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DEFLECTION ANALYSIS OF LATTICE STEEL GIRDERS USING TERRESTRIAL LASER SCANNING

Abstract:

This paper demonstrates the use of terrestrial laser scanning (TLS) to detect deflection in lattice steel girders inside a hall structure. Data were acquired using the Trimble TX8, producing a point cloud of over 349 million points. After registration and classification, the processed point cloud served as the basis for deflection analysis. Girder profiles were extracted from the point cloud data, and a regression curve was fitted to the measured points to describe the girder geometry. Deflection values were determined by comparing the measured geometry with an ideal straight reference line. Results confirm that TLS can identify subtle geometric changes while providing complete spatial coverage, reduced field time, and a rich digital archive for further analysis.

Keywords: laser scanning, girder, deflection analysis

АНАЛИЗА УГИБА РЕШЕТКАСТИХ ЧЕЛИЧНИХ НОСАЧА ПРИМЕНОМ ТЕРЕСТРИЧКОГ ЛАСЕРСКОГ СКЕНИРАЊА

Сажетак:

Овај рад приказује примену терестричког ласерског скенирања (ТЛС) за детекцију угиба решеткастих челичних носача унутар хале. Подаци су прикупљени коришћењем скенера Trimble TX8, при чему је формиран облак тачака са преко 349 милиона тачака. Након регистрације и класификације, обрађени облак тачака послужио је као основа за анализу угиба. Из облака тачака издвојени су профили носача, те је над подацима издвојеним из облака тачака извршено фитовање регресионе криве. Вредности угиба су затим одређене поређењем мерене геометрије са идеалном праволинијском референтном линијом. Резултати потврђују да ТЛС омогућава поуздано откривање малих геометријских промена, уз потпуну просторну покривеност, краће време рада на терену и богату дигиталну архиву података за даљу анализу.

Кључне ријечи: ласерско скенирање, носачи, анализа угиба

1. INTRODUCTION

The field of geodesy, like numerous other scientific domains, has experienced significant technological advancement in recent decades. These innovations have revolutionized not only the speed of data acquisition and the efficiency of processing workflows, but have also enabled the collection of extraordinarily detailed and comprehensive spatial information that was previously unattainable through conventional methods. A key advantage of contemporary technologies is the ability to archive collected data for future analysis and reprocessing. Laser scanning technology exemplifies this transformative shift. This technology represents a groundbreaking advancement in modern geodetic measurement techniques and spatial data collection methodologies, fundamentally changing how spatial information is captured and utilized. The evolution of these technologies has established new standards for precision, efficiency, and data richness in geodetic practice, opening many possibilities for comprehensive spatial documentation and analysis [1], [2].

Laser scanning technology can be broadly divided into three main categories based on the platform used: terrestrial laser scanning (TLS), mobile laser scanning (MLS), and airborne laser scanning (ALS). The rapid evolution of TLS hardware has enabled increasingly accurate and efficient data capture. Modern scanners such as the Leica RTC360, Z+F Imager 5010C, Riegl VZ-400, and Trimble TX8 have achieved sub-centimeter accuracy with extended scanning ranges exceeding 150 meters [3]. This technological advancement has made TLS particularly suitable for diverse applications ranging from industrial quality control to infrastructure monitoring, though its application in indoor environments presents unique opportunities and challenges [4].

The paper shows the application of TLS in the detection of deformations of construction objects, with special reference to the assessment of the deflection of lattice steel girders. Conventional deformation detection methods are also analyzed, after which the advantages of TLS technology are highlighted. In the following, the procedure of data collection and processing is described, while the results of the research are presented and discussed. The paper ends with concluding remarks.

2. OVERVIEW OF CONVENTIONAL DEFORMATION MONITORING METHODS

Traditional deformation monitoring has relied extensively on total stations and theodolites - surveying instruments that measure horizontal and vertical angles combined with distance measurements. These instruments establish precise measurements at pre-selected monitoring points, typically marked by reflective prisms or established survey monuments. The total station approach requires direct line-of-sight to each measurement point and operator intervention to sequentially target and measure each location [5].

For structural applications, total stations have achieved high positional accuracy, with precision comparable to modern TLS systems in terms of individual point measurements, often within 1-2 mm for carefully executed surveys. However, the fundamental limitation involves measurement discretization: only pre-selected points receive measurement attention, potentially missing deformations occurring between monitoring stations [6]. This constraint becomes particularly problematic when deformation patterns are complex or when precise spatial distributions of movement require detailed documentation [5].

The precision of leveling measurements can exceed TLS accuracy for purely vertical displacements, with achievable precision often within 1 mm for carefully executed surveys [5]. However, like total station methods, leveling is inherently limited to measuring heights at discrete points. Moreover, leveling provides no information regarding horizontal displacements, representing a significant limitation for comprehensive three-dimensional characterization [5].

Global Navigation Satellite System (GNSS) measurements have become increasingly important for large-scale deformation monitoring, particularly where ground-based instruments cannot access measurement points. Real-time kinematic (RTK) GNSS systems achieve 1-2 cm horizontal accuracy and 2-3 cm vertical accuracy under optimal conditions, making them suitable for detecting larger deformations but inadequate for small-scale structural movements [7]. Additionally, static GNSS observations, based on longer occupation times and post-processing [8], can achieve millimeter-level positional accuracy, which makes this approach suitable for precise geodetic deformation studies [9], although still limited to discrete observation points. Critically, GNSS measurements remain point-based: only locations equipped with GNSS receivers receive measurements. Unlike TLS, which produces complete spatial coverage, GNSS monitoring necessarily involves sparse, discrete measurement locations.

It is clear from the above that, although traditional deformation detection methods can provide a high level of accuracy and reliability, they simultaneously have certain limitations in terms of spatial coverage, efficiency and degree of automation. These disadvantages are largely overcome or completely eliminated, by the application of laser scanning technology. In the context of deformation detection of construction objects, TLS stands out, which enables a detailed and high-resolution observation of deformation patterns on the entire structure. The following chapter represents the TLS application for particular object data acquisition and deformation detection methodology.

3. TLS IN DEFORMATION MONITORING

Direct comparison between TLS-based deformation monitoring and conventional geodetic techniques (total station measurements, precise leveling, GNSS) provides validation of accuracy claims. Comparative studies evaluating retaining wall deformations revealed that TLS-based measurements using M3C2 (Model-to-Model Cloud Comparison) analysis achieved 1.3 mm accuracy, effectively matching robotic total station precision while providing complete spatial coverage rather than discrete point measurements [10]. For bridge structure monitoring, TLS-based methods achieved 0.1 mm accuracy through the SWSF (sliding window surface fitting) method, exceeding the precision of total station measurements while providing continuous spatial deformation modes rather than isolated measurements [11].

The primary output of TLS acquisition is a dense point cloud consisting of millions of georeferenced 3D coordinates, each potentially associated with intensity values presenting the reflectivity of the scanned surface. This point cloud forms the foundation for all subsequent deformation analysis. The quality and reliability of deformation assessments depend fundamentally on the density, distribution, and accuracy of the acquired point cloud data. Studies have demonstrated that maintaining point cloud densities exceeding 500 points per square meter enables spatial resolution sufficient for sub-millimeter deformation detection in favorable conditions [12].

Based on the presented overview of TLS, the next section details the study area, the applied scanning setup, and the data acquisition and processing workflow.

3.1. STUDY AREA: DATA COLLECTION AND POST-PROCESSING

The subject of the terrestrial laser scanning are the three lattice steel girders, which are an integral part of the hall's construction. A Trimble TX8 scanner was used in the TLS procedure, with specifications shown in Table 1.

Table 1. Specification of Trimble TX8 [13]

Parameter	**Specification**
Maximum range	120 m on most surfaces (up to 340 m with optional upgrade)
Scanning speed	Up to 1,000,000 points per second
Measurement accuracy	±2 mm (standard mode), < ±1 mm (High Precision mode)
Angular accuracy	80 µrad
Field of view (FOV)	360° × 317°
Protection class	IP54 (suitable for indoor and outdoor conditions)

TLS involves the acquisition of spatial data with a laser scanner from different positions, where the number of positions is determined, among other things, by the geometry of the object that is the subject of scanning and the conditions in the field. Based on the tour of the given object, within the scope of the scanning plan, 12 positions were defined from which scanning should be performed in order to fully scan the geometry of the three lattice steel supports. Figure 1 shows one of the 12 scanner positions during scanning, while in Figure 2, the distribution of all 12 scan positions are presented, including the red-marked beams of interest. The scanning was performed in so-called Level 1 regime. A scanning time of 2 minutes per station ensured a point spacing of 22.6 mm at a range of 30 m, with approximately 34 million points collected in a single scan.

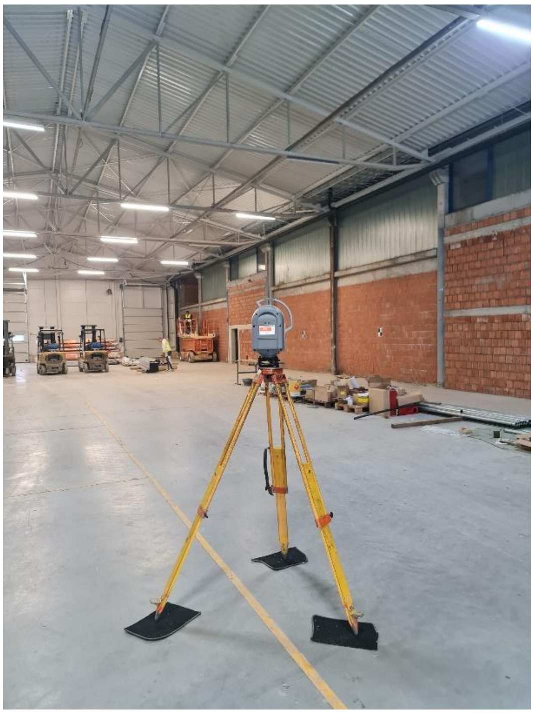

Figure 1. Trimble TX8 scanner position during scanning (photography by author).

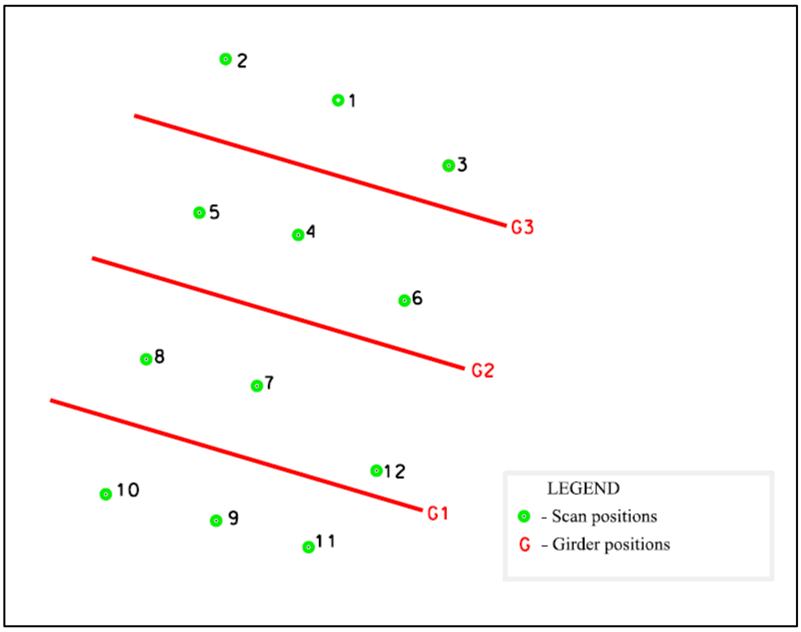

Figure 2. Scanning positions (created by author).

The point clouds collected from each of the 12 scanner positions had to be combined into one single, unified point cloud before any analysis could begin. Since every scan was performed from a different location, the datasets did not initially align with one another. For this reason, it was necessary to carry out a registration process in which all scans were carefully brought into the same coordinate framework. To make this process easier and more accurate, special marker were placed in the scene during field data acquisition. These targets were clearly visible from multiple scanner positions and served as common reference points between the scans. During post-processing, these shared targets were used to accurately match and align the individual point clouds, ensuring that the final unified dataset represented the geometry of the structure as precisely as possible.

The final product of laser scanning is a point cloud of very high spatial resolution, consisting of 349,081,286 three-dimensional points. Thus, the dataset comprises hundreds of millions of points, representing a rich digital archive from which a 3D model, as well as vertical and horizontal crosssections and similar representations, can be generated. Subsequent processing of the acquired data first involved point-cloud registration in Trimble Business Center. The initial alignment was performed using a combination of automatic plane-based registration, relying on the detection and matching of overlapping planar surfaces, and manual pairwise registration, in which corresponding features were selected in overlapping scans when automatic alignment was not sufficient. After the initial alignment, an overall registration refinement was carried out on the resulting station group in order to improve the mutual consistency and final alignment of all scans. The result of this process is a registered point cloud with the Cloud-to-Cloud error 1.4 mm. Figure 3 shows the registered point cloud, with the steel girders subjected to the analysis of vertical displacements, i.e., deflection, highlighted in red.

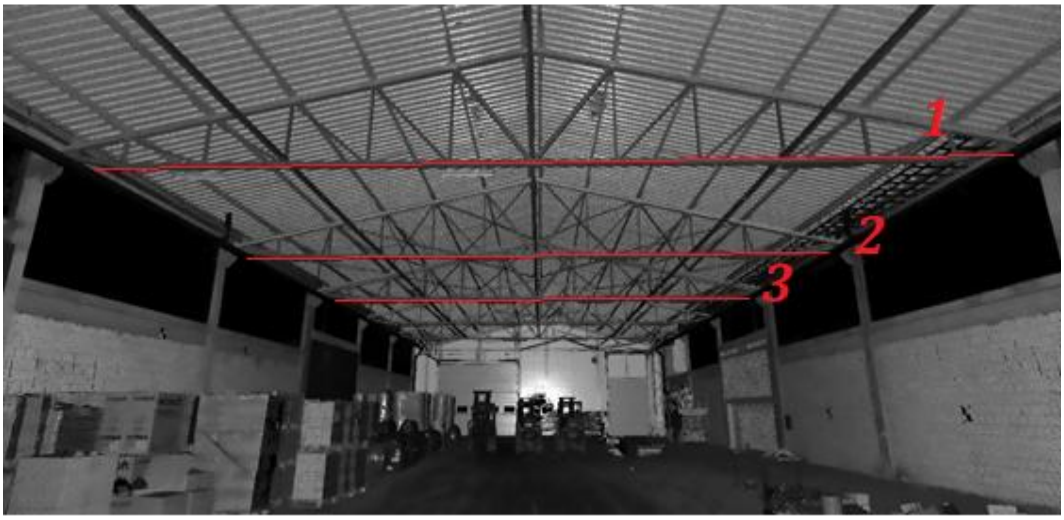

Figure 3. Registered point cloud with red-marked steel girders (created by author).

3.2. DETERMINING THE DEFLECTION OF LATTICE STEEL GIRDERS

Determining the deflection of lattice steel girders was performed using TLS and point cloud analysis, which enabled continuous monitoring of the geometry of the structure along the entire length of the observed elements. First, the registered point cloud was manually filtered and segmented in order to isolate the area of interest from the complete dataset. This procedure involved cropping the point cloud to the part of the structure containing the girders under investigation, followed by the manual separation and classification of the three selected girders from the surrounding scene. The identification of the girders was performed on the basis of visual inspection of the point cloud in appropriate views, where the geometry of the target elements could be clearly recognized, after which the corresponding points were manually selected and assigned to a separate class/region for further analysis. In this way, the steel girder geometry was distinguished from other objects present in the environment, such as walls, floor surfaces, equipment, and residual noise points. By isolating only the relevant structural elements, the dataset became clearer, more manageable, and more suitable for precise geometric analysis. Moreover, restricting the further processing exclusively to the isolated girder point clouds reduced the influence of irrelevant points and improved computational efficiency during profile extraction and deflection analysis. Therefore, all subsequent analyses were performed only on the isolated girder point clouds, since these elements were the primary subject of the investigation.

Within this class, the lower belt of the girders is additionally separated, given that the maximum deflections of bent elements are expected precisely in this area. Figure 4 shows the part of the point cloud, marked in red class girder.

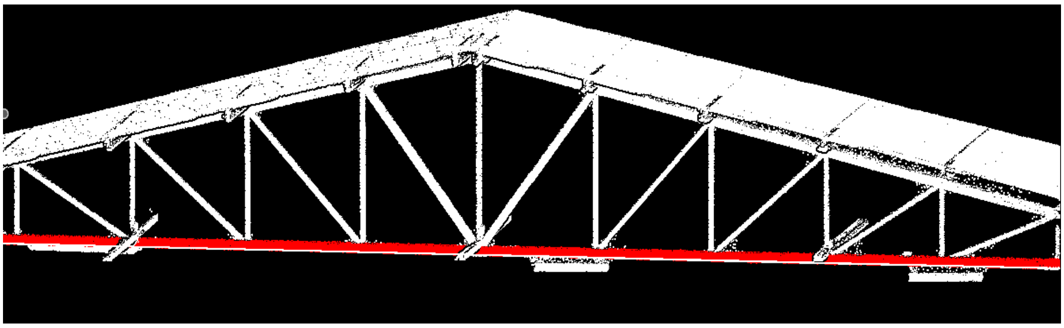

Figure 4. Classified girder in point cloud (created by author).

For each girder, a longitudinal section was formed along the middle line of the element. The profile is defined as a central narrow band of points 1 cm deep, in order to reduce the influence of lateral elements and local irregularities. Three girders were included in the analysis, labeled G1, G2, G3. Each of them represented a distinct class within the point cloud and contained 34,015, 37,565, and 34,744 points, respectively. This approach enabled a comparative analysis of deflections between several structural elements within the same building, where all girders were treated with the same methodology.

The isolated points of the longitudinal sections were used to approximate the curve by regression. The straight line connecting the two end points of each longitudinal profile was adopted as the reference geometry for deflection assessment. In other words, the reference geometry was not taken from design documentation, but was defined as a baseline derived directly from the measured girder profile. This line represents the undeformed chord between the girder ends and was used as the datum for calculating the vertical deviation Δh at each station. Based on the difference between the regression curve and the reference line, the deflection values along the entire length of the girders were determined, whereby the maximum deflection values were identified and quantified for each individual girder.

3.3. RESULTS AND DISCUSSION

The results of the deflection analysis of lattice steel girders are presented in the form of longitudinal diagrams of vertical deviation Δh. They are obtained on the basis of the regression approximation of the point cloud of the lower belt of the girders. The bending approximation was performed by a second-order polynomial, which adequately describes the parabolic shape of the deformation of the bent elements. The third-order polynomial did not significantly improve the results, so a simpler and more stable model was chosen.

The graphic representation (Figure 5) clearly shows the deformation curves for all three observed girders, which enables a direct comparison of their behavior under the effect of their own weight and existing loads.

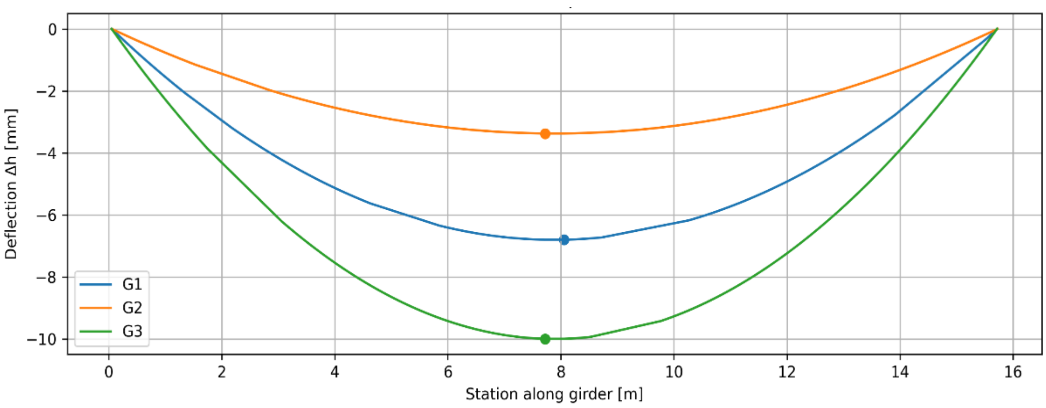

Figure 5. Deflection Diagram of Lattice Steel Girders (created by author).

For all analyzed girders, a characteristic form of deflection was observed, which corresponds to the expected behavior of linearly supported bent elements, with the maximum deflection in the central part of the span. The obtained maximum deflection values are in the range of several millimeters (details presented in Table 2), which is in accordance with the expected values for steel lattice structures of this type and span. It is important to point out that the deflection values were determined with an accuracy of ±1.5 mm, which is the estimated value of the measurement uncertainty of the applied laser scanner, determined during the calibration procedure.

Table 2. Number of points used in the analysis and maximum deflection values

Girder	Number of points used	Maximum deflection Δh [mm]
Girder 1	34,015	−7
Girder 2	37,565	−4
Girder 3	34,744	−10

The application of continuous point cloud analysis enabled the observation of deflections along the entire length of the girder, thus overcoming the limitation of traditional methods that rely on measurements at discrete points. A large number of points per girder (more than 34 000) contributes to the stability of the regression approximation and the reduction of the impact of random errors, while the use of a narrow longitudinal profile additionally reduces noise and local geometric irregularities.

4. CONCLUSION

All geodetic works related to the realization of TLS of lattice steel girders, registration of point cloud and determination of deflection of lattice steel girders from point cloud, were realized using modern technologies and in accordance with all standards and norms. It is important to note that the point cloud generated in this way provides a significant digital archive, from which it is possible to subsequently extract any spatial data of interest. The instruments used for the acquisition of spatial data, as well as the modern software for the processing and interpretation of spatial data, ensure the necessary quality and accuracy of the final data previously presented. This study has demonstrated that TLS represents a reliable and effective approach for the detection and analysis deflection. The applied methodology enabled the identification of deflection in lattice steel girders with an achieved accuracy of approximately 1.5 mm, confirming the capability of TLS to capture subtle geometric changes with high precision.

The field of TLS-based deformation monitoring continues to mature, transitioning from research prototypes toward operational monitoring systems deployed in actual civil engineering and structural health monitoring applications. Continued standardization of methodologies, development of robust uncertainty quantification frameworks, and integration with building information modeling systems will likely characterize near-term developments. For practitioners engaged in indoor object deformation assessment, the comprehensive methodologies, well-established best practices, and demonstrated effectiveness of modern TLS systems offer compelling alternatives to traditional surveying approaches, particularly in applications requiring complete spatial coverage, minimal survey time, and high-resolution deformation documentation.

Key developments enabling this progress include high-precision automatic registration methodologies eliminating the requirement for artificial targets, advanced filtering and preprocessing techniques preserving structural details while eliminating noise, and sophisticated multi-scale comparison algorithms explicitly accounting for surface roughness characteristics [11].

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LITERATURE

[1] D.Vasić, M. Batilović, M. Davidović, and T. Kuzmić, “Application of terrestrial laser scanning methodology in façade reconstruction and rehabilitation projects,” in P*roc. 2nd International Conference on Construction Materials for Sustainable Future*, Slovenia, Apr. 20–21, 2021.

[2] D. Tešić, T. Tomić, N. Tomić, S. B. Marković, E. Tadić, R. Marković, N. Bačević, and M. Davidović Manojlović, “Using LiDAR technology for geoheritage inventory and modelling: Case study of Đavolja Varoš geosite (Serbia),” *Geoheritage*, vol. 16, 2024, Art. no. 41, doi:10.1007/s12371-024-00947-9.

[3] M. Makuch and P. Gawronek, “Development and Validation of an Openable Spherical Target System for High-Precision Registration and Georeferencing of Terrestrial Laser Scanning Point Clouds,” *Italian National Conference on Sensors*, Dec. 2025, doi: 10.3390/s25247512.

[4] A. Al-Saedi, F. Abed, and I. A. Alwan, “Geometric Quality Analysis of Terrestrial Laser Scanning Data for Industrial Usage,” *International Islamic University Malaysia Engineering Journal*, Jul. 2024, doi: 10.31436/iiumej.v25i2.3211.

[5] Y. Zhou, J. Zhu, L. Zhao, G. Hu, J. Xin, H. Zhang, and J. Yang, “High-precision monitoring method for bridge deformation measurement and error analysis based on terrestrial laser scanning,” *Remote Sensing*, vol. 16, no. 13, Jun. 2024, Art. no. 2263, doi:10.3390/rs16132263.

[6] P. Psimoulis, A. Algadhi, A. Grizi, and L. Neves, “Assessment of accuracy and performance of terrestrial laser scanner in monitoring of retaining walls,” *None*, Jun. 2022, doi: 10.4995/jisdm2022.2022.13917.

[7] X.-Y. Ning, K. Zhang, N. Jiang, X.-L. Luo, D.-M. Zhang, J.-W. Peng, X.-X. Luo, Y.-S. Zheng, and D. Guo, “3D deformation analysis for earth dam monitoring based on terrestrial laser scanning (TLS) and the iterative closest point (ICP) algorithm,” *Frontiers in Earth Science*, vol. 12, Jun. 24, 2024, Art. no. 1421705, doi:10.3389/feart.2024.1421705.

[8] Y. Correa-Muños, “Precision and accuracy of the static GNSS method for surveying networks used in civil engineering,” *Rev. Redalyc*, vol. 643, 2018, pp. 1-10.

[9] X. Sun, Y. Zhang, L. Li, and J. Chen, “Evaluation of static precise point positioning and fixing rate performance in long observing sessions,” *PLoS ONE*, vol. 20, no. 1, Jan. 2025, Art. no. e0322622, doi: 10.1371/journal.pone.0322622.

[10] A. Algadhi, P. Psimoulis, A. Grizi, and L. A. C. Neves, “Assessment of accuracy and performance of terrestrial laser scanner in monitoring of retaining walls,” in *Proc. 5th Joint International Symposium on Deformation Monitoring (JISDM 2022)*, València, Spain, Jun. 20–22, 2022, pp. 467–473, doi:10.4995/JISDM2022.2022.13917

[11] Y. Zhou, J. Zhu, L. Zhao, G. Hu, J. Xin, H. Zhang, and J. Yang, “High-precision monitoring method for bridge deformation measurement and error analysis based on terrestrial laser scanning,” *Remote Sensing*, vol. 16, no. 13, 2024, Art. no. 2263, doi:10.3390/rs16132263.

[12] D. Tan, W. Li, Y. Tao, and B. Ji, “Bridge Deformation Monitoring Combining 3D Laser Scanning with Multi-Scale Algorithms,” *Italian National Conference on Sensors*, Jun. 2025, doi: 10.3390/s25133869.

[13] Trimble Inc., “Trimble TX8 Laser Scanner Datasheet,” Trimble Inc., 2019. [Online]. Available: https://www.laserinst.com/content/Trimble%20TX8%20Datasheet.pdf