CONTROL NETWORK ANALYSIS OF THE DAM „WIÓRY"

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INTRODUCTION

Classical techniques of measurement require optical visibility between the measured points of a control network. Monitoring engineering objects also requires that the points or benchmarks be placed outside the area affected by the monitored object. Moreover, the reference points have to be checked for their stability, so mutual visibility between reference points is advisable. In optical measurements, atmospheric conditions are also of great importance. Fog, rain or low temperatures may hamper considerably or virtually make measurements impossible. Fluctuations of atmospheric conditions influence the quality of optical observations and not always can one take them into account in the form of appropriate corrections. In the case of periodic measurements when in subsequent observation periods measurements are made in different weather conditions, their influence is of the systematic character and can be wrongly interpreted as a point movement.

At present, many engineering objects are monitored by means of systems which integrate different kinds of measurements. All the greater role is played by satellite GNSS measurements which, combined with classical measurements and measurement results obtained with inclinometers, piezometres , extensometers, etc., enable to build complete monitoring systems. However, before such a monitoring system is constructed, land surveyors usually set up a control network, which functions as a basis for checking the changes in the object geometry. The paper presents the development work connected with the modernization of a control network of the dam "Wióry" with respect to a combined application of GPS and classical measurements.

CHARACTERISTICS OF THE OBJECT WIÓRY

The water storage basin Wióry was created after damming up the waters of the River Świślina below the place where it is joined by the River Pokrzywianka in the Świętokrzyskie Mountains. The reservoir is situated in three municipalities: Pawłów, Kunów and Waśniów to meet the following aims:

- **incidental flood control in the catchment area of the River Kamienna,**
- **to stabilize the amount of water flowing beneath the dam,**
- **to produce electric energy,**
- **for recreation and tourism.**

The 21- metre- tall dam is situated several kilometers below the village of Doły Biskupie. It took almost 25 years to build the reservoir (the construction started in 1980 and finished in 2005). The reservoir extends over 400 hectares and its total capacity is 35 million m^3 (its flood pool capacity is nearly 19 million m^3 and operational capacity – 1 million m^3). Below are some selected technical data , Figures 1 and 2 present the general view of the dam from the upper and lower water level, respectively.

Fig. 1. View of the dam from the upper water level.

Fig. 2. View of the dam from the lower water level.

Elevation level	Height	Area	Capacity	Average depth
Max.	214.8 m above seal level	408 ha	35 000 000 m^3	8.58 m
Norm.	208.9 m	257 ha	16 000 000 m^3	6.45 m
Min.	208.5 m	248 ha	15 000 000 m^3	6.05 m

GPS MEASUREMENTS

GPS measurements were made with four two-frequency receivers 4700 by Trimble Navigation Ltd and two bi-frequency Leica 1200 receivers by Leica-Geosystems. Four geodesic antennas Microcentered L1/L2 and two of the Choke Ring type were used for measurements. Static technology was used to make observations, assuming that the measuring time will be two complete days for four points of the existing network (101, 104, 122, 125) and one day - for two additionally stabilized points (151, 152). The first four points are placed outside the object and constitute a set of reference points to check point displacements of the dam, while points 151 and 152 are checkpoints located at the crest of the dam (Fig.3).

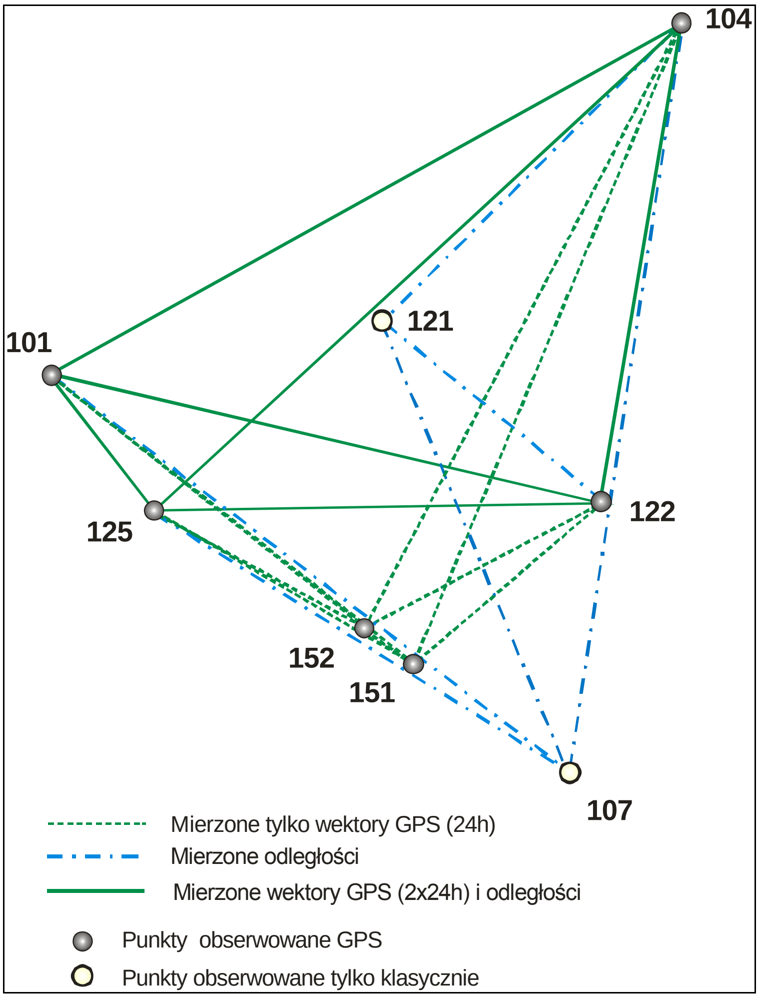

Fig. 3. Network sketch.

Observations were gathered every 15 seconds via satellites positioned at least 10° above the horizon. Moreover, it was assumed that the vector between points 101 and 104 would

be first measured with standard (geodesic) antennas and next with precise Choke Ring antennas. The aim of such an experiment was to assess, to what extend the application of precise antennas will improve the quality of signal tracking and eliminate multipath effect.
GPSurvey 2.35 software package made by Trimble Navigation Ltd was used to process GPS observations. The observations were processed in the WAVE mode, making use of broadcast ephemerides and satellites positioned more than 10° above the horizon. Further, it was assumed that for specified vectors one should achieve the solution L1 fixed, denoting the determined ambiguity of carrier wave L1. The additional criterion was the ratio coefficient (it a numerical value of variation coefficients ratio for the best two determinations of number N), which should not be smaller than 1.5. The assumed criteria were achieved for all calculated vectors of the network.

NET ADJUSTMENT

There were two alternative versions of the net developed. In the first one, only GPS observations were adjusted - with a centering error of ±0.3mm and assuming that all vectors were defined with similar accuracy. For such an assumption the net was iteratively adjusted , scaling mean observation errors so that a typical net error was close to one (the value 0.99 was obtained). On adjustment, the values of mean errors of coordinate net points were in the ±0.3mm - ±0.6mm range, which indicates high observation compatibility in the net but does not reflect its real accuracy. This accuracy seems to be 3 to 5 times overestimated.
In the second version, besides GPS observations, all lengths measured in the net were adjusted. The centering error assumed in the adjustment equaled ±0.3mm and the mean length measurement error - ±1.5mm. Mean GPS observation errors, similar as in the first version of adjustment, were scaled so that a typical net error was close to one on adjustment. The obtained coordinates of net points changed in relation to the previous adjustment (in relation to point 101) by as much as 4mm and their mean errors , on average, increased twice , being in the ±0.6mm - ±0.2mm range. It should be also added that length corrections measured between GPS points were almost all negative (the average length correction was -2.3mm), which goes to show the systematic character of the difference between GPs observations and length measurements. It seems that one of the causes here may be the influence of an atmospheric correction but the final verification of this thesis requires additional experiments.

LENGTH MEASUREMENTS IN THE CONTROL NETWORK

Classical measurements were made by means of a precise measurement technology, making use of motorized TD 5005 tachymeter (fig. 4). This tachymeter belongs to a group of industrial instruments of a length measurement accuracy of the 0.1- 0.9 mm range. The TDA set is additionally equipped with an ATR (automatic target recognition) system as well as that of servomotors , by means of which it is possible to obtain measurement data quickly and objectively. In order to obtain high accuracy, high precision prism reflectors were used and for target measurements - CCRs (corner cube reflectors), as well as certified return?/ reflex? signals.

Fig. 4. TD 5005 Tachymeter.

All observations were corrected atmospherically and geometrically. Targets in the basic network were observed "from both sides" , obtaining very good inner compatibilities (<0.5 mm). A small number of net angles were measured by means of a directional method and these observations should be treated as auxiliary, improving the geometrical accuracy of a net structure. The following accuracy characteristics were assumed for adjustment:
md=+ -0.5mm, mk = 7^{cc}. In a situation like this the classical network underwent the adjustment at mo=0.8, which confirms high quality of observations.

SUMMING UP AND FINAL CONCLUSIONS

The obtained results of the test measurements in the control network of the dam Wióry show that combined usage of length measurements and GPS observations enables to obtain high accuracy and reliability in defining point coordinates. The real determination accuracy of checkpoint displacements in this type of networks is at the level of ±2-.3mm.
However, it should be added that in small networks covering an area up to 1 km in radius, classical measurements (most of all, length measurements) enable to obtain higher accuracies in determining point coordinates, obviously on condition that the net structure is well-designed and length measurement is possible. Having analyzed the obtained results, one can also formulate the following conclusions:

- **the assumed structure of a modified test network shows effective accuracy both for EDM measurements and GPS observations,**
- **satellite measurements enable combined and direct observation of points between which there is no sight line. It is especially important in the case of reference points which are usually located around the monitored object, and it is rarely possible to link them by means of classical measurements;**

- **GPS measurements make it possible to check the monitored network independently, at least limiting the incidence of major and systematic errors in processing the results and defining displacement values; so GPS observations may, in the case of small control networks, be treated as control measurements made periodically (e.g. every year);**
- **accuracy assessment made for TDA5005 tachymeter observations even in the case of considerable target inclinations, made by means of standard reflectors, attested reflexive foil and CCR fulfills monitoring requirements of specific point (targets), enabling to obtain an accuracy of the ±0.5mm range in relation to reference points;**
- **linear measurements in the test network of Wióry, made by means of a TDA5005 tachymeter and high precision reflectors can be accomplished within 2-3 days.**

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