MONITORING OF LOCK CHAMBER DYNAMIC DEFORMATION

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Abstract: Measuring deformations is an important part of geodetic works during carrying out and supervising of various engineering projects. Most used methods currently used for measuring deformations are methods using the total stations and GNSS technologies. An interesting possibility in the area of measuring deformations is the laser scanning technology. This technology does not reach such accuracy for the individual points as in case of the exact total stations or of the long-term GNSS observation but it overruns this drawback in measuring speed, point density and complexity of surface record. This technology can be even used for monitoring of dynamics processes because of its very high measuring speed. Experimental using of the laser scanning technology for monitoring of areal dynamic deformations of the lower lock chamber with huge size 37 x 22 meter is presented in the paper. The process of lock chamber filling and emptying is monitored by the laser scanning system Leica HDS3000. Various interpretations of acquired data are considered and the data accuracy is analyzed. The results are compared with the results of electronic measuring system which is placed in the inner area of the lock chamber door. The electronic system measures relative deformation at 48 points.

1. INSTRUMENTATION, LOCALITY AND DESCRIPTION OF THE MEASUREMENT

The Leica HDS3000 (fig. 1) laser scanning system was used in the experiment. This system consists of the HDS3000 laser scanner and the Cyclone software. The basic specifications of the system are: standard deviation of distance 4 mm, standard deviation of vertical and horizontal angle 60 micro-radians (4 mgon), optimum working range 1 – 100 meters, laser beam diameter 5 mm at 50 meters, measuring speed 4000 points per second.

Figure 1 - The Leica HDS3000 laser scanner

The measurement took place in premises of the Gabčíkovo hydroelectric plant in the working condition. A suitable standpoint of the instrument with maximum view of the measured gate (see fig. 2) was selected.

Proportions of the gate are approximately 37 x 22 meters, proportions of the visible part approximately 32 x 12 meters and average difference in heights of water levels when the chamber is filled is 20 meters. With respect to time of filling or letting out the lock chamber, which is approximately 25 minutes, spacing of points on the gate was selected 0.2 x 0.2 meters and the whole visible plane of the gate with a little overlap was focused. Time of one measurement with this setting is approximately 40 seconds. Because of high measuring speed, it was possible to abandon the original plan to stop the process of filling the chamber every time the water level changes by one meter, because this procedure is very demanding.

The measurement was carried out in the shortest possible intervals and it was synchronized 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 meter were announced to us from the control tower and we noted down times to them.

An important fact is that neither 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 in the same points (see fig. 2).

Figure 2 - Location of the Leica HDS3000 system during experiment on the left and position of measured points and selection of coordinate system on the right

2. EVALUATION OF THE MEASURED DATA

The basic method of evaluating deformations is the digital terrain model (DTM) of differences further called the 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* were placed in direction of the expected displacements. Axis *X* was concretely placed in longitudinal direction of the gate, axis *Y* was oriented into the zenith and axis *Z* completed the mathematical (clockwise) system of coordinates (see fig. 2). The Atlas DTM software version 4.3 was used to create and to analyse the digital models and digital displacement models.

Before generating 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 DTM, does not enable to work with overhangs.

2.1. Creation of the digital displacement models

At first, DTM 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 beginning of filling the lock chamber.

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 blue column (see fig. 3).

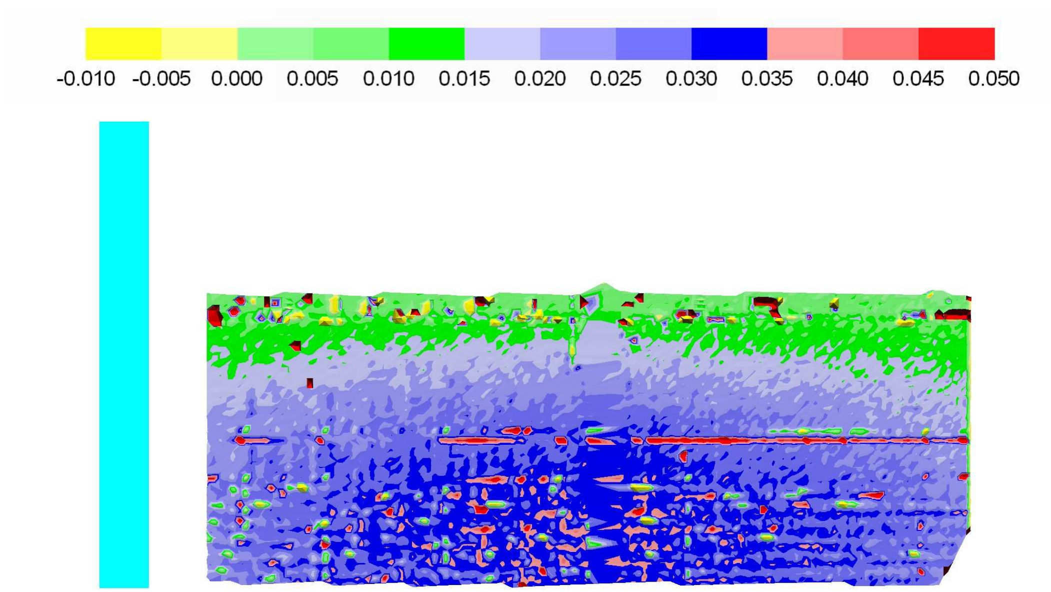

Figure 3 - Digital displacement model of the measurement number 31

2.2. Interpretation of the digital displacement models

In fig. 3 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 fig. 4).

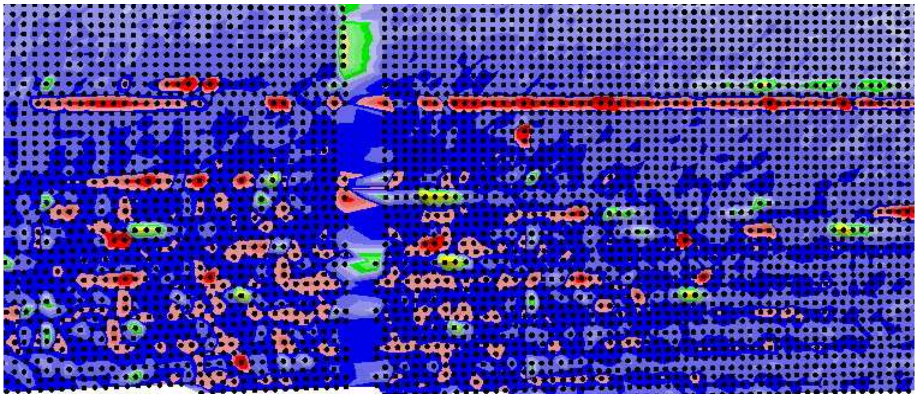

Figure 4 - Cut of digital displacement model number 31 with depicted measured points

In fig. 2 there are visible horizontal I-profiles on the gate. The original idea that the observed phenomenon are caused by stronger displacement of these profiles did not prove true. It was found out that bigger displacement are caused by fall of a laser beam of non-zero diameter (for usable system it is approximately 5 millimetres) on the edge of I-profile and therefore by reflection on differently distant surfaces. The biggest deformations were found out in a line of points bordered in the following figure with a green frame.

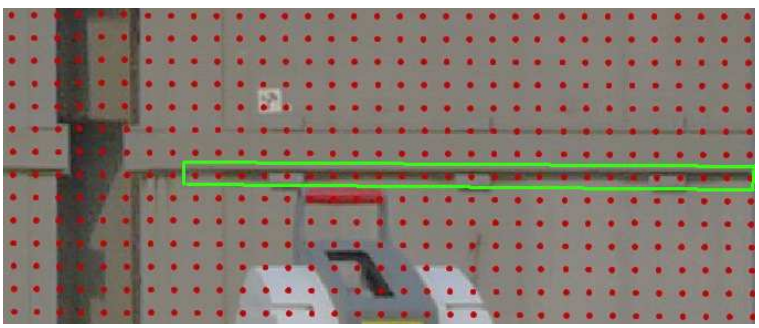

Figure 5 - Points with the biggest shift

It came to a similar effect in the upper part of the visible area of the gate, where a technical deck with a handrail is placed.

The internal process of the HDS3000 system 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 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 that difference in size of their displacement from an average displacement in their surroundings surpassed the empirically found standard deviation of displacement more than two times and a half. This process ran automatically as a part of the average displacement method that is described below.

2.3. The average displacement method

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

This method enables simpler interpretation of the results, their higher accuracy (see chapter Accuracy analysis and (Pospíšil, Koska and Křemen 2007)) and eventually also 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 the following picture we can see three different possibilities how to evaluate and present 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 of size 1 meter is stated and in the last case the previous display is added by numeric values of average displacements. Measurements, which absolute residual was more than two times and half bigger than empirical standard deviation, were automatically excluded from calculation.

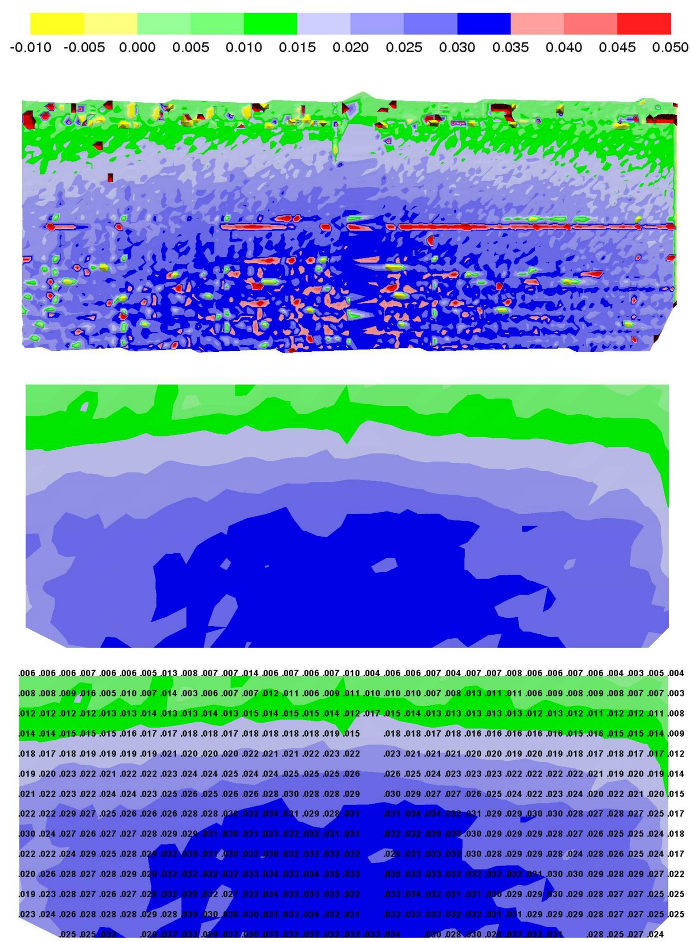

Figure 6 -Various displays of displacement for measurement no. 31

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

2.4. Creation of displacement animation

Digital displacement model of the lock chamber gate during filling were graphically represented in the same way for each of thirty measurements. A video animation was created from these figures.

Representation of displacement model from measurements number 20 and 25 (differences in water levels 15.5 and 18.1 meters) is shown on the following figure.

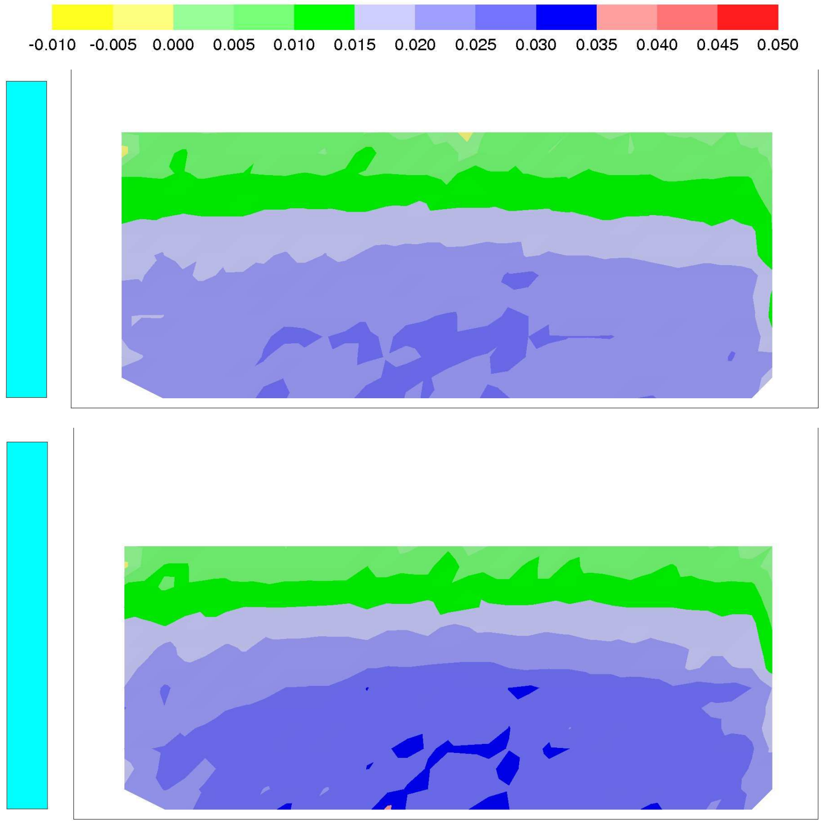

Figure 7 - The digital displacement model from measurements number 20 and 25

3. COMPARISON WITH THE ELECTRONIC MEASURING SYSTEM

An electronic measuring system of deformations is placed in the gate of the lock chamber by means of sensor field for reasons of safe operation. This measurement is ensured by the VÚEZ, a.s. company. One of the reasons of realization of our experiment was comparison of the laser scanning technology with the results of the stated system. Location of the sensors in the gate can be seen on fig. 8.

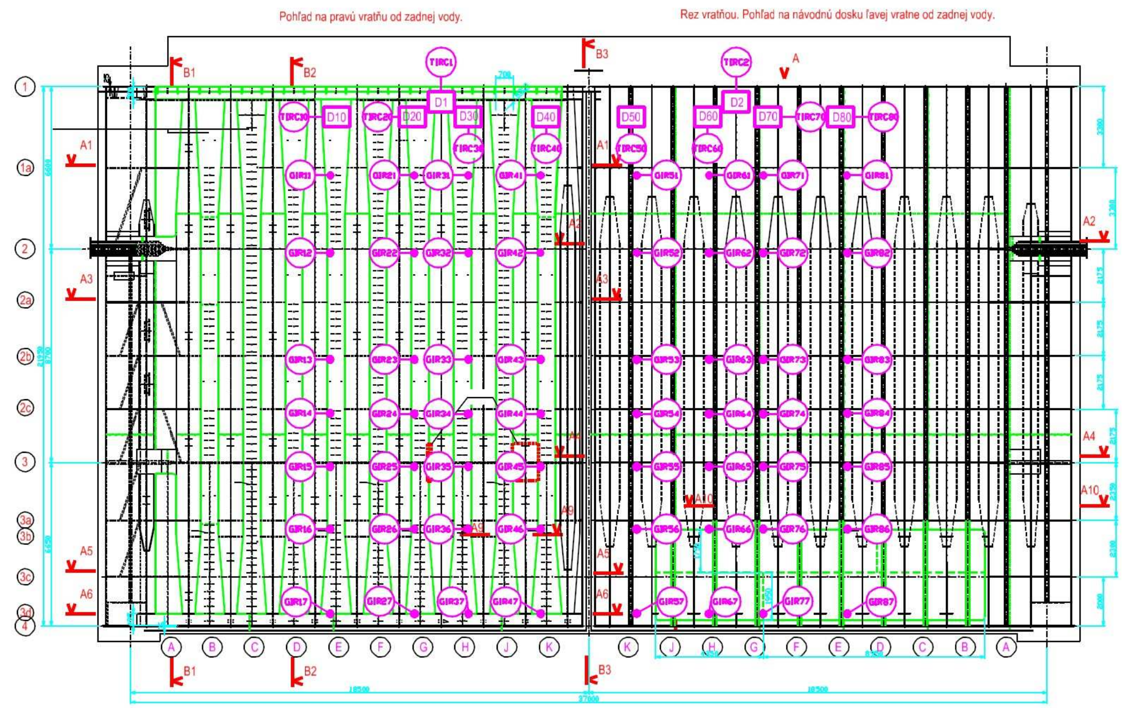

Figure 8 - Scheme of placing the sensors of the electronic measuring system

48 sensors are placed in the gate and they are marked on fig. 8 as GIR11 to GIR86. Time necessary to subtract values of all 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 (fig. 9).

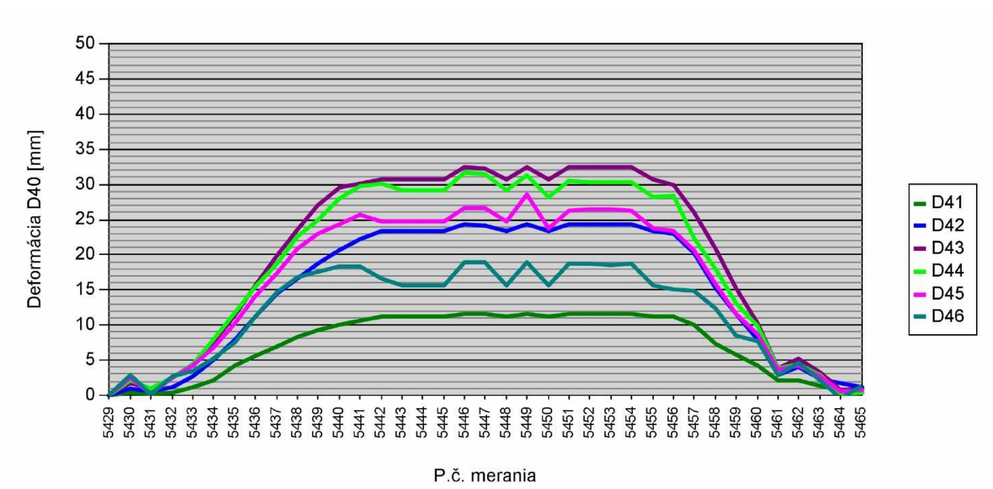

Figure 9 - Graphic representation of shifts on the sensors of the fourth column

The following picture shows the results from the electronic system in the same way as the results from our measurement. The displayed results were interpolated for time agreeing 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.

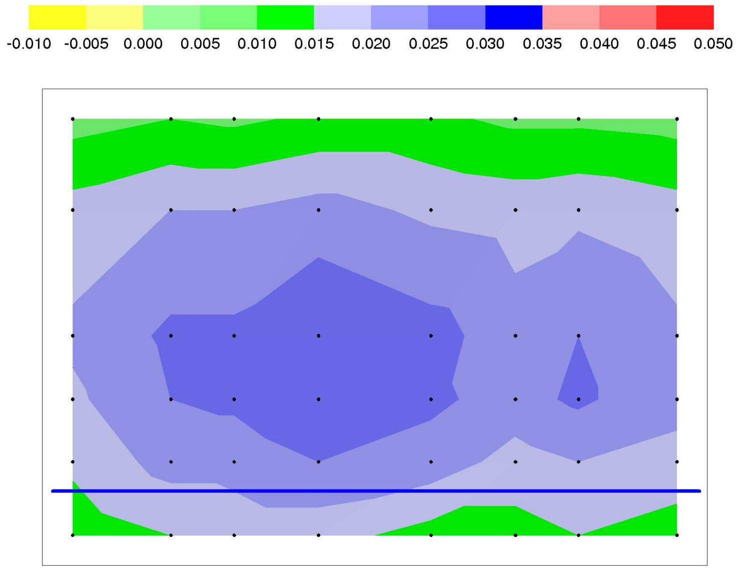

Figure 10 - Hypsometric representation of the results from the electronic measuring system

The next logical step is 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 area size 1 meter.

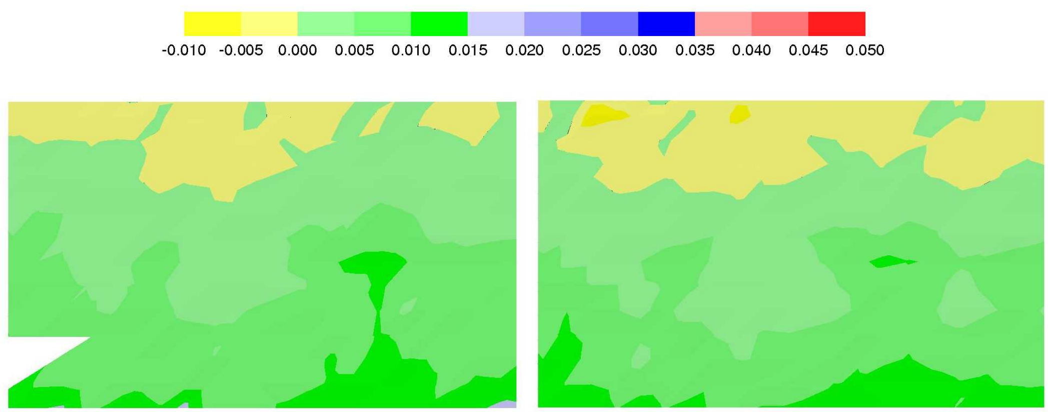

Figure 11 - Difference in the results of both methods fot 25 and 31 measurements

In fig. 11 it is obvious that results from both methods are different and the difference is more significant in case of bigger deformations. The displacements determined by the laser scanning method are 5 to 15 millimetres bigger in the lower part of the visible area of the gate and in the upper part they are on the contrary 0 to 10 millimetres smaller. We failed to obtain explication of the detected differences from the VÚEZ, a.s. company ensuring the electronic measuring system

4. ACCURACY ANALYSIS

Beside the gate, also the part of the surrounding walls was measured, where no displacement were expected (see fig. 12). Standard deviation of the used methods in conditions of the measurement could be estimated in these points. Standard deviation is set on the basis of the same method by which the other data were evaluated, i.e. from the digital displacement model.

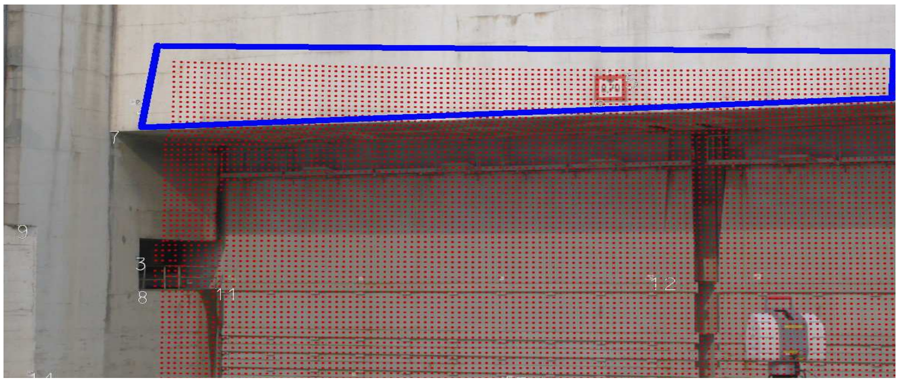

Figure 12 - The measured area without displacements

In 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 summarized in tab. 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

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 squares with side of length one meter.

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

5. CONCLUSION

We designed a method of surface monitoring of dynamic displacements of the lock chamber gate in the working condition with using the laser scanning technology.

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

Accuracy of the used method was estimated on the basis of the experiment.

The method was compared with the electronic measuring system placed in the gate. Significant differences were detected in the results of both methods.

We proved utility and suitability of the laser scanning technology for surface monitoring of dynamic displacements of the lock chamber gate.

Acknowledgments

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References

Pospíšil, J., Koska, B. and Křemen, T. (2007). Using Laser Scanning Technologies for Deformation Measuring, In: Optical 3-D Measurement Techniques, *Zurich 2007: Proceedings 8th Conference on Optical 3-D Measurement Techniques*, Zurich, Swiss Federal Institute of Technology.

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