**Structural Health Monitoring of a Railroad Bridge in Tashkent (Uzbekistan) by Using Laser Scanning**

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**Abstract.** The paper discussed the results of a structural health monitoring project conducted on a railroad bridge in the Sergeli region of Tashkent, Uzbekistan. The bridge was originally designed to support a double-track railroad line, consisting of two parallel tracks, one for trains traveling in each direction. At the time of the field study, only one railway line was constructed. The bridge was investigated using various methods, including laser scanning and measuring its dynamic response to both ambient and forced excitations. The results obtained from laser scanning are discussed in this paper. A terrestrial laser scanner was deployed to acquire the bridge’s current geometry with high accuracy. As a result, a detailed 3D digital twin of the bridge was obtained. The bridge's point cloud was studied to analyze and identify any imperfections or anomalies. The collected information will be used (1) in assessing the quality of construction, (2) in finite element modeling based on the as-built geometry of the bridge, (3) as a reference for subsequent laser scanning projects to assess its condition after major earthquakes, and (4) in monitoring any possible changes due to the ongoing construction of another bridge next to the one studied in the paper.

**Keywords:** railroad bridge, terrestrial laser scanning, structural health monitoring, structural anomalies, point cloud, construction quality control

**INTRODUCTION**

A laser scanning in structural health monitoring (SHM) of bridges is widely employed globally [1]. The latter reference provides an extensive review of structural health monitoring studies that utilize terrestrial laser scanning technology. As is well known, a laser scanner obtains a large number of points, collectively referred to as point clouds. The primary objective of this paper is to investigate the benefits of laser scanning for structural health monitoring of railroad bridges and to increase its adoption in Uzbekistan. As components of the existing infrastructure age over time, an extensive study conducted in [2, 3] revealed a poor structural condition of many bridges in Uzbekistan, clearly demonstrating the need for bridge monitoring. Any bridge represents a structure extended in space. As such, laser scanning is one of the invaluable modern technologies for obtaining its geometry with high accuracy in a short time. The point clouds can also be obtained from the analysis of digital images taken by drones. The advantages of using laser scanners and drones for collecting bridge geometry were demonstrated through the validation of accuracy and a comparison between the two technologies [4]. The advantages of laser scanning for structural assessment of bridges after significant earthquakes are discussed in [5, 6]. A structural assessment project on a brand new bridge, before and after acceptance tests, was discussed in [7]. It was also based on the utilization of a terrestrial laser scanner. This project was conducted to obtain the current geometry of a newly built railroad bridge in the Sergeli region of Tashkent, Uzbekistan. A terrestrial laser scanner was used to achieve this objective. The collected information will be used (1) in assessing the quality of construction, (2) in finite element modeling based on the as-built geometry of the bridge, (3) as a reference for subsequent laser scanning projects to assess its condition after major earthquakes, and (4) in monitoring any possible changes due to the ongoing construction of another bridge next to the one studied in the paper. Only some results related to laser scanning are discussed herein to meet the size limitation of the paper.

**LASER SCANNING: FIELD WORK AND REGISTRATION OF POINT CLOUDS**

This laser scanning project was conducted utilizing a terrestrial laser scanner, RTC360 from Leica Geosystems [8]. The bridge was scanned from multiple positions, which are usually laser scanning stations. Therefore, the self-registering capability of the laser scanner was crucial for accurately collecting the point clouds. Fig. 1a shows a laser scanning process at a typical station. The final registration was generated in the Cyclone REGISTER 360 PLUS, also from Leica Geosystems [9]. The analysis of the collected point cloud was performed in the Cyclone software environment [10]. It is worth noting that the laser scanning work was conducted on June 5, 2025, which was one of the hottest days of summer 2025. The point cloud consisted of two large subsets. One was obtained on the west bank of the Chirchiq River, and another one was obtained on the east bank after crossing the bridge. For example, the point cloud of the west bank is illustrated in Figure. 1b.

|  |  |
| --- | --- |
| A group of people standing next to each other  AI-generated content may be incorrect. | A aerial view of a road  AI-generated content may be incorrect. |
| *a)* | *b)* |

**FIGURE. 1.** Typical laser scanning station (a) and registration of the east bank portion of the point cloud (b)

These two subsets were stitched together to generate a final point cloud registration of the bridge. The resulting point cloud represents a digital twin of the bridge, comprising approximately 600 billion points. The collected point cloud consists of the bridge’s point cloud and the point cloud capturing the large area around the bridge. The overall size of the covered area was approximately 300 meters in the transverse axis of the bridge and 500 meters in the bridge’s longitudinal axis. The overall orientation of the bridge is closely aligned with the east-west axis, with the west side pointing away from the city of Tashkent. The final registration is shown in Fig. 2a, where the point cloud is shown in the actual colors of the object collected by the scanner’s built-in still imaging camera. This figure displays only a narrow strip of the point cloud along its length, which was studied in more detail herein. A local coordinate system with the X-axis parallel to the longitudinal direction of the bridge was introduced. The origin of the coordinate system was selected at the corner of the east embankment of the bridge, as presented in Fig. 2b. The following features of Cyclone were used to compute the new origin location. A section of the point cloud containing the corner of the embankment was best fit to a cube, which was used as a reference object. The top outer corner of the cube was used as the origin of the coordinate system. In Fig. 2b, the reference cube is shown in blue. The coloring scheme of the point cloud is based on the intensity of the returned laser beam. An elevation view of the bridge is presented in Figure. 3.

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| A bridge with a black background  AI-generated content may be incorrect. | A blue cube with orange and yellow dots  AI-generated content may be incorrect. |
| *a)* | *b)* |

**FIGURE. 2.** Final registration of both east bank and west bank point clouds (a) and selection of the coordinate system’s origin at the top outer corner of the blue cube (b)

A bridge with a bridge in the background

AI-generated content may be incorrect.

**FIGURE 3.** Elevation view of the bridge

**LASER SCANNING: OVERALL ANALYSIS**

The remaining portion of the analysis was conducted in the Matlab [11] environment. Although similar results can be obtained in Cyclone, this approach was undertaken for better presentation. In addition, the developed Matlab script can be used in the automation of the monitoring process, which would be essential for continuous monitoring of the same bridge by multiple laser scanning projects conducted at different times.

Sections of the bridge with horizontal planes at elevations of -0.9 m, -4.2 m, and -8.5 m are presented in Fig. 4. This image shows that overall, the columns are well aligned with the longitudinal direction of the bridge. At the same time, there are some small variations from it. It can be observed that the column spacing in the transverse direction is very close to 4 m.



**FIGURE 4.** Sections by horizontal planes at three elevations

Sections of the bridge with vertical planes at the longitudinal coordinate equal to 42.7 m, 68.7, and 94.5 m are presented on the left image of Fig. 5. This image shows that the columns and the rest of the supporting structure are well aligned with the transverse direction of the bridge. At the same time, there are some small variations from it. The elevations of the support structure are also somewhat consistent.



**FIGURE 5.** Sections by vertical planes along the longitudinal axis of the bridge

Sections of the bridge with vertical planes at the longitudinal coordinate equal to 121.0 m, 147.0 m, and 163.0 m are presented on the right image of Fig. 5. They also show similar results.

Sections of the bridge with vertical planes at the transverse coordinate equal to 2.17 m and 6.53 m are presented in Fig. 6. They show that the sections are quite consistent with each other.

A graph with red and blue lines

AI-generated content may be incorrect.

**FIGURE 6.** Sections by vertical planes along the transverse axis of the bridge

**LASER SCANNING: DETAILED ANALYSIS**

A section of the bridge with a horizontal plane at the elevation of -4.05 m is presented in Fig. 7. The point clouds reproducing the first row columns are presented in purple. Additionally, the column numbering is presented in red font, starting from the left and increasing along the length of the bridge.

A graph of a graph with blue and pink circles

AI-generated content may be incorrect.

**FIGURE 7.** Section by horizontal plane at Z=-4.05m: the first row columns

The same section of the bridge with a horizontal plane at the elevation of -4.05 m is shown in Fig. 8. Analogous to the preceding image, the point clouds corresponding to the second row columns are presented in purple. Additionally, the column numbering is presented in red font, starting from the left and increasing along the length of the bridge.

A graph with blue and pink lines

AI-generated content may be incorrect.

**FIGURE 8.** Section by horizontal plane at Z=-4.05m: the second row columns

The point clouds shown in purple in both Fig. 7 and Fig. 8 were best fit by the least squares procedure to a circle to obtain the center of a column’s section and its radius. This procedure was introduced earlier and used in the analysis of an ancient minaret [12]. The results are presented in Table 1. The first and second rows of columns were analyzed separately to account for the case of two steel forms used for concrete casting, which may have a slight variation between the two.

**TABLE 1.** Variations of the estimated radii of the columns

|  |  |  |  |
| --- | --- | --- | --- |
| Column No | Radius, m | Column No | Radius, m |
| 1 | 0.997 | 9 | 1.019 |
| 2 | 0.997 | 10 | 0.999 |
| 3 | 0.995 | 11 | 0.997 |
| 4 | 0.995 | 12 | 0.994 |
| 5 | 0.994 | 13 | 0.994 |
| 6 | 0.994 | 14 | 0.993 |
| 7 | 0.994 | 15 | 0.995 |
| 8 | 0.996 | 16 | 0.995 |
| Mean, m: | 0.995 | Mean, m: | 0.998 |
| COV, %: | 0.14 | COV, %: | 0.87 |

Table 1 shows that the mean radius is very close to 1.0 m and the COV, a coefficient of variation, is under 1%. This can serve as evidence of the good quality of the bridge construction. The respective results for the locations of the centers of column sections are summarized in Table 2. In addition, the table shows computed distances between the columns, *Di*, based on the following formula:

*Di = sqrt((Xi+8*- *Xi)2*+ *(Yi+8*- *Yi)2)*. (1)

where *i* varies from one to eight, and pairs (*Xi, Yi*) and (*Xi+8, Yi+8*) are the center coordinates for the columns of the first and second rows, respectively. Table 2 shows that the distance variations are relatively small with an average of 4.28 m and a COV of about 1.4%. It is worth noting that the largest distance between the columns, 4.41m, was estimated for columns 8 and 16.

**TABLE 2.** Estimated column locations in a horizontal plane and distances between the columns in the first and second rows

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Column No | X, m | Y, m | Column No | X, m | Y, m | Distance, D: m |
| 1 | 16.577 | 2.162 | 9 | 16.568 | 6.451 | 4.288 |
| 2 | 42.555 | 2.191 | 10 | 42.585 | 6.463 | 4.272 |
| 3 | 68.670 | 2.286 | 11 | 68.586 | 6.505 | 4.220 |
| 4 | 94.635 | 2.161 | 12 | 94.653 | 6.412 | 4.251 |
| 5 | 120.825 | 2.179 | 13 | 120.841 | 6.441 | 4.262 |
| 6 | 146.771 | 2.136 | 14 | 146.781 | 6.418 | 4.283 |
| 7 | 172.950 | 2.105 | 15 | 172.939 | 6.329 | 4.223 |
| 8 | 198.944 | 2.013 | 16 | 198.976 | 6.426 | 4.413 |
|  |  |  |  |  | Mean, m: | 4.28 |
|  |  |  |  |  | COV, %: | 1.42 |

A further investigation of the current condition of the bridge is based on the estimation of a residual drift of each column, which can be related to the construction imperfection within the established construction tolerances, following the approach proposed earlier in [13]. It is based on the utilization of two sections along its elevation, as demonstrated in Fig. 9a. The point clouds at the selected sections are shown in red for the lower elevation and in blue for the upper elevation. The corresponding point clouds for these two sections are presented in Fig. 9b. They are shown in the same colors. As illustrated in the image, circles can closely approximate their shape.

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| --- | --- |
| A diagram of a structure  AI-generated content may be incorrect. | A graph of a circle with red and blue dots  AI-generated content may be incorrect. |
| *a)* | *b)* |

**FIGURE 9.** Point cloud of columns No. 3 and 11 with horizontal sections at two elevations (a) and the selected sections overlayed on top of each other(b)

As shown in Fig. 9b, the locations of the sections differ slightly from one another. In other words, they are shifted in respect to each other. A best-fitting procedure was used to fit a circle to each section’s point cloud. Two typical results are depicted in Fig. 10a and 10b. The images show the circle approximating each section and the circle center. There is a noticeable difference between the center at Z=-4.05 m and the one at Z=-7.5 m, which serves as evidence that the column has some residual inclination.

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| A graph of a circle with red and blue lines  AI-generated content may be incorrect. | A graph of a circle with red and blue lines  AI-generated content may be incorrect. |
| *a)* | *b)* |

**FIGURE 10.** Typical results for top and bottom circles approximating respective sections: column No. 11 (a) and column No. 6 (b)

This inclination is studied based on the previously introduced approach [14]. The inclination is represented by a vector called drift, as presented in Fig. 11a. It has a value and orientation. Its orientation is described by two angles, *θ* and *φ,* as presented in the same image. The value is the distance between the center of the top section’s circle and the center of the bottom section’s circle when both circles are overlaid on top of each other. If (*Xtop, Ytop*) and (*Xbottom, Ybottom*) are the coordinates of the top and the bottom circles, respectively, then the angles *θ* and *φ* can be computed from the following expressions:

*φ = atan((Ytop* – *Ybottom)* */(Xtop* – *Xbottom))* and (2)

*θ = atan(sqrt((Xtop* – *Xbottom)2+(Ytop* – *Ybottom)2)/ (Ztop* – *Zbottom)),* (3)

in the last expression, *Ztop* = -4.05 m and *Zbottom* = -7.5 m.

The drift vector for all eight tall columns supporting the deck is presented in Fig. 11b. As can be observed, the columns with the largest drifts are columns No. 5 and 6.

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|  | A graph with numbers and points  AI-generated content may be incorrect. |
| *a)* | *b)* |

**FIGURE 11.** Drift vector definition in spherical coordinate system (a) [14] and vectors of all columns No 3 through 6 and No 11 through 14 (b)

These angles are summarized in Table 3. It is important to note that the inclinations are very small, not exceeding 0.63 degrees (see the table values for *θ*), and are most likely within the construction tolerances. Nevertheless, this analysis enables us to identify the most critical columns to monitor, allowing the inclination angle to be tracked by future monitoring projects for maintenance purposes or to assess the bridge's structural condition after a large earthquake. In addition, the direction of the drift angle provides information about which way the column is leaning. For example, columns No. 3 and 11 are leaning toward the river. Since these columns are installed on piles, this direction of leaning toward the river might progress over time. The future laser scanning projects can help with monitoring to investigate if it is happening or not.

**TABLE 3.** Estimated angles of the drift vector

|  |  |  |
| --- | --- | --- |
| Column No | *θ*, degrees | *φ*, degrees |
| 3 | 0.35 | -19.78 |
| 4 | 0.29 | -5.6 |
| 5 | 0.63 | 20.81 |
| 6 | 0.81 | 100.33 |
| 11 | 0.32 | 32.61 |
| 12 | 0.50 | -37.76 |
| 13 | 0.38 | -2.92 |
| 14 | 0.36 | 84.21 |

**CONCLUSIONS**

A railrod bridge’s current condition was evaluated by using a terrestrial laser scanner. The analysis of the collected point cloud revealed some structural imperfections. Among a few imperfections, some residual inclinations of columns were observed. These inclinations are relatively small, not exceeding 0.63 degrees, and are most likely within the construction tolerances. Nevertheless, this analysis allows the identification of the most critical columns to monitor. It enables the accurate calculation of the inclination angle, allowing it to be tracked by future monitoring projects for maintenance purposes or to assess the bridge's structural condition after a major earthquake. In addition, the direction of the drift angle provides information about which way the column is leaning. For example, columns No. 3 and 11 are leaning toward the river. Since these columns are installed on piles, this direction of leaning toward the river might progress over time. The future laser scanning projects are invaluable for monitoring the progression of these and other structural anomalies.

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