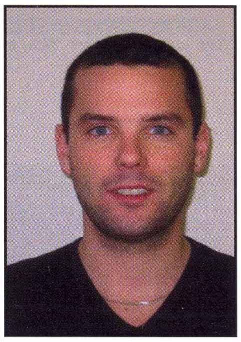
Monitoring lock chamber dynamic deformation



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MEASURING DEFORMATIONS is an important part of geodetic works in various engineering projects. Most methods currently involve the use of total stations and GNSS technologies. Laser scanning technology, while not reaching the same accuracy for individual points as total stations or long-term GNSS observation, can overrun this drawback through measuring speed, point density and complexity of surface record.

Experimental use of laser scanning technology for monitoring areal dynamic deformations of a large lower lock chamber on a hydroelectric plant took place with a Leica HDS3000 laser scanner and Cyclone software. The basic specifications of the system are a standard deviation distance of 4mm, standard deviation vertical and horizontal angle of 60 micro-radians (4 mgon), an optimum working range of 1-100m, a laser beam diameter of 5mm at 50m and a measuring speed of 4,000 points per second.

Measuring the Gabcíkovo hydroelectric plant

Measurements took place on the Gabcíkovo hydroelectric plant on the River Danube between Hungary and Slovakia. A suitable standpoint for the laser scanner was selected with maximum view of the measured gate (see figure 1).

The gate is approximately 37m x 22m in size, with a visible area of approximately 32m x 12m. The average difference in water levels when the chamber is filled is 20m. The time of filling or letting out the lock chamber is approximately 25 minutes, so points on the gate were spaced at 0.2m x 0.2m and the whole visible plane of the gate, including a small overlap, was focused on. The time of one measurement with this setting took approximately 40 seconds. Because of the high measuring speed, it was possible to abandon the original plan to stop the process of filling the chamber every time the water level changed by 1m, because this procedure is very demanding.

Measurements were carried out in the shortest possible intervals and were synchronised with the control tower. The filling process took 26 minutes and 35 seconds and 30 measurements were carried out in this time. Changes in water level after each metre were announced to us from the control tower and we noted down the times.

An important fact is that neither the setting of the scanning area nor the setting of the spacing of the points changed for the individual measuring and therefore the measuring was always carried out at the same points (see figure 1).

Evaluation of the data

The basic method of evaluating deformations is the digital terrain model (DTM) of differences, known as a digital displacement model. Therefore, it is necessary first to retransform all the measured data into such a coordinate system, so that the plane of the gate lies in the plane parallel to axes XY and axis Z was placed in direction of the expected displacements. Axis X was concretely placed in the longitudinal direction of the gate, axis Y was oriented into the zenith and axis Z completed the mathematical (clockwise) system of coordinates (see figure 1). Atlas DTM software (version 4.3) was used to create and to analyse the DTMs and digital displacement models.

Before generating the digital terrain models, it was necessary to choose only those points from the measured points that were situated on the plane of the gate, because the Atlas system, as well as other systems used for work with DTMs, does not enable work with overhangs.

Creation of the digital displacement models

At first, DTMs were created from all cleaned measurements. In the second step, the digital displacement models were created, always by subtracting the current DTM from the first one, which was measured before the beginning of the filling of the lock chamber.

Figure 1: (Left) Location of the Leica HDS3000 system during the experiment. (Right) The position of measured points and selection of coordinate system.

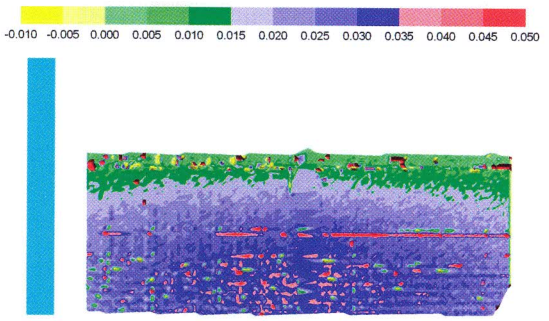


Figure 2: Digital displacement model of the measurement number 31.

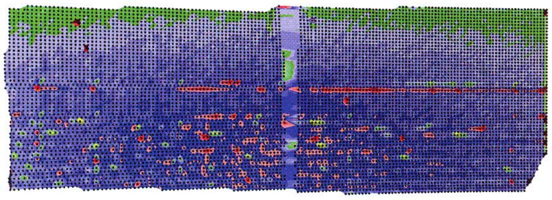


Figure 3: Cut of digital displacement model number 31 with depicted measured points.

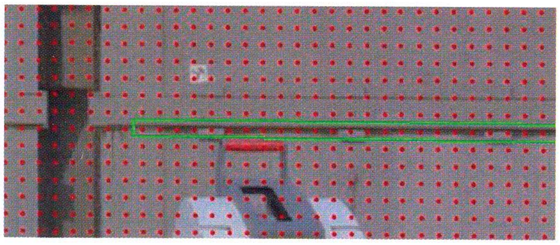


Figure 4: Points with the biggest shift.

Then, it was necessary to carry out interpolation of differences in water level heights in measuring time, which was related to half of its 40-second interval. These differences in heights of water level are graphically illustrated with the blue column in figure 2.

Interpretation of the digital displacement models

In figure 2, it is possible to discover systematic influences in the form of horizontal lines with significantly bigger displacements. If we display measurements and individual points in distance model 31, we find out that bigger displacements are always caused by the individual points and that they are not areal (see figure 3).

In figure 1, there are visible horizontal I-profiles on the gate. The original idea that the observed phenomenon are caused by stronger displacements of these profiles did not prove true. It was found that bigger displacements are caused by the fall of a laser beam of non-zero diameter (for the usable system it is approximately 5mm) on the edge of I-profile and therefore by reflection on differently distant surfaces. The biggest deformations were found in a line of points (bordered in figure 4 with a green frame).

It came to a similar effect in the upper part of the visible area of the gate, where a technical deck with a handrail was placed. The internal process of the laser scanner during evaluation of reflection on the interface of differently distant surfaces is not known, and therefore these points were excluded from other analyses (on the basis of our experience, it is possible to suppose that even a small change in the rate of surface areas of the falling laser beam on differently distant surfaces can cause a significant change in the measured distance). The points were excluded in case the difference in size of their displacement from an average displacement in their surroundings surpassed the empirically found standard deviation of displacement more than two and a half times. This process ran automatically as a part of the average displacement method that is described below.

The average displacement method

An interesting possibility on how to present measured data is the average displacement method. It was first published in 2007 (Pospíšil, Koska and Křemen) and is based on averaging results from the digital displacement model in areas in which identical displacement is supposed.

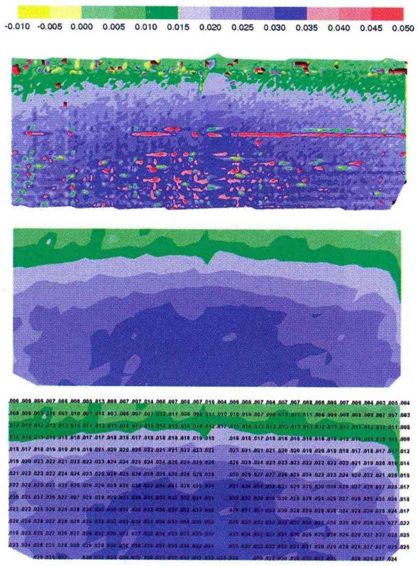
This method enables simpler interpretation of the results, higher accuracy and, eventually, automatic exclusion of the outlying measurements (errors). The average displacement method is based on the least squares method and its results are broadly free of accidental errors.

In figure 5, we can see three different possibilities of how to evaluate and present the digital displacement model number 31. The original digital displacement model is stated first for purposes of remembering and comparison, then the average displacement method with square size of 1m is stated and, in the last case, the previous display is added by numeric values of average displacements. Measurements for which the absolute residual was more than two and a half times bigger than empirical standard deviation were automatically excluded from the calculation.

We subjectively consider the last possibility as the most suitable method of evaluation and presentation, i.e. the average displacement method with numeric display of sizes.

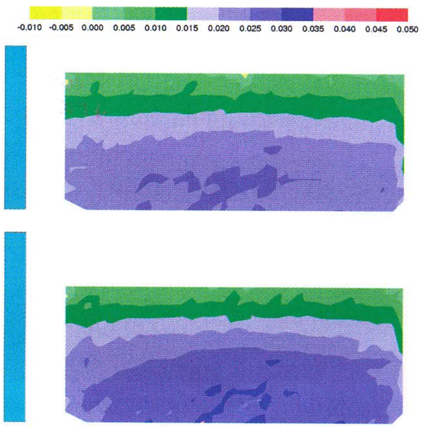
Creation of displacement animation

Digital displacement models of the lock chamber gate during filling were graphically represented in the same way for each of 30 measurements. A video animation was created from these figures. Representation of displacement models from measurements number 20 and 25 (differences in water levels 15.5m and 18.1m) is shown on figure 6.



(Left) Figure 5: Various displays of displacement for measurement no. 31.

(Below) Figure 6: The digital displacement model from measurements number 20 and 25.



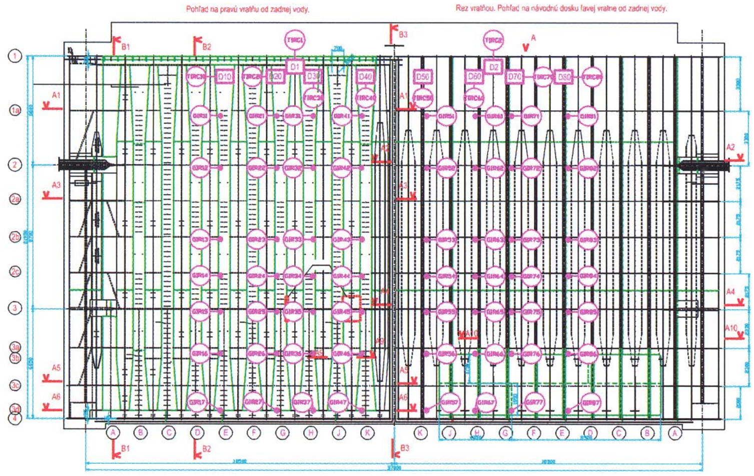


Figure 7: Scheme of placing the sensors of the electronic measuring system.

Comparison with electronic measuring system

A sensor field electronic deformation measuring system was placed in the gate of the lock chamber. This system was managed by the VÚEZ engineering, manufacturing and installation company. Location of the sensors can be seen in figure 7.

48 sensors were placed in the gate and marked as GIR11 to GIR86. The time necessary to subtract values of all the sensors is two minutes and the individual stages follow one after another without time out. The standard output of this system is a table with values taken from the individual sensors and its graphic representation (figure 8).

Figure 9 shows the results from the electronic system in the same way as the results from our measurement. The displayed results were interpolated for time in accordance with our measurement 31. The horizontal blue line represents the current lower water level in the lock chamber and therefore the border of the area measured with the scanning system.

The next logical step was comparison of the results from both methods. The best method for comparison is again hypsometric representation of the digital displacement model. Differences for 25 and 31 measurements are stated. The measurements were first adjusted by the average displacement method with an area of 1m.

In figure 10 it is obvious that results from both methods are different and the difference is more significant in the case of bigger deformations. The displacements determined by the laser scanning method are 5-15mm bigger in the lower part of the visible area of the gate and in the upper part they are 0-10mm smaller. We failed to obtain explication of the detected differences from the VÚEZ electronic measuring system.

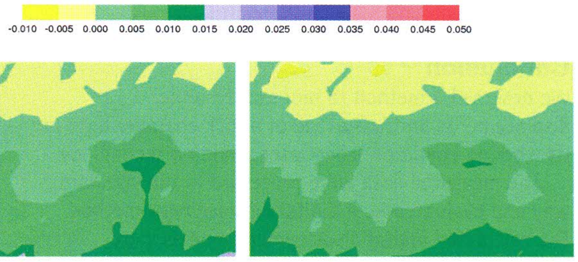


Figure 10: Difference in the results of both methods for 25 and 31 measurements.

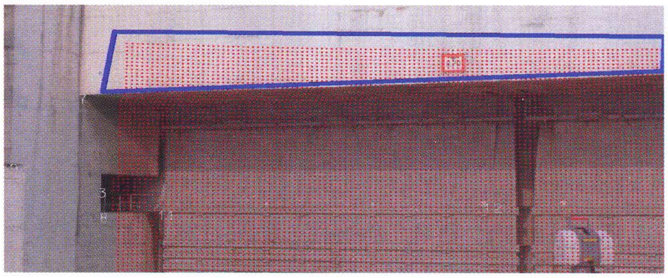
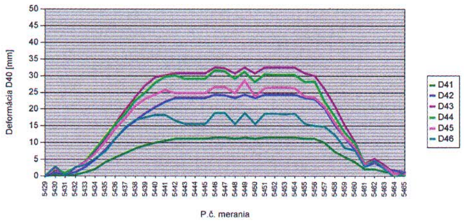
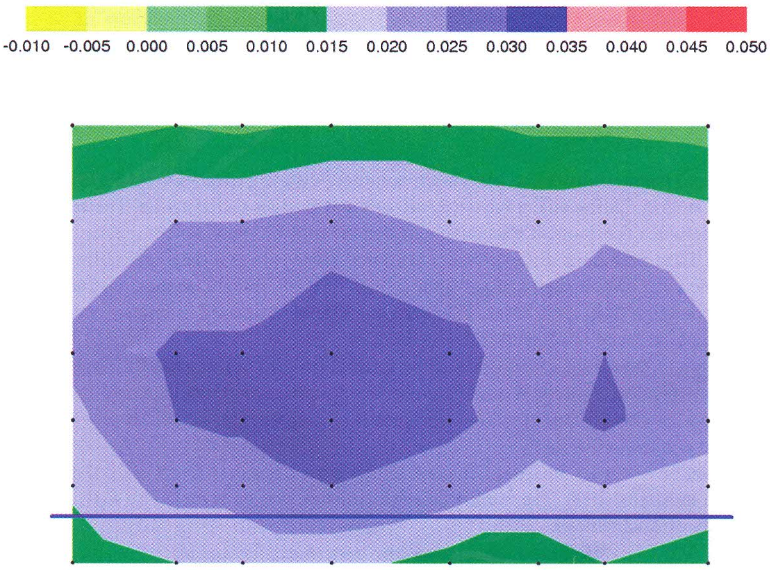


Figure 11: The measured area without displacements.



(Left) Figure 8: Graphic representation of shifts on the sensors of the fourth column.

(Below) Figure 9: Hypsometric representation of the results from the electronic measuring system.



Accuracy analysis

Beside the gate, part of the surrounding walls was measured, where no displacement was expected (see figure 11). Standard deviation of the different methods could then be estimated in these points. Standard deviation was set on the basis of the same method by which the other data were evaluated, i.e. from the digital displacement model.

In the case of non-deformed areas, the results of the distance model should be zero in an ideal case. In our case, the results for several measurements are summarised in table 1.

Differences from meas.n	From points (m)	From averages (m)
01m02	0.0020	0.0004
20m02	0.0020	0.0006
30m02	0.0023	0.0013
31m02	0.0023	0.0011
Average	0.0021	0.0009

Table 1: Standard deviations of displacement determination.

It is obvious that results from both methods are different and the difference is more significant in the case of bigger deformations.

In the first column there are standard deviations determined from the differences in the individual points and in the second column there are standard deviations determined from averages of 1m squares.

On the basis of the above testing, it is possible to estimate standard deviation of one point at 2mm and tens of points at 1mm. These values are in accordance with the results of testing in different conditions (Pospíšil, Koska and Křemen 2007).

Conclusion

We designed a method to monitor dynamic displacements on the surface of a lock chamber gate in its working condition using laser scanning technology.

The measured data were processed in the standard way and evaluated by a digital displacement method. The calculated digital displacement models were adjusted by the average displacement method, for purposes of simpler interpretation and presentation.

The method was compared with an electronic measuring system placed in the gate. Significant differences were detected in the results of both methods. We believe laser scanning technology is both suitable and can be used in the surface monitoring of dynamic displacements of the lock chamber gate.

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References and acknowledgments

Pospíšil J, Koska B and Křemen T (2007), 'Using Laser Scanning Technologies for Deformation Measuring', *Optical 3-D Measurement Techniques*, Proceedings of the 8th Conference on Optical 3-D Measurement Techniques, Zurich, Swiss Federal Institute of Technology

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