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Geometric Monitoring and Assessment of the Deformation State of a Bridge Structure Under Intense Load Conditions

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SUMMARY

The paper presents the results of geodetic monitoring of a reinforced concrete bridge that spans 47.58 m over the Lybid River in Kyiv. Based on GNSS observations and geometric leveling, we determined the vertical alignment of the longitudinal axes of eight main girders. Detailed geodetic monitoring of the bridge along Povitrianykh Syl Avenue recorded the vertical heights of the girders (B1–B8) between 132.82 m and 132.95 m, confirming the stability of the superstructure. We observed a smooth long slope of the bridge deck, with a consistent drop in vertical heights along the bridge axis from Support B (136.14 m) to Support A (133.79 m). We found structural deformations, including vertical displacement at the expansion joint of Support B (136.05–136.69 m) and local damage near Support A. These issues will help shape the reconstruction project. Investigations of the cross-sectional shape confirmed a single-slope or double-slope profile for the roadway slab. We found that, despite the difference in the vertical placement of the foundations (Support B is structurally lower than Support A), the top of the utility channel opening on both sides has a uniform height of 129.90 m, showing it is level.

Keywords: Geometric monitoring; Bridge crossing; Vertical alignment; Deformation contour; Longitudinal slope; Three-dimensional positioning.

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Introduction

Main works of Lantukh-Liashchenko A.I. include estimation of the operational state, prediction of the residual lifetime, and assessment of deterioration of reinforced concrete bridge elements (Lantukh-Liashchenko, 2009). Technical evaluation and reliability of road transport facilities in Ukraine according to industrial standards, such as DSTU 9181:2022 and DSTU-N B V.2.3-23:2012 (DSTU 9181:2022, 2022; DSTU-N B V.2.3-23:2012, 2013). Nevertheless, conventional visual inspection approaches do not provide information about complex spatial deformations.

Engineering geodesy is moving towards automated three-dimensional monitoring. It should be noted that as emphasized by Kovalenko L.O. and his colleagues from geodetic monitoring, the use of high-precision equipment during field measurements is necessary for verification of coincidence of real geometric parameters of the facility with design documentation. Combination of satellite techniques (GNSS) and traditional leveling provides high precision measurement of short-period deformations, vertical displacements, and tilt of load-bearing facilities (Kovalenko, 2022).

It is clear that despite good theoretical bases, each bridge in urban area interacts with the environment in its own way and has unique damages. Bridge over the Lybid River is the object of this research and located in Solomianskyi district of Kyiv city and used for transportation along Povitrianykh Syl Avenue (Fig 1).

Figure. 1. *Bridge facade from Borshchahivska Street (looking towards the Kyiv-Pasazhyrskyi railway station).*

Method and Theory

The principal goal of geometrical monitoring of load-bearing ability is the vertical setting of superstructure girders between important axes: the axis of Support B and the axis of Support A. 8 longitudinal lines of girders have been surveyed (B1 to B8). On each line of measurements, information was taken on three characteristic points: on Support B, in the middle span and on Support A (Fig. 2).

The main specifics of the geodetic support of bridge inspections are related to the strict requirements for accuracy, spatial detailing of structures and recording of small deformations during their operation. High-accuracy methods of engineering geodesy are applied in these problems because the permissible deviations of the bridge structure parts are usually expressed in millimeters. In particular, leveling devices of the first order are applied in the determination of Support settlements giving the standard deviation of measurement of height equal to ±0.3–0.7 mm for 1 km of double run leveling. For the horizontal positioning of structures, electronic total stations with the accuracy of angular measurements of 1–2" and linear distance measurement accuracy of ± (1-2 mm + 1-2 ppm) are used (Kovalenko, & Yemets, 2021).

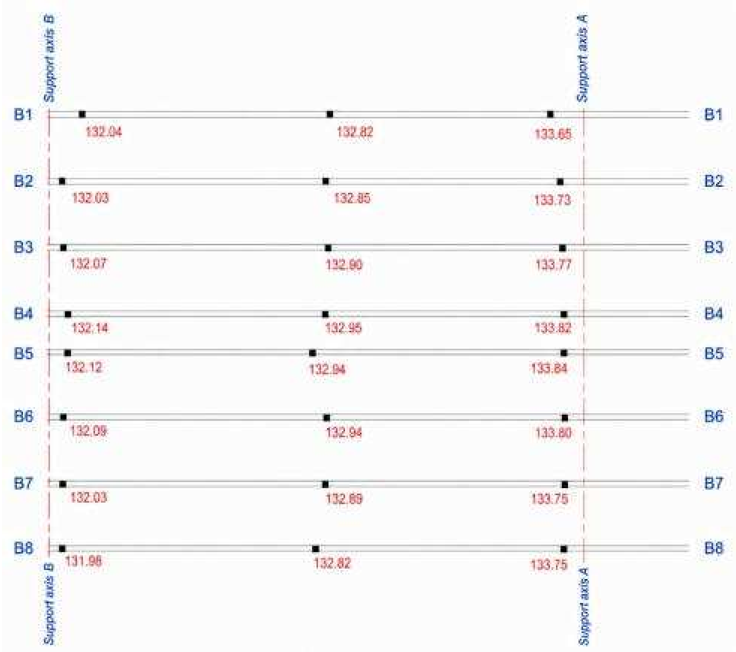

Figure 2. *Diagram of spatial reference and vertical alignment of the bridge superstructure girders: 1–8 — numbers of longitudinal reinforced concrete girder lines (B1–B8); Support A, Support B — alignments of support units. Note: In the mid-span area, a stable distribution of geometric elevations within 132.82–132.95 m was recorded*

To orient the measurements in space, a local geodetic network is usually created, which will have the accuracy of coordinate determination within ±2-5 mm horizontally and ±1-2 mm vertically. The network points are fixed considering their long-term nature, since bridge structure control implies repeating the measuring cycles with the frequency of several months to 1-3 years depending on the class of structure and its technical state (Haidar, 2023).

One of the necessary elements is the application of GNSS technology, namely the RTK method, which makes it possible to obtain coordinates with an accuracy of 10-20 mm horizontally and 15-30 mm vertically in real time. In combination with terrestrial techniques, it allows performing the full-scale control of the spatial coordinates of the bridge structures in the unified coordinate system.

Geodetic works were carried out using two techniques – the surveying with the total station of Sokkia Power Set 250RX digital total station and GNSS measurements in RTK mode with the South Galaxy GIPlus receiver.

Results

Vertical analysis of the Support B along the support axis revealed that the absolute elevation varies from 131.98 m (girder B8) to 132.14 m (girder B4). A gradual increase in the profile up to the middle girders can be seen (B4 = 132.14 m, B5 = 132.12 m), with a drop-off in the sides, in accordance with the cross slope of the Support cap. From the analysis of the deflections at the midpoint of the span, it becomes apparent that the leveling of the midpoints of the beams ensures the establishment of a stable height distribution (range of heights: 132.82 m – 132.95 m). The comparison of the mean values to the reference examples of critical local sagging of the beams along the common axis of inclination of the span structure. The highest height of the midpoint of the span is ensured at the beam B4 (132.95 m).

The coordinate location of the upper deck elements based on the geodetic baseline network allowed for a connection of the structural axes of the object to the topography of the actual surface (Fig. 3). The measurement was made in 3D space based on geometric axes.

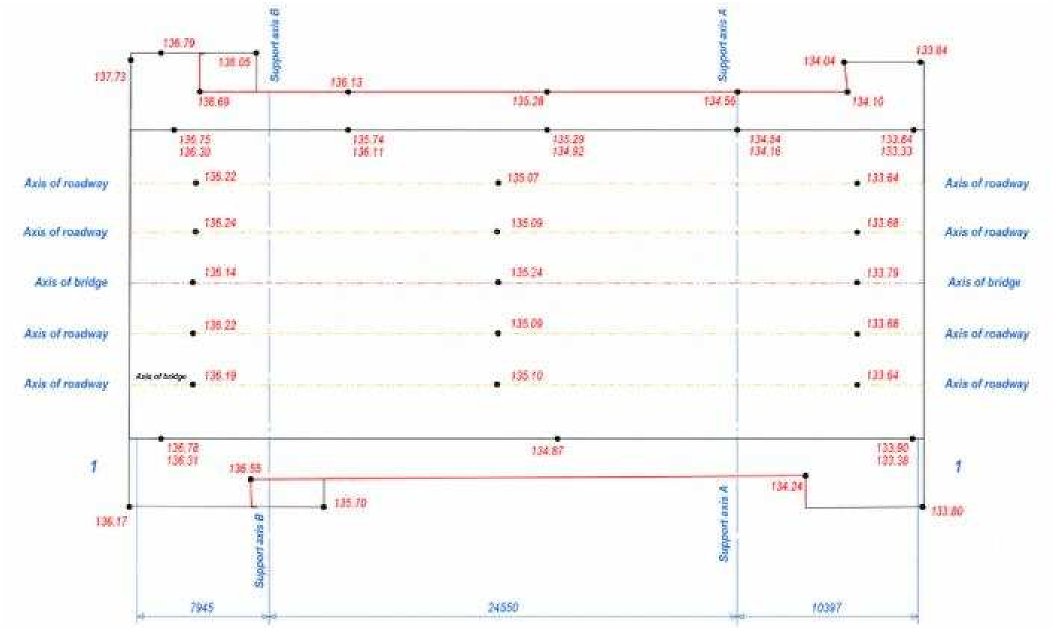

Figure 3. *Graph of deformations and geometric anomalies of the upper and lower defect contours: a) upper contour: vertical jump at the expansion joint of Support B (136.05–136.69 m) and sidewalk profile break near Support A (134.04–134.10 m); b) lower contour: deformation of the sidewalk console and curb, outbound failure zone near Support A (elevation 134.42 m)*

The plan highlights the "Axis of Bridge" and four auxiliary lines – "Axes of Roadway ", which define traffic lane boundaries. Geodetic elevations along the bridge axis smoothly change from 136.14 m at the Support B alignment to 135.24 m at the mid-span center and 133.79 m at the Support A alignment. This indicates a general longitudinal slope of the deck. For the final spatial configuration analysis of the bridge, field measurements of cross-sections were performed directly at the alignments of Support A and Support B (Fig. 4).

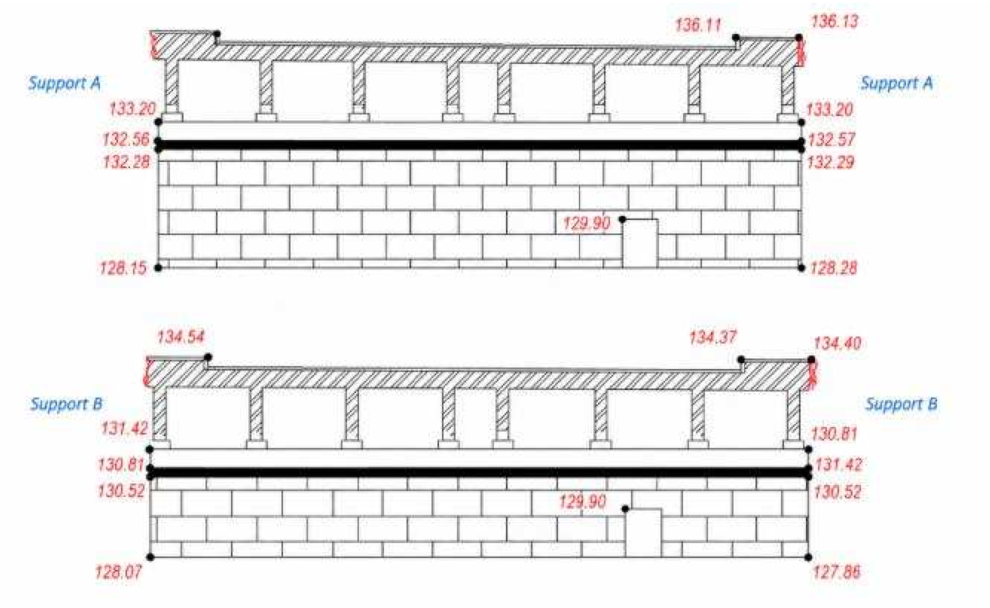

Figure 4. Actual architectural-perspective cross-sections of bridge components: *a) section along Support A; b) section along Support B. Arrows indicate the directions of the single-slope (double-slope) inclination of the roadway slab and the horizontal axis of the utility channel opening (fixed elevation 129.90 m)*

The data in Fig. 4 reflect the seating levels of the girder bearing parts on the concrete caps of the retaining walls:

- **Support A:** the level of the bearing pedestal is fixed at elevations 133.20 m and 132.56 m / 132.57 m. The lower linear marker (contact line with soil or foundation) lies at elevations 128.15 m and 128.28 m. A utility opening (channel) with a top elevation of 129.90 m was also recorded.
- **Support B:** structurally lower. The level of the bearing pedestals is fixed at elevations 131.42 m and 130.81 m. The bottom level of the massive wall is registered at absolute elevations 128.07 m and 127.86 m.

Conclusions

Vertical alignment of the eight girder lines (B1–B8) throughout their lengths relative to the key alignment of Supports A and B showed that the cross-slope design of this Support cap exists (maximal elevations are located near central girders B4 and B5). Mid-span elevation (132.82–132.95 m) belongs to the longitudinal elevation range of the structure and means "absolute range" without indicating the critical local sagging of each girder in a given span relatively to the general slope line at certain intervals.

Therefore, significant geometric defects were found: the upper defect curve includes a sharp jump in the zone of the expansion joint of Support B (displacement 136.05 m/136.69 m), and a critical break of the sidewalk profile while approaching the Support; among the characteristics of deformations of the sidewalk console and curb of Support B belong the lower defect curve, which demonstrates an outbound defect near Support A (elevation 134.42 m).

The resulting 3D geodetic measurements and local defects are the basis for assessing the load-carrying capacity of the bridge and the preparation of the reconstruction/capital repairs project.

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