Revista Brasileira de Cartografia (2014) Nº 66/7 - International Issue: 1505-1515
Sociedade Brasileira de Cartografia, Geodésia, Fotogrametria e Sensoriamento Remoto
ISSN: 1808-0936

POTENTIAL EVALUATION OF THE TERRESTRIAL LASER SCANNER IN STRUCTURAL MONITORING: CASE STUDY MAUA HPP

Avaliação da Potencialidade do Laser Scanner Terrestre no Monitoramento de Estruturas: Estudo de Caso UHEMaua

Igor Ribeiro Lenartovicz[1], Luís Augusto Koenig Veiga[1], Pedro Luiz Faggion[1], Carlos Aurélio Nadal1 & Marcos Alberto Soares2

[1]Universidade Federal of Paraná – UFPR
Depto. Geomática
Po.Box 19001, 81.531-990 - Curitiba, Paraná, Brazil
igor_len@hotmail.com; faggion@ufpr.br; knveiga@gmail.br;
cnadal@ufpr.br

[2]Copel Geração e Transmissão S/A
– Curitiba – Paraná - Brazil
marcos.asores@copel.com

Recebido em 21 de Novembro, 2014/ Aceito em 10 de Dezembro, 2014
Received on November 21, 2014/ Accepted on December 10, 2014

ABSTRACT

With the purpose of evaluating the potential of using a terrestrial laser scanner in the monitoring of dams, with case study in the Power Plant Maua located in the Tibagi River, on the border between the cities of Ortigueira and TelêmacoBorba, scans were performed in the field in two different times, before and after the formation of its reservoir. The laser point clouds were integrated with data from a survey of robotic total station, in the Cyclone software, to refer all results to the same local topographic system. All data were processed using two different software that allow the detection of displacements by comparing the scan, 3DReshaper and CloudCompare. Some comparison procedures were performed: between the scans performed from equal installation points in different periods, between the scans performed from a point and the dam's overall structure scans, and between the scans of the overall structure in the different periods. The results show a large dependence of the calculation with the meshing process, but in areas of highest density of points, we observed a higher precision of the mesh and a better definition of displacements.

Keywords: Terrestrial Laser Scanner, Dam, Monitoring Structures, Geodesic Surveys.

RESUMO

Com o objetivo de avaliar a potencialidade da utilização de medições realizadas empregando-se Laser Scanner Terrestre no monitoramento de estruturas, realizou-se o monitoramento de uma face a jusante da barragem da UHE de Maua (entre os municípios de Ortigueira e Telêmaco Borba no Paraná) em duas épocas distintas, antes e depois da formação do reservatório. As nuvens de pontos foram integradas aos dados de monitoramento obtidos por técnicas de irradiação tridimensional, para referenciar todos os resultados a um mesmo sistema de referência empregado no monitoramento por técnicas tradicionais. Todos os dados foram processados utilizando dois diferentes softwares que permitem a detecção de deslocamentos pela comparação entre os escaneamentos. Foram efetuadas três comparações: dados obtidos a partir de um único ponto de instalação do laser scanner em duas épocas (mesmo ponto ocupado nas duas campanhas);Os resultados mostram uma dependência da posição do equipamento, quanto mais ortogonal a estrutura melhores os resultados obtidos.

Palavras-chave: Laser Scanner Terrestre, Barragem, Monitoramento de Estruturas, Levantamentos Geodésicos.

1. INTRODUCTION

Geodetic monitoring of large structures is important due to factors such as potential aggregate risk of such works, knowledge of the behavior of the structure over time, and the ability to provide information to designers to adapt and change future projects and, in conjunction with other monitoring techniques, support decision-making in cases where the safety of the structure is compromised.

Currently different methods are applied in monitoring structures, one being a geodetic method that uses survey techniques such as triangulation, trilateration, and satellite positioning, performed with the use of specific instruments. Thus, evaluation of new measurement instruments is needed to update the methods in order to reduce costs and execution time while increasing the accuracy of the data generated by the surveys.

The current possibility of surveying and three-dimensional representation of structures through data from terrestrial laser scanners (TLS) opens a new field for research applied to structure monitoring. It is a system used for determining three-dimensional coordinates of points on a surface in addition to the possibility of capturing data with or without the target, and to allow scanning of thousands of points for a short survey time.

This study aims to evaluate the use of a terrestrial laser scanner for monitoring structures, by comparing two surveys carried out at different times at the Maua hydroelectric dam to evaluate the capability of the system to detect displacement. For this analysis, methods will be applied that allow assessment of certain regions of the dam and also the structure as a whole, not using point-to-point methods as done with traditional techniques.

2. TERRESTRIAL LASER SCANNER SYSTEM

The laser scanner is a system used to determine three-dimensional coordinates of points on a surface. Its operation is based on the generation of laser pulses that are emitted in the direction of objects. These pulses are directed to the environment with the aid of a mirror or prism, and also a motor that generates a horizontal rotation (azimuth) about the vertical axis of the instrument, as seen in Figure 1. Upon reaching the object, pulses are reflected and some energy comes back toward the system. With these data points, the system determines the distance between the sensor and the object by measuring the time elapsed from emission to the return of the pulse (DALMOLIN and SANTOS, 2004; SHAN and TOTH, et al. 2008).

According to Brandalize (2002, apud DALMOLIN; SANTOS, 2004), a laser scanner system consists of the following key components: pulse generator; optics for pulse transmission and reception; and signal detector.

2.1 Distance measuring

All operations for laser measuring, profiling and scanning are based on the use of some type of instrument to measure laser distance. The

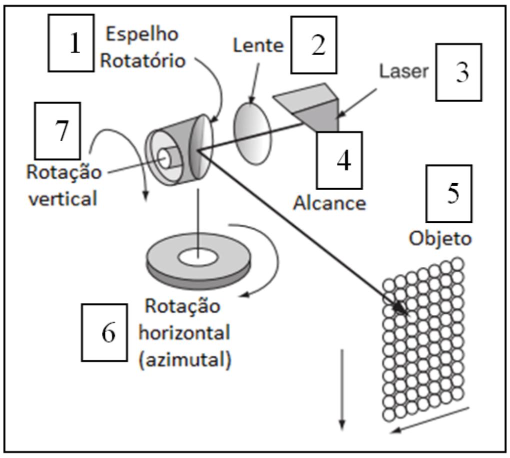


Fig. 1. Operation of Terrestrial Laser Scanner.
1. Rotating Mirror
2. Lens
3. Laser
4. Range
5. Object
6. Horizontal Rotation (azimuth)
7. Vertical Rotation

laser EDM is responsible for the measurement of distances between the sensor and reflected objects. Different principles of operation of the device are used for such a measurement, among which may be cited as being key: the time interval or time-of-flight (TOF) method, where the distance is calculated by precise measurement of the time between the emission and return of the pulse; phase shift method, where the distance is calculated by the phase shift of the modulated wave; and a simple triangulation method using CCD (Charge-Coupled Device) (BOEHLER et al., 2001; SHAN and TOTH, 2008) cameras.

3. SURVEYS AT THE MAUA HYDROELECTRIC PLANT (MAUA HPP)

This studywere realized in the Power Plant Maua located in the Tibagi River, in the Parana State, Brazil.

3.1 Study area

The Maua Hydroelectric Plant is located in the middle portion of the Tibagi River, in the central-eastern region of the state of Paraná, on the border of the municipalities of Ortigueira and TelemacoBorba near the Maua Falls.

The dam for this HPP is roller-compacted with a typical section of riprap, sealed with a concrete slab on the upstream slope of concrete. The width of its crest is 8m and it has upstream and downstream slopes with gradients of 1:1.35 (Vertical: Horizontal). Its axis is rectilinear measuring approximately 700m in extent. The maximum height of the dam is 88m, and its crest is at an altitude of 645.50m. Its spillway has four gates controlled by segment spans and is positioned on the left shoulder, approximately 350m downstream of its axis (CNEC, 2004). The dam is shown in Figure 2.

3.2 Materials

Fig. 2 - Maua Hydroelectric Dam

The main equipment used in surveys at Maua were a TLS, ScanStation C10 and a total station, TCRA1205 (angular accuracy of ± 5” with linear precision ± (2mm + 2ppm)), which was used to determine the coordinates of points on the structure.

The ScanStation C10 is a panoramic class terrestrial laser scanner, with biaxial compensation, high-speed scanning and an attached high-resolution digital camera. It is one of the newest TLS available in the market, manufactured by Leica Geosystems, and has a total station interface, simplifying its use. In addition to the total station features, this equipment also enables the construction of a polygonal field, a feature that is used to reference the different scanning points, which simplifies the procedure and increases the accuracy in the various junction point clouds. This process can also be carried out with the use of targets or methods of georeferencing.

According to the user manual, the ScanStation C10 has the following accuracy values (in a single measurement at 1-50m): position of 6 mm, distance of 4mm, angle of 12” / 12” (60 µrad / 60 µrad), modeled surface precision of 2mm and target acquisition of 2mm standard deviation. The dual-axis compensator has the following characteristics: resolution 1”, dynamic range +/-5’, accuracy of 1.5”. The laser used is pulse type, green in color (visible) and 3R class (IEC 60825-1). The range is 300m with 90% reflection, and 134m with 18% reflection. The scanning rate is up to 50.000 points/second, with spot size at a distance of 0 - 50m of up to 4.5mm (FWHH) and up to 7mm (Gaussian), and fully selectable horizontal and vertical point spacing with a minimum of 1mm. The field of view is adjustable, with a maximum horizontal of 360° and vertical of 270°.

3.3 Methodology

After defining the area, locations were determined for where the installation of the TLS would allow maximum coverage data for the survey. Locations were chosen near the dam and along its entire length, keeping in mind the specifications of the equipment. These points were put on the ground.

Within the methods for referencing and converting the point clouds surveyed, the

ScanStation C10 allows for the creation of a topographic traverse using the points where scanning will be carried out, operating similarly to a total station (each point of installation requires a reference point: a back sight to define its coordinates, and forward point to perform the survey). Its only limitation is the spacing between points of the instrument, which must not exceed 100m (Figure 3). The coordinates of the points of the traverse and cloud scanning are calculated based on the first point coordinates surveyed with the use of the total station. This methodology was adopted in all cloud referencing and converting in this study.

If the points used for the scans are over 100m apart, it is necessary to define a back sight for each location, generating a set of distinct pairs of points (Figure 3).

The determination of topographic coordinates for the TLS placement and reference is performed with a total station survey by triangulation technique (measurement of angle and distance from a known reference line). Once all points used in the TLS survey have been referenced in one coordinate system, the conversion of point clouds can be performed on computational software.

3.4 First season surveys

The survey points from before dam's reservoir formed was carried out on the same day as the area was defined, respecting the planned locations.

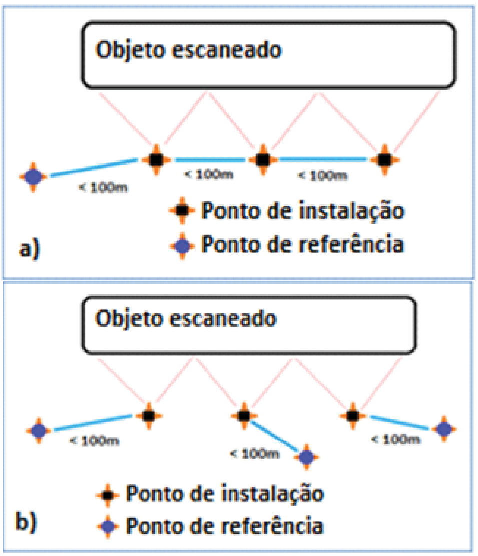


Fig. 3 - Methodology for referencing point clouds for polygon pair examples in point scanning

Eight scans were madewith TLS on the downstream part of the dam, with six points of reference (back sight), in an attempt to ensure data overlap and maximum coverage of the structure (Figure 4). All points were demarcated with the use of pickets to survey the coordinates of scans with the total station. In addition to the dam surveys, in every instrument setup, the back point necessary for referencing was surveyed.

The survey of the points for the TLS, and its reference points, with a robotic total station was carried out with the instrument installed on a geodetic pillar with known coordinates, with a forced centering system located downstream of the dam. As a reference a back sight was surveyed on another geodetic monitoring pillar, also located downstream of the dam and also with known coordinates, which define the orientation of the three-dimensional coordinate system used in surveys with the station and TLS.

3.5 Second season surveys

For surveys after the dam's reservoir formed, it was decided that the same reference points from the first surveys (Figure 4), to try to maintain working conditions and ensure the comparison of scans made from similar positions between the surveys with TLS. However, the opening of the floodgates of the dam due to reservoir formation, prevented access to some of the points used in the first season. Therefore, the area of the dam to be surveyed was reduced, the limit being the beginning of the spillway structures. The TLS survey for the second season was held in November 2012 following advance planning, defining only eight points in the field, six points for the TLS and two reference points (back sights) (Figure 5). Of the installation points, three points were used in the surveys from the first season and there were three new points.

Fig. 4 - Approximate locations of the points in the TLS survey

Fig. 5 - Approximate locations of the points in the TLS survey

As with the TLS survey, the survey with the robotic total station sought to maintain the conditions from the first season, employing the same techniques, the same installation points, and the same back sight (subsection 3.4).

3.6 Data Processing

The processing of data from the surveys with the robotic total station is the initial step towards integration with the survey data from the TLS, subsequently enabling the conversion of point clouds and comparison between surveys of different seasons. Such processing was performed with software from Position Manfra. A local reference system was adopted for the determination of the coordinates.

The first stage of TLS data processing was to import the point clouds collected in the field from both seasons in Cyclone with a demo license courtesy of Leica. Once all points were loaded into the application, the integration of TLS data with the robotic total station was performed. Thus, the coordinates obtained from surveying with the total station were imported into Cyclone and points were assigned to the TLS survey, ensuring referencing to a single coordinate system. In this way, all point clouds were now in the same reference system (Figure 6), and could then be used separately and/ or converted through the import of all clouds for the same file.

3.7 TLS data comparison methods

All analyses of comparisons in TLS data performed in this study were performed using

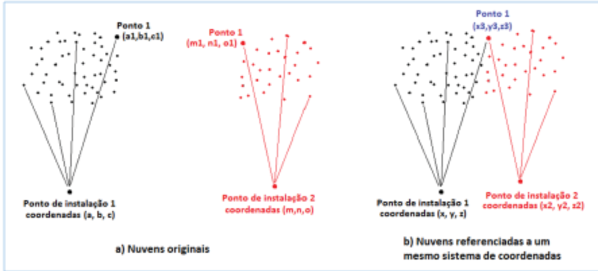


Fig. 6 - Referencing the clouds to the same coordinate system

the 3DReshaper software with a demo license courtesy of Technodigit, and the CloudCompare software freely available on the internet. The main difference between the function of these programs is the method of comparison used.

CloudCompare is free software that provides three comparison methods for point clouds: cloud to cloud, cloud with site modeling and cloud with mesh. In this study the cloud to cloud comparison method was chosen, since this option is not possible in the 3DReshaper software. This method defaults to the calculation of distances between points by the nearest neighbor algorithm. For each point in the cloud to be compared, the software searches for the point in the cloud closest to the reference and calculates the distance (Euclidean) between them. According to the documentation for CloudCompare, the closer the points are, the greater the accuracy of this method.

If the above method is not possible, the ideal procedure would be to compare a cloud with a mesh (grid model, theoretical surface) that accurately represents the surface, a method also offered by the program. But the creation of the mesh is not possible in this software. In such a situation, CloudCompare offers a an intermediate method for a more rough calculation of the distance between the surfaces – local modeling.

In this method, the software determines the closest point of reference in the cloud and locally models the surface of the cloud, by fitting a mathematical model at this point and using some of its neighbors. The distance of each point in the cloud is compared to its closest reference point in the cloud and its distance is replaced by in the model. Also according to the software documentation, this method is statistically more accurate and less dependent on the sampling of the cloud.

3DReshaper is commercial software that allows some comparison methods for scanning purposes, among them: cloud to mesh modeling and mesh to mesh. Both possibilities were used in the comparisons made in this study, and to use these methods the creation of a mesh is required. As the 3DReshaper has a mesh calculator, it was used for creation and no importing from other sources needed. According to the 3DReshaper software documentation, for the creation of the meshes the software presents two methodologies.

(i) In the first method, the software uses all points present in the cloud without any selection criteria. According to the software's help material this method is computationally slower and can create an unnecessary number of triangles in the mesh, as well as distortion in the modeled surface.

(ii) In the second method, the software uses only points classified as more suitable for the creation of the mesh (theoretical surface). These points would be selected for their proximity to a theoretical surface area calculated by the software to represent the cloud surveyed. For point selection, geometric criteria (a) or qualitative (b) may be used.

a - using a standard deviation value for the calculation of intersection points that form the mesh

b - selection of points that constitute the mesh using a noise reduction measurement: the points are selected using a criterion of value of average distance between points and the surface, eliminating the distant points

Once the mesh is created, it can be compared with the cloud or with another mesh. No more detailed information about the methods and mathematical models used to calculate the distance in comparison functions were found.

3.8 Test for mesh creation

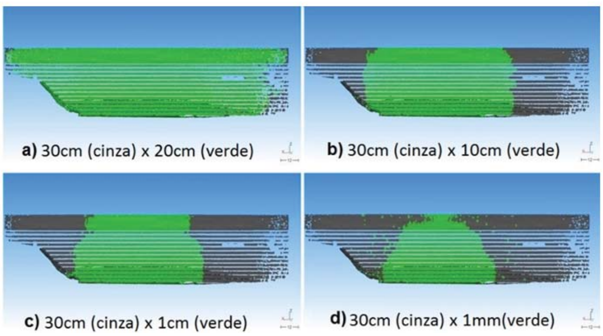
Experiments for mesh creation with the qualitative method and with noise reduction were performed by evaluating five different average distances between points (1mm, 1cm, 10cm, 20cm, and 30cm), for all equal points for equipment positions in both seasons. Figure 7 shows the results obtained in the comparison of the meshes created with the cloud scanned from one of the position points of the TLS.

After the creation of meshes with noise reduction, using the distance values previously mentioned, the comparison of the mesh to mesh method was performed with the distance model created at 30cm (gray areas in Figure 7) and comparing it to meshes created with other values (green areas in Figure 7).

Through this procedure it was observed that the lower the value of the average distance between the points to be selected, the smaller was the size of the mesh created (areas in green in Figure 7). This behavior may be caused by the resolution of the survey with TLS that, due to different angles of incidence of the laser pulse on the surface of the dam, leads to a spacing of different points along the cloud. In attempting to understand these aspects more appropriately, an experiment was conducted on the resolution of the survey with TLS. As such, some regions were selected in one of the point cloud scans of the dam. In Figure 8 the four regions (a, b, c, e, d) chosen for evaluation of TLS resolution are shown. They were arranged by the cloud so that each one would provide the evaluation of different values of angles of incidence between the laser pulse and the surface of the dam, and distances traveled by the pulse. Some regions are at an incidence angle, vertical and/ or horizontal to the laser pulse with the surface, similar to others, defined as such to ensure a relationship between them.

All values found in the four regions were summarized in Table 1.

In examining Table 1, a variation can be seen between the distance between the points of the cloud when the values are changed for the laser pulse angles of incidence and the distance between the object and scanner. While in the center of the cloud (region "a") points are spaced



(cinza = gray; verde = green)

Fig. 7 - Comparison between meshes.

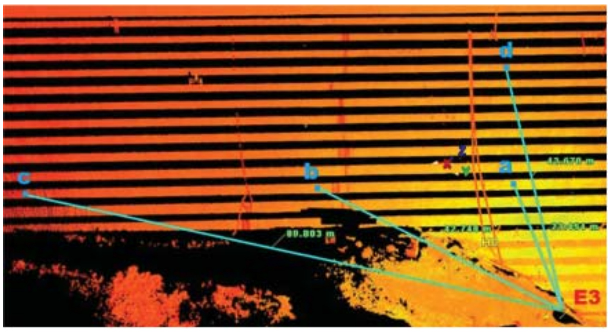


Fig. 8 - Regions chosen for evaluation of TLS resolution.

Table 1:Values of the TLS resolution

	REGIONS			
	a	b	c	d
Distanceto scanner (m)	23.454	42.748	89.803	42.67
Horizontal angleofinci-dence	0.517°	55°	74.826°	1.248°
Vertical angleofinci-dence	10.977°	11.309°	10.251°	34.053°
Average of the highest values the distance between points (m)	0.023	0.084	0.357	0.052

every 2cm, as the assessed region's distance from the TLS and the angle of incidence increase, the distance between points increases, with the highest value in region "c" of 35.7cm.

If, as proposed by Van Genechten et al. (2008), these variations decrease the accuracy of the survey, the need arises to reduce the area of the point cloud used. When evaluating the results found during mesh creation (Figure 7), the most appropriate regions are the surveyed areas with up to approximately 45° tilt angle of the pulse, a range of 90° horizontal opening with a central incidence point equal to zero (45° horizontal opening in each direction from this point). As can be seen in Table 1, the threshold value for this angle of incidence for the spacing between points peaked between 5cm and 8cm, which ensures a high density of points, thus confirming that these regions would be suitable for mesh creation.

Therefore, after the analyses (mesh creation and survey resolution), the creation of two types of meshes to be used in comparisons of scans was set. For final comparisons, mesh creation with the most points in the clouds (with an average distance of 20cm, item "a" in Figure 7) to assess the full extent of the survey, and for local comparisons of mesh creation with standard tridimensional error was defined as 1mm, using the regions defined in the tests (with an average distance of 1cm, item "d" in Figure 7), seeking a more precise investigation of possible deformations in the structure.

4. RESULTS

Three different types of comparisons to be made with the point clouds from surveys with TLS were defined. Their respective results are discussed in the following subsections.

4.1 Comparison between scans performed from the same station (occupation point) in different seasons

Clouds relating to the scans from both seasons were compared, from a common point of TLS installation, in the central portion of the structure surveyed. These were then imported into the CloudCompare and 3DReshaper software and a first comparison was made using the default settings of each program, in order to examine the consistency between the results of these programs.

4.1.1 Initial Comparisons

The initial comparison made with the 3DReshaper software is shown in Figure 9, while the comparison made with CloudCompare is given in Figure 10.

For these comparisons, first point clouds were imported from both seasons into 3DReshaper and CloudCompare. In 3DReshaper, the cloud from the first season was used to create a mesh with an average distance between points of 20cm. It was then possible to compare, calculated by the 3D displacement, the first season mesh and the point cloud from the second season (cloud to mesh).

In CloudCompare, the clouds were compared directly (cloud to cloud) without creating a mesh using the cloud from the first season as the basis of comparison.

As can be seen in Figure 9 and Figure 10, the smallest difference (possible displacement)

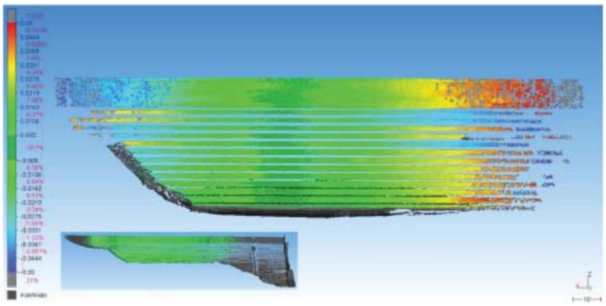


Fig. 9 - Initial comparison in 3DReshaper.

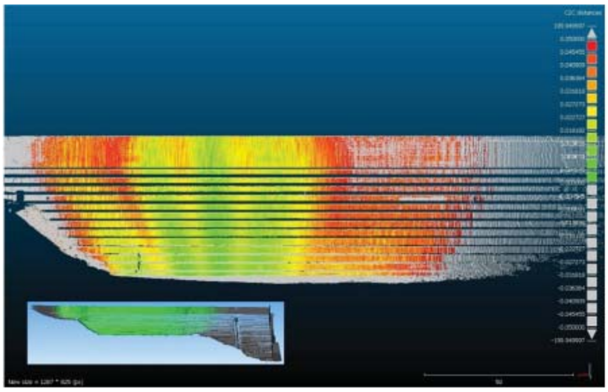


Fig. 10 - Initial comparison in CloudCompare

was found in the central surveyed area. Moving away from this region causes the differences to get bigger, and, of course, do not represent displacements but variances. In the case of Figure 9 (3DReshaper), differences in central region range from +5mm to -5mm, and it can be noted that these results are better distributed in the center.

4.1.2 Comparisons limited to the modeled area

The point clouds of the initial comparisons have undergone a process of editing in order to limit the region of comparison. The specific regions during mesh creation and the initial comparisons, as appropriate for calculating the displacement of the structure (surveyed areas to limit the angle of incidence of 45°, horizontal opening of 90°) were selected for the new calculations, and the other regions were excluded from the clouds.

The final comparisons performed with 3DReshaper and CloudCompareare shown respectively in Figure 11 and Figure 12.

In 3DReshaper the mesh was created from the point cloud from the first season's survey, without noise reduction and with point selection by a dimensional error of 1mm. The

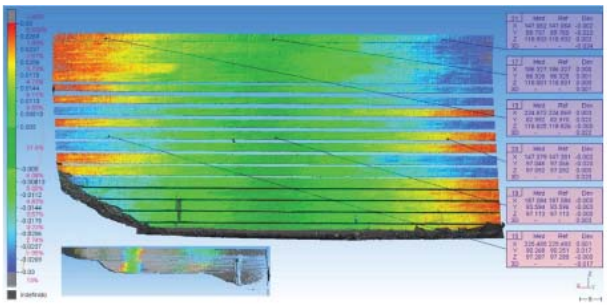


Fig. 11 - Final Comparison in 3DReshaper

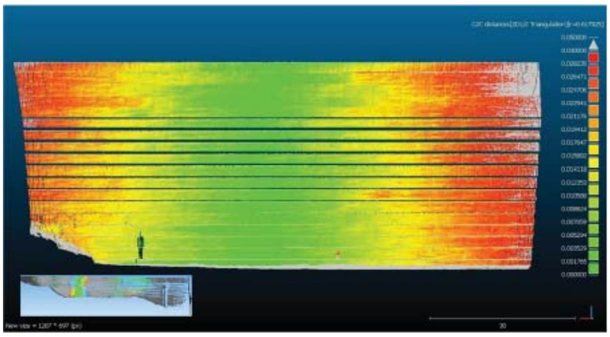


Fig. 12 - Final Comparison in CloudCompare

use of a non-meshing method aims to test other software configurations and the most precise representation of the structure.

In CloudCompare another setting was also used for the final comparison, the cloud from the first season was modeled locally using the method of 2.5D Delaunay triangulation and then compared to the cloud from the second season.

In the result from 3DReshaper, Figure 11, some survey points were selected after comparison and the values of their displacements in three dimensions, calculated on the mesh, are presented in text boxes to facilitate the evaluation of the results.

Analyzing both results together (Figure 11 and Figure 12) the repetition of the same pattern of displacement can be seen between these results and those found in the initial comparisons, where the lowest values are found in the central portion of the scans. Most of the compared area has displacements of less than 2cm and only the edges have values of 3cm. All values found indicate shifts in the direction of river flow.

As such a comparison permits only local evaluations of the dam, other methods have been evaluated and are shown in subsections 4.2 and 4.3, where only 3DReshaper was used due to the similarity of results between this software and CloudCompare.

4.2 Comparison between scanning at an occupied time in the second season and the mesh created with all the scans of the dam from the first season

To evaluate the overlap of data provided by the disposition of the points surveyed in the field, the point cloud from a survey from one of the occupied times in the second season was compared to a mesh created with the clouds of all scans from the first season. This point was selected because of its position in the field and was used only in the second season of the survey. As it is located between two other seasons, the scanning area overlaps a large portion of the areas surveyed from these two seasons. Since there is no similar point in the first season survey in the most precise region in the scan (central region), it did not use the same regions for the sharpest points used to create the mesh.

The mesh used in the comparison was created with a configuration for average distance between points in the 20cm model by the method of noise reduction, which uses most of the surveyed points with little size reduction in the final result. The result of the comparison is shown in Figure 13.

As with the results of the previously performed comparisons, the values of displacement are shown on a scale of color variation, and the areas representing the displacement between 0 (dark green) and 1cm (red and blue) has been defined to evaluate only the regions with more accurate results and creating the mesh. Values greater than 1cm of displacement are represented in light gray. As can be seen in Figure 13, the result is different from those shown in the previous comparisons.

Areas of smaller distance between the cloud and the mesh represent the central regions of surveys from the adjacent installation points to the selected installation point, and not the central area surveyed from this point. As this area was not surveyed in the first season, the mesh employed has no precision for comparison in this region. As the scans from the adjacent installation points are present in the mesh used, its central regions were well modeled. Even if the surveying of these areas from the installation point used for the comparison was performed with angles of incidence greater than 45°, the

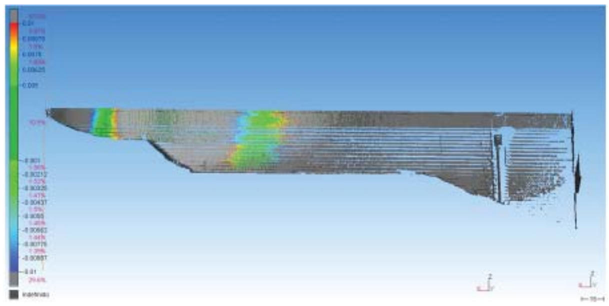


Fig. 13 - Comparison of scanning from one seasons and scans for the entire structure

result of the offset values in such regions presents consistency, similar to those seen in comparisons in subsection 4.1.

4.2 Comparison between scans of the entire structure in both seasons

In search of an analysis of the overall structure, meshes from all scans from each season of the survey were created. The models were created by noise reduction method and proved to be in line with an average distance between points 20cm. The comparison result is shown in Figure 14.

Again the values of displacements are presented in a range of color variations, with a representation of areas of displacement between 0 (dark green) and 1cm (red and blue) and values larger than 1cm in dark gray.

As in previous comparisons the results indicate the smaller displacement in the central regions of the scanned areas from points of common installation between the survey seasons.

5. CONCLUSIONS

The main goal that led to the development of this paper was to study the potential use of a TLS in the monitoring of dams, with a case study for the Maua HPP. The opportunity to evaluate its performance during the reservoir's

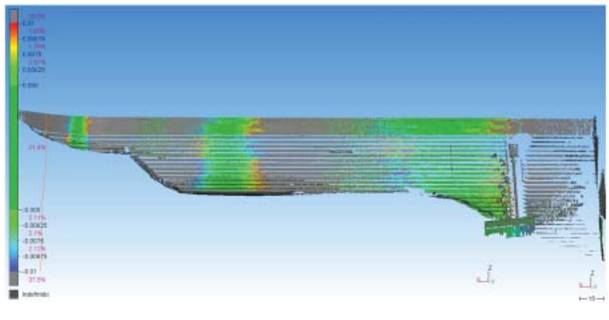


Fig. 14 - Comparison between scans of the entire structure on both times

formation was one of the factors that prompted the use of this technology as well as the ability to add new types of information to other data from the time-honored techniques of monitoring, in addition to other benefits provided by their use (accurate collection of large scale data within a short period of time). The lack of studies related to the subject in Brazil also influenced the choice of the proposed topic.

For this study two surveys were conducted with TLS of the entire structure downstream of the dam in two distinct periods, pre-reservoir and post-reservoir. The survey points of the TLS were subsequently surveyed with a robotic total station using triangulation.

Data processing was carried out using Position software (for data from the total station), Cyclone (data integration for the TLS and the total station), 3DReshaper and CloudCompare (comparisons between scans performed with TLS). The methodology used for the comparisons between the point clouds was calculation of displacement between the point clouds of surveys from each season.

The first comparisons were made between scans performed in the same points for different seasons. They were held in two phases, first using all the points from surveyed clouds, and afterward restricted to the central area with the highest density for points in the cloud and allowing the creation of more accurate meshes. In the initial stage, the values found in the tests apparently did not derive from a displacement of the structure between the two seasons. That was possibly due to the loss of quality in the creation of the mesh in 3DReshaper and local modeling in CloudCompare, as the point cloud moved away from the scanner and the angle of incidence of the laser beam increased (causing an increase in the distance between cloud points). In the final step again most of the results did not seem to express a displacement of the structure, but the accuracy of the models used as reference for comparisons, in a mesh from 3DReshaper and local cloud modeling from CloudCompare. In portions of the clouds where the mesh more accurately represents the surface, due to the angle of incidence, the distance from the instrument to the target, and the density of points, i.e., the areas with more reliable results, the displacement values reach 5mm. These results point to minimum values of displacement in the direction of river flow. But these results can still only display the precision of the processes of mesh creation and calculation of distances, indicating that surveys with TLS and the calculations performed by the software did not detect any movement of the dam. As data were used from only two different seasons, surveying a larger number of observations would be necessary to allow conclusions about the displacement of the structure.

Other types of comparisons were made, where movement between scans of the entire structure in both seasons and between scans from a point of the second season and a mesh of the overall structure of the dam from the first season were calculated. The results for the first type were mostly similar to earlier ones. However, during the second of these comparison methods different results were found. By comparing the scanned point cloud of one of the survey points of the second season to a mesh created using the survey points from the first season, its central area did not have the lowest values of displacement, but the central areas surveyed from these points of installation from the first season. Again this indicates a lack of precision in the creation of the meshes in regions with a low density of points, since the mesh created lacked the survey of installation points from the second season. These results also indicate that there is considerable laser precision even in the most distant regions of the equipment and the low density of points where the angle of incidence was approximately 90°, since their comparison with the areas of highest precision of the mesh resulted in minimum displacement values. Thus, the results indicate that the method of mesh creation had great influence on the results of the experiment in this study, and only represented the structure appropriately in the regions with the highest density of points.

Several aspects of the use of the TLS were evaluated, from planning points to comparisons of surveys, and the results achieved indicate some guidelines to follow to avoid some of the problems and improve the accuracy of surveys. The methods used in creating models for the comparison of data must be evaluated according to their ability to represent the entire point cloud without distortion in areas of low point density.

However, it is also important to plan points for the TLS installation. The larger the number of installations in the field, the more the surveyed areas will have high point density, guaranteeing the representation quality of the structure. So a larger number of observations should be made in the field, allowing for more comparisons of results. Importantly, the results are directly linked to the settings used in the processing software, and the study of other types of settings is essential in the search for more accurate values .

The lack of detection of apparent shifts in surveys with a laser does not rule out the results, but only demonstrates the need for further studies on the use of this technology for monitoring structures.

REFERENCES

DALMOLIN, Q.; SANTOS, D. R. **Sistema Laserscanner: Conceitos e Princípios de Funcionamento.**3. ed. Curitiba: UFPR. p.97, 2004.

BOEHLER, W.; HEINZ, G.; MARBS, A**.** The Potential of Non-Contact Close Range Laser Scanners for Cultural Heritage Recording**.** CIPA - International

Symposium, **Proceedings**. Potsdam, Germany – p.1-2. 2001.

CLOUD Compare. **Distancescomputation**. Disponível em: http://www.danielgm.net/cc/doc/wiki/index.php5?title=Distances_Computation. Acesso em: 10 abr. 2012.s.p.

CNEC WorleyParsons Engenharia S.A. **RIMA – Relatório de Impacto Ambiental da UHE Maua**. p. 11. 2004. Disponível em: <http://www.iap.pr.gov.br/modules/conteudo/conteudo.php?conteudo=1073>. Acesso em:17 abr. 2012.

LEICA GEOSYSTEMS. **LeicaScanstation C10 User Manual**. p. 128-132. Disponível em: http://www.leica-geosystems.com/en/index.htm. Acesso em: 08 abr. 2012.

LEICA GEOSYSTEMS. **Leica TPS 1200+ User Manual**. p. 154-155. Disponível em: http://www.leica-geosystems.com/en/index.htm. Acessoem: 08 abr. 2012

SHAN, J.; TOTH, C. K. et al. **Topographic Laser Ranging and Scanning: Principles and Processing.** CRC Press Taylor & Francis, London. p. 89-92. 2008.

STAIGER, R. Terrestrial Laser Scanning – Technology, Systems and Applications. Em: **Second FIG Regional Conference**, Marrakech, Morocco, December.p. 2-5, 2003.

TECHNODIGT. **3DReshaper documentation.** Disponível em: <http://www.3dreshaper.com/>. Acessoem: 10 abr. 2012.s.p.

VAN GENECHTEN, B; QUINTERO, M. S.; DE BRUYNE, M.; POELMAN, R.; HANKAR, M.; BARNES, S.; CANER, H.; BUDEI, L.; HEINE, E.; REINER, H.; GARCIA, J. L. L.; TARONGER, J. M. B. **Theory and Practice on Terrestrial Laser Scanning: Training material based on practical applications**. UniversidadPolitecnica de Valencia Editorial. p. 3-6. 2008.