, Motovun, Croatia.