The Savone Bridge on the SS 7 “Appia”: Real Time and Topographic Monitoring of Thermal strain

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Abstract

The Savone bridge is located along the SS 7 rural road “Appia” in the southern territory of Francolise town (Caserta county). It overpasses the Savone river and it is about 150 m long. It has been built in the first part of the 50s and now it shows some problems that have been decided to investigate.
Specifically, it has been observed that one of the 8 expansion joints located on the bridge was not correctly positioned. In other words, there was a too high and irregular displacement between the 2 faces of the joint. So, it was time to ask if the whole expansion joint had to be redone or the problem could be located elsewhere.
In order to understand what could it be happened, it was decided to put the expansion joint under control via two different methods: a classic topographical way and an innovative real time way. With respect to the first way, 2 reference points were placed across the joint. The space between the faces has been read 6 times with different outside temperature values. This work was also useful to the second because it had to calibrated. The real time monitoring consisted of 4 displacement sensors placed at the 4 ends of the bridge deck and 1 temperature sensor. The sensors read the displacements and temperature 6 times per day for a 6 months period. The data were collected in a central unit and it was possible to download them by a simple click on the computer desktop. In fact, an innovative GSM connection between the central unit and a remote one has been provided. This was the true “real time” monitoring as in every connection it was possible to read the sensors and to become aware of the passing of a car or a truck (excessive or low displacement). Finally, lots of data have been collected.
They have been first calibrated with the topographical survey and then correlated with the temperature sensor data with a normalization standard. Results showed that 3 over 4 sensor ends had an erratic behavior. So, it was demonstrated the problem was not located only on the expansion joint itself but also on the lower bearing devices of the bridge.

problem explanation

The bridge on the Savone river has been built in the 50’s in order to improve a tortuous part of the SS 7 rural road “Appia”. The bridge itself has a structure made of reinforced concrete and the stathic scheme is a Niagara one with four different decks which bear on Gerber structures. Both decks and piers have a variable section so that the resulting architecture of the bridge is very nice.
The whole bridge has been ordinary mantained in the past. Typical works made on it were: new final layer of pavement, installation and maintenance of new metal guard rail, maintenance of the drainage devices and of the expansion joints. Talking about the uncommon maintenance, just one work on the two piers in the river has been made: it had been observed expulsion of small parts of concrete from the lower part of the pier.
Nowadays, an investigation on the spot was made together technicians of the management society (ANAS) and an unusual displacement of the first deck (on the Capua side) has been observed. The displacement is showed in pic. 1 (left); it can be compared to the other joint (right picture).

Picture 1: unusual displacement of the expansion joint on the first deck of the Savone bridge


The displacement provoked an excessive run of the expansion joint: of course it lost its functionality. So,, works of uncommon maintenance had to provide the replacement of the expansion joint itself but it was decided that investigations concerning causes of the trouble had to be made with the installation of a system of monitoring. The system was based on both topographic and satellite procedures in order to avoid unuseful works.

Picture 2: unusual displacement of the expansion joint on the first deck of the Savone bridge (as seen from the upper side)

3. the topographic monitoring

The left end of the expansion joint Capua side has been made under observation. Two reflecting prism supports have been installed on the deck and a small reinforced concrete pier alongside the Savone river has been built. The pier had a special threading at the top so that the measure instrument could be easily applied. In this way, the theodolite was always in the same position. This system operates so that the measures taken in different moments always have the same referenced fixed points and directions. This allows the system to reduce at the lowest level the position and collimation errors

The bridge axis has been used as a reference one and it has been considered aproximatively aligned along the east - west direction. Specifically, the east side headed toward Capua and the west side headed toward Rome. The small pier used as theodolite base was located southside.

The whole system carried out in the described way allowed a tolerance value of 0,5 mm of the possible measurement error.

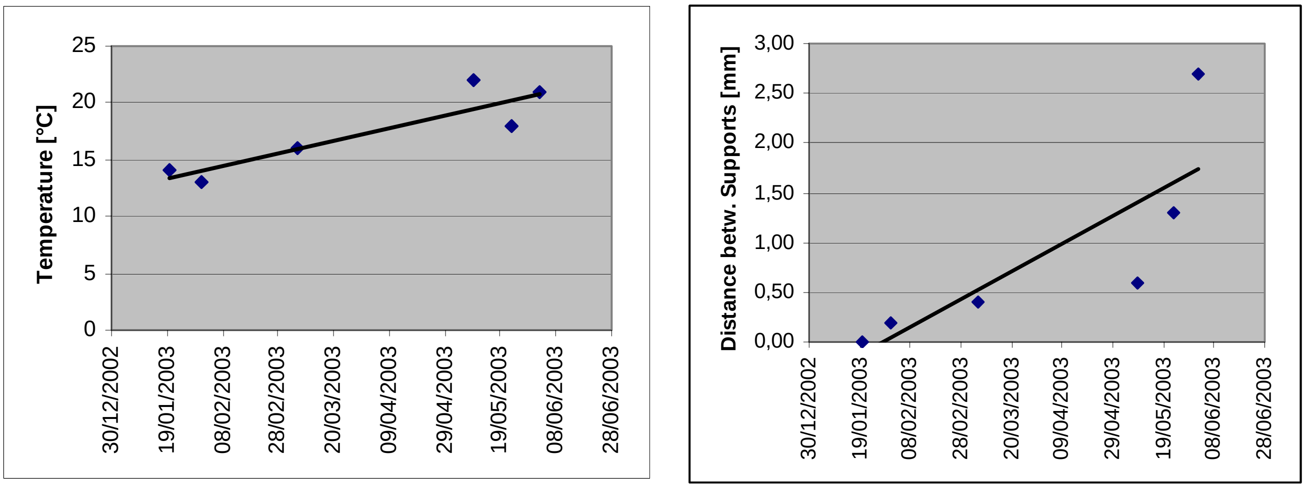
Tab. 1: Displacement trend of the left side of expansion joint Capua side. Survey with topographic instruments

Date	Temperature [°C]	Distance [m]
20/01/2003	14	0,4096
31/01/2003	13	0,4098
07/03/2003	16	0,4100
09/05/2003	22	0,4102
23/05/2003	18	0,4109
02/06/2003	21	0,4123

6 instrumental surveys have been made on January 20th, January 31st, March 7th, May 9th, May 23rd, June 2nd. Results are showed in tab. 1.

They are showed in a graphic way in fig. 1 which follows.

Fig. 1: Diplacement trend observed with topographic instrument and comparison with temperatures



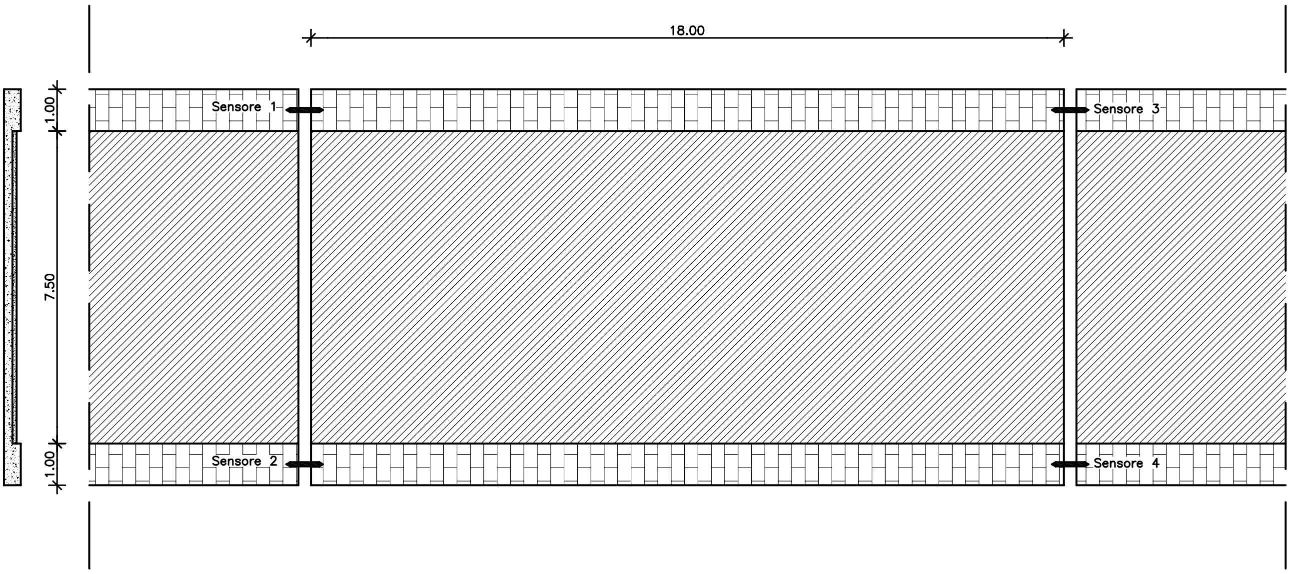
4. the real time monitoring

The survey carried out with digital instruments has been done installing 4 expansion joint gauges. Each gauge was made with a conductive plastic which supplies a voltage variation proportional to the linear displacement read. The gauges have been located in the following way:

- 2 gauges have been placed parallel to the bridge axis and at the ends of the expansion joint of the deck, Capua side;
- 2 gauges have been placed parallel to the bridge axis and at the ends of the expansion joint of the deck, Rome side; the scheme is showed in fig. 2;
- 1 gauge has been dedicated to temperature.

Furthermore, a mainframe has been installed in order to collect all data given by the 5 gauges. The electric supply was given by a couple of batteries with the help of a small solar panel for the battery recharge. There was no external supply for the system and it could be considered as independent.

Fig. 2: Gauge location above the bridge

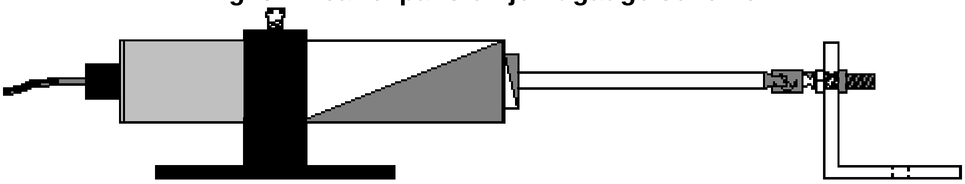


The gauges have been installed inside a protective plastic shell (see picture 3).

Picture 3: linear expansion joint gauge installed

The shell itself has been filled with the appropriate gaskets in order to protect the gauges. Then, the gauges have been placed on the sidewalk of the bridge with the help of a special glue. Finally, the cable wiring and the mainframe setting have been arranged. The linear expansion joint is showed in fig. 3.

Fig. 3: linear expansion joint gauge scheme

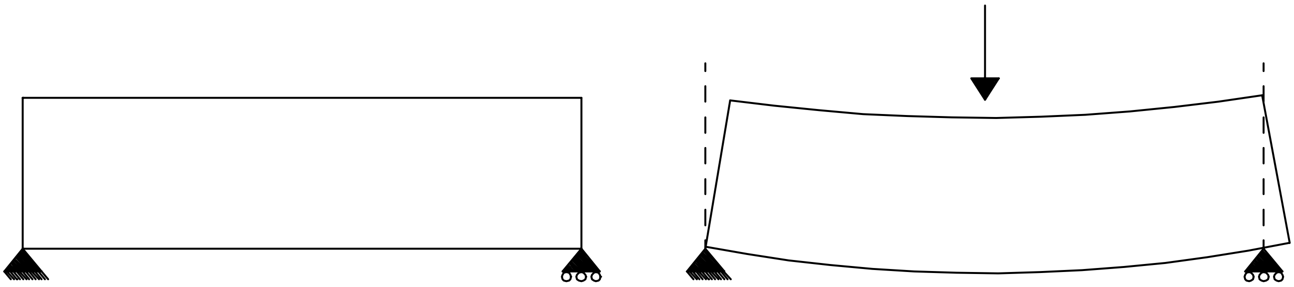


The survey done with both digital and topographic equipment lasted 6 months. All data were first collected in the mainframe and then they could be downloaded in the office PC. In fact, the mainframe was supplied with a GSM frame by which it was possibile to download filed data, to make single gauge readings and so on with a specific dedicated software.

5. results obtained and analyses

6 daily readings have been made for each gauge, together the external temperature. The values resulted with a high dispersion rate due to the high variability of the readings themselves within the same day. This is not unusual. In fact, the longitudinal displacement of the upper part of a beam end can be caused only by 2 phenomena: the thermal strain and the passage of cars and trucks.
The first one is intuitive so it will not be given any explanation. On the other side, the second one is not evident so in the next part it will be provided a small illustration. With reference to fig. 4, let's suppose to have a beam restrained on a hinge and truss. The force showed in fig. 4 on the right entails a longitudinal displacement of both ends of the beam. Specifically, the draw on the left shows the undeformed shape while the right one shows a possible deformed shape.

Fig. 4: deformed and undeformed shape of a beam restrained on a hinge and truss



The draw is necessarily just qualitative but it helps to understand which kind of strain can affect the bridge expansion joints. By the way, it is interesting to highlight that the same kind of calculus can be used to evaluate the total run of the longitudinal bearing devices (the right restraint in fig. 4). The results are very noisy and this can be due to the several daily passages of trucks on the bridge. In fact, the passage of heavy vehicles entails a high vibration rate on the structure: the vibration need about 30 seconds to be spent at all. The time interval of 30 seconds has been determined during the topographic survey. In fact, it has been necessary to stop the traffic on the bridge for about 1 minute: 30 seconds were necessary to stop the vibrations and the last 30 to take the distance between the 2 reflecting prisms located on the 2 ends of the bridge. This has been possible with the help of the ANAS workers.
All data resulting from the digital monitoring have been manipulated in 2 ways in order to bypass the high noisy rate. First, the 6 daily data have been aggragated in an average one so that just 1 datum came out from 1 day. In other words, an average daily displacement has been determined for each gauge. The same has been done with the temperature gauge so that an average daily value of it has been obtained.

Picture 4: in this picture the solar panel and the topographic supports are visible. Note the black reflecting prism installed on the closer support

As we are interested to evaluate the conditions of the expansion joints and the lower bearing devices, the average increase, if existing, of longitudinal thermal strain has been considered together the temperture variation. In other words, a line representing the interpolated strain values has been plotted for each gauge result. As the temperature is average growing in the observed period, it can be expected that the strain bahaviour is decreasing as time passes. In fact, if gauges show a strain decrease this implies that the 2 faces of the deck are approaching themselves because of the average increasing temperature rate. The diagrams obtained are showed in the next figg. 5, 6, 7, 8 and 9.
The first observation to be done is that the temperature has an average increase of about 12 degrees in the period of observation. If the zero is positioned on the lower temperature value, the theoretic displacement results as follows:
$\Delta L = \alpha \cdot L \cdot \Delta T =$ 0.000012 x 18000 x 12 = 2,6 mm

So we expect a total displacent (on both sides of the bridge) of 2,6 mm.

Fig. 5: Results gauge S1

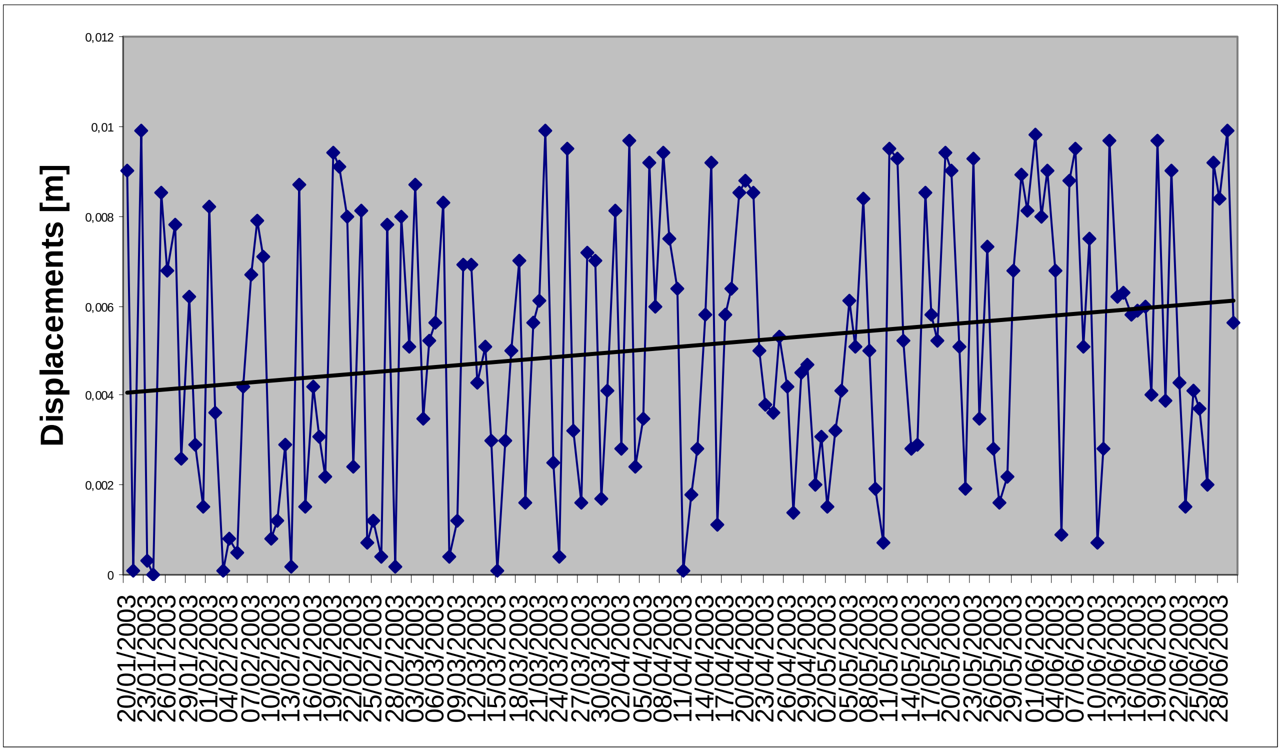


Fig. 6: Results gauge S2

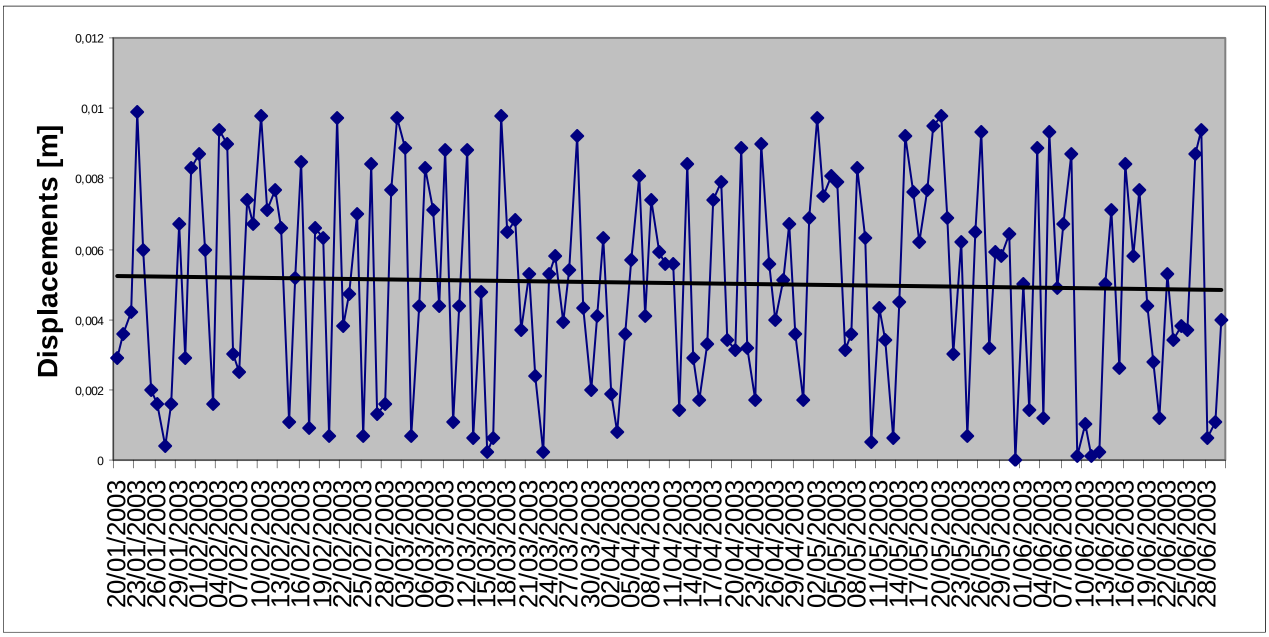


Fig. 7: Results gauge S3

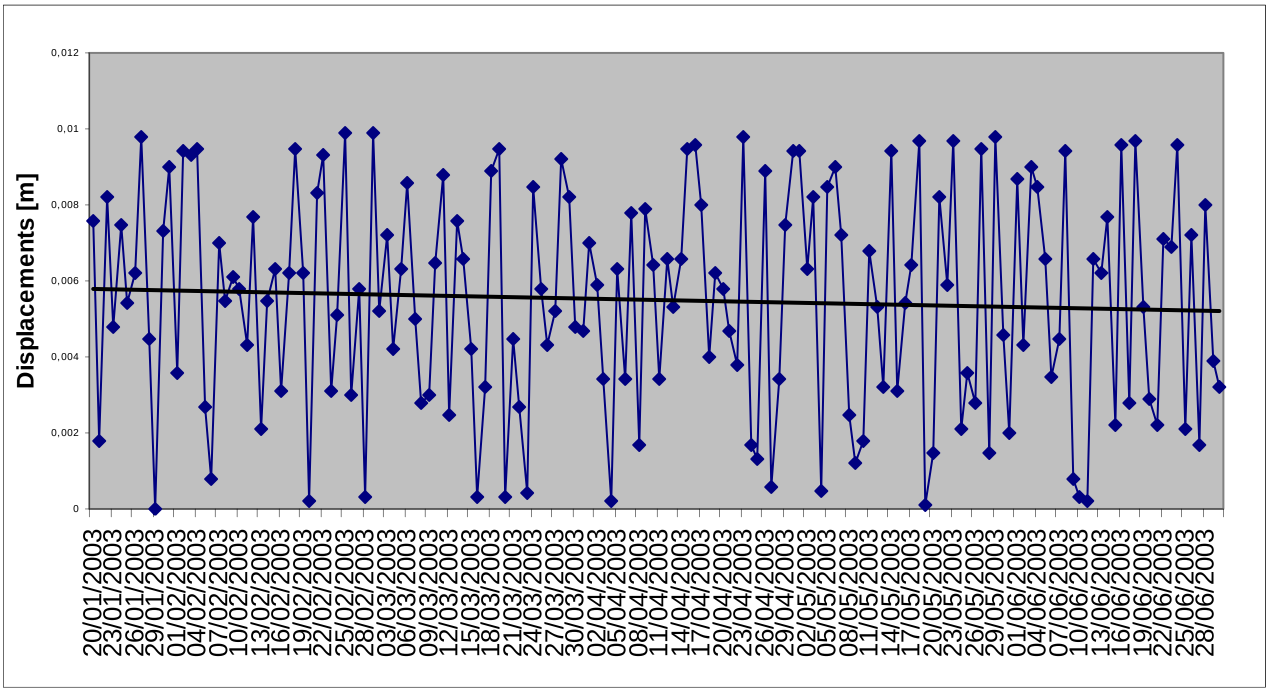
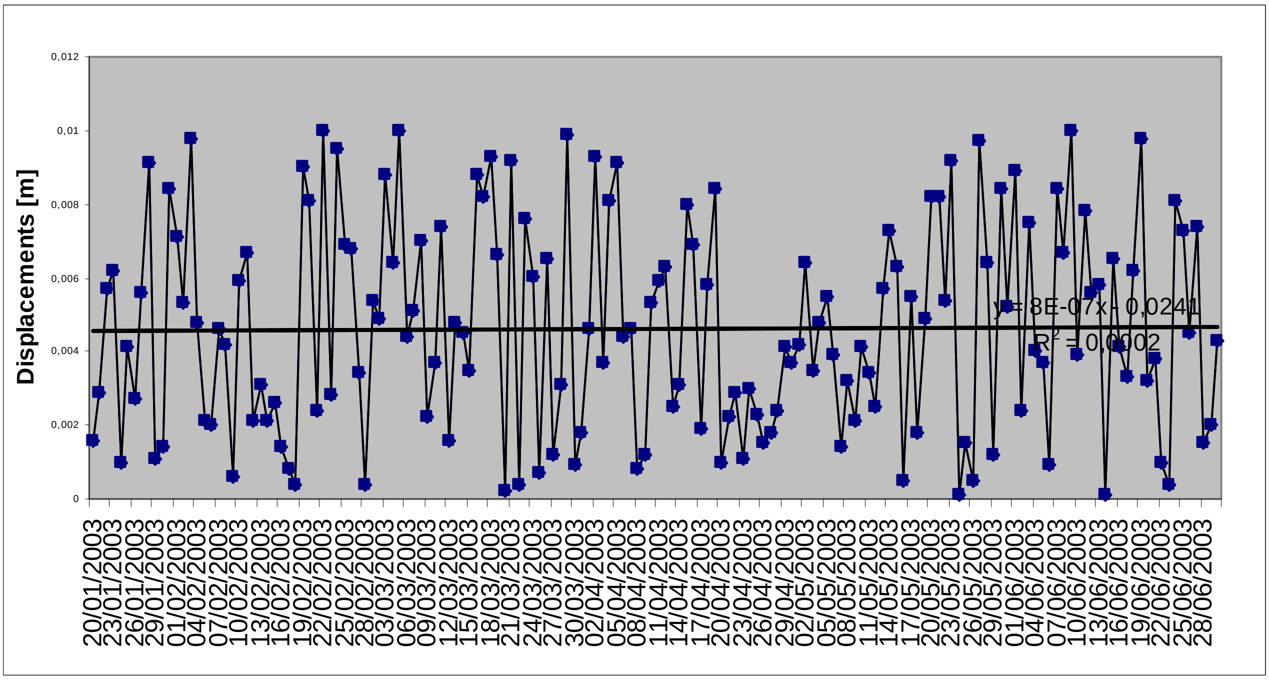


Fig. 8: Results gauge S4

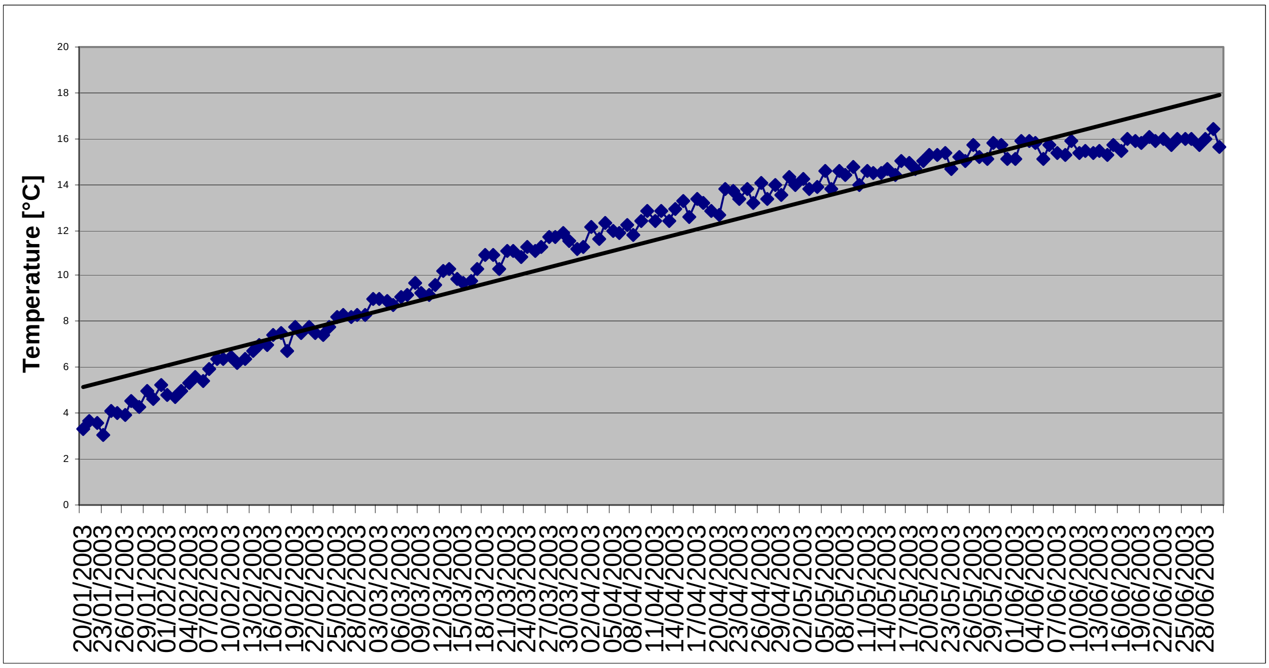


The analyses of diagrams shows the following matters. The gauge 1 showed a lenghtening so the 2 heads of the bridge moved away during the period of observation. Gauges 2 and 3 showed a shorten so the 2 heads of the bridge approached during the period of observation. Gauge number 4 resulted substantially stable. The strain of gauge 1 is besides suitable with the trend of topographic survey as it showed a moving away of the 2 heads of the bridge.

Leaving apart the results of gauge 1, the sum of displacements recorded on the other gauges is 0.326 + 0.652 = 0.978 mm, i. e. about 1 mm. As it is not available the exact position of the hinge and truss, we can consider directly the sum of both values as the final value attended with an average thermal variation of 12 degrees. Now, it is possible to calculate the ratio between the experimental result and the theoretical one:

$$\Delta S = \frac{0.978}{2.6} = 0.376$$

Fig. 9: Results temperature gauge



The real thermal strain is about 40% of the expected one. But if we consider data of gauge 1, the percentage of course decreases furthermore.

A further analyses has been developed on data supplied by gauges S2 and S3 in order to understand the correlation level between the temperature gradient and the approach of the 2 heads. Data have been normalized with the expression

$$\frac{f - f_{\min}}{f_{\max} - f_{\min}}$$

in order to compare them directly on the same scale parameter. In fact, the normalization will supply only values included in the [0; 1] field. As both phenomena have an opposite trend (gauges shorten while temperature increases), we expect to have a negative correlation coefficient between the 2 series. The more the correlation coefficient is negative, the more the 2 series will be correlated.

Vice versa, if the correlation approach zero, the 2 series will not have any correlation between them and we can say that the trend is totally erratic.

In the table 2, correlation coefficients between gauges 1, 2, 3, 4 – gauge temperature are reported.

Tab. 2: Correlation coefficient T – gauge displacements

	Gauge S1	Gauge S2	Gauge S3	Gauge S4
Correlation with T	0.1899	-0.0169	0.0116	-0.0551

All values are very close to zero so it is possible to come to the conclusion that also the correlation analyses shows a bearing device behaviour not congruent to the temperature variations recorded during the period of observation. So, the unusual displacement observed in the first frame of the bridge does not depend just on the expansion joint but also on the bearing devices that don't work properly. The works to be done on the bridge will have likely to include also the restoring of bearing devices as they have an erratis behaviour.

5. Conclusion

A deck of the Savone bridge located on SS 7 rural road “Appia” has been put under control with both a topographic and real time monitoring. The bridge has been under control for 6 months. In this period the average temperature increase was 12 degrees and the theoretical thermal displacement should be 2.6 mm. But the average real thermal displacement between the 2 heads of the bridge was just 40% of the theoretical one, discarding data coming from 1 gauge. The behaviour is probably due to a bad working way of the lower bearing devices which do not allow the structure to move properly.

This situation implies an increase of the tensions in the structure. In the period of monitoring they are compression-like but in the next season they could be traction-like. These tensions could increase significantly in the gerber area as it has a shorter section than the complete one. So, the works to be done on the bridge will have likely to include also the restoring of bearing devices as they have an erratic behaviour.

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