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# GEODETIC CONTROL OF THE GEOMETRY OF THE BRIDGE IN KULA USING TERRESTRIAL LASER SCANNING TECHNOLOGY

***Abstract***

In this paper, the control of the geometry of a bridge located in Kula, Serbia, was performed. This bridge bridges the Danube-Tisa-Danube canal and is a part of road 108 that runs from Bačka Topola to the Croatian border. In order to perform the geodetic control of the bridge's geometry, terrestrial laser scanning of the bridge was conducted, where a point cloud was obtained as a product. The geometry control procedure involved controlling the verticality of the grooves that enabled the movement of the weights used to raise the bridge and allowed for navigation in the canal. The geometry control of the two horizontal beams of the bridge was also examined. The results that were obtained were interpreted tabularly and graphically.

*Keywords: terrestrial laser scanning, bridge geometry control, point cloud*

# ГЕОДЕТСКА КОНТРОЛА ГЕОМЕТРИЈЕ МОСТА У КУЛИ ПРИМЈЕНОМ ТЕХНОЛОГИЈЕ ТЕРЕСТРИЧКОГ ЛАСЕРСКОГ СКЕНИРАЊА

***Сажетак***

У овом раду извршена је контрола геометрије моста који је смјештен у Кули, Србија. Овај мост премошћује канал Дунав – Тиса – Дунав и дио је пута 108 који се простире од Бачке Тополе до државне границе са Хрватском. У циљу геодетске контроле геометрије моста извршено је терестричко ласерско скенирање моста, гдје је као продукт добијен облак тачака. У поступку контроле геометрије извршено је испитивање вертикалности жљебова, који омогућавају кретање тегова помоћу којих се врши подизање моста и тиме омогућава пловидба каналом, као и контрола геометрије двеју хоризонталних греда моста. Добијени резултати су интерпретирани табеларно и графички.

*Кључне речи: терестичко ласерско скенирање , контрола геометрије моста, облак тачака*

# 1. INTRODUCTION

The field of geodetic works in construction has become more complex due to the rapid development of civil engineering and other technical disciplines. A specialized field called engineering geodesy was established to address the numerous challenges faced by the geodetic profession during the construction and exploitation of engineering facilities. Engineering geodesy involves planning, organizing, and implementing geodetic works to ensure the correct spatial location and realization of the geometry of the built object following the designed geometry within the limits of construction tolerances [1, 2]. Geodetic works in engineering geodesy involve various tasks. These include establishing geodetic networks, creating the geodetic basis for designing objects, expropriating land, setting out the geometry of the objects, monitoring displacements and deformations of objects, controlling the geometry of objects during construction and exploitation, shaping construction land, and surveying the state of objects after construction [1]. The focus of this paper is a very challenging task of engineering geodesy – control of the geometry of objects during exploitation.

The traditional approach to controlling the geometry of objects involves the establishment of a geodetic network and the application of conventional measurement methods, which include the use of total stations, GNSS receivers, and geodetic levels. However, an alternative approach to this is using terrestrial laser scanning technology. This technology has come a long way since its introduction. It is now highly effective for capturing a large number of three-dimensional points of objects or areas that are the subject of observation. The main advantage of terrestrial laser scanning is the possibility of mass acquisition of geospatial data, which is very important in procedures for controlling the geometry of objects, where one tries to interpret the geometry of objects in the best possible way.

In the past decade, numerous studies have explored the potential application of terrestrial laser scanning in engineering tasks. Terrestrial laser scanning can be used in testing the verticality of objects [3, 4, 5, 6], creation of as-build projects of objects [7, 8, 9], creation of 3D models of objects [10, 11, 12], projects of reconstruction and rehabilitation façade [13, 14], deformation monitoring of engineering facilities [15, 16, 17], as well as in numerous other geodesy tasks. These studies confirm the justification for applying terrestrial laser scanning technology to control objects' geometry. In this paper, the control of the geometry of the bridge in Kula was performed using terrestrial laser scanning.

# 2. TERRESTRIAL LASER SCANNING TECHNOLOGY

Terrestrial laser scanning technology is currently considered an exceptionally attractive method for acquiring geospatial data. A terrestrial laser scanner detects and collects geometric information about the scanned object. Due to its high resolution, it also collects data regarding the object's texture, reflecting electromagnetic energy. A collection of points in space created by scanning is called a point cloud. The point cloud represents a digital representation of the shape of the scanned object, enabling detailed visualization and analysis of its geometric characteristics. Terrestrial laser scanners function akin to total stations, and the terrestrial laser scanning method of collecting data resembles the polar (tachymetric) technique for detail acquisition. The measurement results of distances using the terrestrial laser scanning method correspond to the distances obtained using a total station. In contrast, the horizontal and vertical deviation of the laser beam matches the horizontal and vertical angle of sight in the total station. Generally, in the data collection process, what differentiates these two instruments is the significantly high speed of collecting a large volume of data with the terrestrial laser scanner, whereas, on the other hand, it concerns the high accuracy of individual total stations [18]. The measurement results in the terrestrial laser scanning include the slope distance $\rho$, horizontal direction $\theta$, vertical angle $\alpha$, and the intensity of the registered radiation I (Figure 1). In geometric terms, scanning an object produces a set of points with high density and regular arrangement, known as a point cloud, in which each point is defined by three spherical coordinates $\rho$, $\theta$, and $\alpha$. The relationship between spherical and Cartesian coordinates can be expressed as follows [18, 19]:

$$x_j = \rho_{ij} \cdot \cos\theta_{ij} \cdot \cos\alpha_{ij}, \tag{1}$$

$$y_j = \rho_{ij} \cdot \sin\theta_{ij} \cdot \cos\alpha_{ij}, \tag{2}$$

$$z_j = \rho_{ij} \cdot \sin\alpha_{ij}. \tag{3}$$

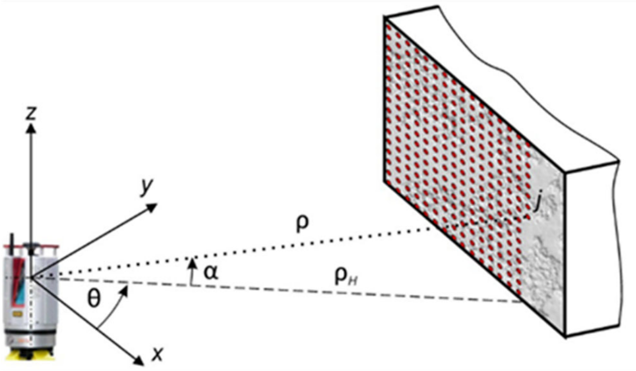


*Figure 1. The principle of terrestrial laser scanning [18].*

In this manner, a detailed point cloud is obtained, representing the position of each scanned point in a 3D coordinate system. The coordinates of the points are located within the scanner's coordinate system.

### 2.2. TERRESTRIAL LASER SCANNING PROCEDURE

There is no standard procedure for scanning, as each object requires a different approach and method of capture and level of detail in the presentation of results. Due to the complexity of the object and the terrain's topography, it is necessary to conduct reconnaissance of the terrain and create a plan for terrestrial laser scanning. The terrestrial laser scanning method requires scanning from selected positions that can cover the object within their field of view. In the scanning process, markers were used, which, due to their simple production, are very commonly used in practice. Markers primarily serve to register point clouds scanned from different scanner positions. The procedures for registration and georeferencing of point clouds are a significant step in the data processing of the terrestrial laser scanning method. To create a comprehensive representation of the scanned object, the point clouds must be registered, aligning them to a common coordinate system (e.g., the coordinate system of a chosen scan) [10]. Following that is the process of georeferencing the point cloud. In practice, indirect georeferencing is usually applied, which, using known 3D coordinates of control points determined by the conventional survey methods, such as the GNSS RTK method, places a point cloud in the desired coordinate system. Detailed analysis and manipulation of the point cloud can be initiated based on the registered and georeferenced point cloud. It is of great importance that the point cloud registration is achieved with the highest possible accuracy. The precision of the registration process directly influences the control of the geometry of objects.

## 3. GEODETIC CONTROL OF THE GEOMETRY OF ENGINEERING FACILITIES

Geodetic control of the geometry of engineering structures is an extremely important task performed directly during the construction of structural elements and on tasks of exploitation and maintenance of engineering facilities. Monitoring the structure and functionality of an object involves a set of activities that include precise continuous geodetic measurement of the geometric characteristics of engineering facilities. Calculations such as hydraulic, dynamic, and static are related to the shape and size of structural elements. The consequences of stress changes lead to the occurrence of plastic deformation of the structure, and the forces causing them are considered disturbances [1]. To avoid the impact of disturbances, it is essential to accurately position the structure within the defined tolerances in absolute and relative systems. Geodetic methods allow for precise object positioning in both systems, whereas other methods typically ensure accuracy only within the relative system [2].

The objective of engineering-geodetic works during the construction of objects is their accurate positioning and the alignment of the object's geometry with the design within the defined boundaries of construction tolerances. This ensures that the structures will have geometry of the necessary quality, facilitating their successful and efficient use. Quality positioning of an object and the realization of its designed geometry depend on fundamental planning, proper organization, and precise execution of geodetic works using appropriate geodetic instruments [1, 2].

### 3.1. CONTROL OF THE GEOMETRY OF STRUCTURAL ELEMENTS AND OBJECTS

During the quality control of a structural element's geometry, it is necessary to approximate the element with a sufficient number of points. The object can form a straight line, a figure with vertices (triangle, quadrilateral, n-gon), a plane, or a surface of an appropriate shape [2]. Verifying the point's affiliation to a particular geometric figure involves testing appropriate mathematical hypotheses (the null hypothesis $H_0$, asserting that the tested figure conforms to a certain mathematical shape, and the alternative hypothesis $H_a$, indicating that the tested figure is not a defined mathematical figure). Testing the congruence between the controlled and the designed geometric element includes:

$H_0$: the controlled geometric element matches the designed one;

$H_a$: the controlled geometric element does not match the designed one.

Structural elements are shaped like ideal figures that can be mathematically defined. During the examination of already manufactured structural elements, it is essential to assess geometric shapes based on a discretized set of points for the most accurate approximation of the structural element [2]. This paper does not define a mathematical model for verifying the congruence of the controlled geometric element with the designed one. As a result of this method, it is possible to determine control over the points belonging to a straight line, control of horizontality, control of verticality, control of inclination, and other possible relational affiliations [1]. The methodology used in this study enables the discretization of a large number of points on certain elements of the bridge under examination. In this study, the control of the geometry of certain bridge elements is reduced to checking the verticality of the bridge's grooves and controlling the geometry of the bridge's horizontal beams.

## 4. CONTROL OF THE GEOMETRY OF THE BRIDGE IN KULA

The subject of the geodetic control of the geometry is the bridge in Kula, Serbia, which is located at 45.611456 degrees north latitude and 19.525444 degrees east longitude. The structure of this bridge was damaged in an accident caused by a cargo truck carrying an excavator that hit the bridge. The bridge is part of road 108 and bridges the Danube – Tisa – Danube canal. It is a movable bridge of steel construction, which is raised using weights and other accompanying equipment and enables navigation on the canal. To control the bridge geometry, a terrestrial laser scanning was performed using a Trimble TX 8 scanner, known for its speed, long range, and precision. The first phase of the work began with a tour of the field and creating a terrestrial laser scanning plan. Terrestrial laser scanning of the bridge was performed with 12 different positions defined within the scanning plan. Since the point clouds obtained during scanning at each of the scanner positions need to be connected into a unique point cloud, during field scanning, tie points (markers) that will be used in the point cloud registration procedure were materialized. Figure 2 shows the positions of the scanner from which the scan was performed, while Figure 3 shows the first position of the scanner.


*Figure 2. Scanner positions during terrestrial laser scanning of the bridge.*

*Figure 3. Bridge in Kula, scanner position 1.*

The first step in processing the captured data is registering the point cloud. The point cloud registration procedure was carried out in the Trimble Business Center software package using a combination of two methods: a manual one that involves tie points (markers) and an automatic Cloud to Cloud method. After manual registration with markers, Cloud to Cloud registration was performed. The point cloud registration procedure was carried out with very high accuracy, where the total point cloud registration error was 4.8 mm. In this case, there was no need for georeferencing the point cloud because the bridge geometry control procedure is carried out in the object's local coordinate system. The product of laser scanning of the bridge in Kula is the point cloud, that is, a set of a large number of three-dimensional points that provides a very high-quality 3D representation of the bridge. The bridge point cloud has 690,541,681 points, indicating how detailed each bridge segment is captured. Figure 4 shows a point cloud of the bridge from scanner position 6.

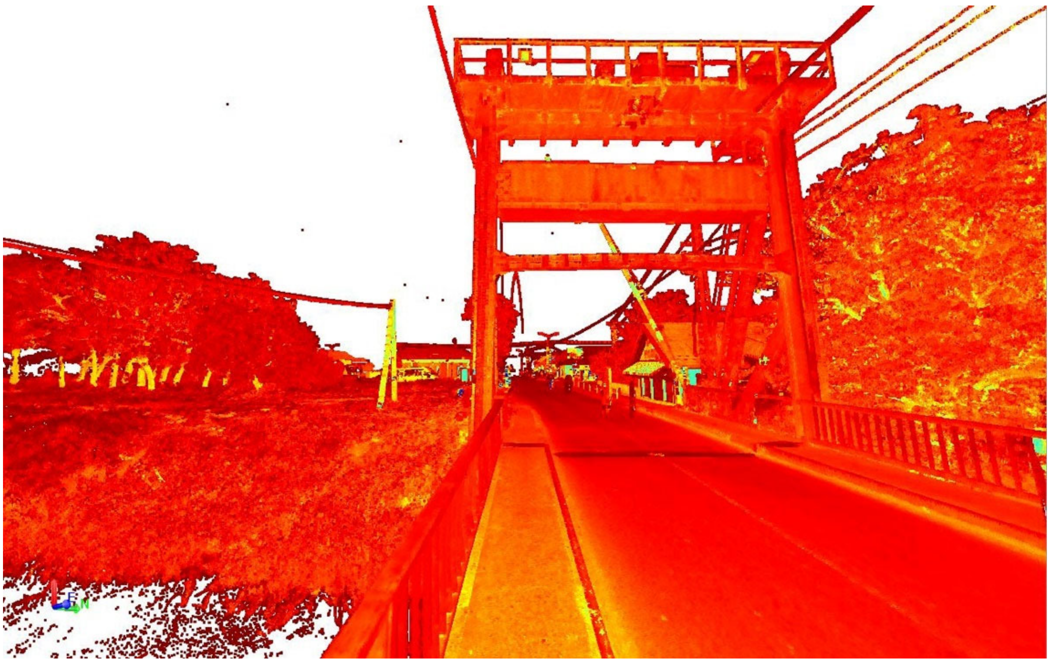

*Figure 4. Point cloud of the bridge in Kula, scanner position 6.*

After laser scanning and processing of the captured data, the product of which is the point cloud of the bridge, the control of the geometry of certain elements of the bridge is performed. In this procedure, it is necessary to examine the verticality of the grooves that enable the movement of the weights that are used to raise the bridge and to examine the geometry of the horizontal beams of the bridge, one of which is visibly deformed because the excavator, which was transported by truck, drove directly into it. Figure 5 shows a deformed horizontal beam and one of the grooves.

*Figure 5. Horizontal beam (left) and groove (right).*

Horizontal beams and grooves, i.e., their geometry, were extracted from the point cloud using the TerraSolid software package within MicroStation. Figure 6 shows the shape of the bridge, the horizontal beams, and the position of the grooves.

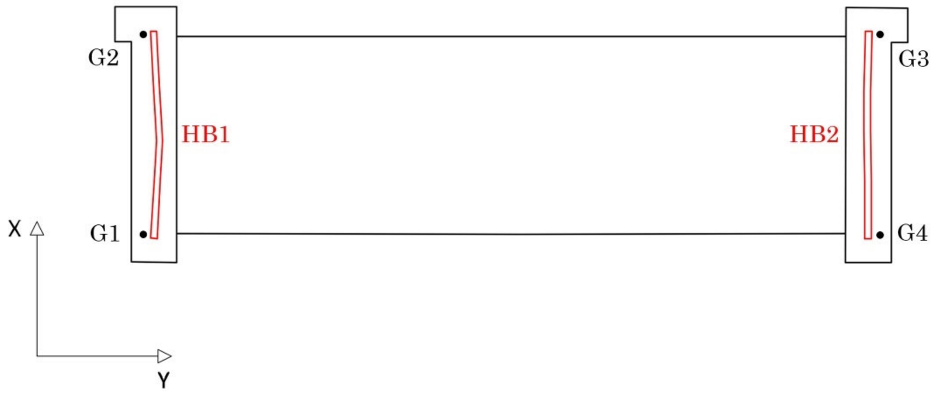


*Figure 6. Horizontal beams and grooves along which the weights move.*

In order to examine the verticality of the grooves, the edges of the grooves were extracted from the point cloud in the form of broken lines consisting of 5 points at a distance of about 2 meters. These points are numbered from 1 to 5, starting from the point of lowest height, for each groove independently. The deviations of the grooves from the vertical are determined by comparing the coordinates of points 2, 3, 4, and 5 with the coordinates of point 1 independently for each groove. Values of deviations from the vertical of grooves G1, G2, G3, and G4 are shown in Tables 1, 2, 3, and 4.

*Table 1. Values of deviation from the vertical groove G1.*

| Deviations | $\Delta Y$ [mm] | $\Delta X$ [mm] | $\Delta$ [mm] |
|---|---|---|---|
| 1-2 | 8 | 12 | 14 |
| 1-3 | 24 | 34 | 42 |
| 1-4 | 25 | 35 | 43 |
| 1-5 | 22 | 31 | 38 |

*Table 2. Values of deviation from the vertical groove G2.*

| Deviations | $\Delta Y$ [mm] | $\Delta X$ [mm] | $\Delta$ [mm] |
|---|---|---|---|
| 1-2 | 15 | -1 | 15 |
| 1-3 | 33 | -5 | 33 |
| 1-4 | 38 | 7 | 38 |
| 1-5 | 41 | 16 | 44 |

*Table 3. Values of deviation from the vertical groove G3.*

| Deviations | $\Delta Y$ [mm] | $\Delta X$ [mm] | $\Delta$ [mm] |
|---|---|---|---|
| 1-2 | -5 | -15 | 16 |
| 1-3 | -7 | -27 | 28 |
| 1-4 | -6 | -36 | 36 |
| 1-5 | -2 | -40 | 41 |

*Table 4. Values of deviation from the vertical groove G4.*

| Deviations | $\Delta Y$ [mm] | $\Delta X$ [mm] | $\Delta$ [mm] |
|---|---|---|---|
| 1-2 | 3 | -1 | 3 |
| 1-3 | -3 | -15 | 15 |
| 1-4 | -7 | -25 | 26 |
| 1-5 | -2 | -20 | 20 |

Figure 7 shows a comparative analysis of the deviations of the grooves from the vertical Δ. The deviation values from the vertical are very close for grooves G1, G2, and G3, while in the case of groove G4, the deviation values are significantly smaller.

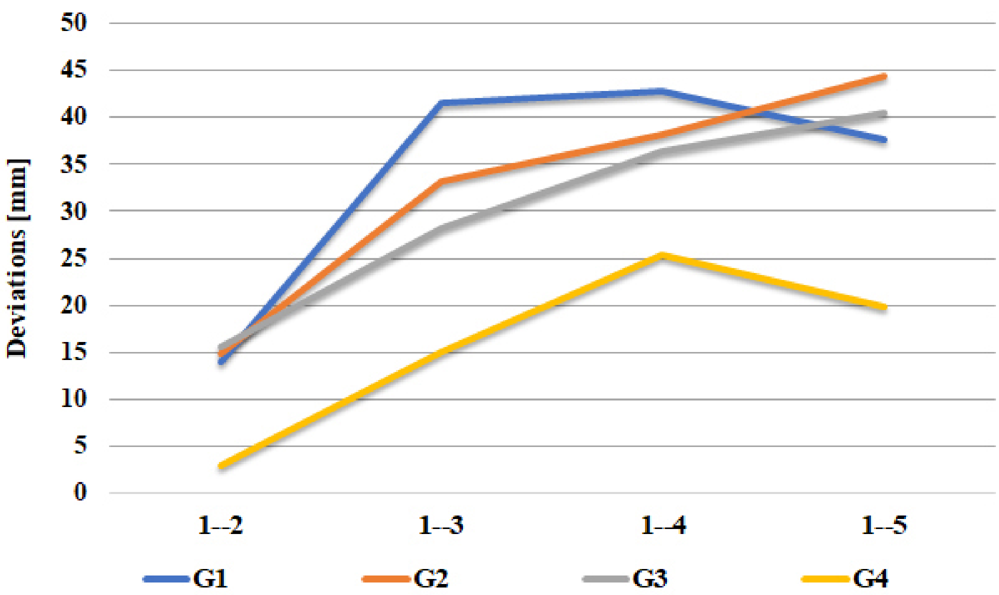


*Figure 7. Diagram of deviations of the grooves from the vertical.*

Control of the geometry of horizontal beams is based on determining the deviation of the geometry of the beams from the original geometry. To determine these deviations, 29 points were analyzed, located 30 centimeters from each other on both horizontal beams. Figure 8 shows the positions of these points on the horizontal beams. For each of the 29 points, the deviation Δ from the original position was determined in the case of both beams. The obtained deviation values are shown in Table 5.

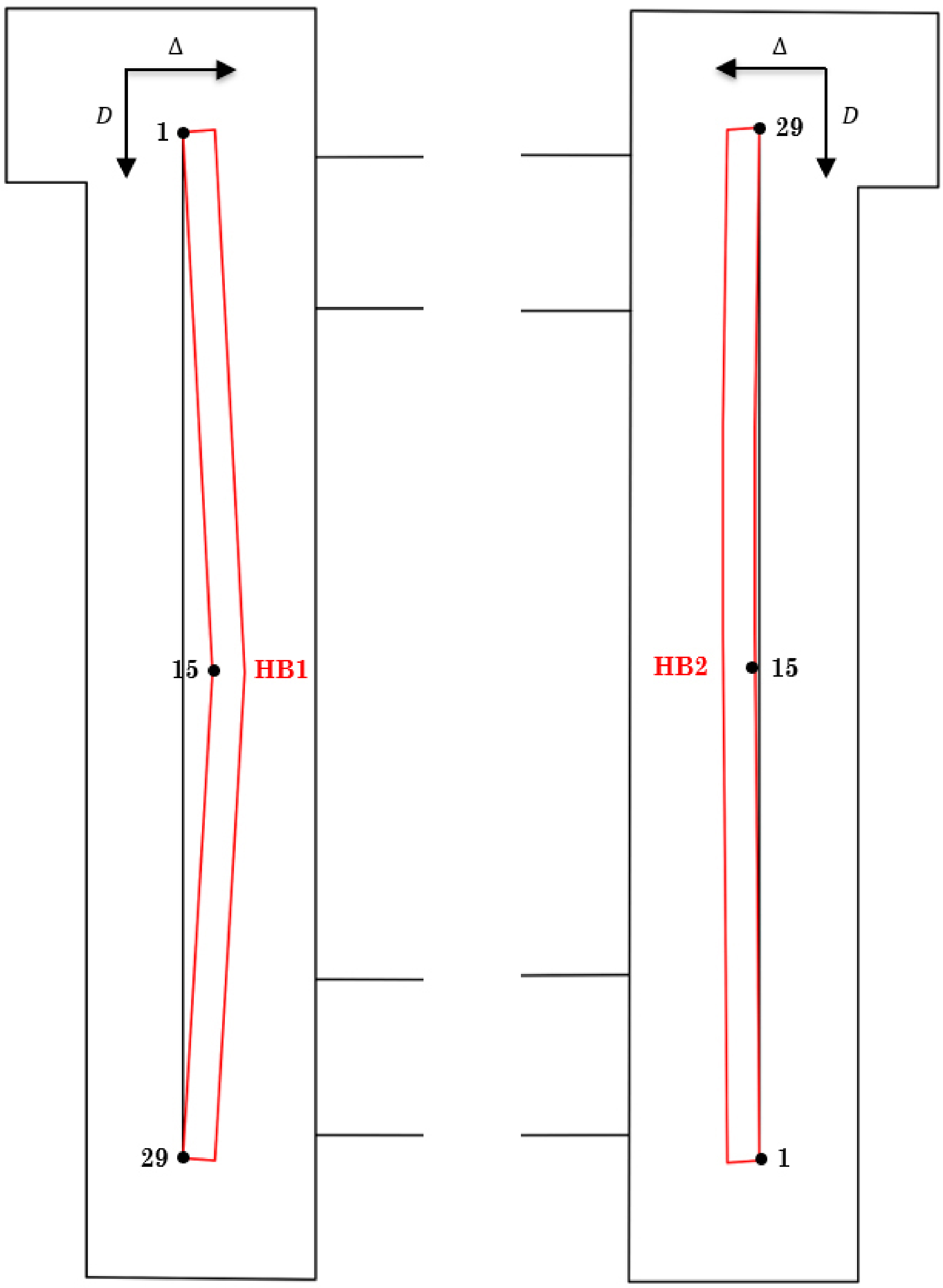


*Figure 8. Positions of control points on horizontal beams.*

*Table 5. Deviations of the geometry of horizontal beams.*

| Points | HB1 | | HB2 | |
|---|---|---|---|---|
| | *D* [m] | Δ [mm] | *D* [m] | Δ [mm] |
| 1 | 0.00 | 0 | 0.00 | 0 |
| 2 | 0.27 | 15 | 0.27 | 2 |
| 3 | 0.54 | 29 | 0.54 | 4 |
| 4 | 0.81 | 44 | 0.81 | 7 |
| 5 | 1.08 | 59 | 1.08 | 9 |
| 6 | 1.36 | 73 | 1.35 | 11 |
| 7 | 1.63 | 88 | 1.62 | 13 |

| Points | HB1 | | HB2 | |
|---|---|---|---|---|
| | *D* [m] | Δ [mm] | *D* [m] | Δ [mm] |
| 8 | 1.90 | 103 | 1.89 | 15 |
| 9 | 2.17 | 117 | 2.16 | 17 |
| 10 | 2.44 | 132 | 2.46 | 21 |
| 11 | 2.71 | 147 | 2.76 | 24 |
| 12 | 2.98 | 161 | 3.06 | 27 |
| 13 | 3.25 | 176 | 3.36 | 30 |
| 14 | 3.52 | 191 | 3.66 | 33 |
| 15 | 3.79 | 205 | 3.96 | 36 |
| 16 | 4.06 | 220 | 4.21 | 36 |
| 17 | 4.34 | 203 | 4.47 | 36 |
| 18 | 4.62 | 187 | 4.72 | 36 |
| 19 | 4.90 | 170 | 4.97 | 35 |
| 20 | 5.18 | 153 | 5.23 | 35 |
| 21 | 5.46 | 137 | 5.48 | 35 |
| 22 | 5.74 | 120 | 5.76 | 31 |
| 23 | 6.02 | 102 | 6.04 | 26 |
| 24 | 6.30 | 85 | 6.32 | 22 |
| 25 | 6.58 | 68 | 6.60 | 18 |
| 26 | 6.85 | 51 | 6.88 | 13 |
| 27 | 7.13 | 34 | 7.16 | 9 |
| 28 | 7.41 | 17 | 7.44 | 4 |
| 29 | 7.69 | 0 | 7.72 | 0 |

A comparative analysis of deviations of horizontal beams is given in the form of a diagram in Figure 9. It is evident that the deviations of beam HB1 are significantly greater than the deviations of beam HB2.

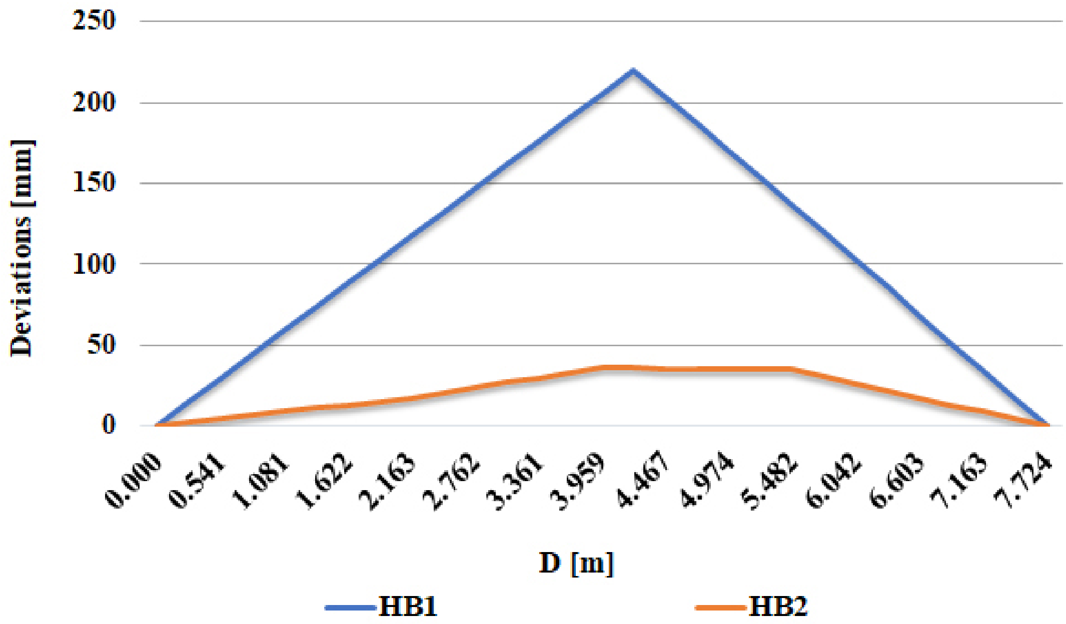


*Figure 9. Diagram of deviations of horizontal beams.*

## 5. CONCLUSION

Geodetic control of the geometry of objects is a very important and challenging task of engineering geodesy, which involves comparing the geometry of the constructed object with the designed geometry of the object. Control of the geometry of the objects is carried out by analyzing the corresponding horizontal and vertical sections of certain elements of the objects that are the subject of the analysis. In addition, in this procedure, it is very often necessary to examine the verticality of certain parts of the object, the horizontality, which implies checking the belongingness of the characteristic points of the object to a horizontal plane and the like. The paper presents a methodology for controlling the geometry of the bridge in Kula using terrestrial laser scanning technology. Based on the point cloud, which represents the product of the application of the mentioned technology, the control of the verticality of the four grooves that enable the movement of the weights used to raise the bridge was carried out, as well as the control of the geometry of the two horizontal beams. An analysis of the deviation from the vertical of the grooves revealed that all four grooves are twisted. The tops of the grooves G1, G2, and G3 deviate from the vertical by about 40 mm, while the top of the groove G4 deviates from the vertical by about 20 mm. The deviation values of the horizontal beam HB1 range from 0 to 220 mm, while the deviations of the horizontal beam HB2 range from 0 to 36 mm. It is important to point out that the minimum deviation values refer to the ends of the horizontal beams, while the maximum deviation values of the horizontal beams correspond to their middles. The obtained results unequivocally confirm the justification for the application of terrestrial laser scanning technology in the process of controlling the geometry of engineering facilities.

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