METHODOLOGICAL BASIS OF CONTROL NETWORK MODERNISATION IN HUGE HYDROTECHNICAL STRUCTURES
LIELU HIDROTEHNISKO OBJEKTU VADĪŠANAS TĪKLU MODERNIZĀCIJAS METODOLOĢISKĀ BĀZE

JANINA ZACZEK-PEPLINSKA

Institute of Applied Geodesy, Warsaw University of Technology,
Plac Politechniki 1, 00-661 Warsaw, Poland, *e-mail*: j.peplinska@gik.pw.edu.pl

Abstract. *Water dams are typical structures which require cyclic and in some cases, permanent control of their conditions. Most of the Polish damming structures are more than fifty years old and funds assigned for their renovation and effective conservation are being continuously reduced. Therefore, it is vital to improve the control of those structures.*

Cyclic geodetic measurements of movements are obligatory elements of control measurement schedule and are important for evaluation of damming structures security. Complex modernisation of geodetic network for movement examination consists of many actions, which goals are:

- *Reactivating devastated network structure,*
- *Modernisation of geodetic process of structures movements determination (concerning steps: measurements and data elaborating),*
- *Enhancing the accuracy of geodetic measurements,*

Increasing a credibility of the movement measurements results.

Keywords: *engineering-industrial geodesy, controls survey of dams, geodetic network, water dam.*

Introduction

Water dams are typical structures which require cyclic and in some cases permanent control of their state. Most of the Polish damming structures are more than fifty years old and funds assigned for their renovation and effective conservation are being continuously reduced. Therefore, it is vital to improve the control of those structures.

In Poland exist 174 water damming structures, which are classified into the 1st and 2nd classes (water damming above 10 m), according to the obligatory classification of importance; their catastrophe would result in considerable material losses and would cause threat to health and life of many people [8].

The age of constructions, as well as the influence of the natural forces, is the crucial factors of water-buildings devastation, which are frequently additionally enhanced by insufficient examination of the geodetic or hydrologic foundations, designers' mistakes, poor quality of building execution, inconsequent realisation of river development programmes and delays in renovation.

Present state of geodetic control

Geodetic control networks for the needs of movements examination.

Cyclic geodetic measurements of movements are obligatory elements of a control measurement schedule and are important to evaluate damming structures security. During the first stage of the movement determination process for a given object a network of control points is established in the course of construction, which is then observed using surveying methods (measurements of angles, distances and elevations) within the entire period of operations performed by the object. Co-ordinates of those points are determined in an external reference system which is independent on conditions of the investigated structure [2], [4].

The term „geodetic network" is very wide and covers: points of the network (their location, construction and equipment), geometric elements of the network (measured angles, directions, distances, differences in elevation), measurement technology and methods of presentation of results.

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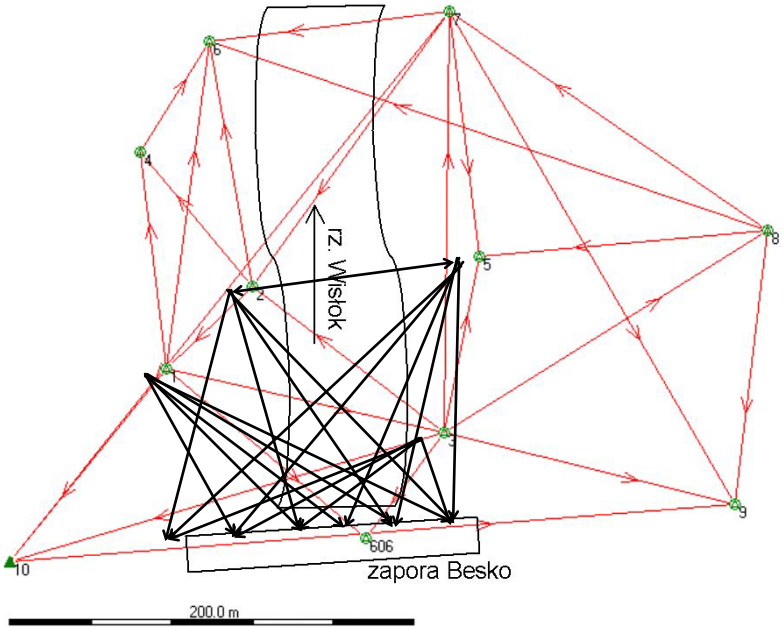
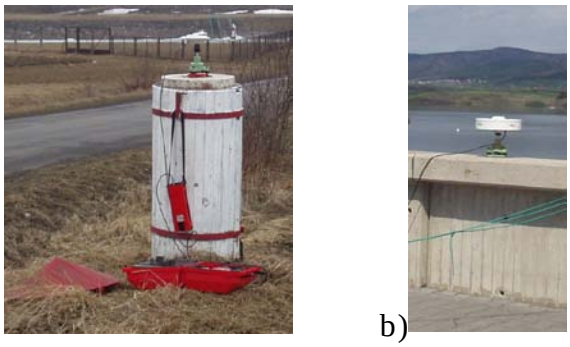


Fig. 1. **A conventional geodetic control network**



a) b)

Fig. 2. **Construction of points in a geodetic control network (during GPS survey):** *a – a reference point, b – a point on a copping of the water damming object*

Suggestions how to solve a problem

Modernisation of a control network.

The term "modernisation of a geodetic control network" should be understood as re-designing and adaptation of the existing network to current needs and utilisation of that network for an object, which plays its roles related to economy, flood protection, tourism, recreation and sport.

In the process of modernization method of measurements are adapted to requirements of modern technology, which will be applied in the modernised network.

Experiences from the past object monitoring should be considered in the process of modernisation.

Necessity to modernise the control network.

The necessity to modernise the control network may result from:

a) degradation of the network (damaging the network in time),
b) economic factors:
   – connected with costs of the network maintenance,
   – connected with costs and time required by performed measurements,
c) introduction of new technologies of measurements (such as GPS),
d) development of communication possibilities between various measuring instruments and the controlling unit,

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e) the necessity to increase the accuracy of geodetic measurements.

Objectives of the control network modernisation.
The basic objectives of the network modernisation are:
- reactivating devastated network structure,
- modernisation of geodetic process of structures movements determination (concerning steps: measurements and data elaborating),
- increasing credibility of the movement measurements results.

Advancement of the control network modernisation.
Advancement of geodetic modernisation depends both on needs and financial as well as technical possibilities of the owner and users of the object. The network modernisation may include:
- Modernisation of one of the network elements, e.g. change in network geometry, rising the efficiency standard of measurement process, creating new computational algorithm, considering additional measurement data;
- Updating many, mutually connected elements of the movement analysing process (e.g. measurement technology and computing of movements data);
- Adding new elements to the existing network – e.g. expanding the network by adding new points, measurement gauges, considering additional measurements and/or new methods of control of measurement reliability.
- In the case of general overhaul and reconstruction of an structure, complex modernisation may be performed, which can include all above aspects.

Assumptions for the process of modernisation.
Modernisation does not mean creating the network from the very beginning; therefore it should be based on the following assumptions:
- Introduction of only those changes which are required, considering the lowest possible financial inputs,
- Widening the measuring process with geometric data collection, as, for example, with the use of feeler gauges, inclinometers and other, non-geodetic data, such as hydrological data (indications of piesometers, volumes of filtration etc.), for the control purposes, in order to increase the reliability of measurement results. In the case of the Automated System for Technical Control of Water Dams (Polish abbreviation ASTKZ) new points should be introduced to the network, which will allow to connect geodetic measurements with hydrotechnical and geometrical measurements, which are performed locally (relative measurements, not referred to an external reference system),
- In the future successive network modernisation should be possible, connected with the use of new measurement technologies and new methods of elaboration of measurement results.

Limitations for geodetic network modernisation.
The basic limitations in the process of modernisation:
a) resulting from location and methods of stabilisation of points of geodetic networks and from distribution and types of gauges used for non-geodetic measurements,
b) resulting from the specific features of construction of hydro technical structures,
c) geologic conditions which occur around the structure,
d) connected with real estate property rights (which mainly concern areas surrounding the structure, where new network points are to be located),
e) resulting from the nature conservation regulations, concerning assurance of required visibility between network points,

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f) in location of new points, resulting from location of living-and-social facilities of an structure, as well as location of housing and industrial areas within surrounding areas (which are often centres for tourism, recreation and water sports),
g) financial, connected with the amount of funds assumed by owners of an structure for modernisation of the network.

Introduction of satellite measurements technology during the geodetic network odernisation.
More than 10 – 20 years have passed from the beginning of construction/ exploitation of the majority of water damming objects. One should also remember about historical objects, which were constructed 100 – 150 years ago or more; which survived after the war and which exist and are currently used, what is economically justified. Cyclic monitoring must also be performed for unused historical structures (for example after the change of the river course), considering their size, in order to ensure security of their constructions.
New measurement technology has become available since the moment of designing and implementation of control networks for those structures; this concerns, in particular, satellite methods (which use signals emitted by satellites of the following systems: GPS -Global Positioning System, GLONASS and GALILEO). Besides their advantages concerning simplicity and speed (GPS RTK – Real Time Kinematic) of measurements, as well as lower constraints concerning point location (no necessity to maintain visibility), the possibility to increase the network scope without the necessity of higher inputs for obtaining comparable accuracy, those methods have also limitations, for example long observation time required for high accuracy (GPS Static), limitations concerning the place of measurements: free horizon, low density of houses and other constructions, location of points far from power supply lines, from axes of radio links, telecommunication masts etc. [1], [6].
Possibilities of performing satellite measurements were not taken into consideration when the existing control networks were designed; points of those networks are often located close to emitters, which cause breaks or disturbances of received signals or they are located at such places where the required horizon is not ensured, for example on steep slopes (this problem occurs mainly in mountainous areas). Sometimes network points are located close to rich vegetation without the possibility to cut it out (this concerns structures located within Landscape or National Parks and within their protection zones).
Another issue concerns location and methods of stabilisation of measuring symbols on a given structure. Besides copping of water dams, where satellite measurements do not cause any troubles, technical elements of sluices, bottom reservoirs, power supply stations are also controlled. In such places there is often no possibility to perform correct satellite measurements as it is impossible to introduce points to a network.
In the process of development and adaptation of the control network to satellite measurements, apart of assuring the geologically stable foundations for points, particular attention should be paid to appropriate construction of points (devices for forced centering), as well as to assurance of the full and uncovered horizon for satellite observations and to lack of radio waves emitting installations located close to the network points (sources of disturbances of satellite signals).

Anticipated issue

Consideration of non-geodetic data in the process of movements examination.
Besides measurements of the geodetic control network, relative measurements are performed for each object, which determine for example changes of inclination to the horizontal plane and deflections of constructional elements from the vertical line, as well as changes of width of expansion joints. Besides those typical geometric values, hydrological data, as well as current information concerning external and internal conditions of an structure, are also registered (temperature and humidity of the air). The majority of sensors are located in control galleries (inside embankments).

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Fig. 3. **A typical control gallery of a water damming structure**

Possibility of control of geodetic measurements of movements basing on additional data.
Additional data used in the process of control of geodetic measurements may include:

- results of levelling (for the control of measurements of horizontal networks),
- geometric data (acquired from relative measurements performed with the use of such instruments as feeler gauges, inclinometers etc.
- data from gauges and direct registering units, e.g. hydrological data, (indications of piesometers) and from units registering external conditions (i.e. temperature and humidity).

Additional geometric data allow to determine foreseen direct relations, for example: the change in elevation will influence the oblique distance between points, the change of the width of an expansion joint may be disclosed in the value of observed angles and distances in the network, between points located in concrete block of adjacent sections of the construction [7].
Data from geotechnical and hydrological gauges and registering units (changes in indications in the period which directly precedes control measurements and forecasts based on performed interpretation of measurement results for the past multi-year periods), may be used for determination of the so-called areas of uncertainty – geodetic measurements of points located within those areas should be performed with particular attention and it should be repeated, if there is no confirmation of changes in additional data. It should be pointed that such confirmation cannot be the condition of continuation of measurements – the nature of data registered by the discussed gauges differs from the nature of data acquired from geodetic measurements and those data cannot be considered at the same level of reliability. Additional data should be considered as control data only at the level of initial, field elaboration of measurement results.
Consideration of additional data in the process of elaboration of results of geodetic network measurements.
Consideration of additional data should be performed by means of implementation of a calculation module, which uses geometric and non-geodetic data in the process of geodetic data control, besides routine results of measurements of a horizontal geodetic network.
Basing on long-term measurements, external (e.g. atmospheric) conditions, the current structure conditions (e.g. the water level in the reservoir) and current measurement data, the calculation module (which ensures additional data control, besides the currently applied control) would generate conclusions concerning modifications of plans of performed measurements.
Data control should be performed at the time when measurements are performed (if the measuring equipment allowing for the current transfer, storing and analysis of measurement data is available) or directly after completion of measurements, before the working team completes its visit to the structure (the initial field checking), in order to allow repeating or amending performed observations with additional elements (angles, distances) [7].
Increase of reliability of geodetic measurements.
Possibility to detect erroneous observations requires supernumerary observations which ensure information surplus of the system with respect to determined parameters.
The higher the reliability level, the lower the probability that outstanding observations are not detected and that they will be used in the process of determination of unknowns, what would lead to deformations of their values [5].

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Modernisation of the geodetic control network and amendment of measurement results elaboration by attaching the analysis of additional data will increase the reliability in the so-called, wide context, which includes various "practical" aspects of measurement technology (e.g. qualifications of personnel, periodic control of measuring instruments, introduction of corrections due to disturbing external influences). Improvement of the field checking elements will increase the reliability of geodetic measurements. For the higher number of performed control activities, based on experiences from various engineering fields (geodesy, hydrotechnology, geotechnology in the discussed case), this will result in higher trust of recipients of measurement results.
Checking, which is based on data registered within the period preceding the periodic geodetic measurements, which considers the existing and forecasted trends of changes, may contribute to elimination of gross errors, and thus, to increase the reliability of the geodetic network.

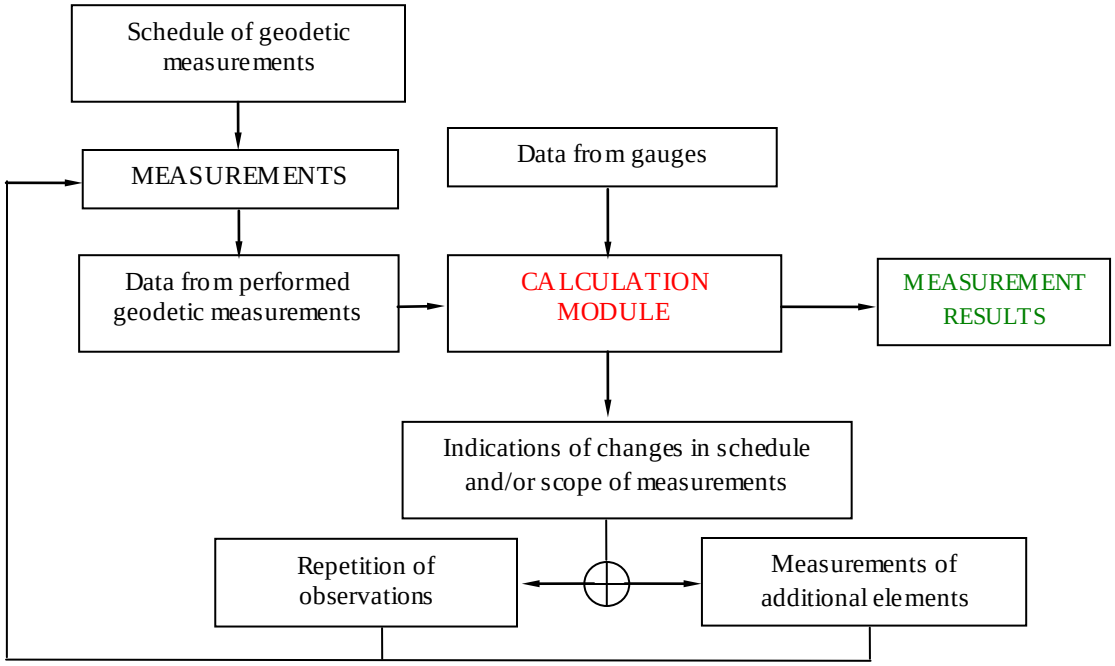

Fig. 4. **A diagram of the initial field checking of geodetic measurements**

Practical use

An example of integration of measuring systems in the process of modernisation of the control network.

An example of the complex approach to modernisation of the geodetic network, used for investigations of movements of a hydro technical structure is the project aiming at modernisation of the control network for the upper water reservoir of the Polish Pumped-Storage Power Station Porąbka-Żar (located in southern Poland, close to Bielsko- Biała, on the Soła River). The project includes:

a) Modernisation of the geodetic network of reference points,
- equipment of all points with installations for forced centering,
- development of the network with long vectors, allowing for reference of satellite measurements to the Euref network,
- transfer of a part of the network from the area of the Landscape Park to the area without any limitations in use,
- if possible, location of points on lands belonging to the Pumped-Storage Power Stations S.A. Company, being the owner of the object, or on the lands belonging to the state.

b) Reconstruction of the geodetic network on the copping of the object:
- possible change of location of existing points and addition of new control points in order to allow for inclusion of non-geodetic gauges, which register geometric changes (shifts and

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inclination), as well as hydrological gauges located in the control gallery of the reservoir, to the elaboration of results of measurements (based on [3]),

- equipment of points with devices allowing for utilisation of satellite technologies,

c) Automation of geodetic measurements – utilisation of direct, radio communication (controlling and data transmission) between surveying instruments and the computer,

d) Development of specialised calculation modules.

Fig. 5. **The upper reservoir, ESP Porąbka – Żar**

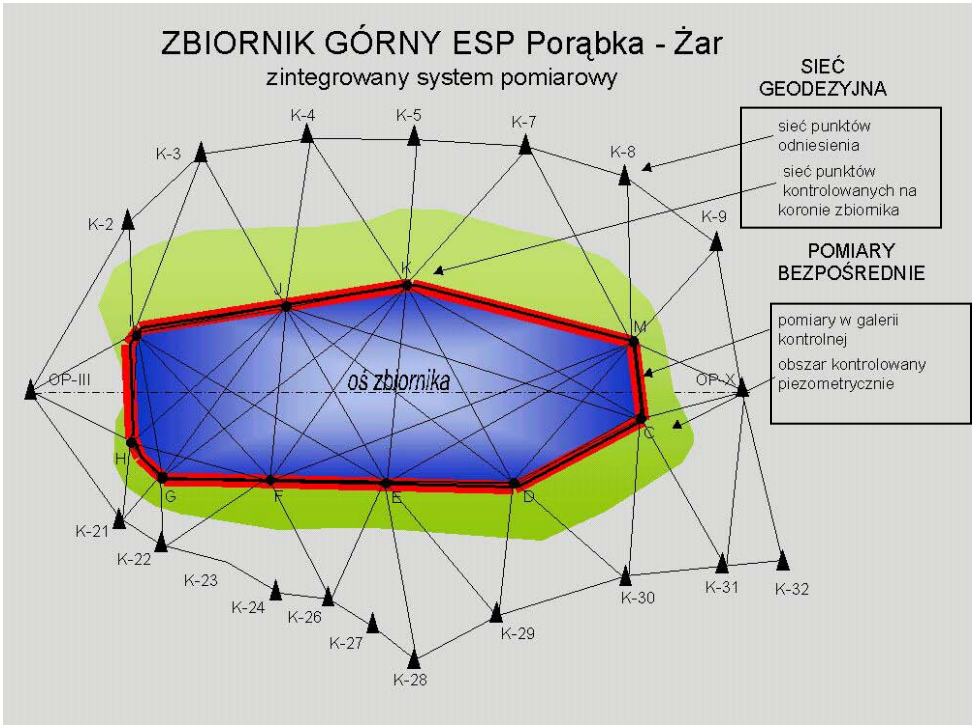

Fig. 6. **The upper reservoir of the ESP Porąbka–Żar – a diagram of the integrated measurement**

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Conclusions

Modernisation of geodetic control networks used for movements investigations is an important issue for the security of the structure utilisation. Following the development of measurement technology, more possibilities of reliable and more accurate monitoring of changes of engineering objects appear. All new technical achievements may be immediately implemented in the course of development of a design of a new structure; it is not possible for an structure, which has been exploited for many years, without introducing any changes and maintenance of the existing control structures. It should be remembered that during elaboration of such issues, history of an structure cannot be neglected; reference to changes which occurred in the past is very important for interpretation of obtained results and for forecasting the trends of changes.

Attaching additional data in the process of elaboration of periodical measurements results, as well as development of a method allowing for comparison and analysis of various types of data acquired within multi-year periods, may contribute to increase the reliability of results of periodic geodetic measurements. The quality of results is extremely important for evaluation of security of engineering structures.

Development of the schedule of measurements, in the course of measurements, performed basing on control with the use of non-geodetic data, will limit the risk of gross errors and will ensure the higher possibilities to detect such errors.

The possibility of direct checking of an object in real time, using automated systems and radio communication will allow for fast reaction to registered changes.

However, it should be remembered, that the possibility to detect gross errors in the process of initial (current) field checking should not lead to neglecting appropriate instruments preparation and lowering the quality of observations.

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