Geodetic Works during the Estimation of the Vertical Displacement of a Bridge under a Load Test

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Abstract

Observation and maintenance of bridges is performed according to the observation and maintenance manual, planned during the design phase. The goal of this research is presentation of necessary surveying activities, performed after the revitalization of the main bridge construction. We will present preparatory geodetic works, measuring results and data processing during the examination of the vertical displacement of the bridge under the load test. Vertical bridge displacements are monitored by the geodetic methods and techniques assuming determination of the point heights in different loading phases and their mutual comparison. Determination of the vertical displacements assume the application of geometric levelling, through the measurement planning, calibration of instruments and accessories, measuring, and processing of the measurement results.

We will analyze all geodetic activities according to the working conditions and prescribed accuracy of the vertical bridge displacements (σ_{VD} = 1 mm), presenting an example of the examination of the main span of the “Gazela” Bridge, over the Sava river in Belgrade.

Key words: metrology, geodetic networks, accuracy, vertical displacement.

1 INTRODUCTION

Observation and maintenance of bridges is done in accordance with the observation and maintenance manual, planned as early as in the design stage. The manual includes the observation and maintenance of the structure surroundings, securing the bank and the river bed in the bridge area, observation of pillars and pylons of the bridge, observation of the main support structure, checking of cables, checking of bearings, inspection of dilatation, roadway, railing, the condition of installations and elements that carry installation. Before putting the bridge in service, after construction or reconstruction, it is necessary to observe the structure of the bridge under full load, to determine how the structure behaves and whether it should be put in service. The values of the vertical deflection, i.e. deviations from the normal state envisaged by the project is determined within the planned phases and disposition of load. The deflection of the structure is determined by using geodetic methods and techniques, which are planned and calculated in accordance with the conditions of accuracy, environment and working conditions. It is necessary to perform zero measurement, within which the position of the structure without load is determined. The position of the structure is determined in relation to the stable points set outside the zone of influence. During the gradual loading carried out by different dispositions, observations are made in order to determine the deflection of the points selected on profiles on the construction until it is maximally loaded. Location of measuring points is determined by the designer.

This paper aims to present the performed surveying activities that determine the vertical deflection of the structure of the Gazela Bridge in Belgrade after rehabilitation.

2 SUBJECT OF RESEARCH

Belgrade's busiest bridge over the Sava River is the Gazela Bridge. Its chief designer is Milan Đurić, Professor at the Faculty of Civil Engineering in Belgrade. The bridge was built in the period from 1966 to 1970, as a combination of beam and vault, and is 332 meters long and 27.5 meters wide.

Total roadway width is 21.8 meters - has three lanes in both directions. The bridge was designed to carry about 40,000 vehicles a day, and nowadays it carries around 165,000 vehicles per day. As a probable consequence of the lack of the bridge maintenance in the last 40 years, in 2010 a crack was registered in the main frame and its rehabilitation soon started.

Within the rehabilitation the load test of the main span of the steel bridge structure was carried out. For the load test, over 500 measuring points along the entire structure were set. More than 20 km of cable were retracted and connected to the measuring stations. For the load test 32 trucks weighing about 25 tons were used. They moved across the bridge on a set formation and in various speeds of 20 to 50 kilometres per hour – Fig 1. During the bridge testing other planned activities were carried out such as improving the dynamic driving characteristics of the traffic, taking samples for testing, inspection and checking of parts of the structure that could not be possible to inspect during active traffic. More than 50 people actively participated in the inspection, which was conducted according to the previously developed plan and programme.

Figure 1 Gazela Bridge

3 SURVEYING ACTIVITIES

Determination of vertical displacements implied the application of geometric levelling through: measurement planning, measurement and processing of the measurement results.

3.1 MEASUREMENT PLANNING

To determine the erase differences in heights of profile points, the application of detailed levelling was used. When using the detailed levelling it is necessary to take into account the non-parallel lines of sight and the level axis, i.e. angle i which the line of sight forms with the horizon. Angle i acts as a systematic error in the function of the distance between the instrument and the rod, Fig. 2.

$$\tan i = \frac{\Delta_j}{d_j},\ j = 1 \dots n, \tag{1}$$

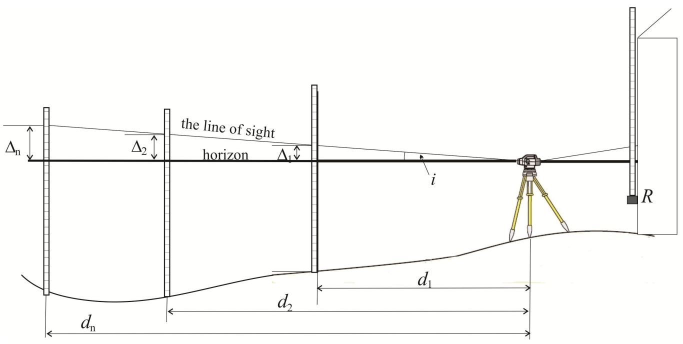

Figure 2 Detailed levelling

Previous assessment of accuracy of geometric levelling is performed starting from certain sources of errors in the expression for the mean squared error of height difference at the station (Mrkić, R., 1991.):

$$\sigma_{\Delta h}^2 = \frac{1}{2n}\left(\sigma_{DR}^2 + d^2\left(\frac{2\sigma_r^2 + \sigma_o^2}{\rho''^2}\right)\right) + \Delta h^2 \sigma_M^2 + 2\sigma_z^2, \tag{2}$$

If we start from the general values for certain sources of errors: $\sigma_{DR} = \pm 20\,\mu\text{m}$ – random error of division of rod; $\sigma_r = \pm 0.05''$ - random refraction; $\sigma_o = \pm 0.38''$- random error in rod readings; $\sigma_M = \pm 7\,\mu\text{m}$ – rod-pair scale error; $\sigma_z = \pm 29\,\mu\text{m}$ – rounded readings error (Mrkić, R., 1991.), mean squared error of the height difference at the station of one levelling side (measured once $n = 1$) for the length of the line of sight of 50 m, with a maximum height difference at the station $\Delta h = 1$ m is 0,079 mm.

Considering that it is a detailed levelling which involves the application of various line of sight lengths, it is necessary to calculate the allowed values of the angle i. The calculation is done so that the accuracy of height difference measurement at the station is within the planned accuracy of determining vertical displacement σ_{VD}=1 mm. Starting from the required accuracy of vertical displacements (σ_{VD}= 1 mm), expression (2) and expression (1), we get:

$$\sigma_{VD}^2 = \sigma_{\Delta h}^2 + \sigma_{\Delta h_i}^2 \tag{3}$$

where $\sigma_{\Delta h_i}$ is error of the height difference at the station that occurs due to the angle i.

By rearranging the expression (3) and substituting appropriate numerical values we get $\sigma_{\Delta h_i} = 0{,}997$ mm. For maximum projected length of the line of sight of 65 m, according to the expression (1) we get the value of the angle i of 3.2″. In accordance with the obtained parameters the measurement was realised.

3.2 MEASUREMENT

Measurements were realised by 4 working groups in the period from 10 p.m. (11/08/2012) to 11 a.m. (12/08/2012). A set of equipment of a working group for performing measurement of detailed levelling on profiles of the Gazela Bridge consists of: Sokkia digital level SDL30, 2 fibreglass barcode rods with the tubular spirit level, tripod, records of measurement, sketch, accessories for computing, Motorola radio transmitters for communications and a lamp to illuminate divisions of the rod. Calibration of Sokkia digital levels SDL30 was made in the Metrology Laboratory ML160 of the Faculty of Civil Engineering, University of Belgrade. Special attention was paid to rectification of *i* angle, so that for all the instruments its value is reduced to the value less than 3″. Metal adapters were built in the rods placed on the points on the road. The adapter's size (additive constant of the rod) for each pair of rods was determined in the laboratory ML160. The working group for the realisation of measurements consisted of two experts and three rod workers. One expert kept the measurement records and managed and led the activities of the working group. The other expert was the operator with the instrument and the assistant in the working group. Other members of the working group followed the dynamics imposed by the group leader.

Height differences were measured in relation to 4 benchmarks R1, R2, R3 and R4, stabilised on columns K1 and K2 from the side of Novi Beograd and columns K3 and K4 from the side of Belgrade. The plan stipulated that two working groups carried out measurements on the Novi Beograd side in the profiles from U- 1 to U- 10, and the other two working groups on the side of Belgrade in the profiles from U- 19 to U-10. The measurements were carried out with different line of sight lengths. For each profile point, the length up to 1 cm was measured, and reading on the rod up to the tenth of a millimetre. Loads were carried out in phases F-A, F-B and F-C. F-A phase refers to 4 profiles and 5 load dispositions of the bridge span along the river bank towards Novi Beograd. Phase F-B refers to 11 profiles and 10 load dispositions of middle span of the bridge. Phase F-C refers to 4 profiles and 5 load dispositions of the bridge along the bank to Belgrade. A total of 20 load dispositions were carried out that lasted an average of 20 min. Figure 3 shows the distribution of profiles and measuring points (the two middle profiles that go mid asphalt are not shown).

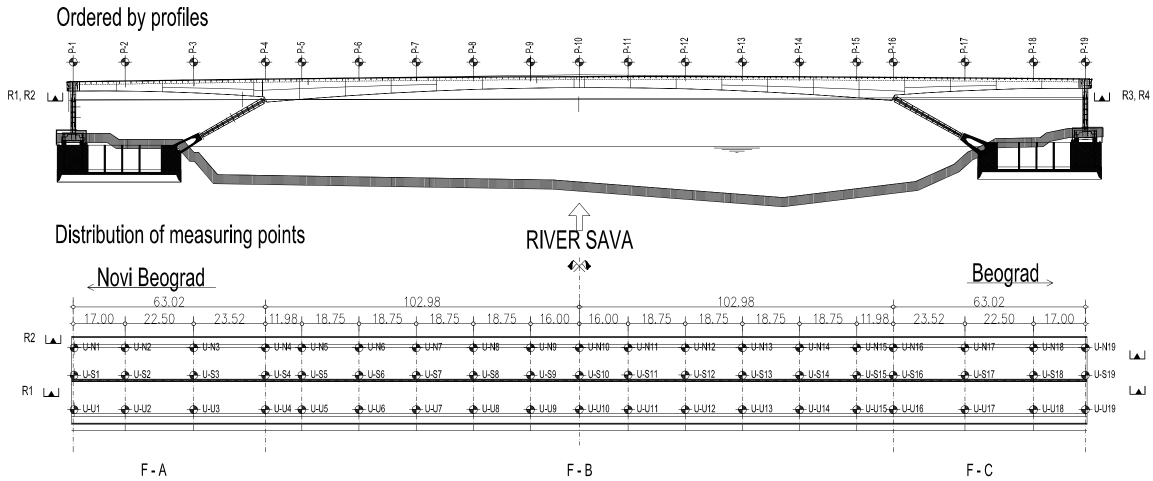

Figure 3 Distribution of profiles and measuring points

3.3 MEASUREMENT DATA PROCESSING AND VALUES OF VERTICAL BRIDGE DEFLECTIONS

Measurement data processing and determination of vertical deflections of 19 profiles with 5 measuring points include: calculating point heights on the profiles, forming differences and comparing the obtained values. The method of calculating deflections, within each phase, is conducted in the traverse of geometric levelling, related to the height of benchmarks H_{R_1} and H_{R_3} and the traverse related to the height of benchmarks H_{R_2} and H_{R_4}. In order to determine heights at measuring points by profiles we first determined heights of binding points H_a.

$$H_a = H_R + \Delta h \tag{4}$$

Based on the heights of binding points H_a and read divisions of the rods l_a that stood on the binding points the heights of the line of sight were determined, separately for each station.

$$H_V = H_a + l_a \tag{5}$$

Based on the line of sight height and the read division of the rod, which stands on the measuring point in the profile, the height of the measuring point was determined:

$$H_{\mathrm{MP_j}} = H_V - l_{\mathrm{MP_j}} : \mathrm{j}=1\ldots19. \tag{6}$$

For the disposition of the loading phase F-B differences in relation to the initial disposition were formed and shown in the diagram (Fig. 4).

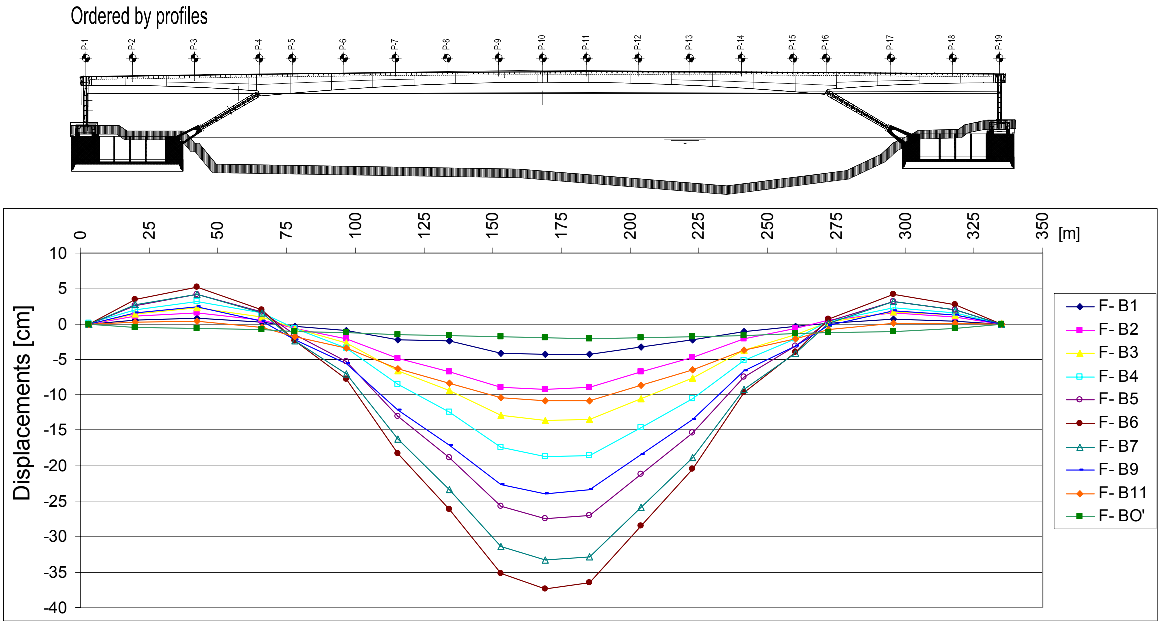

Figure 4 The diagram of the loading phase F-B

The final and independent quality control of the data obtained was carried out by analysing the results of measurements of the profile 10 considering the fact that it was a common profile for the working groups R1 and R3, as well as for groups R2 and R4. By analysing differences in all stages and load dispositions on the common profile 10 for all working groups, the mean value of differences of 0.27 mm was established, which is within normal limits for this type of work.

4 CONCLUSION

Observations of bridges and their rehabilitation aim to provide the proper technical maintenance of the bridge, to timely detect the resulting defects and create optimal conditions for their elimination. General inspection of bridges is done at least once every six years, and includes the inspection of: dilatation devices, protective bumpers and fencing, drainage, bearings and joints, corrosion protection, support structure of the bridge, pillars, geodetic control (supporting points and verticality of the pillars) and other elements whose observation is defined in a special manual on the bridge observation.

For the steel Gazela Bridge on the international road E-75 in Belgrade, it can be said that the programmes of observation, maintenance and rehabilitation have not been carried out or have been carried to a lesser extent (Bojović, A., Velović, N., 2010.). Important dates are shown in Table 1.

Table 1 The programmes of maintenance and rehabilitation for the steel Gazela Bridge

Year	Activity
1962-1966	Project: Directorate for the Construction of Bridges, Beograd
1966-1970	Construction: MIN, Niš; Goša, Sm. Palanka; Mostogradnja, Beograd
1970, December	Opened to traffic
1987	Replacement of guardrails in the separating zone and bearings
1987	Repair of the drainage system
1992	Two pipes of the heating system repaired

The need for rehabilitation was imposed in 2010 when a crack on the main frame was registered. The Gazela Bridge is a part of the highway that goes through the city, carrying the entire transit traffic in the capital. Complete rehabilitation of the bridge lasted 22 months, including the observation of the structure under full load. A part of the observation was carried out using detailed levelling with different line of sight lengths. For the maximum projected length of the line of sight of 65 m, it is necessary to use a level with an angle i smaller than 3.2″. In accordance with this requirement, special attention was paid to adjustment of instruments and accessories.

The size of deflection at the measuring points for realisation of the load disposition is in the interval of +5.2 cm to -38.3 cm. The values obtained are consistent with the expected values confirming the stability of the steel structure, and on August 11, 2012, the project of reconstruction of the Gazela Bridge was completed.

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