

## DAM MONITORING USING TERRESTRIAL LASER SCANNING

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**Abstract:** The paper presents the practical aspects of dam monitoring using terrestrial laser scanning. Monitoring of dams is an important aspect in ensuring their proper functioning. Monitoring can be done on several levels with physical methods or geometric methods (geodetic measurements). Among geodetic measurement methods could be mentioned: the method of triangulation and trilateration, geometric leveling method, satellite measurements methods and terrestrial laser scanning the newest method.

**Keywords:** Triangulation and Trilateration, Geometric leveling, Laser Scanner, 3D Model, Sections, Mesh

### 1. INTRODUCTION

Pecineagu accumulation is located in the upper part of river Dîmbovița in the depression between massive Iezer-Păpușa, Făgăraș and Piatra Craiului (Figure 1), has a water catchment area of 103 km<sup>2</sup>, from which can be stored in the lake, in the normal retention, 69 million m<sup>3</sup>.



Fig. 1 – Location of Pecineagu accumulation

Pecineagu dam, with a height of 105 m, the length of 267 m at the crest and a width of 360 m in the central section at the base and 10 m at the canopy is made of rocks and it is sealed with reinforced concrete mask. The sealing mask has the thickness between 1.2 m at the bottom, and 0.3 m in the upper part, with an inclination of 1:1.7 and a horizontal curvature radius of 2000 m at the crest.

Following the operation of the dam, the upstream mask suffered deformation, the maximum being about 400 mm. Repairs made during operation failed to achieve sealing of

the mask, and thus it was chosen the solution of covering it with a Carpi membrane (up to 1095 m elevation). This solution led to the destruction of tracking landmarks placed on the mask and the impossibility to do the measurements using the equipment previously used. The feasible solution, which was chosen for the measurements of the mask covered with the membrane was the use of terrestrial laser scanning technology [2].

## 2. METHODS USED AT THE MEASUREMENT

Terrestrial laser scanning technology allows measurement of a large number of points placed on the object monitored without the need for them to be accessible but only visible.

The principle of laser scanning system is very simple, the scanner emits a laser beam that is reflected from the object. When measuring a characteristic point on the surface of the object, three observations are made: slope distance and two angles - horizontal angle  $\alpha$  and vertical angle  $\beta$ . Based on these elements the 3D position of the point is determined through conversion from a polar coordinate system to a cartesian system[3].

The measurement result is represented by a set of points that define the monitored object, generally they are called "point cloud".

For the determination of coordinates (X, Y, H) of points from which the scan was performed I used the method of geometric levelling (for altimetry measurements - H) and method of triangulation and trilateration (for planimetric measurements - X, Y).

The geometric levelling is based on the horizontal visa of the instruments. Geometric levelling instrument is placed in the middle, his horizontal axis is leveled and readings are performed on levelling staves from points A and B. The difference in level will be obtained from the readings on the two levelling staves.

Triangulation and trilateration method allows the determination of planimetric coordinates for points using angular measurements (the horizontal directions) and linear measurements (the horizontal distance) using surveying instruments. Measurements can be performed simultaneously if the used instrument allows angular and linear measurements at the same time or independently, using two different instruments for determinations. The method involves stationing of known coordinates points and targeting new points, and where it is possible stationing new points determination will be made to other old and new points.

### a. Equipment used for measurements

For the determination of planimetric coordinates of the network points from which I performed terrestrial laser scanning was used the total station Leica Builder 300RM, which has the accuracy of determining angles of 3", with the electronic angle compensation on two axes, and the accuracy of determining distances using prism of 2 mm + 2 ppm. At determination of the point height has been used a Trimble Dini 0.3 type electronic level, with accuracy of  $\pm 0.3$  mm / km double leveling and possible readings order of 0.01 mm on invar barcode staves with a length of 2 m. Scanning the upstream face was performed with terrestrial laser scanner Leica Scan Station 2, which has the accuracy of determining the spatial position of the points of  $\pm 6$  mm to 50 m and surface modeling accuracy of  $\pm 2$  mm.



Fig. 2 – Equipment used for measurements (laser scanner, level, total station)

### b. Measurements

In order to cover with terrestrial laser scanning measurements the uncovered upstream face (water elevation at 1052.4 m) were marked six projected points (SW1, SW2, SW3, SW4, SW5, SW6 – Figure 3), whose coordinates (X, Y, H) were determined using the triangulation and trilateration method for planimetry and geometric leveling method for altimetry.

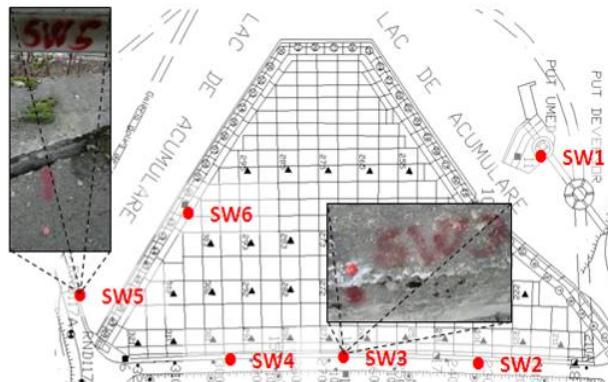


Fig. 3 – New placed points

For determining coordinates of new points in the coordinate system of the dam were used existing old points from the monitoring network.

Aspects from the measurements can be viewed in the following figures.



Fig. 4 – Measurements using laser scanner



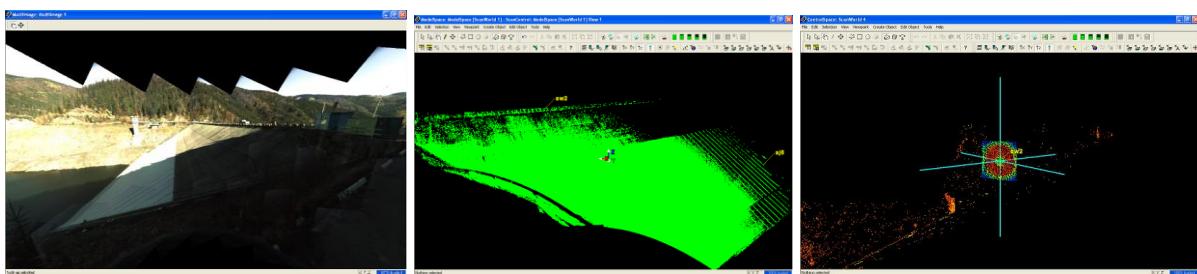
*Fig. 5 – Triangulation-trilateration measurements*



*Fig. 6 – Geometric levelling measurements*

Terrestrial laser scanning was performed from points SW1, SW2, SW3, SW5 and SW6.

Scanning in each point lasted about 25 minutes, during this interval were taken first the panoramic images of the scanned area, after the effective scanning of the area was made and in final recording of sighting targets (Figure 7).



*Fig. 7 – Panoramic images, point cloud and sighting target taken during scanning*

Georeferenced point clouds were put together in the same file, thus obtaining the upstream face unfiltered 3D model containing 2807094 points.

The next step involves filtering (removing) the points that do not belong to the study area, resulting in the 3D model filtered which contains 2312922 points after filtration (Figure 8).

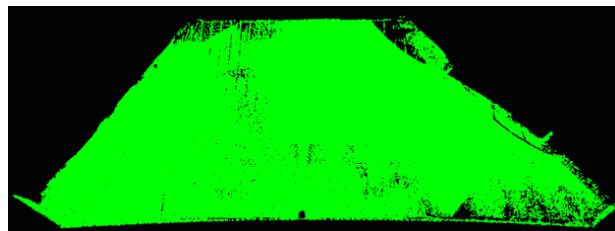


Fig. 8 – Filtrate 3D model – top right view

The final step in managing the point clouds is to unite and uniform them (Figure 9), obtaining the final 3D model of the area, which contains 1889076 points.



Fig. 9 – Unification of point clouds and obtaining the final 3D model

The final 3D model can be managed in several ways and can generate from it sections in any desired direction, which can be compared with the generated section on the same lines for models made at different times or with sections generated from the theoretical model. Another way for the management is to create a "mesh" (that best approximates the measured object) on the entire model or parts of the model. Then by overlapping with theoretical model or "mesh" generated at different times the deformations can be observed.

### 3. Comparisons that can be made between stages of measurements

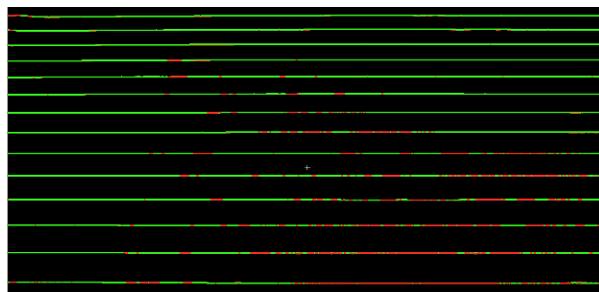
After initial tests at Pecineagu in May 2012 I generated a model (Figure 10) of the upstream face for which at the time the membrane Carpi was installed up to the level of 1060 m, and the water level was at 1056.7 m.



Fig. 10 – The 3D Model - May 2012

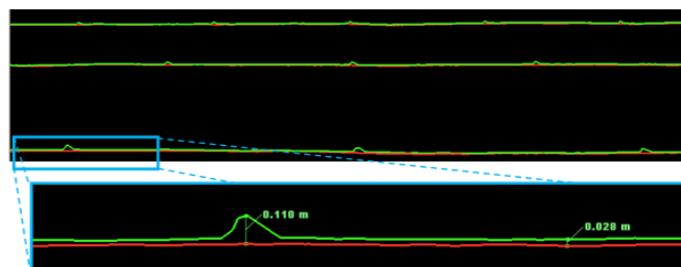
The two models can be compared using the sections or the mesh determined previously.

Comparing the sections generated on the same alignment can be done visually in Cyclone application, where you can see the difference between them [1]. In Figure 11 we have the green profiles generated from the model in November 2012 and with red profiles in May 2012.



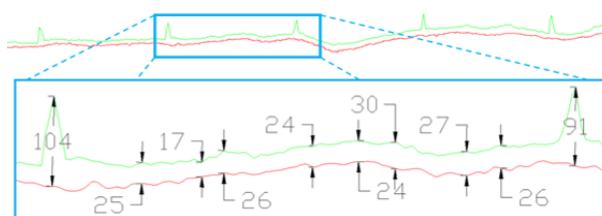
*Fig. 11 – Overlapping profiles*

From the overlap between them we can see the areas where the models intersecting (alternating red-green) and areas where a model is above the other (a single predominant color). In general for areas between 1056.7 m and 1060 m elevation and between 1095 m and 1117 m elevation the two models intersect, there having the same elements measured in the two stages (upstream face covered by membrane - down and uncovered area of upstream face - up), the differences being due to measurement error. In the area between 1060 m and 1095 m elevation the model from November 2012 is above the model from May 2012, this area was covered during this time with the membrane. An example of the values determined in the vertical plane between the two models can be seen in Figure 12, where there is a difference of 28 mm for the flat area and 110 mm for the channel separation.



*Fig. 12 – Measuring the differences between models in Cyclone application*

Comparisons can be made also if sections are exported to other CAD environments. For example, in Figure 13 I generated two profiles for which length scale is 10 times smaller than the scale of heights, here we can notice more clearly the difference between the two sections. The measured values vary between 17 mm and 30 mm for the area between two separation channels, and for two consecutive separating channels the values are 104 mm respectively 91 mm.

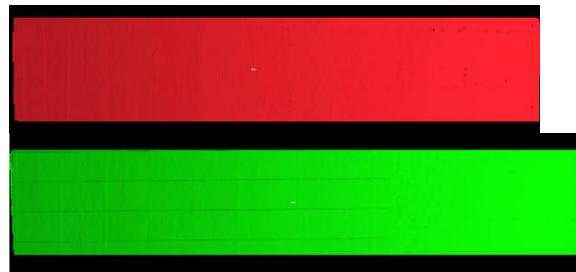


*Fig. 13 – Measuring the differences between models in CAD environment*

Working with sections can be time consuming unless there is the possibility for automated creation of results and allow only comparisons for sections generated through the same point.

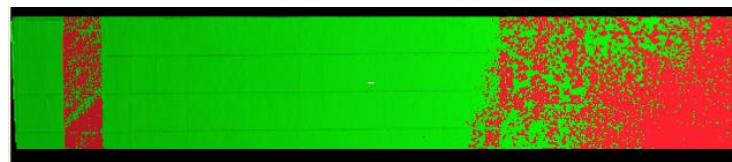
If you want to compare largest areas solution would be to use mesh surfaces, but this mode requires powerful computing equipment and specialized applications.

To see this mode of operation, using Cyclone application the same location has been selected (defined by X = 1000, Y = 400, X = 1150, Y = 420) for the two models, and the corresponding mesh surfaces were generated (figure 14).

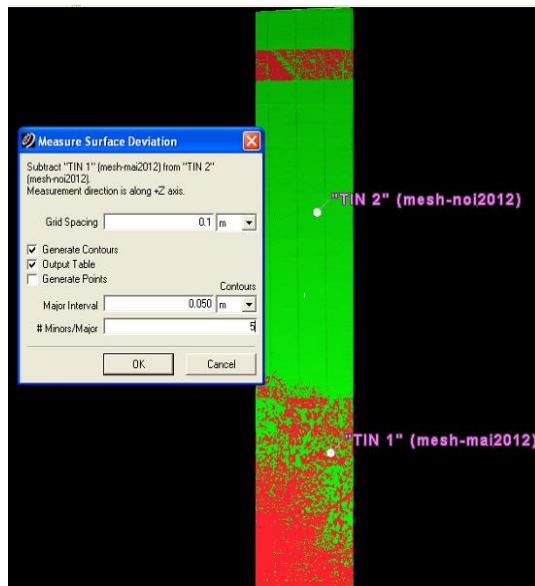


*Fig. 14 – Mesh Surfaces of the two stages (red-May, green-Nov)*

Comparison of mesh surfaces can be made visually (Figure 15) and automatically using the function of surface deviation calculation, this function can determine the deviation from a reference plane or between two surfaces (Figure 16).



*Fig. 15 – Overlapping of mesh surfaces*

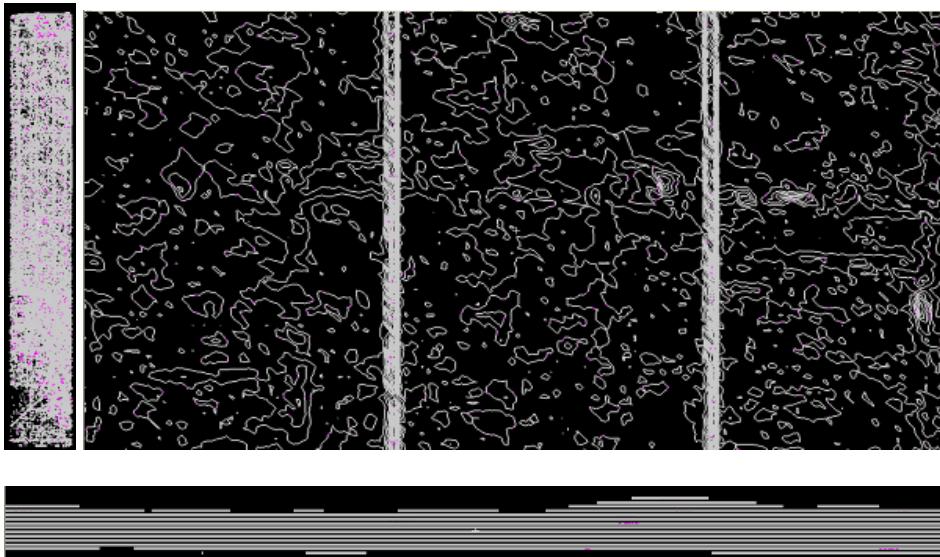


*Fig. 16 – Determination of deviation between two overlapping mesh surfaces*

If you select two mesh surfaces you can set up the following parameters: step grid, the possibility of generating contours of the resulting differences, generating a table with the

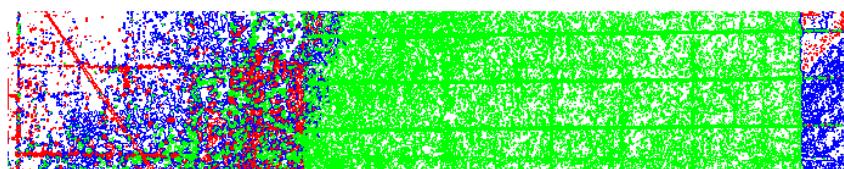
differences or generating points on grid nodes, if it is set the generation of curves you can establish the equidistance of the main level curves and the interval between normal curves.

The result closest to reality is to generate directly the level curves (Figure 17) which will have zero value at the intersection of surfaces, the + sign if the reference surface is below and - sign if the reference surface is above.



*Fig. 17 – Level curves generated from the deviation between two mesh surfaces*

If they are exported to different working environment the curves can be selected independently and you could assign a color for them to be highlighted or they can be selected in groups, assigning to the curves with zero value a color and to those with the + and - sign other two colors, as can be seen in Figure 18.



*Fig. 18 – Color-coded level curves (blue - zero value curve, green - positive value curves, red - negative value curves)*

Similar results are obtained using a dedicated application to compare point clouds (CloudCompareV2 - Figure 19). This has the advantage that it is an opensource application (free) that has implemented various advanced algorithms which allow working with point clouds. It can compare the point clouds, mesh surfaces generated for this, obtaining a map of the deformation.

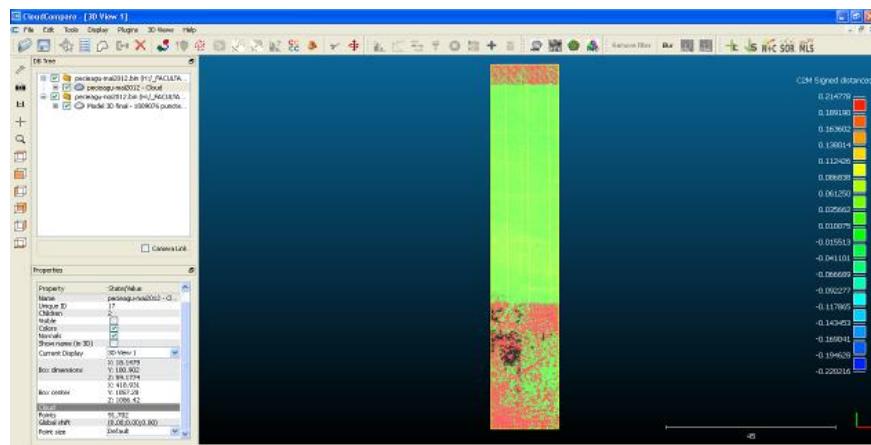


Fig. 19 – Determination of displacements using the application CloudCompareV2

Similar to the use of sections can be compared the level curves generated for each mesh surface in part, the results being similar (Figure 20), since for this case the values are determined in the horizontal plane and for sections in a vertical plane.

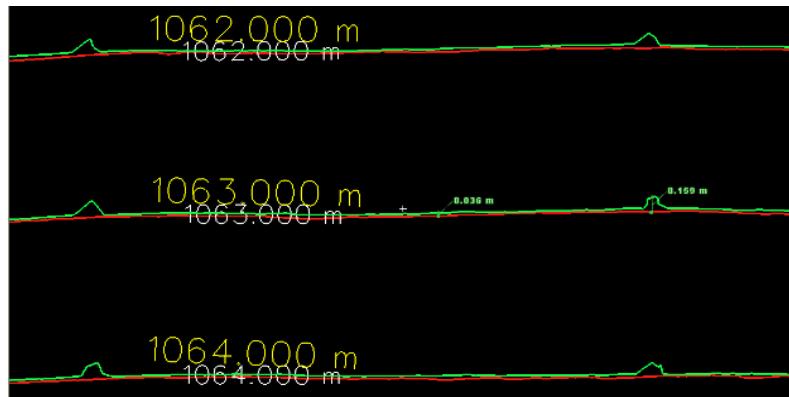


Fig. 20 – Measuring the differences between the level curves

#### 4. CONCLUSIONS

Following the measurements in November 2012 I have obtained the 3D model of the upstream face bared of water, vegetation, and natural household waste. On the basis of final 3D model were generated vertical section, on two alignments parallel to the axes of the planimetric coordinate system. Also on the basis of final 3D model mesh surface was generated, and then for the mesh surface level curves were generated.

Based on a 3D model generated from measurements taken in May 2012 I have generated the same elements as in the case of the model from November 2012 and has been shown the comparisons that can be made on this basis.

The advantage of using terrestrial laser scanning method is that it can be obtained 3D models of the monitored objective in a very short time, at raised density of the points, thereby eliminating the possibility of omitting the measurements on areas of interest [4]. Then based on the 3D model you can make different comparisons to the previous models to see if the monitored object has undergone deformation.

Accuracies that can be obtained are of the order of mm - cm if we respect the methodology and process of making measurements using terrestrial laser scanning.

The disadvantage of this method is that if you don't have the top hardware and software equipment, working time may increase exponentially.

## 5. References

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