Analysis of Possibilities to Utilise Results of Laser Scanning in Technical Inspection of Water Dams

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SUMMARY

Technology of terrestrial laser scanning, which has been dynamically developed, offer new tools, i.e. scanning tacheometers and laser scanners. Using those instruments, periodical control surveys of concrete dams, performed within the geodetic monitoring, enable to obtain quasi-continuous point models. Basing on results of those surveys a series of geometrical analyses may be performed, as well as information useful for detailed analytical-and-computational considerations, may be acquired.

Similarly to a tacheometer, specifying distances and angles, a scanner determines spatial co-ordinates (X, Y, Z) of surveyed points. Registration of the value of intensity of a reflected laser beam, emitted by the scanner, which is called "the 4th co-ordinate", carries new information about the surveyed object. Accuracy of surveys performed by the scanner are at the same level as conventional surveying observations. Due to the high speed of operations and the great number of acquired data, scanners became useful tools in surveyors' work.

The paper presents evaluation of the possibilities to utilise terrestrial laser scanning for investigation of deformations of surfaces and displacements of marked point of construction of a concrete water dam, basing on performed experimental surveys, including:

- utilisation of data acquired from scanning for creating and updating data of geometric models of behaviour of structures under variable loads,
- investigations of occurrence of relations between variations in water level in a reservoir and variations in the structure geometry – using the terrestrial laser scanning technology.

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1. INTRODUCTION

In assessing the safety of hydraulic engineering, combining different measurement techniques, computational and experience of specialists in various fields of engineering is necessary. Development of measurement technologies provides increasing opportunities for more accurate monitoring of changes in structural engineering, as well as speed up the work of measuring, minimize gross errors and reduce costs and time of measuring. As a result, it provides more reliable assessment of technical condition and safety of hydraulic engineering. Integration of measurements, the inclusion of numerical modeling to evaluate the behaviour of the object and the assessment of technical condition qualitatively different data, allow to assess objects more comprehensively, and thus more fully, and gives the picture, which is more clear and transparent.

Location and characteristics of the tested object

- Location: on 172.8 km of Wisłok river in Sieniawa, in Podkarpackie Province (Poland)
- The dam was provided for use in 1978
- Length: 174 m
- Maximum height: 38.2 m
- Volume of a concrete used for construction: about 70 000 m3
- 14 independent, expansion-jointed concrete sections: 12 deaf sections with a width of 12m, 2 overflow sections with a width of 15 m
- Creager’s type of a surface overflow - two overflows of 11.20 max 2.60m sections hatches closed with a height of 2.60 m controlled by a hydraulic drive

Fig. 1. Location and view of Besko dam.

2. TERRESTRIAL LASER SCANNING

Difficult terrain, that is usually associated with the location of dams, determine the selection of specialist equipment and relevant geodetic measurement techniques. Surveying instruments, which are used to perform periodical control surveys should be characterized by a high precision and accuracy of the results. Another advantage of modern measuring equipment is the possibility of execution of a large number of observations in the shortest time and simple operation, thus reducing the size of measuring unit. The proximity of the aquatic environment causes a local climatic micro-conditions, which are not always favourable to the execution of observation with the expected accuracy. Geodetic measurement instruments that can meet these high expectations (high density of observed points, accuracy, speed, economy), are undoubtedly terrestrial laser scanners. Using these instruments allows to create quasi-continuous point models of monitoring dams. On the basis of such models, number of geometric analysis can be performed and detailed information for analytical and computational considerations can also be obtained.

The scanner like tacheometer, specifying distances and angles determines the spatial coordinates (X, Y, Z) of measured points. Intensity values of reflecting laser beam recorded by the scanner, called "the 4th coordinate", and the data contained in this component provides additional information about the measured object (the ability to isolate the types of scanned materials, to detect leakages in the design, selection of information on the scanned object in a specific reflection defined by user, etc.).

Scanners can be divided into phase and pulse . This division is closely connected with the range of measurement: phase solutions are destined for close distances (currently to 200 m), whereas the pulse scanners enable measurements of objects located further away from the measuring position (even up to several kilometers). Depending on the measured distance, scanners are distinguished on: short, medium and long range. This implies another characteristic, i.e. accuracy of measurement. These values, depending on the mode of implementation of distance measurement (phase or pulse) and the type and model of the instrument, are in the range from single millimeters to several centimeters. There remains a number of "standard" factors that significantly affect the final level and the accuracy of results including: weather conditions, the accuracy in determination of tie points of single scan, the accuracy of references to external coordinate system, etc.

With its high speed (the latest model of phase scanners measure with the speed of one million points per second) and large amount of collected data, scanners have become an indispensable tool in the work of surveyors. To maintain the high measurement precision is still necessary to use conventional measurement methods, which guarantee the submillimetre accuracy of the tasks of surveying. Latest tacheometers for industrial applications perform angle measurement with RMSE of 0.5 seconds. They are unable to provide such coverage of object with the data, as presented in this article laser scanning technology. The possibilities of using terrestrial laser scanning to study the surface deformation and displacement of identified points of a concrete dam structures are very large. The evaluation of suitability was based on experimental measurements of the Besko dam performed in 2009 and 2010. Measurement was carried out with Leica ScanStation2 and Riegl VZ-400 scanner.

a) b)

Fig. 2. Measurements of Besko dam.
a) Leica Scanstation 2 scanner during the measurements – first epoch
b) Riegl VZ-400 during second scanning epoch

The main spur for the implementation of scanning is the need for technical control of facilities. The described example shows the extensive possibilities of using laser scanner technology to predicting phenomenons occurring on the technical facilities and appropriate counteract to them in order to avoid dangerous situations such as construction disaster.

The main advantage of scanning is undoubtedly surface coverage of object with measurement data - millions of points are measured, not a group of few or several points stabilized on the dam . It follows that many opportunities for the practical use of observations, including:

– inventory of object - on the various stages of implementation (comparison executed elements with project), as-built inventory, inventory after repair, periodic measurements during the operation,

– creating and updating the geometric data for modeling the behaviour of hydraulic objects under the influence of variable loads (numerical modeling),

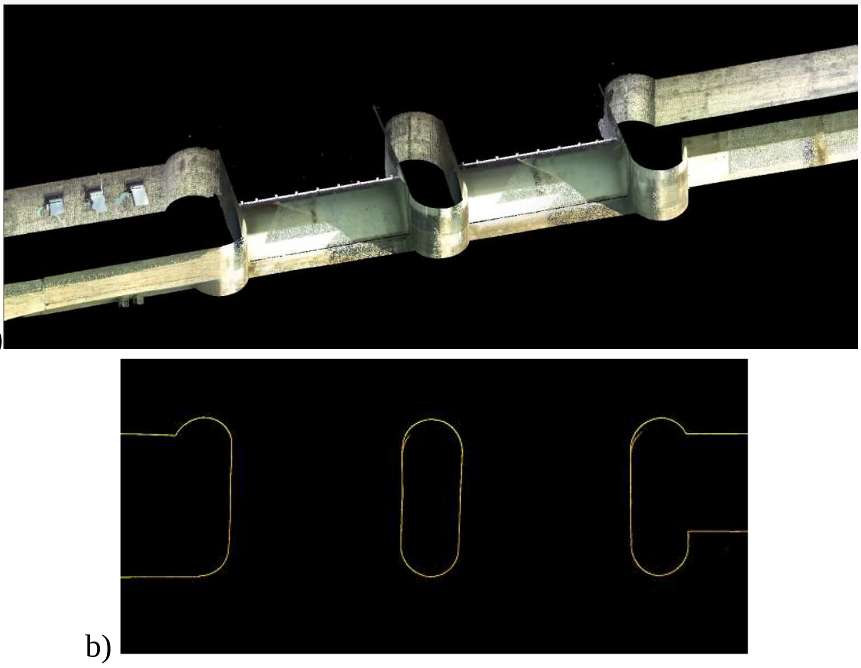
– verification the occurrence of relationships between changes of water level in the tank, and changes in the geometry of the structure,

– assessment of technical condition of the object.

Fig. 3. Results of dam scanning from the windy side.

3. THE USE OF LASER SCANNING DATA AS A SOURCE OF GEOMETRIC DATA IN NUMERICAL MODELING IN HYDROTECHNIQUE

Numerical modeling can concern large areas, e.g. changes in water as a result of the mounting up in the area of the valley where the object is located or locally selected structural elements such as overflow section. In both cases it is necessary to obtain the geometry of the area - digital terrain model or geometry of the structure. Of course, depending on the scope of the model and analyzed phenomenon, a different accuracy of obtained data and a different range of additional information is required. To acquire data, different bands of satellite images, aerial and terrestrial laser scanning could be used (Fig.3). The data can be utilized for different purposes. Starting from the classification of coverage, until generating digital terrain models with a certain accuracy and vertical and horizontal resolution.



a)

b)

Fig. 4. Results of measurements of Besko dam. a) model of dam's external surfaces,
b) horizontal section of the object (above the overflow below the bridge plate on the crown of the dam) obtained from laser scanning.

During the control of the technical condition of earthen and concrete hydraulic structures a visual overview of the structure is very important. Already at this stage of the verification some irregularities are noticeable, to which attention should be paid during the measurements. Observations should include the phenomenon describing the behaviour of the object, surface and the external factors that affect the buildings. The appropriate solution is to scan the selected area. Concrete mounting up structures should be checked for changes of concrete surface condition, excessive leakage and deformation. Any changes noted during the inspection should be documented, e.g. by photographs, so that these changes can be evaluated during the next inspection. Water relief devices whose proper functioning is necessary during the swelling can also be analyzed. When modifying overflow devices, e.g. owing to changes in the nature of the swelling, it is recommended to create spatial models of flow through the facility. In this case another local accuracy of obtained data is needed than in area model. More accurate measurements should concern area of concrete overflow structures (Fig. 5) and elements to disperse energy of flowing water. By analogy to the preparation of the mesh elements (2D model) or volume (in case of 3D model), the geometry of the model should be dense in the region of concentration of the analyzed phenomenon.

Fig. 5. Results of measurements of Besko dam – model of the dam in the area of overflow.

Spatial model of the dam resulting from scanning can be used to verify the compliance of results of numerical modeling of object's work. Model verification based on geodetic measurements, with a discrete nature (measurement of only selected controlled points), is limited by the small number of measuring points on the object, because these points are located in areas where the greatest displacement values are predicted (Fig. 6). Sometimes the numerical models show the greatest displacements between located targets. Point cloud can enable verification of compliance of whole building without the need for measuring additional points as targets. Difference in the displacements, when changing loads, measured geodetic methods (e.g. change the upper water level), acting on an object, allows the execution of backward analysis and verification of material parameters used for calculations. In addition, the measurements can contribute to determine the correlation between mounting up heights, temperature, and rheological changes.

4. GEODETIC MEASUREMENTS OF DISPLACEMENTS AND LASER SCANNING

Buildings and their components as a result of external and internal factors, are subject to change geometrical and structural, that is, displacements and deformations. Displacements are next to the phenomena of filtration basic information which is analyzed and taken into account in the process of interpretation and evaluation of technical condition of hydraulic engineering facilities. During construction and operation of mounting up structures, they undergo deformation and displacements, as well as the escarpments, slope of valleys, the bottom of tanks and area at the tanks.

The possibility of using recorded changes of dam geometry and the environment in different phases of construction allows to efficiently generate the digital model as a basis for further analysis of the object. In the initial phase, during building an object, the main factors influencing the deformation are steadily increasing weight of the structures and processes of concrete bond. In the next phase after completion of construction and first filling of a reservoir, the influence of pressure associated with the mounting up of water in the tank is observed. Knowledge of such large number of displacements in the scanned points allows the confrontation real deformation with the forecast for the whole building, not only in places where checkpoints are located (Fig. 5).

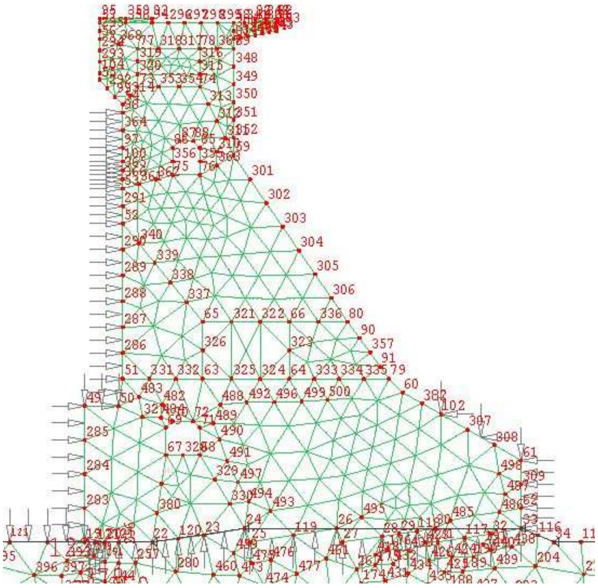


Fig. 6. Digital model of Besko dam sections

Current technology of processing laser scan data does not require stabilization control points on the object. However, the occurrence of these points on the scans allows the increasing or maintaining (depending on the object) the nominal accuracy of technology through its unique identification. With the ability to very precisely determining the location of target points, such as signs of the manufacturer, it is possible to accurately bond and mutually align multiple measurement positions of the scanner. Companies manufactured such target boards (round checkers rotating in both planes), which enable to determine their centers with a very high accuracy regardless of the "twist" their plane to the direction of the scanner measurement (Fig. 7).

Laser scanning is still evolving technology. Measuring ranges are constantly increased by "holding" current accuracy. Global manufacturers are pursuing to construct number of instruments as fast as the current phase scanners (observation of a million points per second) with the possibility of distant measurements (from a few hundred meters to several kilometers), that can be performed using pulse scanners. Also several scientific studies are conducted, which aim is to create and generate such a range of laser wavelength, which successfully will "reflect" from the various currently hard "measurable" surfaces, i.e. the dark surface, pure ice, etc. The appearance of even better, faster and more accurate scanners could be expected soon. Scanning results can serve as a documentation of technical measures implemented at the facility. Construction law obliges users to keep the documentation of buildings and the creation of object databases. Points obtained from scanning have sufficient accuracy for inventory work. Comparison between the results and the project can point on large areas of concrete structures places inaccurately realized.

Fig 7. View of Leica's target which guarantee high precision of determining its center on the scan.

5. PROCESSING DATA

Sets of points obtained during the scanning can be freely processed using appropriate software in order to gain a the most important engineering information about the scanned object. It is possible to work with point clouds by using popular software such as CAD and GIS and specialist programs. On this basis, it can be effectively and conveniently for the user to prepare the geometry of advanced digital models, architectural models, the results of inventory, visual processing for popularizing the region and others.

Knowing the exact coordinates of each recorded point, there is no obstacle to analyze the size of recorded displacements of characteristic points, edges and deformation of the concrete structure at any spatial direction. The specific deformation of the dam body such as deflection from the vertical, arises from changes in mounting up of water in reservoir. Vertical displacements caused primarily by self-weight structures, rheological phenomena in the structure and the ground and filter events (buoyancy). Laser scanning allows not only to determine but also represent the deformation of the body in different cross-sections and at different moments of time (when a model of object is available).

Software gives the ability to isolate individual elements of the building and subjecting them to analysis. Measurement can be subjected to a selected portion of the object in terms of deformation and depth of cracks. Then, having properly prepared geometry of object, digital model could be generated to determine the cause and time of their occurrence.

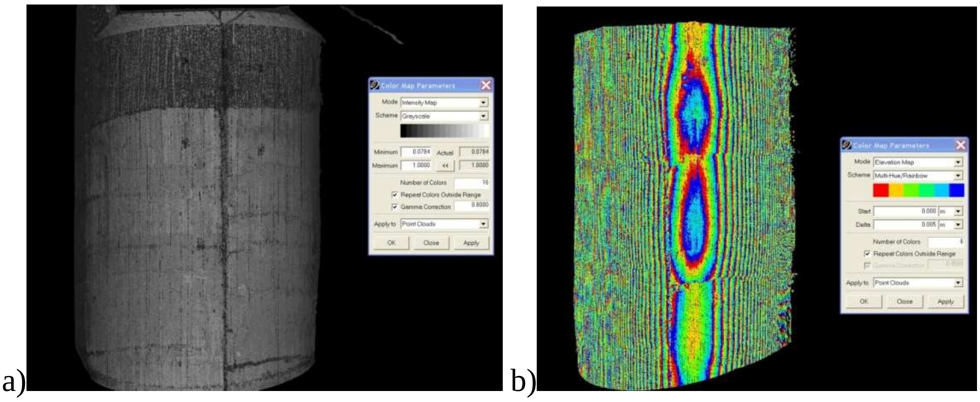


Fig. 8. Analysis of the element geometry - pillar. a) pillar model is made based on scan results b) fitting model of pillar in cylinder - visualization of differences between compared surfaces.

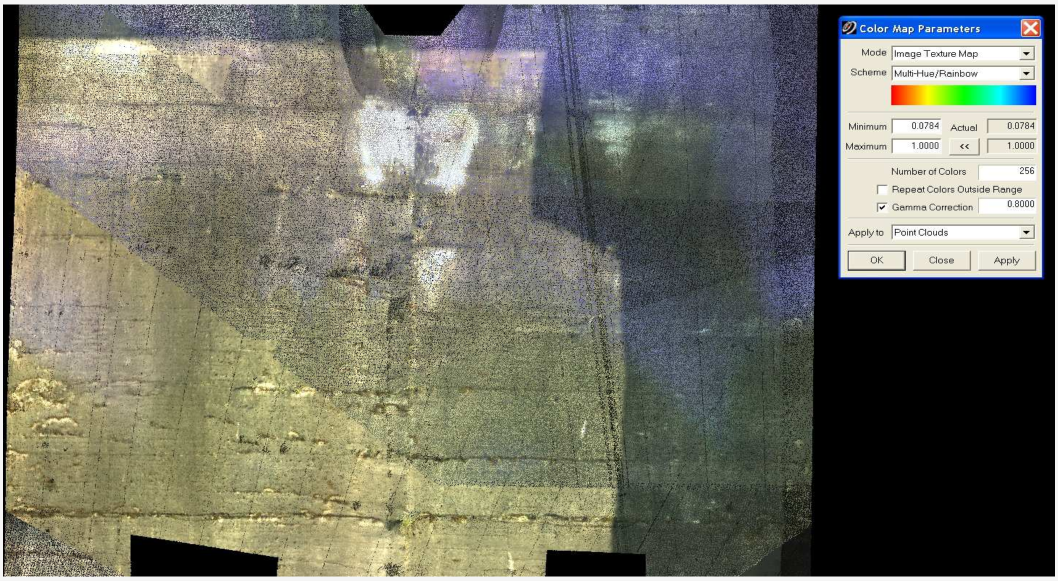


Fig. 9. Analysis of dam elements.

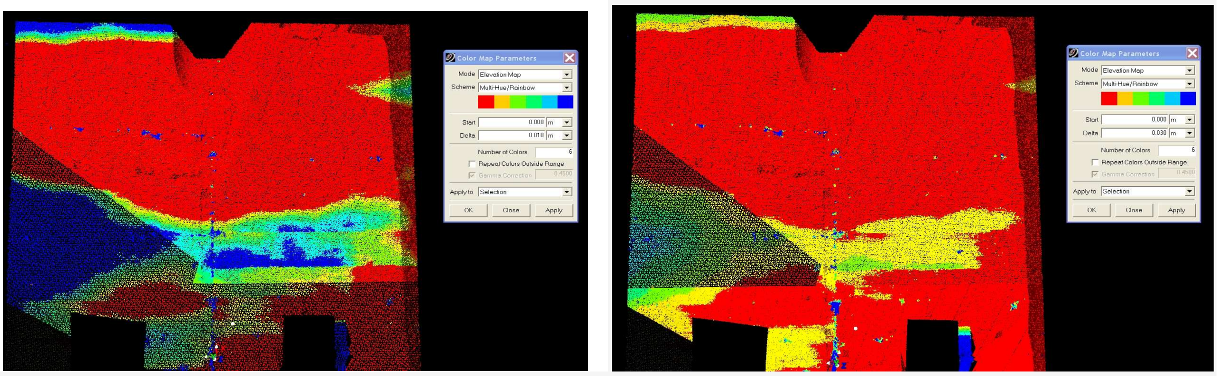


Fig. 10. Analysis of the dam elements – surface comparison.

6. CONCLUSION

Research with scanners are already carried out in the country at various hydrotechnical facilities. But today, scanning technology is still only a supplement the conventional and photogrammetric methods of measurement, not the main way of surveying tasks, resulting from technical control of the dams. There is a need for further research and development of this technology in this direction.
The specific character of hydrotechnical facilities is a need for specific patterns and develop its own methods of measurement using laser technology.
Laser scanners in addition to geometrical quantities have the ability to register returning reflection impulse emitted by the scanner. On the basis of this ability it is able to assess the moisture of outer content layers of concrete using laser scanning. The intensity of the reflection could also provide information about the parameters of materials, for example, the strength properties of concrete, the moisture of the surface elements, etc. Research on the potential use of laser scanning results for evaluation technical condition of concrete are carried out by researchers of the Warsaw University of Technology (Faculty of Geodesy and Cartography - Department of Engineering Geodesy and Detailed Measurements, Faculty of Environmental Engineering – Department of Hydraulic Engineering and Hydraulics).

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