Analysis of leveling network of viaduct Koševo

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Abstract: Special vertical geodetic network was established on the viaduct Koševo. Measurements in the network were performed by using precise geometric leveling in two epochs. Measurements in the first epoch were done in winter conditions, while the second epoch measurements were done in summer conditions. Processing and network adjustment was followed after the measurements. The heights of characteristic points on the bridge resulted from mentioned procedure. Taking into account the standard deviation of measurements, differences in heights of points on the bridge have shown change in the height of individual points on the bridge. These differences suggest possible movements of the pre-stressed concrete viaduct Koševo.

Key words: bridge, precise leveling, adjustment, results analysis

Analiza nivelmanske mreže vijadukta Koševo

Sažetak: Na vijaduktu Koševo uspostavljena je visinska geodetska mreža posebne namjene. Mjerenja u mreži obavljena su metodom preciznog geometrijskog nivelmana u dvije epohe. Prvu epohu mjerenja čine mjerenja obavljena u zimskim uvjetima, a drugu epohu u ljetnim uvjetima. Nakon obavljenih mjerenja uslijedila je njihova obrada i izjednačenje mreže, a kao rezultat su dobivene visine karakterističnih točaka na vijaduktu. Razlike nadmorskih visina točaka na vijaduktu, uzevši u obzir standardnu devijaciju obavljenih mjerenja, pokazale su da se visine pojedinih točaka na vijaduktu mijenjaju, a razlike upućuju na moguće pomake prednapregnute betonske konstrukcije vijadukta Koševo.

Ključne riječi: vijadukt, precizni nivelman, izjednačenje, analiza rezultata

1. INTRODUCTION

In wider terms, bridges are structures used to overcome barriers, and their primary purpose is to extend roads. Viaducts are special and specific field of engineering and construction (Pržulj, 2014), and therefore particular attention is paid to them.

Every bridge structure must meet four basic requirements: the functionality requirement, the requirement of unswerving (safety, stability and durability), the aesthetic requirement and the cost-efficiency requirement (Radić, 2002). Viaducts have been the subject of many studies by researchers of different profiles observing viaducts from the perspective of their profession. In a paper by Huzjan and Ostojić (2012), a detailed study is conducted with respect to static and dynamic analysis of a viaduct using a numerical model previously developed by the authors for nonlinear static and dynamic analysis of different types of masonry structures, but without surveying. Static and dynamic load testing was treated in the papers Henriques and Casaca (2001), Ademović (2016), Ademović (2017), while Jae Kang et al. (2016) conducted an analysis of height displacements of a number of structures, including a viaduct, by using the geodetic method of precise geometric leveling, with measurements being performed over a longer period of time, and not only in critical conditions.

The geodetic measurement techniques most commonly used in geometric monitoring of structural deformations of a viaduct are satellite (Lienhart et al. 2017), terrestrial (Taşçi, 2015) and photogrammetric techniques (Beshr, 2015). They provide global information on behavior of the structure being surveyed (Skoczylas, 2016). The terrestrial laser scanning technique (Mill et al., 2015; Pellegrinelli et al., 2013) has been increasingly used recently to examine structural displacements of viaducts. The precise geometric leveling method provides the best results in situations when spatial displacements of viaduct points in vertical plane need to be determined with high accuracy (Kapetanović et al., 2015).

Staking out of substructure is the most challenging from a geodetic point of view, whether it is the case of abutments or piers during viaduct construction. In addition, surveying displacements of a structure before and after effects of an earthquake is of greatest importance for further use of the structure (Güney et al., 2010; Emniyet et al., 2008). All these procedures for monitoring and analyzing of structures are conditioned by completed geodetic measurements (Kapović, 2010).

2. OVERVIEW OF GENERAL GEODETIC OPERATIONS DURING VIADUCT CONSTRUCTION

During construction of viaducts, geodetic activities can be grouped into six basic stages (Novaković, 2006). When designing and collecting data during the construction of a viaduct, it is necessary to use geodetic maps of different scales. A small – scale maps or plans are used for this purpose, while a large – scale plans are used for development of the main design.

Preliminary geodetic operation for construction of a viaduct includes production of the special geodetic maps and this work is followed by stakeout of viaduct abutments and piers. Construction of any structure, and consequently construction of a viaduct, requires geodetic operations even down to a millimeter level (Becker, 2002), staking out of the viaduct, post-construction control measurements and during viaduct load tests upon completion of its construction. A particularly important geodetic activity, which is actually the basis for all these operations and extends throughout their course, is the establishment of a special-purpose geodetic network. Conclusions on possible movements of the viaduct structure are made based on special-purpose geodetic network data extended by a set of data points on the bridge structure. Depending on the type of load used to test the viaduct structure, two testing methods are mainly applied: static and dynamic.

The static testing of a viaduct is carried out by loading the structure with a load (trucks), while measuring the induced movements by geodetic methods. If the measured values are consistent with the theoretical ones, then the structure is declared technically adequate (Novaković, 2006). The method of testing a viaduct in Bosnia and Herzegovina is in conformity with the standards (BAS U.M1.046, 2005), while in the United States, clear guidelines are provided in (NCHRP-234, 1998). The actual behavior of a structure under load action is generally better than theoretical. Many influences play a role in this. The dynamic testing is conducted in order to determine the dynamic properties of structures, specifically: the natural period of oscillation, the mode of vibration, and damping (Novaković, 2006; Ademović, 2017). Testing of natural frequency and temperature during a continuous monitoring system revealed that the natural frequency and temperature are largely correlated and it is a non-linear dependence (Ademović, 2017; Moser and Moaveni, 2016).

Considering that the purpose of the Koševo viaduct is partly changed (one part of the structure serves as a parking area, while the carriageway, that was supposed to be provided for one-way traffic, is used for two-way traffic), it is necessary to check stability of the viaduct structure and thereby usability of the viaduct as a structure. In order to verify the stability of the structure, it is necessary to perform a calculation based on the updated actions and usability parameters (Šavor and Novak, 2015). Changes in bridge-viaduct loads are recorded, both like in North America according to Sivakumar et al. (2011) and in Europe according to Getachev and O'Brien (2007).

Measuring the actual traffic loads on the viaduct is necessary in order to assess the higher levels of the structure, because load is the main source of all uncertainties on the viaduct. The actual traffic load on bridges-viaducts is determined by the system of weighing vehicles in motion, the so-called weigh-in-motion (WIM) measurements for road vehicles (O'Brien and Enright, 2013, Enright and O'Brien, 2011).

3. VERTICAL GEODETIC CONTROL

From the geometric point of view, geodetic network is defined as a configuration of three or more points on the ground, which are connected by either terrestrial geodetic measurements (horizontal directions, angles, azimuths, distances, height differences), or astronomical or satellite measurements (GNSS) or a combination thereof (Mihailović, 1992).

Considering that errors of the fixed values cannot be influenced, the high accuracy networks are adjusted in the local coordinate system (Kontić, 1995). The points that are established only to obtain a vertical representation of terrain or to obtain heights of characteristic points of the observed structures constitute a leveling network (Muminagić, 1987). Establishing a leveling network for the requirements of engineering work in construction is a complex operation and can generally be divided into three main phases (Mihailović, 1992): network project; realization - implementation of the project; and analysis of measurements.

4. GEOMETRIC LEVELING

Leveling is a geodetic operation by which height differences, or elevations of points relative to a previously adopted level surface, are determined with a leveling method (Tuno and Kogoj, 2012). In special engineering work, height differences are determined using the precise geometric leveling method as the most accurate geodetic operation. Leveling instruments of highest accuracy or precise levels, as they are usually called, are designed for measurements of height differences in higher-order state leveling networks and have an important application in industrial measurements, construction, laboratories, etc. (Pašalić, 1989).

Height differences are obtained by subtracting the reading on the forward staff from the reading on the back staff.
It is necessary to perform the measurement with the instrument placed strictly equidistant from the two points to be measured. When setting up a tripod, two legs of the tripod must be set to be parallel with the leveling line and the third one perpendicular to this line.

Figure 1 Positioning a tripod in relation to the leveling line (Tuno and Kogoj, 2012)

The recommended operating procedure for leveling is BFFB. This operating technique - staff reading procedure involves reading a backsight (B), then a foresight (F), then a second foresight (F), and finally a second backsight (B).

5. LEVELING NETWORK ADJUSTMENT

Measurement processing is performed upon completion of the planned observations. Processing is followed by survey measurement adjustments by least squares, with a mandatory significant redundancy condition. There are three models of least squares adjustment: parametric, conditional, and combined, resulting in minimized measurement errors which remain in the measurements (residuals), the most probable values of a measured quantities and the most probable values of a unknown quantities.

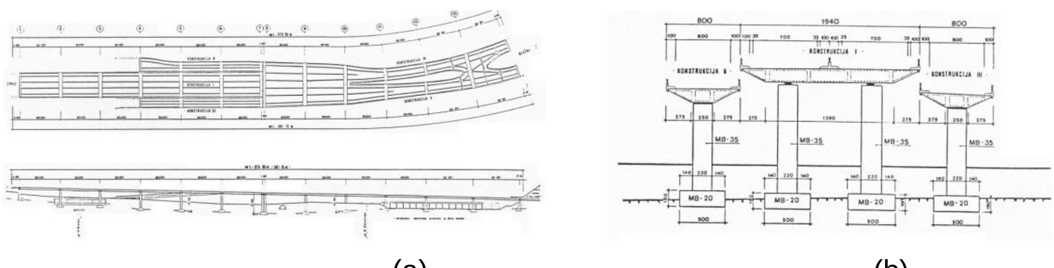
Any measurement used during the adjustment can be carried out several times, and the result of such measurements in the form of arithmetic mean will be treated in processing as a single measurement with the appropriate weight (Gučević et al., 2017).

The network adjustment procedure can be carried out as a constrained adjustment or free adjustment. Constrained adjustment can be performed as a minimally constrained and fully constrained adjustment. A minimally constrained adjustment is an adjustment with only one vertical control point held fixed in the survey network.

6. VIADUCT KOŠEVO

The Koševo viaduct was planned in the part of the city highway, according to which the infrastructure of the Sarajevo City in the direction of northeast to southwest was to be connected.

The structure is a pre-stressed concrete box structure with 12 spans ranging from 30 to 35 meters, constructed in-situ, with the total length of 375.35 meters (Figure 2 – Longitudinal section and base of the Koševo viaduct (PZ Traser, 1976)a).Figure 2 – Longitudinal section and base of the Koševo viaduct (PZ Traser, 1976)



(a) (b)

Figure 2 – Longitudinal section and base of the Koševo viaduct (PZ Traser, 1976)

Due to the large number of piers, special attention was paid to their design. Piers of elongated hexagonal cross-section with contour dimensions 1.40 x 2.20 m were adopted for all structures. The number of piers at each pier position depends of the width of box cross section and ranges from one to four piers. The piers are made of concrete class MB 35, and are based on pad footings MB 20 (Figure 2 – Longitudinal section and base of the Koševo viaduct (PZ Traser, 1976)b).Figure 2 – Longitudinal section and base of the Koševo viaduct (PZ Traser, 1976). The Koševo viaduct was constructed in early 1980.

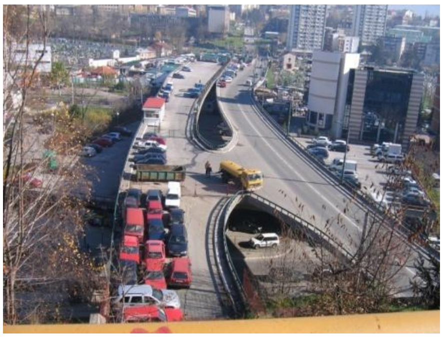


Figure 3 – Present state of the Koševo viaduct

The primary purpose of the paper is to analyze the heights or the height differences of characteristic points of the Koševo viaduct, if the height differences were measured in two epochs. For this purpose, a special-purpose network was established on the viaduct - the leveling network needed for analysis of the behavior of the structure under different temperature effects.

7. THE KOŠEVO VIADUCT LEVELING NETWORK

Figure 4 – The Koševo viaduct leveling network shows the leveling network used for the study, consisting of 21 control points - benchmarks. Ten points were permanently marked on each of the sidewalks situated on the left and on the right side of the viaduct, and in places that are assumed to be safe, i.e. that the points will not be destroyed, e.g. during snow clearing. Control points are stabilized permanently by means of survey marking nails. One point is outside the structure (T5000) and is used as the starting point.

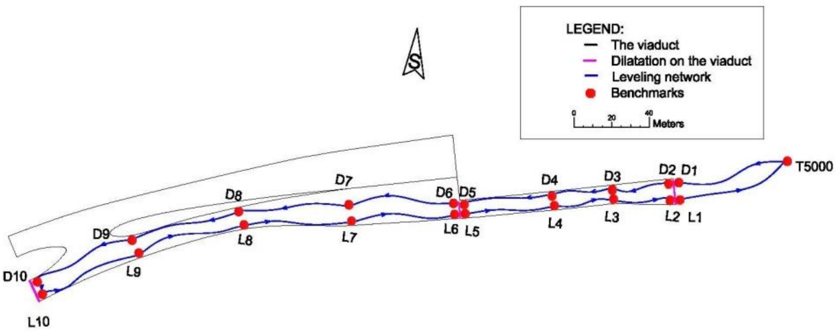


Figure 4 – The Koševo viaduct leveling network

7.1. Measurement of height differences using the precise geometric leveling method in critical conditions

All measurements of height differences in the leveling network were done by the precise digital level instrument Leica Geosystems DNA03. Before beginning the measurements, the instrument was checked using the "Two-Peg Test" and it was found that a collimation error does not exist.

The measurements were conducted under critical temperature conditions and were carried out in two epochs: winter and summer epoch, within each of which three series of measurements were made. Considering the instrumental errors of measurements by the Leica Geosystems DNA03 level instrument occurring at lower temperatures [20], special attention was paid to correcting these errors.

Measurements made during the day in the month of June were considered as summer epoch (morning temp. 13 °C, daily temp. 26 °C, and evening temp. 17 °C. The winter epoch consists of measurements conducted in February (morning temp. – 8 °C, daily temp. 2 °C, and evening temp. -1 °C. Each epoch consists of three series of measurement during the day.

7.2. Adjustment of the Koševo viaduct leveling network

By conducting statistical tests, with a probability of 95% it was concluded that there were no gross errors in the measurements. Conditions for network adjustment are met by this. A minimum constraint adjustment for the whole 1D network was performed, with the R5000 control point kept fixed.

Table 1 – Standard deviations of measurements obtained after adjusting the leveling network - view by series and epochs

Epoch / Series	Winter epoch	Summer epoch
	S_o (mm)	S_o (mm)
Morning series (6-8 h)	1.19	1.56
Midday series (12-14 h)	1.15	1.61
Evening series (18-20 h in summer), (15-17 h in winter)	1.01	1.52

Analysis of the data shown in Table 1 reveals that the standard deviations of the measurements obtained after adjusting the winter epoch leveling network are less than the standard deviations of measurements obtained after adjusting the summer epoch leveling network in all measurement series. The biggest difference is the difference between the evening series of measurements and it is 0.51 mm.

7.3. Analysis of heights of the Koševo viaduct leveling network points

The analysis is based on comparing the definitive heights of the points of the Koševo viaduct leveling network, determined in different epochs and series, taking into account standard deviations of measurements in individual epochs or series. The analysis results are presented in the corresponding graphs.

Comparison results of the evening series of winter and summer epochs (

Graph 1 Comparison of heights difference data of points (a) of the winter and summer epochs in the evening series of measurements; (b) of the winter and summer epochs in the evening and morning series of measurementsa) show that there are evident differences in heights of individual points on the viaduct. Significant differences in atmospheric conditions acting on the viaduct structure in the evening period result in oscillations of the structure, which is reflected in differences in heights of points on the viaduct. The most significant displacements were observed on the benchmark 7 on the left side of the viaduct where the difference in heights is greater than 3 mm. The differences in heights of the left benchmark number 7 are also due to the structural design of the viaduct, i.e. a change in viaduct geometry (road width), as well as the position of the support which is moved in relation to the left traffic lane.

Temperature changes are significant in the early morning and evening hours, when atmospheric temperatures, but also the viaduct structure, substantially oscillate.

According to the results given in

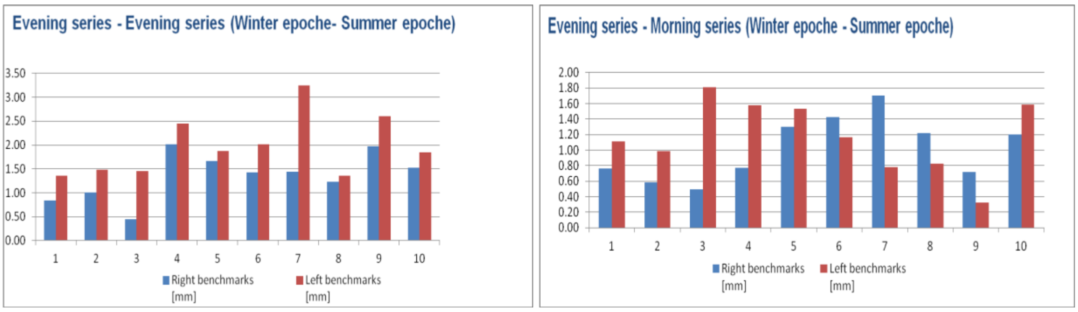
Graph 1 Comparison of heights difference data of points (a) of the winter and summer epochs in the evening series of measurements; (b) of the winter and summer epochs in the evening and morning series of measurementsb, it is observed that a positive displacement occurs on the benchmarks. The displacement results from the change/increase in atmospheric temperature, and thereby in the viaduct structure, because in the summer period there is a change in dimensions - enlargement of the viaduct structure that causes positive displacements (the viaduct structure rises and expands). The viaduct is unprotected from sunrays. Further, analyzing the data of other benchmarks, it is evident that there is an increase in the difference between the right and the left side at the benchmark number 7.

Unlike

Graph 1 Comparison of heights difference data of points (a) of the winter and summer epochs in the evening series of measurements; (b) of the winter and summer epochs in the evening and morning series of measurementsa,

Graph 1 Comparison of heights difference data of points (a) of the winter and summer epochs in the evening series of measurements; (b) of the winter and summer epochs in the evening and morning series of measurementsb generally indicates very small changes in heights of the points on the viaduct, which indicates a considerable stability of the viaduct during the measurement.

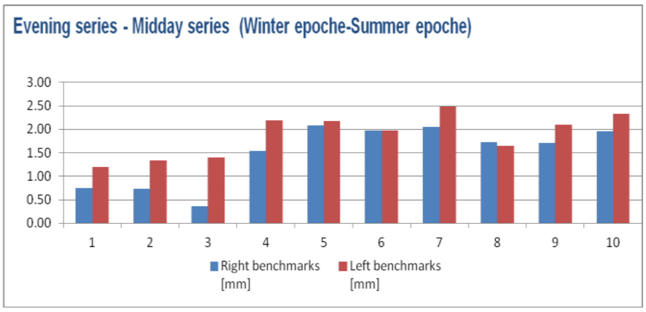
Graph 1 Comparison of heights difference data of points (a) of the winter and summer epochs in the evening series of measurements; (b) of the winter and summer epochs in the evening and morning series of measurements



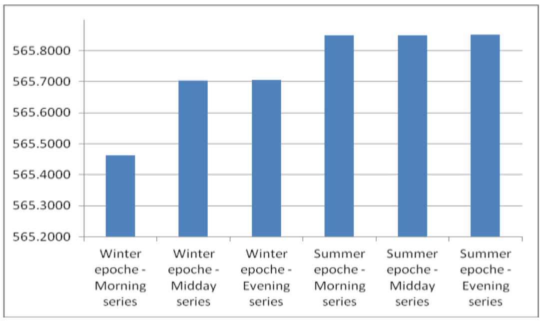
(a) (b)

Graph 2 Comparison of heights difference data of points of the winter and summer epochs in the evening and midday series of measurements shows the differences in heights of benchmarks on the Koševo viaduct obtained in the evening and midday series of measurements of the winter and summer epochs. Close values of differences in heights of the benchmarks 5 and 6 (left and right ones) are evident on this graph too, which is to be expected as these benchmarks are positioned on the opposite sides of the viaduct expansion joint at a short distance from each other. The differences between heights of the benchmarks 9 and 10 (left and right ones) reach a value of nearly 2.5 mm, and considering that they are located at the exit from the Koševsko Hill tunnel near the expansion joint on the viaduct pavement structure, their values indicate a displacement of the viaduct structure.

Graph 2 Comparison of heights difference data of points of the winter and summer epochs in the evening and midday series of measurements



Graph 3 Heights of the benchmark 7 right in different epochs and different series

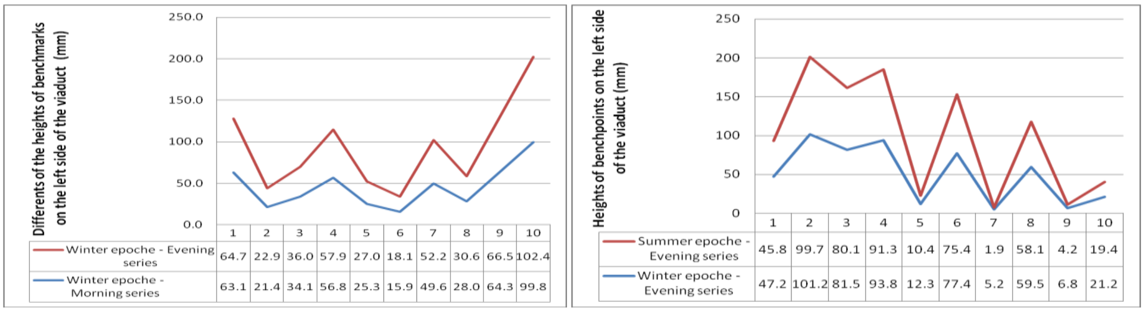


Graph 3 Heights of the benchmark 7 right in different epochs and different series shows the changes - oscillations in heights at point 7 on the right side of the viaduct pavement structure. Due to the noticeable difference in temperature, deviation of the heights of the observed benchmark is the highest in the morning series of the winter epoch of measurements. The midday and evening series are also consistent with each other, but differ from the mentioned morning series in the winter epoch. The heights of points in other series are uniform.

Graph 4 Change of heights of the points (a) on the right side of the viaduct of the morning and evening series of the winter epoch of measurements; (b) on the left side of the viaduct of the evening series of the winter and summer epochs of measurementsa shows a significant difference between heights in different parts of the day. Morning winter temperatures affect the viaduct structure so that the heights of points of the morning winter series are lower than the heights of points in the evening series. Lower heights of points also occur due to low night temperatures, which cause shrinking of the reinforced-concrete structure. Analysis of the heights of points on the left side of the viaduct obtained in the evening series of the winter epoch and the evening series of the summer epoch of measurements (

Graph 4 Change of heights of the points (a) on the right side of the viaduct of the morning and evening series of the winter epoch of measurements; (b) on the left side of the viaduct of the evening series of the winter and summer epochs of measurementsb) provides a picture of uneven displacements of the viaduct caused by different temperature effects. The benchmarks 5, 7 and 9 have approximately the same heights, while the heights of points 2, 4, 6 and 8 are different.

Graph 4 Change of heights of the points (a) on the right side of the viaduct of the morning and evening series of the winter epoch of measurements; (b) on the left side of the viaduct of the evening series of the winter and summer epochs of measurements



(a) (b)

8. CONCLUSION

Development of the country gives rise to the need for planning and practical implementation of work on complex construction projects (viaducts, tunnels, and dams), industrial plants, etc. Work on construction projects (e.g. viaduct) requires many relevant professions to be involved, which facilitates planning and construction, but also allows continuous monitoring of the state of the structure during operation. Multidisciplinarity during construction and operation of a structure also includes the geodetic profession, which plays a very significant role throughout the process.

Construction of complex structures, such as viaducts, creates a need to continuously monitor the constructed structure in order to identify possible displacements and thus define guidelines for preventive actions aimed at preventing deformations. Possible displacements of the structure can be determined using a previously established special geodetic network. In the aim of monitoring the behavior of the Koševo viaduct, vertical geodetic control network was established for the Koševo viaduct and the measurements were carried out under critical conditions. Six sets of point heights in 1D network established on the viaduct pavement structure were used to analyze the behavior of the viaduct structure under various temperature conditions. Analysis of the obtained results revealed that mild uneven changes, due to the effect of air temperature on the structure, occur on the viaduct.

The largest displacement on almost all graphs was observed on benchmark 7, and the assumption for such a behavior of the benchmark is in the structure on the part where benchmark 7 is situated (extension of the viaduct structure with the road).

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