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Terrestrial laser scanning point clouds as a data source for geometric analysis and inventory of hydraulic structures

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Summary

Terrestrial laser scanning (TLS) has become one of the key technologies for surveying and documenting engineering objects, including large-scale and hard-to-access hydraulic structures. Water dams are a prominent example with considerable spatial dimensions, complex geometry, and critical importance for technical and environmental safety. This calls for modern, precise, and comprehensive documentation methods. TLS enables the acquisition of dense three-dimensional spatial data in the form of point clouds, providing a robust basis for geometric inventorying, visualization, and assessment of structural condition. This study uses TLS datasets acquired for the Rożnów and Klimkówka dams to produce 2D technical documentation, 3D models, and geometric analyses of the dams and their associated components. The point clouds support surface-based evaluation of object geometry, verification of structural continuity and integrity, detection of shape changes, and analysis of spatial relationships between the dams and their surroundings. An additional advantage of point clouds is the reusability of the acquired data: cross-sections, plans, and visualizations can be generated repeatedly at later stages without the need for renewed field surveys. The results demonstrate the high utility of TLS as a support for geometric inventorying, technical condition assessment, and long-term monitoring of water dams, particularly in the case of large, geometrically complex hydraulic structures.

Keywords

TLS • inventory • point cloud • water dam • technical documentation

1. Introduction

Hydraulic structures constitute a class of massive engineering works functionally connected to watercourses and reservoirs. Their primary purpose is to control and regulate flow, impound, store (retain) water, and ensure its safe conveyance, as well as to protect adjacent areas from hydrological impacts [Kozlov and Yurchenko 2020, Zaczek-Peplińska and Kowalska 2022]. In normative terms, hydraulic structures comprise civil engineering works together with associated technical devices and installations intended to implement water management tasks, shape water resources, and enable their use Hydraulic structures include, among others, earthfill and concrete dams, outlet and discharge structures, hydropower plants and stations, flood embankments (levees), monk structures (sluice/monk outlets), and other facilities with regulating, protective, and operational functions [Regulation of the Minister of the Environment of 20 April 2007]. From a systems perspective, these facilities are key components of water infrastructure because their presence and operation affect catchment water balance, flood protection, water availability for municipal and industrial uses, and the functioning of river ecosystems. They represent a persistent intervention in the natural hydrological regime through changes in flow dynamics, sediment transport, and retention [Speckhann et al. 2021]. At the same time, due to long-term operation in direct contact with water, hydraulic structures are continuously exposed to hydraulic loads, seepage processes, and environmental factors, which leads to gradual deterioration of technical condition and to geometric and material changes in the structure [Kozlov and Yurchenko 2020]. The assessment of their condition is based on observations of displacements, strains, and surface changes that may indicate degradation processes. Therefore, safe operation requires systematic geometric monitoring, periodic inspections, and technical inventorying, particularly where complete design and operation documentation is unavailable [Kozlov and Yurchenko 2020, Zaczek-Peplińska and Kowalska 2022]. Among hydraulic structures (water dams), spillways, outlet elements, and energy dissipation facilities are particularly important because they determine the capability to safely contain flood loads. Deterioration of these components may increase the risk of failure mechanisms associated, inter alia, with erosion, overtopping, or loss of load-bearing capacity of structural elements [Fiedler 2016].

The most characteristic and, simultaneously, the largest hydraulic structures are water dams, constructed in river valleys as barrier structures that obstruct a watercourse in order to impound water and form a reservoir with defined operational parameters. The form of these structures can vary greatly, ranging from low earthfill dams that are only a few metres to much higher structures. In terms of their engineering solutions, dams can use earthfill, concrete, or reinforced concrete materials [Kozlov and Yurchenko 2020].

These dams are impounding structures designed to create reservoirs on natural or artificial watercourses by closing off the cross-section of river valleys. Their primary functions are to maintain a specified water level in the reservoir and to control releases under both normal operating conditions and during extreme events [Zaczek-Peplińska and Kowalska 2022]. Due to their diverse operational objectives, dams can fulfil protective functions related to flood hazard mitigation, retention and water supply, flow regulation (stabilisation), as well as support economic and recreational functions, often taking a single- or multipurpose form, depending on local hydrological and topographic conditions [Kozlov and Yurchenko 2020, Speckhann et al. 2021]. Their complex structure comprises not only the dam body and crest, but also hydraulic components and systems that ensure the safe transportation of water, including outlet and spillway structures, energy dissipation elements, discharge channels, tunnels, gate and closure equipment, as well as culverts, slope protection, inspection galleries, and the surfaces of walls and slopes. Their technical condition directly determines the safety of the entire facility [Kozlov and Yurchenko 2020]. During operation, dams are subject to deformations and displacements resulting from hydraulic actions, temperature variations, dynamic loads, and material ageing. They are also susceptible to specific damage mechanisms, such as spillway overtopping, an increase in uplift pressure beneath structural slabs, cavitation of concrete surfaces, or failures of moving components, which can lead to loss of stability or watertightness. For these reasons, dam operation requires a comprehensive, detailed geometric inventory as well as a systematic assessment and monitoring of the structure's surfaces and hydraulic components. This enables the acquisition of data necessary to identify shape changes, local damage, potential seepage zones, and structural irregularities and, consequently, supports performance assessment, risk management, maintenance planning, and other safety measures [Speckhann et al. 2021, Fiedler 2016].

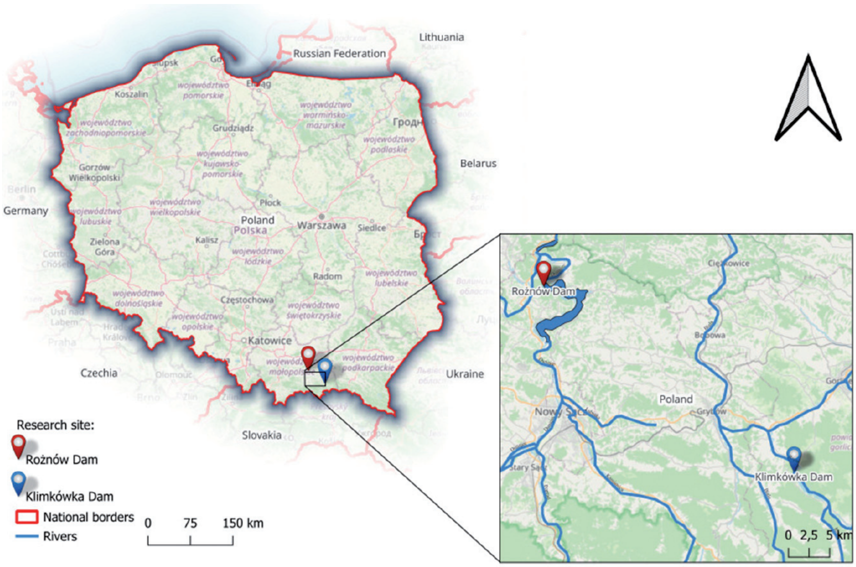
Inventorying hydraulic structures, including water dams, is a process of acquiring spatial and visual information about a facility and its surroundings. These data constitute the basis for verifying the actual technical condition and assessing the safety level of the structure. Systematic observations, measurements, and investigations register changes occurring in the structure throughout its service life [Kledyński 2011]. In practice, such work requires numerous, often repetitive and labour-intensive geodetic measurements. For dams, a comprehensive approach and the highest feasible accuracy are required in order to track material ageing processes, and to identify defects and damage by recording the deformations and displacements of structural components, as well as by verifying compliance with permissible safety limits [Zaczek-Peplińska and Popielski 2007]. Inventory practice employs methods that deliver geometric data and information on displacements, strains, and surface changes. The data are subsequently used to build geometric models, compare successive structural states, and identify changes indicative of degradation processes. This includes both classical geodetic methods and modern non-contact techniques. Classical total station (tacheometric) measurements are used to determine the displacements and deformations of control points during periodic checks, as they offer high accuracy, while providing discrete observations. They have to be complemented with visual inspections and photographic documentation aimed at assessing surface condition and supporting overall visualization of the structure and adjacent areas, which strengthens comprehensive diagnostics and monitoring. Non-contact methods are increasingly important because they enable rapid and safe acquisition of highly detailed data. In particular, terrestrial laser scanning (TLS) provides a quasi-continuous representation of surfaces in the form of a point cloud, which can be used for full geometric inventorying, generation of cross-sections and plans, development of surface models, and analysis of geometric changes across successive measurement campaigns. In addition, laser-return intensity can be incorporated into analyses of surface conditions. Meanwhile, image-based methods – such as terrestrial photogrammetry and unmanned aerial vehicle (UAV) surveys – are applied to document hard-to-access areas and to assess the facility's surroundings. Infrared thermography is used to identify surface non-uniformities, moisture zones, and potential seepage areas, whereas in dynamic analyses, digital image correlation (DIC) may be employed to record displacements and strains in real time [Zaczek-Peplińska and Kowalska 2022]. Inventory work is also carried out during cyclic technical inspections focused on identifying potential failure mechanisms and assessing operational risk. This includes inspecting the dam and the hydraulic equipment responsible for safe water conveyance, as well as the preparation and verification of technical documentation (plans, cross-sections, and other geometric deliverables) as the basis for an unambiguous identification of the structural layout and associated elements. Comparing field-inspection results with documentation provides an overall condition assessment, identification of information gaps, and delineation of areas requiring more detailed investigations, monitoring, or remedial actions. The selection of methods depends on measurement objectives, required accuracy, accessibility, and site working conditions [Fiedler 2016].

Terrestrial laser scanning (TLS) is becoming an increasingly popular primary method for inventorying water dams and acquiring high-resolution geometric data, because it enables the capture of dense three-dimensional point clouds describing the surface of the entire structure. Consequently, TLS allows a transition from point-based control of selected components to surface-based geometric analysis of large and geometrically complex objects. This transition is essential for identifying deformations and geometric changes over successive operational periods [Zaczek-Peplińska and Kowalska 2022]. In a multi-temporal framework, TLS datasets collected during subsequent measurement campaigns can be compared to detect displacements and strains. However, the validity of such analyses requires a stable and unambiguous reference frame that enables reliable georeferencing and integration of multi-epoch point clouds. For this purpose, local geodetic control networks are established to materialise a fixed reference system, and the stability of this system determines whether true structural deformation can be distinguished from errors related to data orientation and registration. TLS surveys are typically carried out from multiple scan positions located at appropriate distances from the dam, which makes it possible to cover a large portion of the surface while reducing adverse effects associated with unfavourable laser incidence angles. The resulting point clouds are then georeferenced using control points and integrated within a common reference frame. A critical stage of point-cloud-based inventorying is the precise registration of datasets acquired at different times. This may be challenging for irregular dam surfaces due to a lack of unique corresponding features and potentially limited stability of the structure itself. For this reason, stable elements in the vicinity of the facility – particularly adjacent rock outcrops – are often used as reference areas during registration. A two-stage registration procedure, comprising an initial coarse alignment followed by fine registration using the iterative closest point (ICP) algorithm, helps to reduce the influence of disturbances caused by vegetation and other non-stable objects. Verifying georeferencing stability – by assessing the fit of point clouds to the control network and the behaviour of control and check points across successive epochs – is crucial for the quality of deformation inference. Reported deviations on the order of a few millimetres indicate that TLS can be applied to dam displacement analyses, provided that appropriate measurement and quality-control procedures are implemented [Li et al. 2021, Gawronek et al. 2017, Alba et al. 2006].

2. Inventorying water dams using TLS

2.1. Survey of hydraulic structures

The study was conducted on two hydraulic structures located in southern Poland (Fig. 1): the Klimkówka Dam and the Rożnów Dam. Differences in their structural design and construction period provide a broad basis for investigating in-service (operational) processes.



Source: Authors' own study

Fig. 1. Location of the study sites: the Rożnów Dam (N: 49.761362, E: 20.663341) and the Klimkówka Dam (N: 49.559160, E: 21.082935)

The first study site is the Rożnów Dam (Fig. 2), located at river kilometre 80 of the Dunajec River (Poland, Małopolskie Voivodeship, Nowy Sącz County, Gródek nad Dunajcem Municipality). The dam is 49 m high, with a crest length of 550 m and a base width of up to 39 m. Construction works commenced in February 1935. Reservoir impoundment began in the second half of 1941, and full supply level was reached in 1943 [www.ekoenergia.tauron.pl]. The dam has been the key element of the Rożnów–Czchów reservoir cascade for over eighty years now. Its monumental structure and the large hydropower plant integrated within it, with an installed capacity of 51.2 MW, make it a facility of particular research relevance, especially in the context of assessing the long-term durability of concrete materials.

a)

b)

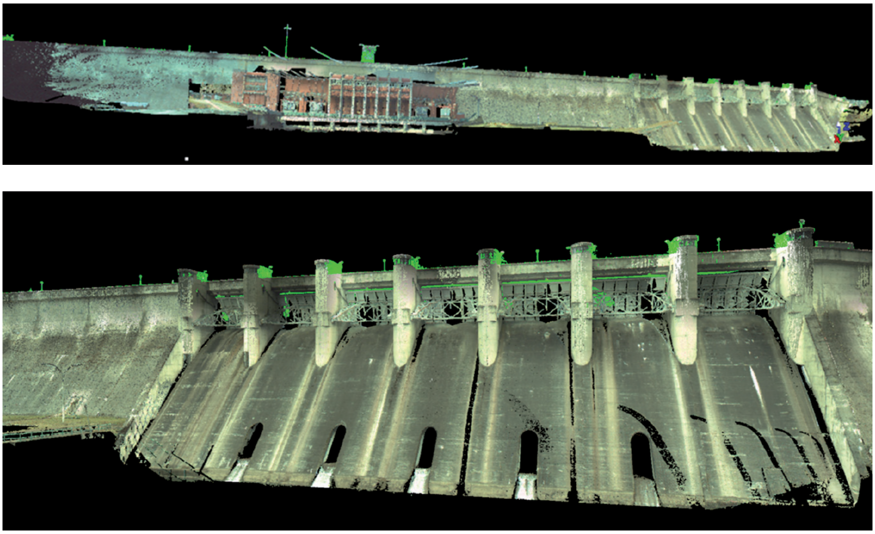
Source: www.geoportal.gov.pl

Fig. 2. Rożnów Dam: a) front view, b) top view

The terrestrial laser scanning of the Rożnów water dam, which is a very large hydraulic structure, was carried out using a pulsed Leica C10 scanner. The scanning resolution was set to 5 mm/10 m. During the field survey, 23 point clouds were acquired and subsequently combined in the orientation process into a single point cloud. The orientation was performed using reference spheres and targets, as well as points that were unambiguously identifiable on the structure. The accuracy of merging the point clouds into a unified representation of the dam was 0.012 m. The data were filtered, optimised, and unified at a resolution of 0.001 m to produce the final point cloud (Fig. 3), which is then used for further analyses.

a)

b)



Source: Authors' own study

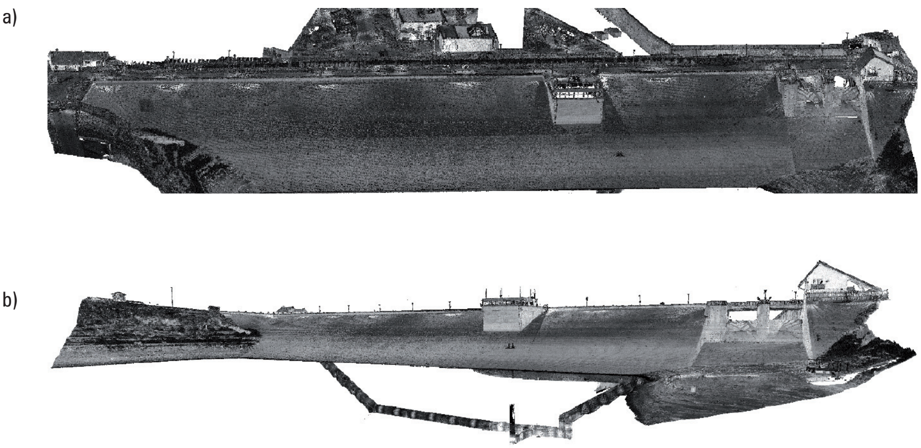
Fig. 3. Point cloud for the Rożnów water dam: a) entire structure, b) view of the water outlet elements

The second facility included in the study is the Klimkówka Dam (Fig. 4) that is situated at the 55 kilometre of the Ropa River (Poland, Małopolskie Voivodeship, Gorlice County, Ropa Municipality). The dam was constructed at a valley constriction historically known as the 'Gorlice Pieniny' [www.gokropa.iaw.pl]. It is an earthfill dam with a height of 34 m and a length of 210 m. The reservoir's construction commenced in the 1970s, and it was impounded in 1994. The downstream slope is protected by concrete slabs, while the upstream slope is covered in grass to prevent erosion. A key structural component, essential for monitoring of the dam's safety, is the grouting and inspection gallery located inside the dam. This enables continuous observation of processes occurring within the embankment and its foundation.

The inventory survey of the Klimkówka water dam was carried out in September 2024 using a Leica ScanStation P40 terrestrial laser scanner. Reference spheres, target boards, and clearly identifiable points distributed across the entire structure were used to ensure orientation of the individual scans. In total, measurements were performed from 108 scan positions, selected to optimise field time and eliminate a substantial proportion of occluded (shadow) areas. The survey covered the entire dam, including the crest and the gallery, as well as adjacent facilities. The scanning resolution was adjusted to each scan position, with extreme values of 5 mm/10 m and 15 mm/145 m. The orientation process included the identification of reference spheres, target boards, and other unambiguously identifiable points that were used for this purpose. The process was performed in Leica Cyclone. The accuracy of combining the individual point clouds into a unified dataset was 0.005 m. After filtering, optimisation, and unification at a resolution of 0.001 m, the resulting point cloud (Fig. 5) was obtained for further analyses.

Source: www.geoportal.gov.pl

Fig. 4. Klimkówka Dam: a) top view, b) view of the dam



Source: Authors' own study

Fig. 5. Point cloud for the Klimkówka Dam: a) top view, b) side view

2.2. Generation of technical documentation

Based on the point clouds (Figs. 3, 5), the 2D documentation (Figs. 6, 7) was prepared in the MicroStation V8i environment using the available tools. The documentation includes cross-sections of the dams at characteristic locations and a plan view of the dam crest, as well as additional cross-sections. In the case of the Klimkówka Dam, the documentation also comprises gallery cross-sections at 10 m intervals and a longitudinal section of the inspection gallery together with the stairwell.

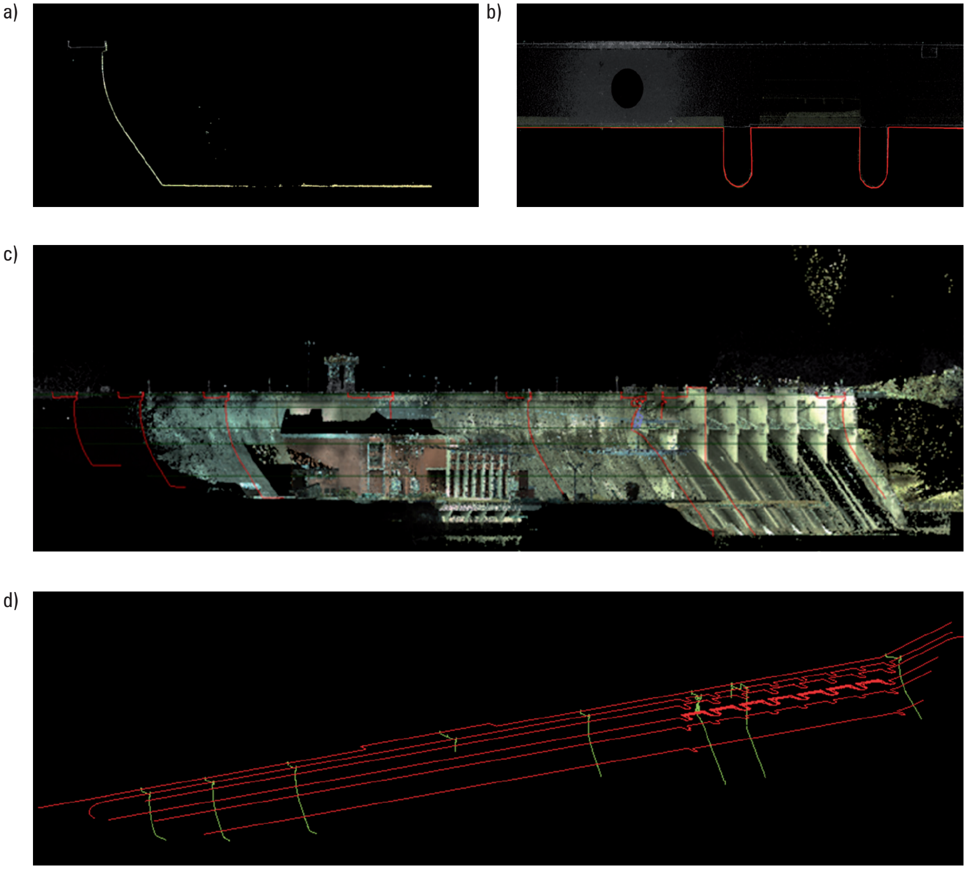


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Fig. 6. Generation of technical documentation based on the point cloud for the Rożnów Dam: a) longitudinal section, b) cross-section, c) location of the sections on the structure, d) generated sections

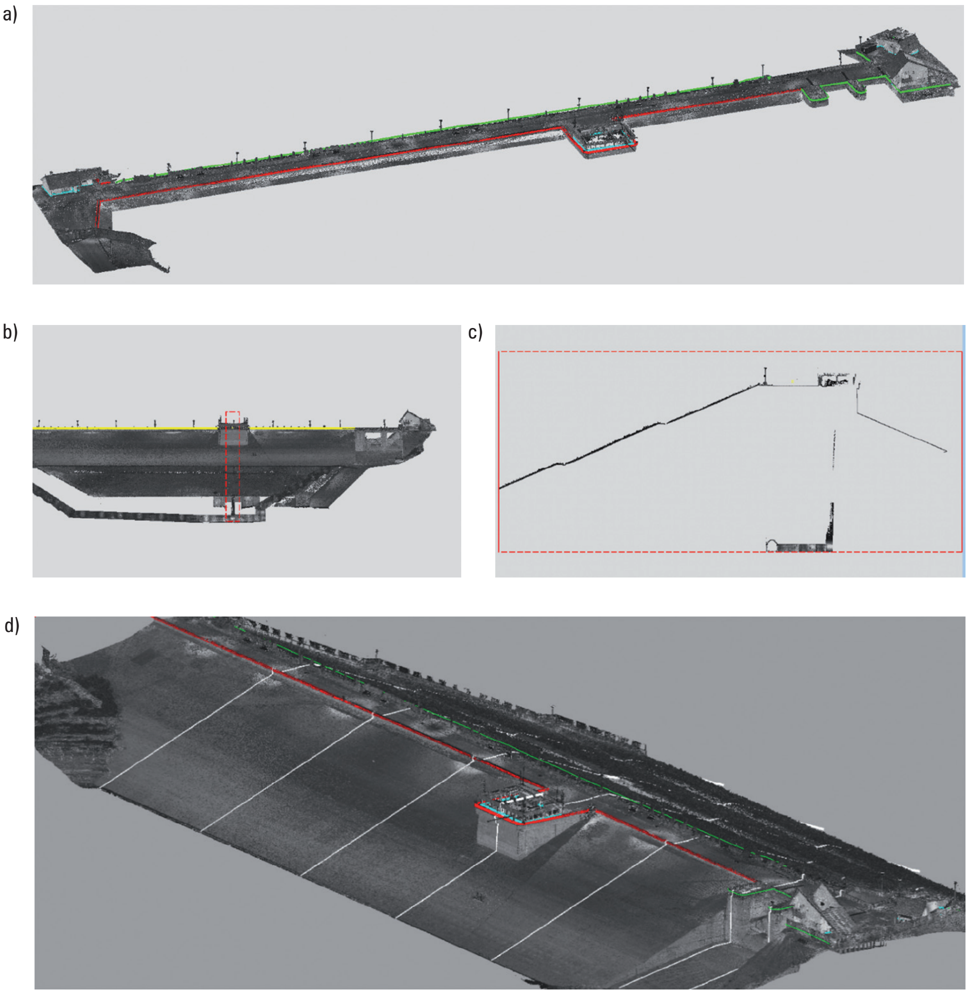

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Fig. 7. Generation of technical documentation based on the point cloud for the Klimkówka Dam: a) crest cross-section, b) location of the cross-section, c) sections of the structure, d) location of the sections in the point cloud

2.3. Surface-based analysis of dam structures using TLS data

The triangulated irregular network (TIN) meshes generated from the point clouds were used for two main analytical and modelling purposes. The first objective was to conduct a detailed assessment of the condition of concrete surface protection in selected areas, identifying local bulges, material losses, and lines of structural discontinuity. The scope of the analysis is consistent with ICOLD (International Commission on Large Dams) recommendations [ICOLD 2016, ICOLD 2001], which emphasise the importance of regular assessment of concrete dam surface condition, paying particular attention to cracks, fissures, and geometric deformations as key indicators of structural safety. The analysis was performed using a TIN model generated in a mesh mode, enabling precise representation of the object geometry while preserving the high resolution of the measurement data (Fig. 8). The adopted approach is consistent with ISO 17123 field procedures for evaluating the precision of terrestrial laser scanners used in civil engineering and surveying applications [ISO 17123-9:2018]. The mesh model was subjected to topological and geometric verification, corresponding to the ISO 19157 requirements for describing and reporting the quality and integrity of geographic (spatial) data [ISO 19157:2013].

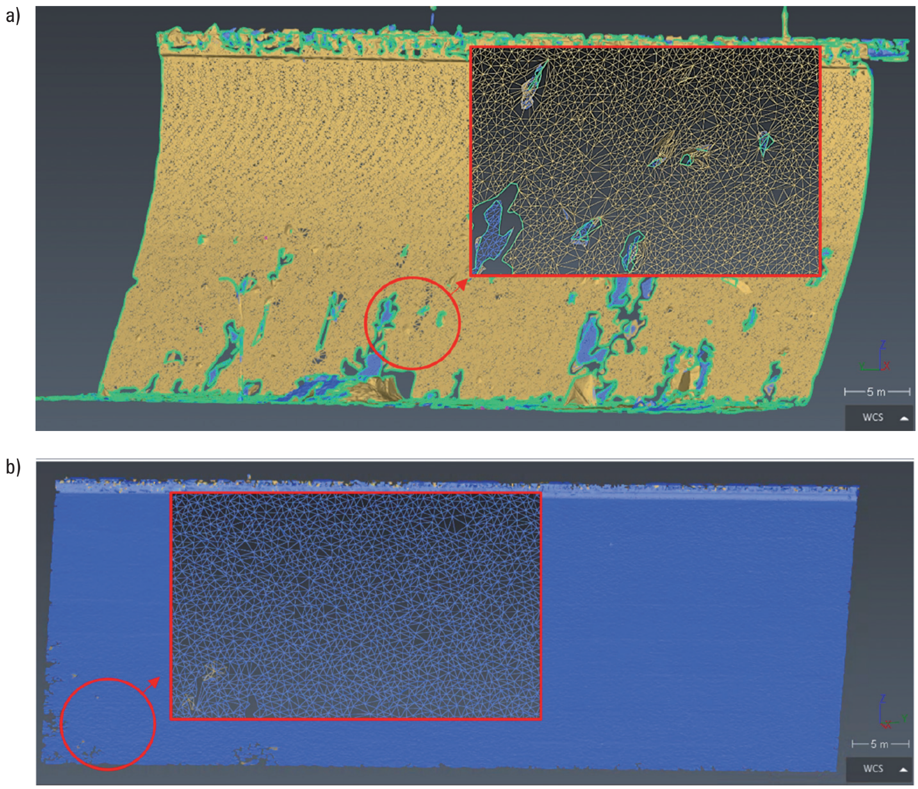

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Fig. 8. TIN mesh mode for the dam faces at: a) Rożnów, b) Klimkówka

The resulting model was exported to the .dxf format to enable integration with CAD-type software, where a detailed analysis of geometric variations of the dam's surface was performed. In this environment, it was possible to carry out height-difference measurements, analyse local surface slopes, and delineate zones with increased concentrations of deformation. This approach is consistent with Eurocode 0 [PN-EN 1990:2004], which emphasises the importance of monitoring structural geometry throughout the service life as part of the assessment of the serviceability limit state. Based on deformation analysis of the TIN mesh, lines of discontinuity and areas of local geometric disturbance were identified, indicating directly the technical condition of the concrete structure. For the Rożnów facility, numerous cracks and mesh-discontinuity lines were identified, primarily within the zone extending from the foundation up to approximately one-third of the dam-face height. The detected discontinuities may correspond to cracks or zones of weakened material. Their interpretation should be run with reference to Eurocode 2 [PN-EN 1992-1-1:2008] for concrete structures and to ICOLD documents for dam monitoring and diagnostics. The spatial distribution of these discontinuities (Fig. 9) supports inference regarding potential degradation mechanisms such as material fatigue, corrosion processes, cyclic hydrodynamic loading effects, or differential foundation settlement. In contrast, for the substantially younger structure at Klimkówka, the analyses revealed only local discontinuity lines that did not exceed 30 cm.

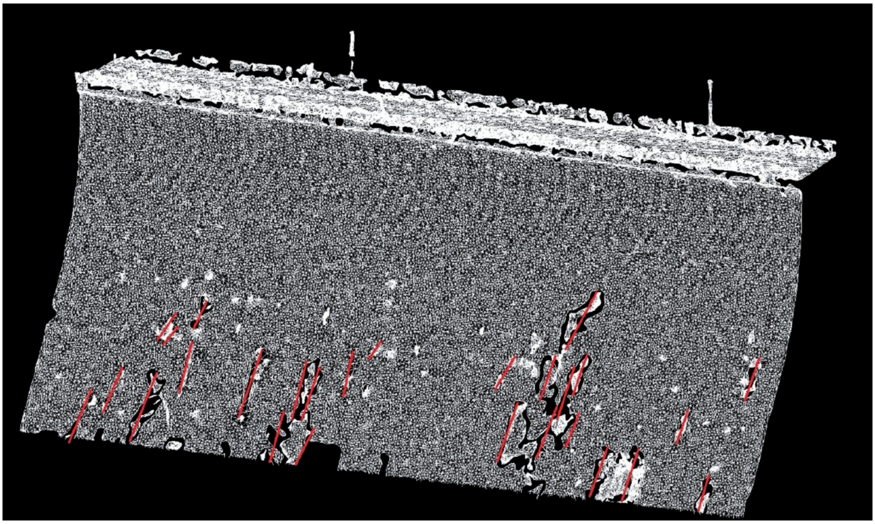

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Fig. 9. Analysis of geometric discontinuities of the Rożnów Dam

As indicated by the analysis shown in Figure 8, a set of parallel discontinuity lines was observed in the lower part of the investigated area, This suggests the action of a uniform external load acting over a prolonged period. Such a deformation pattern is consistent with the deformation mechanisms described in the literature and ICOLD documents, in particular those related to structural settlement or stress redistribution within the near-foundation zone of the dam. Regular, periodic TLS-based monitoring of the dam – consistent with ISO 18674 recommendations for geotechnical monitoring of displacements – would enable spatio-temporal analyses of surface deformation and early detection of adverse geometric change trends .

The second objective in generating the TIN mesh was to obtain a numerical model of a dam segment for further engineering analyses. For this purpose, a smooth-surface generation mode was employed to faithfully reconstruct the actual geometry of the structure (Fig. 10). The resulting 3D model meets the requirements for computational models used in numerical analyses in accordance with Eurocode 7 for geotechnical analyses and Eurocode 2 for concrete structures [PN-EN 1990:2004, PN-EN 1992-1-1:2008].

a)

b)

Source: Authors' own study

Fig. 10. Surface models for the dams: a) Rożnów, b) Klimkówka

Modelling water dams based on numerical data acquired through terrestrial laser scanning is widespread in hydraulic, geotechnical, and structural-mechanics research. In line with ICOLD recommendations and established engineering practice, generating a reliable three-dimensional geometric model enables numerical flow simulations and analyses of hydrostatic pressure distribution.

3. Result and discussion

As a result, high-quality two-dimensional technical documentation was produced for the Rożnów Dam (Fig. 11, locations of cross-sectional profiles and plan views according to the scheme in Fig. 6d) and for the Klimkówka Dam (Fig. 12). This documentation was subsequently used as input for further analyses.

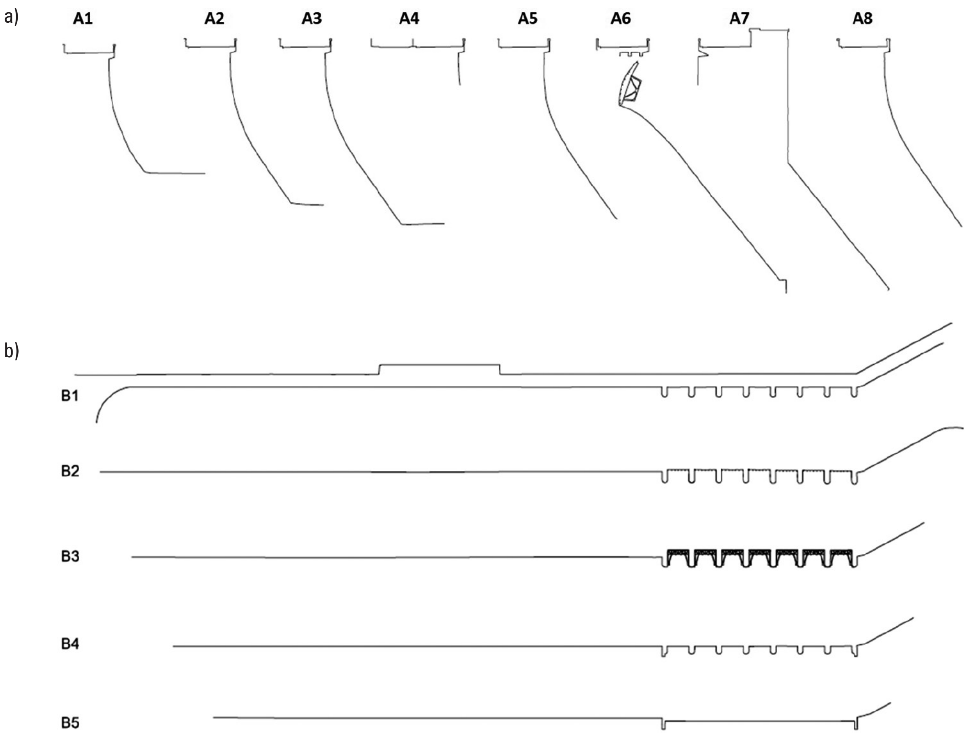

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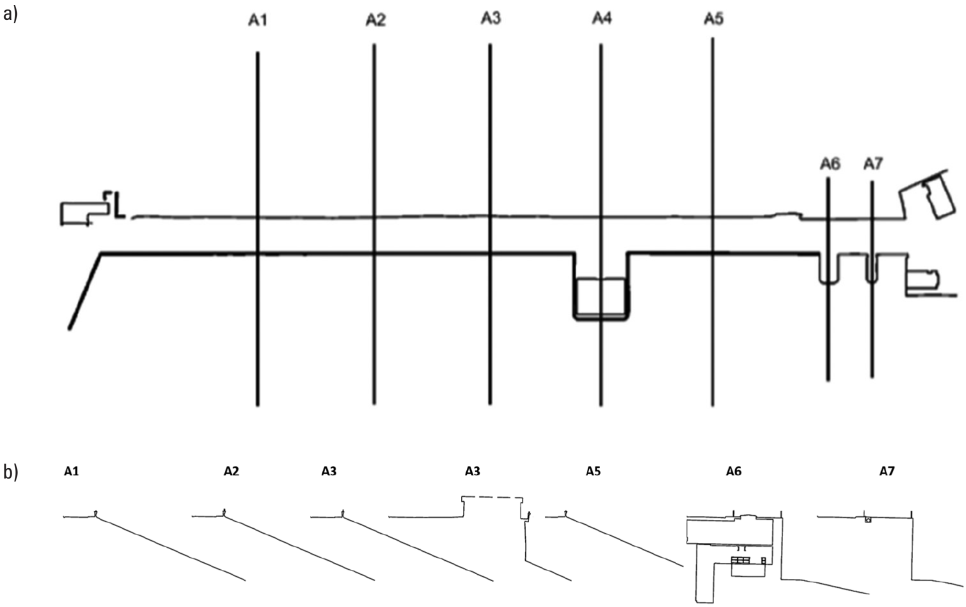
Fig. 11. Technical documentation for the Rożnów Dam (Fig. 6d): a) cross-sections, b) plans

As part of the documentation, a 3D model of the Rożnów Dam was developed (Fig. 13a), together with 3D models of its structural and technical components (Fig. 13b).

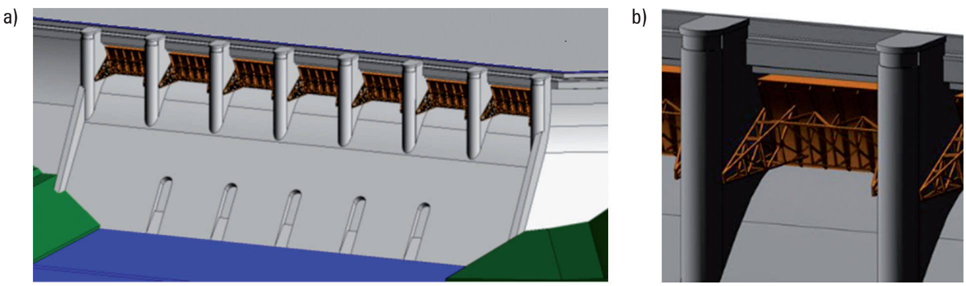
For the gallery of the Klimkówka Dam, an inventory survey of the gallery was conducted. As part of this work, information on the facility was acquired and the corresponding technical documentation was prepared (Fig. 14).

As a result of TLS data processing, a complete and internally consistent set of inventory and analytical outputs was produced, substantially extending the possibilities for assessing geometry and technical condition compared with point-based measurements. During the office stage, full 2D CAD documentation was prepared from the point clouds, including plans as well as transverse and longitudinal sections of the dams at characteristic locations. These deliverables enable an unambiguous reconstruction of the crest geometry, slopes/dam face, transition zones, and hydraulic components (including, among others, culverts, outlets, outlet towers, and structural breaks). In parallel, 3D models of the structures were generated at a resolution that allows additional sections and measurements to be extracted at any location without the need for repeating fieldwork. These procedures can be used both to update archival documentation and to prepare input datasets for engineering analyses (e.g., stability calculations, flow analyses, or numerical modelling).



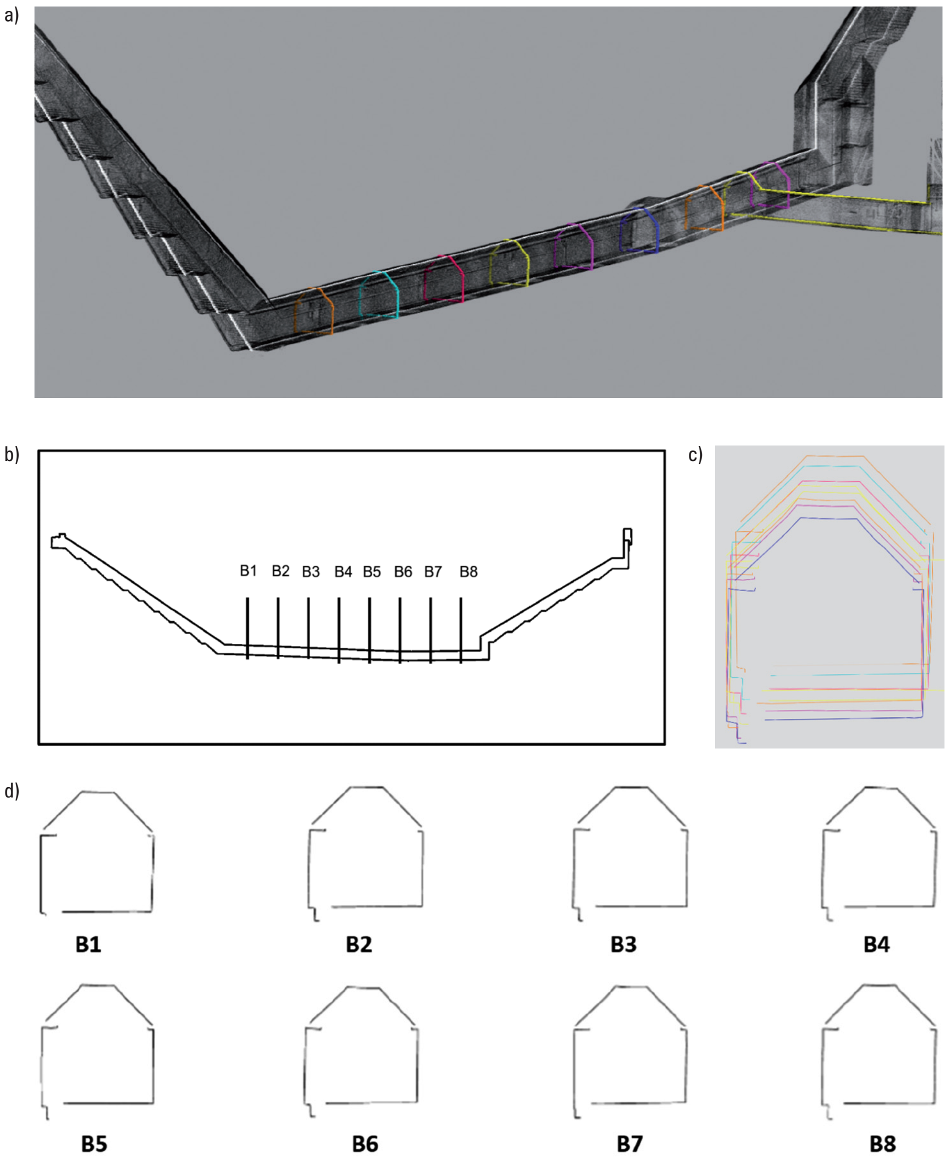
Source: Authors' own study

Fig. 12. Technical documentation for the Klimkówka Dam: a) crest plan with section locations, b) cross-sections



Source: Authors' own study

Fig. 13. 3D model of the dam: a) solid model of the structure, b) model of technical components



Source: Authors' own study

Fig. 14. Inventory of the Klimkówka Dam gallery: a) location of sections, b) section through the stairwell and passage with section locations, c) comparative analysis of sections for the passage, d) cross-sections

For concrete surfaces, TIN-based modelling was applied, enabling a shift from purely geometric description to surface-condition assessment. Based on triangulation continuity and local irregularities, zones of discontinuity and locations of potential material loss and/or deformation were identified. Their spatial distribution (both in elevation and in plan) makes it possible to inspect the most affected areas first, and to indicate locations requiring more detailed diagnostics. The full set of outputs – filtered and unified point clouds, 2D documentation, 3D models, and TIN models – constitutes a coherent reference package for subsequent temporal comparisons. In future measurement campaigns, it can serve as a baseline for differential analyses (e.g., displacement or loss maps), provided that a consistent reference frame is maintained and inter-epoch registration is performed under controlled conditions.

The results confirm that preparing geodetic documentation based on point clouds acquired from terrestrial laser scanning enables comprehensive inventory deliverables and geometric analyses of hydraulic structures. The recorded spatial data can be reused flexibly without the need for additional fieldwork, which substantially increases the efficiency of the documentation workflow and allows supplementary measurements, comparative analyses, and presentation of results at any stage of the study. As noted by Mitka [2007], the possibility of freely selecting parts of the structure for further analyses using a single, previously acquired point cloud is one of the key advantages of TLS in documentation and modelling of geometrically complex objects. High-resolution three-dimensional point-cloud data constitute a key source of geometric information in the inventorying and analysis of engineering structures. Remote-sensing studies indicate that detailed 3D models enable faithful representation of structural geometry and the identification of discontinuities, deformations, and local geometric anomalies. Surface-based visualisation derived from point-cloud analysis guarantees continuity and integrity of the structure to be assessed in a way that is not achievable with classical point-based methods, which provide information only at selected locations. The quality and resolution of 3D data directly affect the reliability of the analyses, and point clouds form the foundation of modern systems for documentation, monitoring, and asset management of engineering and hydraulic structures [Dewedar et al. 2024].

Processing point clouds using surface-based approach for dam inventory analysis enables the spatial visualisation of structural deformation and the identification of affected areas. The obtained distributions of geometric change are consistent with the expected structural response resulting from the dam's static behaviour and variable operating conditions, particularly fluctuations in reservoir's water level. Such results provide an important complement to classical dam-monitoring methods, which deliver information only at discrete control points, whereas TLS enables a quasi-continuous assessment of the behaviour of the entire surface of the structure [Alba et al., 2006]. Similar conclusions have been reported in studies based on multi-temporal point-cloud comparisons, which demonstrated the effectiveness of TLS analysis in detecting displacement changes and assessing the behaviour of arch dams during operation [Li et al. 2021].

The use of terrestrial laser scanning for dam inventorying should also be considered in terms of its practical benefits, such as high accuracy, high data density, and rapid acquisition of spatial information. This technology is particularly useful where access to the structure is limited or hazardous, which is crucial for large hydraulic facilities and for structures with deteriorated technical condition [Dorobek et al. 2018]. The non-invasive nature of TLS measurements, which do not require any interference with the structure, is an additional advantage for hard-to-reach components or elements subject to operational restrictions [Jesionek 2011]. Terrestrial laser scanning has become a well-established measurement method that complements photogrammetry and classical surveying techniques. It enables the production of vector drawings, numerical models of structures, assessment of technical condition, and support for managing a hydraulic facility and its surroundings. This confirms the rationale for its application in modern dam inventory and monitoring systems.

4. Conclusions

Using terrestrial laser scanning (TLS) to survey water dams, such as the facilities at Rożnów and Klimkówka, enables the development of a coherent and complete high-detail geometric documentation package, including both 2D technical drawings and full 3D models of the structures. The point clouds acquired from TLS surveys form a unified spatial dataset that accurately represents the dam bodies, the gallery (in the case of Klimkówka), the associated components, and their spatial relationships with the surrounding environment. The resulting 3D models and visualisations enable analysis of shape, dimensions, and structural continuity in a way that is not possible with traditional point-based methods. This is particularly important for large and geometrically complex hydraulic structures.

Processing point clouds based on their surfaces enables the assessment of geometric coherence and the identification of local shape changes, discontinuities, and potential areas of concern that may be relevant to the operational safety of dams. Geometric models derived from TLS provide a basis for the assessment of technical condition, verification of the actual geometry against archival documentation, and multi-temporal comparisons that support tracking of changes during operation. This approach facilitates comprehensive inventorying by integrating geometric, visual, and descriptive information within a single, consistent data environment.

Analysis of the outputs for the Rożnów and Klimkówka dams confirms that TLS is an effective tool supporting documentation, diagnostics, and control activities for hydraulic structures. The ability to reuse a single dataset to generate drawings, sections, visualisations, and spatial analyses streamlines inventory work and enhances its informational value. These 3D models and their derived products could be an important component of dam management systems, supporting assessment of technical condition, maintenance planning, and long-term monitoring of structural continuity and integrity.

References

Alba M., Fregonese L., Prandi F., Scaioni M., Valgoi P. 2006. Structural monitoring of a large dam by terrestrial laser scanning. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci., 36(5).

Dewedar A.K.H., Palumbo D., Pepe M. 2024. Hydraulic risk assessment on historic masonry bridges using hydraulic open-source software and geomatics techniques: a case study of the 'Hannibal Bridge', Italy. Remote Sens., 16, 2994. https://doi.org/10.3390/rs16162994

Dorobek K., Szostak B., Królikowski W. 2018. Metody inwentaryzacji obiektów znajdujących się w stanie ruiny. Ochrona Dziedzictwa Kulturowego, 1–12.

Fiedler W.R. 2016. Managing dam safety risks related to hydraulic structures. Proceedings of the 6th International Symposium on Hydraulic Structures: Hydraulic Structures and Water System Management, Portland, OR, USA, 27–30 June 2016. https://doi.org/10.15142/T3720628160853.

Gawronek P., Makuch M., Mitka B., Bożek P., Klapa P. 2017. 3D scanning of the historical underground of Benedictine abbey in Tyniec (Poland). 17th International Multidisciplinary Scientific GeoConference SGEM2017, Issue 22: Geodesy and Mine Surveying. International Multidisciplinary Scientific GeoConference & EXPO SGEM, Sofia. https://doi.org/10.5593/SGEM2017/22/S09.001.

GOKROPA ‑ Zbiornik Wodny Klimkówka: https://gokropa.iaw.pl/pl/3385/0/zbiornik-wodny-klimkowka.html [accessed: 2.01.2026].

International Commission on Large Dams (ICOLD). 2001. Geodetic monitoring of dams and structural deformations. Bulletin 121. ICOLD Paris.

International Commission on Large Dams (ICOLD). 2016. Dam surveillance guide. Bulletin 154. ICOLD Paris.

International Organization for Standardization. 2013. ISO 19157:2013. Geographic information – Data quality. ISO Geneva.

International Organization for Standardization. 2018. ISO 17123-9:2018. Optics and optical instruments – Field procedures for testing geodetic and surveying instruments – Part 9: Terrestrial laser scanners. ISO Geneva.

Jesionek I. 2011. Przykłady naziemnych skanerów laserowych. Acta Scientifica Academiae Ostroviensis, 35–36.

Kozlov D., Yurchenko A. 2020. The role of inspection of hydraulic structures in the assessment of their technical condition. IOP Conf. Ser., Mater. Sci. Eng., 883(1), 012049. https://doi.org/10.1088/1757-899X/883/1/012049

Li Y., Liu P., Li H., Huang F. 2021. A comparison method for 3D laser point clouds in displacement change detection for arch dams. ISPRS Int. J. Geo-Inf., 10, 184. https://doi.org/10.3390/ijgi10030184.

Mitka B. 2007. Możliwości zastosowania naziemnych skanerów laserowych w procesie dokumentacji i modelowania obiektów zabytkowych. Archiwum Fotogrametrii, Kartografii i Teledetekcji, 17b.

Polski Komitet Normalizacyjny. 2004. PN-EN 1990:2004. Eurokod 0: Podstawy projektowania konstrukcji. PKN Warszawa.

Polski Komitet Normalizacyjny. 2008. PN-EN 1992-1-1:2008. Eurokod 2: Projektowanie konstrukcji z betonu. Część 1-1: Reguły ogólne i reguły dla budynków. PKN Warszawa.

Rozporządzenie Ministra Środowiska z dnia 20 kwietnia 2007 r. w sprawie warunków technicznych, jakim powinny odpowiadać budowle hydrotechniczne i ich usytuowanie (Dz.U. 2007 nr 86 poz. 579).

Speckhann G.A., Kreibich H., Merz B. 2021. Inventory of dams in Germany. Earth Syst. Sci. Data, 13(3), 731–740. https://doi.org/10.5194/essd-13-731-2021

Tauron. Elektrownia wodna Rożnów. https://ekoenergia.tauron.pl/elektrownie/energia-wodna/ew-krakow/roznow [accessed: 2.01.2026].

Zaczek-Peplińska J., Adamek A., Osińska-Skotak K., Adamek A. 2014. Inwentaryzacja galerii kontrolnej i przelewu zapory ziemnej Klimkówka metodą skanowania laserowego. Archiwum Fotogrametrii, Kartografii i Teledetekcji, 5–6.

Zaczek-Peplińska J., Kowalska M. 2022. Application of non-contact geodetic measurement techniques in dam monitoring. Arch. Civ. Eng., 68(3), 49–70. https://doi.org/10.24425/ace.2022.141873.

Zaczek-Peplińska J., Popielski P. 2007. Możliwości wykorzystania modelowania MES w trakcie geodezyjnych pomiarów kontrolnych budowli piętrzących – model numeryczny dla zapory Besko. Nowoczesne Budownictwo Inżynieryjne, listopad–grudzień 2007.